POLDER AND THE AGE OF SPACE EARTH SCIENCES. A STUDY OF TECHNOLOGICAL SATELLITE DATA PRACTICES

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GENERAL INTRODUCTION

In February 1986 a group of scientists and engineers from in-house laboratories of the Technical Center of CNES in Toulouse, from the Laboratoire d'Etudes et Recherches en Télédetection Spatiale also based in Toulouse (LERTS) and from the Laboratoire d'Optique Atmosphérique based in Lille (LOA) submitted a proposal to the responsibles of the scientific programming of the French space agency (CNES) for building a radiometer to be launched inside a satellite. The experiment was named POLarization and Directionality of the Earth's Reflectances or POLDER and intended to derive some properties of the atmosphere, the oceans or the vegetation cover by interpreting the measurements of the radiation that they emitted and reflected[1]. Ten years would elapse before the instrument achieved the skies. It would be on August 17th 1996 from the space port of Tanegashima when a Japanese launcher H-2 brought the satellite ADEOS-I into orbit. Designed to gather data in support of studies about global warming, depletion of the ozone layer and deforestation, ADEOS-I was a gigantic spacecraft of around 4860 Kg and $4x4,5x5m^3$, which carried 8 different experiments: five realized by different Japanese institutions, two by NASA and the French radiometer POLDER.

The radiometer POLDER belonged to the first generation of experiments conceived, developed and realized in France purposely to support scientific research in diverse disciplines of the Earth sciences by means of space technologies[2]. These experiments materialized a progressive integration of disciplines belonging to the Earth sciences in the scientific programing of CNES, disciplines which had remained in the sidelines of the space venture during the 20 first years of the space age[3]. These

[1] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", prepared by Michel Laporte of the Division Opto-électronique, Marc Leroy of the Division Traitement d'Images (both in-house laboratories of the Technical Center of CNES in Toulouse) and Alain Podaire of LERTS. Pierre-Yves Deschamps of LERTS, Maurice Herman and Richard Santer of LOA would also collaborate in elaboration of the proposal.

[2] For completeness, we can list the other three experiments that came to be launched: a radar altimeter called Poseidon launched in 1992, a radiometer called ScaRaB launched in 1994 and a radiometer called Vegetation in 1998. Apart from these, other experiments and missions would be proposed along the 1980s but their development would be dragged out or even cancelled.

[3] From the dawn of the space age in the 1960s there existed indeed weather satellites, and from the 1970s onwards also Earth Survey satellites, which indeed gathered data about the Earth and its environment. However, as we will develop in our introductory chapter, they were not programs integrated in the scientific programming of space agencies –they would be not conducted following the same socio-epistemological organization than those programs labeled by space agencies as belonging to "space sciences" either.

instruments commenced an era in which experiments in the space would be conducted not only in the original domains of astronomy, solar physics, interplanetary milieu, gravimetry or microgravity physics, but also in the domains of Earth's atmospheric chemistry, glaciology, marine biology, physical oceanography or climate sciences, to mention a few. These experiments pioneered an era of exploring the planet Earth just like other planets were explored, by exporting sensing technologies, approaches to interpret the data, data-handling systems or ways of running and organizing scientific space projects to a new domain of scientific inquiry. This first generation of experiments, conceived between 1980 and 1988 and launched around 10 to 15 years later, between 1992 and 1998, would inherit many of the practices, technologies, representations, social dynamics, epistemologies, policies or ways of running from the original scientific space missions quite consolidated during 20 years of activity since the 1960s; yet, they would also show a number of departures and specificities. They would customarily contribute to define and shape specific ways of conceptualizing, developing and carrying out space missions in support of the Earth sciences. In turn, they would also contribute to mold a particular form of scientific community, a community for which space technologies, instruments and data would become central tools for producing knowledge. All and all, these instruments would help to constitute what we like to call the *age of space Earth sciences*[4]. The purpose of this study is to help understanding how and where certain actors, certain type of knowledge and skills, certain type of technologies, certain type of data, certain systems of data-handling and certain research programs contributed to conforming these *space Earth sciences*: their objects of research, their tools and methodologies, their communities of actors.

We have chosen to approach the question by focusing on the *data* –not the programs, the disciplines, the institutions, the funding agencies, the individuals or the cultural representations, but data. Data, in principle, with more or less resistance, travel and circulate from the original conditions of acquisition and production to distant places of utilization –the attribute "distant" has the double sense referring to space and time distance. Across their journeys, data can be given understanding from different approaches from binary signals to physical measurements to geophysical units or to climatic data-records; they can be contextualized, de-contextualized and re-contextualized, they can be used and re-used, and recycled; they can be intervened with technologies of calibration, inversion or assimilation, to mention three of the most prominent in our essay. The study of these technologies is actually central to our approach. We define *technological data practices* as the processes that transform the measurements gathered with a technology into consistent and meaningful set of data admissible within a domain of utilization. They may include, providing some concrete examples, experimental protocols, instrumental calibration, geometrical corrections, processing software development, mathematical formalisms, display and visualization tools, recording devices, material support for storage or for

[4] We are not arguing that space agencies built Earth sciences in the end of the XXth Century -this is certainly a much longer and nuanced history. We are just claiming that for the years between approximately 1980 and 2000 space agencies would be able to combine their interests in perpetuating space activities and the interests of diverse disciplines of the Earth sciences in an effective manner to them, and that they would be involved in the process that made the Earth sciences the kind of sciences that they are today.

circulation, etc. *Technological data practices* may be material or conceptual, instrumental or mathematical; they can be found all over the processes of data gathering, processing, production, archival, disseminating and utilization. Two sources motivate this approach centered in the *technological data practices*. On the one hand, our focus on the *technological data practices* assumes that we do not take satellite data as finished products, fully developed forms floating out there waiting to be collected. Instead, this is the whole interest of our investigation, we aim to unveil them as the product of a series of *practices* committed to make them so. We aim to elucidate how data become data –and what data. In particular, we intend to trace and reveal the cascade of operations that intervene in the construction of data from the measurements gathered by POLDER and the options for using and re-using that they open up or narrowed down. On the other hand, we aim to shed some light on the objects of research, the tools and methodologies, the communities of actors gathered around the data acquired and produced with POLDER. More precisely, we aim to grasp some of the epistemological imperatives embedded in the data gathering, production, archival, diffusion and utilization, to connect them with forms of knowledge production, to understand some forms of power distribution, to apprehend certain institutional dynamics and inertias or to illuminate some sociological features, which participated in the creation of a research program around the experiment POLDER, the forms of data supporting it, and the technological data practices intervening in their production, the systems of data-handling, and a community meant to work the data.

One of the threading ideas in our work are the twin notions of *reconciliation* and *normalization*. Our argument is that during a process of *reconciliation* happening across the last two decades of the XXth Century, the practices and representations of this *age of the space Earth sciences* would get forged: issues such as the type of satellite data admissible to conduct research, the social group legitimate to produce the data, that credited to control their quality, their know-how and values, the procedures and rules to request such data, the norms for storing, archiving and disseminating them, the research frames, and objects, in which data ought to be used, the very notion of space mission, the type of technologies and infrastructures to collect data, the technical system to handle the data and the social ordering embedded in it. It would be during this process of *reconciliation*, we argue, that a particular form of collective representation of the social, the technical and the scientific orderings to gather, produce, store, disseminate and use the satellite data about the environment would be shaped and progressively *normalized* amongst major space actors. This is the background hypothesis that underlies this work.

One word must be said about these twin notions. The choice of the term *reconciliation* is inspired by the doctoral dissertation of Margaret Courain. She explored how weather forecasters of the US Weather Bureau came to include data gathered with radiosondes and satellites into their daily practices of weather forecasting. This turned out to be a long process lasting approximately from 1960 to 1980, which the author called of *reconciliation*, in which the data derived from these sensing technologies must be rendered consistent with the existing data representations of the weather forecasters[5]. Our use of the term is analogous. We propose calling the process through which space technologies (satellite data, sensors, data-handling systems, space missions, ways of running, and other elements that we will develop along the essay) were rendered congruent with the current practices of Earth sciences as one of *reconciliation*. We shall remark that we understand the notion of *reconciliation* as the process of bringing together two items initially separated but we do not assume anything about their initial separation –in particular, contrary to the common use of this term in French language, and this is why we insist in that precision, we do not assume any previous state of conflictual nature that may have caused the separation. Put it simply, space promoters –a general term including managers of space agencies, operators, mission planners, funding agencies, industrials, international organizations, scientists…- would endeavor to convince Earth scientists that satellite data were credible tools for studying the Earth. Yet, for space technologies to be considered meaningful in the domain, they must get adapted to the current practices and representations of Earth scientists; at the same time, Earth scientists must learn how to integrate satellite data in their corpus of scientific tools and practices, for the kinds of data that would come available were foreign to their previous experience. That means that participants must come to terms with eventually different modes of data handling, of organizing the realization of an experiment, of operating its exploitation, of preparing the interpretation of the data, of allocating power amongst the participants, of defining the ethos of being a scientist, of perceiving the property over instruments or data, of distributing the labor, of understanding the essence of a space mission. Whence our use of the term *reconciliation*.

Having clarified the use of the term *reconciliation*, the use of the term *normalization* comes straightaway to refer to the process of consolidating the results of the *reconciliation* –they are hence twin terms that can be used to refer to the same overall idea. Further the introduction of the Earth sciences in the scientific programming of the space agencies, and as a result of the process of *reconciliation*, a number of practices and representations got integrated in the dynamics of some of the actors as the standard for carrying out space missions in the domain: a particular form of understanding the role of space technologies as tools supporting studies in the domain of Earth sciences, a particular meaning of the notion of space mission, a particular understanding of the Earth sciences, and of the Earth as such, a particular techno-epistemological model to gather, produce and disseminate the satellite data, a particular social organization with a particular type of scientific community, a particular form of expertise, knowledge and *technological data practices*, a particular data-exchange policy, a particular institutional vocation of CNES. They had become the legitimate admissible methodology to be applied more or less uniformly to space missions in any domain of the Earth sciences. They got *normalized.*

We have circumscribed our investigation to study the data practices related to this specific instrument, POLDER, conceived in 1986 by scientists from in-house laboratories of the Technical Center of

[5] "Technology reconciliation in the remote sensing area of the United States Civilian Weather Forecasting, 1957-1987", doctoral dissertation by Margaret Courain, 1991.

CNES, the Laboratoire d'Etudes et Recherches en Télédetection Spatiale (LERTS) and the Laboratoire d'Optique Atmosphérique (LOA) and realized under the coordination of French space agency, the Centre National d'Etudes Spatiales (CNES), which is the organization responsible for public civil space activities in France. The radiometer POLDER measured the light reflected from the Earth-atmosphere system in different polarization degrees and from several angular directions, so that different features of the oceans, the land surfaces and the atmosphere could, with the appropriate processing methods, be derived. Between 1990 and 1993, the development of POLDER would receive some impetus and an enlarged scientific group would be created to prepare the interpretation and analysis of the future POLDER's data (composed mostly, though not exclusively, by scientists from LOA, LERTS, Laboratoire de Modélisation du Climat et de l'Environnement, Laboratoire de Météorologie Dynamique and Laboratoire de Physique et Chimie Marines), which would be, in turn, widened up to international participation by 1995. Three prototypes of POLDER would be put into orbit in three different occasions: two POLDERs would be launched, in 1996 and 2003, inside two satellites of the Japanese program ADvanced Earth Observation Satellite (ADEOS-I and ADEOS-II) carrying a set of experiments intended to study global change; the third one would be embarked in 2004 inside a CNES's satellite called PARASOL to join an international NASA-led group of satellites flying together, called the A-Train, to measure in simultaneity with a NASA's lidar carried by a neighboring satellite of the train[6].

The choice of the case POLDER did not come straightforward from the outset of our research but rather after a period of exploration in different directions. As said, the instrument belongs to the first generation of space missions in France designed by scientific groups to gather data in support of academic studies in the domains conforming the Earth sciences. Therefore, space managers at CNES, scientists conceiving instruments and more generally the community of Earth scientists must come to terms with the novelty of handling satellite data: from learning how to extract meaningful information from the signals to interpret this information in diverse epistemic frameworks or disciplines to convince fellow scientists of the credibility of the data to design a program of research (and the type of technologies, including data, supporting it) to invent a system for data production and delivery to regulate the data-exchange policies to organize the work between the parties. POLDER offers, in that way, because of being one of the pioneers, an opportunity for historical inquiry. Another advantage of taking POLDER is that the number and size of the scientific team and the space managers is one which a single investigator can cope with; it is relative small (although it would get bigger and bigger as years passed by), well-located in the territory, and therefore both identifiable and reachable –it helps, needless to say, the fact that the teams have been open to our research, for what we are grateful. Finally, POLDER is one of the few instruments of the first generation that would be actually launched within a time-period allowing doctoral research to be conducted. This may sound a banality but it must

[6] The A-Train is a group of satellites from different space agencies (NASA, CNES, the Japanese Space Agency and the Canadian Space Agency) that fly, from the mid-2000s, following the same orbit one behind the other separated from seconds to minutes, giving the image of different wagons of a train.

be noted at this point that realizing a scientific space mission uses to be a long process from conception to launching (averaged around 15-20 years), in which multiple factors of scientific, technological, budgetary, institutional, economic, strategic, political, geopolitical, diplomatic or social order may intervene pointing to multiple, sometimes contradictory, urgencies and priorities. Projects may be slowed down, modified, cancelled, looked over again, rejected once more, reshaped and occasionally, perhaps, even launched. Because of being launched three times in a period spanning about 30 years from end-to-end, POLDER constitutes a case allowing inquiry to be conducted at present day. Besides, the fact that POLDER is at present day a closed project facilitates, we believe, the interaction with the actors who may have taken some distance from the events and reflect about the project without pressures for getting it launched[7]. It is therefore appropriate to use POLDER as a barometer to observe the evolutions of the data handling in the long-term, to account for changes and variations as well as to affirm the perpetuation of some practices, technologies, ways of running, dynamics, data policies and representations. On the other hand, POLDER was not alone. A number of other missions were developed during the same period, coordinated by CNES itself but also by other major space agencies, inter alia, NASA and the European Space Agency (ESA). In particular, the projects Topex/Poseidon and ScaRaB will be often referred in the course of the present dissertation, references that pursuit two goals. Considering them is, in the first place, a commitment to illustrate that they all were part of the same process, shaping it and fueling each other, sometimes converging in their practices and some others sharpening differences. The second reason is of methodological order: mutual comparisons is a strategy to better understand some developments and/or elucidate similarities and differences in the practices and logics deployed for handling the data in each mission.

We must admit that the scope of this work is immense and that certain topics have not been covered, or covered only tangentially. After all, all research projects must make choices -if only for practical and material constraints. In deciding to focus on data and *technological data practices* surrounding a particular case POLDER a number of other aspects have been left aside. We could have focus our lens only to one aspect of the data gathering, production, archiving or dissemination like, for instance, examining just the practices related to algorithmic inversion or to calibration, or to data quality control, or to the creation and operation of online databases. Likewise, we could have focus on only one dimension, say institutional dynamics, decision-making procedures, international cooperation, technological change, etc. Our choice has been, *a contrario*, to favor a general overview of the multiple pieces constituting altogether the satellite data practices. Two reasons have motivated this decision. First, data handling is constituted by a set of processes and taking only some of them would have mutilated the whole hampering in so doing the perception of its integral logics. This is particularly important, this is our second reason, being, as it is, our study a first approach to a topic that has not been much treated before by the history of sciences and technologies. We have then

[7] Note that while the project POLDER is closed, a new generation of polarimeters derived from POLDER, called 3-MI, are in the course of being realized under the auspices of the European Space Agency to be put inside the next generation of European weather satellites.

chosen to browse it in several directions at the same time, detailing some aspects more deeply than others, but without losing sight of the whole picture –we may hope that this first exploration will inspire further prospections.

The reader may miss, for instance, a deep reflection on the logics intervening in the procedure for selecting and deciding space missions. The general contexts are provided for our case-study but we do not conceptualize them in any sense; this is certainly a theme that deserves specific attention, as demonstrated by the number of studies dealing with such a question, mainly with NASA's missions, and that stress different aspects such as techno-push drivers, political coalition building, national security concerns, domestic urgencies, technological transfer regulations, foreign affairs strategies, to mention just a few[8]. The international dimension of the project is also almost absent, which may surprise considering the importance that this aspect has in structuring the developments in scientific (and non-scientific) space missions, and viceversa, as has been demonstrated by the historian John Krige[9]. In the case of POLDER, this can be seen from at least two perspectives. First, POLDER-1 and 2 are conducted within the frame of a broader space cooperation with Japan and POLDER-3 is launched to join a group of satellites from different space agencies and to be used together with a NASA's satellite. More generally, in the space technologies domain, projects are rarely conducted by a single nation, at least in the domain of scientific missions. This is literally true in France, where, due to the complexities and costs of the space venture and due to the French political and strategic commitment vis-à-vis the European space project, between 1975 and 2004 CNES did not launched a scientific mission totally in solitary[10]. Second, the logics of CNES's scientific program, as we will develop, cannot be understood apart from the overwhelming broader panorama at the international stage. In particular, CNES's scientific program both shapes and is shaped in complementarity or by reaction to the scientific programs of ESA and NASA. Accordingly, in some passages we will stress particularly the international political and geopolitical context as an element to be accounted for in any explanation of the space developments. Also, some of the data handling practices will be elucidated by considering diplomatic issues, such as data exchange policies, standardization of formats or the building of data flow infrastructures; some other would be considered putting the lens of the international distribution of technological competences amongst major space agencies. But, however essential all these aspects are, they do not constitute the epicenter of our research.

Our investigation suffers also of a occidental-centric bias, and more particularly centered on CNES, NASA and ESA leaving aside developments in the URSS-Russia, India or China, to mention just few, which would also develop space programs to study the Earth and its environment, and the corresponding data practices. Along the same lines, Japanese developments are only addressed insofar they are necessary to understand POLDER-1 and 2, without entering in their details. We believe,

[8] We will refer to some of them when addressing with the historiography in a while.

[9] One of the thesis of the historian John Krige is that since their inception, space activities can be hardly separated from their role as instruments of international relations and foreign policies. We have not explored this dimension in our essay. See for instance: "NASA in the World. Fifty Years of International Collaboration in Space", J.Krige et al, 2013.

[10] Rapports d'activité CNES, 1975-2010.

nevertheless, that such a bias has no fundamental impacts in our findings, considering the fact that the greatest influences on CNES's data handling practices stem, at least in our study-case, from interactions with NASA and ESA. Further research may contribute to elucidate this initial intuition in other cases. Likewise we leave for further research projects exploring the connections between space programs, and the corresponding space agencies, and international research projects like the World Climate Research Program or the International Geosphere-Biosphere Program –or more locally, with national research programs. For instance, the influence of space agencies in defining the major guidelines orientating the scientific goals of scientific projects through, for instance, favoring certain modes of data production and sharing has not been addressed. We certainly provide, following the promptings of the historian Chunglin Kwa, insights connecting the introduction of new technologies and tools and changing notions and practices in the domain of Earth sciences, even changing the notion of Earth sciences itself, but we leave matters at an introductory stage and more research is needed in that point[11]. Neither has not been addressed their influence through promoting (or rejecting) of certain space technologies, instruments, orbits or type of missions or through distributing their technical competences within each other to organize technological change, industrial development or markets. Inversely, the role of scientists, individuals or institutions, in defining tendencies within international space organizations like the Committee on Earth Observation Satellites, or national organizations beginning with space agencies, have been not tackled in our essay either. The investigation of these themes would by far have exceeded the time-frame of our doctoral research; they certainly make interesting pursuits to our work.

Another topic is particular absent in our narration: the information sciences. The two last decades of the XXth Century had witnessed two waves of digitalization of the satellite data-handling: sensing, processing and storing in the 1980s and dissemination and archival in the 2000s. While essential to the evolutions in some of the technological data practices, we have not paid attention to developments to achieve and build computerized information systems, both of national and international scope, or to promote networks for data to circulate, to standardize formats, design directories or data catalogues. Connected to that, a fascination for the phenomena of Big Data has recently irrupted the public and political scene. We could certainly have dedicated some time to investigate the connections between the satellite data practices and the metaphor of data deluge, or considerations regarding the so-called data-driven sciences, or the debates about open access. We could have certainly decided to explore the Bigness of satellite data and of the Earth sciences that they are meant to support[12]. Similarly, the

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[11] The historian Chunglin Kwa has reported the influence of NASA in redefining the practices and the representations in the discipline of ecology in the late 1980s, through the establishment of the International Geosphere-Biosphere Program, in order to render it workable with satellite data. See: "Local Ecologies and Global Science Discourses and Strategies of the International Geosphere-Biosphere Programme », Chunglin Kwa, 2005.

[12] This is a question that has recently given birth to several studies in the domain of sciences studies. Two broad courants of research have emerged so far. On the one hand, those philosophers of sciences, sociologists, anthropologists and historians who had explored how the use of digital data and databases has influenced in the scientific practices, mostly centered in the field of molecular biology. See the works of Geoffrey Bowker, "Biodiversity Datadiversity", 2001; Christine Hine, "Databases as scientific instruments and their role in the ordering of scientific work", 2006; Bruno Strasser, « Data-driven sciences: From wonder cabinets to electronic databases",

representations of satellites, as surveillance technologies deploying panoptical dreams of power and control to manage our planet and our societies have not been the object of our work. We refer to this dimension as a *zeitgeist* browsing some development but we have not dig into the relationship between satellite data and their instrumentalization as policy tools, the interaction between scientists, space agencies, political bodies and public audience, the question of expertise, specifically regarding issues of environmental regulation or planetary management, or into how the space actors (space managers or scientists) would establish satellite data as a source of policy-relevant knowledge, gaining a status of indispensable, permanent in debates and agendas. These are certainly big questions, and we do not intend to deepen into them in this dissertation.

On the other hand, and to conclude with some of the limitations of our investigation, one comment of methodological order must be spelled out. One of the issues raised about studies based on cases is their methodological status and generality. Case studies are particular cases contingent to local circumstances and as such they renounce to any pretension of universality. However, many space Earth sciences missions, at least those of the first generation in France, are structured alike in many aspects: scientific team, data production infrastructures, data archival and dissemination policies, division of labor or budgetary commitment –with a number of local specificities. Therefore it is plausible to suggest that our findings could shed some light also on other space experiments also developed during this period –with precautions due to local specificities. But even in the limit situation that our outcomes would remain strictly local, the questions that we raise are certainly common to all space missions, both in the domain of Earth sciences and of the so-called traditional space sciences - and probably also in all those scientific enterprises, spatial or not, requiring important efforts of data gathering, production, archival and dissemination.

This study is inscribed in an approach to the history of sciences and technologies, which pays attention to the contexts of production of scientific knowledge. It attests that the scientific enterprise is as an activity implying intellectual, technological and social arrangements and it seeks to account for the political, social and cultural contexts of scientific work. It rejects thus the conception of a scientific venture decontextualized, ahistorical or atemporal. It rejects as well the idea that history of sciences and technologies is a conceptual reconstruction of rational scientific ideas, organized by disciplines, which focuses on the evolutions of the content of the corpus of knowledge (theories, concepts) [13]. Instead, it considers sciences as a set of practices, governed by different rules in function of the

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2012; or Sabina Leonelli, « Global data for local science : Assessing the scale of data infrastructures in biological and biomedical research », 2013.

The second stream focuses on examining the different perceptions of data deluge that had been haunting different disciplines in various periods. For this stream see Bruno Strasser, "The "Data Deluge" : The Production of Scientific Knowledge in the 21st Century", 2014; or the works of the research group "Historicizing Big Data" in the Max Planck Institute for the History of Sciences in Berlin published in a forthcoming volume of Osiris, "Histories of data", ed. by David Sepkoski et al.

[13] For introductory approaches to this courant, see those writen by Dominique Pestre: «Pour une histoire sociale et culturelle des sciences. Nouvelles définitions, nouveaux objets, nouvelles pratiques » in 1995 and « Introduction aux Science Studies » in 2006.

scientific domains, institutional frames, technologies available, funding agencies, epistemic cultures, periods or places, to mention just a few aspects.

It is through practices that actors define their relationship with the instruments and techniques, with the object of study and with the data. It is also through practices that they interact with other groups, disciplines and institutions, and that they circulate and expand the data (and the knowledge). It is through practices that they distribute the work amongst each other, that they define themselves as managers, remote-sensing scientists, instrument-builders, technicians, computer scientists, data curators, climate scientists or oceanographers, and that power gets allocated amongst each other. It is through practices that they materialize their choices and decisions, their hesitations and interrogations, their values. It is through practices that they allocate epistemic authority[14] in a given set of instruments, that they trust a given set of data, that they define the admissible strategies to investigate, that they adopt methodologies and norms, or that they formalize descriptions of a given phenomena. It is through practices that a community gets homogenized and distinguished from another. Examining the concrete practices thus is a way to elucidate the multiple actors, the scientific motivations, the ends, the technologies, the methods, the cultural representations, the social rules or the organization procedures. In particular, works about what has been called the *material culture* plead for abandoning the image of scientific practices as focused exclusively in theory-making and instrumental logics; instead, material possibilities or technological developments have been placed at the epicenter for understanding the production of scientific knowledge –we are, in the present essay, adhering this approach[15]. Note that by tools or technologies a large range of both material and conceptual assets that allow manipulation may be considered, including instruments to measure, or to display measurements, machines, gadgets or devices, but more generally also chemical agents, model samples, mathematical formalisms, techniques, computing methods, software, numerical models and simulations, etc. Within this theoretical framework, our work would take on a vast literature stressing the importance of objects, instruments and techniques in the establishment of scientific facts and interpretations, on the importance of calibration of instruments and machines to achieve agreement or on the influence of technological possibilities in orienting the scientific venture. Scientific practices, after all, call for technologies, which, in turn, reshape the practices.

We are, following this approach to the understanding of sciences and technologies, methodologically committed to vary the standpoints in order to provide the most complete account possible, reckoning that there is no a privileged perspective from which any story can be univocally unveiled. Rather, we move across disciplines and remarks of historical order may be combined with thick scientific descriptions, technological examinations, sociological considerations, epistemological interrogations, anthropological insights, (geo)political depictions or provisions of broader cultural order. Remarks of institutional order may be combined with thick descriptions of data calibration techniques, the history

[14] Epistemic authority refers to the capacity of someone or something to explain the world in a credible and legitimate manner. We will further develop this idea all along the essay.

[15] Some referential books deploying the so-called material culture are “Image and logic: A Material Culture of Microphysics”, P.Galison, 1997 and “How experiments end”, ed. by P.Galison, 1987.

of a particular infrastructure to archive the data may be pieced together with reflections about data policies, the technical specificities of a given optical sensor may be connected to epistemological issues. Consequently our arsenal of analytical tools and concepts is varied and borrowed from diverse approaches: in some passages we may analyze events by drawing the attention to the allocation of epistemic authority, in others we may argue in terms of boundary-work, in some others we discuss legitimacy, credibility or trust, we also take on division of labor and industrialized sciences, we may stress professional cultures or institutional cultures or epistemic cultures, or we may use the analytical frame of infrastructure and systems studies, among others. In any case, however, we mobilize these concepts inasmuch they help to analyze and theorize; we take them as our tools, supple notions, far from aspiring to any dogmatic meaning, and we only capitalize them to better understand a given question.

The multiplicity of domains is certainly one of the methodological difficulties of this approach: these dimensions are always meshed and one's logics reshape in permanence the dynamics of the others'. A second difficulty of methodological order is how connecting thick descriptions archetypical of a microstoria study with insights mobilizing macro forces of historical, sociological, strategic or cultural orders. On the one hand, our investigation is centered in a deliberately demarcated object, POLDER's technological data practices. It is aimed to bring into the scene specific scientific teams and laboratories, specific technologies and practices, specific communities, which are situated and contingent to local circumstances. On the other hand, nevertheless, case studies are inseparable of vaster pictures of macro-order and cannot be freed of broader constraints and interpretative landscape. Without pretending to provide any social explanation for the scientific enterprise, our account, rich in detailing the technological practices, will be complemented with references to some general tendencies providing a more comprehensive context, a bigger picture and a transversal narration. In that way, describing the local efforts for calibrating the instrument, preparing the processing algorithms or data quality control, may be complemented by analyzing the drives for constituting a scientific team at a national scale, the institutional pressures driving CNES to gain visibility, the forces that control the flow of data between satellites, programs, agencies, scientists or information centers, pressures for data delivery and sharing or the circulation of data over long distances, or with a broader (geo)political panoramas driving international scientific agendas in different epochs. All these moves can be described as all part and parcel of the same venture of satellite data handling. Putting the lens in one scale or the other will reveal different facets and logics, sometimes converging, sometimes stretching, but complementing each other, that altogether mold the project.

Our topic is actually not a discipline, a methodology, a theoretical concept or a theory as such, but rather a set of practices, including calibration, validation, inversion, or assimilation, which cannot be examined in separation from the technologies, and the actors, that enable their production, reproduction, display, interpretation, circulation or archival. It is the material acts that interest us, not the ideas and concepts, it is the know-how, the ways scientists conceive, decide and built experiments, how do they calibrate instruments and data, how they control and judge the quality of the datasets, how do they archive and circulate data, and how do they interpret and analyze them, a thick description of *technological data practices*.

For around 20 years now (30 or more if we consider NASA's satellites), hence, satellites have been orbiting our planet gathering data to support scientific research in diverse disciplines of the Earth sciences. These satellites orbit following different types of trajectories (geostationary, polar), they are equipped with more or less sophisticated instruments (video-cameras, radiometers, radars, lidars, spectrometers, GPS, etc.) from which different measurements can be obtained (images, radiances, backscattered reflectances, etc.). Arguably these data can be used for a number of purposes, like predicting future states of a given system, managing resources or supporting environmental policies – after all, there is a thin line between knowledge, information and action, like Michel Serres, Geoffrey Bowker and others have pointed[16]; but most of these satellites have been designed as experiments with the ultimate goal of contributing to the production of scientific knowledge. In that sense, our work subscribes the overall analytical frame provided by the historian of sciences and technologies Paul Edwards in his description of techno-scientific endeavors participant to a large *informational global infrastructure,* his terms[17]. These satellites, POLDER being one of them, are technological systems that celebrate the potentialities of worldwide data-collection in order to produce scientific knowledge in the different disciplines embraced under the label of Earth sciences –in turn, other satellites, acting as data relay, may provide communication and data-sharing possibilities to complete the circle of data circulation across the globe. In that sense, and taken as general assets, satellites are one component of what this scholar defined as " robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds"[18]. Within this underlying background, the departing point of our study is to explore the gathering, production, dissemination, archival and utilization of POLDER's data. Intended to collecting, producing and circulating data, knowledge and information about the Earth and its environment, we aim to situate POLDER within this overwhelming *knowledge infrastructure,* Paul Edwards's term again[19].

[16] In his "Contrat Naturel" Michel Serres pointed out that our society is taking the role of managing the planet as a whole. It is about getting data about our planet in order to manage our societies, about producing information in order to drive action. The historian Geoffrey Bowker also has provided several examples to illustrate that data archives had been often connected to state management and control, especially in the domain of natural sciences in which the data contained in the biodiversity databases were being used to support and motivate conservation policies. See "Memory Practices in the Sciences", 2005.

More generally, statistics are an illuminating example of the scope that this epistemological approach to the use of satellite data reaches, predating satellite technologies and well-beyond the Earth sciences. Indeed, gathering and preserving data have been the basis for the State's administrative power throughout the modern era -we are not interested in these topics, which certainly predate and exceed our study-case, and have been illuminated by Michel Foucault, Theodor Porter or Alain Desrosières amongst others.

[17] See « Meteorology as Infrastructural Globalism », Paul N. Edwards, 2006. This study is put in a broader perspective in his book "A Vast Machine", 2010.

[18] "A Vast Machine", Paul N. Edwards, 2010.

[19] Infrastructure studies are a useful analytical source for our investigation also for a second reason. They are methodologically commited to shining light on phenomena whose existence is taken-for-granted; in that sense, their insights can be helpful to unravel internal gears and workings of an object, satellite data, often taken-for-granted. "Sorting Things Out: Classification and Consequences", G. Bowker and S. Leigh Star, 1999. In particular, Paul Edwards and Geoffrey Bowker are amongst a groups of historians that have vindicated a program to study what they have called cyberinfrastructure (what is Europe has been translated as e-science): the infrastructures of getting data,

Considering the multi-approaches character of our dissertation and its large methodological spectra, we have not the ambition to offer an exhaustive bibliography about different methodologies deployed or about different topics and historical questions tackled. That being said, we may be interested in placing our investigation within the existing historiography of the space age. Academic works about the space age have been often conducted by American historians and political scientists[20]. Actually an important number of these works have been carried out by scholars recruited by NASA, provided that, since 1960, the institution maintains a fertile division of history charged to periodically publish books, articles or monographs about certain programs, individuals or technologies, as well as of organizing workshops and meetings[21]. Consequently, they have been centered in NASA's developments[22]. They deliver accounts about the histories of the different technical centers and laboratories associated to NASA[23], the actions of the administrators[24], the great space programs, especially those related with manned spaceflight or planetary exploration[25], the tragical accidents[26], or some aborted projects. Some other studies are focused on technological developments, on research and development policies, or in ways of running and management of the organization[27]. In general, the topics of these studies are recurrent: management, coordination and social organization of the work, risk management, alliances and concurrences with other federal organizations, the power of scientific coalitions, press and public audiences and influences, relationship between space activities and national identity, biographies,

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sharing, storing, leveraging them into major donwstream products. See "Understanding Infrastructure: Dynamics, tensions, and Design", report of a workshop on "History and Theory of Infrastructre: lessons for New scientific Cyberinsfrastructures", eds. P.N. Edwards et al, January 2007.

[20] One of the most exhaustive one relating the early ages of the space age is: "The Heavens and the Earth: A Political History of the Space Age", WalterA. McDougall, Johns Hopkins University Press, 1997.

[21] The NASA History Program was started shortly after NASA itself was established. The historian Roger Launius describes its history in "NASA History and the Challenge of Keeping the Contemporary Past", Roger Launius, http://history.nasa.gov/launiuspharticle.pdf. Find a complete bibliography on: http://history.nasa.gov/publications.html

[22] Two important exceptions to this NASA-centric literature are the studies of the historian Asif Siddiqi who constructs a large narrative that makes important points about the nature of Soviet aerospace efforts (a study also funded and published by NASA) and John Krige and Arturo Russo offer an institutional and political picture of the history of European space efforts centered in an institutional approach (a study funded by ESA): "Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974", Asif A. Siddiqi, 2000; "A History of the European Space Agency, 1958-1987", John Krige and Arturo Russo, ESA 2000.

[23] See for instance: "JPL and the American Space program", C.Koppes, 1982 or "Partners in Freedom: Contributions of the Langley Research Center to US Military Aircraft in the 1990s", J.R. Chambers, 2000.

[24] "Inside NASA: High technology and organizational change in the US Space program", H.McCurdy, 1993 or "The secret of Appollo. Systems Management in American and European Space programs", S.B Johnson, 2002.

[25] See, just to mention few: "Project Mercury: A Chronology", James M. Grimwood, 1998; "On Shoulders of Titans: A History of the Project Gemini", Barton C. Hacker and James M. Grimwood, 1977; "Apollo: A Retrospective Analysis", Roger D. Launius, 1994; "Stages to Saturn: A Technological history of the Apollo/Saturn Launch Vehicles", Roger E. Bilstein, 1996; "The Partnership: A History of the Apollo-Soyuz Test Project", Edward C. Ezell and Linda N. Ezell, 1978; "The Space Shuttle Decision: NASA's Search for Reusable Space Vehicle", Tom A. Heppenheimer, 1999; "Dragonfly: NASA and the Crisis aboard MIR", Bryan Burrough, 1998; "Deep Space Chronicle: A Chronology of Deep Space and Planetary Probes", Asif A. Siddiqi, 2002; "Humans to Mars: Fifty Years of Mission Planning, 1950-2000", David S.F. Portree, 2001; "Interpreting the Moon Landings: project Apollo and the Historians", Roger D. Launius, 2006. All of these are NASA's studies.

[26] See for instance: "The Gemini Paraglider: A Failure of Scheduled Innovation, 1961-1964", B.C. Hacker, 1992 or "The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA", D. Vaughan, 1996.

[27] "The Decision to Develop the Space Shuttle", J.Logsdon, 1986; "The Space Telescope: A Study of NASA, Science, Technology and Politics", R.W. Smith, 1989; "The Space Station Decision: incremental Politics and Technological Choice", H.E.McCurdy, 1990; "Leadership and large-scale technology: the case of the international space station", H.Lambright, 2005; "Competing technologies, national(ist) narratives, and universal claims. Towards a global history of space exploration", Asif A Siddiqi, 2010.

relationship with military instances, gender issues, etc. These studies have contributed to illuminate, inter alia, the institutional dynamics, the decision-making procedures, the socio-political impact of spaceflight, its cultural representations, its juridical forms, its link with the military and defense, the strategic and geopolitics, the conundrum between cooperation and competition, the international relations dimension, the industrial stakes or some gender issues involved space programs or technologies.

Few are the studies that connect the space technologies, programs, institutions or individuals with the scientific disciplines that these projects are meant to support. Although scientific research have been an essential feature, even foundational, of the civil space agencies in different nations, the historiography of civil space age has been overshadowed by the launch of Sputnik, the race to the Moon, space transportation or other space big spectaculars, like the Hubble telescope, the International Space Station or space exploration to Mars or the giant planets. When existing, studies about the scientific programs are mainly focused on astronomy and astrophysics, and stress the effects of bureaucratic management, the consequences of budgetary restrictions or the relationship with the industrials[28]. One important exception may be noted: Erik Conway's history of the atmospheric sciences at NASA, to which we will recurrently refer along our work[29]. In all cases, these are stories about the space sciences, including space technologies, space missions and programs, or space heros, but they rarely connect them with the scientific practices involved in the conception, development, realization and exploitation of such programs. More specifically, within all this copious historiography, as far as we know, satellite data have not been problematized as an object of study before[30]. In these respects, one of the goals of our work, from a methodological standpoint, is to bring a new dimension to such historiography by addressing this tension between the history of space age and the history of scientific practices through the prism of *technological data practices*.

Our work is supported by a number of sources classical in these type of studies. On the one hand, we have consulted the literature provided by the laboratories, by some scientists from their personal archives or obtained through consultation of the Archives Nationales in Pierrefitte and Gif-sur-Yvette

[28] See for instance: "Beyond the Atmosphere: Early Years of Space Science", H.E. Newell, 1980; "Exploring the Sun: Solar Science since Galileo", K.Hufbauer, 1991; "To See the Unseen: A History of Planetary Radar Astronomy", A.J. Butrica, 1996; "Exploring the Solar System: The History and Science of Planetary Exploration", ed. Roger D. Launius, 2012.

[29] "Atmospheric Science at NASA: A History", Erik M. Conway, 2008.

Other accounts dealing with space Earth sciences would be "NASA and the Environment: The Case of Ozone Depletion", Henry Lambright, 2005; or included in specific chapters of the compilations: "Exploring the Unknown. Selected Documents in the US Civil Space Program", J.Logsdon, 1996; "Critical issues in the History of Spaceflight", ed. by S.J.Dick and R.D.Launius, 2006; "Societal Impact of Spaceflight", ed. S.J.Dick and R.D. Launius, 2007.

[30] The existing accounts on satellite data are based on the analysis of images taken from space, especially images of the Earth taken from the Apollo missions, the Shuttle or the International Space Station. They stress the role of such images in shaping environmental perceptions or cultural representations. But in most of these studies, these images are considered as fully developed objects. See for instance: "Image and Imagination: The Formation of Global Environmental Consciousness", Sheila Jasanoff, in "Changing the Atmosphere: Expert Knowledge and Environmental Governance" ed. C.A. Miller and P.N. Edwards, 2001; "Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination", D. Cosgrove, 2001; « Earthrise : How Man First Saw the Earth », R.Poole, 2008; "A la Recherche de l'Environnement Global: De l'Antarctique a l'Espace et Retour : Instrumentations, Images, Discours et Metaphores", S.V.Grevsmühl, 2012.

given that the scientific laboratories involved in POLDER mostly belong to CNRS. We had also access to the digitalized archives of CNES, which contain a huge volume of documents -although poor organized[31]. All these sources include a number of varied documents. For instance, they include institutional documents aimed to report to the funding agencies and/or to the administrations in charge: activity reports, websites, prospective reports, plans and evaluations, budgets, contracts, nominations, projects, newsletters, grants, etc. They include working documents of technical nature (technical specifications of the instruments, of the data systems, drafts and projects, scientific presentations, debriefings of workshops and conferences, internal notices and communications, proceeding of the different “reviews”, etc.) or of other nature (minutes of meetings, letters and correspondence, personal communications, agreements, strategic doctrinal discussions, emails, discussion and position papers, schemas of organization, schedules, budgets, etc.). They include as well outreach material addressed to general audiences like press releases, flyers, announcements and communications, etc. They are however incomplete, spotty and more or less abundant in function of the laboratory, the project, the theme, partner or period. In particular, we have confirmed that a lot of documentation is conserved in the digital memory of CNES –probably, we believe, more as management resources and juridical guarantees than as eventual resources for historical inquiry. In any case, it hosts all kind of the before-mentioned documents, including scanned versions corresponding to old periods. However, many of this material are undocumented. In many cases dates are not provided; in some other cases authorship and/or recipients cannot be identified; in other cases, authorship and/or recipients are referred with acronyms which we have not been able to trace back and decipher; in some other cases, there is no title and the document is referred by its internal code. In some cases we have been able to document the documents via indirect ways; in some other they have remained in the incognita. In consequence, it has been methodologically difficult to refer them as sources. In any case, we provide a list with the most often consulted ones in the annexes (referentied in different degrees according to their degree of self-documentation), while we refer to the digitalized memory of CNES to find the rest. A second type of primary written source has also been consulted: specialized scientific literature elaborated by the actors to communicate their research. These may include peer-reviewed articles, master and doctoral dissertations, publications, chapters of handbooks, conferences presentations, lectures or proceedings of workshops on the topics of remote-sensing, atmospheric physics and chemistry, oceanography, land surfaces studies, climate sciences or numerical modeling. In this case, literature has been minor and the reader may find an exhaustive list in the annexes. Besides, we have attended working meetings (mainly within CNES’s altimetry team in Toulouse) and some scientific manifestations like workshop organized under the auspices of CNES gathering scientists in the domains of land surfaces, oceans and

[31] Archives research was deemed to be also conducted at NASA’s archives. However, our stay in the US coincided with NASA’s shutdown of activities during almost three weeks further a Congress’s decision in autumn 2013. In consequence, access to any NASA facility resulted impossible during that time. We must therefore content with the documents that some scientists and managers kindly provided from their personal archives. By contrast, this setback would barely affect the interviews (on the contrary, some scientists, freed from their daily working duties, had much more time for us) or the consultation of archives in other non-governmental laboratories.

atmosphere (TOSCA in 2012[32]), organized by the Programme National de Télédétection Spatiale in 2012[33] or internal seminars at National Center of Atmospheric Research in 2013.

On the other hand, the other main source of data has been collecting oral accounts of the actors themselves, including interviews also in the United States. We have interviewed a total of 80 different individuals, some of them interviewed at several occasions. A total of 51 recorded interviews (and 29 non-recorded ones) of about 1 to 1,5 hours each one have been conducted -besides, lunch-time, waiting-time in the airport, sharing car or metro travels, or casual encounters have provided scenarios for informal discussions. Find the list in the annexes. The interviews often started with a biographical account of the interviewed, about his or her current area of research, about his or her work practices or the tools he or she mobilized. They were deliberately largely opened to the particular questions deemed important to him or her. While acknowledging that the narration of the actors unavoidably carries bias and subjectivity, interviews, we believe, are a way to have direct access to scientists, to their views and to their practices, or rather, when talking about past events, to the post-hoc self-descriptions of them. The oral and informal narratives of scientists about their work use to be less normative and conventional that the institutional discourses captured in reports, websites or proceedings –they turn out to be even less normative during lunch-time. In a conversation, scientists may adhere or reject the institutional narrations in more or less degree, but certainly they can complete and complement them with their own concerns, opinions, hesitations, proposals and views. They may also emphasize certain explanations or procedures, they may chose a terminology or another, they may reveal events or account for situations which do not appear in the written sources.

It would be naïve however to believe that the interviewees may be willing, or able, to tell everything openly and without reluctance and hesitation –certain distance must be taken in the analysis of the oral records. It must be stressed at this point that written sources are impregnated of subjectivity as well. Of course, it is a subjectivity of a different nature: while oral accounts about past events have been reconstructed and molded under the effects of personal retrospection, written sources tend to be contemporary to the events and may reflect the issues as perceived in the epoch. Another element rendering written archives subjective is the fact that not all the documentation is dutifully conserved -much of it had been lost- and from those archived ones, not all is openly available, not all is properly identifiable, and therefore we have had no access to a complete story. For instance, our account about the setting up of a the scientific team around POLDER (chapter 3) is mostly based on the minutes and proceedings elaborated by the managers of CNES at that time (and oral accounts) –almost no documents on the side of any of the laboratories or other involved institutions (LOA, LMD, CEA, etc.) have been available in duty time for consultation. Third element rendering subjective the written sources: institutional sources such as activity reports, for instance, use to be addressed to funding agencies or to the public audience. The advantage of these official written sources, especially those reports released periodically, is that they enable access to a general evolution of the events, actors,

[32] Workshop organized in 21-22 March 2012 in Paris.

[33] « Journée thématique du PNTS: Problèmes inverses en télédétection spatiale », 14 Novembre 2012, Paris.

institutions, scientific goals and technologies. They enable to chronologically situate the events, to cartography the actors. However, they tend to bring forward the achievements or the research in process, while not mentioning the failures, the delicate controversies, the projects left in stagnation, the delays, the crises or the reasoning driving the scientific decisions. Scientific publications suffer similar bias of not accounting for the failed attempts, the strategic decisions and motivations or other considerations advised as non-pertinent to be expressed in such type of communication support. Personal archives provided by some actors, or found in CNES and CNRS archives, which included personal notes, position papers circulated internally to generate debate, notices or correspondence, have, in such cases, helped to complete the official written documents. In this case, the complementarity with oral accounts is promising. It is through oral accounts, for instance, that we first heard about some of the debates in the building of a scientific team around POLDER in the early 1990s, about the controversies around the efforts of calibrating and validating data, about concurrent methods to retrieve ocean color parameters or about a shutdown of activities in CNES between 2002 and 2003 and some of its effects in current projects.

Many of the interviews have been recorded and transcribed, which constitutes a time consuming method –and which entails, in turn, interviewees allowing to be recorded, for which we are grateful to them. Nevertheless, it results an essential method because by re-listening the interviews we have apprehended some details that we inevitably missed during life discussions or we have been able to fathom different aspects and insights in function of the stages of our investigation. Of course, subjectivity is this case applies to the investigator, to us, for in the exercise of re-listening an interview (or re-reading a document) with sight to looking for a particular insight or hint, it is quite likely to find it. Besides, while interviews are surely useful to us, we like to believe that they may have been useful to the interviewed too, as they oblige them to try to organize and verbalize their views and to make sense of their work practices in a way understandable to profanes. Finally, in so doing, we have ourselves started a data record, hopefully enduring in the long-term, available for other investigators willing to employ it -if we may make the analogy with our own object of study.

A couple of words shall be mentioned about our interviews sampling. In France, most of our interviews, have been conducted to scientists experts in remote-sensing and closely related to the acquisition and production of POLDER's data (from LOA, LSCE or LMD). Next in range would come outsider scientists not involved in the data creation but who take them to use in their scientific inquiries (LOA, LMD, CNRM) in line with space managers (related to POLDER's mission, but also to the radar altimetry missions, to weather satellites and from headquarters). Last in number are computer scientists from ICARE or other actors from non-academic institutions like CLS or Météo-France. This relative unbalance, we believe and we will justify along our essay, reflects actually one of the epistemic specificities of the case-study POLDER, in which scientists dealing with calibration, development of processing algorithms or data outnumber the rest of actors. The most evident effect of such tendency is probably manifested in the very structure of our essay, which concentrates much more attention to the processes of gathering, production, and validation of the data, than on their utilization –to the extent that, when we concentrate on the data utilization we are obliged to appeal to data gathered with other instruments like lidars or radar altimeters. Be as it may, we are aware of such bias and we assume it. Our samples in the United States have been, by contrast, more balanced between scientists and managers from the Langley Research Center of NADA, the Goddard Institute of Space Sciences of NASA, the National Center of Atmospheric Research (NCAR), the National Oceanographic and Atmospheric Administration (NOAA) and the Colorado State University. However, even though in some of our interviews we would make reference to POLDER, our discussions were centered in the projects of the interviewees and in their general views on the topic.

Finally, to come to an end with methodological remarks, our type of research, thorough in the technical details, poses the problem for the investigator that these are forefront domains and that the technologies (material or mathematical) deployed for gathering, calibrating, validating and using the data are complex to figure out for a profane –as exemplified by the fact that none of the involved actors controls all the knowledge and know-how from end-to-end –we do not pretend having grasped all the specificities either. In some occasions it helped having a background in physics, but what certainly helped even more was having the support of some actors available for further explanation and proofreading.

This work has been conducted within the frame of a contract between CNES, Délégation Générale de l'Armement and CNRS-Centre Alexandre Koyré (CAK), inspired by an original request made by the Institut Pierre Simon Laplace (IPSL). It is therefore a study that emanates from the identification by the actors of a current problem: satellite data-handling from gathering to production to preservation to dissemination. Our research was therefore about responding to such a demand while conducting an academic inquiry. This situation, accepted by all the participants, presents certain advantages and challenges. Our investigation constitutes part of a program of a working group of CNES, which since 2009 is committed to engage an institutional reflection about the value (or values) of satellite data; intellectual stimulation has been bred within regular encounters of a piloting committee constituted within this program by members of CNES, DGA, IPSL and CAK and through scientific manifestations organized under the aegis of this working group[34]. Also, financial support has been provided for material logistics, field research or attending to conferences. Needless to say, the program has evolved from the initial request as we learned the issue and received renewed inputs, in function of the available sources, through periodic discussions with the actors and with the individuals in charge of the program, or simply following our personal cycle of scientific maturation and driving it towards our scientific preferences. Other advantages are easy to enlist: proximity to the actors, which allows cartographying rapidly the institutional dynamics and the organization, as well as expediting and facilitating reception of our investigation; the possibilities to put into test and confront regularly the hypothesis and intuitions, and by so doing, helping to progressively shape and frame the object and

[34] A number of research projects, engaging different disciplines (including sociology, management or history of sciences and technologies) and institutions (universities and CNRS) have been engaged ever since to provide elements for the collective debate.

scope of the research; the possibilities of contributing and fueling a broader project, although with a modest contribution; and, connected to that, the satisfaction that our work may be of some interest, even perhaps utility, to third parties. As per the challenges, perhaps the most serious one is the risk of confusing the audience, composed at the same time by academic historians of sciences and technologies, and other social scientists, Earth scientists and space managers. Connected to that, the challenge of achieving a final account susceptible to interest their different expectations, goals, motivations and backgrounds.

This is an important point to be remarked because it orients the form and structure of our work, if not even the content at some point –as in most of the studies actually. History, needless to say, is not necessarily only for historians. One of the methodological goals of our project is to illustrate that it is possible to yield an original contribution to the domain of satellite data, or more generally space technologies and space Earth sciences, by introducing in these fields a perspective from the history of sciences and technologies. As outsiders, we hold a vantage that necessarily illuminates space activities with other sources, bringing forward other issues and mobilizing other rationale, which may come to complement the reflections that the insiders, and ultimately anyone connected to, or simply interested in, the space science venture overall, have about their activities. Precisely because it is not our goal to take sides, our promptings may be useful. We may modestly hope that the materials and questions raised in our essay, besides constituting the result of an academic enquiry, may not be considered only as anecdotic entertainment but also as informative, encouraging and pertinent to the discussions that space mission planners and managers, Earth scientists and decision-makers already have about some of such issues.

In total, this dissertation is constituted by six chapters organized in two parts. It is useful to precise the time period of our investigation. As we have mentioned, POLDER was proposed in 1986; yet, the first important stages of conception, development and realization would take place between 1990 and 1995. It is during that period that the technical specifications of the instrument and of the data system are developed. It is also during this period that the mechanisms for data production and dissemination are defined, that the preparation of the interpretation and analysis of the data is carried out, that a scientific team is created and organized and that the research program is determined. The period just after the launching of ADEOS-I, from 1996 to 1998, represents also an important fraction of our essay because is the period in which the work of quality control of the data was engaged. In total, the three chapters constituting the first part of the essay are dedicated exclusively to this period, 1990-1998, during which POLDER's data is first designed, prepared and developed, and second, produced, checked and disseminated. The period from 1999 onwards is tackled in the two chapters constituents of the second part. It must be said, however, that the last chapter covers a larger time period, from the late 1980s until present day, as it will be explained in its introduction. This temporal divide at the years 1998-1999, of course approximate and conventional, is also used to structure the two moments depicting our dissertation, what we have called the period of *reconciliation* and of *normalization*.

The first chapter is an introductory chapter aimed to provide an historical perspective to the gathering, production, archival and dissemination practices at the dawn of the space age and prior to POLDER, between 1960 and 1985. It overviews some of the space programs of NASA and CNES with the intention illuminate the dynamics between scientific groups, instruments, data and space managers by looking at them through three angles: what were the disciplines considered as "space sciences", who were the credited space scientists and what type of space data were the admissible to conduct scientific inquiry.

Next it comes a semi-chapter reduced in size and which accomplish two functions. First, it introduces POLDER-1 and 2 during the initial stages of conception between 1986 and 1990, pointing to some technical specificities, its proponents and its conditions of approval. Through the case of POLDER we invoke general debates about the epistemological status of a space instrument intended to answer a prefixed scientific question or open to multiple interpretations and about the relationship between the Technical Center of Toulouse and external laboratories. The second function of this semi-chapter is to pose the general hypothesis underlying the rest of the essay.

In chapter two we examine the technologies through which *geophysical datasets* are produced. On the one hand, we analyze the specific knowledge and skills that the creation of physical and geophysical data requires (calibration and inversion). On the other hand, we examine some of the conditions leading to a reorganization of the data handling and to the implementation of a factory-like system to mass-produce and disseminate POLDER's data, and we provide an analysis of such a system from the perspectives of allocating epistemic power to a particular form of data, of organization of labor amongst the actors and of distribution of authority amongst them.

While chapter two is consecrated to study the technological practices to produce *geophysical data*, we dedicate chapter three to study the people producing these data and those deemed to use them in the future. In other words, in a first part we examine how the scientific group is created and how a research program is defined, and in a second part we explore some of the epistemic specificities of this community –we compare some of them to those of the scientific teams of Topex/Poseidon and ScaRaB. We develop in this chapter one of the analytical concepts recurrent in our essay, the notion of *data creators*, those actors holding the expertise in radiation transfer who, by means of technologies of *inversion*, create *geophysical datasets*.

Chapter four offers a picture of what type of space missions are carried out to support research in diverse domains of the Earth sciences. It is divided in three parts. In the first, we explore the practices deployed to assess the quality of the *geophysical data* in three different cases and we connect their particularities to the instruments and technologies available in each case, the social organization, the sources of funding and the object under scrutiny itself. Next, we focus on a particular management tool of CNES, the "Revue de validation", as per seizing the weight of technical institutions in assessing and legitimating the scientific quality control developments. Finally, by stressing the possibilities of field-work and ground-based networks measurements, and relying upon the findings of the first part of the chapter, we try to understand the comprehensive nature of space missions in the domain of Earth sciences that renders them holistic endeavors integrating other technologies besides satellites and satellite-related systems.

A second semi-chapter is then included. Symmetrically to the previous one, one of its objectives is to introduce POLDER-3, conceived in 1999, its proponents and conditions of approval. It is also the occasion to provide some contextual elements browsing the 1990s, when the second generation of experiments in the domain of Earth sciences started to be planned, and to overview the plans and programs at NASA, ESA and CNES for the following decade. It is finally the gateway to the second part of our essay in which we aim to illustrate the *normalization* of the landscape described in the first part.

The primary route to illustrate that a norm is consolidated is with a case reinforcing the practices and representations embedded in it. This is what we do in chapter five through the examination of the technologies to archive POLDER's data. More particularly, we explore scientific insights and technological possibilities driving the creation of centralized datacenters and databases –we pay specific attention to the one dedicated to handle data in the domain of atmospheric physics, called ICARE. We introduce another social group, the *data providers*, charged to produce the data than others will use, and we discuss data preservation, data property, metadata or scientific and social reward.

Chapter six pursuits also the purpose of illustrating a norm but by other means: it looks at the possibility of alternatives to develop. This is a chapter centered in the third of our *data-classes*, the *data users*, those actors using data in contexts distant from their acquisition and production. In a first part we examine a particular use of satellite data as a means to construct a further stage of data, *climatic datasets*, made up from the fusions of *geophysical (*or *physical) datasets* with numerical models. We look at the skills, knowledge and technological practices (assimilation) deployed to produce these data. In a second differentiated part we examine how the satellite data (physical, geophysical or climatic) are recycled and given understanding by looking at three specific casuistic: connecting aerosols properties with epidemiology outbreaks, predicting the quality of the air or evaluating climate models. The possibilities or not for these modalities for re-using the data to achieve are taken as indicators of the existence of a norm that orients forms and prevent alternatives.

Ours is not a history of space programs or technologies, of institutions, of individual trajectories, of international relations, of environmental sciences or of cultural representations of the object space, or of the data obtained from it –ours is a history of the *technological data practices* associated to the gathering, production, archival, dissemination and using of satellite data meant to support studies in diverse disciplines of the Earth sciences. Our story unravels the banal character of data, interrogates their objectivity, neutrality, stability, it examines claims about representations of authority, it seeks to reveal technological developments and practices and tries to connect them to scientific, epistemological, sociological, political or historical features. Assuming that "data are always cooked"[35], our story aims to unveil some of the ingredients, cooking techniques, recipes, cookers, restaurants, suggestions of the chef and dinner guests.

[35] We take here on Geoffrey Bowker's memorable expression quoted in "Memory practices in the sciences", 2005.

1

SPACE SCIENCES, SCIENTISTS AND DATA. A HISTORICAL PERSPECTIVE, 1960-1980.

Devoted to gather data to support the International Geophysical Year, a field campaign organized between 1957 and 1958 to collect data for studies in auroras, cosmic rays, geomagnetism, ionospheric physics, geodesy, meteorology, oceanography, seismology and solar physics, the launching of the first artificial satellite Sputnik is commonly taken as giving birth to the space age. Satellites would rapidly become experiments by their own in domains beyond the disciplines of geophysics that had seen them born, such as astronomy, planetology, physics of plasma, cosmic rays, life sciences and microgravity studies, which came to be known as the “space sciences” within space agencies like NASA[36]. Other domains deployed in the program of the International Geophysical Year like geodesy or meteorology, and, only since the mid-1970s, also oceanography, vegetation studies and atmospheric chemistry, would be often related to a parallel program of “space applications”[37], which would be organized differently in terms instrument building, data processing, data exchange or budget[38]. It would not be before the 1980s that the scientific divisions of space agencies would start looking at our planet just as they looked at other planets and cosmic objects, and that devoted oceanographic, atmospheric, climatic or biospheric programs focused on studying the Earth and its environment would be fostered as part of the so-called “space sciences” program; however, these programs would never be disassociated of their twin mission as “space applications”. By the 1990s, major space agencies would have created a budgetary line specific to what would be stabilized in English language, and under NASA’s influence,

[36] We are referring in this brief introductory paragraph to projects conducted using satellites -projects with sounding-rockets or balloons, as we will point along the chapter, considered these disciplines with another perspective.

[37] We take here the notions of “space sciences” and “space applications” as being the categories used by space agencies (especially NASA, CNES and ESA), without pretending any further analytical meaning.

[38] For instance, at NASA, until 1971, scientific activities would be organized by one of the four offices of research and development, the Office of Space Sciences and Applications. Within this Office, which received 18,8% of the total NASA’s budget (second after the Office of Manned Space Flight, 67,2%), activities would be divided into two rubrics: “space sciences” and “space applications”. While the budgetary line of “space sciences” would be endowed to planetary and lunar exploration (missions Mariner, Lunar orbiter, Voyager, Pioneer, etc.), physics and astronomy (physics of plasma, radiation), biosciences and manned space sciences (microgravity and material sciences), the budgetary line of “space applications” would be devoted to the communications and navigation programs (ECHO, Syncom, etc.), to the meteorological programs (TIROS, Nimbus, rocket-soundings, etc.) and to geodetic satellites. Source: NASA Historical Data Book 1958-1968, NASA Historical Data Book 1969-1978.

under the name of "Earth sciences" (as distinguished from "space sciences")[39]. At CNES, users of the French language, different terms would be used almost indistinctively like "géosciences", "sciences de l'environnement", "sciences de la Terre", "sciences de la Terre, de l'atmosphère et les océans" or "géosciences de l'environnement", just to mention a few[40]. Well aware that language is not naïve and that each label may include subtleties, we propose however a functional common understanding of them as encompassing those disciplines in the domains of oceanography, atmosphere, vegetation, climate or cryosphere. Indeed, it is not our goal to conduct a semantic study but rather to remark that the gradual incorporation of these domains in the scientific programming of space agencies throughout the 1980s and 1990s would result, this is the underlying hypothesis threatening the present essay, in a specific renewed notion of space activities, vocation and practices, a renovated space age sometimes aligning with previous precepts and practices and sometimes departing from them; let us call it, the *age of space Earth sciences.*

Although the center of our investigation starts consequently around the 1980s, when the different domains of the Earth sciences and space technologies would begin their life in common, it may result appropriate to present, in this introductory chapter, a brief overview of the space activities during the initial 20 years of the space age. We propose to do so by looking at these activities from three different angles that may bring into light complementary aspects of the dynamics embedding space scientific missions. In a first part, we will explore the scientific programs engaged by space agencies as a means to understand *what* were considered to be the "space sciences" (and the place of what would came to be known as Earth sciences in this category). In a second part, we will look at the organization of the experiments and the data practices as a means to understand *who* were considered to be the space scientists. Thirdly, we will scrutinize the technologies of sensing to understand *what data* were considered to be the data useful for scientific inquiry. These three general descriptions, which may be read in parallel, have the interest, we maintain, of bringing forward some characteristics defining the original epistemologies embedding the production, dissemination and use of satellite data for scientific research. It is important, we believe, to enquire, even if rapidly, into these practices in order to further better grasp the changes and evolutions as well as the continuities and perpetuations in them that may take place in the following decades in which disciplines of the Earth sciences entered the game. At the same time, this overview will serve to introduce some notions and terminology (sometimes taken as analytical concepts, sometimes as functional descriptions, sometimes borrowed from the actors, sometimes of our own) common in our essay –not with the goal of establishing rigorous definitions but rather to provide common lexicon and understanding and facilitate communication with the reader. Finally, through this overview, the main questions and hypothesis guiding our investigation will be situated.

This chapter, as well as our investigation, is basically centered in France and its space activities. We have however considered useful to include in this overview rapid insights about the same issues as

[39] NASA Historical Data Book 1989-1998.
[40] Rapports d'activité CNES between 1981 and 2010.

they took place at NASA (and eventually the European Space Agency and the Soviet partners) in order to offer a comparative counterpoint to illustrate possibilities, alternatives and mutual influences. Our sources have been basically the annual activity reports of CNES, Laboratoire d'Optique Atmosphérique, Laboratoire d'Etudes et Recherches en Télédétection Spatiale or Laboratoire de Météorologie Dynamique, the Historical Data Books elaborated by NASA including annual and decadal synthesis of programs, budget and orientations, the descriptions of the missions elaborated by the corresponding space agencies as well as synthesis and presentations made by a number of individuals, complemented with few oral accounts.

SPACE SCIENCES[41]

In this section we broadly overview the different meanings that the term "space sciences" may have been given since the dawn of the space age by NASA and CNES by exploring the different disciplines that have been labeled as "space sciences" during this period. We are not entering into many technical and historical details but providing simply an overview, which have the further interest of giving an insight of different ways of organizing and considering space programs and technological developments in both space agencies. In connection, and far from pretending any rigorous and dogmatic definition, one of the goals of this section is to provide a common understanding of some terms (remote-sensing, Earth observation, space sciences, space applications), which are recurrent in our essay. To render this overview of programs easy-reading, we have divided the period from 1960 to 1980 into three sub-periods organized by decades following the classification done by one of our sources (the NASA Historical Data Books).

Categories of "space sciences" and "space applications" are recurrent in all our development. Before continuing, an important point must be remarked regarding the ways in which we conceptualize this distinction: it is not much helpful, as we will argue, to look at these opposed categories through the perspective of the disciplines they encompass. Examples are easy to quote. While typically labeled as "applications" emphasizing its importance in economic and societal activities, weather satellites or Earth survey satellites can be useful for many academic research, including meteorology, oceanography, biology, geology, agriculture, hydrology, geography or others. Similarly, ionospheric satellites are typically labeled as "space sciences" emphasizing the study of auroras, magnetosphere, energetic particles or wave propagation, but they are indispensable for ensuring telecommunications systems. Instead, we suggest to examine these categories through the prism of their organization, the distribution of labor between the participants, the relationship between the conceivers of a given instrument, its manufacturers, the developers of software for data processing, the responsibles for data quality control and the potential users, or still the modes of archiving and disseminating the data. Under this angle, we believe, more interesting insights about the allocation of power and authority

[41] In this section, and in general in all our work, we are just referring to unclassified space missions coordinated by civilian space agencies.

amongst the participants may be revealed. Put it simply, focusing on *how they are realized* rather than on *what they are for* helps to illuminate, we believe, some material, epistemological and social dimensions embedded in the space projects. We start, in the first section, by stressing the materiality of the technologies that carry out space activities.

1960s: Technologies and vehicles for space sciences

Satellites at NASA: Distinguishing "space sciences" and "space applications"

The International Committee for the International Geophysical Year had defined as soon as in 1955, even before the launch of Sputnik, a number of scientific disciplines that, according to the members of such Committee, would gain from being studied with experiments carried aboard sounding-rockets and satellites, which were considered at that time as the space-related technological vehicles: meteorology, ionospheres, energetic particles, magnetic and electric fields, gravity, astronomy and biosciences[42]. By 1958, when the US Space Science Board, a body pending on the National Academy of Sciences conceived to coordinate the American efforts in the domain, was created it adopted these very same disciplines and named them "space sciences"[43], a label that would last until today –although its content would change over the years.

NASA scientific programming would materialize a slightly different signification to this term. Since its inception in 1958, NASA's leadership made the choice of assemble all its programs related to sciences within the Office of Space Science and Applications (OSSA), which would consume around the 20% of NASA's total budget between 1958 and 1970[44]. These programs would be distributed in four main branches, which altogether would constitute what NASA understood as "space sciences": planetary and lunar exploration (interplanetary milieu or solar system with missions Mariner, Lunar orbiter, Voyager, Pioneer, etc.), physics and astronomy (cosmic rays, geomagnetism, high energy physics, astrophysics with the Explorer family, the mission conducted in cooperation with CNES, FR-1), bioscience (life sciences with the Biosatellite family) and manned space sciences (life sciences and physics in weightless with biomedical missions such as BIOS, for instance)[45]. If NASA had satellite

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[42] They would be seven in number: meteorology, ionospheres, energetic particles, magnetic and electric fields, gravity, astronomy and biosciences.

Source: "National Space Sciences program", NASA 1959.

[43] The Space Sciences Board (SSB) was appointed in 1958 at the request of the Executive Committee of the US National Committee for the International Geophysical Year. Ever since, it has been the focus of independent and authoritative advice to NASA, the Department of Defense and the National Science Foundation on all aspects of space science and applications.

"Letter announcing the formation of the Space Science Board", written by Detlev W. Bronk, president of the National Academy of Sciences, to Lloyd V. Berkner, president of the Associated Universities, Inc., 26 June 1958.

[44] NASA would divide its programs into four different offices dealing with manned space flight (67% of NASA's total budget), tracking and data acquisition (5.6%), advanced research and technology (7.5%) and the Office of Space Science and Applications.

"NASA Historical Data Book", 1958-1968 and "NASA Historical Data Book", 1969-1978.

[45] NASA's organization included, in 1970, 9 laboratories distributed across the territory. Those laboratories that would be mainly responsible for "space sciences" would be the Goddard Space Flight Center and the Jet Propulsion Laboratory. In the 1970s, the Langley Research Center began also being involved in "space sciences", although it

programs connected to meteorology or geodesy (like TIROS or Nimbus) it would be as part of what the Agency leadership considered as "applications" intended to weather forecasting or for determining altitude and latitude, and not necessarily optimized for research in the associated domains of atmospheric physics, gravity dynamics or oceanography –even though, some scientists may make use of their data for their scientific inquiries. These programs of "applications" would be also managed by the same Office (OSSA), together with satellite missions in other domains such as communication and navigation (Echo, Relay, Syncom, etc.) and since the 1970s also Earth resources survey satellites (ERTS, becoming Landsat)[46]. A way of grasping the particularities of such classification is to look at the organization of the projects: while projects falling in the category of "space sciences" used to be conceived and built by a scientific team and retained many of the epistemic specificities of an experiment in the classical domain of physics[47] (the scientific team ensured the manufacture, proper calibration, secured the analysis and interpretation of the data, their archival), projects considered as "applications" used to be conceived and realized by space agencies or contractors and were intended to be operated by client entities like weather services, geological agencies, defense instances, including scientific groups –we will analyze this aspects in detail in the second part of the present chapter.

Sounding-Rockets and Balloons at CNES: Science, a foundational mission

Created in 1961 to define the French civil space policy, the Centre National d'Etudes Spatiales (CNES) would be at the dawn of the space age, and still is, a central player in French space research[48] –although not the only player[49]. CNES is headquartered in Paris, but there are various centers across the territory, including the Technical Center initially located in Bretigny and moved to Toulouse (gradually between 1969 and 1974), the Direction of Launchers in Evry (recently moved to Paris) and a launching site in Kourou (French Guyanne). The role of headquarters is essentially to develop agency policy and to provide overall direction and guidance for the agency, as well as to act as the representative before the government and other institutions and agencies. Headed by a President, CNES's headquarters contains several divisions and directorates, the most important ones in our story have been those that oversee all the programs in the domain of geosciences, which have been renamed

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would be coordinated under the responsibility of the Office of advanced Research and Technology. In 1980, the Goddard Institute of Space Science would be created, also pertinent to our essay.

"NASA Historical Data Book", 1958-1969.

[46] NASA Historical Data Book 1958-1968 and NASA Historical Data Book 1969-1978.

[47] A lot has been said about the specificities of the experimental culture in physics. For classical seminal introductions see: "Image and Logic: A Material Culture of Microphysics", P. Galison, 1997; "The Uses of Experiment", D. Gooding et al., 1989; or "Epistemic Cultures: How the Sciences Make Knowledge", K. Knorr-Cetina, 1999.

[48] It is not our purpose to trace the political and institutional history of CNES or space activities in France. Actually, albeit there exist some accounts written by actors themselves (see for instance, "L'école de l'espace: Le Service d'Aéronomie", ed. M.L. Chanin, 2008 or "L'espace, les enjeux et les mythes", A. Lebeau, 1998) and some chronological reconstructions ("Les trente premières années du CNES", Carlier et al., 1994), an exhaustive historical study remains yet to be done.

[49] The Météorologie Nationale or the Centre National d'Etudes de Télécommunications, just to mention two, would also be involved in civil space activities, including scientific research

and relocated in CNES's organizational chart at several occasions –as we have mentioned before[50]. While strategy and policy are also present and defined in Toulouse, the bulk of activities of this center is to conduct detailed engineering and management work on CNES's projects, mainly through feasibility studies as well as design and development of spacecraft, instrumental components or data. Today, many of the Toulouse-engineers deal with project management issues; nonetheless, some in-house work of research and development is still maintained in order to not lose competitiveness and to keep the personnel abreast of the latest developments in the fields, for them to be in position to judge the interest of the missions and the work of contractors. For instance, CNES decided to keep the know-how and technical and scientific capacities in the domains of metrology (time and frequency), electronic developments (circuits, transistors, batteries, wires, connectors, etc.), propulsion systems, optical detectors, simulation chambers, thermic activities or orbital control.

There are a number of differences between the American and the French space agencies in terms of organization, technology, composition or mission, and particularly in the ways in which CNES would conceive its vocation. In particular, the distinction made at NASA between "space applications" and "space sciences" would be less obvious at the outset of CNES. Just like at NASA, science was central to CNES, considered as « l'origine et noyau dur de l'activité spatiale française, mission fondatrice du CNES en 1961 »[51]. It is illustrative, for instance, the fact that the "Division the Programmes", that is to say, the body organizing and coordinating the space projects conducted under the auspices of CNES, would be exclusively focused in scientific programs until 1968. In other words, all programs engaged were considered as scientific experiments. During that time, there was indeed a "Division d'applications" related to the communications and weather forecasting domains, although it would belong to the "Direction d'Affaires Internationales", a directorate separated from the "Division of Programmes". Unlike NASA, for almost all the first decade of its existence, the programming of CNES would only include the launching of experiments in the domains of astronomy, ionospheric physics, cosmic physics, biology, atmospheric physics and meteorology, magnetosphere and geodesy –note that, unlike at NASA, meteorology and geodesy would be thus considered as part of the scientific programming of CNES. Let us just give two examples. Scientists of the Service d'Aéronomie would measure the light Lyman-alpha with sounding-rockets launching frequently during all the decade; the Service d'Électronique Physique du Commissariat à l'Energie Atomique would measure the flux of radiation gamma incoming from the Sun during several launchings of magnetometers and riometers on board of stratospheric balloons[52]. These experiments were proposed, build and interpreted by scientists in universities, research centers or CNRS, and they were carried by sounding-rockets or balloons.

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[50] Within the organizational chart, the divisions coordinating the activities in the domain of Earth sciences have been sometimes called Division des Sciences de la Terre et Applications, Division des Sciences de la Terre, Océans et Atmosphère or simply Division d'Observation de la Terre, to mention few labels.

[51] Rapport d'activité du CNES, 1963-1964.

[52] Rapport d'activité du CNES, 1964-1965

To be sure, it was not that CNES's leadership believed in using the space assets on behalf of any sort of purity of science or that it was blind to the potentialities of satellite assets as useful for meteorological and telecommunications applications. On the contrary, as soon as in 1962 in the annual activity report of CNES, for instance, it was acknowledged that

> "il est possible d'escompter que, dans un petit nombre d'années, les satellites pourront être employés dans d'autres buts que ceux de la science pure. Ce type de satellite est appelé «satellite d'utilisation»"[53].

–from 1963 onwards the appellation "satellite d'utilisation" would become "satellite d'application". The very same year, 1962, this is another example, professor Pierre Morel, by then director of the Laboratoire de Météorologie Spatiale in the University Paris 6, and also director of the scientific program at CNES between 1962 and 1968, acting as secretary of the influent scientific advisory committee assessing and recommending the missions to CNES, would propose a scientific experiment in the domain of meteorology, called EOLE, a scientific experiment which could not be disconnected from its applications in two domains: weather forecasting and gathering and relaying data with satellite[54]. The idea of "satellites d'applications", and particularly using satellites for weather forecasting or relaying data from one place to another, was therefore present since the creation of CNES.

If the programming of CNES did only include scientific experiments during its first years, we argue, it was rather more a matter of technical capabilities than of principles: CNES was unable to launch satellites before 1965[55]. The first years of CNES, and of space activities in France, would pass hence without satellites, but with balloons and sounding-rockets. This is, we argue, an original difference vis-à-vis NASA: NASA was created after the ability to launch satellites had been demonstrated in order to coordinate and organize the civilian space activities in the United States, whereas CNES was created prior to that, precisely in order to acquire such a capability. Put it simply: specificities of the vehicles would orient the programming. Sounding-rockets' trajectories describe one-shot parabolas lasting from seconds to few minutes in the space (or in the air); balloons glide unpredictably following isobars and air streams. While useful for time-limited experiments or to gather specific samples of data or/and as training stages in the learning process to build and launch satellites, these kinematical

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[53] Rapport d'activité du CNES, 1962-1963.

[54] The experiment EOLE would be conducted in 1971. More than 400 balloons would be released simultaneously to glide at three different altitudes (5000, 10000 and 18000 meters) and acting as tracers of air masses. They carried instruments to measure pressure and temperature, and they carried as well beacons that would emit radio signals with such measurements. A satellite would then collect these radio signals, from which, a part from the meteorological data, the exact position of each balloon would be determined. The satellite would store all these data in an onboard storage device and would transmit them to ground stations when entering in their range. While the balloons-part of this project was organized and carried out in an experimental mode by scientific groups lead by the Laboratoire de Météorologie Dynamique, the satellite-part would be qualified as of applications in the activity report of CNES, "EOLE est un satellite d'application, destiné à la mise au point et à l'évaluation d'un nouveau système d'aide à la prévision météorologique globale ».

See: "The EOLE Experiment: Early Results and Current Objectives", P. Morel et al., 1973.

[55] Two satellites were launched in 1965, Asterix and FR-1. While the first one had been launched with an in-house launcher, called Diamant, the second one would be realized in close collaboration with NASA, materializing different stages of apprenticeship.

Rapport d'activité CNES 1965-1966.

characteristics do not make them appropriate technologies for ensuring continual services in the domains of weather forecasts, telecommunications or geodesy. Put it in another way, the notion of "applications" understood as providing continual services (potentially merchandisable) only made sense in connection with a specific technological vector carrying the devices rendering this activity possible: the satellite. Unlike sounding-rockets and balloons, satellites remain in more or less stable orbital trajectories, traceable and for longer periods. This connection can be seen by the fact that as soon as CNES had acquired the ability to launch satellites, two satellite projects clearly associated with applications would be proposed (a telecommunications satellite Symphonie in 1967 and a weather satellite Meteosat in 1968) and the organization of its programs would be reconfigured, as we will see in the following section.

1970s: From outer space questions to "earthly looming problems"

Rendering applications a bit more "scientific" at NASA

By the bend of the 1970, Congress would favor the budget of applications in detriment of that of space sciences[56]. NASA's administrator of the Office for Space Science and Applications said in 1971 that NASA had acquired during the 1960s

> "a basic lead in space exploration, scientific knowledge, and technology. During the next decade, we could apply this experience toward the study and solution of looming Earthly problems identified as derivatives of the continuing growth of the world's population… social needs as improved transportation and communication, pollution, monitoring the environment, etc. (…) We have found increasing interest in the exploitation of our demonstrated space expertise and technology for the direct benefit of mankind in such areas as earth resources, communications, navigation, national security, science and technology, and international participation. We have concluded that the space program for the future must include increased emphasis upon space applications"[57].

It continued by saying that space applications "will bring important benefits to our understanding of Earth resources, climate, weather, pollution and agriculture"[58]. The organization of programs at NASA would change taking into account the increasing importance of applications satellite programs in the space effort: the Office of space science and applications (OSSA) would then distinguish two sub-offices, one dealing with "Space sciences", defined in three branches (lunar and planetary programs, life sciences programs and physics and astronomy programs), and the other dealing with "Applications" (telecommunications, meteorology, navigation or Earth survey and resources).

A number of satellites would be programmed to be launched during the 1970s in the classical domains of satellite applications, but also in new domains such as atmospheric chemistry or oceanography –

[56] It is not the place in our dissertation to scrutinize the motivations and context that would drive NASA's leadership towards a progressively increasing number of missions labeled as applications in detriment of space sciences ones. For a first insight see: "Exploring the Unknown", ed. J.M. Logsdon, 1998 and "Atmospheric Sciences at NASA", E.M. Conway, 2008.

[57] John E. Naugle, Associate Administrator for Space Science and Applications between 1967 and 1971. Quoted in NASA Data Historical Book 1969-1978.

[58] NASA Data Historical Book 1969-1978.

arguably leveraging the first wave of environmentalism emerging in the decade. These two programs intended, for instance, to monitor air pollution or ozone concentration (family of instruments Stratospheric Aerosol and Gas Experiment (SAGE) carried aboard Explorer-60 and different experiments aboard Nimbus-7) and to survey the oceans or optimize maritime routes (like GEOS or SeaSAT). These two programs would be however organized in a form closer to the missions in the domain of "space sciences" than those of weather, telecommunications or Earth survey satellites: it would be a team of scientists from a laboratory or a university who would conceive, and in some cases even manufacture, the instruments to be carried by such satellites and who would prepare the analysis of the data. Unlike in meteorology, navigation or telecommunications missions (missions which were developed at NASA's technical laboratories or by industrials, with no advice of academic community), academic oceanographers and atmospheric scientists from universities or other research centers would participate in the definition of the instruments to be carried by the satellites of the atmospheric chemistry and oceanography programs as well as in their data processing. Clients of such programs were identified, as it was usual in the applications programs, as being weather services, oceanic services, environmental agencies, geological institutes, other administrations, or defense instances. However, because these missions would carry scientific instruments optimized for research in the corresponding field, they would appeal another kind of potential clients as well: scientists specialists in the field domains of oceanography, atmospheric chemistry, meteorology, vegetation studies or glaciology, who had not participated in the design of the instrument or the preparation of the data. In other words, these recently arrived missions in the "applications" program of NASA would have the effect of rendering this program a bit more "scientific", in terms of conception of the instrument, the analysis and interpretation of its data and the users of such data[59]. In turn, the progressive "scientification" of NASA's applications programs in the domains of meteorology, geodesy, physical oceanography, atmospheric chemistry or Earth resources would lay the path towards the conception, during the 1980s, of several missions to study the Earth and its environment and to the creation of a specific division of "Earth sciences", as complementary to the "space sciences".

The shift towards applications at CNES

Winds from opposite direction would blow at CNES once the ability to launch satellites would be acquired. The 1970s would witness a shift towards increased "space applications" (weather forecasting, telecommunications, satellite-aided location and data collection, Earth survey) leading to the loss of the monopole that science had enjoyed until then in the French space program. From then on, balloons and sounding-rockets must coexist, sometimes compete, with satellites. "Space sciences" must henceforth co-exist with another mission, "space applications", seen as of economic and social

[59] NASA Historical Data Book 1968-1978.

importance. During the presentation of the VIème Plan elaborated in 1969, the physicist André Lebeau[60], Directeur de programmes et du plan at CNES since 1965 would claim :

> « C'est la possibilité de concevoir des programmes pré-opérationnels qui est seule, à mon sens, de nature à justifier le maintien d'une activité spatiale de grande ampleur et son développement (…). C'est ce programme qui entraînera tout le reste, notamment la possibilité d'exister d'un programme scientifique »[61].

Nothing prophetical in these words, but rather a reaction to the establishment in 1964 of the global satellite telecommunications system INTELSAT and to the launching of the first satellite of the program Landsat in 1972, which would arise awareness of the economic and political impacts of space activities. CNES new leadership, head by the astronomer Jean-François Denisse, would start to emphasize applications of space technologies, inasmuch they contributed to social and economic development, and programmed and launched satellites in the domains of location and collection of data (starting with EOLE, proposed in 1962 and launched in 1971), telecommunications (Symphonie, proposed in 1967 and launched 1974), weather (Meteosat proposed in 1968 and launched in 1977, after being transfered to the European Space Agency) and Earth resources (Système Probatoire d'Observation de la Terre, SPOT, proposed in 1973 and launched in 1986)[62]. The materialization of such a shift can be rapidly grasped, besides from this previous overview of the satellite programs, with three other moves. First, the organizational chart at CNES would be characterized by the move of the Division d'applications from the Directorate of international affairs to the Directorate of programs, which it shared with its twin Division scientifique[63]. Second, the programs of sounding-rockets, which had been a precious source of scientific experiments since 1961 (and even before the creation of CNES), was closed in 1974. Third, the logo adopted by CNES in 1975 claimed "L'espace utile" making explicit its orientation[64].

This promotion of applications-oriented missions to exploit the satellite economic and societal potentialities was accompanied by a parallel reduction of the scientific missions would take place at CNES, creating the effect of an unbalanced national programming. One element shall not be neglected, however, in this balance: the European space context. Established in 1975, the European

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[60] Physicist expert in ionospheric studies he would participate in one of the expedition to the Antarctica during the International Geophysical Year to build the French base Dumont d'Urville and he would fund the Groupe de recherches ionosphériques in 1961. In 1962 he would enter CNES, first as Director de Programmes et du Plan until 1972, and later on as Director de Programmes et Politique Industrielle until 1975, when he would join the European Space Agency in charge of the weather program Meteosat until 1980. Since then he occupied different responisibilities at MeteoFrance, Eumetsat and the World Meteorological Organization, and he has authored a number of divulgation books. In 1995 he was appointed president of CNES, a responsibility that he would only hold for two years.

[61] « Perspectives et lignes directrices de l'activité du CNES », André Lebeau, director of programs and planning of CNES, presenting the Plan in 1969.

[62] This does not mean that *only* satellites for applications would be launched; rather, contrary to the previous decade, *also* programs of applications would be launched. As a matter of fact, 9 out of the 14 satellites launched by CNES, under its national program, in the decade would be intended to experiments in the domains of ionospheric studies (Aureole 1 in 1971 or Aureole 2 in 1973), geodesy (Starlette or Castor, both in 1975) and astronomy (Aura in 1975 or Signe 3 in 1977).

[63] Rapports d'activité du CNES between 1975 and 1978.

[64] The notion of utility would never abandon CNES's vocation. If we look at the successive logos adopted by CNES, we find it again in all of them: "L'espace au service de l'homme" in the 1980s, "L'espace au service de la Terre" in the 1990s or still "De l'espace pour la Terre" 2000s. Source: Rapports d'activité CNES between 1976 and 2010.

Space Agency (ESA) would assume, among other, an ambitious scientific program oriented towards supporting the research in the domains of the "space sciences" understood as astronomy, planetology, solar physics, geomagnetism and fundamental physics. This program would be of mandatory contribution of all Member States of ESA on a scale based on their gross domestic product. French satellite programs on these domains would therefore not be conducted as part of the national space endeavors but CNES would promote their realization as part of the French contribution to the program of "space sciences" within ESA. CNES's own satellite program in space sciences would concentrate first in ionospheric studies and progressively more and more in geodesy, which was not addressed under ESA's program. This ambitious European program came at a price though. An increasingly greater part of the national French budget endowed to space activities –which remained quite steady all along the decade- would go to ESA's program, which constrained the budget left to national programs. To give a hint of the figures, in 1974 the 33% of the French space budget went to the future ESA and it raised up to 60% in 1979. In 1981, it would suffer a reduction to the 40% (associated to the end of the Ariane-1 program) and from then one it has remained steady oscillating between 40-45% until today[65]. Complementary to this scientific mandatory program, ESA would define a parallel program of "applications", in which Member States could choose to participate or not and with what level of involvement. Missions like the Spacelab platform for the future NASA's space station or the telecommunications satellite Marots would be integrated in this program. The weather satellite Meteosat, transferred from CNES to the European joint effort by 1973, would also become a part of such optional program of "applications". As a result of this reconfiguration of activities, the number of scientific satellites coordinated by CNES alone would be dramatically reduced from 1975 onwards. For instance, between 1965 and 1975 CNES would participate in the launching of 18 satellites (from which 13 devoted to astronomy, ionospheric studies, aeronomy or geodesy and gravimetry) while in the following decade, between 1976 and 1986, the number would be reduced to 5 satellites (from which two devoted to astronomy and ionospheric studies in 1977 and 1981)[66]. We shall note at this point that this description of the French space program straddling between CNES and ESA reflects a more general ways of running at CNES associated to its national and international policies: projects internal to CNES and projects responding to external announcements of opportunities made by another space agency. Internal national projects are space projects under la *maîtrise d'oeuvre* ou *d'ouvrage* du CNES who is in charge of the space system, including the payload, the platform and the launcher. External projects consist in bilateral or multilateral cooperation with other space agencies or operators, in which collaborations with NASA and ESA figure first on the list of strategic priorities. In these cases CNES acts both as the technical provider of a component, usually an instrument of the payload, as well as as the political interlocutor or ambassador between the French and the foreign partners. CNES programming reflects a calculated balance between national and international programs, because both categories are considered as necessary and complementary each other: the national

[65] Rapports d'activité of CNES, 1974-2010.
[66] Rapports d'activité of CNES, 1965-1985.

program fuels a “levier” in order to acquire and maintain sound competences that would then allow to respond to external calls, that is to say, to put French instruments a board of foreign satellites and probes, which would permit to conduct more experiences -and at a reduced cost.

As the space activities were reconfigured, the moving of the Technical Center of CNES from Bretigny to Toulouse would start, achieving its final stage in 1974. With that move, some of the technical capabilities until then held by CNES’s engineers would be transferred to the industrials, together with the technical control of some systems and skills. At the same time, scientific instruments became more and more complex for two reasons: first, simple experiments had been already conducted all along the previous years and they required gradually more sensitive sensors, more long-lived, more resolved or statistically more significant[67] and, second, placing them inside a satellite (instead of a balloon or a sounding-rocket) required complex interfaces with the rest of the components, including the sources of power, the thermic control, the data storage device, the communications system or the ground segment. Many laboratories, holding expertise in building relative simple instruments to be put aboard sounding-rockets, would not retain technical skills for manufacturing the required complex technologies to be placed aboard satellites. They would appeal for technical aid to the new Technical Center of CNES in Toulouse, which in turn used to appeal to industrials. Let it be said, however, and this is an important point for further developments, that capabilities for building instrumentation to be put inside balloons or aircraft or to be deployed in the ground, seen as much more technologically simple and cheap, would be retained in the scientific laboratories. Anyways, in the case of satellite, this would have some effects on the organization, development and realization of projects by introducing, for instance, the figure of the “space manager” at the Technical Center of Toulouse acting as interlocutor between the industry and the scientific laboratories. As scientists lost technical abilities and as industrials got more power, the particular role that scientists had acquired during the first decade in the planning, definition and realization of scientific experiments would vanish. All these developments, to which we will come back in a while, created the impression that CNES was abandoning its original scientific vocation, in favor of a number of programs in different domains considered as “applications”.

The case of SPOT excellently illustrates these worries about the strategic direction that CNES was taking as space agency, perceived as progressively leaving aside its foundational mission of supporting scientific research activities, which had been the linchpin of CNES’s identity. A program for surveying the Earth’s resources had been proposed in 1973, approved by the Conseil d’Administration of CNES in 1974 and received definitive approval by the Government in 1977, in the course of a special session of the Comité Economique et Social devoted to the topic –it would be then that the

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[67] Some space managers like to illustrate this point with the following example: while back in the late 1950s a primitive radiation counter could be a source of astonishing scientific discoveries like the Van Allen belt, two decades later, the “easy-things had been already exploited” and more complex technologies would be mobilized to respond to more complex scientific questions.

Michel Avignon, personal communication.

program would be definitely named Système Probatoire d'Observation de la Terre or SPOT[68]. The radiometers inside SPOT were conceived and developed by in-house departments of the Technical Center in Toulouse and part of their components was entrusted for realization to a number of industrial societies. Few academic scientists of universities, CNRS or other scientific institutions had been consulted in regards of its experimental configuration (wavelenghts, filters, field-of-view, calibration, orbit, etc.) or in regards of the possible processing of the data or preparation of their analysis. In this sense, SPOT exacerbated the ways of running programs of "applications", like it was done in telecomunications satellites, for instance. Yet, so it was argued, the scientific community –a generic term- was targeted as being one major client of the program: after all, high resolution imagery would be certainly useful to support studies in oceanography, hydrology, geology, agriculture, geography, vegetation, biology, cryosphere, or many others, as had been demonstrated with the program Landsat since 1972. However, not having participated in the design of the instruments and their data, the scientific community had little influence not only to define the spectral bands or space resolution more adequate for their inquiries but also to orient the deliverable types of data, the possible modes of data processing, the potential field of applications or the policies of data access. This crystallized exactly the fears amongst space scientists: the fact of being progressively excluded of their influence in defining the scientific programming of CNES, the fear of losing the authority as scientific space experts –an idea which had been reinforced with the recently modified organizational chart of space activities in France in 1976, which created two figures, the Commissaire du gouvernement, placed between the Division of programs and the Direction of CNES, and the Conseil des applications spatiales pending of the Ministry of Industry and Research placed between the advisory scientific group and the Direction of CNES, mediating two links that had been direct until then[69].

More generally, turning to methodology, this example illustrates the interest of conceptualizing the distinction between "space applications" and "space sciences" in terms of organization, conceivers of a given instrument, its manufacturers, the developers of software for data processing, the responsibles for data quality control and the potential users, or still the modes of archiving and disseminating the data –and not of the disciplines or type of activities that they are meant to support.

Box 1.1. « Observation de la Terre »

With the development of SPOT the term « Observation de la Terre » would be introduced in the common parlance of CNES. Indeed, SPOT would be commonly known as the French program of Earth observation. In turn, with this program, the term "télédétection" ("remote-sensing" in English language) would be added to the common vocabulary, simply understood as the activity carried out by SPOT. In the activity report reporting the activities of CNES for the year 1974, the activity of Earth observation would be defined as:

[68] Au cours d'un Comité Economique et Social réuni le 1 9 septembre 1 977 sous la présidence du Premier Ministre, le principe de l'engagement d'un programme de satellite d'observation de la Terre a été approuvé par le Gouvernement. Rapport d'activité CNES 1976-1977.

[69] "Décret relative au centre national d'études spatiales et à l'organisation de la recherché spatiale", décret n° 76-104, 27 January 1976.

« L'observation de la Terre par satellite regroupe l'ensemble des activités relatives à l'obtention depuis l'altitude orbitale de mesures physiques de notre environnement, terre, océan et atmosphère, en vue de:

• dresser les inventaires des ressources,

• améliorer notre connaissance des processus physiques régissant notre environnement,

• surveiller l'évolution de celui-ci et l'impact des activités humaines »[70].

The term "Observation de la Terre" would progressively integrate new missions other than SPOT. Three years later, the low resolution weather program Meteosat and the program of satellite-aided location and data collection systems Argos-based would be included under this label. By 1981, after the proposal of the physical oceanography program Poseidon, this program would be considered as belonging to the Earth Observation category –although within a not minor number of bastions, the term Observation de la Terre, as well as its associated "télédétection", continued, and continues today, to be used in common parlance as referring to the SPOT program[71]. From the 1980s onwards, in terms of organization of programs, no stable orientation would predominate. The Directorate of Observation de la Terre would in some periods only include the program SPOT, in some others also Meteosat, Argos and/or Topex/Poseidon, while in some others even the experimental satellites like POLDER –and all the imaginable combinations varying with leadership, governmental priorities and general context. In some periods the Directorate would not exist as such. In any case, this category had little impacts on budgetary lines, as each particular program, considered inside or outside this category, would have its own budget specificities.

Given that, we believe, the term "Earth observation" does not constitute a category useful for approaching our topic. The expression certainly has a powerful cultural value, even as propaganda tool, which invokes a number of representations of the space activity, but the use of this term does not help to elucidate any of the questions addressed in our work; we are avoiding using it in our essay. In the few cases that we use it, it is mainly for literary purposes to denote a generic type of activities distinguished from other generic type of activities like astronomy (sometimes referred as Observation de l'Univers), telecommunications, space manflight or exobiology, to mention some examples.

1980s: The Earth as another planet

"Earth sciences and applications"

As a result of the "scientification" of NASA's programs of "space applications" during the 1970s, a number of new original missions organized in a "space sciences" mode would be promoted at NASA as part of its "applications" programs, beginning with oceanography and atmospheric chemistry. They would be equipped with original instrumentation designed by scientific teams, who would secure the analysis and processing of the data –without neglecting other potential clients. In other words, NASA's leadership would start looking at the Earth just like it looked at other planets, using the same

[70] Rapport d'activité CNES 1974-1975.

[71] Rapport d'activité CNES 1983.

sensing technologies and encompassing the same scientific goals[72]. The instrument until then mainly used to study the atmospheric dynamics of Venus, Jupiter or Saturn (like polarimeters, radiometers), to study the chemical composition of stars (like spectrometers), to study cosmic radiation properties (geiger-mullers, riometers) or to study gravity fields and internal core dynamics celestial bodies (radars, lidars) could be used to study our planet's atmospheric composition, energy budget or fluid dynamics. Space scientists and laboratories at NASA's laboratories Jet Propulsion Laboratory (JPL), Goddard Space Flight Center (GSFC) or Langley Research Center (LaRC), which until then had been occupied in looking outwards, would start to apply their skills and knowledge to look towards the Earth. After all, whether looking outwards or towards, it was remote-sensing anyways: using the properties of the radiation to characterize the objects emitting it.

The satellite missions to the planet Earth would consist in singular satellites of big dimensions, designed in line with the overall gigantism dominating space engineering culture in the United States (archetypically represented by the Hubble Telescope, the Space station or the Star Wars project), carrying a large number of instruments (radars, radiometers, altimeters, etc.), orbiting following polar trajectories[73], consuming huge amounts of power and needing big antennas[74]. These programs would not be gigantic only in their technological architecture (and cost), but also in what they did not rely uniquely on space systems but they would encompass a myriad of instruments in the ground, balloon or aircraft together with laboratory studies and numerical simulations –an aspect that we will further develop along our essay. Each NASA's laboratory that had some expertise in the traditional "space sciences" would propose at least one of those gigantic missions to be launched during the decade of the 1980s[75]. The Earth Radiation Budget Satellite (ERBS) of LaRC was designed to gather radiation budget data, aerosol data, and ozone data to assess climate change and ozone depletion and would be launched in 1984; the Upper Atmosphere Research Satellite (UARS) of GSFC to get data for better understanding atmospheric photochemistry would be approved in 1978 and launched in 1991 with 10 instruments aboard; and the combination of the Ocean Topography Experiment (Topex), proposed by JPL in 1978 to study oceanic circulation by means of a radar altimeter, and Poseidon proposed in 1979 with the same scientific goals by a consortium of two laboratories, the Centre de Recherches de

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[72] Several aspects have been pointed as explanatory for the shift of NASA's leadership towards the planet Earth happening in the late 1970s. On the basis of an underlying will to regain the confidence of a public opinion reluctant to high-tech developments, and the Congress, they include, for instance, increasing political attention and public sensitivity to environmental concerns, and in particular, NASA's own concerns about CFC's with regards of the realization of the Shuttle, or potentialities for commercialization and economic return of investments.

See "Exploring the Unknown", ed. J.M. Logsdon, 1998 and "Atmospheric Sciences at NASA", E.M. Conway, 2008.

[73] Polar orbits are low orbits in which a satellite travels north-south over the Earth's poles, rather than in the more usual east-west direction. The big advantage of this is that in a single day satellite placed in polar orbits can observe the entire Earth. This is useful for projects that require the complete Earth to be mapped once a day.

[74] For a history of big space engineering see for instance "Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program", H.E. McCurdy, 2001.

[75] Only the recently created Goddard Institute of Space Sciences (GISS), established in 1981, would not propose any mission during the first half of the 1980s. They would however propose a number of programs to exploit the satellite data, like the International Satellite Cloud Climatology Project in 1982 as part of the World Climate Research Program. It was aimed to analyze satellite radiance measurements gathered with the five different weather satellites flying in geostationary orbits to infer the global distribution of clouds, their properties, and their diurnal, seasonal, and interannual variations.

Géodésie Spatiale (a department of the Technical Center of CNES in Toulouse) and the oceanographic department of the Institut de Physique du Globe in Paris, would give birth to the mission Topex/Poseidon launched in 1992.

A second type of programs to study the Earth from the orbits would be fostered by NASA. The Global Habitability program proposed by JPL in 1982 offers an illustrative example. Contrary to the singular satellites realized to study a particular phenomena during a limited period of time (say ERBS, UARS or Topex/Poseidon), the Global Habitability program was meant to be a long-term enduring system of coordinated polar-orbiting satellites designed to monitor and understand key components of the environment and their interactions through long-term observations covering the whole globe simultaneously, complemented by a series of instruments placed in the ground, carried by ships or aircrafts and put inside the Space Shuttle. In other words, instead of shooting time-limited satellites for gathering data for a given punctual experiment, this program aimed to long-term continuous gathering of environmental parameters –mirroring, in so doing, the applications programs in which data are collected and processed permanently. As we will see along our essay, this would constitute a conceptual difference both in the ways space missions are conceived and in the ways in which different disciplines of Earth sciences are conceived. An Announcement of Opportunity for the selection of instruments was issued in 1988. More than 450 proposals were received from teams all over the world (including a proposal to put a prototype of POLDER in one of these satellites). Early in 1990, NASA announced the selection of 30 instruments, along with their science teams. However, this particular program would not be approved by the Congress. That being said, the System Z program, which was the space component of the Global Habitability program, would be redefined into a renewed space program, the Earth Observing System (EOS), as NASA's contribution to a larger national program, the US Global Change Research Program, which would derive in turn into the International Geosphere-Biosphere Program (IGBP) coming to light in 1986. As proposed in 1990, EOS would be composed of four gigantic satellites covering the whole planet to be repeated at least three times so as to achieve 15 years of time span: two spacecraft provided by NASA (the EOS-A and EOS-B), one by the Japanese Space Agency (the Japanese Polar-Orbiting Platform, JPOP) and the fourth provided by ESA (the Environmental Polar-Orbiting Platform, EPOP). After a series of rescoping, successive modifications, budget cuts, concurrent programs[76] and fusions with other programs, a renovated version of EOS would be approved by Congress in 1992. Meant to be the heart of NASA's Mission to Planet Earth established in 1993, it would be composed by a series of around 20 small singular satellites, similar to those spacecraft developed at JPL used for NASA's missions in the domain of traditional "space sciences", carrying different instruments and launched three times as to ensure a continuous period of data-gathering of about 15 years. Coordinated by mixed teams of JPL and GSFC, this program aimed to developing, collecting, analyzing, and archiving space-based

[76] The Goddard Institute of Space Sciences would propose in 1988 a consistent program for collecting data to study climate change, called CLIMSAT, which would be also discussed by Congress before falling for the Earth Observing System of JPL and GSFC. For concrete aspects of this program see: "Low-cost long-term monitoring of global climate forcings and feedbacks", J. Hansen et al,. 1995.

observations of the Earth, with the ultimate goal of improving the world's ability to detect and document changes in global climate[77].

This renewed regard towards studying our own planet, however, would not be disassociated to the potential applications of the satellites and missions. This can be seen with the reorganization that took place in 1983 at NASA. In particular, the Office of space science and applications (OSSA) would be reorganized as to contain seven different branches: “space physics, Earth sciences and applications, solar system, astrophysics, life sciences, microgravity and applications, and communications”[78]. With these categories, besides the traditional space sciences studying stars, planets, galaxies, microgravity properties, exobiology, interstellar plasma, cosmic rays or magnetism, NASA was formalizing the introduction of this new object to be studied by using the same approaches, tools and techniques with which space scientists studied the other objects: the Earth. Note nevertheless that the qualification of “sciences” would not be separated from its twin mission of “applications”. This duality, we argue, constitutes an original conundrum immanent to the satellites orbiting our planet launched to support diverse disciplines in the domain of Earth sciences: generally characterized by a design, and sometimes, manufacture made by a scientific team, who also secures the data interpretation, they serve the purposes of a set of clients, amongst which a wide scientific community (well beyond that that had conceived the instrument), but also weather services, environmental agencies, oceanographic organizations, energy departments, and more recently, with the increasing importance of environmental concerns and issues of planetary management, also security instances. From then on, the category “Earth sciences and applications” would become an essential part of NASA’s mission. For instance, by 1993, the Office of space science and applications (OSSA) would be split again into two sub-offices: “Mission to Planet Earth” and “Planetary Science and Astrophysics”. The first would deal with programs addressing “Earth sciences and applications” while the second addressing “space sciences”, according to NASA’s grammar. In 1998, the program “Mission to Planet Earth” would be renamed into a simple clear self-evident “Earth Sciences” program[79].

Overview of programs at CNES

The 1980s began with a major event taking place in Les Arcs. In 1981, more than 150 scientists from 30 different laboratories would be gathered together in the first scientific meeting organized under the auspices of CNES, called the Séminaires de Prospective Scientifique –a formula that would be ever since repeated every four or five years. This meeting was the first time that scientists coming from all French territory, from all disciplines, using all possible techniques and methodologies, from all types of institutional affiliation, were convened together to talk space and science next to space managers

[77] “Earth Observing System (EOS) Reference Handbook”, eds. G. Asrar and D. J. Dokken, 1993.
On the history of the EOS program, see Erik Conway’s “Atmospheric science at NASA” and Roger A. Pielke’s “Policy history of the US Global Change Research Program”.
[78] NASA Historical Data Book 1989-1998.
[79] “NASA Historical Data Book”, 1989-1998.

and programmers of CNES. During this meeting, scientists were distributed into working groups related to their domains of specialty. Two large blocks were organized, “Sciences de l’Univers” and “Sciences de la Terre”, which in turn had specialized sub-working groups[80]. One point was made clear in the conclusions: scientific programs must be fostered at CNES, by giving priority to those missions proposed by the scientific community:

> “Concevoir des projets spatiaux originaux et assurer leur réalisation en fonction de nos orientations scientifiques prioritaires est la condition pour maintenir la vigueur des recherches spatiales dans notre pays"[81].

In other words, the original vocation of CNES, sciences, had to come back to CNES, which meant that scientists and academic institutions must participate in the conception, building, development, realization and exploitation of the next generation of space projects. In turn, this meant that scientists must be skilled, and active, in proposing space projects in support of their academic inquiries. This convened well to CNES’s leadership, which wanted to spread the use of satellite data as a means to maximize its investments. The more number of scientists involved in a project, so it was reasoned, the more number of users would have such project. But what sciences?

Like in the United States, some French scientists, who had acquired some expertise in the traditional “space sciences” would also start applying their knowledge and skills to study some features of the Earth’s environment. Arguably, these defectors would be motivated by personal research interest or job opportunities in a given laboratory. However, we argue, these choices would also, at least partially, be a reaction to the delays and cancellations of the NASA’s missions in which a number of French scientists worked, like Pioneer Venus or Galileo -a dramatic fact that would be sharpened with the delays and cancellation of some Soviet mission as well, like Venera[82]. Let us look briefly into two specific cases, which are far from being exclusive, but that illustrate this effect. Our first example is the astrophysicist Robert Kandel, expert in the study of cosmic radiation in the Observatoire de Meudon and the Service d’Aéronomie. When in 1981 his temporal contract at the Service d’Aéronomie came to an end, Robert Kandel would not hesitate in putting his knowledge about radiation physics at the service of climate studies funded by succesive grants of the Météorologie Nationale to study the albedo in Sahel by using data from Landsat and Meteosat. After all, climate is about energy budget, that is to say, the balance between incoming and outcoming radiation and, as expert in cosmic radiation, he was well-placed to study Earth’s radiation as well. In 1985 he stabilized his position as permanent researcher in the Laboratoire de Météorologie Dynamique consolidating his conversion towards climate studies with the analysis of the data gathered by the ERBE experiment of NASA. Kandel’s expertise in satellite instrumentation, in interpretation the radiation and his renovated interest in applying it to study the Earth’s radiation budget made him an appropriate candidate to be appointed, just after his arrival at the Laboratoire de Météorologie Dynamique, as scientific

[80] Proceedings of the « Séminaires de Prospective Scienctifique de Les Arcs », 1981.
[81] Pierre Morel Séminaire prospective Scientifique CNES, Les Arcs 1981
[82] « L'école de l'espace : le Service d'aéronomie, 1958-2008 : histoire et science », ed. M.L. Chanin, 2008.

responsible to conceive and realize one of the instruments of CNES's during the decade, the Scanner for Radiation Budget (or ScaRaB) proposed by the Direction of programs of CNES to LMD[83]. Similar career conversions can be found as well at the Laboratoire d'Optique Atmosphérique (LOA), in where a number of physicists had been working in the late 1970s, and in collaboration with the Service d'Aéronomie, in the realization, among others, of the nebulometers to be used in the Pioneer Venus mission as well as in some of the data processing algorithms. Among these *lillois* scientists there were the physicists Maurice Herman and Richard Santer, who worked in studies about planetary atmospheres, mainly of Venus but also Jupiter and Saturn, by means of interpreting photometry a polarimetry measurements. Given the changes and delays in NASA's programming, and given the fact that CNES's was allocating research grants to those projects aimed to study the Earth and its environment (the "Actions Thématiques Programmées" that we will adress below), they would progressively turn towards applying polarization techniques to observe the Earth's atmosphere and characterize some of its properties, specificially the tropospheric aerosols[84] –a career shift that would result crucial to POLDER, as both scientists would be part of the team developing the instrument, in particular in defining some scientific goals and calibration techniques. All and all, as several scientists at Service d'Aéronomie, at Laboratoire de Météorologie Dynamique or at Laboratoire d'Optique Atmosphérique that used to work with American and Soviet space sciences missions found themselves their scientific activity reduced after changes in such missions, on the other side of the balance, they saw that research about atmospheric chemistry, oceanography or radiation budget was increasingly ascending in the political agenda, and therefore funding sources, as exemplified with the allocation of grants through the "Actions Thématiques Programmées" since 1978 or the creation of the Programme National d'Etude de la Dynamique du Climat (PNEDC) in 1980.

At the same time, while maintaining its primary objective of being a tool to monitor and manage Earth resources, the program SPOT also catalyzed this interest of scientists towards studying the Earth with remote-sensing tools. It did that in two ways. First, by fostering the research in the domain of scientific analysis and interpretation of the remote-sensing images provided by the radiometers aboard the satellite in terms of oceanography, forestry, glaciology, climate or geological features. Indeed, because SPOT had been conceived without scientific participation, CNES and CNRS set up a system of grants (the "Actions Thématiques Programmées" –we will come back to it in a while) to rally in scientists, with the ultimate goal of promoting the use of SPOT's data amongst the scientific community. We have just mentioned that a number of scientists, including Maurice Herman and Richard Santer, would benefit of such grants in the domains of "télédétéction", "atmosphère" or "océanographie spatiale". Secondly, scientific teams willing to launch an experiment into orbit could use the satellite SPOT to carry it as an additional instrument, called *passenger*, to the main radiometers of SPOT. The altimeter Poseidon in 1979, the radiometer Vegetation in 1983 and our case study, the radiometer POLDER in

[83] Interview with Robert Kandel, LMD, 2012 and Rapports d'activité LMD, 1979-1986.
[84] Interview with Maurice Herman, LOA, 2014.

1986 are some of the examples of instruments proposed as passengers of the satellite SPOT[85]. In that sense, looking toward the Earth offered the possibility to develop scientific instruments at a national scale. In so doing, the will of CNES's leadership and space promoters to broaden the use of space technologies and satellite data amongst the French scientific community converged with the will of scientists to get back their influence in defining the scientific program of CNES, which passed by gaining back the ability and capability to conceive, build and realize instruments. Given that ESA's scientific program was rather focused on the traditional "space sciences", and provided that SPOT offered potential opportunities for fly, CNES's national program, we argue, would focus on the "Earth sciences", aligning in so doing the trends in NASA's programming as well as in the national and international political agendas related to the environment.

During the decade of the 1980s CNES would start investing in satellites to support research in several domains of the Earth sciences, experiments that had been proposed by scientists through the periodic scientific meetings under the auspices of CNES or through annual calls for ideas released by the French space agency. This is how Philippe Waldteufel, physicist at the Service d'Aéronomie of CNRS, in the conclusions of the second scientific meeting organized by CNES in 1985 in Deauville, put it:

> "La communauté des Sciences de la Terre rassemblée à Deauville a pris conscience de son ampleur et cohérence. Par rapport au précédent Séminaire des Arcs, elle représentait une proportion accrue des chercheurs présents, ce qui témoigne de la poussée qu'elle exerce pour s'affirmer dans la famille spatiale (…) Le séminaire de Deauville marque une date pour les sciences de la Terre : se sont regroupées, en effet, autour du thème de l'instrument spatial, l'ensemble des spécialités qui concourent à la connaissance et la compréhension de la planète (…). Depuis plus de trente ans, les chercheurs ont tenté de placer l'étude de la Terre dans une perspective planétologique. Pour la première fois à Deauville, émerge le fait que la communauté française prend conscience qu'elle sera capable de prendre en charge cette problématique, et exprime son vœu de d'en voir donner les moyens. On voir donc se dessiner les contours d'une communauté apte à mener un dialogue plus riche avec les acteurs de la recherche planétologique »[86].

CNES's imprimatur for scientific research in different specialties associated to Earth's environmental features would come in the early 1980s, driven by a will to study the Earth in a "planetological perspective", just as other planets had been studied –and were still being studied mainly through ESA's and NASA's programs- during the first 20 years of space age. CNES would organize scientific meetings, coordinate the laboratories around instruments and missions, render them institutionally strong, involve scientists from different laboratories and proactively promote the use of the same data across laboratories and disciplines, and made the study of the Earth gain status amongst the hierarchical pyramide of scientific disciplines. These efforts materialized in the following proposals. The radar altimeter Poseidon was proposed in 1979 by Jean François Minster of the department of oceanography of the Institut de Physique du Globe in Paris and by Michel Lefebvre of the Centre de

[85] A number of instruments have been proposed as payload passengers to SPOT. Poseidon and POLDER, for instance, were proposed to be carried as passengers in SPOT-3; PASTEL (PAssager SPOT de Télécommunication Laser) conceived by ESA and VEGETATION-1 in SPOT-4, or VEGETATION-2 aboard of SPOT-5, to mention some.

[86] « Conclusions et recommendations. Groupe de travail Sciences de la Terre", writen by Philippe Waldteufel, Second Séminaire de Prospective Scientifique held in Deauville 1985.

Recherches de Géodésie Spatiale to be launched in collaboration with scientists of the Jet Propulsion Laboratory of NASA in 1992[87]. Robert Kandel and his team of the Laboratoire de Météorologie Dynamique, as already mentioned, would conceive and develop the scanning radiometer ScaRaB launched twice to measure the radiation budget in 1994 and 1998 within the framework of the French-Soviet space cooperation[88]. The radiometer in four spectral bands called Vegetation proposed in 1983 by the Laboratoire d'Etudes et Recherches en Télédétection Spatiale and some internal departments of the Technical Center in Toulouse would be launched inside SPOT-4 in 1998. At the Service d'Aéronomie, Marie-Lise Chanin and her collaborators conceived and developed a lidar called ALISSA to study the interactions between clouds and radiation launched in 1996 aboard the Russian space station MIR[89]. To end this list of instruments conceived and developed by scientific teams all along the 1980s, in 1986, a group of scientists of the Laboratoire d'Etudes et Recherches en Télédétection Spatiale working with some internal departments of the Technical Center in Toulouse, in close collaboration with scientists from LOA, would propose a radiometer named Polarization and Directionality of the Earth's Reflectance (POLDER), that would be launched inside the Japanese platforms ADEOS I and II, in 1996 and 2002[90]. Besides these instrument-based projects, gigantic structures like the huge projects developed by NASA's laboratories would also be conceived in France, like the Bilan Energetique des Systèmes Tropicaux, BEST, proposed in 1985 by a team gathering scientists from four laboratories (Laboratoire de Météorologye Dynamique, Service d'Aéronomie, Laboratoire d'Optique Atmosphérique and Centre de Recherche en Physique de l'Environnement Terrestre et Planétaire) to study the water cycle in the tropical regions as a component of the international program Global energy and water cycle experiment (GEWEX) of the International Geosphere-Biosphere Program (IGBP)[91]. It would be composed by five instruments, including a lidar Doppler from which computing horizontal winds and a radar from which computing precipitations.

All along the 1980s a set of actions would be engaged to introduce space technologies in many of the domains of Earth sciences, new forms of proposing and developing missions would be established, as well as renewed mechanisms of funding, new impetus to the scientific impetus and vocation of CNES would be given, and the first spurs of a space scientific community in the domain of Earth sciences would be manifested. Grounded on the case of POLDER, one of the hypothesis of our essay is that CNES would be instrumental in consolidating, creating if we may, such a scientific community, a

[87] For details of the project, see: "TOPEX/Poseidon. Joint Working Group Final Report", prepared by Jet propulsion Laboratory of NASA and CNES in December 1984, and approved by the corresponding projects managers (Charles Yamarone at NASA and Michel Dorrer at CNES) and program managers (Williamn Townsend at NASA and Jean-Louis Fellous at CNES).

[88]"The ScaRaB project: Earth radiation budget observations from the Meteor satellites", R. Kandel et al., 1992.

[89] "First results of the ALISSA lidar on board the MIR platform", M.L. Chanin et al., 1999.

[90] Other space programs to observe the Earth were developed at URSS, India, China and in a minor maner UK and Italy. However, because they are not directly relevant to our case study, POLDER, we are not developing that in here.

[91] « BEST : Objectifs scientifiques et définition préliminaire d'une mission spatiale dans le-cadre des Programmes GEWEX et Géosphère-Biosphère», issued in 1988.

community that we may call the space Earth scientists. It is the goal of our work to illustrate some of the processes leading to that creation as well as to describe some of its epistemic specificities.

Box 1.2. Plans for studying the Earth

NASA and CNES would use different sensing technologies, including radar, lidar, spectrometry, radiometry or even GPS to measure Earth's environment parameters to support studies in the domains of atmospheric physics and dynamics, atmospheric chemistry, marine biochemistry, physical oceanography, vegetation studies, glaciology or climate studies. The American and the French agencies would however not be alone in this renewed regard towards planet Earth. Let us overview the programs of the two other space agencies pertinent to our essay, the Japanese and the European, with the simple goal of offering the reader with a broader panorama of the satellite plans conceived during the 1980s[92].

In 1977, the Japanese space agency NASDA had launched its first Geostationary Meteorological Satellite (GMS) as a contribution to the international GARP (Global Atmospheric Research Program), and five more would follow before 1995. During the 1980s, NASDA planned to launch the oceanic satellite MOS-1 by 1987 and its twin, MOS-1B, scheduled for 1990. The Japanese satellite for environmental monitoring, JERS-1, was proposed in the early 1980s and had a launch scheduled by 1992 and the program ADEOS for global change had been proposed in 1987[93]. In 1988, first preliminary studies for the Japanese polar platform JPOP started as part of the Earth Observing System of NASA. NASDA was also very active in the preparation of international research programs, like GEWEX, IGBP and the US Global Change Program, by proposing instruments to gather observations from satellite platforms. For instance, the Tropical Rainfall Measuring Mission (TRMM) study precipitation cycles in the tropics had been proposed in 1986 in collaboration with NASA as a central element of the International Geosphere-Biosphere Program.

Reminiscent of the first decades of space age, the mandatory scientific program of the European Space Agency did not include any satellite supporting studies in any domain of the Earth sciences, but only satellites supporting research in the domains of astronomy, solar physics, magnetism, cosmic rays, non-Earth planetology, etc. If ESA had a meteorological program, Meteosat, it was included within the optional program of the agency and depending on the division of "space applications" –at the insistence of the French during the negotiations for transferring Meteosat from CNES to ESA in the early 1970s[94]. In 1979, ESA would agree to develop an optional program of Earth sciences beginning with the European Remote Sensing Satellite (ERS-1), which would be launched in 1991, followed by ERS-2 in 1995, and based on the SPOT-type satellite and carrying several instruments, including a synthetic aperture radar, radar wind scatterometer, a radar altimeter or a scanning radiometer. Further the G-7 meeting of 1982 in which a need for coordinating activities in the domain of satellite Earth observation was strengthened, European countries would take the responsibility of ensuring part of it with

[92] For a directory of past, current and future Earth observation missions, although not totally exhaustive, consult the catalog maintained by the Committee on Earth Observation Satellites (CEOS): http://www.eohandbook.com/. A very helpful reference is also « L'espace, nouveau territoire. Atlas des satellites et des politiques spatiales », ed. F. Verger, 2002.

[93] We only provide an overview of the missions developed by the National Space Development Agency of Japan, NASDA, a governmental agency, since it is the partner of CNES in the story of POLDER. Let it be said, however, that there was another institution with capability to launch satellites in Japan, the Institute of Space and Astronautical Science (ISAS), an older institution pending on the University of Tokyo and which developed a parallel program.

[94] This had been a condition, almost sine qua nom, imposed by CNES when negotiations about transferring the project from CNES to ESA would take place between 1973 and 1975, as reported by John Krige and Arturo Russo in "A History *of the* European Space Agency", J. Krige and A. Russo, 2000.

the realization of the Environmental Polar-Orbiting Platform (EPOP), which would be further included to complete NASA's coverage for the EOS program[95], and which would be launched in 2002 under the name of ENVISAT. It would be one of this gigantic architectonical platforms embarking 10 instruments, including the sensor Medium Resolution Imaging Spectrometer (MERIS) to retrieve, inter alia, the ocean chlorophyill content, a SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), a scanning radiometer, a radar altimeter, Global Ozone Monitoring by Occultation of Stars (GOMOS) to measure ozone and other gazes, or Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) which provides pressure, temperature, and profiles of trace gases NO_2, CH_4, HNO_3 or H_2O in the stratosphere.

SPACE SCIENTISTS: EXPERIMENTERS

After having given an overview of some of the missions starting to be programmed from the 1970s onwards to study the Earth and its environment, we propose in this second part of the chapter to look at them in terms of organization between scientific teams and CNES, and the relationship between the instrument and the data. This regard may be useful to understand who were the "space scientists" conducting "space sciences", what meant to be a "space scientist" and how this category would evolve during the first 20 years of the space age. Our goal is not to provide an exhaustive list of all the existing particularities but rather to accentuate some epistemic commonalities existing amongst the ways of designing and building instruments, getting and processing the data and favoring their archival. As suggested in the introduction, this section offers a parallel reading to the previous one, aimed to bring into light the practices of conceiving, collecting, producing, disseminating and archiving the data by emphasizing the function of the principal investigators and the scientific team, and connecting the evolution of this figure with the industrialization of space missions taking place in France in 1970s, the increasing technological complexity of the experiments and the will to maximize the efforts by outreaching a wider scientific community.

The *Principal Investigator-mode*: a culture of experimental physics

Principal Investigators of the "laboratoires sélectionnés" and "self-made" data: instrument builders

Since its creation in 1958 NASA has employed a variety of approaches to provide space scientists with data. Many NASA projects operated with what we could call a Principal Investigator (or co-Principal Investigator) format or *PI-mode*. In its simplest form, a scientist of a NASA's laboratory, a university or a research center (for instance, the US Geological Survey, the National Oceanic and Atmospheric Administration (NOAA, former Environmental Science Services Administration, ESSA), the Scripps Institution of Oceanography or foreign laboratories) would provide an instrument that would be flown inside a satellite made and launched by NASA. This scientist, commonly called principal investigator or PI, would be directly shipped back the obtained data for analysis in the laboratory. In some cases, a

[95] « Plan à long terme en observation de la Terre», signed by Antoine Mizzi, 1991.

more complex form would be deployed because it would be difficult for a single PI to develop the payload instrumentation, especially when sensing technologies or space vehicles would become more complex. Then, NASA's technical laboratories would begin developing their own scientific instrumentation. Often this would be done in collaboration with teams of interested scientists that had responded to a NASA's "announcements of opportunity" to participate in the experiment, usually open to international participation. These investigators, chosen on the basis of scientific excellence in some specific area like instrumental conception, optical calibration, software processing development, testing with simulations or error analysis, to give some examples, would form a "scientific team", in which each scientist was interested in a particular feature of the experiment. In these cases, a single PI would be named to head the team and co-PIs would be named at each institution participating in the scientific team of the experiment. Many variations can be found in the terminology (PI, co-PI, scientific team, expertise team) and in the concrete distribution of tasks but the functions of such scientists remain stable: technical and scientific overview of the overall instrument, of its calibration and of the instrument integration with the spacecraft, and prelaunch software development activities, tests and coding and/or in the interpretation of the data after the launch. Some missions would be realized in collaboration with foreign space agencies in France, Japan, Canada, United Kingdom, Germany, Italy or Europe. In those cases, specific cooperation agreements would be signed in a case-per-case basis to define the role of PIs and co-PIs, their function, the composition of the scientific team, the limits of collaboration, the technology exchange, the limits to this exchange, the data handling, and so forth. Just to give an example, in 1963 an experiment built by professor Jacques Blamont, at that time director of the Service d'Aéronomie du CNRS, about the luminescence of the night skies would be selected by NASA as a part of the payload of the satellite OGO[96]. Professor Blamont would be considered the PI of the instrument (his laboratory had built it) and would be shipped the data gathered with it in the form of magnetic tapes for further analysis in the Service d'Aéronomie. The point to be remarked is that these scientists, whether called PIs, co-PIs or scientific team (or other), participated in som degree to the conception of the instrument (sometimes even in its building), in the calibration of its data and/or of the elaboration of their analysis. This is why we refer to them as *instrument-builders* in the classical sense of experimental physics, carrying an ethos of an experimenter who builts an instrument, treats the data and interprets them in a given scientific context. Satellite data, hence, used to be *self-made* by the instrument builder, and not necessary shared neither stored.

Since its inception in 1961, one of the major goals of CNES has been to « développer et d'orienter les recherches scientifiques et techniques poursuivies dans le domaine des recherches spatiales »[97], without no intention to shadow off the existing scientific institutions, like the Centre National de Recherche Scientifique (CNRS) or the universities. Actually, the French scientific community working with space-related activities was by then rather small. Because of the technical difficulties

[96] Rapport d'activité CNES 1963-1964.

[97] Loi n^{o} 61-1382 du 19 décembre 1961 portant création du Centre national d'études spatiales.

and budgetary imperatives inherent to the development and realization of space systems, in a first stage CNES leadership preferred to concentrate in consolidating these few areas and groups by promoting a « politique de concentration systématique des moyens dans un certain nombre de laboratoires dits « sélectionnés » »[98]. In 1965, le Conseil d'Administration du CNES « recommande que le C.N.E.S. établisse des liens privilégiés avec un petit nombre de laboratoires dont la liste sera périodiquement révisée et sur lesquels s'appuiera désormais par voie de développer ou de regrouper l'essentiel des activités de recherche dans le domaine spatial (…). On réservera un faible pourcentage du budget aux groupes en formation et aux petites équipes, de façon à ne pas figer le système »[99]. Five laboratories were « selected » in that manner : the Service d'Aéronomie of CNRS, the Service Spatial de l'Observatoire de Paris, the Groupe de Recherches Ionosphériques of the Centre National d'Etudes de Télécommunications (CNET), the Service d' Astronomie Spatiale de Marseille and the Service d'Electronique Phvsique of the Commissariat à l'Energie Atomique (CEA)[100]. Before the end of the decade, CNES encouraged enlarging this small community and it fostered the creation of new laboratories in other disciplines in order to « élargir la participation des scientifiques français à l'effort spatial mondial et susciter en France la formation d'un nombre raisonnable de noyaux actifs et effectivement compétitifs sur le plan scientifique »[101]. Perhaps the more pertinent to our study, would be the creation of the Laboratoire de Météorologie Dynamique of CNRS further to a fusion of the Laboratoire de Physique de la Basse Atmosphère directed by Paul Queney and the Laboratoire de Météorologie Spatiale directed by Pierre Morel in 1968, one of whose missions would be to develop a weather satellite (the future Meteosat[102]), and the creation of the Groupe de Recherche de Géodesie Spatiale created from a fusion of some departments of Institut Géographique National, Centre de recherches en géodynamique et astrométrie, Bureau des Longitudes and the Technical Center of CNES in Toulouse and Grasse in 1971, which would specialized in geodesy, and later on physical oceanography, missions. By 1972 the number of « selected laboratories » had increased to eight and it stabilized to eleven by 1975 (see table 1.2)[103]. Altogether, these eleven "selected labs" would constitute the *center* of the space-related research in France during the first 20 years of the space age, research that turned around the domains of astronomy (gamma, x, ultra-violet, radio), aeronomy, optics and spectrometry, geodesy, ionosphere, meteorology, nuclear and cosmic radiation physics, and space physiology[104]. With the exception of optics and spectrometry, these disciplines would coincide with what had been carved "spatial disciplines" by the scientific advisory committee created in 1958 in

[98] « Les programmes su CNES. Objectifs et premiers résultats », 1972.
[99] « Resolution du Conseil d'administration », 14 October 1965, when the « selected laboratories » where instituted.
[100] « Resolution du Conseil d'administration », 14 October 1965, when the « selected laboratories » where instituted.
[101] « Plan national de recherches spatiales 1964-1973 ».
[102] Hélène Guillemot traces the origins of this laboratory in her doctoral dissertation « La modélisation du climat en France des années 1970 aux années 2000 Histoire, pratiques, enjeux politiques », 2007.
[103] « Les programmes su CNES. Objectifs et premiers résultats », 1972.
[104] These are the disciplines defined in the « Plan national de recherches spatiales 1964-1973".

the US, the Space Science Board, as those scientific domains interesting to be studied by means of space-based experiments[105].

The "selected laboratories" would receive most of the resources allocated for space research in France during the first 20 years of space activities. In a contractual basis, CNES would support their activities by providing technical training for the design, fabrication and testing of the payloads, by purchasing equipment such as computers, testing devices or by providing access to CNES's central computers for data analysis (1700 hours of computer calculation per year per laboratory), by building research facilities, by providing tracking and data-reception facilities, by recruiting technical and administrative staff, by funding PhD research programs and by giving grants for conferences[106], fellowships or summer schools[107]. To get a hint of the figures, under the budgetary line "aide aux laboratoires" these 11 laboratories benefited from 78,8% of the total credits of CNES consacred to its scientific program in 1980. The 21,2% left was distributed between other *peripherical* dispersed teams remote from the centers of scientific space knowledge, which got funded in a project-basis mode through the "Actions Thématiques Programmées", a joint CNRS-CNES program created in 1978 to promote scientific research in the space domain, especially in developing techniques to interprete and analyse satellite data in the fields of planetology, vegetation, oceanography or stratospheric chemistry as a strategy to learn to exploit the data of the future satellite SPOT–to which we will come back in a while[108].

Laboratory and institutional affiliation	**Location**	**Director in 1980**
Service d'Aéronomie (SA) – CNRS	Verrières le Buisson	J.E. Blamont
Laboratoire de Physique Stellaire et Planétaire (LPSP) – CNRS	Verrières le Buisson	R.M. Bonnet
Centre d'Etude Spatiale des rayonnements (CESR) – CNRS	Toulouse	F. Cambou
Laboratoire Météorologie Dynamique (LMD) – CNRS	Paris et Palaiseau	A. Berroir
Laboratoire d'Astronomie Spatiale (LAS) – CNRS	Marseille	G. Courtes
Groupe d'Astronomie Spatiale de l'Observatoire de Meudon (GAS) – CNRS	Meudon	J.L. Steinberg
Centre de Recherche en Physique de l'Environnement Terrestre et Planétaire (CRPE) – CNRS and CNET	Orléans la Source et Issy les Moulineaux	J. Hieblot
Laboratoire de Géophysique Externe (LGE) – Associé au CNRS	St. Maur	J. Delloue

[105] Defined by a Space Science Board created in 1958 to propose scientific experiments to be carried aboard satellites. They would be seven in number: meteorology, ionospheres, energetic particles, magnetic and electric fields, gravity, astronomy and biosciences.

Source: "National Space Sciences program", NASA 1959.

[106] These programs still exist today and constitute the engine of future space scientists and engineers. Our investigation has also benefited from one of such doctoral scholarships, as part and parcel of a movement initiated by some CNES's insiders to introduce a social sciences dimension into the activities of CNES. Gathering scholars in the domain of space policies, sociology, sciences of management or history of sciences, through this program, it is intended to engage a debate and reflection on CNES's own activities.

[107] For instance, between 1962 and 1965, 50 doctoral projects would be funded with scholarships funded by CNES in around 20 different laboratories in France. Summer schools starting in September 1966 and conducted every two years organized by CNES and the university of Toulouse addressed to students of university level. Likewise, a course on space technology for scientific experiments would be organized annually in collaboration with CNES and CNRS dedicated to doctoral students or CNRS scientists and technicians. These two training programs exemplify some of the efforts of the Division of Relations Universitaires of CNES: introducing future scientists in the discipline of space sciences and training current scientists and engineers in the advanced space technologies.

Rapports d'activité CNES.

[108] Rapport d'activité CNES, 1980.

Service d'Electronique Physique (SEP) – CEN/CEA	Saclay	J. Labeyrie
Groupe de Recherche de Géodesie Spatiale (GRGS) - IGN, CNES, CERGA and Bureau des Longitudes	Grasse et Toulouse	B. Lago
Groupe de Recherche de Biologie Spatiale (GRBS) - Université Paul Sabatier	Toulouse	H. Planel

Table 1.2. List of "selected laboratories" by 1980[109].

The notion of "selected laboratory" invoked an approach to the gathering and utilization of satellite data equivalent to the *PI-mode* described before in the case of NASA's missions. A scientist or a team of scientists belonging to a "selected laboratory" would propose an experiment and would built the instrument to be carried by a balloon, a sounding-rocket or, since 1965, a satellite. In some cases, due to the technical complexity of some of the instruments, "selected labs" counted with additional economic and technical support of the Technical Center of CNES located in Bretigny, and later in Toulouse, in specific domains such as thermic control or calibration, which in some occasions delegated the fabrication of some of the components to industrial partners (software development, electronic circuits, optical lens manufacture, and so forth). In the case of experiments aboard satellites, generally, data received from the satellite were decommutated at the ground stations of CNES and shipped directly to the PI (usually recorded on magnetic tapes) for their calibration, processing and interpretation. Each PI, together with his or her team, produced their data by themselves and, in a second stage, analyzed them. To sum up, space scientists at "selected labs" would propose an experiment and take the whole responsibility from its conception to its exploitation; while CNES would just ensure the *maîtrise d'oeuvre* of the satellite spacecrafts and the launchers, usually manufactured by industrials[110]. While the results of the data analysis would generally reach the literature quite fast, since one of the main incentives for scientific productivity are publications, scientists had less incentive to spend their efforts in archiving the calibrated or the processed data for other eventual users and uses. Like described in the case of NASA, data were *self-made*, and not necessarily shared, neither stored.

This would be the case, for instance, of the satellite FR-1, the first satellite developed under the *maîtrise d'oeuvre* of CNES –in collaboration with NASA- and launched in 1965. While CNES would be responsible of the satellite platform, the integration with the instrument, the power source, the telecommand systems, the scientific payload would be realized by a team of scientists head by Robert Storey of the Centre National d'Etudes des Télécommunications (CNET) with the goal of studying the propagation of low frequency waves through the ionosphere and magnetosphere. NASA would provide the launcher, the launching site, the tracking operations and the reception of data, which would be sent to CNES after preprocessing. In turn, the ground segment of CNES would ship the data to the scientific team at the Centre d'Etudes de Télécommunications, as being the responsible of the experiment[111]. The satellite D-2A TOURNESOL launched in 1971 with a launcher Diamant-B from

[109] Rapport d'activité of CNES, 1980.
[110] Rapport d'activité CNES, 1962-1963.
[111] Rapport d'activité CNES, 1963-1964.

the Centre Spatial Guyanais, this is a second example, would embark five experiments all conceived by scientists of the Service d'Aéronomie: an experiment that analysed Lyman-alpha solar emission in a wavelength around 216 Å, another one that assessed the intensity of the emission Lyman-alpha of the nebulae, and three experiments that studied the radiation emitted by hydrogen atoms at different levels of excitation in direction perpendicular to solar direction. Each experiment would be associated to a PI, who would build the instrument and analyse the data after the launch. CNES's agents in the ground segment would receive the data from the satellite and decommute them and then ship them to the scientists of Service d'Aéronomie for further analysis. The satellite Starlette, this is our last example, would be launched in 1975 from the Centre Spatial Guyanais with a rocket of the family Diamant-B, to study the gravity forces generated by the Earth's potential in order to study elasticity and viscosity processes inside the Earth. The goal of such experiment, designed by a team of the Groupe de Recherche de Géodésie Spatiale (GRGS), was to measure the distance between a ground station emitting a laser beam and the satellite reflecting it back to the station, as an indicator of the gravity forces created by the Earth's potential and in particular the deformations due to tides dynamics. For that, several laser emission stations must be distributed across the globe. The team of the Groupe de Recherche de Géodésie Spatiale, PI of the mission, would then create an international team of co-PIs from the United States, West Germany, Finland and other places, which would be in charge of emitting the laser beam, receiving it back, and processing and interpreting these data, which would be pooled at the Groupe de Recherche de Géodésie Spatiale and shared amongst all the members of the international team under some conditions[112].

The payloads conceived (and often also built) by scientists in the "selected laboratories" could be prepared to be put inside a spacecraft realized by CNES, just like in these three examples, but also inside spacecrafts realized by NASA or Soviet Agencies and later on ESA, NASDA and others[113]. Indeed, it was a common practice, initiated by NASA as early as in 1959 as a part of its external affairs mission, for space agencies to offer to fly foreign payloads inside some of their satellites[114]. In what the historian of sciences John Krige has described a softpower instrument of American foreign policy[115], generally, NASA would release a "call for opportunities" and instruments would be chosen by peers on the basis of scientific competition. CNES would leverage of such opportunities to place instruments aboard NASA's platforms at least for two reasons. First, it represented the cheapest way

[112] Rapport d'activité CNES, 1974-1975

[113] We have provided examples of experiments conducted with satellites, by the same holds true for experiments conducted with balloons and sounding-rockets.

[114] One of the goals of the National Aeronautics and Space Act of 1958, the charter for the civilian space program that established NASA, was « cooperation by the US with other nations and groups of nations in work done pursuant to the Act and in the peaceful applications thereof », National Aeronautics and Space Act of 1958.

Two central references to this question are : « US-European Cooperation in Space Science : A 25 Year Perspective », John M Logsdon, Science 223, 1984 : 11-16 and "NASA in the World. Fifty Years of International Collaboration in Space", J. Krige et al, Palgrave Macmillan, 2013.

[115] This is precisely one of the main thesis of the historian: efforts regarding technological transfer, knowledge circulation, scientific collaboration or data exchange in the domain of space activities (in particular at NASA) cannot be separated of American objectives in international relations; more particularly, Krige maintains that NASA and its activities in the international arena serves the purposes of foreign diplomacy in the US.

"NASA in the World. Fifty Years of International Collaboration in Space", J.Krige et al, 2013.

to launch, since the platform and the launcher would be covered by NASA. Secondly, it was seen as an apprenticeship, as a way of learning through working with the leader. Let us provide three examples, one for each main institutional collaboration in the 20 first years of space sciences, to get an idea of that.

We have already introduced the mission Pioneer-Venus of NASA/Ames Research Center launched in 1978 had the goal of measuring the vertical structure of the clouds composing the atmosphere of Venus. The radiometers, conceived, realized and tested by professor Jacques Blamont of the Service d'Aéronomie in Verrières and by professor Maurice Herman and others of the Laboratoire d'Optique Atmosphérique in Lille, would measure the light reflected by the cloud particles illuminated either by the Sun or by a laser. These reflectances, together with complementary data such as the time, the altitude of the probe, the pressure and the temperature, would be received and decommuted at NASA's antennas network in Australia, Spain, Guam, Chile and US, recorded in magnetic tapes and shipped by post to PIs and co-PIs, including scientists of SA and LOA in France, for analysis and interpretation[116]. The PI of the instrument ARCADE, this is the example concerning an instrument put inside a Soviet satellite, would belong to the Centre d'Etudes Spatiale des Rayonnements in Toulouse (CESR), who would conceive it to be put inside the Soviet satellite Aureol, launched in 1971. It would consist in three spectrometres to measure the energy spectra of the protons and electrons precipitated in the event of boreal auroras. By 1972, some representatives of CNES and CESR would go to Moscow to receive from their Soviet colleagues the first magnetic bands with the data transmitted by the satellite, after having been pre-processed[117]. Our last example regards a mission within the European Space Agency (ESA). The satellite HEOS A-2 of ESRO would carry a number of instruments, amongst which one called S-209 realized by the Service d'Electronique Physique du Commissariat à l'Energie Atomique in Saclay (CEA) in collaboration with Laboratoire de Physique Cosmique de l'Université de Milan to measure the flux and the energy of the electrons of 10 to 600 MeV[118]. Both teams would act as PIs of the instrument and, as usual, would get the data for calibration, analysis and interpretation.

Whether they were called PI or co-PI, whether they are national or international projects, in any of the cases what we have called the *PI-mode* would dominate the approach to data handling: scientists conceived and built an experiment and would have, like it was common in the experimental physics tradition, exclusive access to data for calibration, processing and interpretation. This was what meant to be a "space scientist", an experimenter in the classical culture of experimental physics.

Redefining the ethos of a Principal Investigator: data analysts or getting satellite data from others

In the 1970s, a second approach to carry out academic science would parallelly emerge, an approach which did not require participating in the definition and building of the instrument. This would entail a

[116] « Cloud detecting nephelometer for the Pioneer-Venus probes », B. Ragent, J. Blamont, 1974.
[117] Rapport d'activité CNES 1971-1972.
[118] Rapport d'activité CNES 1971-1972.

redefinition of the functions of a space scientist, which was associated to a new form of participating to a space mission, would be promoted at NASA coinciding, we suggest, with the before mentioned move of rendering the so-called "applications" missions in the domains of atmospheric chemistry, physical oceanography or marine biochemistry, to mention just a few, closer to scientific users in universities and research centers. NASA was chief in releasing international « call for announcements » to gather a team of interested scientists, chosen again by peer-review according to their scientific excellence. Sometimes, the call for announcements would be released a posteriori, once the instrument had already been defined by other scientists or NASA's technical departments. The members of such enlarged team (often also called PIs, co-PIs or scientific team) would then be chosen because of the data calibration methods that they proposed, their validation, or original methods of analysis and interpretation of the data, but not to propose any experiment. They were chosen when the instrument and the experimental configuration had been already conceived. While these reflected a novel epistemology relating the scientists and the instrument (an epistemology based on the use of someone else's instrument), their relationship with the data remained unchanged. Indeed, these teams would be shipped the tapes containing the data, most of the times already calibrated in some manner for further processing and analysis, as if data were originated from their own instrument.

CNES would employ several approaches to facilitate French scientists to respond to NASA's calls for exploiting the data of experiments conceived and built by others. Typically, the "selected laboratories" could ask for technical and financial support for data calibration or analysis to CNES in order to present a proposal to become co-PIs of a NASA's mission and therefore have access to the data, without having participated in the design and manufacture of the instrument. Since 1978, a new approach was set up to promote the participation of scientists to such calls: a joint program between CNES and CNRS that we have mentioned in several occasions, the program "Actions Thématiques Programmées", gave grants to those scientific projects that would make use of NASA's satellite data of the instrument SAGE, the satellites SeaSAT or Nimbus-7 to study some features of the planet Earth (and by extension of data from satellites of NOAA (TIROS, GOES) and ESA (Meteosat)). The most imminent objective of such grants and scholarships was to train and generate skilled scientists to exploit the future data of SPOT –of course, in so doing, scientists resulted trained and skilled to exploit other satellite data as well. This would be basically the way through which scientists belonging to non-selected laboratories in France would have access to satellite data from the second half of the 1970s onwards. For instance, some scientists of Laboratoire d'Optique Atmosphérique in Lille could be PIs of some instruments aboard Mariner 10 launched in 1973 to study the atmospheres of Venus and Mercury. Through presenting a proposal in the respective "call for announcements", other scientists at the same laboratory in Lille would be accepted as co-PIs and gain access to data from the instrument Stratospheric Aerosol and Gas Experiment (SAGE) launched in 1979, while some other in Laboratoire de Physique et Chimie Marine in Villefranche sur Mer would be co-PIs of the instrument Coastal Zone Color Scanner (CZCS) launched in 1978 aboard Nimbus-7 of NASA. In some cases, grants of the program ATP would be invested in purchasing data useful for some research projects that had not been selected by NASA or NOAA, as in the case of some additional scenes of Nimbus-7.

The ethos of being a "space scientist" was being enlarged from a form of *instrument-builder* to a form of *data-analyst*, that is, centered in the processing and analyzing of satellite data, regardless these data had been gathered by one's experiment or by someone else's. By so doing, satellite data exploitation was enabled to a larger number of scientists, coming from both those "selected laboratories" deprived from their technical capabilities to build instruments given the increasing levels of complexity of basic satellite systems and technologies and from those non "selected laboratories" that became authorized to get the data. This renovated ethos challenged traditional forms of experimenting pleading for an abandon of the idea of exclusive property over the data and, in particular, privileged access to data –to be sure, as we will point out in a while, it rather widened the scope of owners, for data access kept being after all restricted to them. More pragmatically, because data were shared amongst more scientists, it increased the intellectual competition and the urgencies for publication. This renovated ethos, on the other hand, could do nothing but benefit space agencies in the long-term because the monopole to data access by the scientists who had participated in the conception and building of the experiment certainly limited the interest in satellite data by scientists not related to the instrument -and therefore the scientific return of the investment was not maximized[119]. This evolution was materialized, we argue, through promoting the access to NASA's, or other's satellite data. This was indeed a means for CNES to educating and familiarizing French scientists with the processing, correcting, collecting, analyzing and interpreting of satellite data in views of the future satellites that CNES would certainly launch in the future, beginning with the looming SPOT. In this sense, whilst SPOT heralded the industrialization of technical abilities (the transfer of technical capabilities from scientists in the "selected laboratories" to industrial companies (recall, however, and this is an important point for further developments, that capabilities for building *simpler* instrumentation to be put inside balloons or aircraft or to be deployed in the ground were retained)), it acted as well as a catalyst for training new scientists in the art of data processing and interpreting, without having participated in the instrument building.

We would like to remark that it is not that the form of *data-analysts* came to replace the form of *data-builders*; it was rather that both forms became equally legitimate as defining the ethos of a space scientist. Indeed, we have seen that during the first scientific meeting organized under the auspices of CNES in Les Arcs in 1981 strong emphasis was put in the importance of conceiving and building instruments as a ways of maintaining control over the scientific experiments before the industrials and the managers and influence in defining the scientific programming of CNES –and that capabilities to

[119] In his study of the mission SeaSat conceived by JPL/NASA and launched in 1975, the historian Erik Conway suggests that NASA's programmer's promoted this policy of redefining the functions of the experimenters (and therefore the data access policies) because the experimenter's form undermined the scientific legitimacy of the research done with satellite data in two ways: first, it slowed publication and reduced intellectual competition and discussion and, second, the lack of openness had the effect of discrediting the science done with the data.
"Drowning in data: Satellite oceanography and information overload in the Earth sciences", E.M. Conway, 2006.

build balloon- and air-borne instruments, as well as surface instruments, were still retained in several "selected laboratories". At the same time, strong emphasis was also put in the importance of delivering the data and rendering them available to a wider community of scientists. This is how Gérard Mégie, physicist at the Service d'Aéronomie of CNRS expert in developing methods and instruments to measure the chemical and physical composition of the higher layers of the atmosphere (in particular, lidar), would summarize the notion of being a space scientist[120]:

> "La notion de laboratoire spatial recouvre à l'heure actuelle trois catégories différentes de projets:
> - maîtrise d'œuvre et réalisation des expériences dans les laboratoires (…)
> - développement d'une instrumentation complexe (instruments lourds, plateforme intégrée) pour laquelle l'intervention des laboratoires se limite à des actions amont (recherche et développement, définition des spécifications scientifiques et techniques, simulations) et aval (suivi et vérification de l'instrument, participation aux essais, validation sol) (…)
> - exploitation scientifique de données (segment sol et interprétation) obtenues à l'aide d'instruments spatiaux non développés au sein des laboratoires (…) »[121]

These sentences are extracted of the project proposing the creation of a Space Institute for the Environment (Institute Spatiale de l'Environnement Terrestre), a federation of different laboratories of the Parisian region aimed to pool efforts in the scientific research in the domain of Earth sciences, which Gérard Mégie presented in 1993. In other words, more than a decade would elapse from the first moves made in that direction (the grants of the program "Actions Thématiques Programmées", for instance, would start being allocated in 1978, and the first scientific meeting took place in 1981). These sentences synthetize however the meaning of the renewed ethos of a space scientist and confirm, in our views, its normalization by 1993. Space scientists, whether they would be called PI, co-PI or nothing, would be given an extended and larger meaning. In particular, beyond those devoted to conceive and manufacture instruments, external scientists could also participate in the experiment without intervening in the fabrication of the instrument per se but intervening in the production of the data by preparing the data before the launching, by validating them after it or by interpreting them in a given scientific context. One of the goals of our work is to explore the specificities of this renewed epistemology as it would progressively permeate the project POLDER between its conception in 1986, its first launching in 1996 and 2002, its second launching in 2004 and the last transmission of data in 2013: the particular form it took and the mechanisms for articulating it, the technological practices it mobilized and the social orderings and rules it inflicted.

[120] Gérard Mégie obtained his phD in physics under the direction of Jacques Blamont in the Service d'Aéronomie, which he co-directed between 1984 and 1995, and directed between 1996 and 2000, when he became president of CNRS. His research interests were centered in developing instruments, particularly a lidar (in the ground, balloon, aircraft or inside satellite), to measure the chemical and physical composition of the atmosphere. In the 1970s, for instance, he participated in the establishment of a ground-network to measure the ozone with lidar. Between 1989 and 1994, another example, he instigated the creation of a Space Institute for the Environment, which would give birth to the Institut Pierre Simon Laplace. Influent scientist whose opinions carried considerable weight, we will meet him in several occasions along our essay. Gérard Mégie died in 2004 while he was the president of CNRS.

[121] « Document scientifique de presentation de l'Institut Pierre Simon Laplace. Contrat de plan « Etat-Région » », elaborated by Gérard Mégie in 1993.

Box 1.2. Getting data from missions of "space applications": scientists as clients

We may note that this picture centered on the figure of a scientist or team of scientists may take different forms in other missions in which the payloads have not been designed by any academic scientist or team of scientists and yet they are perceived as potential users of the data (a configuration analogous to SPOT), that is to say, in those missions typically catalogued as "space applications". Two examples will suffice to illustrate this diversity.

Further to a call of opportunities made in 1971 more than 400 scientists would be chosen all over the world to become PIs of the mission ERTS-1 launched in 1972[122], seven from which belonging to French laboratories (Institut Français du Pétrole, Bureau de Recherches Géologiques et Minières, Ecole Pratique des Hautes Etudes, University of Aix, Institut Géographique National, University of Orsay, University of Paris and others)[123]. None of these French scientists, and obviously most of the other 400, had participated in the conception, development or realization of the instruments embarked in these satellites. They had not participated in the calibration, preprocessing or validation of the data either. They had been selected to use the images obtained from these satellites in their particular studies in a number of domains as varied as hydrology, oceanography, geography, agriculture, forestry or petrochemistry –in the same terms than any other client from governmental environmental agencies, geological institutions, private agricultural companies, etc. Put it simply, the advantage of being a PI in this mission would be the possibility of getting the images in a relative quick manner and at a reduced price[124]. More specifically, as we have already mentioned by 1973, and participating in the general shift of space activities towards applications, French government had recognized the interest of developing an own system of high-resolution imagery for monitoring and managing Earth resources, the future program SPOT. As a first step towards developing such a program, a Groupement pour le Développement de la Télédétection Aérospatiale (GDTA) would be created by CNES and the Institut Géographique National in 1973 (by the end of the decade two more institutions would have joined them, the Institut Français du Pétrole and the Bureau de Recherches Géologiques et Minières) in order to learn the skills necessary to process, correct and interpret, as well as to provide the interested laboratories with the technical machines and apparatus necessary for such a task. It would be through subventions given by GDTA, for instance, that scientists from French laboratories like LOA, IGN, INRA or LMD, which had been selected as one of the 400 PIs of Landsat, would purchase data from Landsat satellites already processed and corrected in some form or another[125]. In these cases, thus, these scientists would be given (after purchase) the magnetic tapes containing the high-resolution images already corrected and processed, which would use for their particular studies either in the fields of vegetation, oceanography or hydrology studies, or in the fields of remote sensing per se as a training for developing the skills of data processing in views of the future French system. These scientists would not participate in the buiding of the instrument, not even it its conception; they would not participate in the preparation of the data either, or in their validation. In the Landsat mission the term PI would take a different meaning: all those people (scientists or not) that had presented a project to use the images from Landsat and who, because of being labelled as PI, would receive some samples of Landsat images at a special reduced price.

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[122] "Viewing the Earth: The Social Construction of the Landsat Satellite System", P.E. Mack, 1990.

[123] Rapport d'activité CNES 1973-74.

[124] At least until the early 1980s, when Landsat's operators would change data distribution policy and increased prices considerably.

[125] Several reception antennas would be distributed across the globe to receive the data ranging in a given geographic region. Further to a partnership with ESRO, the ground station covering the European region would be in Italy and managed by Telespazio.

In some other cases getting satellite data from others required institutional agreements. Prominent amongst which would be the collaboration between NOAA and the Direction de la Météorologie Nationale dating of 1964, according to which the French weather bureau would build an antenna to directly receive the data from the satellite TIROS-8, and afterwards the five first NOAA satellites equipped with a radiometer VHRR (Very high Radiometric Resolution) gathering data in two channels, visible and IR, as they crossed over the European region. This reception station would be placed in Lannion and called Centre de Météorologie Spatiale de Lannion (CMS). CMS operators would then decommute the data, correct them, calibrate them and put them at the disposal of the interested scientists of EERM/Direction de la Météorologie Nationale, who would develop processing methods and algorithm to interpret the images. Typically they would elaborate what they called *nepha-analyses*, that is to say, data, typically in the form of maps, illustrating the distribution of cloud masses over a surface from North Cape to Sahara desert and from Moscow to the Açores Islands[126]. Users (scientists or not) could then purchase these nepha-analyses to the Centre de Météorologie Spatiale.

By 1979, a new generation of NOAA's satellites was launched, equipped with a new generation of scanning radiometers, the Advanced Very High Radiometric Resolution (AVHRR)[127]. In 1983 the Centre de Météorologie Spatiale de Lannion, following an agreement between la Direction de Météorologie Nationale et le NOAA/US Weather Bureau renewed their agreement, according to which AVHRR data over Europe were received at CMS in Lannion, where they were routinely corrected, calibrated and navigated, and where nepha-analyses would be regularly elaborated. AVHRR data, typically the nepha-analysis and exceptionally other non-analized data, would be then transmitted to external scientists via a telephone link and processed with their local equipment and methods, including corrections due to missregistration, cloud contamination or the atmospheric perturbations. For instance, scientists at the Laboratoire d'Etudes et Recherches en Télédétection Spatiale (LERTS) would take AVHRR nepha-analyses from CMS and process them in order to retrieve vegetation properties[128]. In 1985, a Service d'Archivage et de Traitement Météorologique des Observations Spatiales (SATMOS) in CMS-Lannion, would be created to archive AVHRR data in magnetic tapes of 1600 bpi put at disposal to anyone interested upon purchase.

To sum up, during the first decade of the space age, broadly speaking, the PIs of a satellite experiment (and also of a balloon or a sounding-rocket experiment) would design, define and built the instrument and process and analyze its data. With some technical help from the space engineers, these so-called PIs would have almost absolute control of the experiment from conception to exploitation. This defined an ethos comparable to that of experimental physics tradition, in which those scientists that propose an experiment control it and its data. As satellite technologies got complex in the 1970s, connected to structural changes took place exemplified by the industrialization of some technical capabilities from CNES to external industry (leading to the introduction of the intermediate figure of the space manager in Toulouse), this notion of PI would evolve. Generally, scientists not having participated in the definition and building of the instrument could, after submitting a scientific proposal to the proponents of the experiment or sometimes directly to space agencies, be part of the

[126] Rapport d'activité CNES 1963-1964.
[127] Launched in 1979, NOAA-6 was equipped with AVHRR.
[128] Rapports d'activité LERTS.

scientific team and get access to some form of data as well for calibration, validation or analysis. The renewed notion of PI would put as much emphasis in being *instrument-builders* (to compensate gradual deprival of competences in favor of industrials) as in being *data-analysts* (to broaden the constituency of people exploiting the data and maximizing return). As a result, in the beginning of the 1980s there would exist in France some small dispersed groups, which had acquired some skills in the analysis of satellite images with or without intervening in the conception of the experiment. Some of them would be located in the "selected laboratories", but some other would include the Laboratoire d'Optique Atmosphérique, the Laboratoire de Physique et Chimie Marine, the ocean biology station in Roscoff, the Centre de Météorologie Spatiale of the Météorologie Nationale, the Institut National de Recherche Agronomique, the Institut Géographique National, Centre National Pour l'Exploitation des Oceans (former Institut Français de Recherche pour l'Exploitation de la MER, IFREMER), among others. One of the goals of our work is to shed some light in how these functions of *instruments-builders* and *data-analysts*, or PIs in a broader sense, co-habited and evolved as missions to support studies of the Earth and its environment would be designed, realized and launched between the 1980 and 2000.

Self-made data

A common specificity of these scientific space missions, regardless of the discipline they were meant to support, was that a group or groups of scientists secured the analysis of the data and, in some occasions, also conceived, built and carried out the experiment. This enlarged group of scientists retained many of the elements from the traditional practices embedded in the epistemic tradition of experimental physics –with the particularity that also people not involved in the instrument-building would be given the status of experimenters. In particular, these people were awarded with "proprietary" and "exclusive" rights to the data, allowing them the opportunity to analyze the data and prepare publications with reduced competition. This customary practice and arrangement was considered as a fair reward for the years of struggle it took to get a new instrument built and sent into space and/or for the efforts made to correct, calibrate and prepare the data analysis. Within this configuration, the interfaces between this scientific group and the agents of the space agencies were limited to technical support during conception and manufacture of the instrument and to the tape-recorded data circulation. Other tasks, integration of the instrument inside the spacecraft, test of performances, orbital control during operations, downlink of data from the satellite and correcting them from noise signals, data quality control, data analysis and interpretation, inter alia, were carefully distributed amongst space agencies' agents or academic scientists. In particular, during flight time, the task of space agencies would be to control the satellite operations and the transmission and reception of data: data would be transmitted to the ground, decommunated by ground segments (that is to say, extracted data critical for spacecraft operation, and they next edited, filtered, reversed, annotated time, smoothed, etc.) and recorded into magnetic tapes 800 bpi, 1600 bpi or 6250 bpi, or in 8-inches floppy disks since the early 1980s, of capacity[129]. Academic scientists would be shipped the data, and their job would consist in calibrate them, assess their quality, and process them by means of the methods that they had previously developed for interpretation.

"Despatialization" of satellite data

It appeared in the 1970s a jargon term, used mostly at the Technical Center of Toulouse that synthetizes the range of pre-processing activities conducted at space agencies' ground segments: "dé-spatialisation", we will translate it into *despatialization*[130]. Although we have found no formal definition of such a term, its common broad understanding designated the area of activities conducted by the ground segment of space agencies intended to manipulate the signal received from the satellite in order to recover from it the original measurements made by the instrument. We can conceptualize the process of despatialization as one of eliminating the "space-part" of the satellite signals, of integrating the information from the contextual environment in which measurements had been taken (the orbit, the time, the instrument, the frequency of transmission, the format, etc.) with the data in order to recreate the original measurements taken by the instrument. Despatialized data would be in this manner commensurate to measurements of the same type equivalent to any other measurements obtained with similar instruments in the ground. Despatialized data would then be mailed to PIs, who, on receipt of the data, would process them to produce various files and would display calibrated data. Next, they would engage the interpretation of the data in studies of interest to them: analyses of errors, algorithmic interpretation, data processing or archiving would be considered as the task of each PI or scientific team, not of space agencies.

The term despatialization would act as a material, technical and social attribution operating a division of labor between space agencies and scientific laboratories, between agents in the ground segments and PIs or co-PIs in the universities or research centers. It informed a division of labor which was, at the end of the day, a way to ensure that the work would be done at each step by whoever was considered to be the best placed to do it; it reflected a rationalization of the tasks as a means to reach efficiency and performance in complex endeavors and entailed, in so doing, a complex social organization and teamwork to achieve common goals –archetypical attribute of what has been called Big Science projects[131].

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[129] bpi are bits per inch, namely, the quantity of data recorded per inch.

"Traitements des fichiers-images", G. Joly, 1986.

[130] We ignore whether in the United States, or at NASA, any analogous expression would be also used.

[131] The term Big Science was coined by Alvin Weinberg to refer to large-scale federal-funded, often derived from military, scientific projects that were developed after the World War II. Far from being an homogeneous mass, there is today enough literature on Big Science, which identifes political, institutional, scientific, technologic and cultural diversity amongst large-scale projects, such as the CERN, the Manhattan project, the superconducting supercollider, the Tokamak fusion reactor, the Genoma project, the Very Large Array or the International Space Station.

For an introduction to the many kinds of activities that are subsumed under the term Big Science see "Big Science. The Growth of Large-Scale Research", eds. by P. Galison and B. Hevly, 1992.

At some point, however, this notion would become as well a *boundary* operating an interpretative division of the world into two broad spheres of activity: the "space", or space technology, and the "science". Theory of *boundary-work*, we believe, can help to conceptualize this separation of tasks between what would belong to "space" and to "science". The sociologist of sciences Thomas Gieryn maintains that actors tend to draw boundaries between fields to ensure their autonomy of action within a given field[132]. In the process of demarcating such boundaries, power is distributed amongst the actors in the form of *epistemic authority*, that is to say, in the form of legitimacy to define, describe and explain reality in a credible, reliable and trustworthy manner. While Thomas Gieryn developed the theory to understand how the contours between what was considered to be science and non-science had been demarcated in a number of historical cases (engineering, technology, religion, politics, social sciences, etc.), we are here using it in a more broad sense to grasp the efforts made by space agencies and the scientific community to delimit their respective domains of action, allocate the privileges and responsibilities of expertise, and decide on the epistemic authority over the definition, production, dissemination, archiving and utilization of satellite data. With this lens, the actions necessary to despatialize the data would be of responsibility of the ground segments of space agencies; once despatialized, data had the property of not being "spatial" anymore and they would be taken over by other non-space organizations for further processing, treatment, analysis or archival. These organizations would be typically the PIs or co-PIs who had built the instrument and/or some of the data processing algorithms, since they held the expertise and knowledge to correct, calibrate, analyze and interpret the data in a given scientific context. The term *despatialization* would define actually what meant to be a scientist working with satellite data in the first 20 years of the space age, regardless of having intervened or not in the conception and fabrication of the instrument: processing the despatialized data, that is to say, selecting the datasets, filtering and reducing them, adjusting the geometries, correcting them of radiometric bias, of atmospheric effects or of other perturbations, interpreting and visualizing the resulting datasets within a given scientific context and, when judged pertinent, ensuring the archival and distribution of the magnetic tapes (in some cases, especially during the first decade of space age, conceiving and building the experiment would also be part of the list of tasks). The term would at the same time define what counted as data of scientific interest: the measurements made with the instrument. It defined hence the frontier between what would be considered as technical signals coming down from the satellite and what would be data meaningful to PIs for their scientific inquiries. The data that would be considered as useful by scientists for scientific

[132] Boundary work as defined by Thomas Gieryn refers to as "the discursive attribution of selected qualities to scientists, scientific methods, and scientific claims for the purpose of drawing a rhetorical boundary between science and some less authoritative residual non-science." Boundaries, according to the author, are "ambiguous, flexible, historically changing, contextually variable, internally inconsistent, and sometimes disputed" and are shaped by the local contingencies of every moment, the actors or the stakes. The sociologist outlines three main types of boundary-work: expulsion, expansion and the protection of autonomy. The first type defines a contest between rival authorities each one claims to be legitimate in a given area; as the boundary gets defined, the insiders hold the monopoly of orthodox practices, and outsiders are denied privileges. Expansion type occurs when parties square off for control over a contested area and seek to extend their frontiers. A third type stresses the walls put by insiders to protect themselves against outside powers; these walls act at the same time as escapatory for blame or accountability.
"Cultural Boundaries of Science: credibility on the line", T. Gieryn, 1999.

inquiry, and with that we advance the following section, would be the original measurements. In other words, it placed the epicenter of epistemic truth at the despatialized, decontextualized radiances[133] (in the case of radiometers[134]).

Big Science, self-made data

Typically space agencies would make a copy of all the tapes sent to PIs and/or co-PIs. Therefore, should a tape be lost or destroyed, or should ever any other scientist want to use them, there would remain still the copy at space agencies' archives. However, it would be difficult for meaningful information to be extracted from the archived tapes at space agencies by anyone other than a PI and/or co-PI because, for instance, in many cases the calibration software would be developed by the PIs on their own computers and not delivered to space agencies' agents. Even though some data archival centers would be created to that purpose in the 1970s, it would take some time before PIs would acquire the habit to forward them the calibrated data –and often they would be forwarded with insufficient documentation. Likewise, it would be also difficult to use the data by non-PIs or co-PIs because processing software was not considered a deliverable item and would remain the property of PIs –it was, after all, the very ethos of being a space scientist, to process the data. It is not clear, hence, whether the self-morality of the experimenter's ethos would have permitted taking someone else's data anyway. Actually, even if they would have wanted to share and exchange data, practical barriers existed because no standards on the format of data processed by the individual PIs and as a consequence, since these PIs were located in a variety of institutions, and in different countries, there were a large number of data formats currently being produced, rendering the use of data impossible unless in provision of the specific reading software that used to be developed by PIs. On the other hand, whereas scientists had a strong incentive to publish and results usually would reach the literature in a timely manner, they had however less incentive to archive the calibrated or partially processed data, once they had obtained and published their results. What mattered, to them, were the scientific conclusions and not the original data. In many cases, once exploited, tapes with calibrated and processed data would be forgotten in the laboratories. It is plausible to suggest that scientists only would factually use the data that they had themselves in more or less degree contribute to conceive and produce. In more or less degree, satellite data were *self-made*, particularly developed for a given specific study-case and generally not shared with others. This was more a customary practice than a written rule, which portrays a picture barely different from the commonplace practices in experimental

[133] Radiance is a variable directly measured by remote sensing instruments. They correspond to the quantity of radiation that passes through or is emitted from a surface and falls within a given solid angle in a specified direction, and they indicate how much of the power emitted by an emitting or reflecting surface will be received by an optical system looking at the surface from some angle of view. The SI unit of radiance is $W \cdot sr^{-1} \cdot m^{-2}$. Put simply, radiances give an idea of how much light the instrument "sees" from the object being observed. Radiances depend on the illumination, the orientation and position of the target and the path of the light through the atmosphere.

[134] In most of our essay we focus on the example of radiances, as it is the type of measurements gathered in our study-case. It must be understood, however, that other instrument may provide other type of measurements like spectras, photographs or backscattered reflectances, among others.

physics, which would consider the space instrument as an experiment and the satellite as a laboratory. Being an experimenter meant, after all, processing and analyzing one's own data. This map would attribute a central role to PIs and co-PIs, who would be allocated epistemic authority over the data, retain complete control and had some sort of property rights over *their* instrument and *their* data. It was difficult by anyone other than a PI or co-PI to get access to data and, if achieved, extract meaningful information from them.

One last remark before concluding. Few, if any, American historical accounts related to space programs do not exacerbate in some way or another the Big nature of the enterprise. Whether they talk about the Apollo program, the American shuttle, the Earth resources satellites, the spy satellites, the Star Wars project, the Hubble telescope or the International Space Station, they emphasize their gigantism, their sophisticated engineering and technology, their exorbitant cost and significant public sponsoring, their complex social organization entailing multidisciplinary teamwork and strict division of labor, their hierarchical form of management and control, and in some cases, the strong ties with the military[135]. All these attributes are characteristic of what has been called Big Science, a concept that has attracted the attention of historians, as well as of actors themselves, as demonstrated by the large amounts of publications proliferated since the 1980s[136]. Whether they take a political sciences approach, an anthropological or sociological perspective, a cultural insight or a historical focus, they all stress the Bigness of the venture being described.

By focusing on data handling practices and the figure of PI (and co-PI) –and not programs, institutions or individuals- this rapid briefing has offered an original contribution to this existing historiography of space programs. The scientific space instruments that we have briefly mentioned may certainly involve an elaborate social organization and size (especially when the industrialization began in the 1970s), a remarkable range of institutions, groups and individuals with different skills, a generous governmental funding, a risky technology to launch, and a strict division of labor –all of them attributes usually allocated to the Big Science endeavor. Yet, this Big Science would inform some specificities: while demanding large-scale equipment, data handling would remain small at the level of scientific practices of experiment conception and data handling. It is plausible to suggest that, excepting for the commercial missions, the practices of data handling in the 15 to 20 first years of space age would subscribe a very specific type of Big Science –that characterized by *self-made data*, or small data. In other words, each experiment would be associated to a rather small group or groups of scientists working autonomously each other, having exclusive access to the data that they had contributed to create (through calibration software, validation experiments, some form of correction, etc.) and publishing the results. This was what would define the ethos of being a scientist working with satellite data: an experimenter linked to the processing of data and their interpretation (and eventually to the design and manufacture of an instrument). One of the thread topics of our work will

[135] See the bibliography for some references.

[136] For an introduction to the many kinds of activities that are subsumed under the term Big Science see « Big Science. The Growth of Large-Scale Research », Ed. by Peter Galison and Bruce Hevly, 1992.

be studying how these practices that constituted the epistemology of the space scientists evolved, if they did, from the late 1970s, as the space agencies would begin incorporating programs in support of disciplines in the domain of Earth sciences.

SPACE DATA: PHYSICAL RADIANCES AND GEOPHYSICAL DATASETS

We address now the third reading of this period, the one that tries to shed some light on the type of data that were considered of scientific interest. We address the topic by means of exploring the technologies of data gathering. Before the 1980s, as we have seen in the previous sections, space agencies or operators extracted data critical for spacecraft operation, and they next edited, filtered, reversed, annotated time, repixeled, smoothed and converted the data into their original form (radiances, images, backscattered reflectances, etc.), which they shipped to the PIs or co-PIs who had built the instrument and/or the processing software. We have seen as well that the term despatialization would contribute to define what meant to be a scientist working with satellite data during the first 15 to 20 years of the space age and what counted as data of scientific interest: the radiances (in the case of radiometers) with which scientists would work. It placed the center of epistemic virtue at the despatialized, decontextualized original measurements.

By the late 1980s, this epistemology centered on the radiances as data of scientific interest would have changed. In a document presenting the scientific program of a future new research institution, initially conceived in 1989 as an space institute for environmental research, which would federate several laboratories of the Parisian region (and that would become in 1994 the Institut Pierre Simon Laplace), its main instigator Gérard Mégie, whom we have already met, instructively wrote that:

> "L'intérêt scientifique des données acquises par les moyens spatiaux résulte pour l'essentiel dans la capacité d'interprétation des variables effectivement mesurées en termes de variables géophysiques pertinentes »[137].

Some of the satellites and space instruments to which Gérard Mégie referred would be spelled out later on in the document as those planned in the 1980s to be launched about one decade later (BEST, ScaRaB, POLDER, GLOBSAT[138], MERIS and other). If we take the example of radiometers, according to this epistemology, it would not be the quantitative measurements of the amount of light detected by the photoelectric sensors of the instruments, radiances, transformed into voltages, which would be of most interest to scientists. Radiances, reflectances or voltages were not necessarily familiar to them, who were used to work with data related to physical, chemical or biological processes and properties. To be meaningful in the areas of oceanography, vegetation or atmosphere, so illustrates this quote, the measurements of radiances must be transformed into "pertinent geophysical variables". The epistemic virtue of the data provided by space instruments would be judged for they

[137] « Document scientifique de présentation du Institut Pierre Simon Laplace. Contrat de Plan Etat-Region », elaborated by a group of scientists on the basis of a document elbaorated by gerard Megie, March 1993.

[138] Satellite to study global change proposed by scientists from LMD, SA and CETP in 1989 at CNES.

ability to represent geophysical variables and not physical measurements of energy.

These two different epistemologies surrounding satellite data illustrate that the epistemic value of data may not be permanent across time and communities. We explore in this last part of the chapter what type of data were considered as admissible to conduct scientific research or, in other words, what kind of data would be allocated with *epistemic virtue*. We attempt to illuminate how it moved from physical measurements of radiances to geophysical parameters derived from them. Our historical question is not to investigate whether radiances or geophysical parameters are *better* representations of nature, but rather to explore how features of scientific practice, knowledge and technologies would be deployed in a given context for allocating epistemic authority and resources in one or another over time, with what consequences and for whom. How did the new norm for admissible data considered as "pertinent" by scientists shore up in France by the 1990s? Who would have the legitimate power to define the data and judge about their quality? On what grounds and in which circumstances affected it to POLDER's data? We trace some of the factors involved in the process of re-allocation the epistemic value/virtue of satellite data between 1960 and 1980, by connecting them with the technologies used to *observe* the Earth's environment and to gather and process the obtained data.

Sensing the Earth's environment: The *morphological approach* and the *physical approach*

At the dawn of the space age, two types of technologies would be embarked to gather data about the Earth and its environment for research purposes: photo/video cameras and radiometers. Photo or video-cameras would observe in the visible range of the electromagnetic spectrum and allowed the identification and interpretation of the shapes, shadows, textures, rugosities, contours, geometry and proportions of the objects appearing in the images in order to identify familiar features like mountains, forests, rivers, agricole parcels, geological structures, urban features, swell, or other. Interpreting the data of these images relied mostly on visual and statistical techniques of photo-interpretation (analysis of threshold effects, changing contrast, histograms of pixel density, etc.), an approach that we'd like to call *morphological*. For instance, when preparing the analysis of the images of the radiometer Meteosat since the mid-1970s some scientists in the Laboratoire de Météorologie Dynamique in Paris (LMD) would develop a method –and the corresponding apparatus called Nebulomètre- to compute the horizontal wind speed by measuring the distance between the same point in two consecutive Meteosat's images. This quantitative method was morphological in nature because it relied on detecting differences in the shape and the geometry of the clouds to derive their speed (and thus the wind speed, assuming that clouds were pushed by the wind), instead of on some eventually phenomenological relationship between clouds' composition, mass, thickness, altitude or color and the wind speed[139].

[139] « Détermination des champs de vents à partir de photographies de satellites géostationnaires », P. Sitbon et al, 1974.

Legacy of weather forecast practices

The nonlinear nature of the hydrostatic equations that rule the dynamics of the atmosphere cause the solution of such equations to be dramatically dependent on the initial conditions. This was one of the reasons why numerical weather forecasters would, even before the advent of satellites, try to integrate ground-surface and rawinsondes data to fuel their models: using (near) real-time data as input to the models would improve the accuracy of the analyses than using other type of data[140]. However, during the 1960s and the 1970s, the morphologically cloud imagery of the vidicon cameras carried by the satellites TIROS and the ATS, and later on also Meteosat, would provide visually powerful images of, say, storms and hurricanes, permitting early warning of approaching meteorological events, or retrospectively confirming events already occurred, but they would not assist prospective routine numerical weather forecasting until the late 1980s[141]. This is how André Lebeau, who would become the responsible of the project Meteosat at ESA, described the functions of Meteosat:

> « Meteosat à l'origine n'était pas orienté vers la prévision du temps; il était orienté vers l'observation du temps qu'il fait. Il donnait une image toutes les demi-heures qui permettait en particulier de vérifier que la situation météorologique évaluait conformément aux prévisions fournies par des modèles numériques intégrant les données des systèmes d'observations terriens ou des ballons de radiosondage »[142].

The images of Meteosat, launched in 1977, were used to confirm a forecast or a past event, but not to provide a forecast per se –in chapter six, we will come back to the prediction abilities of satellite data and we will connect them to a particular form of technological data practice called *assimilation*. Data used to forecast, that is to say, data used in the weather numerical models were data gathered with surface stations or radiosondes, but not with Meteosat.

Part of the problem of using satellite data as initial conditions for the weather models would be how to render comparable and compatible the vidicon images or the infrared radiances obtained by the satellite with the thermodynamic variables that describe the Navier-Stokes equations (temperature, wind speed, pressure and humidity). In 1985, the atmospheric scientist Gérard Mégie described the attempts to render satellite data useful to the weather forecasting community as follows:

> "C'est seulement en cours des toutes dernières années que l'utilisation des données spatiales a été mise à profit de façon significative en météorologie. Les premiers satellites fournissaient sous forme d'images des descriptions à l'échelle synoptique des systèmes atmosphériques perturbés dont l'utilisation subjective a conduit à une meilleure compréhension des phénomènes. De plus la réduction

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[140] This is the topic of the doctoral dissertation of Margaret Courain describing some of the efforts made by certain weather scientists of the US Weather Bureau in developing ways to assimilate remote sensing data inside the numerical prediction models. In particular, she describes the data assimilation techniques developed to ingest the temperature retrieved from rawinsondes and satellite radiometers into the models.

"Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, 1991.

[141] In another order of things, these images, and more generally images of the Earth taken from the space, have yielded numerous researches in the field of visual and cultural studies. See, for instance, "Contested Global Visions: One-World, Whole-Earth and the Apollo Space Photographs", D. Cosgrove, 1994; "Image and Imagination: The Formation of Global Environmental Consciousness", S. Jasanoff, 2001; « Earthrise : How Man First Saw the Earth », R. Poole, 2008; or "La Terre vue d'en haut: l'invention de l'environnement global", S.V. Grevsmühl, 2014.

[142] "Meteosat: De l'espace pour le temps », interview to André Lebeau, 2011, http://www.dailymotion.com/video/x32j1y_meteosat-de-l-espace-pour-le-temps_news

> ainsi obtenue de la maille du réseau des observations traditionnelles a permis l'observation des perturbations naissantes jusque-là ignorées. Les difficultés sont apparues lorsqu'il a fallu passer au stade quantitatif et fournir des mesures des paramètres thermodynamiques d'état de l'atmosphère. Il a fallu plus de dix ans pour que les données spatiales puissent se comparer aux mesures in situ et les systèmes d'analyse actuels de ces données n'ont pas encore été suffisamment adaptés pour en tirer tout le bénéfice possible compte tenu de leur différence de nature par rapport aux systèmes existant précédemment»[143].

The problem was that differences in the type of variables with which weather forecasters were used to work and the measurements from satellite instruments must be reconciled for satellite data to be useful. In her doctoral dissertation describing different ways through which weather forecasters in the US Weather Bureau made use of remote-sensing data from 1960 to 1980 to predict the weather, Margaret Courain noted two, inter alia, not disconnected difficulties to that reconciliation between satellite data and weather models, both illustrated by Gérard Mégie in the previous quote[144]. First, by the 1960s, numerical modeling was being promoted as the step-of-the-day methodology in weather forecasting. Therefore, for satellite images to be useful, meteorologists must investigate ways of transforming the vidicon images into quantitative values to fill the gridpoints of the numerical models. Yet, in the 1960s, numerical modeling was still in a embryonic stage of development and there was a lack of expertise in mathematical numerical methods and in computer science within the weather forecast community to develop techniques to digitize the images and interpolate them within the grids. Besides, meteorologists were familiar in reasoning in terms of temperature, pressure, rainfall or wind speed, which are the parameters determining the hydrodynamic equations ruling the atmospheric circulation, and also the core of the numerical models for weather prediction. Because interpreting visual images of cloud patterns in those thermodynamic terms was far from trivial, they were reluctant about their usefulness within their current practices[145]. As Courain argued, *reconciliation technologies* must be developed to bring together what the satellites measured (images of clouds or infrared radiances) and what the weather forecasters were familiar with (thermodynamic parameters to complete the model grids)[146].

Our point here is to suggest a connection, even a parallel in some degree, between the customary efforts of weather forecasters and that of the space agents and Earth scientists. Just like weather forecasters learned to transform images and infrared radiances into thermodynamic parameters, which

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[143] Gérard Mégie, physicist of Service d'Aéronomie, Séminaire de prospective Scientifique du CNES, Deauville 1985.

[144] The historian John Krige in a study about the establishment of the European weather operational system also noted that weather forecasters were reluctant about the value of using satellite data in their weather forecasts: "Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite", J. Krige, 2000.

We refer as well to the research conducted by our colleague Sylvain Lenfle, which approaches the evolution of weather forecasting by looking at the techniques of assimilating the satellite data into the models: "De la valeur des données spatiales : le cas des données de sondage en prévision numérique du temps.", work in process, 2014.

[145] "Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, 1991.

[146] As defined by Margaret Courain, technology reconciliation is "the function or process by which data products and information derived from a new technology are made consistent or congruent with the existing data representations of a sciences in order to be used effectively".

"Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, 1991.

were the meaningful variables to their scientific work practices of predicting weather by numerically solving Navier-Stokes equations, some space scientists in the domains of oceanography, atmospheric physics and chemistry or vegetation studies would attempt, mirroring this approach, to transform satellite physical radiances into geophysical variables that were meaningful to their scientific representations of the processes occurring in the Earth.

Morphological and physical approaches[147]

Videocameras would be precisely the principal instruments on board of NASA's satellites of the program TIROS (Television Infrared Observation Satellite), launched from 1961 onwards to determine if satellites could be appropriate to study the Earth's environment, with a first priority in the domain of weather forecasting. In 1965, after 10 satellites being launched, the program TIROS would be taken over by ESSA (the former NOAA), while NASA would continue to develop new instrumentation and platforms, such as a weather program of satellites ATS (Application Technology Satellite) flying in geostationary orbit[148], which would be followed up by NOAA since 1975 with its program GOES, or the Nimbus program between 1964 and 1978, both programs carrying some form of vidicons (and radiometers).

Vidicons, like photo-cameras, allowed instantaneous discrete acquisition of the observed scene in the visible range of the electromagnetic spectrum. The satellites Nimbus launched in 1964, 1966, 1969 and 1970 embarked different types of cameras, including the Automatic Picture Transmission and the Advanced Vidicon Camera System. The first one aimed to test a system for transmitting images in real-time to render them useful for timely weather predictions, whereas the second one aimed to test onboard storage systems and furnish higher resolved images in delayed-time. Without entering in many details, both of them had a resolution of 800 lines per image, that is to say, whatever the size of the scene, it could be read out as an image made up of about 800 separate scan lines visualized in a television screen[149]. At an altitude of 800km, and due to differences in the optical systems, this resolution equaled to a space resolution at nadir of around 3 km for the first camera and of 1 km for the second one. Typically, the images obtained with these vidicon cameras, just like the ones aboard TIROS and ATS, would be interpreted morphologically to identify clouds patterns –as time passed by, other patterns like icesheets, geological structures or ocean swells would be also morphologically studied.

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[147] Most of the technical information provided in this section has been obtained from the user handbooks of the corresponding satellites, from the synthetic descriptions available at http://nssdc.gsfc.nasa.gov/earth/nimbus.html, or from the series of books of the collection "Télédétection Satellitaire" directed by F. Verger between 1985 and 1988.

[148] A geostationary orbit is characterized because the position of an object flying following such an orbit remains the same for a stationary observer on Earth. Inversely, a satellite placed in a geostationary orbit observes in permanence the same region on Earth.

[149] The resolution of the previous TIROS program would be of five lines per image. A commercial 1965-1970s home television had a resolution of 525 lines per picture.

« Traitements des fichiers-images », Gerard Joly, 1986.

The advent of higher resolved cameras, like the ones carried by the satellites of the program Landsat in the 1970s would exacerbate the morphological approach to interpret satellite data. Like the majority of former satellites, the three first Landsat satellites (launched in 1972, 1975 and 1977) carried two sensors: a return beam vidicon and a multispectral scanning radiometer. The vidicon onboard Landsat had a resolution of 4500 to 6000 lines per image, corresponding to a space resolution of 30-60 m on the ground surface[150]. This high resolution was celebrated by scientists using the morphological approach, as it allowed discerning significant patterns with great detail. In the early years of satellite imagery, a skilled photo-interpreter provided with a *trained-eye*[151], and helped with statistical methods like metrical analysis, threshold techniques, histogram analysis, or filtering with Fourier transformation and its inverse[152], would look at the data under the support of photographic film or television screen and would discern all kind of morphological patterns[153] -a kind of information that turned out to be precious in studies in geology, geography, agriculture, hydrology, to mention just a few, and which motivated the engagement of the program for Earth survey in France, SPOT, proposed in 1973 and given definitive approval in 1977, after preliminary and feasibility studies at CNES[154].

In parallel, a stream of scientists turned away from the morphological approach and sought an alternative way of analyzing data, especially those images coming from lower resolved instruments, like most of the radiometers carried by these satellites. In the 1960s, the radiometers on board of the TIROS and the NIMBUS would measure in the infrared bands of the spectrum, a range that would be valued for two reasons. First, they provided continuity of observations during nighttime, where the visible videocameras would not work. Second, they provided quantitative information about the temperature of the emission objects. The High-Resolution Infrared Radiometer aboard of Nimbus-1, for instance, would be designed with this very double goal: to map the Earth's nightime cloud cover and thus to complement the measurements made by the vidicon instruments during daytime, as well as to measure the brightness temperatures of cloud tops and surface terrain. It would have a spectral

[150] The satellites of the program Landsat also carried scanning radiometers. Landsat-1 multi-spectral scanner was constitued actually by 24 photoelectrical sensors, 6 sensors for each of the 4 spectral bands between 0,5 and 1,1 micron. Each turn of the mirror scanned a line transversal to the trajectory of the satellite covering 185 km in the ground, and each of the sensors measured the radiances emitted by the ground. Each line of analogic measurements would be digitalized into 3420 pixels corresponding to 57 m length in the ground, and into 2340 pixels, 79m height, giving a space resolution of 57mx79m.

"Traitements des fichiers-images", Gérard Joly, 1986.

[151] We take on here the notion described by Lorraine Daston and Peter Galison in their seminal book tracing the history of the notion of objectivity. They would oppose the notion of *mechanical objectivity* characterized by a will to analyze data by eliminating all human intervention and celebrating the automatic character of the procedures to the *trained judgment*, which considers that only highly socialized people (trained in physics, holding phd or postdocs, having worked with other satellite data in the past) that had been properly trained can discriminate and interpret the data.

See « Objectivity », L. Daston and P. Galison, 2007.

[152] « Cartographie topographique et thématique », P. Foin, 1987 ; « Data management and computation. Volume 1 : issues and recommendations », Space Sciences Board, 1982.

[153] As Pamela E. Mack explains, in the early years of Landsat, data analysis was usually done literally by a*n interpreter*, for it was a person and not a computer who analysed data, since the procedures were not yet fully automatized and each image contained so much data that their processing required too much of computer power. Source: "Viewing the Earth: The Social Construction of the Landsat Satellite System", Pamela E. Mack, MIT Press, 1990.

[154] On the multitude of uses of satellite for Earth observation see Doug Stewart "Eyes in Orbit Keep Taps on the World in Unexpected Ways", Smithsonian, n 19, December 1988:70-76.

resolution allowing measuring temperatures from -63°C to -58°C approximately and a ground resolution of approximately 8 km at nadir. In contrast to the vidicon cameras, this type of radiometers would use a different principle of detection: the photoconductive sensor would transform the received radiation into an electrical voltage, which would be recorded on a magnetic tape for subsequent playback when the satellite would come within range of a ground-reception station. No image would be actually formed within the radiometer[155].

The second satellite of the family, Nimbus-2, would carry a second type of infrared radiometer of lower space resolution, the Medium-Resolution Infrared Radiometer, which would use still another principle for measuring, the *scanning*, conceived to sequentially acquire information proceeding from narrow bands of the observed scene or lines: a mirror oscillated, helped by a motor, and scanned the scene on the ground; each mirror turn corresponded to a line. The mirror reflected the light onto a small array of photoelectric detectors, which produced an electric signal that depended on the intensity of the light reflected. Nimbus's scanner was multispectral, that is, a prism was placed between the mirror and the sensor breaking the beam up into different colors, and thus different spectral bands could be selected for observation. With time, multispectral scanners would be capable to observe thus in those spectral wavelengths where television cameras (and photographic films) would not work, like infrared, microwave or ultraviolet. This multi-spectral scanner could beam up five different spectral bands, including bands for measuring not only temperature but also water vapor, CO_2 or albedo. At a satellite altitude of 1100 km, a horizontal resolution of 55 km could be obtained[156]. These would characterize in fact the two main differences vis-à-vis vidicons: scanning radiometry technologies would measure in (quasi)-continuity and they would widen the spectral range of observation. As a by-product, however, data volumes would increase –a point that we will consider later on, when introducing the silicon sensors and processors.

These space resolutions of the earlier radiometers (8km and 55km for NIMBUS 1 and 2) were coarser than the vidicon ones (3km and 1km for the same NIMBUS, or 30-60m for the Landsat program). By contrast, they would gradually cover a larger range of wavelengths with more and more spectral resolution. However, most of the spectral bands were unfamiliar to human eyes' visual interpretation. Equally important, there were no direct images to look at per se, but AC signals that must be transformed into images. Analyzing radiometric data would emphasize in these cases the physical properties of radiation: it was about interpreting the amount of radiation captured by the sensor in terms of some physical properties of the observed scene, or what is known as the "inversion problem" –we will address this problem in chapter 2 focusing on a particular example related to POLDER[157]. Instead of privileging an approach taking on forms to identify and study natural phenomena, scientists

[155] "Nimbus-I High Resolution Radiation Data Catalog and User's Manual", edited by the Laboratory for Atmospheric and Biological Science of the Goddard Space Flight Center of NASA, July 1966.

[156] "Nimbus-II User's Guide", Goddard Space Flight Center of NASA, July 1967.

[157] Put it simply, an inverse problem is a general framework that is used to convert observed measurements into information about a physical object or system: given the data that we have available, what can we say about the physical properties of this object? This would be a recurrent concept in our essay.

would endeavor to reveal the physical laws, or at least some phenomenological relationships, underlying such phenomena by exploiting the physical properties of radiation and the theory of light – whence it is pertinent to call it the *physical approach*. For instance, to follow with the early Nimbus examples, the physical interpretations would consist in applying the properties of radiation to associate the electromagnetic signals to information about the distribution of temperature, water vapor or CO_2.

Along the 1970s, as we have already introduced, several other satellites would be launched by NASA to test the feasibility of different sensing technologies (and signal transmission, storage devices, orbit control capabilities, etc.) to provide information about environmental features from the space, other than intended to weather forecasting. Most of them would be scanning instruments, like the ones aboard SeaSat in 1978[158], Nimbus-7 in 1978 or SAGE-1 in 1979. As low resolution evolved into medium by the late 1970s (and high with the instrument AVHRR/TIROS-N launched since 1978[159]), several other instruments using non-visible wavelengths to observe, like several types of radars, would be launched in orbit. All of them would take on physical interpretations of their data[160].

Instruments, we suggest, and by so doing we adhere Peter Galison's thesis, influence our way of seeing by favoring or compromising certain interpreting modalities[161]. Introducing radiometric low resolution technologies, which had been developed for use during nighttime to complete vidicons' coverage, but whose range of uses would be rapidly broaden to take advantage of the infrared thermal properties of the spectrum (and other bands), would orient what scientists could see in and from the data. This technology would become more and more promoted at NASA in detriment of photography or vidicon. For instance, from 1972 onwards, the series of satellites Nimbus would not carry vidicons anymore, but progressively improved versions of radiometers, with finer spectral resolution, more spectral bands optimized for detecting specific features (color of the ocean, ozone, stratospheric aerosols) or some ability to discriminate vertical layers. Even in those programs, like Landsat, whose vidicons were highly resolved (30-60m), radiometry replaced the vidicons due to its ability to measure during nighttime and the wider spectral bands range for measurement potentially providing much more information than only the visible range of the spectra: the satellites of the Landsat family launched from the 1980s onwards would only carry an improved version of their scanning radiometer called Thematic Mapper, with finer space resolution and more spectral channels.

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158 Seasat would embark a total of 5 instruments: two radiometers, one scatterometer and two radars.

159 The Advanced Very High Resolution Radiometer (AVHRR), would be optimized to be carried aboard NOAA's weather satellites since 1978. AVHRR was a four-channel scanning radiometer (ranging between 0,5-11,5 micrometers) capable of providing global daytime and nighttime sea-surface temperatures and information about ice, snow, and clouds, transmitted to ground-stations in two resolved forms of 4km or 1,1km at real-time.

160 Find an exhaustive compilation of the satellites in « L'espace, nouveau territoire. Atlas des satellites et des politiques spatiales », ed. F. Verger, 2002.

161 We do not defend a technological determinism, but rather a materialism like Peter Galison proposes it as stressing the role of experiment and observations and the importance of the material culture in which they are conducted. To have a first approach, see "Image and Logic: A Material Culture of Microphysics", P.Galison, 1997.

Learning the physical approach: the "Actions Thématiques Programmées"

In 1973, barely a year after the first launching of Landsat demonstrating the potentialities of high-resolution imagery[162], CNES would propose to enlarge its scope of activities as per include a program of high resolution imagery for Earth resources surveys, which would be approved by the Administration Council one year later (and named Système Probatoire d'Observation de la Terre or SPOT in 1977 after being approved by the government). This very same year, 1974, a report « Esquisse d'une politique française de télédétection spatiale » would be released, which spelled out the objectives of such a program in France specially underlining its interest in the management of land surfaces, forecasting and management of agriculture, forestry, pastoral or fisheries resources and corresponding policies. This report also concluded that in order for such a program to be successful "un très grand effort de recherche doit être fait dans les techniques infrarouge, hyperfréquences et les méthodes d'exploitation des données »[163]. In other words, research efforts must be conducted in what we have been calling the physical approach to satellite data.

Three were the aspects that would require specific research efforts. First, from a technological perspective, this program, SPOT, involved a new technology to gather measurements, a radiometric camera of a type called *pushbroom* (also known as along track sensor). Like the radiometers typically embarked at NASA's satellites described before, this was a radiometer with a number of spectral windows –four in total. The originality laid in the way through which the "scanning" effect was achieved: instead of incorporating a mechanical rotating mirror, a line of sensors were arranged perpendicular to the flight direction of the spacecraft[164]. Radiation would be captured by one or more linear arrays of photocells located one next to the other on a line transversal to the observed scene. The more number of sensors per array, the more resolved would be the observed line. Each scene would be then composed by the aggregation of a number of such lines –in turn, the more number of arrays, the more resolved would be the scene. Each image line of the instrument High Resolution Visible a board of SPOT-1 launched in 1986, for instance, would be registered simultaneously by 6000 sensors in four separate 1728-point CCD arrays, using 1500 sensors each whereas the one launched in 2002, SPOT-5, would double its figure, 12000 photocells per line, and providing a space resolution of 10m to 20m[165]. Different areas of the surface would be then imaged as the spacecraft flew forward. Because it looks at a particular area for a longer time, like a long exposure on a camera, a push broom scanner can gather

[162] First images from Landsat returned down in 1972. One of these images revealed a streak of white acid off the coast of New York, indicating that an industrial barge had dumped illegally thousands of gallons of iron wastes into the Atlantic Ocean only days before. Anecdotary images like this one demonstrated, according to many actors, the potential for environmental monitoring.

« Data management and computation. Volume 1 : issues and recommendations », Space Sciences Board, 1982.

[163] Rapport d'activité CNES 1974-1975.

[164] We have seen two different ways of obtaining a swath across the track of the satellite: mechanical rotating mirror and pushbroom arrays. Meteosat offered still a third solution to secure the scan effect: instead of rotating a mirror, it was the whole satellite that rotated over itself.

[165] SPOT would carry two identical instruments, HRV-1 and HRV-2 (High Resolution Visible) operating in two modes, namely the Multispectral Mode (composed by three bands : green, red and infra-red) and the Panchromatic Mode (one channel with a spectral range between 500 nm and 730 nm) with a ground spatial resolution of 20 m and 10 m respectively.

more light than a mechanic scanning radiometer[166]. The second and third efforts would be dedicated to investigate the techniques of "télédétection" per se, or remote-sensing in English language. Indeed, the data would be obtained through interpreting the electromagnetic properties of the radiation in different wavelengths, emitted, reflected or scattered by different objects and transmitted though different mediums. This would require in a first stage a complex mathematical treatment in order to render such measurements into the form of images, and in a second stage learning how to interpret such images in terms of Earth's resources (fisheries, agriculture, forestry, hydrology, and so forth)[167] –in other words, to learn applying the *physical approach* to satellite data interpretation.

While several laboratories of the Technical Center of CNES in Toulouse would be dedicated to investigate the pushbroom technology, a series of activities would be engaged in the following years dedicated to the preparation of such a program, centered in the training and formation of the scientists that would ultimately be using the data for their studies and the acquisition of material equipment necessary to process and interpret the images. For instance, CNES and the Institut Géographique National would create the Groupement pour le Développement de la Télédétection Aérospatiale (GDTA) as soon as in 1973, through which, inter alia, scientists could get grants to purchase data to NASA and NOAA. Coordinated actions between CNES and CNRS would be conducted as well. For instance, they would organize summer schools, fund research using data from ERTS/Landsat satellites seen as training for the future French program or specific lectures in universities[168]. In 1976, for instance, the scientific advisory committee of CNES, the Comité des Programmes Scientifiques (we will introduce it when discussing the origins of POLDER), would renovate composition as per include, together with representatives of the traditional space disciplines of astronomy, geodesy, ionosphere and magnetism, meteorology, cosmic rays or biology, a branch of « Télédétection des Ressources Terrestres ». This advisory committee would recommend two priorities in clear views of the future SPOT program: the studies of the interaction between several wavelengths and the land surfaces with different types of vegetation and the preparation of the data analysis of future NASA's instruments Heat Capacity Mapper and Nimbus-7 both launched in 1978[169]. The efforts of learning how to interpret satellite data would be fostered by establishing since 1978 of a joint CNES-CNRS program of "Actions Thématiques Programmées" allocating annual and pluriannual contracts to those teams willing to investigate methods for analyzing the satellite data. A number of projects would be then conducted under research programs in several fields such as "Atmosphère moyenne", "Bilan radiatif", "Océanographie spatiale", "Planétologie" or a generic one called "Télédétection"[170]. Once again, these grants were allocated in views of the future interpretation of SPOT's data. In that sense, it is plausible thus to suggest that SPOT would act as a vehicle to introduce and foster the physical approach in France through the discipline of remote-sensing, as a catalyst of most of the research in the domain of

[166] Rapport d'activité CNES 1976-1977
[167] Rapport d'activité CNES 1982
[168] Rapports d'activité CNES between 1974 and 1983.
[169] Rapport d'activité CNES 1975-1976
[170] Rapports activité of LOA, LMD and SA.

satellite data production, correction, processing, analysis and interpretation at least until the early 1980s when new projects would start to be proposed[171]. By so doing, SPOT would act as reinforcing the renewed notion of PI, in which participating in the early stages of conceiving a mission was not required to be legitimate to get and analyze its data. Indeed, this would be, just like we have mentioned before, how scientists from "non-selected laboratories" like Laboratoire d'Optique Atmosphérique or Laboratoire de Physique et Chimie Marines or the ocean biology station in Roscoff, but also non-academic scientists from the Institut Géographique National, the Centre de Météorologie Spatiale of the Météorologie Nationale, the Institut National de Recherche Agronomique, the Institut Géographique National, Centre National Pour l'Exploitation des Oceans amongst many others, would get access to satellite data from NASA's and NOAA's satellites, and later on SPOT's.

Creating the Laboratoire d'Etudes et de Recherches en Télédétection Spatiale (LERTS)

The promotion of the physical approach by CNES and CNRS would continue throughout the early 1980s culminating with the creation of an endowed laboratory in 1984[172]. Drawing upon the constatation of the « faiblesse numérique et la relative inorganisation de la communauté française s'intéressant à la télédétection »[173], CNES set up a team in 1980 pending on the department of Etudes Thématiques of the Technical Center of CNES in Toulouse to « mettre en place un noyau solide, capable de maîtriser les méthodologies de télédétection et de dépasser le stade de la photo-interprétation », as summarized in the report issued in 1983 assessing the pertinence of establishing such a laboratory[174]. Composed by five agents of CNES[175] with a background in varied domains of physical engineering, such as electronics or thermodynamics, their goal was to study radiometric and geometric processing techniques of satellite data, corrections of the directional effects, and to develop algorithmic methods to derive physical information from satellite data. In 1982, Pierre-Yves Deschamps, a CNRS physicist expert in remote sensing of ocean properties (ocean color, sea surface

[171] In 1989 these "Actions Thématiques Programmées" would renovate their methodology and organization giving birth to the Programme National de Télédétection Spatiale (PNTS), which still exists at present day. It is funded by the Institut National des Sciences de l'Univers of CNRS, CNES, Institut Géographique National, Institut de Recherche pour le Développement and Météo-France.

[172] The setting up of this new laboratory subscribed several actions that both CNES and CNRS were conducting together since the late 1970s, incremented in the 1980s, in order to secure the development and the utilization of the Earth observation data gathered, and that would be gathered in the future. They created, for instance, a Groupement intérêt scientifique « Télédétection spatiale » in Strasbourg in 1982 and another one in Toulouse in 1987. The latter one, in which LERTS would be a member, would give birth in 1995 to the Centre d'Etudes Spatiales de la Biosphère (CESBIO). As another example, we will mention that the ATP « océanographie spatiale » lead to the creation of the Groupe de recherches et d'études d'océanographie spatiale (GREOS) in 1981, which would give birth in 1987 to the creation of the Mission oceanographique utilisant l'etude des données de traceurs et de l'espace (MOUETTE), which would become Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS) in 1995.

Rapports d'activité LERTS/CESBIO and MOUETTE/LEGOS.

[173] « Rapport d'évaluation de André Berroir », president of the division Terre, Atmosphère, Océans of CNRS, assessing the request of the team of CNES to be associated at CNRS, October 1983.

[174] « Rapport d'évaluation de André Berroir », president of the division Terre, Atmosphère, Océans of CNRS, assessing the request of the team of CNES to be associated at CNES, October 1983.

[175] Gilbert Saint, Yann Kerr, Catherine Leprieur, Alain Podaire and Jean-Marie Durand. Some of them would, several years later, obtain a doctoral degree in remote-sensing, some disciplines of the Earth sciences or astrophysics.

Rapports d'activité LERTS.

temperature and related atmospheric corrections) working at LOA, requested to spend a year working with that group at CNES –he would remain in Toulouse until 1990. In 1984, this provisional partnership between CNES and CNRS would be perpetuated by creating a new laboratory, the Laboratoire d'Etudes et de Recherches en Télédétection Spatiale (LERTS)[176], composed by six persons, the five agents of CNES and the physicist of CNRS former attached to LOA[177]:

> « L'équipe ainsi constituée a pris comme thème l'approche physique en télédétection, cherchant à faire des données spatiales une utilisation quantifiée, traduisant les données numériques en propriétés physiques »[178].

LERTS's scientific program would vindicate the development of techniques for interpreting satellite data following the physical approach. It would be structured in two main axes: on the one hand, studying physics of measurement per se (light theory, spectral signatures, calibration methods, correction techniques, inverse problem, radiation models, error analysis) intended to conceive new experiments and, on the other, applying these measurements in particular scientific domains (study of the vegetation, the atmosphere or the oceans)[179]. In other words, this laboratory was meant to be a source of PIs of future space missions: training scientists to design instruments, maybe even build some components of them, and to interpret and analyze the corresponding satellite data. Although the team had been, back in 1980, originally set up as an internal department of the Technical Center of CNES in Toulouse in views of preparing the analysis and interpretation of the data gathered by the instruments inside the future satellite SPOT, these scientists would display a set of tools and resources valid for other types of measurements and would soon enough extend their scope of interest including other types of instrumental configurations. Without advancing much of our story, let it be said that this team, because of their training and because of their close ties to CNES, would be crucial in conceiving and realizing POLDER.

CONCLUSIONS

We have looked at the space activities related to scientific research between 1960 and 1980 focusing on three angles. First, we have overviewed the programs of space agencies as a means to shed some light on what were considered to be space sciences by stressing the original conundrum between Earth sciences and applications. Next, we have explored the relationship of scientists with the instrument and the data in order to reveal what kind of scientists were considered to be space scientists. Finally, we have scrutinized the technologies of sensing and data analyzing to illuminate what type of data

[176] LERTS would be the first laboratory mixed CNRS and CNES, but other would follow, including MOUETTE in 1987, that would foster the oceanographic space research, by participating in the CNES-NASA joint mission Topex/Poseidon. See our footnote 140.

[177] « Projet de Convention : Règles d'organisation et de fonctionnement du laboratoire mixte CNES-CNRS de Toulouse », 1984.

[178] « Rapport d'évaluation de André Berroir », president of the division Terre, Atmosphère, Océans of CNRS, assessing the request of the team of CNES to be associated at CNRS, October 1983.

[179] Rapports d'activité LERTS.

were considered to be admissible for conducting scientific research. Let us now summarize the main ideas.

At the dawn of the space age, the culture of experimental physics dominated the space missions labeled as “space sciences”: a PI designed an instrument, often also built it, elaborated the calibration software and analyzed the data obtained from the experiment. In this PI-mode of data handling, data usually remained under the “property” of the experimenter and were rarely shared –they were also rarely archived in a systematic and organized manner. Complexity of technologies, their industrialization or endeavors to maximize effort by widespreading the use of data would contribute to perceive the PI-mode of data handling as inefficient for optimizing the use of data (we will see in chapter two that the abundance of data and the technically constraining conditions of processing and storing them would also favor changes in the ethos of the “space scientist”). The meaning of space scientists would be enlarged as per including scientists that had not intervened in the conception of the instrument but wanted to exploit the measurements. This was a way to widen the scope of use of satellite data beyond the reduced number of scientists who had designed the experiment. This was a way as well for space agencies to gain visibility. Several moves in France would be promoted to favor the training of such scientists (grants to get data from NASA or NOAA, grants to learn the physical approach, creation of a endowed laboratory) in views of the exploitation of the future data from SPOT, which was in the course of being realized.

This would happen coinciding with the progressive incorporation of a new domain of activities in the space agencies: the mission who looked at the Earth as another planet to be studied but without losing views of the potentialities in economic, commercial and societal terms. At the same time, we have suggested, as new missions to support the research in the disciplines like physical oceanography, atmospheric chemistry, climate sciences, meteorology, marine biology or glaciology, to mention a few, were being programmed to be developed during the 1980s, the epistemic virtue of data would change from being located on physical radiances to being located on geophysical parameters. The point, aligning with the will of space agencies to maximize the investments through maximizing the use of satellite data, was to render satellite data usable for studies of the Earth and its environment, which required the data to be integrated within the representations of Earth scientists about the processes and phenomena ruling the Earth’s dynamics. This renewed epistemology regarding the type of data valuable for scientific inquiry, which will be further developed in the following chapter, began to see the PI-mode of data handling as inefficient as well. Instead, it would advocate for more participation of space agencies in the production of datasets, for greater effort in standardization, for full data sharing, for central importance of archiving, for a renewed division of labor, for including field-work activities within a given space mission, for a novel relationship with the instrument and the data or for a reconfiguration of the scientific community, beginning with a renewed understanding of the ethos of being scientists working with space assets.

It is within this reading key that we propose to interpret the events and moves that, during the 1980s and 1990s, would transform everyday practices and attitudes to varying degrees, in an attempt to reconcile the space technologies (particularly the satellite data) with the later arrived disciplines constituting the so-called Earth sciences. By taking POLDER as a barometer of the practices, it is, in fact, these evolutions in the data gathering, production, storage and diffusion across the roughly thirty years elapsed between POLDER conception in 1986 and the last transmission of data from an evolved version of in 2013, together with the continuities and perpetuations, that we aim to explore in our work.

PART I:
RECONCILIATION

One of the instruments conceived in the mid-1980s in France as part of this first generation of missions to study the planet Earth would be an imaging radiometer to measure the light in polarization and from multiple directions, POLDER (POLarization and Directionality of the Earth's Reflectances), proposed in 1986. A group of scientists from the recently created Laboratoire d'Etudes et Recherches en Télédétection Spatiale (LERTS) associated to CNES in Toulouse and from the Laboratoire d'Optique Atmosphérique (LOA) associated to the University of Lille would ensure the scientific responsibility of the instrument conceived and developed with the support of several in-house laboratories of the Technical Center of CNES in Toulouse. The project was headed by the physicist Pierre-Yves Deschamps, former scientist at LOA expert in remote sensing of the oceans and working in Toulouse since 1983, who personified the only non-CNES scientist of LERTS. It would be proposed to be embarked with the instrument VEGETATION, also conceived at LERTS, as part of the payload of the third satellite of the family Système Probatoire Observation Terre, SPOT-3, scheduled for launch in the early 1990s. This project would be sent to different divisions of CNES-Toulouse, to Direction of Programs in CNES-Headquarters in Paris, to the chairman of the CNES's scientific advisory group (the Comité de Programmes Scientifiques) and to representatives of the societies SPOT Image and SPOT Image Corp that had been created to operate the satellites of the program SPOT[180]. Around 10 years would elapse before the launching of POLDER, in August 1996. The radiometer would be instead carried aboard of a Japanese satellite called Advanced Earth Observing Satellite (ADEOS) dedicated to study the Earth and its environment, as a first step towards the eventual deployment of a Japanese program for monitoring the environment in a global and real-time

[180] The authors of the "Proposition de passager SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986, would be Michel Laporte of the Division Opto-éléctronique, Marc Leroy of the Division Traitement d'Images (both in-house laboratories of the Technical Center of CNES in Toulouse) and Alain Podaire of LERTS. They would be helped with contributions of two more engineers of the Division Opto-éléctronique of CNES in Toulouse and by the scientific contributions of Pierre-Yves Deschamps of LERTS, Maurice Herman, R. Santer of LOA and Yves Fouquart signing as the at that time director of LOA.

The project would be diffused to a number of services and departments of the Technical Center in Toulouse, to Geneviève Debouzy and Jean-Louis Fellous of the Direction de Programmes in Paris, to René Pellat (chair of the scientific advisory committee of CNES, the Comité de Programmes Scientifiques), and to Gérard Brachet and other responsibles of SPOT Image and SPOT Image Corp.

manner, just like it was done with the weather since the late 1970s. ADEOS was a huge platform that carried a total of eight different instruments provided by different institutions (including NASA, the Japanese Space Agency (National Space Development Agency of Japan (NASDA), and other Japanese organizations). POLDER's spare version would be launched in a second shot onboard of the second satellite of the Japanese program, ADEOS-II, around six years later in 2002. Both satellites had been built to be functioning at least during three years, and both satellites would fail roughly few months after the launching. A third prototype of POLDER, with a maximal life span of two years, would be launched in 2004 onboard of a CNES's microsatellite called PARASOL, which would be gathering data during around 9 years, until it would be disconnected in December 2013. In this semi-chapter we are concentrating in POLDER 1 and 2, leaving for a second one the case of POLDER 3, which we consider as being part of a different experiment –even if using essentially the same instrument POLDER.

This semi-chapter pursuits two goals. First, we are introducing the instrument POLDER, during the initial stages of conception between 1986 and 1990, decision to fund preliminary studies in the laboratories and the material realization of a prototype in 1990, and formal engagement of the French and Japanese space agencies in 1992. We point to some considerations about its technical specificities and about its conditions of approval, by stressing the multiplicity of determinations, dynamics and layers, objectives and agendas of the different participants in the project. Through the example of POLDER we invoke debates, still pertinent at present day, about the vocation of a space instrument (as responding to a given set of well-posed scientific questions and/or opened to diverse non-prestablished usages) or about the weave that ties together, or apart, the technical departments of CNES in Toulouse and the external laboratories (typically, but not exclusively, CNRS or universities) when it comes to propose, support, develop and realize space instruments.

Secondly, by tracing back the original plans for POLDER as conceived in 1986 (its scientific vocation, its modes of data handling, its technical configuration, its procedures for realization, its mechanisms of data dissemination, etc.) and connecting them to the ones developed in the instrument factually launched in 1996 (and in 2002), our further aim is to lay down the grounds of the main hypothesis threading our investigation and that browses the developments of all the chapters in the first part of our essay: for satellite data to be used by the later arrived in space activities, the Earth scientists, space missions must be embedded within their current more or less rooted, flexible and/or stable set of goals, practices, understandings, ambitions and circumstances. That means that participants must come to terms with eventually different modes of data handling, of organizing the realization of an experiment, of operating its exploitation, of preparing the interpretation of the data, of allocating power amongst the participants, of defining the ethos of being a scientist, of perceiving the property over instruments or data, of distributing the labor, of understanding the essence of a space mission. They must mold each other within a process that we like to call of *reconciliation*. One word must be said about the choice of this term. The term reconciliation is not to be taken as the process of restoring a relationship after a conflict[181] –there was, in the 1980s and 1990s, no relationship to restore, because, as we have argued in our introductory chapter, the first satellites devoted to study the Earth and its environment conceived and developed by scientists (and not industrials or commercial partners) would start to be proposed in the 1980s; therefore, there simply existed no relationship between space agencies and Earth scientists before the 1980s. Rather, we propose to use the term *reconciliation* according to the second and third entries given by the dictionary edited at Oxford defined as "the action of making one view or belief compatible with another" and "the action of making accounts consistent; harmonization"[182]. In other words, we understand the notion of *reconciliation* as the process of bringing together two items initially separated –without, unlike the common meaning in French-language, assuming anything about the causes of their initial separation and previous separate state (original, conflictual, consensued).

The instrument POLDER

In France, polarized measurements taken from the astronomical observatories Meudon and Haute Provence had been used, at least, all along the 1970s to study the surface and the atmosphere of other planets, especially Venus, Saturn and Jupiter[183]. Some space missions of NASA, the Pioneer Venus for instance in which some scientists of Laboratoire d'Optique Atmosphérique and the Service d'Aéronomie had participated, carried polarimeters to study planetary atmospheres[184]. The Goddard Space Flight Center of NASA was planning to put a polarimeter inside the shuttle to measure, this time, Earth's atmosphere properties –although first flights would not take place before 1988[185]. In 1985, scientists at LOA experts in Venusian, Saturnian and Jovian atmospheres directed by Maurice Herman, would put a polarimeter, PIRAT, inside a tropospheric balloon of CNES over the ocean to test the ability of this technique as applied to the troposphere of the Earth, a capacity that had been already demonstrated for the stratosphere with severals flights of the balloon-borned polarimeter RADIBAL, also developed by a team at LOA, from 1983 onwards[186]. The rather poor quality data obtained with the balloon-experiment of 1985 would confirm that atmospheric aerosols had a highly perturbative effect on the oceanic signal and that great effort of calibration and correction was necessary –it confirmed, at the same time, that with proper calibration and correction, polarized

[181] We are aware that this is the meaning commonly given in the French-language term "reconciliation".

[182] "The Oxford English Dictionary", published by the Oxford University Press, edition of March 1989.

[183] Professor Maurice Herman and R. Santer, two of the scientific godfathers of POLDER, had during the 1970s worked in polarization light to study planetary atmospheres. See, for instance:

"Analysis of some Venus ground-based polarimetric observations", R. Santer and M. Herman, 1979.

"Optical reflectance polarimetry of Saturn's globe and rings, IV. Aerosols in the upper atmosphere of Satum", R. Santer and A. Dollfus, 1981.

This was also a field of research of NASA's scientists: « Interpretation of the polarization of Venus », J.E. Hansen and J.W. Hovenier, 1974.

[184] "Imaging and polarimetry with the Pioneer Venus Orbiter Cloud Photopolarimeter", L.D. Travis, 1979.

[185] « Polarisation of the solar light scattered by the Earth-atmosphere system as observed from the US shuttle », JC Roger, R Santer, M Herman, JL Deuzé, remote Sensing of Environment, Volume 48, issue 3, Pages 275–290, 1994.

[186] Rapport d'activité LOA.

measurements could be used to characterize the tropospheric aerosols[187]. Improving atmospheric corrections and calibrations would become the main scientific objective of POLDER, a low space resolution wide field-of-view imaging radiometer that captured, from multiple angles, polarized light emitted by a point[188].

Experiment of a PI-type

POLDER was conceived as a small instrument of around 13 kg and power consumption of 25W in 20V. It would consist in a photo-detector, a wheel with filters for selecting the wavelength and the polarization, and an optical system. Three were the technical main features of POLDER: its coarse space resolution, the novelty of measuring polarized light and the ability to measure the same point from multiple directions.

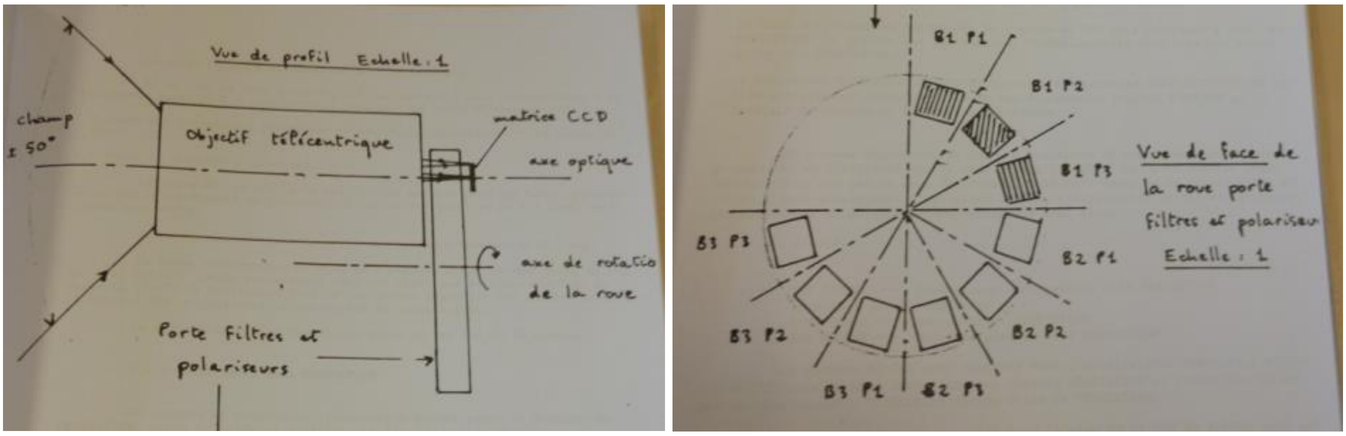

Fig. I.1.1. Left: Optical configuration of POLDER : objective, wheel with the filters and CCD. Right: Frontal view of the wheel with the filters to select spectral bands and polarizers[189].

The sensor of POLDER would be a camera CCD of 8,8mmx6,6mm placed at the focal of the optical objective[190]. The camera would be an off-the-shell model commercialized by Thomson of 288 lines and 384 columns, composed by silicon photo-detectors. Each chip would reproduce an electric signal proportional to the amount of detected energy for each wavelength with or without polarizer and would provide a digital signal in 8 bits. The Earth would be scanned square per square, meaning that each image would be read in the screen as a composite of 288 horizontal lines and 384 vertical columns. Given the configuration of POLDER, each pixel would correspond to 42km2 in the ground providing a space resolution of 6x6km2. This was a quite coarse space resolution if compared with

[187] "Stratospheric aerosol observations from a ballon-bome polarimetric experiment", M. Herman et al, 1986.

[188] The technical details of this section are based on the "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

[189] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

[190] The sensors of a Charge-Coupled Device are capacitors that convert the incoming photons into electron charges of more intensity where the light is the brightest. The image is then read out in the camera. We will further explore this technology when discussing the perceptions of data deluge in chapter 2.

other radiometers being flown in the early 1980s like AVHRR (1km), or with those prepared to be launched like VEGETATION (1 km), MERIS aboard the future ESA's environmental satellite EPOP (300m at nadir) and MODIS aboard of the future NASA's satellite Terra (250m, 500m and 1km depending on the latitude) or the high-resolved HRVIR (10m to 20m). As we will see along our essay, the coarse resolution of POLDER would be often pointed as insufficient to generate data accurate enough for some studies (especially those related with the characterization of some biological properties of the sea waters and those related to the characterization of the vegetal surfaces).

The channel sequence would be repeated every 2,5 seconds, which corresponded to a rotation of the filter wheel scanning a surface of 42km2. During a wheel turn, the camera would take 10 images: 1 image per polarizer and spectral band (3x3 images in total) plus 1 image in the dark. This cycle of 10 images would be repeated every 25,2 s, the time corresponding to a line of 4pixels. The total duration of a sequence would be of 30 minutes. As the satellite would pass over a target, because of the large swath and field of view (2000x1500km2), the point would remain under POLDER's field of view during consecutive snapshots: a total of 12 measurements would be performed per each point. In other words, the same point in the ground would be seen under different viewing directions separated around 11°. POLDER would observe, hence, a terrestrial target from different directions during the same orbit enabling to infer those properties of the emitting object depending on the direction, like the bidirectional reflectance function[191])[192]. There existed already some other radiometers with multiangular vision, like ERBE, and the value of multidirectional measurements in improving such estimations had consequently been already demonstrated.

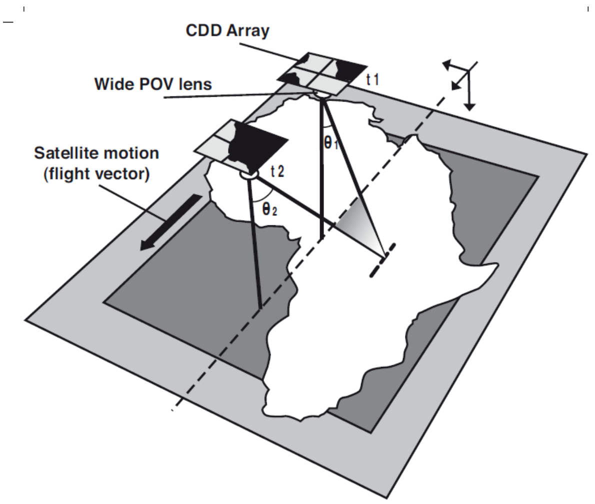

Fig. I.1.2: POLDER looked at the Earth through two directions: with a field-of-view of ±50° in a plan perpendicular to the motion trajectory of the satellite and with a field-of-view of ±42° within a plan parallel to the motion*. Successive snapshots would enable to measure the radiances of a given target from 12 different viewing angles. Figure obtained from: See footnote 192.

*Erratum: POV shall be read as FOV, standing for "field-of-view".

[191] The interaction between the incoming solar radiation and the Earth surface is characterized by the bidirectional reflectance distribution function (BRDF), a function that defines how light is reflected at an opaque surface. This function depends of a number of factors: the wavelength, the physical and geometrical properties of the surface, the environmental conditions, and a set of angles, including the angles of incidence and reflection and the sensor viewing (and therefore of the time of the measurement and the orbital position of the satellite). Because POLDER would measure the light reflected by a point from around 12 different directions and with a high repetitivity, directional information about a landscape could be derived while considering the environmental conditions as constant. In consequence, the computation of the BDRD would simplified, enabling the further retrieval of the corresponding physical parameters from the emitting object.

[192] « Documenter pour le climat », G. Cirac Claveras, 2014. Adapted from "The POLDER Mission: Instrument Characteristics and Scientific Objectives", Pierre-Yves Deschamps et al, 1994.

The originality and novelty of POLDER with respects all these existing radiometers would be the ability to measure in different degrees of polarization. It would be with the filter-wheel of 80mm of diameter that the polarization effect would be achieved. A motor would ensure the rotation of the wheel, which would be made up by three spectral channels defined according to SPOT's wavelengths (B1 (green, 0,5-0,59 micron), B2 (red, 0,61-0,68 micron) and B3 (near infrared, 0,78-0,89micron)) and 9 polarizers (3 per spectral band), producing a multispectral effect, including polarization. The interest of such measurements had been suggested by theoretical, laboratory and previous measurements (from the surface, with balloon or in Venus), but it had to be proven. Indeed, POLDER would be the first satellite radiometer measuring polarized radiances emitted by the Earth. And it was as such that it had been conceived, as an experiment to check feasibility and interest of this particular type of measurements.

POLDER was thus conceived as a technological exercise to demonstrate the feasibility and the potential scientific interest of measuring the light in polarization. It was proposed to be carried by one of the SPOT's satellites, the third one, and as a passenger of the instrument VEGETATION[193]. It would be defined as an « expérience d'investigation scientifique et technologique et non de système opérationnel »[194]. Therefore, exigencies in terms of data handling would not be much constraining. For instance, it was not necessary for POLDER to measure in continuity and to receive the data in real-time. Instead with few spotty and lacunar measurements summing 1,5 hours per day during 2 to 3 years would be more than enough to get enough samples to develop and test new algorithms of correction and interpretation of the data –without any aspiration of permanent measuring and real-time processing. In terms of data storing and transmitting, this would entail that, compared to VEGETATION of HRVIR, POLDER's volumes of data would be very tiny. Actually it would no need a specific storing device, but rather it would use VEGETATION's one –POLDER's signals would only occupy the 5% of the VEGETATION's recording device capacity, around 12,3 Mbits per snapshot. In turn, POLDER data would be sent and play back to the ground station together with VEGETATION data, and decommutted and despatialized by the ground segment of the instrument VEGETATION, without establishing any specific ground computing center for POLDER. The data processing software of VEGETATION, created mostly by scientists at LERTS, would only include partial radiometric calibration, since it was thought that geometric corrections depended too much on the further utilization and therefore each scientist should develop the methods adequate to his/her study –so it would be done, as a consequence, with POLDER data. Just like it was commonplace with satellite experiments, partially calibrated data of POLDER would be then shipped to the scientists of

[193] Scientific teams willing to launch an experiment into orbit could use the satellite SPOT to carry it as an additional instrument, called a *passenger*, to the main radiometers of SPOT, the HRVIR. The instrument VEGETATION won a ride-ticket as passenger of SPOT-3. In consequence, SPOT-3, as it was defined by 1986, was meant to carry two instruments : one of high space resolution (HRVIR, 10m to 20m) and one of medium space resolution (VEGETATION, 1km). The overall goal of the mission was to gather data to support descriptions of the evolution of the parameters characterizing the land surfaces and vegetation.

[194] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

LOA and LERTS, appointed as the scientific responsibles of the project, for further processing, analysis and publications. In terms of data archiving, assuming that POLDER would measure three snapshots per day, that is 1,5 hours per day, data would correspond to 5Moctets, which could be recorded in a standard tape of 6250 bpi of radiometric corrected data every 20 days aproximately. To get the data interested scientists should contact CNES who would ship the magnetic tape with the requested samples of data.

POLDER's proposal reflected the classical *PI-mode* of organizing the data handling that we have described in the previous chapter as predominant during the first 20 years of the space age: a handful of scientists conceived and build an instrument (more or less helped and supported by the Technical Center of CNES), prepared the software for data calibration (which in this case would be integrated in a computing facility at CNES equipped with powerful enough machines to systematically process the data[195]) and were shipped the calibrated data for further analysis and interpretation. The epistemic virtue of data was then placed, just like in the space experiments conducted before the 1980s, on partially radiometrically calibrated radiances. This was, at the end of the day, the whole essence of being the scientists: to interpret the measurements following a physical approach in order to infer some type of knowledge about the measured objet or about the perturbing atmosphere. While the results of the analysis would be perpetuated through eventual publications in specialized journals, no plans for conserving and archiving the data were spelled out.

Scientific objectives: Research in remote-sensing

Several aircraft and satellite missions of the 1970s, in which POLDER's responsibles of LOA and LERTS had participated, especially with NASA's Heat Capacity Mapping Mission launched in 1979 and the Coastal Zone Color Scanner launched aboard Nimbus-7 in 1978, had evidenced that the atmospheric corrections, necessary to interpret satellite data, depended dramatically on the tropospheric aerosols content and species[196] -this had been as well the overall conclusion of the balloon-borned experiment PIRAT in 1985. They were particularly perturbative in the oceanic signal: calm oceanic big surfaces have very low reflectance (they are very dark); in consequence a big part of the signal received by an instrument in orbit corresponds to noise coming from the atmosphere located between the ocean and the satellite, and not from the ocean itself.

The primary objective of POLDER, as stated in the initial proposal dating of 1986, would be to « améliorer la qualité des observations de VEGETATION et HRVIR au moyen d'une meilleure

[195] This centralization was required for HRVIR and VEGETATION data, whose volumes were deemed to be important. Strictly speaking, it would perhaps not had been necessary to cope with POLDER's data measuring not more than 1,5hours per day. However, POLDER's data handling was associated to VEGETATION's one.

[196] "Preliminary Results of CZCS Nimbus 7 Experiment for Ocean Colour Remote Sensing: Observation of the Ligurian Sea", M. Viollier et al., 1981.

"Algorithms for ocean colour from space and application to CZCS data", P.Y. Deschamps et al., 1987.

"Sea surface temperatures of the coastal zones of France observed by the HCMM satellite", P. Y. Deschamps et al., 1984.

calibration relative des instruments et d'une meilleure correction des effets perturbateurs et atmosphériques »[197]. The idea of POLDER's advocates consisted in taking advantage of the presumed ability of polarized light to characterize aerosols to develop more adapted tropospheric correction functions to be applied to the data of HRVIR and VEGETATION, given that they would measure the same regions in the same time and with the same spectral bands than POLDER. The ultimate goal would be to gather enough data to generalize these correction functions so that they could be applied to other radiometers. POLDER would be hence not proposed as a central payload inside SPOT-3, role reserved to HRVIR and its passenger VEGETATION, but as an instrument whose measurements would be used to improve the measurements made by other instruments. The central corpus of the project would be focused in justifying, describing and providing calculations and theoretical studies supporting this scientific objective; the annexes, nonetheless, included a second scientific objective. It would consist in taking advantage of the data gathered by POLDER to support studies about the oceans, the atmosphere or the land surfaces, the three general themes that had been shaping the agenda of environmental research in the latest years. For instance, it was said that assuming that polarization could be useful to characterize the aerosols, it would be pertinent not only to use the data to develop improved correction and calibration methods but also to study the aerosols per se. Some optical and radiative properties of the aerosols could be identified and eventually correlated to processes of cloud formation. Along the same lines, it was suggested that multiangular features could result interesting in studying the radiative effects of clouds and their influences on the Earth's radiation budget, or to study the color of the oceans or yet some properties of land vegetal surfaces. The authors of the proposal suggested that data gathered with POLDER could be applied within a research program centered in studying the atmosphere, the land surfaces or the oceans but, unlike the description of the remote-sensing objectives, nothing very specific was stated about such a program (no conditions of measurement, no algorithms of processing, no preliminary studies quoted). We shall conclude, in the light of the respective weight and degree of details in the proposal, that POLDER would be proposed as an instrument to conduct research in the domain of remote-sensing and only secondary as applying its measurements to a given discipline in any domain related to the Earth sciences.

Conditions for approval

People in charge of SPOT-3 would not accept this proposal. In the following months, POLDER advocates would keep looking for flight opportunities and responded to NASA and ESA calls for instruments. NASA was preparing its Earth Observing System program and wanted to enroll some small foreign instruments –in 1988, the Goddard Space Flight Center responsible of the overall program released a call for opportunities. ESA was also preparing its huge first environmental platform, the Environmental Polar-Orbiting Platform (EPOP), scheduled for launch in the mid-1990s,

[197] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

and also called for instruments to put inside it. NASA would not be interested in POLDER by then[198]; ESA, on the contrary, was[199]. By 1987, ESA started funding a preliminary study of feasibility of POLDER to be put aboard of the satellite (EPOP). At the end, however, POLDER would be flown in 1996 and 2002 inside two Japanese satellites called ADEOS dedicated to study the environmental changes[200].

The « Comité de programmes scientifiques » (CPS) and the « Séminaires de Prospective Scientifique »

NASA's scientific policy was informed by in-house scientists located in different laboratories across the territory (in the field of Earth sciences, they would be mainly Goddard Space Flight Center in Maryland, Jet Propulsion Laboratory in California[201], Langley Research Center in Virginia and Goddard Institute of Space Sciences in New York) as a way to maintain direct control over the projects that NASA funded complemented by an effort towards engaging also non-NASA scientists, located at universities or research centers, to ensure the higher quality of science possible, the widespread of NASA's instruments and data amongst the scientific community, and, as has been suggested by the historian Robert W. Smith, to help defusing opposition to NASA's plans[202]. CNES wanted also both to maintain control over the projects it funded while consolidating a strong competitive space scientific community in France, but it would yield on different organizational principles: as we have seen, it had chosen to concentrate its efforts in a number of selected laboratories external to CNES. In order to draw advice on future programs from the scientific community in an intimate and frequent fashion, a "Comité des Programmes Scientifiques" (CPS) would be created as early as in 1962, composed of scientists reporting directly to the Direction of Programs of CNES and aimed to define its scientific program[203]. Representatives of the selected laboratories would be invited to participate in an advisory manner to CPS meetings. Although their power was strictly consultative and ultimate decisions were in hand of the higher authorities of CNES and the government, through the Conseil d'Administration, this small scientific elite rapidly gained a lot of influence to determine

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198 Actually, the Goddard Institute of Space Sciences (GISS) of NASA had also proposed a scanning radiometer measuring polarized light as a payload of the Earth Observing System, the Earth Observing Scanning Polarimeter (EOSP) –the project was not selected either. To complete the account, in its own program CLIMSAT proposed in 1988, GISS/NASA included this instrument –CLIMSAT was not approved by the Congress.

"EOSP: Earth Observing Scanning Polarimeter", L. D. Travis, 1993.

199 « Plan à long terme en observation de la Terre», prepared by Antoine Mizzi, 1991.

200 "Special issue on ADEOS", 1999.

201 Unlike in the Goddard Space Flight Center, the Langley Research Center and the Goddard Institute of Space sciences, the employers of the Jet propulsion Laboratory are not recruited by NASA but by the California Institute of Technology. However, NASA funds facilities, technical resources, projects and their research, as in any other of NASA's labs, and albeit being officially part of the Caltech, JPL works in effect as a NASA center.

202 In his study about the decision and selection mechanisms at NASA through the case of the Hubble telescope, the historian Robert W. Smith argued that the choice of a CCD device as the sensor of the telescope by the astronomers had been driven by a need to gain the support of the community of planetary scientists, initially reluctant to the project, as a tradeoff to defuse their opposition.

« The space telescope. A study of NASA, science, technology and politics », Robert W. Smith, 1989.

203 It was created during the first meeting of the Conseil d'Administration, February 27th 1962, with the goal of elaborate the annual CNES's scientific program.

the scientific program of CNES. During around 10 to 15 years, these scientists would be almost the only scientists with enough knowledge, expertise and resources to propose new projects and to realize them from their conception to their exploitation, they would be the space scientists in France -this had been the whole point of investing in the "selected laboratories" in the first place. Consequently, scientists of the "selected laboratories" would be the ones assessing the projects and proposals that they had themselves brought in the forum. When, for instance, Pierre Morel proposed in 1968, as vice-director of the "selected laboratory" Laboratoire de Météorologie Dynamique, to realize a weather satellite, he was proposing it before a CPS in which he had served since 1962 as secretary. When professor Jacques Blamont, this is another example, proposed before the CPS to build some experiments to measure hydrogen radiation in Venus, he did is as director of the "selected laboratory" Service d'Aéronomie, while he was at the same time Director of the scientific programs at CNES since 1962.

The 1970s would be characterized by governmental changes in the organization of the space policy and the space program, by the consolidation of satellites as spacecraft (in detriment of sounding-rockets), increasing in so doing the technical complexity of the experiments (both because of being integrated inside satellites but also because simple instruments had already been exploited), progressive externalization of skills and capabilities from the Technical Center of CNES to the industrials, and thus progressive industrialization of the projects (and the emergence of the space manager as a central figure), changing priorities towards increased ratio of applications missions (weather forecasting, telecommunications, location of data collection, and Earth survey), the consolidation of the European Space Agency as a major space power, the redefinition of the functions of the "space scientists" with regards of the complexification and industrialization of the experiments and the data handling, to mention few contextual elements. At the same time, this would coincide with the incorporation of a new generation of scientists, formerly students with renewed blood, in the selected laboratories and/or in the scientific advisory committee (the Comité de Programmes Scientifiques, CPS). It is not the topic of our investigation to analyze this context in detail, let it be only said that CNES leadership would renovate structures and procedures for defining CNES scientific program. In 1976, the approval of the "Décret relatif au Centre National d'Etudes Spatiales et à l'organisation de la recherche spatiale", would formalize a renewed composition and functioning of CPS. CPS became a consultative body itself, reporting to the Conseil d'Administration du CNES and aimed to assessing the scientific interest of projects soumis au CNES as well as "formuler, compte tenu des moyens disponibles, toutes propositions utiles concernant le développement de la recherche spatiale"[204]. It would be composed by a maximum of 12 members, elected by the Ministre de l'industrie et de la recherche further the advice of the Secrétaire d'Etat aux universités. The president of the CPS was to be elected by the Ministre d'industrie et de la recherche under recommendation of the president of CNES. CPS would be renovated every four years, with a possibility of re-election for

[204] "Décret relative au centre national d'études spatiales et à l'organisation de la recherche spatiale", décret n° 76-104, 27 January 1976.

any of each members[205]. To support its tasks, CPS would be assisted by six working groups, including experts in those disciplines recently « spatialized » like oceanography, stratosphere (atmospheric chemistry) or remote-sensing (clearly addressed to the future SPOT), chaired by a member of the CPS and composed by 10 to 15 members chosen by the scientific community. To elaborate CNES scientific program, this renewed CPS would formalize a selection procedure based on the evaluation of proposals in response to annual "calls for ideas". Anyone could answer to the call. The six working groups would then examine the proposals concerning their topics, would eventually work them further, by synthetizing them, reagruping different proposals or completing their objectives or scope, and would emit recommendations to CPS, which, in turn, after considering scientific interest and budgetary constraints, would elaborate a formal recommendation to the Direction of Programs of CNES. From 1981, CPS would be divided in two general groups: the group "Terre, Océan et Atmosphère" (TOA, later on TAOB, the B standing for Biosphère, and today TOSCA, SC standing for Surfaces Continentales) and the group "Sciences de l'Univers" (today named CERES, Comité d'Evaluation sur la Recherche et l'Exploration Spatiales), who would examine separately the assessments and then gather together to consensuate general recommendations and orientations. From 1981 onwards, as we have insinuated in the previous chapter, the methodology of proposing and selecting scientific missions at CNES through the annual calls, would be complemented by the organization of periodic scientific meetings hold every 4 years called the "Séminaires de Prospective Scientifique". Gathering scientists from "selected" and "non-selected" laboratories, experts in remote-sensing or not experts, the goal was to establish the overall scientific guidelines, and eventual some concrete projects, which the space projects should subscribe in the following 5 to 10 years[206].

When in 1986 the POLDER's dossier was sent to the Direction of Programmes in Paris and Toulouse as well as to the chair of the Comité de Programmes Scientifiques, and circulated through a number of technical department at Toulouse, all these renovated ways of proposing, selecting and deciding missions were promoted. The Comité de Programmes Scientifiques annually evaluated the scientific propositions and discussed budget allocations –although before the 1990s the number of proposals was rather poor- and two scientific meetings had already been hold in 1981 (Les Arcs) and 1985 (Deauville). The idea of the instrument POLDER had to be integrated within the procedures of CNES if the instrument were to be built, for it was CNES that would provide its funding. That meant that

[205] The first of these new Comité de Programmes Scientifiques was set up in 1976 and it illustrates the fundamental difference with respects the previous CPS: only one of its members would belong to a selected laboratory, the rest would be external scientists. The CPS would be chaired by Raymond Castaing (Professeur à l'Université Paris-Sud) and composed by Claude Allègre (Director of the Institut de Physique du Globe de Paris), Guy Aubert (Vice-director of the Institut National d'Astronomie et de Géophysique), Jean Auboin (Director of the Laboratoire de Géologie Structurale de Paris VI), Jean Audouze (Director of the Institut d'Astrophysique de Paris), André Authier (Director of the Laboratoire de Minéralogie et Cristallographie de Paris VI), Philippe Delache (astronome at the Observatory of Nice), Michel Maurette (Laboratoire René Bernas de l'Université Paris Sud), Gaston Meyniel (Doyen de la Faculté de médecine de Clermont-Ferrand), René Pellat (Laboratoire de Physique fondamentale de l'École Polytechnique), Joseph Taillet (Scientific director of ONERA) and Philippe Waldteufel (Director of the Institut et observatoire du Puy-de-Dôme).

Rapport d'activité CNES 1976-1977.

[206] The first would be hold in Les Arcs in 1981, followed by Deauville in 1985, Cap d'Agde in 1989, Saint-Malo in 1993, Arcachon in 1998, Paris in 2004, Biarritz in 2009 and the last one in La Rochelle in 2014.

CNES's scientific advisory groups (the Comité des Programmes Scientifiques) would have to back the instrument, that CNES would have to be prepared to commit budget, manpower and technical resources to POLDER, and that all the parties would defend POLDER's cause before external scientific, and non-scientific, institutions. For it to come into being, the design and development of such radiometer would have to be embedded within CNES's set of goals, policies, ambitions and circumstances, as well as the agency's technical, management and selection procedures. This all would start by entering the circuit of selection and decision, that is to say, by presenting the project before the Comité des Programmes Scientifiques.

Racing for the most space-resolved data

Since 1981 an annual meeting between the Direction de Programmes of CNES and the representatives of the scientific laboratories that participated in space experiments was hold to discuss the state of the art of the research conducted in these labs, which included the analysis of research perspectives, instrumental projects and missions. Although these discussions were informal in nature, and did not find any official place in the well-established CPS-decision making procedure, they constituted however a space for exchange and lobbying between scientists of CNRS or universities and CNES program managers. Attendees may eventually agree of the worthiness of a research line in detriment of another one, shaping and forging an informal consensus which would be consequently transposed their laboratories by reinforcing or weakening determinate topics of research. In 1986, Alain Ratier, who has just step in the office of the oceanography program in the Technical Center of Toulouse and who had received a copy of the project POLDER a board of SPOT-3, would invite LOA's director to attend the meeting in 1987 and to introduce POLDER to his fellow scientists. Convincing the attendees to that meeting, would give some weight and credibility to POLDER, as a first step towards an eventual positive consideration at the Comité de Programmes Scientifiques. Professor Maurice Herman had just been appointed as acting director at LOA by mid-1986 and, as such, he would present the instrumental concept of POLDER before the rest of directors, stressing the originality of its multidirectional measurement of polarized light, as well as its usefulness and interest for improving the data about some land surface properties, aerosols and clouds[207].

It is very difficult to know exactly what happened at this meeting (and the others that followed), as we only have some oral accounts, quite confused in the details[208]. It seems however that one first main critic crystallized: the coarse space resolution of the instrument. POLDER had a space resolution of 6kmx6km. This was a resolution of the same order than that of the first vidicons launched inside NASA's weather satellites 20 years ago; radiometers flying since 1978 had much higher resolution, like AVHRR reaching 1km and the new generation of instruments being prepared by NASA

[207] Professor Maurice Herman took over the direction, as acting director, of the Laboratoire d'Optique Atmosphérique further the resignation of Yves Fouquart in April 1986.
[208] Interviews with Maurice Herman and Pierre-Yves Deschamps.

(MODIS), ESA (MERIS), NASDA (OCTS) and CNES (VEGETATION) would reach the order of 500m –not to speak about the high-resolution commercial imaging like Landsat or SPOT, which achieved 10 to 20 meters of space resolution. However interesting may turn out to be the polarization and the multiangular measurements, would they be really of any value anyways, given their coarse space resolution? It was argued, for instance, that some oceanic features occurred at space scales of the order of 1 km or below (small eddies, meanders, coastal effects); looking with a zoom of 6km^2 would certainly not contribute to discriminating them. In the competitive world of space technologies, and of the scientific publications made with the resulting data, in which instruments and assets race for providing the best, the most and the first, it was not clear that this instrument would provide enough accurate measurements with sufficient precision to be meaningful for original and novel scientific investigations in the domain of oceans, atmosphere or land surfaces –or to reflect any cutting-edge space technology either.

“Multimissions”, technopush and well-posed scientific questions: Interpretative flexibility versus consensued interpretation

There was a second critic as well. POLDER seemed a project focused on gathering polarized data but without really specifying what for. In other words, POLDER was supposed to be given approval by scientists of the Comité de Programmes Scientifiques experts in vegetation, atmosphere or ocean studies; yet, the scientific program that POLDER would subscribe to support these disciplines was not spelled out. Would POLDER’s data be a tool for studying the relationship between oceanic vegetation and climate? For studying atmospheric pollution? Or for assessing the radiative impact of clouds? This was important, for instance, to define the processing software appropriate to each objective or the methods and places for data validation activities, to choose the wavelengths of the channels optimized in function of the target, to determine the orientation of the camera which may differ if, for instance, oceans or clouds are privileged, as well as in function of the time of the day one decides to measure, or to establish the requirements in the accuracy of the measurements, which may depend on what kind of aerosols scientists want to understand (volcanic ashes, desertic dust, oceanic salt, etc.), just to mention some examples[209]. POLDER reasoning seemed to operate technical and instrumental concepts but not scientific questions regarding the oceans, the vegetation or the atmosphere. Indeed, POLDER observational configuration had originally been conceived as an efficient means to observe the bidirectional reflectances and the aerosols in order to improve the atmospheric correction algorithms to correct the observations made by other satellite instruments. In other words, polarized multiangular measurements was what seemed to distinguish and characterize POLDER -and not any scientific disciplines of application, which were announced as vast categories such as oceans, atmosphere and vegetation studies. Whereas the original goal of POLDER was legitimate for conducting research in

[209] These are not random examples, but scientific and technical choices that would be discussed between 1990 and 1993 during the technical definition of the instrument with views to its material realization.
See for instance, “POLDER/ADEOS Implementation Plan”, October 1991.

the discipline of remote-sensing, it was insufficient to define by itself a credible program to study the Earth –this had not been the goal of its proponents, who had originally designed it as a complementary tool to improve the measurements made by other instruments. POLDER had not been conceived as the most efficient way to accomplish an a priori set of scientific goals related to the understanding of the Earth and its environment. This lack of specification was seen by some as insufficient to define a credible program in support of any discipline of the Earth sciences.

More generally, the case of POLDER serves to illustrate an epistemological debate that still today divides the actors. On the one hand, there is the idea that satellite data ought to be *potentially* useful to the larger number of scientists and scientific fields, no matter conditions and objectives of gathering and processing; while on the other, the idea of pre-defining a number of well-posed scientific questions and optimize the experimental conditions to achieve the specific set of goals. The first idea had been suggested as soon as in 1984 during the establishment of the Committee of Earth Observation Satellites (CEOS), an international organization originally composed by space agencies and operators managing satellites dedicated to weather monitoring, high-resolution imagery, satellite aided-location and collection of data or scientific experiments, aimed to coordinate the exchange of technical information to encourage complementarity and compatibility of satellites and their data:

> « Remote sensing from space has evolved from an early period of limited applications satellite programs to a point where distinctions among existing missions result from the technology employed, rather than from the disciplines served. In the future, a number of international, national, and regional space-borne Earth observations systems will operate simultaneously, and support both interdisciplinary and international applications (…) There is no such thing as a uniquely ocean satellite or land satellite or weather satellite. The Earth operates as a system and specific techniques for observing the Earth can provide useful information about many aspects of the complex system of our planet. Thus, rather to perpetuate discipline-specific groups, CEOS brings all Earth observation satellite operators together »[210].[211]

[210] "Terms of Reference of the Committee on Earth Observations Satellites", adopted during the constitution meeting hold in September 25 1984 in Washington D.C. Attendees, and signatures, were the Canada Centre for Remote Sensing, CNES, ESA, ISRO (Indian space agency), INPE (Brazilian space agency), NASA and NASDA.

[211] On to other matters, we would like to point that the authors of this quote, dated of 1984, consider the Earth as a "system". This invites some reflections proposing further research on the topic. Although scientists started reasoning more on interactions between components of systems rather than single-discipline studies with the emergence of systems science in the 1960s, commonplace history of the Earth and the environmental sciences suggests that this notion, "Earth system", was introduced in 1986 further the publication of the landmark "Bretherton Diagram", after Francis Bretherton (University of Wisconsin) who chaired the committee mandated by NASA, which authored a seminal report titled "Earth System Science: A Closer View". This report laid the groundwork for research in global climate change and understanding natural and human-induced changes in the land surface, atmosphere, oceans, biosphere and Earth's interior that affect all aspects of life. In particular, this report would give birth to NASA's "Earth system science" program, including a renovated program of Earth Observation System suite of satellites, a data distribution network, advanced computer modeling capabilities, and basic research. With NASA's imprimatur, and through the International Geophysical and Biological Program, whose first planning also started in 1986 further several reconfigurations as a national US program, the concept would be progressively widespread. See, for instance, Erik Conway's account in "Atmospheric sciences at NASA".

Without denying the generics of such overview, and well aware that dates merely mark events that may have been incubating for a while, CEOS's quote provides a number of elements that invite deeper research. For instance, chronology suggests that CEOS, as institution, had already assimilated such a notion in 1984 –and that it sought to promote it. Of course, it is dangerous to take international organizations as homogeneous blocks –just as dangerous as to take singular dates as turning points. We are not saying that the whole story needs to be revisited from the scratch; we are just accentuating that there is a complex international dimension weaving space agencies, research programs, scientific institutions, committees and working groups, which, we believe, is not negligible in the process of molding

This idea, labeled as *multimissions* instrument (or multipurpose or multifunction), would progressively penetrate in a systematic way from 1990 onwards as an attribute to describe POLDER[212]. A multimissions instrument was flexible enough to cover the greatest possible number of disciplines and scientific questions at the same time. Instead of building an instrument in the light of a given well-posed scientific question or in relation with a sound research program, a multimissions instrument would emphasize the versatility of specific, original and quality measurements. This is how a scientist of Laboratoire des Sciences du Climat et de l'Environnement, involved in the conception of POLDER and its data since 1991, put it:

> « Le type d'applications et le type d'utilisation des observations satellitales c'est... quasiment infini! (…) En regardant les données on trouve des choses inattendues (…) On a les données et puis on va chercher des façons de les utiliser. Et puis avec le temps on se pose d'autres questions, on a des machines plus puissantes qui permettent de faire des nouveaux calculs, on a d'autres données, on a plus de connaissances…"[213].

This approach underlines an epistemology that acknowledges the prospective value of the instrument and its data. It reckons that the options of using the data are not closed from the beginning but that novel possibilities may appear in the course of development, realization or exploitation –a point that we will address in chapter five. Once an instrument is recognized as "multimissions", it is in vain to try to list its scientific applications. By exacerbating the *interpretative flexibility*[214] of an instrument,

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the nature of the relationship between scientific knowledge and space technologies in the 1980s, and in particular in shaping the so-called "Earth systems sciences". Our point is simply that international organizations like CEOS (or the myriad of committees set up for organizing the international research programs like World Climate Research Program or the International Geophysical and Biological Program), and their role as ideas-widespreading agents (or even as ideas-generating agents) has been understudied in this story. This is why, we believe, further investigations to shed more light on the role of CEOS (IGBP or WCRP, to mention some cases) in the construction and consolidation of the concept of Earth systems sciences, on the particular space agencies (and is so doing illuminate on the more general historical question regarding the role of technical institutions in the development of scientific knowledge), or on some its individual figures (like the influent Dr. Shelby G.Tilford, NASA's Director of the Earth Sciences and Applications programs established in 1983 and instigator of NASA's Mission to Planet Earth program in 1990, who used to be NASA's representative at CEOS and many other international fora during the 1980s and the 1990s, but also professor Pierre Morel, to mention a name the reader may be familiar with), or still on some of the concepts and the terminology enhanced (like "multimissions" that suggests connections with the multidisciplinarity promoted within the frame of Earth systems sciences), is suggested. This makes an interesting pursuit for research.

[212] We find the attribute "multimissions" in the website of CNES describing the mission, in the activity reports of CNES and LOA, in documents of internal circulation between the actors or in presentations done by the scientists.

[213] During our interview, François-Marie Bréon provided an example pointing precisely to the potentialities of interpreting the data in multiple manners, once the data begins to be available:

« Quand on a reçu les premières images polarisées on a vu un truc qu'on ne s'attendait pas du tout. C'était tellement bizarre que pendant quelques jours ont a cru qu'il y avait un problème avec l'instrument. Pour nous tous les nuages sont blancs mais en fait quand on a regardé les nuages en polarisation on a vu des trucs complètement colorés. L'image en polarisation des nuages donnait des cercles rouge, puis vert, bleu… comme un arc en ciel, mais avec plus de longueurs d'ondes. Alors qu'on avait des modélisations des goutes liquides dans les nuages qui disaient qu'il y avait des goutes à 1-15micron les unes coté les autres, une distribution en taille très large. Et quand on a une distribution en taille très large on ne s'attend pas à observer ce phénomène d'arc en ciel. C'est parce que en fait la distribution des tailles est plus étroite, j'exagère mais disons qu'on a que 10micra, du coup c'est ça qui conduit aux arcs en ciel. L'intéressant a été que, par conséquent, puisque on voyait ces arcs en ciel on a pu déduire la taille des gouttelettes liquides dans les nuages. J'ai mis au point un algorithme avec lequel on peut déduire la taille des goutes à partir de la couleur de polarisation. Ceci c'est un exemple d'un truc qu'avant le lancement on n'avait pas du tout imaginé ».

[214] In their pivotal article « The Social Construction of Facts and Artefacts » pleading for a program of social studies of technology, just like it existed the program for social studies of science, the sociologists of sciences and technologies Trevor J. Pinch and Wiebe E. Bijker displayed, through the examples of the meanings given to the bicycle tire and the television by different social groups, the concept of "interpretative flexibility" to accentuate not only that there is flexibility in how people think of, or interpret, artefacts, but also that there is flexibility in how artefacts are designed.

that is to say, its data is open to more than one interpretation, the possible utilizations of its data would not be limited to a given pre-defined scientific framework, but rather it would be affirmed that they could serve as several and varied scientific goals as scientists would take the data. The use of this term is appropriate, we believe, because different interpretations of the measurements, so the advocates of this idea claimed, can be materialized in different processing algorithms pertinent to different domains of application of the data -just like *interpretative flexibility* of an artifact, as Trevor J. Pinch and Wiebe E. Bijker claimed, is usually materialized in quite different design lines. Different scientific groups, driven by different chains of problems and solutions, may lead to different further developments in the applications of data. The *passe-partout* character of the data would be emphasized. In that way, the lack of a priori scientific project in any given discipline may appear as a positive attribute. POLDER-1 and 2 would certainly resist to be placed inside a discipline or research area, moving across different scientific areas and engendering multiple uses –this would be not be the case of POLDER-3, as we will argue along the dissertation, and this is only one of the reasons why we consider POLDER-3 an experiment apart from POLDER-1 and 2. POLDER's scientific program would remain faithful to the epistemological tenet according to which satellite instruments and their corresponding data were to be potentially beneficial to all disciplines. Instead of being pointed as an instrument to support a given predefined scientific goal, POLDER-1 and 2 to would be rather sold as instruments open and eventually capable of supporting different type of studies at the same time.

On the other hand, the opposite views claimed that, just like all experiments, space missions must be conceived in the most efficient manner to accomplish an a priori set of scientific goals. They plead for conceding a pre-established *consensued interpretation* for the data, to frame the concrete objectives driving the experiment –or at least some of them. Otherwise, experiments risk becoming too general to be meaningful; the *passe-partout* character would turn against them. It is not that this ideal rejects possible serendipity and unexpected results; it is rather, that, striving for being useful for anything instruments run the risk of ending up by being useless for everything. To ensure proper results, and therefore to ensure that efforts and investments are returned, they advocate for clearly depicting the goals of the experiment a priori. Professor Pierre Morel, co-funder of the Laboratoire de Météorologie Dynamique in 1968 and former vice-director of it between 1968 and 1975, ensuring the direction of scientific programs of CNES between 1975 and 1982, and who was since 1982 director of the World Climate Research Program, would express more than once these beliefs. In the second scientific meeting auspiced by CNES, the Séminaires de Prospective scientifique du CNES, hold in 1985, for instance, he said that:

> " Une contrainte imposée par le souci d'efficacité est la concentration des efforts sur un problème bien posé, avec des conditions aux limites claires, que l'on puisse raisonnablement embrasser dans sa totalité avec les moyens envisageables. (…) Le mérite du GARP a été de définir les limites d'un système à peu près fermé –l'atmosphère globale- au sein duquel se déroulent pour l'essentiel les processus qui déterminent l'evolution du temps à échéance d'une dizaine de jours. Il devenait alors

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"The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other", Trevor J. Pinch and Wiebe E. Bijker, 1984.

> possible de concevoir un système d'observations cohérent. (…) Il est banal de dire que la météorologie aussi bien scientifique que pratique, avance actuellement et pour bien des années encore, sur l'élan donné par le GARP (…) GARP est un modèle d'adaptation à un problème bien posé. On peut espérer que le programme WOCE fera aussi bien pour la circulation de l'océan global. Au contraire, le concept Earth Observing System (EOS) étudié par le Jet Propulsion Laboratory est l'illustration parfaite de ce qu'il vaut mieux éviter. En se donnant un champ d'application immense, on garantit les dispersions des ressources et on programme un demi-succès généralisé, en assurant d'ailleurs aux promoteurs une bonne position défensive qui leur permettra de faire passer les demi-échecs en s'appuyant sur les demi-succès. Mais s'agissant de l'étude de systèmes naturels fortement interactifs, le demi-succès technologique est un véritable échec scientifique. La mission EOS et ses semblables peuvent constituer des exercices technologiques utiles : il convient d'en juger l'efficacité au vu des ressources qu'elles laisseraient disponibles pour une véritable investigation scientifique »[215].

Professor Morel would oppose the notion of "technological exercise" to an approach, exemplified by GARP (the Global Atmospheric Research Program[216]), in which space platforms would be designed to respond to a specific set of reduced, well-posed questions in a well-limited program. He would not mention explicitly POLDER in this particular speech (the speech was given before POLDER came to light), but some others would not hesitate in doing that. For instance, the influent atmospheric chemist Gérard Mégie would, in 1990, while he co-directed the Service d'Aéronomie of CNRS, in a project for the creation of a Space Institute for Environmental Research, opposed the virtues of a space mission « cohérente définie en fonction d'objectifs scientifiques précis » to the « projets de plate-formes opérationnelles en orbite polaire (projet de l'ASE, de la NASA et de la NASDA) dont la charge utile résulte le plus souvent de compromis technologiques »:

> "La caractéristique essentielle de ces projets [refering to Topex/Poseidon, ERS-1, BEST and GLOBSAT] est leur conception en terme de mission spatiale cohérente définie en fonction d'objectifs scientifiques précis. Ils diffèrent ainsi des projets de plate-formes opérationnelles en orbite polaire (projet de l'ASE, de la NASA et de la NASDA) dont la charge utile résulte le plus souvent de compromis technologiques (…) Il s'agit en effet, dans le cas de BEST comme dans celui de GLOBSAT, de mettre en orbite des instruments définis en fonction d'objectifs scientifiques précis et dont la fiabilité doit assurer une période d'observation de deux à trois ans nécessaire pour appréhender les variations intra et inter annuelles des principales variables atmosphériques et océaniques »[217].

The satellite POEM/ESA, the EOS/NASA programs and ADEOS were, according to Gérard Mégie, and unlike Topex/Poseidon, BEST or GLOBSAT, satellite instrumental endeavors that must be "avoided", taking Pierre Morel's expression, because they were not optimized for conducting scientific research in any given question. To them, before launching a satellite, the scientific interpretation of the data must be consensued: How can otherwise the technical specificities of the instrument be defined (spectral channels, field-of-view, orientation of the focal, processing software, orbital characteristics, time of observation)? In the most extreme position of this views lays, actually, the idea that the attribute "multimissions" represents little more than a discursive ploy reflecting a

[215] Source : « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.

[216] GARP took place between 1969 and 1979 under the auspices of the World Meteorological Organization, which Pierre Morel participated to coordinate. Not surprisingly, therefore, professor Morel's constant references in this quote, and more generally during his career, as a model to pursuit.

[217] Rapport « Pour un Institut Spatial de l'Environnement Terrestre », Gérard Mégie, 11 October 1990.

mere instance of technology push to get instruments and satellites launched even if they were not embedded in any particular scientific problem.

Beyond epistemological beliefs (according to which satellite data can have a myriad of diverse scientific applications, depending on how and what for they would be used, and by whom), multimissions instruments are meant to provide data useful to a large number of scientists, no matter conditions and objectives of gathering and processing. Because there is not just one possible way of designing an instrument or interpreting satellite data, or one best way, everybody can use them. This notion reinforces the goal of space agencies to widespread and normalize the use of satellite data in any scientific domain, and therefore to maximize the scientific return of their investments. Multimissions instruments would place the space instrument and its data at the center of scientific inquiry -and not the scientific program applying them in a given discipline. On the other hand, maybe nature or the instrument do not force towards a given program per se, but the social institution of sciences does. Scientific academic groups are integrated within well-demarcated disciplines, which act as a social mechanism that limits the interpretative flexibility, and thus promote consensus on one given interpretation –a social mechanism inexistent within space agencies. Labeled as marine biologists working in a laboratory of marine biology and publishing in journals of marine biology, scientists may tend to interpret satellite data for marine biology studies. This leads to defining the instrument as the best optimal tool for such studies (spectral bands in the yellow interval, with space resolution lower than 500m and narrow field-of-view, data validation campaigns in the coastal regions, correction algorithms accounting for the aerosols perturbation, orbit with major observing time over the oceans, etc.), which may be contradictory with the requirements optimized for other studies (continental vegetation studies, for instance, may require major time of observation over lands or spectral bands highly resolved in the green wavelengths). More generally, because interpretations by different social groups lead via different chains of problems and solutions to different further technical developments, academic groups tend to advocate, and we insist that this tendency is nuanced in any individual, for choosing and creating consensus in advance. One typical way out of the debate, one typical way to *reconcile* the two separate positions, is by achieving the following compromise: launching such "technological exercises", so it would be argued, is not to be seen as an instance of engineering getting in the way of scientific research, but rather as an efficient way to demonstrate, in a first stage and without engaging many risks, the potential feasibility and interest of a given instrumental configuration. Any instrumental failure (or deception concerning its scientific potentialities) inside a cheap and simple satellite would be by far less dramatic than inside a huge expensive platform like the American UARS, the European EPOP or the French BEST, in which all instruments may eventually be interdependent. In a second stage, once the feasibility and the interest of the technology is demonstrated, the experiment could be conducted in a more comprehensive and consistent manner, consistent with a set of given scientific questions in the domain of, for instance, marine biology, Earth's radiation budget, water cycle or transport of aerosols through the atmosphere.

Our point is not to judge any best option but rather to point that these are two ways of understanding the relationship between space technologies and Earth sciences –perhaps more generally all sciences: promoting architectural technologies and rely on the interpretative flexibility of the measurements or carefully designing instruments focused on a small set of well-defined consensued pertinent questions -needless to say that we have presented two extreme poles and a continuous gamma of positions may be actually displayed inbetween in any individual. These are different ways of understanding the relationship between space technologies, satellite data and Earth sciences, in which strategy, policy, authority and pragmatism make an integral part of their epistemology: promoting architectural technologies and rely on the interpretative flexibility of the measurements or carefully designing instruments focused on a small set of well-defined pertinent questions and securing its success, while restricting, by so doing, the scope of exploitation. The oscillation between these two extreme epistemologies is far from being and abstract philosophical debate, but it is translated into different institutional research policies within space agencies: isolated singular technological exercises to test new instruments without much context versus comprehensive missions aimed to respond to a pre-defined scientific question and accompanied of the resources to exploit it. It is then impregnated of pragmatic mundane considerations such as budgetary hypothesis, technological risks, competition amongst space agencies, strategy to maximize the scientific return of satellite data, disciplinary demarcations and issues about publication.

Scientific experiments, the Technical Center of CNES and decision-power of program managers

This reflection being proposed, we shall come back to POLDER. Apparently, LOA's director would not convince his fellow scientists, which would point POLDER's coarse space resolution and its lack of scientific program in any discipline (or its "multimission" character) as important shortcomings of the experiment. Yet, POLDER would be approved by CNES in 1988, LOA would be allocated funding to realize a prototype of the instrument to be carried inside an aircraft to study performances and feasibility and LERTS would start working out the details of the calibration and data preprocessing. Given the scarcity of written sources about the details of the decision and the confusing oral accounts that we have been able to gather, our hypothesis is that two issues played a central role in the approval of POLDER by the Direction of Programs at CNES, in spite of such reluctance per part of some scientific groups. First, the fact that POLDER was a sort of *made-in-CNES* instrument and received the support of the laboratories of the Technical Center in Toulouse. Second, the convincement and impetus of the program manager at CNES, Alain Ratier.

It would be professor Maurice Herman who, as scientific responsible of POLDER, would present the instrument before his fellow scientists, but in fact POLDER was an instrument quasi-internal to the Technical Center of CNES in Toulouse. This can be seen by looking at the people proposing the instrument in 1986: one was affiliated to the Division Traitement d'Images of the Technical Center of CNES in Toulouse, three to the Division de Techniques Instrumentales, particularly to the department of opto-electronics also of the Technical Center of CNES in Toulouse, two were affiliated to LERTS (a mixed laboratory CNES-CNRS, which held the status of Division of the Technical Center of CNES) and three to LOA (a laboratory CNRS-University of Lille). An important percentage of the designers were agents of CNES –or closely linked to them. Actually, the proposition is written on a CNES's model-sheet and it is identified with a code for classifying and organizing the documents generated by the space agency, indicating a degree of self-appropriation of the project. At least three laboratories belonging to CNES had been working for a while in the instrument and POLDER had the support of these engineers who wanted to build it because, as optical experts, electronic experts, data processing experts or physical approach experts, they found it interesting and challenging to construct and realize such a device. It was their job to build instruments, to create experimental devices and to investigate technological space systems. They had certainly associated to LOA to ensure scientific pertinence (as well as to ensure receptivity and to broaden constituency), but the instrument had been mostly conceived by CNES in-house departments. This, we believe, may have played out in approving the instrument.

On the one hand, this aspect stresses the importance of working together the different technical divisions of CNES and the scientists of the laboratories willing to launch an experiment since the very inception of the instrument. In this case, this working together was facilitated through two connections. Primo, one of the laboratories, LERTS, was partially a CNES-laboratory itself. Secondo, the only non-CNES member of such a laboratory, Pierre-Yves Deschamps, was a former physicist at LOA, where he had conducted his doctoral research and began his career in the domain of satellite remote-sensing of the oceans. There is a reverse side though. While this stresses the efficiency of this methodology (the working together or rather the mixed laboratories CNRS-CNES) as a means to realize satellite experiments, it raises in turn a fundamental question regarding the intertwined relationship between external scientists and in-house scientists or engineers of the technical laboratories of CNES. CNES has from its inception boasted about not eclipsing the existing scientific institutions (CNRS, universities or others) with the creation of its own laboratories but it has rather supported their developments with in-house technical capabilities, grants or equipment[218]. This was the driver of the policy of "selecting" laboratories fostered in 1961. On the one hand, thus, there are these external laboratories conceiving experiments and proposing them to be launched inside a satellite by CNES or another space agency. As these technologies get complex, and expensive, they may require

[218] This rhetoric often goes followed by the expression "as NASA did", in an attempt to demarcate an original difference between both institutions. While it is true that NASA created the Goddard Space Flight Center, the Goddard Institute of Space Sciences or the Langley Research Center, which are laboratories dealing with the space sciences in a general sense (astronomy, life sciences, planetary, Earth sciences, microgravity, etc.), as belonging to the NASA instition, historical research about the establishment of such laboratories suggests that at least three nuances may accompany this presumed original difference between NASA and CNES. First, their creation was not always with the status of scientific centers as they are today but this was rather a progressive conversion over time (see the Langley Research Center history, for instance), and far from being straightforward. Second, in some cases these laboratories are closely connected to universities (see the Jet Propulsion Laboratory history, for instance). Third, since its outset, NASA also put great efforts to reach out universities and other academic scientific communities (as CNES did) as demonstrated by the number of instruments and experiments proposed by non-NASA scientists (see, for instance, Verner Suomi's).

the technical support of the space agency to build them. In turn, the Technical Center of CNES may often demand to be in charge of their total manufacture in order to control the compatibility with the satellite or with the ground segment –and often delegating its fabrication to industrials. Then the figure of space managers comes into the game as coordinating the technical and the scientific work. The question turns about the role of these external scientists in manufacturing instruments, or at least in overseeing, their manufacture. Are external scientists willing to cede major parts of the conception and manufacture of *their* instrument, if not all of it, to the technical laboratories of CNES (or to industrials)? When an instrument, conceived in an external laboratory, is taken over by CNES's space managers, what is the remaining role of the external scientists that have proposed it? The question can be put inversely: do they receive the same support than instruments developed by the in-house laboratories or mixed laboratories (like LERTS created in 1984 or the physical oceanography laboratory MOUETTE in 1986)? Do they proposals have the same weight before decisions by the Direction of Programs in allocating budget to research and technology projects? As we have insinuated in our introductory chapter with the flagship example of SPOT, these issues are closely related to retaining power at external laboratories, for a loss of technical presence means a loss of decision-authority: first, retaining power over a given experiment that scientists may consider as their own and, second, to define the scientific program of CNES. Once again, issues can be put inversely, as a loss of power by the ones translates in a gain of it by the others. These questions rarely emerge, and when they do they are internally solved, when instruments are conceived and developed by in-house technical departments of CNES or by mixed laboratories. However, they constitute classical bones of contention in the relationship between scientific laboratories and the Technical Center of Toulouse when it comes to experiments proposed by the former "selected laboratories", which have inherited a strong culture of instrument-builders developed during the first 20 years of space age (and promoted by CNES's policy of privileging the "selected laboratories"), tend to defuse industrialization and to retain control over *their* instrument and the data. Indeed, things got still more complicated when industrials reclaim also a say. Issues about professional ethos and perceptions of the other, about legitimacy in deciding about the technical specificities of a given instrument or about epistemic authority lay at the heart of the debate. We have not enough elements to conclude (we are actually not sure that a general conclusion is ever possible) and we prefer to leave the issue opened for further discussion[219].

Back to POLDER, arguably it was an instrument made and grown up at least with full support of the Technical Center in Toulouse –if not almost fully conceived and made by them. While this may have

[219] An interesting topic of research, which we cannot do more than merely suggest, would focus on studying these tensions from a perspective stressing their formational and education culture. Many of the space managers of the Technical Center in Toulouse had been trained as engineers, typically *polytechniciens*, whereas most of the academic scientists of "selected labs" come from universities typically *normaliens*. The influence of the formational cultures that they embody in their ways of doing and understanding the relationship with the instrument, the data, the industrials and the other social groups may reveal interesting features. To complete the cartography, we could add a third actor in this research program: the people chairing the Direction of Programs in Paris, often ensured by a scientist (CNRS or university) or by a *normalien*.

played in favor of its broad acceptation by different divisions of the Technical Center in Toulouse pushing towards its realization, we suggest that it is plausible to believe that precisely because of that, a wider scientific community was reluctant to it, seeing the instrument something like a toy of a handful of space engineers. Perhaps, and we have not had the chance to check this hypothesis with the actors, this would be an underlying element causing some opposition amongst the large scientific community dominated by the 1980s by “selected laboratories” (beyond the already mentioned coarse space resolution and the lack of well-posed scientific program in any field discipline).

Alain Ratier, let us now turn to our second thought, would energically promote POLDER before other scientists and CNES managers. For POLDER to come into being it was crucial to be embedded into CNES’s own set of interests, as it would be the main, if not the unique, funding agency. POLDER was a relatively cheap instrument and technologically rather simple. Chances of failing would be then reduced and, if eventually failing, the loss would not be much dramatic in economic terms and technology investments. The question of assigning budget, although important even if it is only for preliminary studies of a mission or instrument, is one that CNES would examine at length, and it is certainly not simply a matter of the quality of the science promised by the project. We suggest that Alain Ratier had a number of reasons to promote POLDER and that, not only his opinions carried considerable weight but also, as program director, he was in the position of influence the decisions. First, the efforts to enlist more of the scientific community in the execution and utilization of space experiments and, in particular, to attract Earth scientists to enter a domain until them dominated by astronomy, planetology or geodesy, we suggest, offer a reading key to understand the insistence in getting POLDER approved. POLDER would result a particularly appropriate instrument for accomplishing that goal, because, unlike other projects proposed in the early and mid-1980s like ScaRaB, Topex/Poseidon, ALISSA or BEST, POLDER was the first instrument that had been proposed to the Comité de Programmes Scientifiques by scientists of peripherial non-selected laboratories: the Laboratoire d’Optique Atmosphérique[220]. CNES would send the message that it had left behind the era of privileging some selected laboratories in favor of a renewed space program open to all. POLDER would be hopefully only the starting point to enroll more scientists to propose experiments in a domain, the Earth sciences, increasingly important in terms of budget, social status, number of institutions and number of research programs, both in France and in the world governmental policies. POLDER was seen, and we will develop this point along our essay, as a means

[220] To be sure, by the same period, the oceanographer André Morel of the Laboratoire de Physique et Chimie Marines of Villefranche sur Mer (a non selected laboratory) proposed to embark a radiometer to measure the color of the oceans as a passenger of the satellite SPOT-3, just like POLDER. However, the instrument was not conceived by him but by a team of the Goddard space Flight Center of NASA. The proposal was never accepted.

Strictly speaking, this is the other example, the radar altimeter Poseidon had been proposed, at least partially, also by a non-selected laboratory. Indeed, it had been conceived by a group of scientists from the Groupe de recherches de géodesie spatiale, a “selected laboratory” considered as an in-house department by CNES, and a group of the Institute de Physique du Globe of Paris, which, like LOA, was not as “selected laboratory”. In any case, regardless of the institutional affiliation of the proponents (selected or not), due to its possibilities of being undertaken in collaboration with NASA, this project would follow specific decision procedures alternative to the Comité des Programmes Scientifiques.

to gather external scientists around a space program and to start incubating a large community of field scientists who would start proposing and using space technologies.

Second, the international community was moving fast in the domain of realizing satellites to study the Earth and its environment. In a few years not only NASA, but also Europe or Japan (and Canada, Italy, United Kingdom and Germany, URSS, or India and China) had started to define their respective programs. As associate director of programs, Alain Ratier had a broader view of the state-of-the-art of space programs abroad and of the fact that all major space agencies were engaging programs in the field. He understood the acute urgencies for CNES, too, to initiate a number of new programs in a domain, the space technologies, in which technological competition is step-of-the-day. As we have seen, some gigantic missions had been proposed in France, and some of them engaged, like the oceanographic satellite Topex/Poseidon with NASA or the ambitious satellite BEST to study energy transfers in the tropical regions. However, small and simple instrumental payloads were not much abundant. Exemplifying these lack of ideas, for instance, is the other instrument in course of being defined in the mid-1980s, the radiometer ScaRaB intended to map the Earth's radiation budget, which had emerged from a top-down proposal from the director of programs at CNES, Jean-Louis Fellous, who ordered scientists of the Laboratoire de Meteorologie Dynamique the instrument -in turn, it had been professor Pierre Morel, former vice-director of the LMD and currently secretary of WMO, who, aware of the lack of ideas, had suggested CNES's direction of programs this mission done by advance order[221].

It would be the National Space Development Agency or NASDA, the Japanese space agency[222], which in 1988 would release an "announcement of opportunities" similar to those usually released by NASA, calling for international interested scientists to put instruments inside a big platform, ADEOS, to be launched by the mid-1990s as part of the ambitious Japanese satellite Earth observation program to observe and measure some components of the Earth's environment, especially to help understand global warming and ozone depletion. Actually, responsibles of the Japanese and French space activities had started, since the early 1980s, certain contacts to study possible collaboration. Yet, they seemed to have troubles in finding the spark to get started. In this context, the program ADEOS would be interpreted by CNES's program managers as an opportunity window to start such a Franco-Japanese cooperation. From a scientific point of view, participating in ADEOS would open up the possibility to access to the data of the eight instruments aboard the satellite (including the ocean color instrument OCTS or the ozone instrument TOMS), which was not a minor reason given the fact because its objectives converged with those of the satellite GLOBSAT being studied at CNES, and

[221] Interview with Jean-Louis Fellous, COSPAR, 2012.

[222] NASDA, funded by the Japanese government was one of the two official interlocutors for space activities in Japan before 2003; the other one was the Institute of Space and Astronautical Science (ISAS), an older institution pending on the University of Tokyo. Actually, both NASDA and ISAS were the only institutions that could launch spacecrafts. Many other agencies and institutions were interested and conduct some kind of space activities, like Ministry of International Trade and Industry (MITI), the Ministry of Posts and telecommunications and the Ministry of Transport (from which the Japanese Meteorological Agency depends). Japanese space policy –defining all space programs of Japan- was contained in the Annual Space Development Plan issued by the Space Activity Commission every March.

therefore data could be potentially analyzed in synergy –or used to prepare GLOBSAT's data future interpretation. On the other hand, several of the Earth observation programs of the major space agencies (the Environmental Polar-orbiting Platforms (EPOP) of ESA and the Earth Observing System (EOS) of NASA) were suffering delays and budget restrictions and it was not clear when they would be launched. Perhaps the sole opportunity to launch small instruments given this situation at ESA and NASA, was NASDA. This is how Alain Ratier reported the situation in 1990 after a meeting with the Japanese counterparts:

> « Actuellement, le programme spatial de la NASDA est, dans le domaine de l'étude du changement global, l'un des seuls programmes crédibles encore ouverts à l'horizon 2000 (…). C'est sans doute un élément important à prendre en compte pour notre programmation. ADEOS apparaît comme une importante opportunité pour la communauté scientifique nationale au début des années 1995-2000 »[223].

POLDER suited the overall budgetary, timing and scientific conditions imposed by the Japanese program. Could CNES not afford taking this opportunity? There was no other instrumental candidate available for ADEOS or any other satellite available for POLDER anyway.

Launching POLDER

Within two years, by 1989, an aircraft version of POLDER had been built ready to fly, by 1993 a sound scientific program to support atmosphere, ocean color and land surfaces studies would be rigorously defined and even the coarse resolution would be balanced (or at least attempted to) with accurate correction, calibration and retrieval algorithms –we will precise all these features along our essay. From an instrumental standpoint, POLDER would get concretized as well departing from its original features in several points. The rotating wheel, which would have a steady period of 4,9s, would support the interference filters and polarizers that select the spectral bands and polarization directions. It would carry 16 slots, one of which would be an opaque filter to estimate the CCD's dark current. The remaining 15 slots would carry 6 unpolarized and 9 polarized filters (3 polarization directions for 3 different wavelenghts). The spectral sensitivity of the CCD arrays would extend between 400 and 1050 nm divided in 8 channels: six optimized for aerosols, clouds, ocean color, and land surfaces and the other two would be centered on the H2O and O2 absorption bands for retrieving atmospheric water vapor amount and cloud top altitude, respectively[224]. The optics would have a focal lenghts of 3,57mm with a maximum field of view of 114°, which, combined with the heliosynchronous orbit of ADEOS at an altitude of 796Km would provide a cross-track swath of about 2200km[225]. This meant that the points would be measured several times a day from consecutive

[223] CR Mission au Japon de 29 Octobre - 2 Novembre 1990, elaborated by Alain Ratier.

[224] "The POLDER Mission : Instrument Characteristics and Scientific Objectives", P.Y. Deschamps et al., 1994.

[225] A satellite following a helio-synchronous orbit would ascend or descend over any given Earth's latitude at the same local solar time. The surface illumination angle will be nearly the same every time, which is useful in order to remove a variable that may affect the measurements and simplify the corrections. With a cycle of 41 days (and 4 days of subcycle) the coverage of ADEOS I and II would be minimum at the Equator, where a given target is observed 4 times

orbits.This also meant that almost all the Earth's surface would be covered within a day or, in other words, that in about 6h POLDER would scan aproximately 25% of our planet's surface, excluding polar regions when the Sun would remain below the horizon. As per de CCD camera, it would be a more resolved one that the first proposal, a model composed of 242x548 photoelements that are 27x16μm in size.

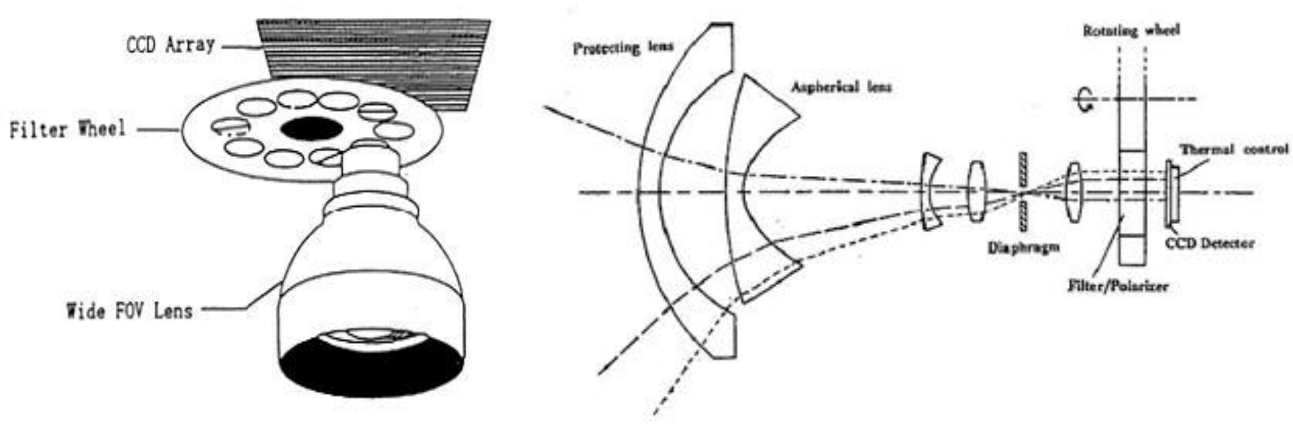

Fig. I.1.3. Optical design of the POLDER instrument[226].

General charateristics of the POLDER instrument aboard the ADEOS satellite		
	Size (m3)	0,8x0,5x0,25
	Weight	33kg
	Power consumption	42 W
	Pixel coding	12 bits
	Data rate	882 Kbit/s
	Altitude	796 Km
	Period	100 min
	Local cross time	10:30h
	Inclination	98,59°

Table I.1.1: POLDER's characteristics[227].

Some changes in the data handling would also be reported. First, there were 8 instruments aboard ADEOS and they needed to share power, memory and transmission devices[228]. Besides, POLDER would measure during the daylight portion of ADEOS orbit, meaning that the number of hours per day depended on the season, but it was certainly more than 1,5 hours per day. This would increase the

per 5 days period (at 10:30h local time), and a point located poleward of 37° may be observed several times a day from consecutive orbits.

226 "The POLDER Mission : Instrument Characteristics and Scientific Objectives", P.Y. Deschamps et al., 1994.

227 « The POLDER Mission : Instrument Characteristics and Scientific Objectives », P.Y. Deschamps et al.,1994.

228 For instance, the mass of POLDER shall not exceed 33 kg, its electrical power 40W and the data rate shall be equal or minor than 882 kbps.

"POLDER/ADEOS Implementation Plan", approved by program managers and gournd segment project managers of NASDA and by project manager of CNES in 1991.

amounts of data to be processed with respects the original proposal as a passenger of a passenger inside SPOT-3, but also the organization of the downlink, preprocessing and processing lines in two aspects. First, it must be organized with NASDA, as it would be NASDA's antennas which would receive the data from the satellite at a rate of 882kbit/s during the three years it was expected to live. The provisions of the data exchange policy between the different instruments of CNES, NASDA and NASA would be actually a bone of contention that would take around two years to be solved. To give a hint of the content of the discussions, for the scientists interested in measuring the color of the ocean, one of the main interests of ADEOS was the possibility for POLDER and the Ocean Color and Temperature Scanner (OCTS, an instrument of NASDA aboard of ADEOS) to measure simultaneously the same scene. This had a double interest: primo, allowing the possibility of combining the data from the two instruments and using them in wider research programs and, secondo, rendering possible the intercalibration of the two instruments with respects of each other[229]. However, this entailed that POLDER's scientists would have access to OCTS's data, and viceversa, which was far from obvious in the 1990s, when neither CNES nor NASDA had a totally well-defined data-exchange policy.

Secondly, NASDA would send in a continuous manner POLDER's data to CNES recorded in magnetic tapes, two weeks after they had been downlinked (which would be the time needed to decommute them at NASDA's ground stations), which must be equipped with the infrastructures to cope with them. Therefore, CNES must develop a ground segment specifically devoted to process POLDER's data, that is, to despatialize, calibrate, process data and disseminate them –an aspect that we will tackle in chapters 2 and 3. Once processed, POLDER data would be distributed to interested scientists upon request, and a copy would be sent back to NASDA, recorded into CDs, DVDs or, if linked, through telephonic lines[230]. POLDER-2, launched in 2002 on board of ADEOS-II, would be the spare version of POLDER-1. No significant changes in the technology, the scientific goals, the organization, or the contextual setting would take place. Essentially, all along our dissertation, we consider them as part of the same experiment prolonged over time.

Conclusions: Reconciliation

The historical process by which POLDER came to be aboard of ADEOS cannot be explained in purely scientific and technical terms. On the contrary, from this perspective, while providing an original and novel type of measurement, it is not clear that POLDER would be ever realized given the skepticism of the scientific advisory groups by 1988 regarding its coarse space resolution and its lack of scientific program within a well-demarcated discipline in the domain of Earth science. Rather it would result the product of a complex interplay of technical, scientific, institutional and political layers. The essential

[229] « Compte Rendu de mission POLDER/ADEOS au Japon », Tokyo, 16-20 November 1992, elaborated by Alain Ratier.
[230] « The POLDER Mission : Instrument Characteristics ans Scientific Objectives », P.Y. Deschamps et al., 1994.

reconversion of POLDER from a technological exercise to an instrument to gather data for Earth sciences, and the relative rapid acceptation by CPS, would be proactively fostered by CNES program managers, who sought to develop both a competitive environmental program at CNES (already started with Topex/Poseidon in 1981, BEST in 1985 and ScaRaB in 1986) as well as a domestic clientele for that program beyond the former “selected laboratories”, by gaining visibility amongst scientists to spread the use of satellite data and space systems in these disciplines. An alliance of CNES managers with LOA (and LERTS) scientists would help selling the instrument to CPS, and the whole would be made possible because of the contingent opportunity window opened up by NASDA in opening its program ADEOS to the international community and the pre-existence of a political and institutional commitment towards engaging a cooperation with Japan in the domain of space science and technology.

More generally, together with scientific and technological arguments, other elements may come into play when selecting and deciding scientific space missions. Space agencies may take into account as well the political receptivity of the project (how the scientific community, other than the mission proponents, will accept it? and the public opinion? does the mission align with governmental goals?), the envisaged flights opportunities (will it be compatible with the launchers on time? is there any foreign space operator offering to carry the payload?), the potential competitors (are other projects that might be more opportune? how choosing between a mission to measure CO2 and one to measure O3, both considered as scientifically pertinent but addressing different question? what are other institutions doing in the field? shall we bandwagon them or initiate original programs?), the international scene (is the mission consistent, and if possible *better* in some way or another (original orbit, new sensing technology, novel data system, more radiometric channels, etc.), with the missions of other space agencies?), the internal means (does CNES has enough people, money and resources to engage it? are industrials competent in the domain?), institutional urgencies (will this project entail long-term partnerships? or attract long-term funding needed to sustain its realization over years?), among others. These different layers that involve different people, locations and time, are integral elements in the process of winning approval, deciding and realizing space missions.

That purely rational choices are hardly ever achievable has been demonstrated by several studies[231]. Put it simply, choices about technological and scientific objectives lay not outside a wider context, and, typically, the final decision makers, in our case CNES’s higher hierarchies that ultimately sign in or out, often lack the fine expertise, the time or the information. Without entering in theoretical debates on the topic, our point is simply to illustrate that there is no one sole rationality driving space missions. The universe of social actors includes, quoting only few, instrument builders, remote-sensing scientists, Earth scientists experts in a given discipline, opto-electrical engineers, mechanical experts, project managers, computer scientists, software specialists, satellite manufacturers, administrators, decision-makers, and all them distributed straddling Japan and France. In our case,

[231] See for instance the before mentioned account about the Hubble telescope by Robert Smith or the history of CERN coordinated by J. Hermann et al.

program managers may privilege institutional partnerships or gain visibility before the wider scientific audiences and the international space community, advisory scientific groups may defend the definition of a sound scientific program consistent with the current questions and methodologies or aligned with the disciplines that they particularly control, experts in the physical approach may want to develop atmospheric correction algorithms generalizable to all radiometric measurements, while instrument-builders may just expect getting the instrument done and flown –not to speak about the industrials, the government, the international organizations or other actors that may certainly influence all decisions with more or less weight in function of the stage of the process. The decision-making of space missions is generally hammered out in a variety of arenas according to malleable rules, a process in which few persons, if any, have overall knowledge of all the aspects and stakes. It is a process that operates in multiple directions and that may last months, if not years, during which the involved individuals and institutions may change, as well as their orientations and priorities, and their respective weight. Even once a project has been selected it may take some more years to be developed and realized (10 to 15 years would be a fair estimation in the case of space missions), during which not only individuals and institutions, their objectives and interests, may change, but also technologies may become obsolescent, scientific priorities may evolve and the contextual social, political and economic background may vary. Over this time, space missions would be rethought, their advances would sometimes be hindered, sometimes they would be diverted, and some of them would be eventually launched.

Back to POLDER, in 1988, CNES would engage funding to realize an aircraft version of the radiometer, coordinated by LOA, as a first stage to preliminary study the feasibility, the technical specificities, the scientific potentialities and the limitations of a future eventual space instrument, considering the technical (size/mass, power consumption, communications system, etc.) and timing (schedules of delivery of components, assembling inside the satellite, general tests, etc.) constraints imposed by NASDA. Scientists of LOA, LERTS, INRA and IGN, supported by a number of technical departments of CNES-Toulouse (opto-electronic engineers who study the photo-sensors, mechanical engineers simulating attitude control, computer scientists developing software, electronic technicians manufacturing chips, engineers that study the maintenance of thermal conditions, etc.), would spend around two years in studying, through aircraft field-flights, computer simulations and laboratory tests, several aspects of the future POLDER, such as calibration techniques, different wavelengths of the radiometric channels, performances of different polarization filters or atmospheric corrections to improve accuracy. In parallel, NASDA would announce in 1989 the definitive selection of payloads to be carried by ADEOS, confirming a flight-ticket for POLDER. By 1990 the president of CNES Jacques-Louis Lions would inform his Japanese homologue, that the material realization of the space version of the radiometer would start, and both presidents would sign the Memorandum of Understanding, that is, the overall agreement contract, in 1992. Once POLDER would be approved, it would enter the routines of CNES production system: it would be then that, at CNES, a specific team of managers would be set for the project, a budgetary line would be endowed, that a plan and program would be carefully defined coordinating all the until then dispersed preliminary actions and that tasks would be distributed amongst participants –we will detail some of these in the next chapters.

As we move forward from the time when POLDER was conceived in 1986 to when it was launched 10 years later in 1996, POLDER would suffer several evolutions –a part of some modifications in its technical characteristics. First, it would become an instrument for its own sake and not a passenger of another instrument. Second, besides its goals in the domain of remote-sensing (improve corrections), the experiment would be integrated in an exhaustive and well-specified scientific program dedicated to study the Earth and its environment –and with views of an eventual long-term monitoring (this was the original goal of the ADEOS program). Third, the scientific team associated with POLDER would widen up. From an instrument conceived by a number of in-house engineers and scientists of the technical laboratories of CNES and LERTS, and supported by some scientists of LOA, POLDER would become an experiment mobilizing scientists of at least three more French laboratories: the Laboratoire des Sciences du Climat et de l'Environnement, le Laboratoire de Météorologie Dynamique and the Laboratoire de Physique et Chimie Marines (but also contributions of other institutions), Japanese and American counterparts, and an International Science Team. Not only more people than the original proponents were involved in the development and realization of POLDER, but more people could have access to its data as well. Anyone requesting data, whether they had participated in the conception, manufacture and preparation of POLDER and its data or not, could have access to the geophysical datasets retrieved from POLDER's measurements upon request. This major evolution was connected to another one: the epistemic virtue of satellite data had moved from the measurements (or calibrated radiances) to geophysical parameters. What counted as data for the Earth scientists were not the measurements of the radiation captured by POLDER's photocells, but rather values expressing geophysical properties such as the content of chlorophyll in oceanic waters, the size of the water droplets of the clouds or the level of humidity of the vegetal surfaces. Actually, a complex system of mass-producing and disseminating these geophysical parameters would be implemented, a production chain partially centralized at CNES instead of at the scientific laboratories proposing the experiment. Finally, provisions for archiving the data during 10 to 15 years were engaged (POLDER-3 would introduce still another change, this time affecting the production, storage and diffusion practices: data would be produced by an external datacenter and openly available from an internet database upon free registration). This overall description portrays a picture departing from the *PI-mode* of data handling in which the original POLDER, as well as most of the experiments designed at least during the 20 first years of space activities, had been integrated.

Conceived in 1986 as a classical experiment in the space sciences following a *PI-mode* of data-handling, but progressively reshaped and reconfigurated leading to its final structure launched in 1996 (to give a closed interval of time), POLDER offers a case-study to explore, this is the hypothesis underlying our work, the process of *reconciliation* between space technologies and the disciplines in the domain of Earth sciences occurring during that very period. It is the purpose of the rest of our essay to illustrate some of the features characterizing such a process (sometimes aligning with former precepts and practices, sometimes departing from them); a process that would lead, by the bend of the 2000s, to the determination of a set of rules, insights, practices and attitudes, *normalized* as the admissible ones to conduct research in the disciplines of Earth sciences using satellite data. The case of POLDER-3 proposed in 1999 serves the purpose of illustrating such a normalization and, in this ways, we use it as a case to demarcate a separation between the two periods that structure our essay.

2

FACTORIES OF GEOPHYSICAL DATASETS. TECHNOLOGICAL DATA PRACTICES OF CALIBRATION AND INVERSION: PHYSICAL DATA AND GEOPHYSICAL DATA.

As we have seen in our contextual introduction, for many years after the Sputnik, or the International Geophysical Year, the pursuit of space sciences would be the province of a small number of principal investigators and their associated teams based in a university or laboratory. In France, helped by CNES technical laboratories and/or industrial contractors, the eleven "selected labs" would have the monopole of building instruments and payloads to be launched by CNES or by other space agencies; before the late 1970s they would be also the soles in securing and analyzing the data they obtained. As per non-selected laboratories, beginning in the late 1970s they would get the data by other means, including NASA's "announcements of opportunity" to constitute scientific teams around a given instrument. In any of the cases, once the satellite would be in orbit, PIs and associates would be shipped more or less preprocessed data from space agencies or operators and would develop the analysis tools to cope with them in their particular scientific study. They would decide what data was worthy enough to store in a backup tape, what data would be sent back to space operators and what data would be forever forgotten in the drawer of their offices. Generally, data would be *self-made* and not necessarily shared amongst scientists and teams of different instruments, laboratories or disciplines.

In 1988, during one of his stays at the Jet Propulsion Laboratory of NASA, the electronics engineer Yann Kerr, one of the five initial members of the Laboratoire d'Etudes et Recherches en Télédétection Spatiale (LERTS) created in 1984, who would become a recognized scientist in the domain of water and energy budgets at the land-atmosphere interface, addressed a letter to his colleagues at LERTS and to the Directorates of Programs of CNES in Toulouse and in Paris:

> « La Télédétection se caractérise par l'emploi de données satellitaires en provenance de différents capteurs et même de différentes sources de diffusion. Ceux-ci sont multiples et se différencient par leur formats, mode de commande, etc. de ce fait, tout chercheur se heurte donc rapidement au problème de l'accession aux données et au prétraitement de celles-ci.
>
> La solution couramment pratiquée en France dans les laboratoires est donc de rechercher la source de données la plus appropriée (ou souvent la plus facilement accessible), récupérer celles-ci ainsi que

toute documentation nécessaire, écrire avec plus ou moins de bonheur les programmes de lecture et de mise sous forme de données géophysiques avant de pouvoir commencer à travailler. Cette procédure prend au mieux plusieurs semaines et parfois plusieurs années. Une fois ces opérations terminées, le chercheur aura tendance à se restreindre a son jeu de données afin de ne pas avoir à refaire ce « parcours du combattant », d'où une certaine sclérose et surtout un grand conservatisme. De plus, par son cloisonnement, cette pratique donne lieu à une multiplication d'archives redondantes de traitement incessamment refaits, d'où perte considérable de temps, d'argent et d'efficacité. (…)

Dans les prochaines années existera aux États-Unis un système d'archivage et de diffusion des données permettant (encore plus qu'actuellement !) aux chercheurs de faire de la recherche et non de la chasse aux données, d'écrire des algorithmes d'analyse et non des algorithmes de prétraitement. [In the United States] cet effort est financé par la NASA et ne recouvre pas uniquement les données satellitaires »[232].

On the one hand, these thoughts align with what we have already illustrated in the previous chapters: that, by the late 1980s, the epistemic value of data for scientific inquiry did no longer lay in the physical radiances measured by the satellite instruments but in the geophysical variables that these radiances, after a physical interpretation in terms of radiation transfer, would enable to retrieve. These words, on the other hand, illustrate as well that the current modes of data gathering, production, storing and dissemination were considered, at least by some scientists, inefficient because requiring a "parcours du combattant" before being able to use the data, a path that may last from weeks to years from getting the radiances (or other type of measurements), writing down the reading software, developing the calibration and correction algorithms and finally applying the analysis methods to interpret the datasets within a given research context.

These two aspects (the change in the type of data attributed with epistemic virtue and the obsolescence of the PI-mode for data handling) are not disconnected of each other. The topic of this chapter is to study how the practices of data handling, which we have called *PI-mode*, and that constituted the epistemology of space scientists, would start to evolve as a number of disciplines of the Earth sciences started to be included in the scientific programming of space agencies. Central to this evolution, we argue, is a shift in the type of satellite data considered as valuable for scientific inquiry, as illustrated by Yann Kerr's quote: from the measurements of radiances to some form of geophysical units. A shift that, we argue, was reinforced, if not driven, both by the reconversion of some scientists experts in the physical approach towards applying their skills in a given discipline and by the arrival of Earth scientists not experts in the physical approach[233]. In turn, a new set of technological practices to reconcile the measurements with the scientific imperatives of using geophysical parameters would be

[232] « Note au LERTS : Banques de données satellitaires », written by Yann Kerr in January 1988.

[233] The evolution of LERTS, we suggest, reflects this defection of a number of experts in the physical interpretation of the data towards a more applied approach of the data in a given disciplinary field in the domain of Earth sciences (especially vegetation studies). The tension between the two approaches would reach a peak between 1989 and 1995 and would certainly be an element (even though not the sole: cultural differences due to the CNRS-CNES double institutional affiliation of the laboratory, priorities of the direction, or difficulties of recruiting scientists and getting funds, given that remote-sensing was not a recognized discipline in the CNRS's department of Terre, Atmosphère et Océans can be also pointed) favoring the creation of a new laboratory, the Centre d'Etudes Spatiales de la Biosphère (CESBIO) in 1995 as the fusion of part of the selected laboratory Centre d'Etude Spatiale des rayonnements (CESR), the Laboratoire d'écophysiologie vegetale of the University Paul Savatier and the LERTS, with the goal of "provoquer, dans le domaine de la biosphere, le rapprochement entre physiciens et biologistes dans une dynamique synergétique », as quoted in the "Projet de creation du CESBIO", presented in 1994.

Rapports d'activité of LERTS and CESBIO, 1984-1996 and « Projet de création du CESBIO », 1994.

developed (especially inversion methods), which would have the effects of dividing the scientific community into those with expertise in creating geophysical parameters and those with expertise in analyzing them within a given discipline.

We illustrate that the evolution of the PI-mode of data handling lead to a factory-like system for mass-production and dissemination of geophysical data. We connect the implementation of such complex and its progressive *normalization* as the admissible manner to organize the data handling, with two aspects: first, technological changes at the level of sensors and microprocessors perceived by scientists as threatening their capabilities to cope with the data and, second, the will of CNES to gain visibility amongst a larger community of scientists, not necessarily experts in the physical interpretation of the satellite measurements. This chapter offers hence a picture of what kind of data became the norm as those satellite data useful in the disciplines of the Earth sciences, of how scientists understood the measurements, of the ways that data would be deployed to be meaningful for scientists, of the technological practices articulated to transform signals into data, of what it meant to be a space scientist in this renovated order, their relationship with the instrument and the data, and with the space agencies. It addresses these epistemological questions by looking at the scientific insights and the technological assets that drove the gathering, transmitting, processing and storing of data together with the social order associated to them. We argue that this system of mass-production would reflect what had become the epistemic norm in the domain by the late 1980s amongst a particular social group, the space managers and the scientists involved in the conception of the instrument and its data: growing degree of intervention of CNES in the production and dissemination of geophysical data, growing tendencies towards geophysical data sharing, and a growing separation of the Earth scientists into those who create the data and those who consume them. We argue that these adjustments, deemed necessary to overcome the issues exemplified with Yann Kerr's expression "parcours du combatant" to handle the satellite data, are part and parcel of the moves of *reconciliation* between space technologies, embodied in satellite data, and scientific disciplines willing to study the Earth and its environment. The case of POLDER's data handling, defined between 1990 and 1993, offers an instructive example.

To provide the context we have rather based on reports issued by different institutions, proceedings of workshops and scientific meetings organized by NASA and CNES, handbooks on satellite data management, minutes of meetings or interviews with some of the actors, both American and French. For the technical and scientific parts, we have consulted several documents indicating the technical specifications of the instruments and of the data processing line, the activity reports of the concerned institutions (mostly LOA, LERTS and CNES), articles and publications in peer-reviewed journals, and completed again with dialogue with the actors.

COPING WITH ABUNDANCE

Advances in the domain of semi-conductors in the 1970s would lead to the development of charge coupled devices (CCD), the solid-state imaging devices used today in home videocameras. CCDs would work on a principle different from that of the vidicons or scanners described in our introductory chapter. The light pattern falling on a CCD chip would produce a charge replica of itself, with more charge produced and collected where the light was the brightest. The light therefore would produce a sort of electrical photograph. The image would be, in effect, developed in the silicon chip and could be amplified and then displayed on television screens. CCD chips would be much more sensitive than the eye and the film (that is, they could produce images of objects that varied enormously in brightness), lighter, smaller and would consume less power (because, for instance, no motor would be necessary to rotate any mirror) –attributes that are put forward in systems meant to be embarked inside a spacecraft. More generally, CCD's chips constitute a major change in imaging technology, because they digitalize both inputs and outputs and enable to transfer and process the data electronically. They do not only render data-gathering more sensitive, abundant, cheap or power-efficient, but they render data-analysis independent of the direct observation of its object: field-sciences like astronomy, so it has been argued, would become laboratory data-processing sciences[234].

Electronic revolution as *Reverse salient*

The use of CCDs chips for sensing would be only an element of a more general shift from mechanical to electronic devices, a shift that would give birth to a new generation of instruments started to be launched in space by the mid-1970s providing the same type of continuous measurements than a scanner but more resolved, more sensitive to light and, equally important, deprived of the mechanical rotation and its constraints. For instance, the field-of-view of scanners was conditioned by the angle of scanning, which was produced through mechanical rotation of the oscillating mirror, connected to the sensors with wires: it was ultimately the length of the wire that conditioned the field of view of the instrument before getting tangled[235]. Freed from wires, CCDs' field-of-view would easily be amplified. Also, this is another example, silicon chips were more durable, precisely because some of the causes of scanning failure (the deterioration of the wires due to friction or the failures in the motor to rotate the mirror), would be eliminated[236]. As a consequence, it was estimated that the volumes of the gathered data would be increased by two orders of magnitude by 1985[237].

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[234] For an overview of CCD's technology, centered in astronomy, see "Replacing a Technology: The Large Space Telescope and CCDs", R. Smith and J. Tatarewicz, 1985.

[235] This is a classical problem in telescopes and antennas on the ground, known as wrap, and provides an instructive illustration: the finite length of the cables prevents the antenna to indefinitely keep turning around itself. At some point, the cable reach the limit and the antenna must slew back to its source position –which takes several minutes, which are discounted of the observation time given to the astronomer. In order to optimize their time, when programming their observations, astronomers must then account from the initial position (including the motion direction) left by the previous astronomer and the length of the cable.

[236] Interview with Jean Louis Monge, 2012.

[237] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

At the same time, silicon technologies would be also used as storage devices and processors, both aboard and in the ground. This would also contribute to increase the data volumes. If the aboard storage devices were electronic-based they would be easily interfaced with the computers in the ground for control and data transmission. This would easy and increase the data-rate transmission from the satellite to the ground. Secondly, silicon chips would allow storing higher volumes of data in smaller pieces and would enable on-board preprocessing to reduce significantly the amount of data that must be returned to the ground, allowing the transmission of more, and eventually somehow preprocessed, data. Also in the ground, high-speed signal processors and computers would provide the capability to acquire, process and store the data as they would be received. Finally, archival capacity would also be increased. By the early 1980, it was expected that semiconductor-based capacity would double every 18 months[238]. Since the volume of gathered satellite data, while increasing, was not expected to double every 18 months, it would inevitably become cheaper to process and maintain the satellite data and the record, favoring, in turn, the processing and the storage of ever more data.

The issues in the satellite data handling raised by the increasing data volumes due to electronic technological changes in sensing, storing and processing would be reckoned in a study elaborated between 1978 and 1980 by a group of American space scientists under a mandate of the Space Science Board of the National Research Council[239]. This study would be driven by the perception that the satellite data chain from satellite to ground to preprocessing to principal investigator to reduction, analysis and archiving suffered from inefficiencies all along the line, and by the intuition that, as electronic technologies would become commonplace from the 1980s onwards and the volume of data would consequently grew, inefficiencies would be sharpened unless they would be properly anticipated and addressed:

> "Science data management in the 1980s and beyond has the potential to be dramatically different from what has been experienced in the formative years of the space program. The differences will result through advances in technology at the microelectronic component levels, in storage technologies, in fiber optics, and in many other related areas. The effects of this technology will be evident from both cost and performance viewpoints and will influence every aspect of data management from acquisition in space to final processing, distribution and presentation of data for interpretation (…) The ability of computers to handle large quantities of data has also given us a major problem: since large amounts of data can be obtained, they are obtained. Torrents of data bits descend upon us from our instruments in space. How do we process the data, store them, retrieve them for scientists to use?"[240].

The American report went further and pointed out that the body of data that the new technologies instruments equipped with electronic sensors and storage devices would return during their lifes as well as the body of data that electronic-based processing computers would generate and archive, would potentially be so vast that it would surely overwhelm a handful of PIs and their teams, so that

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[238] We have found in several documents of the early 1980s references to this general trend, known as Moore's law. See for instance: "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

[239] Some of these scientists would be Thomas Vonder Haar, Ichtiaque Rasool, James Van Allen and Carl Wunsch, who we will find again all along our dissertation.

[240] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

much of the data would never be examined. This perception of a data overload was masterfully spelled out in the quote: “since large amounts of data can be obtained, they are obtained”, it was said[241]. Similar concerns were also expressed in France. For instance, the annual cycle of conferences organized by CNES in the University of Toulouse as part of its efforts to attract new students, was devoted in 1981 to the topic of “space sciences and technologies”. The scientists who imparted the lectures, mostly belonging to “selected laboratories”, expressed this very same concern:

> « Une fois que l’expérience a été conçue, réalisée et lancée on est confrontée à son exploitation. Il s’agit de récolter des données et surtout d’en faire quelque chose. Si la récolte est en général assurée, le fait d’en tirer quelque chose n’est pas forcément inné »[242].

Simply said, something must be done with the collected satellite data. Otherwise, efforts of gathering them, and therefore the enterprise of satellite launching, would be pointless.

This was closely related to another major issue. It was not only a matter of greater volumes of data, but also of the nature of these data. By introducing silicon CCD chips, the scientific work of data interpretation would become digitalized from end-to-end, that it to say, from gathering to correction to analysis to display to diffusion and storage. The scientific practice would become then centered in processing electronic data, which implied that scientists must be trained for this new job. As space sciences became more and more dependent on the silicon technologies (for sensing, for storing, for transmitting, for processing –and later on, as we will see when discussing the internet-based databases in chapter five, also for archiving and disseminating), it was necessary to learn to cope with the perceived data deluge in a manner meaningful for scientists.

The idea that certain technological advances can jeopardize the collective development of the system in which they are integrated was exploited by the historian Thomas Hughes with his notion of *reverse salient*[243]. In his seminal book « Networks of power », the historian introduced the concept referring to a technical or social component of a technological system that, due to its insufficient development, would prevent the system in its entirety achieving its targeted development. « As technological systems expand », wrote Hughes, « reverse salients develop. Reverse salients are components in the

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[241] See Ian Hacking’s “The Taming of Change”, 1990, for a description of what he termed the avalanche of data that hit the sciences in the early decades of the XIXth.

Recently, probably influenced by the recent fascination about the phenomenon of Big Data, a number of scholars have been interested in tracing back the history of huge datasets and in exploring how, if so, the digital era influenced and changed scientific practices. As far as we know, a great bulk of such research is done in fields of natural history from the XVIIth natural history to the XXth molecular biology. See, for instance: the special issue of Science on “Dealing with Data” of 2011; the special issue of Studies in the History and the Philosophy of the Biological and Biomedical Sciences on “Data-driven Research in the Biological and Biomedical Sciences” of 2012; “Towards 'A natural history of data': evolving practices and epistemologies of data in paleontology, 1800 – 2000”, D. Sepkoski, 2013; “The “Data Deluge”: The Production of Scientific Knowledge in the 21st Century”, B. Strasser, 2014; or a forthcoming special volume of Osiris on “Histories of Data”, edited by D. Sepkoski et al.

[242] The proceedings and lectures of this cycle of conferences were compiled in the handbook « La technologie des expériences scientifiques spatiales. Cours de technologie spatiale », ed. CNES, 1981.

[243] The metaphor comes from the military jargon, where the term reverse salient has been commonly used to analyze military campaigns in the World War I, where opposing military forces created uneven sections in respective battle lines. The significance of the reverse salient lies is the idea that in its presence, the forward progress of a military front is slowed down or halted. “Networks of Power: Electrification in Western Society, 1880-1930”, T.P. Hughes, 1983.

system that have fallen behind or are out of phase with the others »[244]. The idea of reverse salient is also pertinent to conceptualize the issues raised by the ever-growing volumes of digitalized data, especially the issues of data management. All and all, the whole issue that worried the space scientists was, according to the authors of this American report, how to organize the science, the technology and the people to obtain information, understanding and knowledge from all these data and to maximize the scientific return of the space efforts[245]:

> "There are problems with the way data are currently managed. The distribution, storage, and communication of data currently limit the efficient extraction of scientific results from space missions. Technological barriers are not the major impediment to improved data handling. While certain areas of technology will need continued development, most of the technology required for successful science data management either exists at present or will be available in the near future. Nevertheless, although economic factors will continue to impose technical limitations on data management, the current problems are due mainly to the structures and limitations of our institutions and management operations. Data-handling problems can be significantly reduced by restructuring the data chain (from acquisition to analysis). (…) The large amount of data that have been acquired in the past, currently being acquired, and planned to be acquired in the next decade presents a challenge that will require the establishment of principles and scientific, technical and organizational solutions"[246].

There was a perception of a mismatch between these electronic technological developments applied to space technologies for gathering data and the organization of the handling of data in the ground. While reckoning the importance of technological changes in limiting the efficiency of data exploitation, the scientists authoring the report would reiterate that it was not a problem of current technologies not capable to tackle with the data volumes, but rather a problem that must be addressed at the same time from a scientific, technical and organizational standpoints. In other words, what this handful of space scientists were pleading all along the report was that usefulness of satellite data (quality, timeliness, accuracy, cost, access) would require a methodic reorganization of the scientific, the technical and the social orderings.

Reorganizing the scientific, the technical and the social orderings of the satellite data chain

The American report pleaded in 1982 for new ways of organizing the chain of acquiring, processing and interpreting the data, since the traditional PI-mode did not optimize the use of data because of the technical and economic inability of individual isolated PIs to handle the ever-growing data volumes. The report maintained indeed that most of the scientific laboratories that proposed a satellite experiment, even those belonging to NASA, did not have the capacity to cope with the expected data. It was one thing to handle well-selected samples of data requested to space agencies and shipped in the material support of a magnetic tape ready to insert in a reading-machine, and it was another to actually deal with a continuous voluminous digital data downflow. In his historical study about NASA's oceanographic and geodetic mission SeaSat launched in 1975, the historian Erik Conway suggested

[244] "Networks of Power: Electrification in Western Society, 1880-1930", T.P. Hughes, 1983.
[245] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.
[246] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

that the future users of the data, including scientists of Jet Propulsion Laboratory of NASA (but also from laboratories of the National Oceanic and Atmospheric Administration, from the US Navy's Fleet Numerical Weather Center, the U.S. Geological Survey, the U.S. Coast Guard, the Woods Hole Oceanographic Institute, the Scripps Institution for Oceanography, and the American Petroleum Institute) were unable to handle with them. The prompt failure of the satellite only 106 days after its launching was seen, in a ways, as a sort of release because, according to the author, they had not been prepared to cope with the data that SeaSat would have sent down[247].

To address the question of satellite data management, the authors of the report pleaded, inter alia, for three points. First, they recognized that not all data are meaningful for scientific inquiry in all domains. Therefore, satellite data must reach the scientists in a manner suited to their scientific research needs –the concrete nature of these needs would not be generalized in the report but rather spelled out through some examples in different scientific fields. Second, because laboratories in universities or research centers were reckoned to be unable to handle all these data, an increasing participation of NASA in the chain from gathering to archiving both during development and operations was seen as indispensable to achieve a scientific exploitation of the data. Indispensable were also, this is the third point that we are stressing, enhanced efforts in rendering data accessible and interpretable to scientists not associated with their acquisition. In other words, to extend the availability of satellite data beyond those PIs who had built the instrument or the data software[248] and to outreach scientists who had not participated in the design of the instrument –we find, in this third point, here a parallel with some moves made in France to spread the use of satellite data amongst the scientists, beginning with SPOT, since the late 1970s (like the grants of the program "Actions Thématiques Programmées", for instance). First step for such an outreach, so the report suggested, would consist in establishing specific units equipped with suitable computational resources for coping with the data, standardizing the processing software, coding languages or protocols amongst laboratories, agencies, industry and universities, and devoted to distribute the data amongst a wider audience of scientists[249]. Second step would consist in convincing external scientists that satellite data were appropriate and credible tools for their respective scientific researches.

We have not found traces suggesting direct influence of such report on NASA's leadership or on PIs of different NASA's instruments, besides the fact that some of the authors were influent scientists directing teams in universities that proposed instruments to NASA –it must be noted that our research has not been exhaustive on that point either and only conducted through our interviews. We ignore

[247] "Drowning in data: Satellite oceanography and information overload in the Earth sciences", E.M. Conway, 2006.

[248] By software we refer to a set of programs and codes capable to realize the operations of data manipulation, from geometrical corrections, radiometric calibrations, recoding, filtering, processing and visualization.

[249] They also pleaded for data should be made the access of scientists to all data, whether they had been obtained from scientific or from operational missions, for the standardization of software, coding languages or protocols amongst laboratories, agencies, industry and universities, for increased effort in documenting the data to make them interpretable to scientists not associated with their acquisition, and for a general increase in the funds devoted to the data analysis activities. We will find each one of these issues all along our dissertation.
"Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

hence the degree of influence of the document as such; nevertheless, consciously following it or not, all the projects conceived and developed during the decade (starting with Topex/Poseidon, the Upper Atmosphere Research Satellite (UARS), and the Earth's Radiation Budget Experiment (ERBE)), as well as the Earth Observing System program (EOS) would be designed in compliance with the overall principles and guidelines laid down in this report.

CNES and satellite data handling: Space technologies and ground technologies

We ignore as well the actual relevance of such report in France. What we know is that, whether connected to that report or not, similar worries started to flourish. For instance, as we have mentioned, the series of conferences that CNES organized annually in the University of Toulouse about space technology, would be centered in their edition of 1981, and for the first time, on the topic of space scientific experiments. More particularly, about a third of the conferences would be focused in data management topics associated with the data obtaining, processing and distributing. These were lectures addressed to an audience of students with the clear goal of getting adepts to further make career in the space sciences or technology domain and therefore they discussed scientific and technical details of the data gathering and processing. None the less, most of them would emphasize some of the contention issues of such activities, such as the inability to cope huge volumes of data due to not enough powerful computers, the lack of skilled personnel familiar with the new digital techniques of processing and interpreting the signals or the need for reorganizing the activities in their laboratories and at CNES[250].

"Fundamental change in space agencies' life": Gathering data –and processing, curating, archiving and diffusing them

Also in 1981, the first scientific meeting organized under the auspices of CNES would take place in Les Arcs gathering more than 150 scientists[251]. Claims for involving CNES, identified as the institution technically competent for satellite data handling, in the management of the data systems would be heard in that meeting –and repeated all over in those that would follow between 1981 and 1998- intending to "rechercher les meilleures conditions d'exploitation des missions en orbite et consolider la definition des segments sol des programmes en développement de façon à promouvoir l'utilisation la plus large des données"[252]. These regular demands of the scientific community, which

[250] « La technologie des expériences scientifiques spatiales. Cours de technologie spatiale », ed. CNES, 1981.

[251] See the proceedings of the Seminaires de Prospective Scientifique du CNES, in particular : « Conclusions des groupes de travail « Sciences de la Terre » », presented by M. Petit, Séminaire Les Arcs 1981 ; « Conclusions et recommendations. Groupe de travail : Sciences de la Terre », presented by Philippe Waldteufel, Séminaire Deauville 1985 ; « Les sciences de l'atmosphère, de l'océan et de la biosphère », several authors, Cap d'Agde 1989 ; « Conclusions et recommendations du groupe de travail « Sciences de la Terre et de l'environnement », presented by Jean-Claude Duplessy, St Malo 1993.

[252] « Conclusions et recommendations du groupe de travail « Sciences de la Terre et de l'environnement », presented by Jean-Claude Duplessy, Seminaires de Prospective Scientifique du CNES, St Malo 1993.

crystallized in the proceedings of the scientific meetings or via sporadic manifestations like the letter of Yann Kerr in 1988, would only start being materialized in the 1990s. For it would be by then, after all, that the first missions started to be realized at CNES. Excepting for Topex/Poseidon, the rest of the missions conceived in the 1980s like BEST, ScaRaB, POLDER or GLOBSAT would not start their material realization before the 1990s, after a period of preliminary studies and prototypes[253]. It would be then that the ground segments must be designed, including the data management systems. It would be then, hence, that the issue of data handling would take specific form to be faced. In 1993, for instance, the atmospheric physicist Isaac Revah, responsible of the at the at time called Environmental Division at CNES, in a conference presenting the French program in the domain stated:

> "L'effort du CNES de mise en œuvre des systèmes d'observation sera complété par une action d'accompagnement dans les domaines de la formation des chercheurs et de la mise à disposition des données. En effet, l'accroissement significatif du nombre de systèmes spatiaux consacrés à l'étude du climat et de l'environnement global, au cours de la prochaine décennie, va conduire à une augmentation considérable du volume de données à traiter par les scientifiques. Les principaux défis de cette période seront certainement la formation de cette communauté, l'accessibilité aux données et les moyens de traitement en masse. Pour faire face à ces flots de données, la conception et la réalisation de centres et systèmes de traitement et de gestion de données suffisamment opérationnels et bien dimensionnées doivent être engagés parallèlement au développement des programmes spatiaux »[254].

These words synthetized some of the issues brought forward by the American report about a decade before: perception of data deluge, efforts for training scientists in the art of digital data-processing, mass-production of data and rendering data available to a wider community. We would like to remark, once more, that this vision represented a departure from previous modes in which CNES's functions consisted in *despatialize* the data and ship them to PIs, and not to participate in any degree of the processing, disseminating, archiving or, even less, in educating scientists in those tasks (unless required specifically in particular missions).

The persistence of the national scientific community aside, international pressures, we believe, may not be neglected in pushing to that vision. Indeed, issues about the satellite data management and more generally the management of all types of environmental data, had risen as a focus of attention in the international scene, as exemplified by the discussions and actions engaged at international fora like the Committee of Earth Observation Satellites (CEOS) or the international research programs like the International Geosphere and Biosphere Program (IGBP) and the World Climate Research Program. For instance, further the proposal of the Japanese delegation in 1989, CEOS's members were establishing a global network of satellite data dedicated to the environment, a network that would be supported by regional datacenters ensuring the pooling, dissemination and archiving of the data[255]. This project materialized some years later, in 1993, with the preparation of ADEOS, for which NASDA requested CNES, as its European partner in the mission, to be the responsible of archiving

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[253] Some of them would never make it though. In 1992, for instance, BEST would not be given green light for realization and the project was dismantled.

[254] "L'étude du climat et de l'environnement: les apports de l'espace", Isaac Revah, 1993.

[255] "Final Minutes of the Fourth Plenary Meeting of the Committee on Earth Observations Satellites", held in San José dos Campos, November 1990.

and disseminating the data of ADEOS to the European scientists, as a first stage of becoming the nodus for distributing data from all the Japanese satellites to European scientists[256]. In the meantime, a working group preparing the IGBP, directed by the recognized atmospheric scientist Ichtiaque Rasool, one of the authors of the American Space Science Board report discussed before who was by then working in collaboration with the Laboratoire de Météorologie Dynamique, was defining a data and information system based in three axes: developing and producing different datasets, diffusing them and coordinating data exchange within the research program. Institutions may volunteer to become regional datacenters pooling the data and ensuring their circulation. Even though the project intended to manage all kind of data, not only satellite data, CNES, alone or in partnership, appeared as a candidate for the European datacenter –and, indeed, a regional cell was established in Paris[257]. At a national level moves towards organizing the data about the Earth and its environment were promoted too. The French government had affirmed the will to implement a national environmental data policy, grounded on a data information system, for which CNES was preparing a proposition called GEODIS, in complementarity of the data information system called Earthnet, being developed by the European Space Agency and through which data of ESA's missions (catalogued by mission, instrument or discipline) would be available to scientists in different levels of processing and within a set of conditions for access[258]. These are only some examples, far from being exhaustive, to illustrate our point: that CNES's actions subscribed all these moves taking place in the international arena illustrating the complex imbrications of the national with the international in the domain of space activities –and, from a methodological perspective, that to grasp a complete understanding, different scales may be complemented through constantly zooming in and out.

In the wake of all these trends, CNES gathered pace towards the adoption of this renewed mission, including data production, diffusion and archiving, which would materialize during a reflection started in 1996 about CNES's mission and vocation as space agency[259]. The outcomes of such reflection would be issued in 1999 in the form of a strategic plan for the period 2001 to 2005[260]. With respects to data management, the first draft version of this plan concluded that a "fundamental change" in CNES's activity was getting underway, an evolution towards a "more intervention in the dissemination of space data to the scientific community":

> « Le CNES doit veiller à la qualité du segment sol d'exploitation, en intervenant davantage dans la mise à disposition des données spatiales à la communauté scientifique (…) La complexité croissante des instruments exige des compétences poussées, des méthodes structurées de gestion de projet, et de nouvelles charges résultent du traitement, de la distribution, de l'archivage, de la réhabilitation des

[256] « Nœud de données ADEOS –Spécification générale de besoins (proposition) » prepared by Paul Kopp, April 1993.

[257] « Banques de données. Système d'accès aux données spatiales», prepared by F. Chabanne, March 1993.

[258] « GEODIS. Spécifications techniques des besoins. Rapport préliminaire de phase A», prepared by R. Bru, April 1993.

[259] We are not entering here in the context that drove this general deep reflection. We suggest that some elements may have been the new political order, emergence of multiple space powers, increasing pressure for commercialization of space assets, importance of space technologies as force-multipliers in wartime, new international political agenda, amongst other. We provide a more detailed description in the intermezzo that divides our essay.

[260] « Plan stratégique du CNES 2001-2005. Tome 1 », ed. Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, December 2001.

données spatiales. Ces différents facteurs légitiment une redéfinition des rôles respectifs de tous les acteurs, nécessaire au bon développement d'une mission et une mobilité accrue (…) Il s'agit là d'un changement fondamental dans la vie des agences spatiales»[261].

The second volume of the final version strategic plan edited by the Technical Center in Toulouse would confirm the general trends towards enlarging beyond its traditional actions of *despatialization* – being this very term used in the document. In the list of 32 actions in which CNES would be engaged between 2001 and 2005, an action would be devoted to "provide an increased support for data exploitation":

> « Action 8 - Fournir un support accru à l'exploitation des données des missions spatiales :
>
> Le CNES avait jusqu'à présent fourni un support aux utilisateurs de l'Espace en "déspatialisant les données" des expériences conduites en orbite pour en faciliter leurs exploitations. Or nombre de ces expériences spatiales ne constituent qu'une contribution à un ensemble d'essais menés de manière complémentaire au sol. Les techniques de fusion de données sont complexes et le CNES doit faciliter l'utilisation de ces données spatiales en s'impliquant jusqu'au résultat recherché, qu'il s'agisse de missions scientifiques ou de programmes opérationnels. Par-là, il s'agit de redéfinir les responsabilités, les objectifs et l'organisation du CNES pour la valorisation, l'archivage et la mise à disposition des données. Le CST [the Technical Center of CNES in Toulouse] étudiera, entre autres, sa participation aux programmes nationaux du CNRS pour soutenir l'exploitation des données spatiales, ainsi que la mise en place d'une banque de données interopérables»[262].

According to this action, CNES was redefining its participation in the satellite data handling, from being an institution focused on *despatialization*-related activities (understood, recall, as decommutation, location, datation, repixeling, and some eventual corrections and calibrations) to one dedicated also to processing, archiving and distributing the data –tasks, which were, during the 15 to 20 first years of space age reserved to space scientists, for they defined their ethos as such. "Redefining the respective roles of all actors", as quoted in the fragment, was a matter of efficiency and technical capabilities vis-à-vis the data handling, since CNES was better equipped for such a task than laboratories. It was also a matter of strategy in views of outreaching and spreading the use of satellite data amongst scientists. Indeed, on the one hand more scientists would have access to data if CNES ensured their wide and open dissemination beyond the scientists that had designed the experiment; on the other hand, these data must be made available in a ready-to-use form, as blackboxed products to be mass-consumed by scientists, as per avoiding the "parcours du combattant". Two points deserve to be pointed out. First, it represented a new repartition of responsibilities between space agencies and the laboratories proposing and conceiving the experiment and, until then, coping with the data. This renewed repartition of responsibilities amongst CNES services and the scientists would re-demarcate the boundaries between what was of the domains of "space" and of "science", to take the categories introduced in the introductory chapter. In order to secure the handling of the data gathered with its satellites and to reach a maximum number of scientists, and certainly pushed by the events taking place abroad, CNES was committing to the task of calibrating, processing, correcting,

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261 « Plan stratégique du Centre National d'Etudes Spatiales », ed. Comité de Pilotage du Plan Stratégique. First draft version dated of July 1996.

262 Plan stratégique du CNES 2001-2005, Tome 2, Centre Spatial de Toulouse, Édité par la Direction de la Stratégie, de la Qualité et de l'Évaluation du Centre National d'Études Spatiales – Siège, December 2001.

filtering and reducing, transforming the physical measurements into geophysical parameters, judging the quality of the resulting datasets, ensuring the archival and distribution of the data in a mass-production manner. Second, this task represented a "fundamental change in space agencies' life"[263], as suggested in the quote. This new vocation and identity of space agencies was arguably closer to the until then scientific activities of data processing and storing than to technological development of new space assets and systems[264].

With the incorporation of missions to study the Earth and its environment, and we conclude with that, CNES, and space agencies more generally, were incorporating a new function: apart from being space technologies providers they became satellite data providers. Besides the big engineering commonly associated to the space venture, missions for studying the Earth and its environment vindicated the ground-work of satellite data handling. Apart from, and in some occasions instead of, developing more resolved sensors, more safe engineering platforms, efficient motors, vehicles, systems for orbital tracking, data transmission systems or power sources to optimize energy consumption in space, CNES was committed to develop technologies on the ground -a point that we will further develop with more examples when discussing the data quality control and the integration of data into models. It is plausible to argue, then, that this "fundamental change in space agencies' life", can be interpreted as part of the efforts for *reconciling* with the demands and practices of the scientists in the domains of environmental sciences like atmospheric chemistry, physical oceanography, marine biochemistry, meteorology, glaciology, and so forth.

Organizing POLDER's data system

Let us look in some detail the case of POLDER. In September 1990, Jacques-Louis Lions, current president of CNES, would formally confirm CNES's commitment to POLDER to his Japanese homologue. It would be then that a team would be specifically assembled intended to work exclusively in the development and realization of POLDER, the so-called "groupe projet" lead by a Project Manager advised by a Project Scientist in the Technical Center of Toulouse (Jacqueline Perbos and Alain Podaire (one of the five original scientists of LERTS) by then, although they would be changing over time). The "groupe projet"[265], would be the overall coordinator of the mission, taking the

[263] « Plan stratégique du CNES 2001-2005. Tome 1 », ed. Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, December 2001.

[264] « Plan stratégique du Centre National d'Etudes Spatiales », ed. Comité de Pilotage du Plan Stratégique. First draft version dated of July 1996.

[265] We are not analyzing in detail the management rules and ways of organizing the work at technical institutions such as CNES. We just need to know that CNES, importing the running rules of NASA, calls most of its activities programs or projects. Broadly speaking, a program is understood as a series of undertakings which are funded with a specific budgetary line, which continue over a period of time, and which are designed to pursue a broad scientific or technical goal. A project is a defined, time-limited activity with clearly established objectives, workforce and schedules. A project is normally an element of a program. While a program manager, for instance, is deemed to remain in the chair during the long-term, a project manager and the "group projet" are abolished once the project is over and reorganized to manage another project. For instance, the project POLDER was considered a component of a broader program, which has received different names across time (see Box 1.1), but that is known in common parlance as "Earth Observation", which also included the projects ScaRaB or Topex/Poseidon.

responsibility of overseeing instrumental, scientific and industrial developments as well as implementing and operating the software for the ground segment –it would be also missioned to create a scientific group larger than the scientists that had proposed the instrument in 1986 charged of preparing the scientific utilization of the future POLDER's data, a point that we will develop in the next chapter. The "group projet" was also mandated to define a ground segment for POLDER, a task that it would accomplish between 1990 and 1993. The example of POLDER, not only constitutes an appropriate case to illustrate the issues, attitudes, expertise, technologies and organization mobilized to determine the data systems, because of the fact that it belongs to the first generation of instruments to study the Earth and its environment launched by CNES, but also because, as we have been able to read in ulterior minutes, it would become as well a customary precedent for organizing further missions. Before continuing let us give a hint of the figures to better seize the nature of the enterprise of POLDER's data handling.

As we have mentioned, POLDER's sensors would take advantage of the silicon advances. Instead of being aligned in an array like in the pushbroom mode of SPOT, the CCD chips of POLDER would be placed in a bi-dimensional matrix of 274x242 pixels of 288 lines and 384 columns (with a pixel covering a more or less rectangular area of 42kmx42km (depending on the Earth's curvature, on the gravity forces and on other spacecraft orbital instabilities)[266], giving a space resolution of around 6x7 Km^2, producing the effect of scanning entire surfaces at once instead of line per line. Data were to be downlinked at a rate of 882 Kbps (kilobit/second), giving around 35 Gigabytes of data per day during the three years that POLDER was meant to function, resulting in an estimated number of 150000 magnetic tapes, to be curated and conserved during at least 10 years[267]. Moreover, POLDER exploitation infrastructures were planned to persist beyond the lifespan of the satellite: these data could be processed and reprocessed in a myriad of different ways according to varied scientific objectives during seven more years. The exploitation of such a system was hence a quasi-industrial project, which expected to mobilize around 40 persons and 6MF per year[268].

The issue rapidly crystallized. Until the 1980s, as we have seen, according what we have called the *PI-mode* of data handling, "ce sont les experimentateurs qui realisent les opérations utilitaires telles que les réception, stockage, distribution des données, traitement en temps reel et en temps diféré"[269]. However, given these magnitudes, were the space scientists proposing POLDER ready to cope with such a data handling plan? The responsibles of POLDER at LOA had the expertise in analyzing the data that they had been receiving through "calls for opportunities" or "Actions thématiques programmées" since 1978. But one thing was to handle some samples of data that had already been at

[266] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

[267] We are not in the position of affirming with certainty the number of years that the data archive was planned to last, as we have found some documents stating 10, some others 12 and some others 15. But this does not change our point.

[268] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[269] « La technologie des experiences scientifiques spatiales. Volume IV : Traitement des données des experiences spatiales », Cours de technologie spatiale, ed CNES 1981.

least pre-processed (decommuted, filtered, dated, that is to say, *despatialized*) and another thing was to deal with data from the outset, insuring the instrumental control, the continuous receiving of the data fluxes, their calibrating and correcting in a semi-operational mode, as well as receiving and storing of exogenous data necessary to locate, calibrate or process data, the storing of the data, and the processing and reprocessing during a period of around 10 to 15 years after the end of the measurements, and their storing and diffusion during this time. They had no technical resources and human expertise, and budget, to cope with POLDER data exploitation as it was planned. For POLDER's data to be properly handled, the solution must involve actors other than the PIs of LOA and LERTS. In other words, the *PI-mode* of data handling must be abandoned.

One of the missions of the "groupe projet" would be then to explore the most desirable organization to produce, store and distribute POLDER data as well as to prepare the system requirements and specifications for an operational system guaranteeing the production of data during the duration of the mission and to recommend an appropriate institutional framework for its implementation[270]. To that purpose, they would convey a working group composed by the scientist responsible of the instrument, Pierre-Yves Deschamps and Maurice Herman of LOA. Other scientists would in 1991 join the group, like François-Marie Bréon recruited at the Laboratoire de Modélisation du Climat et de l'Environnement (LMCE) after his postdoctoral fellowship at the Scripps Oceanographic Institute in La Jolla (California) and Jean-Claude Buriez, expert in remote-sensing of properties of clouds at LOA. Other would eventually, with more or less regularity in function of the concrete topic of the meeting, join also this core-team, like, inter alia, Marc Leroy (expert in geometric calibration, moved from the Technical Center of CNES to LERTS in 1993), Jean-Luc Deuzé (expert in remote-sensing of the aerosols of LOA) or Gérard Begni (expert in developing information systems of the Technical Center of CNES in Toulouse), to mention just a few[271]. This working group was mandated to define "une architecture, une organisation et un partage des tâches et responsabilités de développement, un plan de développement, un plan préliminaire d'exploitation et une première estimation des coûts"[272]. They had about two years to find a solution, which must be presented and submitted to evaluation during the "Revue de phase B du segment sol de POLDER" [273], which was at that time scheduled for the fall of 1992[274].

[270] « Compte rendu de le réunion de la Division Qualité et Traitement de l'Imagerie spatiale sur les « Travaux et responsabilités de la Division concernant le Projet POLDER » », October 1990.

[271] These are the individuals appearing as regular attendees of the meetings, whose minutes we have been able to consult. It must be said, however, that a number of itinerant scientists and engineers would eventually participate depending on the particulars to be addressed in each meeting. Computer scientists of the Technical Center in Toulouse like Alain Gaboriaud, calibration experts of the Technical Center in Toulouse like Olivier Hagolle, experts in remote-sensing of the radiation budget like Yves Fouquart of LOA, and many others, would often participate in those meetings. Besides, as we will see when discussing the creation of a scientific team around POLDER, a part from the individuals regularly taking part in these meetings, a number of scientists, professors, students, postdoc fellows and visitor scientists, would be working in diverse specific components of the project in different laboratories –as illustrated by the individuals signing the papers and articles in peer-reviewed journals.

[272] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

[273] It may be useful to get familiar with the structural chain set up by CNES to realize its projects. Since its industrialization beginning with SPOT, a space mission is planed according to several "phases" adopted from the practices followed in industrial engineering projects –and, once again, imported from NASA's ways of running. In

With that goal, two questions crystallized at the heart of the debate, two questions which were not totally new at CNES by the early 1990s, because they had been present, for instance, when discussing the data management for the Topex/Poseidon satellite in collaboration with JPL/NASA some years before -actually, in the minutes that we have consulted, we have noted numerous references to the Topex/Poseidon project. First, CNES was ready to participate in supporting the technical development of such infrastructure for data gathering, processing, storing and distributing as the *maître d'ouvrage*. In this way, CNES satisfied the demands of the scientists, unable to deal all alone with the data, while maintained some overall control on the project, given the fact that CNES was accountable vis-à-vis the Japanese counterpart NASDA[275]. However, after a testing period of time, the space agency was determined to transfer it to an external institution who would take over the responsibility for its exploitation[276]. In consequence, this external operating institution was to be identified: should a new institution be established or should it splice to an existing entity, and if so, which one? The second question that rose concerned the role of scientists, both those that had proposed the instrument and also a wider scientific community, in the development and exploitation of such system, including as well the different departments of the Technical Center in Toulouse. The scientists who were preparing the instrument and the future data were caught in the tension between a heritage as experimental instrument builders assuming that they would maintain some control over their instrument and the data that would be produced from it, and the current insights pointing to higher degree of data-sharing, which CNES aligned as a means to gain outreach and visibility amongst the external scientists that potentially making use of the satellite data for their respective scientific inquiries[277].

Within a few months this working group had converged on the technical specifications, cost, and

phase A the feasibility of the project is evaluated in terms of technology availability and budget. Preliminary studies of theoretical order are engaged, without any material realization being performed. Phase B is essentially a pre-conception phase, the project is defined and its feasibility confirmed after preliminary tests, models and prototypes. Changes are often made during this phase as the entire mission design is evaluated and reevaluated. The project is conceived in complete detail and in its final form during phase C. Phase D is the realization stage, when spacecraft components, instruments and systems are being constructed and tested in industry, at CNES's labs or at scientific labs. Typically, models of different subsystems are constructed and tested first so that different aspects of the spacecraft can be independently tested. Also, integration models are developed. Mission development culminates with the launching. Once launched, the project is considered "in operation" and phase E starts, that is, the exploitation of the mission. At the end of each phase (and very often also inbetween for a given sub-system), a "review" is elaborated to evaluate the state and progress of the project and to decide about the pertinence for beginning the following phase, the need for deeper studies before getting further or the stand-by, even cancellation, of the project. On the other hand, a space project is in turn composed by several components: the platform (solar panels, batteries, propulsion systems, thermic control, communications systems, etc.), payload (in our case, a scientific instrument), the ground segment (typically the data reception ground station, the orbital control center and the data preprocessing line, and, since the 1980s, also the computer center for data processing and archiving, the software, etc.), the launcher, etc. Typically, each of these components advances in a relative autonomous manner during the first stages of development, following their own cycle of phases and they can evolve asynchronically from each other. Only in the moment of assemblage, when they all have independently reached phase C/D, everything is brought together to prepare the launching.

274 « Compte-rendu de la réunion du groupe mission POLDER », April 1991.

275 « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

276 « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

277 These are two questions, the transfer from a developmental system towards an operational and the role of users in the development of data infrastructure, and in their operations, closely connected to each other, as several historical studies have shown. See for instance the case of Landsat and the case of Meteosat described by P.E. Mack in "Viewing the Earth. The Social Construction of the Landsat Satellite System", 1990 and J. Krige in "Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite", 2000 respectively.

management scheme for POLDER's data handling infrastructure[278]. In formalizing it, the group proposed to distinguish three functions:

> « - le Centre de Production POLDER (CPP) chargé du traitement des données de niveau 0 en produits de niveau plus élevé, de l'archivage des données de niveau 0 et des produits POLDER, ainsi que de leur diffusion aux utilisateurs.
>
> - le Système Qualité Image (SQI) chargé de l'élaboration des paramètres d'étalonnage et de la vérification de la qualité radiométrique et géométrique des produits de niveau 1.
>
> - le Système Expertise Scientifique (SES) chargé de la vérification de la qualité et de l'expertise scientifique des produits de niveau 2 et 3 »[279]

Before analyzing how these functions were distributed amongst the several actors, these so-called "niveaux 0, 1, 2 et 3" of data deserve a bit more of our attention. It is to that point that we turn in the following.

FACTORIES OF GEOPHYSICAL DATASETS

We have studied in our introductory chapter what we have called the *physical approach* to data interpretation (as opposed, or complementary, to the *morphological approach*), that is to say, the analysis of the measurements made by a given instrument by using knowledge and expertise about radiation transfer, spectral signatures or theory of light, an approach that talks flux, solid angle and directional reflectances. We are, in this part of the chapter, moving a bit forward in the cascade of operations involved in the construction of satellite data. We address what we may call the *geophysical approach*, understood as the interpretation of data in relationship with a given domain of the Earth sciences and integrated in a vaster epistemic domain (oceanography, biology, atmospheric chemistry, meteorology, glaciology, climate sciences, etc.) –and not as a physical entity in terms of energy and radiation.

The center of epistemic virtue of satellite data: The *geophysical approach*

As we hope to have illustrated, the introduction of microelectronic technologies would be an important factor pleading for more degree of intervention of space agencies, and CNES in particular, in the satellite data handling activities. It would be however not the sole factor. The changing location of the epistemic virtue of satellite data, from radiances to geophysical properties, as illustrated by the introductory quote of Yann Kerr, would be an important factor as well. Indeed, a number of scientists from the "selected laboratories" or not would progressively reorient their scientific interests in using

[278] To give some basic chronology: Phase A of POLDER ground segment started in April 1991, aimed to finish simultaneously with the phase B of the instrument scheduled for ending in October 1991; the Review of phase B ground segment was planned for the fall of 1992.
« Compte-rendu de la réunion du groupe mission POLDER », April 1991 and « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

[279] « Compte rendu de le réunion de la Division Qualité et Traitement de l'Imagerie spatiale sur les « Travaux et responsabilités de la Division concernant le Projet POLDER » », October 1990.

satellite data as a tool to solve problems in a given scientific discipline (like oceanography, atmospheric chemistry, glaciology, vegetation, meteorology, etc.), and not as an object of inquiry per se. As a result, they would demand data ready-to-be-used in the form of some geophysical variable, so as not to waste their time and resources in preprocessing, repixeling or correcting the data by themselves.

This tendency would be reinforced by the consideration that there may exist a number of external scientists with no experience in the physical approach for interpreting satellite data, that may eventually also be interested in using the satellite data for their scientific inquiries. This belief was fundamented by the past experiences of NASA (Landsat, Nimbus-7, HCMM), NOAA (AVHRR) and Meteosat, in which, with endowed strategy, resources and efforts of outreaching, a number of scientists external to the instruments and the data building, had been found to be interested in using their data in their investigations. CNES leadership was determined to outreach these type of scientists, experts in disciplines like marine biology, meteorology, climate, vegetation, oceanography or glaciology, so as per capitalizing on them as a means to maximize the use of the data. However, these external scientists potentially interested in using the data were not trained to interpret directly the measurements of radiation; their domain of expertise was oceanic tide dynamics, carbon cycle or tropical monsoons, to mention three examples, not physics of light. In other words, if they were to make use of satellite data, the data must suit their representations of the Earth's processes as well as their capabilities –this had been precisely one of the conclusions of the American report in 1982. In particular, data must be delivered in terms talking *geophysics*, and not *physics*; data must be delivered in terms of the level of the sea, the concentration of chlorophyll in oceanic waters or the amount of water vapor in the lower layers of the atmosphere, to continue with the three previous instances, and not of physical radiances.

Standardizing the data production

Most programs involving satellites orbiting the Earth with scientific instruments would be directed to produce and deliver geophysical datasets from the measurements, a production and delivery in which the corresponding space agencies would be involved in an important degree. For instance, the instruments aboard Nimbus-7 launched in 1978 by Goddard Space Flight Center of NASA would organize the production of data by distinguishing two levels of processing: Level I corresponding to calibrated radiances of each instrument and Level II corresponding to varied geophysical products like phytoplankton concentration, ozone concentration or density of stratospheric aerosols. The data production of the radar altimeter inside the oceanographic satellite SeaSAT launched in 1975 by the Jet Propulsion Laboratory of NASA would follow a quite similar organization. The First Global GARP Experiment (FGGE) in 1978-1979 centralized the processing and communication of the data from the weather satellites in three datacenters that organized the data in radiances of levels Ia and Ib and geophysical variables of levels IIa and IIb corresponding to cloud fraction and wind speed[280]. In 1982, GISS/NASA coordinated a project to produce data about cloud fraction from the radiances measured by all geostationary American, Japanese and European weather satellites, the International Satellite Cloud Climatology Project (ISCCP), organizing and producing the data following the system of the FGGE[281]. Some weekly and monthly means would be additionally produced, naming them as data of level III. The Earth Radiation Budget Experiment of Langley Research Center of NASA launched in 1984 and 1986, this is another example, used a totally different system based on 10 different types of processed data, a system that would be the inspiration of the one developed by the Laboratoire de Météorologie Dynamique to process and organize the data gathered with ScaRaB that would be launched in 1994 (and a second shot in 1998)[282]. SPOT would use still a different organization, with different levels of radiometric corrections, but not including any geometrical correction processing. We could keep unfolding the list, as almost each instrumental configuration conceived in the 1970s and early 1980s, discipline or laboratory, was associated to a specific way of defining and organizing the production of geophysical data and their forms of delivery.

This lack of standardization of the organization of the data production, including the terminologies, classification criteria and catalogs, and the policies of dissemination, would be accompanied also by a lack of harmonized software, coding languages and protocols between different programs and institutions. This was seen an element that hampered the circulation of the data amongst scientific groups and the comparability of data from different sensors; therefore, it prevented the use of data by scientists not associated with their production[283]. This had been denounced by the authors of the American report, who pleaded for efforts in unifying and harmonizing procedures for data production and dissemination. These efforts would start being endeavored in the United States as soon as in 1982, when defining the Global Habitability program. It was meant to include a number of satellites with instruments conceived by different laboratories, NASA's or not, and complemented by a series of instruments placed in the ground, carried by ships or aircrafts and put inside the Space Shuttle. For all the data to circulate, harmonization and standardization of the corresponding data systems were required. With the further transformation of this program into the Earth Observing System in 1988, approved in its first version by Congress in 1990, NASA would create an endowed data system EOSDIS, which would harmonize all the diverse classifications, production schemes and data policies

[280] The First GARP Global Experiment (FGGE) was one of the several field campaigns, conducted between 1978 and 1979, organized under the auspices of the Global Atmospheric Research Program (GARP) organized by the World Meteorological Organization and the International Council of Scientific Unions to study the dynamics of atmospheric behavior with the goal of improving the accuracy of weather forecasting.

[281] The International Satellite Cloud Climatology Project was established in 1982 as part of the World Climate Research program to collect and analyze satellite radiance measurements to infer the global distribution of clouds, their properties, and their diurnal, seasonal, and interannual variations. The project would be coordinated by a team of scientists of the Goddard Institute of Space Sciences of NASA.

[282] It must be noted the particularity of studying the Earth's radiation budget : the geophysical parameter of interest for such studies is the balance between the incoming and outcoming radiation, namely, a form of radiation, which is the observable of radiometers. This means that the measurements made by the radiometers do not need to be further transformed into different parameters, for them to be meaningful within the discipline. That being said, they need to be corrected and processed in several other ways.

[283] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.

used by NASA's different laboratories. The system of Goddard Space Flight Center –similar to the one used in Jet Propulsion Laboratory -would be then adopted in all NASA laboratories, missions and projects in the domain of Earth sciences[284]. The program Earth Observing System was meant to be the centerpiece of a larger national program, the US Global Change Research Program and the Congress signed the "Global Change Research Act" in 1990, which provided, inter alia, for an information management plan to "establish, develop, and maintain information bases, including necessary management systems which will promote consistent, efficient, and compatible transfer and use of data; create globally accessible formats for data collected by various international sources; and combine and interpret data from various sources to produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change"[285]. As a matter of fact, between 1990 and 1991, NASA's system would be expanded and adopted by other American agencies participating in the US Global Change Research Program like NOAA, US Geological Survey, US Navy, US Energy Department, and others[286]. NASA's system would also be progressively adopted abroad. NASA (with the complicity of NOAA) had, at least two ways, to enhance the use of its system by foreign institutions. On the one hand, it used the international existing frames, like the Committee on Earth Observations Satellites (CEOS) or the committees preparing the International Geosphere-Biosphere Program (at the end of the day, this program was an extension of the US Global Change Research Program), to promote coordination, standardization and data exchange through common procedures. It would be, for instance, during the Plenary meeting of CEOS, held in 1992, that its members, further a proposition presented by NASA's and NOAA's delegates two years before, would endorse a "Data production guidelines" favoring the adoption of the common procedures for geophysical data production based on NASA's ones[287]. The second way to export its system was through bilateral particular projects. Any foreign space agency, operator or scientific team working with NASA or with NASA's datasets would tend to adopt NASA's system, if only to facilitate day-to-day efficient technical work. This would be the case, for instance, of the French team working in the Topex/Poseidon project in collaboration with the Jet Propulsion Laboratory, which as soon as in 1984 would start organizing the production of geophysical data following NASA's guidelines for the project Topex/Poseidon proposed by JPL/NASA[288]. In an instructive example of what the historian John Krige called the softpower of NASA (materialized in this case via the exportation of data and information systems), these procedures for data production

[284] "Earth Observing System (EOS) Reference Handbook", eds. G. Asrar and D. J. Dokken, 1993.
[285] The text of the Act is available at: http://www.globalchange.gov/about/legal-mandate
[286] "Policy Statements on Data Management for Global Change Research", US Global Change Research Program 1991.
[287] "Resolution on Satellite Data Exchange Principles in Support for Global Change Research", endorsed in the CEOS Plenary meeting of 1992.
[288] The first description of such datalevels that we have found at CNES is included in the handbook "Mathématiques spatiales pour la projection et réalisation de l'exploitation des satellites", ed CNES 1984, in a chapter written by Michel Avignon entitled "Les expériences scientifiques. Prétraitrement des données scientifiques". In this chapter an exhaustive description and development of the datalevels, accompanied by schemas, is provided. The author confirmed via personal communication that he borrowed the system from JPL/NASA.

would be gradually self-imposed by space agencies[289]. Today most, if not all, satellite data production lines associated with Earth's environment missions have adopted equivalent data processing and archival descriptions –if not identical- that we are describing in the following section. CEOS/NASA guidelines would become also the standards that the project managers of CNES would propose to the scientific community involved in POLDER in 1991 for producing geophysical data from the radiances measured with the instrument.

Mass-producing and disseminating POLDER's geophysical datasets

Indeed, in one of the first meetings of the working group set up to define the data handling hold in 1991, the "groupe projet" would propose a data production plan describing the production of geophysical data retrieved from POLDER's measured radiances in which two levels of data would be distinguished in function of their degree of processing, delivering geophysical data in three scientific domains of application: oceans, land surfaces and clouds. All along the following years, in accordance with CEOS's guidelines, this schema would concretize and more datalevels would be made explicit, like level 0 and level 3 (see figure 2.1). Data of level 0 would be the signals that come down from the satellite to the Japanese's antennas, which would be sent to CNES's ground stations. The level 1 (sometimes divided into 1A and 1B) would represent the signals that have been decommuted and transformed into the measurements, filtered and pixeled, located and dated, and radiometrically and geometrically calibrated pixel per pixel, interpolated in space grids corresponding to 6kmx6km approximately, namely *despatialized* radiances. From these radiances of level 1, geophysical parameters of level 2 would be delivered in the three different scientific domains: ocean, land surfaces and clouds. They would be produced per pixel and displayed per orbit. Data about the cloud fraction, about the vegetation index in the surface, about the optical depth of the tropospheric aerosols, their refraction index, or still about the phytoplankton concentration in the oceanic waters, are just few examples of such geophysical parameters, around 12 in total, which would be elaborated from the radiances of level 1. Datasets of level 3 would correspond to some synthesis of the geophysical parameters of level 2, datasets typically averaged per day, week or month, or reagruped per regions of interest.

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[289] The historian John Krige argued that, more generally, the importation of NASA's managerial practices (like the organization of missions by projects and programs, the structuration by phases of development, the implementation of reviews, the signature of Memorandums of understanding, etc.) was one of the tenets of the CNES-NASA collaboration since the creation of CNES in 1961 used to align the French space agency with NASA's ways of running and attitudes.
"NASA in the World. Fifty Years of International Collaboration in Space", J. Krige et al, 2013.

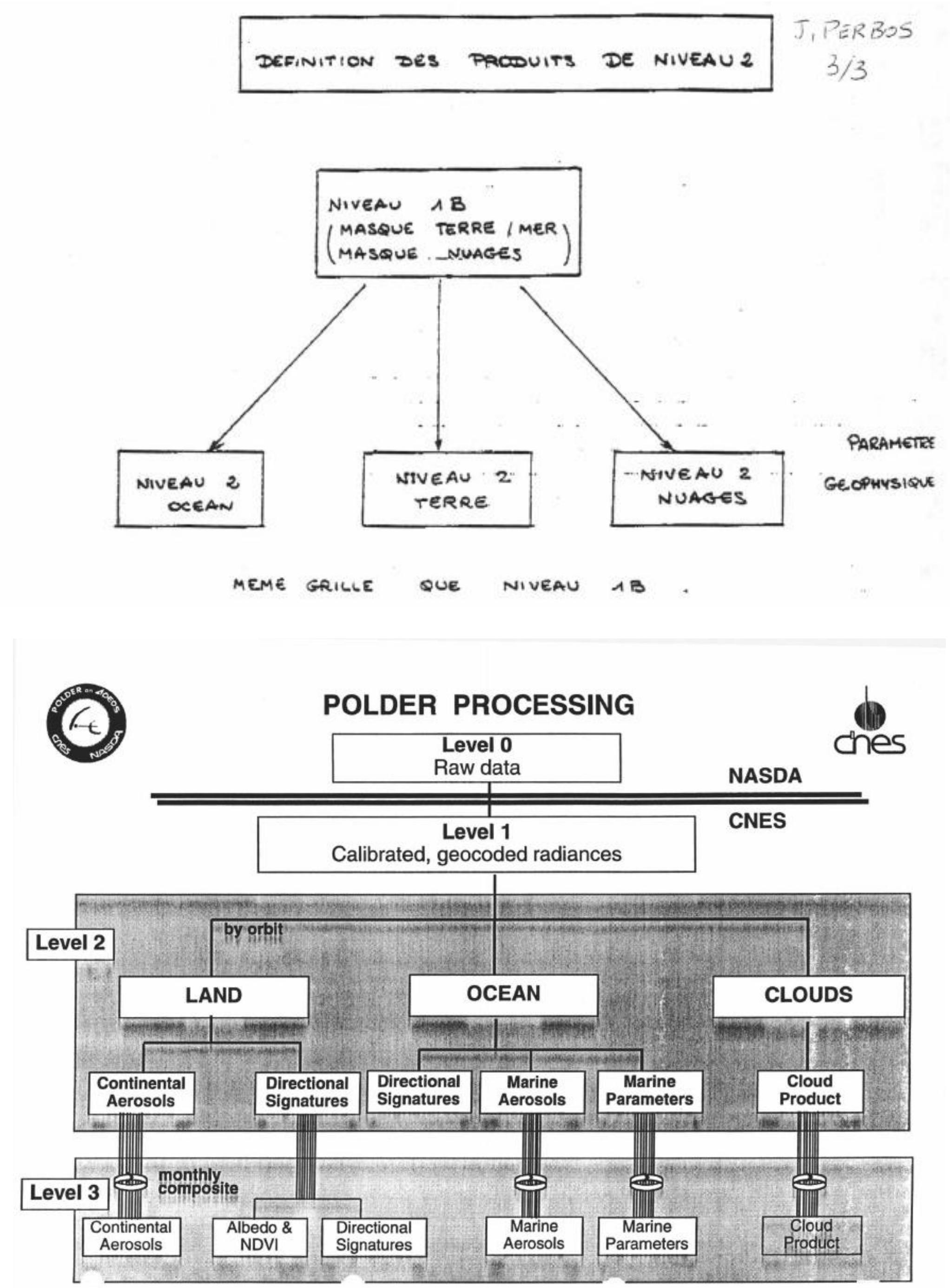

Fig. 2.1. Organization following successive « levels » of POLDER data processing. The top figure corresponds to the first schema that we have found for POLDER-1 data, dated of 1991[290]. At the bottom, a sophistication of such schema presented during the Validation Review of POLDER data hold in 1998[291].

The socio-technical complex for labor-organization

We have seen before that POLDER's data handling infrastructure would be organized in three different functions:

[290] « Compte-rendu de la réunion du groupe mission POLDER », April 1991.
[291] "Polder Validation Review Proceedings », summer 1998, prepared by the POLDER project scientist Anne Lifermann.

« - le Centre de Production POLDER (CPP) chargé du traitement des données de niveau 0 en produits de niveau plus élevé, de l'archivage des données de niveau 0 et des produits POLDER, ainsi que de leur diffusion aux utilisateurs.

- le Système Qualité Image (SQI) chargé de l'élaboration des paramètres d'étalonnage et de la vérification de la qualité radiométrique et géométrique des produits de niveau 1.

- le Système Expertise Scientifique (SES) chargé de la vérification de la qualité et de l'expertise scientifique des produits de niveau 2 et 3 »[292]

We are now in the position to describe how each function, or responsibility, was allocated amongst the actors. Four options were envisaged. On the one edge of the spectrum, it was suggested that both the development and the exploitation of the POLDER data handling infrastructure would be implemented and operated at the Technical Center of CNES in Toulouse[293]. This was discarded, since it allocated to CNES the scientific responsibility of overseeing the quality of scientific data –a point in which all actors agreed in disagree. Scientific guidance, so it was argued, was necessary on the one hand to make sure that the data would be of quality and on the other that they would be used –at least by the participant scientists[294]. It was, we suggest, also a way to make sure that scientists would not be excluded of the project, like it had happened with SPOT. A second option gave a central role to the scientific laboratories: during the development stage, they would conduct tasks of algorithmic definition and validation; they would be responsible also of data processing and distribution during the exploitation stage. This was also rapidly ruled out, as the principal investigator's laboratory, LOA and LERTS, were not equipped to handle with POLDER data all alone[295]. There were still two other options. In both of them, during development, and also exploitation of the data, the scientists participated in the definition, testing and validation of the scientific algorithms. Whereas in one of the options, the whole ground segment was developed, implemented and exploited at the Technical Center of CNES in Toulouse in a permanent way during its whole life, in the other one, the exploitation was to be eventually transferred to an external scientific institution to take over the responsibility of data handling in the long-term[296]. This latter option was the preferred by the working group. After a period of test, CNES would transfer the "Centre de production de POLDER" to an external institution who would take over the responsibility of producing, storing and disseminating POLDER data during its exploitation[297]. This required looking for scientific institutions ready to cope with the semi-operational burden of POLDER data processing, storing and distribution infrastructure –a question that we will tackle in the next chapter.

By now, let us concentrate in how the duties were distributed during the developmental phase, a distribution which would be done following the rule of efficiency through the division of labor, by

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[292] « Compte rendu de le réunion de la Division Qualité et Traitement de l'Imagerie spatiale sur les « Travaux et responsabilités de la Division concernant le Projet POLDER » », October 1990.

[293] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[294] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[295] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[296] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992 and « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[297] « Compte-rendu de la réunion du groupe mission POLDER », April 1991.

allocating each task to that actor deemed to be the best placed to conduct it, as expressed in the minutes of the meeting in which the first data production schema was presented (the one in the top of the figure 2.1), the allocation of duties would be made explicit as follows:

> “Les niveaux des produits sont définis conformément aux spécifications CEOS et EOSDIS. Les grandes lignes de ces propositions sont :
>
> -le projet [head by a project manager and a project scientist of CNES] assure la responsabilité des produits de niveaux 0, 1A et 1B. Les produits de niveaux 1B prennent en compte les spécifications de mission et les besoins pour les produits de niveau supérieur émanant des scientifiques. Ils doivent être validés par le groupe scientifique.
>
> -la responsabilité de la définition des produits de niveau supérieur ou égal à 2 incombe au groupe scientifique. Cette définition doit prendre en compte les contraintes de planning du projet pour la définition du segment sol.
>
> Il est donc proposé que le groupe scientifique fasse ses remarques et demandes de compléments par rapport à la définition proposée par le projet pour les produits de niveau 1B. Le groupe scientifique devra également proposer sa définition des produits de niveau supérieur ou égal à 2. Cette définition devra prendre en compte les entrées (niveau des données POLDER, données exogènes) et leurs caractéristiques (résolution spatiale et temporelle,....) ainsi que les algorithmes de traitement et leur "état" (robustesse, niveau de validation, capacité d'évolution)»[298].

In that way, the Technical Center of CNES in Toulouse, was judged to be the best placed to process in (quasi) real-time the signals as they would be transmitted from ADEOS ground segment in Tanegashima to CNES’s antennas –due to its physical proximity with the reception antennas and its previous expertise in receiving and *despatializing* data. To that purpose, it would prepare a computer with the pre-processing software, intended to correct and calibrate, which would be called the Centre de Production de POLDER (CPP), and taking the nomenclature of the datalevels mass-production line, would be aimed to transform data of level 0 into data of level 1. The development of this software for preprocessing, calibrating, correcting, etc, or the “Système Qualité Image”, according to the description made by the working group, would be conducted under the responsibility of the department of Qualité et Traitement de l’Imagerie Spatiale in the Technical Center in Toulouse (under the responsibility of Olivier Hagolle) in collaboration with LERTS (under the responsibility of Marc Leroy, moved from CNES in 1993), as both had been working for more than a decade in developing analogous methods for the images of SPOT. However, calibrating POLDER data also included some specific features like radiometric corrections of polarized measurements. This was a domain of expertise of some scientists at LOA (under the responsibility of Maurice Herman), who since the 1970s had been working with polarized radiometry to study the atmospheres of Venus, Saturn and Jupiter and who had in the 1980s start using these techniques to study the Earth’s atmosphere[299].

It was argued that the Technical Center of Toulouse did not possess the expertise and knowledge, and neither the vocation, to develop methods for interpreting radiometric measurements in terms of geophysical datasets. Instead, it was the role of experts in the domains of applications to define the necessary parameters and performances. Deciding what were the parameters, determining the accuracy

[298] « Compte-rendu de la réunion du groupe mission POLDER », April 1991.

[299] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

of the measurements, developing the scientific algorithms, their software, and testing all this was considered to be a scientific task to be engaged under the responsibility of scientists that had proposed the instrument. The data handling system that emerged would require that the scientific laboratories that had built the instrument also produce the basic data processing algorithms for producing geophysical datasets, namely, the data of level 2 or superior. It was hence scientists at LERTS and LOA, leaded by a principal investigator Pierre-Yves Deschamps, who shall develop the processing software, validate it, and promote the use of data[300]; these algorithms would be coded in FORTRAN and integrated in the Centre de Production de POLDER's processing line. In other words, they were to be the "Système Expertise Scientifique" –we will see in the next chapter how this initial group of two laboratories would be widened up by 1993 to include other scientists from other laboratories, especially from LSCE, LMD or LPCM (in 1994 it would be opened to international participation).

Dividing the scientific community and changing the ethos of a "space scientist": Data creators and data users

The schema of geophysical mass-production in different levels of processing would constitute hence a skeleton around which a certain form of division of labor between some departments at the Technical Center of Toulouse and scientists of LOA and LERTS would be operated. In a sense, the schema of data production organized in datalevels would operate a similar division and organization of labor that the one operated by the notion of *despatialization* described before, which portrayed a world divided between the "space" (belonging to CNES) and the "science" (belonging to scientists of CNRS, universities or other non-CNES research centers) –with the particularity that the department of data quality of the Technical Center of CNES, in its work of developing the software for despatialization (decommutation, location, datation, repixeling, and some eventual corrections and calibrations), would be supported by scientists at LOA and LERTS. During the stages of exploitation, namely, once the satellite would be launched and measurements would be factually be gathered, one essential difference would stand out with respects to the PI-model prevailing during the 15 to 20 first years of space age: *despatialized* radiances would not be shipped to individual scientists for them to apply *their* algorithms to derive geophysical parameters; instead, the algorithms defining the characteristics of these geophysical parameters developed by the scientists would be integrated in a central processing and dissemination line, which would run them in continuity as new measurements would be introduced. Once mass-produced, the geophysical datasets (or data of level 2 or superior) would be delivered to a wider audience of external scientists.

This description invites to several thoughts. First, the schema crystallized a new meaning of the notion of data exploitation, a meaning that emphasized the mass production and mass diffusion of

[300] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992 ; « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992 ; and « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

geophysical parameters. Conceptually, it implied that geophysical parameters were the best tool to study the planet or, in other words, that the processes occurring on the Earth could be represented and understood through in geophysical terms –we will insist in that point when discussing an alternative form of representation in the second part of our essay. In practice, as we have suggested, this would be achieved through redistributing the labor between the actors[301]. This social reorganization would denote a major epistemological departure from previous data processing methods of having the processing of data from each experiment the responsibility of each PI; it would operate a reconfiguration of the old practices of satellite data production. Before the 1980s, and with the exception of SPOT in France, a single PI and his/her collaborators designed, built, calibrated, analyzed and interpreted the data. By contrast, the description in different levels of data processing was built precisely upon the idea of widespreading the geophysical parameters well beyond the group that had developed the algorithms and the instrument with views to maximize the scientific return. While a handful of scientists more or less related to the conception of the instrument POLDER would define the algorithms and datasets, the resulting geophysical data were supposed to be widely diffused well-beyond such group of scientists. In other words, this factory for geophysical data mass production and dissemination was sustained by the abandon of the idea, deeply rooted in the culture of experimental physics and of space scientists, that the scientists that had proposed an instrument and/or the algorithms to create the geophysical parameters should have exclusive access to the resulting data.

Connected to that, the schema organized the social ordering of the data production, dissemination and further utilization, as it assumed the existence of two separate groups of scientists, those who would produce the geophysical parameters during the developmental stages of the project before the launch of the satellite and those who would consume them after being issued out of the factory, those who would produce the geophysical datasets during the developmental stages of the project before the launch and those who would consume them after being issued out from the factory. In other words, changes in the scientific insight (moving from the epicenter of epistemic virtue from physical radiances to geophysical units) would transform the PI-mode of data handling into a factory-mode of geophysical data production and dissemination characterized by a stratification of the labor. A new formula powered by the principle of division of labor that allowed actions carried out by different actors to be successively and accumulatively pieced together. While this socio-technical complex would render data manageable and meaningful for Earth scientists, it would have the effect of transforming the PIs into the type of workers workable in this socio-technical complex, adopting specific forms and rules of working classical of big management enterprises like CNES (like the elaboration of reports, attendance to regular meetings, preparation of periodic reviews, schedules and plans, etc.) –a point to which we will come back in the next chapter. What we want to stress now is

[301] This factory-like picture would be comparable to experimental cultures presented by other laboratories in the domain of physics and molecular biology in the XXth Century or in astronomical observatories described in the XIXth. See, for instance: "History of CERN. Volume II: Building and Running the Laboratory, 1954-1965", A. Hermann et al, 1990; "Science as practice and culture", A. Pickering, 1992; or « Astronomers Mark Time: Discipline and the personal equation », S. Schaffer, 1998.

that the epistemic virtue of geophysical data also transformed the laboratory, giving birth to the type of scientists that could transform physics into geophysics: a specific social group supported by their knowledge and expertise in radiation transfer, theory of light, spectral signatures, experimental procedures or error analysis, and who would mobilize a specific set of technological data practices (in particular the so-called *inversion*, which we will explore in a while), would rise up as the holder of epistemic authority for creating the geophysical datasets, judging their quality and defining the scientific frames admissible to be addressed[302]. As a result, it would inform a separation between those scientists who would hold expertise in remote-sensing radiometric techniques and knowledge in radiation transfer functions and light theory, and those who would be experts in some physical, chemical or biological processes affecting the oceans, the land or the atmosphere. It would reinforce a divide between those scientists interpreting the satellite data in physical terms and those interpreting them in geophysical terms. In other words, what had been, before the 1980s, one single community, that we have been calling until now with a generic "space scientists", would suffer a process of divorce between those who would create (and use) the geophysical data and those who would take (and use) them, in our case, between scientists creating the geophysical data from POLDER's measurements, let us call them *data creators*, and external scientists potentially taking them, the *data users*[303] –a process that has been noted by the historian Erik Conway in his study of Topex/Poseidon, and that will be a recurrent topic in our work[304].

Secondly, geophysical datasets would be the "product" of series of discrete phases in a chain of production, carefully planned and controlled, subscribing a positivist ideology of linear progression from the measurement in orbit to the transmission, corrections and quality control, and the successive filters of data processing. At the end of the chain, would lay the "products" that would be consumed by the *data users* in order to produce, in turn, some form of scientific knowledge in their respective domains of oceans, land surfaces or clouds[305]. Indeed, satellite data would be useful and usable in their form of final "products" of level 2 or superior, and not in any of their intermediate stages of the process of construction, as made it clear in this the presentation of the data levels system that the POLDER's Program Manager presented to the Direction de Programmes in Paris in 1991, which stresses that the *data users* may be interested on data of level 3, that is, one synthesized form of level 2:

[302] As defined by Thomas Gieryn, epistemic authority is the legitimate power to define, describe ad explain reality in a credible, reliable, trustworthy manner.
"Cultural Boundaries of Science: Credibility on the Line", T. Gieryn, 1999.

[303] These are two broad categories proposed to conceptualize the relationship between the scientists, engineers or technicians vis-à-vis the processes of gathering, production, dissemination and storing of satellite data. By using them, we do not aim to suggest that they conform homogeneous groups. Inside each category, scientists may differ in disciplines, methodologies, approaches, expertise, scientific goals, institutional cultures, practices, attitudes or styles. It is useful, however, to articulate them in regards with the technological data practices that they deploy and employ.

[304] "Drowning in data: Satellite oceanography and information overload in the Earth sciences", E.M. Conway, 2006.

[305] At the same time, such a metaphor of a production chain embeds a vision of data as the product of human activity and as such potentially merchandisable, instead of, for instance, a common good to be freely shared and circulated. However interesting, we are not entering this discussion in our essay. Let it be just said that our case study, POLDER's data have not suffered, at least not yet, any attempt of being directly merchandized.

« Le segment sol POLDER a été développé pour traiter et distribuer les données et produits dérivés de POLDER sur ADEOS-1 (POLDER-1). Ces produits sont de niveau 1 (données brutes « dé-spatialisées »), 2 (produits géophysiques de base) ou 3 (synthèse spatiale et/ou temporelle de produits géophysiques de base). Il faut noter que les utilisateurs finaux (y compris les modélisateurs) sont préférentiellement demandeurs de données de niveau 3 »[306].

The use of the term "product", commonly spread amongst data creators and space managers, reveals two features about the conception and construction of data. First, it acknowledges that satellite data are not costless in time, budget, work and manpower, that considerable work is necessary in order to elaborate them, and that they are embedded in some social organization form specifically designed for that purpose: produce data. By emphasizing the epistemic virtue of geophysical datasets, this schema for factory data production was based upon the premise that satellite measurements were not fixed entities that had to be taken as they were obtained; on the contrary, they must be manipulated for them to become meaningful data to external scientists to be used in their investigations of oceanic, atmospheric or vegetation phenomena. Measurements, for them to be useful to *data users*, must be transformed into geophysical datasets through a series of physical laws and phenomenological correlations properly translated into computing algorithms. Ironically enough, considering the name given to the satellites orbiting the Earth for scientific studies in common parlance (Earth *observation* satellites), allocating the epistemic value of data in geophysical datasets reflected a doctrine of *intervention* over data, and not of mere *observation* –we will insist in that point in our last section[307]. Indeed, when products are stabilized they become blackboxes, given for granted, the process to produce them are rendered invisible. Second, it assumes the existence of a consumer of that product. Or, in other words, it portrays a vision in which satellite data are products that respond to a pre-established demand and must satisfy the accuracy, the format, the frequency and other requirements of a given set of consumers –whoever they might be[308].

In any case, the implementation of this technological complex of levels of processing to produce and disseminate geophysical data would change the relationship between the scientific practice of data producing and analysis and the data. The underlying epistemology of such a schema for a factory-like mass-production and dissemination was that geophysical parameters, and not radiances, laid at the epicenter of scientific inquiry. Geophysical attributes, and not physical measurements, were conceded

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[306] « Développement du segment sol et coût à achèvement du programme POLDER », Alain Podaire, POLDER's program manager, July 2001.

[307] The use of term "intervening" is the focus of analysis of the philosopher of sciences Ian Hacking's book in which he proposes to studying experimental practices instead of theory construction. To the author, experimental practice is about actively doing, rather than merely "representing", since the primary goal of experiments is to manipulate and control nature, to "intervene" on it, for it to be understandable, namely, to change the world in order to make sense of this changed world. We will further develop this thread in the final section of this chapter.

"Representing and Intervening: Introductory Topics in the Philosophy of Natural Science", I. Hacking, 1983.

[308] The question of users of technologies and uses of technologies has been widely explored by social studies of sciences and technologies accentuating the departures of the linear model often pointed out by technology developers. See for instance: « Inventing Accuracy : An Historical Sociology of Nuclear Missile Guidance », D. MacKenzie, 1990, which illustrates that the technology of ballistic missiles was conceived and realized at the same time that the social demand for them; "Masters of Theory: Cambridge and the Rise of Mathematical Physics", A. Warwick, 2003, which stresses the various representations that users (bankers, insurance companies, naval companies, astronomers, State administrators, engineers, etc.) made of the logarithmic tables in the Victorian period.

with epistemic virtue, namely, meaningfulness for conducting studies about the Earth and its environment. Data would only made sense to *data users*, including numerical modelers, as the quote suggests, if they represented some geophysical variables. This would change the essence of being a scientist working with satellite data. Before the 1980s every PI received the data as it came down from the satellite only with few preprocessings operations done by space agencies and operators. Processing one's own data was, after all, what meant being a space scientist: the scientific work would consist precisely to calibrate, correct, analyze and interpret the data obtained from their experiment –we have seen that along the 1970s an enlarged modality of being a space scientist would include as well the possibility of processing the data gathered by others. But it was processing data all the way, in the sense of applying the physical approach to understand the measurements. As the epistemic virtue of data moved from physical measurements of radiances to geophysical variables, the normative practice and the ethos of being a scientist working with satellite data would also change, just like illustrated by the introductory quote of Yann Kerr, from "écrire des algorithmes d'analyse et non des algorithmes de prétraitement »[309]. Studying the Earth with satellite data would no longer imply correcting, calibrating and interpreting radiances, but rather using stable geophysical datasets to correlate some variables, understand the processes involved in any given phenomena, find out some empirical laws or modeling the constituting systems.

This schema, which would progressively penetrate all the layers of a satellite project (space agencies, principal investigators, industrials, external scientists), would become the linchpin of interpretative explanations of the epistemic authority of each actor as well as justificative of their actions –at least, for those actors involved in the proposition and realization of experiments. By the late 1990s it would have become one of the quasi-unquestionable pillars of the mutual relationship between the project managers, the program managers, the data creators and the data users as well as of their perception of the other. Invented to conjure the world into a form that made it manageable and workable, this complex of data mass-production can be interpreted, in our views, as one of the socio-technical dispositions acting as *reconciliators* between the space technologies and the scientific practices in the disciplines of Earth sciences, because, by transforming the measurements into geophysical parameters, it mediated the possibilities of using satellite data by scientists not experts in remote-sensing technologies. This came to a price. At the same time, by organizing the discourses and the social ordering by reinforcing a certain epistemology (grounded on the value of geophysical datasets), this is our general point, this normalization would interfere with the traditional practices and epistemologies developed during the first 15 to 20 years of space age by organizing the social relations in different manner, in terms of distributing the labor, shaping the rules of data production, dissemination and access or allocating epistemic authority to different actors associated to different levels of data processing. In particular, it would lay the foundation for technological and scientific practical developments. Let us see in the following, through two concrete examples, some of the technological practices deployed in the process of creating geophysical parameters or, in other words, two of

[309] « Note au LERTS : Banques de données satellitaires », written by Yann Kerr in January 1988.

technologies that would figure central in the process of reconciliation between satellite data and environmental scientific disciplines: calibration and inversion algorithms.

Technological practices of calibration: Fabricating the physical measurements

Since 1988, further a recommendation of the scientific advisory group (Comité de Programmes Scientifiques) of 1987, CNES financed the realization, by a team of scientists at the Laboratoire d'Optique Atmosphérique (LOA), of a prototype of the radiometer POLDER to be carried inside an aircraft, as a first stage to study an eventual future adaptation to fly inside a satellite. Several field campaigns embarking this airborne version would be conducted by scientists at LOA and LERTS, in collaboration with scientists of the Institut Géographique National, the Institut National de la Recherche Agronomique, the Laboratoire de Météorologie Dynamique and some Japenese scientists in the following years flying over different carefully selected types surfaces: cultivated and barren areas (La Crau 1990 and 1991)[310], coniferous forests and corn fields (Landes 1990), savannas and deserts (HAPEX Sahel 1992)[311], boreal forest (BOREAS 1994)[312], the Mediterranean sea (MEDIMAr 1991)[313], the Antarctic Ocean (RACER 1992)[314], clouds over land (CLEOPATRA 1991)[315] and stratocumulus over the ocean (SOFIA-ASTEX 1992)[316]. These flights intended to investigate the technical and scientific properties of the future space instrument, the optimized radiometric bands to detect different parameters, the bands to be polarized, the size of the pixels, the geometrical projection of the images, the importance of the different types of noises, and so forth[317].

One of the goals of such flights would be to study the calibration coefficients of the instrument necessary to convert the digitalized voltages into the original measurements of radiances. Different sorts of calibration would be developed for POLDER mainly by scientists at LERTS, LOA, INRA, CNRM, LSCE and engineers of the Technical Center in Toulouse: smoothing, data normalizing, spectral bands combinations, superposition, recoding, filtering, repixeling, contrast reinforcing or compressions. Prominent amongst them were the radiometric and the geometric corrections. Geometric corrections would be developed in a joint effort between LERTS and the department Qualité et Traitement de l'Imagérie Spatiale of the Technical Center of CNES in Toulouse, under the responsibility of Marc Leroy and Olivier Hagolle, and drawing upon the expertise that was being

310 "Surface reflectance angular signatures from airborne POLDER data", M. Leroy and F.M. Bréon, 1996.

311 « Analysis of POLDER airborne instrument observations over land surfaces », J.L. Deuzé et al, 1993.

312 "BOREAS: experiment overview, scientific results and future directions", P.J. sellers et al, 1997.

313 "Multiple scattering analysis of airborne POLDER image data over the sea", Y. Kawata et al, 1998.

314 « Optical and physical parameter retrieval from POLDER measurements over the ocean using an analytical model », F.M. Bréon and P.Y. Deschamps, 1993.

315 "Analysis of the POLDER airborne instrument observations over cloud covers", P. Goloub et al, 1994.

316 « Optical properties of snow and ice derived from aircraft POLDER data », P. Goloub et al, 1993.

317 Some technical departments at CNES would also start to characterize the performance of the sensor, the reliability of the polarized filters, the gabarit of the different components, the thermal conditions for stability, and so forth.

developed since the early 1980s to correct the images of the future satellites of the family SPOT[318]. Radiometric corrections, the topic of the present section, would be developed essentially at LOA under the direction of professor Maurice Herman.

When instrumental calibration becomes data calibration

Calibration is crucial in all experimental sciences, but it becomes a big issue in space experiments. The quality of the data depends on the performances of the sensors (sensitivity to light, field of view, spectral resolution, radiometric accuracy, etc.), but also on the reliability of these performances during the life of the instrument. For just like all instruments, satellite instruments age and deteriorate with time and need to be adjusted regularly to ensure that experimental conditions are maintained constant –or at least controllable. To understand the issues related to calibration, and this is of general validity for almost all space instruments, one must keep in mind two points. In several domains of experimental physics, this is the first point, standards of reference ensure the calibration of the instrumental devices. These standards are usually defined in relation with absolute metrics. While active instruments (like radar altimetry and lidars) can, at least in theory, trace an absolute accuracy based on metrological standards of time[319], a number of other instruments, including radiometers, lack of metrological absolute standards. In particular, there is no a set of metric references that could provide the absolute accuracy of the radiances measured with POLDER. Therefore, calibration would be done with respects to relative references –this would have consequences in the building of long-term datarecords made of measurements taken by different successive instruments, a point to which we will come back when studying the production of climate data records in chapter 6. Also of prime importance in the calibration of space instruments, this is the second point, is the fact that they are put inside a satellite, functioning in orbits located between 400km and 36000km from the surface -around 700km in the case of ADEOS-I, II, and PARASOL[320]. This entails that once in orbit the instrument becomes inaccessible to human manipulation, the instrument is impossible to adjust, tune or repair. Yet, during the launching and once in orbit, the satellite is submitted to vibrations, accelerations,

[318] Geometric calibration consists, to provide some intuitive examples, in modifying the space disposition of the objects and their geometrical relationships without changing the content of the observations, establish correspondences between pixels, correct from the effects of the Earths' rotation, of its curvature, of the movement of the platform, etc.

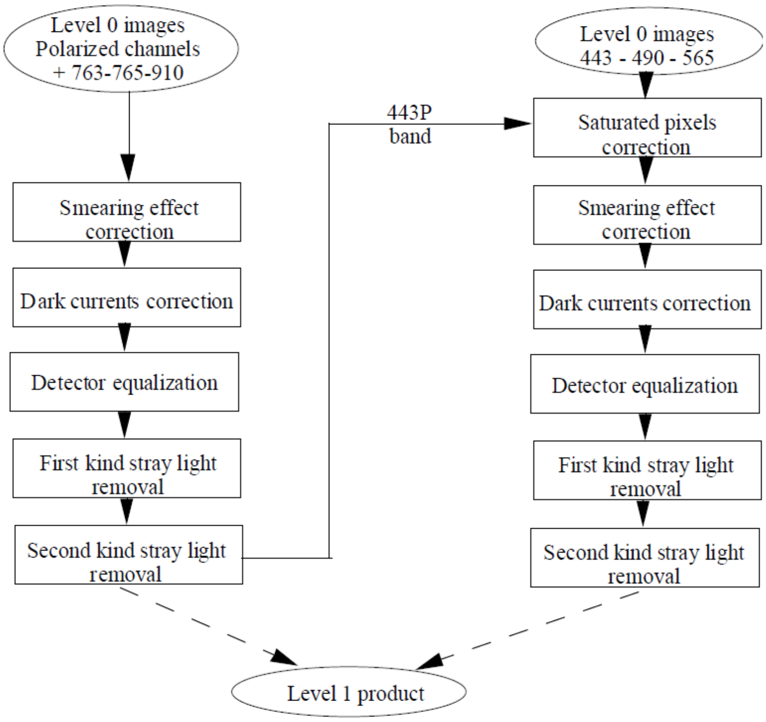
[319] This is how a space radar altimeter (and radar and lidar technologies) works to measure the sea level: sea level is actually directly related to a measure of the distance between the satellite and the sea, given a stable reference against which compute the differences (the geode surface). The radar altimeter measures the time that the radiowave takes in go from the satellite to the sea surface and back; because it moves at known speed (light speed), a distance can be derived. The sea level calculation is thus a parameter that involves a standardized metrological unit: time. Therefore, its accuracy can be established by reference to these absolute time (or a derivative, space) standards. The nature of the measurement (time-derived) makes it a high accurate measurement, as time can be determinate in absolute terms. This contrasts with other type of measurements, especially radiometric ones, which by definition, they cannot be determinate in an absolute manner. This does not mean, on the other hand, that altimetric measurements do not need to be corrected. They must be corrected, especially from the atmospheric effects of ionization, atmospheric pressure, water vapor, etc.

[320] POLDER 1 and 2 flew at a mean altitude of around 800 km and POLDER 3 of around 700 km. Note that these are approximate averages, since the trajectory of a satellite through an orbital path is submitted to several oscillations, mainly of gravitational origin.

variations of gravity, temperature gradients, friction of the cables, among others, which modify its behavior. The instrumental parameters must be controlled by manipulating the electromagnetic signals transmitted by the satellite, that is to say, the data. In other words, space instrumental calibration is not conducted on instruments but on data. More particularly, the calibration algorithms would usually be applied to decommute data, together with other corrections (from atmospheric effects, for instance), in order to transform the digital numbers into radiances, that is, to transform level 0 data into level 1 - whence the common understanding that data of level 1 are calibrated data.

POLDER's data must be corrected and calibrated in a number of ways (see figure 2.2), from which we will only concentrate here in the radiometric corrections. These techniques, which are commonly necessary to all radiometric measurements, had been developed along the firsts 20 years of space age, and by the time POLDER would be materially designed, some general principles were already established. For instance, calibration in the laboratory before the launching was considered as necessary to establish the characteristics of the instrument. This would be usually done by illuminating the radiometers with lamps full of different gases (or with laser sources), whose spectral profile is known in the literature[321], in order to study the bias of the sensors, the behavior of the polarized filters, the decay of the performance due to exposition to temperatures or to degradation of the materials, etc. Another method for determining the calibration coefficients before the launch consisted in gathering data with an airborne prototype of the future instrument in order to complement the laboratory studies with empirical data gathered through remote-sensing –we will see in chapter four the implications of calibrating data before the launch through collecting data with aircraft with respects to the notion of space mission. Because POLDER-1 was a new instrument, these methods must be adapted to the new type of measurements; for POLDER-2 and POLDER-3, a contrario, the overall basis for their calibration would be already settled by the prior studies conducted for POLDER-1; therefore, we are mainly focusing in POLDER-1.

[321] Typically, the long wavelengths bands would calibrated using a blackbody source and the shortwave bands by using some of these incandescent lamps –or even the Sun itself as a source of light.



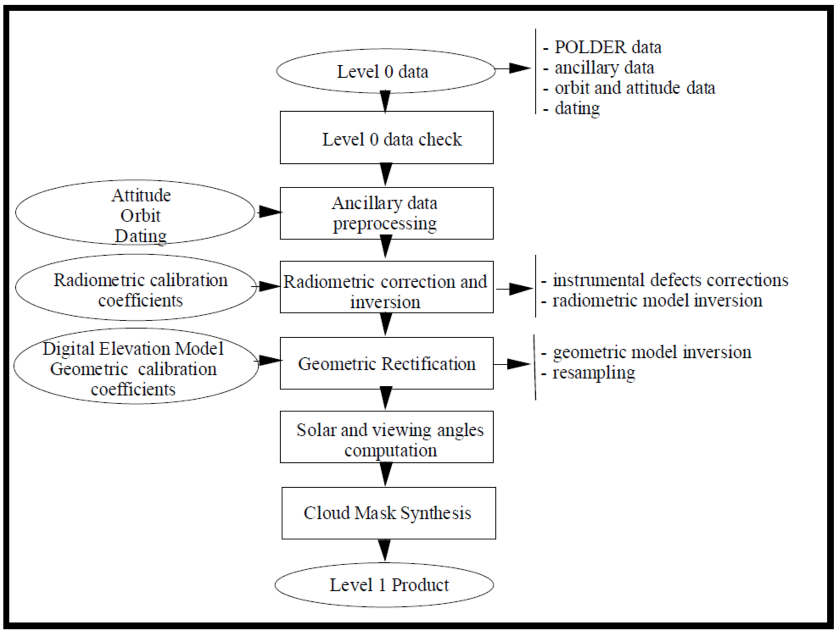


Fig. 2.2. Top: Algorithm for removing sensor artifacts: POLDER is affected by some low intensity artefacts which come either from electronic problems (dark currents, smearing effect, non uniformity of elementary detector sensitivity) or from optical defects (stray light)[322].

Bottom: Data level 1 processing line. The first step extracts channel images, eliminating images with a lot of saturated pixels and interpolating missing or faulty pixels. During the second step, the necessary informations are extracted from ancillary data (position, dating). In the third one, each elementary measurement is converted into radiance after some radiometric sensor artefacts are removed. Next, the geometrical processing resamples each image onto the fixed reference grid. The last two steps consist in the estimation of viewing and solar angles and in the evaluation of the crude cloud mask.

[322] « POLDER level 1 processing algorithms », O. Hagolle et al, 1996.

Decontextualized data

Instrumental calibration means, for an instrument placed inside a satellite, establishing the relationship between the incoming radiation captured by the instrument in orbit and the digitalized numbers displayed in the sensor, with the goal, like in all calibration procedures, of distinguishing between the effects caused by the measuring device (instrument, propagation milieu, sensors) and the effects due to the variability of the object under scrutiny, and with the ultimate goal of applying the appropriate corrections to restore the displayed numbers into the measured radiation. Given an incoming energy, the numerical signal displayed by the sensor CCD depends on the transmission of the objective, the inclination of the incoming beam with respects to the optical axis, the intrinsecal polarization of the objective resulting from the path throughout several lenses, the efficiency of the polarizing filters, the sensibility of the sensor, among other factors. All these factors would be measured before the launching in the laboratory by using an integrating sphere available at CNES facilities in Toulouse (see figure 2.3). By combining these empirical results with the theoretical acquis regarding the interaction of light and matter, two radiometric models would be developed for POLDER, one corresponding to natural light and the other to polarized light. The prelaunch aircraft flights would then provide empirical data to test the performance of such radiometric correction algorithms.

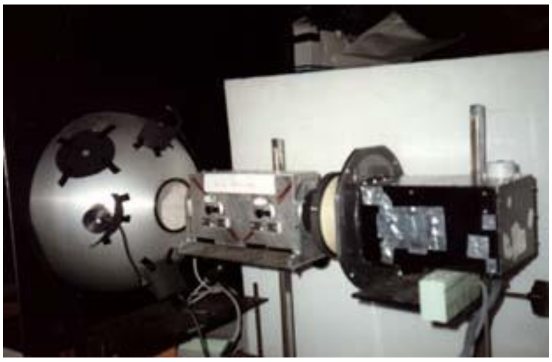


Fig. 2.3.: Calibrating the aircraft version of POLDER with the sphere. http://www-loa.univ-lille1.fr/Instruments/fr/polarimetres/polder/carac.php

As we have mentioned, POLDER was an instrument with a coarse space resolution. This poor instrumental capability, so it had been argued, could be however compensated by accurate calibration (and processing) algorithms and, by so doing, producing data meaningful for scientific inquiry. “The instrument design”, these were the concluding sentences of the article describing the experiment released in 1994, “will achieve higher accuracies than previous instruments, namely the CZCS for ocean color monitoring and the AVHRR for global vegetation monitoring”[323]. Therefore, highly precise calibration must be achieved. This may explain the fact that the accuracy judged as sufficient to ensure POLDER’s data quality was of 2% for the shorter wavelengths channels ($\lambda < 565$ nm) and 3% for the longer ones, which is a lot (as a comparison figure, it suffices to be said that these were far

[323] “The POLDER Mission: Instrument Characteristics and Scientific Objectives”, P.Y. Deschamps et al, 1994.

more accurate goals than the calibration of SPOT estimated at 10% to 14%)[324]. Best estimates of such prelaunch calibration work would result nevertheless in a data accuracy, which would be considered as insufficient (4% to 7%)[325]. Consequently, the scientists estimated that the continuous calibration during the whole lifespan of the instrument in orbit must be accurate enough to balance the poor results obtained in the ground. The point was that ADEOS's size, mass and power consumption constraints did not allow carrying aboard calibration devices (such as spheres, lamps or blackbodies); therefore, there would be no internal light source or blackbody in ADEOS for on board POLDER calibration[326]. Other methods must be developed to guarantee the calibration of the instrument during its life in orbit. The scientists would take on previous studies conducted for other instruments like SPOT, the Advanced Very High Resolution Radiometer of NOAA's weather satellites (AVHRR) and the radiometers of the Earth Radiation Budget Experiment of NASA and NOAA (ERBE), which did not embark calibration devices onboard either. Instead, in these experiments in-orbit calibration was obtained by using highly reflecting stable targets on the surface, such as the White Sands desert (New Mexico) or La Crau (Provence), as references for absolute calibration[327]. Similarly, in-orbit POLDER calibration would be insured by such indirect means of viewing specific targets of known homogeneous and flat reflectance signatures[328].

One of such targets would be, for instance, cloud-free ocean surfaces. In this situation, the radiances measured with POLDER would be dominated by the reflectance of molecular scattering, whose physical principles were well-known (it depends only on the wavelength and the pressure) and hence data could be properly corrected from its effects. Some numerical simulations at LOA had shown that, if applying the corresponding correction algorithms, an accuracy of 2% in the measurement could be attained, provided the oceanic target was "carefully chosen", as spelled out in the paper published to present POLDER in 1994 –a figure compatible with the accuracy goals[329]. "Carefully chosen" meant avoiding taking as calibration targets scenes with significant aerosol concentration, water vapor, unknown surface pressure, as they were major perturbative agents of the signal. How would be the scenes appropriate for calibration selected? An automatic procedure would be developed to identify these scenes by analyzing exogenous measurements, if possible from other sensors flying on board of ADEOS to make sure that they were observing the same scene at the same time. In other words, the algorithm would import temperature and pressure data from the Ocean Color and Temperature Scanner (OCTS) and ozone concentrations from the Total Ozone Mapping Spectrometer (TOMS) also

[324] Michel Avignon, personal communication.

[325] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.

[326] For instance, we have seen that the radiometers aboard the Nimbus satellites (HRIR and MRIR) were equipped with blackbodies for on-board-calibration (see figures 1.2 and 1.3).

[327] "In flight calibration of large field of view sensors at short wavelengths using Rayleigh scattering", R. Vermote et al, 1992; "Etalonnage absolu de POLDER sur la diffusion atmosphérique moléculaire", P.Y. Deschamps et al, 1992 ; "POLDER in-flight calibration results ", O. Hagolle et al, 1999; "Calibration of satellite sensors after launch", R.S. Fraser and Y.J. Kaufman, 1986.

[328] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.

[329] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.

carried by ADEOS to choose those scenes clean enough to be used as calibration references[330]. However, this calibration could only be conducted for those wavelengths (λ<565nm) for which molecular scattering is significant enough. Therefore, only observations made with the spectral band of 443nm could then be calibrated with this procedure. The calibration coefficients obtained when calibrating the 443nm band by looking at clear oceanic surfaces must then be transferred to the other spectral channels with an interband calibration method, which analogously consisted in comparing the coefficients of the other bands with the 443nm's ones when observing other target scenes, such as clouds, ocean glitter or desertic surfaces. For instance, when viewing glitters over the oceanic surface[331], the color bands (443, 490 and 565nm) would present a flat signal and this could be used to intercalibrate these spectral bands, considering that in these conditions, and in these spectral ranges, measured spectral variations would result primarily from atmospheric transmission. Again, these glittering scenes would be chosen with an automatic procedure of analyzing exogenous data, from OCTS, TOMS or other sources. Still, some uncertainty would result from the aerosol transmission and it would be necessary to correct the measurements from the atmospheric scattering, which would be done by combining POLDER's own measurements of aerosols properties with exogenous data on aerosols provided by ground sun-photometers and, in the case of POLDER-2 and 3, also from the Moderate Resolution Imaging Spectroradiometer (MODIS, aboard of NASA's satellite Terra since 1999)[332]. To sum up, the channel 443nm would be radiometrically corrected by adjusting the calibration coefficients when looking to clear and calm oceanic surfaces; next, the flat signal generated when observing sunglint would be used to extrapolate the calibration coefficients computed for the channel 443 nm to some of the other bands.

These were some of the principles on which pre-launch and post-launch radiometric calibration algorithms would be developed. Both laboratory and aircraft measurements helped to empirically establish the coefficients of such algorithms, which called for exogenous data to be applied; they would then be coded with FORTRAN and the software, representing approximately 20000 instruction lines, would be integrated in the POLDER processing center at CNES in order to ensure systematic data calibration once POLDER would be in orbit[333]. These codes, and the resulting calibrated radiances, would not be considered deliverable items and would remain a sort of "property" of the data services of the computing center of CNES, who would ensure their proper ways of handling in terms of archival or eventual diffusion only upon request. At the end of the day, that was the *raison-d'être* of the system: there was no point in delivering physical radiances because, according to the whole representation, they were deemed to be *useless* for scientific inquiry.

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[330] "Etalonnage absolu de POLDER sur la diffusion atmosphérique moléculaire", P.Y. Deschamps et al, 1992.

[331] A glitter is the bright sparkling light formed when sunlight reflects from water. In the absence of scattering atmosphere, the stain is totally white, in other words, the spectral reflectance is flat (in POLDER's channels). This property renders the glitter a very efficient reference to control the intercalibration coefficients.

[332] « L'instrument POLDER où la polarimétrie comme alternative pour la télédétection des particules atmosphériques », Habilitation à Diriger des Recherches by P. Goloub, 2000.

[333] « POLDER level 1 processing algorithms », O. Hagolle et al, 1996.

We suggest, and with this we come to an end, to look at the data calibration as an operation of *decontextualizing* the data. In the process of calibration, original radiances are restituted from the transmitted signal and they are also being *despatialized*, that is to say, all the information that could give clues about their origins (orbit, instrument, date, resolution, etc.) has been removed from the data and only incorporated as additional information, or *metadata* (data about the data, a notion that we will find later on in our essay). At the end of the process of calibration, calibrated data would appear as *simple* radiances, apparently equal to any other radiance, a number given in $[W \cdot sr^{-1} \cdot m^{-2}]$ that could be obtained by a similar instruments put inside an aircraft or on the ground surface.

Technological practices of inversion: Transforming physics into geophysics

Calibration would only be a step in the production of geophysical parameters. POLDER was a radiometer and radiometers measure radiation, a form of energy. The whole issue would be reconciling these calibrated measurements of a form of energy with the data carrying epistemic virtue for *data users*, namely variables of geophysical significance. This would be an exercise of physical interpretation of the radiances by solving the inverse problem in remote-sensing -we may dedicate some time to briefly recall the scientific problem before getting underway with our particular example in the case of POLDER.

The inverse problem

An inverse problem is a general framework that is used to convert a set of measurements into information about the measured object. Interpreting the measurements done by remote sensing in terms of geophysical properties is an archetypical case of solving an inverse problem by deploying the *physical approach* to satellite data. Located "outside" the atmosphere[334], space radiometers like POLDER measure the emitted light coming from the Earth after it has crossed the atmosphere. The inverse problem consists in transforming measurements of such radiation into physical properties related to the object that has originally emitted the radiation (oceans, ice sheets, surface vegetation, clouds, etc.) and/or to the medium through which it has been propagated (the atmosphere)[335].

Solving the inverse problem requires three streams of work. First, it requires modeling the sensor, that is to say, controlling how the material and physical characteristics of the instrument affect the measurement. The measurements can be affected by optical aberration of the lens, radiometric distorsions, by gravitational effects over the satellite platform or by overheating of the system –to mention only few of them. Controlling part of these effects is precisely the goal of calibration before and after the launching that we have studied in the previous section. Secondly, during its journey

[334] Technically there is no outside or inside in the atmosphere as it is a continuous fluid that progressively extinguishes as we move farther from the gravity center of the Earth.
[335] This is the central problem in astronomy: analyzing the light measured from stars, galaxies, planets or other sources in order to get some information about the source or the milieu of propagation.

across the atmosphere, the radiation emitted by an object suffers a number of modifications, sometimes not totally independent of each other, which cause multiple complex scattering, absorption and emission effects, described mathematically with the so-called equation of radiation transfer. While this equation can be solved analytically for a number of ideal situations, solutions involving complex cases require developing numerical methods adapted to each situation. This is the case of the propagation of radiation across the atmosphere, which is far from being an ideal dynamic fluid, but rather composed by non-stable types of heterogeneous clouds, gases, aerosols and other pollutants, varying with latitude, from day to night in different time and space scales from each other and affecting different wavelengths in different ways. To solve the inversion problem requires thus modeling the radiation transfer equation, which, in turn, requires modeling the chemical and meteorological atmospheric conditions in which the equation is to be solved (cloudy, windy, polluted, daytime or nighttime, etc.). Note that while this would allow discriminating the perturbative effects of the atmosphere from the original emitted radiation, this would allow at the same time to study the atmosphere per se. Finally, while the emission of radiation is ruled by well-established laws, conditions of emission vary in degree of complexity and in function of the nature of the emitting object, the time of the day, the meteorological or the environmental conditions. The radiation emitted by a vegetal in the continental surface, for instance, depends on the biochemical nature of the vegetal, its phenology, its phytosanity, the orientation of leafs with respects to the Sun, the time of the day, the slope of the surface, the weather conditions, etc. The emissivity of large homogeneous water surfaces like the oceans, this is another example, is more stable, but still the swell, the crest of the waves, the presence of phytoplankton, salt or other suspended matter, or the position of the Sun dramatically influence on the emissivity patterns. To solve the inversion problem requires hence modeling the emission of radiation by the observed object, which, in turn, requires modeling the object itself.

All these considerations must be incorporated in what are called the *inversion algorithms*, or retrieval algorithms, which, after being coded and integrated into a computer, would allow solving the inversion problem in a numerical manner, that is, to derive from the radiances some attributes of interest to *data users*. In the following we will briefly present one example of such inversion algorithms developed for retrieving some properties of the clouds from POLDER's measurements.

Intervening on measurements: Theory of light, exogenous data, thresholds and assumptions

The basic geophysical parameter to be retrieved from POLDER's radiances related to clouds would be the detection of clouds by itself, that is to say, determining whether a pixel was cloudy or clear-sky. The algorithm for detecting clouds would be based on a series of threshold tests applied to each individual pixel and to every viewing direction -a pixel would be declared cloudy if one of these tests would prove positive. Some of these tests would be based in comparing the measurements provided by different channels of the radiometer, some others in comparing them with a fixed reference, while some others in comparing with exogenous measurements provided by other instruments. For instance, the first test would be based on the apparent pressure at the top of the cloud, which is related to oxygen transmission derived from the ratio between radiances measured in the 763 and 765 channels. This ratio would be then compared to the values of the pressure provided by the European Center for Medium-range Weather Forecast. If lower, then the pixel would be classified as cloudy. Three more tests would be applied. Should they prove negative, two more tests would be added in order to identify the clear pixels: a pixel that has not been declared cloudy would be labeled as clear if, for instance, the R_{865}/R_{443} ratio was less than a previously fixed threshold value of 0,35 over ocean and more than 2,2 over land. These thresholds had been established upon analysis of precedent datasets from other satellites (especially from those of NOAA's weather satellites). In case that a pixel would fall all the six tests, it would be labeled as clear or cloudy depending on the classification of the neighboring pixels[336]. Ironically enough, what might seem to be one of the most basic measurements imaginable for us profanes standing on the ground –is there any cloud up in the sky?- would be actually dependent on a set of previously established thresholds and values of exogenous datasets.

Should the algorithm for cloud detection give a positive, several other algorithms could be more or less independently applied to characterize different properties of the detected cloud. The figure 2.4 describes all the possible clouds' properties that could be derived from measurements of the experiments POLDER-1 and 2, like optical thickness, altitude, thermodynamic phase, water vapor content, microphysics properties. On the other hand, determining if a pixel was cloudy or not was also crucial for other non-cloud related studies, being clouds strong modulators of radiation so that their presence may perturbate both the radiation as it crosses the atmosphere and the atmospheric properties per se. Therefore, the algorithm for determining the cloud cover is very often an essential first step before applying any other algorithms in other the domains of land surfaces and oceans. For instance, the bio-optical algorithm to retrieve the concentration of phytoplankton in ocean waters would only be applied to those pixels that had been previously flagged as cloud-free -this procedure was not of course because phytoplankton only appears in the absence of clouds, but rather because the presence of clouds perturbates the measurements in a way that they were not possible to correct while maintaining the desired accuracy. As a result, data about marine chlorophyll concentrations retrieved from POLDER's measurements would only be produced in clear-sky conditions. Note that, as we will further develop in a while, this would frame the range of possible studies: someone willing to study the eventual influence of atmospheric water vapor on the marine carbon cycle may not be well-advised to use POLDER's data.

A point to be noted concerns the changes in the algorithms over time. As the scientists put their algorithms into test in different situations, as the instrument changed from POLDER-1 to POLDER-2 and then POLDER-3, or as new numerical methods matured, the algorithms may evolve on behalf of more scientific pertinence, more accuracy, more computer affordability. For instance, if a pixel would be labelled as cloudy, the optical depth of the clouds, that is to say, their thickness could be retrieved.

[336] "Cloud detection and derivation of cloud properties from POLDER", J.C. Buriez et al, 1997.

The first version of the algorithm developed for POLDER-1 would assume that all clouds were composed by water droplets of an effective radius of 10 micron[337]. Later on, as more data were available from satellites (including POLDER-1) and aircrafts during the second half of the 1990s, the water droplet model was found to be inadequate for ice clouds[338] and the algorithm for POLDER-2 was modified, providing for a more complex manner of determining the size of the water droplets of the clouds and, in particular, distinguishing clouds made by icy and by liquid water particles[339]. Our point is that different algorithms (assuming different hypothesis about the thermodynamic phase and the size of the particles composing the clouds) would be then applied in the radiances measured with POLDER-1 and POLDER-2 for retrieving the very same parameter, how thick was a cloud. This would result in two different datasets, even though measured with the same instrument and representing the same parameter. This heterogeneity would prevent their combination or fusion – unless inconsistencies between algorithms were compensated. Anyone willing to use them together must account for such inconsistencies; otherwise, his or her analyses could be compromised by artificial bias generated by differences in the algorithms. Actually, as we will argue in chapter 6, such evolutions in the inversion algorithms would turn out to be a major obstacle to the use of the data by scientists distant from the contexts of production as well as to the construction of climate datarecords.

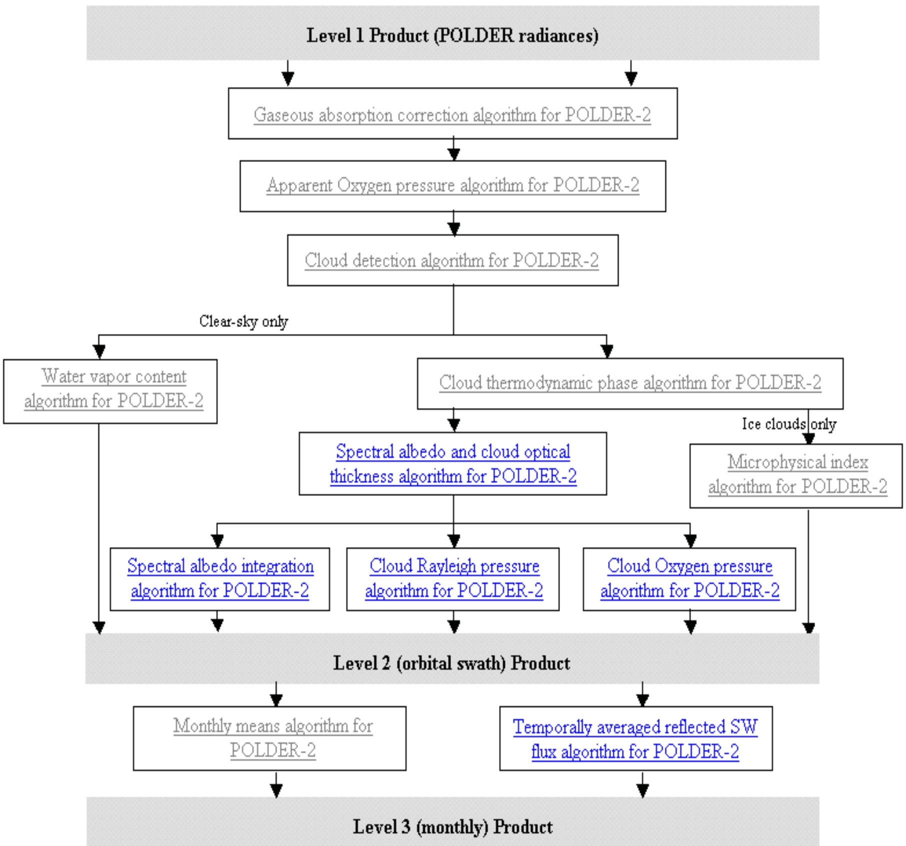

Fig. 2.4: Chain of geophysical parameters retrieved from POLDER radiances in the domain of clouds. The schema in the figure would be designed for POLDER-2 but in general the geophysical parameters retrieved would be identical for POLDER-1 and POLDER-2, excepting for one additional parameter (called "atmosphere") that would be added in the POLDER-2 chain of land surfaces. None the less, some algorithms to retrieve such parameters would change from POLDER-1 to POLDER-2, like the example quoted in the text regarding the optical depth of the clouds, which would assume different hypothesis about the thermodynamic phase and the size of the particles composing the clouds.

337 "Cloud detection and derivation of cloud properties from POLDER", J.C. Buriez et al, 1997.

338 "First results of the POLDER Earth Radiation Budget and Clouds Operational Algorithm", P. Parol et al, 1999.

339 « Spectral Albedo and Cloud Optical Thickness Algorithm for POLDER-2 », J. C. Buriez, 2002.

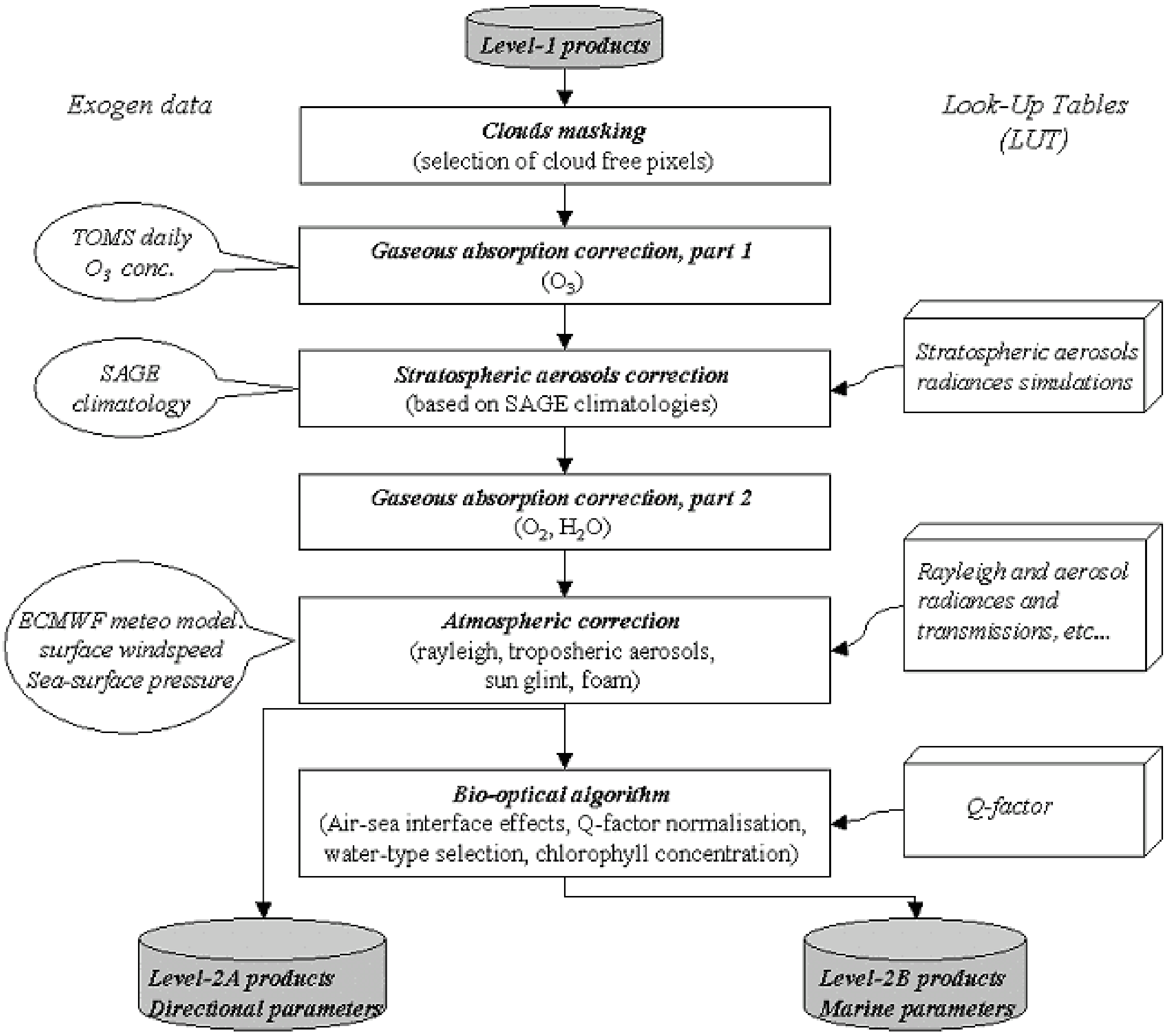

Fig. 2.5: To provide another example, this is the POLDER' data processing flowchart for ocean color domain. The algorithm for estimating the content of chlorophyll in the ocean surface, known as bio-optical algorithm, would only be applied on cloud-free pixels. After having selected the clear-sky scenes, corrections of gaseous absorption (based on thresholds with respects to ozone concentrations derived from TOMS aboard Nimbus-7 for filtering out to much polluted scenes), stratospheric aerosols contamination (based on thresholds with respects to the optical depth values retrieved from the space instrument SAGE to filter out too much contamined scenes), and after other atmospheric corrections like the sunglint or foam (based on ancillary data provided by the European weather center ECMFW), then the bio-optical algorithm could be applied to those pixels that had survived all the tests. Actually, two different algorithms existed depending on a previous selection of the type of waters under scrutiny (based on a threshold on the marine reflectance at 565nm used to classify the waters in two types): clear oligotrophic or turbid coastal waters affected by river discharge[340].

Similar schemas were developed for the retrieval algorithms corresponding to land surface properties and aerosols' properties. they can be found at: http://smsc.cnes.fr/POLDER/SCIEPROD/organigram_oc.htm

[340] "POLDER-2/Ocean Color ATBD Bio-Optical Algorithms", H. Loisel et al, 2005.

Let us illustrate the workings of one of such algorithms devoted to retrieve the thermodynamic phase of the cloud particles, liquid or crystalline, and developed by a team of scientists at LOA. Usual techniques developed in the 1980s for thermodynamic phase retrieval were based on the measurements of temperature in the infrared channels of radiometers. Threshold on brightness temperature would be used to select cold clouds that would be then assumed to be composed of ice particles: a threshold for discriminating between ice and liquid particles was established at -10°C, a value that had been observed as the minimum of temperature of liquid water solidifying. This would be the method used, for instance, to retrieve the cloud phase from the observations made by the radiometer AVHRR aboard of several NOAA's satellites since 1978 or with the future Moderate Resolution Imaging Spectroradiometer of NASA (MODIS) scheduled for a first launch in 1999[341]. On the other hand, hydrostatic equations describing the genesis and evolution of clouds, and in particular the equations of Clausius-Clapeyron describing the phase transition, are also temperature-dependent. In consequence, the equations and models describing the clouds phase would not be actually independent of the observations reporting them, as both depended on the same variable –what's more, they used actually the same threshold of -10°C. This posed problems because there was no way of guaranteeing an independent quality control: retrieved data and computations would be always in agreement, as they were dependent on the same parameter and on the same threshold. The limitation of such a method would be made evident by the early 1990s when aircrafts flying inside high clouds would observe liquid water at temperatures of -40°C[342]. Liquid water at this low temperature would never have been detected by using the algorithm based on the temperature threshold nor computed by the simulations because they both put the threshold for phase transition at -10°C[343]. Only when eliminating the variable temperature of the retrieval algorithm, a hydrostatic theory-independent characterization of the cloud phase would be enabled.

Determining the cloud phase from POLDER's radiances would not be based on temperature thresholds but rather on the premise that water droplets and ice crystals were different from a microphysical and radiative standpoint, in particular, they had different shape (and size) distribution. Indeed, scientists at LOA took on some theoretical results developed since the 1970s about normalized radiances in polarized light (which had been confirmed in the 1980s by several observations with lidar,

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[341] "Remote sensing of cloud, aerosol, and water vapor properties from moderate resolution imaging spectrometer (MODIS)", M.D. King, 1992.

[342] Determining the phase is possible theoretically with the equation of Clausius-Clapeyron which describes the conditions for thermodynamic equilibrium between the three states of the water. However, even though the theory predicts that water solidifies below 0°C, there have been reported clouds composed with liquid water droplets at around -40°C. Below -40°C it seems that water droplets solidify into ice crystals.

[343] Similar threshold issues have been reported in other cases involving the inversion of geophysical parameters from satellite measurements. Perhaps the most studied one in the domain of social sciences has been the case of detecting ozone in the stratosphere, which has been described, inter alia, by P.K. Barthia, the PI of the Total Ozone Mapping Spectrometer (TOMS, aboard Nimbus-7), « Role of Satellite Measurements in the Discovery of Stratospheric Ozone Depletion », 2009; E.M. Conway in "Atmospheric sciences at NASA", 2008; and our colleague S.V.Grevsmühl in his doctoral dissertation "A la Recherche de l'Environnement Global: De l'Antarctique à l'Espace et Retour", 2012.

the measurements of the Forward Scattering Spectrometer Probe (FSSP)[344], AVHRR or in situ balloon-borned observations) that suggested that ice clouds were composed by non-spherical particles and water clouds by spherical particles. This would be the central hypothesis of the method: water droplets are spherical and ice crystals are not spherical[345].

Based on these acquis, it was then about studying, by means of computer simulations, how polarized features depended on the shape (and size) distribution of a given object and in particular how polarized light of POLDER type could discriminate spherical and non-spherical shapes in different types of atmosphere (see box 2.1). Next stage would be to translate this physical principle into an algorithm – and then into a computer code to be integrated in the overall processing software. The algorithm would be simulated in the laboratory before the launch, confirmed by the aircraft flights of the POLDER prototype and validated with actual data from POLDER-1 after the launch of ADEOS-I in 1996. Only after this cycle of developments and tests, it would be described in a paper published in 2000[346].

This algorithm had been developed based on theoretical acquis and empirical observations, but, as suggested in the previous paragraph, its performance had to be assessed before integrating the software into the POLDER's processing line for mass production once the satellite would be operating. This would be done by comparing the results of applying this algorithm on some data samples of simulated POLDER radiances with the results of applying other methods to the same simulated data. Because by the 1990s the only method for deriving cloud phase was the one based on infrared thermal detection, which presented the limitation that independent quality control was not possible, original methods based on other type of measurements must be developed. For instance, in collaboration with scientists of the Laboratoire de Météorologie Dynamique, a method to retrieve the cloud phase from ground-based lidar observations would be developed. However, although lidar observations were considered as very promising, they were by the 1990s still a relatively new technology not enough mature to enable assessing the quality of POLDER's retrievals[347]. The results would be also compared against radar ground observations of the American network called Atmospheric Radiation Measurement[348]

[344] The Forward Scattering Spectrometer Probe (FSSP) is an instrument developed by the University of Manchester and commercialized by an American company. It measures the cloud droplet size distributions. The sensor is used primarily for the study of cloud microphysical processes, particularly the nucleation and growth of cloud droplets through condensation and coalescence.

[345] "Cloud thermodynamical phase classification from the POLDER spaceborne instrument", P. Goloub et al, 2000.

[346] It would consist of three tests: angular slope (the slope of the curve between normalized polarized radiance and scattering angle), standard deviation of the least squares and primary rainbow. For scattering angle within 60° and 140° the angular slope would be positive for water droplets and negative for ice particles. For scattering angle within 140° and 180° the angular slope had been showed to be negative both for water droplet and ice particles, but the standard deviation of the least squares fit is typically 10 times larger for liquid than for ice. Finally, if the particular 135° to 145° range was completely observable, the presence or lack of the primary rainbow could be detected using a threshold on the polarized radiance. Thus, a combination of the slope and the standard deviation of the least squares fit on the primary rainbow would be used to make discrimination between ice and liquid phase.

"Cloud thermodynamical phase classification from the POLDER spaceborne instrument", P. Goloub et al, 2000.

[347] "Cirrus cloud properties derived from POLDER-1/ADEOS polarized radiances: First validation using a ground-based Lidar network", H. Chepfer et al, 1999.

[348] "Comparison of POLDER cloud phase retrievals to active remote sensors measurements at the ARM SGP site", J. Riedi et al, 2001.

and with the classifications retrieved from the observations done with the radiometer aboard Meteosat[349]. All these data had been retrieved using different inversion algorithms and therefore comparing them would provide some insight of their mutual degree of reliability –we will come back to that methodology when discussing the validation of POLDER data after its launch. In this case, it was found, for instance, that high cirrus would tend to be over-interpreted as liquid or that results would tend to be biased when different types of clouds overlapped at different altitudes because they tended to be confused in one single cloud[350].

Box 2.1. Thermodynamic phase of water droplets with polarized light

In the case of water droplets, the optical properties could be derived from standard Mie theory. The simulations were computed using a model developed in the mid-1980s[351] for solving the equation of radiation transfer in situations of polarized light and assuming that clouds were plano-parallel, that their optical thickness was of 10, and that the surface albedo[352] was zero. These simulations would show that the polarization of cloud water droplet exhibited a strong maximum, called the primary rainbow, at about 140° from the incoming incident direction, which would be easily detectable and whose intensity would increase with the radius of the droplets. Also, the position of this maximum depended on the radius of the droplet and a minimum of polarization, called the neutral point, was computed at a position ranging from 75-130° depending on the radius[353] -note that this method would also be used, in turn, to determine the size distribution of the water droplets[354].

As per the icy clouds, in the 1980s it had been observed with balloon and aircraft that the crystals of clouds were extremely heterogeneous in non-spherical shape, size, and density depending on temperature and humidity in the cloud. To study the sensitivity of the polarization signature to the shape of ice cloud particles, different models of ice crystals would be used (hexagonal plated monocrystalline and polycrystalline particles) randomly oriented in the space. For such particles, computations of optical properties would be based on a ray-tracing method supplemented by calculations of the Fraunhofer diffraction. These calculations would be simplified to be valid only in the geometrical optical approximation for a constant radius equal to 20 micron. The radiative transfer computations would show that there was a decrease of the polarization for increasing scattering angle and that the neutral point for scattering angle was at about 160°.

These theoretical and simulated features would be tested and confirmed by measurements obtained with the POLDER airborne prototype used during several field campaigns in the 1990s, like CLEOPATRA in 1991, ASTEX in 1992 or EUCREX in 1994, flying over different types of clouds at different altitudes. Airborne images would confirm specific polarization features of a rainbow for scattering angles near 140°, which would be associated to the scattering characteristic of spherical particles; inversely, the rainbow characteristics disappeared as soon as the particles would depart from the spherical shape[355]. Therefore, all these previous studies confirmed that the polarization could be used to discriminate between spherical and nonspherical particles, that is to say, liquid cloud droplets and ice crystals respectively.

[349] « Cloud cover observed simultaneously from POLDER and METEOSAT", G. Sèze et al, 1998.
[350] "Cloud thermodynamical phase classification from the POLDER spaceborne instrument", P. Goloub et al, 2000.
[351] "A generalized spherical harmonics solution for radiative transfer models that include polarization effects", R.D.M. Garcia et al, 1986.
[352] The ratio of reflected radiation from a surface to incident radiation upon it.
[353] „Cloud droplet effective radius from spaceborne polarization measurements", F.M. Bréon and P. Goloub, 1998.
[354] Interview François-Marie Bréon, 2013.
[355] "Analysis of the POLDER airborne polarization measurements performed over cloud covers", P. Goloub, 1994.

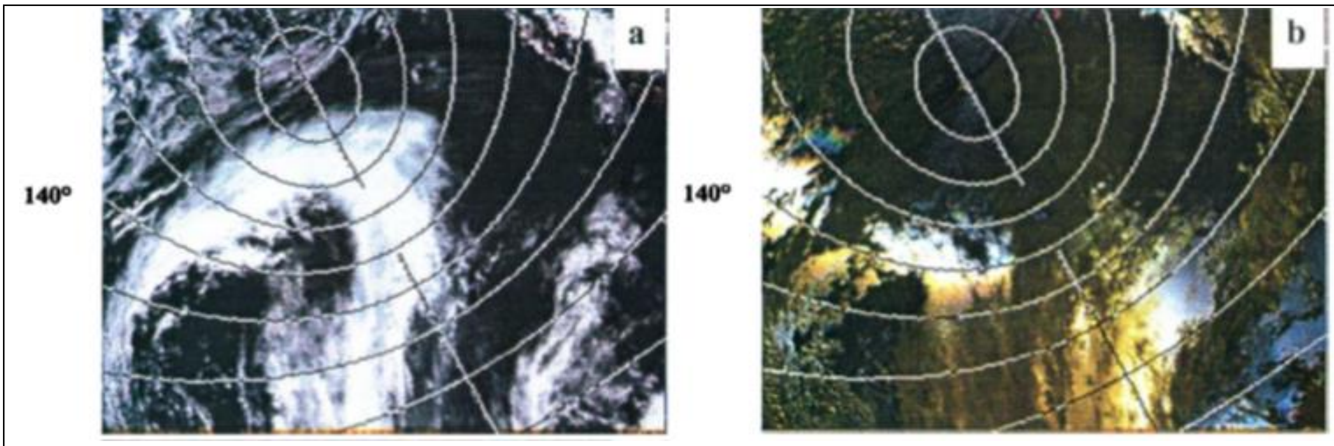

Fig 2.6: Images of a three color composite (blue, green and red) of the radiance measured by POLDER over a 1600x 2200km^2 over the Atlantic Ocean. The black/white lines overlaid on the images indicate the scattering angle in 10° increments as well as the solar principal plane. The left figure shows the total radiance and is similar to what would be observed with an instrument without polarization capabilities. The right figure displays for the same area the polarized component of the total radiance. The white band along the 140° scattering-angle line, corresponds to a maximum in the polarized radiance, which is characteristic of water droplets with a radius larger than the wavelength. For the same scattering angle, a dark/brown zone (low polarization), when associated to cloudy pixels, indicates the presence of ice particles alone in the atmosphere or overlapping low-level clouds, as can be seen in the right figure near the Sun principal plane. These features make possible the discrimination with clouds composed of ice particles and water droplets[356].

We would like to conclude by stressing that the design of inversion algorithms for retrieving geophysical (like this example concerning the phase of the water droplets in the clouds) data would be inseparable of a sound fundamental theory of light to develop polarized radiation transfer models as well as of empirical exogenous data, to assess the performance of these models. Also, we would like to insist in that point, exogenous data and assumptions about the experimental conditions would be necessary to very create the algorithms, for instance, for selecting the thresholds upon which they would operate, for which data obtained from other sources would be appealed (from the European Center for Medium-range Weather Forecast, from the satellites NOAA, SAGE, TOMS, etc.). At the same time, this algorithm would be built upon several hypothesis and approximations: it considered the clouds as plano-parallels, the refraction index of the particles as constant, it neglected the effects of molecular scattering, and so forth. This kind of background hypothesis would be generally accepted by the community as necessary simplifications to render algorithms feasible and computable. The most important assumptions would be however the principles underlying the given inversion method. In our example, that *all* water droplets were spherical and *all* ice particles were non-spherical.

[356] "Cloud thermodynamical phase classification from the POLDER spaceborne instrument", P. Goloub et al, 2000.

Inevitably, this method would have limitations due to the hypothesis underlying the inversion (in our case about the sphericity of the water molecules). By definition, for instance, this algorithm would be unable to determine the thermodynamic phase of thin clouds or it would present bias in the determination of cold clouds phase (in the poles or at high altitudes) because it would label all spherical particles as liquid, even though they might be icy. Somebody wanting to study the cirrus in the Arctic may rather not use POLDER data about the thermodynamic phase, because the POLDER's algorithm considering all spherical shapes as liquid would probably result in an overestimation of the amount of water droplets in the polar clouds[357]. But it would imply still more local hypothesis that would carry uncertainties and bias and that would constrain the interpretation and utilization of geophysical parameters. When the scientists would make use of the datasets about the thermodynamic phase of clouds particles, they would be making hypothesis about the size of the water droplets, the radius of the crystalline particles, about the thickness and altitude of the clouds, about the interactions between liquid water and icy particles with light, about the microphysical properties of the particles (such as the shape), about the interaction of the light as it crosses the atmosphere, about the behavior of the radiometer, about the relationship between the voltages and the amount of detected light, or about the type of atmosphere (more or less polluted, over the ocean or the land, in the poles, cloudy, daytime, etc.). Each algorithm would delimit hence the scientific frame of application of the resulting datasets. But there would be still more hypotheses integrated in the daily practices of the scientists, like that data would be only gathered during daytime, that they would be only produced from Monday to Friday (and 8 hours per day), that periodically the production would be interrupted for maintenance, that data must formatted in x-bits or coded in FORTRAN[358].

We have presented here some details for the retrieval of thermodynamic phase but all the other inversion algorithms present this very dependency on theory, models, empirical data and assumptions that limit their scope of application. For instance, the bio-optical algorithm to quantify the amount of chlorophyll in oceanic water would assume that the water of the oceans could be discerned into two main types, oligotrophic waters and turbulent coastal waters –any intermediate typology would automatically be considered as one of these two categories, meaning that it would not be appropriate to apply these algorithms in cases far from those ideal-types[359]. Similarly, the algorithms for land surfaces would reduce the diversity of vegetation configuration into three types: developed vegetation like tropical forests, quasi-isotropic standing for desert and snow, and intermediate vegetation. These means, for instance, that applying POLDER's algorithms would give similar results over semi-arid surfaces or in alpine tundra, or that they could not be used to distinguish different types of cultures. This would entail that studies in the domain of agriculture would not benefit much from POLDER's datasets. The algorithm for determining the cloud thickness, this is still another example, would

[357] "Cloud thermodynamical phase classification from the POLDER spaceborne instrument", P. Goloub et al, 2000.
[358] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.
[359] "POLDER-2/Ocean Color ATBD Bio-Optical Algorithms", H. Loisel et al, 2005.

consider all surfaces as not snowed, meaning that studies of the radiative relationships between clouds and highly reflective snowed surfaces could not be conducted with POLDER because clouds and snowed surfaces would never be detected simultaneously with this algorithm[360]. Last example, the algorithm for retrieving the optical depth of the aerosols would only be applied in cloud-free pixels, meaning that studies that may relate aerosols and cloud formation (like studying the relationship between the formation of aerosols and meteorological conditions, or the radiative impact of both), could not be conducted with POLDER data.

Our point is not only that every algorithm would imply and entail some hypothesis and assumptions, some simplifications and approximations, which would produce bias in the corresponding geophysical dataset. Our point is twofold. One, because geophysical data were appreciated as the admissible epistemology to POLDER's data, all these assumptions would be considered as necessary hypothesis that would give meaning to the decontextualized radiances. Two, as suggested before, this would shape the scope of possible scientific questions that POLDER's data was able to support by framing the possible areas of application of POLDER's datasets. In that sense, the manipulation of radiances to produce geophysical parameters can be actually seen as a *recontextualization* of the radiances. Contextual elements (other data, information, tools, assumptions, knowledge, scientific questions) would be reintroduced to provide a new local meaning to decontextualized data. In the process of creating such geophysical parameters, physical radiances would be pieced together with information about particular environmental conditions, with the body of existing data (empirical or simulated, satellite or not), with assumptions required in some physical situations and with conclusions derived from the theories, laws and ancillary data describing them. This was after all the whole point of producing geophysical data: providing a specific scientific context within which meaningfully interpreting the radiances measured with POLDER. In turn, however, this *recontextualization* would have the effect that the data would only be meaningful in this specific scientific contextual frame within and for which they would have been created. In other words, in the process of creating the algorithms, scientists would define the type of studies in which each dataset would be considered to be meaningful, they would define the scientific program that the experiment POLDER would support.

Data users, the recipients of such geophysical datasets, would not be thus delivered actual measurements, but rather manipulated entities derived from measurements, which had been fabricated by *data creators* –this was precisely the epistemological credo underpinning the whole complex of the factory-like mass-production and dissemination of geophysical datasets. More generally, we can conceptualize the display of satellite data in different levels of contextualization[361]. Some scientists,

[360] « Spectral Albedo and Cloud Optical Thickness Algorithm for POLDER-2 », J.C. Buriez, 2002.

[361] The tension between decontextualized and recontextualized data is comparable to the account provided by the sociologist of sciences Trevor Pinch in a study comparing the interpretation of data in two experiments in the domain of high energy physics. Pinch argued that scientists would interpret different manipulated entities displayed in what he named different *levels of exteriorization*, in function of the questions asked. Some experimenters, he argued, may interpret the signals of the experiment to detect solar neutrinos as solar neutrinos (the most exteriorized level), some others as disintegrated atoms of argon, some others as points in a graph plotting the energy/amplitude pulse, while some others as peaks in a Geiger counter (the less exteriorized level).

for instance, would instill POLDER's data into a *physical* understanding, while some others into a *geophysical* one. Some scientists would interpret the signals of the radiometer POLDER as *decontextualized* radiances, while some others as *recontextualized* thermodynamic phase of the clouds particles. The more contextualized would be the interpretation, the more chances to contribute to the progress of knowledge in the specific field for which they had been created (oceans, land surfaces and clouds). In exchange, the scope of use of such recontextualized datasets would be very contingent and specific to the conditions of data creation. By contrast, the more decontextualized, the less manipulated would data be and more open to a wide field of diverse eventual interpretations; however, because of lacking of precise contextualization and interpretation, they would be considered as meaningless for the particular community of scientists used to work with geophysical parameters -we will see when discussing the utilization of POLDER data, and satellite data more generally, that in the process of re-using the data in contexts distant from the ones in which they have been produced, a third stage of interpretation would emerge, a stage which fuses the *physical* or *geophysical* datasets with numerical models (let us call it the *climatic* approach, see chapter six), articulated by the technological practices of *data assimilation*, allowing the resulting data to be used in general contexts independent from the experimental conditions. It is not our aim to judge about the pertinence of producing data contextualized in a more or less degree; but rather to emphasize that these are two different manners of understanding the data that can be produced from satellite measurements and that they inform different degrees of intervention, different types of expertise and knowledge, different representations of the Earth and of the appropriate ways of unraveling its mysteries, different forms of data dissemination and that depict different categories of *data creators* and *data users*. We suggest that looking at the technological data practices (like inversion algorithms) is a useful way to grasp their epistemic specificities.

Let us sum up. We have discussed the process of geophysical data production as a tension between decontextualizing and recontextualizing the measurements. These ideas are useful as they highlight the ways in which different types of data and information move in and out of specific contexts of interpretation and work practice. They are also useful to describe how geophysical data, after having been decontextualized and recontextualized, would transcend their context of gathering and could be put into circulation. These data would become then Latourian *immutable mobiles* that are transportable and combinable, intelligible and understandable to any field scientist in the world without further information about the acquisition and production conditions. Indeed, for geophysical datasets to be consumed by *data users*, there would be no need to get into the internal gears of data production. As a matter of fact, there would not be the possibility either, because in this socio-technological complex intended to create and deliver geophysical datasets, the process of producing such data would be blackboxed to *data users*. The datasets that would be available to the wider audience of outsiders would be the finished closed stable "products" (geophysical datasets) and previous stages of their production (radiances), as well as the instruments, knowledge, practices, people or technologies

"Observer la nature ou observer les instruments", T. Pinch, 1985.

deployed to produce them, would be apparently erased. Geophysical data would become, after being decontextualized and recontextualized, intelligible opaque artifacts. This was, after all, the whole point of the geophysical data production and dissemination chain: providing the product that was considered to be meaningful to scientists in the domain of Earth sciences.

"Data must be cooked with care"

The use of ground stations records (like ECMWF's weather data, lidar measurements, FSSP datasets), aircrafts (POLDER prototype) and other satellite data (MODIS, OCTS, TOMS, SAGE, Meteosat, etc.) would become indispensable tools for studying POLDER capacity to be transformed into geophysical datasets. Running simulations based on theoretical results would be as equally essential to develop and test calibration and inversion algorithms as it would be the theoretical acquis in several domains of light theory. One of the epistemological lessons to be learnt from the practices of calibration and algorithmic inversion is that both calibrated and inversed data, and this can be said for all satellite data for studying the Earth, are both intrinsically *theory-laden* and *data-laden*, taking Paul Edwards's expression[362]. Satellite data only would make sense if created and interpreted within the collective that they would constitute with theories, models and exogenous data. In a sense, as *seeing* devices, POLDER's radiometer per se would be myopic; its measurements must be combined with theories, simulations and other data, which only when used in concert together would be capable to see some form of data.

This invites several concluding thoughts. First, creating geophysical parameters would mobilize technologies of *intervention*, as the philosopher of sciences Ian Hacking described[363]. It would involve the manipulation, control and careful preparation of the objects under study, the measurements. The epistemology embedded in the production of geophysical data was one based on a doctrine of interference of the scientist with the measurements, not in a doctrine of integrity and purity of the observations –how could such a doctrine be sustained if the whole point of the data mass-production and dissemination epistemology was precisely to create geophysical data from the measurements and deliver them to *data users*? On the other hand, this epistemology would assume that measurements do

[362] Paul Edwards ideas need to be understood within the framework provided by the controversy about the technology of numerical modeling in the domain of climate change, which was a fertile topic generating a lot of studies in the philosophy, history, anthropology and sociology of sciences during the decade of 2000.

In his article « Global Climate Science, Uncertainty and Politics: Data-laden Models, Model-filtered data », 2001, he argued that the debates and controversies that had been centered on legitimacy and credibility of numerical models as scientific tools (as opposed to observational data), were fruitless because just like data were not raw but « model-filtered », numerical models incorporated data in their internal gears (through parameterizations, initial conditions, etc.) and he coined them « data-laden models ».

In his book "The Vast Machine", 2010, the author developed further the relationship between numerical models and observational data, showing that numerical models themselves are used to filter and process data (in a technique known as data assimilation) and to create series of long-term datasets (in a technique known and reanalysis). We shall come back to these techniques when studying the building of long-term datasets in chapter 6.

[363] As we have mentioned before, the philosopher of sciences Ian Hacking would emphasize the interventionist-nature of experimental settings. Experiments and observations require the world to be manipulated and controlled, to be reduced and sampled, to be prepared for being studied.

"Representing and Intervening: Introductory Topics in the Philosophy of Natural Science", I. Hacking, 1983.

not speak by themselves, but they need a trained and socialized expert capable to provide meaning to them. They need what Daston and Galison have called the *calibrated eye*, an interpreter capable to manipulate the measurements and discern phenomena to be studied where the non-trained crowd simply would appreciate colorful photos, they need a *data creator*. Who would have said that the white stains in the 140º angle in the images of figure 2.6 corresponded to liquid droplets inside clouds? The scientists creating such algorithms would perform a form of objectivity close to what these authors have called *trained judgement*, defined by these authors as opposed to an objectivity of the type *truth-to-nature*, characterized by considering the observations as faithful representations of the observed phenomena[364].

The doctrine of interventionism exemplifies the fact that data are never raw, which has been studied by a myriad of historians, philosophers, sociologists or anthropologists of sciences –and this is not only valid for satellite data, or for measuring some Earth's properties with space technologies, but common to other types of data, instruments and disciplines[365]. Producing and interpreting satellite data in the fields of astronomy, solar physics and magnetism brings also in theories about light and matter, about propagation, about the conditions of observation and about the processes under observation themselves: calling for theories, hypothesis and other data, is not essentially different when producing and interpreting satellite data about the Earth than about a far-away galaxy scrutinized with the space telescope Hubble. Likewise, data obtained in the surface with telescopes, synchrotrons, submarine radars, rain gauges or fruit flies, as well as polls about vote intention or statistics about poverty indexes, to mention just few, are imbued with theories, approximations and auxiliary data as well needed to provide an interpretational frame. Our description of some of the technologies, knowledge and practices for calibrating POLDER radiances and for creating geophysical parameters through inversion algorithms, confirms indeed that data are never raw, but they carry assumptions, theories, knowledge and exogenous data with them. Most interesting, perhaps, is that the epistemology surrounding satellite data embedded in the schema of data production and dissemination imperatively *demands* data not to be raw. It assumes axiomatically that measurements do not speak by themselves and that must be interpreted to be meaningful. Geophysical parameters, and not radiances or voltages, would be by the 1990s the legitimate datasets admissible to do research in the field of sciences of the Earth and its environment, and they required, by definition, that data *ought not* to be raw. It was precisely because geophysical data were transformed from their original measurements, recontextualized and interpreted in a given specific local frame that they gained scientific virtue. The epistemic norm prevailing within the community required the datasets to be as much processed,

[364] "Objectivity", L.J. Daston and P.L. Galison, 2010.

[365] Philosophers and historians of science as diverse as Ian Hacking, Harry Collins, Peter Galison or Bruno Latour, and many others, have long coincided, each one with his own methodology, approach and background, in that the image of pure data is illusory: in all sciences data are corrected, reduced, multiplied, interpolated, manipulated, fabricated. A recent publication, arguably motivated by the phenomena of Big Data, and compiling a set of empirical essays entitled "Raw Data is an Oxymoron", confirmed, if needed, that data are *anything but raw*. Through the book, several case studies stressed how the material, historical and social context of producing datasets may affect their interpretive possibilities. "Raw Data is an Oxymoron", ed. L. Gitelman, 2013.

manipulated, corrected, calibrated and inversed as possible before being disseminated to *data users*. Radiances only become data after manipulation. The historian of sciences Geoffrey Bowker coined a memorable metaphor that remarkably fits this epistemology: “Raw data”, he wrote, “is both an oxymoron and a bad idea; to the contrary, data should be cooked with care”[366]. We have seen in this chapter, if we may continue the metaphor, some of the ingredients, recipes and cooking techniques. Let us explore in the next chapter some of the cookers, the restaurants and the suggestions of the chefs.

CONCLUSIONS

By the 1980s many of the selected laboratories were not equipped, materially, technically or skillfully, to cope with the deluges and nature of the data that was perceived to be generated with electronic sensors, recorders and processors. At the same time, the epistemic virtue of satellite data moved from radiances of level 1, to follow the classification, to geophysical units of level 2 or superior, a move that cannot be disconnected to the progressive incorporation of missions to study the Earth and its environment at CNES and to the assumption that it existed a wider audience of external scientists experts in some discipline or other of the Earth sciences willing to make use of satellite data in their scientific investigations. Unlike the experimenters dominating the space sciences and the “selected laboratories”, these recently arrived scientists wanted to analyze and interpret the data in their given context of study, not to process them; they wanted recontextualized data, not decontextualized data.

The system of data handling suffered a departure from the PI-mode that had prevailed during the first years of the space age. For POLDER, two were the features of the new system, a technology-supported organization of the mass-production and dissemination of geophysical datasets composed by different levels of processing, in which the technological data practices of calibration and inversion would figure prominently. First, it called for major participation of CNES in satellite data handling, from gathering to processing to archiving to distributing, given the fact that most selected laboratories lacked the means and the skills. Equally important, some of the scientists lacked the will, as they had become interested in applying their knowledge about remote-sensing to study some processes in nature like the carbon cycle, the tropical monsoons or the ocean tides dynamics, and not to study remote-sensing per se. In so doing, boundaries between the actors would be remapped, labor would be stratified, and higher degree of collaboration between the participants would be needed. This factory-like system, this is the second feature, would deliver geophysical parameters, and not any other intermediate form of data (like physical radiances or, descending even more, AC currents). This reflected that the production and dissemination of data would be embedded in a novel epistemology – an epistemology in which the epistemic virtue of satellite data would be located in the geophysical

[366] This expression was written by the historian Geoffrey Bowker when exploring what motivates and mediates the creation and curation of databases. He argued that the process of building the technologies for conserving and sharing data, the databases, the temporalities; spatialities and materialities of the objects to be represented in the databases deserved careful “cooking”.

« Memory Practices in the Sciences », G.C. Bowker, 2005.

properties that could be derived from the physical radiances. As a result, we argue, the scientific community would be progressively divided into those with expertise in the creation of geophysical parameters from radiances and those with expertise in the interpretation of such datasets in a given discipline, those looking at the data physically and those looking at them geophysically, the *data creators* and the *data users*.

The resulting schema for geophysical datasets mass-production and dissemination portraying a factory-like mode can be seen, we maintain, as a socio-technical disposition enabling the *reconciliation* between space technologies (satellite measurements of radiances) and the practices in the varied disciplines in the domain of Earth sciences closely connected to geophysical appreciations. In turn, we may consider the technologies enabling this transformation, inversion algorithms, as cases of technological data practices mediating *reconciliation*. The epistemic ordering imposing the centrality of geophysical data for scientific inquiry and the socio-technological factory-like complex would progressively stabilize in the decade of the 1990s in France and became the normalized regime of satellite data production and delivery in the Earth sciences. It would become the linchpin of the conceptual map of the ontological realities of the participants in a space project, the cradle of their epistemologies, the pillar of their social relationships, and would act as organizational noeud for allocating power and epistemic authority amongst the actors. A particular social group would rise up as holding such epistemic authority, the *data creators*. They and the enlarged scientific team created around POLDER are the center of our next chapter.

3

POLDER'S COMMUNITY. DATA CREATORS.

The production and delivery of geophysical datasets from POLDER's measurements convened, as we have seen, the development of a data system, which, after a period of test of about 6 months in the Technical Center of CNES in Toulouse, would be transferred to a scientific institution that would take over the responsibility of producing, disseminating and archiving POLDER's data during the three-years life of the instrument and the ulterior 10 to 15 years that was planned for the data to be available to scientists for analysis or retreatments. Setting up the infrastructures and systems for POLDER data processing, storing and distributing might be seen as the building of a more or less complex technological data flow network to get POLDER data usable and available[367]. However, in the course of the present chapter we intend to reveal a different face of this process. We intend to understand how, in the process of defining the data handling of POLDER, a scientific community was created. In this chapter we trace how, between 1990 and 1994, enough critical mass support was gained to generate a scientific community around the instrument POLDER and its future data and we examine the epistemic specificities of such a community.

We have divided the chapter in two parts. In the first part, special attention is given to the ways of creating such a community: how individuals, disciplines, laboratories were selected? How scientific goals were defined? How research objectives and methodologies were legitimized? How the epistemic authority of the resulting community was credited? To explore these questions, we examine in particular one of the elements of this process: seeking for partners to whom entrusting the production

[367] The system of satellite data production, circulation and archiving would make arguably an interesting case to be analyzed from an infrastructure and systems studies perspective, an approach characteristic of the studies pioneered by Thomas Hughes in the early 1980s, and which has produced a lot of literature around "large technical systems", ranging from telephones and railroads to air traffic control networks. More recently, this courant has been adopted and adapted in studies dealing with e-sciences -or cyberinfrastructure, as they are called in the United States- and information systems, especially in the United States and lead by Paul Edwards and Geoffrey Bowker, who have even vindicated an agenda for "Infrastructure studies".

For an outline of that program see the "Understanding infrastructure: dynamics, tensions and design", Report of a Worskhop 2007 or the special number of the "Journal of the Association for information systems", eds. P.N. Edwards et al, 2009.

of data during the three years that POLDER would be operating and the subsequent preservation and archiving duties. We are thus interested in this chapter in following the connections between scientists at LOA and LERTS that proposed the instrument in 1986, project managers and programmers of CNES, laboratories of the Technical Center of CNES in Toulouse and other eventual actors appearing along the story (scientists of Laboratoire de Modélisation du Climat et de l'Environnement, Laboratoire de Physique et Chimie Marines, Laboratoire de Météorologie Dynamique, the Commissariat à l'Energie Atomique, future Institut Pierre Simon Laplace, the region Nord-Pas de Calais, and others) with respects to each other, but also with respects to POLDER's data, to the instrument, to technological data practices and to scientific programs. We try to understand how they arranged together resulting in the creation of a particular form of community around POLDER. We argue that the seek for a scientific reliable partner to which transferring the exploitation of the factory would drive the composition of what would constitute the scientific community of POLDER, which received the name of "groupe mission", the definition of a scientific program for POLDER and a particular ontology of the production, dissemination and utilization of its data. The second part of the chapter is devoted to describe the epistemic specificities of the POLDER's community. A useful approach to discern them is, we believe, to identify its components (through looking at the authorship of the peer-reviewed articles and the attendees in the preparation meetings), their institutional affiliation, their training and professional background, the ways and rules of working together, their interpretational approach to data (physical, geophysical) and the technological data practices mobilized. All along our description we occasionally provide references to other missions (Topex/Poseidon, ScaRaB and CALIPSO) as a means, through the methodology of comparison, to better grasp the commonalities, similitudes and particularities. We argue, simply said, that POLDER's community was not a community tied by shared scientific questions, disciplinary interest or institutional frameworks, but rather by a common interpretational approach to the data through the technologies of algorithmic inversion; a community with a culture of what we have called *data creators*, a social group supported by their knowledge and expertise in radiation transfer, theory of light, spectral signatures, experimental procedures or error analysis. We argue, as well, that its legitimacy was credited by a technical institution, CNES.

This chapter embraces, like the previous chapter, the period between 1990 and 1994 approximately. It was in 1990 when POLDER was given green light as payload inside ADEOS and it began its phase of planning, development and realization, including the scientific and technological preparation of the future utilization of the data and the search for "clients" for such data, which would materialize in the creation of the scientific team. The developments analyzed in this chapter complement and must be read in parallel to those described in the previous chapter (which was focused in the data production per se, beginning with the type of data to be produced and delivered, the social organization of the production and dissemination chain and the data technologies enabling their creation). The main sources grounding the chapter are, like in the previous chapter, the minutes of the meetings hold between the "groupe projet", the "groupe mission" and other actors, which were reported most of the times by space managers of CNES. Additionally, other written sources like the Rapports d'activité of the involved laboratories or scientific publications issued in peer-reviewed journals have been also consulted. Like usual, they have been complemented with oral accounts of several of the actors, which served the purpose of both getting information and testing hypothesis.

CREATING THE COMMUNITY POLDER

In this first part of the chapter we aim to shed some light in the processes, motivations and attitudes involved in the establishment of a scientific team around the experiment POLDER. We propose to explore the issue by looking at the institution which became committed to mass-producing, archiving and disseminating data during POLDER's lifetime –or rather by looking at the process of looking for such institution. Indeed, in the process of transferring the developmental data processing line from the Technical Center of Toulouse to an operational entity, three questions crystallized. First, a partner willing and capable to assume the responsibility of the data factory was to be found. Second, the role of the scientists that had proposed the experiment was to be defined. Third, the role of external scientists, assumed to be the recipients of the data, was to be determined as well. We will illustrate in this part that these questions cannot be separate to the construction of the scientific program around POLDER –which, we shall recall at this point, was inexistent at the moment of its proposition back in 1986. We shall also note that the analysis provided in this chapter is closely connected and predates the examination of the establishment of an atmospheric data center in Lille in 2003 that we will address in chapter five.

Characteristics of POLDER's data

The orbital specifications of ADEOS combined with the recording capacities of the instrument POLDER, resulted in that, once in orbit POLDER would return images at a rate of 882 Kbps and of as much as 35 GB per day for at least three years. The Japanese ground stations would receive these data directly from the satellite, preprocess them generating data of level 0 (that is to say, voltages) and record them in magnetic tapes SONY (each tape containing a week of collected data), which would be mailed to CNES's computing center in a delay of 4 weeks after their gathering[368]. Four weeks was the time estimated for Japanese agents to preprocess the data (we may bear in mind that POLDER was only one of the 8 instruments aboard of ADEOS) and for the postal services to travel from Tanegashima to Toulouse. Once in Toulouse, POLDER's commuted data had to be processed on the ground as quickly as they were received or they would accumulate uncontrollably. Processing meant transforming the voltages sent by the Japanese ground segments acquired during a week into radiometrically corrected and geometrically rectified calibrated radiances, and then transforming these

[368] « Spécifications techniques de besoin des évolutions du segment sol POLDER », elaborated by F. Bailly-Poirot et al, 2000.

radiances into the 20 different types of geophysical datasets that had been proposed by scientists. Ideally, each orbit was to be processed in about 30 minutes in order to ensure a fluid flow of data and avoid backlogging[369] -for more details in the figures, we may direct the reader to chapter two[370].

This required a sort of *operational system* for data processing to avoid data accumulations – and with the term *operational*, we refer simply to the fact that some form of continuity in the services of data processing must be guaranteed. At the same time, however, POLDER did not intend to meet constraining requirements present in other missions (for instance, weather forecasting satellites) like real-time processing, 24/24 production or backup of the computing services in the event of any failure; actually people at the POLDER's processing center in Toulouse worked from Monday to Friday and 8 hours per day[371]. To be sure, the expense of a constraining data processing system could have not been justified either, because, POLDER was a *proof-of-concept instrument*, that is, an instrument whose utility and feasibility was yet to be demonstrated.

This feature of not requiring real-time processing points to the existence of different types of data (physical or geophysical or climatic, never mind) in function of the urgency of processing for the ultimate purpose driving the data gathering and utilization. More generally, different modes of utilization the data may require different types of data in terms of their abundance, their accuracy or their historical continuity. Real-time forecasting data requirements offer an illustrative example as opposed to POLDER's data requirements. For forecasting objectives (weather, state of the ocean, air pollution, etc.) speed in the data gathering, transmission and processing is a priority, because predictions must be generated in a timely manner, namely, in advance –for the weather forecasts conducted at the European Center for Medium-range Weather Forecast (ECMWF) this time ranges typically from 3h to 6h to 12h. Along the same lines, new data must be transmitted frequently from satellites –every 15 minutes for the case of Meteosat at present day (30 minutes in the 1980s and 1990s). Similarly, forecasters do not benefit much of using huge massive volumes of all data available which may slow down computing tasks –actually, each computation only uses the 5% of the satellite data received[372]. Also, far less important than speed is, for instance, the accuracy of the data. For

369 « POLDER level 1 processing algorithms », O. Hagolle et al, 1996.

370 Because of a backlog of data to commute at NASDA's ground segment, shipping to CNES was delayed: instead of receiving data 4 weeks after their gathering as it had been planned, data were received around 15 weeks after their gathering. Besides, some of the tapes turned out to be defective and new deliveries were to be needed; other tapes included some coding errors in the data format, which caused errors in the software line to produce calibrated data.

« Spécifications techniques de besoin des évolutions du segment sol POLDER », elaborated by F. Bailly-Poirot et al, 2000.

371 This had some impacts on the efficiency of the data processing. For instance, the material support in which voltages coming from Japan were recorded (magnetic tapes) as well as in which the processed radiances and geophysical datasets were recorded for shipping to scientists (magnetic tapes and CD-ROM) required human intervention (to change the media, for instance). Therefore these operations cannot be done on weekend, holidays or beyond working hours, which lead to a production of 80% in a week without holidays.

« Spécifications techniques de besoin des évolutions du segment sol POLDER », elaborated by F. Bailly-Poirot et al, 2000.

372 It is estimated that in operational weather centers like the European center ECMWF, at present day satellites provide around the 98% of the 75millions data items managed by each 12hour weather analysis. Only about 5% of these total data enters the computer to be analyzed.

"Global observations and forecast skill", L. Bengtsson et al, 2005.

instance, satellite data must adjust to the resolution of the grids of the numerical models; for the weather model of the ECMWF grids are typically about $100km^2$. If satellite data are more space resolved, this resolution will be degraded in the process of introducing them in the model anyway. To finish with the example, forecasters are only interested in the most recent data accounting for the state of the system being predicted (for instance, atmosphere or ocean) in order to provide pertinent initial conditions to the numerical model. In other words, they do not need datasets dating of older periods than 3h to 6h ago. By contrast, they require continuity in the services 24/24 and with backup systems. Equally important, they require perpetuity of the observing systems across time, for predictions keep being released. That means that provisions may be done for launching successive satellites one after the other equipped with identical, or at least comparable, instruments ensuring, in so doing, the perpetual collection of the same type of measurements.

POLDER's data convened for some requirements of opposite sign. Real-time was not an issue, given the fact that the data were not to be used, a priori, for real-time predictions. Likewise, 24/24 services and backups, although it was desired, was not an imperative either. After all, characterizing the size of the water droplets of the Arctic clouds can be done today, tomorrow or next week. POLDER, as it was proposed in 1986 and as it was redefined between 1990 and 1995, would not require perpetuity of the measurements either: it was conceived as a single-shot experiment to gather data during a limited-time period of three years, with no provisions for continuing the measurements –the issue of perpetuating the measurements will be a recurrent topic all along the second part of our essay when introducing the production of climatic data. A contrario, data were to be accurate enough to distinguish artifact signals from natural ones (which was to be achieved through calibration algorithms); they were to be accurate enough also to discriminate oceanic or land surfaces signals from aerosols' one (which was to be achieved with atmospheric corrections algorithms); and finally they were to be accurate enough to establish relationships between the physical radiances and a given geophysical variable to further discern patterns and their respective origins and dynamics, phenomenological relationships, and identify correlations (which was to be achieved through inversion algorithms). On the other hand, because scientists using POLDER's data were not constrained for real-time operations they could afford longer computer-time processing, which meant that they could incorporate huger volumes of data, which was crucial to provide data with statistical significance. Finally, and contrary to forecasters, POLDER's users required data to be preserved over long periods of time, 10 to 15 years. Indeed, POLDER's data, and satellite data about the Earth and its environment more generally, were valued because of their uniqueness. They were unique certainly because of their technical specificities (each instrument was somehow different than the existing others[373]), but the value of their uniqueness resided in that they captured, regardless of the technologies used, a series of unique moments that never would be repeated again. "We cannot go back in time and observe what we have failed to

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[373] Operational systems like Meteosat or Landsat, a contrario, commit to embark always the same instrument –or very slightly modified.

observe", told us the climate scientist Kevin Trenberth during our interview[374]. Bearing that in mind, preserving the data would stem from two different, though convergent, sources. On the one hand, while scientists may have some a priori ideas in how using the data in their immediate scientific problems, if data must be preserved during longer periods of time is also because scientists ignore how data could eventually be used in their future research problems. In the future, maybe tomorrow, next month or in ten years, new processing algorithms may appear to be more accurate for studying the same questions in a more precise manner or a given type of data may turn out to be precious for studying new scientific questions –conceptual parallelisms with the notion of "multimissions" discussed before are remarkable. On the other hand, some environmental phenomena occur in long periods of time and therefore they can only be detected and identified if there do exist data records long enough, which implies the conservation over time of the data gathered with each singular limited-timed instrument, a problem to which we will come back when analyzing the building climate series of data in the second part. In spite of constituting two different approaches to using satellite data, and as we will see evenopposite in some terms (like for instance the design of the launchings or the delivery of the data), they both have in common the requirement of data preservation. For POLDER, as we have already mentioned, this preservation was estimated to be enough with 10 to 15 years after the finishing of the functioning of the instrument[375] -we will further develop these points in chapters 5 and 6.

All and all, the entity taking over the exploitation of POLDER's data after the initial period of test at the Technical Center of CNES in Toulouse must be capable of such a calibrate the data in continuity as they were mailed from Japan, but with no real-time constraints, to process them in parallel according to the 20 different inversion software to be integrated in the computer, to proceed with eventual new corrections, inversions or reprocessing, to archive them during at least a decade, and to ensure their delivery to requesters.

Entrusting the factory to external institutions

This is a problem that mirrors what is commonly known as the transition from experimental satellites to operational ones, or more generally from R+D technological systems to operational ones –in this case, the term operational refers to 24/24, with backup system, committed to replace one satellite after the other in the long-term or in case of prompt failure, real-time processing. In the launching of Meteosat[376], for instance, since the very beginning of its preparation in 1968, when it was still a French radiometer proposed by professor Pierre Morel of the Laboratoire de Météorologie Dynamique, it was

[374] Interview with Kevin Trenberth, National Center of Atmospheric Research, 2013.

[375] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

[376] Meteosat was a satellite launched in 1977 by ESA in a geostationary orbit with the goal of providing data in support of weather forecasts. The project was transferred to Europe in 1973. Seven satellites were launched in what was known as the first generation of the family (1977, 1981, 1988, 1989, 1991, 1993, 1997). Since 1995, Eumetsat engaged the development of the second generation of satellites known as MSG (Meteosat Second Generation, launched in 2002, 2005, 2012) and since 2010 the third generation is in course of development.

hoped by CNES that the weather services would eventually take over the responsibility of exploiting the satellite. When it was europeanized in 1973, the same hope prevailed: after a rough transition period of around 10 years that has been described by the historian John Krige, the European Space Agency (ESA) would transfer the exploitation of the family of weather satellites Meteosat to a specific body established to that very purpose, EUMETSAT. In other words, EUMETSAT would handle the production, dissemination and archiving of the data obtained with the Meteosat satellites whilst ESA would dedicate to develop new systems (instruments, platforms, data processing, etc.) that would be then transferred to EUMETSAT for exploitation[377]. This solution had been actually a sort of adaptation of the model between NASA and NOAA in place for exploiting the weather satellites TIROS and GOES in the United States since 1965 and 1975 respectively: NASA, after funding a first phase of instrument and platforms realization, would step back to leave the responsibility for a second phase of exploitation to NOAA, in order to concentrate, completing the circle, on a third phase of demonstrating new capabilities.

A similar model is the one being deployed for the case of radar altimetry satellites of the family Topex/Poseidon. NASA would be deeply involved in the production, preservation and dissemination of the data gathered by its radar altimeter Topex. During the duration of the mission, data from this instrument would be processed at the Topex ground segment with the scientific algorithms developed by the 38 PIs (selected through a “call for opportunities”) previously integrated in a processing line. A specific “Science Data Team”, which was composed by managers of the Topex project and located at the Jet Propulsion Laboratory of NASA (the scientific laboratory responsible of the radar altimeter), would be in charge of the production and distribution of the scientific data and responsible for archiving these data for the life of the mission. Besides, all the processed data would be sent to the Physical Oceanography Data Active Archive Center (PoDaac) which had been purposely established in 1987 for long-term archiving of the data about the oceanographic physics. During the life of Topex, the data team at PoDaac would be reinforced with NASA’s engineers specifically designated to ensure the physical distribution of copies of the Topex data to the PIs within the required time span. Once the project would finish, PoDaac would take full responsibility for storing and archiving data as long as it would be considered of scientific value[378]. Emulating this model, CNES would also be involved in the production, dissemination and stocking of the data collected by the twin radar altimeter Poseidon: a specific team of engineers was designated at CNES to create a ground segment to operate the production of data, its validation, distribution and archiving, SALP (Service d'Altimétrie et Localisation Précise); an entity responsible for archiving and disseminating the data was set up by CNES, AVISO; and even a subsidiary was created to commercialize with the data, CLS (Collecte

[377] Discussions about the creation of such an entity started as early as in 1973, when Meteosat was Europaneized. Eumetsat convention was signed in 1983 but it was so frail that ESA must back all the decisions, and it did not held it first council until 1986, in ESA facilities. The historian John Krige discusses the process in “Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite”, J. Krige, 2000.

[378] “Topex/Poseidon Project. Data Management Plan”, compiled by scientists of Jet Propulsion Laboratory of NASA on October 1991.

Localisation Satellites)[379]. Topex/Poseidon would be the first of a series of satellites carrying radar altimeters and developed by a partnership between CNES and NASA. Progressively, the data handling has been ceded to external entities following the same model than for the weather satellites. The exploitation of the fourth of such radar altimetry family of satellites (Jason 3 to be launched by 2015) is planned to be totally transferred to a consortium made of EUMETSAT and NOAA, leaving CNES and NASA the task of developing new systems[380].

Some historical studies exist that have explored this transition by looking at the continuity of the engineering (satellites) or at the institutional framework (space agencies or operators)[381]; we propose to look at the problem by looking at the continuity of the data systems. To what extend must space agencies be involved in the production, dissemination and preservation of satellite data during the exploitation of a mission? Or, to what extent are they ready or willing to intervene? Should CNES assume the tasks of dealing with the data? Should a new entity be created and given full responsibility, or rather a responsibility shared with CNES or with the scientists proposing the instrument? Shall the groups supposed to use the data intervene? Space agencies institutional discourse typically claims that they are mandated to develop and test new technological systems (satellite platforms, launchers, instruments, data systems, etc.), but once the feasibility is demonstrated another agency must take over the responsibility of operating it. Reality is much more complex, as illustrated by these two examples (it took around 10 years to render the European weather program operational and at least 20 for the radar altimetry program), and factors specific of every mission may intervene in the direction that the final system would take leading to different degrees of intervention from space agencies. How would the POLDER's data handling scheme be? Who would exert the function of "operator"?

At risk of over-repeating ourselves let it be said one last time that, as described in the period chapter, it would be the mission of the "groupe projet" established in 1990, directed by a project manager and a project scientist of the Technical Center of CNES in Toulouse, to look for a solution concerning the transfer of capabilities from CNES to an external entity. Throughout this process they would be advised by a number of scientists, including the principal investigators of POLDER and other scientists of LOA, LERTS or Laboratoire de Modélisation du Climat et de l'Environnement and eventually also from Service d'Aéronomie and Laboratoire de Météorologie Dynamique. The model they favored would precept that after a period of test, CNES would transfer the computing center to an external scientific institution who would take over the responsibility of producing, storing and

[379] To complete the history of the program Topex/Poseidon we shall address the reader to the research in process of Jerôme Lamy, which constitutes a chapter of his Habilitation à diriger les recherches: "La mesure de toute chose. La mission Topex/Poseidon et l'océanographie spatiale dans les années 1980 et 1990", inside the dissertation « Faire de la sociologie historique des sciences et des techniques », Habilitation à Diriger les Recherches, 2014.

[380] In the case of radar altimetry, the issue has been often described by actors themselves. See for instance: "Space-based observations in the global ocean observing system: the operational transition issue" Alain Ratier, 1999 or "Transitions toward operational space-based ocean observations: from single research mission into series and constellations", H. Bonekamp et al, 2009.

[381] Besides John Krige's study on Meteosat, we shall refer the reader to Pamela Mack's study on Landsat in "Viewing the Earth. The Social Construction of the Landsat Satellite System", 1990.

disseminating POLDER data during its exploitation[382]. This required looking for scientific institutions ready to cope with the semi-operational burden of POLDER data processing, storing and distribution infrastructure.

We shall note at that point, and for the sake of chronological clarity, that the process of seeking for a reliable partner to which transfer the data factory, that is the process that we are describing in this section, would occur more or less concomitantly, and conducted by the very same people, to the process of defining the technological complex of data mass-production and dissemination in different levels of processing described in the previous chapter, namely between the end of 1990 and the beginning of 1993. In turn, a parallel stream of work that had been already engaged by scientists of LERTS, LOA and LMCE (and at the beginning back in 1988 also the Institut National de Recherches Agronomiques and the Institut Géographique National), aimed to prepare the future data of POLDER to study the calibration and the inversion algorithms, also just as described in the previous chapter.

The Laboratoire d'Optique Atmosphérique (LOA), a "partenaire incontournable" but insufficient: distributing the data-handling in « pôles thématiques »

LOA was considered at the eyes of the "groupe projet" as "a partenaire incontournable pour la mission POLDER"[383]. Back in 1986, POLDER had been proposed and conceived by a consortium of scientists of LERTS and laboratories of the Technical center of CNES in Toulouse, and LERTS and LOA had been given the scientific responsibility of the project. It had been LOA's scientists that had defended the project before the scientific advisory committee of CNES (Comité de Programmes Scientifiques) and CNES's programs managers. The principal investigator, Pierre-Yves Deschamps, had just returned to Lille after his stay in Toulouse. It would have been at least bizarre not taking this laboratory in consideration. But it was not only a matter of maintaining forms. LOA's scientists had been working with the aircraft prototype and therefore they reunited the competences about the instrument, its radiometric performances, the optical configuration, polarized light, and some calibration techniques. More generally, this laboratory was recognized by its expertise in the domains of radiation transfer, remote sensing of aerosols and algorithm development and testing, which made it a source of workforce for developing and testing scientific algorithms[384]. Taking some of the categories introduced before, LOA embodied the figure of an experimenter, a figure which was materialized by the denomination of a principal investigator, Pierre-Yves Deschamps. But LOA also materialized, because of its vocation in the study of radiation transfer, the figure of the expert in interpreting satellite radiances within a physical approach. But one thing was to hold the knowledge and the expertise for developing the software for calibration and inversion, that is to say for *creating*

[382] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.
[383] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.
[384] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

the data, and another one to be capable to implement and exploit a semi-industrial system for mass-*producing* them, disseminating and archiving. As we have already mentioned in the previous chapter, LOA was not equipped to ingest such amounts of data and process them systematically within relatively short time delays: it had no source of funds, technical expertise, human resources or material equipment to absorb any of those exploitation responsibilities, and its host institutions (University of Lille or CNRS) were not capable or willing to make the substantial investment in the development, implementation and exploitation of semi-operational data processing necessary to support POLDER's data factory.

In an attempt to find a powerful partner for LOA willing to invest in skilled personnel, powerful computers, information networks, data pipelines to transmit the signals from CNES's ground stations in Toulouse to Lille, and other technical material for the factory, during 1991 and 1992, representatives of LOA, the University of Lille and CNES prepared a dossier known as "Pôle thématique atmosphère"[385] to be submitted to the Conséil Régional du Nord-Pas de Calais[386]. The project they proposed was very ambitious and considered the experiment POLDER only as a first step towards implementing a larger data management facility in the region. This ambitious datacenter would be devoted to centralize the processing, diffusing and storing of satellite data from all missions related with measuring atmospheric properties that were planned to be launched along the coming two decades by CNES and ESA, including data obtained from the radiometer ScaRaB (to be launched aboard a Russian satellite by the end of the decade), the radiometer MERIS (to be launched aboard ENVISAT), the spectrometer Stratospheric Aerosol and Gas Experiment (SAGE-III, to be launched for the third time aboard of a Russian satellite by the end of the decade), the spectrometer SCIAMACHY (to be launched aboard ENVISAT) and the spectrometer Global Ozone Monitoring Experiment (to be launched aboard ESA's satellite ERS-2)[387]. This facility was to be a *calculation center*, not only making a case for the Latourian metaphor, but taken it literally: facilities in which parallel series of software would more or less continuously run to produce geophysical datasets from the calibrated measurements received systematically from CNES's or ESA's ground stations. They materialized a central nodus for data circulation, they were *points de passage obligés,* to continue with Latour-ish[388], intended to outpace the "parcours du combatant", taking the by now familiar expression, that *data users* must undertake before being able to analyze the datasets[389].

This project emulated similar initiatives conducted since the mid-1980s in France consisting in the creation of specialized datacenters to handle the data collected by a given satellite. A Service d'Archivage et de Traitement Météorologique des Observations Satellitaires (SATMOS), for instance, was created as a reaction to the "difficultés qui font actuellement obstacle à l'utilisation scientifique

[385] « Compte-rendu de la réunion du groupe mission POLDER », November 1992.

[386] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[387] « Compte-rendu de la réunion du groupe de travail du segment sol POLDER », October 1992.

[388] We refer to the famous concept introduced by Bruno Latour in « Les vues de l'esprit », 1985.

[389] « Note au LERTS : Banques de données satellitaires », written by Yann Kerr in January 1988.

des observations spatiales météorologiques [referring to those of the satellites Meteosat and NOAA handled by the Centre de Météorologie Spatiale in Lannion, described in the Box 1.2]"[390], which had been denounced by the scientific community during the first scientific meeting organized under the auspices of CNES hold in 1981 in Les Arcs. In that meeting, scientists specialized in the domain of atmospheric physics, dynamics or chemistry, oceanography, glaciology, vegetal surfaces and climate scientists demanded

> "unanimement la création d'un service d'archivage et de traitement des observations spatiales météorologiques (projet SATMOS) accompagné des moyens humains indispensables. Un tel service est nécessaire pour mener à bien les études de physique de l'atmosphère (compréhension de processus, paramétrisation) et de climatologie (bilan radiatif, couplage nuage-rayonnement)"[391].

Around four years later, in 1985, the French weather service Meteo-France, the Institut des Sciences de l'univers of CNRS (INSU) and CNES would create SATMOS with the vocation of « d'archiver et de diffuser auprès de l'ensemble de la communauté scientifique les données des satellites météorologiques » operated by the Centre de Météorologie Spatiale in Lannion. Beginning with data from the satellites Meteosat, today the archives comprise data from all the weather satellite flying in geostationary orbits (Meteosat, Indian-Meteosat, Japanese GMS, the Americans GOES-East, GOES-West, and GOES-South), as well as from the polar-orbiters passing through the acquisition range of Lannion (NOAA and METOP). Also at the European level, facilities for handling the data obtained by each satellite were being established. For instance, the Centre d'Archivage et de Traitement for data collected by the satellite ERS (CERSAT) was created in 1991 as part of ESA's ground segment for, as it names indicates, handling the data of the future satellites ERS-1 and ERS-2 (standing for European Remote Sensing). A number of managers of CNES, including the manager of the program POLDER in Toulouse, Alain Ratier, would be actively involved in the impulsion of such a datacenter, which would be established in Brest in a partnership between CNES, ESA, MeteoFrance and Ifremer (French Research Institute for Exploitation of the Sea)[392].

In the wake of these developments, scientists of LOA pleaded for establishing a datacenter for POLDER (and extendable to all missions concerning the physics of the atmosphere) to be located at Lille. The regional authorities in Nord-Pas de Calais supported the project with the hope that the establishment of a satellite datacenter in Lille dedicated to the atmosphere would foster a « identité spatiale » in the region, an idea « inspirée par l'example de CERSAT en Bretagne », as stated in the minutes of a meeting of the working group in 1992[393]. The region Nord-Pas de Calais had been actually quite impacted by the creation of CERSAT, in the sense that it came to reinforce a general restructuration of the scientific research in France promoted by CNRS. In particular, this restructuration of CNRS promoted the Bretagne as a center of scientific expertise in the field of

[390] "Conclusions des groupes de travail Sciences de la Terre", presented by M.Petit in the Séminaire Les Arcs 1981.

[391] "Conclusions des groupes de travail Sciences de la Terre", presented by M.Petit in the Séminaire Les Arcs 1981.

[392] CERSAT has evolved towards a "multi-mission data centre", that is to say, a center that organizes and deals with data obtained with different sensors and satellites. We will come back to this concept in chapter 5.

[393] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

oceanography –being the setting up of CERSAT only one of the actions engaged for that purpose (two of the key instruments of the satellite ERS were a radar altimeter to measure the level of the sea and a scatterometer to compute the wind-speed, especially at the sea surface). One immediate effect of this reconfiguration would be the migration of several scientists of LOA and the University of Wimereux (located in Nord-Pas de Calais) to Brest, Roscoff and CERSAT itself (located in Bretagne): to give a figure, further to this migration, the team in the domain of remote-sensing of the oceans at LOA, which had been one of the original and fertile research topics at LOA since the 1970s, was reduced to only one scientist, Pierre-Yves Deschamps, and deprived from some of his collaborators in Wimereux[394]. Just like CERSAT had contributed to promote the Bretagne, so it was argued, a datacenter at Lille specialized on atmospheric physics would attract more researchers to the region and thus would give impetus to the regional scientific activities in a revived program for space atmospheric studies, entailing recruitments, grants and scholarships (phD and postdoc) as well as important technological investments. By April 1992, it was agreed that a 10% of the regional budget would be allocated to the project for implementing such atmospheric satellite datacenter. In a preliminary developing and testing phase, it was agreed as well that the project would only deal with data from POLDER, with the ultimate goal to be completed in a medium-term future by integrating and absorbing other satellite data coming from other space instruments[395].

Nonetheless, this contribution was still insufficient for operating a whole ground segment for POLDER data processing, storing and distribution during POLDER exploitation phase. First, it contemplated only to cope with the data associated to the atmospheric properties, but it had been planned for POLDER to produce also data in the domains of vegetal surface studies and oceanic biochemistry. Equally important, time was pressing because POLDER-1 was scheduled to launch in 1995 and there was some skepticism about the possibilities of setting this facility from the scratch in about 2 years. The first point, dealing only with part of the data, would be solved by reconfiguring the very concept of ground segment: from a centralized unique system like SATMOS or CERSAT, to a distributed delocalized one, where different institutions, perhaps located in different towns, shall assume different functions in the data-handling[396]. This solution was described as "configuration et développement distribués" in some of the proceedings that we have consulted[397]. Put it clearly, the consortium of Lille (LOA, University of Lille, Région Nord-Pas de Calais, CNES and CNRS) would be dealing with the atmospheric component of POLDER's data - others would deal with the rest (we will explore them in a while). The second point, making sure that it would be ready on time, would be solved by reducing the duties of such center. Instead of becoming, as initially planned, a data factory equipped to process, disseminate and archive the data, the tasks of this center would be narrowed to assess and verify the scientific quality of the data that would be manufactured elsewhere. To conduct

[394] Rapports d'activité LOA, 1989-1995.

[395] « Compte-rendu de la réunion du groupe de travail du segment sol POLDER », October 1992.

[396] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[397] « Compte-rendu de la réunion du groupe de travail du segment sol POLDER », October 1992.

such a task more workforce would be engaged under the form of phD candidates or technical personnel, but no major investments in material or information networks would be needed (excepting for some minima like, for instance, a telephonic line for the data to circulate would be run between LOA and the entity hosting the data factory).

Such distributed model had already been tested in the United States and was being promoted by the European Space Agency (ESA). In the minutes we have consulted, the working group mentioned quite often NASA's and ESA's plans as examples supporting the case for a distributed data infrastructure[398]. At NASA different datacenters across the country were organized in function of the instruments, the disciplines and/or of the geophysical variables being retrieved. For instance, in the early 1980s there were a number of laboratories dealing with satellite oceanographic data, including the Jet Propulsion Laboratory (JPL), the Goddard Space Flight Center (GSFC), the Scripps, NOAA and a myriad of university departments. During the decade, in an effort for rationalizing resources that we have mentioned in the previous chapter, NASA would reorganize them by themes. While JPL, for instance, would handle the oceanographic physical data, the biological one would be handled by GSFC, even if in both laboratories there were scientists working with the other's data (although, they would progressively specialize in the corresponding domains). In consequence, for instance, the data gathered by the instrument Moderate Resolution Imaging Spectroradiometer (MODIS) regarding the color of the ocean would be managed at the datacenter of GSFC, whereas the data gathered by the same instrument but related to the surface temperature of the ocean would be managed at JPL[399]. Also at ESA, the ground segments of ERS-2 and Polar-Orbiting Environmental Mission (POEM, future ENVISAT) that were in the course of being designed provided for a distribution of specialized domains of research across different sites in Europe –some of those in Villefranche sur Mer, as we will see in a while.

These different loci had been named in 1982 by NASA, after they had been proposed already by the authors of the 1982's report issued by the Space Sciences Board discussed before, "thematic poles"[400] and came to be known in France easily as "pôles thématiques". As understood by 1992 the POLDER thematic poles, henceforth just "poles" for the sake of lighting the reading, would constitute scientific centers erected around a scientific problem[401]. During the instrument preparation and development phase of the data infrastructure, scientists in these poles would develop the scientific algorithms, their coding, their "maquettage" and integration, and would plan their test and validation. After the launching, they would be responsible of assessing the quality of the data through a procedure known as data validation (which we will address in the next chapter), of improving their scientific algorithms or of developing new ones. They would be a sort of scientific branch associated to the data factory, which assembled the technical workings of mass-production, dissemination and storing. Taking this

[398] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.
[399] "Earth Observing System (EOS) Reference Handbook", eds. G. Asrar and D. J. Dokken, 1993.
[400] "Data Management and Computation. Volume 1: issues and Recommendations", Space Science Board, 1982.
[401] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

hypothesis of a distributed ground segment for POLDER's data, LOA was proposed in 1992 to take in charge the atmospheric mission of POLDER, without ever losing sight of eventually implementing a data factory dedicated to process, store and disseminate the data of all satellites related to atmospheric physics that were about to be launched by CNES and ESA[402]. By then, being the "pole atmosphere" of POLDER signified developing and testing the scientific algorithms, and later on assessing the quality of the datasets generated with them to detect aerosols and characterize a number of their properties, in particular quantifying their radiative impact at a global scale, their cycle of generation at the surface, rise and transport in the atmosphere, and some forms for correcting the signal from their effects. They would represent the figure of data creators, those scientists whose main function is to articulate a physical interpretation of the satellite measurements in order to prepare their further interpretation in geophysical terms.

Box 3.1. Characterizing the tropospheric aerosols with POLDER

Studying the climate forcing, or radiative forcing, that is the difference of radiant energy received by the Earth (mostly coming from the Sun) and energy radiated back to space, was a hot topic of scientific research in the early 1990s and one of the main goals of the international scientific program World Research Climate Program (WRCP). That changes in the forcing emanated, among others, from changes in the concentration of aerosols in the troposphere was common knowledge by then (they impact on the Earth radiation budget directly by modifying the Earth's albedo, and indirectly by affecting clouds' optical properties); however, a quantitative assessment of such an impact was not yet achieved, because no data about their global distribution and characteristics existed. This would be defined as one of the scientific applications of POLDER data: characterizing the aerosols and quantifying their radiative impact at a global scale. Another one would be to globally map the type and concentration of tropospheric aerosols in order to study their generation at the surface, their rise and transport in the atmosphere. This aligned with the two main goals of the International Geosphere-Biosphere Program: to study the carbon cycle (aerosols may affect phytoplankton primary productivity and vegetation growth) and to study the energy changes between the surfaces (land and ocean). There was still another incentive for the determination of aerosol optical properties: the fact that they induce a large perturbation in remote sensing of the surface. In particular, the correction of the aerosol signal is of uppermost importance for ocean color detection since the aerosols reflectance is often larger than the desired ocean surface reflectance signal. Similarly, in the visible spectrum, vegetation reflectance and atmospheric aerosol reflectance have the same order of magnitude. To observe the oceans and the vegetation cover it is therefore necessary to correct the signal from aerosols' optical effects accurately[403].

From a technical standpoint, to detect and characterize the properties of the aerosols, POLDER would exploit the novelty of its polarized measurements. Over continental surfaces, the difficulty of detecting aerosols resides in separating the contribution of the radiation reflected by the target and that reflected by the atmosphere because both range in the infrared bands of the spectra. It was concluded that POLDER's ability to characterize aerosols over land surfaces would not be accurate enough to be scientifically significant. However, over the large water surfaces (like the oceans), and provided that there are no clouds, measurements at the top of the atmosphere

[402] « Compte-rendu de la réunion du groupe de travail du segment sol POLDER », October 1992.
[403] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps et al, 1994.

correspond majorly to the atmospheric component (oceans are dark) and can be used to derive the properties about the tropospheric aerosols, such as their shape, size, refraction index or chemical composition.

The Commissariat à l'énergie atomique (CEA), a federative, long-term and industrialized partner: Nuclear reactors and satellite instruments

If the atmospheric pole was to be located at Lille, where were to be located the pole (or poles) for oceans and land surfaces? Studying the color of the ocean was a useful manner to remotely assess the biological productivity of ocean waters, which in turn was a way to evaluate marine biosphere resources and to study their role in the global carbon cycle. The scientific interest of such measurement had been demonstrated in 1978 with the observations taken by the instrument Coastal Zone Color Scanner (CZCS) aboard of Nimbus-7, in which Pierre-Yves Deschamps had been a co-PI (of the data-analyst type) leading a project to improve the atmospheric corrections of the signals measured by the scanning radiometer. Ever since, the field of remote-sensing the color of the ocean had shot up and several instruments were being developed to that purpose, including the Japanese Ocean Color and Temperature Scanner (OCTS) aboard of ADEOS-I (which was considered by NASA and NASDA as the successor of the CZCS[404]), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) of Goddard Space Flight Center of NASA (successor of OCTS), the Moderate Resolution Imaging Spectroradiometer (MODIS) of Goddard Space Flight Center of NASA or the MEdium Resolution Imaging Spectrometer (MERIS) of ESA. The measurements gathered by this succession of instruments launched from 1978 up to date would be all processed with similar algorithms, deriving from those developed in 1974 by André Morel[405], a physical oceanographer director of the Laboratoire de Physique et Chimie Marine (LPCM) based in Villefranche sur Mer, who was also involved in MERIS, MODIS and SeaWiFS. They would constitute a kind of standardized line of data production about the biological properties of the oceanic water, producing much more spatially resolved datasets than those that POLDER would produce (SeaWiFS's space resolution was from 1,5km to 4 km, depending on the scene, MODIS ranges from 1 km to 500 m, reaching in some occasions 100m, while POLDER's remained in the order of 6km). In other words, POLDER's retrievals about biological properties of the sea water would be less accurate to study some of the biochemical processes, the interest of POLDER's measurements would rely, by contrast, in the highly precise atmospheric corrections that it would allow due to the possibility of accurately characterize the aerosols and their effects on the oceanic signal.

[404] "Ocean Color Imaging: CZCS to SeaWiFS", S.B. Hooker et al, 1993.

[405] Actually, one of André Morel's most cited studies is devoted to scattering and attenuation coefficients of pure water and pure seawater. It was, for instance, used as the theoretical basis for developing the processing algorithms of CZCS at GSFC (and later on OCTS, SeaWIFS, MODIS and MERIS): "Optical properties of pure water and pure seawater", A. Morel, 1974. Some applications for CZCS and MERIS are: "Atmospheric corrections and interpretation of marine radiances in CZCS imagery: use of a reflectance model", A. Bricaud and A. Morel, 1987 and "MERIS potential for ocean colour studies in the open ocean", A. Bricaud et al, 1999.

Box 3.2. The ocean color seen by POLDER

When POLDER overflew the oceans, what POLDER captured was the energy reflected by the oceans, that is the color of the oceans, after propagation upward through the atmosphere. Measuring the color of the ocean is actually a direct measurement, since the color is associated to the reflectance. The presence of chlorophyll, sediments, or other material in the water modify such radiation, due to absorption, and so the measured color. Therefore, the measured color can be used to retrieve, with the appropriate inversion algorithms, several quantitative parameters to map chlorophyll concentration in water, sediment distribution, salinity or temperature of coastal waters, by relying on physical relationships between these elements in the water and their absorption properties. In addition, because phytoplankton materials behave like passive tracers, ocean color observations could also be used to depict specific dynamic oceanic features like eddies, plumes and meanders. POLDER's measurements were actually reckoned not to be the most accurate for retrieving biophysical properties from the reflectance, because of the coarse spatial resolution of the instrument. Indeed, the relevant scales for global biogeochemical studies of ocean color variability range from more than 10km over the open oceans to less than 1km over coastal areas, whereas the resolution of POLDER was limited to $6km^2$. While for global studies it would be appropriate, for coastal water studies, POLDER resolution would be insufficient[406].

Instead, the strenghtheness of POLDER's measurements was considered to rely in their capacity to provide information about the aerosols. When observed from space, the ocean signal is mixed with an atmospheric scattering signal that is typically 10 times larger. It is technically quite difficult to accurately correct these atmospheric effects: while Rayleigh scattering is easily computed from a theoretical model using geometry, atmospheric pressure, atmospheric ozone amount, wavelenghts and a good calibration, aerosols scattering is much more complicated, partially due to the lack of information about the aerosols. POLDER's measurements were especially appropriate for that because the multiangular measurements of polarization light allowed characterizing some optical properties of the aerosols, including their radiative scattering, and therefore corrections may be improved[407]. This had been, after all, the original objective of the POLDER instrument as proposed back in 1986: to use the polarized multi-directional measurements of POLDER to correct the signal of SPOT's measurements from the aerosols' perturbations[408].

In the search for scientific partners for transfering the responsibility of the "pôle océan", and eventually also of the whole data factory, the "groupe projet" contacted the responsibles of the data handling of the spectrometer MERIS, whose primary function was to measure the color of the ocean, and which was in the course of being developed after being selected by ESA to be put aboard its flagship environmental satellite, POEM (the future ENVISAT). In 1992, two French companies, AEROSPATIALE and ACRI, had associated with the Conseil régional Provence-Alpes-Côte d'Azur to begin the studies for the realization of a « Pôle d'Excellence Couleur de l'Eau » in the technology park of Sofia Antipolis. They intended to present a proposal for a datacenter, essentially similar project to CERSAT (for ERS-1 data), for which they expected to be conceded a contract by ESA in the frame of

[406] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.
[407] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.
[408] "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

the industrial “fair return” of the investments of France in the European project ENVISAT[409]: it was a computing facility where data from MERIS would be processed, stored and distributed. This datacenter counted with the scientific support of professor André Morel, the director of the Laboratoire Physique et Chimie Marine, internationally reckoned for his work in remote sensing of ocean bio-optic properties by means of analyzing the color of the water, including the determination of optical properties of the sea, bio-optics of organisms, bidirectional properties of the water leaving radiances, chlorophyll distribution and primary production, relationship between primary production and CO_2. This project, still in the course of being preliminary studied, constituted a scientifically sound initiative (it was supported by one of the most acknowledged experts in remote-sensing of the ocean color) and technologically feasible (these industrials and software societies were deemed as competent in the domain).

In the light of this project, hence, it was envisaged a combination of efforts to establish a thematic pole dedicated to handling the data of the color of the ocean gathered by POLDER and by MERIS[410]. However, it was concluded that this initiative was « peu attrayant »[411]. We have not found enough reliable sources to enter into the details and to conclude, but it appears that several points of different nature appeared to hinder such joint endeavor. First, it was not clear whether POLDER’s algorithms would receive scientific credentials per part of the responsibles of the MERIS-data factory, who believed that POLDER was not an appropriate instrument for marine biology studies because data were not resolved enough. Secondly, and connected to that, POLDER’s algorithms presented an alternative to those semi-standardized of MERIS and it was not clear either whether the computer system would be powerful enough to implement different lines of processing –or whether the budget would be large enough. Third, the MERIS project intended to take a commercial orientation that POLDER’s responsibles refuted. Fourth, this possibility raised a number of institutional frictions between CNES and ESA about the distribution of budget and its effects on other programs. Moreover, fifth, it existed a more “attracting” option, one named Commissariat à l'énergie atomique (CEA).

CEA had a long story in relationship with space activities (recall that one of the “selected laboratories” back in the 1960s was the Service d’électronique physique of this organization) and also a long story in relationship with studying the Earth and its environment. However, it had only recently merged them through creating a new laboratory in 1991, le Laboratoire de Modélisation du Climat et de l’Environnement (LMCE) with a scientific program based on ocean and atmospheric physics

[409] ESA’s policy of “fair retour”, or the set of rules relating to geographical distribution of the industrial contracts, provided by a ratio between the share of a country in the weighted value of contracts, and its share in the contribution paid to ESA’s budget. The more you contribute, the more industrial contracts you are allocated back.

[410] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[411] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

emphasizing the use of satellite data to study marine and continental biomasses[412]. François-Marie Bréon, who often was solicited to participate in the meetings gathering scientists and the "groupe projet", had been precisely one of the first scientists recruited at LMCE, after his return from his fellowship at the Scripps Institution of Oceanography in La Jolla in 1991. We ignore the influence that the young scientist could have ever had at that time in any institutional decision of CNES or CEA, but he certainly had his own career perspectives and scientific interests and goals, and participating in the project POLDER was certainly one of them.

According to the minutes of one of the many meetings hold during 1992 between CNES and CEA representatives, the partnership would suit both parties. The Laboratoire de modélisation du climat et de l'environnement (LMCE) would be

> « vivement intéressé à une contribution au développement et à la gestion d'une part à définir du segment sol POLDER (…) Cela serait conforme avec ses priorités scientifiques, valoriserait sa capacité de participation à des projets à caractère semi-industriel, permettrait les reconversions internes des personnels et permettrait d'affirmer une identité CEA environnement en se positionnant dans le spatial »[413].

The recruitment of François-Marie Bréon responded exactly to the scientific objectives of the new created laboratory; expert in atmospheric corrections to be applied to satellite measurements over the oceans or the land surfaces, he personified the new directions taken by CEA.

On the other hand, the LMCE was also a convenient partner to CNES because

> « une contribution du CEA pourrait réduire les coûts de développement et d'exploitation du segment sol POLDER à la charge du CNES »[414]

and because of its expertise in semi-industrial data handling and computer coding (of data generated by nuclear reactors), could

> "établir les spécifications des produits des niveaux 2 et 3 du segment sol POLDER, coordonner et assurer les développements algorithmiques et les maquettages logiciels associés, établir des spécifications industrielles pour le développement des chaînes de production au sein du Centre de production, valider les chaînes et les produits"[415].

Indeed, because of its ties with CEA (and particularly due to the reconversion of many of the former nuclear-data experts into some other form of data-experts[416]), LMCE had the technical means, skilled personnel and material for coping with data in an semi-industrial manner –data coming from a nuclear

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[412] In 1998, the Laboratoire de modélisation du climat et de l'environnement would fuse with the Centre des faibles radioactivités of CEA to become the Laboratoire des sciences du climat et l'environnement (LSCE), a mixed laboratory tied to CEA-CNRS-UVSQ (University of Versailles and Saint Quentin).

[413] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[414] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.

[415] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992

[416] This point has also been noted by Hélène Guillemot, who found a number of nuclear physicists reconverted into climate modelers further to a reorientation of the French research priorities in the 1980s.

"La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », H. Guillemot, 2007.

reactor or coming from a satellite, data about sub-atomic structures or about the chlorophyll content of the oceans, were all digitalized data at the end of the day.

Finally, to the program managers at CNES,

> « aucun autre organisme à part le CEA n'a les moyens d'établir une politique de coopération inter-organismes, susceptible d'assurer la pérennité et l'évolution du système de gestion de données, conformément à une politique scientifique à moyen terme cohérente avec les investissements spatiaux"[417].

Savings, expertise and semi-industrial capabilities in digital data processing, and possibilities for long-term partnership. The later was very important to CNES, because it was also about placing the participant organizations within a long-term perspective of collaboration in order to eventually transfer also the mass-production, dissemination and storing of the data of the future projects[418]. Besides, CNES sought to gain visibility amongst national institutions involved in scientific research, and a long-term inter-organism partnership with CEA, so it was argued by CNES managers, could do nothing but promote this visibility[419].

Along these lines, the Laboratoire de modélisation du climat et de l'environnement (LMCE) presented still another feature that favored the collaboration. LMCE was not only institutionally bound to CEA, but also to a new research institution, originally called Institut Spatial de l'Environnement Terrestre, whose constitution, composition and scientific program was at that time being discussed and that had received support from the president of CNES since its very gestation[420]. This institute had been instigated around 1989 by Gérard Mégie, physicist at Service d'Aéronomie of CNRS, whom we have already met in several occasions[421]. This institute aimed to federate all the laboratories specialized with different disciplines of the Earth sciences of the Parisian region -which together summed more than 50% of the national scientific effort in these fields[422]. The "selected laboratories" of the Parisian region involved in these disciplines were actually actively participating in the federative move (the Service d'Aéronomie as the main instigator, but also the Laboratoire de

[417] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

[418] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[419] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[420] In a letter addressed to Gérard Mégie, Jacques-Louis Lions, president of CNES, confirmed that « je suis 100% favorable au dossier « Institut Spatial… ». Je vais faire mon possible pour le faire soutenir pour le CNES ». Letter of J.L.Lions, president of CNES to Gérard Mégie, 22 February 1991.

[421] As explained in Hélène Guillemot's dissertation, even though at the outset of the project for establishing the Institut Spatial de l'Environnement Terrestre, as its name suggests, a big focus was put on the role of satellite projects (both instrumentation realization and data analysis and storing), as the project got maturity and was established, the space component resulted quite tempered, even disappearing from its name, called henceforth Institut Pierre Simon Laplace (IPSL).

"La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », H. Guillemot, 2007.

[422] This Parisian project for a data archive was contested by several fronts. Most critics denounced precisely that the centralization of resources jeopardized the scientific developments of non-Parisian regions. Along the same lines, some others argued that satellite data management must be a national issue addressed by an effort coordinated at a national scale in order to guarantee equal data access possibilities to all scientists, and not a regional one providing only data access to Parisian laboratories.

"Rapport d'automme 1994 sur l'état de dévéloppement de l'Institut des Sciences de l'Environnement Global », prepared by Philippe Bougeault, September 1994.

Météorologie Dynamique and the Centre de Recherche en Physique de l'Environnement Terrestre et Planétaire), which would be constituted in 1994 under the name of Institut Pierre Simon Laplace (IPSL). Being bound with such federative institution through LMCE was seen important to both to POLDER's advocates in three connected ways. First, there was some skepticism concerning the stability and orientation of this CEA's new laboratory, the LMCE, which appeared to overlap some research problems and methodologies already addressed by other centers. However, belonging to this new institution provided credibility and soundness to LMCE's scientific program and a guarantee that it would be properly oriented –this was, at the end of the day, the whole point of such a federation, to join efforts[423]. This argument was transposable to the instrument POLDER itself, and this is the second way: by introducing POLDER within the framework of what would become a federation of scientific laboratories mobilizing more than the half of the scientific production in France in the field of Earth sciences, POLDER would be backed by the scientific credibility of such a force. As a consequence, a credible scientific program around the instrument could be finally constructed, mitigating by so doing one of the main critics to POLDER, namely, its lack of scientific project. Ties to this federative institute through LMCE, this is the third argument, provided as well a framework for connecting POLDER to a number of laboratories working in the fields of oceanography, atmosphere and vegetation studies which were not involved in the preparation of the instrument and its data (such as the Laboratoire d'Océanographie Dynamique et de Climatologie, the Laboratoire de Météorologie Dynamique, the Centre de Recherche en Physique de l'Environnement Terrestre et Planétaire and the Service d'Aéronomie). In other words, it was a way to smooth the outreach of future *data users* of POLDER and to seek to optimize its utilization, and therefore to maximize the investments.

There was however one sensible point of contention with respects to the possible partnership with the future federative Institut Pierre Simon Laplace: as a part of the future institute, a working team had been set in 1991 to study the establishment of a datacenter charged of archiving and distributing satellite data about the Earth's environment. This datacenter aimed to maintain an internal data archive and to put it at disposition of the different laboratories of the institute; eventually, it would also, may deal with some forms of data processing. Since POLDER was scheduled to launch in 1995, its data were considered as an opportune test for the information system developed in this datacenter: POLDER would constitute a case to test a first prototype for developing, in a second stage, a complete information infrastructure for archiving and distributing satellite (and non-satellite) data in areas like tropospheric and stratospheric physico-chemistry (with data coming from POAM, GOME, GOMOS and IASI)[424] or radiation budget and atmospheric sounding (ScaRaB and IASI)[425].

Similarities with the project of a datacenter at Lille were obvious. The projects in Paris and Lille were just too similar to be both approved, as confirmed by the Director of the division of "Terre, Océan,

[423] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992.
[424] « Document scientifique de présentation. Contrat de plan Etat-Région », prepared by Gérard Mégie, February 1993.
[425] « Convention de création de la fédération d'unités Institut Pierre Simon Laplace », July 1994.

Espace, Environnement" in the Ministry of Research in a letter addressed to Gérard Mégie in 1991 in which he warned that "la communauté scientifique française est trop faible pour que des projets concurrents puissant se développer, en particulier dans le domaine de la recherche climatique"[426]. Some of the documents that we have consulted reflect that the most immediate capabilities of the concurrent project in Paris, which counted already with the powerful computer center of CEA in Orsay or with a critical mass of scientists major than in Lille, were perceived by the consortium LOA-University of Lille-Région Nord Pas de Calais as threatening their plans of setting up in the near future a data factory for satellite data in the field of atmospheric physics. LOA's scientists' reluctance was, at least partially, rooted in their own experience of the damages that could be done when two projects competed for a limited budget. Pierre-Yves Deschamps, for instance, had lost the chances of reactivating an oceanographic branch at LOA when CNRS decided to centralize the expertise of such discipline in Bretagne, as we have described. We have also already mentioned the cases of concurrent projects at NASA, which lead to reducing budgets in its missions to Venus and Jupiter[427] with the consequence, in France, that a number of LOA's scientists, including Maurice Herman, must recycle their domains of expertise. LOA's scientists feared that the most immediate capabilities of the Parisian proposition, the interests of CNES as an institution to support the future Institut Spatial de l'Environnement Terrestre or the critical mass of scientists involved in the project would wreck their chances to become the "atmospheric pole" of POLDER and eventually one day a datacenter for atmospheric physics[428].

We do not however want to leave the impression of a dramatic and conflictive situation: the proposition of concurrent projects is after all commonplace in scientific and technical developments. If this particular one was especially conflictive, we have not found any trace of that. We have not found either in the archives the particulars about how the choice was made. According to some interviewers, Gérard Mégie's people skills and tactfulness were crucial to reach a solution[429]: while, as planned, a lillois consortium (LOA-University of Lille-INSU-CNES-Région Nord Pas de Calais) would assume the role of the "atmospheric pole" for POLDER data, that is, responsible to ensure the scientific quality of POLDER algorithms and data, the Parisian project would then be dedicated to data in the domain of atmospheric chemistry involving other missions than POLDER. To complete the panel of actors, and to conclude this part of the chapter, let it be added that LMCE would become the "ocean pole" of POLDER. Its responsibilities would be the same as the pole lillois but regarding the data about marine biochemistry. As per the processing of the data, after a period of test at the Technical Center of CNES in Toulouse, the system would be transferred to the Commissariat à l'énergie

[426] Letter of J. Labrousse, Director of the Directorate Terre, Océan, Espace, Environnement of the Ministry of Research and President of the Executif Comittee of PIGM, to Gérard Mégie, 5 April 1991.

[427] For the interested readers, in his book "The Space telescope: A Study of NASA, Science, Technology and Politics", 1989, the historian Robert Smith offers an account, from a political sciences perspective, of the decision of NASA and the Congress that favored the realization of the space telescope Hubble in detriment of the planetary probes.

[428] Interview with Maurice Herman, LOA, 2014.

[429] Interview with Didier Tanré, LOA, 2014.

atomique, which would ensure the production, dissemination and storing of the datasets during the time life of the instrument and their archiving during 10 to 15 years afterwards.

Enlarging the team: Disciplines and institutions of the "groupe mission"

By 1992, with a partner, the Commissariat à l'Energie Atomique, capable and willing to take over the responsibility of the factory of data during the exploitation of POLDER, the range of scientific participants in the POLDER project was widen up. They would conform what came to be known as the "groupe mission POLDER" or just "groupe mission", a sort of scientific team around the instrument POLDER or rather around its data. The function of such a team would be to design the technical specificities of the instrument, its calibration coefficients and methods, the preparation of the inversion algorithms, the setting of some data quality control and the conduction of such controls once the data would start to be produced after the launching of the satellite. In a sense, this team encompassed holistically the functions of a principal investigator of the ancient times.

In conducting his oceanographic program, Pierre-Yves Deschamps would collaborate with LMCE's scientists, provided that one of LMCE's objectives was precisely to make use of satellite data for oceanography research. In turn, in its oceanography program LMCE was expected to work closely together with the Laboratoire de Physique et Chimie Marine (LPCM)[430] and the Laboratoire d'Océanographie Dynamique et de Climatologie (LODYC), as they were also Parisian laboratories and thus involved in the federative project leading to the future Institut Pierre Simon Laplace. The field of expertise of LODYC was the numerical modeling of the oceans. They had no expertise in the physical interpretation of satellite measurements or in transforming such measurements into geophysical parameters, or in the building of instruments. In a questionnaire dated of 1990 in which the laboratory was asked about its eventual interest in participating in the before-mentioned project for archiving and disseminating satellite data that the Parisian future Institut Spatial de l'Environnement Terrestre was intended to implement, we can read that "le LODYC n'a pas pour vocation de construire des experiences spatiales. Il est utilisateur de données acquises par télédétection: SEASAT, SSMI, GEOSAT dans le passé et ERS-1, TOPEX, SeaWIFS dans le futur, puis GLOBSAT"[431]. It was not the vocation of LODYC, thus, to participate in developing POLDER's inversion algorithms or in assessing the quality of the resulting data –it represented an archetypical form of *data user*, interested in getting the geophysical datasets ready-to-be-used, and it defined itself as such.

A contrario, some of the scientists of the Laboratoire de Physique et Chimie Marine, especially those associated in the branch located in Villefranche sur Mer, had been working for some years in the domains of oceanic biology and chemistry with remote-sensing technologies, aircraft and satellite,

[430] The Laboratoire de Physique et Chimie Marines had two sites, one in Villefranche sur Mer and the other in Paris.

[431] Answer of L. Merlivat, director of LODYC, to a preliminary poll launched by Gérard Mégie called « Sur l'opportunité de participer à un « Institut Global Change » », October 1990, in views of starting up the project for establishing the Institut Spatial de l'Environnement Terrestre.

under the direction of André Morel, the oceanographer whom we have already met before. Actually, back in the early 1980s a number of joint field campaigns had been organized by teams of Villefranche, Lille, Roscoff and Wimereux. They were nonetheless not much interested in POLDER. In particular, as we have developed, some of them were already working in algorithmic development for some satellite projects in relation with the color of the oceans and atmospheric corrections: MERIS of ESA, SeaWIFS and MODIS, both of GSFC/NASA. This may suggest actually one of the reasons why scientists of such laboratory would not seem much enthusiastic about the idea of developing an oceanographic program using POLDER's data. Considering that there existed other instrumental toys to play with, and better resolved than POLDER, they saw no interest in investing to develop algorithms for retrieving biochemical properties from POLDER's measurements, whose coarse resolution did not enable some type of oceanic studies anyway. Besides, it is plausible to suggest that the oceanic part of this program may have been felt as a concurrent to the "pôle couleur ocean" in the course of being studied in the Provence-Alpes Maritimes-Côte d'Azur region for handling the data of MERIS, in which the Laboratoire de Physique et Chimie Marines was investing time and resources. Mirroring the concurrence between the atmospheric datacenter in Lille and in Paris, because of the limited resources, only one oceanic pole would be supported in France. And the partnership with the Commissariat à l'énergie atomique and with the future federation of laboratories was the clear preference of CNES, as clearly stipulated in several minutes[432]. To be sure, MERIS was an ESA's project and as such the ultimate decision laid on ESA's hands; CNES remained nevertheless a great influence in that decision in the sense that the chances for a space project to be approved by ESA use to be higher with CNES's imprimatur than without it.

In spite of that, there were some evident advantages in participating in POLDER for advancing in the studies about marine biology. POLDER's measurements of the ocean color per se were perhaps not such a precious asset; yet, POLDER's data on the aerosols properties did constitute a promising asset to develop improved and more accurate atmospheric correction algorithms to be further applied to the data from MERIS, SeaWiFS or MODIS. Besides, ADEOS embarked another radiometer, the Ocean Color and Temperature Scanner (OCTS), a mechanical rotating scanning devoted to the measurement of ocean color and sea surface temperature. This radiometer, because of its technology and performances, was considered to be the successor of a similar instrument, the Coastal Zone Color Scanner, aboard of Nimbus-7 and the predecessor of SeaWiFS. Those scientists working in the analysis of Nimbus-7 data or in the preparation of SeaWiFS data, and there were a number of them in LPCM, were well advised to take into consideration the data of the Japanese instrument OCTS aboard ADEOS-I. Given the fact that Japanese data-sharing policies were quite constraining by then, the easiest way to have access to such data was through participating in the "groupe mission" because, as

[432] « Compte-rendu de la réunion entre le CNES et le CEA/LMCE sur le Segment Sol POLDER et les perspectives de coopération », April 1992 and « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992.

we will emphasize in a while, being a part of the scientific team involved having some privileges on the data access.

The atmospheric program around POLDER, even if the pole was to be located at Lille, would result also reinforced by bringing in the Institut Pierre Simon Laplace, in particular the Laboratoire de Météorologie Dynamique (LMD). From a scientific perspective, LOA's atmospheric program was centered in the characterization of the aerosols with less emphasis, although not inexistent, in the domain of clouds. LMD's scientists would complete the program of characterizing clouds. Besides, by quantifying the relationship between these two components and the radiation budget a climatological program would be also built around POLDER's measurements –a domain in which some scientists of LOA and LMD had actually been long collaborating[433]. It was interesting to bring LMD, as an institution within the project POLDER, from another standpoint. LMD had been created in 1968 as a "selected laboratory" and counted with a long tradition and expertise in space research and in working together with CNES. Some teams of LMD had a long expertise as satellite instrument builders, for instance, in the project EOLE in 1971, the radiometer inside Meteosat, or the scanning radiometer ScaRaB. LMD was indeed a recognized laboratory in the space domain, but it was also well-known because of its instrumental capabilities with aircraft, balloons and surface instruments (mostly radiometry, spectrometry and lidar), the theoretical works about turbulence and convection, and the research related to one of the two global circulation numerical models being developed in France[434]. These capabilities and skills would certainly be useful in preparing the data and in assessing their quality. Besides, LMD counted with 78 members by 1991 (from which 33 permanent scientists, 26 doctoral students, 8 fellows and 45 technicians) almost triplicating LOA's manpower (28 permanent scientists in total), which made it a source of potential manpower working with POLDER[435]. Not that everybody at LMD would work in the project, but certainly some of them would do. Equally important, involving LMD in the project, so it was argued, may eventually contribute to give POLDER a certain standing, to place in a more central position a peripherical space project[436].

Box 3.3. POLDER, clouds and radiation budget

One was the scientific reason to develop a program in supporting the studies of clouds and Earth's radiation budget, apart from estimating the cloud level, optical depth, phase and horizontal structure. Several space instruments had been launched to observe the Earth radiation budget, such as the Earth Radiation Budget experiment on board of Nimbus-7 and the three-satellite Earth Radiation Budget Experiment, ERBE. Others were being developed such as ScaRaB and CERES at LaRC. The main source of error in these observations was,

[433] From an instrumental perspective, they had been working together, for instance, in the project ScaRaB. From a numerical modeling perspective, they had been working together in the codes of radiation budget of the model LMD. Rapports d'activité LOA, 1980-1995.

[434] See Hélène Guillemot's work for a history of the Laboratoire de Météorology Dynamique, especially of the numerical modeling branch: "La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », H. Guillemot, 2007.

[435] Rapports d'activité of LMD and LOA, 1990-1991.

[436] « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

apart from the challenging instrument calibration accuracy, the radiation field anisotropy. These instruments provided radiance measurements, as opposed to flux measurements. Since the solar radiation field reflected by the Earth system is not isotropic, the reflected flux can only be estimated with a priori knowledge of the bidirectional reflectances, which was often a very simplified approximation (see Box 3.4. for further explanations on the bidirectional function). POLDER provided simultaneously multidirectional radiance measurements, permitting the determination of new methods to derive the bidirectional reflectance signatures for various surfaces, cloud types and cloud amounts, which would help to improve the estimations of radiation budget measured by other instruments[437].

The last domain of applications of POLDER was the studies of the land surfaces and vegetation. Back in 1990, POLDER's measurements were expected to contribute to understand the carbon cycle by measuring global biomass and vegetation primary productivity over the land surfaces and in particular to identify the land cover, to detect changes, and to specify surface parameters. By 1993, however, scientists at LERTS, were no longer interested in POLDER's measurements in the vegetation carbon production. It turned out that studies evaluating the spatial resolution needed for global land surface surveys had recommended a resolution of the order of 500m, which POLDER was far to reach. Therefore, other instruments were considered significantly better than POLDER. This was the case of the instrument MODIS of NASA (with resolutions ranging 500-1000m depending on the spectral bands) or the instrument VEGETATION conceived and developed by a team of scientists of LERTS and planned to be launched aboard SPOT-4 (with a space resolution of 1km). Just like for the study of marine biology, the coarse space resolution of POLDER played againts its ability to support studies about vegetation. In the paper presenting POLDER issued in 1995, it was simply recognized that "POLDER spatial resolution is not optimum for vegetation remote sensing"[438]. That being said, like in the case of the measurements of the ocean color, POLDER may not be resolved enough to detect vegetation changes, but it provided unique information about the bidirectional reflectance signatures (the BRDF), which was needed to retrieve and process all data of any vegetation property.

Box 3.4. POLDER and the Bidirectional reflectance distribution function

The interaction between the incoming solar radiation and the Earth surface is characterized by the bidirectional reflectance distribution function (BRDF), a function that defines how light is reflected at an opaque surface. This function depends of a number of factors: the wavelength, the angles of incidence and reflection, the sensor viewing (and therefore of the time of the measurement and the orbital position of the satellite), or the physical and geometrical properties of the surface. This function is important twofold. First, it is of climatic importance, because it influences the exchanges of energy in the surface-atmosphere layer and therefore the global energy budget. Secondly, it is essential to solve the inverse problem and retrieve physical properties from the observed

[437] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.
[438] "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.

surfaces (like for instance, the photosynthetic activity of the vegetation and its density and, in consequence, assessing some of the parameters involved in the primary production).

It is however very difficult to determine due to its variability in function of environmental conditions (time of the day, weather conditions, presence of aerosols and other pollutants in the atmosphere, rainfall, humidity of the soils, etc.) and due to the lack of appropriate empirical data. Indeed, estimations about the parameters determining the BRDF used to be conducted before the 1990s with instruments measuring in one singular angular geometry (geostationary satellites) or with instruments measuring in multiangular geometries but introducing a number of assumptions about the environmental conditions (AVHRR and Vegetation). Since 1986, ERB carried instruments capable to observe in multidirection and in wide-field, but the spectral bands are not optimized to compute energy budgets in the surface but rather at the top of the atmosphere. Because POLDER measures the light reflected by a point from around 12 different directions and with a high repetitivity, directional information about a landscape can be derived while considering the environmental conditions as constant. In consequence, the computation of the BDRD is simplified, enabling the further retrieval of the corresponding physical parameters from the continental surfaces.

Legitimizing the "groupe mission": When technical agencies become creditors of scientific authority

POLDER had been proposed in 1986 to provide data to improve the measurements made by other instruments aboard SPOT-3 (the high-resolved radiometers and VEGETATION) by means of furnishing improved atmospheric corrections and characterizations of the angular functions. No scientific program in any domain related to disciplines of the Earth sciences had been originally developed, although it was broadly suggested that studies about clouds, oceans and vegetation would gain from using POLDER's data. This was the whole point of having been qualified with the attribute "multimissions", as discussed when introducing the instrument in the intermezzo: exacerbating the *interpretative flexibility*[439] of its data in a number of disciplinary fields. Being labeled as "multimissions" entailed *naturally* that a number of different disciplines would be supported by the data and that, we will come back to that point, the scientific program would be heterogeneous. Indeed, between 1990 and 1993, a concrete scientific program would be defined for POLDER's data, which would be characterized by two features: on the one hand, it would support research in a number of disciplines like marine biology, aerosols' cycle or the climatic effects of clouds, and, on the other, it would support research in the domain of remote-sensing per se (atmospheric corrections and determination of the bidirectional reflectance function).

What we want to address now is related to the way of depicting a scientific program around an instrument. In our case study, the scientific program of POLDER in the domain of Earth sciences came after POLDER: it was set after the conception and the approval of the experiment and in parallel

[439] We use the term introduced by Trevor J. Pinch and Wiebe E. Bijker, as we have argued in the intermezzo, to emphasize that different physical interpretations of the satellite measurements can lead to different geophysical datasets.

with the process of looking for reliable partners to transfer the data factory from CNES to an external scientific institution. It would be in the process of securing the exploitation of POLDER's data that a scientific team (or "groupe mission") would be gathered around the instrument and that a scientific program would be defined, stemming from the diverse expertise and interests of the members of such a team. These scientists were allocated with the epistemic power which authorized them to create geophysical datasets from POLDER's measurements and, by so doing, to define the type of studies that would be supported with the experiment POLDER. This way of doing may suggest that POLDER was an instance of technology push to get instruments and satellites launched even if they were not embedded in any particular scientific question –and with that we come back again to the discussion raised in the previous semi-chapter. While this interpretation may be appropriate in the sense that the experiment emanated from a team of scientists and engineers interested in manufacturing an instrument and testing its potentialities, it must be nevertheless recalled that POLDER did have scientific objectives to accomplish since its very inception: it had been conceived to improve the corrections of the signal by detecting and characterizing the perturbations originated by the presence of aerosols in the atmosphere or to determine the bidirectional reflectance function in the continental surfaces, which were two aspects essential for interpreting satellite radiometric measurements of any kind[440]. It was only that these objectives were scientifically meaningful in the domain of remote-sensing research, and only indirectly linked to the understanding of the physical processes governing the Earth and its environment. While these were scientific goals satisfactory for an experimenter of the instrument-builder type, they resulted meaningless to field scientists like marine biologists, climate scientists, physical oceanographers, meteorologists or glaciologists. These were objectives admissible for a physical approach to satellite data but not for a geophysical approach.

The definition of a scientific program to support such field disciplines would be only done through the selection of the members of the "groupe mission" in parallel with the process of looking for a reliable and appropriate partner to whom transferring the data-factory during the exploitation of POLDER. This process had been orchestrated between 1991 and 1993 by the "groupe projet" (project manager, program manager and project scientist, all agents of CNES), advised by some scientists associated with the instrument, in the process of looking for partners to entrust the factory-like mass-production, dissemination and archival of POLDER's data. It was this group of people who had ultimately configured the "groupe mission", or the scientific team of POLDER, and had confined its perimeter of functions.

Looking for scientists proactively was seen as a way « acquérir rayonnement national, bénéficier d'un nombre plus élevé de chercheurs et promouvoir un dynamisme scientifique à l'échelle nationale »[441]. We propose to interpret this proactive orchestration of the "groupe project" in the selection of scientists that would eventually compose the "groupe mission" of POLDER as a component of a

440 "Proposition de passage SPOT-3. POLDER: Polarisation et Directionalité des Réflectances", issued in February 1986.

441 « Document d'appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

general move to bring satellite data closer to a number of scientific disciplines (like oceanography, atmospheric chemistry, glaciology or vegetation studies) which had not taken full advantage of space technologies until then. By creating a scientific group *à la carte*, the "groupe projet" was actually assembling a handful of dispersed scientists around a particular object and providing them with means and tools to work in the preparation of POLDER's data, its validation and its further interpretation in their corresponding fields of expertise. In that way, CNES ensured that an enlarged French scientific community, who might not otherwise have participated, would be rallied around one of the satellite missions of the decade, POLDER. From these lens it is plausible to suggest that in the process of proactively creating a scientific team of data creators around POLDER, the "group projet" was contributing to the *reconciliation* between space technologies and scientists in the domains of marine biology, vegetation studies or atmospheric physics by means of setting up the pillars of a French scientific community well beyond the scientists that had proposed the instrument in 1986 and incubating a basis for eventually outreaching also to external *data users*.

By constituting the "group mission" a number of people and laboratories were brought in, which certainly participated to the clustering together, structuring and cohesionating of a community. In exchange, though, they renounced to two of the dearest principles of the institution of science: competition and peer review. This is precisely why some voices criticized such mechanism of creating a scientific team, which to their views was based on a proactive attitude of space managers in detriment of a genuine competition on the grounds of scientific excellence[442]. Instead, they advocated for opening an international call for proposals and selecting, through peer-review, those propositions judged more pertinent[443]. To them, POLDER was a scientific experiment and the social institution of science established the methodology of competition as a warrant of the quality of the research done with its measurements, since only the most scientifically excellent projects would be chosen by peers, which were considered to host the authority to judge on science affairs. This had been the way, as we have described before, through which a number of French scientists from the Laboratoire d'Optique Atmosphérique, the Laboratoire de Météorologie Dynamique, the Laboratoire de Physique et Chimie Marines or the Service d'Aéronomie (including the principal investigator of POLDER and closer collaborators) had got access to NASA's data from several instruments on board of Nimbus-7, Mariner 10, HCMM and AVHRR in the second half of the 1970s, or to ERBE in the 1980s; and this was being the way as well through which they had gained access to data from future instruments such as MODIS, MERIS or SeaWIFS. Opening to international proposals was not only a means to ensure scientific excellence, but also a strategy to outreach and widespread the use of data. NASA, for instance, was chief in opening international calls as a means to make sure that data would be used by a maximum number of scientists and as a means to gain visibility and credibility amongst non-NASA scientists. The responsibles of the project Topex/Poseidon at CNES and NASA, for instance, had released a joint announcement of opportunities as early as in 1985 (that is, almost six years before the

[442] Interview with Pierre-Yves Deschamps, LOA, 2014.
[443] « Compte-rendu de la réunion du groupe mission POLDER », October 1992.

scheduled date for launching the satellite (1991 by then)) as a means to "ensure maximum scientific participation in planning for and implementation of the Topex/Poseidon mission, thereby optimizing the scientific utility and reliability of the data"[444] –and around 38 PIs had been selected on the basis of an assessment of the projects presented in response to that call. To be sure, POLDER would have also an international "announcement of opportunities" released. But not before 1994, once the national "groupe mission" had been already settled, once many of the preparation activities were already underway (calibration, inversion) and once the plans for post-launch quality controls were being specified -and barely one year before of the scheduled date for launching (by then in 1995)[445].

Topex/Poseidon and POLDER missions portrayed two different maps of legitimizing the distribution of *epistemic authority*, that is, of crediting the holders of the expertise in a given field. The scientific team, both in the case of POLDER or in Topex/Poseidon, would be given the competence in describing techniques of calibration, in developing inversion algorithms, in evaluating the quality of the data and, in so doing, in defining a research program that the experiment was deemed to support. In other words, the authority to conduct science would be in both cases put in the scientific team made up of scientists that had participated in the design of the instrument and/or of its data –in the case of Topex/Poseidon, as we will see in a while, scientists external to the design of the instrument would also participate in the scientific group; however, the sources of legitimacy would differ. While the scientific team of Topex/Poseidon was credited by one of the most common practices of the scientific institution (a process ruled by a "call for opportunities", competition and peer review), the team of POLDER would be credited by an authority located in the "groupe projet", that is, stemming from the project manager, the program manager and the project scientist of POLDER, all agents bounded to a technical institution, CNES, all agents that ultimately would not create the data or use them –we insist in that this was not an imposition per part of the space managers but a process done in consultation with a number of scientists. What matters to us is that by evacuating the peer review and the competition, the role of the agents of CNES in the selection of the scientific partners became crucial. And this selection, as we have seen, was not driven, or at least not exclusively driven, by the traditional mechanisms like scientific excellence, but rather by other arguments, including the pressures for ensuring a smooth transition towards a factory-like data mass-production, dissemination and archival facility, the possibilities for long-term institutional partnerships or the urgencies in creating a community potentially user of space assets in France within a number of disciplines in the domain of Earth sciences, which had not taken full advantage of space technologies and which were growing in importance in the territory. More generally, this point illustrates the importance of technical institutions, CNES in particular, in legitimating the epistemic authority held by the "groupe mission". Underlying all these arguments and moves, the attentive reader may have already identified

[444] "Altimetry research in ocean circulation Topex/Poseidon**.** Announcement of Opportunity", calling released in the fall 1985, with the goal of constituting the team by December 1986.

[445] « Appel à Propositions de Recherche CNES-NASDA "POLDER sur ADEOS" », calling released in March1994.

the hypothesis overriding our essay, namely, the *reconciliation* between space technologies and Earth sciences.

EPISTEMIC SPECIFICITIES OF THE COMMUNITY POLDER

We have described the organization of the data-handling in two thematic poles centered in Lille and Paris regions intended to define the scientific program that POLDER was meant to support in the several domains of the Earth sciences. This bipolar configuration, as we have said, was reinforced by scientists from other laboratories, regrouped in what was called the "groupe mission", which would also participate in the specifications of the instrument, the calibration, the development of retrieval algorithms and in the subsequent quality control of the datasets.

The creation of the *groupe mission* would be actually comparable to the creation of a scientific group around an instrument in other experimental practices in other domains. In particular, the parallelism with the building of scientific teams in the case of the European particle accelerator CERN, studied by the historians Dominique Pestre and John Krige is striking –we will provide in some occasions certain elements of comparison[446]. We aim in this part of the chapter to shed some light in the epistemic specificities and the attributes that characterized this community. To that purpose we look at four features: the ways of working together, their disciplinary and institutional affiliation, the technological data practices that they articulate and their access to data. If we have chosen to explore the question from these four angles is because they contribute to define the relationship that individuals have with the data, the instrument and the experiment, and amongst each other. In other words, they illustrate the epistemology, the social organization and power relations, and the materiality of the practices defining POLDER's community.

Open and flexible membership

Scientists of POLDER's community would mostly belong to five different French laboratories, which would constitute the core of the POLDER-related scientific expertise, that is to say, those scientists defining the preparation of the data and therefore the scientific program that POLDER deemed to support: Laboratoire d'Optique Atmosphérique of Lille (LOA), Laboratoire des Sciences du Climat et de l'Environnement of Saclay/Paris (LSCE/IPSL), Laboratoire de Physique et Chimie Marine of Villefranche sur Mer (LPCM), Laboratoire de Météorologie Dynamique of Paris and Palaiseau (LMD/IPSL) and Laboratoire d'Etudes et de Recherches en Télédétection Spatiale of Toulouse (LERTS). In 1994, once the basic scientific and technical features of the instrument would be defined, the *group mission* would launch a call for propositions to constitute an international scientific team, widening the scope and number of scientists potentially interested in the calibration, validation or

[446] "History of CERN. Volume II: Building and Running the Laboratory, 1954-1965", A. Hermann et al, 1990.

utilization of the measurements gathered with POLDER[447]. Around 30 teams would be chosen by 1995, mostly from Japan and US[448].

Although we can deduce some of the members of the "groupe mission" because their names appear regularly in the minutes of the meetings or because they sign the presentations done at the numerous periodical reviews organized by CNES's managers to control the progress of the project, we have not found, among the archives that we have consulted, any document spelling out the names of the components of the "groupe mission". This lack of specification for membership suggests at least two points. First, it suggests that there it not existed a closed list and that, a part from what we may call the core scientists (the scientists usually participating in the meetings with the "group projet"), the "groupe mission" was opened to a larger workforce willing to invest in the project. Actually, if we look at the names and institutional affiliation authoring the publications related to the preparation of POLDER's data, we find more than 30 different names belonging to around 7 French laboratories (there were also authors from Japanese, Canadian and American laboratories)[449]. When we look at the people publishing articles about the activities of assessing and checking the quality of the geophysical datasets after the launching of ADEOS, then the number rises up to around 50 different names related to also around 7 laboratories –although some of the laboratories changed (again, without counting foreign scientists and research centers)[450]. Students, doctoral candidates, postdoctoral fellows, professors and visitor scientists in the main five laboratories or in others (like in the Centre National Recherches Meteorologie of Meteofrance in Toulouse, Institut National de Recherches Agronomiques in Avignon, the Institut Géographique National, the Goddard Space Flight Center of NASA or the Scripps in La Jolla). Not all these laboratories would participate in the activities of the group with the same intensity though. At LOA was where the activity was the most intense. The number of scientific effectives would increase from 28 in 1991 to 42 in 1995; an increase due mostly to the increase in the number of doctoral students and other temporary fellowships "grâce en particulier au côté attractif de POLDER", as it was stated in the Rapport d'activité of 1995 (from 10 doctoral students in 1991 to 19 by 1995). Likewise, the number of technicians increased from 10 to 14 during the same period –note that 4 and 9 of them were recruited under contracts of CNES[451]. Actually, at LOA more or less every scientists or technician was in some degree related with the project POLDER, whether in instrument calibration, in atmospheric correction, in radiation transfer models, in developing inversion algorithms, in preparing validation plans, in developing the network of sun-photometers development.

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447 « Appel à Propositions de Recherche CNES-NASDA "POLDER sur ADEOS" », released in March 1994.

448 "POLDER Validation Review Proceedings", prepared by Anne Lifermann, July 1998.

449 We have based this counting on a fusion of the lists of publications that can be found at the website of the mission POLDER maintained by CNES and at that maintained by the datacenter ICARE. Although both lists are incomplete –we have found ourselves peer-reviewed articles missing- its figures are indicative of the main tendencies: http://smsc.cnes.fr/POLDER/A_publications.htm and http://icare.univ-lille1.fr/drupal/publications

450 See the lists of publications: http://smsc.cnes.fr/POLDER/A_publications.htm and http://icare.univ-lille1.fr/drupal/publications

451 Rapports d'activité of LOA, 1990-1995.

Second, membership would not be static either, but rather flexible, changing, variable. Different institutions and colleagues may be enrolled at different stages of the project development as scientists moved from one laboratory to one other before obtaining a permanent position or as their research interest evolved rendering them interested by POLDER or making them abandon the project. The scientists of the laboratories of the Technical center of CNES in Toulouse, for instance, were very numerous and present during the early stages of designing the instrument and calibrating it in the laboratory; as POLDER was materially realized, constructed and basic calibration was done, these scientists would leave the project. A similar move would take place at LERTS: those scientists involved in the geometric calibration of POLDER would abandon the project once the satellite was launched and the calibration methods were stabilized around one year later. Similarly, the scientists of the Laboratoire de Physique et Chimie Marines who had developed some inversion algorithm for retrieving biological properties from the measurements of the color of the Ocean Color and Temperature Scanner ocean, would not participate in POLDER-2 probably because ADEOS-2 did not carry the instrument Ocean Color and Temperature Scanner. By contrast, other scientists would join the project as it advanced in its stages of development. From 1996 to 1998, when first data would be available, the number of scientists at LOA working in the validation of the geophysical datasets would increase from 42 to 49[452]: these would be scientists that had developed some algorithms and wanted to test them with real data or other scientists experts in other instruments (aircraft lidar, ground networks of radiometers, data from Meteosat, and so forth) who wanted to assess the quality of POLDER data with respects to these alternative datasets –we will come back to this activity in the next chapter.

The absence of a closed and fixed list does not mean, this is a third point, that anyone could be a member of the “groupe mission”. Rather, it illustrates that membership was characterized by other means. Let us now explore three of them.

Epistemic specificities

Common ways of working: CNES’s rules of management

The goal of the scientists of the “groupe mission” would be then to prepare the utilization of the future data of POLDER. This included defining the characteristics of the instrument, scientific objectives of the experiment, studying the prelaunch and post-launch calibration methods, developing the algorithms to convert the measurements into meaningful geophysical parameters, planning a validation plan to control the quality of the resulting geophysical data, and studying how to display the derived parameters in the most useful forms for scientific investigations conducted by a broader number of scientists, the *data users*, not involved in these preparation duties. The results of their work of preparation of the utilization of the data would be compiled in a document called the “technical specifications” or “specs”, which would be released in its first version in 1992 and successively modified as new scientific and technological insights would occur before the effective launch of

[452] Rapports d’activité of LOA, 1995-1998.

ADEOS-I in 1996. The "technical specifications" refer to an explicit set of requirements to be satisfied by the project POLDER and constitute the reference document describing the basics of any given project (detailed description of the sensors, the processors, the integration with the rest of the satellite, the frequencies, the orbit and conditions of measurement, information systems, deadlines of production, etc.), a sort of contract between proponents of an instrument (the scientists) and the manufacturers of its components (the industrials) mediated by the space managers of the Technical Center in Toulouse (directed by a project manager), and understanding and agreement upon all the requirements of the project. The "specs" constituted actually one of the numerous documents that POLDER, and more generally all space projects, would generate in the course of its preparation. This was one of the effects of the industrialization of space projects and of the introduction of managerial rules in the Technical Center of Toulouse: increasing the production of paperwork as to facilitate the circulation of information between different parts working more or less autonomously. This was, after all, an effect of the division of labor and specialization characteristic of Big Science projects; because different sectors may work in parallel separate each other –sometimes in the distance, and sometimes even in time (because space projects lasted at least a decade to be developed and realized), so the managerial argument goes, everything needs to be kept to make sure than anyone can take over the project.

One other characteristic of the ways of running POLDER, and space projects more generally, were the high frequency of meetings. Once or twice per month, or even more frequently in function of the stage of the project, meetings gathering the scientists of the *group mission* would be convened with the goal of defining the technical specifications of POLDER. The "groupe project", typically the Project manager or the Project scientist, would ensure the secretariat of these meetings by animating them, proposing the agenda, assembling the conclusions, diffusing the minutes and convoking new meetings. In the course of these meetings the work of each scientist, who tended to remain autonomous one of the other working in their particular scientific question, would be presented before the rest of the audience, which collectively would assess the performance, potential, improvements or limitations. These regular meetings obliged every scientist to synthetize his/her results, to communicate and share them with the rest and to discuss the work carried out by the others. The individual contribution of every scientist would be made visible in these meetings, the different activities would be coordinated and the different pieces of work would be brought together, creating the perception of a whole. Through these meetings the different visions of each scientist would be confronted and a common vision of the project would be constructed, in spite of the heterogeneous origins, goals and affiliations of the participants. A common shared representation of what POLDER data would be and what they would be for would be collectively created. One particular form of such meetings, which exacerbates their cohesion properties, are the so-called "reviews". Typically, they are highly formal meetings used as control gates at critical points in the cycle of development and realization of a project, for instance, when the development of a component of the project, or a particular stage of it, comes to an end in order to assess whether it has achieved its objectives, or when unexpected developments have come into play in order to determine the pertinence of continuing with project as planned, modifying it or abandoning it. For instance, at the end of each phase of development of space projects, participants conduct a "review" to determine whether the system development process should continue from one phase to the next, or what modifications may be required. In chapter four, we will analyze with some detail one of these "reviews", the one taking place when the quality control of data comes to an end and the pertinence of disseminating them to a larger audience needs to be assessed.

Each step of the technical and scientific development would be discussed: continual trade-offs between what physical variables to retrieve, with what accuracy, quality, latency, cadence, scale, format, methods of analysis and modes of distribution and preservation would be negotiated. Scientists would define the calibration techniques, the inversion algorithms, their translation into software, the criteria to judge the quality of the resulting datasets, the means and conditions for disseminating them. This would involve scientific problems but also technical details. For instance, discussions took place to decide the orientation of the camera CCD with respects to the orbital trace of the satellite: it turned out that the optimal orientations for observing the color of the ocean and those for observing the radiation budget and clouds were opposed ones, because the scientists privileged the observation of different latitudes. The angular step between different snapshots, this is another example, must be agreed: the lesser the angular step, the more measurements and the more resolved would be the data, but this would increase the data volume and must be balanced with storage, transmission and processing capabilities of the ground segment in the course of being developed by the information departments of the Technical Center of CNES in Toulouse. Sometimes, industrials also played the game in these tradeoffs. At some point, for instance, they communicated that it was not possible to adjust the gabarit to the specs of the polarized filters and as a consequence, a new configuration must be redone assuming new technical constraints. When the Japanese partners working with the instrument Ocean Color and Temperature Scanner (OCTS) announced, this is another example, that they would move the spectral band initially planned to be at 665nm to 670nm to be compatible with the future NASA's radiometer SeaWIFS, some scientists of the group argued that the same must be done in POLDER, for POLDER's data to be compatible with the data of OCTS for intercalibration and common use of data from both sensors. Others argued that, given the material specificities of the instrument, the optimized band was the one centered at 665nm and moving it would cause a loss of quality of the retrievals. Also, with limited funding, the quality controls of the data to be conducted after the launch of ADEOS must be agreed amongst those participants who favored ship journeys to measure the color of the ocean and those who favored aircrafts flights to measure some clouds' properties, or between those who favored the collection of samples over desertic surfaces, tropical forests or snowed planes. Similarly, and with this case we close this rapid list of examples, the threshold of pressure to consider a pixel as cloudy or the thresholds of the amount of ozone or stratospheric aerosols to consider a pixel as polluted must also be fixed. This was important because, recall the examples given in the previous chapter, the threshold value would necessarily cause bias in the detection of clouds, for instance, either underestimating or overestimating them, which would in turn cause bias in the retrieval of all those cloud-dependent geophysical parameters. Along the same lines, different thresholds for atmospheric contamination would affect the retrieval of those parameters dependent on them. The point was to agree in what would be the acceptable bias for all the involved disciplines, which had different objectives and observational needs. For instance, those scientists willing to study the relationship between clouds and the energy budget pleaded for using the thresholds of cloud detection used by the weather satellites of NOAA, in order to align with the current existing definition and provide data comparable and continuous with NOAA's (we will address the problem of creating continuous data in chapter six). These thresholds, which tended to detect an elevated number of clouds (that was the point of studying clouds), were seen as inappropriate by those scientists willing to study the optical properties of the ocean water, for their studies may benefit if the pixels were considered as clear skies situations.

These are only some examples of the kinds of trade-offs that the members of the "groupe mission" were confronted to. Each particular question would be studied in depth, without losing sight that technology must be designed to meet the scientific goals that they themselves had defined, while remaining safe, cheap and feasible. More generally, any negotiation about the conception of an experimental device that would be used by many, and of the corresponding data, involves these archetypical arguments around certain technological and scientific choices. Meeting after meeting, trade-off after trade-off, agreement would be forged and a common representation of the instrument and its data would be shaped. They were creating the methods appropriate to calibrate the radiometer and the data, the angular steps of the snapshots, the wavelengths of polarization, the precision with which data were deemed to be useful, the rules for creating inversion algorithms, the theories admissible for analyzing the data, the size of the data files, the power of the computers, the external instruments that would be used to assess the quality of the data, the number of doctoral students that would be recruited, or yet the foreign scientists who would participate in the project.

Frequent meetings, including "reviews"[453], and abundant paperwork are of course management rules and methods to efficiently maintain control over a given project, to ensure that it evolves in accordance with the stipulated technical requirements, schedule and budget. We shall argue as well that they are tools that create cohesion amongst the members sharing them. The managerial tools of CNES would contribute to create this shared and unified vision: they were obliged to report, to share their findings, to fulfill formulars following a common language and terminology, to synthetize results, to fly to Toulouse or Paris frequently to attend meetings. We have described in the previous chapter the new formula for data mass-production and dissemination powered by the principle of division of labor that allowed actions carried out by different actors to be successively and accumulatively put together. While this socio-technical complex would render data manageable and

[453] We have mentioned before that the development of a space project is typically organized in successive phases. At the end of each phase (and very often also inbetween for a given sub-system), a "review" is elaborated to evaluate the state and progress of the project and to decide about the pertinence for beginning the following phase, the need for deeper studies before getting further or the stand-by, even cancellation, of the project. We will study one of these reviews in chapter four.

meaningful for the actors, it would also have the effect of reconfiguring the scientists into the type of workers workable in this socio-technical complex, adopting specific forms and rules of working, those deployed by CNES. Scientists would be introduced in a sort of administrative hierarchy governed by CNES's managerial rules, exemplified by the numerous meetings, Reviews and documentation generated in the developmental stages of the project. All these elements, we maintain, can be understood as generating a common discourse and practices amongst the scientists, the project manager and the project scientist, and participating, in so doing, in the unification of a community.

Disciplinary and institutional diversity

In spite of the shared ways of running and views with respects POLDER and its data, certain degree of heterogeneity prevailed within this community in terms of scientific interests, expertise and involvement in POLDER data realization and development. The laboratories of the "group mission" would differ, for instance, in the disciplines that they addressed, the approach and the methods, they also would differ in size, resources, organization, as well as in expertise in the domain of space science. Indeed, some scientists would belong to CNRS laboratories, others would be professors in the university, some others would work in governmental organisms like the Commissariat à l'Energie Atomique or la Météo-France. They would embody therefore different institutional cultures, different epistemic priorities or different daily obligations. Those scientists conducting time-limited research (doctoral or postdoctoral) would be funded by a diverse type of agencies, including CNES, universities, Météo-France, Ministry of environment, regional governments, Centre National Pour l'Exploitation des Oceans, the European Space Agency, the Ministry of Quality of Life, the European Communities or the Electricité de France[454], just to mention few of them. Some of the scientists would be "selected laboratories" counting with strong and long ties with French space activities and working in collaboration with CNES; some others had been working in peripheric laboratories entering the space domain in the 1970s; while yet some others had just been initiated to the world of satellite data. Some of the scientists belonged to laboratories that had strong expertise in manufacturing their own instruments (satellite, aircraft or in the ground surface) and part of the scientists of the "groupe mission" would be, or would become, experts in the instrument per se: the performances of its photocells, the properties of the polarized filters, the aberrations of the optical system, their degradation with time. Some of the laboratories would be more familiar with theoretical developments; some would had strong links with other scientific activities a part from instrument building, like numerical modeling of the atmosphere and the ocean, organization of field campaigns or maintenance of networks of surface measurements, while other would be specialized almost exclusively in satellite remote-sensing.

During the first years during which the instrument must be designed, a number of the scientists of the "groupe mission" would be hence experts in material instrumentalization like opto-electronics,

[454] Rapports d'activité LOA, LMD and LERTS.

thermics, blackbodies sources, performances of polarizers, spectral signatures. Some others in remote-sensing per se, skilled in radiation transfer theory, in theory of light, in radiometric signal. Some of them would solve radiation transfer functions numerically, some others would approach the problem by extracting phenomenological relations from empirical data or computer simulations, while some other from laboratory experiments. They would be concerned with the instrument and its calibration, without any preferential field of application. As the instrument achieved its technical design, the composition of the "groupe mission" evolved: experts in the instrument and its calibration would step back to leave place to experts in interpreting data following the physical approach in diverse fields such as marine biology, continental biosphere, clouds, aerosols or radiation budget. Several had conducted their doctoral research funded by CNES in one specific space project and many of them had spent some formative time as postdoctoral research or other kind of stays at laboratories of NASA (especially the Goddard Space Flight Center responsible of MODIS and SeaWiFS), or the Goddard Institute for Space Sciences responsible of the International Satellite Cloud Climatology Project, the Scripps Research Institute, the National Center of Atmospheric Research or a number of universities (Miami, Colorado State University, Wisconsin University), working in applying the satellite data to a particular domain of study, oceanography, atmosphere or vegetation. Most of the scientists, excepting those students that were starting their careers, had already worked in space projects coordinated by CNES, ESA, NASA or the Hydrometeorology Service of the Russian Federation (ROSHYDROMET, responsible of space missions in the domain), whether in the conception and realization of an instrument or in the analysis of its data (like scientists working with Meteosat, Pioneer Venus or Venera, Nimbus-7, AVHRR, etc.). Some others were collaborating in some manner in other missions being currently prepared like ScaRaB, MERIS or MODIS. Some of them had participated –or participated still- in international projects or field campaigns with a strong space component, like the European Association of Scientists in Environmental Pollution (EURASEP), a consortium of European scientific laboratories organized to exploit satellite data for the environmental protection of the sea and marine life policy, which would be based on conducting field campaigns to analyze the data gathered with the instruments of Nimbus-7 launched by NASA in 1978[455], the First GARP Global Experiment (FGGE) whose data gathering phase, including data from satellites, aircrafts, buoys, balloons and surface stations, was conducted between 1978 and 1979 or the International Satellite Cloud Climatology project (ISCCP) consisting in generating global data about the cloud cover by means of combining the measurements made by all weather satellites together[456].

[455] Since the mid-1970s, the European Communities had begun to be interested in the domain of remote-sensing, especifically to support its policies of environmental protection of the sea and marine life. Coordinated by the Joint Research Center, the European Association of Scientists in Environmental Pollution (EURASEP) promoted research programs to find ways of applying the satellite observations and it would be entirely based on the observations of the CZCS instrument aboard Nimbus-7 and the exploitation of its data. The major participants in EURASEP would be scientists from Germany, The Netherlands, UK, Belgium, Italy and France, including some scientists of LOA, LPCM, CNEXO or IGN.

"Remote sensing from space. A research activity of the Commission of the European Communities", published by Joint Research Center of the Commission of the European Communities.

[456] Rapports d'activité of LOA, LMD and LERTS.

In our views, this variety of domains of expertise, methodologies, background and goals of the members of the "groupe mission" cannot be disconnected of the fact that POLDER had been defined in 1986 as a "multimissions" instrument, namely, an instrument flexible enough whose data could support studies in a large number of disciplines and scientific questions at the same time. Let us better illustrate this point with two rapid counterexamples. The radiometer ScaRaB was defined from its inception between 1984 and 1986 to support studies in the domain of the Earth's radiation budget. Its scientific team was made up of scientists who were experts in applying remote-sensing radiometry techniques in the domain of radiation budget studies. In France, the high degree of socialization of the laboratories and the policy of not duplicating efforts, reduced the scope of experts to one single laboratory, the Laboratoire de Météorologie Dynamique –although individuals from other laboratories would participate in concrete aspects of the project. The instrument Topex/Poseidon, this is our second example, had also its scientific goals well-stipulated from the outset (physical oceanography, geodesy and climatology) and its scientific team would be mainly composed by experts in applying satellite altimetry measurements in these domains. Actually, the scientific team of Topex/Poseidon would include as well some scientists not necessarily experts in the remote sensing techniques, but rather experts in the domains of application of such techniques like, for instance, oceanographers experts in the formation of eddies, experts in lithospheric dynamics or climate scientists experts in the study of the steric effect, who would use the altimetric data in their respective research. In any cases, the teams were quite monolithic from a disciplinary perspective: Earth radiation budget and physical oceanography, respectively –we are not suggesting with this that their members were homogeneous in other aspects, but only that the disciplinary boundaries of the fields that the satellites were meant to support were confined from the outset of the experiment. POLDER, a contrario, had no a scientific mission commissioned from its conception in any given discipline of the Earth sciences (its original scientific objectives responded to remote-sensing investigations). Instead, it had been deliberately defined as "multimissions". It was then *natural* that the corresponding scientific team, the "groupe mission", included a multiplicity of varied fields of applications for POLDER's data. This was, we maintain, a specificity of the POLDER's community: the multiplicity of disciplines involved in the scientific team. The scientific program of POLDER was organized around a technology: the instrument and the data it would gather, not around a specific discipline for applying these data. Put it another way, sharing data was a way of achieving multidisciplinarity –as has been noted by others[457]. By so doing, and with that we align one of the thesis of the historian of sciences Chunglin Kwa, we suggest that defining an instrument as "multimission", that is to say, supporting a number of scientific disciplines, served one of the goals of CNES: gaining visibility amongst a wider number of scientists

[457] This was actually the whole point of the International Geosphere Biosphere Program (extension of the US Global Change Program, in which NASA's program Earth Observing System (EOS) was a centerpiece). The IGBP brought together a substantial number of disciplines, including meteorology, solar physics, atmospheric chemistry, oceanography, physical geography and ecology, but the research was organized around two technologies, satellite remote-sensing and computer modeling.

In his article "Local Ecologies, Global Science: Discourses and Strategies of the

International Geosphere-Biosphere Programme", 2005, the historian Chunglin Kwa discusses the effects of such "interdisciplinary" imperative, through the use of shared satellite data, on the practices of ecology.

in order to maximize the use of satellite data amongst them[458]. In that sense, we suggest that in defining an instrument as "multimission", willingly or not, consciously or not, scientists were favoring the *reconciliation* in the sense that it paved the way for a number of disciplines in the domain of Earth sciences to make use of space technologies.

Common technological practices: Inversion algorithms

Participants in the group mission may be heterogeneous in some respects, like their scientific disciplines and approaches, institutional cultures or individual trajectories and objectives, though converge and be commensurable in other ways. Central amongst them, they had been trained as physicists and shared a cognitive map mostly shaped and influenced by observational activities and analysis of empirical data. In particular, their job was to interpret the measurements in a physical approach manner, that is to say, develop inversion algorithms allowing transforming the radiances into some form or other of geophysical parameters in a given domain of applications. These scientists held the technical expertise and knowledge about radiometric instruments, spectral signatures, signal-to-noise ratio, radiances, light theory or radiation transfer. They had been trained and socialized to fully understand the particularities of polarized radiometry and because of that they had acquired the expertise, the tacit and formal knowledge and the intellectual (and material) resources to properly interpret all the details of the measurements. They knew as well how to exploit it in their given disciplines: they knew how to make energy appear as chlorophyll concentration, size of the water droplets in the clouds or shape of the tropospheric aerosols species.

The community of POLDER would not be, then, gathered around a given object of study but around a given approach to satellite data: while the disciplines, the goals, motivations, conceptual frameworks, scales, organization, institutions of the scientists gathered around POLDER may be varied and multiple, differences were bridged by their common understanding of data and the use of shared technological data practices to interpret them, the inversion algorithms. Indeed, they all instilled POLDER's measurements with a physical interpretation; they all deployed a number of inversion technologies to give meaning to the radiances. These technologies played in this manner an integrating role as unifying the ambitions of all the members of the community.

These were the scientists who would control the techniques, means and conditions of the production of POLDER's data. They also would control how to test and check the quality of these data –a point that we will deal in the following chapter. And eventually, in a second stage, after they had tested and validated the quality of the geophysical data, some of them would eventually move a bit forward and

[458] In the same article, Chunglin Kwa maintains that NASA took the lead in defining the technological needs and standards for data-gathering in the frame of the International Geosphere-Biosphere Program as centered in satellite remote-sensing, for adopting satellites and their data as the leading technologies during the program could only benefit NASA in the long-term by spreading the use of the data amongst a number of disciplines.

"Local Ecologies, Global Science: Discourses and Strategies of the International Geosphere-Biosphere Programme", Chunglin Kwa, 2005.

make use of these data to analyze some phenomena occurring in nature. They would also be tied by being conceded specific privileges over data access –it is to that point that we turn now.

Common data rights: The world in data-classes

If one thing characterized the PI-mode of data handling during the 15 to 20 first years of the space age was that the data obtained with the experiment were sort of a property of the instrument builders –this is often the case of scientific teams gathered around an experiment in experimental physics as well[459]. The extreme position, whether because of rudimentary means of data circulation (lack of standards or inappropriate material supports) or because of moral principles (part of the work of an experimenter consisted precisely in generating his or her own data), maintained that the instrument builders were the sole recipients of the data, which were not shared at all. Along the decade of the 1970s, as we have illustrated, both the possibilities of data-sharing and the notion of principal investigator of a space mission evolved in parallel. Instrument builders, when existing, became more flexible about enabling the circulation of their data, albeit some control existed still regarding what data were to be shared, with whom and for doing what (for instance, under the form of "announcement of opportunities" for gathering a group of PIs or co-PIs, in a renewed meaning of the term, or under the form of "purchasing the data"). Even though it has evolved and nuanced with time, this social practice, and this sense of ownership, persisted amongst the tradition of experimental physics as a customary reward to the scientists who have invested time, efforts and money in the design, manufacturing and operations of the experiment: after all, exclusive access to data enables original publication and therefore gaining scientific credentials and advancing in the career.

Mechanisms of data circulation kept evolving in the 1980s and 1990s. The factory-like system for mass-production and dissemination of geophysical datasets was widespread. The underlying assumption of such a data factory was that there existed a potential number of external scientists waiting for the geophysical datasets and willing to use them in their studies. The whole point of the system was, in other words, to outreach other scientists not involved in the data acquisition and creation. The extreme position of such an outreach materialized in the data policies of full and free data-sharing encouraged by NASA since the mid-1980s and which were progressively impregnating all the spheres of satellite data production and dissemination. For instance, in complicity with NOAA, NASA's representative at CEOS, WRCP and IGBP, would promote the full and free data-exchange of satellite data in the domain of what was called "global change research". This policy raised some reluctance by some space operators which merchandized the data gathered by SPOT or by the weather satellites Meteosat. Indeed, the institution coping with the data of Meteosat, Eumetsat, and the corresponding weather centers in Europe tended, and this is also valid today, to distribute weather data only in the form of thermodynamic parameters (temperature, pressure, rainfall), in the form of nepha-analysis (cloud cover) or directly in the form of an analysis (a prediction) –and certainly this

[459] "History of CERN. Volume II: Building and Running the Laboratory, 1954-1965", A. Hermann et al, 1990.

distribution is not costless, but only upon purchase. Analogous rules of commercialization were applied to the circulation of the high-resolved images obtained with the French satellite SPOT, for which an entity, called SPOT-Image, had been established to ensure the running of the business. Not to mention the strict rules for accessing some of the data of the reconnaissance satellites, even if civil, deemed to be highly sensitive for security concerns, and whose resolution could prove very useful to "global change" studies[460].

This expression, "global change", was a transposition from the expression used in the research program that NASA had just succeeded in establish at home the US Global Research Program in which the space component played a central role basically through the Earth observing System of NASA, which was a variant of the Global Hability Program that had not been approved by Congress some years before. Actually, it would lead between 1984 and 1990 to establishing the International Geophysical and Biological Program. With this international program, NASA was hoping to reach in the international domain what it had reached domestically: expand the scope of users to non-NASA, and even non-American, scientific groups, as the historian Chunglin Kwa has revealed[461]. Indeed, open and free availability would contribute to normalize the use of satellite data in such fields of research and this could only benefit NASA, as the major provider, in the long term. Essential to that, data must freely circulate. In 1992, after more than five years of debate, in the plenary session of CEOS a resolution for the free data exchange for scientific investigations in the domain of "global change" was endorsed –the final resolution moderated, however, the claims of full and free access by stating that "data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data" [462]. We shall also note, for completeness purposes, that these moves occurred in parallel, and also lead by NASA's representatives at CEOS, to the development and implementation of common protocols for data circulation, standards of interoperability and information pipelines, networks and directories discussed in the previous chapter.

Our point is that all along the 1980s, and this is valid still today, when it comes to satellite data about the Earth and its environment, whether they have commercialization possibilities, whether they involve security sensitivities or whether they are meant to study "global change", the discourses thrust between conceding data a status of common good full and free available to that of (private) products of human work, and they entail multiple, sometimes contradictory, implications. All and all, and back to POLDER, there was a tension between the universal, totalizing perspective of the planetary gaze and

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[460] Minutes of the Plenary meetings hold by CEOS between 1990 and 1992.

[461] In an article Chunglin Kwa describes the role of NASA in redefining the epistemological practices of ecology in its pursuit of new and more users of satellite data.

[462] CEOS's "Resolution on Satellite Data Exchange Principles in Support for Global Change Research", endorsed in the CEOS Plenary meeting of 1992.

It took more than two years of periodic meetings of the working groups specifically devoted to discuss the issue of data-sharing. The cost or price of the data was not the only issue raising disagreement. For instance, Isaac Revah, director of programs at CNES, proposed that all references to "global change research" would be replaced or, at least complemented, by the expression "climate and environmental research", as that was the accepted terminology in France, a proposal that would be accepted as a amendment to the resolution. Minutes of the Plenary Meeting of CEOS of 1991.

the using of meaningful data for scientific practice within a given normative epistemology. POLDER's data policy must be then a compromise between the international trends to disseminate data for "global change" studies to all and the accepted social rules promoting exclusivity rights to the scientists that had invested in their realization. How both tenets would be *reconciled*?

The resulting data policy for delivering POLDER's data would reflect this tension –and it parallels the data access policy at CERN[463]. It would be constituted of three features. First, during the first months after the launching of ADEOS-I (a number originally set at six months), in a period known as "recette en vol", the technical feasibility of the computer center in Toulouse as well as the performances of the software for calibrating and correcting the signals received from the Japanese ground stations would be tested. Only those scientists and engineers directly involved in the information system, the software development, the corrections and the calibration methods would have access to the data in order to assess the functioning of the computer center and the quality of the calibrations and corrections. If all worked as expected, the computer center would start working in full operations producing calibrated data in a systematic manner. A period of six months, which was enlarged to ten, known as "validation phase", would be then begin. The "groupe mission", its associates and the international scientific team would have exclusive access to the calibrated radiances in order to conduct the post-launch calibration and validation plans that they have previously prepared. This privilege to data access illustrated that POLDER was, in this respect, perceived as an experiment in the classical sense, that is to say, serving the physicists that had conceived it before outsiders: the scientists that had conceived and prepared POLDER would be conceded some rights over the data, understood as a reward for the investments made in their building and preparation, and allowing them some exclusive time for publication without much concurrence. More generally, it served a specific *data-class*, the *data creators* –we are scrutinizing this term in a while. Second, this temporal embargo of data would come to an end formalized with the "Revue de validation", organized as one of these managerial rules of CNES, in which the quality of the geophysical datasets and the functioning of the computer center would be assessed. If all worked as expected, the computing center would be transferred to the facilities of the Commissariat d'energie atomique established for that very purpose, the mass-production of geophysical datasets would start and validated geophysical parameters would be distributed to any scientist upon request, and for free, aligning in so doing the tendencies towards data sharing. In other words, after a given period of time, geophysical datasets retrieved from POLDER's measurements would be available to scientists who had not participated in their acquisition and production, to the external scientists, the *data users*. Third, the computer center of Toulouse would continue to produce calibrated data from the signals received from the Japanese partners during the whole life of the instrument and thus responsible to transfer them to the facility of the Commissariat d'energie atomique for further processing, dissemination and archival during 10 to 15 years. In other words, physical radiances would never be transferred to CEA for wide and open delivery to data users, but they would remain at the computer center of CNES in Toulouse. Their delivery would be restricted to data creators

[463] "History of CERN. Volume II: Building and Running the Laboratory, 1954-1965", A. Hermann et al, 1990.

upon request to CNES[464]. Consequently they would be the soles admissible to develop new inversion algorithms, the characteristics of the corresponding geophysical datasets retrieved from them, their scientific objectives, their format and the scientific frameworks in which they would be meant to be used.

In a sense, as we have been mentioning, this schema portrays a different model that the commonplace during the first 20 years of space research, based on the PI-mode, in which there were no external scientists because data were *self-made,* namely the scientists that had conceived the experiment and built the instrument typically handled themselves with the data processing, archiving and analysis. This data policy provides for geophysical datasets openly and freely available to anyone. In another sense, though, it does not depart much from the epistemologies prevailing during the earlier years, because a specific group of people retain some fundamental attributes characteristic of the experimental physics, like a sort of sense of ownership over the physical datasets. POLDER data policy would participate to the unbundling, but not total abolition, of data ownership and property rights over data, by offering the data to the world, while yet retaining some embargo.

This model was a choice of the “groupe projet” and “groupe mission” and other scientific teams may articulate arguments differently in other experiments. For instance, the scientific team of the instrument CALIOP, a lidar developed at LaRC/NASA flying aboard the satellite CALIPSO decided to divide the access to data in two stages. During a pre-fixed period of eight months (dictaminated by NASA/Headquarters), only the scientific team (chosen after an international “call of opportunities”[465]) would have access to calibrated data, as a reward for their previous efforts in preparing the instrument, its calibration and some scientific algorithms. Eight months, so it was argued, should be enough to let these scientists obtaining some results for publication. After this period, regardless of the state of their validation process, both calibrated and scientific data would be publicly released. Anyone willing to conduct some kind or validation, to test some self-developed algorithms to obtain a specific scientific parameter or simply to take a look at the data would be able to do that[466]. In this example, our hypothesis about NASA’s priority to maximize the use of data as a means to justify its activities before the Congress and the public audiences was well-received during our interviews: the more rapidly, widespreadly and easily data would be disseminated, the more people would potentially take and use them producing original forms of data, which, in turn, may be used by other scientists in their research[467]. In a way, told us Bill Rossow, former physicist at the Goddard Institut of Space Sciences,

[464] « Compte-rendu de la réunion CNES-CEA/LMCE sur le Segment Sol POLDER », July 1992 and « Document d’appui présenté lors de la Réunion du Segment Sol POLDER », October 1992.

[465] Scientists of the Service d’Aéronomie and of the Laboratoire de Météorologie Dynamique are part of it, either as responsible of the instrument Imaging Infrared Radiometer aboard of the satellite CALIPSO (Service d’Aéronomie) or as part of the team preparing and validating the data gathered by the lidar CALIOP.

[466] Interview with Dave Winker, LaRC, 2013.

[467] In the course of our interviews we have also been referred in several occasions to what was called by the American scientists as “European culture” and “American culture” of data disseminating. Typically, the open access to data characterizing NASA’s policies responded to the “American sense that federal funded projects must be useful to the nation and to its citizenry” and “must return to contribuents” (Tony Del Genio, GISS and Bill Rossow, NOAA-

at present day recruited at the NOAA Cooperative Remote Sensing Science and Technology Center, “data dissemination is seen by NASA, the governmental institution, as a leverage permitting keep doing business”[468].

Topex/Poseidon exemplifies this model, in the sense that its scientific team comprises 38 groups from all over the world chosen for the scientific excellence of their projects after a “call of opportunities”. During a pre-fixed period of time, they all have all privileged access over data to develop new scientific algorithms to exploit the calibrated data and to perform some form of validation as well. The point is that, unlike the cases of POLDER or CALIPSO, the scientific team is composed by both *data creators* and *data users,* that is to say, some of the members of this team had not participated in the design of the instrument and/or the acquisition and production of data[469]. Again, we argue that this data policy reflects an instance of NASA’s urgencies of widespreading satellite data as a means to stimulate their use. Probably it also reflects a means to share costs during the field-work campaigns for preparing the data before the launch and validating their quality after the launch, which involve aircrafts, the maintenance of a network of more than 3000 tide gauges in the oceans, and ship expeditions. In our views, it also reflects the tenet that there might exist *data users*, not familiar with the specificities of instrument or the techniques of data acquisition, perhaps not qualified enough to intervene in the manipulation of the physical radiances and to develop inversion algorithms by themselves, but certainly qualified to propose geophysical parameters (or eventually other types of data) to be derived from measurements, their precision or their format. After all, so this argument goes, these scientists are the ones supposed to use the data and therefore it make full sense to consider them as part of the scientific team.

Back to POLDER, the data policy adopted for POLDER reconciled the tension between exclusive access to data and urgencies for data sharing in a particular manner so that as emphasizing a divorce between the experts in POLDER’s data and external scientists, the members of the “groupe mission” and their associates and the external scientists. As such, this was not a big deal; after all, this was the traditional and generally accepted meaning of belonging to a scientific team in experimental physics: given the efforts spent in preparing the experiment, having some form of privilege over the data obtained with the experiment as a social reward for your work. More interesting is the fact that the case of POLDER presents the particularity that the functions of creating the data, assessing their quality, judging their limitations and scientific interest, and depicting the scientific questions that could be addressed with them, or in other words the functions of the *data creators*, would coincide with the mandate of the scientific team or “groupe mission”. Put it simply, the scientists of the “groupe

CREST, 2013). Citizenry and contribuents are considered, according to what was named by the interviewees as the “American culture”, as individuals. While the overall goal to maximize and return efforts may be equally valid in Europe, the basics differ: according to the so-called “European culture”, the return goes not directly to individuals but it is mediated via public institutions. We have not enough elements to provide a deeper analysis in here and, in order to exceed what may appear as a cliché, we can only encourage more research connecting the data access policies, if pertinent, to some form of national technological cultures of data sharing and exchange.

[468] Interview with Bill Rossow, NOAA-CREST, 2013.

[469] “Topex/Poseidon Project. Data Management Plan”, compiled by JPL scientists on October 1991.

mission" or the international team were all *data creators* -and we shall stress that it is not necessarily so (see for instance the case of Topex/Poseidon, in which some *data users* take also part of the scientific team, and therefore have also privileged access to data). As a result, the social rules of data access would actually translate in giving privilege to *data creators*. The two distinguished social groups that had splice out/emerged in the process of *normalizing* the factory-like mass-production and dissemination of geophysical parameters, the *data creators* and the *data users*, would be given different rights concerning the data access, they would constitute two different *data-classes* (we will conceptualize this notion with the appearance of a third data class, the *data providers*, later on in our essay)[470]. By using this term, *data-classes*, we stress that the social organization of the project POLDER was operated around the data –and not around disciplines (like ScaRaB and Topex/Poseidon), institutional affiliation, social status of the scientists (student, professor, postdoc, director, etc.), national belonging, or any other criteria that we may come up with. In other words, the use of this category stresses that the difference between the social groups involved in the project POLDER was mediated by their degree of direct connection with the instrument and the data: what bounded together the different members of the POLDER community was their common approach to the data (a *physical approach*), which was leveraged because of holding knowledge about radiation transfer and controlling the technologies of inversion. In turn, they were conceded some privileges over data access, which suggests that, at least in the case of POLDER, different epistemic groups can be distinguished when looking at their data ownership and access rights. The use of this category, data-class, stress as well, and with that we move to the following section, the position that the different social groups occupy with respects to the cascade of operations involved in the gathering, the production, the circulation, the storage and the dissemination of satellite data. We are not saying that *data creators* do not use the data, but rather that, unlike *data users*, they are part and parcel of the systems of data handling, they are central actors of the factory of data production and dissemination from end to end.

Common culture: Data creators

This divide in *data-classes* would mediate the allocation of epistemic authority. This allocation would be operated on the basis of technical expertise and knowledge: those scientists who had some knowledge about radiometric instruments, spectral signatures, signal-to-noise ratio, radiances, radiation transfer or inversion methods, and those who did not. Of course, as we have seen when examining the constitution of the "group mission", in the selection of those partners, other

[470] As far as we know, the social scientists Lev Manovich coined this term in his analysis of the use of digital data in social sciences (The Promises and the Challenges of Big Social Data", 2011). He portrayed what he called the "Big Data society" in three "data-classes": those who use the web and/or mobile phones and create digital data, those who have the means of collecting them, and those who have the expertise of analyzing them. We are not taking this classification which, we believe does not stands in our case study; we are, however, appropriating the term data-class and providing it with a renovated meaning.

considerations also played a role, like institutional collaborations, budgetary hypothesis, will to outreach and gain visibility, and some degree of opportunism, but the authority of the “groupe mission” would be grounded in their expertise and knowledge in manipulating technological practices of algorithmic inversion. It was simply that, because scientists of the group mission held the knowledge and expertise in remote-sensing and of the particular instrument POLDER, so it was argued, they were considered as the best placed to interpret the measurements, they became the legitimate data-speakers that credibly could create geophysical parameters, judge their quality and profile the scientific questions to be addressed. At the end of the day, they had been trained and socialized to fully understand the particularities of polarized radiometry and because of that they had acquired the expertise, the tacit and formal knowledge and the intellectual (and material) resources to properly interpret all the details of the measurements. As time went by, they would become more and more experts, their authority would appear as more and more fundamented and their expertise would become more convincing, in a vicious circle of ever-growing expertise by differentiating from the *data users*. This is, we believe an important specificity of POLDER’s community; while it is certainly not exclusive of POLDER, other communities may operate other criteria. The category *data classes* described before, we believe, illustrates precisely that the criteria for social organization were fundamentally operated via the expertise, the technological data practices, the scientific knowledge in radiation transfer, the technical skills to develop inversion algorithms, their methodology of interpreting data from a physical approach. The *data creators* would be hence the admissible practitioners holding the *epistemic authority* to map out the credible methods to calibrate the measurements, to define what geophysical parameters could be retrieved, to determine the criteria for judging on the reliability of their results, or to define the admissible circumstances for using the datasets (the scientific frame, the hypothesis, the bias, the format, etc.). Despite the heterogeneity of the members of the “groupe mission”, they would have all one common feature: they would all interpret the satellite measurements with a physical approach, they embraced all a culture of *data creators* from head to toes. POLDER’s community was a community of *data creators*, who controlled the techniques, means and conditions of the production of POLDER’s data. Those left aside, the *data users*, perhaps mobilizing alternative data technologies and approaches, by contrast, would not belong to POLDER’s ontology and they would be excluded of the data production, storing and distribution system. Once again, we must not dramatize: all scientific communities have their specificities and map their limits and areas of influence (in terms of discipline, technological tools, methodology, representations, institutions, etc.), this is precisely what enables self-defining and distinguishing one another.

To sum up, in POLDER the social divide between the scientific team and the external scientists coincided with the functional divide between *data classes*, which portrayed a social ordering made up of two groups: the group that would hold the epistemic authority to interpret the signals and create the geophysical datasets (in which some scientists from LOA, LSCE, LMD or LPCM would figure prominently) and the others (not precisely identified in any of the documents that we have consulted, but whose existence was assumed anyway). The invocation for producing geophysical parameters, and the material technologies and knowledge necessary for that, would thus involve a very specific set of socio-technical ordering differing from the one that prevailed during the 20 first years of the space age, the *PI-mode*, in which the group that had conceived the instrument would be also the one examining their self-made data. In this emergent social ordering, a social group (may we say *data-group*) would be emphasized, the *data creators* and concede it a privileged position in the socio-technical ordering embodied in the data mass-production and in the elaboration of scientific program. This central position emanated from the simple fact that they were considered to be the best placed to work out the satellite radiances, that is to say, it hold the epistemic authority of data interpretation (radiation transfer, light theory, etc.) and controlled the technologies of data production (calibration and especially inversion), which in turn enabled to define the scientific program that POLDER's data was to support. More generally, the issues of tempo, and type of data, with respects to the dissemination of data cannot be disconnected to one of the major issues in the history of science: who are the actors holding the epistemic authority, who are the legitimate actors to speak in the name of science? Historical studies have demonstrated that the epistemic authority have been given to different instances and communities in different historical moments and contexts[471]. For instance, if one believes that only highly trained and socialized scientists that understand the nature and the optical properties of the measurement are capable to interpret data, data would only be released after a period as long as necessary of preprocessing, processing and testing, once experts have made sure that the geophysical datasets can be fully entrusted. To give a figure, it took almost two years before geophysical datasets from POLDER-1 would start to be available for *data users* –we will come back to that in the next chapter. A contrario, if one believes, for instance, that the more people looking into the data, the more likely to understand their interpretation, one may control the diffusion of data differently and be more flexible in their dissemination. Similarly, one may belief that the builders of the instrument and the algorithms may have certain privileges over the data as a social reward for their previous job and investments and as a means to advance in their careers, or one can belief that this sort of property right hampers scientific competition damaging the quality of the science done. Other mundane arguments may render the game much more complex, such as perspectives of advancing in the career (need for original publication), institutional interests of the space agencies or the laboratories (pressures to reach out to the broader public to gain visibility or institutional partnerships), possibilities for data commercialization (and, if so, at what price), degree of sensitivity of the data (high space resolution imagery), and so forth. Whichever model is adopted, within the factory-like data production system promoted by space agencies, the scientists that have access to calibrated

[471] The question of allocating epistemic authority, and legitimizing for it, constitutes a central question in the history of sciences and technologies, because all body of reliable knowledge requires identifying trustworthy speakers. Excellent introductory insights can be found in: "A Social History of Truth: Gentility, Credibility and Scientific Knowledge in Seventeenth-Century England", Steven Shapin, 1994, where the author illustrates that in the XVIIth Century, solutions to problems of credibility and trust were found in the practices of "gentlemanly culture". Gentlemen, unlike courtiers or merchants or servants or women, were deemed to be truthful owing to their material independence and moral integrity. A supplement to Steven Shapin's study, relating early-modern truth-telling to present-day scientific practice, may be found at Theodore Porter's "Trust in Numbers", 1995.

physical data and that develop the algorithms to transform them into geophysical play an essential role in determining the eventual modes of using the data, in what scientific domains and for what kind of research. They would also play a role in determining the good practices to produce satellite data and in judging their quality –which is very precisely the topic of our next chapter.

We would like to conclude with two remarks. First, we want to stress that this was a choice stemming from considerations of the "groupe projet", the "groupe mission" and some external scientists in the particular case of POLDER, and that other missions may portray a different socio-technical ordering (typically Topex /Poseidon, in which some *data users* are included in the scientific team[472]). In other words, this portray, which would be *normalized* by all participants of POLDER, was ultimately legitimated and credited by the technical institution CNES, who had contributed in the definition of the data production and dissemination system, in the seeking of institutional partners for transferring it, or in the selection and appointment of the scientific laboratories, in some cases even individuals, composing the "groupe mission" and admissible to create and access the data –illustrating a beautiful case of interventionism of technical institutions in the scientific activities.

Our second remark is a word of caution. We have presented here a landscape of data production and access dominated by the "groupe mission" build up under the legitimacy of CNES and who has exclusivity over the access to calibrated data, and as a result, is the only admissible in defining the type of research that it would be done with POLDER data, as it is within this group that the scientific data would be developed. The distribution of power embedded is this portrait shall be relativized though. We have already mentioned that a list of the people composing this "group mission" was never spelled out: a part from the scientists that we have found regularly attending the meetings, a number of colleagues in their respective laboratories, especially at LOA, as well as students, postdocs, and visitor fellows would also work in developing scientific algorithms and would have access to POLDER's data. As the mission evolved, individual and institutional membership changed –although, in the case of POLDER, they would remain always *data creators*. As a matter of fact, we have not been reported of any case of a scientist that has been denied the access to POLDER's data, calibrated radiances or geophysical datasets, because of not being part of the "groupe mission" –if something, the access would be denied due to the unexpected technical complications that the computer center in Toulouse suffered during the first years of functioning rendering it unable to satisfy all the demands[473].

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[472] We have been told that this is as well the model of Megha-Tropiques. However, we have not studied this case in detail.

[473] With the satellite functioning as planned, the computer center in Toulouse began to receive some samples of data to integrate them in the processing line in order to test both its functioning and the performance of the correction and calibration algorithms. These data were mailed from the Japanese space agency, NASDA. As we have mentioned, the shipping to CNES was delayed. Besides, some of the tapes turned out to be defective and new deliveries were to be needed; other tapes included some coding errors in the data format, which caused errors in the software line to produce calibrated data. The computer center of CNES in Toulouse also encountered a number of technical difficulties by itself, especially with a mechanism developed for recuperating exogenous data, like the ozone concentration coming from TOMS or the atmospheric pressures coming from METEOSAT (necessary to compile many of the correcting and calibrating algorithms, as we have described in chapter two). Furthermore, some frequent failures in a certain number of material components (like computers, tapes-reader, CD-ROM recorder or the printers) penalized the functioning of the computing center, generating an indisponibility rate of up to 20% during some months and the corresponding

On the other hand, the portrait depicting a narrow group of people controlling the production and access to data must be modulated and not given more weight that it had: the “groupe mission” was a temporal body set up to organize and prepare the POLDER mission and the utilization of its data. Few time after the satellite was launched, the “groupe mission” as such dissolved, some of the space managers that had been part of it reorganized themselves and began a new project, some scientists reshaped their careers (especially those interested in the early stages of instrument development). What remained were the social rules of data access and the principles for allocating epistemic authority attached to the customary imaginary of the community. What remained were the *data-classes*, the technological-operated divide between *data creators* and *data users* operated by means of their respective approach to data, *physical* or *geophysical* (or, as we will introduce later on, *climatic*)[474].

CONCLUSIONS

In order to gain enough critical mass support, and to be put in place, we argue, a scientific community had to be mobilized around POLDER beyond the handful of scientists of the laboratories of the Technical Center of CNES in Toulouse, LERTS and LOA, and who had initially proposed it before the scientific advisory committee of CNES in 1986. We are more interested in our conclusion on an inverse reading: by developing and realizing POLDER, a scientific community beyond the founding fathers would be created. For this was one of the first urgencies of the scientific programmers of CNES in the late 1980s: to establish and shore up a social group who would consume the technologies that the space agency provided, in particular, the satellite data, to create and “fidéliser” a clientele amongst the French scientists in diverse disciplines associated to the Earth sciences, to secure a demand for satellite data, or “products”, in the future. The process of creating such a community and its resulting epistemic specificities would be particular to the contingencies of the project POLDER. This community had been established through particular institutional goals (long-term partnership for future satellite data handling, CNES not having mandate for operations, will to outreach the use of satellite data), through particular attributes of the experiment (being “multimissions”) and through local settlements of the boundaries and allocations of epistemic authority (only *data creators*). The

delays in the data processing due to reparations and interventions. An important asset was that the material support (tapes and CD-ROM) need human intervention (to change the media, for instance) and therefore these operations cannot be done on Sunday, holidays or beyond working hours, which lead to a production of 80% in a week without holidays. These problems were typical forms of what the historian of sciences Paul Edwards’s called *data friction*, or difficulties encountered when data move between people, organizations, material supports, and/or disciplines. They were evident all along the course between collecting the observations and delivering the finished calibrated datasets and resulted in enormous expenditures of time, energy, and human attention. These difficulties did not nonetheless deter the *data creators*, who requested very specific treatments of certain months, certain days and certain orbits. Twenty different scientific algorithms had been developed and they must all be tested. In parallel, it was needed to implement the new versions of the correction and calibration software accounting for the continuous evolutions in the calibration methodology. As a result, the services got overloaded and, instead of processing each viewing segment in 30 minutes as was planned, it may take from days to even weeks in some cases.

« Rapport du Groupe de Revue de la Revue de fin de Recette en Vol POLDER », June 1997 and « Spécifications techniques de besoin des évolutions du segment sol POLDER », September 2000.

[474] « Appel à Propositions de Recherche CNES-NASDA "POLDER sur ADEOS" », mars 1994 (polder 96)

resulting community reflected these contingencies: disciplinary heterogeneity, institutional multiplicity, common approach to data interpretation by means of shared technological data practices, and common data access policy. In a way, the creation of such a particular community around POLDER, and generally around any source of satellite data, can be interpreted as part of the process of *reconciliation* between space technologies and field sciences.

We would like to conclude by remarking that CNES would be proactive in federating these dispersed and heterogeneous scientists in two ways. First, in defining its membership. Contrary to other cases, there would not be an open "call for opportunities" or peer review competition to become a scientist of POLDER; instead, and without ever definitely closing any list, scientists would be proactively targeted. Second, in framing the research topic of the group and the technologies admissible to conduct such research. The group would be intended to defining the specificities of the instrument, the calibration methods, preparing the algorithms of inversion, elaborating a plan for validating them, and carrying out it, judging the quality of the data, shaping the domains of application of the data, and thus the scientific program. These tasks required a certain type of expertise and skilled manpower, namely controlling the technologies of calibration and inversion, which became the data practices characterizing the group. In other words, the epistemology of the group, their relationship with the instrument and the data, was defined as being composed of *data creators*. Within this heterogeneous community of scientists bounded by the common epistemology regarding the data and the instrument that we have called *data creators*, the actors possessed epistemic power which authorized them to produce POLDER data, to judge about their quality and to have some privileges in their access and utilization. This was the POLDER's scientific community, a community with the particular characteristic of being composed of *data creators*. *Data users* were indeed assumed but never spelled out explicitly in the documents that we have consulted. Third, CNES was also crucial in establishing ways of running and managerial rules (regular meetings, periodic reviews, documents to fulfill, protocols to follow), funding studies and research in the laboratories and facilitating technical staff and facilities. These common procedures acted as unifying through creating a type of scientists workable within this rules, through fostering the sharing and the creation of a perception of a whole, and through creating shared ways of working and understanding. Most of the decisions and planning were taken and prepared under the umbrella of the "groupe projet", which coordinated the whole and centralized some of the control, but it left finer and specific decision to each partner to conceive and execute technical and scientific decisions. Finally, by defining a common data policy (reuniting many of the epistemic features characteristic of the traditional experimental physics tradition, but nuanced with urgencies informed by the pressures for data-sharing) that reinforced their epistemic authority and their privileged relationship with the instrument and the data by allocating them some data access rights. All these elements (common specific technology (inversion and calibration), common data policy, common working procedures, common vision of the ethos of their job as scientists and their group, common epistemological approach to the data) were particular of POLDER's contingencies (we have provided alternative forms along the chapter) and acted as elements that unify the people and distinguish them from others. They are all elements that contribute to create a community around the instrument POLDER. In this sense, hence, this group materialized an *epistemic community* around the instrument, or rather, around its future data. We do employ this term in Knorr-Cetinas's sense referring to a group of scientists bound through certain affinity, necessity or historical coincidence that shares a certain number of common practices, research objects, and interpretative frames and values that oriented their scientific, technical, political decisions regarding POLDER data[475]. And CNES, through its varied hierarchies and running practices (management rules, project manager, program manager, technical laboratories, funding, technical staff) contributed proactively to settle it and to credit for its scientific authority.

[475] We refer here to the seminal book "Epistemic Cultures", 1999, by Karin Knorr Cetina where she argues that different scientific fields exhibit different epistemic cultures.

4

SPACE, GROUND AND FIELD. HOLISTIC SATELLITE MISSIONS.

> « A : Pendant 2 ans les données étaient uniquement exploitables par les gens qui avaient participé à la campagne et puis après ouvertes à tout le monde.
>
> Q : 2 ans?
>
> A : Bon, je dis 2 ans, je ne sais plus, mais oui à peu près 2 ans. Pensez que la première année... même les données in situ ont besoin de validation!
>
> Q : Et avec quoi on les valide ?
>
> A : Avec des autres observations !! C'est un peu fou… »[476].

With this joke-like opening, emanating from a discussion with a *data creator* at LOA, we aim to introduce the main question threading this chapter: what are *good* scientific data, or rather what are *good* practices to produce *good* scientific data[477]. The key word that interests us from this quote is "validation", understood by the actors as a set of activities and processes deployed to assess the quality of the geophysical datasets -a second aspect to which we will refer along the chapter is also the timing during which such quality control is carried out, in this case 2 years.

In this chapter we aim to shed some light in some of the means, attitudes and practices of data quality control, in how scientists build trust on POLDER's data and how the authority to emit such a judgment is allocated amongst the actors. We also aim to elucidate the place that POLDER's data holds within the myriad of other scientific tools that compose the scientific ontology, including other data, theories, models, hypothesis, uncertainties or computer codes. We address questions of trust, veracity, credibility, objectivity and acceptability of data, their performances and limitations, their virtues and deviances; we address at the same time questions about ownership of data, and of knowledge, their sharing and exchange. These are questions of epistemological order and may be bestowed traditionally to the discipline of philosophy of sciences. Far from the philosophical approach, though, our approach echoes the methodology of what the historian of sciences Hélène Guillemot, and others, has called

[476] Interview with Jérôme Riedi, LOA, 2012.

[477] We are using the term *good* because it is commonly used by participants without pretending, by employing it, to emit any judgement about the morality or pertinence of the practices, norms and ideologies that we are describing. Good refers here hence to what is considered as legitimated and accepted by the community as ways of practicing. It is precisely one of the goals of this chapter to contextualize the *goodness* of data, to understand their moral norms in the case of POLDER, and we will explore it by connecting it with the material and social contexts in which scientists' views and practices are embedded.

bottom-up epistemology, stemming from the analysis of the scientific practices and not from abstract logical reasoning. « C'est dans les pratiques », wrote Guillemot, « que se forgent les rapports des scientifiques à leurs objets, et c'est en les analysant qu'on peut saisir comment elles contribuent à façonner une épistémologie et une ontologie chez ces chercheurs »[478]. By so doing, we aim to grasp how this epistemology is reflected in their daily practices and actions and how, at the same time, the daily practices and actions contribute to shape and conceptualize their epistemology.

This opening dialogue illustrates as well one of our main general points in this section: the scientific credibility of the geophysical datasets retrieved from satellite measurements is evaluated through a constant reference to the corpus of existing data. In particular, confronting satellite geophysical datasets against datasets obtained from networked measurements or collected through extensive field-campaigns would be progressively *normalized* as the admissible practice for testing the quality of the satellite retrievals. In turn, this possibility converged well with the current practices of many disciplines in the Earth sciences: going to the field. Therefore, the incorporation of such practices by Earth scientists, we argue, did not require dramatic transformations in their attitudes and practices; it would require, by contrast, and this is the hypothesis developed in this chapter, some transformations in the ways of doing of the space agencies (affecting at least their missions to the Earth) and of some of the most deeply rooted tenets concerning the epistemological power of space technologies and satellites as tools for the production of knowledge.

Three parts compose this chapter. In the first part, we aim to illustrate how scientists build trust in POLDER's geophysical datasets. To that purpose we have looked how scientists harmonize and compare three types of data embedded in what we have called three different *regimes of trust* (aerosols, ocean and clouds) that differ each other by the observed object, the material culture of the scientists and the available technologies, their social organization and the sources of funding. In the second part we aim to bring into light the importance of technical agencies in legitimazing, even orienting, the scientific activity –a point that we have suggested when discussing the constituting of a scientific team and in crediting for its epistemic legitimacy. We focus on a particular managerial tool of CNES (and other spaces agencies as well like NASA and ESA), the "Revue de validation", through which judgement about the scientific adequacy of the geophysical datasets is emitted and the dissemination of the data (or not) is controlled. In a third part we argue that the integration of field-work as part of the activities of space agencies (just like developing optical systems, thermic control, assembling payload, testing it, orbital control, *despatialization*, etc.) instilled a renewed epistemology abandoning the idea of the all-powerful satellite but rather requiring a holistic approach not only to carry out scientific activities but even to very create and produce satellite data. We conclude by connecting these ideas with what we have called the *reconciliation* of the notion of a space mission and the field-work tradition of Earth sciences.

[478]"La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », Hélène Guillemot, Doctoral dissertation, 2007.

We have chosen to study the validation processes for data produced mostly from the observations of POLDER-1 that have the interest of being the first –successors would actually inheritate much of the pratices. POLDER-2 and POLDER-3 are nevertheless called in occasionally as complementary sources when POLDER-1 insights are considered insufficient to provide a broad understanding. Our analysis is mainly based in the verbal description that scientists make of their work themselves: on the one hand, activity reports, scientific publications, internal communications and minutes from meetings have been consulted, and on the other, this has been a topic often raised by the interviewees in our semi-open interviews, which illustrates the importance that this activity holds in their representations and practices.

THE SPACE AND THE GROUND: DATA QUALITY CONTROL

Before diffusing the geophysical datasets to a wider audience, POLDER's *data creators* must make sure that the data being produced are good enough. Recall that the people and the tempo involved in this exercice depended on each mission (see Topex/Poseidon and CALIPSO in chapter 3). This process is known as "data validation". From an epistemological standpoint, the importance of the validation of geophysical parameters stems from the fact that, as we have described in chapter 2, creating geophysical parameters from measurements requires the technological practice of inversion, which involves a number of assumptions, hypothesis and exogenous information to be assumed in the process of transforming the physical measurements into some variables of geophysical meaningfulness. Professor Pierre Morel described it in a speech during the second scientific meeting organized by CNES in 1985:

> « La détermination de paramètres physiques (niveau II) à partir des données satellitaires brutes (niveau I) est toujours une opération délicate, fondée la plupart du temps sur une bonne dose de connaissances empiriques et un effort de validation par des observations directes coûteuses »[479].

Professor Morel made it clear that efforts of what is known as "data validation" were needed to create parameters of level 2 from measurements of level one: because geophysical datasets are recontextualized and intervened, through the technologies of inversion, scientists must test their degree of acceptability, assess their quality. It is precisely the doctrine of intervention on data which appeals for validating them after being intervened. Given a dataset, how do data creators make sure that it represents faithfully the reality? Even if assuming perfect calibration, how do they distinguish between a genuine result and a result that is an artifact created by the inversion algorithms?

This question is not a minor one in the domain of epistemology and has been longwhile food-for-thought for philosophers and historians of science: how scientists come to trust in an experimental

[479] « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.

outcome or in a set of observations? Many practices, or *epistemological strategies*[480], designed to establish, or to help to establish, the validity of an experimental outcome or observation have been described, emphasizing different aspects such as: the role of theories to explain experimental results or to predict them, the elimination of alternative explanations, the multiplicity of experiments, or still statistical validation and sophisticated error analysis[481]. One of the strategies usually adopted in experimental physics to assess the quality of the data is to compare them with other data, typically with some form of standards of reference whose properties and errors are well-characterized.

Comparing the satellite geophysical parameters with other data, in particular with "costly direct observations", like professor Morel claimed in the previous quotation, is also the strategy commonly deployed in experiments aboard satellites that measure some properties of the Earth and its environment. This is how a scientist specialized in studying the cycle of the aerosols put it during one interview:

> "On compare tout avec tout, toutes les observations qu'on peut avoir. Parce que quand tu fais une mesure tu as une incertitude et tu as un avantage et un inconvenient. On n'a jamais créé un instrument qui permet de tout voir. Forcément il y a des erreurs qui sont faits, il y a des limites à chaque mesure, donc si tu as d'autres instruments qui peuvent valider, tu peux analyser les erreurs et interpréter tes mesures»[482].

Comparison of satellite retrievals with other data, all possible data, constitutes the widespread strategy to verify the quality of the retrievals and of the geophysical datasets that will be disseminated. This is actually one of our main general points in this first section: the scientific credibility of the geophysical datasets retrieved from satellite measurements is evaluated through a constant reference to the corpus of existing data gathered with stations on the surface, by aircraft, buoys, ships or balloons, with other satellites, or whether they are the outcomes of numerical simulations.

More generally, the importance of the program for validating satellite data began to be recognized and widespread in the 1970s at NASA's missions, as satellite programs began to look at the Earth as a planet. We do not mean by that that assessing the quality of the satellite data was not a central question for earlier space scientists working in the traditional domains of "space sciences" –on the contrary, analyzing the errors, studying the characteristics of the data and the truthfulness of their interpretation is central to any activity in the domain of experimental physics. Rather, we would like to suggest 2 points. First, unlike the atmosphere of Venus, the chemical composition of galaxy clusters or the density of the interplanetary milieu, it was possible to measure some properties of the Earth's oceans, the vegetation or some layers of the atmosphere in the *field*. As banal as it may sound, there is a

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[480] We borrow here the meaning of the expression used by the philosopher of sciences Allan Franklin in « The epistemology of experiment », Allan Franklin in « The uses of experiment. Studies in the Natural Sciences », eds. D. Gooding et al, 1989.

[481] The question of how scientists come to believe in an experimental result obtained with a complex experimental apparatus and how do they distinguish between a valid result and an artifact created by that apparatus is fundamental in epistemology of sciences and has been tackled by several authors. We refer here only to the classical ones that propose several cases studies dealing with those issues: "*Representing and Intervening », I. Hacking,* 1983; « How experiments end », ed. P. Galison, 1987; *« Changing Order: Replication and Induction in Scientific Practice », H. Collins, 1985; "The Uses of Experiment", eds.* D. Gooding et al, 1989.

[482] Interview with Fanny Minvielle, LOA, 2012.

difference between many of the traditional “space sciences” (astronomy, solar physics, microgravity, etc.) and the late arrived oceanography, atmospheric chemistry, climate sciences or biology: the possibility to measure certain parameters in situ. It is possible to install surface instruments, continental or oceanic, and measure certain properties; it is even possible to move upwards up to the stratosphere, or higher, with balloons, radiosondes, aircrafts or the Space Shuttle to measure certain atmospheric properties in situ -or to descend the ocean in some depth[483]. This entailed, we maintain, a particularity in how *data creators* supporting the Earth sciences experience the confrontation of satellite data with nature because satellite data about Earth’s properties, or at least many of them, can factually be put into test by the real world, a test that cannot be easily performed in traditional “space sciences” such astronomy, interplanetary milieu or solar physics. This possibility opened up a number of options to confront the geophysical datasets retrieved from satellite measurements with data collected with different instruments, at different times and places, and processed with different algorithms. The collection of measurements with aircraft, balloons or buoys, this is the second point, aligned well with the existing instrumental capabilities of the former “selected labs”, which had retained expertise in developing and realizing novel instruments and sensing technologies but had no means (skills and budget) to build space-prototypes. In the third part of the present chapter we further develop these aspects.

As new missions and instruments to support studies about the Earth and its environment were engaged at CNES during the 1980s, they would progressively come impregnated with this tenet, which would be progressively accepted as the admissible practice to “validate” the satellite geophysical retrievals. Accordingly, all the work of algorithmic development conducted to prepare the production of the geophysical datasets before the launching of the satellite must be, after the launching, “validated” as the measurements and the data production would start for real –POLDER would be one of the cases through which these practices got implemented in France (reinforced by analogous practices of the concomitant missions like Topex/Poseidon). In order to illustrate how scientists build trust in POLDER data, we have looked into how scientists harmonize and compare data in three situations that differe each other by the observed object, the material culture of the scientists and the available technologies, their social organization and the sources of funding.

Regimes of trust

[483] Note however that not all properties of the Earth, its oceans or its atmosphere are measurable in the surface or by plane. Let us give two examples. First, measuring the net flux of incoming and outcoming energy of the planet (related to the Earth’s energy budget) requires being placed outside the atmosphere. Technically speaking, measurement of energy at the top of the atmosphere made by satellites are measuremenst *in situ* of the Earth’s energy flux. Second, radar altimetry, gravimetry and geodesic missions, for instance, require a high degree of precision in determining the position of the instrument (in order to determine with precision the altitude of the sea or the variations in the gravity field). Locating an object with centimetric precision is possible to achieve in the outer space where the satellite is “freed” from gravity forces; by contrast, aircrafts are submitted to intence accelerations due to the gravity field and it is not possible to establish their position with enough precision.

The epistemological strategy underlying our three cases is, as we have mentioned, the comparison of POLDER data with other data. However, we shall argue that each case is ruled by, what we may call, a different *regime of trust* that shape and is shaped by the organization of material sources, as well as by social, economic and political considerations. This notion draws upon Dominique Pestre's famous concept of *régime de savoir*[484]. In his original sense, it is an overwhelming idea related to the fact that each historical moment embeds a particular relationship between the production of scientific knowledge and its political, social and economical regulation and appropriation. Different regimes are gouverned by different social contracts between science and society, contributing to forge the societies, their organization and their values and norms. In the contemporaneous societies, for instance, the production of knowledge is integrated with an amalgam of industrial practices, political regulations, juridical norms, ethical descussions or societal inputs, which are part and parcel of the scientific activity. We are not discussing in our essay many of these dimensions and therefore we are taking here in a soft meaning of the term regime intended only to accentuate different aspects that integrate the particular practices embedded in assessing the quality control of the data **(**technological and scientific practices, social organization of the scientists, sources of funding**).** Our aim is simply to stress that at the micro-scale of data validation practices the notion of *regimes of trust* allows us to characterize the particular articulation between the data production and the building of trust in them, taking in consideration technological and scientific developments but also the social organization of the scientists, the sources of funding and the very nature of the observed object itself.

"Ground-truths" used as standards: the network of sun-photometers AERONET and the validation of data about the optical depth of the aerosols

Back in the 1980s, professor Maurice Herman of the Laboratoire d'Optique Atmosphérique (LOA), in an attempt to apply his expertise in polarimetry to measure some properties of the Earth's atmosphere (instead of the Venusian or the Jovian), had built a polarimeter called PIRAT to be carried by a balloon to measure polarized light from which retrieving, by means of the appropriate inversion algorithms, the optical depth of the tropospheric aerosols[485] -or rather, to test whether such a retrieval

[484] In this we are following the expression coined and defined as "un assemblage d'institutions et de croyances, de pratiques et de régulations politiques et économiques, qui délimitent la place et le mode d'être des sciences » in "Science, argent et politique », D. Pestre, 2003. The notion has been since the early 2000s extensively used especially in the field of science studies to characterize different forms of knowledge production in contemporaneous societies, in which industrial practices, political regulations, juridical norms, ethical discussions or societal inputs are part and parcel of the scientific activity. We are taking here in a soft meaning intended only to accentuate different aspects that integrate the particular practices embedded in assessing the quality control of the data **(**technological and scientific practices, social organization of the scientists, sources of funding**)**. See also « Regimes of knowledge Production in Society: Towards a More Political and Social reading », D. Pestre, 2003,

[485] The optical depth gives an insight about the thickness of the atmosphere or its transparency; it can be divided into several components related to the presence of aerosols, clouds or molecules. Let us illustrate the phisycal sense of such parameter with two extrem examples. After raining, the atmosphere is mostly exclusively composed by molecular gases (O_2, N_2, CO_2, etc.) because most of the suspended particles (aerosols) have been « cleaned » by the rain. In these situations, the atmopshere is very transparent and optical depth of the aerosols is very low. At the other extreme, high concentration of water vapour condensation, like brume and fog, reduce atmospheric transparency and then optical depth related to water vapor can reach very high values. Between the two extremes, a myriad of situations corresponding to different aerosols content can be found.

was feasible with such a polarimeter. PIRAT was launched only once in 1985 inside a ballon provided by CNES and hold in a static position over the oceans. The resulting dataset was considered of poor quality because the lack of calibration and the simplicity of the processing algorithms[486]. The point was that, until then, the tropospheric aerosols had been barely measured and characterized. Therefore, their physical, thermodynamic, chemical or optical properties, including how they affect the radiation and the measurement, remained unknown. In other words, the presence of aerosols perturbated the measurements in a way which was unknown and which himpered their own characterization. These conclusions lead to the design of a prototype of a sun-photometer to measure the optical depth of the aerosols from the ground. The overall idea was to use these measurements on the ground to correct PIRAT's measurements from the effects of the aerosols. This sun-photometer was a detector that pointed to the Sun all along the day (whence the name sun-photometer), capturing the solar energy arriving to the surface (W/m^2). Because the solar energy at the top of the atmosphere follows a well-known theoretical function[487], measuring its value in the surface, after having crossed the atmosphere, permits to derive the atmospheric transmission, which is related to its transparency[488]. In turn, atmospheric transparency is related to its optical depth, which is an indicator of the presence of aerosols (and other elements like clouds or molecules, for instance). Sun-photometers provide a value of the aerosols optical depth by means of well-known direct algebraic operations, that is to say, the values of the displayed tension are proportional to the number of incident photons, that is, to the values of incident energy and, through an exponential relationship, to the atmospheric optical depth. In other words, they do not require the solution of any inversion equation and therefore they do not require any a priori assumption about the conditions of measurement (weather conditions, levels of pollution, type of surfaces, etc.).

In a sense, the lessons taken from the experiment PIRAT would motivate an important development that occurred barely around five years later. A collaboration between some scientists at LOA and the Goddard Space Flight Center of NASA (GSFC) lead to the conception by the early 1990s, of a global network of ground-based sun-photometers, which would become by 1993 the AErosol RObotic NETwork (AERONET). From a single photometer located at LOA's roof, around 600 identical sun-photometers are spread across the globe roughly 25 years later, around 180 of which are located in permanent sites. They are all identical instruments, illustrating a case of a measurement that has become standardized: industrialized automatic sun-photometers built by the French company CIMEL (under the scientific supervision of LOA and GSFC/NASA), whose instrumental performances are well-known, the calibration methods are stipulated and all the eventual failures are handled by specialized operators, usually from universities, research centers or national agencies, that move in situ

[486]"Stratospheric aerosol observations from a ballon-bome polarimetric experiment", M. Herman et al, 1986.

[487] This function in known as the « semisinoidal courbe » reaching its peak of incident energy at local solar midday.

[488] In mathematical terms, the incoming energy arriving to the ground, E_s(surf), is related to the incoming energy at the top of the atmosphere, E_s(toa), by the equation : $E_s(surf) = E_s(toa) \times \exp(-EOT / \cos(A_s))$

The angle A_s is the angle between the direction of the Sun and the vertical in the ground. EOT is the total atmospheric optical depth, composed in turn by the molecular and the aerosols components : $EOT = EO_M + EO_A$, where EO_M is known (it depends on the wavelenght and the atmospheric pressure) and EO_A is our incognita.

to report the deficiencies and, if possible, repare them. A sub-network called AERONET-PHOTONS, which nowadays manages the about 35 permanent sites located in Europe and Africa (and some in Asia), is coordinated by a team of scientists of LOA –a team of GSFC/NASA is responsible of managing the other sites. It is interesting to look at the consortium of institutions which maintains the sub-network AERONET-PHOTONS: it is majorly financed by CNES and CNRS (through its Institut National de Sciences de l'Univers, INSU), with some smaller contributions from MeteoFrance, Instituto Nacional de Meteorología (Spain), the University of Lille or the French private companies CIMEL and ACRIS, amongst others. From all these institutions, we want to draw the attention to CNES. The French *space* agency turns out to be one of the major institutions maintaining the network of *ground-based* sun-photometers. This is, at least at first glance, not a fact to be taken for granted – and we will insist in the third part of that chapter. Let us prospect a bit more on that point.

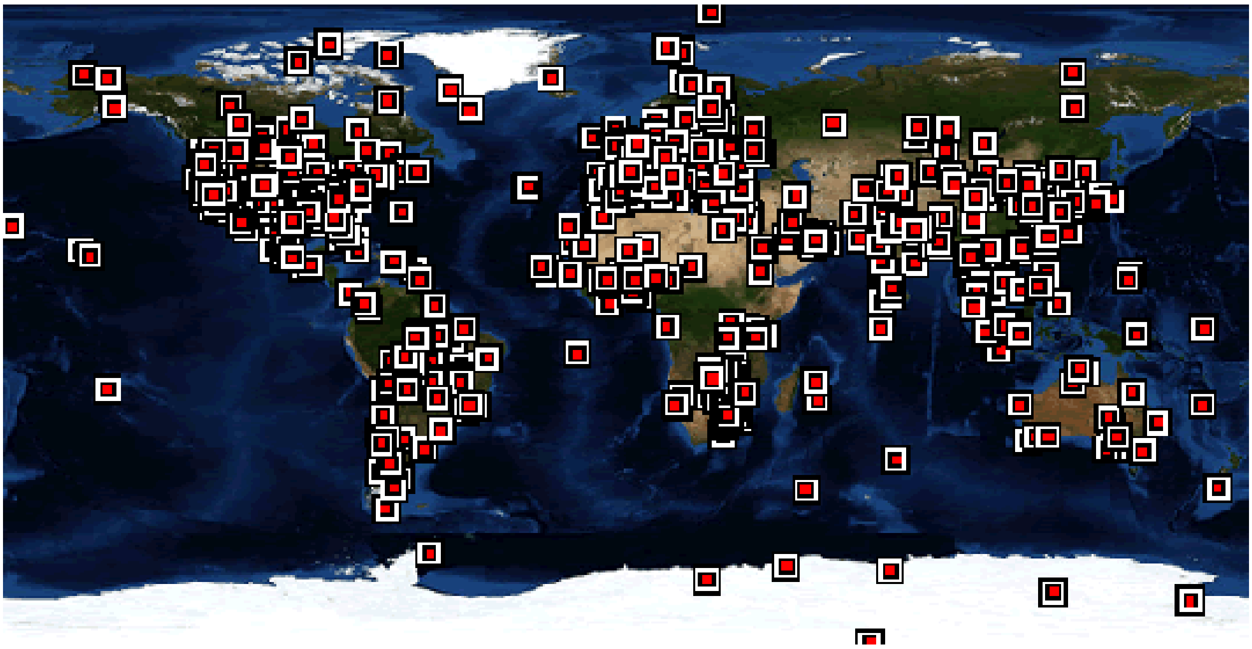

Fig. 4.1: Distribution of AERONET's stations across the globe. This map visualizes one of the limitations of the sun-photometers network: AERONET's ground-based sun-photomters are mostly deployed on continental surfaces, leaving the oceans and the poles uncovered. This geographic distribution, as we will argue, will affect the validation practices and outcomes for data gathered over lands and over oceans[489].

The establishment of this ground-based network to measure aerosols' optical depth coincided in time with the preparation of two satellite instruments deemed to provide data on the tropospheric aerosols, the radiometer POLDER and the Moderate Resolution Imaging Spectroradiometer (MODIS), whose scientific responsibility laid on the hands of the two main advocates for such a network, the

[489] The image is taken from AERONET's website maintained by the Goddard Space Flight Institut of NASA: http://aeronet.gsfc.nasa.gov/cgi-bin/type_piece_of_map_opera_v2_new?long1=-180&long2=180&lat1=-90&lat2=90&multiplier=2&what_map=4&nachal=1&formatter=0&level=1&place_code=10&place_limit=0

Laboratoire d'Optique Atmosphérique and the Goddard Space Flight Center. This was far from being accidental. On the contrary, the deployment of the network of ground-based sun-photometers AERONET was first and foremost motivated by the perspectives of the future launching of such satellites; the idea was to provide a set of data against which comparing the quality of the satellite retrievals. These sun-photometers were to provide a direct measurement of the optical depth of the tropospheric aerosols, which could serve two different purposes: on the one hand, to assess the quality of the inversion algorithms applied to the measurements obtained by the satellites; on the other, to study how the presence of aerosols modified the measurements and therefore the radiance –note that, in turn, apart from being useful for improving the measurements, characterizing these effects would be useful as well for climate studies related to radiation forcing. Because sun-photometers provide direct measurements, the error in retrieving aerosols' properties from photometers in the ground had been thus estimated to be substantially lesser than the one committed from satellite remote-sensing, which involve a number of assumptions inherent to the inversion algorithms. Because of that, comparing POLDER data (and other satellite data, including MODIS data) about aerosols with the independent sun-photometric ground-based measurements provided by AERONET seemed a strategy to verify that, after all the algorithmic manipulations exerted over the signal, the resulting satellite data would still represent faithfully the state of aerosols. This is, for instance, how the physicist Didier Tanré, a *data creator* of LOA, specialized in the interpretation of satellite measurements in terms of the properties of tropospheric aerosols and PI of the future PARASOL, described the relationship between the geophysical data retrieved from POLDER's radiances with the measurements of AERONET:

> "Dans la mesure spatiale [des aérosols] il y a une interprétation ; il y a des algorithmes, alors que la mesure in situ par le photomètre est censée d'être bonne. C'est vraiment la verité-terrain. Il y a de l'ordre de 180 instruments repartis par tout le globe et ils mesurent tous les jours l'épaisseur optique en aerosols, la taille... et ces données sont utilisées pour valider les inversions spatiales. On a tendance à considerer AERONET comme un standard de référence en termes de mesures des aerosols et on va interpréter nos données [of POLDER, but also of MODIS and other satellite instruments] par rapport aux données AERONET »[490].

Two lessons are to be learnt from this quote. We learn first the notion of "ground-truth" ("vérité-terrain" in French language), which is a key concept in the domain of remote-sensing the Earth and its environment. The term is certainly an abuse of language: first, scientists are well aware that no measurement can ever be fully freed of errors and represent the "truth" without some degree of uncertainties; second, the term "ground" refers less to the locus in which the measurements are conducted (the Earth's surface) than to the fact that they are alternative measurements providing independent dataset. In any case, and without pretending any rigorous characterization the point to be retained is that the term "ground-truth" refers to those datasets ideally directly measured, that is to say, not involving inversion algorithms, which hold authoritative epistemological power to be considered as trustful by the community -we will encounter this term all over the chapter. From this quote we learn as well that the measurements taken by the photometers of the network AERONET are

[490] Interview with Didier Tanré, LOA, 2012.

considered the "ground-truths" for the datasets concerning the optical depth of the aerosols. They are stable instruments, reliable enough to be considered as "standards of reference", said this scientist. More than 10 interviews with experts in the aerosols domain, both in France and in the United States, confirm these views[491].

A way to illustrate the degree of standardization of such a measurement is by looking at the routines involved in the operations of the instruments, like the calibration protocols or the sequence of measurements. Studies of performance in the laboratory stipulated that every 6 to 12 months this sun-photometer must be recalibrated since the long term stability of the calibration coefficients decreased from 1 to 10% per year. There was one central calibration facility located at NOAA's Mauna Loa Observatory in Hawaii, whose location at high altitude and isolation from most local and regional sources of aerosols provided a very stable irradiance regime in the mornings, and it was considered to be ideally suited to calibration purposes. It handles direct solar calibrations and radiance sphere calibrations and maintain a "master" sun-photometer against which all the other sun-photometers of the network must be calibrated every 6 to 12 months. Because the number of ground-stations increased rapidly and reached around 200 instruments by 1998, it could take the agents at Mauna Loa from 4 to 6 months to recalibrate a given sun-photometer, which meant that each station was only operational for half or ¾ of a year. Therefore two auxiliary calibration sites were established at Izaña (Tenerife) and Canberra (Australia) to complement the central facility, provided with reference photometers, which were in turn calibrated every three months with respects to the Mauna Loa's master reference. In 2001 an auxiliary calibration site was installed in Pic du Midi (French Pyrenees). This distribution of calibration sites reduced the waiting-calibration time of each instrument to 2 months. Because instruments cannot always be moved to these calibration stations at least once per year and because sometimes urgent adjustements and calibrations are needed, secondary calibration sites were set up, which conduct only some forms of partial and temporary calibration. For instance, in Europe the stations at Lille (LOA), Carpentras (MeteoFrance, fig 2.2.), Izaña (Instituto Nacional de Meteorología) and Autille (University of Valladolid) are adapted for that purpose –the GSFC, for instance, would also adapt some facilities for partial calibration of sun-photometers. If, for any reason, sun-photometers cannot be calibrated at due time, they are considered as inoperative and their measurements are considered not reliable.

As per the sequence of measurements, a routine is programmed starting at 7 in the morning and ending at 7 in evening (there is no sunlight during the night). Two types of measurement are conducted: looking at the Sun and looking at the sky. The Sun-measurements are conducted in 8 spectral bands (340, 380, 440, 500, 670, 870, 940, 1020 nm) and last 10 seconds. For each wavelength a sequence of three measurements is conducted during 30s generating three values of the optical depth, the attenuation due to Rayleigh scattering and the absorption by ozone and gaseous pollutants**.** Because

[491] Probably these views are much more shared worldwide. For instance, we discussed the issue with a scientist working in the environmental department of the Catalan government and they also operate instruments for monitoring local pollution according to AERONET's standards.

the temporal variability of clouds usually is higher than that of aerosols, the operation is repeated every 15min, which allows discriminating between clouds and aerosols contributions to the optical depth by comparing successive measurements. Optical depth is then computed using the exponential algebraic relationship described before that has been coded and integrated in the software. Sky-measurements are conducted in 4 wavelengths and used to compute the size of the particles, their phase function and their refraction index.

At present day, data are transmitted hourly or half hourly from the memory of the sun-photometer microprocessor to one of the three geostationnary weather satellites GOES, METEOSAT or GMS that, acting as relay, retransmit the signal to the appropriate ground receiving station. In that way, the data can be retrieved for analysis and interpretation by satellite linkage resulting in near real-time acquisition from almost any site on the globe –excluding polar regions, which are poorly covered by geostationary satellites. Alternatively, data may be downloaded automatically from the sun-photometer and stored on the local computer. This computer can run software to automatically transfer files to the AERONET processing system through the internet. AERONET's data diffusion illustrated an example of data-sharing, in the sense that the optical depths of the aerosols computed with the network of sun-photometers can be**,** under the form of maps and graphs, freely displayed on the website http://aeronet.gsfc.nasa.gov/cgi-bin/bamgomas_interactive **-** they can be also freely downloaded, in other formats, provided that one is equipped with the corresponding software for data reading and visualization.

Fig 4.2. View of the instrument platform with eight sun-photometers in the Carpentras site (operated by MeteoFrance) used for outdoors radiometric calibration of other sun-photometers. Multiplied by 600 and covering the whole globe (or at least the continental surfaces of it), the networked sun-photometers interweave two twin narratives: instruments for producing scientific knowledge and troubling manifestations of Big Brother.

It can be said, thus, that to validate the quality of the data about the optical depth of the tropospheric aerosols retrieved from POLDER's measurements, *data creators* organized themselves around a unique instrumental model, the AERONET network of reference, providing a unique set of data considered as the "ground-truth", holding authoritative epistemological power over all the other datasets. At the least, we maintain, three elements were essential in the stabilization of AERONET as a standard of reference. First, the theoretical soundness of the principles allowing computing the optical depth from photometric countings had been demonstrated and did not require any inversion. Second, the technical simplicity of the instrument allows replicability. It is affordable in cost, transportable in size and it does not require complex infrastructural machinery to be implemented and operated. Third, it counts with institutional commitment for continuous long-term funding for supporting and maintaining such network, particularly through CNES and CNRS annual budgets. Altogether, we argue, have contributed to some regulatory mechanism for creating a network endowed with strong authoritative epistemologic power aimed to long-term accuracy and precision, which renders AERONET a reliable source of reference datasets. Indeed, AERONET's metrological principles were defined, manufacturers were controlled, legal certification of quality control were stipulated, markets were organized for the instruments as well as for the calibration devices, funding sources were administred, the implementation of new sites was meticously assessed, responsibles were attributed, users were inventoried, and various means were mobilized to guarantee the uniformity and precision of the measurements, and so their continuity over and over time. At the same time, the AERONET network contributed to shore up and unify a community of scientists because it make communication between scientists possible, as different groups may use the network data in different ways and for different purposes, making it their own. Besides, once stabilized, the network progressively would attract a critical mass of scientists, acting as a social connection amongst the aerosols scientific community, nourishing in turn its epistemological authority, its widespread and its longevity in a circle of mutual alimentation of the authority of the instrument and the scientific community using its data. More generally, once a instrument has been stabilized as standard, the authority is clearly localized and the place and role of each actor, instrument and dataset is well defined vis-à-vis each other[492]. The technological stability achieved by the AERONET embodies at the same time a network of credibility and confidence, and it creates a hierarchy of trust, where AERONET photometers are placed at the top. The scientific community working with aerosols may compare their data about the aerosols (coming from POLDER, MODIS, numerical models or other sources) against AERONET data and in case of inconsistencies, they would study the divergences, analyse the errors and try to understand the differences, assuming that AERONET is the "ground-

[492] We shall refer to an article published in 1998 by the sociologist of sciences Alexandre Mallard. The author described three different procedures attempting to judge about the quality of measurements made by different scientific groups, laboratories and disciplines. In the first, there existed juridical standards stabilized through a legal metrical system and a Bureau of standards, which acted as an authority of reference against which the quality of data ought to be assessed. In the other two, these standards and references did not exist. Mallard described then different strategies that the scientists followed to create such references. For instance, in one of his exemples, the author described that scientists would contract an external industrial to artificially fabricate a composite that would become the standard reference.In the other example, the reference was selected by scientists themselves after a process of comparison between different instruments.

« Compare, Standardise and Settle Agreement: On Some Usual Metrological Problems », A. Mallard, 1998.

truth" –note that being qualified as a reference does not mean, to scientists, being exempt of error; indeed, to physicists "all measurements have always an error"[493].

These descriptions inspire us three more remarks -and with them we are concluding this section[494]. Fabricating homogeneized and standardized data about the optical depth of the aerosols through the ground-based network of sun-photometers, recalls other stories of standardization in the XXth Century that put emphasis in the processes of blackboxing and rendering invisible the procedures of fabricating scientific material and, as a consequence, rendering it *as if they were raw*. We think, for instance, on Jean-Paul Gaudillière's famous account about the transformation of the Jackson Memorial Laboratory of genetic research in the 1930s into a Fordian factory in the aftermath of World War II, which mass-produced standardised mice and commercialised them to other research institutions. Just like AERONET data, inbred mice were considered « organismes de référence » for studying genetical diseases, their quality (in his case, associated to their health) was meticulously controlled and their diffusion was routinized. This parallel, which is just one amongst many others[495], confirms the importance of the production of homogeneous and standard material, whether they are data about the optical depth of the aerosols or mice, as one major topic in the history of science and technology, at least of the XXth century.

The increase in the production of Gaudillière's mice lead to the development of a factory of mice separated from the users of the mice. Similarly, the production of AERONET data become more and more an autonomous activity by its own separated from the scientists that may use those data –sun-photometers are automatic and they self-compute optical depth. This parallels the process of separation between satellite *data creators* and satellite *data users* that we have already introduced when studying the factory-like system for geophysical data production and dissemination and the expertises involved in the creation of geophysical datasets through inversion algorithms. At the same time, the sun-photometer became a commercial product detached from its original designers at LOA – and so did their datasets. Data produced with the sun-photometers became industrially-produced, central to experimental practices, though perceived as self-evident and thus remain invisible. As a consequence, the intimate relationship between the scientists and their instruments and datasets fades away as they got industrialized (the case described for SPOT exacerbates this move) -we can even make the hypothesis that in a few generations there will be no trace tying the instrument and dataset with the scientific laboratories from which it emerged.

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[493] The particular quote is from our interview with Frédéric Parol, LOA, 2012.

[494] They inspire also a reference to the doctoral investigations of our colleague Régis Briday, in which he studied the construction of the international networks for measuring the atmospheric ozone and, more generally, the atmospheric composition, including the Global Atmosphere Watch under the auspices of the World Meteorological organization. "Une histoire de la chimie atmopshérique globale. Enjeux disciplinaire et d'expertise de la Couche d'ozone et du Changement climatique", Régis Briday, 2014.

[495] Industrially-produced instruments, data or samples are central to experimental practices but they are often perceived as self-evident and thus remain invisible. This is one of the topics discussed in "The Invisible Industrialist. Manufacture and the Construction of Scientific Knowledge", eds. J.P. Gaudillière and I. Löwy, 1998. More generally, the book discusses the role of industry in the construction of scientific knowledge. Another similar story taking the casuistic of the Drosophila, or fruit fly, is told by R.Kohler in "Lords of the Fly", 1994.

Identical data are produced in a massive blackboxed manner. All photometers are identical, they measure the same variables within exactly the same routines, they compute with identical algorithms and software. They are automatic, they follow their own cycle of measurement from 7am to 7pm every 15 minutes and they keep measuring no matter the circumstances, only interrupted by eventual punctual failures that are handled –or at least reported. Data are gathered, circulated and stored through the network across the globe and over decades –more than two decades at present writing. The production of measurements of the aerosols' optical depth is rendered banal, invisible, blackboxed or, as Geoffrey Bowker and Susan Leigh Star would say, it gets *infrastructured*. The internal workings of gathering, calibrating, producing or disseminating, tend to disappear -becoming only visible upon breakdown[496]. This raises two different narratives. On the one hand, by gridding the Earth's surface, AERONET sun-photometers are integrated in the *global infrastructures* of data gathering that characterize the scientific research about the Earth and its environment, takin Paul Edwards's term, networked infrastructure to gather, produce, store and circulate data at a global scale and that aims to the production of scientific knowledge[497]. Earth sciences have gained a lot with activities of worldwide data-collection and data-sharing, exemplified by the practice of field-working from Humboldtian expeditions in the XVIIth to the International Polar Years in to the International Geophysical Year in 1957-1958 to the First GARP Global Experiment in 1978-1979 and to current field campaigns organized under the aegis of the World Climate Research Program (established in 1979) and the International Geosphere Biosphere Program (established in 1986). They require going to the field and deploying a networked instrumentalization, but also normalizing the rounding system, standardizing the units, protocolizing the calibration procedures, building the pipelines for data to flow, etc. The first narrative celebrates this infrastructuralization as being the technological manifestation of the triumph of science, of the progress of knowledge about our closest environment -and of its conquest. The second narrative interprets these technologies as manifestations of the global environmental technocracy intended to control our planet –and our societies. They are part and parcel of a Foucaultian network of technologies that have instrumented our planet and put it under surveillance, a troubling manifestation of Big Brother, producing gigabytes of data that are systematically gathered and stored, even if no particular have ever requested them, accumulated somewhere in the net until someone may eventually look at them –points that will be raised again in the introduction to the second part of he essay.

[496] That standards play a fundamental role in constituting the infrastructure upon which our lives are lived was excellently demonstrated by G.C. Bowker and S.Leigh Star in « Sorting Things Out: Classification and Its Consequences », 1999.

[497] Paul Edwards develops the case for meteorological networks in "Meteorology as Infrastructural Globalism », Paul N. Edwards, 2006. Extended accounts can be found also in his book "A Vast Machine", 2010.

Co-existence of multiple "ground-truths": SIMBAD/A and the color of the ocean

Measuring the color of the water with a radiometer is a direct measurement, because, when ranged in the visible interval of the electromagnetic spectra, radiances are colors -what requires inversion is retrieving biochemical properties of the ocean from such measurements. It is then the quality of the geophysical datasets like the concentration of cholorophyll in the waters or the type of suspended matter (salt, phytoplankton, pollutants), to mention two examples, which, according to POLDER's community ethos, need to be validated before being released to a wider community. However, as we have already mentioned, the presence of aerosols suspended in the atmosphere induces a large perturbation in the radiation that crosses throughout it. In particular, the correction of the aerosol signal is of uppermost importance for the detection of the ocean color since the reflectance providing from the aerosols is often larger than the one providing from the ocean surface, which renders difficult to discriminate the two signal sources. To derive properties related with the biochemical properties of the ocean from measurements of the ocean's color it is therefore necessary to previously correct the signal from the aerosols' optical effects accurately, which means that is necessary to measure the content and characteristics of the aerosols suspended over the ocean[498]. Unlike the previous case, there did not exist in the 1990s any permanent infrastructured network providing systematic measurements of the marine reflectances (namely, the color of the ocean) or of the biochemical properties of the oceans; there no existed any network measuring the aerosols' optical depth over the oceans either (AERONET's ground-based stations were majorly located on the continental surfaces).

Between 1993 and 1995, scientists and technicians at LOA directed by Pierre Yves Deschamps in collaboration with Robert Frouin, former colleague in Lille who was at that time working at the Scripps, conceived a prototype of a radiometer called SIMBAD (Satellite Intercomparison for Marine Biology and Aerosol Determination), aimed, as indicated by its name, to verify the satellite retrievals of the aerosols content and the biological oceanic properties from the measurements of POLDER-1[499]. SIMBAD was a radiometer measuring, like POLDER, polarized light in five different spectral bands ranged from 410nm to 870 nm (and thus covering partially the wavelenghts measured by POLDER). These scientists would use it to measure the ocean's reflectance in order to, after the appropriate inversion algorithms, derive several parameters necessary to study the atmospheric corrections of the signal like the optical depth of the aerosols, their refraction index, Angstrom coefficient or size[500]. Because SIMBAD was a radiometer, deriving the aerosols' properties from its measurements required

[498] Similarly, in the visible spectrum, vegetation reflectance and atmospheric aerosol reflectance have the same order of magnitude. To observe vegetation cover it is therefore also necessary to correct aerosol optical effects accurately. "The POLDER Mission: Instrument Characteristics and Scientific Objectives", P.Y. Deschamps, 1994.

[499] « SIMBAD : A field radiometer for ocean color validation », P.Y. Deschamps et al, 2004.

[500] « Contribution à l'observation de la couleur de l'océan à partir du capteur spatial POLDER », Doctoral dissertation defended by B. Fougnie, 1998.

also inversion algorithms. This enabled to have a signal not perturbated by the atmosphere eliminating by so doing an important source of error[501].

None the less, SIMBAD was not used after the launch of POLDER-1 to validate the retrievals made from the physical measurements of the color of the water. It is interesting to explore this point because it illustrates that incorporating validation-related activities as part of the space agencies was, between 1990 and 1996, only in the process of being promoted and that it required a reconciliation of the satellite-work activities with the field-work activities. During early negotiations of the mission ADEOS between 1991 and 1992, one of the topics of discussion between the space agencies involved (NASDA, NASA and CNES) was establishing procedures to assess the quality of the data produced from the different instruments aboard the satellite after the launching, that is to say, defining a data validation plan. Initially, the program ADEOS only included activities to prepare the satellite, the instruments and the data prior to the launching[502]. NASDA was clear in that point: after the launching of a satellite, the space agency's function was to guarantee attitude control, orbital tracking, detecting anomalies and correcting them, ensuring data transmission and decommutation, but not to interpreting (and so validating) the data, which was left to scientists. NASDA would not finance the development of ground-based instruments or field-work needed for that purposes. On the other hand, by 1993, the budget scheduled for ADEOS had been already consumed in pre-launch activities; therefore, even if willing to participate in such activities, NASDA had no resources left[503]. NASA, by contrast, planned field-work for validating its instruments aboard ADEOS, particularly the Total Ozone Mapping Spectrometer (TOMS). The American space agency, in particular scientists of the Goddard Space Flight Center working in marine biology, was also very interested in the data gathered by the Japanese instrument Ocean Color and Temperature Scanner (OCTS) because, as we have mentioned, it was considered as the successor of the Coastal Zone Color Scanner (CZCS) and the precursor of the SeaWiFs –actually, SeaWiFS was planned to be launched in 1997 providing for a period of flight-coincidence with ADEOS, which scientists celebrated for possibiliting the combination, mutual calibration, comparaison or fusion of the data gathered by the two different sensors. Also in France, scientists of the Laboratoire de Physique et Chimie Marines hoped to access to data from OCTS, whether to combine them with POLDER's or to prepare the data of the future MERIS. At the end, OCTS would be the only Japanese instrument aboard ADEOS-I for which NASDA would invest in post-launch validation activities: NASDA created a Japanese scientific team to discuss the modalities for common filed-work with the French and American partners and it increased its budget for

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[501] Note that before the launching of ADEOS-I, SIMBAD would be used to study the radiometric calibration of the airborne version of POLDER in the cours of the campaigns MEDIMAR, RACER and SOFIA-ASTEX described before, as well as to develop retrieval algorithms adapted to the observation of the oceans.

« Vicarious Calibration of the POLDER ocean Color Spectral Bands using in-situ measurements », B. Fougnie, P.Y. Deschamps and R. Frouin, 1999.

[502] « Compte-rendu Mission au Japon de 29 Octobre - 2 Novembre 1990 », elaborated by Alain Ratier.

[503] « Compte Rendu de mission POLDER/ADEOS au Japon », Tokyo, 16-20 November 1992, elaborated by Alain Ratier.

scientific post-launch studies in 40% in 1996[504]. In this move, let it be said, the influence of NASA was remarkable. NASA, backed by the Japanese scientists and by CNES, would pressure NASDA to invest to the extent that some teams of the Goddard Space Flight Center had already developed a whole plan for validating OCTS's data and were ready to coordinate and partially fund it. We would like to point out two aspects. First, the influence of the leader in orienting the scientific program of others, in this case through the active initiatives of the remote-sensing scientists at Goddard Space Flight Institute in defining the strategies, experiments, dates and places for validating the data produced from a Japanese instrument. Second, data validation implied field-work, post-launch temporalities and some form of data-analysis and processing. These were three features that had remained outside the scope of activities of the space agencies when dealing with space sciences before the arrival of Earth sciences. This illustrates the progressive incorporation of the data validation practices within the grammar of space agencies.

In any case, as a result of the pressures exerced mostly by NASA, who suggested organizing, coordinating and funding some of the post-launch activities to validate the data of POLDER and OCTS regarding the marine biological properties, some plans for deploying a number of joint permanent stations in coastal sites in the Japanese sea equipped with specific instruments yet to be built (which would include SIMBAD) and an oceanic expedition were suggested[505]. At the end, though, none of these actions would be conducted. According to some minutes of the managers and programmers reporting about these franco-nipon-american meetings, it seems that CNES's representatives were reluctant to leave matters too much under the control of NASA, which after all, was not the responsible of any of the instruments in the game, POLDER or OCTS[506]. We suggest that this reluctance, which was complemented by the poor coordination with the Japanese scientists, as recalls Pierre-Yves Deschamps, could have contributed to restrain the course of such activities[507]. Besides, the unexpected failure of the satellite barely 8 months after its launching, and roughly some weeks after the dissemination of calibrated data[508], reduced the time-scope of the validation period and did not favor the realization of field campaigns specially devoted to collect data on the surface –a point that would also have impact in the assessment of the quality of data about the clouds. Equally important, because of the failure, ADEOS-1 missed the coincidence with the NASA's satellite SeaWIFS, which was one of the major reasons for which American scientists had shown interest in

[504] "Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space", 30-31 January and 4 February 1997.

[505] "POLDER/ADEOS Implementation Plan", approved by program managers and ground segment project managers of NASDA and by project manager of CNES in 1991.

[506] « Compte Rendu de mission POLDER/ADEOS au Japon », Tokyo, 16-20 November 1992, elaborated by Alain Ratier.

[507] Interview with Pierre-Yves Deschamps, LOA, 2014.

[508] On the one hand, the Japanese ground stations had scheduled a delay of 4 weeks in delivering the decommunted data (level 0) to CNES's computing center. It was estimated that this was the time needed to preprocess the data and to mail them to Toulouse. Backlogs in the preprocessing would entail that tapes arrived 15 weeks after acquisition. Besides, the computing center of Toulouse would also suffer technical frictions and operations did not achieve 100% of performance. Finally, calibration algorithms turned to be less accurate that expected and their improvement lasted more months than planned. We will address these points in the second part of the chapter.

OCTS's data, and this certainly made walk away major efforts, including the analysis and interpretation of the few obtained datasets[509]. This lack of validation, we will discuss in the following sections, would have further consequences during the « Validation Review » conducted in 1998, resulting in the consideration that POLDER-1 data about the biological marine properties was of insufficient quality and thus they could not be fully disseminated to *data users*.

POLDER's *data creators* interested in using the data to support studies of marine biology learnt the lesson; they would be better prepared for validating POLDER-2. On the one hand, an improved version of the radiometer, called SIMBADA (Satellite Intercomparison for Marine Biology and Aerosol Determination - Advanced), was developed at LOA, which observed in 11 channels ranged from 350 to 870 nm, covering the majority of spectral bands not only of POLDER, but also of all space radiometers in orbit detecting the color of the ocean, such as MODIS, SeaWIFS and MERIS. On the other, twenty replicas of this prototype were ordered in an attempt to spread the circulation and use of such an instrument, as a first step to establish a stable network of permanent measurements in coastal regions. Space agencies also learnt the lesson and CNES and ESA co-financed part of these technical developments –once again, we find the case of two space agencies investing in ground instrumentation[510]. However, ADEOS-II did not carry the instrument OCTS. This was seen somehow as a relief, as French scientists would not have to act following the tedious procedures that dominated the coordination with their Japanese counterparts. But it was also a loss in several senses. First, there would be no options for mutual intercalibration between the two instruments and therefore POLDER-2 data would be probably less accurate than POLDER-1's. Secondly, there would be less interest in the data per part of the scientists working with SeaWIFS, MODIS and MERIS, which considered their instruments (and also OCTS) as belonging to a long dinasty started with CZCS aboard Nimbus-7 in 1978, and who, according to the algorithmic methodology established in this instrumental line, did not considered the measurements of the radiometer POLDER resolved enough to be useful for studying marine biology. With most of the world-experts using the data from SeaWIFS (Goddard Space Flight Center of NASA), MODIS (Goddard Space Flight Center of NASA) and MERIS (Laboratoire Physique et Chimie Marine, launched by ESA), there was little space for alternative interpretations and inversion algorithms like POLDER's to gain visibility and critical mass amongst scientists.

This did not deter the team of LOA, in collaboration with some scientists of Scripps, to keep working in their studies for validating POLDER's data. After the launching of ADEOS-II, field measurements intensified in the Atlantic Ocean, Mediterranean Sea, North Sea and Baltic Sea, gathering almost 2300 spectra of marine reflectances between April and October 2003 in simultaneity with POLDER-2 observations. However, a strong heatwave stroke Europe in the summer of 2003, reminding that fieldwork is always submitted to the conjunctural vagaries of nature. As a result, the atmosphere was

[509] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[510] For instance, the research conducted within a phd program at LOA was co-funded by both space agencies, CNES and ESA. « Contribution à la vérification des observations spatiales de la couleur de l'ocean à l'aide du réseau de radiomètres optiques SIMBADA », doctoral dissertation of G. Becu defended in 2004.

anomalously charged with suspended particles –in some occasions the signal of the aerosols triplicated that of the ocean-, which radically complicated the works of atmospheric correction of POLDER-2 data. The data retrieved from POLDER-2 measurements were, in certain spectral bands, in high disagreement with the data retrieved from SIMBADA measurements. However hard worked the scientists at LOA and Scripps (and some of the Goddard Space Flight Center who, albeit not interested in POLDER's data as such they were attracted by the anomalous atmospheric situation, seen as a school-case for improving atmospheric corrections for SeaWiFS and MODIS), their results, once more, would be considered as of insufficient quality in the corresponding « Revue de validation » and therefore only released under specific conditions.

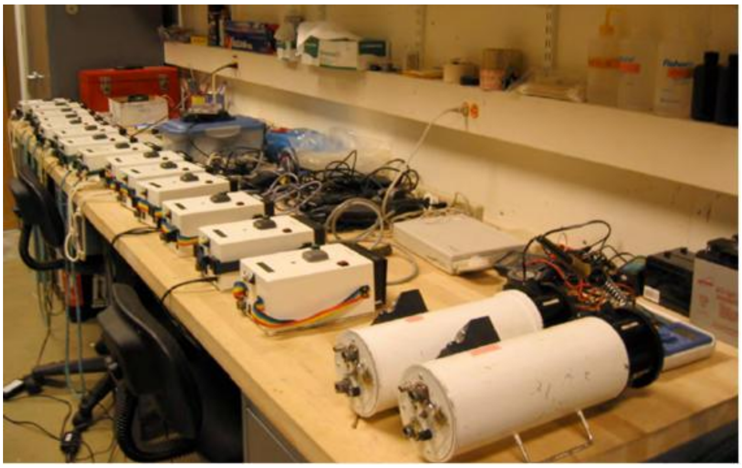

Fig. 4.3: Two SIMBAD (cilindrical) and several SIMBADA radiometers (tetraedrical), which measure the two basic parameters for the validation of ocean color: marine reflectance and aerosol optical depth.

To avoid repetition with the previous section we are not describing here the material properties and technical caracteristics of SIMBAD/A, their calibration, measurements or data analysis. What interests us here is to draw the attention to two specificities that distinguish the regimes of trust in which AERONET and SIMBADA operate. Just like AERONET, SIMBADA aimed to generate a collection of data (marine reflectance and optical depth of the aerosols, as well as other parameters influencing the inversion algorithm like the size, the angstrom coefficient or the refraction index of the aerosols) in the long-term and over the globe –and since 2001, twenty instruments are available to realize such measurements. Just like AERONET, SIMBADA was motivated by the will to validate satellite data. Unlike AERONET, however, when POLDER-II was launched, SIMBADA was still in an experimental stage. The specifications of the instrument had not been studied with detail yet, the calibration methods were still under examination, the instrument had not been industrialized. No stable source of funding was allocated by any organization –as a matter of fact, when the temporal contracts funded by CNES and ESA ended in 2004, all funding ended. No organization was established to institutionalize and systematize the regularity of the measurements, to control their quality, to centralize the data in a consistent database or to coordinate and distribute them amongst different dispersed scientific groups. There was not yet a plan for locating permanently such instruments in a precise coastal locations and establish operational procedures to routinely operate them. Instead, with the exception of two prototypes, which were given to the Goddard Space Flight Institute to be used in a systematic manner during their oceanic campaigns in relation to the validation of the data obtained from MODIS and SeaWIFS[511], at that stage of development, the other eighteen prototypes of SIMBADA were used sporadically. In particular, they were ceded to scientific teams eventually willing to use them in their own field campaigns**.** In other words, the radiometers SIMBADA were entrusted to scientists external to any satellite project, whose main goal was not getting data for the purpose of validating any satellite retrievals but rather of getting data for their own scientific studies. Scientists of Laboratoire d'Océanographie de Villefranche (the former Laboratoire de Physique et Chimie Marines), Institut français de recherche pour l'exploitation de la mer (Ifremer), Scripps, Laboratoire d'Océanographie Dynamique et de Climatologie (LODYC) or the Norwegian Institute for Water Research amongst others, would conduct oceanic measurements with SIMBADA during their own field campaigns. Prototypes were also entrusted officers of the French navy who, quite often without any scientific formation in the domain of optics, physics or marine biology, volunteered to carry one of the remaining eighteen replicas of SIMBADA and operated them during their oceanic journeys. They were amateurs that conducted measurements and observations not because it was their job, but because they wanted to do it, without expectation or pressure[512]. In total, some of the datasets obtained during these campaigns and journeys may be used as well by scientists of LOA to validate the retrievals of POLDER-2, but the majority may not, because the trajectories or regions in which these experiments took place did not always coincide with the track of ADEOS-II or the environmental conditions in which POLDER-2's retrieval algorithms could be applied. To conclude, measuring with SIMBADA during the period of validation of the data retrieved from measurements made with POLDER-2 had in 2003**,** nothing about systematic and operational and the existence or not of SIMBADA measurements (excepting for few campaigns specifically designed, but whose data resulted corrupted due to canicule) depended mostly of the ocasional scientists and navy officers external to the POLDER-2 project that volunteered to carry it[513].

Connected to that, unlike the sun-photometers of AERONET, which had acquired a status of reference in the domain of characterizing some properties of the tropospheric aerosols, especially their optical depth, more or less accepted by scientists working in the field, the radiometers SIMBADA would not achieve such form of authority. We would like to point now to several distinctive aspects between AERONET and SIMBADA that may constitute some of the explanatory elements for such different distribution of authority. First of all, radiometers SIMBADA measure directly the color of the ocean,

[511] « Contribution à la vérification des observations spatiales de la couleur de l'océan à l'aide du réseau de radiomètres optiques SIMBADA », doctoral dissertation of G. Becu defended in 2004.

[512] Amateur scientists have always played an important role in scientific research, especially in astronomy, biology, meteorology, and this is still true today with more disciplines in the list, like computer sciences or climate sciences. Recently, a courant in the history of science focuses in the study of the practices and narratives related to the open science and collaborative research where the role of the amateurs is celebrated within the framework of the ideals of what has been called citizens sciences. We will adress these points in chapter six.

[513] « Contribution à la vérification des observations spatiales de la couleur de l'océan à l'aide du réseau de radiomètres optiques SIMBADA », doctoral dissertation of G. Becu defended in 2004.

but inversion algorithms are needed to transform such mesurements into data about the biological properties of the sea water or of the content of aerosols of the atmosphere. These computations necessarily require some physical hypothesis and approximations, which may prevent many scientists to consider them as "ground-truths" -AERONET's sun-photometers provide, by contrast, direct measurements of the optical depth of the aerosols. Second, the unexpected failure of ADEOS-II may have influenced as well the incentives of deploying a stable network in two ways: by reducing the opportunities of conducting specific campaigns to demonstrate the utility of SIMBADA and by not having POLDER-2 data to validate[514]. By constrast, efforts to implement AERONET started well-before the launching of ADEOS. A third element may have also had some influence: it is plausible to say that the studies of the biological marine properties with POLDER-2's data received poor attention by a critical mass of scientists, who considered them short, poorly resolved for their needs and coincident with a period of high atmospheric pollution rendering them useless, and who would rather use the data from other sensors like SeaWIFS, MODIS or MERIS which constituted a stabilized line of measurements, a line of measurements perceived by a majority of the community of marine biologists as holding epistemological authority. It is not our goal to assess the pertinence of such scientific choices -what matters to us is to note that with reduced material and human resources, and with a powerful concurrent line of measurements, efforts to deploy a permanent network to validate a series of data were not straightforward. Besides, the radiometers SIMBADA were not the sole instrument pretending to supply ground data about the color of the ocean from which retrieving other properties. As far as we know, there existed at least seven other instruments dedicated to validate the satellite data about the color of the ocean, including the spectroradiometers TrIOS developed by Robert Frouin at Scripps and the sun-photometers MicroTops developed by the Goddard Space flight Center in collaboration with André Morel of the Laboratoire de Physique et Chimie Marines[515]. These instruments aimed to institutionalize a network with periodical measurements aiming to create long-term global databases about the color of the ocean. The GSFC/NASA, for instance, was developing a network called SIMBIOS (Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies) to merge and bring together all the in situ measurements of the color of the ocean made by different sensors, including TrIOS, MicroTops and SIMBADA. These attempts to institutionalize and regularize the measurements in situ of the colour of the ocean resorted an essential difference with respects AERONET: they did not promote one sole instrument, but rather they were committed to multiplicity. A scientist, *data user*, confirmed this epistemological commitment towards a multiplicity of datasets as follows:

[514] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[515] Others would be radiometers and sun photometers MER, PRR, SPMR, TSRB, and BOUSSOLE instruments for marine reflectance and CIMEL and Microtops for aerosol optical thickness. « Contribution à la vérification des observations spatiales de la couleur de l'océan à l'aide du réseau de radiomètres optiques SIMBADA », doctoral dissertation of G. Becu defended in 2004.

> « Avec deux instruments on peut avoir plus de confiance aux resultats : c'est quand même plus rassurant d'avoir des resultats convergents obtenus de manière indépendante. Avec un seul instrument on est moins sûr; c'est franchement bien pouvoir en utiliser plusieurs »[516].

Multiplicity was celebrated. In that point the ideals involved in validating datasets retrieved from measurements of the ocean color fundamentally differ from those involved in the aerosols case : instead of committing to one measurement as the reference (AERONET for the case of aerosols optical depth), independent measurements provide confidence in the results and act as data trust-builders. Be as it may, validating the biological properties or the atmospheric corrections obtained from the measurements of the color of the ocean, whether obtained from POLDER, OCTS, SeaWIFS, MODIS or MERIS, was certainly less institutionalized than the validation of the data about the aerosols. They were often the result of individual initiatives and their funding depended on varied unstable sources. Just like the sun-photometer network AERONET, validating the oceanic datasets was dominated by the notion of "ground-truth", that is, by comparing the satellite retrievals with other measurements or retrievals; nevertheless, the plurality of ground-truths was reaffirmed through the co-existence of several instruments, algorithms and datasets –and their respective scientific teams and associated space agencies. These elements, we shall argue, shaped a regime of trust characterized by an epistemological commitment towards the multiplicity of measurements as a confidence builder.

The absence of references: datasets comparisons and the properties of clouds

This epistemological commitment vis-à-vis the plurality of measurements may also be essential in our next and last study case. The philosopher of sciences Ian Hacking suggested, in his discussion about the miscroscope, that if something could be observed using different microscopes then it must exist. The fact that the same pattern of dots—dense bodies in cells—was seen with different microscopes (ordinary, polarizing, phase-contrast, fluorescence, interference, electron, etc.) argued, in Hacking's exemple, for the validity of the observation because it would be too much of a coincidence if the same pattern of dots were produced by totally different kinds of observing physical systems. Different instruments have different backgrounds and systematic errors, making the coincidence, if it was an artifact, most unlikely[517]. The more different are the technologies that observe the pattern, the more confirmation received its factual existence. This is actually a formalization of the practices described to measure the color of the ocean in situ with spectrometers Trios, sun-photometers MicroTops or polarized radiometers SIMBADA. Different is a theory-laden term referring to the fundamental physical theory (interaction of light with matter), which says how different are radiometers from sun-photometers, from spectrometres, or from lidars or videcons. The theory-ladenness of the observations is therefore seen as a virtue because it constitutes a strategy to assess the validity of observations. It was on this basis that the quality of POLDER's data about the clouds would be assessed too.

[516] Interview with Isabelle Chiapello, LOA, 2012.
[517] "Representing and Intervening: Introductory Topics in the Philosophy of Natural Science", I. Hacking, 1983.

It is quite difficult –and costly- to maintain a permanent network for observing clouds in situ. Under the term clouds there are more or less heterogeneous objects located at different height and evolving at different scales of time depending both on their composition as well as on external factors like wind, latitude, air pollution or time of the day. A permanent network of measurement would require different types of aircrafts able to fly at different altitudes distributed across the globe ready to immediate takeoff in the event of a cloud (and in clear-sky to have comparative data), a deployment very difficult to achieve if we consider that, globally speaking, most of the Earth is covered permanently by clouds. Besides, it is sometimes simply very difficult to measure the properties of the clouds in situ –at least some of them, as this scientist illustrates[518]:

> « Les avions ne peuvent pas s'éloigner beaucoup des côtes, ils ont des contraintes géographiques assez importantes… sans parler des frontières et des législations concernant les espaces aériens! Par exemple, près de côtes du milieu du Pacifique il y a un type de nuages, les stratocumulus. Plus on s'éloigne des côtes plus la couverture devient fractionnée, ils deviennent des nuages plus multiformes. Dans ces régions on observe par satellite des tailles de goutes plus grosses qu'ailleurs. Quand on a fait les premières inversions [from POLDER data] pour ces régions, les gens qui avaient fait des mesures in situ disaient que ce n'était pas possible parce qu'ils avaient jamais observé ça. Et oui, ils n'ont jamais observé parce qu'ils n'ont jamais volé au-dessus de ces nuages: ces nuages sont trop loin des côtes et les avions n'y arrivent pas. Aussi, il y des contraintes météo. A part quelques kamikazes qui ont volé parfois dans systèmes convectifs intenses, d'habitude les pilotes ne s'amusent pas à y entrer pour prendre des mesures! Or, il s'agit souvent de situations très intéressantes à étudier… »[519].

This quote illustrates, with some humor, the inherent difficulties of establishing a network of permanent measurements of the properties of the clouds. Insofar scientists are deprived of any standard of reference in situ allowing identifying, comparing and evaluating the satellite data, the question of ground-truth, or shall we say air-truth, and of the veracity of data and their authenticity is delegated to other approaches. Tipically this meant participating in field campaigns where different instruments provided data about comparable properties of clouds.

In the summer of 1997, one international major experiment had already been planned independently of POLDER validation activities, ACE-2. ACE-2 was the second experiment of the International Global Atmospheric Chemistry Core Project of the International Geosphere and Biosphere Program to characterize the aerosols and it was funded primarily by the European Commission under the 4th Framework Program of Environment and Climate[520]. The factual measurements took place place from 16 June to 24 July 1997 over the sub-tropical North-East Atlantic. More than 250 scientists, 70 scientific teams, 45 different laboratories and 15 countries participated in providing different type of measurements. In France, the main participants were MeteoFrance, the Centre National de Recherches Météorologiques and the Service d'Aéronomie, with some rather sporadic contributions from Laboratoire de Météorologie Dynamique, Laboratoire d'Optique Atmosphérique and others. The

[518] An interesting point to further explore focuses on whether these practices are evolving with the recent advent of non-manned aircraft and drones. Put it another way, are these technologies modifying all these practices, either for validating satellite data or for field-working in any domain of Earth sciences? Our case-study, POLDER, predated these developments and we cannot conclude on that point.

[519] Interview with Jérôme Riedi, LOA, 2012.

[520] "The second Aerosol Characterization Experiment (ACE-2): General overview and main results", F. Raes et al, 2000.

methodology consisted, as usual in this type of campaigns, in a cross-comparaison of various measurements taken with a myriad of differents instruments, including conventional meteorological instruments and sounders, condensation particle counters, radiometers, ion chromatographs, lidars, radars and spectrometers, placed inside 6 different aircrafts, one ship, balloons and several surface stations located in Portugal and the Cannary islands, together with the instruments inside the satellites that would be overflying the region during that period. This intensive and exhaustive deployment of personnel and means aimed to address a given specific scientific question: to study the physical, chemical and radiative properties of the aerosols from Europe and of desert dust from Africa as they were transported over the North Atlantic Ocean.

POLDER's *data creators* working with clouds' algorithms would not let the opportunity away to organize, in the framework of this campaign, some measurements especifically optimized to validate POLDER's data taking advantage that ADEOS-I would fly over the region twice during this period, on June 26th and on July 9th. Three aircrafts (Merlin of MeteoFrance, Dornier of DLR, and C130 of UKMet) were flown in parallel at three different heights following the satellite track in order to make measurements in coincidence with the satellite's using both the traditional instruments for sounding the atmosphere and the airborne version of the POLDER instrument, placed onboard of Merlin (together with conventional meteorological instruments). Besides, the Ukraneo-American ship "Vodyanitskiy » carried specific ground stations and atmospheric sounders provided by Pacific Marine Environmental Laboratory of NOAA and the Delft University of Holland[521]. To POLDER's *data creators*, the specific goal of this particular exercice was not other that gathering data from different sources in order to compare and correlate them with POLDER's retrievals about some of the properties of the clouds, and to conduct corresponding error analysis –of course, these data could be in turn used to study the clouds by themselfes, but this was a secondary goal for *data creators*. Frédéric Parol, for instance, a young professor at LOA who had defended his thesis studying the detection of ice cirrus based in the gradient of temperature measured with the radiometer AVHRR, had developed an algorithm for retrieving the cloud optical depth and the cloud albedo from POLDER's radiances, and he compared these parameters, measured on June 26th, retrieved by the two POLDER instruments, airborne and spaceborne[522]. A second identical instrumental configuration took place again for July 9th taking advantage that ADEOS would cross over again the region; by then, however, ADEOS-I would no longer be in operations and the measurements would not be taken.

[521] "The second Aerosol Characterization Experiment (ACE-2): General overview and main results", F. Raes et al, 2000.
[522] "Cloud optical thickness and albedo retrievals from bidirectional reflectances measurements of POLDER instruments during ACE-2", F. Parol et al, 2000.

Box 4.1. Space-borned and air-borned POLDER's data

These are some of the images produced from the data gathered during the field-campaign ACE-2 in summer 1997. The circular lines indicate the scattering angles in a step of 10°, starting with the central one corresponding to a scattering angle of 170°. The straight line corresponds to the solar principal plane. A polarized ring can be distinguished around 140°-150°, which is always observable in the presence of scattering particles, like the aerosols. Whence the possibilities of POLDER to characterize aerosols by analyzing the ring. As per the clouds, excepting for some specific types of clouds or geometries of observation, clouds generally do not polarize –as seen in these images, which present small polarized rings. Actually, the polarizing properties of clouds are associated to the microphysical properties of the clouds, like the size of the particles or their shape. Whence the possibilities of POLDER to characterize these properties.

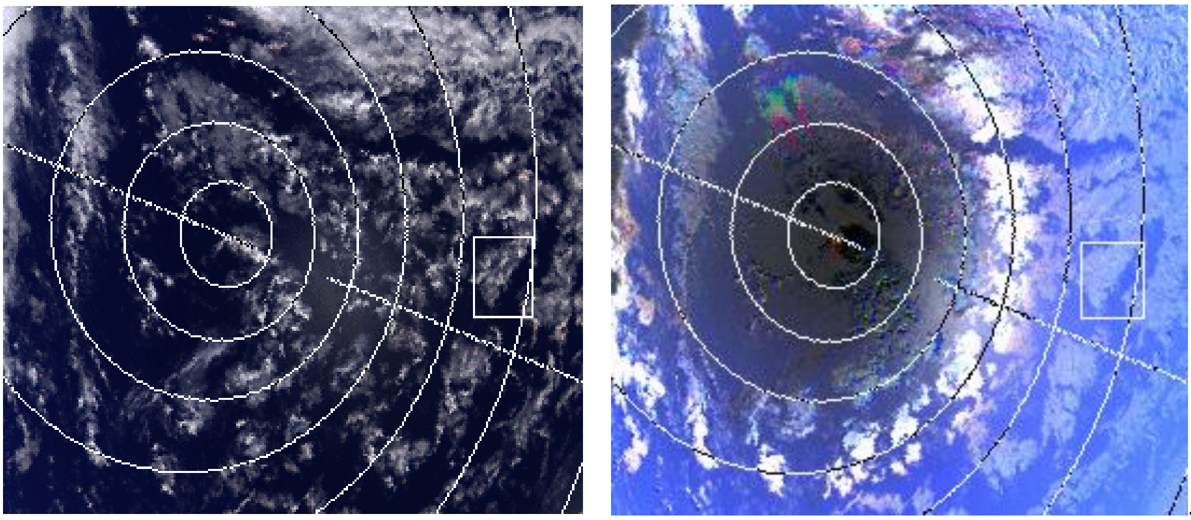

Fig. 4.4: Images produced from the data gathered with the satellite-borned POLDER aboard of ADEOS in the surroundings of the Cannary Islands, June 26th 1997, flying at around 860km. In the left, total luminance and polarized luminance in the right.

Next images are a zoom of the previous ones, corresponding to the rectangular area. Because these particular clouds generate, through scattering, a poor polarized radiation, they are useful for calibration purposes when compared to aircraft data. Indeed, clouds constitute a source of natural light which can be used to control the performances of some parameters of the polarized channels of the space-borned POLDER.

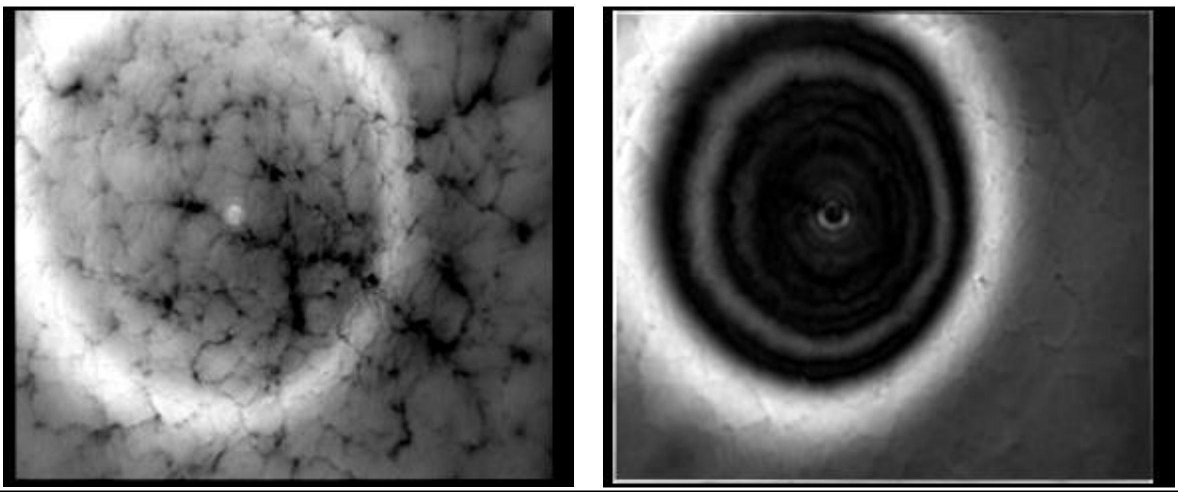

Fig. 4.5: Images acquired by the airborne version of POLDER, June 26th 1997, corresponding to the rectangular area of the previous images flying at about 4500m. Total luminance in the left and polarized luminance in the right.

Some other field campaigns had been planned to assess the quality of POLDER-1 data about the cloud properties during 1997 and 1998, including several joint flights with Lidars aéroportés pour l'Etude des Aérosols, des Nuages, de la Dynamique, du Rayonnement et du cycle de l'Eau (LEANDRE) developed at the Laboratoire de Météorologie Dynamique and specific radiosondes releases[523]. However, as we have seen mentioned when discussing the validation of the data of the biological marine properties, the delays in the delivery of calibrated data together with the precipitated failure of ADEOS-I provoked that the field campaigns planned specifically for validating POLDER-1 data would just not be conducted –similar issues happened with POLDER-2.

These two precipitated POLDER failures and their consequences in the data validation practices, mostly in the ocean and clouds domains, emphasize an important element in the debate regarding data dissemination that we have introduced when discussing the data policy in chapter three: the more time it takes to release data, the more risk of dramatic aleas may occur, aleas which may drastically drop down possibilities for further data utilization –like illustrated with POLDER-1 and 2. It took an average of 15 weeks to receive the data from the Japanese ground station after acquisition, about 8 to 10 months to stabilize the calibration procedures in the computing center of Toulouse (and yet, they would be assessed as poor performant)[524] and around 8 to 10 more months to validate the quality of the geophysical datasets by *data creators*[525]. Almost two years elapsed from the launching of ADEOS-I and the release of the first geophysical datasets to *data users*. In the meantime, ADEOS-I had failed and no more measurements were available. On the other hand, releasing too soon the data before being validated could provoke what some scientists called "mauvais usage des données"[526]. We have been told of a case, for instance, of a recent publication which reported an inverse correlation between the concentration of aerosols and the presence of clouds observed by the lidar aboard of the satellite CALIPSO where the author of the publication, a *data user*, derived some concrete conclusions about the direct impact of aerosols in the formation of clouds. Some of the *data creators* specialized in the retrieval of clouds properties were highly convinced that the conclusions were not clear and that they were rather a result from the way in which the algorithm for detecting clouds with the lidar was built: if the concentration of aerosols in the observed scene is relatively elevated then the algorithm for clouds detection is too noisy and it does not distinguish clouds anymore, and it classifies the pixel as uncloudy, although there might or not be clouds[527].[528] It is, to *data creators*, precisely the whole point

[523] The validation plan for POLDER-1 and 2 can be found at: http://smsc.cnes.fr/POLDER/SCIEPROD/rb_validation_plan.htm

[524] "Rapport du Groupe de Revue de la Revue de fin de Recette en Vol POLDER », June 1997.

[525] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[526] Interview with Frédéric Parol, LOA, 2012

[527] Interview with Jérôme Riedi, LOA, 2012.

of data validation to identify and neutralize, or at least make explicit, these artifactual effects. But the scientific team of CALIPSO, as we have mentioned in the previous chapter, had chosen to partially release their data after 6 months before the validation was over and the data was accessible to everybody without fully having assessed their quality. The author of the publication using these data associated a physical process to a phenomenon, whereas it was probably an artifact of the algorithm. "C'est dangereux », said a *data creator* commenting on another similar case he encountered, « parce que faire de la recherche avec des observations qui ne sont pas validées, c'est prendre le risque d'avoir de fausses interprétations »[529]. Another scientist, this time a *data user*, told us that she had conducted some research with a given dataset of the instrument MODIS released also 6 months after first acquisition, which was later considered as incorrect and therefore her analysis had no value[530]. Bill Rossow, a scientist of the Cooperative Remote Sensing Science and Technology Center of NOAA, bounced off these ideas claiming that "it is the duty of each scientist to make sure that the data he is using are appropriate, just like it is the duty of each PI to provide data of quality »[531]. As we have illustrated when discussing different data policies in chapter three, the tempo of data dissemination, what data is to be disseminated and to whom, is an open question and each scientific team has the legitimacy on deciding about them.

Let's go back to the validation of POLDER's data about the properties of clouds. Conducting all the field campaigns that were planned to validate the datasets was not possible due to the conjunctural delays in the delivery of calibrated data and the unexpected failure of ADEOS. POLDER's datasets would then mostly be studied by comparing them against two other sources of data: data from ground stations providing a local measurement under the track of the satellite and data from other satellites which would fly in the same period than ADEOS and, if possible, over the same region. For instance, data about the content of water vapor retrieved from POLDER observations were compared with data from the traditional meteorological radiosonde measurements taken twice per day[532]. Data about the thermodynamic phase and the cloud pressures derived from POLDER-1 were compared with the instrumental set conceived by the US Department of Energy known as Atmospheric Radiation Measurement (ARM)[533]. This kit, composed of around 15 instruments including radiometers, interferometers, particle counters, radars, lidars, sun-photometers and conventional meteorological instruments, was placed in 1992 in a facility in Oklahoma, which was the first of a series of facilities that would constitute the remote-sensing Climate Research Facilities of the US Department of Energy.

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528 He have been told of similar cases in other domains too. For instance, a publication was issued providing for a rate of the rise of the sea level, which turned to be a product of the artefactual assumptions introduced by the algorithms for retrieving sea level height from radar measurements with Topex/Poseidon. Juliette Lambin, Technical Center of Toulouse, personal communication, 2011.

529 Interview with Frédéric Parol, LOA, 2012.

530 Interview with Isabelle Chiapello, LOA, 2012.

531 Interview with Bill Rossow, NOAA-CREST, 2013.

532 « Cloud detection from the spaceborne POLDER instrument and validation against surface synoptic observations", F.M. Bréon et al, 1999.

533 "Comparison of POLDER apparent and corrected oxygen pressure to ARM/MMCR cloud boundary pressures", C. Vanbauce et al, 2001.

By 1996, data from the stations ARM were the only ground data available providing some of the properties of clouds, like their thermodynamic phase[534]. The properties of cirrus of POLDER-1 were also compared with some lidar measurements conducted from Meudon and the Observatoire de la Haute Provence[535]. By the time POLDER-2 was launched, the ground remote sensing observatory SIRTA (Site Instrumental de Recherche par Télédétection Atmosphérique) had been built in Palaiseau. Like the ARM facilities, SIRTA is an observatory that gathers and operates a set of active and passive instruments to observe the atmosphere, including lidars, radar, several radiometers, a sunphotometer belonging to AERONET network, and several other conventional weather instruments like anenometers, rain gauges, barometers, and so forth. SIRTA represents one of these examples in which CNES, the space agency, is involved in the development and maintenance of ground-based measurement stations[536]. Data about the clouds retrieved from POLDER-2 observations would be then compared with data from SIRTA[537].

Ground measurements are done in a very particular given situation and in punctual sites. They are extremely local exercices and temporal and space resolutions mismatch POLDER's ones, which are provided in a continuous time sequence and in grids of around 6x6km2. Despite of this locality, ground measurements are considered to provide an indirect validation to satellite data. If satellite data are good in a given place, so the argument goes, why shouldn't they be good at all places –or at least in those places with similar conditions than ours? Of course, this extrapolation must be done with care and scientists must control the characteristics of the measurement and the instrument, as well as the methods of rendering local data commensurable with satellite data. We will address some of the work required to render local ground data and POLDER data comparable when describing the creation of another type of data, that we have called *climatic datasets*, in chapter six.

Apart from these comparisons with ground local measurements, data about clouds properties were however mainly compared with data derived from other satellite instruments. We must not lose sight that POLDER was not by far the only space instrument observing the clouds in the late 1990s. Not to forget that once a satellite has been launched using its data is, compared to field campaigns, relatively costless because all that is needed is a computer (and the adequate software); no aircrafts, balloons, ships, no travels for scientists, no maintenance of any network –other than the satellite. This certainly

[534] The program was approved in 1990 and the first instrumental site was built in 1992 in Oklahoma, a site that today includes around 30 instruments. Ever since, the US Department of Energy has extended the number of stations for Climate Research Facility equipped with ARM instrumental packages providing strategically located in situ and remote sensing data to scientists. Today, four central sites complemented with a number of smaller ones cover the US territory (and overseas) and are complemented with ground mobile units and aircrafts. Like the AERONET, the instruments of the instrumental package are highly standardized and commercialized. See: http://www.arm.gov/

[535] "Cirrus cloud properties derived from POLDER-1/ADEOS polarized radiances: First validation using a ground-based Lidar network", H. Chepfer et al, 1999.

[536] The Site Instrumental de Recherche par Télédétection Atmosphérique (SIRTA) is a French atmospheric observatory with around 20 instruments dedicated to cloud and aerosol research, located in a semi-urban environment in the south of Paris, and operated and maintained by the Institut Pierre Simon Laplace, with support of the Institut National des Sciences de l'Univers of CNRS, CNES and the Centre d'Enseignement et de Recherche en Environnement Atmosphérique.

[537] "Validation of POLDER/ADEOS data using a ground-based lidar network: preliminary results for semi-transparent clouds", H. Chepfer et al, 1999.

favored the widespread of satellite-to-satellite data comparisons since they could be conducted with a small budget. For instance, scientists from LMD would compare POLDER's data about cloudiness, that is presence or not of clouds, with those from geostationary weather satellites such as METEOSAT and GOES (and MSG/SEVIRI when available)[538]. Data about the water vapor content would be compared with their equivalents from DMSP-SSM/I[539]. A lot of comparisons of data about the cloud fraction, the water vapor content, the cloud phase, the cloud optical thickness, the cloud top pressure and the cloud droplet effective radius were made between POLDER data and MODIS data, taking advantage of the good coincidences in time and space between ADEOS-2 and Terra[540]. The derivation of the shortwave albedo from the spectral albedoes derived from POLDER measurements, known as spectral integration, was compared between POLDER-1 data and ERB-scanner and ScaRaB measurements[541]; for POLDER-2, this would be done using Terra-CERES measurements and SCIAMACHY[542].

These are only but some exemples that illustrate that it was believed that the best way to assess the quality of satellite data about the clouds and their properties was to operate them simultaneously against other data: aircraft data, local ground measurements or satellite data were all used to interpret and asses the quality of POLDER's datasets about the clouds' properties. In this sense, these activities for validating the data of the clouds are analogous to those described in the two previous sections insofar as they all rely on the comparison amongst datasets coming from different sources. However, the comparisons for validating the properties of clouds resorted some specifities. In the absence of an accepted ground-truth, or of several of them, how the results of a given data comparison validate or not a given dataset? Ultimately, comparing satellite datasets against each other cannot prove that they are correct. Yet, even if data comparisons did not provide proof in any strong sense, they would help to building trust, provided that the results converge in a consistent manner. "Consistency" between datasets and "reasonably approximation"[543] were often quoted as key aspects to build trust in data in the course of our interviews. The epistemology of comparisons, in the case of the validation of clouds data, did not claim the truthness of a dataset but rather its plausibility. Through data comparisons scientists would measure the individual differences between the data, the algorithms and the instruments, understand their uncertainties and interpret the errors. The objective of these comparisons was not to determine a reference measurement to be adopted as a standard by the collective. It was not about allocating authority of one instrument before the others, it was not about building a hierarchy among instruments. What prevailed here was, like in the comparisons made between the groud instruments measuring the color of the ocean, the epistemological commitment towards the

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[538] "Cloud cover observed simultaneously from POLDER and METEOSAT", G. Sèze et al, 1998.

[539] « Contribution of POLDER to water vapour observation », M. Vesperini et al, 2000.

[540] « Comparisons between POLDER 2 and MODIS/Terra aerosol retrievals over ocean », B. Gerard et al, 2005.

[541] "Monthly means of reflected solar flux from POLDER(ADEOS-1) and comparison with ERBE, ScaRaB and CERES", M. Viollier et al, 2002.

[542] "Earth reflectance and polarization intercomparison between SCIAMACHY onboard Envisat and POLDER onboard ADEOS-2", L. Tilstra et al, 2007.

[543] Interview with Didier Tanré, LOA, 2012.

multiplicity of measurements. No instrument can pretend to provide better measurements than the others, but all they rather had their avantages and inconvenients, as one of the scientists quoted in our introductory paragraphs said. In that sense, the comparison process to evaluate the quality of the data about clouds is a relative one: there is no absolute reference to situate the performance of a given instrument, but only the relative reference provided by all the other instruments[544]. Likewise, the results of the comparisons were local, a result only applicable to the particular situation corresponding to the analysed dataset. Other situations, it was assumed, may give other results.

The goal of the comparisons was not to reject or recommend any dataset, but rather to characterize them depending in their strengthenesses and limitations. They documented and reported. In this sense, data comparisons reckoned the value of each instrument and algorithm as a piece of a wider common effort of reporting the nature, a part and parcel of the global infrastructures to produce knowledge about the climate, a venture that could only be achieved in collaboration. At the same time, they reinforced the stratification and the fragmentation within the whole effort. They recognized the value of the ensemble, but did not abandon the unique value of each instrument. Unlike other accounts in the history of sciences where the multiplicity of instruments, data, theories, models, institutions, ideologies and practices may result in a frenetic competitive struggle to reach the absolute epistemic authority[545], comparing data about clouds against each other was not controversial because it did not aim to establish any set as better than the others. We cannot leave matters only at the epistemological level though. One possible explanation for the absence of controversy, and the celebrated multiplicity, may be illuminated when considering that every instrument is associated to a scientific group and space agency, who have long invested on its development, realization and analysis and that wish to see their effort rewarded –or at least not left in the sidelines. How could a space instrument be rejected after the herculean efforts, in terms of expertise, time, budget, done by the scientific team and space agencies to get an instrument launched? How would all these efforts be maximized if the datasets were considered *bad*? Instead, while recognizing each other's limitations, all instruments, and therefore all datasets, were celebrated. As long as multiplicity of datasets, algorithms, instruments and scientific teams would be admitted as the practice for validating satellite data, a large and vast range of datasets, algorithms, instruments and scientific teams would be enabled to keep doing business[546]. By contrast,

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[544] In his study about the creation of references for measuring the air-quality with differential optical absorption spectrometry, Alexandre Mallard found similar conclusions.

"Compare, standardize and settle agreement: on some usual metrological problems", A.Mallard, 1998.

[545] The AERONET exemple would be one of those. Prominent historical studies illustrating that the multiplicity of approaches can lead to controversial confrontation leading to winners and losers would be : « Leviathan and the air-pump : Hobbes, Boyle and the experimental life », Simon Schaffer and Steve Shapin, Princeton University press, 1985 and « Pasteur : Guerre et paix des microbes », bruno latour.

[546] We may wonder, and this shall remain as an interrogation, whether similar arguments may apply to other domains of research. We think particularly to the multiplicity of Global Circulation Models and the methodology of comparing each other promoted by the International Panel of Climate Change. Within this methodology, climate modelers are given future economic scenarios, which would be associated to scenarios of CO2 emission, which would be associated to concentrations of CO2 in the atmosphere, which would be introduced in the numerical climate models, which would run and provide a climatic scenario. There are around 20 climate models in the world that compare their respective results following well-stipulated protocols. Without denying the importance of the epistemological commitment to multiplicity as trust-builder and of the comparison-practice to identify uncertainties, errors or bugs, and to understand

when one of such instruments or instrumental lines was chosen as the stabilized norm, no alternative ways for measuring and interpreting the data were left possible -the marine biology line of POLDER may be seen under these lens and was left in the sidelines by the powerful concurrent legacy of CZCS-OCTS-SeaWiFS-MODIS and MERIS.

Scientists had, after all, enough flexibility to decide up to what point data from different sources must converge and up to what point discrepancies were tolerated. They put their own limitations. If, after all the error analyses and algorithmic interpretations, discrepancies between data persisted, they were simply reported and documented. In other words, once the data had passed all the quality controls, no data was rejected. Instead, divergences were notified and published, and eventually someday understood, and used to evaluate what dataset was more appropriate for study a given situation. Comparisons of data about the clouds were thus aimed to evaluate data against each other; with the goal of identifying convergence points and discrepancies between data produced from different instruments and with different algorithms, to judge in what situations what data are good enough and with what precision. This regime of trust was, like the ocean color one, dominated by the plurality of instruments and datasets, which was celebrated as an added-value reinforcing trust on data, without any aspiration of declaring a best ever dataset, to the extent that references and ground-truths rarely existed.

Box 4.2. The Climate Change Initiative: Satellite-to-satellite comparisons all over

Nothing illustrates better the epistemological commitment to multiplicity and satellite data comparison, or the need to maximize the efforts to get a satellite launched, than the Climate Change Initiative program of the European Space Agency[547]. To make this point, we must however step forward in time. The Climate Change Initiative was initiated by ESA in response to a G-8 meeting hold in 2002, when decision-makers endorsed the establishment of a space-based system for studying and monitoring the climate at the global scale, mirroring the existing infrastructures for gathering, processing and disseminating data for weather forecasting purposes (we will come back to this program in the second part of our essay). Although it only provided an umbrella where actions were carried out by individual actors, mostly within Europe (individual laboratories and space agencies), many important collaborative projects were conducted.

One of such projects began around 2010 and involved more than ten satellite instruments, including POLDER aboard PARASOL, MODIS, MERIS, TOMS, OMI, GOMOS or MISR, and ten scientific groups, amongst which a team led by Didier Tanré, the scientific responsible of PARASOL of LOA. It consisted in the analysis of various aerosol inversion algorithms to retrieve six basic different parameters related to the properties of the aerosols, which had been considered one of the Essential Climate Variables to be produced (angstrom coefficient, optical depth, aerosol type, absorving aerosol index, strastospheric extinction). The methodology consisted in applying the different algorithms to one month of data corresponding to September 2008 and comparing the results obtained each other. The point of this exercice was to validate the geophysical datasets retrieved from these instruments. In a classical comparative approach, like the ones discussed before, this would

and improve them, we must bear in mind, we believe, that a methodology based on comparison is a win-win methodology that enables keep doing business to all, and so to maximize the previous efforts engaged to develop complex, and expensive, climate models.

547 « The ESA Climate Change Inititative. Description », ESRIN, 30.09.09, EOP-SEP/TN/0030-09/SP

allow identify differences, analyse errors, study the adequacy of the algorithms. The results were also compared against AERONET's data. Data were shared, protocols of comparison were standardized, error analysis methods were made explicit. Funded by ESA's grants, participants spent three years comparing data against each other. While maintaining a stable reference on the ground, AERONET, no satellite instrument was, in absolute terms, better than the others. This was a win-win scenario in which all instruments were accepted and no datasets were rejected, enabling in so doing to capitalize the efforts made by scientific teams and space agencies to get the instrument launched.

Our interest here is not to give detailed description about the Climate Change, but providing just one illustrative exemple on the importance that the activity of comparing datasets with each other had achieved within *data creators* and space agencies by the mid 2000s, both as an epistemological tool to assess and judge the quality of the satellite geophysical datasets and as tool to maximize the efforts and render visible the outcomes.

Calibrated eye

The different arguments and configurations outlined in this section illustrate that considerations about truth, validity, trust and acceptability may vary in different situations. What counts as good data depends on the material techniques available, on the very nature of the observed object, on the social organization of the communities and the stability or scarcity of the funds. These factors impose their own practical rules and result in different regims for judging and assessing the quality of satellite data. Different collectives mobilize different strategies to assess the quality of the data that they produce. For the aerosol data, these are quite classical: they include devices which are standardized and calibrated by an external institution (AERONET), they can be found in the market, and their authority is rooted in their technical accuracy, their institutionalization and their widespread use amongst the scientific community. In this case, when comparing two datasets, the authority is otorgued a priori to the reference -of course, it can be contested a posteriori once the comparisons between particular datasets have been made. By contrast, the satellite comparison strategy that we have found for validating POLDER data about clouds features a process which does not aim to establish references, but rather to distribute authority among the instruments. It does not call for reducing the technological variety of instruments, but rather for maintaining it as an asset to build trust in the datasets. The authority is constructed during the very process of comparing datasets and may vary as the variables of the comparison vary (instruments, algorithms, orbits, observed scene). These are two different ways of appreciating authority that deploy two opposed regimes of trust: we trust in a given universal external authority or we trust in the relative and local authority that we create. In any of the cases, though, in order to assess the quality of the data, a refined knowledge of the data gathering and production is required. It is to that point that we turn now.

All these comparisons of data acted thus as data quality controls and mobilized the usual tools of statistical error analysis methods, such as xi quadrat or least squared; other quality controls tipically included the checking for correct code formats, for data gaps and missmeasurements. This approach draws upon an epistemology in which statistical methods are used to build a kind of objectivity that could be qualified as *mechanical objectivity*. As described by Lorraine Daston and Peter Galison, mechanic objectivity is characterized by a will to analyze data by eliminating all human intervention, all personal fingerprint is erased by the automatic character of the procedures and of the employed techniques[548]. All these methods helped to reject any observation deviating too much from the accepted error; in turn, a separate analysis of these rejected data would help to identify problems with instruments, procedures and interpretations. After all these automatic filters, discrepancies between data were however still commonplace. Then validating the data implied descending to the very physics of the measurement and of the algorithms to understand what hypothesis may influence over what bias, to understand how the algorithms behave, what are their characteristics and their limitations, their sensibility when confronted to different error sources, the impacts of the coding. A *data creator* of Laboratoire des Sciences du Climat et de l'Environnement put it this way:

> "Celà demande une certaine expertise. Je sais que ma mesure satellitale est très sensible à l'aérosol, par exemple, qu'elle est perturbée par tel truc et tel truc. Si je suis dans telle situation je sais que j'ai une grosse perturbation et du coup je ne ferai pas trop de confiance à mes mesures ; par contre, selon ce que je comprends de la physique du phénomène, dans une autre situation il n'y aura pas de perturbation, donc le signal sera complétement dominé par mon aérosol et je ferai confiance à ma mesure. Typiquement quand on fait une mesure d'aérosol sur terre ferme on va etre perturbé par le signal qui vient de la surface, donc c'est difficile de mesurer ces aérosols parce qu'on a du mal à faire la différence entre ce qui vient de la surface et ce qui vient de l'aérosol. Par contre, sur mer, on sait que ce qui vient de la surface est très faible et du coup on sait que la mesure va être plus précise sur mer que sur terre. Quand on comprend bien le transfert radiatif, quand on comprend bien comment fonctionne cette mesure, on est capable de dire que la mesure va être très précise ou très perturbée »[549].

Arguably, the algorithms themselves become an object of study considered as necessary, a full-time job prior to understanding the phenomenology of the situation that they are supposed to report, and one must be trained to do that job and to understand the data and the algorithms : one needs to know about radiation transfer, about the optical system of the instrument, about the absorption and scattering properties of the atmosphere, and about the radiation properties of the object that one is observing. This work can be hardly verbalized and, in some cases, it implies a big deal of tacit-knowledge. "The eye-brain combination is very important", told us a *data creator* of the Goddard Institut of Space Sciences of NASA working with climate datasets, "some kind of human sens of the plausibility of the data. You can call it knowledge, expertise, common sense or 20 years in the business! »[550]. He pointed that the "eye-brain combination" may act as an alert by raising a flag when something seems strange and he illustrated his point with an exemple of discrepancies between data about the water vapor measured by different sources.

The department of energy in the US had been working for a long time in detecting water vapor with other means (recall for instance the ARM stations mentioned before against which POLDER's retrievals about the clouds' properties had been validated). It had been demonstrated, further to the

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[548] We refer to the work of Lorraine Daston and Peter Galison who have historicised the notion of objectivity. See « Objectivity », 2007.

[549] Interview with François-Marie Bréon, LSCE, 2012.

[550] Interview with Tony Del Genio, GISS, 2013.

analysis of these long-term datarecords, that clouds that rain a lot use to be higher than clouds that do not rain a lot. A group in Australia had recently deployed a network ground-based radars to observe clouds properties like water vapor. When analyzing these records, this scientist found the inverse correlation. Radar data had passed all the quality control filters and therefore the correlations were as robust as the US's ones –but indicating opposite effects. "The eye-brain combination", said this scientist, "when looking at the Australian radars data, does not expect these results and so one suspects that something happens»[551]. The "eye-brain combination" may act as a barometer of the plausibility, an indicator of weirdity of the data and signaling when more research –or other action- is needed. However, only highly socialized people (trained in physics, holding phd or postdocs, having worked with other satellite data in the past) that had been properly trained can discriminate artifacts where other would see facts. The eyes of the eye-brain had been *calibrated* and taught how to see the essential and overlook the accidental, to differentiate between the typical and the anomalous, and what are the limits of variability in data and in nature. In the practices of data validation, this is our conclusion, *trained judgment*, as Daston and Galison would put it, is a supplement to any result that *mechanical objectivity* produced, they both complement each other[552].

This is the underlying epistemology justifying why, according to POLDER's community, the credit for judging the quality of POLDER's data reposed in a number of specialized scientists, those who were legitimated as *data creators* holding knowledge about radiation transfer, electromagnetic signal, noise perturbation or the instrument, in other words, the "groupe mission" and their collaborators. Only those who had learned were legitimated to emit judgments about the quality of the data; in a sense, that was the point of being an expert, after all. This commitment justified a data policy according to which, after the launch, the members of the "groupe mission" would have a temporal embargo over the data and that during the whole life of the mission they would be the ones having exclusive access to radiances –*data users*, so the argument went, would not know what to do with calibrated data, level 1, physical radiances, anyway. As we have argued in the previous chapter, epistemology left aside, it was also a matter of labor division on behalf of efficiency (the job must be done by the best placed to do it) and of respecting the rules of the scientific institution accrediting a form of reward for the investments and the job accomplished (in terms of time for publication without the pressure of a competitive atmosphere that may lead to prompt results). Besides, we have argued that POLDER was, in many senses, seen as an experiment and as such it would serve its scientific

[551] After some months of analysis, Tony Del Genio solved the enigma. The causes of the discrepancy and inconsistency illustrate an issue that we are discussing in chapter five and six: metadata. Indeed, it turned out that during the precise period that Del Genio was analysing there had been a shutdown in the power of the network, and the radars had measured with a quite different calibration. This temporal difference in the protocols of measurement, however, had not been reported with the datasets (metadata) giving place to inconsistences in the interpretation. In this case, we conclude, inconsistencies had been indentified by what Del Genio called "eye-brain combination". We will see in chapter five and six that, when data are massively produced or when datarecords involve massive amounts of data, and data analysis are delegated to machines, this combination is hard to realize.

[552] « Objectivity », L. Daston and P. Galison, 2007.

team before the others –just like it was done in so many other domains of experimental physics[553]. We shall recall, coming to an end, that other views may be articulated in the choice of the legitimate actors for validating satellite data, just like illustrated with the examples of CALIPSO and Topex/Poseidon in the previous chapter.

Box 4.3. Actors of POLDER's data validation

POLDER's data validation was a matter reserved to the "groupe mission" and their collaborators, to the POLDER's community of *data creators*. Because they knew the algorithms and the details of the instrument, they were considered to be the best placed to emit a judgment about the quality of the scientific data. Around 30 scientists associated to the group mission (mainly from LOA, LSCE, LERTS/CESBIO, LMD and LPCM), to the International POLDER Science Working Team members (especially at Scripps and at GSFC), and their respective collaborators, including phD students, postdoc fellows and temporary visitors, were mobilized in such venture between 1996 and 1998, most of the work would be done from March 1997 when radiances started to be produced and delivered systematically by the computer center in Toulouse. They were assisted by technical staff and material provided by CNES, either recruited purposedly in 2-years or 4-years temporal contracts or put at disposal when needed. Also important was the participation of the software and computing company CSSI, which provided the technical expertise in optimizing the coding of the algorithms.

Lab	Number of people	Task
LOA	11p+4cdd+1phd	Expertise for atmosphere: aerosols, ocean color and clouds
CESBIO	1p+1cdd+1phd	Land surfaces
LSCE	1p+1cdd+1phd	Cloud screening and surface polarized surfaces
LMD	1p	Cloud classification
LPCM	1p	Bio-optical algorithm
LSCE/CEA	4p+1cdd	Development of the processing chains (computer codes), software validation
International Science Team	32 scientific teams selected through call for opportunities in 1994	

Table 4.1. POLDER validation did not receive equal attention in all the laboratories of the group mission[554]. At LOA was where this activity was most frenetic: around 52% of the total permanent scientists, 50% of the technical personnel and 50% of the doctoral and postdoctoral fellows were dedicated to validation of POLDER's data in 1997-1998)[555].

Closing the validation process was accompanied with the publication of some of the scientific algorithms and some samples of the data in several specialized periodicals: only at LOA, 21 articles were published in peer-reviewed journals between 1997 and 1999, followed by 9 more before the launching of POLDER-2 in 2002 dealing with calibration and validation[556].

[553] See for instance, "History of CERN. Volume II. Building and running a laboratory. 1954-1965", A. Hermann et al, 1990 and "Image and Logic", P. Galison, 1997.

[554] Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[555] Rapport d'activité LOA, 1997-1998.

[556] We have counted on the basis of the publications catalogued on CNES's and ICARE's websites: http://smsc.cnes.fr/POLDER/A_publications.htm and http://icare.univ-lille1.fr/drupal/publications.

***BREAKING THE REGRESS*: THE "REVUE DE VALIDATION"**

All these activities (and the rest that we have not described) of data validation for POLDER-1 had been laid down before the launch of ADEOS-I, in March 1996, in the "Plan de validation", a document elaborated by the "groupe mission" and the "groupe projet". POLDER-1 was launched on August 17th 1996 on board of ADEOS-I. On October 2nd 1996, NASDA's ground segment sent the first images to the Centre de Production in Toulouse, who started the « recette en vol ». This was a period intended to test on the one hand the functioning of the computer center and, on the other, the performance of the software for calibrating and correcting the signals and transforming them into radiances of level 1, according to the production schema. Only those scientists involved in the calibration, hence, would have access to the data in order to assess the quality of the corrections and calibrations and, if pertinent, improve the algorithms and the software. On June 27th 1997, this phase got underway and the « Revue de Fin de Recette en Vol de POLDER » took place in Toulouse. The experts of the computer center and of the algorithms for correcting and calibrating would then present their conclusions before an external committte which would give green light to starting up the systematic production of calibrated data at the computer center in Toulouse and disseminating them to data creators for them to start testing their inversion algorithms to produce geophysical datasets even though it was emphasized that calibration methods had not achieved the expected quality performances and more analysis and development was needed to attain a data accuracy of the 2-3%[557]. Some samples of calibrated data had been released since October 1996 for preliminary tasks of data algorithmic validation, but the bulk of calibrated data would not start being provided to data creators before March 1997. It was then, around 6 months after the launching of the satellite, that the *data creators* would start to apply the algorithms they had developed during the prelaunch preparation of POLDER data and test their performance. Approximately one more year would elapse before the process of POLDER data validation would find its closure. It would be in the event of another "review", the "Revue de validation" hold in July 1998 specifically dedicated to assess the quality of the geophysical datasets, that a decision about their dissemination to *data users* would be taken. To prepare this review, a "Rapport de Validation" together with auxiliary documentation was sent to the members of a "Comité de Revue" and a "Comité Directeur" especially set up for that event. The members of these committees had then time to send questions and comments to any of the scientists involved in the validation activities before July 2nd, when the « Revue de validation » took place[558]. Some representatives of the scientists that had worked in data validation would present the results before the Comité de Revue, which would meet on the following day to write down some conclusions and recommandations to be sent to the Comité Directeur, who would then take a decision concerning the quality of the geophysical datasets derived from POLDER-1's physical measurements, their scientific value and their delivery (or not) to *data users*.

557 « Rapport du Groupe de Revue de la Revue de fin de Recette en Vol POLDER », June 1997.

558 "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

By examining this “Revue”, which was one of these management tools deployed at space agencies to both control the evolution of a project and to unite the community, as we have argued in the previous chapter, we aim to complement the previous section devoted to the practices of satellite data validation in the laboratories and their underlying epistemologies with another element playing out in this process: the weight of technical institutions, in this case CNES, in the judgement and assessment of the quality of POLDER’s geophysical datasets and in authorizing their dissemination.

The Review as a *regress breaker*

In a sense satellite data validation constitutes a neverending activity, insofar new data are gathered every day, new inversion or correction algorithms are developed and field campaigns are regularly carried out. Therefore, there is always new data to be compared with satellite datasets. On the other hand, validation practices involve recurrent circularities between instruments, algorithms and data, perpetual regresses between different sources of observations –which, we insist, are intrinsically imbued with theories, models and other data. The joke-like introductory quote exclamating “c’est un peu fou” claimed by one of the data *creators* involved in these activities, incarnates the idea of a “crazy” loop according to which data are validated against other data, which in turn are validated against other data –it indicates also a certain degree of awareness amongst the *data creators* of such circle. This brings in what the sociologist of sciences Harry Collins called the *experimenter’s regress*. In his analysis of the experimental devices to detect gravitational waves, the question that guided Collins was what the right outcome of an experiment is:

> “What the correct outcome is depends upon whether there are gravity waves hitting the Earth in detectable fluxes. To find this out we must build a good gravity wave detector and have a look. But we won't know if we have built a good detector until we have tried it and obtained the correct outcome! But we don't know what the correct outcome is until... and so on ad infinitum”[559].

According to Collins, experimental work comes to an end only when anyhow scientists are able to *break* this regress and agree in the outcome of an experiment. It is then that their results become scientific knowledge. The question is then how to break the regress. In our case-study, the question may be posed as how do scientists stop validating POLDER’s geophysical datasets for these datasets to be disseminated (or not) to a wider audience of *data users*. We shall argue in this section for considering the “Revue de Validation” as a regress breaker, because, like all the “Revues” taking place routinely during the cours of the development and realization of a space project (like the “Revue de phase B de segment sol” or the “Revue de recette de vol”, to mention just two that we have recently mentioned in our account), it constitutes a formalized event allowing the closure of a bulk of activities and the departing of the following ones. By so doing, we aim to point to the importance of technical

[559] « Changing Order: Replication and Induction in Scientific Practice », H. Collins, 1992.
This concept has generated a lot of literature in the fields of history, sociology and philosophy of sciences. See for instance the series of articles replying each other between H. Collins and A. Franklin and that, ironically enough, materialize themselves a form of regress: « How to Avoid the Experimenters’ Regress », A. Franklin, 1994 and the corresponding replica «A strong confirmation of the experimenters’ regress” by H. Collins, 1994

institutions, in our case CNES and its ways-of-running, in the legitimation of the quality of satellite datasets[560].

The peer-Review: Expertise, formality and familiarity

The main goal of the "Revue de validation" was to « verify that the geophysical products delivered by POLDER are of good quality and suitable for scientific investigations"[561] and to evaluate the convenience of "starting of the systematic processing of the POLDER data to allow the delivery of level 2 and 3 POLDER products to all users"[562]. In other words, to assess the quality of the validated geophysical data and to make sure that errors and uncertainties were controlled before the routine data production would be engaged. On the other hand, this Revue was seen as a "première", a public presentation of the POLDER-1 geophysical datasets to a wider audience that had not been involved in their production or validation, including *data users* and international partners of NASDA or NASA. A third objective was, finally, to get some elements to start up the preparation of POLDER-2 data, in views of the launching of ADEOS-II scheduled, at that time, by 1999 or 2000.

The Review was conducted following the principle of independent control guaranteeing scientific objectivity: the scientists that had participated in the validation of POLDER would present their results before an external "Comité de revue", who would asses them and address some recommendations to a "Comité directeur", who would ultimately authorize the routine production or not, hence the dissemination or not, of the geophysical datasets. The "Comité Directeur" was established through a "MoU for the development and exploitation of the POLDER Ground Segment" signed by LOA, CNES and the Commissariat à l'Energie Atomique (CEA) and was chaired by the engineer Joel Barre, the Director of programs at CNES. It was composed of six members: two representatives corresponding to high-level hierarchies of each organism (directors of LOA and LSCE as the scientific representatives of the "pôles thématiques", presidents of the University of Lille and the Commissariat à l'Energie Atomique, and program managers at CNES -see table 4.2). They ensured the level of institutional decision-making.

The nine members of the Comité de Revue had been chosen because of their expertise in the fields of remote sensing of the color of the ocean, aerosols, land surfaces, clouds, radiation budget, atmospheric corrections or radiometry. We can easily recognize some familiar names amongst them. We already know André Morel from Laboratoire de Physique et Chimie Marines in Villefranche sur Mer, one of the most internationally recognized experts in remote sensing of the ocean color, co-PI of MERIS, MODIS and SeaWIFS, who had been the professor of some of the scientists of his laboratory working

[560] This point deserves further study by exploring, for instance, the importance of managerial rules in the development and realization of space projects –a topic that exceeds the scope of our investigation. We may refer however to a doctoral dissertation in process by Kevin Herlem provisory entitled "La conception d'écosystèmes dans les projets d'exploration: Le cas des projets d'observation de la Terre ».

[561] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[562] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

in the marine biology algorithms of POLDER. Michel Desbois was also a well-known scientist in the field of atmospheric physics and cloud climatologies, participating in the preparation of the data analysis of the radiometer Meteosat and in validating POLDER's data about the cloud cover by comparing to Meteosat's datasets –we have already met him, although indirectly, when discussing the project for creating the Institut Spatial de l'Environnement Terrestre that he instigated, for he was the scientist chairing the group that studied implementing a datacenter in the Parisian region. He had been the mentor of some scientists of LMD who worked in the algorithms to retrieve cloud properties from POLDER's measurements; they were still working together in some projects[563]. Robert Frouin had been a student of Pierre-Yves Deschamps at LOA working with the remote sensing of the sea surface temperature and the color of the ocean until he got a position at the Scripps in California. As we have seen, he had himself conducted several field campaigns with the SIMBAD/A radiometer to validate POLDER data about the color of the ocean. Olivier Boucher, a physicist of LOA expert in clouds and radiation budget had participated in some analysis of POLDER's data during validation phase and was interested in using them for numerical modeling studies. Gérard Dedieu of CESBIO, the former LERTS, was a former CNES-engineers expert in geometric calibration of satellite data who had become an expert in the interpretation of data in terms of vegetation properties. Jean-François Minster, the president of the committe, shared his duties of general director of the Institut National des Sciences de l'Univers of CNRS with those of director of the laboratory MOUETTE dedicated to ocean altimetry, for he had been one of the impulsors of the radar altimeter Poseidon. The rest of the names of the members of the committee correspond to *data creators* in the domain of radiation budget (Norman Loeb of LaRC/NASA was a scientific participating in the experiment ERBE, with whom data creators of LMD and LOA had worked before), N.T. O'Neill was a Canadian scientist of the Centre d'Applications et de Recherches en teledetection of a University in Sherkaton expert in land cover and vegetation detection, who had been one of the PIs in the field campaign BOREAS, where an airborned version of POLDER undertook measurements over boreal forests. He had henceforth worked together in several occasions with some scientists at LOA and GSFC[564]. Frédéric Baret was expert in remote sensing of the land surfaces with visible and infrared radiometry, especially in calibrating and determinating the bidirectional reflectance function, and had worked with CNES and LERTS during the 1980s in studying models of vegetal radiative properties. He had also participated in several campaigns with the aircraft version of POLDER between 1989 and 1992 to study its feasibility for agriculture studies[565]. The absence of Japanese delegates, considering that POLDER flew inside a Japanese platform and that considerable effort had been made to place common validation activities between POLDER and OCTS (although at the end they would not be carried out),

[563] That reviewers and revieweds had worked or were working together can be seen by looking at join publications. See for instance these collaborations: "Cloud cover analysis from satellite imagery using spatial and temporal characteristics of the data", G. Sèze and M. Desbois, 1987 or "Automatic cloud screening in NOAA-AVHRR day-time imagery", L. Wald, G. Sèze and M. Desbois, 1991.

[564] "Atmospheric correction of images acquired over the BOREAS southern study area", N.T. O'Neill et al, 1997.

[565] "Sail : un modèle de reflectance de couverts vegetaux. Presentation et analyse de sensibilité », F. Baret and A. Podaire, Report to CNES, 1990 or « The 1991 AVIRIS/POLDER experiment in Camargue », F. Baret et al, 1992.

strikes us. Besides, we have found a number of publications authored by Japanese scientists prooving that they somehow participated in the validation of POLDER's data with their own means[566]. Unfortunately, we do not have enough data to conclude about their absence. Perhaps it was just a matter of travel bureaucracy –which has been often pointed in our interviews as dragging out traveling to Japan in the 1990s.

In our case-study, some of the members of the committee had not directly participated in the conception of POLDER, the preparation of the data and in prelaunch calibration activities, in the laboratory and in the field while some others however did –but they were not part of the core members of the "groupe mission". In that sense, the organization and functioning of the "Revue" mirrored peer-assessment procedures, which were considered by the actors as legitimate ways for evaluating scientific outcomes. Peer review by an external authority (in this case the "Comité de Revue") was seen as guaranteeing neutrality in the judgment, because it prevented data to be quite biased by individual perceptions or interests of the scientists of the "groupe mission". It was perceived as a way to secure objectivity of assessments, because reviewers were not emotionally linked to what they did review. However, two points must be accentuated. First, they were all *data creators*. Note that choosing the membership of the Comité de Revue was a decision made by the "groupe projet" and "groupe mission", and different missions may have engaged different choices. In some cases, the reporters of "Reviews" may include *data users* (like in Topex/Poseidon), that is, scientists that do not work in remote sensing (in some cases even non scientists, like representatives of environmental agencies), and that may not catch all the technical details of the algorithms, but that represent the community of recipients of the data and as such have a say in evaluating the usefulness of data from a outsider perspective. This particular composition reinforced one of the specificities of the community POLDER: just like the POLDER's community was made of *data creators*, the committees reviewing POLDER's geophysical datasets would be made of *data creators*. Second, reporters and reported were linked and they knew each other. Few were the scientists of the committee who had not previously worked with one or other of the teams working in the validation of POLDER's geophysical datasets or with POLDER's datasets by themselves. People chosen belonged, or at least had some ties, with the community linked to POLDER. We shall note that both points are connected: if it was considered that data creators were the best placed to judge POLDER's geophysical data quality, it was likely that members related each other, given the fact that experts were, in the late 1990s, still limited. The Review was characterized by a delicate balance between formality and familiarity.

This format suggest three hierarchical levels of organization. One, the scientists working daily with the data validation who are the *data creators* experts in their respective field of remote-sensing of the oceans, atmosphere or land surfaces. These are the experts in POLDER and are the producers of the

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[566] These publications deal with the detection of aerosols for correcting oceanic signals, the inversion of ocean color parameters and the intercalibration POLDER/OCTS. Somes examples are: "Inverse problems in the atmosphere-ocean system: estimation of aerosol characteristics and phytoplankton distribution", S. Mukai, I. Sano and Y. Okada, 2000, "The estimation of aerosol optical parameters from ADEOS/POLDER data", Y. Kawata et al, 2000 or "Cross-calibration of ADEOS/OCTS and polder and the influence on aerosol retrieval", S. Mukai, 2000.

data that is under evaluation. Two, those experts called to elaborate a recommendation about the quality of the data produced by the first group. Whether they are familiar or not with the topic under evaluation, whether they are more or less competent in ocean color remote-sensing, inversion algorithms or polarized filters is not as important as the function they are appealed to accomplish: consensuate an advice for the third group. Three, the group of decision-makers reunited to decide aboute the pertinence of disseminating the data to a wider community of data users. Again, they may or not may be competent or reputed scientists in the domain; their function is to emit a decision, to engage an action. This reflects the very principle of expertise in its traditional sense: dividing those who produce the knowledge, those who assess and elaborate a recommendation, and those who ultimately decide an action. We do not intend to analyze the model of expertise in deep; our intention is simply to point the parallelism[567]. In the case of POLDER, the second group was composed by *data creators* (related to POLDER and/or to other missions), because they were considered as the best placed to judge the work of other *data creators* of the first group. This was the principle of peer-reviewing to assess the quality of scientific work. At the same time, however, it was a peer-review characterized by familiarity. It depicted tensions between anonymat and distance, attributes characterizing objective scientific assessment in contemporaneous scientific practice, and forces of emotional order and personal ties[568]. In the third group, representatives of the institutions involved in the project were reunited to consensuate a decision further their recommendation.

Presentations by community POLDER	**Members of Revue Comite or Groupe de Revue**	**Members of Comite Directeur**
J.L. Counil (CNES) A. Lifermann (CNES) O.Hagolle (CNES) P. Y. Deschamps (LOA) A. Bricaud (LPCM) C.Moulin (LSCE) F.M. Bréon (LSCE) M. Leroy (CESBIO) M. Vespérini (LOA) J.C.Buriez (LOA) C.Vanbauce (LOA) G. Sèze (LMD) F.Parol (LOA) P. Goloub (LOA) P. Couvert (LOA) H.Chepfer (LMD) J.P. Duvel (LMD) A.Gaboriaud (CNES)	***Président*** : J.F. Minster (INSU) ***Membres*** : F. Baret (INRA) O. Boucher (LOA) G.Dedieu (CESBIO) M. Desbois (LMD) R. Frouin (SIO/UCSD) N. Loeb (Hampton Univ./NASA LaRC) A. Morel (LPCM) N. O'Neill (CCRS)	***Président*** : J. Barre (CNES) ***Membres :*** C. Césarsky (CEA/DSM) M. Turpin (CEA/LSCE) Y. Fouquart (LOA) J. Duveau (USTL) M. Pircher (CNES)

Fig 4.6: In the first column, the list of the scientists, managers and CNES's engineers who presented results during the validation review. Besides the core members of the "groupe mission" (Pierre Yves Deschamps, François Marie Bréon, Marc Leroy, Jean Louis Counil or Anne Lifermann, etc.), there are other scientists

[567] We are not developing here the issue of expertise, which is not a central question on our account. For further accounts see "Entre savoir et decision, l'expertise scientifique", P. Roqueplo, 1997 or "La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », H. Guillemot, Doctoral dissertation, 2007.

[568] The case of POLDER, relying in the balance between formality and familiarity, between institutional forces and emotional ties, particularly recalls the « late modernity » framework described by the historian Steve Shapin : even though modernity seems to celebrate modes of authority, which are institutionalized and anonymous, when examining the ways in which POLDER data gets legitimate we find that the personal, the familiar, and even the charismatic, is of great importance. "The Scientific Life", S. Shapin, 1989.

distributed between different laboratories and CNES, especially LOA, LSCE, LMD and CESBIO. In any case, they only represent a tiny fraction of the workforce involved in data validation[569].

For POLDER-1, the Review took the form of a scientific workshop organized in two days, open to outsider scientists and managers. More that 75 people attended it. During the first day results about the algorithms and the data were presented: global maps showing certain variables (aerosols, clouds), graphs illustrating the calculations and the errors analysis, new algorithms proposed for retrieving other parameters, the calibration problems that persisted, among others[570]. They discussed both the strengths and validity of the data as well as their limitations and uncertainties. The committee interrogated about varied topics from technical questions related to the quality of the image, calibration, the algorithms for modeling the reflectances in the surface, to questions about the architecture of the ground segment, insisting in the comparisons of POLDER data about other existing data, like cloud climatologies and aerosols' data from the sun-photometers in the surface. One of the most animated discussion turned around the futur of POLDER, as one of the issues of the Review was to study a new generation of algorithms to be applied to the observations of POLDER-2[571]. The following day, the committee met privately, assessed the results and elaborated the "Conclusions et recommandations", which would be presented before the Comité Directeur some days later.

When managerial tools control the quality of data and their dissemination

After one day and a half of hearings, the Comité de Review chaired by professor Jean-François Minster met at closed door and discussed the results in order to elaborate some recommendations to the Comité Directeur. The main questions guiding the assessment of the Comité de Revue were, as they figure in the minutes of that meeting:

> « 1. Les produits actuellement définis sont-ils pas du tout, raisonnablement ou très bien validés et étalonnés ?
>
> 2. Y a-t-il un intérêt scientifique pour ces produits, compte tenu de leurs caractéristiques (précision, durée de vie) ? Quelle est la population activement impliquée ou potentiellement concernée ?
>
> 3. Les chaînes de traitement sont-elles à mettre en œuvre dès maintenant ?
>
> 4. Faut-il continuer les études algorithmiques, de validation et d'étalonnage ? Sont-elles susceptibles d'induire des évolutions majeures des algorithmes et à quelle échéance ? Faut-il mettre en attente certaines chaînes pour bénéficier de telles études ?
>
> 5. Faut-il prévoir un rejeu des traitements Polder-1 avant le lancement de Polder-2 ? »[572]

The exact content and tone of such discussions does not interest us here. Instead, we would like to point some contextual elements that were considered in the discussions about the pertinence of

[569] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[570] "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », september 1998.

[571] "Polder Validation Review Proceedings », summer 1998, prepared by the POLDER project scientist Anne Lifermann.

[572] "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

beginning the systematic production of POLDER data. Some arguments claimed for prudence in the dissemination of the geophysical datasets. For instance, the technical capabilities of the computing center in Toulouse (soon to be transfered to the Commissariat à l'énergie atomique) must be taken into account –as we have mentioned, several frictions had reduced its performance to less than 80%[573] and one thing was to use some samples of calibrated data and see how the algorithms behave, and another was to routinize the production of 20 different scientific types of data simultaneously in a massive manner. Disseminating the scientific data was, therefore, constrained by the technical capacities of the computer center in Toulouse[574]. Besides, the capacity of the computing center must be distributed between the different tasks. Processing the calibrated data to transform them into scientific data was only one of them, which shall be done in parallel with the updating of the calibration coefficients, the reception and processing of exogeneous data from other sensors necessary to process POLDER's data or internal maintenance procedures. The Comité de Revue was also aware of the delays in the delivery from NASDA that had slowed down the process of calibration and validation, the poor quality of calibrated data due to inaccurate methods as well as the unexpected failure of ADEOS, which only left 8 months of data. More importantly, ADEOS had failed only some weeks after the bulk of calibrated data was made available and therefore scientists have had limited time to organize coincident measurements in the ground to compare satellite data against, which was essential for a proper validation. All these facts certainly had affected the validation of the data and claimed also for prudence in the delivery of data to *data users* because geophysical datasets may be easily less *good* than originally expected. According to the proceedings of the "Revue de Validation", resources in terms of material, people and overall funding had been also limited[575]. As consequence of such conjuncture, the validation of certain data was, two years after the launching in July 1998, still incomplete (error budgets were incomplete, space and time consistencies not fully developed, for instance)[576]. These were all arguments that called for prudence in judgements about the data quality and therefore in their wide dissemination. On the other hand, arguments of several order argued for their full diffusion. POLDER-1 datasets had been expected by some *data users* that had been exercing pressure to get them. If POLDER-1 data were not disseminated, so it was argued, not only *data users* would get frustrated but the credibility of CNES as reliable provider of satellite data would get undermined and the utility of satellite data per se would get questioned. Besides, *data users* would perhaps walk away of using the future data from POLDER-2[577]. Actually, disseminating POLDER-1 data was seen as a strategy to promote the future utilization of POLDER-2 « tout en en suscitant

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[573] "Rapport du Groupe de Revue de la Revue de fin de Recette en Vol POLDER », June 1997.

[574] "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

[575] "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

[576] "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

[577] "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

l'envie, par exemple, des groupes scientifiques des instruments MISR ou CERES »[578]. Finally, disseminating the data would demonstrate capabilities for « réaliser des premières et les diffuser au monde dans un calendrier de compétition avec d'autres instruments qui imposait de ne pas attendre »[579]. It would be seen, in the concurrent world of satellite data production and diffusion, as a proof of scientific excellence.

The general tone of the Revue was rather satisfactory. To sum up the outcomes, the committee considered that data about radiation budget, clouds and some surface parameters were *good* enough and to have scientific interest and they should be mass produced and disseminated, which would be done from the summer of 1998. This optimism was not shared for data about the ocean color that were considered as « peu compétitives » and about the properties of the aerosols over land surfaces that were considered « non diffusables » because of their poor quality[580], as attested by one of the recommendations that the committe sent to the Comité Directeur:

> "Les trois chaînes géophysiques POLDER peuvent être mises en production. Les produits géophysiques élaborés par ces trois chaînes peuvent être diffusés à l'ensemble de la communauté utilisatrice à l'exception des trois produits « Couleur de l'eau » et du produit « Aérosol sur terres ». Les produits « Couleur de l'eau » peuvent être diffusés au sein du groupe scientifique POLDER et aux équipes qui ont collaboré au plan de validation POLDER par la fourniture de données de validation. Le produit « Aérosol sur terres » n'a pas un niveau de qualité suffisant pour être diffusé»[581].

In the case of aerosols over land and surfaces, we have already mentioned the technical difficulties of discriminating the signal providing from the land surface from that providing from the aerosols –this is still a challenge for measurements at present day. Over the oceans, by contrast, as long as they are no clouds, it is technically easier to detect aerosols. We would like to connect these decisions about the delivery (or not) of datasets with the *regimes of trust* that we have introduced in the first part of the chapter and in which the practices of data validation operated. The aerosols' regime was dominated by a highly stable reference, AERONET, considered as an external authoritative ground-truth: any difference exceeding the reasonability (whatever reasonability means) was just considered as not good enough. As we have seen, nevertheless, most of the ground-based sun-photometers of AERONET were placed over continental surfaces. As a consequence, there were no AERONET stations providing a reference of optical depth at the oceanic surfaces to be compared against, no external stable ground-truths. Therefore, the scientists and the reporters had more flexibility in deciding up to which point errors and uncertainties were tolerated –consequently, data could be released. Similar logics could operate in releasing the data about the clouds and the radiation budget, which were considered by the Comité as « très bonnes, au-delà peut-être de ce que l'on pouvait espérer »[582] based on the relative

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578 "Polder Validation Review Proceedings », prepared by the POLDER project scientist Anne Lifermann, July 1998.

579 "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

580 "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

581 "Compte-Rendu de la 2ème réunion du Comité Directeur CNES/CEA/USTL pour le Segment Sol POLDER », September 1998.

582 "Rapport du Groupe de Revue de la Revue de fin de Recette en Vol POLDER », June 1997.

comparisons with the other existing data but without any stabilized reference. As per the data about the color of the oceans, a series of organizational and conjunctural elements hindered their proper validation (lack of coordination with Japanese and American counterparts, lack of long-term budgetary commitment, heatwave hiting Europe). Above all, we believe, it existed a powerful concurrent line of instruments, measurements and algorithms providing data about the color of the ocean for biological studies (especially those coming from the recently launched SeaWiFS and the future MODIS and MERIS) and considered by a huge part of the community as more appropriate than POLDER's. To be sure, the usefulness of POLDER's data about the color of the ocean had been questioned since the beginning of the project in 1986 due to its coarse space resolution; the existence of a powerful concurrent, and the fact that one of its advocates was a member of the Comité de Revue, only reinforced the position of POLDER as secondary instrument for marine biology studies. This offers an example, opposed to the celebrated multiplicity of instruments in the domain of clouds, illustrating the effects that concurrent instruments and measurements can have each other: its data were qualified as "peu compétitives" and only released amongst the POLDER's community.

The point of these reflections is twofold. First, to illuminate how the different *regimes of trust* in which the scientists build confidence in their data, may have resulted in different sensibilities when it came to authorize or not the dissemination of such data. Particularly important are then the material culture embedded in a given regime of trust, the technologies and instruments available to compare data againts each other, as it oriented, at least partially, the sensibilities and judgements about their quality. Also influent were, as we hope to have illustrated, the social organization, the funding sources and the very observed object by itself. Every regime of trust defined its own epistemical practices, discourses and rules and produced different values for judging the quality of the data. The second point to be noted is the importance of the institutional rules and ways-of-running in the control of the data dissemination, through the judgements about their quality for scientific inquiries. The "Revue" exerced as a particular form of peer-review under the ultimate legitimation of a technical organization, CNES, which had established it as a norm, which had participated in choosing the membership of the committees and which had itself some representatives in one of the committees.

THE SPACE AND THE FIELD: HUMBOLDTIAN SATELLITE MISSIONS

The previous sections have illuminated that the validation of POLDER's geophysical datasets generates a lot of scientific activity, which includes a number of devoted field campaigns or networked measurements in the ground. As we have illustrated in the previous chapters with the examples of the determination of the calibration coefficients or the elaboration of the inversion algorithms, the preparation of the data before the launch require as well a number of non-satellite activities, like the flight of aircrafts, laboratory studies or theorerical modeling. The intervention of CNES, the *space* agency, in such activities illustrates, in our views, a major change occurring in the 1980s and the 1990s: a change in the understanding of the very notion of "space mission" from space-based technologies to gather data to a holistic approach encompassing also data-gathering in the ground. During the first years of the space age, space scientific missions were majorly about space technologies: it was about developing platforms, launchers, spacecrafts, solar panels, electronics, pressurization chambers, payloads, antennas, communication links, tracking stations, control systems, recovering systems, etc. This vision would contrast by the renewed meaning of the notion of space mission introduced in the late 1970s, and shoring up all along the two following decades, a meaning in which the space technologies would become only a component of the mission. Our regard at the gears of gathering, producing and dissemination of the satellite data reveals at least three features through which this renewed meaning and shift towards the ground is materialized. One stream has been illustrated in the previous chapters 2 and 3 stressing the progressive growing levels of intervention of space agencies in the surface-tasks of data-handling, which required them to invest in informational ground-technologies, surface-based computing centers or data-systems to be developed, used and maintained from the ground. In this chapter we have stressed, through the example of the activities of data validation, a second stream of this shift towards the ground: the instrument inside a satellite constitutes only one component of the corpus of instrument deployed like the network of surface instruments, flote of aircrafts or ships, the balloons or the buoys. We insist in that the need for such measurements is fundamental: the creation of satellite data calls for them. To gather and to produce satellite data, satellites alone do not suffice. We will see in chapter six the third stream of this shift, the use of ground-based numerical models to produce data.

The trends towards this shift can be illustrated already in the first scientific meeting organized by CNES in 1981, in which scientists participating in the working group of scientists working in oceanography, atmospheric physics and chemistry, climatology, geodesy and biology concluded that:

> "Pour étayer le développement des programmes Poseidon et ERS-1, la communauté scientifique souhaite entreprendre un *programme d'accompagnement* comprenant des *campagnes préparatoires*, puis de validation sur le terrain, mettant en oeuvre les instruments prototypes existants, en particulier le scattéromètre bance C du CRPE. Dans ce cadre, l'intérêt d'un soutien à un projet *d'avion de recherche* mixte pour les sciences atmosphériques et la télédétection a été souligné »[583].

This was a specific claim directed to the oceanographic missions Poseidon and ERS-1, which had been proposed respectively to CNES and ESA in 1979, following the leak of Topex proposed at NASA in 1978; after all, by then, Poseidon was the only existing approved mission with participation of French scientists in the domains of Earth sciences[584]. However, the vision of a holistic space mission, encompassing, apart from satellites, a "programme d'accompagnement" involving field campaigns (prelaunch to prepare the interpretation of the data and post-launch to validate the quality of the data) would progressively shore up during the period beginning in the 1980s in the preparation of those missions that would be launched in the 1990s. The missions realized during that period, including

[583] « Conclusions des groupes de ravail des « Sciences de la Terre » », presented by M. Petit in Les Arcs 1981, italique in the original.

[584] In the first scientific meeting held in Les Arcs in 1981, a second mission was proposed called Gradio intended to measure the Earth's gravity field. At the same time, the European programs Meteosat and ERS-1 were being developed and a number of French scientists, supported by CNES, would participate in them.

POLDER, would participate by ways of customary practices in the *normalization* of such a holistic notion of “space mission”. We argue in the following that the progressive consolidation of this novel meaning by space agencies can be interpreted in terms of a *reconciliation* between space technologies and field scientists: while the incorporation of such activities as part of a space mission would not change dramatically the current practices of Earth scientists; it would however introduce fundamental changes in the space agencies’ values, in particular, space agencies would abandon the idea that space technologies were all-powerful panaceas.

Satellites as a tool for gathering data in field-campaigns: The views from space

The connection between satellites and field-work is as old as satellites themselves. As soon as in 1957, during the realization of the International Geophysical Year, a field experiment of global scope to gather data about the auroras, cosmic rays, geomagnetism, gravity, ionospheric physics, longitude and latitude determinations, meteorology, oceanography, seismology and solar activity coinciding with a peak of the solar activity cycle, the idea of launching a satellite as a means to gather complementary data to those being gathered with surface stations, aircraft, ships and sounding-rockets was invoked. This resulted in the famous launching of Sputnik, which is however better known for the space race that it enchained than for being part of a field-campaign at large scale[585]. A number of field campaigns would from then on make use of this new tool for collecting data, namely the instruments placed inside a satellite, to complement the data gathering activities conducted in the ground with the traditional instruments.

This was, for instance, the whole point of the Global Atmospheric Research Program (GARP) conceived in 1967 under the auspices of the World Meteorolical Organization and the International Council of Scientific Unions to better understand the physical processes involved in the atmospheric dynamics and their dependence with geographic, synoptic and climatic parameters. GARP was a fifteen-year international research programme which organised several important local and regional field experiments including the GARP Atlantic Tropical Experiment in 1974 (GATE), the Monsoon Experiment between 1976 and 1981 (MONEX) and the Alpine Experiment in 1982 (ALPEX). Probably the most noteful of all these field campaign was the First, and last, GARP Global Experiment (FGGE) conducted from December 1978 to November 1979, also known as the global weather experiment, because it was designed to observe and measure the development of global weather systems and to accumulate an enormous data set for investigating the physics and dynamics of the global atmospheric circulation and for understanding the mechanisms governing changes in weather and climate. The First GARP Global Experiment exemplifies a classical field experiment at a superlative scale. The tools for gathering data during the FGGE consisted actually of the World Weather Watch (WWW), completed by additional tropical wind observing ships, meteorological

[585] Interested readers may find some historical episodes about this launching in « Reconsidering Sputnik : Forty Years since the Soviet Satellite », ed. R.D. Launius et al, 2000.

reconnaissance aircraft and stratospheric constant-level balloons deployed during special observing periods[586]. The WWW observing system consisted of 1030 upper-air stations, 2390 surface stations, surface synoptic reports from stations placed on ships and 5091 sondes that yielded temperature, pressure and humidity from below the flight altitude (200-400mb) to the surface. Flight level data were supplied by almost 100 commercial aircraft equipped with stardardized instrumentation providing temperature and wind measurements. Three polar orbiting satellites NOAA-5, TIROS-N and NOAA-6 contributed temperature and humidity profiles, sea surface temperature data, high resolution pictures of clouds, surface wind speed over the oceans, total atmospheric water vapor and stratospheric soundings. NIMBUS-7's data were also used. TIROS-N and NOAA-6 also supported the ARGOS data collection and platform location system associated with 301 buoys (located in the southern hemisphere gathering sea surface temperature and pressure data and additional buoys distributed by aircraft as gaps developed) and the 313 balloons (at the 140mb level to provide wind observations). The five geostationary satellites, METEOSAT, GOES-Indian Ocean, GMS, GOES-WEST and GOES-EAST provided upper-air wind vectors from cloud motions, sea surface temperature and communication support acting as data relay satellites[587].

Within this field-campaign, the weather satellites would be only part and parcel of the whole *knowledge infrastructure*, we use Paul Edwards' concept discussed before[588], deployed to collect the data, produce information and circulate it. Actually, one of the motivations for proposing Meteosat in 1968 by scientists of the Laboratoire de Météorologie Dynamique, for instance, was being the French contribution to such an experiment by providing coverage of the African-European regions not covered by the American (and Soviet) geostationary satellites. The First GARP Global Experiment as about taking advantage of all the possible means for collecting data, including the weather satellites that were being launched. The epistemological idea behind Global Atmospheric Research program (GARP), and in general behind all field-campaigns involving a large number of instruments and tools for gathering data, is that no single instrument or measurement can provide a complet account. Rather, it is the complementarity of data which may represent and illustrate the complex reality. GARP, and particularly FGGE, illustrated the benefits of complementing the data gathered with different sources and it established this methodology as the most accepted one when it comes to understand the processes involved in complex systems, like the Earth's environment.

Professor Pierre Morel would be one of the most fervor defenders of such a methodology consisting in gathering together what he called a "composite system" made up of different measurements from

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586 We will discuss this program a bit more in the introduction to our second part. In the meantime, Paul Edwards offers an exhaustive historical account in his book "A Vast Machine", 2010.

587 World Meteorological Organization, GARP Publication Series Number 26, Vol. I and II, April 1986.

588 In his essay "A Vast Machine" explaining how political and scientific institutions, observation networks, and scientific practices evolved together over several centuries to culminate in the global climate knowledge infrastructure we have today, the author defines *knowledge infrastructures* as comprising « robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and the natural worlds ».

"A vast machine: Computer models, climate data, and the politics of global warming", P. N. Edwards, 2010.

different sources, and he would often mention the FGGE as a model –which is not surprising considering that he had been one of the instigators of it in the 1960s:

> « Le programme d'observation nécessaire pour faire progresser la compréhension des variations climatiques sera fondé sur un système composite incluant de nombreuses mesures in situ en même temps que des observations extensives à distance à partir des plateformes spatiales (…) les satellites ne mesurent pas tout et le système composite d'observation qui sera nécessaire pour acquérir une base de données complète incorpore nécessairement des observations complémentaires terrestres (par exemple, bouées océaniques pour mesurer la pression atmosphérique ou le contenu thermique en dessous de la surface). De ce point de vue, le système d'observation composite de GARP conjuguant les satellites avec de nombreuses plateformes terrestres (navires, avions, ballons, bouées…) est un modèle d'adaptation à l'étude d'un problème scientifique bien posé »[589].

Professor Morel went on in his speech to claim:

> « Il est essential de se rappeler que l'observation spatiale n'est pas une panacée"[590].

In a sense, professor Morel defended the methodology based on the completitude, synergie and complementarity of all measurements ever possible, including satellites. The First GARP Global Experiment would mark the transition towards the full incorporation of space assets in the traditional field campaigns as one more instrument to gather data, a tendency that would be emulated all along the 1980s, 1990s, 2000s and still today, through the research campaigns coordinated under the umbrella of the World Climate Research Program (WCRP) established in 1979 (and often defined as the "climate branch" of the GARP) and the International Geosphere and Biosphere Program established in 1986 –we have seen some examples in the previous sections (like ACE-2, the field campaign to study the aerosols discussed before). Within this epistemology, satellites are not a "panacea", taking on professor Morel's terms, but only a piece of the whole campaign to gather and produce data in a given field of the Earth sciences. On the other hand, this representation of satellites as integrated in a whole, we suggest, aligned well with the technical skills that the former "selected laboratories" had retained after the complexification and industrialization of space instruments taking place since the mid-1970s in France. Indeed, while developing and realizing instruments to be put inside satellites required a set of abilities, materials, testing facilities and budget that they did no longer possess, developing instruments to be put inside a balloon or an aircraft was a way to reaffirm their instrumental expertise and to pursuit it in a more or less autonomous manner.

Nevertheless, there is a substantial difference between organizing a field campaign to gather data for supporting a given scientific research program and including the satellites amongst all the possible sources of data, and organizing a field campaign as part of the preparation of the launching of a satellite itself or as part of the production of data themselves. One thing is to maintain an epistemology based in the complementarity of all the measurements (including satellite ones) for data gathering and production, while the other is to maintain an epistemology based in that ground-based data is needed

[589] « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.
[590] « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.

to gather and produce satellite data. There is nothing essentially revolutionary in integrating the newest technologies available in the long-life tradition of data field-gathering; by contrast, we argue, integrating field-work in the realization of a space mission as a necessary element to create the future satellite data was a novelty appearing, we believe not accidentally, simultaneously with the increasing number of missions to the planet Earth. As a result, we argue, the idea that satellites alone were powerless and that their data needed other tools to exist (aircraft data, networked data, numerical models) was introduced. This is our next, and main, point.

The field as a tool for producing satellite data: The views from the ground

As early as in 1969, NASA and the US Weather Bureau had arranged for two weeks of special observations to evaluate the performance of the Satellite InfraRed Sounder (SIRS) aboard Nimbus 3 and 4: radiosondes would be launched simultaneously to satellite overpasses to provide in situ temperatures to be compared with the SIRS's ones retrieved after algorithmic inversion[591]. This was the first time that an exercice of validating satellite data was conducted. It had been defined a posteriori, and not planned during the inception of the mission, as a test. All along the 1970, as NASA would commit to missions like SeaSAT and SAGE, it also started to realize field campaigns prior to the launching of a satellite: understanding the behavior of the instrument and the interpretation of data that satellites would send back, so it was argued, often mean to test the instruments before on the ground, inside an aircraft or in the laboratory. This field-work was then aimed to calibrate the instrument and to prepare the retrieval algorithms previously to the launching of the satellite[592].

What had begun in the late 1960s as sporadic simultaneous measurements with balloons would culminate, after a progression intensified since the mid-1970s, with the mission Nimbus-7 of NASA, characterized by the organization of devoted field-campaigns before and after the launch of the satellite. We can make the hypothesis, and this must remain as such, according to which planetary scientists migrated into Earth scientists during the second half of the 1970s, brought with them the practice of calibrating instruments before the launching of a satellite, a practice which converged with field-work imperatives of Earth sciences. In any case, since 1975, international scientific teams organized by disciplines in three main world regions (North-America, South-Africa and Europe) would be field-working to prepare the algorithms to retrieve parameters from the different instruments aboard Nimbus-7; after the launch of the satellite in 1978, these efforts would continue through the organization of field campaigns to validate the corresponding geophysical parameters. For instance, a

[591] "Nimbus-III User's Guide", Goddard Space Flight Center, 1967 and "Nimbus-IV User's Guide", Goddard Space Flight Center, 1968.

[592] Some observers have argued that NASA included calibration-work because its leaders wanted to achieve credibility with the American non-NASA scientific community (in order to demonstrate the interest of remote-sensing). Given that by the 1970s, scientific committees in the US were mostly dominated by physicists, NASA would focus a great deal of attention on issues of calibration and intercomparison, which were dear to the physicists' community as an admissible approach to empirical science.

See Erik M. Conway's "Atmopsheric Sciences at NASA", 2008.

consortium of European scientific laboratories, EURASEP (European Association of Scientists in Environmental Pollution), would be established to manage the access to the data about the color of the ocean gathered with the instrument Coastal Zone Color Scanner (CZCS) and to coordinate their exploitation for studies regarding environmental protection of the sea and marine life. Scientists of several laboratories, including the Laboratoire d'Optique Atmosphérique, the Laboratoire de Physique et Chimie Marines, Institute Géographique National or Centre National Pour l'Exploitation des Oceans in France, would organize a number of field campaigns of regional scale in the Mediterranean, the North or the Baltic seas to prepare the algorithms of calibration and inversion and to validate them after the launching –and similar extensive campaigns would be carried out in the American and South-African regions, and for all the eight instruments embarked inside Nimbus-7[593].

Ground measurements, between space technologies and field-work

From then on, and beginning with the missions Topex and UARS proposed in the very same year 1978, NASA's missions orbiting the Earth would incorporate, already from its conception, huge and extensive pre-launch and post-launch field-work. The emphasis on the "data validation" through field-work became so important at NASA during the 1980s that, even the data obtained from those satellites who had been launched in the 1970s and that had not been integrated in post-launch validation activities, but that would be still flying in the 1980s would be validated during the decade. For instance, scientists at LOA, would develop the radiometer RADIBAL to be put inside stratospheric ballons to gather data in coincidence with SAGE (launched in 1979 with reduced and limited, by then, data validation plans) to validate the retrievals about the stratospheric aerosols' properties and several balloon releases would be conducted, funded by CNES, from 1986 onwards[594].

The epistemological perception of satellite data as entities needed to be validated through field-work would marry remarkably well with the long-standing tradition of field-work characteristic of the Earth sciences –it married well too, as we have just suggestes, with the technical abilities that the laboratories could afford to develop and maintain by their own. We argue that field-work and ground-truths would be seen as a solution to the inherent interpretational bias introduced by the technological data practices of algorithmic inversion. Because the process of transforming physical measurements into geophysical units was a process of *intervention* appealing to a number of exogeneos data, environmental hypothesis, physical assumptions or mathematical approximations, an anchorage to reality was deemed necessary to control the quality of the resulting geophysical datasets. Field-work would be seen, in that way, as a response to the disenshrinement of satellite geophysical data: given

[593] After the launch of Landsat in 1972, the European Communities had begin to be interested in the domain of remote-sensing to support its policies. One of these policies was environmental protection of the sea and marine life. It created the European Association of Scientists in Environmental Pollution (EURASEP) to exploit the data from the Coastal Zone Color Scanner aboard Nimbus-7. The major participants in EURASEP would be scientists from Germany, The Netherlands, UK, Belgium, Italy and France.

"1980, Annual Status Report, Remote sensing from space", Commission of the European Communities.

[594] Rapports d'activité of LOA, 1982-1988.

that satellite geophysical data broke the ideal of faithful representations of nature, due to their production by means of the technological practice of algorithmic inversion, the need for controlling their quality against ground-truths was seen as an imperative. Nimbus-7 exploited the view from the Earth by deploying both prelaunch and postlaunch extensive field campaigns both to prepare and to validate the satellite data. The practices of data validation, which we have described in the POLDER case, materialize this tie between the satellite data, the ground-truths and the field-work. This is, we believe, a specificity of the Earth sciences using space assets or, put it inversely, a specificity of the space missions to support research in the field of Earth sciences. Earth sciences and satellite data have become interwoven by the ground-based measurements to the extent that, ironically enough, what gives value to observing the Earth from the space resides precisely in measuring it from the ground[595]. It is precisely this test against ground-truths, which is not possible in many other sciences, that renders satellite data about the Earth and its environment meaningful.

A point to be remarked is that while the practices of "data validation" through field-work converged smoothly with traditional practices in the domain of Earth sciences, major transformations must be assimilated at space agencies. To be sure, CNES had long funded projects for launching balloons (recall that it had been one of the original programs at its inception in the 1960s), calibrating instruments in the laboratories or in the field before being put inside a satellite, and realizing instruments to be embarked in an aircraft (for instance, LMD had developed several airborne radiometers prototype of Meteosat in the 1970s)[596]. They were considered often as a previous step to the space mission: space experiments often needed to be previously calibrated and tested before being carried by an spacecraft. However, the approaches mobilized in the processes of "data validation" implied a holistic approach to space missions. It was not about an activity that took part prior to a mission or posterior to it; instead, it became part and parcel of the mission. Satellite missions are conceived as experiments, retaining much of the epistemic specificities of the experimental culture of physics; yet, for satellite data to come into light, field-work is also needed. These renovated space missions straddling between the field-work and the space-laboratory illustrate what the historian of sciences Robert Köhler showed in his study about the evolution of the classical categories of "field-science" and "laboratory-science" in biology: the boundaries between field studies and laboratory research are blurred and in many occasions such categories are intrinsically connected[597].

Both, CNES and the scientific community –both taken in a large sense- would reap benefit in incorporating such activities within the grammar of space missions. This is why arguing in terms of

[595] We would like to complete this discussion about ground measurements by emphasizing that the connections of satellite data with ground-based data goes beyond satellite data preparation, calibration and validation, even though so far we have focused in such activities. Three other assets of the field-work have been put forward during our interviews as illustrating their necessity vis-à-vis satellite data. First, they provide a "local aspect" (that is to say, conducting geographically limited studies). Second, there exist variables that cannot be measured from a satellite (for instance the absorption of the aerosols or certain chemical compounds present in the atmosphere). Third, ground-networks are needed to calibrate long data records –we will develop this latter point in chapter six.

[596] Rapport d'activités LOA, SA and LMD.

[597] "Landscapes and Labscapes: Exploring the Lab-Field Border in Biology", R. Köhler, 2002.

reconciliation seems appropriate. CNES, worried in broadening the constituency of space research and reach out to a scientific community that would be quite skeptical about the endeavor, would trade on scientific imperatives to legitimize its activities before the government and the public audiences: after all, the more scientists using satellite data the more justified would be its raison-d'être as space agency. The reshaping of the notion of space mission served the goal to get closer to the community of scientists experts in the fields of oceanography, atmospheric chemistry, biology or glaciology, amongst other disciplines, that were not familiar with satellite data. In exchange, scientists could better promote and achieve their scientific objectives and imperatives –they would be also better funded with the support of CNES than without it. And equally important, it was a way to maintain capabilities and research in technologies and instruments in the laboratories, provided they were unable to develop satellite instruments from end-to-end. In a long-run win-win scenario, CNES involvement would render the agency indispensable in the domain, while scientists presence would produce pressures that CNES would be forced to respond. In exchange, though, the idea of all-powerful satellites must be abandoned.

Humboldtian space missions or the end of the all-powerful satellites

Let us conclude with two remarks. First, by promoting such practices involving field-work and laboratory studies both before and after the launching of a satellite, the community POLDER (and more generally all the missions and scientific teams) were reproducing Humboldtian practices of calibration, massive data gathering, data exchange and intercomparison of data from different sources. The renewed conception of space missions, echoing Humboldtian field expeditions deploying extensive means to gather data characteristic of field sciences since the late XVIIIth Century, would contrast with the practices normalized in most of the traditional space sciences during the first 15 to 20 years of space age, consisting in embarking an isolated instrument inside a spacecraft and wait for the data in the laboratory. This notion evokes two narratives. At the least, this traditional conception embedded a vision of the experimental work made up of singular autonomous instruments without direct connection with other experiments, it reflected the vision of laboratory sciences –taking it in the classical sense. Satellites were accordingly experiments put in orbit to produce data about a given phenomena, data would be analyzed and the phenomena would be described or explained. At the most, this embedded also a vision of panopticism of satellites and space technologies, considered as self-sufficient by themselves, all-powerful to conduct research, capable to gather data that would allow to decipher the mysteries of the universe, or at least of the studied phenomena, with no need for any instrument in the surface anymore[598]. This renewed vision however would require abandoning the idea that satellite data alone were all-powerful.

[598] On the other hand, the abandon of a vision of all-powerful satellite data, would not mean the total submission of satellite data before ground-truths. In fact, it is reckoned that there remain objects for which satellites offer measurements in situ, like the radiation incoming to the Earth system and outflowing from it (the basis to compute planetary energy balances); there are also measurements whose quality control depends on absolute calibration and not on comparison against ground-truths (like computations from GPS measurements).

Indeed, in this novel concept of Humboldtian space missions that was being introduced along the 1980s, the full potential of the space-based observing capability could only be realized within a "composite system", taking the expression of Pierre Morel, including both satellites and in-situ elements, whether they were other data, data handling infrastructures or numerical models. In other words, this renovated notion of space missions would reject the vision of the *all-space*, the panopticism ruling space missions in the infancy of the space age. A *data creator* expert in theory of radiation transfer at LOA put it as follows:

> « On peut tendre à penser que les satellites peuvent tout, qu'ils sont très preformants et qu'on peut se passer des observations au terrain. Mais il faut valider avec des mesures locales, c'est indispensable. C'est vrai que les satellites sont de plus en plus precis, mais on aura toujours besoin d'un contrôle pour voir si à un moment donné on n'a pas fait une erreur. Et le contrôle sont les mesures des verités-terrain»[599].

It appears paradoxical, at least at first glance, the fact that as space technologies become more sophisticated, ripen, precise and reliable, their admissibility depends on a process of returning to the field, to the source, to the Earth.

The panopticism ruling the all-powerful satellites would be then abandoned. This novel notion of space mission, this is our second remark, would nevertheless embrace another sort of panopticism, one in which our planet would be fully instrumented weaving together data from the surface, aircraft, balloons, radiosondes, buoys, and numerical modeling, gridding not only the surface of the Earth but also the skies and the orbits, which, brought to the limit would project a troubling manifestation of Big Brother, as we have suggested before. This panopticism echoes a general remark of cultural order. Satellites belong to the larger issue of globalization, particularly by creating information about the world and linking the production of such information with communication infrastructures, a topic which consumes a lot of scholarship and that extends well further the topic of our dissertation[600]. With this lens, the advent of the satellites bandwagon a movement that already existed of gathering data of every corner in the world and transmitting them, by bringing in the ability to observe the whole planet with the single same instrument –and of communicating this information. We will develop these points along the second part of our essay.

CONCLUSIONS

Because the production of geophysical datasets requires inversion, namely a degree of intervention on the data originating certain interpretational bias, POLDER's *data creators* considered that the quality of the datasets must be assessed before delivering them to a wider audience of *data users*. In this final section we are picking up on some of these main findings.

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599 Interview with Philippe Dubuisson, LOA, 2012.

600 Manuel Castells's trilogy "The Information Age » (1996, 1997, 1998) is one of the most pertinent references.

First, in assessing the quality of POLDER data it was not their lack of error and their perfection which was under examination, because it was reckoned that all data will have always some degree of error and uncertainty. What mattered was rather to control them through the *good practices*, what we have called *regimes of trust*, which differ depending on the instruments available and the material culture of the scientists, the social organization of the participants, the stabilization of funding sources and the observed objects themselves. Second, we have stressed three different elements upon which the assessment of the quality of POLDER's geophysical datasets was articulated -without claiming with that that these are exhaustive strategies for "data validation", nor are we suggesting that these strategies are exclusive of satellite "data validation". One, it relied in a sound fundamental theoretical knowledge about the interactions between light and matter, about atmospheric scattering, absorption and diffusion, about error analysis methods and about computer coding, or in a sound calibration, instrumental principles supporting the experiment, a dose of tacit-knowledge and calibrated-eye. In turn, this exacerbated the prominence of a specific social group, the *data creators*, as the holders of such expertise controlling the details of the instrument and the algorithms, as the credited group admissible to conduct data validation and, as we have argued in chapter 3, were the members of POLDER's community. Two, evaluating the quality of POLDER's geophysical datasets relied as well in institutionalized procedures and rules of management, such as the "Revue de validation", which acted as a regress breaker to end with the validation stage. Practices conducted in the laboratories must be assessed and approved by an external albeit familiar authority, composed by individuals externals to POLDER's community, which exemplifies the weight of the institutions in legitimating data production. Three, at the level of practices, the different *regimes of trust* were dominated by a common epistemology based on comparing against data obtained with networks of standardized instruments, through extensive field campaigns, with other satellites or with the outcomes of numerical simulations. In other words, the scientific credibility of the geophysical datasets retrieved from satellite measurements was evaluated through a constant reference to the corpus of existing data gathered with stations on the surface, by aircraft, buoys, ships or balloons, with other satellites, or with the outcomes of numerical simulations.

Second, the normalization of such practices would be a gradual process occurring all along the 1980s and the 1990s, in parallel to the programming, developing and realizing of space missions in the domain of Earth sciences. POLDER would be framed within this integrative approach, in which assessing the quality of the inversion algorithms and the corresponding geophysical datasets, through the organization of field-campaigns or networked measurements, would constitute an essential part of the process of data production. Just as *data creators* would consider that validating the data was part of the process of producing the data (necessary to control the bias generated by the technologies of inversion), space managers would progressively consider that field-work was part of a space mission and they would incorporate in their programming different types of "programmes d'accompagnement", in which the realization of field campaigns before and after the launch would figure prominently (also the investments in numerical modeling, specially in the technologies of data assimilation, that we will address in the following chapters). The incorporation of such activities as part of a space mission would not change dramatically the current practices of many oceanographers, climate scientists, biologists or atmospheric scientists. Or, put the other way round, field-working would converge with the imperatives for controlling the quality of the geophysical datasets retrieved through the technologies of inversion. It would also benefit the goals of the former selected laboratories that had retained some ability to conceive and build remote-sensing (or not-remote-sensing) instruments but had not enough means (intellectual, material, budgetary) to build them for satellites. Aircraft, balloons, ground-stations or buoys-based instruments were seen a solution to avoid losing these technical abilities. However, it would introduce fundamental changes in the space agencies' values, attitudes and practices. In particular, by redefining a novel holistic notion of space mission, in which non-satellite activities would be only one component of it, space agencies were abandoning the idea that space technologies were all-powerful. Instead, for satellite data to come to a very existence and to be meaningful in studies related to the Earth sciences, they must be considered within the Humboldtian collective that they form with other tools (instruments, models, datasets, theories) –we will come back to this feature when dealing with the technologies of data assimilation. The progressive *normalization* of this novel meaning of the notion of "space mission", we suggest, can be interpreted as an indicator of the ongoing *reconciliation* between space technologies and Earth sciences.

PARTIAL CONCLUSIONS

From 1980 onwards, approximately, space agencies began to incorporate in their scientific programs missions to study the Earth and its environment –just like they had been studying other planets or celestial bodies during the 20 first years of the space age. This was a period characterized by the exportation of space technologies to the disciplines like oceanography, biology, atmospheric chemistry, glaciology or climate sciences –or what we have been called more generally the domain of Earth sciences. Put it inversely, this was a period in which the disciplines of Earth sciences must learn how to integrate and make use of satellite data, beginning by being convinced of their legitimacy as credible tools for producing knowledge. By ways of partial conclusions let us depict the general arc portrayed in these first chapters.

The *epistemic virtue* of satellite data moved from physical radiances to geophysical units. While the first interpretation of the data made sense to physicists experts in radiation transfer, instrumental calibration, spectral signature, signal-to-noise ratio or the inverse problem, they could only be interpreted by Earth scientists if transformed into geophysical parameters. Underlying this move was the tenet that the processes occurring in the oceans, the atmosphere, the polar icesheets, the climate or the vegetation surfaces were usually described in terms of geophysical parameters and not physical radiances. A standardized technological-supported complex of mass-production and dissemination of geophysical datasets was then established, which departed from precedent forms of data production, at least, in two ways. First, it was characterized by an increased participation of space agencies in the production, archival and dissemination of the satellite data. Second, the social organization embedded in this system was ruled by *data-classes* characterized by the technological data practices they articulated, which is connected with the interpretational approach that they articulated. In particular, the specific social group which we have called the *data creators*, raised up as the holders of the epistemic authority to create the data essentially through the *technological data practices of inversion* –as well as to judge about their quality and frame the scientific research admissible to be conducted with the data. At the same time, pressures for gaining visibility amongst a maximum number of Earth scientists to capitalize efforts lead to policies of increased diffusion of data. The metaphor of a chain of production entails that only at the end of the internal workings and mediations data are delivered. The more complete the geophysical datasets are, the more blackboxed they are. In turn, the more *recontextualized* and intervened they are. The possibility of measuring some parameters on the ground via field-work emerged as a solution to the inability of satellites to conduct direct measurements –in France, it appeared also as a solution both to the generational relief in the "selected laboratories" (a number of instrumentalists getting retired), to the progressive industrialization of the manufacture of satellite instruments and to increasing complexity, leaving the laboratories unable to build them –but skilled to build prototypes to be put inside aircrafts, balloons, ground-networks or ships. While field-work was commonplace to many of the Earth sciences, it entailed major changes in the practices and representations of space agencies. By incorporating field-work in their space missions, the idea of the all-powerful satellite was abandoned; not only satellite data alone are disarmed, amputations, but they cannot even exist without exogenous data, theories and models.

More particularly, between 1986 and 1998, the period approximately encompassed in the first part of our essay, the radiometer POLDER was conceived, proposed, developed, realized and launched aboard ADEOS-I. This instrument contributed to shape and was shaped by the developments browsing this period; the resulting system for data gathering, production, archival and dissemination reflected and reinforced these trends. For POLDER's data to be used, as banal as it may sound, two things were indispensable: the existence of the data and the existence of a community willing to use them. The modes of production of POLDER's data were to be designed between 1990 and 1993 by a team of space managers of the Technical Center in Toulouse advised by a number of scientists, including those who had proposed and defended the instrument between 1986 and 1990. The final schema aligned with the factory-like general trends providing for the dissemination of geophysical datasets, and not any intermediate form of data, understood as the basic units meaningful to Earth scientists. However, while CNES was ready to participate in the development and testing of the system during early stages, another organization must take over the data production, archival and dissemination during the 3 years that POLDER was supposed to be flying, during 7 more years during which data could be reprocessed, and during 10 more years that data must be archived and disseminated. This institution would be the Commissariat à l'Energie Atomique –even though, due to the prompt failure of ADEOS-I, the computing center endowed to produce, disseminate and archive POLDER's data would be never transfered to CEA and would remain centralized in the Technical Center of CNES in Toulouse, which would also ensure the archival of the data. The creation of the community POLDER cannot be disassociated to this configuration. Consequently, we have argued, instead of being constituted through "call for opportunities" and "peer-review procedures", the scientific team of POLDER would receive its legitimacy because being constituted under CNES's auspices. This community would be subject to the local contingencies particular to POLDER. Unlike the scientific team of ScaRaB, the community of POLDER would be characterized by its heterogeneity in disciplines and scientific objectives. Unlike that of Topex/Poseidon, the community of POLDER would be characterized by being composed exclusively of *data creators*. The members of the community, in which scientists of Laboratoire d'Optique Atmosphérique predominated in number and degree of implication across the years (other scientists of the Laboratoire de Modélisation du Climat et de l'Environnement, Laboratoire de Météorologie Dynamique or Laboratoire de Physique et Chimie Marines also played important roles), would be united by their common approach to satellite data (*physical approach*) and, accordingly, by the *technological data practices* that they mobilized to interpret the data (inversion). The recipients of the geophysical datasets that they produced, the *data users,* were assumed, though never explicitly spelled out, and they would not belong to POLDER's community ontology.

Space managers, scientists of the "selected laboratories" and Earth scientists adapted each other, molded their representations to each other, reframed some of their practices, made some concessions and gained visibility, power to decide, funds and grants, or perpetuity of their activities. It is through these mutual concessions and gains that the reconciliation took place. This would be the particular way in which the age of space Earth sciences would materialize in the project POLDER.

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Nothing changed radically from POLDER-1 to 2, which was by then scheduled for a launching by 1999 or 2000. ADEOS-II was another one of these big architectonic platforms that celebrated the prowess of space Big engineering. It would carry five different instruments, among which the spare version of POLDER, an instrument identical to the one launched on board of ADEOS-I. The timing plan was shortened in an attempt to accelerate the delivery of data -the failure of POLDER-1 was fresh in the memory. Much of the software for processing POLDER-2 data, both radiances and geophysical algorithms, would be improved versions of the algorithms inherited from the previous POLDER-1 mission. The organization and distribution of work among actors also remained unchanged: "groupe projet", "groupe mission", thematic poles of scientific expertise based at Lille and Saclay, rules of data access, testing phase at the computing center in Toulouse with a transfer to the Commissariat à l'energie atomique which would handle the data production, dissemination and archival during the exploitation phase[601]. People were also more or less the same and coming from more or less the same laboratories: PhD students that had become postdocs, postdocs that had become professors, professors that had recruited new students –all data creators. One change lay be worthy to note: the oceanographic program was reduced in number of scientists because several scientists of the Laboratoire de Physique et Chimie Marine of Villefranche sur Mer would no longer be involved, given the fact that ADEOS-II did not carry the instrument OCTS and that other instruments like SeaWiFS had already been launched. A renewed initiative to settle a datacenter at Lille for processing, storing and disseminating the data of POLDER-2 as a first step to build a facility capable to cope with the data coming from all satellites in the domain of atmospheric physics was again attempted[602]. In

[601] "Logique de développement des évolutions du segment sol POLDER », préparé par A. Gaboriaud, February 1999.
[602] « Spécifications techniques de besoin des évolutions du segment sol POLDER », préparé par F. Bailly-Poirot, A. Budowski, C. Proy et A. Gaboriaud du CNES et J. Poitou du CEA/LMCE, 22 septembre 2000 (polder 92).

that sense it is plausible to affirm that POLDER-2 was actually part of the same experiment than POLDER-1, a prolongation, an appendix.

The launching of ADEOS-II suffered a series of successive delays. It was finally launched on December 14th 2002 from Tanegashima. Like ADEOS-I, ADEOS-II was conceived to live for three years; like ADEOS-I too, ADEOS-II broke down several months after the launching, on October 25th 2003, due to a failure in the solar array paddle (power generation decreased from 6kW to 1kW)[603]. During these months, like for POLDER-1, data had been processed in the computing center of CNES in Toulouse, as part of the initial period of test. With no more data to process, it was judged as not pertinent to transfer the computing center from its testing form at CNES-Toulouse to its semi-industrial form at the Commissariat d'energie atomique (CEA) –just like it had been the case of POLDER-1. Therefore the archiving functions of POLDER-2 data, as well as those of POLDER-1, both calibrated of level 1 and validated of level 2, would also remain centralized in the computing center of CNES in Toulouse[604].

[603] POLDER-1 was launched on August 17th 1996 on board of ADEOS-I. On June 30th 1997, all communication with the satellite ADEOS-I, including data transmission and reception, was cut off due to a breakdown in the solar cells of the satellite.

[604] « Spécifications techniques de besoin des évolutions du segment sol POLDER », prepared by F. Bailly-Poirot, 2000.

PART II:
NORMALIZATION

We propose, now that we are there in halfway, an intermezzo that operates two functions. First, it is the occasion to introduce the instrument POLDER-3 aboard the satellite PARASOL proposed in 1999, its proponents, conditions for approval, its scientific objectives, its institutional and strategic dimensions, insisting particularly in the conditions that led to its exceptionally rapid selection, realization and launching that would last barely five years. The departing point of this second part of the essay is thus the year 1999. This timing molding the organizational division of the present essay is of course conventional and approximate, though not arbitrary, and coincides with several contextual events of technological and (geo)political order taking place between 1998 and 2002, both internal and external to POLDER and CNES, and more generally to the Earth sciences and to space activities. In order to better understand them, we consider useful, and this is the second function of this short chapter, to provide a contextual background of the evolution of the space activities in the 1990s. It is with this overview that, without more introductory explanations, we begin, leaving for a second part the introduction of PARASOL.

Renewed identity for space agencies: The Earth as *a* planet and the Earth as *our* planet

The development of a number of controversial space projects in the United States, including the Star Wars, the space station Freedom and the space shuttle, would fuel a process, in gestation since the late 1970s, of disenchantment and turnoff of governments and public opinion vis-à-vis space technologies. The Challenger accident in 1986 would fuel the fire and raise more suspicion, injuring the technical credibility of NASA as space agency. Roughly a couple of years later, the bipolar order, which had orchestrated and structured space activities since their dawn, collapsed. We do not aim to develop these events in here, but just to take them as contextual background illustrating the obsolescence of the original vocation of NASA and the need for redefining its political and diplomatic functions as a governmental organization, adapted until then to serve international relations and geopolitics during

Cold war[605], in a new world. It has been argued, for instance, that the renewed NASA's program Earth Observing System as approved in 1990, and in particular the environmental program Mission to Planet Earth since 1993, including ground-based and space-based elements, were conceived as a vehicle for restoring the confidence of American citizenship, suspicious about space technologies as reminiscent symbol of state power in a divided world and at the same time concerned about the environmental degradation[606]. More generally, the image of space technologies as symbols of State power in a divided world must be renovated. At the same time, the end of the Cold War enabled decision-makers to promote defense space programs through enlarging the doctrine of the *duality* of space technologies, as potentially serving civil and defense goals, a doctrine that would browse many of the space developments in civil space agencies from the 1990s onwards[607].

At the European level the image of space activities as symbol of some sort of European-region prowess was not as pregnant as in the United States. That being said, the changing world would also wreak on space activities. Space activities at a European scale had been managed since their dawn in the 1960s by successive organizations, the European Space Agency (ESA) since 1975, autonomous to the process of the European integration[608]. As Europe moved towards increased integration, a number of resolutions about the applications of space activities would be issued by the European instances, which would mark the starting point of collaborating with ESA, beginning with the Single Act of 1987 which recognized, for the first time, that space domain could be a tool to foster research and development, applications market and security[609]. Such discursive declaration would not become any effective engagement before 1992, when some joint committees between the European Commission and the European Space Agency would regularly meet to discuss possible domains of collaboration. The Amsterdam Treaty in 1999 opened doors for joint undertakings between EU and ESA and, in 2000, under French presidency, the European Commission and ESA issued the "European Union space strategy", which constituted the first doctrinal approach towards the definition of a common space policy, centered on satellite applications like transportation, environment, research and security. It has been argued that essential to this evolution would be the military conflicts browsing the decade,

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605 "NASA in the World. Fifty Years of International Collaboration in Space", J. Krige et al, 2013.

606 "The Evolution of Earth Science Research from Space", J.H. McElroy and R.A. Williamson in J.M. Logsdon ed. "Exploring the Unknown: Selected Documents in the History of the US Space Program », 1998.

607 These are some of the dual uses for space assets, as they would be synthetized later on in 2003, in a report on the orientations of the French space policy: in the telecommunication domain (high debit, new frequencies, security of the communications, anti-interference et anti-locating), in the high-resolution imagery (visble, infrared and radar, guaranteeing the continuity of the observations, combining data from aircraft and drones), signals intelligence (localization and characterization of telecommunications systems), warning and space surveillance (anticipate the proliferation of missiles), location and positioning in space and time (securing Galileo's signal, anti-noise), military applications of meteorology and oceanography satellites, and guaranteeing an European autonomous access to space through a competitive rocket program..

"Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

608 The differences in the membership in both organizations illustrates this degree of autonomy. For instance, while Canada or Norway sit on the Council of the European Space Agency without being European Union members, Croatia, Malta or Cyprus are not members of ESA.

609 For an institutional and political history of ESA prior to the 2000s, see « A History of the European Space Agency", J. Krige and A. Russo, 2000.

from Kuwait to the Balcans to Afghanistan, which had demonstrated the ability and potentialities of space assets as force-multipliers in war time and their importance to information warfare, an aspect in which US would enjoy absolute hegemony[610], as demonstrated in several occasions during the conflicts, when access to GPS services would be blocked or the dissemination of satellite images would be jammed by US defense agents. Not by accident, the programs proposed in 1998 by the European Commission around which the European space policy would be defined would be a positioning system with global coverage (called Galileo) and a program for *Global Monitoring* for Environment and Security (GMES, currently known as Copernicus)[611], which would receive formal authorization by ESA's members during its annual Council of 2003. The same year, in 2003, a Space Council was created, which met for the first time in November 2004 and became the first body dedicated to discuss space affairs in the Commission. It was during the 4th meeting of the Space Council in May 2007 that the 25 members of EU, plus Canada, Norway and Switzerland (as members of ESA) adopted the EU space policy that had been jointly elaborated by ESA and the European Commission during the precedent years, which entered in vigor with the signature of the Lisbon Treaty in 2008[612].

In France, CNES would have its own dilemma. The annual state subvention to CNES had quadrupled in the 1980s (from 2146 MF in 1982 to 8559 MF in 1992, while inflation rounded 50%), a figure which, given CNES's programming for the following decade (with central importance to ambitious projects such as a new launcher Ariane-V, a human spacecraft Hermès and the contributions to the International Space Station), was likely to shoot up: it was estimated that an increase of 50% was needed only before 1995[613]. The Comité National d'Evaluation de la Recherche would release in 1992 a report about the French space policy making explicit the idea that CNES was confronted with the following situation[614]: given the hegemony of the United States in space activities of (almost) all range

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610 A look at the budgets percentages in 1999 can give an idea of the American dominance in military space activities: the 94,8% of the total international budget devoted to military space activities was expended in the US. The European part would correspond to a 3,9% and the Russian part to 1%. The remaining 0,3% would be distributed amongst all other states.

« Plan stratégique du CNES 2001-2005. Tome 1", elaborated by the Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001.

611 Albeit being a program of the European Commission, Copernicus, formerly Global Monitoring for Environment and Security (GMES), has been designed and overseen mostly by ESA. It aims at achieving an autonomous, multi-level operational Earth observation capacity. The objective is to use data to get a timely and quality information, services and knowledge in relation to environment and security on a global level. Copernicus builds upon 3 components: the space component (observation satellites and associated ground segment, comprising two types of satellite missions, ESA's five families of dedicated Sentinel satellites and missions from other space agencies, like Jason-3 or weather satellites), in-situ measurements (ground-based and airborne data gathering networks providing information on oceans, continental surface and atmosphere) and services to users. Currently the program is in its pre-operational phase. We will recurrently refer to it in the following two chapters.

612 Characteristic of European instances, a lot of documentation reporting these resolution, agreements and plans would be generated. Find it on: http://ec.europa.eu/enterprise/policies/space/documents/esp_en.htm

613 « Evaluation du Programme spatial français. Avis et recommendations du Comité National d'Evaluation de la Recherche », 10 September 1992.

614 CNER was created in 1989 to assess the evolution of the national research policy defined by the French Government. Evaluating CNES would be included in the first round of evaluations conducted by the 10 members of the Committee, who had been elected during a Ministry Council and included Jean-Pierre Causse, former director of the Technical Center of CNES in Brétigny (the Technical Center of CNES before moving to Toulouse). During their

(from military to telecommunications to science[615]), the increasingly powerful ESA consuming about 40-45% of CNES's budget[616], and the growing interest of European instances in space activities, did CNES, a national space agency, still make sense? Describing the context, the main programmatic lines and their economic, industrial and strategic impacts, the report would raise the alarm bells about a number of aspects regarding CNES's organization and *raison-d'être* (decision-making procedures, administrative structures, financial organization and programming guidelines). In particular, the authors of the report would plead for abandoning the program of human spacecraft Hermès and redefining the program of launchers Ariane-V[617].

Observing (or rather intervening and experimenting) and surveying

On the other hand, the fall of the bipolar world order would generate room for new preoccupations and priorities, new international political agenda and adversaries of new nature, including environmental degradation. Indeed, a wave of environmental preoccupations would rise up in the 1990s as exemplified by the fostering of international debates and regulations from Rio to Kyoto. This would offer space agencies and funding bodies possibilities of a renewed mission in the post-Cold war. Missions to study the Earth and its environment were typically cheaper than interplanetary probes and easier to put into orbit (less combustible, flying closer, therefore less likely to fail), their results were more immediate (it took only some days to receive the first data), their social utility was relatively easy to bring forward (in terms of science, predicting global changes, evaluating the effects of humans in the environment, forecasting environmental events affecting societies or other). While retaining a positive image of space agencies as committed to the green cause (at least in Europe), they would reconcile with other political priorities, especially by stressing the duality between civil and military technologies and allowing the ascent of a security dimension of space assets (surveying critical sites, intervening in humanitarian crises, managing natural disasters, surveying borders and migratory fluxes, following the transportation of sensible material, etc.) or they could eventually derive in commercial products or services in a data-based economy. Space agencies and operators would thus leverage such ascendant generalized environmental sensibility, as it allowed to reconcile their goals in keep doing business at a reasonable cost, risk and projecting a positive image, with governmental domestic ends and international trends.

As soon as in 1990, for instance, a large number of interconnected institutions (space agencies and operators, the Committee of Earth Observation Satellites, the World Meteorological Organization, the International Council for Science (ICSU), representatives of the World Climate research Programs and

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investigation, they included the advice of experts, amongst which the atmospheric physicist Gérard Mégie of the Service d'Aéronomie.

615 The domains of commercial launchers and high resolution imagery were two exceptions in which Europe and France would provide an important counterbalance to US assets.

616 Rapports d'activité of CNES, 1985-2000.

617 « Evaluation du Programme spatial français. Avis et recommendations du Comité National d'Evaluation de la Recherche », 10 September 1992.

of the International Geosphere Biosphere Program, of the Intergovernmental *Oceanographic* Commission of UNESCO, environmental organizations and funding agencies, among others) would met in Paris in the "Space and the Global Environment Meeting" and would converge in a set of scientific and technological requirements for observing the environment[618]. Almost at the same time, the Second Climate Conference hold in response to the first assessment report issued by the Intergovernmental Panel on Climate Change (IPCC) concluded, inter alia, on the importance of deploying a system to monitor the evolution of the environment, which was named Global Climate Observing System (GCOS):

> "There is an urgent need to create a Global Observing System (GCOS) built upon the World Weather Watch Global Observing System and the Integrated Global Ocean Service System and including both space-based and surface-based observing components"[619].

The World Weather Watch (WWW) is a program engaged in 1960 as the core of the programs of the World Meteorological Organization and aimed to produce and circulate weather information across the entire globe. Established in 1963, the WWW combines data-gathering systems (in the ground and in the space), telecommunication facilities, and data-processing and forecasting centers to make available meteorological and related environmental information needed to provide efficient weather services in all countries. Through the efforts coordinated under the umbrella of the World Weather Watch, weather services had reached the status of given-for-granted infrastructure based on the coordinated effort of data gathering, processing, circulation and interpretation. The idea behind the proposed Global Climate Observing System (GCOS) was to emulate this infrastructuralization focusing on data-gathering, production, dissemination and securing services, in the domain of climate and environment. It was to be a sweeping system made up of satellites, ground stations, aircrafts, balloons and ships coordinated to gather data, complemented by computing datacenters, modeling centers and expertise centers coordinated to analyze and interpret, and to archive, the data and generate information, and by the whole network and pipelines through which the data and the information would flow from one place to another. Put it differently, the goal would be to render the monitoring of the environment as banal as the monitoring of the weather was: a reliable perpetuate taken-for-granted system. This general idea has been famously conceptualized as a *global infrastructure*, described by Geoffrey Bowker, Susan Leigh Star and others, that is to say, technical infrastructures deployed all over the world and that have facilitated globalization –like roads, telephone lines or coordinated postal services[620]. In particular, GCOS was meant to be a global infrastructure intended to produce knowledge, one of these huge international techno-scientific initiatives based on permanent shared infrastructure described by the historian of sciences Paul Edwards "projects for permanent, unified, world-scale institutional-technological complexes that generate globalist information not merely by

[618] Minutes of the "Fourth Plenary Meeting of the Committee on Earth Observations Satellites", held in Sao José dos Campos, November 1990.

[619] "Climate Change; science, impacts and policy", Eds. Jäger J and Ferguson HL, Proceesdings of the Second World Climate Conference, Cambridge University Press, 1991: 578.

[620] *"Sorting Things Out:* Classification and Its Consequences", G.C. *Bowker* and S.L. Star, 1999.

accident, as a byproduct of other goals, but by design"[621], an *informational global infrastructure*. It was about creating a panoptical infrastructure that would gather, produce and circulate data, knowledge and information about the environment and in a global scale[622], global both because of the scope of its deployment and because of the type of data that it produces about the Earth. One last word to conclude with these reflections. There is a thin line separating the two narratives embedded in these panoptical systems and the globalist perspective. On the one hand, these technological systems celebrate the potentialities of worldwide data-collection and data-sharing in order to produce scientific knowledge in the different disciplines embraced under the label of Earth sciences. These potentialities have been demonstrated by and through the numerous extensive field campaigns conducted, at least, since the International Geophysical Year in 1957-1958, whose legacy is at present day personified by the campaigns mostly organized under the aegis of the World Climate Research Program (established in 1979) and the International Geosphere Biosphere Program (established in 1986). On the other, these very same technologies can be interpreted as manifestations of the global environmental technocracy intended to transform the scientific knowledge into information for the purpose of management and control at a planetary scale. From *observing* (or rather *intervening* or *experimenting*, as we have illustrated along the first part of our essay) to *surveying* there is a very thin line[623]. Under this Foucaultian surveillance narrative, the Earth is not only considered as *a* planet to be explored and studied, but as *our* planet to be monitored and controlled. It is about getting data about our planet in order to manage our societies, about producing information in order to drive action –we will come back to this point in chapter six.

Back to the Global Climate Observing System, two years later, in April 1992, a Memorandum Of Understanding would be signed by those who would be the sponsors of such system (the World Meteorological Organization, the International Council for Science (ICSU), the Intergovernmental *Oceanographic* Commission of UNESCO and the UN Environmental Program), establishing an international, interagency, interdisciplinary framework for meeting the full range of national and international needs for climate observations, dominated by a space-based component that would be coordinated by CEOS. Like the WWW, GCOS would be a framework, not an institution properly speaking, that is to say, it would have no political power, no budget and no technical means for

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621 Meteorology as Infrastructural Globalism », Paul N. Edwards, 2006.

622 Paul Edwards noted, in the domain of meteorology, a fundamental shift in the visions underlying the construction of networks and driving the exchange of data: "The history of meteorology from the 1850s to the present illustrates a profoundly important, albeit messy and incomplete transition: from voluntarist internationalism, based on an often temporary confluence of shared interests, to quasi-obligatory globalism based on more permanent shared infrastructures. Therefore, I will speak not only of informational globalism but of infrastructural globalism: projects for permanent, unified, world-scale institutional-technological complexes that generate globalist information not merely by accident, as a byproduct of other goals, but by design". Or, put in other words, the building of technical systems for gathering global data is contributing to create global institutions and ways of thinking globally.

For a detailed historical analysis of the World Weather Watch see « Meteorology as Infrastructural Globalism », Paul N. Edwards, 2006. This study is put in a broader perspective in his book "A Vast Machine", 2010.

623 We may refer here to a recent publication edited by Simon Turchetti and Peder Roberts "The Surveillance Imperative. Geosciences during the Cold War and Beyond", 2014. The different essays in this book illustrate different modes of surveying the Earth by stressing the connections between the imperatives to know the enemy and those to know the Earth in the context of the early Cold War.

implementing and conducting effective action –it would instead specify the technical requirements and recommendations for establishing the monitoring system and coordinate different institutional efforts and contributions to achieve it, inspired by what had been done some decades before with the WWW. One of the actions would be for instance the creation of the notion of Essential Climate Variable as those variables currently measurable, with impact on environmental change and whose monitoring from space should be guaranteed in the long-term[624]. More than 50 geophysical parameters have been labeled as essential at present day[625] -we will come back to that point also in chapter six.

To be sure, a system for gathering and producing data about the environment had been the topic of discussion of Earth scientists and space agencies and operators representatives since the early-1980s, as exemplified by several initiatives discussed under the auspices of CEOS, like the one initiated by the Society of Japanese Aerospace Companies pleading for a World Environment and Disaster Satellite Observation System that would monitor natural and man-made disasters or a more comprehensive proposal, ENVIROSAT, a regime analogous to INTELSAT and INMARSAT to provide climate, meteorological, ocean and land observations in an operational manner -just to mention two of them[626]. At the national level, a number of scientists had been pleading in France for the deployment of such system, amongst which Pierre Morel in his speech during the first scientific meeting under the auspices of CNES in 1981:

> « Des expériences « passagers », telles que celles envisagées dans l'appel à propositions scientifiques de l'Agence Spatiale Européenne pour le programme ERS-1 ou celles qui pourraient être embarquées sur SPOT-2, devraient constituer une approche satisfaisante pour faire progresser les techniques instrumentales dans ce domaine à l'exception de certains instruments très ambitieux pour lesquels l'usage de la plateforme SPACELAB (dans un cadre nécessairement coopératif avec la NASA ou les partenaires européens) pourrait se révéler nécessaire. Il faut insister sur le fait que dans ce contexte des problèmes climatiques, une mesure isolée, même excellente, est de peu poids : une surveillance systématique étendue sur plusieurs années est nécessaire pour faire apparaître, parmi les fluctutations météorologiques, le « signal climatique » toujours faible »[627].

Pierre Morel insisted in the importance of ensuring the continuity of the measurements over the long-term, by comparing this climatic approach to the opposite approach aimed to "advance in the instrumental technologies" –professor Morel would even use the term "surveillance", which relates to the previous discussion about the twin narratives embodied in the missions orbiting our planet. He would be, between 1982 and 1994, the director of the World Climate research program, and he would

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[624] "Second report on the Adequacy of the Global Climate Observing System in support of the UNFCCC", GCOS-82, 2003.

[625] The 50 "essential climate variables" are classified in three main groups (atmosphere, oceans and land surfaces). Some of them are: River discharge, Water use, Ground water, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosyntheticallyactive radiation, Leaf area index, Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture, Sea-surface temperature, Sea-surface salinity, Sea level, Sea ice, Surface current, Ocean colour, Ocean acidity, Phytoplankton, Nutrients, Oxygen, Tracers, Air temperature, Wind speed and direction, Air pressure, Precipitation, Surface radiation budget, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance), Carbon dioxide, Methane, and other long-lived greenhouse gases, Ozone and Aerosol.

[626] To know more about these projects see for instance "Development of a Global EDOS: Political Support and constraints", J. Johnson-Freese, 1994 and "The case for ENVIROSAT », J.McLucas and P. Maughan, 1988.

[627] Pierre Morel, Séminaires de prospective scientifique CNES, Les Arcs 1981.

recurrently refer to the World Weather Watch, and its experimental phase GARP, as an example to follow:

> "L'Expérience Météorologique Mondiale du GARP [GARP stands for Global Atmospheric Research program and it was supposed to be a set of actions in preparation for the World Weather Watch] a été l'occasion de déployer, pour la première fois, un système d'observation composite et suffisant pour caractériser complètement les aspects dynamiques et thermodynamiques de la circulation atmosphérique globale. Il est devenu possible de concevoir un système d'observations cohérent constitué par des ballons sondes, des navires météorologiques, des bouées et des avions opérant en même temps et d'une manière complémentaires des observations des satellites météorologiques polaires et géostationnaires mis en place pour l'Expérience Mondiale. La stratégie immédiate du Programme Mondial de Recherche sur le Climat s'inspire de cet exemple, mais pour traiter cette fois un système plus vaste englobant, au minimum, l'atmosphère et les océans »[628].

All these initiatives and plans had however remained quiescent during the decade of the 1980s, only emerging sporadically without real commitment per part of major space agencies. As the problem of global warming would shore up in the political agenda, or as space agencies sought a renovated vocation in the new world order, the context would become gradually more favorable. Plans for implementing such environmental global observing system would be definitely bolstered after the Kyoto-era, which had been focused on establishing international regulations and not on establishing any observing system. At the European scale, for instance, the concept of monitoring for environment and security (the program Global Monitoring for Environment and Security/Copernicus mentioned before) would impose as a structuring element of the European space policy in 1998. Such moves would be endorsed during the G-8 meeting hold in 2002, which would give momentum to the establishment of a space-based system for studying and monitoring the environment at the global scale, giving birth to the "Group on Earth Observations" under the leadership of the Committee on Earth Observation Satellites (CEOS) aimed to put into place a so-called Global Earth Observation System of Systems (GEOSS), in which GCOS would serve as its climate-observation component – points that we will develop when discussing the continuity of space systems in chapter six.

On Explorers and on Sentinels

These moves had consequences in the programming of the missions in support of Earth sciences studies at space agencies. One thing was to study the Earth and another thing to survey it. One thing was to consider the Earth just like a planet to be explored and the other to consider the Earth as our planet to be monitored and controlled. One thing was to consider the Earth sciences as a particular form of space sciences and the other to consider them as a source of valuable information to manage the Earth and its environment. One thing was to launch one single-shot satellite to study a given process or to gather data during a limited period of time (just like there were launched to study Venus, the cosmic rays or far away galaxies) and another thing was to deploy a permanent system for surveying the Earth's environment. One thing was to launch Explorer-type satellites (go and take a

[628] « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.

look) and the other Sentinel-type (go and keep the eye)[629]. One thing was to launch a POLDER to gather measurements during three years and the other was to implement a system for ensuring the perpetuity of the measurements gathered by a POLDER-type instrument over time, just like it was done with weather satellites. The two twin narratives embedding the space missions in the domain of Earth sciences materialized two different epistemologies vis-à-vis the satellite data, the instrument or the notion of scientific team, and demanded different technical requirements (in terms of spacecraft, data processing, archival and dissemination), organizational structures and funding mechanisms. By the late 1990s, both approaches would coexist. On the one hand, those missions inheritors of the experimental culture in physics as transposed in the domain of Earth sciences, characterized by single time-limited shots of satellites equipped with a number of instruments designed and manufactured by a team of *data creators*, who have also the epistemic authority for preparing and interpreting the *geophysical data* (POLDER-type). On the other hand, those missions inscribed in long-term plans for permanently monitoring and surveying our planet and intended, by design, to provide information useful not only for academic purposes but also for decision-making.

The increased urgencies for the surveying imperative awaking from the quiescence in the 1990s, would coincide in time with the launching of the first generation of satellites and sensors to study the Earth, those conceived during the 1980s to study the planet Earth, like the Upper Atmosphere Research Satellite (UARS) and the European Research Satellite-1 in 1991, Topex/Poseidon in 1992, ScaRaB in 1994 or ADEOS in 1996, to mention those we are familiar with. It was by then, also, that the second generation must begin being designed and planned to be launched in the following decade, from the 2000s onwards. Throughout the 1990s then, major space agencies, with more or less support of their funding governmental bodies in function of domestic political cycles, would consolidate their investments in missions to study the Earth and its environment, as seen as an admissible recycling of some of the no longer admissible ancient programs. The major development with respects the first generation of satellites would be that they included, in their plans, also missions endowed to survey – although their factual realization would result harder than expected.

In the United States, the Congress would approve the renovated version of the Earth Observing System as part of NASA's Mission to Planet Earth approved in 1993 providing for a series of small satellites. Their technology would actually be similar than the ones used in NASA's planetary program Explorer and would be characterized by innovative design, novel instrumentation and relatively rapid implementation[630]. Each mission would be developed following the process consolidated since the

[629] Explorer and Sentinel are actually the names of two programs of satellites: the first corresponds to the NASA's series of satellites launched in the domain of the traditional space sciences since the 1960s and the second one to the satellites specifically manufactured by ESA for its *Global Monitoring* for Environment and Security program. We take these names because they are instructive metaphors of the type of mission that they represent: single-shot satellites launched to gather data during a limited period of time and shut off, just like the explorers participating in a time-limited expedition and coming back home; like sentinels, permanent systems of satellites act as guardians looking after the planet at all time, they are launched to remain in their positions until the successor satellite will come to replace them, like guardians.

[630] "Earth Observing System (EOS) Reference Handbook", eds. G. Asrar and D. J. Dokken, 1993.

1980s: a team of scientists would propose an instrument, a call for opportunities would be opened to involve other scientists in the preparation of the data and in its use, data would be produced and disseminated in the factory-like complex designed to that purpose, and geophysical datasets would be made available to external scientists eventually willing to use them. Each mission was an experiment. Apart from NASA's program of exploration, NASA, the Department of Defense and NOAA studied since the 1999 the implementation of a joint program of surveillance, called NPOESS (National Polar-orbiting Operational Environmental Satellite System). It was focused on measuring some environmental parameters and providing for a series of six satellites, launched in two rounds of three (the first of which to be launched by 2013) and providing global permanent coverage during at least 10 years, when the new generation of satellites of the program would be ready to launch, and so successively as per guaranteeing continuous monitoring. The White House announced on 2010 that the NPOESS satellite partnership was to be dissolved, and that two separate lines of polar-orbiting satellites to serve civilian and military users would be pursued instead. The first of such satellites, on the civilian side, the National Polar-orbiting Partnership (NPP) also known as Suomi in honor to the scientist proposing the first radiometer launched back in 1959 aboard of Explorer-7, would be launched in 2013[631].

The program of ESA also illustrated this coexistence instructively. An optional program on environmental missions would be approved in 1998 composed by two parallel lines of projects. On the one hand, the "Earth Explorer" providing for the launching of 7 to 9 satellites between 2000 and 2010 intended to, aligning the logics of one single-shot experiments, carry new instrumentation to study particular scientific questions and processes in a time-limited period. The Earth Explorers were designed to be missions to address key scientific challenges identified by the science community while demonstrating breakthrough technology in observing techniques. This program would be accompanied, on the other hand, by its twin program suggestively called "Earth Watcher", which was developed following the logics of monitoring and designed to facilitate the delivery of data for use in operational services. The "Earth Watcher" would be majorly composed by the European weather forecasting program (satellites Meteosat and next generations) and the *Global Monitoring* for Environment and Security/Copernicus's satellite missions –by the way, talking names, the satellites specifically developed by ESA for such a program (GMES) would be not accidently named Sentinel, projecting the image of the guardians of our planet[632].

On the history of the EOS program, see Erik Conway's "Atmospheric science at NASA" and Roger A. Pielke's "Policy history of the US Global Change Research Program".

[631] "The National Polar-orbiting Operational Environmental Satellite System (NPOESS)", Patricia Vets, NOAA Public Affairs Office.

[632] The first Earth Explorer mission, the Gravity Field and Steady State Ocean Circulation Explorer (GOCE) would be selected by 2001 and launched in 2009. Ever since three more missions have been launched: Soil Moisture and Ocean Salinity satellite (SMOS), Cryosat 1 (lost) and 2, and SWARM to map Earth's magnetism, and three more are under preparation with scheduled launches between 2015 and 2020, AEOLUS (laser to measure winds), EarthCARE (clouds and aerosols) and BIOMASS (forest carbon cycle). As per the Sentinels, the first one was launched in 2014.

In 1996, CNES would start an exercise of reflection to define a strategic plan for the internal organization and main orientations of its programming. Issued in 1999, three would be the axes of actions around which CNES would put space technologies at the service of: the environment, the science and the information society[633]. According to the strategic documents that we have consulted (like the strategic plan issued in 1999 or in the contract between CNES and the State issued in 2002[634]), missions in the domain of Earth sciences would rarely be classified under the axe of sciences, which would be reserved to traditional space sciences and materials sciences. They would be instead considered as part of the environmental axe. This axe, the environmental axe, would consist in helping decision-making in issues concerning natural resources, environmental policies and regulations, including a security dimension in a large sense. This would mean, for instance, transforming satellite data into information about water resources, climate change, natural disasters, alimentary security, provision of energy, deforestation, health or borders control and migration fluxes, inter alia. This was the very logics of transforming satellite data into information and information into action. Missions in the domain of Earth sciences were hence conceptualized in connection with the goals of helping decision-making, weaving in so doing scientific research in the domain of Earth sciences with political and social urgencies. We shall note that this conundrum may have certainly taken a renewed urgency in the new post-Cold War world, but it existed, though under another shape, since the very dawn of satellite activities and that dreams of using satellite data to manage and control our planet are as old as satellites are (the first weather satellites in the 1960s and Earth survey satellites in the 1970s had already been used for these very purposes; recall the descriptions about “applications” satellites in chapter one). Satellites orbiting the Earth would inherently embody both instruments for producing scientific knowledge and instruments for supporting action.

The president of CNES from 1996 to 2003, Alain Bensoussan, would go as far as to recognize that this renewed impetus constituted a “chance” for space agencies, because satellites were in good position to provide the basic units necessary for action, global data:

> “Des nouveaux services publics prennent de l'importance : ceux liés au développement durable, à la protection de la planète, à la sécurité environnementale. C'est une chance pour le spatial, qui peut fournir des données utiles et nombreuses, à condition qu'elles soient facilement accessibles et surtout rapidement transformées en informations facilement utilisables. C'est un domaine qui peut justifier un effort de financement public”[635].

Environmental (and security) preoccupations would then appear as a « chance » to CNES, as rendering possible the renovation of its strategy and programming in the new post-Cold War context. Lexical similarities with the European program *Global Monitoring* for Environment and Security are not accidental, given the fact that programs at CNES and ESA use to evolve in parallel -we have already

[633] « Plan stratégique du CNES 2001-2005. Tome 1 », edited by Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001.

[634] « Orientations du CNES à l'horizon 2005 », Alain Bensoussan, president of CNES, 2000, « Plan stratégique du CNES 2001-2005. Tome 1 », edited by Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001 and « Contrat pluriannuel État-CNES 2002-2005 », edited by CNES, 2002.

[635] « Orientations du CNES à l'horizon 2005 », Alain Bensoussan, president of CNES, 2000.

mentioned that ESA is a privileged partner of CNES and that one of the strategies of CNES is to develop a national program to fuel, and so lead, the European program.

Actually, in the strategic plan of CNES issued in 1999, it would be pointed that “l'observation de la Terre constitue-t-elle, après les lanceurs, la seconde priorité de la politique spatiale de la France »[636]. As we have suggested in our introductory chapter, the term « Earth observation » is a vast term enabling different types of missions, sensing technologies, modes of organization, types of spacecraft or modes of data-handling. Within this vast label, not all missions would receive the same degree of priority, being high-resolution imagery with commercial and/or defense goals the first in the list (programs SPOT, Helios and Pleiades). By 2002, SPOT alone would consume 9% of the total budget of CNES (without counting the investments of CNES to the subsidiary SPOT-Image dealing with the commercialization of the images and without counting the investment through the programs Pleiades or Helios). The weather program, the oceanographic program (successor of Topex/Poseidon) and all the single-shot missions together (POLDER-3, ScaRaB-3 and new projects engaged since 1998) would not reach the 3%. As a comparative figure, the program Ariane-V would receive 48% of CNES’s budget[637].

Proposing PARASOL: The Afternoon-Train

The strategic plan of CNES issued in 1999 would define three domains of technological excellence that must be maintained and privileged at CNES: radar altimetry (Topex/Poseidon), radiometry for Earth radiation budget measurements (ScaRaB’s type), and polarimetry in continuation of the instrument POLDER[638]. The technological evolution of POLDER, as planned by then, would aim to widen its field of view, improve the angular and space resolutions and increase the number of spectral bands. Several options to build and launch a third version of POLDER would be proposed between 1998 and 2002 and we will provide a brief overview when discussing the continuity of polarized measurements in chapter six. One of those proposals would become the satellite PARASOL. In January 1999, a meeting would be convened in the Alps to present some results of the POLDER-1’s data analysis and prepare POLDER-2’s one, encompassing experts in aerosols, clouds, Earth radiation budget, and polarized measurements from the Laboratoire d’Optique Atmosphérique, the Laboratoire de Sciences du Climat et de l’Environnement, the Laboratoire de Météorologie Dynamique that had participated in the creation of the data, but also from a number of other laboratories like the Service d’Aéronomie, the Centre National de Recherches Météorologiques or foreign colleagues, from the United States, Canada or Germany. During this meeting it would be suggested that a lot could be

[636] « Plan stratégique du CNES 2001-2005. Tome 1 », edited by Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001.

[637] « Contrat pluriannuel État-CNES 2002-2005 », edited by CNES, 2002.

[638] « Plan programmatique du CNES. Observation de la Terre. Programmes à caractère scientifique » and « Plan programmatique du CNES. Observation de la Terre. Programmes Opérationnels à caractère institutionnel et commercial », proceedings and report of the Séminaire de Programmation held in January 1998.

“Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space”, January and February 1997.

gained from combining the polarized radiometric measurements of a POLDER-type instrument with measurements obtained with a lidar[639]. Data collected by a polarimeter, as had been demonstrated with the analysis of POLDER-1 data, would allow data creators to establish the quantity, effective radius and size distribution of aerosols over ocean regions, their turbidity index over land surfaces, their refractive index or Angstrom exponent, among others, and to evaluate radiative forcing from solar radiation. They would also help to detect clouds, determine their thermodynamic phase and altitude, and estimate reflected solar flux; the integrated water vapor content could also be estimated. However, all these parameters were vertically integrated, that is to say, they corresponded to a whole column of the atmosphere, from the surface to the height of the satellite, without distinguishing eventual differences in function of the altitude. If combining the measurements of the polarimeter with the ability of the lidar to discriminate different altitude layers, the vertical profiles of the parameters retrieved with a POLDER-type radiometer could be estimated[640].

These suggestions of combining the data from a lidar with polarized radiances would became a sound proposal to launch a satellite carrying a POLDER-type instrument to fly next to another satellite that carried a lidar with the goal of improving the characterization of the clouds and aerosols microphysical and radiative properties. The proposal would be led by Didier Tanré of LOA, a scientist who had been working in the remote sensing of tropospheric aerosols since the late 1970s, and in particular in the development of algorithms from POLDER-1 and MODIS measurements, and who would become the Principal Investigator of the project. The project would be suggestively named Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar, or PARASOL[641].

These ideas of combining POLDER measurements with a lidar's ones were backed by the fact that a lidar, called CALIOP, was actually been developed by the Langley Research Center of NASA to be launched by 2004. Sending a lidar to space had long been dreamed by some French scientists, which since the early 1970s had been using this technology in the surface as well as inside aircrafts to study chemical composition of the atmosphere[642]. Several attempts to put a lidar inside a spacecraft had been

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[639] Interview with Didier Tanré, LOA, 2014.

[640] A lidar (LIght Detection And Ranging) can be understood as a transposition of a radar in the optical domain: a laser emits light narrow beams and the backscattered signals are collected in the focal of a telescope, amplified and analyzed. The time that takes the signal to go and go back, and its intensity all along the path, is used to deduce the distance from the emitters to the reflecting object.

For instance, if the lidar is placed in a satellite and the reflecting objects are atmospheric molecules (N2, O2 or water, for instance), their distribution in function of the distance to the satellite (that is from the height from surface) can be deduced.

[641] "Remote sensing of aerosols by using polarized, directional and spectral measurements within the A-Train: the PARASOL mission", D. Tanré et al, 2011.

[642] See for instance some of the efforts lead by physicists at the Service d'Aeéronomie: "WIND: an airborne Doppler lidar for atmospheric applications developed in French-German cooperation", A.M. Dabas et al, 1992, *"The French airborne* backscatter *lidar LEANDRE 1:* Conception and operation", J. Pelon et al, 1990, or « High accuracy FIZEAU wavemeter for DIAL airborne measurements », O. Blanchard et al, 1991.

carried out in France since the 1980s[643]. For instance, the mission Bilan energétique du système tropical (BEST) proposed during the second scientific meeting organized by CNES in 1985 by scientists from the Centre de Recherche en Physique de l'Environnement terrestre et planétaire, the Laboratoire d'Etudes et de Recherches en Télédétection Spatiale, the Laboratoire de Météorologie Dynamique, the Laboratoire d'Optique Atmosphérique and the Service d'Aéronomie was dedicated to study the energy transfers in tropical zones, particularly those involved in the water cycle, as part of the Global Energy and Water Cycle Experiment of WCRP (GEWEX). The satellite would carry three main instruments, one of those would be a lidar doppler to measure vertical profiles of winds. In addition, two other instruments would be considered as optional to be put inside the satellite, one of those would be again a lidar, this time to measure vertical profiles of humidity[644]. As such, BEST would never be realized, because passage to phase B would not be recommended in 1992 – nevertheless, some of the components (radar and radiometry) would be adapted and launched in the frame of other missions to study the water cycle in the tropics, like Tropiques proposed in 1993, which would become Megha-Tropiques launched in 2011. In a beautiful example that illustrates the distribution of technological competences amongst technical agencies, or the maintenance of a certain degree of specialization, after considering strategic, technological and economic considerations CNES would step back of the efforts to build a space-based lidar to concentrate in two other technologies: radar altimetry and radiometry[645]. NASA, who had long been working with lidars, and who was in a slightly more advanced stage of development[646], would take the lead in the lidar technology.

NASA's lidar CALIOP would be actually put inside a French satellite[647], together with a Imaging Infrared Radiometer conceived at Service d'Aéronomie (to detect cirrus and particle sizes) and a modified version of a commercial off-the-shelf wide field camera developed by the American industrial Ball Aerospace. The satellite, initially called PICASSO-CENA, and changed to CALIPSO

[643] The first French lidar to be put in space to measure the atmosphere would be ALISSA (Atmosphere par LIdar Sur SAliut), in the frame of the Franco-Soviet cooperation to be carried inside the space station MIR by 1992 and finally launched 1996. It would be a relative simple technology measuring the altitude of the top clouds.

« Le lidar spatial ALISSA embarqué sur la plateforme sovietique MIR », ML Chanin and A HAuchecorne, 1992.

[644] The other two main instruments of the satellite BEST would be a radar to measure rainfall and a radiometer in the domain of hyperfrequences. Some other instruments were in the list of optional measurements, including a infrared radiometer to compute Earth's radiation budget (ScaRaB-type).

« BEST. Bilan energetique du système tropical. Objectifs scientifiques et définition préliminaire d'une mission spatiale dans le-cadre des Programmes GEWEX et Geospère-Biosphère », elaborated by managers at CNES and scientists of LERTS, LOA, CRPE, LMD and SA, 1988. See also the techical specifications defined in 1989 : "BEST. Spécifications de mission», elaborated by managers at CNES and scientists of LERTS, LOA, CRPE, LMD and SA, 1988.

[645] « Rapport du Groupe de Revue BEST », February 1992. and « Comité Directeur de la Revue Charge Utile BEST», March 1992.

[646] A team in the Langley Research center would put the Lidar In-Space Technology Experiment (LITE) inside the Space Shuttle Discovery during a nine-days mission in 1994, measuring the Earth's cloud cover and track various kind of particles in the atmosphere. See for instance: "Scientific investigations planned for the lidar in-space technology experiment (LITE)", P.M. McCormick et al, 1993.

[647] Specifically inside a *minisatellite* of the family Proteus.

after a quarrel with the painter's family for copyright[648], was actually a component of a larger space observatory called the Afternoon-Train, or A-Train, associating different instrumental technologies to measure atmospheric properties, including the interactions between the clouds, the aerosols and the radiation, and planned to be into orbit by 2004. From an engineering perspective, the A-Train was a novel concept for satellite flight in which several satellites would fly in formation one after the other along the same orbital path separated only by some minutes, seconds sometimes, the first from the last giving the appearance of wagons of a train -the train would barrel across the equator each day at around 13:30h local time, giving the constellation its name. The idea aligned with the current architectonical trends of space engineering in the 1990s rejecting the spectaculars, and aligning with restricted budgets[649]: instead of building gigantic missions carrying 10 instruments, it was about launching a series of smaller satellites carrying one or two instruments each one and put together in the same orbit close enough for them to measure quasi in simultaneity the same region. In this way, missions were cheaper, technically simpler, the instruments were more autonomous, and so the organization of the program, and in the eventual failure of the satellite, the overall loss would be less dramatic. Because of flying behind the other separated only by some minutes, respective measurements could in that way be used in combination with each other *as if* gathered simultaneously, as long as data would be used to study phenomena occurring in larger time scales and, equally important, inasmuch as appropriate data sharing policies would be established between space agencies and scientific teams responsible of each instrument. The A-train would be initially composed by the satellite AQUA of NASA heading the train (which was still a huge satellite of the first generation of environmental satellites, planned within the first version of NASA's Earth Observation program), CALIPSO of NASA/CNES and Cloudsat of NASA/CSA, carrying 10 instruments in total measuring the same region with different wavelengths, wide swath, instrumental principles, and providing different types of measurements and data. With time it would be expanded with more satellites, including PARASOL, summing up to more than 15 different instruments flying together in some periods[650]. In particular, PARASOL would fly after CALIPSO separated from it by around 1 minute;

[648] Personal communication, Jean-Louis Fellous, Executive Director of COSPAR (Committee on Space Research), 2012. At CNES, he was the program manager of Topex/Poseidon and Director of programs of Earth Observation until 2001.

[649] This engineering shift, which was accompanied by changes in management procedures, has been historically described by: "Faster, better, cheaper: Low-Cost Innovation in the U.S. Space Program", H.E. *McCurdy, 2001.*

[650] At the front of the train, Aqua carried six instruments that produced measurements of temperature, water vapor, and rainfall, including MODIS and CERES. It was launched in 2002.

Next in line, launched in 2006, CloudSat, a cooperative effort between NASA and the Canadian Space Agency carrying a cloud profiling radar and running 1 minute behind AQUA, and CALIPSO, a joint effort of CNES and NASA, carrying a lidar that offers three-dimensional views of clouds and aerosols, a Wide field camera and an Imaging Infrared Radiometer, and running around 12 seconds behind CLOUDSAT.

PARASOL followed barely 1 minute after CALIPSO, carrying POLDER-3.

The caboose, Aura, was launched in 2004 and laged AQUA by 15 minutes. It carried a suite of instruments that produced high-resolution vertical maps of greenhouse gases, among many other atmospheric constituents, including the Ozone Monitoring Instrument (OMI).

In the following years, the A-Train was to be enlarged with two more satellites, which failed to reach the orbit: OCO, launched in 2009 to measure the concentration of CO2 in the atmosphere (OCO-2 is planned for launching this year 2014) and Glory that would have collected data on the chemical, micro-physical and optical properties of sulfate and other aerosols failed to put in orbit in 2011. In 2012, JAXA launched the first of its satellites Shizuku or Global specific provisions were needed for the responsibles of the lidar CALIOP at NASA and the radiometer POLDER-3 at CNES to share each other's measurements.

PARASOL's scientific objectives would be hence to characterize the clouds and aerosols radiative and microphysical properties using the data complementarity from the different sensors on board the different satellites of the A-Train, particularly of the lidar CALIOP. Unlike POLDER-1 and 2, POLDER-3 was a mission devoted to atmospheric studies –after all, oceanic or land surfaces studies did not gain much additional bonus of being combined with the lidar's ability to discriminate altitudes, given the fact that the layer of importance for these studies was the surface and its closest interfaces with the atmosphere. However, after the failure of ADEOS-II launched in 2003, and because there were no plans for launching in the near future more instruments measuring the color of the sea waters with polarized radiances, it would be agreed that PARASOL's data would be used as well for ocean biochemical studies. In practice, this meant that the inversion software for retrieving biological data would be also integrated in the computing system of PARASOL[651]. Let it be said, though, that PARASOL's data would barely be used for that purpose. If we look at the list of publications available at the website of the datacenter ICARE and of the CNES, only the 8,5% of studies using PARASOL's data were devoted to themes related with the ocean color and the biochemical properties of the ocean waters (while the percentage is of 52,5% for studies dealing with tropospheric aerosols and 34% with clouds and radiation budget; the rest are calibration publications, instrumental descriptions, generic accounts or studies about the land surfaces properties)[652]. On the one hand, POLDER-3 had been modified with respects to POLDER 1 and 2 in terms of observing frequencies and polarization filters to optimize the atmospheric measurements, and not the surface or oceanic ones. On the other hand, with the launching of Sea-Viewing Wide Field-of-View Sensor (SeaWiFS in 1997), MODIS in 1999 and MEdium Resolution Imaging Spectrometer (MERIS in 2002), but also Aquarius or VIIRS, the concurrent line of measurements achieved a peak attracting a critical mass of scientists. As a result, the set of methods for interpreting ocean biologic and chemical properties promoted by the Goddard Space Flight Center using André Morel's theoretical and empirical results would be normalized amongst the community, producing the effect of practically dismissing any alternative methodology and technique for such studies, including inversions developed for interpreting POLDER's polarized light.

From a technical point of view, the sensing principles of POLDER-3 were identical to those of POLDER-1 and 2: a digital staring camera (274x242 pixels CCD detection array), wide field-of-view telecentric optics (± 51º cross-track and ± 43º along-track) and a rotating wheel carrying spectral and

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Change Observation Mission (GCOM, the successor of the ADEOS program) to observe the water cycle with an Advanced Microwave Scanning Radiometer 2, that was placed 4 minutes before AQUA.

[651] « Constats et recommendations du Groupe de Revue Définition préliminaire PARASOL pour le Comité Directeur », prepared by Patrick Saunier, November 2003 .

[652] We have based this counting on a fusion of the lists of publications that can be found at the website of the mission POLDER maintained by CNES and at that maintained by the datacenter ICARE. Although both lists are incomplete –we have found ourselves peer-reviewed articles missing- its figures are indicative of the main tendencies: http://smsc.cnes.fr/POLDER/A_publications.htm and http://icare.univ-lille1.fr/drupal/publications

polarized filters. POLDER-3 had a mass of about 32 kg, a size of about 80 cm x 50 cm x 25 cm, a power consumption of about 50 W and the data rate was of 883 kbit/s at 12 bit quantization. Compared to POLDER-1 and 2, the telecentric optics array was turned 90° to favor multidirectional viewing over daily global coverage. Likewise, a new spectral band was added (1020 nm) to conduct observations for comparison with data acquired with the lidar. In total, thus, POLDER-3 had nine spectral channels, three of which are implemented with polarized filters (total of 15 channels, three channels are needed for each polarized band). Like for POLDER-1 and 2, there would be no calibration system on board PARASOL, but POLDER-3 relied on the vicarious techniques developed for POLDER-1 and 2, using in particular the sun's reflection from the ocean surface, clouds and desert areas as targets to validate inflight performance[653].

Conditions of approval

We have mentioned before that decision-making concerning scientific programming at CNES is characterized by the existence of the Comité de Programmes Scientifiques (CPS), an advisory group composed of scientists appointed by CNES, who evaluates the scientific and technical pertinence of proposals. To be realized, PARASOL must enter such established procedures for selecting missions, beginning with submitting a proposal to the advisory scientific group. This was done in January 1999 and by December of the same year decision would be taken to recommend the mission as priority from a set of six candidates, and engage a budget for its preliminary studies for an eventual launch, in a tough calendar, to join the A-Train by 2004.

Microsatellites Myriade: Technopush and data creators

Apart from the platforms used to launch the satellites of the program SPOT that could carry some instruments as passengers (or that could be used for some missions, like ERS) during 1980s and 1990s, CNES had no satellites of its own. Either the payloads were designed to be placed aboard foreign platforms, which rendered their launchings dependent on the calls for opportunities released by other agencies (like POLDER aboard of ADEOS-I and II), or a specific satellite platform must be designed for every given project, which increased costs and time of development (like BEST). This would change by the mid-1990s, when CNES would start developing two families of satellites, the “minisatellites” Proteus and the “microsatellites” Myriade.

The prefixes mini and micro would refer to the low mass, size, power consumption, cost and time of development of the satellites, a technological choice that would align with the tendency of architectural design of space scientific missions shifting from the gigantic platforms characteristic of the 1980s towards smaller, lighter and more affordable ones, a tendency started to be mainstream at

[653] “Rapport du groupe de Revue d’Etudes Préliminaires”, prepared by J.M. Martinuzzi, February 2001.

NASA by the late 1980s with the doctrine known as “faster, better and cheaper” adopted in 1990[654]. The overall rationale underlying this development at NASA was to cut costs and time of development by fabricating simpler satellites from a technical point of view, while maintaining reliability and performance of the space missions[655]. The primary route to simplicity would be, according to such doctrine, size reduction, a development made possible by micro-electronics advances in miniaturizing the components as a means of reducing mass: lighter satellites cost less to launch (cost of launching is often given in dollars/euros per kg) -if they are mass produced, they cost also less to construct. And they have the advantage of being realized quickly and cheaply, providing a rapid response to demands and allowing bigger allowance for engaging risky missions, because losses are less dramatic in terms of budget, efforts, time. The precept underlying this approach was that, while acknowledging that because being simpler they may have less capabilities than larger and more complex devices and therefore big architectural missions would remain necessary in some cases, small satellites may nevertheless deliver excellent results for a set of given limited tasks[656].

These very same arguments were brought forward by CNES managers defending the development of microsats and minisats. In its strategic plan issued in 1999, for instance, it would be clearly stipulated that NASA’s doctrine had inspired CNES’s organization and programming, in particular to the development of the family of microsatellites[657]:

> « Les systèmes spatiaux de 2010 connaîtront des mutations profondes par rapport à ceux d'aujourd'hui, à la fois par leur conception, leur architecture, leurs modes de fonctionnement et leurs capacités. Ils sont l'aboutissement réussi des approches "better, faster, cheaper" entreprises aux États-Unis dans les années 1990 et qui ont notamment conduit le CNES à développer et mettre en œuvre les microsatellites »[658].

And that

> « Satisfaire, à moyens égaux, les besoins toujours croissants de la communauté scientifique en matière d'expériences, passe par le développement de filières de plates-formes (cadence de "production" plus élevée donc coût unitaire dont ressources internes nécessaires-réduit) et par le management de mission en " design to cost ". Ce sont les principes retenus au CST [Technical Center of CNES in Toulouse]

[654] The minisatellites of the family Proteus would weigh less than 500 kg and the microsatellites of the family Myriade less than 100kg. These figures are more talkative when compared to the 3,5 tons of ADEOS-I and II, for instance.

“PARASOL, a Microsatellite in the A-Train for Earth Atmospheric Observations”, A. Lifermann et al, 2005.

[655] Rocket engineers had sought to reduce the costs before by, for instance, mass-producing common components, such as the data recorders that all spacecraft carry or by re-using hardware. This latter strategy was, for instance, the original rationale behind the Shuttle: to use the same spacecraft for different missions.

[656] See « Faster, better, cheaper », H.E. McCurdy, 2001.

[657] Actually, CNES had already been working with small satellites purchased to the University of Surrey in the UK, which had been developing, and commercializing, these miniaturized technologies since 1979. In France, CNES had launched, for instance, the satellite S80/T in 1992 carrying experimental transponders for tests of mobile communications and location-finding, or the satellites CERISE and CLEMENTINE of the Ministery of Defense launched in 1995 and 1999 respectively.

« Myriade : Note d’organisation du projet Myriade. Ligne de produit microsatellite », prepared by C. Bouzat, head of Microsatellite Division at CNES, February 2001 and « Myriade. Données sur le positionnement de la filière et réflexions sur les voies d’évolution », prepared by B.Tatry, June 2002.

[658] « Plan stratégique du CNES 2001-2005. Tome 1 », edited by the Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001.

sur les filières minisatellites (une mission tous les deux ans) et microsatellites (deux missions par an) »[659].

The microsatellites Myriade would be, within this strategy, often also called as "filière "low-cost" pour la science et la technologie"[660], as defined in a presentation made by the project manager of the Myriade family in 1999, characterized by their small weight (100-120kg), small size (0,6x0,6x0,8m3), low cost (10MEuros by 1998, although increasing up to 35MF by 2001, without counting the launching, the payload and the operations once in orbit). It was not only about constructing small, light and simple satellites, but constructing them in mass-production: it was estimated, for instance, that microsatellites would be constructed with the goal of having platforms on-the-shelves ready to be launched at a rate of twice per year. The whole rationale was to render the access to space autonomous through the development of technologically, budgetary and organizational affordable spacecraft. What is more important in our story, they were characterized by a relative short lifetime of operations from 1 to 2 years, maximum 3 –we will insist in that aspect later on. Also important to our story is that the satellites Myriade were integrated in a programmatic commitment privileging the use of satellites for experimental scientific missions. Indeed, the availability of microsats would accelerate the time of development of a mission, increasing the options to scientists to embark their payloads with more celerity and flexibility –and taking major technological risks in the launches and therefore promoting missions that otherwise would be discarded. Another argument came into light: the availability of microsats would allow to create opportunities for international cooperation opening calls for embark foreign payloads in the Myriade satellites –just like other major space agencies, like the Japanese or the European, were capable to do[661]. Last, but by no means least, industrial considerations were also in the game, as important partnerships between CNES and industrial corporations had been settled to construct that endeavor: a partnership with a consortium of industrials Astrium, ASPI and Alcatel Space, to whom CNES had already ordered 16 prototypes, had been endorsed in 1997[662].

In a sense, this would be a somehow disturbing development: by 1997 sixteen prototypes of microsatellites had been already ordered to the industrials to be used preferentially for scientific programs, but there was nothing to put inside them. So strong was the emphasis on the development of microsats (and minisats) that we might think of it as a case of technology-push, that is to say, the availability of technology taking precedence over the user's demands, in our case the scientific community. We must not nevertheless stigmatize such effects of techno-push by systematically opposing them to the interests and ends of the entire scientific community. Arguably, the development of the two families of satellites (Proteus and Myriade) had been motivated, at least in certain degree,

[659] « Plan Stratégique 2001-2005 du CNES. Tome 2 », edited by the Direction de la Stratégie, de la Qualité et de l'Évaluation of CNES, 2001.

[660] « Etat avancement programme microsatellite », Point Clé Microsat, 1999.

[661] For technical descriptions of the satellites see : « Microsat », presentation by P.L. Contreras in the "Séminaire de Politique Technique », organized by the Direction de Programmes, March 1998 and « MYRIADE: CNES Micro-Satellite Program » , presented by M.H. Thoby of the Microsatellite Division of CNES in the 15th USU Annual Conference on Small Satellites, 1999.

[662] "CNES Myriade Program", presentation of C. Bouzat, head of Microsatellite Division at CNES, 1998.

by the will to give momentum to the R+D program of the Technical Center of CNES in Toulouse, to foster the industry and to align with the technological developments taking place at NASA (and major space agencies), and not stemming from a demand of the scientific community. But, procedures left aside, the scientific community –or at least a part of it- would certainly benefit of the outcomes of this technopush. This can be seen by the number of projects that the eventual users of microsats would send proposing different experiments to be conducted inside satellites of the family Myriad. In April 1997, CNES would release a call for ideas "Missions spatiales sur micro-satellites » addressed to scientific and industrial communities to request proposals of payloads to be eventually carried inside the future 16 microsats. More than 65 responses with 87 experiments would be received barely two months later from about 60 scientific laboratories and industrial teams. This was the higher number of proposals ever received. In particular, 12% of which were related to a domain of the Earth sciences, that is to say, around 10 proposals would come from Earth scientists from around 7 different laboratories. This was not a spectacular figure if compared to the 35% of experiments proposed by internal laboratories of the Technical Center of CNES in Toulouse or the also 35% proposed in the domain of the traditional space sciences[663]. But it is, we believe, impressive enough if we recall that by the early 1980s CNES and the Japanese space agency had troubles to find any instrument to spark their collaboration because no instruments existed (see the conditions of approval of POLDER-1 aboard ADEOS). Another figure to recall is that there were 11 selected laboratories by 1980, from which 4 dealing with some domain or other of the Earth sciences (see chapter one) –by 1997, the number of laboratories capable to propose an experiment had increased, at least, to 7. In our views, this augmentation can be interpreted as an indicator of the path towards *normalizing* the vision of the disciplines of the Earth sciences as a particular form of space sciences, customary paved during the previous decade by the missions Topex/Poseidon, ScaRaB or POLDER.

That scientists, at least some of them, celebrated the technological move can also be seen by looking at the minutes of the meetings of the advisory scientific committee of CNES, the Comité de Programmes Scientifiques. For instance, in one of their meetings in 1998 they would assess:

> "Les programmes de mini-satellites et de micro-satellites, à coûts réduits et à délais de réalisation rapprochés, décidés par le CNES, ont suscité au sein de la communauté scientifique l'espoir de voir ses priorités rapidement prises en compte. Le Comité estime qu'il est important de lui permettre de se maintenir à un niveau scientifique élevé et compétitif au plan international. C'est pourquoi il recommande au CNES de mettre en place les moyens humains et budgétaires nécessaires à la réalisation d'une mission sur mini-satellite tous les 18 mois et de 2 micro-satellites par an »[664].

They celebrated the move because, so it was argued, microsats enabled access to space in a reduced delay and budget and therefore maintaining a competitive scientific excellence at the international stage. Amongst the scientists, those experts in building instruments and developing retrieval

[663] « Dépouillement de l'appel à idées « Missions spatiales sur Microsatellites» », prepared by F. Buisson, June 1997.

[664] « Compte Rendu du Comité des Programmes Scientifiques », prepared by I. Sadourny, March 1998.

algorithms from the measurements were particularly happy. With two satellites per year, they would increase chances to see their experiment launched[665].

The pursuit of the Myriade family of microsatellites, and of the Proteus one of minisatellites, would be formally endorsed during the 5th scientific meeting organized under the aegis of CNES in Arcachon the same year 1998, in which their development would receive formal support from the scientific community gathered in that meeting –the Conseil d'Administration of CNES hold in December 1998 would then give the definitive green light for engaging their material realization[666].

Geophysical data and Climatic data

As we have mentioned, the Myriade family of satellites was characterized by a relative life span of 1 or 2 (maximum 3) years in orbit and by a programmatic commitment of CNES towards using them for experimental missions, but not to launch recurrent instruments[667]. This frame conditioned a particular form of data gathering based on the production of data during a short period of time with a different instrumental concept at each launching. This form of data-gathering was useful to test new instruments, sensing concepts, gather data samples to improve correction algorithms, to test new inversion methods or to study local short-time processes occurring in nature –the production of *geophysical datasets*. By contrast, this form of data-gathering was not useful for producing *climatic datasets*, that is to say, series of homogeneous global data during long-periods of time. First, the point of long-term studies, or climate studies, was to detect and identify with statistical significance interseasonal environmental variability and interannual or interdecadal tendencies. For that, as banal as it may sound, data must be collected in a continuous manner at least during 10 years. The shutting off of the microsatellites after 1 to 2 years of functioning was not compatible with this requirement. PARASOL, for instance, was not designed to support studies of the long-term trends in the aerosols cycle or in the Earth's radiation budget; what kind of long-term variability could it be detected with 1 or 2 years of life? A satellite lasting 10 years was, let it be said, an utopic panacea; as illustrated by the fact that insurances and operators did not take the risk and typically engage as to cover from 3 to 5 years of functioning at the most. This is connected to the second reason: acknowledging that satellites are not built to last long periods of time, the climatic approach pleaded for the launching of identical successive technologies or at least similar enough to enable the continuity of the measurements between consecutive satellites. The mandate of the family Myriade, however, privileged the launching of new experimental concepts and not recurrent instruments. To these scientists willing to produce climatic data, one single shot short-lived satellite was only useful as long as the data they gathered

[665] To give a comparative figure, in the decade of the 1990s, satellites in the telecommunications domain had been launched at a rate of 20 to 25 per year, in particular they represent the 80% of the launches made by Arianespace. "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

[666] « Etat avancement programme microsatellite », Point Clé Microsat, 1999.

[667] « Microsat », presentation by P.L. Contreras in the "Séminaire de Politique Technique », organized by the Direction de Programmes, March 1998.

could be integrated in a larger corpus of data, for instance, by filling gaps in the long-data records (like ScaRaB designed to take measurements during a period in which NASA's radiometers were absent) or by providing complementary variables describing a particular event important in the environmental larger trend (like El Niño or intense volcanic eruptions). In these cases, "certains jeux de données, en dépit d'une couverture spatio-temporelle limitée peuvent apparaître comme potentiellement intégrables à un corpus plus étendu »[668]. We will further develop these issues of the perpetuity of the measurements and the climatic approach in chapter six.

There is also one aspect not to be neglected in this debate about the perpetuation of the measurements, which we have already pointed before in our essay –and to which we will insist once more in chapter six: space agencies are mandated for research and development and not for ensuring the operations and exploitation of their technologies. Ideally other organizations must take over the responsibility of operating the satellites in a recurrent and continuous manner and to provide the services. Nonetheless, actors are well-aware that, and many scholars have demonstrated, this transfer is far from being smooth[669]. In this case, the research and development impetus given through the realization of the Myriade family of microsatellites at CNES, had the effect of orienting the scientific program related to Earth sciences to those studies of Explorer-type in detriment of those of Sentinel-type, to the production of *geophysical data* instead to the production of *climatic data*, which aligned with the renewed international agenda for environmental surveillance and monitoring. We propose, and with that we close the section, to look at the dilemma by posing in terms of the *data-classes* categories that we have introduced. The concept Myriad was welcomed by those scientists, the *data creators,* with a culture of instrument builders, experts in calibration or developers of inversion algorithms to retrieve more and new geophysical parameters from the measurements. Myriade was a tool privileging single shot launchings increasing in so doing the options for launching new instrumental capabilities, to demonstrate new calibration techniques, to study new correction methods, to test inversion algorithms with data samples and to use the resulting geophysical data to study a given local and time-limited observed natural phenomena or to characterize the state of the observed system during the corresponding period of time. This was the job of what we have called a *data creator* producing *geophysical datasets*. While favoring the study of some processes and the study of remote-sensing techniques, these microsats, including PARASOL, would prevent other type of studies. Those scientists interested in some features of the atmospheric physics of climatological nature, that is to say, requiring long-term datarecords would not reap much benefit from this engineering tool. The concept Myriade did not support, a priori, the production of *climatic data* to study patterns about the influence of the North Atlantic oscillation on the desertic aerosols cycle or in studying the effects of the size of the liquid water droplets on the Earth radiation budget. Conceptually, the issue was parallel to that

[668] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », report elaborated by a CNES-CNRS committee and issued in 1999 -we will further analyze it in chapter five.

[669] See the cases of Landsat "Viewing the Earth: The Social Construction of the Landsat Satellite System", P.E. Mack, 1990 and Meteosat "Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite", J. Krige, 2000.

illustrated by Pierre Morel's expression in 1985, quoted in the introduction to the first part of the essay and referring to NASA's program Earth Observing System, qualifying these missions of "interesting technological exercises", but to be avoided from a climatological perspective[670].

In other words, this was a tool for *geophysical data creators;* distant from the instrument and from the development of algorithms, *data users* interested in the climatic approach could only made sense of the gathered-data if they could be eventually integrated in a larger corpus of measurements –let it be said, that other *data users* interested in the geophysical approach would reap full benefit of this program. In other words, by committing to the Myriade family of microsatellites (and minisatellites Proteus) as the spacecraft inside which scientific payloads were to be carried, the programming strategy of CNES with regards the missions in the domain of Earth sciences, would reinforce the epistemologies, social organization and the technological system of data handling described in the previous chapters, characterized by a dominant role of the figure of *data creators* in the processes of conceiving the instrument, preparing the data analysis prior to the launching, checking the quality of the data after the launch, framing the scientific questions to be addressed with the data –which were *geophysical datasets*. In this sense, it is plausible to say that the development of the Myriade by 1998 reflected that this mode had become the *norm* for conducting missions in the domain of Earth sciences of national scope at CNES.

Selecting a payload for a microsatellite: "Quasi-recurrent stable instrument" or new risky technologies

From the more than 80 proposals received by 1997, the Comité des programmes scientifiques (CPS) would retain around 25 for discussion during the scientific meeting in Arcachon in 1998[671]. CNES had announced that it could engage the preliminary studies of a maximum of five of such missions, with a perspective of choosing, at the end of the year, two of them for being launched by 2001/2002. The following year, in 1999, a second round of selection would be engaged picking two more missions from a number of five previously pre-selected, to be launched by 2003, and so successively as to maintain a rate of two launches of microsatellites per year from 2001/2002 onwards. In the first meeting of the CPS after Arcachon, the members of the committee would assess the proposals and would recommend their priorities for initiate studies on the five following instruments[672]: DEMETER (electromagnetic sensors and particle detectors for studies about the connection between seismic and volcanic activity and ionospheric perturbation), DORIS (orbitography and positioning system for

[670] Here is part of the quote (see the introduction to the first part for the complete account) : « La mission EOS et ses semblables peuvent constituer des exercices technologiques utiles : il convient d'en juger l'efficacité au vu des ressources qu'elles laisseraient disponibles pour une véritable investigation scientifique », quoted in « Perspectives spatiales dans le domaine des recherches sur le climat », Pierre Morel, Séminaires de Prospective scientifique du CNES, 1985, Deauville.

[671] « Compte Rendu du Comité des Programmes Scientifiques », prepared by I. Sadourny, March 1998.

[672] « Compte Rendu du Comité des Programmes Scientifiques », prepared by I. Sadourny, March 1998.

studies about the Earth's crust, the reference system and the rotation), MICROSCOPE (accelerometers to test the equivalence principle between the inertial and the gravitational masses with an accuracy of 10^{-15}), ORAGES (climatologies of storms in intertropical regions) and SAPHIR (microwave sounder for studies of the daily cycle of humidity distribution in the lower atmosphere and its influence in tropical convection). Finally, DEMETER and the latterly proposed PICARD (telescope, radiometers and sun photometers to study the solar activity and its effects on Earth's climate)[673] would be chosen as the first priority to inaugurate the first round of microsats by 2001/2002 –DEMETER would be finally launched in June 2004 and PICARD in 2010, with the delays partially due to shutdowns and stagnation of the general activity concerning the scientific programming at CNES in 2002 and 2003, a point to which we will come back in a while.

In January 1999, after the meeting in the Alps, a group of scientists head by Didier Tanré of the Laboratoire d'Optique Atmosphérique would propose the microsatellite PARASOL to be assessed by the Comité de Programmes Scientifiques as a candidate for the second round of missions Microsat. PARASOL would rapidly become one of the priorities for the Comité des Programmes Sscientifiques, together with two projects reminiscent of the previous round (DORIS and MICROSCOPE) and three new proposals (Oeil gamma, TARANIS with a set of particles detectors to study the magnetosphere-ionosphere-atmosphere coupling through detection of lightnings and sprites, and "Roue interferometrique" radar consisting in a set of three microsatellites to listen the signals emited by a radar). During the following months, complementary preliminary studies of all these missions would be provided to CPS by the technical departments of the Technical Center in Toulouse and the respective laboratories responsible of the payloads and of the scientific project. By December 1999, the two satellites conforming the second round of microsats must be selected.

At this point we shall make a break in our account to talk launches and rocketry. Manufacturing the instrument or payload (say a radiometer measuring polarized light) and the spacecraft (say a microsatellite Myriade) constitutes only a component of a space mission. A vehicle to convey the satellite into its orbit, and a launching port, are obviously also needed. The satellite and the launcher must be technically compatible in terms of mass, volume, electronics or thermics, and the launcher must be able to fly up close to the final orbit of the satellite –and all this at an affordable price that the scientific community, or rather the CNES's budget for scientific missions, may be able or willing to pay. Finding launch opportunities compatible with the budgets of the scientific missions generally is far from straightforward, in spite of the attempts of rocketry engineers to reduce the launching costs. For instance, a procedure of multiple launchings had been put in the market to launch several satellites at the same time, instead of single launches, with the condition that they agree to be put in similar orbits, if not the same, and therefore issues about transmission frequencies, eventual interferences, operations control, tracking or reception of the signal, but also launching day, to mention few, must be arranged amongst the responsibles of each satellite. By the year 1999, the Russian rocket Dnepr, for

[673] « Myriade : Note d'organisation du projet Myriade. Ligne de produit microsatellite », prepared by C. Bouzat, head of the Division of Microsatellites at the Technical Center of Toulouse, February 2001.

instance, would offer multiple launches capacities at a competitive price of 1,5 million dollars per kg (against an average of 15millions per kg offered by a single launch). Another way of reducing costs of launching would be the so-called piggy-back mode ("passager auxiliaire" in French) allowing carrying small satellites as passengers of a main satellite. In this mode, the main client must agree in piggybacking passenger satellites, which must conform the launching date, the orbital characteristics, the frequencies of data transmission, and sometimes even the sensing technological features, imposed by the main satellite. This concept would be developed, for instance, by the European rocket Ariane in the 1980s and initiated with flights of Ariane-IV, which incorporated a structure allowing launching up to six auxiliary satellites per flight. For instance, by 1999 Ariane-IV would offer carrying microsats aboard of commercial telecommunications launches to be put in near-geostationnary orbits for 1million dollars (a satellite of 100kg) and 3 millions dollars (a microsatellite of 200 kg). Specific structures adapted to the new launcher Ariane-V would also be developed capable to accommodate up to eight microsatellites of 100 kg per launching[674].

Initially, then, Ariane-V was meant to be the natural launcher of the microsats of the family Myriade. In fact, these microsats would be actually designed as per fitting the technical requirements to be accommodated in this auxiliary structure of the new European rocket. However, the main clients of Ariane-V would be telecommunications companies[675], which used to launch their satellites in geostationary orbits at around 36000km, which were of little interest for most of the scientific missions requiring polar sun-synchronous orbits between 700 and 900km. Only in rare occasions, Ariane-V would have clients willing to fly to such altitudes[676]. By 1999, the Direction Générale de l'Armement announced the launch of its reconnaissance satellite Helios-2 aboard of Ariane-V by 2003. It would piggyback four military microsats ESSAIM for signals intelligence and a nanosat built by the Spanish space agency for experimental telecommunications with polar regions. The whole would be transported to an exceptional low orbit of around 700km compatible with several scientific missions. There was still a free sit in the ride for a 200kg-satellite, an opportunity for a piggy-back launch not to be missed by the managers of the scientific program of CNES.

If we have introduced these paragraphs is to remark that compatibility with the launch of Helios-2 (in altitude, orbital position, timing, mass, signal operations and cost) would become an important criteria for choosing the missions for the second round of launches at the end of 1999. Without entering into the details, the missions selected for the second round of launching of the Myriade series would be MICROSCOPE and PARASOL[677]. These were two missions of very different nature, not only

[674] Figures are taken from the article "ASAP 5 , des passagers auxiliaires sur Ariane 5" by P. Balaam, published in the special issue of CNES-MAG dedicated to microsats in the year 2000 : http://www.cnes-multimedia.fr/cnes_fr/cnesmag/cnesmag9_FR_dossier.pdf

[675] "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

[676] "Myriade. Données sur le positionnement de la filière et réflexions sur les voies d'évolution », prepared by B. Tatry, June 2002.

[677] Without entering into many details about the selection process, which would deserve an entire work by its own, let us just briefly write down some words in order to provide an insight about the reasoning dynamics and logics.

regarding the scientific field that they were deemed to support (fundamental physics and atmospheric sciences), but also in the mission concept. MICROSCOPE constituted an original and innovative experiment proposed by the Office National d'Etudes et de Recherches Aérospatiales (ONERA); challenging from a technological standpoint and therefore interesting to CNES's technical departments. After all, "se concentrer sur les projets à risques au détriment des projets à caractère récurrent »[678] was what Microsat was about, namely taking risks and launching new technologies. The expected costs of this experiment slightly exceeded the budget of a payload for a microsat program (it was planned to cost 17,7MEuros, face to the 15MEuros planned for Myriade scientific payloads[679]), but CNES was ready to assume the overcosts. A weakness that would be pointed was that, beyond the handful of scientists of ONERA preparing the experiment, the scientific communities eventually interested in such data had not been identified or organized, both at a national and international level; there was still a lot of work to do to gather a larger community and prepare the use of the data[680]. PARASOL, by contrast, was an instrument leveraging on the expertise and scientific teams involved in POLDER-1 and 2, and complemented with the international collaboration of NASA's CALIOP (and to a lesser extent CLOUDSAT and other A-Train satellites) scientific teams. The laboratories potentially interested in the data were well identified as, at least, those participating in the "pole atmosphère" of POLDER-1 and 2, namely, the Laboratoire d'Optique Atmosphérique, the Laboratoire des Sciences du Climat et de l'Environnement and the Laboratoire de Météorologie Dynamique. Besides, because of being coupled with a lidar, scientists of the Service d'Aéronomie were interested in the data. Its calibration, data validation methods, uncertainties or data interpretation possibilities, and scientific interest had already been demonstrated. Its cost and time needed for development were also known, as it had been built before -actually POLDER-3 would use some of the spare components of its precedents, which would contribute to save some money (it was budgeted at 13,3MEuros[681]).

Both missions would be selected as flying by 2003 in the second round of microsats. It was about choosing which one would piggyback Helios-2 and ensure the flight, and which one would have to keep looking for other options for launch. The members of the scientific advisory committee of CNES were caught on the dilemma between privileging a new original, and therefore risky in technological and budgetary terms, and also calendar ones, mission in consistence with the precepts for developing the family of microsats Myriade, or to play safe and chose "un instrument quasi recurrent » like

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Actually, the proponents of Oeil gamma would retire their proposal further to a change of scientific priorities of their laboratories. The project of a Roue Interferometrique was considered to largely exceed the budget for a microsat program and was actually derived to be studied in the frame of the program of high-resolution imagery Pleiades which had its own budget. As per DORIS, there were already three other DORIS planned to launch before 2003 and it was not certain of the scientific interest of a fourth one. In addition, it was not clear either about the final DORIS's data availability, given the fact that it would fly close to Helios-2 and that the military services may not agree in openly diffusing highly precise data on localization and positioning.

« Recommandations du Comité des Programmes Scientifiques du CNES », October 1999.

[678] "Etat avancement programme microsatellite », Point Clé Microsat, 1999.

[679] « Contrat pluriannuel État-CNES 2002-2005 », edited by CNES, 2002.

[680] « Recommandations du Comité des Programmes Scientifiques du CNES », October1999.

[681] « Contrat pluriannuel État-CNES 2002-2005 », edited by CNES, 2002.

PARASOL's, as it had been named in several meetings and presentations[682], whose budget was more certain and whose technological performances and scientific interest had already been demonstrated. The tough calendar for a launch scheduled by 2003 resulted in less than two years for gathering a team, and engaging development, realization, integration and test. Through this prism, POLDER-3 was better placed than MICROSCOPE, as it benefited from previous expertise and inherited not only some material components and human skills but also the technical and management teams at CNES, and an already established work-dynamics between CNES's managers and the POLDER's community[683]. However, and this played in favor of MICROSCOPE, the whole interest of PARASOL was to fly simultaneously with the satellite CALIPSO, which would be launched in 2004 with a lifetime of 2 years. In other words, launching PARASOL by 2003, considering that the satellite had a lifespan of 1 to 2 years, would reduce the time of flight in simultaneity with NASA's satellite and therefore its scientific raison-d'être[684]. When DGA announced in 2001 that the launch of Helios-2 would be delayed to the end of 2004, the advisory scientific committee, CNES and the Direction Générale de l'Armement would come to terms: PARASOL would piggyback Helios-2[685].

The military chance or how to survive to a shutdown

In March 2002, the Direction des programmes of CNES would announce the cancellation of all the projects not officially engaged as well as the delay and stagnation of some of the projects in course of being developed, including several of the scientific missions to be put inside micro and minisatellites, like for instance MICROSCOPE. Important debts and an overload in the programming would oblige to stop expenditures at CNES and « tant que la remise en ordre de la gestion des projets n'a pas été réalisée, il y aura limitation des ressources nouvelles, tant du point de vue financier que du point de vue humain »[686].

Reactions of certain scientists and CNES's managers to such cancellations and stagnations would be actually quite hostile. We have found a number of letters, notes and circulars written by individuals openly criticizing the shutdown decision, especially coming from scientists and managers related to missions in the domain of traditional space sciences such as astronomy, solar physics and fundamental physics. Stopping or cancelling a mission which was already in advanced stages of development and realization, they would argue, not only generated economic losses, technical non-profits and frustration amongst the scientific community, but also affected the credibility and reputation of CNES, as it violated the non-written code of conduct accepted by all space agencies and scientific teams

682 « Constats et recommendations du groupe de Revue pour le Comité Directeur », elaborated by Patrick Saunier chairing the Groupe Revue PARASOL, November 2003.

683 « Recommandations du Comité des Programmes Scientifiques du CNES », prepared by J. Barre, October 1999.

684 "Rapport du Groupe de Revue du complément de d'Exigences Préliminaires de la mission Parasol », June 2001.

685 « Rapport du groupe d'analyse Point Clé de définition de charge utile et AMT », November 2002 and « Recommandations du Comité des Programmes Scientifiques du CNES », November 2002.

686 "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

according to which one must have very good reasons to cancel missions that are already in phase C or D of realization (or in phase B when they are conducted in international cooperation). This situation projected, according to them, a poor image of "inefficacité de l'organisme qui engage des projets et ne les finit pas ; irresponsabilité d'avoir entraîné dans une impasse nos partenaires des laboratoires et des pays coopérants (que nous avons souvent nous-mêmes sollicités) ; perte de crédibilité pour ne pas respecter des accords signés et pour prendre les décisions unilatérales sans consultation et sans concertation préalables avec nos partenaires"[687]. Actually, this shutdown would be considered by certain sectors of the scientific community as the last straw of a series of scientific policies of CNES which were, since the late 1990s, having the effect of distancing the space agency from the scientific realities to the extent that it would be even attested that "CNES a perdu les moyens de sa propre stratégie scientifique"[688]. For instance, CNES continued to propose contracts on an annual basis, whereas progressively more and more current types of research would need longer timing to be conducted and/or maintained. This can be seen with the example of the instruments developed to be used on the ground or inside an aircraft. As we have seen in chapter four, CNES used to finance the development and realization of non-satellite instruments with the double goal of preparing the interpretation of the future satellite data and of validating the quality of the satellite after the launching. However, so the scientists argued, these instruments had the potential to be used in many other contexts independent of the space mission for which they were built. Yet, it was very difficult to get funds for using them in these contexts. This is how a physicist of the atmosphere at the Laboratoire de Météorologie Dynamique expert in the theory of turbulence, and that would become the scientific responsible of the future datacenter for atmospheric data established in Lille in 2003, puts it:

> « On arrive à se faire financer les travaux basés sur les vols des avions pour valider les données des satellites. Or, si on dit qu'on veut un avion par exemple pour collecter des données pour étudier une turbulence atmosphérique donnée, c'est beaucoup plus difficile! Le CNES est un grand financeur de la recherche en France, or il a une vocation spatiale et donc il finance surtout des recherches dans la mesure où ça permet de valider les données satellitales. C'est difficile de se faire financer au-delà de la calibration ou de la validation des données, pas impossible mais très difficile. Pour essayer d'obtenir de l'argent des agences spatiales pour faire voler des avions il faut utiliser le prétexte d'utiliser les données des avions pour valider les donneés satellitales. Par exemple, le CNES n'a aucun avion pour faire de la recherche, ce qui est déjà indicatif… Les avions sont bien moins coûteux que les satellites et sont des outils indispensables. Aux Etats-Unis par exemple l'essentiel de la flotte des avions est opérée par la NASA ; c'est vrai qu'il y a d'autres avions de la NOAA, par exemple, et en fait en France on a aussi un avion qui appartient à Meteo-France, mais le CNES n'a aucun avion »[689].

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[687] See for instance : "Raisons de principe qui militent contre l'arrêt d'un projet decidé et engagé en phase de réalisation », position paper elaborated by Alain de Leffe, vice-director of de Division of Etudes Systèmes et Développements in the Technical Center of Toulouse and circulated internally to CNES in April 2003 or an anonymous position paper circulate in September 2003 entitled « Une réorganisation à contre temps et à hauts risques ».

[688] "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

[689] Interview with Bernard Legras, LMD, 2012. Interesting enough, during our interviews in the US, we have been reported quite often about similar worries about the difficulties of developing field-work beyond satellite-related activities both at NASA and NOAA.

The point made by this scientist is that it is difficult to get funds for using the aircraft instruments developed under funding of CNES other than for calibration or validation of the satellite data. Apart from that, funds are rarely given to maintain the instruments or to use them in endowed field campaigns when there is not satellite whose data needs validation. Note, by the way, that these words can also be interpreted as indicating to what extent the practices of calibration and validation the satellite data through field-work, before and after the launching, that is to say, the notion of a holistic space mission discussed in chapter four, was impregnated into CNES programming in support of Earth sciences. Along these very same lines, some other scientists would point similar issues about the utilization of the data. The studies about data validation (that we have described in chapter four) outnumbered all other studies and lead to "aberrant" situations, as denounced by the following climate modeler also working at the Laboratoire de Météorologie Dynamique and member for some years of the scientific advisory body of CNES, the Comité des Programmes Scientifiques:

> "C'est terrible de faire voler un avion pour calibrer pour la 50ème fois un instrument au lieu d'investir dans l'exploitation des données ou des instruments… Pour eux [space agencies], exploiter les données c'est la comparaison du produit PARASOL avec celui du MODIS. Mais en quoi ça nous apporte de la connaissance sur la physique des nuages ? On comprend bien que ce n'est pas chez le CNES, la science, mais du coup les gens qui travaillent dans les labos n'ont plus d'intérêt en exploiter les données scientifiquement, ce qui est aberrant. Les gens s'adaptent au système et s'il y a de l'argent pour calibrer ou valider alors on va calibrer ou valider. Je ne veux pas dire que la calibration et la validation ne soient pas importantes, c'est nécessaire. Mais c'est de la recherche sur la télédétection, et non la recherche sur l'étude du climat. Du coup on s'amuse à améliorer toujours les données, mais on ne se pose pas la question de à quoi il sert finalement, qu'est-ce que cette calibration va apporter à ma recherche, d'utiliser leurs connaissances sur l'instrument pour approfondir nos connaissances sur le climat. Je crois en fait que ce n'est pas un problème français, mais assez général des agences spatiales, à l'ESA c'est pareil et à la NASA aussi, peut-être moins grave à la NASA parce qu'ils ont plus d'argent! »[690].

What is denounced by this scientist is a form of unbalance between the funds devoted to analysis for calibration and validation of the satellite geophysical datasets and those devoted for further stages of interpretation of these datasets. These two quotes illustrate, on the other hand, what had become the norm at CNES in regards of data gathering, production, dissemination and utilization, and that can be conceptualized in terms of *data-classes*: the ethos of *data creators* was considered as part of the ontology of a space mission, while that of *data user* was external to it –a social order archetypically illustrated with the experiment POLDER-1.

These two cases (the possibilities of using the ground-based and aircraft-based instruments and the satellite data for purposes other than for preparing the calibration or for assessing the quality of the satellite data) illustrate some of the debates emerging in the mid-1990s, when data from the first satellites started to be factually gathered, and opposing the ways in which the scientific community, more specifically the *data users*, and the space managers understood the space activities and the role of CNES with respects to its mandate of supporting scientific research. But there were more bones of contention between both communities and it was even said that « les stratégies respectives ont de plus

[690] Interview with Jean-Louis Dufresne, LMD, 2012.

en plus tendance à s'écarter", giving birth to a number of tensions[691]. For instance, CNES had polemically eliminated in 1998 the budgetary line "soutien aux laboratoires", which constituted the main source through which the laboratories maintained and updated their equipment, machines and facilities[692]. Laboratories would recurrently complain that scientists were often not consulted in decisions concerning big equipment taken by CNES (computers, telescopes, network stations, etc.). Perhaps more important, in some cases scientists would not be even consulted about the decisions affecting the scientific programing of CNES or ESA to the extent that the representatives of the advisory scientific committee of ESA were often space managers of CNES and not academic scientists. Also, the first generation of technical personnel specialized in space instruments was in the course of being retired, which was leaving the laboratories without technical and instrumental experts –and CNES (nor CNRS) seemed to make any move to replace them by recruiting new skilled workforce[693].

Back to the shutdown of activities by 2002, so few was the space-related scientific activity being carried out (both at the Technical Center of CNES but also in the laboratories in which the workforce recruited by CNES had interrupted their daily duties or scientists had no access to data), the advisory body would recommend to cancel the 6th scientific meeting that was supposed to take place in spring 2002 in Arles until the activities and the financial situation would be restablished, for a pertinent and consistent scientific programming to be defined[694]. More generally, the situation was perceived with so much anxiety by the public instances that the Ministeries in charge of space affairs (Défense and Recherche et Nouvelles Technologies) would commission a study, in October 2002, to an independent group chaired by professor Roger-Maurice Bonnet, COSPAR's president at that time and former Director of scientific programs at ESA, to evaluate CNES's situation and the perspectives of the French space policy, from a budgetary standpoint but also from a strategic one[695]. The conclusions could not be clearer: this crisis, according to the authors of the report, had emanated from an inappropriate programming choices leading to an overload of activities poorly managed from an administrative and financial standpoints. The president of CNES, Alain Bensoussan, would resign 10 days after the release of the report. Whether the points stressed in the report were more or less fair, does not concern us here. What interests us is that its recommendations would have direct effects on CNES's organization and scientific programming, both in content and in procedures. During 2002 and 2003, during the paralysis, the scientific projects planned or in course of being developed would be submitted to a number of audits, both internal and external, and they would be assessed with new management tools, for instance the so-called "atouts-attraits" analysis methodology, used to establish

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[691] "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française, January 2003.

[692] « Compte Rendu du Comité des Programmes Scientifiques », prepared by I. Sadourny, October 1998.

[693] "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française chaired by Roger-Maurice Bonnet, January 2003.

[694] "Recommandations du Comité des Programmes Scientifiques du CNES », November 2002.

[695] "Rapport de la Commission de Réflexion sur la Politique Spatiale Française », Commission de Réflexion sur la Politique Spatiale Française chaired by Roger-Maurice Bonnet, January 2003.

priorities between missions in a *rational* manner with views to define a renewed programming -a methodology which would be criticized by the scientific community, as it did not account for other essential factors in decidion-making, such as "excellence scientifique, rôle et équilibre des diverses communautés scientifiques, opportunité de découvertes, innovations méthodologiques et technologiques, prise de risques (notamment dans la filière microsatellites), complémentarité avec les missions programmées au niveau européen et international »[696]. In any case, by the restablishment of activities in May 2003, several of the scientific projects to be launched aboard of microsats and minisats would be delayed (MICROSCOPE, PICARD, COROT, MEGHA-TROPIQUES or projects connected to the International Space Station) or even cancelled (Mars, VAGSAT) because failing the "atouts-attraits" test[697].

In spite of such crisis PARASOL seemed to follow its course in an impressive fast and tough schedule for a launch by 2004 without receiving important cuts and savings. Just like the other scientific projects, it had been checked with the new "atouts-attraits" method obtaining quiet good results[698]. Certainly, PARASOL would be a relatively cheap and save satellite with not much technological new developments, as the instrument was the third of its family and the third of the microsatellites (note that, after the delay of PICARD, which would be severely affected by the shutdown, it would become the second Myriade). Cheap and save only tell a part of the story. Several discussions with scientists and space managers who were involved in the conception, development and realization of PARASOL or other projects, have provided insiders' perspectives that illuminate other parts of it. Some would stress that PARASOL had benefited from the renewed impetus that Earth sciences missions had acquired at CNES, and more generally at space agencies, which would privilege environmental missions before traditional space missions. If a choice must be made, non-environmental missions would have more chances to be rejected[699]. It was also suggested that if PARASOL was not launched by 2004, it would take more than four years between the first microsat launched (DEMETER in 2003) and the second one (PICARD or MICROSCOPE delayed, by then, to 2007), while the whole concept embedded in the family Myriade was to launch at a rate of two launches per year. Canceling PARASOL would take out the credibility of the whole microsatellite program[700]. Some others were convinced that questions of image and reputation were equally important in not blocking PARASOL. Albeit PARASOL was a French project it was nevertheless to be a part of the NASA's lead A-Train, as its main scientific goal was to get data simultaneously with the lidar CALIOP. A number of projects in common with the NASA's lidar's team at LaRC (and to lesser extent with the University of Colorado (PI of the satellite CLOUDSAT also flying in the A-Train)), had already been conducted and withdrawal roughly one year before the launching would have certainly damaged the credibility of

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[696] « Conclusions et recommandations du Comité des Programmes Scientifiques du CNES », April 2003.
[697] « Conclusions et recommandations du Comité des Programmes Scientifiques du CNES », April 2003.
[698] « Conclusions et recommandations du Comité des Programmes Scientifiques du CNES », April 2003.
[699] Interview with Jérôme Riedi, LOA, 2013.
[700] "Recommandations du Comité des Programmes Scientifiques du CNES », November 2002.

CNES before one of the most important partners, NASA[701]. On the other hand, from a scientific point of view, the launch of PARASOL would be argued to be more urgent than other launches, as its interest resided in the use in combination with another satellite that was planned to be launched in 2004; delays are always grim, but unlike other missions, a delay in PARASOL would entail simply losing its raison-d'être[702]. Finally, and this aspect would be probably a decisive one, we must not forget that PARASOL had been scheduled to be launched with Ariane-V as an auxiliary satellite to the launch carrying the military satellites Helios-2 and ESSAIM. This launch would take place as planned in 2004, with or without a crisis haunting CNES. Given the fact that there was in the launching of Helios-2 a ride-ticket reserved for PARASOL, it made little sense not to take it[703].

Conclusions: Normalization

On December 18th 2004 an Ariane-V launched from Kourou would transport PARASOL to an altitude of 700 km. After some manoeuvres it would be placed in the A-Train orbit at 705km following the satellite AQUA a little more than 2 minutes behind it. For more than one year, PARASOL would fly alone because the satellite CALIPSO would suffer some delays in its launch; during that time, consequently, PARASOL could not accomplish its original mission of combining data with the lidar. PARASOL had been planned, as all the microsatellites of the family Myriade, to be shut off after 1 or 2 years of functioning. Because when CALIPSO was launched in April 2006, around 1,5 years after the launching of PARASOL, PARASOL was still functioning, the advisory scientific committee would recommend the managers of CNES to continue the operations of PARASOL. After some months of discussions and "reviews", the mission was prolonged for at least two more years in order to meet the scientific goals of performing measurements of the polarized and multi-directional radiances on the same areas measured by the lidar. Being conceived as a mission of Myriade-type planned to operate during 1 to 2 years, PARASOL would end up by flying during 9 years -almost 8 of which in simultaneity with the lidar CALIPSO. This is a case of an experiment designed to combine measurements gathered with two different instruments, which becomes, by accident, appropriate for studied about atmospheric medium-term tendencies. Designed as a mission serving the interests of the *data creators* composing the scientific team, a number of *data users* interested in climatological studies would reap benefit of the relative long datarecords produced from these measurements.

PARASOL was an exploratory satellite, one single-shot and time-limited experiment included in a particular form of laboratory (the A-Train). The scientific objectives of POLDER-3 slightly differed from those of POLDER-1 and 2, being the study of the atmosphere its central goal (and only incorporating the marine biology as a last-minute mission further the failure of ADEOS-II in 2003). Some technical specifications had been also modified in order to optimize the characterization of

[701] Interview with Didier Tanré, LOA, 2014.
[702] "Recommandations du Comité des Programmes Scientifiques du CNES », November 2002.
[703] Interview with Didier Tanré, LOA, 2014.

atmospheric properties and for combining the measurements with the lidar's ones. Some of the individuals responsible of the experiment also changed –including the scientific responsible. In these senses, we can consider PARASOL as a different experiment from POLDER-1 and 2. But this is of minor importance for our conclusions. We would like to draw the attention in the similarities instead. The instrument POLDER-3 had been conceived by a team of scientists from the Laboratoire d'Optique Atmosphérique, the Laboratoire de Météorologie Dynamique, the Laboratoire des Sciences du Climat et de l'Environnement and the Service d'Aéronomie, who in very close collaboration with managers of the Technical Center of CNES in Toulouse would establish the technical characteristics for the industrial to manufacture it (EADS-Sodern). These scientists inherited many of the epistemic specificities characterizing the previous POLDERs, like the fact of being legitimized by CNES instead of through classical procedures of scientific competition, the institutional heterogeneity, scientific goals and disciplines (less diverse than POLDER-1 and 2, given that ocean biochemistry and vegetation would not be part of the mission, but still varied regarding studies of aerosols, clouds or Earth radiation budget). As a matter of fact, excepting from those interested in oceans and vegetation studies, people were also more or less the same: phD students that had become postdocs, postdocs that had become professors, professors that had recruited new students. This team of scientists inherited as well the function of the "groupe mission": prepare the use and interpretation of the future data, that is to say, develop calibration methods, inversion algorithms to retrieve geophysical parameters and conceive plans for validating these retrievals after the launching. They held the same type of knowledge (radiation transfer, spectral signature, etc.), they mobilized the same type of technological data practices (inversion) and actually much of the software for processing POLDER-3 data would be either improved versions of the algorithms inherited from the previous missions or new algorithms exploiting the combination with the lidar's measurements. They would inheritate a culture of *data creators*, whose end was to produce *geophysical datasets*.

They inherited as well the factory-like mode of data production and dissemination based on the delivery of geophysical datasets considered as the data with epistemic virtue for studies in the disciplines of Earth sciences –in this case, atmospheric sciences. To be sure, this was not a specificity of PARASOL: this model would be adopted for all the missions involving any discipline in the domain of Earth sciences conducted under the auspices of CNES. Within this model the social group of *data creators* raised up as holding epistemic authority to build the data, judge their quality and frame the scientific contexts of utilization, because it held the knowledge and expertise of *intervening* on physical radiances through *inversion* methods. They inherited the social organization and distribution of work remained unchanged, just like they inherited the growing separation of the scientific community in *data-classes*. Also efforts to settle specific datacenters for processing, storing and disseminating the satellite data would be pursued in all missions in the domain; however, although the archival and dissemination technologies changed (internet), rules of access and delivery remained unchanged –this is actually one of the topics of chapter five.

With more or less epistemic specificities particular of each scientific team of each space mission (in terms of disciplines, ways of selecting the members, institutions, *data-classes* of the members, technological practices of the members, etc.), most space missions engaged by CNES would be embedded in the vision of the Earth as another planet to be explored and, with that, in the vision of Earth sciences a particular form of space sciences. These are missions that retain some of the characteristics of traditional space sciences (or experimental physics) like rewards and privileges in the data access, constitution of a scientific team in close connection with the conception and manufacture of the instrument and committed to prepare the data, which will be delivered to data users in terms of geophysical parameters. At the same time, they depict some particularities like massive dissemination of the data (of geophysical data), the assumption that there exist some community out there willing to use the data and a holistic vision of a space mission, no longer exclusively composed by a satellite and its associated systems, but also including a great deal of field-work. This would be the form of space age, we argue, that would be *normalized* in the practices and representations of CNES further the introduction of the Earth sciences in its scientific programming. By using the term *normalization* we aim to stress that alternative forms did exist (as illustrated with the parallel twin vocation based on the idea of considering the Earth as our own planet and intended to monitor the Earth and its environment for management and control purposes gaining visibility from the late 1990s onwards) and the closing into one of these forms was the result of the process of *reconciliation* taking place from the 1980s onwards. In other words, by using the term *normalization* we want to stress that the use of satellite data in support of studies in different disciplines of the Earth sciences became, by 1998 approximately, a standard. And that this standard was *normalized* as embedding a particular form of understanding the role of space technologies vis-à-vis the domain of Earth sciences, a particular meaning of the notion of space mission, a particular techno-epistemological model to gather, produce and disseminate the satellite data, a particular social organization with a particular type of scientific community and the industrials, a particular form of expertise, knowledge and technological data practices, and a particular institutional vocation of CNES had become the legitimate admissible methodology to be applied uniformly to each space mission in any domain of the Earth sciences. It is plausible to say that POLDER-1 (and 2) and PARASOL herald this process from end to end.

The two chapters of the second part of the present dissertation intend to illustrate the *normalization* of the use of satellite data in the domain of Earth sciences in two different ways. The first one, chapter five, focuses on the ways of preserving data about the Earth and its environment, in particular, on a datacenter created to archive and disseminate the data regarding atmospheric physics (including POLDER's). Through this case we illustrate the *normalization* of the factory-like data production system, of the social organization in data-classes exacerbated with the introduction of data centers (which would gave rise to a third *data-class*, the *data provider*), the commitment to concede epistemic value to *geophysical units*, and therefore to celebrate the social group of *data creators* and their technological practices of inversion. This is a chapter that, while introducing a new important actor (datacenters), reflects the consolidation of the exploratory character of missions in the domain of the

Earth sciences within CNES's scientific programming. Chapter six moves a step forward and aims to explore the *normalization* of the use of satellite data by Earth scientists by looking at how data is used in contexts distant of their acquisition. We put special attention in those *data users* that bring forward a stream of data production parallel to the *geophysical data*, what we have called before the *climatic data*, whose production requires alternative approaches to the data interpretation (numerical instead of physical), alternative technological data practices (assimilation instead of inversion), alternative expertise and knowledge (numerical modeling instead of radiation transfer), and we connect them with the *normalized* methodologies.

5

THE MEMORY OF THE EARTH. PERPETUATING SATELLITE DATA.

MEAN OCTOBER RADIATION BUDGET (WATTS/METER^2)

LAT	NET	IR	ALB	ABS	REF
85	-168.5	169.0	0.0	.5	0.0
75	-158.6	174.6	61.5	16.0	17.0
65	-134.8	185.3	48.9	50.5	48.3
55	-103.8	201.3	42.0	97.5	78.6
45	-65.2	222.9	32.7	157.7	74.6
35	-37.1	246.2	29.1	209.1	85.8
25	-6.4	264.1	25.7	257.6	88.1
15	38.4	254.8	24.6	293.2	95.7
5	64.1	251.3	24.8	315.4	104.0
-5	71.3	261.5	23.9	332.8	104.6
-15	70.9	269.9	23.0	340.8	101.8
-25	66.4	261.5	24.6	327.9	107.0
-35	51.0	242.4	29.2	293.5	121.0
-45	26.5	222.2	34.9	248.7	133.3
-55	-11.1	202.0	43.7	190.8	148.1
-65	-59.4	181.3	57.7	121.9	166.3
-75	-72.1	163.6	65.2	81.6	152.8
-85	-77.1	143.9	68.0	66.8	141.9

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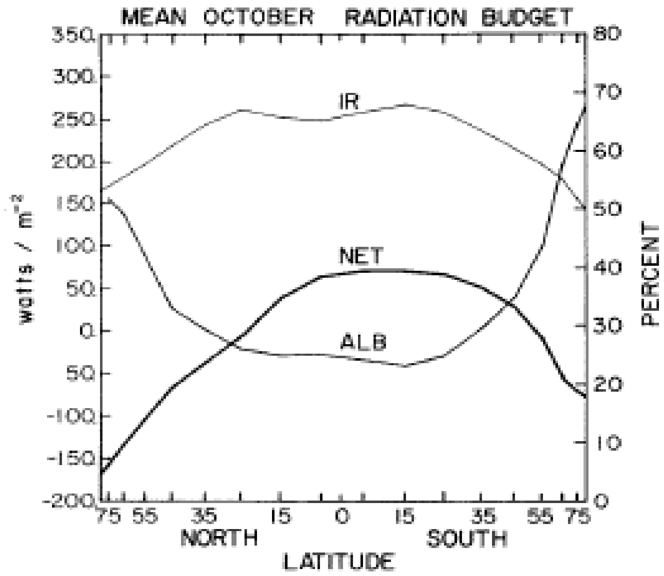

35

These images are a sample of the data compiled in the atlases published by professor Thomas Vonder Haar, an atmospheric scientist at the Colorado State university, corresponding to the measurements of the radiation budget made by different satellites: TIROS-4, TIROS-7, Nimbus-2, ESSA-3, ESSA-5, ESSA-7, ESSA-9, ITOS-1 and NOAA-1 between 1962 and 1970. Professor Vonder Haar periodically gathered together the data from successive satellites in order to produce long-term data records, also known as climatologies[704]. These particular ones correspond to monthly computations; but data can be averaged for various periods of times from weeks to years. Some type of studies call for the preservation of data in the long-term. This is the case, for instance, of climatological studies. The goal of professor Vonder Haar was clear: analyzing the evolutions of the radiation budget was a way to

[704] "Atlas of Radiation Budget Measurements from Satellites (1962-1970)", by Thomas H. Vonder Haar and James S. Ellis, Dpmt of Atmospheric Sciences, Colorado State University, 1974.

study the evolution of the climate, evolution which occurs over long periods of time[705]. More generally, some scientists may be interested in identifying trends and variability along large time scales. For that, long data records are required. For data, data must be preserved over time.

These atlases were the ways in which scientists visualized the data; the data were however recorded in magnetic tapes archived into libraries. In chapter six we will address some of the issues involved in preserving these data over long periods. In this chapter we address the issue of how do we keep and diffuse information about the environment and the Earth sciences, a question which is in continuity with those that we have introduced when studying the data infrastructures deployed for POLDER-1 in chapter 3. During the first decades of space sciences, the experimenters remained a sort of owner of the data that they produced and analyzed, in the sense that they established, through their customary and daily practices, the policies of data sharing and dissemination and they selected as well what data were worthy to save (from what instrument, at what level of processing, what samples, format) into magnetic tapes or paper-supported atlases. All along the 1980s and 1990s, it emerged an urgency for data to travel quick and efficiently between *data creators* and distant *data users*. Satellite data about the environment would change their status of item of private property and gradually becoming "patrimoine collectif", entailing that efforts must be endowed to perpetuate them and render them accessible. In France, it would be from the early 2000s that specific satellite data computation centers and online satellite databases were established devoted to produce, archive and disseminate the satellite data so that distant scientists (not related to the processes of acquisition and creation) could take and use them. Intended to perpetuate ad infinitum the data gathered by limited-lifetime satellites, they aimed to become the memory of the Earth and its environment, a memory materialized through the organized digital files of satellite data about the properties of the oceans, the vegetation, the atmosphere, the cryosphere, or the solid Earth.

The departing point of this chapter is a report issued in 1999, the so-called Waldteufel's report, further a request made by CNES and CNRS, and mandated to recommend a data management plan in the domain of Earth sciences with views to archival and diffusion of data at national scale. We analyze it in terms of the scientific urgencies motivating the perpetuation of satellite data and stressing the issues emerging in this endeavor. We connect them to the descriptions provided in the previous chapters about data-classes, epistemic virtue, factory-like system for mass-production or technological data practices. In the second part, we focus on a particular case, the datacenter ICARE (Interactions Clouds Aerosols Radiation Energy) and its corresponding internet database, devoted to handle the data of several space missions to study the aerosols, the clouds and the radiation budget (POLDER-2, PARASOL, CALIPSO, Megha-Tropiques, MODIS, amongst others) –it would also handle non-satellite data from field-campaigns or networked ground stations (like AMMA or AERONET). We pay special attention to the practices mediating how data flow through the datacenter, that is to say, how *data creators* fuel the memory and how *data users* retrieve data from it. We emphasize the figure

[705] Interview with Thomas Vonder Haar, CSU, 2013.

of a third data class, which we shall call the *data providers*, those people curating the database, maintaining the records and working out the data that others will use. We also examine some of the technologies that bridge the three categories each other. In particular, in the interface between data creators, data providers and data users lies, we argue, the provision of *metadata*, which acts as a gateway between classes and, in consequence, epicenter of frictions and tensions. The conclusion explores, for the case of ICARE, implications of the penetration of such datacenters and databases in the ways in which satellite data are gathered, produced, archived, disseminated and used; it explores the extent to which the introduction of such new actors and institutions modify or reinforce the current data practices and epistemologies in the domain of space Earth sciences.

PERPETUAL AVAILABLE DATA

Use value of preserving data: Climatic datasets

The example of the atlases of professor Vonder Haar illustrates that climatological studies using satellite long data records, or *climatic datasets*, have been pursuit since the early 1960s. From the 1980s onwards, the arrival of diverses discipline in the domain of Earth sciences, exacerbated this tendency. As early as in 1981, Pierre Morel defended in the first scientific meeting organized by CNES in Les Arcs very precisely this value of preserving satellite data in the long term for climatological uses:

> "On a besoin de constituer une base globale d'observations atmosphériques et océaniques cohérentes pour caractériser le climat actuel défini comme le résultat du lissage des fluctuation météorologiques et pour établir l'existence d'un "signal climatique" reconnaissable au terme de 1 à 10 années et, éventuellement, des tendances à plus long terme"[706].

Climatological studies exemplify what the historian of sciences and technologies Geoffrey Bowker called the *use value* of preserving data[707]. It refers to a current use of the data to study a given well-posed scientific question. The *use value* of data would embrace all the scientific questions that scientists had identified a priori as gaining from being studied by means of the given set of data records. In the domain of Earth sciences, a classical argument driving the use value of preserving data is their utility for studying long-term variability and trends, the climatological argument. We may call this type of data, characterized by the long-term, their consistency and global scope, *climate data*, and their production is one of the topics of the last chapter.

Although the climatic approach has long existed we shall argue that it gained momentum by the 1990s due at least to two reasons. First, this decade was portrayed by an international agenda depicting what the historian of sciences Amy Dahan has called the *climate regime* in which politicians and scientists together passed from promoting studies of the climate to promote studies of the climate change, in particular of the anthropogenic factors. Within this regime, heralded by the creation in 1988 of the

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706 « Conclusions groupe des Sciences de la Terre », Pierre Morel, Séminaire de prospective scientifique, Les Arcs, 1981.

707 « Memory Practices in the Sciences », G.C. Bowker, 2005.

International Panel of Climate Change (IPCC), scientific research about climate could be henceforth hardly separated from the ascension of such questions in the international political arena, leading to major evolutions in considerations of economy, geopolitical forces or consumption lifestyles, to mention only a few[708]. Second, some of the first satellites launched in the late 1970s were still flying providing for 10 or 15-years long datasets. For instance, some instruments inside Nimbus-7 launched in 1978, like Color Zonal Coastal Scanner or T*otal Ozone Mapping Spectrometer*, would still be functioning by 1995, providing around 20 years of consistent data about the biological properties of the marine waters or about the ozone concentration in the stratosphere. The very existence of these data records would motivate, at least partially, the climatic approach.

Option value of preserving data: Geophysical (or physical) datasets

Apart from the immediate value of using the long-term data records for well-identified climatological studies of tendencies and variability in the long-term, the will for perpetuating the satellite data emanated from another source, illustrated by this wonderful passage of Arthur Clarke's opera "2001 Space Odyssey":

> "Since the first satellites had orbited, almost fifty years earlier, trillions and quadrillions of pulses of information had been pouring down from space, to be stored against the day when they might contribute to the advance of knowledge. Only a minute fraction of all this raw material would ever be processed; but there was no way of telling what observation some scientist might wish to consult, ten or fifty, or a hundred years from now. So everything had to be kept on file, stacked in endless air-conditioned galleries, triplicated at the three centers against the possibility of accidental loss. It was part of the real treasure of mankind, more valuable than all the gold locked uselessly away in bank vaults"[709].

This passage, written in 1968 visioning a futuristic scenario in which satellites would continuously generate data which would be systematically processed and archived, would be a mere anecdote, were it not be quoted frequently in the introduction of several reports and documents dealing with the question of data management at NASA and CNES in the 1980s[710]. We take here this passage as prefigurating what we call, after Geoffrey Bowker, the *option value* of preserving data[711]. Scientists collect vast amounts of data about the environment, which frame, like a photograph would do, the present instant of our planet. Whether these descriptions of the present would be carried forward into

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[708] « Le régime climatique, entre science, expertise et politique », Amy Dahan in « Les modèles du futur », 2007 and "Putting the Earth System in a numerical box? The evolution from climate modeling toward global change" Amy Dahan, 2010.

[709] "2001: A Space Odyssey", Arthur C. Clarke, 1968.

[710] This passage of Arthur Clarke's Space Odyssey has been employed in several briefings and reports dealing with satellite data management, written by NASA and CNES. See for instance "Data Management and Computation. Volume I: Issues and Recommendations", Space Science Board, 1982.

[711] Geoffrey Bowker complements the notion of use value to that of option value –and he still adds a third value, the existence value. This portrays a vision of what Bowker coined an "epoch of potential memory", where the archive of data constitutes a management tool for exercising control on our planet, as the philosopher Michel Serres pointed out. With Foucaultian influences, Bowker explicitly connects this with the principles of governance and control: grounded on the archived data of the past and the present, the state may decide the public measures for the future. Similarly, grounded by the data, institutions may decide how to manage the environmental issues. « Memory Practices in the Sciences », G.C. Bowker, 2005.

the future and used in new ways, remains unknown –but scientists cannot afford not keeping them, as they are “more valuable than gold”. Data collected under this approach are conferred an epistemological *option* value related not to what scientists know about a particular phenomenon, but rather what they could know shall the question ever arise. The option value reflects the interest that scientists have in keeping the current stock of data against possible future uses. Two sources motivate this interest in preserving for the sake of preserving. The first one related to the fact that each event is unique and not repeatable and, given that scientists cannot foresee what their scientific interests will be in the future, a trace of it must be conserved. We have already mentioned an instructive quote of the climate scientists Kevin Trenberth “we cannot go back in time and observe what we have failed to observe”[712]. On the other hand, this is the second source, this epistemology reinforces to the notion of a “multimissions” instrument, an instrument whose domains of applications are not totally fixed from the outset and whose data is open to prospective usages that may appear in the future –an instrument like POLDER. We would like to suggest, and this must remain as a suggestion, a connection between the emphasis put on the value of preserving data for optional potential uses and the culture of project management at CNES archetypical of industrialized efforts. As part of the managerial rules, all actions must be reported, documented and properly archived from working meetings to laboratory technological tests to changes in the door-gate code access. While this allows communication between distant highly specialized parties and centralization of information for control and coordination, it also guarantees protection and insurance before potential audit or juridical assessment and potential learning from past actions. It is plausible to think that preserving data for prospective uses follows same logics of potentialities.

In any case, the data records related to the concentration of CO_2 collected in the Mauna Loa observatory in Hawaii since the 1950s are an example of the option value of preserving data often quoted by scientists. While these measurements were taken for studying chemical processes occurring in the atmosphere and their relationships with radiation, weather conditions and suspended particles, 50 years later, scientists looked at them differently and used them as evidence of global warming[713].

Michel Avignon, an engineer at CNES working by the late 1980s in organizing the data infrastructure for the mission Topex/Poseidon reflected this approach it in the following way:

> “Les outils satellitaires d’observation spatiale souvent apportent des solutions à des questions non posées. Ensuite, une fois que l’utilisation de l’outil se consolide, les exigences des utilisateurs se multiplient et dépassent la maturité de la technique”[714].

This was a view commonly spread among data creators as well:

> « en regardant les données on trouve des choses inattendues (…) On a les données et puis on va chercher des façons de les utiliser. Et puis avec le temps on se pose d’autres questions, on a des

[712] Interview with Kevin Trenberth, National Center of Atmospheric Research, 2013.
[713] Interview with Kevin Trenberth, NCAR, 2013.
[714] “Acquérir des données spatiales: quelles types de données et de capteurs en réponse à quelles types de besoins?”, Michel Avignon, 2004.

machines plus puissantes qui permettent de faire des nouveaux calculs, on a plus de connaissances… L'usage des données n'est pas figé du départ"[715].

This was precisely the rationale underlying the need for preserving data in the long term: the acknowledgment that scientists did not know what they may want to know in the future, what they could know given the technological and scientific contexts, what their scientific interests would be in the future, the value of data in prospective.

Databasing the world

In any of the cases, whether stemming from a use or from an option approach, satellite data were to be conserved. Closely associated to the perennisation of satellite data is their access and availability, an issue that had been raised all along the 1980s in several occasions. We have already mentioned that the scientific community had acknowledged during the first scientific meeting organized by CNES in 1981, for instance, the difficulties to get access to weather data from Meteosat and they requested "des solutions doivent être trouvées pour preserver les données Meteosat et archiver les données de Meteosat 2" and they requested "unaninement la création d'un service d'archivage et de traitement des observations spatiales météorologiques accompagnée des moyens humains indispensables"[716]. During the second scientific meeting organized by CNES in 1985 in Deauville, the Séminaires de Prospective Scientifique, the group of scientists in the field of Earth Sciences, set up a specific working group to discuss collegially the issue. In the conclusions of that meeting they wrote:

> "Un des défis importants à relever dans l'utilisation de l'espace pour l'observation de la Terre est d'organiser l'accès aux diverses sources de données et surtout leur analyse de façon coordonnée et automatique. En effet, la quantité de données reçues est considérable et d'origine très variée (divers types de satellites, dates différentes, mesures au sol, stations en réseau interrogées, etc…). Il est donc indispensable de pouvoir ramener toutes ces données sur une grille de référence au sol, générer des fichiers cohérents (en luminance calibrée ramené au sol pour les satellites, dans les diverses mesures pour les réseaux sol) et d'organiser ces fichiers pour qu'ils puissent être utilisées dans les modèles d'exploitation. Cela implique la mise en place d'un système de base de données (banque de données + logiciels d'accès + programmes utilitaires (recalage géométrique, correction atmosphériques, étalonnage, ré-échantillonnage, etc…)) qui doit évoluer vers un système expert (base de données + système logique de commande des divers logiciels de la base de données). Des travaux de ce type sont déjà en cours en France (comme dans la plupart des pays utilisateurs de l'espace) et doivent être développés de façon harmonieuse entre tous les utilisateurs des satellites d'observation de la Terre »[717].

The interest of developing a database where all data would be accessible, including ground data, was emphasized. Just to provide another last witness, let us take again the letter than Yann Kerr, the data creator of LERTS, wrote in 1988 comparing the situation of data access in France with that in the United States:

[715] Interview with François-Marie Bréon, LSCE, 2012.

[716] Conclusions of the group Earth sciences in the Seminaires Les Arcs 1981, elaborated by M. Petit

[717] « Gestion des données – Banque de données – Base de données – Système expert », Conclusions du groupe de travail des Sciences de la Terre rédigées par Philippe Waldteufel, Séminaire de Prospective Scientifique, Deauville 1985.

> « [Aux États-Unis] les grandes disciplines de la télédétection telles que l'océanographie par exemple, ont mis au point des centres (National Oceanic Data Center, NODS) où toutes les données sont archivées et accessibles de tous les Etats-Unis. Un Catalogue informatique fonctionnant par mots clés peut être consulté, permettant de connaitre ce qui existe sur une zone donnée, à une période donnée, etc… et de commander celles étant d'intérêt. Maintenant les « workshops » se succèdent, ayant pour but d'uniformiser ces centres de données, de générer un catalogue les regroupant avec un choix de mots clés satisfaisant toutes les disciplines, etc…
>
> Il est donc clair que dans les prochaines années existera aux Etats-Unis un système d'archivage et de diffusion des données permettant (encore plus qu'actuellement !) aux chercheurs de faire de la recherche et non de la chasse aux données, d'écrire des algorithmes d'analyse et non des algorithmes de prétraitement »[718].

Yann Kerr's words pleaded for mirroring NASA's practices in the domain of organizing and accessing satellite data. Kerr added that « [aux Etats-Unis] cet effort est financé par la NASA et ne recouvre pas uniquement les données satellitaires » and the scientist asked CNES to head an « effort à l'échelon national »[719] for developing, implementing and operating a data management plan, based on building specialized facilities and online databases, in order to easy the work of scientists. Indeed, the question of archiving the data and organizing them in databases had already converged in the US in the 1970s. Scientists involved in Nimbus-7 were concerned, since 1975, about data storing and sharing and actively promoted an ethos of extensive data exchange between the scientists that responded to the call of opportunities to create a scientific team. These scientific responsibles requested NASA to set up a data facility established to specifically deal with the storing and dissemination of the data produced with the various instruments aboard of Nimbus-7. Each scientific group processed its own data. They were then asked two tasks. First, to notify to the central data facility what data they had produced together with the corresponding algorithms, error estimation, orbits, etc. Secondly, they must send a recorded copy of the data to the central facility. This facility would maintain a catalogue with the existing data, keep a copy of them and record and ship a copy to any scientist requesting them[720]. The oceanographers of JPL also stumbled in the early 1970s with the difficulties of how rendering accessible and distributing what they called an "overload of data"[721] coming from Seasat across an expanding oceanographic community not technically equipped to cope with the data. This community would promote in the early 1980s through the mission Topex/Poseidon the establishment of dedicated datacenters, which would not only handle the storage and the diffusion of the data, but also centralize the data processing. To give a final example, the First GARP Global Experiment that took place in 1978 and 1979 was also strictly organized in terms of data handling, by setting up three world data centers that would, like in the Nimbus-7 case, receive a copy of all the datasets, organize them in a library and provide copies to scientists requesting them[722].

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[718] « Note au LERTS : Banques de données satellitaires », Yann Kerr, 1988.
[719] « Note au LERTS : Banques de données satellitaires », Yann Kerr, 1988.
[720] "The Nimbus-7 User's Guide", Prepared by the Landsat/Nimbus Project, GSFC/NASA, 1978.
"Nimbus Program History. Earth-Resources Research Satellite Program », NASA, 2004.
[721] "Drowning in data: Satellite Oceanography and Information Overload in the Earth Sciences", E.M. Conway, 2006.
[722] "FGGE Operations and Data Management", J.L. Rasmussen, 1981.

Similar efforts were not without precedent in France, and Europe, as exemplified by the establishment, following the model of NASA, of datacenters and databases such as SATMOS or CERSAT to organize data from European weather and oceanographic satellites respectively in 1985 and 1991 (Meteosat and ERS), or with the attempts to establish a datacenter for POLDER in the Région Nord-Pas de Calais and Région Paris, which we have discussed in chapter 3. We argue, and this is our hypothesis, that these efforts gained momentum along the decade of the 1990s due to several factors. First, technological developments in the domain of information technologies (internet), and we join Geoffrey Bowker's materialist thesis in this point[723], rendered it easier, faster and cheaper to archive data in the net and to circulate them between distant users in time and space. In this sense, available technologies, digital technologies, appeared as a newly efficient material solution to an old problem. But we cannot leave things at materialism. A renewed post-Cold war political international agenda in which space technologies must renovate their raison-d'être and in which environmental concerns figured prominently, added urgency to the question of detecting and studying changes in the environment, with special attention to changes of anthropogenic origin. In this context, satellite data would not only be used for academic research and scientific publication but also as a tool for helping decision making and managing the planet. Urgencies for organizing the data would exceed the academics. Finally, as the number of satellites scheduled for launch to gather data about oceanographic properties, atmospheric chemistry, marine biology or tropospheric aerosols proliferated, so did the possibilities of combining data from different sources to get new datasets to study interactions between phenomena and processes. The synergy between data from different space instruments, and non-space instruments, to create new algorithms and parameters would appear as a scientific insight casting for specific forms of organizing the data through data bases in order to centralize the access of data from different sources.

During these two decades, 1980 and 1990, the managers of the scientific programs at CNES would progressively get awareness of the importance of preserving the data, culminating in 1998 with the creation of a working group devoted to study the situation of the databases in the domain of Earth sciences in France and to emit some recommendations. One year later this group, chaired by the physicist Phillipe Waldteufel of the Service d'Aéronomie of CNRS, would release a report.

The Waldteufel's report : "Les bases de données pour les géosciences"

In October 1998, CNES convened its 6th scientific meeting in Arcachon. After a recommendation issued of this meeting, the Délégation à l'Etude et l'Observation de la Terre de la Direction des Programmes du CNES and the Institut National de Sciences de l'Univers of CNRS set up a working group to discuss the management of satellite (and non-satellite) data in the domain of Earth sciences.

723 « Memory Practices in the Sciences », G.C. Bowker, 2005. For a materialist thesis about the effects of the internet on our ways of knowing see "Too Big to Know: Rethinking Knowledge Now that Facts aren't the Facts, Experts are Everywhere, and the Smartest Person in the Room is the Room", D. Weinberger, 2011.

Philippe Waldteufel of the Service d'Aéronomie, a well-known physicist that had been member of Comité de Programmes Scientifiques in the 1970s and 1980s and who, at that time, was not directly involved in any of the missions engaged by CNES, accepted to chair the working group, which would be composed by four representatives of the scientific community, including the oceanographer Annick Bricaud member of POLDER's "groupe mission", working in collaboration with technicians, engineers, managers and administrative personnel, amongst which the CNES's computer scientist developer of the POLDER-1 and 2 data infrastructures Alain Gaboriaud[724]. The group must inventory the existing databases in France (and also some international ones, especially American ones) and assess the expectations and intentions of the scientists, and other concerned organizations, in the use of data for the 10 years to come[725]. From this information, the group must propose schemas for managing the data.

The methodology of the study took the form of a poll with more or less open questions that was sent to the 43 laboratories and institutions that had been identified as working in the domain of Earth sciences in France, most of them familiar to the reader, including Centre d'Etudes Spatiales de la Biosphère (CESBIO, former LERTS), Institut National de Recherche Agronomiques, the laboratories federated in the Institut Pierre Simon Laplace, Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Laboratoire Interuniversitaire des Systèmes Atmosphériques, LOA, LPCM or the biological station in Roscoff) complemented with interviews with representatives of the 17 different organisms operating with data in the domain (including CEA, CNES, ESA, Meteo-France, Service Hydrographique et Océanographique de la Marine (SHOM) or SPOT Image[726]).

Renewed scientific urgencies: The end of the mono-instrument era or enter data of level 3 and 4

The report started by reckoning that Earth sciences were mainly observational sciences and as such they required collections of as much data as possible:

> "La recherche en géosciences repose sur l'idée qu'existent des relations, basées sur les lois de la physique au sens large, entre les grandeurs caractéristiques modélisant le monde réel: il s'agit de préciser le comportement de ces grandeurs, de trouver ces relations, de les confronter éventuellement à des prévisions théoriques, de les valider, d'en améliorer la représentativité et le caractère général. Pour cela le point de référence indispensable c'est une description de la réalité observée, sous forme de champs (nombreux) de quantités physiques selon des séries spatio-temporelles »[727].

[724] Members of the commission belonged to the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS), Laboratoire de Physique et Chimie Marines, Institut de Physique du Globe de Paris, Institut de Recherche et Développement, and CNES.

« Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

[725] « Lettre de mandat établie par le CNES et l'INSU », October 1998.

[726] Some of the non-academic institutions consulted would be BRGM, CEA, CLS, CNES, ESA, IFEN, IFREMER, IGN, IFP, INRA, INSU, IRD, MEDIAS-France, Meteo-France, SHOM and SPOT Image.

« Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

[727] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

The authors reaffirmed that all kinds of empirical data were essential (satellite and in situ) -and also simulated data, that is to say, the outcomes of numerical models, insofar they were used as empirical data to evaluate theoretical hypothesis, to increase representativeness of the field campaign local-gathered observations or to fill the satellite data gaps between series of observations. The authors of the report pleaded for datacenters and databases capable to handle satellite data obtained from different instruments and of combining them to generate new datasets. The particularity was that data that should be made available were intended to be complex datasets created by fusing data gathered from different instruments (recall, for instance, the will for combining the data from POLDER-3 and the lidar CALIOP). This was a scientific urgency that had emerged in the late 1980s, not disconnected, we suggest, of the new notion of conceptualizing the Earth as a system, complex and global, beginning to penetrate all disciplines of Earth sciences, instigated by scientists of the Goddard Space Flight Center of NASA and mediated through the realization of the International Geophysical and Biological Program (IGBP). Gérard Mégie, when presenting his project for creating the Institut Spatial pour l'Environnement Terrestre in 1990 would put this scientific urgency clearly:

> «Les géosciences de l'Environnement sont aujourd'hui à un tournant de leur histoire. Une évolution conceptuelle est en cours, fondée sur une prise de conscience accrue de la globalité et de la pluridisciplinarité des problèmes que pose la compréhension de l'environnement global de notre planète (…) Comprendre le fonctionnement de l'environnement terrestre et prévoir son évolution à l'échéance du siècle prochain est un enjeu majeur du progrès des connaissances dans le domaine des géosciences. De la globalité des problèmes et de la nécessité d'une prédiction réaliste découle une approche quantitative et planétaire de l'environnement terrestre. Or celui-ci, qu'il s'agisse du climat ou des équilibres physico-chimiques, fait interagir plusieurs composantes aux constantes de temps caractéristiques très différentes : atmosphère, océan, biosphère, cryosphère. les processus d'interaction intra- et inter-composantes, la non linéarité qui résulte de couplages multiples rendent difficiles une approche qui doit prendre en compte des échelles d'espace allant de la fraction de millimètre à la Terre entière, et des échelles de temps couvrant des périodes de la fraction de seconde au siècle»[728].

Earth sciences were experimenting what Gérard Mégie called "une évolution conceptuelle", in which the globality and plurisdisciplinarity of the scientific questions was acknowledged. This required the combination of data from several sensors, satellite and non-satellite, to create a synergy between data collected from different instruments. Complex interactions and processes, so the argument went, required complex datasets made up from combining different measurements. This was a substantial difference with previous data management systems: this was a recognition that the world was much more complex than geophysical parameters of level 2 (although they were essential) and that meshed, messy, intertwined datasets representing different variables of level 4 would better contribute to understanding such a complexity. Indeed, this can be posed in terms of datalevels. What was required to understand complex systems was to produce and delivery datasets levels: some form of weekly, monthly or annual synthesis of the geophysical parameters (level 3) and combinations of geophysical parameters obtained from different space instruments (level 4). This was a change with respects to the organization of the production and distribution of data in the 1980s and 1990s. Recall, for instance, that the schema for POLDER's geophysical data production and dissemination (fig 2.1) ends at data of

[728] « Sur l'opportunité de participer à un « Institut Global Change » dans le cadre de l'Université 2000-Versailles », Gérard Mégie, 18 October 1990.

level 3, some synthetic form of geophysical datasets, but does not includes the possibility of combining POLDER's data with other data to create a new dataset of level 4. Indeed, CERSAT or SATMOS were datacenters handling the data of single space missions, the weather satellites Meteosat and the oceanographic satellite ERS, but they did not contemplate the possibility of combining the weather data and the oceanographic data to generate a new dataset of level 4. They were datacenters focused in one single mission and producing datasets from one single instrument.

By 1999, because a number of satellites, equipped with different instruments conceived and realized under the auspices of CNES (POLDER-1, ScaRaB) or NASA (MODIS, CERES, SeaWiFS, to mention just a few the reader may be familiar with), had been launched it became feasible to combine data from them. As more satellites were scheduled for launching before 2005, prominent amongst which the components of the A-Train (but also ESA's satellites carrying instruments conceived and developed by French laboratories like ERS-2, ENVISAT or the new generation of Meteosat), the feasibility became an imperative. In the specifications of one of the datacenters to be implemented (the one that we are studying in the second part, ICARE) this imperative was announced as the end of a "monosensor"-era:

> « Le schéma classique de développement par le CNES d'un segment sol scientifique dédié pour chacune des missions spatiales se révèle mal adapté et inefficace pour traiter la synergie des prochaines missions. En effet, la mise en place de ces segments sol s'appuie sur une logique monocapteur, avec un ensemble prédéfini de produits qui sont développés, intégrés, puis exploités en continu. Des modifications sont permises sur ces produits, mais les capacités de retraitement sont en général limitées par les contraintes d'exploitation. La dimension multi-missions induite par la synergie des observations impose de repenser le schéma de gestion des données spatiales. Il est en effet nécessaire de disposer de schémas d'exploitation souples, et adaptés aux « rétroactions » induites par le développement de nouveaux produits combinant les observations acquises par des instruments de même nature, mais aux capacités de mesure complémentaires, ou des instruments différents observant des phénomènes identiques. Le premier besoin est d'aider l'utilisation de ces données, en permettant aux chercheurs d'acquérir des ensembles de données immédiatement utilisables pour conduire leurs analyses Ces analyses porteront tout d'abord sur des données ou produits mono-capteurs, qu'il s'agira de valider et de croiser avec d'autres informations. Le second besoin, qui interviendra après le résultat des analyses de données et produits monocapteurs, est de favoriser le développement de produits multi-capteurs, combinant les informations provenant des instruments à différents niveaux d'élaboration, afin de concrétiser la plus value apportée par la synergie entre les missions »[729].

In that sense, the A-Train was a celebration of the *multi-sensor era* in which, by synergistically combining the data from different measurements, so it was hoped, important insights on the complex nature would be yielded. A lot was expected, as we have mentioned before, from the combination of polarized radiances with lidar backscattered reflectances. This was actually the whole point of the mission PARASOL: the vertical columns of optical depth computed from POLDER-3 data could be discriminated by altitude levels by using CALIOP's information aboard CALIPSO. The scientists would engage in developing algorithms, and testing them, to retrieve different parameters from the two sets of measurements. Several field campaigns would be organized during which the airborne lidar LEANDRE developed by the Institute Pierre Simon Laplace and the aircraft prototype of

[729] « Synthèse du dossier de Définition Préliminaire du Pôle de compétence thématique ICARE (Interactions nuages-aérosols-rayonnement-vapeur d'eau) », elaborated by Anne Lifermann, A.Podaire and contributions of LOA, 2002.

POLDER would fly together. Also, the Institute Pierre Simon Laplace operated a ground observatory in Palaiseau with more than 20 instruments (SIRTA), including a LEANDRE-type lidar and a POLDER-type radiometer. The few months of data from POLDER-1 would be also used in combination with ground and aircraft lidar data. From all this previous work, a specific retrieval algorithm, which was called Caltrack, had been developed by data creators of LOA and LMD, able to created this combined dataset[730]. Let us give a second example in a much more recent mission, Megha-Tropiques[731]: it was thought that by combining the microwave data about the precipitation retrieved from the microwave radiometer MADRAS in a very specific orbit with the geostationary data about the brightness temperature provided every 15 minutes, new information about the precipitation rate in the tropical regions would be provided[732].

To sum up, the authors of the report concluded that this was the end of the era in which geophysical datasets coming from one single instrument would suffice for conducting research; what was deemed necessary instead were complex datasets created from the combination of measurements obtained with different instruments. In turn, this entailed the end of the era in which the space ground segments were devoted exclusively to one single mission; what was needed instead was to reunite the ground segments of different missions in one single centralized datacenter capable to handle the data of the different instruments. In other words, the epistemic virtue of satellite data had moved from data from level 2 to data of superior levels 3 and 4 –consequently, it must be these data that must be delivered through the databases. It shall be noted, nevertheless, that even though they were data of superior levels, they kept being datasets corresponding to *geophysical units*. Therefore, their production continued to entail expertise in radiation transfer and *technologies of inversion*; *data creators* continued to be at the epicenter of data production.

Original conundrum: Scientific research, information and action

This call for reporting on the databases in the Earth sciences was largely influenced by a development that had been occurring since the dawn of the space age with the satellites for weather forecasting and Earth surveys: the archives containing these data had the potential of being used not only to conduct

[730] The algorithm extracts some variables issued of different sensors (CALIOP, IIR, MODIS, PARASOL, CERES, ECMWF analysis, CLOUDSAT, and more in the future) with pixels in coincidence with the CALIOP measurements either at 333m or 5km horizontal resolution.

« Caltrack Product Guide », elaborated by ICARE's technicians in 2007. Other technical information about the algorithm, the software and the data: http://www.icare.univ-lille1.fr/projects/calxtract/index.php?rubrique=documentation

[731] Launched in 2011, Megha-Tropiques is a satellite to study the water cycle in the tropical atmosphere conducted in collaboration between CNES and the Indian Space Research Organisation. In a sense, it is renewed version of the old BEST proposed in 1985, in the sense that it has similar overall scientific objectives and carries some of the instruments scheduled to be launched inside BEST, like a Microwave radiometer to detect rain (MADRAS), a renovated version of ScaRaB and a sounder for vertical profiles of humidity (SAPHIR). It carries also an Italian Radio Occultation Sensor for Vertical Profiling of Temperature and Humidity.

[732] The TAPEER-BRAIN algorithm is a combined Microwave-Infrared accumulated precipitation estimation product implemented as a Megha-Tropiques Level 4 product. It provides precipitation estimations and associated errors.

"TAPEER-BRAIN product. Algorithm Theoretical Basis Document. Level 4 », P.Chambon et al, 2012.

academic research but also to manage our planet. Beyond connecting empirical data with scientific theories, the data archives articulated also information and action –in that aspect, satellite data joined an already existing tendency, as has been pointed by a number of scholars[733].

Close ties between information and action in the domain of the Earth sciences were featured in this report through three different casuistic. First, in their census of institutions intervening in the gathering and production of satellite data (and non-satellite data) in the domain of Earth sciences. They identified a number of non-academic institutions like weather services (Meteo-France), the military (SHOM), commercial organizations (SPOT-Image or CLS (Collecte-Localisation-Satellites, working with the physical oceanography data)) or the space agency (CNES). They were, according to the authors of the report, “des incontournables”[734] in the gathering and handling of data that academic scientists used. Although the primary goal of such organizations was not to conduct academic research, they were part and parcel of the Earth sciences research landscape anyway. Second, the utilization of the data was not reserved to academic scientists either. Particularly, through the possibilities for predicting certain phenomena (weather, ocean tides, earthquakes, volcano eruptions, etc.) mediated by the technological practice of *data assimilation*, which we will address in the next chapter, a direct connection was made between information and action. This connection, this power of data to engage and commit action, and this is the third casuistic, was materialized by a program, the Global Monitoring for Environment and Security (GMES), precisely proposed in 1998 as a joint undertaking of the European Space Agency and the European Commission, backed by some national space agencies and industrials including CNES. It consisted in deploying an array of technological capabilities for gathering information about the Earth’s environment, directed to support the decisions and actions taken by policy-makers in Europe. By explicitly articulating information and action, GMES is archetypical of global planetary management and global informational infrastructures, as discussed in the introduction to the second part of the essay.

The presence of non-academic actors committed both to gather and to produce data as well as to use them, rendered the landscape much more complex, especially when they were private operators or commercial entities. For instance, the authors of the report discussed some juridical aspects emanating from the question of the ownership of data. Put it simply, if data were considered as information, or a common good, no property legislation existed at that time. A contrario, if data were considered as a

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[733] Examples of Napoleon’s trip to Egypt and Cook’s travels to Australia are numerous and show the imperial drive to archive information about the natural world in order to exercise control well before the advent of satellites. In his “Contrat Naturel”, for instance, Michel Serres pointed out that our society is taking the role of managing the planet as a whole. The historian Geoffrey Bowker also has provided several examples to illustrate that data archives had been often connected to state management and control, especially in the domain of natural sciences in which the data contained in the biodiversity databases were being used to support and motivate conservation policies. See “Memory Practices in the Sciences”, 2005.

More generally, statistics are an illuminating example of the scope of the connection between knowledge, information and action, predating satellites and beyond the Earth sciences. Indeed, gathering and preserving data have been the basis for the state's administrative power throughout the modern era. We are not interested in our dissertation with the origins in the raise of statistics, which predates the period we are looking at and has been described by Theodor Porter, Michel Foucault or Alain Desrosières, each one from his perspective.

[734] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

product of a human activity, they were ruled by EU's property rights (similar to authorship's legislation but belonging to the institutions that have produced the data)[735]. As we have seen, space agencies tended to consider data as "products" of a production chain. However, the production of data does not go back to a single individual and it is not obvious to whom attributing ownership. On the other hand, this contrasted with the EU's based-knowledge society beginning to take shape in the late 1990s, which considered data as information; at the same time, however, this based-knowledge society was embedded by the market logics driving the EU construction. And, as we turn into a data-based economy, there is an increasing privatization of knowledge and data, and it is not clear to what extent the vaunted openness of the scientific community will last. Without entering in the details, this cul-de-sac carried with pragmatic issues, some of them affected directly the scientific community. For instance, there was the issue of the price to pay for data. Discussions opposing scientists and commercial operators about the free availability of data (especially of high-resolution radiometric images from SPOT and Landsat satellites) had been at the heart of several debates at CEOS since its very inception in 1984[736]. The scientific community that responded to the Waldteufel's questionnaires, unanimously defended that data, regardless of the ultimate motivation for gathering them and of the institution producing them, shall be available to them for free. Some institutions, on the contrary, argued that satellite data have a cost of production and maintenance and public instances cannot sustain it. Another question discussed in the report focused on the temporal limits that delayed the full accessibility of data. The scientific community was less unanimous on that point. As we have seen, some scientists believed that data could not be made available before being "good enough", which required some time for their validation. Some others believed that a temporal data embargo was justified as a reward for their effort in the preparation and realization of the instruments and the data. Some others, by contrast, echoed what we have called before the "American culture" and believed in the principle of full and complete access to all data by anybody since the very beginning of the processing.

"Patrimoine collectif" and ownership

The authors stressed both what we have called the use and the option value of preserving data. On the one hand, data were to be conserved for the sake of building data records in the long term to be used for detecting climatological variability and trend. On the other, they were to be conserved because "certaines données peuvent, longtemps après qu'on les ait collectées, présenter une valeur insoupçonnée et considérable"[737], which called for preserving data in an "extensive" manner, that is to

[735] Directive 96/09/CE of the European Union legislation, affecting the data that are organized in databases.

[736] Proceedings of Plenary sessions of the Committee on Earth Observations Satellites, 1984-1999.

[737] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

say, “dès qu’on n’a pas la certitude qu’elles seront inutiles à moyen/long terme”[738]. It was a preserving data for the sake of preserving data –just in case, just to make sure that data would be there if we ever need them in the future. Conceptual similarities with Arthur Clarke’s passage are obvious. In any case, data was qualified by the authors of the report as “patrimoine collectif”[739], as a metaphor to make explicit the urgency of conserving them. However, the heterogeneity of actors involved in the gathering and production of data in the domain of Earth sciences (academic, commercial, military, public, private…) rendered also complex the allocation of responsibilities for data preservation. The authors of the report could not identify any institution in the France of the late 1990s with an explicit heritage vocation of storing, conserving and rendering available the data in the domain of the Earth sciences. They identified however one institution equipped with the technologies needed for such a task, at least in the domain of satellite data: CNES.

Whether CNES was willing to assume the task is not clear. Some groups of the Technical Center at Toulouse had been siding with some scientific groups, both at national and international scale (through the meetings for organizing and defining some programs within the International Geosphere-Biosphere Program and the World Climate Research Program), and lobbying during the 1990s for dealing with issues of data management. This is the case, for instance, of a very specific group of professionals who has been almost absent in our account: the information scientists. They were excited with the idea of building a complex information system at national scale hosting all satellite, and eventually non satellite, data. Paul Kopp, a computer scientist at the Technical Center of CNES, who actively participated in the working groups of data management under the auspices of CEOS across the 1990s, and one of the experts gathered to elaborate the Waldteufel’s report in 1998, circulated in 1995 an internal position paper amongst several directorates and departments of CNES in which he emphasized the role of CNES in addressing the question of handling the data obtained with space technologies:

> «La communauté utilisatrice, au sens large du terme ayant pris conscience que les données archivées sont la trace d'événements qui ne se reproduiront plus et dont il faut alors conserver indéfiniment le souvenir dans la perspective d'investigations nouvelles (…) Le défi que les systèmes d'information à venir sont appelés à relever est de mettre des données foisonnantes et diverses, à la disposition d'une population éventuellement nombreuse et variée. Ces données sont géographiquement dispersées, diversement organisées, d'origines multiples, enchevêtrement de thématiques abondantes, en évolution constante (…) En résulte pour le CNES l'obligation d'organiser les archives plus ou moins dormantes dont il est gestionnaire en conservatoire actif d'un patrimoine appelé à la réutilisation continue. Cette organisation a déjà commencé sous la forme d'opérations de "réhabilitation", au bénéfice de certains laboratoires, des données spatiales issues de missions anciennes (Viking, Phobos, etc). Laborieuse et coûteuse, indésirable par essence, la réhabilitation des données démontre a contrario la nécessité d'une vision à très long terme dès la conception des segments "sol", au-delà des seules exigences de leurs promoteurs. Il appartient à la puissance publique, préservée des contraintes économiques de

[738] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

[739] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

> l'immédiat, de promouvoir cette vision par l'intermédiaire d'agences comme le CNES et d'imaginer les systèmes de demain »[740]

There was, in these words, a message of « obligation », of duty and responsibility, a message of public service vis-à-vis the scientific community. To be sure, these computer scientists were not particularly interested in data related to Earth sciences, but rather in *digital data* as a generic concept –as illustrated with the mention to the planetary missions Viking and Phobos for which they already started a work of recovery and reprocessing. They were information engineers ready to work with new challenging projects of data management: creating catalogues and libraries, directories, pipelines for the data to circulate, standards, data gateways, interoperable systems. Actually, apart of projects of recovery old data from planetary missions, their first project and plan for satellite data management as such would involve a community in the domain of plasma physics with sights of transposing it, in a following stage, to all environmental satellite data, beginning with atmospheric physics[741].

Apart from the information scientists of the Technical Center in Toulouse, the managers responsible of scientific programs, according to our examination of the transcribed interviews that the authors of the report conducted with CNES's representatives, seemed also favorable in intervening in the data handling. However, our analysis of these interviews confirms the lack of uniformity in the data management policies at CNES, just like we have described in previous chapters. Based on a general non-written rule of ensuring the production and storage of levels 0 and 1 data, data management was actually negotiated in a case-by-case basis. In some cases, especially in those missions in collaboration with the CNRS-CNES mixed laboratories (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Centre d'Etudes Spatiales de la Biosphère (CESBIO, former LERTS), and Centre de Recherches en Géodesie Spatiale (GRGS)), CNES intervened in the production, archiving and dissemination of data up to level 3, and included even some types non-satellite data (for instance, in Topex/Poseidon data from the oceanic network of tide gauges were handled). In some other a big part of the task was delegated to external institutions (like POLDER-1); whereas still in some other CNES was almost not engaged at all (like ScaRaB in which the main responsible was the Laboratoire de Météorologie Dynamique). The projects in collaboration with ESA and EUMETSAT provided still other complex models of intervention in the data management.

On the other hand, it is not clear either whether the scientific community was willing to cede the full data management responsibility to CNES. In the Annexes of the report, there are the data concerning the polls and questionnaires answered by scientists, which show certain reluctance to that. The organization of the data management effort into a CNES-centered venture, so the scientists believed, would certainly deprive the scientific community of its power (at least part of it) of intervening in the definition of the scientific data, their technical specifications, their formats and mode of dissemination, and eventually perhaps of the design and conception of the very instrument. The scientific community,

[740] « Quelques idées directrices pour la conception de systèmes d'information et de données spatiales», prepared by Paul Kopp, Technical Center in Toulouse, June 1995.

[741] « Banques de données. Système d'accès aux données spatiales », prepared by F. Chabanne, Technical Center in Toulouse, March 1995.

concluded the authors of the report, considered their own participation in the data management as a "plus-value" complementary to CNES's expertise. "S'agissant de projets scientifiques", so concluded the Waldteufel's group, "il revient normalement aux scientifiques de les porter, même s'ils ne les exécutent pas"[742]. They recommended, in other words, that the development and operations of data management must be the product of a consortium between organisms, in particular, but not necessarily exclusively, between CNES and Institut National des Sciences de l'Univers of CNRS (INSU).

To sum up, the authors of the report proposed creating a number of "pôles de compétence thématique" across the territory focused in a given scientific area, like atmospheric chemistry, atmospheric physics, marine biology, continental biosphere or physical oceanography. They would pool all the scientific expertise of *data creation* in their corresponding domain to make sure that complex datasets beyond singular geophysical parameters would be produced at the demand of the *data users*. In other words, they would create the algorithms for producing new datasets or improving old ones, as well as validate the whole, with particular accent put in algorithms to create complex data from the combination of measurements obtained with different instruments. Each pole would be associated to a technical datacenter, responsible of integrating these inversion algorithms to the software of data mass-processing. These poles would be also in charge of archiving and disseminating the resulting datasets, which would be done through online databases open to all scientists and institutions working in the field of Earth sciences.

We would like to conclude by stressing that in spite of some important novelties (in particular the end of the "monosensir"-era for data processing and interpretation), the recommendations emitted by this report reflected a continuity in the practices and representations of the data gathering, production and dissemination. First, the report reproduced the factory-like commonplace accepted model of data production according to which observations gathered by the space instruments are transformed into several geophysical parameters following different levels of preprocessing and processing. The system maintained along the 1990s defined, as we have seen, a boundary of expertise regarding the production of satellite data. Typically, while CNES assumed the production of level 1 data (calibrated physical radiances) for the sake of controlling the corrections and image distorsions, it did not engaged in the production of superior data levels, which were considered to be of scientific domain of expertise. The conclusion of the report described this very same distribution of labor:

> " Une "frontière" de compétence existe dans l'élaboration de ces niveaux de données, c'est le niveau 1: jusqu'à l'élaboration des données de niveau 1, la compétence se trouve plutôt dans les organismes spatiaux ; au-delà (données de niveau 2 et supérieur), la compétence est du domaine des laboratoires de recherche scientifique »[743].

This extract reflects the very same division of tasks deployed for producing and disseminating the data obtained with POLDER-1 (discussed in chapter two) seen as an efficient manner to allocate

[742] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.
[743] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

responsibilities and expertise to those deemed to be the best placed to conduct a given task. To our views, the fact that the authors of the report (different communities, computer scientists at CNES, and administrative personnel) conclude on that picture, after having asked to scientists from 43 laboratories belonging and 17 non-academic institutions, illustrates that the socio-technological system of data mass production and dissemination was, by 1998, consolidated as the admissible schema for data production and dissemination.

We shall remark at this point that beyond epistemology and social distribution of work, nonetheless, there was also strategy –as reckoned by Philippe Waldteufel himself in a personal communication:

> « Fin 1998 les correspondants de la communauté scientifique dans la Direction des programmes du CNES étaient conscient-e-s de la difficulté, et identifiaient plus ou moins le fait que le manque le plus critique concernait les niveaux 3 et 4, ceux des centres thématiques multi missions. Ils cherchaient un moyen de "protéger" ce qu'on arriverait à mettre comme moyen sur l'archivage. La meilleure façon de protéger consiste à faire des conventions avec d'autres organismes partenaires, et ensuite on est un peu obligé de respecter sa signature ! D'ailleurs s'agissant des niveaux 3 et 4 les institutions de recherche sont valablement concernées il est légitime qu'elles cotisent »[744].

This "protection" refered to the fact that previous experience with POLDER and Topex/Poseidon had showed that, in the course of developing and realizing stages of the ground segment, the budget used to inflate beyond what had been initially planned. Given that mission's budget was closed, managers used to "steal" the resources from other elements of the project, typically from the last stages of the project which were of no immediate need, namely, those envelops reserved to the data handling during exploitation of the satellite. In consequence, when it was time for data exploitation the remaining budget usually was insufficient. "Protecting" is to be understood here as ensuring resources and funds through the investments of another institution, in this case CNRS, who would participate in the later stages, during the exploitation of the satellite (from levels 2, 3 or 4).

Connected to that, this is a second aspect that we would like to remark, the novel imperative of multi-instruments and multi-missions did not change the type of knowledge and the skills necessary to create the data. The epistemic virtue of the data had scaled up one or two levels (from 2 to 3 or 4), but the development of algorithms required the same expertise in technological data practices of inversion. According to this approach, satellite data were interpreted from a physical approach to create geophysical datasets; they were certainly complex fusions and combinations of multiple physical measurements, but they remained being geophysical datasets after all. In consequence, what we have been calling *data creators* continued to hold a central position in the world of satellite data gathering, production and dissemination, because they were the holders of the knowledge. The socio-technical ordering remained unchanged, which proves a certain degree of consolidation.

Third, by alleging that scientific capabilities were hosted at scientific institutions (CNRS) and that technical were hosted at CNES, the authors of the report recommended that the task of centralizing and handling the data, satellite and non-satellite, related to the Earth and its environment would be

[744] Philippe Waldteufel, personal communication, 2014.

endeavored in partnership between CNRS and CNES. To be sure, while the report gave central attention to satellite data, it also dealt with non-satellite data gathered with surface instruments, standardized networks, through extensive field campaigns or issued from computer simulations. Both institutions, CNES and CNRS, were committing to handle all these data. In other words, the resulting configuration of the data management system assumed the intervention of CNES, the *space* agency, in the archival of *non-space* data. In other words, it consolidated the idea of holistic space missions which included non-space assets.

In all these senses, the report provided no visionary ideas for data management but it rather *normalized* the customary practices deployed, or at least planned to deploy, for the missions launched in the 1990s, Topex/Poseidon, POLDER-1 and ScaRaB. It made explicit the existing practices for data production and dissemination, it confirmed the distribution of labor between the actors deemed as the most efficient one, it reflected and reinforced the representations of power between them and their boundaries of action, it strengthened the centrality of the technologies of calibration and inversion in the production of geophysical datasets (certainly, intending to create data of superior levels, but geophysical datasets after all). It reaffirmed the existing epistemology. In a way, this shall be of no surprise if we look at the people and laboratories that participated in the polls: responses from scientists of LOA, CESBIO (former LERTS), LEGOS and IPSL, those involved in the missions Topex/Poseidon, POLDER-1, ScaRaB and VEGETATION, which were the missions of the first generation, correspond to more than 70% of the total responses[745]. That is, scientists of the type what we have been calling *data creators*.

It is plausible to assume that the merit of the report was instead to institutionalize the management of data as an issue. By requesting the scientists, in an individual manner or in a collective manner within their laboratories, and other institutions like CNES, MeteoFrance, Service Hydrographique et Océanographique de la Marine (SHOM) or SPOT-Image to answer a few set of questions, this report constituted an exercise of common reflection at a national scale, involving, at least in theory, a number of actors well beyond the *data creators* used to work with satellite data. It brought the issue of data handling on the table and created a very simple consensus on two points. First, it defined a general schema based on thematic poles (scientific group supporting a technical datacenter). Second, it allocated responsibilities, by concluding that such as effort must be conducted in a joint collaborative manner, especially between CNES and INSU/CNRS. Both institutions would derive some formal commitments, budgetary lines and institutional agreements from the recommendations issued in this report –some of them would give birth to a thematic pole devoted to the aerosols, clouds and radiation budget, which would be named ICARE (Interactions Clouds Aerosols Radiation Energy). The corresponding datacenter and its database are the topic of the rest of the chapter.

[745] « Les bases de données pour les géosciences. Eléments pour un schéma directeur », Rapport du groupe de travail CNES-INSU sur la Gestion des données, 1999.

CONSOLIDATING THE SYSTEM: THE DATACENTER ICARE (INTERACTIONS CLOUDS AEROSOLS RADIATION ENERGY)

POLDER-2 was one of the firsts instruments scheduled for launch after the release of the Waldteufel's Report in October 1999. Actually, even though having been planned prior to the elaboration of the report, the data infrastructure of POLDER-2 crystallized already some of the recommendations issued from the report: as a heritage of POLDER-1, two thematic poles had been established (atmosphere at Lille and ocean color in Paris) and a data production, dissemination and storage system had been developed based on an initial production at the Technical Center in Toulouse with a transfer to the Commissariat à l'énergie atomique (CEA), which would handle the data processing during the exploitation and their archiving during 10-15 years. POLDER-2 would however be followed by the launchings of PARASOL, CALIPSO, and the rest of the satellites of the A-Train, and Megha-Tropiques, all them satellites carrying instruments to observe atmospheric properties. Building upon the legacy of POLDER-1, the data management for POLDER-2 must be transformed as per include the main requirement underlined by the Waldteufel's report: enlarging the scope of the center as to integrate the management of data from other satellites in order to ensure that datasets of superior level were created by combining measurements of different instruments.

A working group was convened to present a concrete proposal for establishing a thematic pole devoted to handling the data related to the aerosols, the clouds and the radiation budget before the launching of ADEOS-II. The proposal was named ICARE, standing for Interactions Clouds Aerosols Radiation Energy[746]. The launching of ADEOS-II was delayed several times taking place finally in 2003. This would give more time to the group to develop and realize a sound project for such datacenter. During 2002 the support of CNES and INSU to the project got concretized. CNES would allocate 0,3ME annually to support the ordinary functioning of ICARE. This basis could be completed by specific attributions related to the ground segments of CNES's missions like ADEOS-II, CALIPSO, PARASOL or Megha-Tropiques. CNRS would recruit technical manpower[747]. By January 2002, following the classical procedure of Reviews at CNES, a proposal was presented before a Review Group, which would emit some recommendations to a Steering Committee about the pertinence or not to open a budgetary line at CNES to start up the project ICARE. In this meeting, the working groups would present the rationale for their project, possibilities for development, options for partnership, budget and calendar[748].

During the meeting of January 2002, a tight schedule was proposed to achieve the goal of being operational by the launching of ADEOS-II. In a first stage, *data creators* must develop algorithms for

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[746] Similar moves were made to create a thematic pole, called POSTEL, in close collaboration with scientists of CESBIO (former LERTS), INRA and CNRM, directed by Marc Leroy, devoted to handling the data for studies related to the land surfaces, which would handle data from POLDER-2 as well as from the future instruments Vegetation and SMOS. They would both work in parallel, sometimes even together, in the definition of the two datacenters.

[747] « Développement du segment sol et coût à achèvement du programme POLDER », elaborated by Alain Podaire, July 2001.

[748] Proceedings of "Point Clé ICARE", prepared by Anne Lifermann, January 2002.

creating data of level 3 and 4 by combining measurements gathered with POLDER-2 and MODIS (which had been launched in 1999 aboard the satellite Terra and planned to be launched again in 2002 aboard the satellite Aqua, both as part of the Earth Observing System program of NASA). The software was to be integrated into the ICARE's computer facility in order to test its feasibility and performances during a period of 6 to 8 months after the launching of ADEOS-II scheduled at the end of 2002. In a second stage, from December 2004, after the launching of PARASOL and CALIPSO, ICARE's software would integrate in an operational manner the data from A-Train[749]. This planning implied less than two years for developing and realizing the whole system. This calendrier did not convince the reviewers in that meeting in January 2002, who considered it "irrealistic" and "absolutely not credible":

> « Le calendrier présenté par le projet apparaît au GR comme trop tendu et, de ce fait, assez irréaliste, surtout lorsque l'on mesure la difficulté des tâches à venir (décision de programme, financement, ouverture à l'Europe, utilisateurs...) : la nécessité du choix du lieu d'implantation de la structure thématique fixé en mars 2002, alors qu'aucun financement ne semble acquis, n'est, par exemple, absolument pas crédible »[750].

Four were the urgencies to be done (technical and scientific developments, allocating funds, selecting a location, and looking for users) in less than 2 years. This plan must be readjusted, and the reviewers recommended a very specific way to readjusting it, which would directly impact of POLDER-2:

> « [Le Groupe Revue] n'est pas convaincu, par exemple, qu'il y ait urgence vis à vis du projet POLDER qui devra pour ce qui le concerne, et dans un premier temps, valider ses produits mono-capteur issus des nouvelles chaînes scientifiques de niveaux 2 et 3 avant d'envisager un croisement et une fusion avec des produits issus d'autres capteurs. Seule semble importante l'influence du planning concernant CALIPSO et, peut-être, PARASOL »[751].

ADEOS-I had failed without leaving consolidated results concerning the quality of the data. Recall that calibration methods, the datasets about the color of the ocean and those about the aerosols over land surfaces had been considered to be of insufficient quality to be disseminated. POLDER-2, so it was argued, must yet verify the quality and feasibility of its own datasets before committing to combinations and fusions with other data. Above all, it was made clear that the major goal of ICARE was to cope with the data from the satellites of the A-Train, specifically "CALIPSO and, perhaps, PARASOL"[752]. That the possibility of having data from the different instruments of the A-Train would become the leitmotif of ICARE can be unraveled and confirmed further the examination of the detailed plans for developing ICARE. Almost everything turned around the A-Train: the computational needs of the system would be defined in function of the A-Train volume of data to be processed and stored; the information system would be dimensioned in function of the data flow rates between the computing data center of NASA and ICARE's; the planning timing would be elaborated to be ready just the launching of A-Train; the budget was estimated with respects of the annual A-

[749] « Développement du segment sol et coût à achèvement du programme POLDER », elaborated by Alain Podaire, July 2001.
[750] "Recommandations du Groupe de Revue ICARE », 27 February 2002.
[751] "Recommandations du Groupe de Revue ICARE », 27 February 2002.
[752] « Rapport du groupe de Revue du complement REP», 7 July 2003.

Train estimations. Actually, the handling of POLDER-2 data had been only considered as a test of the system before rendering it operational for the A-Train[753].

All and all, POLDER-2 would be left out of the project. As a consequence, like POLDER-1, the ground segment of POLDER-2 would consist, as we have seen, in a computing center of "mono-instrument type" processing the calibrated data generated from POLDER's measurements in the Technical Center of CNES in Toulouse and transferring it to the Commissariat à l'Energie Atomique for processing superior levels, archiving and disseminating them. Like ADEOS-I, ADEOS-II was conceived to live for three years; like ADEOS-I too, ADEOS-II broke down several months after the launching, due to a failure in the solar array paddle. The factory-like system for mass-producing and disseminating geophysical datasets planned for POLDER-2, like the one planned for POLDER-1, would never had the chance to be implemented in a routine manner, but only for a limited number of data during the testing stages. In particular, like the computing center for POLDER-1, the computing center for POLDER-2 would be never transferred and entrusted to the Commissariat à l'Energie Atomique and would remain centralized in the Technical Center of CNES in Toulouse, which would also ensure the archival of the data. However, this did not imply however that POLDER-2 data would not reap benefit from ICARE: it was planned that once processed, geophysical datasets retrieved from POLDER-2 measurements would be transmitted to the online database of ICARE for further archival and dissemination.

Enter field-work data

As a consequence of this decision, POLDER-2 measurements combined with MODIS measurements could not be used to test the performance of the computer facility of ICARE. Yet, the conduction of a pilot project was considered necessary before engaging full operations with the data of the A-Train. Two reasons were brought forward to justify the need for a testing project. On the one hand, it was a way to assess the technical capabilities of the system, to detect deficiencies, to weight limitations and eventually correct and improve it. On the other, it was a way to enroll future users. Mobilizing the scientific community around a particular pilot project was a strategy to rally in scientists who had not participated in the conception and realization of the project[754]. In 2002 an international field campaign to study the West African Monsoon, its variability and its impacts on communities in the region would start, the African Monsoon Multidisciplinary Analysis (AMMA)**.** This campaign**,** initiated by French laboratories and strongly funded by French institutions, including CNRS, MeteoFrance, Ifremer or CNES, and European Community's Sixth Framework Research Programme, would gather more than 140 laboratories from 30 different countries (around 40 of which from France, including LMD, LOA

[753] « Synthèse du dossier de Définition Préliminaire du Pôle de compéténce thématique ICARE (Interactions nuages-aérosols-rayonnement-vapeur d'eau) », elaborated by Anne Lifermann, Alain Podaire and some contributions of LOA, February 2002.
[754] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

or LSCE)[755]. A myriad of ground instruments would be deployed, prominent amongst which the standardized set of instruments of the climate facility of the US Department of Energy –that we have mentioned in a number of occasions (extending by so doing the network of such instruments to African territory, which was until then poorly covered), which would be complemented with periodic launchings of radiosondes, balloons and/or flights of the aircraft Falcon 20 of MeteoFrance equipped with a number of radiometers, lidars, radars and conventional weather instrumentation. It would be the data from this campaign that would be used to test the computer facility of ICARE (processing, disseminating and archival through internet database). For instance, LOA's scientists, majorly funded by contracts from CNES[756], would take measurements made by different ground-based and aircraft-based instruments deployed during the first months of AMMA to elaborate algorithms that would be integrated in the computers and run in operational manner.

We would like to conclude with two comments. If a major goal of the pilot experiences conducted at ICARE was to gain visibility and gather scientists in, just like it was mentioned in several documents[757], using data from extensive field campaigns like AMMA, in which a very large amount of French scientists from more than 40 laboratories were involved, was certainly more effective that using data from POLDER-2, in which only a relative small number *data creators* would be allowed to work out the data. Whether this aspect was decisive in privileging the tests of ICARE with data from AMMA instead of from POLDER-2 has not been however confirmed by any interviewee. Secondly, AMMA was a field campaign in which the main instrumentation would be deployed in the ground (on a permanent or temporary basis) and gathered by airborne instrumentation. Unlike other field campaigns[758], there was no plan for launching any satellite endowed to gather data for such precise campaign. Of course, nothing prevented scientists to use the data gathered with the existing satellites – for instance, Meteosat was located in a geostationary orbit and covered permanently the region in which the field campaign AMMA was conducted (Niger, Mali, Benin)- but no plans for launching any

[755] The objectives of the campaign were threefold. First, to improve the understanding of the West African Monsoon and its influence on the physical, chemical and biological environment, regionally and globally. Second, to provide the underpinning science that relates variability of the West African Monsoon to issues of health, water resources, food security and demography for West African nations and defining and implementing relevant monitoring and prediction strategies. Third, to ensure that the multidisciplinary research carried out in AMMA is effectively integrated with prediction and decision making activity. A first period of data-gathering between 2002 and 2010 would be followed by a period of data analysis, which still last at this writing.

Rapports d'activités LMD.

[756] For instance, CNES would fund a computer scientist for two years to work on these pilot project and would provide annually approximately 400 K€ between 2002 and 2004 for developing the system.

« Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

[757] « Synthèse du dossier de Définition Préliminaire du Pôle de compéténce thématique ICARE (Interactions nuages-aérosols-rayonnement-vapeur d'eau) », elaborated by Anne Lifermann, Alain Podaire and some contributions of LOA, February 2002.

[757] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

[758] Two casuistic may appear, according to the conceptualization presented in chapter four. On the one hand, those projects conceived to support field campaigns: this would be the case of the satellites BEST or TRMM, conceived within the framework of an international program of the WRCP, the Global Energy and Water Cycle Experiment designed between 1985 and 1990. On the other hand, those projects designed to support a space mission: this would be the case of the World Ocean Circulation Project, 1986, of the World Climate Research Program designed around the launching of Topex/Poseidon and ERS.

specific satellite were committed. And yet, CNES's contribution (and NASA's) to the campaign in terms of technical, material, human and funding resources, directly in taking measurements in the field and in the laboratories preparing the instruments or analyzing the data, was not minor. This intervention exemplifies, in our views, the normalization of the integration of non-satellite measurements as part of the grammar of space agencies, an instance of the holistic nature of space activities involving the ground, the field and the space, as described in chapter four. Because to create future satellite data, to manage it, to validate it, non-satellite data are needed, so the argument went, space agencies allocate resources to field-work even when no satellites are specifically launched – although in the perspective of any space activity is in the sight.

"On nous prend le Soleil mais on nous file un PARASOL"

We have mentioned that the location for implementing ICARE must be decided by March 2002. Two candidates crystallized, LOA and IPSL –bringing into light again the concurrent projects that had materialized for POLDER-1. The choice was difficult from a scientific point of view. The responsibles of the French instruments that ICARE was supposed to handle were distributed between LOA and IPSL: Pierre-Yves Deschamps of LOA for POLDER-2, Didier Tanré of LOA for PARASOL, Jacques Pelon of SA/IPSL for CALIPSO and Michel Desbois of LMD/IPSL for Megha-Tropiques. Whereas LOA reunited most of the expertise in the creation of data in the aerosols domain in France, IPSL hosted an important team working with clouds and radiation budget. In terms of eventual data users, IPSL had arguably a stronger human mass than LOA, at least working in numerical modeling (climate models, chemical models, oceanography models, vegetation models); none the less, several of the codes and parameterizations of these models were provided by LOA's scientists, especially those working with the team of Yves Fouchart[759]. Besides, several scientists of LOA, directed by Olivier Boucher, worked also close together with modelers of the European Center for Medium Range Weather Forecasting in Reading (some of them were even based in the United Kingdom, like Jean-Jacques Morcrette and Michèle Vesperini)[760]. In terms of expertise and technical capabilities for managing data, IPSL hosted already two datacenters: ETHER, dedicated to data from atmospheric chemistry and PLASMA, dedicated to physics of plasma. While some considered this expertise as a levier upon which to yield, some others considered it as a dangerous centralization of resources. In terms of workforce, on the one hand, IPSL representatives, backed by the fact that the scientists at IPSL outnumbered by far the scientists at LOA, emphasized the advantages to be reaped from the proximity between the technical and the scientific personnel –this had been pointed as an advantage in the precedent experiences like Topex/Poseidon[761]. Some IPSL's laboratories, like SA and LMD, had already requested ITAs specific for ICARE to be recruited from January 2003. On the other hand, LOA and University of Lille had been long negotiating with the Région Nord-Pas de Calais, and

[759] Rapports d'activité LMD and LOA, 1979-1990.
[760] Rapports d'activité LOA, 1982-1995.
[761] « Rapport du groupe de Revue de la REP », 1 February 2001.

vindicated their "historical right". By mid-2002 the region had specified its commitment: between 2002 and 2007, it would allocate 0,5 M€ to LOA and 1,65 M€ to the technical facility, to be consumed in equipment and personnel. Besides, the Région envisioned requesting FEDER's specific funds, which would cover 40-50% of the project during its development. The University of Lille would support the project also by recruiting a systems engineer, an operator and an algorithms specialist, as well as by providing 200 m2 equipped with basic computer equipment[762].

By 2001 the two regions had been competing also for hosting the synchrotron SOLEIL, which would be finally installed at Saclay's plateau[763]. We ignore exactly the weight that this decision might have had over ICARE's one but, by mid-2002, roughly few months after SOLEIL would be attributed to the Franciliens, the Comité Directeur of ICARE felt the choice in favor of the Lille's option[764]. In the Lille actor's folklore this succession of events won the joke of "on nous prend le SOLEIL et on nous file un PARASOL"[765] and it is considered as a non-negligible factor contributing to the decision. Be as it may, CNES, CNRS, Région Nord Pas-de-Calais and the University of Lille started to negotiate the Convention to create ICARE, which would be signed on October 24th 2003[766].

The archive: Physical or geophysical datasets (or climate records)?

What data would be archived in this datacenter? This decision would have implications on the access to data: all the data integrated in the ICARE computing facility would be in principle accessible through its online database –upon registration and perhaps with some sporadic exceptions or conditions. They could consequently be used by *data users*. On the contrary, the data not handled by ICARE would be much more difficult to be accessible through its database. The issue can be posed with two questions: What are to be archived and where? This was a bone of contention between space managers, *data creators* and *data users* during the negotiations for defining ICARE –this is still an issue at present day. Ideally, and reflecting a logics of giving optional value to data according to which data has a perspective of potential use, all data has to be archived. However, pragmatic issues prevail given that resources are limited. How balancing the need of perennially archiving as much data as possible with more prosaic factors that may hamper this endeavor (like budget limitations, technical capabilities, technological changes, sociological issues, local experimental circumstances and practices, etc.)?

[762] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

[763] This project had been suffered a number of delays, cancellations and recoveries largely covered by the media. For instance: a search of "synchrotron Soleil" in the online version of Le Monde between 2000 and 2001, provides more than 40 entrances headlined as suggestively as "Le Nord envoie ses cerveaux au charbon », « Où ira le Soleil », « Bataille pour le synchrotron », « Réactions contrastées au choix de Saclay pour le Synchrotron Soleil », inter alia. The synchroton would be inaugurated in 2006, after the project was finally conceded in October 2001 to a partnership between CNRS, CEA Ile de France region, the General Council of l'Essonne and to a lesser extend the Central Region.

[764] « Rapport du Comité directeur du point clé de fin de recette en vol QI et de la QO du système POLDER-2 sur ADEOS II », prepared by F. Bermudo, project manager, December 2003.

[765] « Rapport du groupe de Revue du complement REP», 7 July 2003.

[766] "Relevé de conclusions de la réunion du Comité directeur ICARE", 14 june 2002 at CNES-Paris, elaborated by Alain Podaire.

Some said that because the data of superior levels (2, 3 and 4) could be reconstructed from the data of law levels (0 and 1), provided that the algorithms, computer codes and software would be properly archived and conserved, perpetual archiving would be only necessary for those low datalevels: « toutes les données éventuellement archivées de façon non nécessairement pérenne devront pouvoir être reconstituées à partir des archives primaires »[767]. Computing services of the Technical Center of CNES, as we have seen with the words extracted from a position paper of one of its components Paul Kopp, vindicated this task as their responsibility. In general, the institution CNES would argue that because it was the responsible of producing the physical data of level 1, it was part of its duty to ensure their "quasi-eternal primary archives" and to

> « maintenir de façon sécurisée et pérenne les données d'archive primaire produites par les missions dont elles ont la responsabilité (approximativement les niveaux 0 et/ou 1), et des moyens conséquents ont été mis en place au CNES pour assumer ce rôle au Centre Informatique, à travers le "Service de Transfert et d'Archivage de Fichiers" »[768].

This portrayed the very same limits posed by *despatialization* in the production and dissemination of geophysical datasets. In the domain of data archival, too, CNES ensured lower levels and some entity in the scientific community must ensure superior levels, from 2 upwards. In a sense, this ideal of reconstruction reflects a sort of positivist vision of data production (explicitly illustrated by the data production chain): because data are rolled into a code, to get them back one shall only run the code forward. This vision underestimates several of the elements of research practice that have been identified by scholars in science studies as being captured in the development of any experimental practice: tacit-knowledge, expertise that comes from daily engagement with experimental systems, familiarity with the laboratory's "ways of doing", theoretical commitment and framework, scientific objectives, interests of the individual or the laboratory, material changes in the equipment, etc[769]. Grounded on these acquis, we would not give for granted the reproducibility of the data. Each retrieval algorithm depends on the experimental setting, the instrumental devices, the scientific assumptions and the scientific question posed by the scientists who creates it; then, turning it into a code, depends on the language code, the style of writing it down, its optimization by the code developers, the computer power, the objectives with which they had been mass-produced, auxiliary data necessary for processing not always available, and so forth. Each code enfolds not propositional knowledge and expertise which constitute the circumstances under which scientists can retrieve the data from a given code, and yet they are hardly incorporated in the code itself. In chapter six we will concretize some of these issues –and some of the solutions found by the community.

That being said, to some data users, preserving data had the interest of being able to build data records about a given geophysical parameter (or a fusion of several parameters) in the long term, not about sets of physical radiances. It was not enough in conserving data for prospective usages, current usages

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[768] "Recommandations du Groupe de Revue ICARE », 27 February 2002.

[769] One of the most prominent examples illustrating the issue of reproducibility of experiments is provided by Harry Collins analyzing the attempts for replicating the experiments with a new type of laser in different laboratories: "Changing Order: Replications and induction in scientific practice", 1985.

were also to be accounted: if data must be conserved it was to exploit its usage from a climate approach, to enable the construction of *climatic datasets*. The point was that, even if *physical radiances* were dutifully archived, reproducing *geophysical data* from inferior levels of measurements gathered with different instruments during a period of 10 years was not that obvious: material support of the data changed and rendered them unreadable with new devices, auxiliary data became no longer available, the retrieval algorithms also evolved without traces of the successive modifications, coding languages also changed requiring other algorithmic structures and formalisms, changes in computer power allowed different degrees of precision in the computations, people also changed putting the accent in different aspects –in chapter six we will develop some of the issues involved in the production of *climatic data*. To them, all data must be archived and, for that, CNES's resources were necessary[770]. There was still a third option. To some other voices this system prevented the use of data of inferior levels. Some studies, they argued, may need using data of inferior levels (we will describe some of them in chapter 6). They pleaded, thus, for all the data, including physical radiances, to be archived and accessible through ICARE as a way to guarantee full access to all data[771].

Numerous discussions on that topic took place between 2001 and 2003, which would be resolved in a distribution of duties and data policies identical to the existing ones for POLDER: CNES assumed the task of perpetuating data of level 0 and 1, leaving ICARE with the responsibility of perpetuating the data of level equal and superior to 2. In a case-per-case basis, CNES's data services could study the possibility of engaging in the archival of superior levels or in the cession of inferior levels to ICARE's archival responsibility[772]. One exception would be the physical measurements of the Earth radiation budget whose epistemic virtue, as we have argued before, was held in the physical radiances per se and not in any geophysical parameters. ICARE would ensure their archiving and not CNES.

Two points, we believe, are worthy to be highlighted. First, these discussions illustrate that satellite data are not embedded in a unique epistemology but their modes of usage, and requirements of access, depend on the epistemic group requesting them. In this case, for *data creators* willing to develop inversion algorithms from physical radiances it is enough to preserve the radiances: superior data can be, if needed, derived from them by means of their algorithms. Yet, some recognize that processes of reconstruction are not always possible (for material, budgetary, timing or simply because of the lack of metadata and auxiliary data provided with the codes). They campaign instead for conserving all data of superior levels. In particular, these are *data users* interested in conducting climatological studies of processes, trends and variability: to very construct these *climatic datasets*, they must have access to all *geophysical data* and not depend on their eventual reconstruction from *physical radiances*. While yet others, may still campaign for giving ICARE the responsibility to archive inferior data as well as per ensuring that they will be easily accessible to all. These may be *data creators* (and *users*) interested in

[770] « Synthèse du dossier de Définition Préliminaire du Pôle de compéténce thématique ICARE (Interactions nuages-aérosols-rayonnement-vapeur d'eau) », elaborated by Anne Lifermann, Alain Podaire and some contributions of LOA, February 2002.

[771] "Recommandations du Groupe de Revue ICARE », 27 February 2002.

[772] « Rapport du groupe de Revue du complement REP», 7 July 2003.

studying the Earth's radiation budget (these may be also *data users* willing to use radiances in their numerical models, we will encounter in chapter six). The point is that different uses and usages, different approaches to data unfold different needs of data, of their perpetuation and of their modalities of access. These varied types of scientists provision for different degrees of data access for different users.

Second, the model for data archival would be based on the model developed for POLDER-1, which was characterized by a separation between the tasks of CNES (despatialization) and of the scientific community. It was not only that this epistemology did not introduce dramatic changes in the process of data archival conceived in the 1980s and effectively established in the 1990s with the first space missions in France, but it exported it to the rest of missions that would be handled at ICARE: it was about developing inversion algorithms (taking measurements from different instruments instead of from one single instrument), coding them and integrating them into the software for factory-like mass production and dissemination. Data access policies would remain grounded on the very same logics: because *data creators* held the epistemic authority (grounded on their expertise in radiation transfer and instrumentation) they would be the legitimate scientists to access data of level 1 giving the reward of original publication or, seen from the other reading, because epistemic virtue of data was located in geophysical parameters (of higher level) this would be the datasets delivered to *data users*, and not radiances or, seen from a third reading, because CNES was responsible of producing calibrated radiances it developed a sort of sense of property over these data which would not be delivered. By the same token, the social organization introduced during the formative years (1980s-1990s) was reinforced: centrality of data creators, dominance of technologies of data inversion and of the physical approach in order to create geophysical datasets.

The raison d'être of ICARE was to provide geophysical datasets of superior levels to *data users* and to ensure their preservation. In its mission of rendering data available, only some highly standardized forms of *geophysical data* tended to be disseminated fully openly; *physical radiances* were archived and disseminated by CNES, with access upon request –*climatic data* were simply not part of the program. In other words, we argue that ICARE was built to fit the current practices. Instead of capitalize in the number of *data users* that eventually could have access to the data and promote new modes of usage, ICARE presented the data in a way in which they invited to use a very specific type of data to conduct a very specific type of research. ICARE was an agent *normalizing* the practices established with POLDER[773].

[773] The philosopher of sciences Sabina Leonelli and the anthropologist Christine Hine have conducted studies about the influence of digital data-basing in the current practices of molecular biologists. The approaches of both scholars differ, and they differ also with ours; yet, they have also found similar conclusions: databases archive and disseminate very particular forms of data to a well-identified community who is prepared to use them in their research. The potential users are identified through their scientific questions, the scientific frameworks in which they operate, institutions they belong or their epistemic cultures. Data can certainly be recycled and used beyond these research contexts (we will study some of these variety in the following chapter), but the use of data accessed through databases is more or less circumscribed by the archiving conditions. See: Christine Hine, "Databases as scientific instruments and their role in the ordering of scientific work", 2006 and Sabina Leonelli, « Global data for local science : Assessing the scale of data

Box 5.1. ICARE and Big Data

A group of computer scientists at the Technical Center of CNES in Toulouse had been working since 2001, under the supervision of Alain Gaboriaud, in the architecture of the computer system needed to handle all these data coming from these diverse space and non-space instruments. Their estimations about the data volumes for processing and for archiving, as well as the time required for such procedures (as they were estimated in 2002):

Mission	Estimated data volume	Source of data	Archived data	Estimated volume of archived data/during the expected flight time
CALIPSO	25 Gb/day	Langley Research Center	L2 of IIR L2 of CALIOP L4 combining IIR and CALIOP	40500 Gb/3 years
CLOUDSAT	63 Gb/day	Colorado State University	-	68040 Gb/3 years
MODIS	32 Gb/day	Goddard Space Flight Center	-	34560 Gb/3 years
POLDER-2	10 Gb/day	CNES	L2 and L3 of aerosols, oceans and radiation budget L3 of the atmosphere product	12420 Gb/3 years
PARASOL	10 Gb/day	CNES	L2 and L3 of aerosols, oceans and radiation budget L3 of the atmosphere product	8280 Gb/2 years
Megha-Tropiques	2 Gb/day	Indian Space Agency	L2 of Saphir L2 of Madras L2 of Scarab L4 combining Madras and Saphir	11124 Gb/3 years
Exogeneous data	40 Gb/day	ECMWF, MeteoFrance, EUMETSAT, etc.	-	72000 Gb/5 years
Total	130 Gb/day simultaneously			247158 Gb

Table 5.1.These preliminary studies concluded then that the scenario A-Train achieved a data volume of 140 Gb per day. The internal data flow was estimated to 450 Gb per day. The data flow towards the external users was estimated to 1 Mb/s if all circulation was conducted through the network[774]. At its inception ICARE was meant to handle data from PARASOL, CALIPSO, other A-Train data (CLOUDSAT or the Infrared Imaging Radiometer), and the instruments inside Megha-Tropiques (ScaRaB, MADRAS and SAPHIR). Today it processes as well some of the data from the instruments SEVIRI, OMI, CERES or MERIS. It also processes the data from some field campaigns and ground observatories. Data are contained and disseminated through a web-based database, which also functions as an archive where data from other instruments, including the older POLDER-1, POLDER-2 and PARASOL or weather analyses from the European Center for Medium-range Weather Forecast also classified and preserved.

It was considered that 4% of the daily volume of data (5 Gb/day) must be available from ICARE in less than 12h after gathering. In other words, these data would be circulated from the source processing center (NASA, CNES or the Indian Space Agency (ISRO)) to ICARE through the net and their integration and further processing

infrastructures in biological and biomedical research », 2013. See also the special issue of Studies in the History and the Philosophy of Biological and Biomedical Sciences on "Data-driven Research in the Biological and Biomedical Sciences", 2012.

[774] « Etude d'architecture informatique du pôle ICARE », January 2002 and « ICARE. Dimensionnement du pôle thématique ICARE », prepared by Alain Gaboriaud, January 2002.

(when necessary) would start automatically. The rest of the data would be then shipped through CD-Rom, DVDs or DLT[775] (or through the net depending on the capacities of the existing networks) and integrated in the database after reception. This system provided that seven days of data would be fully integrated in the ICARE database in four days[776]. It would require at least five devoted technicians to operate and maintain it and its implementation would cost 3000K€ in software and computer material[777]. We must not overestimate these figures. Although these were certainly big amounts of data, these volumes were manageable with the appropriate computers existing in the market –actually, the computer center at CNES could cope with these data[778]. Scientists and space managers who had been by the late 1970s impressed by the volumes of data coming down from the satellites, were by the early 2000s, as we have been recurrently told in our interviews, not impressed anymore, as these volumes were actually far less than current computer capacities[779].

This preconizes what several scholars in science studies have cautioned against in these recent years: the fascination with the phenomena of Big Data, in particular about the Big part of the term, in terms of data volumes[780]. Some historians have recently showed that perceptions of data overload or data deluge have been recurrent in the history of sciences. The historian of natural sciences Bruno Strasser, for instance, has traced back up to the Renaissance and showed that naturalists were inundated with new data due to the expansion of travel. They were confronted with a wave of huge incoming volumes of data –or specimens- and with issues of how storing and conserving them[781]. Along the very same lines, the historian David Sepkoski, in his study in the domain of paleontology refuted that earlier eras of science coped with less amounts of data than contemporary digitalized eras –at least, in their perceptions[782]. These findings point to some continuities in the perception of data avalanches that has characterized different scientific communities at different times with recent fascination in the digitalized era –not that surprisingly, in a sense, as historians like to push a given origin further back in time. By pointing these continuities, they send a message of caution and moderation vis-à-vis this fascination about Big Data.

Our case study about the data that the datacenter ICARE was meant to handle adheres this moderated regard from another standpoint: scientists (data creators, data users, space managers, computer scientists) just did not perceive any sense of data avalanche, deluge or overload. By the 2000s, they did not perceive any Bigness of satellite data in terms of volume. In the light of this, the question then raised, we believe, is not how Big satellite

[775] Digital Linear Tape, a magnetic tape data storage technology.

[776] « Etude d'architecture informatique du pôle ICARE », January 2002 and « ICARE. Dimensionnement du pôle thématique ICARE », prepared by Alain Gaboriaud, January 2002.

[777] « Etude d'architecture informatique du pôle ICARE », January 2002.

[778] That being said, CNES was prone to purchase new equipment for less than 100kE: a SUN Entreprise 5500 of 6 CPU 400 MHz, together with internet network connections, printers, support readers and recorders, jukeboxes.

« Etude d'architecture informatique du pôle ICARE », January 2002.

[779]That computer capacity was not seen as a challenge in terms of capacity and power has been pointed out in a number of our interviews including Didier Tanré, Bill Rossow and Thierry Phulpin. Interviews with new generation of scientists, grown up and trained with digitalized data services, share these views. In general they have pointed however one eventual challenges in terms of data volumes: data obtained through eventual new generation of high-resolution imagery which may eventually constitute very large files.

[780] For an overview of the arguments mobilized by discourses of Big Data and scientific research see The Fourth Paradigm: Data-Intensive Scientific Discovery", ed. T.Hey et al, 2009 or the special issue of « Science » called « Dealing with Data », 2011.

[781] « Data-driven sciences: From wonder cabinets to electronic databases", Bruno J. Strasser, 2012.

[782] "Towards 'A natural history of data': evolving practices and epistemologies of data in paleontology, 1800 – 2000". David Sepkoski, 2013. See also the forthcoming volume of Osiris "Histories of data", ed. D. Sepkoski et al.

data were, but rather how came that we as a society, whoever the society is, get bothered about that Bigness in this very given historical moment of ours. We can do nothing but leave this as an open question.

Quest for *data users*

The organization of a thematic pole as preconized by the Waldteufel report, and *normalizing* the practices and representation defined in the mission POLDER-1, shall be articulated by a set of scientific expertise centers, cradle of *data creators*, developing and validating the scientific algorithms (they would be named in the internal jargon as « Centres d'expertise »). The technical branch of the pole would be organized as an archetypical computer center in the ground by acquiring, processing, archiving and disseminating the data –with the novelty that they would handle data from different sensors and they would develop algorithms for creating data of levels 3 and 4. They would take the algorithms proposed by the scientists at the "Centre d'Expertise" and would integrate them in ICARE's software for mass production. An archive would be developed to preserve the data and a web-based database would be developed to circulate them to users. Besides these tasks of processing, archival and dissemination, ICARE would offer another service to scientists: a super-computer was put at disposal for *data creators* to run their algorithms for testing or investigating purposes[783]. To coordinate the whole, a "Comité d'Utilisateurs" and a "Comité Directeur" (composed by the representatives of the partners CNES, CNRS, University of Lille and Region Nord-Pas de Calais) would be established, which would become the two decision-making instances of ICARE[784] -we will briefly discuss the users' committee in a while.

ICARE was a novel initiative. But NASA joined a widely recognized expertise in handling data through multi-missions datacenters. Even though NASA's system was far from being perfect, scientists all over the world, including French ones, had been using its multiple databases located at in-house laboratories like the Goddard Space Flight Center, the Langley Research Center or the Jet Propulsion Laboratory, but also in collaboration with external institutions like the US Geological Survey, the National Oceanographic and Atmospheric Administration or the US National Snow and Ice Data Center, to mention few. Scientists had been downloading datasets from these centers to their working computers at least since the late 1990s. ICARE was entering a market, the market of archiving and delivering satellite atmospheric data, which was already partially served by NASA's datacenters. Two questions emerged. First, it was not granted that scientists would turn to ICARE to retrieve the data that they could retrieve from NASA's databases (MODIS, CALIOP, CLOUDSAT, etc.). ICARE would have the monopole of providing some unique data produced from the measurements collected with the French instruments (POLDER-3, Infrared Imaging Radiometer inside CALIPSO and later on from those inside Megha-Tropiques) and from some combinations amongst

[783] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.
[784] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

them, and with MODIS and CALIOP, but it was not granted that these products would be "bought" by clients around the world. ICARE's promoters must plan a strategy to rally in future clients.

In that sense, first thing was to ensure a competent service. Competent meant to provide quality data and to provide them in duty time. NASA planned to release all its data in a quite rapid delay. For instance, physical measurements from CALIOP were to be released in quasi-real time only after a period of 1 to 2 months of calibration tests; the temporal embargo that CALIOP's *data creators* would have over these physical calibrated measurements had been fixed a priori and would not extend 6 to 8 months. After this time, the systematic production of geophysical data would start and they would be made available through online databases at the datacenter of the Langley Research Center of NASA. Excepting for some specific clausules, calibrated physical data would be also made available upon request[785] –in particular, some agreements between CNES and NASA had been provided for ICARE receiving the physical measurements of CALIOP[786]. For ICARE data to be competitive, similar data delivery schedules shall be met:

> « Il est important de réaliser que le contexte A-train est international et qu'une concurrence forte existe entre les équipes de recherche, en particulier européennes et américaines. Les services ICARE se doivent d'être au rendez-vous de A-train faute de quoi ils perdraient une grande partie de leur intérêt »[787].

For instance, one of the leading products of ICARE was the geophysical datasets retrieved with the algorithm Caltrack, combining data from the lidar CALIOP aboard CALIPSO with a number of other measurements including PARASOL's[788]. Producing this dataset required that the measurements from the both instruments were made available in similar timing enabling their combination. In other words, unlike POLDER-1, POLDER-3 could not afford to engage in calibration and validation processes lasting two years –that being said, regardless of the urgencies in the release of physical radiances for synergy purposes, PARASOL could not afford a validation process of two years for another simple reason: it was a microsatellite Myriade designed with an expected life from 1 to 2 years. There was no point in launching such a satellite if data were only available when the satellite was no longer in operations[789].

Secondly, as we have mentioned, some scientists beyond those advocating for the project must be sought to be the "clients" of ICARE. ICARE's promoters felt under pressure to demonstrate that their system would be used, a pressure that organized many of the project's priorities -for instance, as said before, conducting pilot projects to show the potentialities of ICARE was a way to rally potential users in by demonstrating capabilities and binding scientists to the project. The quest for users would

[785] Interview with Dave Winker, LaRC, 2013.

[786] "Définition du pôle ICARE. Périmètre, Fonctions, Organisation », Point Clé Phase 0, prepared by Anne Lifermann, January 2002.

[787] « Synthèse du dossier de Définition Préliminaire du Pôle de compéténce thématique ICARE (Interactions nuages-aérosols-rayonnement-vapeur d'eau) », elaborated by Anne Lifermann, Alain Podaire and some contributions of LOA, January 2002.

[788] « Caltrack Product Guide », elaborated by ICARE's technicians in 2007.

[789] Interview with Didier Tanré, LOA, 2014.

become one of the central preoccupations of ICARE's promoters between 2002 and 2004. A way to find and rally in *data users* potentially getting data from the ICARE's database would be to give decisional power to the people that were expected to become these future *data users*[790]. The atmospheric physicist of the Laboratoire de Météorologie Dynamique Michel Desbois, expert in computing radiation budget and clouds properties from satellite measurements, and whom we have met in the "Review" for validating POLDER-1's data, was appointed with the task of creating a "Comité d'Utilisateurs"[791]. He identified a particular form of *data user* eventually interested in the satellite data that ICARE was meant to provide: the numerical modelers in diverse specialties related to the atmospheric physics. He contacted then numerical modelers from a number of laboratories that have been so far absent of our account, which reinforces our thesis that the epistemic community of POLDER-1 and 2 had the particularity of being exclusively composed by *data creators*. These *data users* belonged to the Groupe d'étude sur l'Atmosphère Météorologique of Météo-France (GAME), Laboratoire d'Aérologie in Toulouse, Laboratoire Associé de Météorologie Physique in Clermond-Ferrand and Laboratoire Interuniversitaire des Systèmes Atmosphériques in Créteil. He identified also European laboratories working in those topics in Belgium, the United Kingdom, Italy, Spain, The Netherlands and Germany. The "Comité d'Utilisateurs" was finally established by the end of 2002 and was composed by a balanced number of *data creators* and *data users* (identified as numerical modelers) giving slightly more weight to the first group. Amongst the members of this "Comité d'Utilisateurs" we find familiar personalities closely related with the project POLDER, including François-Marie Bréon (working since 1991 in POLDER-1, LSCE), Didier Tanré (the scientific responsible of PARASOL (LOA)), Geneviève Sèze (working in clouds and radiation algorithms in POLDER-1 (LMD) or Anne Lifermann (project scientist of PARASOL, CNES). We find as well *data creators* from other projects, like Jacques Pelon (scientific responsible of the Infrared Imaging Radiometer inside CALIPSO (SA)) or from the « selected laboratory » Centre d'Etudes des Environnements Terrestre et Planétaires. As per the data users, they were all numerical modelers belonging to LOA, including Olivier Boucher of LOA, who had participated in the "Review" for validating POLDER-1 geophysical datasets, to the Laboratoire d'Aérologie, the Centre National de Recherches Météorologiques or the European Center for Medium-range Weather Forecast[792]. Apart from confirming a strong presence of *data creators* in the committee, this list confirms a second feature: a strong presence of POLDER-related people.

This group would have the decisional power of orienting the tasks of the technicians working at ICARE. They would choose the priorities in the datasets to be processed, propose new datasets, determine the possible reprocessing of certain datasets, or specific processing (some specific orbits or with some specific projection), distribute the hours of computing of the super-computer to be attributed to different data creators, demand the technicians to intervene in some of the technical

[790] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

[791] "Relevé de conclusions de la réunion du Comité directeur ICARE", elaborated by Alain Podaire, June 2002.

[792] « ICARE. La lettre d'information », n° 1, June 2005.

aspects of the data exploitation (develop data reading and visualization tools, specific software for manipulating the data once produced like reprojecting, reformatting or extracting). They would even propose that, in the long term, ICARE would eventually operate its own atmospheric model[793] -we have lost trace of this particular development and all we can say is that, at present day, this is not an ongoing discussion.

Some chronological references of the establishment of ICARE

In June 2003 the "Convention portant création of ICARE" was signed by CNES, the University of Lille (UTSL), the Institut National des Sciences de l'Univers of CNRS and the region Nord-Pas de Calais. By 2005, the center adopted its definitive form and function, ready to become fully operational few months after the launching of PARASOL.

1990-1993	Discussions data center atmosphere POLDER-1 at Lille Discussions data center in Paris (Institut Spatial de l'Environnement Terrestre)
1996-1998	Discussions data center atmosphere POLDER-2 at Lille
October 1998	Séminaire de Prospective Scientifique Arcachon
October 1999	Issue of the Waldteufel's Report
2000	Setting of the working group to define ICARE, Didier Tanré as acting scientific responsible
2000	Preliminary studies of the technical architecture and the data dimensions of ICARE
2001	Meetings of the working group: architecture, data levels of archiving, functional and decisional organization, location, partners, scope, instruments, interfaces with other databases, definition of the scientific project, timing and plan
January 2002	Point Clé 0: Review to present the concept to Comité de Revue
January-March 2002	Working meetings to discuss and implement the Comité revue recommendations
March 2002	Comité de Revue presents the project to Comité Directeur
March-June 2002	Meetings with UTSL and Région Nord to negotiate partnership
June2002	Partnership, location and functional organization defined
June 2002	Establishment of Comité Utilisateurs, chaired by Michel Desbois
July 2002	Meeting Working group and Comité Directeur
March –September 2002	Working meetings to discuss and implement the Comité Directeur recommendations
September 2002	Meeting Working group and Comité Directeur
2002	Choice of the project manager: Philippe François Choice of scientitic responsable : François-Marie Bréon
2002	Decision of not including POLDER-2 as a test
14 December 2002	Launching of ADEOS-II
24 October 2003	Convention Constitutive du Pôle Thématique ICARE between CNES, CNRS, UTSL and Région Nord-Pas de Calais
2003	Project pilot AMMA
April 2004	Approval of technical specifications of the data products processed at ICARE
4 July 2004	Point Clé
13 July 2004	Comité Directeur Point Clé
18 December 2004	Launching of PARASOL
June 2005	ICARE operational, and begins treating PARASOL data
28 April 2006	Launching of CALIPSO

The emergence of a new *data-class*: Solving the problem of scientific reward

We are in this section examining how data flows in an out ICARE. Here is how the system works for *data creators*, that develop inversion algorithms to produce new datasets eventually available through the database, as explained by a *data creator* of the Laboratoire de Sciences de l'Environnement et Climat (LSCE), who has been the scientific responsible of ICARE during seven years:

[793] « Rapport du groupe de Revue du complement REP», 7 July 2003.

> “Disons que j’ai une nouvelle idée pour mettre au point un nouvel algorithme pour passer de niveau 1 au niveau 2, par exemple, une nouvelle idée pour mesurer l’altitude des nuages. Je vais aller récupérer trois jours de données, qui est un volume raisonnable avec lequel je peux travailler sur mon ordinateur, je mets ces données sur mon laptop et j’écris l’algorithme. Je regarde la qualité du produit, je fais des tests, j’améliore mon code, et quand je crois qu’il marche je voudrais avoir les données non pas sur trois jours mais sur trois ans. Trois ans de données de niveau 1est trop volumineux, je ne peux pas les mettre sur mon ordinateur. Au lieu de celà, je vais mettre mon algorithme sur les machines d’ICARE et je vais le lancer pour qu’il traite trois ans de mesures de niveau 1et pour qu’il donne trois ans de données de niveau 2 directement sur les machines d’ICARE. Du coup je n’ai pas besoin de copier les données chez moi. Avoir des données chez soi c’est pratique, mais on ne pourrait pas en copier beaucoup. L’avantage d’ICARE c’est de pouvoir faire tourner nos algorithmes avec leurs ordinateurs avec les données qui restent à ICARE, sans besoin de les rapatrier. Donc je fais trois ans de données, je valide en comparant avec les observations au sol, par avion ou avec les sorties d’un modèle. Et si je trouve que mon produit va être de qualité et utile au-delà de mes propres recherches, alors je vais demander à ICARE de faire un traitement systématique avec cet algorithme pour mettre les données résultantes à disposition de toute la communauté»[794].

Data creators download a relative small number of data-samples of typically level 1 through ICARE which gets them from CNES (or from other databases, like NASA’s or the European Center for Medium-range Weather Forecast’s) in their computers in order to develop their algorithms. They may eventually use ICARE’s supercomputer, in case they wish to work with large amounts of data. Occasionally they may believe that their algorithm may be of interest to a larger scientific community of *data users* and they request the technicians of ICARE to integrate it in the software for systematic production. This procedure is quite formalized. All proposals require the approval of accredited scientists before being mass-produced and added to the software and the database: it is ultimately the “Comité d’Utilisateurs” who decides on their scientific pertinence, given the objectives, the priority of the actions, the number of hours devoted to them, the number of parallel projects and demands, etc. Sometimes it is the “Comité d’Utilisateurs” that requests *data creator*s to give their algorithms for the dataset to be mass-produced or to develop a specific dataset that have been requested by a *data user*. In any of these cases, if an algorithm is to be integrated in the software and mass-produced, the staff of ICARE must take it and code it in a way compatible with the computers and with the rest of software as well as faster and simpler as per requiring less computer time, power and capacity. They will integrate the resulting code in the software, and this dataset will be produced systematically, and archived in the database for access. We are in the following drawing our attention to this profession located at ICARE, whose role is to optimize the codes, to render the algorithms compatible with the software and runnable with the computer in an affordable timing, to maintain the database, to organize the library and to curate the data. Let us call them *data providers*.

Invisible data people

By 2002 it was estimated that at least five people would be needed to operate and maintain the computer system and the data-base at its beginning of operations after the launching of PARASOL

[794] Interview with François-Marie Bréon, LSCE, 2012.

and CALIPSO in 2004 –when we last checked the team in December 2013, it was composed by 12 persons. The tasks of these people would include coding the algorithms that *data creators* provided, updating them, processing and reprocessing the data, responding to data-demands of scientists about particular datasets, maintaining a database, etc. Their job was often labeled as “librarian”, “curator” or “technician”, and was rarely admitted as peer-reviewed article in the journals of the disciplinary specialties that the data in question were deemed to support. In that sense, so it was argued, the tasks and mode of functioning and organization of ICARE were very close to the organization of some services, like MeteoFrance or European Center for Medium-range Weather Forecast, which were committed to some research, some technical development and some operational exploitation[795]. ICARE’s objectives and tasks were also close to those of the datacenter ETHER dealing with data related to atmospheric chemistry located at Institut Pierre Simon Laplace. However, the organization of ETHER established with the juridical status of a « Observatoire des Sciences de l'Univers (OSU)” was a case providing for a formula not to be repeated[796]. Indeed, because of being an OSU, ETHER’s personnel typically were scientists recruited by CNRS. As such, they were submitted to the allegiances and pressures dictated by the scientific institution to advance in their careers, like peer-reviewed publications, conference communications, supervising students, and so forth. However, their job was rarely admitted as peer-reviewed article in the journals of their corresponding disciplinary specialties; it was also difficult to find schools to validate doctoral degrees and students interested in curating the data that others would use. Perspectives of getting promoted were in turn small and sometimes this generated frustration amongst the scientists that did not see their job rewarded. They were data people, who were fundamental to conduct research in the domain of atmospheric chemistry, institutionally bounded to the institution of research and yet not recognized by it. They were invisible data people. Not invisible in the sense of non-important but in the sense of not recognized by the institution they ultimately worked for. This brings forward the problem of scientific rewarding.

To avoid the tensions that appeared when scientists must conduct non-reckoned tasks (like in the ETHER case) ICARE, so it was argued, must have its own technical staff not belonging to the scientific community[797]. Rather, the corpus of people of ICARE *must* be at the *service* of the scientific community. ICARE would take the juridical status of a Unité Mixte de Service[798]. In that way, the coding of the algorithms, the development of the database and its maintenance and exploitation would not be carried out by scientists in any laboratory, but by a different professional community (computing and information specialists[799]), belonging to a different entity, embedded in a different

[795] “Recommandations du Groupe de Revue ICARE », 27 February 2002.

[796] “Recommandations du Groupe de Revue ICARE », 27 February 2002.

[797] « Recommandations Groupe de Revue », prepared by Alain Gaboriaud, 8 March 2002.

[798] « Convention Constitutive du pôle thématique Icare "Aérosols, Nuages, Rayonnement, Eau" », signed on 24 October 2003 between CNES, CNRS, region Nord-Pas-de-Calais and University of Lille.

[799] From the 12 persons working full-time at ICARE by December 2013, 8 of them have been trained as computer scientists, 3 held phD in physics and 1 was a mathematician.

institutional culture (service-oriented[800]) and even working in a different geographical space[801]. ICARE personnel, because of not being part of the scientific institution (typically CNRS or universities), did not experience pressures to gain recognition for input to scientific progress. Their pressure was rather to demonstrate usefulness before the scientists. The division of labor through institutional divide between service providers and scientific staff would resolve, so it was argued, any tension between service provision and scientific reward.

We would like to conclude with two thoughts. This episode reflects actually a more general sociological issue in the context of the information economy: on the one hand there is an increasing demand for access to more and more complex datasets and on the other there is the perception of low-status work not attractive to incoming students willing to engage in scientific careers in the domain of Earth sciences[802]. How to restructure scientific careers so that curating data (coding the algorithms made by others, running data reprocessing, building and maintaining databases for others) result in an attractive path? How to overcome this institutional friction that renders invisible this professional group? More generally conceding credit, allocating responsibility or establishing authority belong to the question of organizing the routine work in a scientific enterprise that becomes more and more fractioned and specialized. This is an issue central to the history of science and a number of studies have demonstrated that the ways in which the question of rewarding (connected to organizing the labor) has been solved varies enormously amongst laboratories, institutional structures, disciplines, and epochs. In the field of biomedicine, molecular biology and genetics, for instance, a new whole discipline has emerged, the bioinformatics, with its presence in traditional disciplinary structures in the university, with specific training both in biology and computer science. In that way, data people are fully recognized by the scientific institution[803]. In other cases, like in high energy physics, a strategy to solve the issue of invisibility and reward is authorship in publications –this is why in many cases the number of authors reaches the hundred[804]. In many other laboratories the issue of authority is solved by credentials: phD holders credit for the work and non-phD holders (students, technicians) remain in the shadows. In astronomical laboratories in the XIXth Century, gender was an important criteria to allocate credit: the systematic iterative additions and multiplications were often entrusted to invisible and poorly remunerated women, while analysis requiring complex mathematical tools were left to

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[800] In her doctoral dissertation, Hélène Guillemot characterized these different institutional cultures, research and services-oriented at LMD and MeteoFrance/CNRM respectively, in the domain of global climate modeling.

“La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », H. Guillemot, 2007.

[801] Actually during the first months, ICARE would share offices with LOA, until their own locals would be ready in campus of the University of Lille.

[802]Some interviewees went as far as denouncing that, even those students who get interested, do not receive the appropriate training because the educational system is not adapted to the career of scientific data curating in the domain of Earth sciences. Interview with Bill Rossow, NOAA-CREST, 2013.

[803] See Hine for an ethnographic account on the practices of bioinformaticians and biologists in a laboratory, and Leonelli for the role of bioinformaticians in developing databases. Christine Hine, “Databases as scientific instruments and their role in the ordering of scientific work”, 2006 and Sabina Leonelli, « Global data for local science: Assessing the scale of data infrastructures in biological and biomedical research », 2013.

[804] “History of CERN”, A. Hermann et al, 1990.

astronomers who would credit for their calculations[805]. It has been described that in the XVIIth laboratories, the accreditation was established through the distinction between master and servant[806]. We could keep unfolding the casuistic. In the case of ICARE, professional difference through institutional independence was seen as an efficient solution to the problem of reward.

Our second thought is of methodological order. One of the objectives in dedicating some time to these data providers is to highlight a feature of contemporary science that has been so far roughly addressed by the social sciences: those people whose job consists in produce the data that others will use. If we are turning towards an information data-based society, as Manuel Castells and others argue[807], and if data have to be laboriously done, or "cooked with care" to take on Geoffrey Bowker's metaphor, and not merely to be gathered, then some attention must be paid, as historians, philosophers, sociologists or anthropologists of sciences and technologies to these people, institutions, practices and skills the scientific venture depends upon. While these has been addressed in historical accounts in the domain of astronomical observatories or baconian natural philosophers (as illustrated in the previous paragraph), social scientists of contemporary epochs have shown little interest in studying the roles of what we have called the *data providers*[808].

Back to ICARE, then, institutional separation organized the labor and mediated the issue about scientific reward and social recognition for the job. The institutional separation operated a professional separation to the extent that even when holding phD in physics, the *data providers* at ICARE did not identify themselves as atmospheric scientists, but rather as computer engineers or technicians. Their job was to optimize the codes to put data at the service of data users, to maintain and curate the database or to respond to the demands of data access of the users. The maintenance of the division of labor between the service-oriented computer scientists at ICARE and the data creators was reaffirmed by both communities. A computer scientist trained as a mathematician that works as code developer at ICARE gave descriptions of his role at ICARE and in relationship with the data creators community:

> "Nous on n'est pas du tout des scientifiques. Il y a des centres d'expertise, comme le LOA ou le LMD, qui fabriquent les algorithmes scientifiques qui sont mis au point avec des savoirs sur la physique de l'atmosphère et le transfert radiatif. Et ils nous fournissent ces algorithmes, le plus souvent sous la forme de code informatique. Mais ce sont des codes qui n'ont rien à voir avec des codes opérationnels, parce que les chercheurs travaillent toujours sur des exemples. Nous on doit les opérationnaliser, extraire tout ce qui n'est pas purement scientifique pour les rendre robustes, rapides,

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805 These divisions of labor between data providers and the rest echoes the development of many forms of scientific work organization. For instance, instrument-making has long been a skilled pursuit that requires scientists to work alongside other specialists reflecting and reinforcing hierarchical social relationships. See Schaffer: "Late Victorian Metrology and its Instrumentation: A Manufactory of Ohms", 1992.

806 "The Invisible Technician", Steven Shapin, 1989.

807 « The Information Age », M. Castells Olivan, 1996-1998.

808 Two exceptions shall be noted in the domain of Earth sciences. In an ongoing research the historian of sciences Elena Aronova explores data handling by examining the history of the World Data Centers established during the International Geophysical Year in the US and USSR: "Big Science in the Archive: The IGY Word Data Centers and the Political Economy of Data Exchange in the Cold War, 2013.

Erik Conway explores the origins of the datacenter in the mission Topex/Poseidon by looking at how data were handled in the antecessor mission, Seasat: "Drowning in data: Satellite Oceanography and Information Overload in the Earth Sciences", 2006.

et surtout faisables. (…) Ici on ne fait pas de développements scientifiques mais techniques, on fournit un outil aux scientifiques. Forcement on travaille avec eux et on finit par s'intéresser pour la physique… mais ce n'est vraiment pas notre métier. En revanche, nous on a les compétences pour dire qu'il y a quelque chose qui ne va pas dans ce code. Si c'est une erreur informatique alors on va le gérer, mais si c'est une erreur dans la physique, on n'a pas les compétences »[809].

The boundaries and labor division were similarly described by data creators:

« Nous les chercheurs on va avoir une idée et on va mettre en place un code qui ne tourne pas très bien ou pas très vite, et les gens d'ICARE vont reprendre notre algorithme pour le fiabiliser, l'accélérer pour qu'il puisse tourner sur les machines Icare. Icare peut faire ce genre de développements, mais ils ne font pas de la recherche, ce ne sont pas eux qui imaginent l'algorithme. Ils peuvent l'écrire, mais l'idée vient du laboratoire scientifique »[810].

These descriptions place a very clear boundary between computer service specialists at ICARE and data creators, and allocate responsibilities on either side of that boundary: data creators have responsibility for ensuring the accuracy of the science carried in the algorithms and the data providers are responsible to get these algorithms run in a timely manner and respecting the science.

Social reward seen through metadata: Data providers and data creators

While this division of labor, articulated by means of institutional arrangements, alleviated tensions related to career paths and social forms reward, other sources of difficulties would stem from it. During the course of our interviews with *data providers* of ICARE at least two occasions were described on which the perception of priorities between *data creators* and *data providers* diverged:

« IDL est un langage qui est totalement orienté pour les données à l'échelle d'observation de la Terre par satellite mais aussi océanographiques ou mesures au sol. Par exemple, IDL marche très bien pour quelqu'un qui veut faire une représentation de la température de brillance globale sur une carte de la Terre ; cela doit être 3 lignes de code. En plus c'est assez sympa à utiliser. IDL permet de maquetter un code très rapidement. Mais il a un énorme inconvénient : il est propriétaire. Et il est très cher : il faut avoir une licence pour chaque instant du langage en cours. Et nous on a une quantité phénoménale de codes, d'instants de code qui tournent en même temps, et c'est trop cher, une fortune, on ne peut pas utiliser IDL. Donc on décode le code que les scientifiques ont fait, et on en fait un de nouveau. Mais les trois lignes de code IDL que le chercheur nous a fournies comprennent beaucoup d'informations implicites que nous n'apercevons forcément pas »[811].

« C'était un code qui m'a été livre il y a longtemps. Il a évolué au fil du temps, mais il a toujours été confié à des thésards ou des postdocs. Ce qui fait qu'ils ont travaillé l'un après l'autre pendant 1, 2 ou 3 années chacun sur le code et après on passe au suivant, et après au suivant, et au suivant. Quand vous avez des codes qui sont faits par des gens différents, à la fin vous vous trouvez avec une chose qui est impossible de décrypter. Quand vous mélangez les façons de coder de plusieurs personnes, chacune avec un style propre qu'il faut savoir lire, ça devient… et en plus ils ne s'imposaient pas une discipline de codage commune, ça mélange du FORTRAN, du C, du IDL… il y a de tout, c'est une catastrophe. J'y travaille depuis des mois et je ne vois pas la fin…»[812]

[809] Interview with Bruno Six, ICARE, 2012.
[810] Interview with François-Marie Bréon, LSCE, 2012.
[811] Interview with Nicolas Pascal, ICARE, 2012.
[812] Interview with Bruno Six, ICARE, 2012.

In both instances, the data provider is faced with the challenge of interpreting the scientific content of a given code, which he perceives as not been written clearly. The first exemplifies that the language which is friendly to data creators for their experimental sample-scale runs turns to be inappropriate when it comes to operational software integrated in large datacenters. The information folded in a small code, must be unfolded and interpreted to elaborate an operational code, which is not a trivial task –we have already discussed the myriad of hypothesis integrated in an inversion algorithm. The second exemplifies what happens when a same algorithm is developed by different persons, each one with his/her style, language and assumptions[813]. In all cases, the computer scientist, without being a radiation transfer specialist, must interpret the physics of the code in order to write a new one.

Mirroring archetypical descriptions of the relationship between physicists and engineers, the distance between the two groups, data creators and data providers, is sketched out in the distinction between tasks that are trivial and those that entail substantial work. While scientists think, for instance, that providing the codes may help the task of the data providers and so accelerate the process of rendering them operational, in the before-mentioned occasions, we have been told, code developers would prefer the data creators to provide the algorithms instead of codes. Likewise, scientists frustrate when, on behalf of robustness, code developers rewrite their code and alter few parameters that may change the physical content of the algorithm. In spite of their cultural differences, these two groups see themselves as a part of the same project of producing data and are capable of achieving mutual understanding and work together.

One critical point of divergence exemplifying these different priorities is, for instance, the degree of metadata to be provided with the codes or the algorithms. Given the scientific complexity of some algorithms, given the number of hypothesis and assumptions involved in the inversion algorithms, given the fact that in many occasions data providers must deconstruct the codes in order to construct a totally new ones, and given the fact that they are not experts of radiation transfer or atmospheric physics, metadata is considered crucial for *data providers* in the datacenters to properly interpret the codes delivered by the data creators and integrate them to the software for an operational mass-production. Metadata (data about data) is to them the reading key for understanding the algorithm that they are meant to optimize.

Metadata deals with the issue of how data is worked out into processing software, storable forms, communicated and eventually used by outsiders. This latter point is, we believe, also crucial: metadata refers to the information about data providing sufficient context for anyone to be able to use them. For metadata are not only needed for *data providers* to properly interpret the algorithms and transform them into operational codes for mass-production and dissemination; they are also necessary to maintain the database properly documented. Indeed, metadata are also necessary to interpret the data by distant scientists that have not participated in the creation of the algorithms, the data users. To

[813] We have been told that coding is like handwriting. Everyone has its own style both in form and in content. In some cases, after some years of expertise *data providers* can easily identify the author of an algorithm by looking at the code.

interpret data produced by someone else, data users need to acquire as much awareness as possible of the conditions under which data were originally produced, including the goals of the data collection, the instruments and their technical characteristics, the orbits, the inversion algorithms and hypothesis assumed in their treatment, their uncertainties, the ground data and validation methods, the scientific framework and goals in which they were conceived, and so on. In the case of satellite data, metadata typically are information about the conditions of acquisition (instrument, orbit, time, day), technical specificities (resolutions, swath, repetitivity), means of production (computer language, algorithms, errors), format or means of validation (statistics, field data used). In other words, *data users* must be able to access information about the data. When data were only available to *data creators* and their associates, or when communities were smaller in number and size, this information circulated informally through apprenticeship, personal communication or presentations in conferences. If data are however made widely available through online databases like ICARE, the scope of potential users gets widened across the world well beyond those who are familiar with the local setting in which data have been produced. Data is available to distant *data users*. Distant has here both a space and a time meaning. Data produced in one place, say Lille, can be downloaded and used in another place, say Palaiseau or Virginia. Data produced at one time, say today, can be downloaded and used tomorrow or next year, because databases are meant to run in the long-terms and used by several generations.

Conclusions are net: other mechanisms to incorporate this information must be operated. Typically, this information is provided in each data file or dataset by reserving some bits to those aspects of the provenance of datasets that are considered to be of key relevance for their distant use. Metadata is seen as the gateway between time and space connecting the here and the there, the data about the past with the data about the future. In that sense, metadata can be thought as a form of contextualizing the data. Scholars who have recently been interested in metadata use to interpret them as a way *historicize* a data-record. The notion of "historicize" shall be understood as providing the context in which data have been collected and produced, tracing back to the origins of the data –just like an historian would do[814]. We like to conceptualize metadata as a form of transparency. In his book "Too Big to Know", the philosopher David Weinberger pictures a web-world in which scientific knowledge is data-based, continuously public, more open to differences and hyperlinked. In this world, Weinberger argues, transparency has begun to do some of the epistemological tasks formerly done by objectivity[815]. He points, in particular, to transparency of the sources as a means to certify their validity, legitimacy, credibility, and ultimately their objectivity. In that sense, by providing the information needed to reconstruct and retrace back the data, we argue following Weinberger's rationale, metadata is a form of transparency and would operate some of the epistemological roles of objectivity.

[814] The notion of "historicizing" the data to conceptualize metadata has been developed in "Data Interpretation in the Digital Age", Sabina Leonelli, 2013 and "Metadata, trajectoires et "énaction"", F. Millerand and G.C. Bowker in "La Cognition au prisme des sciences sociales", ed. C. rosental et al, 2008.

[815]"Too Big to Know: Rethinking Knowledge Now that Facts aren't the Facts, Experts are Everywhere, and the Smartest Person in the Room is the Room", David Weinberger, 2011.

In any case, so important is having this information for *data providers*, and so few are the *data creators* that provide it, that ICARE's staff elaborated a document, a kind of manual for scientists detailing the basic info they needed to properly code an algorithm and/or to document a given dataset available through the database. And yet, not all *data creators* developing algorithms provide metadata. This is how a young scientist of LMD that produces his own data from CALIPSO, MODIS and PARASOL for studying the radiative impact of Arctic cirrus, described the tension:

> « Le but de notre recherche c'est d'avoir de résultats et de publier des articles. Or la mise en place opérationnelle d'une chaîne de traitement prend beaucoup de temps, parce qu'il faut que les jeux de données soient documentés (quelles sont les valeurs qui évoluent dans un intervalle numérique bien déterminé, que les incertitudes soient connues, les dates et orbites, etc.). Mais nous quand on produit des jeux de données, on fait notre analyse et on ne se préoccupe pas vraiment de ce genre de questions. Nous on traite les données nous-mêmes, on a des résultats, on sait où et quoi traiter temporairement, pendant le temps que dure l'analyse. On devrait le faire, parce qu'il nous arrive qu'au bout de 6 mois si on revient à une analyse faite précédemment, on a oublié comment on a traité les données ! Et cela est catastrophique parce que on ne peut plus réutiliser ces jeux de données parce qu'on ne sait pas comment on les a produit (…) On ne le fait pas assez. On s'en fout un peu de la mise en place de toute cette chaîne opérationnelle, parce que a priori quand on a déjà fait la recherche initiale et on a mis au point l'algorithme, on a déjà tout ce qu'il nous faut pour tenir des résultats et publier. A la limite on pourrait s'arrêter-là, ça ne nous pénaliserait pas ! Il n'y a pas forcement beaucoup de motivations pour les chercheurs à se lancer dans ce genre d'exercices »[816].

These are words of a scientist demonstrating fully awareness of the importance of providing metadata and recognizing, at the same time, that "on ne le fait pas assez". For scientists, especially PhD students and post-doctoral researchers that must still ensure their positions, publishing is vitally important. It is certainly much more important than compiling information about their own algorithm a posteriori. Plus, the timescale of a phD student or a postdoc fellow implies that they are unlikely to benefit directly from future uses of having the algorithm put under mass-production. Even scientists with stable positions insisted in our interviews that compiling all the information about the algorithms necessary to render them operational "ce n'est même pas intéressant pour nos carrières de continuer à implémenter la chaîne, car c'est du temps qu'on n'investit pas dans des autres sujets"[817]. To some extent, as illustrated by the quote, whether their code is ever rendered operational for data mass production or not, is not essential to them. What matters to *data creators* is to develop data algorithms to gain a doctorate, or to get one's name on a publication and gaining recognition. Toughly and rudely, *data creators* have better things to do than altruistic gestures to render the database richer and useful for other external scientists, the *data users*[818]. And yet, knowledge about the conditions of production (in the form of metadata) is essential for *data users* for them to make use of a given dataset and for

[816] Interview with Vincent Noel, LMD, 2012.

[817] Interview with Jérôme Riedi, LOA, 2012.

[818] We have observed analogous sociological issues in the domain of climate modeling development. The climate models are so complex that it requires more and more time to get an understanding of their internal gears as a whole. The time scale of phd or postdoc is too short to get this knowledge. Therefore doctoral and postdoctoral research is oriented to assess small fragmented parts of them like some particular parameterization, a particular simulation, or a representation of a very particular phenomena. Improvements and developments in the core codes however are barely done, since only stable positions can allow this kind of research in the long-term.

data providers to properly code the algorithm and integrate it in the software for mass-production –and with that we circle back the tension.

Of course, this is an extreme reading, which must be nuanced in every individual. For instance, we have been told in several occasions by *data creators* that they feel their duty to make their data available; in other occasions, they invest in rendering their algorithm operational for the personal satisfaction of seeing the data built upon their algorithm being extensively used by external scientists. Some scientists are well aware of the importance of providing descriptions of the data and campaign to raise awareness among the scientists that produce the algorithms to commit to some forms of providing metadata. Some institutions have committed efforts to such a task as well. We have seen when discussing how POLDER data is validated, for example, the initiative Climate Change Initiative of ESA aimed to compare different satellite datasets and to classify and organize them in a catalogue in function of their technical specificities, errors, conditions of data gathering, sampling, correction and retrieval algorithms, and so forth. In a sense, they produce a form of metadata. Exercises of this sort constitute a wayout that recognize and institutionalize the work of metadata provision. For this is, in our views, the fundamental issue underlying the provision of metadata: the lack of social recognition by the corresponding scientific institution, the sociological tension enacting service provision and scientific reward. On the one hand, ICARE, in its mission to serve *data users*, requests the scientists to elaborate new algorithms in order to put the corresponding data at the service of a largest scientific community; while on the other, the individual *data creators* have their own projects and goals for career advancement. Provision of metadata to render the codes operational, as exemplified in this section, is one of the ways in which this tension is manifested.

That providing metadata is not straightforward has been illustrated by several scholars studying digital data practices, mostly in the domain of molecular biology. The philosophers of sciences Sabina Leonelli and Rachel Ankony in an article published in 2011, for instance, compared the data communicated through four different databases in the domain of biology. They illustrated how difficult is to choose what information scientists provide with the data for them to make sense for another epistemic community, given the differences in theoretical commitments, interpretational frameworks, experimental procedures, even common terminology used with different meanings[819]. So far, our investigation has revealed at least two other aspects to be highlighted as challenging the provision of metadata. The first one is of sociological order: the more information you provide with the data to maximize their use by data users, the more effort you have to do to gather and maintain all this information. Yet, as we have illustrated, *data creators* often do not feel incentivized to spend their time in reporting their own data for their use by *data users*. The second aspect is also delicate. In providing metadata, the *data creators* are asked to put themselves in the position of any *data user* – maybe even a *data user* of the future, since data are being asked to be preserved and kept in the long term. In order to provide the necessary information about the data in a way that might be useful to *data*

[819]"Re-Thinking Organisms: The Impact of Databases on Model Organism Biology", S.Leonelli and R. Ankony, 2011.

users, future or current ones, *data creators* are requested to assume what are the *data users*' expertise and training, their objectives in using the data, their cultural embeddenness, institutional belonging, or even their ethical credos. Given that data is often conceded with prospective value which, by definition, cannot be pre-established and given the findings in the domain of sciences studies stressing the locality of scientific practices, it is, we believe, an open question whether a full empathic commitment is ever possible –this does not mean that it may not be attempted.

The third data-class: Data providers

Aside from the division of labor between scientists providing algorithms and code developers (and data curators) compiling and running them, the logics of service embedded in ICARE would enact still another separation: these scientists who would provide input material to the datacenter and other scientists who would retrieve output material from it. Or to take the categories used along our essay, *data creators* and *data users*. While in the earlier space age, a single group of scientists designed, built and calibrated an instrument, and then processed and analyzed its data, through datacenters, and their databases, data would be also made available to distant users that were not familiar with the instrument. This enactment would be mediated through a third *data class*: the *data providers*, that is to say, those scientists, engineers or technicians experts in computer sciences, coding languages, information sciences, software development or database curation. In the case of ICARE, these actors do not belong to any academic institution and therefore they are not submitted to the allegiances for publishing to get their careers promoted. Instead, they are submitted to the pressures of the scientists, whether they are *data creators* or *data users*, as they are meant to provide a service to both: providing data in a timely manner, with the required quality, in the adequate format.

The creation of such datacenters portrays hence a picture with three separate socio-epistemic *data-classes.* We have been using this category in previous chapters in our essay; time has come to further develop it. We take the term, as coined by the social scientist Lev Manovich in his analysis about the use of digital data in social sciences:

> "the explosion of data and the emergence of computational data analysis as the key scientific and economic approach in contemporary societies create new kinds of divisions. Specifically, people and organizations are divided into three categories: those who create data, those who have the means to collect it, and those who have expertise to analyze it. The first group includes pretty much everybody in the world who is using the web and/or mobile phones; the second group is smaller; and the third group is much smaller still. We can refer to these three groups as new "data-classes" of our "big data society""[820].

We take from him the general idea of three different social worlds articulated through *data-classes*: let us call them *data creators, data users* and, in between, *data providers*[821]. Each class enacts with data

[820]"The Promises and the Challenges of Big Social Data", Lev Manovich, 2011.

[821] We take from the author the lexicon "data-class" but we operate it differently. Indeed, his description about internet data in the domain of social sciences, we believe, does not reflect the situation in Earth sciences –at least related to ICARE, as we hope to have illustrated.

in different manners, because they are placed in separate organizations, they relate to the instrument in different manner, their connection with the space agency and its representatives is of different nature, they have different scientific or technical objectives, they publish in different journals, they attend different conferences, they carry different knowledge and expertise, and they operate in different layers of the institution of knowledge production. In a sense, metadata operates as one of the gateways binding them together, metadata act as a bridge to the division of labor that operates the production, storage, dissemination and utilization of data, to the specialization, to the *data-classes* divide. And, as such, it is at the interface of frictions between them.

We would like to stress, by ways of conclusion, a specific features that participates in this social divide and enables conceptualizing these three *data-classes* in connection with the learnings brought forward in the previous chapters. They approach satellite data by means of different *technological data practices*. Because being the dominant in our study case POLDER, we have invested great bulk of our essay in studying those of the *data creators* (*calibration* and *inversion*) to transform physical measurements into geophysical datasets. While we are not developing the technologies of the other two classes in detail, in the light of our previous analysis, we are however in the position to appreciate that they require different knowledge and skills. *Data providers* deploy computer coding and data curation technologies, mobilize a binary-approach to data; *data users*, at least those identified as climate modelers, would deploy numerical modeling technologies -note that one particular technological practice of the *data users* would be developed in chapter six, the so-called *assimilation*.

CONCLUSIONS

Some technological, scientific, epistemological and historical evolutions occurred between 1990 and 1993 (when the data management for POLDER-1 was designed) and 1998 and 2003 (when the report about the management of data in the domain of Earth sciences was ordered and when our case study ICARE was established). The wave of launching satellites to scrutinize different properties of the Earth and its environment scheduled from the mid-1990s onwards generated important amounts of data, the underlying *climate regime* understood in Amy Dahan's sense[822], accelerated by pressures of planetary management, and the not-disconnected notion of considering the Earth as complex system requiring complex datasets, pushed towards endowed efforts of data preservation in the long-term in France. At the same time, the availability of different sensors (and the perspectives of having more of them) favored the creation of datasets more complex than singular geophysical datasets of level 2 retrieved from a given instrument: it required the elaboration and delivery of data of level 3 (space or

[822] Within this regime, heralded by the creation in 1988 of the International Panel of Climate Change (IPCC), scientific research about climate could be henceforth hardly separated from the ascension of such questions in the international political arena, leading to major evolutions in considerations of economy, geopolitical forces or consumption lifestyles, to mention only a few.

« Le régime climatique, entre science, expertise et politique », Amy Dahan in « Les modèles du futur », 2007 and "Putting the Earth System in a numerical box? The evolution from climate modeling toward global change" Amy Dahan, 2010.

time synthesis of geophysical datasets) or level 4 (fusion of measurements gathered with different instruments). In other words, the epistemic virtue of satellite data moved from geophysical datasets of level 2 to more complex datasets of level 3 or 4. In turn, mass-producing and disseminating such datasets based on the fusion of measurements from different instruments required complex ground segments centralizing all these measurements at one computing facility. A renewed concept of ground segment, based on the centralized handling of multiple missions instead of dealing only with one single satellite, was to be put in place.

Our main point draws the attention to another aspect though. In spite of these changes and evolutions heralding what was called the "end of the mono-instrument era", major trends, developed in the early 1990s for POLDER-1 or Topex/Poseidon mirroring the practices done at NASA, persisted. The epistemic virtue of data moved from level 2 to superior levels; yet, we believe, this was nothing but a prolongation of current practices. The very raison d'être of ICARE was to deliver the valuable resource that were data *ready-to-use*, that is data of level 2, 3 or 4 and the factory-like schema for data mass-production and dissemination remained unchanged. It distributed the labor in the very same way between the Technical Centers of CNES and the scientific laboratories associated to the project; it reflected and reinforced the same representations of power between them and their boundaries of action. It kept emphasizing the role of data creators as holders of the epistemic authority (grounded on technical knowledge, training, socialization and expertise) to elaborate the datasets; it strengthened the centrality of the technologies of calibration and inversion in the production of geophysical datasets. The chain had been extended reaching levels 3 and 4, but it was the kingdom of data creators all the same. The social divide between *data creators* and *data users* was maintained (and technology practices continued to shape the divide); it was even sharpened with the emergence of a third data-class, the *data providers*, mediating their relationship. The material means and support through which data were archived and circulated certainly changed (internet) but the data access policies and rules would remain essentially the same: the access to data continued to be governed by experimental physics-approaches to scientific practice, including temporal embargos, accreditation and peer-review assessment and the Technical Center of CNES continued to have some degree of control over the archiving and distribution of radiances (CNES archiving level 0 and 1 and ICARE archiving superior levels; data creators access to level 1 and data users access to superior levels). Also the importance of field campaigns and ground measurements were consolidated as part and parcel of the renewed epistemology defining a space mission. In that sense, the introduction of this new actors and institutions provided no visionary ideas for data management but it rather *normalized* the customary practices deployed, or at least planned to deploy, for the missions launched in the 1990s. It made explicit and confirmed the current practices for data production and dissemination and it reaffirmed the existing epistemology. It is plausible to affirm, in the light of our investigations based in this study-case, that the epistemic attributes and the socio-technological order embodying the particular form of space sciences that had been emerging all along the 1980s and 1990s, and that we have called the space Earth sciences, was *normalized* at the bend of the XXIth Century. This was the specific form of space sciences constituting space Earth sciences that became the norm within space agencies (and *data creators* and *providers*); yet, as we will see in the following chapter, this was not the only form developed by *data users.*

In that sense, building ICARE did not involve radical adjustments to scientific practices of data production, storing and dissemination. Rather, ICARE can be interpreted as the culmination of what we have been calling the *reconciliation* process. It was built to fit current practices and specificities of the space Earth sciences and, if something, it exacerbated them. Note, and with that we conclude, that this interpretation contrasts with the abundant speculations that have been defended about the transformation of scientific practices through the use of new information and communication technologies, in particular of internet databases, and about the impacts of the Big Data society in scientific research[823]. New technologies, such as internet databases, may certainly provide occasions for developing new work practices in science, and may lead to the exploration of new areas of knowledge, but these do not flow predictably from the technology. In particular, we shall argue that the ICARE database was deployed not as a radical transformation of scientific practice, but as a relatively small-scale intervention that reaffirmed and sharpened the work practices that had been progressively shaped and molded during what we have called the *reconciliation* period.

[823] Some scientists, especially some computer scientists, and especially a group working at the Microsoft Research Center, go as far as claiming that the proliferation of computational tool for data handling taking place since the late 2000s, such as databases and other digital infrastructures, heralds a new methodological paradigm in science, often referred as data-intensive, even data-driven research. Ours is a case far from those.

See for instance: « Here is the evidence, now what is the hypothesis ? The complementary roles of inductive and hypothesis-driven science in the post-genomic era", Douglas Kell and Stephen G Oliver, 2004 and "The Fourth Paradigm: Data-Intensive Research Discovery", Tony Hey, Stewart Tansley and Kristine Tolle, Microsoft Research, 2009.

6

USES AND RE-USES OF SATELLITE DATA. TECHNOLOGICAL PRACTICES OF ASSIMILATION: CLIMATIC DATA.

We discussed, when describing the technological practices of calibration and inversion, the process of production of geophysical data from physical measurements as one enacting a tension between *decontextualizing* and *recontextualizing*. In a first stage, measurements would be decontextualized from their origins through a set of calibration (and other) techniques and reconverted into *despatialized* radiances or the *physical measurements*. In a second stage, the recontextualization of radiances through inversion algorithms would entail the re-introduction of contextual information to give a singular local meaning to the resulting *geophysical datasets* (of level 2, 3 or 4) ready to travel beyond the *data creators* and reaching a larger audience of Earth scientists, the *data users*. We have been suggesting that this conceptualization of the production chain became a *norm* within space agencies –and data creators. The production of data about the Earth and its environment from satellite measurements do not necessarily stops here though. Parallel forms of data production may co-exist with the chain of production and dissemination of geophysical datasets; physical measurements (or geophysical datasets) can be alternatively contextualized, by means of different technological practices resulting in the construction of data of different nature. The underlying goal of this long last chapter, and corresponding methodology, is to confirm the shoring up of a norm by examining the alternative forms that it enables or not to develop.

So far our analysis has been fundamentally based on communities of *data creators* (their interpretational approaches to satellite data, their connections with the instrument, their technological practices, their epistemic specificities) only referring to the *data user*s as assumed existing entities outside the ontology of *data creators*. This has not been an accidental methodological bias of our investigation, but rather a manifestation of the moral economies depicted in our study-case, POLDER, whose socio-technical ordering was made by, of and for *data creators*. As we have seen in the previous chapter, *data users* only entered the POLDER's world via the experiment PARASOL from 1999 onwards; and yet, this was rather a by-product of establishing the datacenter and database ICARE than a committed goal of the project PARASOL, whose scientific community, social organization and data-handling inherited most of the features of archetypical *data creators* of the previous POLDERs. But can satellite data be circulated so as to be re-used in research contexts distant than the one in which they have been created? If yes, how would data users make sense of these data and recycle them in new contexts? This last chapter is dedicated to data users.

This chapter is divided in two parts. In the first one, we explore how satellite data (*physical* or *geophysical*) are re-used to produce a form of data that we have called *climatic data*, understood as long-term, stable, consistent and global datasets. We will dedicate some time to study the scientific objectives driving the production of this alternative form of data, the location of epistemic virtue, the community of *data users* involved in the *creation* of these data (numerical modelers) and one of the technological data practices mediating it, the so-called *data assimilation technique* (based on the fusion of satellite data and numerical models), a technological practice that does not interpret satellite data from a *morphological approach*, from a *physical* one or from a *geophysical* one described so far, but rather from a *climatic* one. We examine in particular a specific form of climate data, called *reanalysis*. The example of the *climatic approach* is instructive because it illustrates two points. One, that parallel forms of data production and dissemination alternative to the factory-like production of geophysical datasets exist, which articulate different technologies, skills and knowledge, scientific objectives, epistemologies and techno-social worlds. Second, at the same time it illustrates a way of re-using the data by scientists distant from the context of acquisition. We dedicate a differentiated second part precisely to explore diverse manners in which data users recycle and re-use satellite data, to explore how satellite data (whether in their form of *physical measurements*, *geophysical datasets* or *climate data-records*) are given understanding by scientists that have not participated in their conception and production. We scrutinize in detail three examples: constructing data about the future (or re-using optical depth of the aerosols from POLDER and MODIS to predict the quality of the air), connecting climatic, meteorological and epidemic phenomena (or re-using climate series of the aerosols' optical depth from TOMS and Meteosat to correlate desertic dust cycles and meningitis outbreaks) and participating in climate modeling (or re-using physical measurements from CALIOP to evaluate climatic models). We hope to shed some light in how different data users forge their epistemologies and their relationship with different forms of satellite data intervened in varied ways.

Our main argument along this chapter is that, as satellite data move from *data creators* to different forms of *data users*, distant alternative scientific urgencies and technologies may be articulated, including the production of a renovated type of data, the *climatic data*, elaborated from the fusion between satellite data and numerical models. Different intellectual and cultural landscapes may embody the re-use of the data, which would have the effect of destabilizing the location of epistemic virtue, which would become more mobile and flexible varying in function of the re-use and the re-user, as well as the technological practices, the knowledge and skills needed to produce them, the socio-technical system for mass-production and dissemination or the rules of data access.

The first part of the chapter, because it aims to explore the production of a type of data occurring in parallel with the previous descriptions involving physical and geophysical datasets, embraces a large period of time concomitant to the previous chapters, from approximately 1988 to present day, paying some attention to some events occurring between 1998 and 2002. The second part, focused in three ways of re-using satellite data is more limited in time at the period from 2002 to present day. We may warn that we provide some analysis involving the data produced from POLDER's measurements; however, to complete the casuistic we have enlarged the scope as per including data obtained with other instruments like MODIS, Meteosat, TOMS or CALIOP. Our primary sources have been scientific publications, position papers of conferences, proceedings and minutes of meetings and workshops, reports issued by space agencies, operators or international organization complemented with oral accounts. This chapter may be focused on examining some forms of using satellite data by distant users, including the production of some forms of climatic data; nonetheless the methodology and one of its goals is ultimately to demonstrate a norm by examining alternatives to it.

THE CLIMATIC APPROACH

> "La caractéristique commune à tous ces phénomènes est la très grande variabilité dans le temps et dans l'espace. L'étude de la dynamique des variations climatiques n'est pas la planétologie où quelques heures d'observations suffisent pour asseoir une carrière scientifique[824]. Dans ce domaine de la géophysique, les informations significatives ont une signature faible au milieu d'un bruit météorologique intense. La connaissance scientifique ne peut progresser que sur la base d'observations systématiques et de haute précision prolongées pendant plusieurs années »[825].

These are the words of the meteorologist Pierre Morel, whom we have already met in several occasions, illustrating in the second scientific meeting organized by CNES in 1985 one of the scientific imperatives in the domain of Earth sciences: having high precision global data records over long periods to detect environmental variability and trends in the long-term. As the problem of global warming would shore up in the political agenda, crystallized with the creation of the International Panel Climate Change (IPCC) in 1988 and the UN Conference in Rio de Janeiro in 1992, concerns about changes occurring in the environment and the role of human activity in those changes would grow in importance. Priority would be given to those scientific programs directed not only to discriminate meteorological variability from climatic one, as suggested by professor Morel, but also to discriminate natural variability from anthropic one.

Many of the environmental changes were believed to be minuscule on a year-to-year and decade-to-decade basis. Detection of slow, small changes, which were often confused with other effects, would require meticulous, high-precision measurements continuous in the long-term and of global scope. For instance, changes in CO_2's distribution in the atmosphere, just to provide an example with clear

[824] Some planetologists, we have been told, profoundly disagree with that affirmation: some investigations also require long-term data-records, like secular accelerations, determination of constants, solar influence or planetary climate dynamics, to mention few.

[825] Pierre Morel, Séminaires de prospective scientifique CNES, Deauville 1985.

connections to anthropic forcings, had been proven to be very difficult to detect because the current radiative changes expected from increases in this molecule are very subtle and they occur slowly. Therefore they need high-accurate instruments, with corresponding transfer of calibration from one to another, measuring continuously in the long-term- even today, some *data creators* experts in the sensing of such molecule claim that the current satellite instrumental and algorithmic capacities do not meet the accuracy and precision needed[826]. There exist some long-data records of measurements of the surface (for instance, Mauna Loa's one), but they are local and it is not obvious how to extrapolate them into a global scale. With this introductory example we want to illustrate the characteristics of the data needed for long-term studies of global variability: highly accurate (to discern environmental patterns from other overlapping effects), long-standing data records (to discern trends in the long-term) and planetary coverage (to identify global patterns and to associate local phenomena to global events). Let us call this type of data simply *climatic data*.

We are, in this first part of the chapter, addressing three features related to the gathering and production of climatic data, putting special emphasis on their production from satellite measurements: the problem of homogenizing the data collected with different instruments, the problem of ensuring the perpetuity of the measurements and the problem of achieving global coverage. Next, we study the production, dissemination and utilization of a particular case of climatic data, the so-called *reanalysis*.

The problem of producing homogeneous data records

Whether data are fossils, skeletons, bugs, pictures of nebulae, stellar spectra, embryos, values of temperatures, medical histories or celestial ephemerides, scientists have often organized and reorganized them under the form of temporal series and time successions in order to render them meaningful and to look for patterns, changes or analogies. In the domain of Earth sciences, some data records, especially meteorological and oceanographic measurements, can be traced to the XIXth Century. When pieced together they would form a form of climatic data or *climatologies*, that is to say, long-term data records of a given geophysical parameter or sets of geophysical parameters. These data would come from many locations across space and time, each one with their specificities regarding their collection, processing, quality control, recording and circulation. We are stressing in this section the problem of assembling together data gathered by different sensors over time and space, of harmonizing their specificities and of rendering them consistent and homogeneous with each other.

Data friction: Tracing the history of the datasets

Data only become homogeneous over time and space if they measure the same thing day to day and year after year. Yet, conditions of gathering and processing vary, whether environmental, human or technological. Across time most data series have been adversely impacted by inhomogeneities caused

[826] Interview with François-Marie Bréon, LSCE, 2012.

by, for example, changes in instrumentation (new sensors may be more accurate while older ones age and deteriorate) or in calibration techniques. Also, measurements would be affected by station moves and changes in the local environment such as urbanization or deforestation. Surface-based instruments are also submitted to human corruption. We have been told of a tide gauge located in a relative quiet coastal area in the North of France that became in the 1980s industrialized and the regular deposition of sewage changed the daily pattern of the tide measurements[827]. People also change with time. New students and scientists are recruited cyclically, perhaps a little taller or less myopic than the precedent ones, so as to produce different bias in the readings, as excellently illustrated by the famous "personal equation" or the "mental aberration" of the astronomers in the XIXth Century[828]. Scientists may introduce different observing protocols such as different observation intervals or a new formula for calculating averages or interpreting errors. Data may not be gathered with the same frequency over time: measurements may intensify during field campaigns and relax afterwards; societal factors (wartime, governmental priorities, environmental legislation) may impact as well in the frequency of measurements; and technological changes as well (for instance, the volumes of data since the 1980s have been larger than before due to the satellite input). The scientific appreciations concerning the observed objects or the admissible data uncertainty may vary as well. Data would come from different places in the world, which may be ruled by different norms and practices, like different rules for rounding or different units of measurement. Data would be stored in different supports (paper, card punch, tapes, etc.) and under different formats. Finally, there may also be disparities in their geographic distribution: while some European countries have been instrumented since the XIXth and some of the data have been dutifully archived and conserved, some Southern countries have no data archives at all. Similarly, there are fewer data in the Arctic, the oceans (other than the maritime routes) or in the great deserts. These issues are archetypal of dealing with old data and have been noted by other historians of science[829]. Data would move through complex networks of people, places, institutions, technologies and documents and at every move data would encounter *friction*, we take

[827] In their chapter entitled "Data Bite Man: The Work of Sustaining a Long-Term Study" included in the book ""Raw Data" is an Oxymoron", 2013, David Ribes and Steven J.Jackson reported of changes in the measurements of rainfall biased by some wicked kids using the rain gauges as a toilet.

[828] The "personal equation" was the name given by astronomers in XIXth British observatories to the differences in measured transit times recorded by observers in the same situation. As per described by the historian Simon Schaffer, aware of the personal bias their solution was a division of labor in the observatories, a network of observing sites, a mechanization of observation. See: « Astronomers Mark Time : Discipline and the personal equation », Simon Schaffer, 1998.

In her study of data practices in astronomical observations of different transits of Venus in the XIXth Jessica Ratcliff stressed a number of frictions: difficulties to locate the data, to date them, different calibration or what was called by the astronomers at that time, the "mental aberration" caused by a spreading of the excitement of the nerves of the retina which gave rise to the sensation of vision over a sensible space. See: "Models, metaphors, and the transit of Venus in Victorian Britain", Jessica Ratcliff, 2007.

[829] See for instance an issue of History of Science (vol. 48, n°161, 2010) entirely dedicated to "Seriality and Scientific Objects in the nineteenth century" edited by Nick Hopwood, Simon Schaffer and Jim Secord dedicated to the scientific practices of the XIXth in constructing series of objects in the longue durée.

See also Simon Schaffer's « Astronomers Mark Time : Discipline and the personal equation », 1998; Geoffrey Bowker's « Memory Practices in the Sciences », 2005; Jessica Ratcliff's "Models, metaphors, and the transit of Venus in Victorian Britain", 2007; David Ribes's and Steven J.Jackson's "Data Bite Man: The Work of Sustaining a Long-Term Study", 2013; or Paul Edwards's, "A Vast Machine", 2010.

here Paul Edward's notion, which must be controlled. In Edwards's sense, the metaphor expresses the resistance that must be overcome for data to be circulated, namely "the costs of time, energy, and attention required simply to collect, check, store, move, receive, and access data"[830]. At every move data can be lost or corrupted, threatening the production of homogeneous long data records, which may eventually lead to misinterpretations of the studied phenomena.

These issues have been also well documented by scientists themselves, who agree in the importance of removing the inhomogeneities or at least determining the possible bias and error they may cause[831]. Over the last almost three decades, many Earth scientists, especially those *data users* interested in the climate approach, especially oceanographers and climate scientists, have put a great deal of effort into two separate, though connected, activities. First, assembling old data in order to enlarge the record as farther in time as possible and, second, developing techniques to identify inhomogeneities and to adjust data series to compensate for the possible biases between the diverse data. Perhaps the most commonly emphasized tool to render data homogeneous is examining *metadata* files in order to acknowledge the conditions of production of the data and to proceed with a proper integration with the other data. To *data users* interested in the *climatic approach,* data have no value if they are not properly documented. For instance, in the case of satellite data, because all geophysical data comes within a context, when *data creators* develop inversion algorithms, they must think how much information they need to provide in order to make data maximally useful over time and space. However, the more metadata is provided accompanying every inversion algorithm, the more work must be done, and not all scientists are motivated to invest in documenting data beyond what is necessary to guarantee their immediate usefulness -we are not repeating here the discussions about metadata that we have suggested in the previous chapter. More generally, metadata can be found in station records, meteorological yearbooks, observation forms, station inspection reports and various technical manuscripts; sometimes metadata can also be acquired from interviews with persons responsible of the measurements. In a sense, thus, enquiring into metadata information to build long-term data implies tracing back the historical archives of each dataset to discriminate what belongs to fact and what to artifact –whence some scholars have called the process of analyzing metadata as *historicizing* the data, that is to say, contextualizing the conditions of acquisition and production of every dataset in order for it to be used properly[832].

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[830] Friction, in physical systems, means resistance occurring at the interfaces between objects or surfaces, which consumes energy. Analogously, data friction opposes to the circulation and utilization of data. vast machine, p 84.

[831] In the domain of satellite data, publications of oceanographers and climate scientists from the early 1990s to present day illustrate this awareness: "Detecting Climate Variations and Change: New Challenges for Observing and Data Management Systems", T.R. Karl et al, 1993; "The need for Systems Approach to Climate Observations", K.E. Trenberth et al, 2002; "Endowments and New Institutions for Long-Term Observations", D.J. Baker, R. W. Schmitt and C. Wunsch, 2007; «Observational network design for climate », Carl Wunsch, 2009.

Recently, during the conference entitled **"**Climate Research in Service to Society" organized under the aegis of the World Climate Research program in Denver in 2011, for instance, several position papers would be endorsed synthetizing many of these issues in the construction of climate data. For instance: http://www.wcrp-climate.org/conference2011/index.html

[832] As we have discussed, using the notion of "historicizing" the data to conceptualize metadata shall be understood as providing the context in which data have been collected and produced, tracing back to the origins of the data –just like

Assembling the data together: Trusting crowds

The climate approach to data needs for climatic data to exist, which poses the problem of producing these homogeneous, global and long data-records spanning 5, 10, 20 or 50 years. Few scientists have the professional and intellectual incentives of devoting their careers to producing data sets whose scientific insights will primarily benefit their descendants. This conundrum mirrors the mismatch of incentives that we have found when examining the provision of metadata related to the inversion algorithms per part of *data creators*: while of clear value to a larger community, assembling old data to produce climate data-records offers little to those tasked with producing it. For instance, one key step, prior to any analysis of long-term records, is to digitize the old data, since archives predating the 1980s (or even 1990s) exist mostly only in hard copy archives. Actually, since the dawn of the space age, scientists have witnessed at least four different storage media to record and conserve satellite data: paper, magnetic tapes, CD-ROMs/DVDs/DLTs and online databases. Generations of data have been lost with changes of storage technology. Professor Thomas Von der Haar, one of the authors of the atlases of measurements of radiation budget computed from satellite observations from 1962 onwards with which we have introduced the previous chapter, showed us his collection of dusty canisters full of data gathered with several satellites (TIROS, Nimbus and others) dutifully recorded and conserved. Yet they are unreadable with our present powerful supercomputers. The climate approach implies that periodically data must be transferred from one material support to another because so far no storage media has been permanent and definitive –and this is likely to remain this way for a while. The need to maintain the stability of the record in spite of the changes is likely to persist. As it has been shown by several historians of technology, it is as harder to develop a new system, as to maintain it[833]. This means that old data records like hand-written almanacs, punch-cards or magnetic tapes must be converted into material support compatible with the current reading and processing machines –and given the fact that the materiality of data (and/or of the processing machines) is likely to keep evolving, this conversion must be maintained forever, which, of course, has its cost in terms of budget, time and workforce. It is plausible to say that maintaining data over the long term is as much as difficult than gathering them in the first place. Digitizing large numbers of observations is labor intensive and time consuming because optical character recognition software is not yet capable of dealing with handwritten entries. Therefore, they must be keyed by hand. A junior scientist, even less a doctoral student or postdoc fellow, may not be well advised to become involved with a program consisting in digitize old data, whose record will be interesting at least 20 years from now, whose maintenance relies on grants that must be renewed every three years, and for which he or she would unlikely receive any scientific reward in terms of publications or job positions.

an historian would do. See: "Data Interpretation in the Digital Age", Sabina Leonelli, 2013 and "Metadata, trajectoires et "énaction"", F. Millerand and G.C. Bowker in "La Cognition au prisme des sciences sociales", ed. C. Rosental et al, 2008.

[833] One seminal example on development (and maintenance) of technological systems can be found in Thomas Hugues's "Networks of Power: Electrification in Western Society, 1880-1930", 1983.

The example of digitizing old data is a particularly appropriate one to illustrate that new forms for organizing this kind of data curation, like digitizing old data, would be experimented in the last decade. Prominent amongst them would be the crowd science projects. A number of them have been created since the mid-2000s, taking advantage of the easily available data through the internet and of a crowd of enthusiastic amateur workforce motivated to tape, scan, locate and date large numbers of environmental measurements, satellite and non-satellite. The source oldweather.org, for instance, has been developed by NOAA, the UK Weather Service Office (MetOffice) and others and consists in transcribing the weather reports made by ships since the mid-XIXth century during their oceanic journeys. More than 300000 records have been digitalized since its creation in 2010[834]. Recovering old data also affects satellite data –before the 1980s, most of the data would be stored, if stored, in photograph paper, numeric tables or magnetic tapes, like professor Vonder Haar used to do. The “Nimbus Data Rescue Project” of NASA and the US National Snow and Ice Data Center, for instance, consists in scanning black-and-white film images and infrared radiometer data obtained with the Nimbus 1, Nimbus 2, and Nimbus 3 satellites (launched in 1964, 1966 and 1969) and stored under the support of canisters of 35-millimeter film. As a matter of fact, this program would be applauded by the scientific community and awarded with the prize during the American Geophysical Union’s annual meeting of 2013, which indicates the importance that crowd science projects are acquiring amongst the scientists in this area[835]. Not all crowd science projects related to the building of long-term data consist in digitizing old data. The source surfacestations.org, this is our last example, relies on people that volunteer to visit a given surface station, take some photos and report about its surroundings that may have some effect on measurements (for instance, an anenometer placed behind a wall or a thermometer placed next to heating source)[836].

The recent development of crowd science[837] would complexify the labor organization between data creators and users, by bringing forward the work done by anonymous amateurs –amateurs, to be sure, have long been present in the field sciences endeavors (recall, as an instance that we have mentioned, that several officers of the French navy had volunteered to conduct measurements with the radiometer SIMBADA in 2003 in their oceanic journeys)[838]. The production of geophysical datasets is clearly organized on the principle of a rigid distinction between the holders of epistemic authority (legitimized by their knowledge in radiation transfer and their technological practices of inversion) and the others – we can add the data providers in between. The production of climatic datasets integrates a new category to this division of labor: the crowd. Much of the work of assembling data is done by unskilled anonymous crowds, not belonging to scientific institutions. This raises questions of trust and credibility: who are the legitimate social groups to conduct scientific research? Whom do we trust to

[834] http://www.oldweather.org

[835] http://nsidc.org/data/nimbus/index.html

[836] http://www.surfacestations.org/

[837] Crowd source projects have proliferated in the recent years, but the idea of capitalizing in home-computers can be traced back at least to the Search for extraterrestrial intelligence (SETI@home) project launched in 1999.

[838] See as one example : “Institutional Ecology, Translations and Boundary objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology”, S. Leigh Star and J. Griesemer, 1989.

speak on behalf of science? The historian Steven Shapin magistrally dealt with the question of trust in his study about the experimental practice in the XVIIth: legitimate philosophers trusted “invisible technicians” to carry out the experiments for which they would credit. They carefully chose whom to trust and under what circumstances[839]. Contemporary perceptions of trust, legitimacy, credibility or authority surely differ from those of the XVIIth, they are embedded in different institutional, sociological, political, cultural and even ethical sensibilities. Yet, invisible people continue to exist in contemporary scientific practices. It appears to be certain fundaments that have remained unchanged: at the end of the day, it is scientists accredited by their phD (and their collections of post-docs), by their institutional affiliation, by their number of publications or by their reputation, who are the legitimate responsibles to interpret the data assembled by the crowd. It is not, and with that we adhere the philosopher David Weinberger’s thesis, that the availability of data through internet would eliminate the need for credentialed scientists. Our investigations do not suggest any change in the distribution of epistemic authority: in all the projects into which we have looked related to the assembling data for producing climate data-records, the task of the participants does not require high scientific skills –actually amateurs do precisely what scientists do not want to do (like digitizing old data or reporting changes in the measurement conditions). Trusting the crowds, in our views, is simply a solution to a pragmatic problem: unless scientists are to make the perceived as tedious job of visiting stations to report measurement conditions, assembling all data, scanning old data, hand-typing them, digitalizing them by their own hands, they must delegate the task. The boundary between what is considered as institutionally scientific and amateur’s practices is, we believe, maintained. In addition, access to data is still carefully controlled by legitimate scientists: not all the data is available online and not all the people have access to the data available online. The journals are still exclusive to legitimate scientists, majorly after peer-reviewing, and university departments still rely on credentials. In the building of climate records, and this may be a difference with other domains reaching the public sphere (we think typically in biomedicine, nuclear issues or GMO[840]), citizens have not become experts and they do not vindicate their right to participate and shape scientific discussions and conclusions. On the contrary, people contributing to the production of climatic data do not expect and intend, at least not yet, to engage any scientific analysis or interpretation, to participate in the regulation of the research or to intervene and orient political debates about climate change and eventual actions[841]. They seem satisfied in being invisible, just like the computer scientists that optimize algorithms for mass production at ICARE or the curators that maintain databases, anonymous crowds carefully preparing the data for scientists to use them but without having any scientific

[839] “A Social history of Truth: Gentility, Credibility and Scientific Knowledge in Seventeenth-Century England”, Steven Shapin, 1994. An excellent complement to this book extending the historical problem of trust to modern periods is “Trust in Numbers: The Pursuit of Objectivity in Science and Public Life”, Theodor Porter, 1995.

[840] As described, for instance, for collectives of patients, green-partisans, women or consumers who would vindicate their right to participate and shape scientific discussions and conclusions in a number of scientific domains, typically “Sciences, techniques et société”, Christophe Bonneuil and Pierre-Benoît Joly, chapter « Le retour de l’amateur ? », 2013.

[841] Not all the sources are focused in curating data. The source http://www.climateprediction.net/ , for instance, uses computer power of the participants to run climate models.

pretension and aspiration. To sum up, in the areas of producing climate data records, these evolutions, we believe, do not question the model of knowledge production by credited socialized experts. However, this mode of organizing the labor renders the map of epistemic authority less rigid creating a territory where more can participate and more fluidly.

The ill-nature of geophysical datasets: The problem of changing inversion algorithms over time

Satellite data do not escape frictions, inhomogeneities and bias. Satellites have a span life from 2 to 5 years, meaning that new satellites must be launched within these delays to replace the older ones, for measurements to be perpetuated over time. In the meantime, technologies may become obsolescent or fail. Observing time, and orbits, may also change from one satellite to the following one, as processing and communications technologies enable new forms of on-board storage and downlinking to the ground stations. For instance, POLDER aboard ADEOS would only be working during 6 hours per day because the limited capacity and power of the aboard storage and transmission device must be shared between the eight instruments inside the satellite. Inside PARASOL, however, POLDER would be gathering measurements quasi 24/24. Very often, there are actually no plans for successive satellites, so that discontinuities and gaps in the measurements are therefore generated between one mission and the following on, which compromises the production of climatic data-records -in most cases, in fact, there is simply no following on satellite ever planned and the climatic approach is not possible. For instance, all the satellites conceived as limited-time experiments to gather a number of data for further analysis in the laboratory (like the payloads embarked inside the microsatellites Myriade) do not pursuit interpreting the data with a climatic approach –as illustrated in the introduction to the second part of our essay.

Equally important, and we would like to stress this point, dependence of satellite geophysical datasets on inversion algorithms would render geophysical datasets vulnerable to changes in the algorithms. In some cases, today’s inversion and correction algorithms belong to a long heritage based on incremental modifications of the multiple previous successive missions over the past three (or sometimes four) decades. They may vary amongst scientific teams and time. For instance, to take a familiar example, the algorithms for computing some biological properties from the marine reflectances gathered by the radiometer currently flying MODIS of the Goddard Space Flight Center of NASA are the heritage of the algorithms developed for computing similar parameters with the radiometer aboard Nimbus-7 (CZCS launched in 1978), aboard ADEOS-I (OCTS, launched in 1996) and SeaWiFS (launched in 1997). The data creators of each of these missions may vary and, even though the fundamental principles may not change, different perceptions of the data, their accuracy or the observed object may appear. Each of these missions would base the algorithms on similar theoretical grounds (those developed by André Morel in the early 1970s). However, the translation of the physical principles into algorithm, the coding, their integration in the software architecture and design may differ. Also, data production infrastructures may change. The pre-launch calibration may have been done with different models and prototypes, different instruments and empirical data, just like the post-launch verification of the data quality has certainly been done with different ground-based instruments and specific field campaigns. Each algorithm would result in a slightly different version of its predecessor carrying its own assumptions and tacit knowledge.

The multiplicity of algorithms may take another form as well. In other cases, there co-exists a multiplicity of instruments providing similar geophysical variables, each one with their specificities. For instance, there are at present day around 42 space instruments that provide data on the optical depth of the aerosols, which means that at least 42 retrieval algorithms co-exist, each one with its own assumptions about what is the threshold of detected cloudiness, about the presence of chemical compounds or water in the atmosphere, about how do aerosols absorb this water, and their effects, about discriminating between aerosols types (thresholds on sizes, forms, life-span, mass, emission sources, etc.), about discriminating surface signal, and so forth[842]. Assembling all these data together, whether they are produced in series or in parallel, requires accounting for the implicit details of the inversion algorithms with each dataset is produced.

That issues of multiple varied or changing retrieval algorithms could be problematic had been demonstrated with a controversial episode concerning the measurements with the Microwave Sounding Unit (MSU) carried aboard nine successive satellites from NOAA-6 to NOAA-14 (between 1978 and 2005). The MSU measures radiances by scanning the atmosphere beneath its flight. Although the instrument measures columns and cannot discriminate vertical layers of the atmosphere, an algorithm would be designed to retrieve the temperature at the lower troposphere, at an altitude from the surface to 8 km, by assuming conditions regarding the atmospheric chemical composition, weather conditions, the Sun's position, the orbital path, techniques for removing stratospheric radiances that overlapped the 0-8km radiances, bias corrections, and several other factors. Some scientists assembled together the geophysical datasets of the surface temperature retrieved from the physical measurements of these nine different instruments over these more than 25 years and produced a climate data-record about the temperature at the surface. The analysis of this climate data-record showed certain cooling. This trend was in disagreement with other data, especially with radiosondes[843], as well as with numerical model outcomes[844], which showed a warming[845]. Because of its direct implications on global warming assessments, this conflictual episode would cross the scientific borders in the 1990s: scientists would be called to testify before Congressional and Senate committees, political positions would take the most advantageous data to their cause, and climate- or

[842] Habilitation à Diriger des Recherches entitled « Apport des observations satellitaires à l'étude des aérosols et de leurs impacts », Isabelle Chiapello, defended in 2011.

[843] "Tropospheric temperature change since 1979 from tropical radiosonde and satellite measurements", J.R.Christy et al, 2007.

[844] "A comparison of tropical temperature trends with model predictions", D.H. Douglass et al, 2007.

[845] "Temperatre above the surface layer", J.R. Christy, 1995 and "Satellite and surface temperature data at odds?", J. Hansen et al, 1995.

scientific-skeptics would discredit the scientific endeavor in general[846]. It is not the goal of our essay to analyze the political impacts of such a controversy, but rather to underline the importance of inversion algorithms in it. Over the years, the algorithms to inverse the temperature at the lowest layers of the atmosphere from radiances gathered with MSU had been progressively modified as new findings about the radiative effects of some type of atmospheres or about the environmental conditions in the surface have been provided, as new validation instruments have been deployed to provide "ground-truths" or as new processing technologies allow optimized computation. Some scientists argued that the mismatches between the satellite geophysical datasets and those of the radiosondes (and simulations) could be produced by changes in the hypothesis inherent to each version of the inversion algorithms causing inherent interpretative bias, which had not been properly accounted when producing the 25-years data record (issues about calibrating the different sensors against each other were also pointed–a point to which we will come back in the following section). Since 1998, an improved version of the radiometer MSU, called Advanced MSU, is being flying inside NOAA's satellites NOAA-15 to NOAA-19 enlarging the climatic data-record for the surface temperature – according to some scientists that we have interviewed the debate is not closed yet[847].

More generally, the point is that geophysical datasets are created with specific algorithms adapted to be applicable in particular circumstances, they carry their own sources of uncertainties and, perhaps more importantly, their own interpretational bias. To be properly interpreted, each dataset may be deployed in a recontextualized situation. To produce long-term and global datasets requires homogenizing these datasets, which entails studying the inversion algorithms with which the particular geophysical parameter (the temperature in this example) has been retrieved in each case. However, as the divide between *data creators* and *data users* sharpened, coinciding with possibilities to circulate the data through the internet, producers of climatic data (a form of *data users*) often would not have the tools, the knowledge, the time or the incentives of descending to the level of inspecting individual algorithms in order to check their applicability. And here we circle back the problem of metadata.

The problem of calibrating different instruments: Satellite flights in overlap

In the first report of the Intergovernmental Panel on Climate Change (IPCC) issued in 1990 a whole chapter entitled "Sea Level Rise" would synthetize the conclusions of around 15 data analyses corresponding to measurements with coastal tide gauges, some of which expanded to the early 1800s. All of them pointed to a tendency for the sea level to rise. However, quantitative estimates of the rise diverged from annual increases ranging between 0,5mm and more than 10cm -and error estimations

[846] Paul Edwards reported this episode emphasizing the conflict between models and data. Edwards's point was that it has no sense to depict the issue as a conflict data versus models, since both data and models have been created by a symbiosis of each and the other. MSU data about the surface temperature are not observations, they have been converted into temperature and then made global by a data assimilation scheme by putting them inside a model. The model, too, integrates data and semi-empirical data through parameterizations and boundary conditions, and each simulation is confronted to data. See: "A Vast Machine", 2010.

[847] Interview with Karen Rosentof, NOAA, 2013.

also diverged[848]. This IPCC report highlighted several problems that affected the quality of such datarecords and consequently of the corresponding estimates, all of them archetypical sources of inhomogeneites and frictions that we have already mentioned. First, the sampling distribution in time and space was not uniform but mostly concentrated since the 1970s and areas of Africa, Asia, ocean islands and Polar regions were sparsely represented –so were the deep oceans, as most of the tide gauges were located in the coast. Second, lack of standardization of the measurements (regular times of measurements or using metric system). Third, lack of calibration between the tide gauges[849]. And fourth, there was a problem of interpreting the data-series: tide gauge records contain many signals other than a secular trend, like large interannual meteorological and oceanographic forcings on sea level, vertical land movements and tectonic influences, or local human influences like spills into the water. Different hypothesis about these phenomena would lead to different data analysis and therefore different estimates. Because most of them had not been properly documented at the time of measuring and analysis, the interpretations of these datasets at present day were far from being reliable.

In 1995, an American scientist member of the Topex team, published that the sea level had been rising at a rate of 3,9±0,8mm per year since 1992, when the satellite Topex/Poseidon had been launched[850]. Of course, three years of data were not enough to conclude on climatic oceanographic dynamics. They were however enough to demonstrate the ability of the instruments placed inside a satellite to overcome some of the issues related to in situ tide gauges: time and space sampling, standardization, calibration or interpretation. Unlike coastal tide gauges, Topex/Poseidon could observe the whole oceans, Northern, Southern and in the poles, in a regular and repetitive manner. Besides, the data would be all gathered with the same instrument. Therefore, issues about instruments built with different materials, calibrated in different manners, maintained under different conditions, deteriorating and aging differently, operated by different scientists or integrated in different environmental conditions would be removed from the equations, because one single radar altimeter would be reporting over all the regions and time. Finally, all the data would be treated with the same correction and processing algorithms -indeed, different groups would develop different analysis, but each group would treat all the data in a consistent manner.

The expected life of Topex/Poseidon was of 3 years, sufficient for testing the ability and reliability of a given technology but certainly not enough to detect and identify changes in the sea level with significance in climatic terms, because they were expected to occur in longer periods of time. The climatic approach, that is to say, the analysis of long-term consistent, stable, homogeneous and global data required the launching of a successor to continue with the measurements started by the radar altimeter aboard Topex/Poseidon. In 2001 its successor, Jason-1, would be launched carrying an improved version of Topex/Poseidon instruments, which would be flying until 2013. In the meantime,

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[848] Chapter 9 of the 1st IPCC report, "Sea Level Rise", 1990.

[849] Chapter 9 of the 1st IPCC report, "Sea Level Rise", 1990.

[850] "Measuring global mean sea level variations using TOPEX/POSEIDON altimeter data", R.S. Nerem, 1995 and "Global Mean Sea Level Variations from TOPEX/POSEIDON Altimeter Data", R.S. Nerem, 1995.

Jason-2 would be launched in 2008 (and still flying) and Jason-3 is planned to be launched in 2015. Jasons are all satellites of the same family, legacy of the ancestor Topex/Poseidon, carrying similar instruments, flying following similar orbital paths, being operated by the same space agencies and associated laboratories. With all this similar satellites gathering data one after the other, building climatic data records should be as easy as to assemble together all these datasets. The example of the retrieval of the temperature surface from the radiometers aboard NOAA's satellites illustrates that a number of factors affected the data gathering, production and recording across time: the successive instruments were not identical but rather slightly improved versions of the former technologies, their orbits were not identical either (and, besides, perturbations are local and unique (gravity, radiation)), the retrieval algorithms to compute the sea level had also been improved and optimized across time, so had been the algorithms for atmospheric correction, and finally their data storage and transmission capabilities had also changed. Given that the measurements of each instrument were not identical, the whole point would be relating the measurements of one satellite to those of its successor in order to make sure that artifactual differences did not impact on the interpretation of the datasets.

A technique to achieve consistency between measurements made by successive satellites is calibrating the different instruments against each other. The standards for calibration are generally defined in relation with absolute calibration and accuracy. Radar altimeters are well placed for that, since an absolute accuracy based on metrological standards of time can be traced[851]. However, most satellite instruments, including spectrometers and radiometers, lack of metrological absolute standards. As we have mentioned when discussing the calibration of POLDER data, for instance, there is no a set of radiometric references that could provide an absolute accuracy in orbit; instead, accuracy is relative amongst instruments and must be achieved with indirect arguments. One of these indirect strategies admissible by the community to ensure the stability of measurements and to make sure that the old and the new satellites would continue commensurable measurements, would be to make successive satellites fly simultaneously overlapping one with the other for a given period of time in order to calibrate the new instrument with respects the older one. In a position paper presented during the conference "Challenges of a sustained climate observing system" organized under the aegis of the Wolrd Climate Research program, Kevin Trenberth, a renowned climate scientist of the National Center of Atmospheric Research (NCAR) explained this strategy –and denounced the lack of means devoted to guarantee the overlapping of satellites:

> "Observations of decadal climate change require stability over decades, and unless overlapping observations are sustained, absolute accuracy is required. However, few observations provide the rigorous onboard calibration and cross-calibration needed (…) It is becoming clear that there is

[851] Sea level is actually directly related to a measure of the distance between the satellite and the sea, given a stable reference against which compute the differences (the geoide surface). The radar altimeter measures the time that the electroni pulse takes in go from the satellite to the sea surface and back; because it moves at known speed (light speed), a distance can be derived. The sea level calculation is thus a parameter that involves a standardized metrological unit: time. Therefore, its accuracy can be established by reference to these absolute time (or a derivative, space) standards. The nature of the measurement (time-derived) makes it a high accurate measurement, as time can be determinate in absolute terms. This does not mean that altimetric measurements do not need to be corrected. They must be corrected, especially from the atmospheric effects of ionization and tropospheric delay.

> significant probability of a lack of overlap between the EOS platforms [for instance, the satellites of the A-Train] and the next generation. Lack of overlap will provide challenges to demonstrating observation continuity needed for space-based climate observations. Cross-calibration from old to new sensors while both are still in orbit is essential for retaining continuity for multiples decades. The potential delays of JPSS [the environmental operational NASA-NOAA mission, follow on to A-Train and EOS] could seriously jeopardize cross-calibrations with the EOS sensors nearing the end of their lifetime".[852]

For instance, Topex/Poseidon and Jason-1 would overlap during 6 months (February to August 2002) to cross -calibrate the respective altimetric datasets[853]. Note that cross validation between TOPEX/Poseidon and Jason-1 radar measurements insured that calibration and correction procedures would be homogeneous between the two successive missions. However, it was deemed necessary to control their accuracy with an independent source of information to evaluate their accuracy: a ground-based network of tide gauges was deployed to provide ground-truths from which non-oceanographic signatures (meteorological bias, tectonic movements, gravitational forces, etc.) in the altimetric data sets could be quantified –and so allowing a seamless transition between the altimetric data sets from Topex/Poseidon with the new mission Jason-1, and onwards[854]. We find again the importance of completing the satellite-program with a ground-measurements program. Back to the radar altimetry family, Jason-2 would then overlap with Jason-1 and it is planned for Jason-3 to overlap with Jason-2 during 6 months for calibration purposes. Even more, apart from the family of altimeters derived from Topex/Poseidon, another family of satellites measuring with radar altimeters would be also launched in parallel in the 1990s and 2000s: ESA's satellites ERS-1, ERS-2 and ENVISAT. Like Topex/Poseidon and Jason-1, ERS-1 and ERS-2 would also fly in tandem for inter-calibration purposes. In turn, ENVISAT would be cross-calibrated with respects to Jason-1. In this way, measurements and data from all these satellites would provide certain consistency with each other and their collective interpretation would be possible.

If we have chosen to illustrate the strategy of overlapping to achieve calibration in order to build of homogeneous long term data records with the case of Topex/Poseidon is because the measurements taken with radar altimetry technologies constitute one of the few cases in which consecutive satellites have been planned to pursue the measurements and overlaps have succeeded one after the other. Most of the parameters retrieved from satellite instruments, and this has been repeatedly denounced by some *data users*, like illustrated by the extract of the paper presented by Kevin Trenberth, are obtained however through single-shot time-limited missions for which no plans for continuity are designed. Even those satellite programs conceived, by design, with views to perpetuate a given line of measurements have often failed to be launched in a timely manner for overlaps to be possible. For instance, when the European Polar-Orbit Observation Mission was first conceived in 1981 it was designed as the first of a series of environmental satellites. It would be launched in 2002, under the

852 "Challenges of a sustained climate observing system", K. Trenberth et al, 2011.

853 "Inter- and intra-calibrations of TOPEX/POSEIDON and Jason-1 with inferences for decadal basin-scale sea-surface variability", Gary T. Mitchum, 1999 and "Calibration of TOPEX/Poseidon and Jason altimeter data to construct a continuous record of mean sea level change", E.W. Leuliette et al, 2004.

854 "Monitoring the stability of satellite altimeters with tide gauges", G.T. Mitchum, 1998.

name ENVISAT, which would be flying during around 10 years. In spite of this unexpected longevity, it would not be enough time for its successor (the satellites Sentinels of the program Copernicus to be launched from 2014 onxards and EarthCARE scheduled for a launching in 2016 or 2017) to be launched in a timely manner for an overlapping for calibration purposes to be possible. Similar issues happened with the program ADEOS. It was designed to be followed on by the Global Change Observation Mission (GCOM), which was launched in 2012, creating a period of around 9 years between them. We are now turning to this other fundamental issue involved in the production of climate data: having data during long periods of time. In the following section we examine some of the attempts for guaranteeing the perpetuation of satellite measurements.

The problem of achieving perpetual measurements

Crucial to the continuity of satellite data is the continuity of satellites themselves. Given that they wear out in space, they must be replaced every few years, carrying instruments similar, or comparable, to the ones carried by their antecessors. In this section we examine some efforts endeavored to put in place an observing system perpetuating the measurement of environmental parameters in time *ad infinitum*.

Data gaps

To *data users* interested in the climate approach successor satellites must be launched and they must be launched timely to replace the old ones in order to avoid any gap or discontinuity in the data-record. Two sources motivate this necessity. First, in order to detect and identify trends in the long-term, datasets must be continuous and without interruptions. Avoiding data gaps is still more crucial, this is the second source, in the case of satellite data, because instruments are renovated in a relative high frequency every 2 to 5 years and, as we have just seen, proper calibration between them often relies on intercalibration between the current dataset and the future one. So important is avoiding data gaps on behalf of calibration purposes that a number of satellites have been launched all over the years with the explicit purpose of measuring in circumstances in which the main instrument is temporally out of service –just to ensure the continuity. This is for instance the case of the first radiometer ScaRaB conceived by the Laboratoire de Météorologie Dynamique in 1986. Since 1975 measurements of the Earth radiation budget were secured by a series of radiometers developed at NASA and launched in successive satellites[855] (Nimbus-6 in 1975, Nimbus-7 in 1978, and the Earth Radiation Budget Experiment (ERBE) experiment in 1984 and 1986[856]). A new generation of radiometers, called the Clouds and the Earth's Radiant Energy System (CERES), was being developed in the 1980s to

[855] Interview Jean-Louis Fellous, COSPAR, 2012 and Interview Robert Kandel, LMD, 2011.

[856] ERBE experiment would be composed of three satellites computing the Earth radiation budget during around 5 years and by means of a new generation of radiometers: ERBS/NASA and NOAA-9 launched in 1984 and NOAA-10 launched in a 1986.

follow on the measurements from the 1990s onwards, just when the ERBE experiment was scheduled to come to an end. However, delays in the launching of this new generation of instruments CERES threatened the continuity of the measurements during the period between the last transmission of the ERBE experiment and the first CERES. ScaRaB would be conceived with the primary goal of bridging a possible gap of measurements between ERBE and CERES: ScaRaB's mission would be to provide measurements during these about five years in which no NASA's instrument would be operating as per guaranteeing the stability of the long record[857].

From the perspective of producing climatic data records, the main problem of a gap is, thus, not that during certain number of years there are no data of a given type; the main problem of gaps is the non-possibility for calibration between the old instrument and the following one, which jeopardizes the proper interpretation of the new measurements with respects to the older ones. Without calibration between successive instruments there is no way to discern whether differences in the climate data are factual or artifactual, whether they belong to natural variability or to instrumental artifices. If there are discontinuities and interruptions in the measurements the new geophysical data record and the old one cannot be pieced together to compose climatic series.

Keep launching: Infrastructural globalism epicentered on satellite data

The obvious way to avoid satellite data gaps is to keep launching satellites in a timely manner –just like it has been done in the case of radar altimetry satellites or the MSU to measure temperature aboard of NOAA's series, or more generally in the case of weather satellites. However, as we have mentioned, most of the satellite launchings are not integrated in a long-term vision intended to perpetuate the provision of continuous data. Almost 20 years separate the following two fragments, which send remarkably similar messages: the time scales involved in the climate approach render it a scientific problem that requires long-term commitment to launching successive satellites in a timely manner:

> "It is clear that the success in monitoring [the Earth's environment] will be extraordinarily difficult. It will take a long time, perhaps decades, and will require a new generation of scientific talent, institutional resolve, and financial resources. Some will counter argue that the problem is too difficult and too unglamorous to command the sustained resources and commitment required. It will be then important to remember the challenge facing us all: we are faced with nothing less than the need to identify how the Earth system is changing over the next century, explain why the changes are occurring, separate natural from anthropogenic change, and learn if our predictions are correct or incorrect. If we in the scientific community cannot step up to this challenge, it is a safe prediction that all of us will be held accountable"[858].

[857] Delays in the preparation and the launching of ScaRaB, however, would impede this purpose of covering the gap as it would be launched in 1994, but only flying during several months, and then again in 1997-2002.

This would not be dramatic because NOAA-9 and 10 would be flying until 1997 and ERBS until 2005. CERES, the follow on, would be launched in 1997, so that at the end there would be no gap to cover anyway.

[858] "Monitoring issues from a modeling perspective", paper presented by Jerry Mahlman in the GISS Workshop on "Long-Term Monitoring of Global Climate Forcings and Feedbacks" held on February 3-4 1992 at GISS/NASA, NASA Conference Publication 3234. Ed. by James Hansen, Bill Rossow and I. Fung.

> "The time scales involved in climate change greatly exceed human working time spans, lifetimes, and the duration of the longest instrumental records. It is a disservice to the science and to society to claim that five or 10 more years of data will lead to a breakthrough in understanding: it is not going to happen. The major effort must be to create observational systems that can be sustained, in a practical way, for many decades so that future generations will have the data giving them the possibility of ultimately claiming understanding. The sustenance of such systems requires keeping in mind all of the structures listed above---the purpose of it all, the (probably changing) requirements on accuracy, precision and sampling, all while the technologies and scientific insights evolve"[859].

The first is extracted from the proceedings of a workshop organized by Bill Rossow and James Hansen of the Goddard Institute for Space Sciences of NASA in 1992 to assess the current situation regarding the implementation of observing systems in the long-term and some perspectives. Recall that in 1990, in response to the 2nd World Climate Conference, provisions for implementing a Global Climate Observing System (GCOS) had been endorsed and that a Memorandum of Understanding between the sponsors had been just signed in 1992. Their workshop, in which they proposed an observing system called CLIMSAT[860], must be integrated in these series of events. The second one corresponds to a position paper presented by the oceanographer Carl Wunsch, one of the first non-NASA scientists engaged in the use of satellite data since the 1970s with the first oceanographic NASA's satellites SeaSat (he was also a member of the Space Science Board when it issued the report about data management in 1982 that we have discussed in chapters 1 and 2), during the annual conferences OceanObs in 2009.

Challenges to the implementation of such perpetual observing system have been often identified by *data users* themselves: short time horizon of the political process that renders difficult for governments to sustain programs over years and decades, national priorities other than monitoring the climate, or difficulties to sustain scientific interest long enough as generations in laboratories renovate, and even more given the ever-reducing time scale of projects and grants, to mention few[861]. We are not entering in examining these issues. What interests us is that perpetuating the measurements requires repeated launching of the same, or at least similar enough, instruments as to provide comparable data. This design forms a conflicting interest within space agencies, with a strong mandate to support the development of new observation techniques for both existing and new observables, and not interested in perpetuating the launching of the same technology over and over. An illustrative example of such a mandate is the development of the family of microsatellites Myriade at CNES (and the minisatellites Proteus) explicitly intended to launching single shot missions for experimental purposes and without any vocation of continuity of the measurements. By contrast, this is a format for which some operators had been precisely conceived. For instance, Eumetsat was specifically established to deal with the exploitation of the European satellite weather program and to guarantee the continuity and perpetuity of the services, which includes the periodic launching of satellites as to provide permanent data-

859 «Observational network design for climate », Carl Wunsch, paper in OceanObs 2009.

860 "Long-term Monitoring of Global Climate Forcings and Feedbacks", James Hansen et al, Proceedings of the workshop held in Goddard Institute for Space Studies, 1992.

861 For recent analysis made by scientists see: "Climate Change as an Intergenerational Problem", C. Wunsch et al, 2009 and "Challenges of a sustained climate observing system", K. Trenberth et al, 2011.

gathering, production and subsequent weather services. This was also the case of the US National Oceanic and Atmospheric Administration (NOAA) –actually, the model ESA/Eumetsat in the case of weather satellites had been conceived mirroring the model NASA/NOAA. NASA, after funding a first phase of instrument and platforms realization, would step back to leave the responsibility for a second phase of exploitation to NOAA, in order to concentrate, completing the circle, on a third phase of demonstrating new capabilities.

Some data users have been pleading for organizing the institutions at the international level (operators, space agencies, scientific organizations) in a form so as to guarantee the perpetuity of the satellite measurements Earth scientists and representatives of space operators would discuss possibilities to develop and foster observing capabilities in the international arena[862]. The Global Climate Observing System was actually conceived to that purpose: to coordinate the gathering, production and circulation of climatic data, to establish an *informational global infrastructure*, in which measurements would be taken-for-granted, as discussed in the introduction to this second part of our dissertation. One of the actions conducted within the frame of GCOS would be for instance the creation of the notion of Essential Climate Variable discussed before. These variables would be those geophysical parameters currently measurable, with impact on environmental change and whose monitoring from space should be guaranteed in the long-term[863]. The solution found in the case of weather satellites resulted exportable to other variables, like the case of radar altimetry satellites. Framed within the classical model of migration from demonstration to exploitation from space agencies to space operators, Topex-Poseidon and Jason-1 would be considered scientific satellites operated by NASA and CNES, Jason-2 would be the pivoting mission towards continuity encompassing four agencies operated by a consortia of NASA, CNES, NOAA and EUMETSAT to ensure on the one hand an operational procurement and on the other hand a continuation of the research involved and Jason-3, and the following ones, is planned to be fully operated by NOAA and EUMETSAT, just like weather satellites are[864]. [865] Other solutions may be found in other cases. For instance, at a regional level, as we have already mentioned, the European program Global Monitoring for Environment and Security (GMES or Copernicus) proposed in 1998 would be approved in 2001 and given impetus in 2003, just after the G-8 recommendations of boosting GCOS[866]. It was meant to be a regional contribution to the monitoring of some of the so-called Essential Climate Variables through satellite and non-satellite means (although the space component would clearly dominate) during around 15 years. Some American *data users* would propose in 2007 the creation of a new institution (in the US) exclusively endowed to guarantee

[862] "Climate Observing System Studies: An element of the NASA climate research program", NASA, September 1980.

[863] "Second report on the Adequacy of the Global Climate Observing System in support of the UNFCCC", GCOS-82, 2003.

[864] See the description of this process made by actors at different stages: "Space-based observations in the global ocean observing system: the operational transition issue", Alain Ratier, 1999 and "Transitions toward operational space-based ocean observations: from single research mission into series and constellations", Hans Bonekamp et al, 2009.

[865] Another example that has been analyzed from a historical perspective is that of Landsat, as we have mentioned before. See: "Viewing the Earth. The Social Construction of the Landsat Satellite System". Pamela E. Mack, 1990.

[866] The relationship of political institutions, international research programs and space agencies and operators needs to be explored more than is possible here, since this tough chronology suggests interesting connections.

the long-term continuity of measurements of a number of such variables. In order to render it independent of any particular government funding source or governmental interests existing at a particular time, this institution would be a private foundation sustained by benefactor patronage[867] -this was a ways, to them, to gain independence from the political cycle and to ensure perpetuating the measurements. Interesting enough, as these scientists pleaded, by the late 2000s, for fundamental structural changes as a way to tackle the issue of perpetuating the observational systems in the US (through the creation of a private foundation), structural arrangements of opposite sign were factually being set in Europe to deal with the same issue (progressively growing involvement of public governmental institutions): the GMES/Copernicus program is a partnership between the European Space Agency and the European Union. Public initiatives were also endowed in the United States. By 2001 NASA, Department of Defense and NOAA developed a joint program NPOESS (National Polar-orbiting Operational Environmental Satellite System), focused on measuring some of the Essential Climate Variables parameters and providing for a series of six satellites, launched in two rounds of three and providing global permanent coverage during at least 10 years, when the new generation of satellites of the program would be ready to launch, and so successively[868]. There is no point in keep unfolding the casuistic as we have already provided enough examples.

Given the fact that at present day most of the 50 Essential Climate Variables are not guaranteed to be perpetuated, perhaps through GCOS the international community has not, at least not yet, succeeded in involving the space agencies and other operators in implementing a permanent *informational globalist infrastructure* to gather, circulate, process and preserve environmental data. In this sense, and for some scientists, GCOS has so far failed[869]. Perhaps the strategy proven to be efficient for the World Weather Watch in the 1960s and 1970s is no longer valid in a renewed political context, with different social concerns, technologies, scientific urgencies or space actors –that is why the before-mentioned American scientists plead for private funding. Perhaps is just that governments (and space agencies and operators) have priorities for consuming their space budgets other than in environmental monitoring. Perhaps is a lack of leadership, whether it comes from the World Meteorological Organization, NASA or a group of enthusiastic individuals. Perhaps it is a matter of time.

We would like to temperate this perception of failure though by pointing a major achievement. Indeed, through GCOS (or through any other of the existing satellite programs intended to monitor the environment in the long-term, like GMES/Copernicus, the American private initiative or NPOESS), the objective of implementing a *informational globalist infrastructure* for climate data has not been (yet) reached. Yet, the *climate approach* for producing data from satellite measurements is omnipresent in all debates, forums, within space agencies, space operators, scientific communities or

[867]"Endowments and New Institutions for Long-Term Observations", D.J. Baker, R. W. Schmitt, and C. Wunsch, 2007.

[868] "The National Polar-orbiting Operational Environmental Satellite System (NPOESS)", Patricia Vets, NOAA Public Affairs Office.

In his book, Conway describes very briefly the fate of such a program from an institutional perspective.

[869] Interview with Bill Rossow, NOAA-CREST, 2013.

political instances, of national, regional or international scope. In our views, and from the perspective of a historian of sciences and technologies, this omnipresence reflects a perhaps more important achievement: satellite remote sensing has become a mainstream tool in the disciplines of the domain of Earth sciences –note that the 50 Essential Climate Variables cover all current disciplines. The renovated momentum that these initiatives received between 1998 and 2003 reflected and reinforced the credibility of satellite data as tools to conduct research. Indeed, GCOS, GMES/Copernicus, NPOESS, CLIMSAT, EOS, the old ENVIROSAT and many other attempts to monitor the environment, consisted in creating a panoptical globalist infrastructure whose basic pillar would be satellite data. In the course of discussing, designing, slowing down, reconsidering again, cancelling, redefining, developing, rebudgeting, and in some cases, eventually launching, satellite remote sensing would acquire the status of dominant necessary tool for inquiry in any domain of the Earth sciences. With this lens, the attempts of establishing such a globalist infrastructure, even if not fully achieved, reflect and reinforce our hypothesis regarding a *normalization* of satellite data as legitimate source and practice in the domain of Earth sciences. This normalization of the use of satellite data for scientific inquiry would define satellite data as *points de passage obligés* for any investigation in the field of Earth sciences, a representation that could only benefit space agencies and operators in the long-term. This had been, we suggest, and with that we adhere Chunglin Kwa's overall frame, one of the main goals of space agencies, beginning with NASA, striving, since the late 1970s, to put remote-sensing technologies at the center of epistemic authority for environmental studies[870].

Perpetuating polarized radiometry

At CNES, the organization of the budget and programming reflected, since the late 1960s, a split between those missions with vocation for continuity devoted to applications of economic or public interest (including weather forecasting through the program Meteosat) and those singular launches devoted to scientific research (traditionally planetology, astronomy or geodesy) conducted as a time-limited experiments. As we have argued, Earth sciences would become normalized as a form of space science organized as experiments conceived by a group of *data creators* to gather and produce geophysical data. In that sense, they were useless to *data users* interested in the climate approach. While useful to *data creators*, inheritors of the experimental culture embodying the scientific missions of the space sciences at the dawn of the space age, and interested in developing new instruments and producing new geophysical datasets to respond a given scientific question, this configuration would result poorly adapted to those *data users* willing to study the long-term and mobilized a *climatic approach*.

[870] The historian of sciences Chunglin Kwa illuminated how in the late 1980s the discipline of ecology was transformed, pushed by NASA and through the International Geosphere-Biosphere Program, as to adapt to the utilization of satellite data. « Local Ecologies and Global Science : Discourses and Strategies of the International Geosphere-Biosphere Programme », 2005.

CNES's leadership was by 1998 well-aware of the increasing importance that the climatic approach was acquiring. The conclusion of a workshop organized by the Direction de Programmes to decide the agenda lines and orientations for the 5 to 10 years to come, and the corresponding budget preferences, confirmed a commitment to the continuity of consistent high precision measurements:

> « Ces programmes [WRCP and IGBP] ont besoin de données et d'observations suffisamment précises, régulières, objectives, fiables et répétitives dans le temps et dans l'espace. La continuité et la cohérence à long terme est particulièrement importante pour ces recherches. Seul l'espace est en mesure de répondre à ces besoins. Cette réponse par la technologie spatiale suppose une programmatique volontariste, dotée de vision à long terme, située dans une perspective de concertation et coopération internationale pour la mener à bien. C'est donc dans ce cadre que nous allons définir la programmation du CNES »[871].

In the course of that workshop, three would be the scientific programs labeled as "filières d'excellence"[872] which would be emphasized with priority to perpetuity: the altimetry mission providing data on the sea-level (Topex/Poseidon already launched, and Jason-1 in preparation), the radiation budget mission (giving continuity to ScaRaB's measurements) and the technology of polarized radiometry in wide-field of view that would provide data on several parameters related to the aerosols, the color of the ocean or the clouds (giving continuity to POLDER-type measurements)[873]. Let us look now to the perpetuity of polarized multidirectional measurements (POLDER's type) with some detail.

Just after the workshop of the Direction de Programmes in 1998, CNES opened a R+T budgetary line allocating 41,5MF for the period 1999-2005 to study and develop these concepts, in what came to be known the POLDER-NG, NG standing for New Generation. The technological evolution of the instrument, as planned in 1998, would aim to widen its field of view, improve the angular and space resolutions and increase the number of spectral bands. It would be conceived in two parallel ways: the new generation of POLDER could maintain the wide range of application themes (ocean color, land surfaces, aerosols, clouds and radiation) or it could be divided in different instruments optimized for each particular theme[874].

Just after the launching of ADEOS-I, and until the early 2000s, several options would irrupt to launch the future POLDER-NG in cooperation with NASDA. Apart from POLDER-2 aboard ADEOS-II, by 1997, NASDA had proposed CNES to embark one POLDER-type instrument in its GOSAT satellite (Greenhouse gases Observing SATellite) to be launched by mid-2000s[875]. One year later, NASDA would also propose two more POLDERs to be carried by its satellites of the program GCOM (Global Change Observation Mission), considered actually as the successor of the program ADEOS and

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[871] « Plan programmatique du CNES. Observation de la Terre », proceedings and report of the Séminaire de Programmation, January 1998.

[872] « Plan programmatique du CNES. Observation de la Terre », proceedings and report of the Séminaire de Programmation, January 1998.

[873] « Note aux membres du groupe de travail de la Direction de Programmes », Gérard Brachet, General Director of CNES, January 1998.

[874] Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space, January and February 1997.

[875] Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space, January and February 1997.

intending to consolidate long-term environmental monitoring[876]. Our examination of the records of these developments suggests that to CNES's program managers the primary motivation for such eventual launchings was the institutional goal to keep alive the cooperation with Japan in the future post-ADEOS era. Whether through this cooperation the continuity and perpetuation of the polarized measurements would be guaranteed or not was not the main concern. The proceedings of the first CNES-NASDA Symposium on cooperation in space hold in January 1997 synthetized by CNES's program managers, for instance, made this point clear[877]. We have not found any trace of a long-term vision and program scheduling dealing with budget hypothesis, technical options, convergent and co-ordinated initiatives, or possible partners that could suggest proactive moves to rendering POLDER part of the continuous global climate system. Perpetuating POLDER measurements, if achieved, would be rather a byproduct of perpetuating the cooperation with Japan: for instance, if NASDA would commit to the perpetuity of some of its Earth observation missions (like it was the intention for GCOM[878]), then, if POLDER was accepted in the project, its measurements would be consequently perpetuated, but no specific commitment would be worked out by CNES in this frame.

Other opportunities for launching POLDER would also irrupt by the early 2000s, a part from these Japanese propositions. In December 2001 CARBOSAT would be proposed to ESA as part of its Earth Explorer program, and one of its instruments would be a POLDER-type radiometer optimized for the detection of tropospheric aerosols, which would be called Optical Carbonaceous and anthropogenic Aerosols Pathfinder Instrument (OCAPI) –JAXA (the new Japanese space agency after institutional reconfigurations taken place in 2003[879]), would be also interested in launching a prototype of OCAPI in 2003[880]. A POLDER optimized for measuring over land surfaces, called Terrestrial Ecosystem Monitoring Sites (TEMS), would also be studied as a combination of the instrument VEGETATION and polarized filters[881]. These propositions were clearly missions of opportunity, without any sense and vocation for continuity. Rather, it was about shooting a series of singular and punctual experiments, as options for launch irrupted. The most illustrative example of such singular shots, and the only one factually launched at present day, would be PARASOL. With a life span of two years and particularly optimized to combine its measurements with the lidar CALIOP aboard NASA's satellite CALIPSO (which in turn had a life-span of three years), PARASOL represented, at its outset, everything but perpetuation of the measurements. It was a mission made by and for *data creators* to generate samples of more or less complex geophysical datasets and poorly adapted to those *data users*

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876 « Plan programmatique du CNES. Observation de la Terre », proceedings and report of the Séminaire de Programmation, January 1998.

877 Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space, January and February 1997.

878 « Panorama des programmes du CNES en Observation de la Terre », Jean-Louis Fellous, Division of Study and Observation of the Earth at CNES, July 1999.

879 The National Space Development Agency of Japan NASDA was one of the official interlocutors for space activities in Japan; the other one was the Institute of Space and Astronautical Science (ISAS), an older institution pending on the University of Tokyo. It was in 2003, with the creation of JAXA, that the activities of these two entities got coordinated in one single space agency.

880 « Présentation de POLDER-2 », Project Polder, 17 December 2003.

881 "Proceedings of the First CNES-NASDA Open-Symposium on cooperation in space", January and February 1997.

interested in the climatic approach –at this point, it shall be noted that, as PARASOL and CALIPSO lasted more years than scheduled, around 8 of coincident measurements, some degree of long-term would be accomplished and therefore some form of climate datasets could be produced by accident.

Other attempts to perpetuate the measurements of POLDER-type have been made. For instance, NOAA proposed in 2001 a polarimeter of POLDER-type as a payload for the program NPOESS (National Polar-orbiting Operational Environmental Satellite System)[882]. As we have described before, NPOESS was a joint program between NASA, Department of Defense and NOAA composed by a series of six satellites, launched in two rounds of three (the first of which to be launched by 2013) and providing global permanent coverage during at least 10 years, when the new generation of satellites of the program would be ready to launch, and so successively. The American project would be slowed down and redefined in several occasions before taking its final form in 2010[883], in which no POLDER-type instrument would be included and "le dossier POLDER a du mal à progresser", wrote POLDER's project manager in 2001[884]. The continuity of polarized radiometric measurements would not be institutionally engaged and the instrumental line of POLDER would not become operational –at least not yet.

In 2013, the European Space Agency approved the passage to phase B for the realization of a new generation of the radiometer POLDER, called 3-MI (Multi polarization Multi directional Multi spectral) and conceived by a team of Laboratoire d'Optique Atmosphérique, as the French contribution to the second generation of the Meteorological Operational (MetOp) satellites in the timeframe of 2020 to 2040, targeting an operational system of 21 years of operations, and primarily aimed at providing aerosol characterization for climate monitoring, numerical weather prediction, atmospheric chemistry and air quality[885]. With the instrument 3-MI embarked in a weather satellite, polarized measurements get indeed infrastructured, banal, taken-for-granted –at least during the years that the weather program will be orbiting. At the same time, though, the instrument gets externalized and enters a cycle of industrial production, in which the scientific team proposing it loses its control. Something similar can be said for the data: data will be routinely produced and disseminated at the computer center of EUMETSAT (the operator of the European weather satellites) and ruled by the access policies of this body. In this configuration, once infrastructured, the category of data creator will disappear as all scientists will become *data users*; by contrast, the data providers, materialized by the weather services will come into the game, giving birth to a different technical configuration, social organization and epistemological signification.

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[882] « POLDER - Perspectives futures », by F. Bermudo, project manager of POLDER, 2001.

[883] The White House announced on 2010 that the NPOESS satellite partnership was to be dissolved, and that two separate lines of polar-orbiting satellites to serve civilian and military users would be pursued instead. The first one of the civilian ones was launched in 2013, called NPP or Suomi, in honor to Verner Suomi.

Source: "The National Polar-orbiting Operational Environmental Satellite System (NPOESS)", Patricia Vets, NOAA Public Affairs Office.

[884] « POLDER - Perspectives futures », by F. Bermudo, project manager of POLDER, 2001.

[885] "The MetOp second generation 3-MI mission", Ilias Manolis, Jean-Loup Bézy, Maurizio Betto, Hubert Barré and Graeme Mason, European Space Agency.

The problem of global data

So far we have concentrated in two issues featuring the production of climatic data-records (rendering all the data homogeneous and perpetuating their gathering). We are now very briefly drawing our attention to a third feature needed to ensure studies about environmental variability at the planetary scale: data records must be global in scope.

A sole satellite cannot provide a picture of the whole planet at once. Depending on the orbit of the satellite and on the field of view of the instrument, data from the entire planet can be amassed within more or less large intervals of days -in some cases, these satellites located in geostationary orbits (like Meteosat), global coverage can never be amassed with a single satellite, as they are permanently immobile keeping their eye always over the same region[886]. For instance, to get a picture of the whole planet with POLDER aboard ADEOS-I and ADEOS-II we needed four days; to get a picture of the whole planet with geostationary weather satellites, we need five satellites measuring at the same time (recall that this was what the International Satellite Cloud Climatology Project of the Goddard Institute of Space Sciences of NASA was about in 1982: piecing together the data of the five weather satellites orbiting in geostationary paths in order to create global datasets about the cloud cover –this was actually an example of producing climatic data)[887]. Global satellite coverage, when attainable, is achieved within the interval of days and/or by combining data from different satellites. In addition, even if a mosaic of data covering all regions can be assembled, most of the algorithms for retrieving geophysical parameters have some kind of limitation: some cannot, for instance, observe in the presence of clouds (this is particularly constraining given that statistically speaking around 75% of the planet is permanently covered by clouds), over some kinds of land surfaces (snowed, desertic, etc.), in high polluted atmospheres, during nighttime, etc. This means that even if the measurements exist (level 1), in many cases the geophysical parameters (level 2, 3 or 4) cannot be retrieved or are retrieved by means of a specific set of hypothesis. Data, as Paul Edwards expressed, must be rendered global[888] –we will insist soon in that point.

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[886] Satellites placed in a geostationary orbit are placed directly above the Earth's equator at an altitude of around 36000km with a period equal to the Earth's rotational period and an orbital eccentricity of approximately zero. An object in a geostationary orbit appears, to ground observers, as motionless at a fixed position in the sky allowing a fixed antenna to maintain a link continuously with the satellite. Viceversa, the Earth appears motionless to the satellite, allowing them to observe in permanence the same region of the planet. Several weather satellites are placed in geostationary orbits, like GOES, Meteosat and GMS.

[887] "ISCCP cloud data products", W.B. Rossow and R.A. Schiffer, 1991.

[888] Paul Edwards defined making data global as "building complete, coherent, and consistent global datasets from incomplete, inconsistent and heterogeneous data sources" and complemented this process with what he defined as making global data, that is to say, "collecting planetary data in standard forms, through interconnected networks, to build data images of global weather and general circulation". "A Vast Machine", 2010.

Technological practice of data assimilation: From physical and geophysical datasets to climatic data-records

We have so far presented three of the attributes of the climatic data necessary for studying long-term planetary variability and trends and some of the issues related to their gathering and production. We are in the following describing the most common technological data practice deployed by data users in order to render data homogeneous, continuous and global: the technological practice of *data assimilation.* After describing its basics we will scrutinize a particular case in which this technology is used to produce a specific type of climatic data-records: the "reanalysis".

Legacy of weather forecasting, again

Let us illustrate the problem of data assimilation with the familiar example of numerical weather forecasting, which actually was the domain in which this technology started to be developed in the 1950s. The atmosphere is a heat-conducting fluid and as such obeys the hydrostatic equations of Navier-Stokes that describe the thermodynamic fields such as temperature, pressure, air density, wind speed and humidity of the fluid –of course, like all physical systems it is constrained by the fundamental laws of conservation of energy/mass and momentum. These are non-linear equations and therefore weather predictions are highly sensitive to initial conditions[889]. Since the advent of numerical weather prediction in the 1950s, some weather forecasters would intend to insert data on temperature or wind speed retrieved from rawindsondes and ground stations to initialize the weather models in order to improve the accuracy of the forecast; since the 1960s they would also intend to integrate satellite data of the families TIROS and ATS[890]. We know at this point that the quantities measured by radiometers, and later on spectrometers, radars and lidars, would only be indirectly related to the geophysical variables of interest to the equations of the models and must be rendered comparable through a set of inversion schemas involving sophisticated non-linear radiative transfer models. However, not all the variables would be easily retrieved from the instruments existing in the 1960s and 1970s: while the temperature would be retrieved from infrared soundings, values of wind-speed or rainfall were much more complicated to derive and, during the early years of space age, no data would exist on these parameters to fuel the numerical models. Besides, these equations must be translated into algorithms –and then to computer codes- constituting the core of the computer model. Although the atmosphere is a continuum fluid, the equations would be only solved for determinate points, both

[889] The equations of Navier-Stokes are a set of partial derivative nonlinear equations that describe the motion of fluid substances. They arise from applying the mechanical and thermodynamical conservation principles to a fluid, and are useful to describe the atmospheric dynamics, the ocean currents, the water flow in a pipe, the air flow around a wing, or even economic patterns. As applied to the atmospheric dynamics, they establish the relationship between its temperature, pressure, air density, air speed and other dissipative terms. Excepting for a reduced simplistic situations there is no analytical solution to these set of equations and therefore numerical approximative methods are required.

[890] In her doctoral thesis, Margaret Courain described some of the efforts made by certain weather scientists of the US Weather Bureau in developing ways to assimilate remote sensing data inside the numerical prediction models, in particular, to ingest the temperature retrieved from radiosondes and satellite radiometers.

"Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, doctoral dissertation, 1991.

as a consequence of the digitalization of the equations and to reduce the computation time (the shorter is the distance between these points, the more capable is the model to simulate phenomena of smaller scale, implying more time for computing). All these points would constitute a tridimensional grid that must be filled point-per-point for the software to compile. However, satellites would only provide measurements of the gridpoints corresponding to their orbital path (and after readjusting dimensions); there existed no data for most of the gridpoints of the model. Summing up, satellite data, when existing, usually did not come under a form compatible with the models necessary inputs –and most of the gridpoints were left empty anyway. Some methods to reconcile the characteristics of satellite data with the requirements of weather models in terms of data input must be invented. One of these techniques would be the so-called *data assimilation*.

Put it simply, data assimilation was a form of data interpolation. Not only a mere mathematical interpolation, as it was constrained by the physic-chemical relationships and correlations governing the components of the atmosphere, the hydrodynamics laws governing the fluid and the general conservation laws governing all physical system. Interpolation is vital for satellite data at least seen from three perspectives. First, space and time interpolation. Due to their limited and sequential sampling satellites would provide a fragmented picture at a given time. And due to the interpretational bias inherent to the inversion of geophysical datasets, satellites only provide data interpretable in a given set of conditions (no clouds, over the ocean, no polluted atmospheres, etc.). Just like described, the model and the assimilation schema act as an interpolator of the data into all the globe, whether the satellite has overflown the region or not and regardless of the environmental conditions assumed in the inversion algorithm. Second, dynamic interpolation of observables. Through relationships expressed in the governing equations of the model, parameters that are factually being measured can, through a data assimilation schema, provide information or constraints on those that cannot be measured adequately. For instance, some chemical species are hard to measure with a satellite (like CO_2 mentioned at the introductory example); they can nevertheless be estimated from the measured evolution of other species by using the physic-chemical relationships integrated in the appropriate numerical model of atmospheric chemistry[891]. Similarly, the sea level can be retrieved from measurements with radar altimeters and, by running data on the sea level into an oceanographic model, other ocean parameters, which can be hardly measured from space, like salinity, can be extracted. Third, sources interpolation. Data assimilation techniques are also useful to combine data from different sources, characterized by different virtues and deficiencies, varying in nature, accuracy, coverage, as well as spatial and temporal resolution. For instance, by combining the sea level retrieved from several radar altimeters like the one carried inside Topex/Poseidon and the one carried inside ERS, scientists would have access to a two-satellite system, with increased space-time sampling and coverage of the global ocean,

[891] "Data assimilation: From photon counts to Earth System forecasts", P.P. Mathieu and A. O'Neill, 2008.

and more observables, including the sea level from Topex/Poseidon and the wind-speed from ERS scatterometer[892].

Given the physical frame of the model, by fueling it with data and through applying an assimilation schema, the model serves as a non-linear interpolator to fill in missing spatial and temporal information as well as missing observables. Data assimilation is, put simply, a problem of interpolating data in a physical system constrained by its dynamics and whose consistency must be respected (for instance, conservation of mass or momentum). In the example of the weather forecasting, satellite (or non-satellite) data about the current state of the atmosphere would be plugged into the grid as the initial conditions for solving the equations. As the model would be run forward in time, the assimilation schema would interpolate the lacunary data (in space and in observables), and the solution of the equations computed by the model would correspond to the future state of the atmosphere in each of the gridpoints and for all the parameters of the equations, namely the numerical weather prediction, also called *analysis*. More generally, given any numerical model, a set of data to initiate and constrain it and a code of data assimilation, these data can be interpolated to fill all the gridpoints with the corresponding observables and at all times.

When (physical or geophysical) data users become (climatic) data creators

Beginning with weather forecasting in the 1960s, this technological data practice is at present day applicable for interpolating data in any type of model: physical oceanography, atmospheric chemistry, climate or carbon cycle and vegetation –to mention a few. A numerical model describing a system, some data as input to the model and a data assimilation schema is all what is needed. Scientists developing assimilation codes must be experts first and foremost in numerical modeling, that is to say, in numerical methods to solve problem, including data interpolation and filtering techniques (variational, nudging, filters, covariance matrix), minimizing cost-functions, statistical estimation methods or probability distribution. They do not need to control radiation transfer properties, they do not need to develop inversion algorithms to create geophysical data, they are not associated to any space instrument; they are not geophysical data creators in the sense that we have described so far. They do not even appear in the schemas of the factory-like system for geophysical datasets mass production and dissemination. If something, they are some of the users of such data –a particular form of *data users* external to the space project, in this case the numerical modelers. It is not our goal to characterize this community (in part, because it is not a homogenenous block, as has been showed by others[893]), but simply to insist in two main differences with respects to the *data creators* we are

[892] "Data assimilation for marine monitoring and prediction: The MERCATOR operational assimilation systems and the MERSEA developments", P. Brasseur et al, 2005.

[893] Hélène Guillemot described, in her doctoral dissertation, two of these communities of numerical modelers, the climate modelers in the Centre National de Recherches Météorologiques and Laboratoire de Météorologie Dynamique and stressed a number of differences, sometimes clashing, embodied in their institutional culture. See: « La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », 2007.

familiar with. First, in general, they are scientists distant from the contexts of acquisition of the measurements. The metaphor distant refers to the skills and knowledge, the scientific culture, the institution they are affiliated to, the scientific objectives they pursuit, but also the geographical and time location they are placed. In the case of POLDER, the three versions, they did not participate in the early stages of conceiving the scientific objectives of the experiment or the material properties of the sensing instrument and their calibration. As we have argued, *data creators* were considered to be the best placed to carry out the job. Second, one of the ways in which this distance materializes is through the approach with which they analyze the measurements and the technological data practices they articulate to interpret them. In their re-use of data, these particular form of *data users*, the numerical modelers, deploy a particular technological practice: assimilation (instead of inversion), which in turn requires different expertise and training. Unlike (geophysical) *data creators* of POLDER-type, these *data users* are not interested in interpreting the measurements with a physical approach in order to produce geophysical units; they rather interpret the measurements (or the geophysical datasets) from a numerical approach in order to produce climatic datasets. While remaining users of the satellite measurements (because they use to be distant from the conditions of experimenting), they are however creators of climatic data: they hold the knowledge, skills, material resources, working environment, scientific motivations and technological practices to produce climate datarecords.

The case of reanalysis: Constructing climatic data about the past

We have discussed before some of the scientific, technical, sociological and institutional frictions involved in the piecing together of data gathered by different sources. What if scientists wished to reprocess a given data series at once? It has been described, for instance, how the astronomers in the XIXth Century periodically re-evaluated the reports and the almanacs of their predecessors, together with their own ones, to produce new values of certain constants and published their new analysis – which would be re-evaluated by the following generation of astronomers.[894] In a similar spirit, Earth scientists may find worthy to periodically reprocess data records at once, as substantial evolution of the gathering or treating technologies has taken place, in order to produce a single homogeneous consistent global dataset covering the whole period of measurements. On the other hand, as we have mentioned, sometimes getting the readings of one single instrument may not be enough because it

In his article the ethnographer Simon Shackley also distinguished different styles of climate modeling, implying different practices and rules to build and validate their models and therefore producing different ways of knowing and knowledge. He stressed in particular differences in the practices in function of national cultures. See: "Epistemic Lifestyles in Climate Change Modelling", in C.A. Miller and P.N. Edwards, eds, "Changing the Atmosphere: Expert Knowledge and Environmental Governance", 2001.

[894] Literature is abundant in the domain of astronomy. Matthew Stanley, for instance, explains how the astronomers in XIXth must look at old data to get the secular acceleration necessary for the equations of the Moon's motion and a number of frictions they encountered in the process (for instance, in calibrating their observations with previous ones). See: "Where is that Moon anyway? The problem of interpreting historical Solar eclipse observations", in "Raw Data is an Oxymoron", ed. Lisa Gitelman, 2013.

does not cover all the space, time or observables required. What if, to take the example of the long series derived from the family Topex/Poseidon, scientists wished to add also in this reprocessing the data measured by other radar altimetry satellites like ERS-1, ERS-2 or ENVISAT, or the data collected routinely by the network of 3000 ocean tide gauges distributed across the oceans to complete the series? Or what if they wished to move further in time and build records of not the 20 most recent years, but 50, 60 or 100 years (satellites did not existed yet) by adding the data of ancient tide gauges and buoys? And, what if scientists wished to include in this reprocessing not only the data related to the sea level but also weather data, data on icesheets, data on oceanic biology or chemistry, data on solar input, hydrologic data or geodetic and gravimetry information, in order to have a general picture accounting for more processes influencing the sea level? One of the aspects of such expanded data records is that they are composed of data from heterogeneous sources. The data would be heterogeneous in terms of types of instruments and the nature of the data obtained; the sampling would frequently be spotty in space and sporadic in time. The systems would be dynamically incomplete, meaning that some observables may be more available than others. Much of the data would be in the form of extended time series that contain gaps, bias, errors and/or calibration problems. How combining and synthetizing all these data inconsistencies in a single coherent dataset in order to produce climatic data?

In the late 1980s, the technique of data assimilation being developed for weather forecasting would seem appropriate for that task. The model would bring consistency to the observational data by interpolating them into data void regions in space and time and by providing the parameters that had not been measured. In its common use, data assimilation fused the data and the model to produce an estimate state of a given system, or *analysis* -for instance a weather analysis. By applying the same assimilation scheme and the same model to all the old data at once, a consistent estimate would be generated during the whole period of time –symmetrically, this came to be called *reanalysis*. Reanalyizing data would consist, thus, in using a numerical model and a data assimilation scheme, which would ingest all available data over the period being reanalyzed (radiosonde, satellite, surface stations, buoy, aircraft and ship reports with a different weight depending on the period and the region), producing a comprehensive series of global analyses, a form of climate data-records.

In 1988, scientists at European Center for Medium-range Weather Forecasting (ECMWF) and at the Goddard Space Flight Center of NASA (GSFC) would joint efforts to propose the running of a 10-years reanalysis[895]. Scientists of the US National Center for Atmospheric Research (NCAR), which had, for many years, undertaken an extensive program of data collection and rehabilitation, would support the exercise and would start studying their data archives and sorting out the data that could be used as input to the model[896]. These initiatives would lead to three major re-analysis projects conducted by the mid-1990s: a 5-year analysis from 1986 onwards produced by GSFC, which would be extended to a 15-year analyses starting on March 1980 under the responsibility of the, to that

[895] "Integration of space and in situ observations to study global climate change", L. Bengtsson and J. Shukla, 1988.
[896]"Summary of the NMC/NCAR Reanalysis Workshop of April 1991", E. Kalnay and R. Jenne, 1991.

purpose established, Data Assimilation Office of NASA; a 15-year analysis starting with data from 1979, ERA-15, produced by ECMWF; and a 35-year analysis from 1958 produced by the US National Center for Environmental Prediction (NCEP) in collaboration with NCAR, which would be extended to an ambitious 60-years analysis[897]. A second generation of reanalyses would start by the late 1990s just as these first experimental exercises would come to an end. They would extend over longer periods and they would use more sophisticated models and data assimilation techniques. One of those would be the so-called ERA-40, which would begin with the data gathered during the International Geophysical Year in 1957 and run until 2001, though it would be finally extended until 2003[898]. The European Center for Medium-range Weather Forecasting would be the coordinator of the project, which was conducted in partnership with meteorological research institutes and national weather services, including MeteoFrance[899].

Running a reanalysis depended upon numerous geographically and timely separated and not uniformly distributed data. One of the first urgencies was assembling and harmonizing all these data. During the two years of preparation of ERA-40, between 1998 and 2000, 10 scientists at the European Center for Medium-range Weather Forecasting would work in the location, collection, acquisition and organization of as many data as possible since 1957. Their job had been smoothed out by the previous efforts of assembling data realized some years before for the first round of reanalyses -only at the US National Center for Atmospheric Research the process of assembling and preparing data of 50 years necessary to the first reanalyses in the 1990s would require 30 full-time persons working during more than 8 years[900]. Actually, because the data archives of ECMWF only started in 1979 (the institution had been created in 1975), data covering the period from 1959 to 1979 together with extensive associated library information, metadata and historical details of observing stations, would be supplied free of cost by NCAR itself –in exchange, NCAR would have full access to the reanalyzed data. It was important to get the data free of cost because, given the number of data involved in this 45-years reanalysis, purchasing them would have considerably increased the budget. This would be actually of the challenges in getting the data. Indeed, European weather services, holders of important archives on past and current meteorological data, satellite and non-satellite, would not be easily convinced to

[897] "Reanalysis: Data Assimilation for Scientific Investigation of Climate", Richard B. Rood and Michael G. Bosilovich, 2011.

[898] The preparation of ERA-40 started in 1998, funded under EU's Fifth Framework Program in Energy, Environment and Sustainable Development, and the effective simulation would be run between 2000 and 2003. See: "The ERA-40 Project Plan", ERA-40 Project Report Series N°1, A.J. Simmons and J.K. Gibson, 2000.

Building upon this experience, ECMWF would begin a third generation of reanalises, called ERA-Interim, which would cover a modest twenty year time period from 1989 to 2009, financed also under EU's Framework Program in Energy, Environment and Sustainable Development. ERA-Interim would use an improved data assimilation system and an improved forecast model coupling atmosphere and ocean, in preparation for a new comprehensive reanalyses to be started by 2015; it would, in principle, reanalyze satellite radiances instead of geophysical variables.

"Overview of satellite data assimilation in the ERA-INTERIM reanalysis", Paul Poli, Dick Dee, Paul Berrisford and Jean-Noël Thépaut. Internal newsletter, ECMWF.

[899] The partners would be weather services of France (Météo-France), the Netherlands and the United Kingdom, as well as meteorological research institutes from Germany (Max-Planck-Institut für Meteorologie, MPIfM) and the USA (NCAR) and the Meteorology Department of the University of Reading.

"The ERA-40 re-analysis", Uppala et al., 2005.

[900] "Initiative to Prepare Data Inputs for Reanalyses", R. Jenne, Internal NCAR Report, 1991.

deliver their data costless[901]. In total, meteorological data from many sources, including radiosondes, balloons, aircraft, buoys, scatterometers, weather stations, ship measurements, paleodata and, since the late 1970s, also some satellite sources would be provided by different national weather services and space agencies. In addition, ECMWF would acquire a comprehensive oceanographic record, which contained weather reports from voluntary observing ships taken from log books since the 1870s[902], analyses of sea-surface temperature produced by the UK weather service (pre-1981) and NOAA's National Center for Environmental Prediction (NCEP) (post-1981) or data on the snow cover made available from the former Soviet Union weather services, among others. Just like mentioned before, a key step would consist in digitizing these vast number of figures that existed often only in hard copy archives. This would be done by endowed scientists at ECWMF but also, as mentioned before, through crowd science projects[903].

The archives of satellite data of the European Center for Medium-range Weather Forecasting would be also extended in sight of the ERA-40 reanalysis. By 1998 they were composed basically of retrievals of the wind speed from the geostationary weather satellites Meteosat, GOES (US) and GMS (Japan) spanning from the 1980s. ECMWF would acquire complementary wind-data retrieved from the European Remote-Sensing Satellite of ESA (ERS-1 launched in 1991 and ERS-2 in 1995) supplied by the datacenter CERSAT, which also would supply sea level data from the radar altimeter aboard the same satellites. Sea-ice concentrations computed from the Scanning Multichannel Microwave Radiometer (SMMR) aboard Nimbus-7 and from the Special Sensor Microwave/Imagers (SSM/I, aboard of the satellites of the US Defense Meteorological Satellite Program) were also supplied since 1978 and 1987 respectively. Data from two more instruments aboard Nimbus-7 were also acquired: data about ozone concentration from the Total Ozone Mapping Spectrometer (TOMS) and about atmospheric temperature from High Resolution Infrared Radiation Sounder (HIRS). Ozone data was also provided from the Solar Backscatter Ultraviolet Instrument (SBUV) launched in November 1979 aboard NOAA-6 and from its second generation SBUV/2 since NOAA-9 in 1985. Data about the temperature were complemented with the data from NOAA's Microwave Sounding Unit (MSU) aboard of NOAA-6 to NOAA-14 satellites since 1979 and its successor Advanced Microwave Sounding Unit (AMSU) aboard of NOAA's weather satellites since 1998. Besides data about the stratospheric and surface temperature were also acquired from the retrievals made from the Stratospheric Sounder Unit the aboard NOAA's satellites since 1979. NOAA provided the physical radiances measured by the Special Sensor Microwave/Imagers (SSM/I) since 1987 and from earlier instruments Vertical Temperature Profile Radiometer (VTPR, the precursor of the High-Resolution

[901] "The ERA-40 re-analysis", Uppala et al., 2005.

[902] "The Importance of COADS for Global Reanalysis", Roy L. Jenne.

[903] "On the Reprocessing and Reanalysis of Observations for Climate", Michael G. Bosilovich, John Kennedy, Dick Dee and Alan O'Neill. Position paper presented at Denver 2011, WCRP Conference.

Infrared Radiation Sounder (HIRS)) mounted on the NOAA-2 through NOAA-5 spacecraft providing radiances from 1972 to 1979[904].

Satellite and/or instrument	Period	Type of data	Data provider
NOAA-2 to NOAA-5/VTRP	1972-1978	Radiances	NOAA
Nimbus-7/TOMS	1978-1993	Ozone data	NASA
Meteosat, GOES and GMS	1979-2003	Wind data	EUMETSAT and NOAA
NOAA-6 to NOAA-17 HIRS/MSU/SSU/SBUV/AMSU	1979-2003	Radiances, atmospheric and surface temperature, ozone data	NOAA, NCAR
Nimbus-7/SMMR	1979-1987	Sea-ice data	NOAA
DMSP/SSM-I	1987-2003	Radiances, Sea-ice data	NOAA
ERS-1 and ERS-2/scaterometer and radar altimeter	1991-2003	Wind and wave-height data	ESA/CERSAT

Table 6.1. Satellite data assimilated in ERA-40[905].

Each of these missions would involve retrieval of parameters based on theoretical grounds and empirical data, the translation of the physical principles into algorithm, their coding, their integration in the software architecture and design for data production, the results of the validation with ground measurements and specific field campaigns, post-launch modifications and eventual changes. All these elements would be considered by *data users* as sources of interpretational bias that could impact severely on the outcome of the assimilation. One major manner in which ECMWF's data users would try to reduce the bias of the data was by using, when available, physical radiances instead of geophysical parameters. in so doing, two possible sources of major errors were eliminated. On the one hand, as we have argued, radiances had been submitted to fewer human interventions than geophysical retrievals and therefore, so it was argued, would carry less contextual bias. Second, in using radiances, the bias caused by changes in the successive inversion algorithms, which was one major source of error, uncertainties and misinterpretations related to geophysical datasets, was avoided.

Acquiring physical radiances, instead of geophysical datasets, was not trivial because most data services in the satellite weather offices had been designed since the 1970s (or before) by and for weather forecasters to deliver geophysical variables, such as temperature, pressure or wind-speed, since they were considered as the parameters that made sense for initializing numerical models to solve the hydrodynamic equations of Navier-Stokes. The same could be said for space agencies and their associated datacenters, which delivered satellite data corresponding to the geophysical parameters conceded with epistemic virtue in the domain of Earth sciences. They had deployed since the 1980s a complex factory-like socio-technical infrastructure that had normalized the production and dissemination of geophysical data like cloud fraction, aerosols optical depth, oceanic phytoplankton concentration, sea level or greenhouse gases concentration, because these type of data had been assumed as the type of data meaningful to *data users* in the disciplines of Earth sciences. By the early 2000s, both weather services and space agencies would have developed a customary precept of considering radiances as a not deliverable item remaining, in a way, of their "property". Weather

[904] "The ERA-40 Project Plan", ERA-40 Project Report Series N°1, A.J. Simmons and J.K. Gibson, 2000.
[905] "The ERA-40 Project Plan", ERA-40 Project Report Series N°1, A.J. Simmons and J.K. Gibson, 2000.

services and space agencies would not be ready, or willing, to deliver physical radiances instead of geophysical data. Factually, only NOAA would deliver radiances to conduct the ERA-40 reanalysis; it is plausible, though we have not been able to confirm it, that the controversial episode about the surface temperature retrievals from the microwave sounder MSU aboard NOAA's satellites, which was alive at that time, may have contributed to the decision of providing radiances. The rest of the satellite data providers (weather services, space agencies and the associated datacenters) would supply geophysical variables in levels equal or superior than level 2 (data about the winds speed and direction, the ozone concentration, the sea level and the snow cover) and in different forms of synthesis (monthly, annual, regional, global).

These obstacles, or frictions, for getting radiances reveal two things about the state of satellite data production and dissemination in the late 1990s and early 2000s in the domain of Earth sciences, when the reanalysis ERA-40 would be prepared and carried out. First, they confirm that the dominant epistemology within space agencies (and weather services) would be the one centered in the use of geophysical parameters as sources for knowledge production in the domain of Earth sciences (and for weather forecasting). This is connected to the vision of space projects as single-shot experiments serving to the scientists that had conceived it, the *data creators* who defined the data and their properties. As we have argued, this vision dominating the space agencies since the dawn of the space age was partially a legacy of weather practices as providing data serving to the forecasters and their weather prediction models and partially an inheritance of the culture in experimental physics of the instrument builders. From the 1980s onwards geophysical data would be made available to *data users*, an availability exploding since the mid-2000 due to the possibilities of data-basing the world via the internet (like in the case of ICARE). However, only a very specific type of data users would take advantage of them: those Earth scientists working with geophysical parameters (we will describe some of them in the second part of the present chapter). Other communities, like these *data users* willing to get to physical radiances and intervene them to produce climatic data would have more difficulties to re-use satellite data. Complex and sensitive to Earth sciences priorities understood in terms of geophysical datasets, the data production and dissemination schema would result for this reason poorly adapted to the demands of outsiders willing to access to physical measurements. Complex and sensitive to a geophysical approach to the Earth, it would be poorly adapted to a climatic approach to it. Second, it illustrated also a tremendous inertia of the recent created data gathering, production and dissemination system –which, in turn, indicates the power of the institutions sustaining it (space agencies and weather services). This socio-technical complex of data handling had been gradually established and adopted by all space agencies and operators as the epistemic norm for data production and dissemination during the 1980s (since the 1960s in the case of weather services). It was not a millennial institution rooted in the social and cultural landscape, large sense, but only established worldwide in the 1990s, when satellites in support to the Earth sciences started to be launched by others than NASA. Yet, by 1998, when the ERA-40 began to be realized, this socio-technical order would result very difficult to overthrow.

Box 6.1. Climatic data: Fusing data and numerical models

Preparing the data was only one of the elements of a reanalysis: the model and the assimilation scheme must be prepared as well. The system must be simple enough to let the model run in an affordable amount of time, while precise enough to provide accurate outputs to scientists. ERA-40 would use a 4D-variational data assimilation method[906] ran into the global numerical weather forecast model of the ECWMF specifically adapted to a spatial resolution of 1,125°x1,125° in the geographical grid, corresponding to 125km in the Equator, with 320 columns and 160 rows and 60 different pressure levels located between the surface and a height of about 65km. The time step of the runs would be of 6h (during which the computer would ingest approximately 7 to 9 million observations), meaning that the computer would provide, for the period between 1957 to 2003, a dataset every 6h for every single day, every relevant parameter derived from the equations of the model (weather model) and at every single spatial grid. The resulting climate-record would be composed then of homogeneous, consistent and global data computed every 6h during this period. Besides, the computer could also provide monthly and annual means upon specific request. Finally, the model could be run forward in time to produce weather forecasts every 3h[907].

Organization (name of the reanalysis)	Time period reanalyzed	Space resolution of the model*	Assimilation technique
NASA Data Assimilation Office	1980 to 1994	280Km, L20, top at 10hPa	Optimal interpolation with incremental analysis updated
ECMWF (ERA-15)	1979 to 1993	125Km L31, top at 10hPa	Optimal interpolation with non-linear normal mode initialization
NCEP (NOAA) and NCAR (R1)	1948 to present	200Km L28, top at 3hPa	Spectral statistic interpolation
NCEP (NOAA) and NCAR (R2)	1979 to present	200Km L28, top at 3hPa	Spectral statistic interpolation
ECMWF (ERA-40)	1957 to 2003	100Km L60, top at 0,1hPa	3D variational direct radiance assimilation
JMA and CRIEPI (JRA-25)	1979 to 2004	125Km L40, top at 0,4hPa	3D variational direct radiance assimilation
ECMWF (ERA-Interim)	1989 to present	80Km L60, top at 0,1hPa	4D variational bias correction of radiance data
NCEP (CFSRR)	1979 to 2009	38Km L64, top at 0,2hPa	Grid-point statistical interpolation
NASA GMAO (MERRA)	1979 to present	74Km L72, top at 0,01hPa	Grid-point statistical interpolation
JMA (JRA-55)	1958 to 2012	63Km L60, top at 0,1hPa	4D variational bias correction of radiance data
NOAA-CIRES (20CR)	1870 to present	Under development	Under development
*Reading key: The number of Km corresponds to the space resolution at the Equator. The figures in the raw below correspond to the number of pressure levels (that is to say, vertical layers, Lx) and to the maximal height (top at xhPa).			

Table 6.2: Global atmospheric reanalysis. The most cited are the NCEP/NCAR and ERA-40[908]. Both of them span the transition from a predominantly conventional observing system (ground-measurements) to the late XXth Century period, starting in 1978 and 1979 with Nimbus-7 and NOAA-6, in which satellite data dominate. This table shows reanalysis conducted with global atmospheric models, but they can be certainly conducted with

[906] Four dimensions variational data assimilation methods consist in minimize a function that quantifies the differences between the real state and the a priori state. Two versions of this method have been developed: when there are several observations, scientists can either integrate them one after the other or define a time window and integrate all them simultaneously. The first case is 3D, while the second is 4D, the fourth dimension is thus the time.

[907] "The ERA-40 Project Plan", A.J. Simmons and J.K. Gibson, 2000.

[908] "On the Reprocessing and Reanalysis of Observations for Climate", Michael G. Bosilovich, John Kennedy, Dick Dee and Alan O'Neill, 2011.

oceanographic models, vegetation models, coupled models. For instance, NCEP Climate Forecast System Reanalysis became available in early 2010 and it is ran with a coupled ocean-atmosphere model.

However accurate the ensemble would be, the reanalysis would always combine some degree of bias caused by the parameterizations of the model, the simplifications of the assimilation method, the heterogeneity and uncertainties of the input data and, if data were geophysical satellite parameters, the assumptions carried with the inversion and correction algorithms. In consequence, the quality of the reanalyzed data must be, just like it was done both with data and with models, evaluated. A first strategy would be, as usual, to compare the resulting reanalysis with exogenous data: weather records in the surface or in the ocean (temperature, rainfalls, pressure), satellite datasets existing in the long durée (like Nimbus-7, geostationary weather satellites and ERS) or other reanalyses, which had been ran with slightly different input data, numerical model and data assimilation techniques (including NCEP)[909]. Epistemologically, this practice posed some issues of independence of the sources: if all the data of the period in question had been ingested by the model, when comparing the reanalyzed data against singular datasets, scientists would not be comparing totally independent datasets. A complementary strategy of validation was deployed, a strategy based on the belief that observation of a predicted behavior helps to trust an outcome and its related process. For instance, the period covering ERA-40 saw a pronounced change in atmospheric circulation characteristics over the North Atlantic and in the associated ocean waves and ocean circulation and it encompassed several instances of the El Niño phenomenon, including the extremes ones in 1982-1983 and 1997-1998. A way of testing the quality of the reanalyzed data would be to study how they represented these phenomena that had been reported by other means. In a way, and this is an epistemological strategy commonly used in experimental sciences, documenting the phenomena that was expected to be observed would provide confidence in the reanalyses. It took 2 years to prepare the reanalysis (prepare the data, adapt the model, develop the assimilation code), 3 to run it and 2 more years to validate its data.

At present day, some data users (or climate data creators) campaign for extending the reanalyzed period backward in time, including the beginning of the XXth century and even part of the XIXth Century. Some environmental variability, they argue, may occur in longer periods, 100 years or more, and not few decades. To detect it, thus, 100-years long-term comprehensive and consistent dataset are necessary. For example, the 20th Century Reanalysis (20CR) project carried out by the Cooperative Institute for Research in Environmental Sciences (a partnership between NOAA and the University of Colorado) would use the available surface pressure observations and sea surface temperature record reconstructed through the 1870s[910]. Extending them back so far in time does not make consensus within the scientific community, because as farther away one goes back in time, more difficult is to assess the quality of the original data, due to the difficulty of recovering the metadata providing contextual knowledge about data records (how were they gathered, where, when, errors, instruments,

909 Some examples of these comparisons: "Climatology and changes of extratropical cyclone activity: Comparison of ERA-40 with NCEP-NCAR reanalysis for 1958-2001", X.L.L. et al, 2006; "Evaluation of NCEP–CFSR, NCEP–NCAR, ERA-Interim, and ERA-40 Reanalysis Datasets against Independent Sounding Observations over the Tibetan Plateau", X. Bao and F.Zhang**,** 2007.

910 "On the Reprocessing and Reanalysis of Observations for Climate", Michael G. Bosilovich, John Kennedy, Dick Dee and Alan O'Neill, 2011.

calibration, etc.). Therefore, it is difficult to quantify the bias that these ancient data could introduce in the reanalyzed outcomes. At this writing, this is an open question.

"Observation-based data products"

Another open question is the ability of reanalyses to detect natural variability in the long term. This had been –and still is- one of the main scientific motivations to run reanalyses in the first place: they are the technological practice mediating the production of past climatic data, which are necessary to study variability and trends occurring at large time and space scales, and discriminating natural from anthropic sources. The results of the first round of reanalysis by the late 1990s however had not met this goal. It turned out that the reanalysed datasets were not accurate enough and that the bias in the reanalyzed data-record was of the same order than the expected environmental variability. Therefore, it resulted impossible to detect. This is actually one of the reasons why the following generation of reanalysis was developed with particular emphasis in assimilating physical measurements and not geophysical datasets, as a means to reduce the errors, bias and uncertainties and achieve higher accurate outcomes.

Actually, reanalysed data would be used by climatic data users for many other purposes apart of the detection of environmental variability. The reanalysis ERA-40 would produce around 40 different types of geophysical parameters extended over 45 years including, inter alia, wind components, temperature, upper air pressure, precipitation, evaporation, high and low cloud cover, ice surface temperature, mean sea level pressure, mean wave direction and period, total columns of ozone and water vapor, top net solar and thermal radiation, soil temperature, snowfall, snow melt or volumetric soil water. These datasets were taken as any other source of data: to establish correlations between variables and phenomena, to understand a particular process and influences, to provide contextual background in which studies are conducted, as initial conditions to run simulations, for routine forecasting, to develop a given parameterization, to diagnose bias and uncertainties in the models and the data, to conceive new instrumental configurations, to provide climatologies and statistics, to support decision-making, and even to develop new data assimilation schemes. In other words, reanalyzed data would be used by data users, involved in the reanalysis or distant from them, *as if* they were empirical data.

While the community involved in realizing the reanalyzes (climatic data creators) are well-aware that reanalyzes are not observational or empirical data, perceptions may vary when reanalyzed data cross this community. In a paper issued in 2011, some scientists of ECMWF, NCAR and NCEP would warn about the dangers of confusing reanalysis with empirical data –in fact, they cautioned against confusing *observations* of all kind and *data*:

> "There is a tendency to consider observations as unproblematic data points which one can use to challenge theories and hypotheses regarding the climate. In reality, the observations themselves form a system of hypotheses concerning the means by which the observed quantity is related to the

climatological variable of interest. For example, satellites typically measure radiances which can be related to sea-surface temperature only by a process of modeling the atmospheric profiles and the near-surface ocean stratification. The most sophisticated examples of such systems are reanalyses (…) [Reanalyses] cannot replace observed data products. It is very important, especially for new reanalysis users, to understand that reanalyses are not observations, but rather, an observation-based data product"[911].

Reanalyses, so these scientists acknowledged, are not "observed data products" or "observations"; they rather result from the combination of data, numerical model and data assimilation technique. They are hybrids of observation and modeling and carry, consequently, the effects of model uncertainties, of the hypothesis of the assimilation system and of the bias in the geophysical data obtained through inversion algorithms.

Reanalyses reflect a profound mutual integration of the data and the numerical models. Just like Hélène Guillemot, Paul Edwards and others have shown, models contain data, phenomenological principles derived from data (parameterizations), fundamental physical theories, mathematical models for interpolating, fixing, filtering and so on. At the same time, reanalyzed data also contain phenomenological principles derived from data, fundamental physical theories, assumptions and hypothesis as well as mathematical models for interpolating, fixing, filtering and so on. A lot has been said about this interdependence between data and models, particularly in studies focused in the domain of climate modeling, which has even been called as *symbiotic*, a Paul Edwards's metaphor used to illustrate "a mutual beneficial but also mutually dependent relationship" between numerical models and data[912]. Reanalyses may probably be, as underlined in the previous quote, the "most sophisticated examples" of the interdependence between data and models. We cannot leave matters at that though. Just like reanalysis, analysis *tout court*, that is to say, the solution of the equations computed by a model further the introduction of data as initial and/or boundary conditions, also involve an inherent interdependence between data and numerical models. This is precisely the point stresses by the authors of the previous quote, that data (or observations) are nothing but "systems of hypothesis concerning the means by which the observed entity is related to the parameter of interest". The production of geophysical datasets from physical measurements magistrally illustrates this point: a number of assumptions, hypothesis about the conditions of measurement, equations about radiation transfer, the atmosphere and the system being measured, exogenenous data, thresholds are modeled to develop the inversion algorithms.

More generally, through a cascade of operations involving exogenous data, models of the instrument, models of the atmosphere and of the observed object, numerical models of the physical state, thresholds or conceptual models, the measurements are transformed into data. Indeed climatic data and geophysical data involve modeling of different nature (say, to simplify, numerical models and physical

[911] "On the Reprocessing and Reanalysis of Observations for Climate", Michael G. Bosilovich, John Kennedy, Dick Dee and Alan O'Neill, 2011.

[912] "Data-laden Models, Model-filtered Data: Uncertainty and Politics in Global Climate Science", Paul Edwards, 1999 and « La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », Hélène Guillemot, 2007.

models); indeed, they are intervened with different technologies, from different approaches, mobilizing parallel knowledge and skills, with different scientific objectives, and recontextualized in different epistemic frames –they are even integrated in different socio-technical forms of production and dissemination, portraying different relationship with the conditions of acquisition, with the instrument, with the space agency. But the point is the same: satellite measurements are intervened in order to produce data. Or viceversa, whether data are climatic or geophysical, they are the product of a series of operations deliberately planned to make them so. In spite of the commonplace jargon used to refer to the activity of gathering data from satellites (Earth Observation), both climatic and geophysical data are intervened and recontextualized, they are elaborated artifices derived from carefully manipulating the measurements. Whether global or local, whether short-term or long-term, whether from one single instrument or fusioning different instruments, data are not *given* out there (past participle used as a noun), waiting for scientists to be gathered together, but *gifts* that have been intervened, manipulated, produced and then *given* to a broader audience (past participle used as a verb)[913].

Circling back: When (geophysical) data creators become (climatic) data users

This interdependence can also be pointed from another perspective centered in producing and using the data. One of the most valuable features of reanalyzed data would not be, according to the scientists that we have interviewed and the papers that we have read, their value for climatic studies of the long-term variability or trends. Rather, that they “are available at all points in space and time, and that many ancillary variables, not easily or routinely observed, are generated by the forecast model subject to the constraints provided by the observations”[914]:

> « Grâce aux réanalyses il y a plein d’endroits où on n’a pas d’observations qui vont être remplis ; s’il y a des jours où on n’a pas des observations, avec les réanalyses on va en avoir. C’est un gros dataset, 30 ou 40 ans où il y a tout. Si on a besoin de savoir un profil de température à un moment et endroit donnés, et qu’on n’a pas forcement d’idée a priori de l’instrument qui peut donner ça, on peut aller voir la réanalyse directement, a priori ça va pas être complètement fou »[915]

What this scientist, a data creator working at LMD creating algorithms to study the higher clouds in the poles by use of measurements made by PARASOL and CALIOP, and several others, emphasized would be the ability of reanalyses for extrapolating data to the whole globe, and at any time, and about any parameter, even if observations do not exist.

> « On considère les réanalyses comme des observations, en sachant que ces réanalyses sont un mélange de modélisation et d’observations. Mais c’est mieux que rien quand on n’a pas de mesures in situ. Par

[913] We adapt here the suggestive terminology proposed by Jerôme Denis and Samuel Goëta in a recent ethnographic article describing the internal workings involved in rendering data open in some French local administrations. « La fabrique des données brutes. Le travail en coulisses de l’open data », Jérôme Denis and Samuel Goëta, in « Penser l’écosystème des données. Les enjeux scientifiques et politiques des données numériques », 2013.

[914] “On the Reprocessing and Reanalysis of Observations for Climate”, Michael G. Bosilovich, John Kennedy, Dick Dee and Alan O’Neil, 2011.

[915] Interview with Vincent Noel, LMD, 2012.

> exemple, le lidar [SIRTA in Palaiseau] tire tous les jours donc il nous faut des données tous les jours, il faudrait lâcher un ballon plusieurs fois par jour pour les avoir et il n'y a personne qui puisse le faire. On n'a pas des mesures si fréquentes sur les profils atmosphériques. En revanche, au Centre européen on a un profil toutes les 6h, donc on va les prendre comme si c'étaient des observations [refering to ERA-40 reanalyzed data]»[916].

These are the words of a data creator at LOA developing radiation transfer codes. To him, again, the value of these datasets is not the possibility of studying the long-term, he is not interested in the climatic approach. What interests this data creator is the possibility of having data everywhere and everytime. Both data creators agree in the ways of using the reanalyzed datasets: where and/or when no data exist, any source of data is better than none. For instance, in their work of developing retrieval algorithms *geophysical data creators* may require understanding how the atmosphere behaves, how the observed object responds to radiation, how it emits, how the presence of pollutants affects the radiation, and all this in different atmospheric or environmental situations. They may also require the examination of data in order to establish the thresholds for cloud cover, ozone concentration, water droplets solidification, aerosol nucleisation, to mention some of the examples we have been describing so far. They would take the existing reanalysis corresponding to the atmospheric and environmental conditions for which the retrieval algorithm is to be used as data to derive these features. Next, once the retrieval algorithms have been developed, and the satellite launched, they will test them using the reanalysis, for instance, as data to be compared against:

> « Quand on fait une inversion de l'altitude des nuages on a besoin de connaître le profil de température de l'atmosphère. Du coup on va prendre les réanalyses du centre européen [ERA-40] pour avoir une meilleure connaissance du profil atmosphérique, le centre européen utilisant lui-même des profils atmosphériques qui auront été inversés à partir des données d'un satellite donné. Parfois on ne s'en rend pas compte, mais je trouve ça très compliqué, cette relation entre l'observation et la modélisation, parfois il y a des relations confuses... C'est presque de l'inceste ! On ingère... pour contraindre nos modèles on réutilise... on n'est pas finalement surs d'utiliser des choses très indépendantes »[917]

These are the words of a data creator well-aware of the interdependence or symbiosis, which he ironically called incest. Just to conclude with this aspect, we would like to draw the attention to the fact that the roles of creation and using the data get inversed: geophysical data creators are users of this particular form of climatic data, the reanalysis, and symmetrically, the creators of climatic data are users of the geophysical data. This is the incest to which this geophysical-data-creator-user-of-climatic-data refers to. More generally, categories of users and producers are contingent of the type of data is to be used and produced and the technological practices articulated in that process, which in turn is contingent to the epistemic frame and the objectives of the scientists. In turn, the modes of production and dissemination of the data may also be multiple and varied.

On the powerless of satellite measurements alone

The ability of extrapolating of the data assimilation technologies invites to re-evaluate the widespread idea that satellite data are implicitly global, an idea that, whether by belief, by abuse of language or by

[916] Interview with Philippe Dubuisson, LOA, 2013.

[917] Interview with Jérôme Riedi, LOA, 2013.

propaganda, is found constantly in accounts about satellite data. But the coverage of one single space instrument is limited by its swath and repetitivity, as well as by the specificities of the inversion algorithms. It is data assimilation that would allow dealing with the inefficiencies of the measurements. Irregular datasets, local and contextual, would become complete, homogenous and consistent gridded points through the assimilation technique. Data assimilation is a technology that *makes data global* –Paul Edwards's expression[918]. It is important to remark that our understanding of global is a dynamically consistent one in the sense that it embraces space, time and observable dimensions. Scientists construct the globality of satellite data, scientifically complete in terms of variables and dynamic across time, through computer modeling based on some interpolation methods. In a sense, just like the inversion algorithms would entail the assumption that satellite data were not given-truths faithfully representing the nature, but they rather needed to be intervened, manipulated, created and validated (data need to be "cooked with care"), data assimilation would entail the assumption that satellite data were not global per se, but their globality, in a dynamically consistent manner, must be built. Inversion algorithms and data assimilation techniques were two major technologies deployed to use the satellite measurements in different domains of the Earth sciences. They enrolled two different epistemic communities (interchanging configurations of data creators and users), they portrayed different relationship with the data and the instrument, they get socialized and trained in different laboratories and universities' departments, they publish in different journals, they articulate different knowledge, expertise and skills, they call for different forms of data gathering and production and for sometimes opposed rules of data dissemination and data access policies. Yet, they would have one feature in common: they would participate in two major shifts in the notion of space mission and satellite data departing from the original space sciences at the dawn of the space age. Through the inversion algorithms scientists would abandon the ideal of purity of satellite observations; through data assimilation techniques they would abandon the ideal of globality of satellite observations as well.

More generally, data assimilation techniques would enfold a doctrine reckoning the powerless of satellites alone in the production of satellite data–a point that we have already suggested when describing the renewed meaning of space missions as per including extensive field campaigns and networked ground measurements. These techniques would acknowledge that all observing systems are incomplete in the sense that they will never be able to measure everything, everywhere, all of the time with perfect accuracy and sustained calibrations. It is the combination of satellite data with the numerical models through a data assimilation technique that would allow a complete dynamic picture, for all the grids in the model, for all the variables of the equations and evolving with time. In particular, a characteristic of the climatic data is that they notice that the best analysis is that that

[918] We use here Paul Edwards expression referring to the processes deployed to create coherent data of global coverage from heterogeneous and time-varying observations. As defined by the author, making global data is "collecting planetary data in standard forms, through interconnected networks, to build data images of global weather and general circulation", while making data global is "building complete, coherent, and consistent global datasets from incomplete, inconsistent and heterogeneous data sources". See: "A Vast Machine", 2010.

encloses all existing data. Climatic data are grounded on the principle that the average of the total available means would be likely to be closer than the estimate made out from any singular source. Climatic data would embody an epistemology of integration: statistically, all is better than only some. Data, if collectively exploited, know more and better. More generally, through the technology of data assimilation, the collective and social character of satellite data would be reaffirmed, rendering each piece meaningless without the other. In other words, data assimilation would transform the very meaning of the term satellite data in the Earth sciences, rendering them meaningless unless integrated with other data and models.

Underlying the techniques of data assimilation is the recognition that scientists would never get perfect data, because no observing system would ever account for all the huge range of space and time scales of energy and motion taking place in the Earth, from the molecular to the global, from the miliseconds to the centuries, and for all the parameters describing these processes with the appropriate accuracy and calibration, and that, furthermore, there will be always errors and imprecisions in the models, in the data, in the instruments, in their interpretation or their frictional circulation. Even if this impossible goal could be achieved, the measurements would still need to be interpreted in concert with previous measurements, background conditions and to be explained scientifically with the help of other exogenous corpus of data or numerical models. Data assimilation techniques would flourish upon the belief that satellite data alone were powerless, they could not give a complete description of a system; instead, so the doctrine would go, assimilating the satellite data in a model would allow overcoming the shortcomings of satellite data and provide a coherent and consistent picture and its evolution.

We come to an end. In a way, thus, the appeal to data assimilation could be seen as a substitute for an inability of satellites to observe. The technology of data assimilation would participate in replacing the panopticism ruling satellite programs before the 1980s by an epistemology grounded on the collective mobilization of all the available resources, both in the space and on Earth. As we have seen in chapter fours, mirroring the Humboldtian tradition, satellite data must be used in concert with surface and aircraft data, laboratory results and theories for them to have any epistemological value. Our investigation enables us to add a new tool to that corpus: numerical models. This epistemology emphasizing the collective nature of satellite data would align the moves that we have described in chapter 4 towards an integrative approach to space missions, including surface, balloon and aircraft data, as well as simulated data. In turn, the idea of considering the Earth as a complex holistic system ascended amongst the communities of different disciplines in the Earth sciences. Connections between these two concomitant developments certainly make an interesting further research project[919]. Just like all along the two last decades of the XXth Century, space missions would gradually include field campaigns and ground measurements as components of the mission in the domain of space Earth

[919] Some particulars have been already suggested. For instance, the historian Erik Conway argued the influence of the so-called Bretherton's report depicting the Earth as a system of systems in orienting the architecture of the space missions of its program Earth Observing System. In turn, with the imprimatur of NASA, this concept would be spread amongst those scientists using the satellite data. See: "Atmospheric sciences at NASA", 2008.

sciences (necessary to produce the satellite data), they would also include, although more moderately, data assimilation programs, especially, as we will see in the forthcoming second part of the chapter, when they involved potential for short-term prediction.

USING AND RE-USING THE DATA

The discussion in the first part of the chapter has served two purposes. It illustrates a stream for producing data from satellite measurements, the climatic approach, parallel, complementary in some aspects while incompatible in some others, to the geophysical approach that we had studied so far. By so doing, this is the second of our purposes, we have illustrated a way of using satellite data by scientists distant of the conditions of acquisition. We are in this second part completing this second aspect. We are examining how data users make sense of data in three cases: prediction of short-term events, analysis of climatologies and evaluation of numerical models. This casuistic, far from exhaustive, is deliberately varied in order to illustrate the diversity in the forms of re-using data.

Producing data about the future: Predicting the air quality

We have studied the technological data practice of assimilation as used by a community willing to build climatic records. This technology can however be deployed in many other forms and for many other purposes. Considering the context prevailing in the field of Earth sciences, which accentuates the human influence on global changes and the impacts of global changes in human life, predicting such changes would become one of such forms and purposes. In this section we focus in a particular study case in which a form of *data users*, who are, like in the previous example, numerical modelers, re-use satellite data by means of the technology of data assimilation. However, they do not use it to produce climate data about the past, but to produce data about the future, to predict a future state of a system. The same technology can be used symetrically backward and forward articulating different temporalities. When ran in the long-term and/or backward in time it allows the study of climate, whereas when ran forward and in the short-term it enables the elaboration of forecasts.

Although simple in concept, data assimilation schemas would turn out to be complex to develop and to integrate in the models to the extent that, in the case of meteorology, for around 20 years data assimilation schemas would not provide substantial improvements in the weather predictions – actually, in some circumstances they would even degrade forecast accuracy[920]. A number of aspects had been given by scientists and historians that may explain this path: often the model variables would outnumber the data, the data would not sample in a homogeneous way, auxiliary information would be necessary both to locate and date the data and to fill certain data gaps, radiometric observations would not correspond directly to the model thermodynamic variables, computers would be slow and the pipelines through which data circulated were rudimentary so that data would often arrive too late for a

[920] “Impact of satellite temperature sounding and wind data on numerical weather prediction”, R. Atlas et al,1985.

meaningful weather forecast[921]. It would not be before the 1990s that diverse data assimilation techniques would start to be implemented in most of the forecast weather services centers in an operational manner like MeteoFrance, the European weather service (European Center Medium-Range Weather Forecasts, ECWMF) or several American weather service (like the NOAA's National Center for Environmental Prediction (NCEP)). Typically, these weather forecasting systems would assimilate two variables: temperatures retrieved from satellite infrared radiometers and wind-speeds vectors retrieved from geostationary radiometers and use them to generate the analysis. With these two variables, a model and an assimilation scheme, the computer would provide a dynamically consistent future state of the weather.

Weather forecasting would be certainly the driver for developing such technique -and an instructive example for grasping its basics. However, data assimilation is a generic technique that can be eventually applied to other types of problems and data[922]. The community of oceanographers is arguably one of the most active that began, in the 1990s, to develop data assimilation schemes intended to forecast the physical state of the ocean. More inquiry is needed into the historical process that would lead to it –particularly into the relationship between space agencies and international research programs. What we can suggest is that the launch of several satellites in the early 1990s (Topex/Poseidon and ERS) would give impetus to the development of the, at that time rudimentary, oceanographic numerical models and to their coupling with atmospheric ones. This venture had been actually the ultimate objective of the international program World Ocean Circulation Experiment (WOCE) conducted within the frame of WCRP, one of these Humboldtian endeavors designed to fostering the research in numerical oceanography by emulating the success of the First GARP Global Experiment in 1978-1979: after meteorology, so it was thought, the turn was for oceanography to fully benefit from satellites[923]. In a first stage between 1990 and 1998 data would be gathered through extensive field campaigns and satellites and a second, lasting until 2002, would be devoted to the analysis, modeling and interpretation[924]. Since the mid-2000s, estimates of the state of the ocean and its evolution, activity referred as *operational physical oceanography*, would be achieved routinely in a number of centers in a similar way as done in weather forecasts, by assimilating radar altimetry data from the satellites Jason-1 and 2, from the sea surface temperature, and from surface stations providing salinity and wind speed[925]. We are describing in the following still another case: the efforts to assimilate the satellite data about the tropospheric aerosols in order to forecast their evolution.

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[921] See: "Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, doctoral dissertation, 1991 and "De la valeur des données spatiales : le cas des données de sondage en prévision numérique du temps", Sylvain Lenfle, non-published ongoing research.

[922] Some examples in the domain of chemical composition or carbon cycle are developed in: "Data assimilation: From photon counts to Earth System forecasts", Pierre-Philippe Mathieu and Alan O'Neill, 2008.

[923] Interview with Kevin Trenberth, NCAR, 2013.

[924] We might refer to a research project in process by Jérôme Lamy: "La mesure de toute chose. La mission Topex/Poseidon et l'océanographie spatiale dans les années 1980 et 1990", 2014.

[925] For an account given by some actors see: "Data assimilation for marine monitoring and prediction: The MERCATOR operational assimilation systems and the MERSEA developments", P. Brasseur et al, 2005.

Assimilating POLDER's aerosols' optical depth in the model INCA-LMDz

Concerns about air quality and atmospheric pollution had by the 1990s shout up to the scene of research in the domain of atmospheric chemistry, as demonstrated by reading the papers and publications of the time, in which an introductory mention to environmental issues, whether to justify or to motivate the research, would become the norm. Several attempts to develop routine forecast of greenhouse gases and ozone distribution would be engaged in that decade, components which were considered as indicators of global warming and UV radiation levels respectively. This research would lead to establishing different forecast systems around the world, including the system called Prev'Air in France since 2003 that uses two models of chemical transport (CHIMERE developed by INERIS and IPSL and MOCAGE developed by MeteoFrance) and their corresponding assimilation programs. The data used as input in the models come from different sources, in situ and satellite, including those delivered through the database ETHER managed by Institut Pierre Simon Laplace and analysis coming from the NOAA's National Center for Environmental Prediction[926]. With these three basic ingredients, at least two modalities of computation can be done. When ran forward in the short-term, routine forecasts of ozone, NOx and some types of aerosols are computed by Prev'Air, whereas when ran in the long-term (or in past situations) it allows the laboratories to study climatic effects of greenhouse gases and their evolution given different scenarios. As the prediction of these gases was routinized, some attempts would start investigating the assimilation of different species of aerosols as well. They were considered to have important radiative impacts; nonetheless, they were by far less known than those of the other atmospheric components. One of these research teams would be located at the Laboratoire des Sciences du Climat et de l'Environnement (LSCE).

The whole idea of the research done at Laboratoire des Sciences du Climat et de l'Environnement, to put it simple, was to take satellite data about the optical depth of the aerosols and use them to initialize a chemical model in order to generate, by means of an assimilation scheme, an accurate future state of the aerosols in the atmosphere. Should an appropriate method be developed, it could be then generalized and optimized for routine forecast, as it was done with the weather, the physical state of the ocean or the greenhouse gases. This required the triplet of ingredients: input data, numerical model and assimilation code. The datasets chosen by this team at LSCE to develop the assimilation code would be the optical depths of the tropospheric aerosols retrieved from the past POLDER-1's measurements available for a period of 8 months between 1996 and 1997, which constituted enough data sampling for research purposes. As per the model, chemical models describe the chemical

[926] Chemical weather forecast would typically provide the foundation for monitoring air quality or level of ultraviolet radiation for health safety. In France, for instance, the Ministry for Ecology, Sustainable Development and Spatial Planning established in 2003 Prev'Air, a forecast system with the aim of generating and publishing daily air quality forecasts and maps resulting from numerical simulations on different spatial scales. The Ministry coordinates the effort, which is conducted by scientists at IPSL, MeteoFrance, the Agency for the Environment and Energy Management (ADEME) and the National Institute for Industrial Environment and Risks (INERIS), who develop the data assimilation techniques and operate the system. Prev'Air constitutes one of the services of monitoring and surveying the air quality integrated in the European program GMES/Copernicus.
"Data assimilation: From photon counts to Earth System forecasts", Pierre-Philippe Mathieu and Alan O'Neill, 2008.

composition of the atmosphere, focusing on stocks and flows of specific chemical species (CO2, CH4, N2O, O3, marine salt, desertic dust, volcanic ashes, etc.). They resolve non-linear equations accounting for the photochemical processes in order to accurately represent the entire cycle for the species of interest, including production, circulation and deposition. Since the late 1990s, the tendency was to couple the chemical models of a given species into general circulation models in order to study the feedbacks of these species in the general circulation and climate. In this case, a model developed at LSCE, called INCA (Interaction with Chemistry and Aerosols), which had been developed to simulate greenhouse gases like CO2, CH4 and N2O and tropospheric O3, and had been adapted in the early 2000s to simulate different types of aerosols as well. It would be coupled to the global circulation model developed at LMD, called LMDz, composed, just like all general circulation models, by a core dealing with the large scale dynamical processes and a physical part describing the adiabatic processes: while the equations of the dynamic core are solved in a numerical form and provide for wind speed, temperature and pressure, the physical part is accounted through parameterizations. The couple INCA-LMDz would compute the emissions of the atmospheric components, their transport and diffusion through the atmosphere, their photochemical transformations, and the sedimentations and precipitations processes for each species[927].

Now the technique of assimilation. Amongst all the existing techniques for assimilating data, these scientists would use the method of Kalman, a variational method consisting in combining the information provided by a model, taken as a priori information, with the data in function of their respective errors –a technique, by then, widespread amongst weather forecast services[928]. In this method, solving the interpolation equation would require characterizing the errors, which must be computed at each time step of the integration. How would that be done provides an illustration of the problem of space interpolation. In order to characterize the errors of the model, the outcome of the aerosols' optical depth computed by the model LMDz-INCA in each grid (7008 grids in total) would be compared to the reference ground-truths, namely, the AERONET data. The point was that the number of AERONET stations used was only of 118 and their distribution across the globe was not homogeneous, but rather concentrated in western countries and almost absent in the oceans and the poles. The schema of assimilation must interpolate the measurements of the AERONET sun-photometers to all those grids of the model left empty. Something analogous would be required for determining the errors of the POLDER's retrievals: only the AERONET sites measuring in coincidence with the passage of the satellite, which covered about a quarter of the Earth's surface in

[927] "Interactive chemistry in the Laboratoire de Météorologie Dynamique general circulation model : Description and background tropospheric chemistry evaluation", D. Hauglustaine, et al, 2004.

[928] In the Kalman method, the a priori of the first integration is given by the model. Then the model runs and the outcome analysis will constitute the a priori for the following integration. The optimal interpolation equation is then writen as follows : x1=x0+K(y0-Hx0), where x0 are the a priori conditions at t0, x1 is the optimal estimation at t1 (the analysis), y0 are the "real observations" at t0 and Hx0 are the simulated ones. H is the operator that allows to move from the space of the model to the space of the observations, and K is the Kalman filter, a matrix that ponderates the errors of the a priori and the real observations ($K=BH^t(HBH^t+R)^{-1}$) where B is the matrix of covariance of errors of the a priori and R of the observations.

every integration step of the data assimilation code, must be considered. The rest would be interpolated.

There were more issues to resolve when assimilating observations into models. For instance, reconciling the space resolutions of the data and of the models. While POLDER data have a resolution of 6x6km2 at nadir, the grid of the model corresponded to 375x250km2 in the equator. The assimilation program must include a module to relocate POLDER's measurements as if corresponding to the same grid as the model. Note that, as a consequence, the satellite data would be significantly degraded with respects to the capabilities of the instrument. Also, this is another example, because of the very large dimension of the system, the numerical problem was computationally non-tractable to solve unless approximations were made. To give a hint of the difficulties, within the interval of time of a time step (6 hours), POLDER scanned about a 25% of the globe, which provided typically between 300 and 1000 observations to integrate in every time step, depending on the region –recall as a comparative figure, that the reanalysis ERA-40 ingested 7 to 9 million observations. Only a small fraction of data of the totality of POLDER measurements would be taken, all the rest remaining unused[929]. In general, degrading the data quality would not represent a big issue to scientists intending to real-time forecasts. This illustrates a characteristic of the data needed for forecast goals, as we have introduced in the introduction to the second part of the essay: reliable quick access to data and fast processing in order to provide a timely meaningful prediction in detriment of high space resolution (and in preference, data must adjust to the space resolution of their models). Forecasters would accept as necessary tradeoffs the reduction of volumes and filtering out of data, even if this meant degrading their quality. Note that this contrasts with the requirements to identify and discern environmental variability in the long term, in which time-pressures are absent of the equation and what prevails is analyzing the maximum number possible of data for the statistics to be meaningful.

Another important point to be solved was defining the very parameter that was to be assimilated as input to fuel the model. Chemical models used to compute in terms of mass of aerosols which makes full sense to *data users* in the domains of atmospheric chemistry. However, the parameter usually retrieved from physical measurements by the *data creators* is the optical depth of the aerosols. Therefore, the assimilation schema must include in their codes an additional parameterization to compute optical properties from physical ones and allow models and data to "speak the same language" –an often-used metaphor amongst scientists in the field[930], to which we will insist when discussing the technology of *observables simulators*. That means in turn, that, once the assimilation is

[929] In the domain of weather forecasting these figures are quite shivery: it is estimated that satellites provide around the 98% of the 75millions data items managed by each 12hour weather analysis made at the European Center for Medium-range Weather Forecast. Only about 5% of these data enters the computer to be analyzed. Still, satellite data outnumber at least by 10/1 those data from all other sources combined. These figures leave in 95% the amount of satellite data gathered and never used for a 12h weather prediction.

Source: "Global observations and forecast skill", L. Bengtsson et al, Tellus 57, 2005.

[930] This is apparently a commonplace parlance amongst scientists. We have found at least three investigators (four counting ourselves) reporting its usage in different domains: Hélène Guillemot documents being used amongst climate modelers, Chunglin Kwa amongst ecologists and Margaret Courain amongts meteorologists.

done, the resulting analysis in terms of optical depth must be transformed again into mass concentrations, for them to be interpretable by atmospheric chemists. Generally, in this transformation and subsequent retransformation a lot of information gets lost –and some hypotheses are added. For instance, the INCA-LMDz is a three-dimensional model that provides information of the aerosols masses discriminating different vertical layers, whereas POLDER datasets provide the total value of the optical depth in an entire vertical column. Transforming mass concentrations into optical depth implies thus foldering from a 3D variable to a 2D one, losing in the process information about the mass concentration per altitude. Defoldering the resulting analysis of the optical depth into 3D mass loading again is delicate because there is not a univocal relation between optical depth, mass and altitude, and therefore mass cannot be mathematically restituted in function of altitude. On the other hand, by mid-2000s there were no empirical data providing some phenomenological correlations between these parameters that could have helped to orient the retransformation –this was precisely one of the reasons why scientists campaigned for launching lidars, because they allow discerning vertical layers. In consequence, some additional hypotheses would be necessary, like considering, as it was done in this case, that the vertical layers would be homogenous in aerosol content –which is generally not the case.

Once the assimilation code had been developed, it must be put into test to assess its performances and limitations. Two simulations would be then made: one covering from November 1996 to June 1997, when POLDER-1 data were available, and a second one from April to October 2003, when POLDER-2 data were available. Aerosols' optical depths retrieved from POLDERs would be re-used to nourish the LMDz-INCA model in intervals of 6 hours, as initial conditions to compute the state of the aerosols in the following time step. The outcomes would be then compared with data of optical depth retrieved from the instrument Total Ozone Mapping Spectrometer (TOMS) that had been in orbit during both periods and optical depths could be retrieved (aboard of ADEOS-I and of NASA's Earth Probe for the first and second periods respectively[931]); additionally, they would be also compared with the measurements of the AERONET stations region by region, considered, as we know, as the ground-truths of reference[932].

[931] While TOMS was initially conceived to measure the total content of ozone in the atmosphere, the measurements in the ultra-violet spectral bands resulted useful to characterize the absorbing aerosols, such as desertic dust and carbonate aerosols, which were difficult to characterize due to their high reflectivity in the visible domain. See : "Derivation of aerosol properties from satellite measurements of backscattered ultraviolet radiation. Theoretical Basis", O. Torres et al, 1998.

[932] « Etude des interactions entre aérosols et climat : assimilation des observations spatiales de POLDER dans LMDz-INCA », Thèse doctorale de Sylvie Generoso directed by François-Marie Bréon, Université Paris VII, spécialité Méthode physiques en télédétection, 2004.

Assimilating optical depths and assimilating physical radiances: Perpetual continuous real-time measurements

Once the potentialities of the technique to predict the state of the aerosols demonstrated with these particular experimental cases, it would be about transferring the software to an operational center to be routinized. For that, the computers of LSCE were not enough powerful, the code developed was not optimal and the laboratory was not connected to real-time data sources –after all, this was not the vocation of the laboratory. At the European Center for Medium-Range Weather Forecasts (ECMWF), by contrast, the use of satellite data had, since its establishment in 1975, the very particular goal of improving forecast systems. Since 2005, ECMWF would coordinate a project called Global and regional Earth-system (Atmosphere) Monitoring using Satellite data (GEMS) established under European Commission's 6th Framework Program, in which 32 European partners from 13 different countries (including LOA, and LSCE) would participate[933]. A component of this project, coordinated by scientists of LOA directed by Olivier Boucher, whom we have met first in 1998 during the "Revue de validation" of POLDER-1 and second as member of the "Comité d'Utilisateurs" of the datacenter ICARE by 2004, would be to develop an assimilation scheme to ingest satellite data about the optical depth of the aerosols in the ECMWF's numerical weather forecast model in order to produce routine forecasting of the aerosols with the goal of daily monitoring the quality of the air in the European region.

The code developed at LSCE to assimilate POLDER's data in the INCA-LMDz model would be used, amongst other similar codes developed by other European teams, as a basis to develop an assimilation schema optimized to run in real-time the numerical model of the ECWMF. It would take three years to finish the assimilation code. It must be then, as usual, tested to check validity. One simulation of the aerosols' state during a situation in the past, specifically during the year 2003, was conducted. The period chosen may be familiar to the reader: it was that extreme canicula summer that had prevented a proper validation of the retrievals of the biological properties from the measurements of POLDER-2 due to anomalous abundance of aerosols in the atmosphere. This pollution, which had compromised the validation of POLDER-2's data derived from the ocean color, would result very advantageous to those scientists interested in studying the aerosols. In this particular case, it would be useful for testing how the ECWMF's assimilation system forecasted the aerosols optical depth. Results of these simulations would be evaluated through comparisons with other data: measurements of optical depth of around 40 sites of the AERONET network and retrievals from the 8 months of POLDER-2

[933] GEMS's objective was to create an assimilation and forecasting system for monitoring the global distributions of atmospheric constituents important for climate, air quality and UV radiation: aerosols, greenhouse gases and reactive gases. The project concluded on 31 May 2009 and a follow-on project, the Monitoring Atmospheric Composition and Climate project, also funded by the European Commission, would explore since 2009 the feasibility of preoperational implementation of the GEMS assimilation system for reanalysis and real-time forecasts of aerosols. In turn, both projects would be realized under the umbrella of still a wider European program, the originally called Global Monitoring for Environment and Security (GMES-Copernicus) established in 2001 by the European Commission. See: http://gems.ecmwf.int/ and http://www.gmes-atmosphere.eu/

measurements in 2003 -activities conducted by scientists at LOA and LSCE[934]. Since 2008, a version of this system would start to be used for near-real-time sporadic forecasts of aerosol fields for several days ahead. The input data would be the optical depths retrieved from the measurements of the instrument MODIS on board of NASA's satellite Terra and Aqua, which were circulated in quasi real-time from NASA's datacenter to ECMWF's facilities[935]. For instance, the assimilation code would be activated after the eruption of Eyjafjallajökull in 2010 and data about the optical depth retrieved from MODIS measurements would be used as input to run short-term forecasts of the air-quality in terms of concentration of volcanic ashes (mainly sulfates) in the following days[936].

Recently, to forecast the state of the aerosols researchers at ECMWF would start investigating techniques to assimilate physical radiances measured by the weather satellites, especially with the radiometer SEVIRI aboard METEOSAT, instead of optical depths. Two tenets would drive this development. First, the accuracy of a prediction depends on the model, the assimilation method and the input data. Improvement of any, or all, of these components would, at least in principle, contribute to improve a prediction. A way to improve the input data would be, as we have mentioned in the case of the reanalyses, to reduce the bias caused by using interpreted geophysical parameters instead of measurements of radiances. In that way, for instance, hypotheses about the distribution of aerosols with altitude could be avoided, reducing in so doing, the bias of the datasets. We will develop this rationale when discussing the reconciliation technology of the *observables simulators*.

On the other hand, this is the second tenet, near-real time short term forecasting is critically dependent on the existence of data to routinely fuel and initialize the assimilation system. By 2004 POLDER-1 and POLDER-2 were no longer in operations. Their data had been useful to develop and test a data assimilation scheme, but useless for constructing data about the future –atmospheric systems are too much dependent on initial conditions for past data of 1996-1997 and 2003-2004 to be of any meaningfulness for current predictions. MODIS would turn out to be a long-lived instrument flying quasi-uninterruptedly since 1999, but this had been a consequence of its fortunate longevity, not a result of a design. It had been designed as a singular experiment without vocation to perpetuity. The same can be said of TOMS/Nimbus-7 between 1978 and 1994, OMI/Aura since 2004 (conceived as the successor of TOMS) or POLDER-3/PARASOL between 2004 and 2013. All them had indeed lasted longer than scheduled but this was by accident, not by design. They had been designed as single-shot experiments to produce geophysical datasets during a limited period of time and without vocation of perpetuating the measurements. With that we provide a new angle-point to the discussion about perpetuating the measurements: we have mentioned before that continuity is necessary to avoid gaps in order to calibrate data from different instruments which is necessary to produce climate data

[934] Rapports d'activité LOA.

[935] "Aerosol analysis and forecast in the ECMWF Integrated Forecast System. Part I: Forward modeling", J.J. Morcrette et al., 2009 and "Aerosol analysis and forecast in the ECMWF Integrated Forecast System. Part II : Data assimilation", A. Benedetti et al. 2009.

[936] Barely a month after this eruption, ESA and EUMETSAT organized a workshop to assess in retrospective the ability of operational prediction centers in monitoring and predicting the ashes plume. "Monitoring volcanic ash from space", ed. C. Zehner, 2010.

records of the past. We are now providing a different perspective: continuity of the measurements is also necessary to routinely fuel the models to produce data about the future. Routine forecasts require routine data inputs, which require continuity of the measurements. A data assimilation schema based in ingesting aerosols' optical depths is fragile in the sense that it depends on the existence of these instruments that have an expiring date without leaving any successor. By contrast, the radiometer SEVIRI inside the weather satellite METEOSAT, and more generally all space instruments aboard weather satellites, as we have discussed, are part of a weather *informational globalist infrastructure*, which convenes for a sound system of backup satellites, instruments, processing lines and sophisticated ground segments[937]. It convenes for timely replacement of satellites one after the other to keep doing business. Because this system ensures the continuity and readiness of the data, almost by the very existence of the infrastructure, data users are pushed to learn how to assimilate radiometric measurements obtained from weather radiometers, even if not optimized to study aerosols, instead of geophysical parameters derived from specialized, and singular satellites: in so doing, forecast of aerosols may be available as long as there would be weather satellites.

Note, to conclude, that using POLDER's data for developing systems to create data about the future, to predict the air quality, was far from the original scientific objectives of POLDER when it was conceived in 1986, giving full meaning to the notions of "multimissions" and to the value of preserving the data for prospective utilization. This aligns with a number of studies showing that the uses of a technology (or data) are as varied as its users –and that almost anyone can become a user. Different social groups with different ends, needs, means and representations may take data derived from satellite measurements, whether in their physical, geophysical or climatic form, and appropriate them in a number of epistemic frames, which, in many occasions are unimaginable for those who conceived the instrument in the first place[938] -we will provide more examples in the following section.

Climatologies of the aerosol cycle: Satellite data, information and action

As we have just mentioned, instruments like TOMS, MODIS, OMI or POLDER-3have been flying more years than originally expected providing different records of data about the tropospheric aerosols of around 10 or 15 years each one generating a relative long, and multiple-source, climatologies –satellite climatologies that would be completed with the data obtained from the sun-photometers of the AERONET network measuring since the 1990s. To some data users, it makes no difference whether these satellite decadal records were achieved by design or by accident –what matters to them is that they exist. And therefore they can be used. We are interested in this section in illustrating a mode of re-using these satellite climatologies to establish correlations between phenomena.

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[937] « Meteorology as Infrastructural Globalism », Paul Edwards, 2006.

[938] The historian Andrew Warwick, for instance, showed how different social groups used the logarithmic tables during the Victorian period: bankers, insurance companies, naval companies, astronomers, navy, engineers and physicists, arms designers, State administrators, etc. Each group exploited the same data in a particular manner in function of their ends, needs, means and representations of the logarithmic figures. See: "Masters of Theory: Cambridge and the Rise of Mathematical Physics", 2003.

Because of the existence of long-term satellite data records, statistics would start to make some sense. Scientists interested in studying the seasonal cycle of the emission, transport and precipitation of aerosols may take these decadal records to identify and study seasonal and annual patterns and variability in the cycle. Some others would be interested in studying the associations between shorter-term processes, like chemical or meteorological effects, on the long-term patterns of the cycle. For instance, scientists interested in studying the cycle of the desertic dust could analyse these data records of 10 to 15 years, more than 30 years in the case of Meteosat and TOMS, of the optical depth of the desertic aerosols, which came to be known by the community as the "dust archives". For instance, they would allow determining the effects of two major meteorological phenomena, the North Atlantic Oscillation and the Sahel drought, on the interannual variability of the African desertic dust cycle[939]. Some other scientists would be interested in understanding the relationship between anthropic processes and the aerosol cycle, an avenue of research fostered from the 2000s onwards within the cultural frame encompassing the Earth sciences in the 2000s, dominated by environmental preoccupations, the human influence on them and their influence on humans. To give just one example, some scientists would aim to study the impacts of the mineral dust on epidemiology propagation, in particular relating the annual variability of desertic dust and the meningitis outbreaks in West Africa[940]. This is a study in process under the framework of a Groupe d'Intérêt Scienfique called « Climat-Environnement-Société », which brings together physicists from LOA, epidemiologists of the Centre de Recherche Médicale et Sanitaire (CERMES), geographers of Centre de Recherches de Climatologie (CRC) and numerical modelers at Laboratoire Inter-universitaire des Systèmes Atmosphériques (LISA). Because the satellite data composing the dust archive (Meteosat, TOMS, OMI, MODIS and PARASOL) would not restitute the vertical profile of the optical depth, but only total vertical columns, and because the dust affecting population is the one located in the lower atmospheric layers, scientists would consider that the satellite dust archives were not pertinent for this study; local data from AERONET ground-sun-photometers were better placed. However, satellite climatologies would provide essential background information to determine the general conditions in which the local AERONET measurements were integrated, the broader context to interpret the local measurements[941]. In this study, scientists would take climatologies from TOMS since 1979 and

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[939] Habilitation à Diriger des Recherches, entitled « Apport des observations satellitaires à l'étude des aérosols et de leurs impacts », Isabelle Chiapello, defended in 2011.

[940] Project ADCEM (Impact des Aérosols Désertiques et du Climat sur les Epidémies des Méningites au Sahel) started in 2009 within the program Groupement d'Intérêt Scientifique Climat-Environnement-Société directed by Béatrice Marticorena at LISA. See : http://www.gisclimat.fr/projet/adcem

The hypothesis underlying this research is that dust episodes, which are especially intense and numerous in some regions of West Africa, may irritate mucous membranes. This may become a gate for certain bacteria to get in the organism. This research aimed to find out whether outbreaks of meningitis may be related to dust coming from Sahara and Sahel.

[941] Similar studies have also proliferated, for instance, using these climatologies derived from satellite data to monitor conditions in the breeding regions of certain disease vectors, such as malaria-carrying mosquitoes. Data on rainfall, temperature, local vegetation, and soil moisture from satellites such as Landsat 7 and NASA's Terra are used to build a profile, which is combined with high-resolution imagery from commercial satellites, such as Ikonos and QuikBird, to determine where mosquito-spawning areas are likely to appear. Alerts are issued when the conditions for outbreaks can be predicted.

Meteosat since 1984, monthly or annually, that is data of level 3 or 4 according to the schema of levels of processing, and would use them to set the overall setting in which local measurements must be analysed. Scientists would then correlate the climatologies of AERONET with the data about meteorological parameters obtained through analyses and reanalyses of the European Center for Medium-range Weather Forecasts (temperature, humidity, wind) and the data about the number of cases of meningitis in a weekly frequency in several countries available since 2003 obtained from World Health Organization/UN[942].

In order to avoid repetition with analyses provided in previous sections, we use this example to underline one of the urgencies characterizing a part of the scientific research in the domain of Earth sciences: the ties between research, information and action. This is how one of the scientists participating in the project stressed the stakes of this project:

> « L'enjeu est bien là : si l'on arrive à établir le lien entre les paramètres climatiques (incluant les poussières) et le moment où apparaît la maladie, on ouvre la voie de la prédiction, particulièrement utile à la lutte et au contrôle de la méningite (…) La tâche est complexe car de nombreux facteurs se combinent dans ce type de pathologie, à la fois d'ordre démographique (mouvement des populations), socioéconomique (surpopulation des habitations, pauvreté), épidémiologique, et climatique (…) Si l'existence d'un tel impact est soupçonnée, elle n'est pas clairement établie, l'enjeu de ce projet est d'examiner conjointement les mesures de poussières et les données de méningites dont on dispose, ainsi que d'autres paramètres environnementaux (humidité, vent, température) pour fournir des éléments de réponse»[943].

To this scientist it was not only about studying the physics and dynamics involved in the desertic aerosols cycle, and eventually linking it to epidemic outbreaks, but about providing « éléments de réponse". Once the link between dust and meningitis would be, if so, established and understood, prediction would enter the play –which would be done with a numerical model especially adapted to this study by scientists at the Laboratoire Inter-universitaire des Systèmes Atmosphériques (LISA) of the Institut Pierre Simon Laplace (and the corresponding data input and assimilation scheme) –the model would be actually a version of the model of air quality CHIMERE of IPSL. But it was not only about producing data about the future. Then, once the information would be there, it would be time for decision-making, for an action. Geophysical data about the Earth's environment would be used, not only to conduct scientific research, but also to generate information about, and manage, our society. To be sure, as we have recurrently mentioned along the present dissertation, the links between space activities and Earthly applications can be traced back to the very origins of the satellite effort: weather forecasting and Earth survey missions are nothing but providing information about the weather or about the territory intended to manage our societies. However there is one essential difference between these earlier surveillance imperatives and the current ones: the possibility of extrapolating the current state forward in time via the assimilation technology. Before the widespread use of the technologies of

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"Utilization of Operational Environmental Satellite Data. Ensuring Readiness for 2010 and Beyond", Space Studies Board, 2004.

942 "Assessments for the impact of mineral dust on the meningitis incidence in West Africa", Nadège Martiny and Isabelle Chiapello, 2013.

943 Apport des observations satellitaires à l'étude des aérosols et de leurs impacts », Isabelle Chiapello, 2011.

assimilation (weather forecasting in the 1980s, oceanographic forecasting in the mid-1990s, chemical forecasting and other uses from the 2000s onwards), satellite data were stuck in time. They were static, local and perishable; actions were allowed only in present or in retrospective: assessment and mitigation. The possibility of using these data to produce data about the future came with the technological practice of data assimilation –and with it, possibilities for anticipative action. We are not interested in engaging any study about these technological data practices and the common parlance used, for instance, in the reports of the Intergovernmental Panel on Climate Change, but merely to point out remarkable connections.

This example illustrates also that preoccupations of environmental changes, their impact in our societies, mitigation, adaptation, the urgencies in planetary management would permeate the domain of space Earth sciences –as they had permeated other domains. By the 2000s, it would be very difficult to propose a space mission in the domain of Earth sciences without addressing such questions -one of the major expressions of such a zeitgeist would probably be the program proposed in 1998 by the European Commission to provide timely and quality information, services and knowledge in relation to environment and security, a project that would become Copernicus. The inescapable links between environmental research and social relevant issues, or institutional urgencies to get funding, not only as discursive ploys, institutional hallmarks or symbols, but also as effective research programs would lead to new contexts for re-using satellite data and new scientific urgencies, giving a renewed meaning to the study of physical, chemical and biological processes. Public health is one of such contexts, but other areas of public action would also take advantage of the long-term climatologies–not to speak of the private initiatives. For example, climatologies of rainfall or temperature would be used to determine where to build homes by calculating the return periods of large floods, whether the length of the frost-free growing season in a region is increasing or decreasing, and the potential variability in demand for heating fuels. Regulatory actions to deal with local pollution, for example, would take into account statistical local environmental factors. Certification of environmental parameters and variation in them has the potential to become critically important in relation to bilateral or multilateral treaty obligations, particularly with respect to global climate change initiatives. Private insurance companies also would make use of such climatologies when deciding insurance house contracts or, this is our last example, transportation companies, road, air and sea, when tailoring the routes and budgets[944]. And with this arsenal of diverse modes of exploiting and using the climatologies derived from satellite data we circle back to the previous discussion of multiple, potential uses.

[944] These are not random examples, but existing ones. For more specificities, see for instance: "Utilization of Operational Environmental Satellite Data. Ensuring Readiness for 2010 and Beyond", Space Studies Board, 2004.

Evaluating numerical models

For our last example of re-using satellite data by data users distant from the contexts of acquisition and production, we have chosen to explore another practice mediated by numerical modelers: evaluating the numerical models. In her study about the climate modeling practices in CNRM/MétéoFrance and LMD/CNRS, Hélène Guillemot observed a number of interactions between observations and models (top-down validation, local evaluation of parameterization, validation of climatic effects of small scale processes, evaluation of a model's capacity to simulate particular phenomena), all of them driven by the ultimate goal of using observations to evaluate a particular aspect of a given model[945]. She stressed actually that modelers would spend much of their time testing their models and one way in which they do that is by comparing the outcomes of their simulations with data[946]. We expand in the following upon Hélène Guillemot's work by providing first an example of the classical approach for evaluating a model (comparing its outcomes against *geophysical parameters*) and then a recently developed technology based on the comparisons against *physical radiances* –in this last example, hence, *climatic data* are not in the game. We are connecting the practice of evaluating numerical models with the technological data practices mobilized by the modelers, with the type of data that they re-use and with the knowledge and expertise required in each case, with the ultimate goal of describing two distinguished epistemologies: one subscribing the normalized data gathering, production, dissemination and using system, and one deviating from it.

Traditional epistemology

By the late 1990s several laboratories had developed different numerical models of chemical transport, including the before-mentioned model INCA of LSCE representing the cycle of production, circulation and deposition of some chemical compounds and, as we have introduced before, by the early 2000s some scientists would try to extend this model also to simulate the aerosols. Given that the model INCA had been developed for studies in the domain of greenhouse gases and ozone, whose chemical and dynamical properties generally differ from those of the aerosols, it must be assessed to what extent this model was appropriate to represent the latter. In other words, scientists must evaluate the capacities of the model to simulate the emission of aerosols, their transport through the atmosphere and their deposition.

To assess how the model INCA represented the emission of the aerosols, scientists would simulate a very particular situation occurred in the past and that had been observed by some satellites, including POLDER-1: the emissions of carbonate aerosols during the summer season of biomass fires associated to agriculture burnings and deforestation in South America and Sub-Saharian Africa in 1997 and

[945] "Connections between simulations and observation in climate computer modeling. Scientist's practices and ''bottom-up epistemology'' lessons", Hélène Guillemot, 2010.

[946] Other approaches for evaluating models exist that do not involve comparison against observations. They have been developed, inter alia, in « La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », Hélène Guillemot, 2007.

1998[947]. The outcomes of the simulations would be confronted to the geophysical datasets about the optical depth of carbonate aerosols retrieved from POLDER-1 measurements, using an inversion algorithm optimized to specifically detect this type of carbonates[948]. As per the evaluation of INCA's capacity to simulate the transport of the aerosols through the atmosphere, the methodology would be essentially the same: eight different episodes of circulation of aerosols' plumes occurred in 1997 and 1998 (originated in South America and Sub-Saharian regions and directed towards the Atlantic, the Pacific and the Indian oceans) would be simulated with the model and compared against the data about the optical depth retrieved from POLDER-1.

The point was that, as we have announced before, while the optical depth of the aerosols was a parameter commonly retrieved from satellite radiometric measurements (and directly measured with ground-based sun-photometers), it was not a parameter that could be directly derived from the Navier-Stokes equations that rule the dynamics of the atmospheric circulation -and therefore the transport of aerosols through it. Actually, the models of chemical transport would describe the mass of the particles –or they number. Consequently, before comparing the outcomes of the simulation with the satellite data both datasets must be rendered comparable. This would be *simply* done by developing a parameterization for computing optical depth from mass-profiles, which would require some hypotheses like, for instance, about the content of water in the troposphere (in a wet troposphere, for instance, some aerosols may absorb water resulting in changes in their mass, which affects the optical depth[949]). In turn, the performance of such parameterization must be evaluated before being incorporated to the INCA's model software. To that purpose, scientists would run another simulation (with the parameterization incorporated) to compute the global means of the optical depth for the year 2000, and would compare the outcomes against the global means of optical depth calculated by the ground sun-photometers AERONET during the same period[950].

Part of the problem of using satellite data for evaluating the model would be thus how to reconcile both types of datasets, the outcomes of the simulations and the satellite geophysical retrievals. Scientists use to refer to such a problem as a problem of "not speaking the same language" -to take an often-used expression. "Not speaking the same language" would be sometimes used as a metaphor referring to the cultural differences, scientific approaches, research topics, and so forth, that do not render easy the dialogue between simulated data and satellite-retrieved data. In some other occasions it could be taken literally. For instance, in this case, POLDER's data talked "optical depths" whereas

[947] This was actually part of the topic of one doctoral research. « Etude des interactions entre aérosols et climat : assimilation des observations spatiales de POLDER dans LMDz-INCA », doctoral dissertation by Sylvie Generoso directed by François-Marie Bréon, 2004.

[948] "Global observation of anthropogenic aerosols from satellite", D. Tanré et al, 2001.

[949] The amount of water absorbed by each type of aerosol can range from 50% to 90% depending on the type of the aerosol, which is not negligeable. Not accounting for that engenders thus important errors in the computation of optical depth.

« Etude des interactions entre aérosols et climat : assimilation des observations spatiales de POLDER dans LMDz-INCA », Sylvie Generoso, 2004.

[950] « Etude des interactions entre aérosols et climat : assimilation des observations spatiales de POLDER dans LMDz-INCA », Sylvie Generoso, 2004.

INCA's outcomes talked "mass". In some other cases, as we will see in the following section, the same term implied different understandings. Scientists may apprehend the same phenomena differently in function of, inter alia, differences in scientific approaches, in research topics or in the technologies that they use to interpret it. Just like weather forecasters had learnt, between 1960s and 1980s, how to transform vidicon images and infrared radiances into thermodynamic variables meaningful to their predictions[951], atmospheric chemical modelers must learn to reconcile the geophysical parameters retrieved from satellite physical radiances and the variables outcoming from their simulations in terms of mass. The differences in the type of variables with which some scientists are used to work and those derived from satellite observations must be reconciled for satellite data to be re-used to evaluate models. In this particular example, the model INCA simulated masses, whereas the radiometer POLDER retrieved optical depths. The strategy to reconcile the two types of variables, or to make them "speak the same language", would be to add some more lines of code to the software of the model in the form of a parameterization relating mass distribution and optical depth.

Epistemology of purity

Other solutions may be envisaged though. During the pre-launch work conducted between 1999 and 2004 to prepare the utilization of the data obtained with the future PARASOL, some scientists at the Laboratoire de Météorologie Dynamique would use the measurements of a lidar in a surface station, SIRTA, located in Palaiseau –recall that POLDER-3 aboard PARASOL was meant to be used in combination with the measurements of the lidar CALIOP aboard CALIPSO of the A-Train. When data users would intend to compare the data about clouds retrieved from the lidar's measurements and the outcomes of the simulations of the climate model LMDz in terms of clouds, they would stumble with a similar problem of "language":

> "Dans un modèle, soit CHIMERE ou LMDz, les nuages sont une quantité d'eau en g/cm3 dans une maille de 1 km de résolution verticale et 20 km en horizontal, chaque tétraèdre est un nuage. Pour un profil lidar de SIRTA, de résolution 15 m en vertical et 3 m en horizontal chaque pic de réflectance est un nuage (…). Quand on dit qu'on va comparer les deux, par exemple pour évaluer les performances du modèle… on ne peut pas, on ne peut pas comparer des tétraèdres et des pics, des oranges et des pommes, les nuages ne sont pas définis de la même manière!"[952].

The fundamental problem was that the models and the lidar did not represent the object of study, clouds, in the same manner. For the ones, a cloud was a volume of water whereas for the other it was a ratio of energy. For instance, climate models may predict clouds at any atmospheric level where condensation occurs, while inversion algorithms may only detect those clouds thicker than a fixed value. There was no a consistent definition of clouds (and cloud types) between the LMDz model and the lidar measurements. In this case too models and data would not "speak the same language". The classical approach to reconcile these differences in language and in the definitions was to transform all

[951] As described in "Technology Reconciliation in the Remote Sensing Era of United States Civilian Weather Forecasting: 1957-1987", Margaret Courain, 1991.
[952] Interview with Hélène Chepfer, LMD, 2012.

variables into geophysical parameters, which were commonly retrieved from satellite measurements like the optical depth of the clouds, the thermodynamic phase of the water droplets or their size –just like in the example previously examined. Since the early 2000s, a new approach started to emerge: instead of comparing the geophysical parameters, scientists would compare direct measurements, namely, the physical radiances.

Let us examine this approach with an example of how scientists at LMD would evaluate the representation of clouds' processes and feedbacks under different circumstance in the climate model developed at home, LMDz. Before the 1990s, climate models would be a technology in its infancy, not much complex, robust or accurate[953]; it had occurred in several occasions, for instance, that, due to their poor quality and accuracy, divergent datasets would all fit within the error intervals of the simulation outcomes[954]. As models would mature, partially boosted under what the historian Amy Dahan called the *climate regime*, however, data precision would become important[955]. Geophysical data were indeed also more precise as sensors evolved, error analysis techniques sophisticated and inversion algorithms improved. Yet, they would carry always, by definition, an artifactual bias due to interpretations imbued in their process of recontextualization. The issue was that, as geophysical data would reach out to a wider audience, many of the *data users* would ignore the nature of such interpretations and therefore they would ignore the impacts of the corresponding bias. A contrario, moving away from recontextualized data and using instead *true data*, as argued by the following scientist, one of the first in developing this approach in France, would bring the advantage of working with data freed from previous interpretation and hypothesis:

> "On fait confiance à une bonne calibration et on prend les données comme vraies, comme la vérité à partir desquelles comparer et évaluer les modèles. Mais les niveaux 1 [physical measurements], qui sont riches en information, les niveaux 2 [geophysical parameters] surtout pas, elles sont chargées d'hypothèses qu'on ne connaît forcément pas ! »[956]

Radiances carried less interpretational bias, were more "true" and, therefore, unlike geophysical parameters, which had been intervened, they could be trusted as references against which evaluating the quality of the numerical models. Geophysical quantities would be considered as manipulations too much recontextualized to have any value. This would entail a change in the epistemology of satellite data. During the first 20 years of space age, weather services assumed that after having been converted

[953] For a history on climate modeling see « La modélisation du climat en France des années 1970 aux années 2000. Histoire, pratiques, enjeux politiques », Hélène Guillemot, 2007 -and its references.

[954] Bill Rossow showed us a non-published paper in which he plotted some cloud properties, and their error bars, retrieved from different geostationary weather sensors in the mid-1980s (Meteosat, GOES and GMS). Most of the datasets diverged significatively amongst each other; yet, the numerical simulations were so coarse that all the datasets were still inside the error range of the model outcomes and in agreement with them.

[955] Within this regime, heralded by the creation in 1988 of the International Panel of Climate Change (IPCC), scientific research about climate could be henceforth hardly separated from the ascension of such questions in the international political arena, leading to major evolutions in considerations of economy, geopolitical forces or consumption lifestyles, to mention only a few.

« Le régime climatique, entre science, expertise et politique », Amy Dahan in « Les modèles du futur », 2007 and "Putting the Earth System in a numerical box? The evolution from climate modeling toward global change" Amy Dahan, 2010.

[956] Interview with Hélène Chepfer, LMD, 2012.

into thermodynamic variables, radiances had no value anymore and could be discarded. In the 1980s, space agencies and *data creators* followed this ideal by allocating the epistemic virtue of satellite data in the geophysical parameters and establishing a socio-technical production and dissemination complex centered in such tenet: geophysical datasets had value to Earth scientists (first of level 2 and later on also in some form of synthesis of level 3 and 4). Since the 2000s, some data users would begin to understand satellite data differently. Because radiances carried less contextual interpretation, they were more objective, as they had been less manipulated by human mediation –these scientists defended an epistemology of purity.

When trying to compare the outcomes of the LMDz about cloud fraction with the observations of CALIOP, scientists at LMD would face similar problems than the scientists at LSCE when trying to compare the outcomes of the INCA's simulation in terms of mass distribution with POLDER's data in terms of optical depth of the aerosols: a problem of reconciliating different datasets, a problem of "not speaking the same language". But they would address the issue differently. While the ones would convert the model's outcomes into parameters similar to the geophysical variables retrieved with the inversion algorithms (in our example, optical depth of the aerosols), the others would convert the model's outcomes into the radiances measured by space instruments (in our example, lidar's radiances or reflectances). These are two approaches of evaluating models, and more generally to the re-use of satellite data, that would deploy different epistemologies, putting forward different types of data and taking on different technologies to reconcile the outcomes of the model and the satellite data (inversion algorithms and observables simulators, as we will see in the following section). All these scientists would agree that satellite data are useful to evaluate numerical models, but the location of their virtue would vary in function of the interpretative community drawing upon different professional background, technologies and material culture, institutional culture, phenomena under study, scientific goals and expectations or tacit knowledge. A particular technological practice would be mediated by those scientists using physical measurements to evaluate their models: the *simulation of observables*.

Technology of simulating the observables

Whether using geophysical or physical data to confront the models, the problem of reconciling the satellite data with the outcomes of the climatic simulations would persist, since the climate models provided their outcomes in terms of thermodynamic or physical variables and not radiances -in particular, when talking about clouds, simulated data came in volumes of water. In the early 2000s, scientists at the National Center of Atmospheric Research, the European Center for Medium-range Wetaher Forecasting and others, started to develop a new tool, the *observables simulators*, aimed to solve this reconciliation problem[957]. Scientists at LMD would emulate these developments and develop a simulator for the ground-based lidar SIRTA to be integrated in the software of the global climate model LMDz with views in adapting it to the specificities of the future space lidar CALIOP, scheduled for launch in the mid-2000s. The idea behind this technological data practice was to make models simulate what the satellite-instrument would measure if it was looking at the model-simulated scene. In our case, it was about simulating the measurements of the lidar if it observed the atmospheric conditions simulated in the model LMDz[958], In these conditions, both the model and the lidar would understand clouds as profiles of physical reflectances, the ones obtained from the measurements and the others computed by the model. All that would remain to be done would be a matter of defining a threshold: “Un nuage c’est tout ce qui dépasse une valeur seuil fixée. Et on applique exactement la même valeur seuil dans les deux profils, de sorte que quand je dis que c’est un nuage je parle de la même chose dans les deux profils”[959]. In that way, scientists would not be comparing “oranges-to-apples” anymore, but rather “apples-to-apples” –also an often quoted metaphor used by data users when describing this technology[960].

An observable simulator would be, at the end of the day, a few coding lines of radiation transfer calculations to be added to the model software, so that the atmospheric profiles predicted by the model in terms of volumes of water (for instance) would be converted to an ensemble of subgrid-scale measurements (reflectances in this case) similar to those observed from space. In other words, the outputs of the model in terms of thermodynamic and physical parameters would be transformed into their corresponding radiances. Developing software to convert back the outcomes of a simulation into the original radiances would be, after all, inversing the inverse problem: transforming geophysical parameters into physical measurements. Therefore, it would require a deep knowledge and expertise to articulate radiation transfer theory with the specificities of the given measurement -the very same kind of training than those of *data creators* who develop inversion algorithms to retrieve new variables from radiances.

We would like to conclude with two remarks. First, it can be said that the re-using of radiances by means of observables simulators would change the epistemology and the technology encompassed in the re-use of satellite data but without changing the social order: the distribution of power and epistemic authority would remain allocated to those scientists experts in radiation transfer and theory of light capable to develop the software of the observables simulators –as a matter of fact, in France,

[957] Actually the notion of simulator was developed within the project ISCCP in the mid-1980s to analyse the data of all the weather satellites: “ISCCP cloud data products”, W.B. Rossow and R.A. Schiffer, 1991 and “Advances in Understanding Clouds from ISCCP”, W.B. Rossow and R.A. Schiffer, 1999.

[958] For instance: "Simulation of satellite lidar and radiometer retrievals of a general circulation model three-dimensional cloud data set”, M. Doutriaux-Boucher et al, 1998; “Use of CALIPSO lidar observations to evaluate the cloudiness simulated by a climate model”, H. Chepfer et al, 2008; and « A CALIPSO lidar simulator to improve cloud representation in climate models”, H. Chepfer, 2009.

[959] Interview with Hélène Chepfer, LMD, 2012.

[960] The expression is taken from several presentations and internal notes describing the observables simulators at LMD, at Mettofice and at NCAR. See for instance, "The Climate Data Guide: COSP: Cloud Feedback Model Intercomparison Project (CFMIP) Observation Simulator Package", eds. Jen Kay.

the scientists pioneering this approach would be *data creators* of LOA and LMD trained in the algorithmic or instrumental interpretation of remote-sensing technologies who were currently working within numerical modeling research teams. This is a technological data practice requiring the skills of a geophysical data creator but serving the needs of data users, in particular of numerical modelers. That this technology was serving the numerical modelers' needs can be seen also with our second remark. We have considered the example of the simulator of the measurements of the space lidar CALIOP compatible with the model LMDz, but other simulators would be developed associated to different satellite measurements, including ISCCP, CLOUDSAT, MISR, MODIS or POLDER-3[961]. In fact, since the mid-2000s virtually all climate modeling groups around the world would actually develop their own simulators of different satellite instruments compatible with their corresponding models. These efforts to develop and exploit these simulators as a way to evaluate the global climate models would be coordinated internationally within the framework of the WCRP's Working Group on Coupled Modeling, an international group of scientists who foster the comparisons of climate models with the goal to prepare the elaboration of several reports of the Intergovernmental Panel on Climate Change (IPCC), especially the tetra-annual Assessment Reports. Indeed, mutually evaluating the quality of models against each other would constitute an element of the methodology of IPCC since its inception and scientists of LMD, for instance, would participate in these exercises since the mid-1990s -at present day, a big part of their time is devoted to this task, especially when the elaboration of a new assessment report approaches, as has been noted by several scholars studying the influences of IPCC in the structuration of research in the domain of climate modeling. More generally, according to some scholars, the establishment in the 1990s of what the historian of sciences Amy Dahan called the *climate regime* would participate in boosting this area of research and in placing numerical modeling at the center of epistemic authority in the domain of climate change. Within this regime, heralded by the creation in 1988 of the International Panel of Climate Change (IPCC), scientific research about climate could be henceforth hardly separated from the ascension of such questions in the international political arena, leading to major evolutions in considerations of economy, geopolitical forces or consumption lifestyles, to mention only a few. It has even been suggested that the very understanding of what constitutes climate, and climate change, has been transformed and today research related to climate modeling is derived from the IPCC methodology: defining future economic scenarios, which would be associated to scenarios of CO2 emission, which would be associated to concentrations of CO2 in the atmosphere, which would be introduced in the numerical climate models, which would run and provide a climatic scenario. Within this methodology, assessing the performance of the global climate models, that is, evaluating a model, would aim to assess different future climatic scenarios provided by each model in a given set of circumstances[962]. It was within this purpose of evaluating models that, in the third round of model comparisons exercises conducted in 2005 and 2006 to prepare

[961] "COSP: satellite simulation software for model assessment", A. Bodas-Salcedo et al, 2011.

[962] « Le régime climatique, entre science, expertise et politique », Amy Dahan in « Les modèles du futur », 2007 or "Putting the Earth System in a numerical box? The evolution from climate modeling toward global change" Amy Dahan, 2010.

the elaboration of the 4th Assessment Report, integrating software of observables simulators to the climate models had been incorporated in the protocol to evaluate the models, establishing this technique as an admissible approach to evaluate the climate models[963]. Within this lens, the integration of the *observables simulators technology* as indispensable for evaluating models within the methodology of the IPCC, exemplifies a case of a satellite data technology impregnated in the climate knowledge infrastructure and serving to climate modeling purposes –more particularly, IPCC needs[964]. It exemplifies a case in which the skills archetypical of a geophysical data creator are not used to create geophysical data but put at the service of a particular form of data users, the climate modelers.

CONCLUSIONS

With the example of climate data-records we bring to a closure the cascade of possible operations for producing different types of data from satellite measurements: from decontextualized physical radiances, to recontextualized geophysical datasets (of level 2, 3 or 4), to climate data made up of fusions of satellite data with numerical models. While technologies of *calibration* mediate the production of radiances and technologies of *inversion* mediate the production of geophysical datasets, the production of the climate data is mediated through the so-called technologies of *data assimilation*. As we have described all along our essay, each technological practice requires specific expertise and skills, deploys different types of knowledge, calls for access to different data processing levels, depicts different relationship with the instrument, defines different epistemologies vis-à-vis satellite data, varied connections with the space agency, or with the source of measurements. A notorious feature of the data assimilation technology is that, unlike calibration and inversion, it constitutes a technological data practice associated to data users' field of expertise –specifically to a particular type of data users, the numerical modelers. It can be interpreted, therefore, also as providing an example of re-using satellite data by scientists distant to their acquisition and production. More generally, while the data creators would define some of the standards, the tools and the problems that would be regarded as admissible in the field of Earth sciences, some data users would vindicate the *re-use* of data for other purposes, with other approaches, requiring different types of data and different forms of access, and re-using them by means of other technological practices. In particular, while geophysical data creators would interpret satellites data with a physical approach to generate geophysical datasets, some form of geophysical data users (which in turn are climate data creators) would interpret the measurements with

[963] Several scholars have studied the implications of IPCC in the research practices, especially in the domain of numerical climate modeling. Although the official rhetorics, often reaffirmed by the IPCC, is that this organization only assess the outcomes of the existing research, it has arguably contributed to reconfigurate the research in this domain. Some even say that the very understanding of what constitutes climate, and climate change, has changed.

See for instance: « Changement climatique : Dynamiques scientifiques, expertise, enjeux géopolitiques », Amy Dahan Dalmedico and Hélène Guillemot, Sociologie du travail, 2006.

[964] Is spite of their origins as instruments of the IPCC's climate infrastructure, the codes of different simulators are now available on the web. Their utilization is now widespread, not only amongst global climate modelers but also amongst other scientists, who wish to evaluate their small or medium-scales models to improve their understanding of a given process.

a numerical approach to generate climate data. These are two ways of interpret the measurements and two ways of represent the Earth and the Earth sciences: through a, what we have called a geophysical perspective or through a climatic one. This can be summarized with two simple sentences. First, what counts as data varies profoundly across the approaches even within the same domain of Earth sciences; second, multiple technological practices coexist, demanding different expertise and skills, articulating different relationship with the instrument, demanding different social organization, and the data and calling for different policies of data access. For some, data is a question of recontextualized geophysical variables (cloud cover, temperature, aerosols radius, rainfall or size of the vegetal leafs); while for others, data is a form of energy, physical radiances, as decontextualized as possible and yet to be interpreted; and still for some others, data is what comes out of a numerical model as a complex interpolation of existing satellite (and non-satellite) data in form of climate data-records –perhaps for still some others data are AC currents or binary-sets.

In turn, many of the issues emerging in the re-use of satellite data come precisely from the divergence of purpose between the original frames in which the geophysical parameters had been created in the first place and the distant contexts of re-utilization, as exemplified with the cases of climate studies intended to detect and understand variability, the short or medium-term forecasts aimed to predict the state of a system, the use of well-established climatologies to correlate phenomena, or the use of data to evaluate models. The technical characteristics of the data needed to conduct research in each contextual approach would differ just as it would differ the technological data practices deployed to re-use the data. Forecasting urgencies would ask for real-time data, as predictions are dramatically sensitive on data to initialize the running and to provide a timely analysis; they privilege speed before precision or data volumes. A contrario, the purpose of studying long-term patterns, tendencies and variability, and discriminating natural from anthropic from random effects with statistical significance, would require highly accurate datasets, consistent, global, continuous and homogeneous over time. They require different types of data but use the same technological practice to mediate with them, data assimilation. Evaluating models re-using radiances, by contrast, would still call for a third technological practice, the simulation of observables –which is a sort of variation of the inversion technology.

Some of the cases illustrated in this chapter align with the epistemologies that would become the norm by 2000 and would define the epistemic specificities of what we have called the space Earth sciences, which placed the epicenter of scientific inquiry in geophysical parameters. Only recontextualized geophysical data, interpreted in a specific given context would be considered as meaningful to the current practices of Earth scientists used to understand physical, chemical and biological phenomena in geophysical terms. Satellite data would be useful precisely because they came under a form that inherently carried with an interpretation, inserted in a specific frame of study that made sense to Earth scientists. Actually, until converted, through inversion algorithms, into geophysical quantities such as optical depth, cloud cover, sea level or chlorophyll concentration, radiances would not count as data at all –they would not even be archived in scientific data centers, but confined to space agencies.

This picture contrasts with other examples, which locate the epicenter of scientific inquiry to the original measurements, the radiances. We have suggested three sources driving this move towards re-using radiances. The first one would fortify in the 2000s, as numerical modeling technologies had matured and improved, and would emanate from the precept that geophysical datasets had become suspect, because they inherently carried contextual bias. Decontextualized data, not intervened, would serve as an alternative to geophysical datasets; observation would serve as an alternative to intervention. It would embody an epistemological doctrine accentuating the purity of data, their integrity, their objectivity in what the historians of sciences Lorraine Daston and Peter Galison would describe as a *truth-to-nature* sense[965], emphasizing the absence of human mediation, an ethos of renunciation on the part of scientists to intervene in the production of data. Data, to be meaningful, must be as less submitted as possible to human intervention.

However, now we refer to the second source, we cannot regard the inclination towards using physical radiances as exclusively born out of a faith in pure data irrupting in the 2000s. The re-use of radiances would be promoted by some scientists as early as in the 1980s and driven by the belief the satellite data alone were powerless. Instead, satellite data needed to be assimilated –and we shall insist in the importance of the development of such technology in shaping this world-view. By rejecting the panopticism that had ruled the space sciences during its infancy, these Earth scientists would, along the 1980s stress the collective nature of satellite data. In this crusade towards a holistic approach to space Earth sciences missions, in which satellite data would only be a component of it, surely indispensable but insufficient by its own, scientists would face some pragmatic urgencies like the need to initialize the models in a timely and continuous manner, the need to fill all the gridpoints for the model to compile, the need to build accurate homogeneous long data records or the need to reprocess all the data at once (all them needs that could only both appear and be satisfied when using data assimilation techniques), urgencies that would gradually favor the re-use of radiances instead of geophysical parameters. It may result worthy to develop a bit this suggestion from a more epistemological standpoint. A lot has been said in the philosophy and history of science about empirical data being a tool to models or theories. For instance, we have ourselves explored the re-use of data to evaluate the pertinence of a given set of simulations. This epistemology deploys a methodology in which satellite data intervene in the current practices of numerical modeling: data and models are more or less worked out autonomously by different epistemic communities, data creators and data users of a numerical modeler-type, and only put together at the end for quality control (or in some modalities at the beginning to initialize a model and the results serve to test a theoretical claim). The accent is put in how models make use of data. Far less has been said, however, about the inverse epistemology that considers models as a tool to exploit the data. Within this epistemology, data are what results of applying the models –and this connects to the third source. We have exemplified this case in the use of models to produce climate data (in the particular case of reanalyses). From this angle, numerical models are considered as necessary tools to create the data; they become a

[965] "Objectivity", L. Daston and P. Galison, 2007.

component of the technological practice to produce climate data, and with that we circle back to the normalization of the technology of data assimilation, which assumes that the full potential of the space-based observing capability can only be realized in a synergetic context of an integrated system including numerical models (and other in-situ elements).

Whatever the sources for re-using physical radiances might be, this epistemology would have direct implications for practices as well as for the self-definition of professional ethos. To data creators, data users would take data, in the form of meaningful physical, chemical or biological parameters, and would study relationships, phenomena, tendencies, evaluate models, etc. However, there existed parallel alternatives to this approach: some of the data users would use radiances, that is to say, data representing energy per solid angle and surface, without any given geophysical meaning. Data, the source of empirical studies, is not necessarily given in terms of geophysical parameters. We would like conclude twofold. First, this parallel economy of sciences of using radiances instead of geophysical data would challenge the epistemological hierarchy, which reduced the ultimate interpretation of satellite data to physics of light. Excepting for the case deploying the observables simulators in which skills in radiation transfer and instrumentation would be still required, generally the social order dominated by the groupe mission-type scientists would be challenged and data users would acquire also legitimacy to talk satellite data. Meritocracy based on theory of light knowledge and expertise in the building of the instrument would be ousted by a democracy in which different expertises would be all authoritative. But this renewed distribution of power would find obstacles to be put in practice: acting as the guardian of the original order, the socio-technical factory-like complex of data production and dissemination would produce and disseminate geophysical parameters obstructing the access to those who would vindicate the re-use of alternative types of data.

Secondly, the scientists re-using radiances would drop the idea that conducting research in the domain of Earth sciences meant to analyze geophysical data, an idea that had been underpinning the prestige the domain considered as applied physics since, at least, the beginning of the XXth Century[966], and that, in particular, had shaped the definition of the space Earth sciences during the 1980s and 1990s. The representation of nature as made up of measurable processes understandable through mathematical skills and geophysical parameters would contrast with a vision in which radiances, a form of energy, would be admissible also to describe and apprehend it, promoting a more inclusive conception of the environment and of the Earth sciences. The historical question here is not to point the best approach to describe the nature, by means of radiances, of geophysical variables or of climate data-records, but rather to notice that different assumptions of the environment may lead to different manifestations concerning the manageability of data. Normalizing the use of geophysical parameters

[966] It has been reported that one of the most important developments in the US Earth sciences in the XXth Century has been the increasing domination of geophysics and deductive physical methods, displacing the geological tradition, a development that would be reinforced by the military patronage during and after the WWII. See: “Geophysics and the Earth sciences”, Naomi Oreskes and Ronald E. Doel, 2003; “Constitutiong the Postwar earth Sciences: the Military’s Influence on the Environmental Sciences in the USA after 1945”, Ronald E. Doel, 2003 and “Quelle place pour les sciences de l’environnement physique dans l’histoire environnementale?”, R. Doel, 2009.

or the use of radiances or climate data-records, or both, would not merely be a matter of an abstract epistemological choice, but it would structure relations between scientists and space agencies –and the satellite data. For instance, different epistemologies would involve different types of missions: one-single shot experiments or program for recurrent launchings. Or, a second example, different epistemologies would involve different rules to access to data. Within the current mechanisms of data access designed to disseminate geophysical parameters[967], based on the tenet that geophysical data are the epistemic virtue in Earth sciences, radiances are not considered as deliverable items –they are not even considered as scientific items and remain under some form of property of space agencies and operators. Based on this very same tenet, climate data-records are not part of the mission. Access to radiances is instead constrained to data policies of each satellite operator and often negotiated in a case-per-case basis upon request. In particular, radiances of POLDER or CALIOP discussed in this chapter are not available through the online database ICARE, but rather remain as a sort of property of space agencies CNES and NASA respectively, so that to get them specific requests must be sent to CNES's data services (CALIOP's radiances are available through NASA's online database)[968]. This does not mean that the data cannot be accessed: we have not found any scientist to whom CNES's services have denied access to radiances, yet there is no doubt that access is not as direct as it would be through a database –this is one of the reasons why ICARE was created in the first place, to facilitate the widespread of (geophysical) data to scientists. This does not mean either that climatic data cannot be produced. For instance, spotty 8-months of POLDER-1 data can be eventually integrated in a reanalysis for creating a global homogeneous consistent record of past data. Or, after 9 years of measurements, PARASOL left a record long-enough for some type of climate studies. But they have not been designed for that. This simply illustrates the tension between the existing infrastructures of data production and dissemination and alternative epistemologies that may currently exist or emerge in the course of the years, as scientific urgencies, technologies or contextual elements evolve. Complex and sensitive to Earth sciences priorities in building geophysical datasets, the metaphor of a chain of production of geophysical data central to the representation of nature as geophysical, would result poorly adapted to the demands of those outsiders willing to access to physical radiances or to produce climate records. It shall be remarked at this point, that it is not that all practices are infused with this epistemological regime in which physical radiances have come to replace the former use of geophysical parameters –or at least not yet. Geophysical parameters keep being precious to certain data users and types of investigations; it is rather a coexistence of multiple approaches to the re-use of satellite data.

In other words, the re-use of radiances would prove that the world was not inherently geophysical, but that data creators and space managers had made it geophysical all along the 1980s to better manage it. The *normalization* of the centrality of the geophysical parameters as epistemic virtue may have

[967] We have seen that some exceptions exist, especially concerning the data about radiation budget.

[968] In the US, for instance, some forms of level 1 data are available from the DAACs. See, for instance, some of the level 1 data of CALIPSO (from CALIOP but also from the French instrument IIR) are available through https://eosweb.larc.nasa.gov/project/calipso/calipso_table#quickset-calipso_level_tabs=1

rendered logical, even natural and inevitable, all the achievements and decisions about the socio-technical complex of production and dissemination displayed in different levels of data processing. However, after examining some approaches to the re-use of satellite data and to the production of alternative forms of data from satellite measurements (climatic data from the past, prediction of the future, etc.), alternative understandings of satellite data have crystallized, co-existing, which would prove that this complex infrastructure of data handling had been the result of a design to solve a set of particular problems –in particular, responding to strategic issues raised in the 1980s (some years earlier at NASA) about gaining visibility amongst Earth scientists to maximize the scientific return of space investments. This chapter has illustrated how the imagining of satellite data as geophysical parameters has been recalibrated as distant scientists had access to data, bringing forward other scientific (and certain non-scientific) urgencies, articulating different technological data practices and embedded in other contextual settings and approaches. The gaze informed by data creators has given way for a more complex imaginary dominated by a coexistence of geophysical and climatic interpretation of data as well as by the diverse multiple possibilities, and difficulties, of *re-using* data in multiple alternative ways.

GENERAL CONCLUSIONS

By taking the case of POLDER as a barometer, our work has aimed to examine closely the set of technological data practices involved in the gathering, producing, archiving, disseminating and using satellite data in a number of disciplines in the domain of Earth sciences, and their evolution across roughly 30 years, as scientific urgencies, technological developments, socio-economic pressures, political priorities, geopolitical forces or the broader cultural context evolved. We have explored the contingencies of this particular episode, POLDER, in order to shed some light on the shifting and varied understandings of satellite data and on the interactions between the mutually constitutive scientific, technological and social orderings that give rise to diverse socio-epistemic maps contextually tailored by the actors, their objectives, their needs, their material resources, their scientific understandings, their representations and the frames in which they operate.

By way of conclusion, let us begin portraying the general arc depicted in our essay. One of the main preoccupations of space agencies' scientific divisions during the 1980s was to enlist more of the recently arrived scientific community, scientists of several disciplines of the Earth sciences, in the execution and utilization of space technologies and satellite data. In other words, to attract atmospheric chemists, vegetation scientists, physical oceanographers, glaciologists, climate scientists or marine biologists, to mention few, to enter a domain until then dominated by astronomy, ionospheric studies, cosmic rays, planetology or geodesy, to mention another few. The scientific divisions of the space agencies would then step up endeavors to persuade the late starters in the space age, the Earth scientists, that remote-sensing technologies were credible tools for studying the Earth and its environment. Just launching satellites would not be enough to enroll and rally around these scientists into the use of space technologies, for Earth scientists must be convinced of the utility of the arsenals of data that the space instruments would provide; even if convinced, they must learn to familiarize themselves with the novel technique for gathering and producing data and must acquire skills and practices to extract useful information from the data.

One of the strong theses of our investigation, which provides a reading key to interpret the sources of the satellite data practices spanning through the period 1980 to 2000, refers to the process of *reconciliation* during which a number of strategies and moves would be committed to bring together the space technologies, in particular satellite data, and the current practices and representations in different disciplines of the Earth sciences. By calling it reconciliation we are stressing the fact that it would not be an imposition of any of the parties (at least not in France), but rather a mutual adaptation which would smooth the articulation of space technologies and diverse disciplines of the Earth sciences. Space technologies would gain visibility in a domain which was growing in importance, both scientifically and politically, whereas Earth sciences would leverage the options offered by space technologies, including their generous budgets and grants (typically more generous than universities' or CNRS' ones). In the process, though, both would be reshaped, giving birth to a particular form of space sciences, which required a particular form of space missions. We like to call them *space Earth sciences*, preconizing a set of practices and representations that we have analyzed and which, by 2000, would become a sort of admissible *norm* for conceiving, developing, realizing, launching and exploiting a space mission in the domain. The developments described in the last 400 pages enacting such reconciliation can be synthesized in two major points, which can be extended to the rest of the missions of the first generation like Topex/Poseidon, ScaRaB or the heritage of BEST.

First, a scientific community potentially soliciting and using the satellite data must be created. This would entail two parallel, perhaps overlapping, aspects: creating a community to conceive the experiments and another one (or the same one) to use the data. One, in order to enlarge scientific community skilled to design and realize space technologies and instruments beyond the former "selected laboratories", from 1981 onwards, CNES would organize periodic scientific meetings to involve scientists in the conception and planning of experiments and would launch annual "calls for ideas" to realize instruments or missions proposed by the scientists, which would be evaluated by a renovated scientific advisory committee composed by independent scientists (Comité de Programmes Scientifiques). A laboratory was even created in 1984 in partnership CNES-CNRS, the Laboratoire d'Etudes et Recherches en Télédétection Spatiale (LERTS) and one of its objectives was the study of new instruments –note that roughly two years later another one would be created specifically dedicated to space oceanography (the Mission Océanographique Utilisant l'Etude des données de Traceurs et de l'Espace, MOUETE). Two, to enlist more scientists in the utilization of satellite data, CNES would invest, since 1978 in complicity with CNRS, in training scientists to the physical interpretation of satellite measurements through allocating grants to those research projects that would use NASA's or NOAA's data –the second function of LERTS was actually to study the interpretation of data. Ever since, CNES allocates doctoral and post-doctoral scholarships, ensures the recruitment of technical staff at the laboratories, distributes funds for material end equipment. In 1986 POLDER would be one of the first fruits of these investments.

Second, the production, dissemination and archival of satellite data must be organized and access to data must be fostered to incentive utilization. Importing NASA's mode of satellite data-handling, in order to render satellite data legitimate and admissible to Earth scientists used to represent processes and phenomena in terms of geophysical variables while remaining manageable and controllable by space agencies and *data creators,* project managers at CNES would delineate a socio-technical map in which the center of epistemic virtue would be *normalized* at the level of *geophysical datasets*. Within this factory-like complex the technological practices of calibration, inversion and data validation would figure prominently. In turn, this would rise up the central role of a type of physicists, the *data creators*, conferring to them the legitimate epistemic authority for creating geophysical datasets, for judging their quality and for defining the scientific frames admissible to be enquired with such data. This social order would function as work-organizer, budget-dispenser and authority-provider. It separated the scientific community between the *data creators* and the *data users*, a divide that would be sharpened with the widespread of the internet as archiving and dissemination technology and with the establishment of specific datacenters to deal with satellite data, exacerbating a socio-technical fragmentation into three *data-classes*: those who create the data, those who curate them and those who use them, conceded with different rights for data access, ownership and conditions for use. Such data-hierarchy, we have argued, would be authorized because of the ways in which data handling practices had been designed, based on the tenet, in accordance and legacy with the customary rules of work-rewarding in experimental physics and, in particular, commonplace in the traditional space sciences, that experiments served their builders in the first place and in which conceding data privileges to them was seen as a social recognition for their job, as a means to allow original and novel publication.

POLDER's system for producing, archival and dissemination embodied such a socio-technical ordering, contributing by customary practice to normalize it and export it to other missions, especially from 2003 onwards through the establishment of a datacenter, ICARE, tailored mainly by POLDER's community. Back to POLDER, the community that would be created around the experiment reunited certain specificities. For instance, designed as technological experiment to test a new instrumental concept and without any specific research program in any domain of the Earth sciences, the space programmers of CNES resulted crucial to get POLDER accepted amongst the scientific advisory committee. The scientific program of POLDER would be defined a posteriori, as other scientists (data creators) joined the project in the process of setting up the system of production, dissemination and archival of the data. In a sense, the credibility of the scientific team was ultimately legitimated by CNES, not because it owned the sensing technologies, but because the space agency had been pro-active and crucial to establishing the scientific goals, the means, the people and the institutions of the scientific community gathered around the future POLDER's data. The assembled team had the epistemic specificities of involving scientists of different disciplines, from different institutions, with different scientific objectives, giving full meaning to the notion of "multimissions" with which POLDER had been labeled. An important specificity of this team was that it was a team of *data creators*, that is to say, of physicists experts in electromagnetic radiation, light theory, spectral radiances or photon transport, many of whom retained close ties with the instrument, as they had participated to conceive it and/or to define part of its technical specificities and calibration methods – many of them, especially the early conceivers of the experiment, retained also close ties with the Technical Center of CNES in Toulouse and its engineers and managers (through past work experiences or professional affinity). These were scientists that articulated the technological practices of inversion (and calibration) in order to interpret physical measurements to create geophysical datasets. In the case of POLDER, *data users* external to the acquisition and production of the geophysical datasets were assumed to exist, but never spelled out or considered.

This was the scientific community of POLDER (*data creators* experts in *inversion technologies*), the Earth sciences that POLDER's data were meant to support (those phenomena, processes or interactions studied with *geophysical datasets*) and the forms of data acquisition and collection (experiment). This was a socio-epistemic order delineated by space managers and *data creators* to better manage the satellite data, control their gathering, production and dissemination, and conform and incentivize their utilization. In this world order, other types of data (*physical measurements*) would not be deliverable but remained items of "property" of CNES, while still other types (*climate data-records*) would not be produced, because they were no part of the ontology of POLDER. Perhaps, if we had centered our study in other cases, epistemic specificities of the community had been different: in Topex/Poseidon we would have probably included in the community also scientists distant from the context of data acquisition (even also non-academic scientists from operational institutions, the military and data-commercial societies), in the case of ScaRaB we would have limited the scope to scientists belonging to the one discipline, the Earth's radiation budget and the study of some climate processes. Different communities, we suggest, may have been connected to different forms of data-handling.

On to different matters, our study illustrates the cascade of operations articulated in order to produce some form of data from the satellite measurements. From the physical measurements obtained, after due calibration, from the instrument readings (the physical radiances), *geophysical data creators* integrated in the normative system of data gathering, production, archival and dissemination, transform the measurements into a parameter in close connection with a discipline in the domain of Earth sciences, a geophysical variable. In this process the physical measurements take a specific meaning, they get recontextualized within a particular frame of research. *Geophysical data users* experts in the particular domain integrate then these geophysical datasets into their corpus of tools for knowledge production, they may eventually re-appropriate and give them more precise meanings in function of particular specific questions. They can deploy the data through a number of methodological approaches, used and re-used in multiple manners: use them as background information, to establish correlations between phenomena, to initialize a model representing a particular process, to study a given forcing, to elaborate a prediction, to study new instrumentation, to mention few. In parallel to that norm, nevertheless, alternative streams may take the physical measurements and through a cascade of different manipulations, interventions and interpretations, they may produce a different type of data. We have particularly developed the example of producing *climatic data* through the technologies of *assimilation*, that is to say, through fusing numerical models with physical measurements. The original satellite measurements are then given a different scientific significance; they are recontextualized in a different epistemic frame, integrated in a different representation of the planet Earth –a planet that does not necessarily "speak" geophysics.

Indeed, the data users interpreting data from these approaches would drop the idea that conducting research in the domain of Earth sciences meant necessarily to analyze geophysical data and that the world was inherently of geophysical nature. Instead, our investigation has made clear that the complex infrastructure of data handling delivering geophysical datasets had been the result of a design of space managers and data creators to render satellite data meaningful while remaining manageable. A design intended to produce geophysical units and, because of that, poor adapted to produce other types of data like climatic data. At least two aspects reflect this opposition. First, it delivered geophysical datasets whereas progressively more and more data users became also interested in getting physical measurements as a means to produce climatic datasets (or to produce predictions, or to evaluate numerical models). Second, it provisioned for single-shot launchings to collect data during a limited period of time (and in most cases without plans for following on) for *data creators* to conceive new instruments and develop new inversion algorithms, whereas a number of scientific urgencies required continuity and perpetuity of the measurements (producing climatic data, producing predictions, etc.).

In one sense, our story brings into light a tension between a central normalized form of gathering, production, dissemination and use of satellite data, legitimated by space agencies (single-shot missions) with the support of *data creators* (production of geophysical datasets), and a peripheral one based on alternative vindications campaigned by some particular forms of *data users* interested in the climatic approach. As data moved, facilitated by the internet, from the contexts of conception and acquisition and were given meaning by data users, distant scientific urgencies and technologies would be articulated, as well as different intellectual and cultural landscapes, which would have the effect of flexibilizing and relativizing the original epistemic authority located on data creators, on geophysical datasets and on technological data practices of inversion. POLDER itself, we maintain, makes a pertinent illustration of the tension: because the ontology of POLDER was confined to the *norm,* these alternative epistemologies (for instance, the production of climatic data through assimilation) did not manifested in any of the versions of POLDER. Alternative forms of producing and using data would not be given berth in POLDER's moral economy.

In another sense, however, our story also shows that uses of data are more or less circumscribed by original conditions of acquisition. We are not, with that, aligning any form of data-determinism; on the contrary, we have illustrated that the uses of data are certainly not totally pre-fixed from the beginning and that prospective multiple uses may be developed in varied manners, as data moves from creators to users to other users and re-users. Yet, our study case shows as well that the type of data that can be produced is conditioned by the conditions of data acquisition and the system of data-handling. POLDER was designed for fly during 3 years (or 1 to 2 in the case of PARASOL) to respond to the needs, the goals, the technological data practices and the representations of the particular community of data creators endowed to deliver geophysical data. POLDER's data can certainly be circulated, recycled, used and re-used in different research contexts and in different frameworks of interpretation, but they remain geophysical parameters with an expiring date of 3 years. A rose is a rose is a rose –as it is said. Gathering and producing data involve a long series of actions, epistemological commitments, power arrangements, socio-technical dispositions and technological practices, to make them so. Our study has illustrated that the data derived from satellite measurements are relative to the infrastructures upon which they are gathered, produced, stored, diffused and used, and this influences, orients and conditions the types of uses.

Our historical question is not to pick the best approach to describe nature, by means of physical, geophysical or climatic parameters, or the three, but rather to notice that different assumptions may lead to different manifestations considering the manageability of the data. Normalizing the use of geophysical datasets, or physical or climatic ones, or the three, would not merely be a matter of abstract epistemological choice, but it would structure relations between scientists, space managers, instruments and data –and the industrials, operators, public services and general audiences. Our study has illustrated that different epistemologies not only involve different representations of the Earth, the space technologies and the Earth sciences, but they involve mundane features like different rules for data access, different architectures for launching programs, different types of expertise located at different places. Put it in another way, our study shows that by the year 2000, at the settling of the *reconciliation*, scientists would agree in that satellite measurements had scientific value and were indispensable in any domain of the Earth sciences; yet, the location of epistemic virtue would vary, depending on the scientific goals, technological data practices, data-class position or interpretative approach.

We do not wish to conclude without referring to another point. Some of the type of climate datasets that we have studied are the product of the fusion between numerical models and data (preferentially physical measurements, but also can be geophysical datasets). Similarly, geophysical datasets are the product of physical measurements with field-worked data (and other tools that we have described) -to the extent that in some cases CNES, the *space* agency, and is still more exaggerated at NASA, in collaboration with Earth scientists, would carry out intensive regional-scale field campaigns even without deploying any space asset in the game. In other words, the production of data from satellite measurements, whether they are geophysical or climatic, emphasizes two things. First, the collective character of data which own their very existence to the existence of other scientific tools like models or exogenous data. Second, and more specifically, the powerless of satellite measurements alone to produce satellite-derived data, since the very existence of the data depends on non-satellite assets. This preconizes another of our strong thesis: the rejection of the idea that space assets are all-powerful technologies, in favor of promoting a holistic vision of a space mission, in particular including great efforts in field-work exercises (aircrafts, balloons, surface stations, networks of instruments) and numerical modeling developments. This renewed meaning of space mission, in which the space assets are only a component of a Humboldtian venture involving extensive field-campaigns previous and after the launch and numerical modeling, we suggest, would not happen independently of other developments in the domain of Earth sciences, which would also witness some conceptual and methodological transformations, including the construction of an integrative concept of the planet Earth as a system. More generally, the temporal coincidence between the incorporation of the disciplines of Earth sciences in the scientific programming of space agencies and the conceptual transformation of these domains towards a holistic system, as the use of satellite data gets progressively normalized, suggests interesting connections that remain to be further unveiled. In any case, it appears paradoxical, at least at first glance, the fact that as space technologies become more sophisticated, ripen, precise and reliable, their admissibility depends on a process of returning to the field, to the source, to the Earth.

We are almost there. There are important historical studies of space programs and data studies and we have referred to some of them recurrently in our work. But our work has taken a different approach. Our goal has not been to add the history of one more program, POLDER, to the extended NASA-dominated historiography dealing with space programs –or at least not only that. Instead, we have looked at this episode focusing on the data technological practices, considering POLDER as a scientific example involving people, infrastructures, tools, practices and representations. Our work has tried to insert space programs into the historiography of sciences and technologies, by devoting great deal of attention to technological practices (material or formal) and by offering an empirical example and some analytic concepts that may help understand how satellite data practices work –hopefully others will dig deeper prospections completing and extending our account. At the same time, by raising issues about the drawing of boundaries between domains, about changing forms of allocating epistemic authority and credit amongst scientists, technicians, managers and amateurs, about expertise, about division of labor, about trust, credibility and legitimacy, about quality control of data, about how to make sense of data, about how to share and communicate the sources and the outcomes, about mechanisms of work-reward, about social organization, institutional dynamics and inertias, about data-classes, about control of data production and dissemination, about data commercialization, about legitimacy, about public good, about institutional rules, about abundance of data, about authorship, about property of data, about preservation issues, access and sharing of scientific data, about modalities of use, etc., we hope to have provided a social sciences dimension to an activity, satellite data handling, or more generally space technologies, widely perceived uniquely as a technological and scientific venture. Obviously our perspectives to the age of the space Earth sciences constitute just one of the possible accounts, certainly biased, as all accounts, by the available sources, the analytical tools mobilized, our background, our personal preferences and interests, and the context in which the research has been conceived and evolved. They may or not may correspond to the perception that insiders have of it; either way, they may be served as food for debates and prolongations of such reflections.

On December the 18th 2013 there was a celebration in Toulouse. Nine years after its launch, POLDER-3 aboard PARASOL would emit its last data transmission to the ground control. CNES would then deliberately shut off the satellite after having turned off the payload in October –the satellite was then taken out of the A-Train zone and started its long free-falling agony towards the Earth's surface, lasting around 26 years -in compliance with the international orbital instructions for controlling space debris[969]. No more signals would be downlinked and no more data would be produced from new measurements, whether physical, geophysical or climatic, singular or combined with field-work, other satellite data or fused with models, real-time or reprocessed. However, old data may keep being used. New generations of scientists may take some data samples to conduct their research about a given phenomena, to retrieve new geophysical parameters, to evaluate their hypothesis, to improve their models, to elaborate new assimilation codes. Old data may still be combined with concomitant data from the lidar CALIOP, or other instruments; they may eventually be reprocessed, as new processing methods will evolve -all the acquired nine-years data set is actually in course of being reprocessed at this writing. They may eventually be used to produce climate data of past situations through, for instance, reanalysis. Old POLDER's data may be used to prepare the future data as well, like for the future polarimeter 3MI, starting in so doing a new cycle of data gathering, producing, archival, dissemination and utilization. Just like scientists today use old data from Meteosat, AVHRR, Modis, Nimbus-7 or many others, nothing impedes, a priori, that POLDER's data may keep being used in the future, insofar they are dutifully archived and accessible, perpetuated and available. POLDER's data handling, and more generally satellite data handling, these are our last words, was part of a larger effort within the space promoters to sustain their activities by enrolling relevant communities, such as the Earth scientists in the 1980s, which would receive renewed and definitive impetus in the changing geopolitical context of the 1990s, with a renovated ascent of environmental surveillance urgencies. Our work has described some of the strategies and technological practices taken to reconcile space technologies and Earth sciences and has revealed certain perpetuations and novelties, capacities and limitations, convergences and tensions, in their respective practices. Even though this process has achieved a certain degree of stability and normalization within the practices and representations of space agencies, CNES in particular, circumstances never cease to change and evolve, and pressures are pushing in many directions. It remains to be seen how the age of the space Earth sciences will glide in the decades to come.

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[969] An international code of conduct endorsed at the UN Committee on the Peaceful Uses of Outer Space to ensure the long-term sustainability of outer space activitie by minimizing the effects of space debris in progressively more crowded low orbits and bycontrolling the reentry of space objects to the surface, although not juridically bending, recommend the satellites to stay a maximum of 25 years in orbit after their shut off of operations. To meet such requirement, PARASOL must be moved, after its mission, to a lower orbit from which it would decay in 26 years.

ACRONYMS

Only the recurrently used :

A-Train: Afternoon-Train
ADEOS: Advanced Earth Observing Satellite
AERONET: AErosol RObotic NETwork
AMMA: African Monsoon Multidisciplinary Analysis
ATP: Actions Thématiques Programmées of CNES/CNRS
AVHRR: Advanced Very High Radiometric Resolution
BEST: Bilan Energetique des Systèmes Tropicaux of CNES
CALIOP: Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO/PICASSO-CENA: Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CCD: Charge-Coupled Device
CCI: Climate Change Initiative
CEA: Commissariat à l'Energie Atomique
CEOS: Committee of Earth Observation Satellites
CESBIO : Centre d'Etudes Spatiales de la BIOsphère
CMS : Centre de Météorologie Spatiale
CNES: Centre National d'Etudes Spatiales
CNRS: Centre National de Recherche Scientifique
COSPAR: Committee on Space Research
CPS : Comité de Programmes Scientifiques of CNES
CRPE: Centre de Recherche en Physique de l'Environnement terrestre et planétaire
CST/CNES : Centre Spatial de Toulouse
CSU : Colorado State University
CZCS: Coastal Zone Color Scanner
DAAC: Distributed Active Archive Centers
DMN: Direction de la Météorologie Nationale
ECMWF: European Center for Medium-range Weather Forecasts
ECV : Essential Climate Variables
EOS : Earth Observing System (NASA)
EOSDIS : Earth Observing System Data and Information System
EPOP : Environmental Polar-Orbiting Platform of ESA
ERBS: Earth Radiation Budget Satellite of LaRC
ERS: European Remote Sensing Satellite
ESA: European Space Agency
EURASEP: European Association of Scientists in Environmental Pollution
FGGE: First Global GARP Experiment
GARP: Global Atmospheric Research Program
GCM: Global Circulation Models
GCOM: Global Observing System
GEMS: Global and regional Earth-system (Atmosphere) Monitoring using Satellite data of EU
GEOSS: Global Earth Observation System of Systems
GEWEX: Global Energy and Water Cycle Experiment of WCRP
GISS/NASA: Goddard Institute of Space Sciences
GMES/Copernicus: Global Monitoring for Environment and Security/Copernicus
GPS: Global Positioning System
GRGS: Groupe de Recherche de Géodesie Spatiale
GSFC/NASA: Goddard Space Flight Center
HCMM: Heat Capacity Mapping Mission of
ICARE: Interactions Clouds Aerosols Radiation Energy
ICSU : International Council of Scientific Unions
IGOS : International Global Observation Strategy
IIR : Infrared Imaging Radiometer
IGN: Institut Géographique National
INRA: Institut National des Recherches Agronomiques

INSU Institut des Sciences de l'univers of CNRS
IPSL: Institut Pierre- Simon Laplace pour les sciences de l’environnement
IPCC: Intergovernemental Panel on Climate Change
IPGB: International Program Geosphere Biosphere
ISCCP: International Satellite Cloud Climatology Project of WCRP
JAXA: Japan Aerospace Exploration Agency
JPL/NASA: Jet Propulsion Laboratory
LaRC/NASA : Langley Research Center
LERTS: Laboratoire d’Etudes et Recherches en Télédétection Spatiale
LIDAR : LIght Detection And Ranging
LISA: Laboratoire Interuniversitaire des Système Atmosphérique
LMCE: Laboratoire de Modélisation du Climat et de l’Environnement
LSCE: Laboratoire des Sciences du Climat et de l’Environnement
LMD: Laboratoire de Météorologie Dynamique
LOA: Laboratoire d’Optique Atmosphérique
LODYC: Laboratoire d’Océanographie DYnamique et de Climatologie
LPCM: Laboratoire de Physique et de Chimie Marine
MERIS: Medium Resolution Imaging Spectrometer of ESA
MODIS: Moderate Resolution Imaging Spectroradiometer
MoU: Memorandum of Understanding
MOUETTE: Mission Océanographique Utilisant l’Etude des Données de Traceurs et de l’Espace
NASA: National Aeronautics and Space Administration
NASDA: National Space Development Agency
NCAR: National Center for Atmospheric Resarch (à Boulder, dans le Colorado)
NCEP: National Center for Environmental Prediction of NOAA
NOAA: National Oceanic and Atmospheric Administration
NPOESS: National Polar-orbiting Operational Environmental Satellite System of NASA, NOAA and DoD
OCTS: Ocean Color and Temperature Scanner of NASDA
PARASOL: Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar of CNES
PI : Principal Investigator
POLDER: POLarization and Directionality of the Earth's Reflectances of CNES/LOA
PNEDC: Programme National pour l’Etude de la Dynamique du Climat
PNTS : programme national de teledetection Spatiale
SA: Service d’Aéronomie
SATMOS: Service d’Archivage et de Traitement Meteorologique des Observations Spatiales
ScaRaB : Scanner for Radiation Budget of CNES/LMD
SAGE: Stratospheric Aerosol and Gas Experiment
SeaWIFS: Sea-Viewing Wide Field-of-View Sensor
SEVIRI: Spinning Enhanced Visible and Infrared Imager
SIMBAD/A: Satellite Intercomparison for Matine Biology and Aerosol Determination/
SIRTA: Site Instrumental de Recherche par Télédétection Atmosphérique
SPOT: Systeme Probatoire d'Observation de la Terre of CNES
SSB/US: Space Science Board
TAOB/CPS: Terre, Atmosphère, Océan et Biosphère
TOA/CPS: Terre, Océan et Atmosphère
TIROS: Television Infrared Observation Satellite of NASA
TOMS: Total Ozone Mapping Spectrometer of NASA
TOPEX/POSEIDON : Topographic Experiment/Poseidon
TOSCA/CPS : Terre, Océan, Surfaces Continentales et Atmosphère
UARS : Upper Atmosphere Research Satellite of GSFC
UNEP: Programme des Nations Unies pour l’Environnement
UTSL: Université Lille
WMO/UN: Weather World Organization Organisation Météorologique Mondiale
WWW: World Weather Watch
WCRP: World Climate Research Program
WOCE: World Ocean Circulation Experiment of WCRP

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