A compact history of urban climatology & planning

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A compact history of actors, events and concepts of urban climatology and design, written by Dr Fionn MacKillop, Research Fellow, University of Manchester, UK.

Website: http://www.sed.manchester.ac.uk/architecture/research/csud/

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The following report provides an overview of the evolution of urban climatology over the past 50 years or so, based on original research for the ESRC 'Climate Science and Urban Design' project at the University of Manchester. We list the main individuals and their publications; summarize the main events in the field and their consequences; describe the main organizations of relevance to the field; and discuss the main reviews and bibliographies that were published since 1938. This material is available from a variety of sources, but was scattered among web resources, archival material, and information gathered from interviews with major figures of the discipline. Our work was to bring all this data together in a convenient format which we hope may serve as a reference for future work, especially on the links between urban climatology and planning.

We show the evolution of urban climatology from a descriptive endeavour based on measurement campaigns that aimed to establish the facts (the urban heat island being the central one), to a science of increasingly sophisticated models, from the budding computer technologies of the early 1970s (creatively mobilised by Werner Terjung) to the complex world of Computational Fluid Dynamics today. We also chart the shift from a focus on the developed world's cities, to the growing body of work on tropical latitudes, under the influence of figures such as Tim Oke. Also the potential range of contributions from urban climatology to the emerging debate on climate change becomes evident. The evolution of urban climatology closely mirrors global changes: an increasingly (now mainly) urbanised world, especially in the South, coming to realise that cities are creators of weather, and also the main potential victims of climate change.

The data sets also show the evolution of the actors and networks that have attempted to structure and polarise the world of urban climatology, especially in its linkages with planning. We see a gradual move from a fragmented scene, with many actors (IFHP, ISB, WMO and others) attempting, without much success, to take the lead between the 1950s and the 1980s, to the efforts of the International Association of Urban Climatology (IAUC), which seem to be paying off in the shape of a loosely structured, internet-based association. The community now seems to be able to speak with one voice on the international scene, giving more weight to the prescriptions of urban climatology.

Indeed, the heart of the matter covered in our data sets is the progress of urban climatology towards the status of a more applied science. The great problem for

the discipline has been its lack of success with planners, the inability to convey its multiple benefits in terms that make sense for the planning community. Apart from a few isolated examples of application of climatological principles, in Germany and Israel particularly, planners have tended to ignore the teachings of the discipline and take advantage of technical evolutions, air conditioning being an example, to manufacture pleasant climates in their buildings. The debate around anthropogenic climate change, and the growing urban population in cities of the South often located in tropical climates, has reignited the interest in drawing on urban climatology as an energy and cost-effective approach to the challenges at hand. However, the challenge of better communication between the fields remains; there is still insufficient mutual education of planners, architects and climatologists, and this is stressed in the latest 'white paper' produced by the discipline's leading experts for WMO.

CSUD datasets

I) Individuals (names followed by * have been interviewed for the project).
This data set is to be used in conjunction with the document entitled 'bibliography', which lists the references mentioned here.
All organization abbreviations refer to the 'organizations' data set.

Aronin, Jeffrey Ellis (1927-). Author of *Climate and Architecture* (1953),

Baumuller, Jurgen*. City of Stuttgart engineer. Head of the city's municipal office for urban climate from its inception in 1951, until his retirement in 2008. He directed the production of the city's climate atlas (*Klimaatlas*) and also presented the influential film *Climate and Development* at the UN Habitat conference in 1976. Baumuller has profoundly shaped planning in the city of Stuttgart, ensuring building regulations reflect the concern with the preservation of the city climate (Baumuller 1999, Baumuller 2009). His daughter Nicole is also involved in the city of Stuttgart's environmental office. He has been succeeded in the department by Dr Ulrich Reuter.
Baumuller's contribution to urban climate research can be found online in the form of an extremely useful tool. The International Urban Climate Website, or Stadtklima (www.stadtklima.de) is a cooperative project developed by the Department of Urban Climatology in the Office of Environmental Protection of the City of Stuttgart, Germany, and the Meteorological Institute at the University of Freiburg, Germany. The origin of the project occurred during the second Japanese-German Meeting on "Climate Analysis in Urban Planning" which took place in Kobe, Japan, in September 1997. It has now been operational for six years and has proven very popular, receiving more than 10,000 hits per month. The objective of the International Urban Climate Website is to focus, and to provide information on, urban climate, which comprises both the thermal and the air quality component. Its primary intention is to facilitate information exchange within the Urban Climate community and promote its research. The website features a list of cities worldwide for which climate information is available, general information about these cities, contact persons and institutions

that work in the field of urban climate, as well as climatic and air pollution data. Also included is information about past, present and future planned investigations and projects in urban climatology for the listed cities. These include software and instruments for investigating urban climates and an urban climate forum for dialogue within the community.

Bitan, Arieh. Israeli, emeritus professor of geography at Tel-Aviv University. Prof. Bitan is one of the leaders of urban and settlement climatology in Israel and in its arid regions. His long-standing interest in climate-relevant planning and the use of planning principles to mitigate the adverse climatic effects of cities on human health and performance is probably his most important legacy (Bitan 1974, 1992).
Prof. Bitan was also a founding member of the International Association of Urban Climatology (IAUC). From 1982 until 1995 he was the head of the Expert Committee for Urban Climatology and Building Climatology of the International Federation for Housing and Planning (IFHP), and since 2003 has been a member of the Commission on Climatology of the International Geographical Union (IGU). In 2005 he was invited to join the international research group of the World Health Organization (WHO) for improving public health responses to extreme weather (EuroHEAT).

Bornstein, Bob. Professor at the San Jose State University department of meteorology, specialist in boundary layer and dispersion meteorology. He was a key figure in bringing urban climatology into mainstream meteorology, and communicating internationally. His work is important both for his numerical modelling and his precipitation analysis (Bornstein 1986). His major empirical work is on sea breezes in New York City (Bornstein, 1968, 1979) and their links with air pollution dynamics (Bornstein, Thompson 1981), but he has also carried out research on air quality in many other cities and areas (Atlanta, Los Angeles, Israel and Jordan; see Bornstein 1999, Bornstein 2000).
Bob Bornstein is the US representative at the WMO since 2004, and was a member of the board of directors of IAUC from 2003 to 2006, and is still active in the organisation, and other major organisations such as AMS and WMO

Chandler, Tony (1928-2008). Major figure of urban climatology, author of highly influential work on London (Chandler 1965), where he made use of innovative measurement techniques, such as automobile-mounted devices, during research which he carried out for over 6 years, as part of his doctoral thesis. The first element of this work involved a mobile recording station, housed first in a second-hand car, later in a new Land Rover, that Chandler drove along traverses through London monitoring temperature and humidity at various hours of the day and night. The second element involved more than sixty schools, teacher training colleges and private individuals maintaining climatological recording stations. The survey soon attracted the attention of academics and town planners around the world. London's 'heat island' and pattern of air pollution, which Chandler delineated, were discussed widely in the media. Chandler also authored an important bibliography on urban climate (Chandler, 1970b) and penned a technical note on the applications of urban climatology (Chandler,

1976). Chandler joined University College London as a lecturer in 1956, and was made professor in 1969.
Influential in WMO and WHO, Chandler was a rapporteur on urban climates from 1965 to 1969, a position from which he convened the groundbreaking 1968 WMO/WHO symposium on urban climates and building climatology in Brussels (Chandler 1970a). He pioneered urban climatology at the University of Manchester, where he moved to a chair in geography in 1973, whilst also serving in many institutions (RCEP, NERC etc.).
Obituaries: *The Times*, 29 September 2008; IAUC *Urban Climate News*, 31 March 2009; Royal Geographical Society, *The Geographical Journal*, Vol.175, No.1, March 2009, p.82-83.

Changnon, SA. As a researcher at the Illinois State Water survey, he directed the influential METROMEX (Metropolitan Meteorological Experiment, 1971) research programme, covering the Saint Louis metropolitan area (Changnon et al 1971, 1977). Observations were taken over a 6 year period, to study the effects of a large metropolis on the summer atmosphere in a humid continental climate. The project an important milestone in regional scale research since it provided systematic data on some aspects of urban meteorology. METROMEX confirmed some earlier statistical analyses, highlighted important physical processes, and posed some new questions on the nature of precipitation development. A controversy around the 'Laporte anomaly' erupted between Changnon and one of his colleagues on the project, over the precise relationship between cities and precipitation patterns (Lowry 1977).

Geiger, Rudolf. (1894-1981). German meteorologist and climatologist. Geiger was a prominent meteorologist who helped found the science of microclimatology. From 1912 to 1914, he studied at Erlangen and Kiel, and was made research assistant in physics at the Darmstadt school of technology in 1920. From 1927, after obtaining his PHD at Gottingen University, to 1933, he was a lecturer at the Meteorological and Climatological institute of Munich University. From 1928 to 1935, he worked as an observer at the Bavarian State weather station. The year 1937 saw Geiger become professor of Forestry at Eberswalde, and in 1948 he was made professor of meteorology, climatology, and microclimatology at the University of Munich. In 1955, he was admitted to the German Academy of Naturalists.
Between 1930 and 1939, Geiger worked on the *Handbuch der Klimatologie in Fünf Bänden*, with W. P. Köppen, an ambitious project that was never completed (but still ran to five volumes during the 1930s). In 1927, he published his groundbreaking *Das Klima der Bodennahen Luftschicht.* His *The Climate Near the Ground* (1950) stands as a milestone publication in the history of micrometeorology. The original edition of *Climate Near the Ground* is a classic treatise on how temperature, wind and light vary over and under crops and forests, in valleys, on mountains, and over the land surface during daytime and nighttime thermal stratifications. Further editions contain chapters on the earth's energy balance, characteristics of the air layer over ground without vegetation, the effect of the underlying surface on the adjacent air layer, the effects of plant cover on the surface air layer, forest climatology, the influence of

topography on microclimate and interrelations of animals and humans to microclimate. The strength of this book is its historical recount of information on the climate of soils, forests, crops, valleys, mountains and caves. This work must not be forgotten and should be used by modern scientists so we don't reinvent the wheel. In essence, the book has a naturalist spirit, which is to compile and catalog data. It does not synthesize and extract information for diagnostic and predictive purposes. Another of Geiger's interests was climate classification, where he helped Köppen develop and extend his famous systemization.

Givoni, Baruch. Israeli researcher, Professor in the department of architecture at University of California, Los Angeles. Givoni graduated from Technion Haifa in Israel in 1953. He then studied public health, and as such consulted in the WHO research programme on health aspects of housing and buildings (Givoni 1972). He is one of the foremost authorities on bioclimatic architecture, since his groundbreaking *Man, Climate and Architecture* (1969). After a PhD in public health, he taught and researched at the Building Research Station and Israel's Technion University of Haifa.
Closely associated with the Passive and Low Energy Architecture (PLEA) movement, a famous application of his work lies in bioclimatic comfort charts (or Givoni diagrams), based on Olgay's work on the topic (Givoni 2003). His latest work (Givoni 1998), explores such pressing issues as designing more comfortable dwellings in cities without the need for costly air conditioning or heating, viewing the architect as an active contributor to public health outcomes.

Grimmond, Sue*. A New-Zealand born and educated climatologist, Grimmond joined Kings College London in 2006, where she is professor and chair of Physical Geography, after having been a professor at Indiana University. She completed her undergraduate degree at the University of Otago, New Zealand, and graduate degrees at the University of British Columbia (where she did her PhD under the supervision of Tim Oke in 1989). Her fields of specialisation are the modeling of energy and mass exchanges in areas of heterogeneous terrain (including urban areas), and the micrometeorology and hydroclimatology of urban areas (see Grimmond and Oke 2002; Grimmond et al 2003). Sue Grimmond is a renowned specialist in the measurement and physically-based modeling of these aspects of urban climate (Cleugh and Grimmond 2001).
She is past president of the International Association of Urban Climate (IAUC), and a Lead Expert for the WMO (where she also participates in training for the Commission for Climatology) and AMS (from which she received the Helmut Landsberg award in 2009 for 'numerous important contributions' on urban and building climatology), as well as an advisory member of the city of London on climate change issues.

Imamura, Takeshi. Born 1970 in Hyogo prefecture. In 1998, he completed his research doctorate, with a major in Earth science, at Tokyo University. The same year he was made research assistant. IN 2002, he moved to assistant professor. His field of specialisation is planet atmospheric science.

Kawamura, Ryuichi.

He has the chair/lectureship for earth dynamics (?) and is a specialist in meteorology and something called climate energy/strength (maybe power)o He became assistant professor at Toyama in 1998, engineering dept. He became a full professor there in 2004 and professor in Toyama graduate school research div in 2006.

Landsberg, Helmut (1906-1985). German-born scientist, educated at the university of Frankfurt, he moved to the USA in 1934 to teach geophysics and meteorology at Pennsylvania State University, where he taught the first graduate course on bioclimatology in the history of the country. During World War Two, Landsberg advised the US Air Force on climatic and meteorological matters and was officially commended for his work. Landsberg authored influential work on particulate matter, and on urban pollution and its health effects. He was the first to write in English about the use of statistical analysis in the field of climatology. Landsberg's interests were vast, stretching beyond the field of meteorology per se. His work in urban climatology is underpinned by an important synthesis of research in the field, which remains a textbook to this day (Landsberg 1981). Among his 400 or so published works are papers on bioclimatology and indoor climates, on the climates of cities and urbanisation effects, and others on dust and pollution.
Landsberg was the director of the US Weather Bureau office of climatology from 1954 to 1967, and became a key architect of the modern-day NOAA. He was a member of the International Society for Biometeorology (he chaired the publications committee of the society from 1960 to 1985; see also Landsberg 1969), the work of which he supported and helped to diffuse within WMO, an institution where he occupied a place of prominence as head of CoSAMC from 1971 to 1983 (and then an ISB observer at CoSAMC meetings; see also Landsberg 1976, 1982). He was a member of a WMO advisory working group from 1978 to 1981, and, perhaps fittingly for such a dedicated person, Landsberg died while attending a WMO meeting.
Obituaries and tributes:
Schneider, SH, 1985, Editorial: Three Essays of remembrance on the life of Helmut Landsberg, *Climatic Change*, Vol 9, Number 3, 259.
Munn, RE, 1986, Obituary Prof. Helmut Landsberg, *Meteorology and Atmospheric Physics*, Vol 36, Numbers 3-4, 381-382.
Mitchell JM 1987, Helmut Landsberg, Climatologist Extraordinary, *Weatherwise*, 1940-1310, Vol. 39, Issue 5, p. 254-261.
Baer, F., Canfield, N.L., Mitchell, J.M. (eds), 1991 *Climate in Human Perspective: a Tribute to Helmut E. Landsberg*, Kluwer Academic Publishers, Dordrecht.

Lindquist, Eric. Associate Director and Associate Research Scientist Institute for Science, Technology and Public Policy (ISTPP), Bush School of Government and Public Service, Texas A&M University. His most recent projects are in the area of climate change, the use of climate science in intergovernmental decision making, the public understanding of science in regard to global climate change, and nanotechnology. He was a co-principal investigator on major grants from NOAA and the EPA focusing on the utilization and understanding of climate variability and climate change science. Dr. Lindquist is also developing a research agenda on natural hazards as focusing events and their impacts on post-flood policy changes. Prior to joining ISTPP, Lindquist held a joint appointment with ISTPP

and the Texas Transportation Institute, where he worked for ten years in the areas of transportation planning and policy. He was recently a co-principal investigator on a joint USDOT and USGS project examining the impact of climate change on transportation infrastructure along the U.S. Gulf Coast (*Potential Effects of Climate Change and Variability on Transportation Infrastructure in the Central U.S. Gulf Coast. Phase I*. U.S. Climate Change Science Program Synthesis and Assessment Product 4.7). The 2008-2009 Capstone project was a regional climate change and adaptation study conducted for the Houston-Galveston Area Council.

Manley, Gordon. 1901-1980. British geographer and climatologist, coined the term 'urban heat island' in 1956. He assembled the Central England temperature series of monthly mean temperatures stretching back to 1659. This is the longest standardised instrumental record available for anywhere in the world. It provides a benchmark for proxy records of climatic change for the period covered, and is a notable example of scientific scholarship and perseverance (it took over thirty years to complete). Educated at Queen Elizabeth's School, Blackburn, took his first degree at Manchester, andthen spent two years at Cambridge, where he read Geography at the time. His first post was at the Meteorological Office in 1925. At this time he also went on his first expedition to Greenland. He was appointed to an assistant lectureship at Birmingham in 1926 where he stayed for two years, after which he became lecturer and head of Department at Durham in 1928. He remained there until 1939, when he was appointed demonstrator and later lecturer at Cambridge. In 1948 he became the first Professor of Geography at Bedford College, London. In I964 he became Professor of Environmental Sciences at the new University of Lancaster. He retired in I968 and was made Professor Emeritus and research associate.
Throughout his academic life he combined teaching with a great amount of research, and achieved much success in both fields. His first investigations were largely in the high Pennines. He ran an observing station at Moor House above Teesdale, where conditions were often severe. It was at this period that he made his well-known study of the Helm wind. He will, however, be best remembered for his long study of observations on meteorological instruments and also his studies on snow in England and Scotland. He had a remarkable knowledge of primitive instruments and their use by early workers. He also compiled a very carefully checked rainfall series for Manchester from I765. This detailed and distinguished work is known mainly to specialists. In his writing he is most likely to be remembered by his excellent book *Climate and the British scene*, which was published in The New Naturalist Series and received its fifth printing in 1972. His other writings appeared in scientific journals. His work was recognized in many ways. He received the Buchan Prize from the Royal Meteorological Society, and in 1947 the Murchison Grant from the Royal Geographical Society. He was President of the Royal Meteorological Society in 1945-6,. He was correspondent for glaciology for the British National Committee for the International Geo-physical Year 1959-61, and was also a member of the Air Ministry Sub-Committee for Meteorological Research from 1958 to 62.
Obituaries: J. A. Steers (1980), Gordon Manley 1901-80, *Transactions of the Institute of British Geographers*, New Series, Vol. 5, No. 4, pp. 513-517

Mayer, Helmut. (1947-), Professor and head of the meteorology department at the University of Freiburg, Germany. Specialist in forest meteorology, urban climate and pollution (Mayer 1999), and regional climatology, with important papers on human comfort in cities and thermal stress (Matzarakis, Mayer 1991 and Matzarakis, Mayer, Iziomon 1999). One of his major outputs was the Stadtklima Bayern (Mayer 1988) research programme (1981-1988), which used thermal mapping in the Bayern urban region, and extensive measurements in the city of Munich, with the objective of providing useable climatological data for planners and contributing to bridging the gap between the disciplines. Mayer is now working on the KLIMES research project on human thermal comfort in cities (Mayer 2008), after having worked on the BUBBLE (Basel Urban Boundary Layer Experiment) project, which produced a detailed investigation of the urban boundary layer of mid-sized European city (Rotach et al 2005).
Helmut Mayer was a member of the IAUC board from 2000 to 2004, and is still very active in the organization. He is the editor for *Climate Research* and *International Journal of Biometeorology*.

Mills, Gerald*. Professor at University College Dublin, Mills received his first degree in history and geography (University College Dublin 1980), and then a Masters in 1981 on the distributions and origins of rainfall in 1970s Ireland. After this, he went on to complete a PhD at Ohio State University on radiation balances based on the work of John Arnfield. He then worked at UCLA for 7 years, researching building temperature modeling (Mills 1993). Gerald Mills is especially interested in the climates generated by urban areas and the potential to plan for comfortable and healthy outdoor environments (Mills 2006). Mills also has a focus on spatial data analysis and GIS.
Gerald Mills became involved in the activities of the IAUC through the influence of Tim Oke and Sue Grimmond, and is current president of the organisation. Furthermore, Gerald Mills is a member of WMO (Expert team for urban climate) and the Royal Meteorological society.

Munn, R.E. (Ted). Born 1919, Winnipeg, Canada. Founder of the influential *Boundary Layer Meteorology* journal in 1970, and editor of the same for 25 years. Senior Scientist with the Atmospheric Environment Service of Canada in the early 1970s as Deputy Director of IIASA in Laxenburg, Austria from 1985 to 1989, then an Associate with the Institute for Environmental Studies at the University of Toronto. He graduated in 1941 from McMaster University Hamilton, Ontario with a BA in Mathematics. He soon joined the Meteorological Division of the Canadian Department of Transport, forerunner of the Atmospheric Environment Service (AES). He was posted as a forecaster to Gander, Newfoundland. Ted's duties included forecasting for trans-Atlantic aircraft ferry operations and North Atlantic operational patrols. After the war, in 1948, Ted moved to the Public Weather Office in Halifax. In 1956 he won a competition to become an air pollution research meteorologist in Windsor, Ontario, where he was seconded to a project with the Canada-US International Joint Commission. Windsor is just across the river from Detroit, Michigan, and Windsor's air quality is strongly affected by emissions from Detroit and the Ohio valley. Shortly afterwards, Ted commenced part-time studies at the University of Michigan (Ann Arbor) under Gerry Gill, Don Portman and Wendell Hewson.

These led (in 1961) to his PhD thesis on intermediate-range Lagrangian diffusion modelling, and the publication of his first book, *Descriptive Micrometeorology* (1966).
Descriptive micrometeorology filled a need for an English language text in this area as an alternative to Sutton's rather theoretical treatment (*Micrometeorology*, McGraw-Hill, 1953) and Geiger's classic climatological textbook, *The Climate near the Ground*. Significant advances, especially the general acceptance of Monin-Obukhov similarity theory, had occurred after the publication of Sutton's and Geiger's books, and *Descriptive Micrometeorology* includes a good introduction to these developments. It served as the primary text for many university courses for several years. In 1959 Munn moved to Toronto to head the new Micrometeorology section being established by Transport Canada's Meteorological Branch. From this group he published extensively throughout the 1960s and 197Os, in the *Quarterly Journal of the Royal Meteorological Society*, the *Journal of Applied Meteorology*, *Atmospheric Environment* and elsewhere. His papers focused on air pollution, turbulence and micro- and meso-scale meteorology, including lake-breeze studies and urban heat-island effects.
In 1977 Munn retired from AES and began a new career, with the University of Toronto's Institute for Environmental Studies. From that time he became more and more concerned with Environmental Policy, Risk Assessment and Sustainable Development. In these fields he was able to use his experience in evaluating and synthesising scientific research results and in many instances served as an interpreter of these results for the broader, non-scientific audience of policy makers. After returning to the Institute for Environmental Studies at the University of Toronto, Munn focused on long-term global change and global environmental issues. In total, Munn has published or edited 20 books and monographs, authored or co- authored more than 200 papers and received numerous international and national fellowships, awards, medals and prizes.

Ng, Edward. Architect and Professor at the Chinese University of Hong Kong, with a specialty in environmental and sustainable design. As an environmental consultant to the Hong Kong SAR Government, he developed the performance-based daylight design building regulations and the Air Ventilation Assessment (AVA) Guidelines. Edward's research interests are in the areas of daylight design, urban climatology and sustainable architecture (Ng 2003, 2009).
Edward Ng is a daylight and solar energy expert advisor to the Chinese Government, and is involved in designing ecological schools and building sustainable projects in China.

Oke, Tim*. Born in the UK and a Canadian citizen since 1971. Professor of Geography at the University of British Columbia from 1978 to 2006, now emeritus. Following from a seminal paper in 1973 which stimulated an intense debate and lots of research (Oke 1973), his WMO reviews on urban climates, with their focus on the physical processes behind modification of the urban radiation, energy, and water budgets provided periodic landmark reviews of the evolution of our understanding of urban climate (Oke 1974, 1979, 1991). His book *Boundary Layer Climates* (Oke 1988) is a cornerstone for the teaching of climates in the lowest layer of the atmosphere: broader than just urban

climatology, it covers geography and micrometeorology and significantly changed what was taught in urban climatology. When his review of urban energy budgets was published (Oke 1988), Tim Oke was already established as the leading international expert on urban climates. His over 200 published papers cover a wide range of important urban topics, including energy fluxes, urban heat islands, turbulent fluxes, heat storage, dew deposition, evapotranspiration, aerodynamics, remote sensing, and modeling. Most recently, Tim Oke has produced WMO guidelines for siting meteorological equipment in urban landscapes, an important and difficult task (Oke 2004).
Oke is of the major figures of contemporary urban climatology and one of the founders, and first chair of, the International Association for Urban Climatology (IAUC). He was the first recipient of that organization's Luke Howard prize in 2004 for his 'pioneering and seminal work in the field of urban climatology'. Oke also acted as a key facilitator of contacts between international organizations such as WMO, CIB and ISB, convening the WMO conferences in Mexico and Dhaka for instance, and insisting on a greater research focus on the heretofore neglected tropical latitudes. Tim Oke's numerous Ph.D. and Masters students have also impacted urban climate research around the globe, both in continued collaboration with Tim and through their own efforts and students. Examples include Dr Helen Cleugh, Prof. Sue Grimmond, Dr. Rachel Spronken-Smith, and James Voogt.

Page, John*. (b. 1926) After graduating in Natural Sciences and Chemical Engineering, Page joined the BRS, where he worked on solar energy, sound-proofing and low-cost energy in tropical building, publishing a review of colonial building regulations in 1958 (*Colonial Building Notes*, BRS, 1958), where he worked on defining building performance standards. In 1960 he was appointed to the Sheffield chair of building science within the department of architecture. With his team he developed innovative research on solar energy, emphasising the 3-dimensional nature of the urban environment. He went on to found the university's city and regional planning department. More recently, after retiring from university duties, his work on building climatology has been incorporated by the IPCC.
John Page has been very active within international organisations such as WMO, which commissioned him to write the Technical Note on urban and building climatology (Page 1970) and CIB, and he prepared the technical briefing on building climatology for the first UN Habitat Conference in Vancouver in 1976. Page also worked with the WHO on buildings and human health.

Terjung, Werner. Professor emeritus at UCLA. A physical geographer by education, he was one of the first to use computer modeling tools in climatology. Disappointed by the lack of formalisation and hence predictive potential of urban climatology in the 1960s, Terjung attempted to remedy these shortfalls by focusing on mathematics and computer programming, in the overall framework of probabilistic science. He produced some modeling of the urban surface, based on rigorous knowledge of the physics (Terjung 1970). Terjung built a strong following among his students at UCLA until he left in 1987, and was an innovative scientist, although most of his research is now forgotten. As a modeller, he played a role in the transition from old climatology to

quantification, and had the ambitious aim to build a total model of the urban energy budget (Terjung 1980). His *Climatology for Geographers* (Terjung 1976) is considered a classic in the field.

Tromp, SW. (1909-1983) Dutchman and founder, with Frederick Sargent II, of the International Society for Biometeorology (ISB) in Paris in 1956. Tromp, an amateur para-psychologist and a geologist by training and former Shell Oil employee, developed an interest in biometeorological phenomena in the early 1950s, and went on to found the Biometeorological Research Centre in Leiden, The Netherlands. Over his academic career, Tromp produced an ambitious body of research, with his *Biometeorology* (Tromp 1967), containing over 4,000 references, becoming a central textbook of the discipline.
Following expressions of interest from other scientists, Tromp, drawing on his UNESCO connections, as well as on a generous donation from Scottish paper mill owner Major David Russell, founded the International Society of Biometeorology and Bioclimatology. In 1960 the name was shortened, and the *International Journal of Biometeorology* was launched. ISB obtained consulting status with WMO (1961), UNESCO (1962) and FAO (1963). Also, on request from WMO, Tromp produced a *Survey of Human Biometeorology*, (Sargent, Tromp 1964). Tromp's connections with Landsberg, himself a member of ISB and WMO, played an important role in diffusing biometeorology and establishing it in the scientific world (Sargent, Tromp 1966; Weihe 1967). A sign of the specific focus on urban applications of biometeorology was given by the constitution, in January 1975, of a permanent study group on 'architectural, urban and engineering biometeorology' chaired by B. Givoni.
Obituaries:
Krasnow, S., Plasterk, KJ, 1984 In memoriam Dr. Solco Walle Tromp, *Int. Journ. Biomet.*, Vol 28, Number 4, 257-260.
Haufe, W.O., 1991 Solco Tromp, promoter and developer of biometeorology, *International Journal of Biometeorology*, Vol.35, Issue 3, pp.131-132.
Folk, GE, 1994, In Memoriam, The Professional lifetime of Solco W Tromp, a primary advocate of environmental influences, *International Journ. Biomet.*, Vol. 38, Number 1, 3-4.

CSUD datasets

II) organizations
References to people and publications are detailed in the respective data sets.

Building Research Establishment (BRE). In 1917, the UK Department of Scientific and Industrial Research proposed the creation of an organisation to investigate various building materials and methods of construction suitable to use in new housing following the First World War. In 1921 the Building Research Station (BRS) was formed to carry out research work. Some of the earliest work of BRS studied the behaviour of reinforced concrete in floors, and the development of the British

Standard for bricks. BRS also designed codes for individual buildings and carried out work on codes at the neighbourhood level. Today, one of its most famous certifications is the BREEAM label for 'environmentally friendly' buildings. In 1972, BRS was renamed BRE, and then privatised in 1997.

CIB. CIB is the acronym of the abbreviated French (former) name: "Conseil International du Bâtiment" (International Council for Building). CIB was established in 1953 with the support of the United Nations to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a world wide network of over 5000 experts from about 500 member organisations active in all fields in building and construction related research and innovation. In the course of 1998, the abbreviation was kept but the full name changed into 'International Council for Research and Innovation in Building and Construction'.
CIB was active, especially in the 1970s and 1980s, in organizing international conferences, in collaboration with IFHP and WMO for instance, on the applications of urban climate science.

CoSAMC (Committee for Special Applications of Meteorology and Climatology). A special committee created inside WMO in 1971, it attempted to broaden the applications of climatological research, especially in the field of urban climatology. Formerly known as the Commission for Climatology, it was first headed by Helmut Landsberg. It was dissolved in 1983. During its existence, CoSAMC worked at diffusing awareness of urban climatology in urban planning, but overall failed as it remained a rather narrow circle of experts, of essentially Germanic origin. National weather services, for instance, were not sufficiently involved in this process of diffusion. CoSAMC reverted to being called the Commission for Climatology, with a more narrow remit.

International Association for Urban Climatology (IAUC). Founded in 2001 by Tim Oke, as an international arena for research and debate in urban climatology. Mainly web-based in keeping with a low-cost, low-maintenance philosophy. IAUC started to emerge in 1999 as a breakaway organization within the International Society for Biometeorology (ISB), illustrating the fact that urban climate topics had reached a critical mass within the latter. IAUC organized a series of high profile international conferences, pursuing the cycle started by IFHP, CIB and WMO. Gerald Mills is now president of IAUC.

International Federation of Housing and Planning (IFHP). The International Federation for Housing and Planning is a world-wide network of professional institutions and individuals active in the broad fields of housing, urban development and planning. With a focus on sustainable development, the Federation organises a wide range of activities and creates opportunities for the international exchange of knowledge and experience in these professional fields. IFHP was founded in 1913 by Ebenezer Howard, the father of the 'garden city', and was originally known as International Federation of Housing and Town Planning.

The IFHP held a series of seminars on urban climate and design in the 1980s, and also briefly featured a 'steering committee' which tried to bridge the gap between the two disciplines. It held conferences together with WMO and CIB on these topics.

International Society for Biometeorology (ISB). Founded in Paris in 1956 by Dutchman Solco S. Tromp and the American Frederick Sargent II. Dedicated to research on the links between climate and human health and well-being, including in urban contexts. ISB was active in the 1970s and 1980s, together with IFHP and WMO, in attempting to diffuse urban climatology more widely, but this effort gradually petered out. Biometeorology is now mainstream in climatology and planning, as concepts such as Physiologically-equivalent temperature (PET) and Baruch Givoni's 'climagrams' have become widespread. However, the most widely diffused tool to come out of bioclimatological research is certainly the Universal Thermal Comfort Index (UTCI), developed through the European COST programme, in order to define a 'universal standard' of human comfort. This illustrates the coming together of biometeorology and mainstream climatology. The ISB is also important for its *International Journal of Biometeorology*, published by Springer. The *Journal* acts as a sort of clearing house, bringing together everyone with an interest in the health aspects of climate science, including the urban aspects, from zoologists to veterinarians and building engineers.

World Health Organisation (WHO). When diplomats met to form the United Nations in 1945, one of the things they discussed was setting up a global health organisation. WHO's Constitution came into force on 7 April 1948. WHO is dedicated to furthering human health and wellbeing over the world. This has taken the form of partnerships with other organizations such as WMO (see entry) in urban climatology research and application, for instance the co-organization of the major conferences of 1968 in Brussels and 1984 in Mexico.

World Meteorological Organisation (WMO). Founded in 1951, and based in Switzerland. The WMO is the successor to the International Meteorological Organisation (IMO), and an arena for debates around climatology and its applications to the urban context. A series of important conferences on urban climatology were co-organised with WHO from the 1960s, the first one being held in Brussels in 1968, in conjunction with CIB, IFHP and ISB. Gradually the effort at diffusing urban climatology as such has declined within the organization, especially following the dissolution of CoSAMC, but WMO is a key supporter of IAUC.

ocation	Dates	Title	Lead agency	Other agencies	Key actors	Theme	References	Outcomes/ Context
russels	1968	Conference on urban climates	WMO	WHO, CIB	T. Chandler, H. Landsberg, J.Page, T.Oke	'Analysing and publicising the 'urban effect' on climate'	Chandler (1970a) Page (1970)	-Agreement on follow-up conferences .

								-Need for 'mutual education' of climatologists and planners (CC. Wallen) -Chandler (1970)
sheville	1972	12th conference on applied climatology	WMO		H. Landsberg (organizer)		WMO (1974)	-Identified the nee for better technology transfe between WMO and national met services to help them support better practice in urban planning: p177 'This would allow many to benefit from the developments in the use of meteorology which are localised at present'
tockholm	1972	'Teaching the teachers'	CIB	WMO, IFHP	B.Frommes	How to best transmit awareness of urban climatology in planning?		-B.Frommes questionnaire (1978) -Frommes (1980)
hiladelphia	1972	Second conference on the urban environment and second conference on biometeorology	AMS					
ad lomburg	1973	CoSAMC, 6th session		ISB, CIB (invited representatives)	Landsberg (presiding), RH Clements, WH Weihe	-Widen horizons of climatology, especially urban applications -Liaise with planners, architects, engineers	-CoSAMC minutes (consulted at WMO library, Geneva)	-Strengthen links with CIB -Rising WMO interest in biometeorology ; ISB achievements seen as 'limited' (Landsberg)
ollege Park MD)	1975	ISB 7th international congress	ISB		Landsberg, Tromp, Sargent, Weihe	-Celebrating the society's 20th anniversary	-Tromp, Booma (1976)	-Illustrates strong links between Landsberg and ISB
Iontreal	1976	Habitat Conference	UN		J.Baumuller, J.Page		Presentation of city of Stuttgart's film 'Climate and Development'	
ienna	1976	Planning and Construction in conformity with climate	CIB, WMO, IFHP, ISB		B.Frommes, E.Liepolt, S.Jovicic		See especially 1) Ewald Liepolt's summary of the history of the S4 Working Group 2) Slavka Jovicic, WMO Activities in Urban and Building Climatology	CIB report 15, *Meteorological information for architects and building*
eneva	1978	CoSAMC, 7th session	WMO	ISB (observer)	MK Thomas (president), Landsberg (ISB observer), F.Becker (ISB)		-CoSAMC minutes (consulted at WMO library, Geneva)	-Joint WMO/WHO symposium on human biometeorology is recommended
Vashington	1982	Commission for Climatology and Applications of Meteorology, 8th session	WMO	ISB (observer), IFHP (observer)	MK Thomas, Landsberg (ISB observer)		-CCl minutes (consulted at WMO library, Geneva)	-Appointment of rapporteur on urbanization, with emphasis on developing world -How to promote knowledge transfe

								from climatology t practical applications?
eneva	1983	Expert meeting convened by WMO	WMO IFHP UNEP ISO WHO UNECE		T Oke R. Taesler		WMO (1983)	1) promote cooperation with users through workshops, missions and designation of 'focal points' for Urban & Building Climatology within national met services 2) document climate impacts on buildings and settlements 3) education and training through WCP brochures targeted at 'decision-makers, planners, architects, builders and engineers'
el Aviv	1983	2nd International Symposium	IFHP	Planning and Building	A.Bitan, S.Jovicic and T Oke		Bitan A ed (1984) See especially Oke (1984) which has interesting comments on national differences in cultural awareness of climate	
lexico City	1984	International conference on urban climates in tropical cities	WMO and WHO	IFHP, CIB	T.Oke, H. Landsberg, A.Bitan, B.Givoni, G.Levermore, S.Grimmond, R.Bornstein, J. Baumuller, T.Kawamura, IR Imamura	The challenge of applying climatology in developing countries	Oke (1986)	Decision to hold international year of climate in 1992; emphasis on planning applications; more research required on tropical world See: Ernesto Jauregui (1990) *Bibliography of Urban Climatology for the Period 1992 5*
eneva	1985	Commission for Climatology, 9th session	WMO	IFHP, CIB and ISB as observers	JL Rasmussen (president), A.Bitan (observer for IFHP), Landsberg (for ISB), VB Torrance (for CIB)		Revision of WMO/CIB report *Matrices for land use, town and building planning as related to climatic parameters* (published 1972)	-Rising weight of climate change topic -'Impressive' results of World Climate Applications Programme in urban and building climatology are noted -Decision to focus on developing world
arlsruhe	1986	3rd International Symposium	IFHP	Climate, Building, Housing	K Hoeschele (organiser) A.Bitan, H.Mayer		*Energy & Buildings*, Vol. 11, 1-3, 22/3 1988 (special volume)	-'Mutual education required -Too many organizations and lack of international cooperation

Moscow	1987	New developments in building climatology	CIB	Building and housing	J.Page	'Creating more comfortable living and working conditions'		Setting up of working groups to cooperate with ISC Reflection on computerisation o data
Kyoto	1989	4th international conference on urban climate, planning and building	IFHP, CIB		A.Bitan, S.Grimmond, Yasuko Nakamura		*Energy & Buildings* (1990 and 1991) Vol 15 pts 3 & 4	
Berlin	1991	Planning applications of urban and building climatology – but most of the papers were building science – measurement. modelling, wind tunnel simulations etc	IFHP, CIB		K Hoeschele A.Bitan		IFHP/CIB (1992)	The only urban planning papers were the German contributions on Munich, Heidelberg, Waldkirch, Kassel and Cologne
Dhaka	1993	Meeting on tropical urban climates	WMO, WHO, IGU, UNEP		T.Oke, A.Bitan	Urban climatology in the world's tropical cities	WMO (1994)	Conference was linked to WMO's tropical urban climate experimen (TRUCE) which was identified as a key activity within WMO's Long Term Plan Urban heat island as 'best documented evidence of human induced climate change' (Oke)
Essen	1996	International Conference on Urban Climate	Essen University, ICUC		T.Oke, S.Grimmond, W. Kuttler, E. Jauregui, H. Mayer, D.Pearlmutter, A.Bitan	-Air pollution issues in the Ruhrgebiet -Encouraging planners to apply urban climatology through focused workshops	*Atmospheric Environment* (1999)	Emergence of IAUC originally as email contact list
Kobe	1997	German-Japanese meeting of experts			J. Baumuller	Climate Analysis in Urban Planning		-Origin of Stadtklima information network and IT tools
Sydney	1999	International congress of biometeorology and international conference on urban climatology	ISB, IAUC, WMO, UNEP		G.Mills, T.Oke, S.Grimmond, J. Arnfield, B.Bornsetin	'Biometeorology and urban climatology at the turn of the millennium'	De Dear et al (2000)	Formal constitution of IAUC
Davis	2000	Third Symposium on the urban environment	AMS		S.Grimmond, B.Bornstein, M.Roth, J.Barlow, W.Kuttler, J.Arnfield.T.Oke. M.Kanda, I.Eliasson, V.Masson, J.Voogt, H.Mayer	General urban climatology	-Proceedings available at www.ametsoc.org	
Norfolk, VA	2002	Fourth symposium on the	AMS		S.Grimmond, J.Voogt, T.Oke,	General urban climatology	-Proceedings available at	

		urban environment			B.Bornstein, M.Roth, W.Kuttler, H.Mayer, M.Kanda, E.Jauregui, J.Arnfield		www.ametsoc.org	
odz	2003	International Conference on Urban climate (ICUC 5)	IAUC, WMO		T.Oke, G.Mills, S.Grimmond	General urban climatology	Klysik K. et al (2003) ; *Theoretical and Applied Climatology* Vol 84 nos 1-3	
ancouver	2004	Fifth symposium on the urban environment	AMS		T.Oke, S.Grimmond, H.Mayer, M.Roth	General urban climatology	-Proceedings available at www.ametsoc.org	
eattle	2004	Annual Meeting	AMS		B, Bornstein, M.Kanda, S.Grimmond	'Planning, nowcasting and forecasting in the urban zone'	-Proceedings available at www.ametsoc.org	
oteborg	2006	International Conference on urban climate (ICUC 6)	IAUC	WMO, AMS, IGU, ISB	T.Oke, S.Grimmond, G.Mills, M.Roth, M.Kanda, J.Arnfield, B.Bornstein, J.Page. A.Bitan	General urban climatology	-Conference report in *IAUC Newsl*etter, Issue no.18, August 2006 (online)	-Establishment of official 'working arrangement' IAUC/WMO
an Diego	2007	Seventh symposium on the urban environment	AMS	NOAA, NASA	B.Bornstein, S.Grimmond	General urban climatology	-Proceedings available at www.ametsoc.org	
okohama	2009	International Conference on urban climate (ICUC 7)	IAUC	WMO, ESA, IGU, AMS, PLEA	D.Pearlmutter, S.Grimmond, H.Mayer, G.Mills, T.Oke, M.Kanda, M.Roth	General urban climatology	-Preprints available online -Special report in *Urban Climate News*, No.33, September 2009 (www.urban-climate.org)	-New online bibliography of urban climatology sponsored by WM -Urban Flux Network is launched
eystone	2010	Symposium on the urban environment	AMS		H.Mayer, T.Oke	General urban climatology	-Proceedings available at www.ametsoc.org	
une	2010	Inter-regional training workshop on urban climatology	WMO	India Institute of Meteorology	G.Mills, M.Roth, R.Emmanuel	-Understanding role of cities in modifying weather and climate at various scales -Creating urban databases of met data	N/A	-Better mutual education betweer meteorologists, climatologists and planners
ublin	2012	International Conference on Urban Climate (ICUC 8)	IAUC	WMO	G.Mills (chair)	N/A	N/A	N/A

1. All references, unless otherwise specified, refer to the document entitled 'bibliography'

A chronological review of the 'state of the art' in urban climatology.

Starting with Kratzer's seminal work (Kratzer 1937)[1], we review the evolution of the discipline through an analysis of the documents (books, articles, reports etc.) that have attempted to lay down the 'state of the art' in urban climatology at different periods in history. We will not review every single document published in the period of course, but the major milestones and the transformations in the discipline that they highlight. The aim is to map the significant shifts in the discipline over these last 70 years, and especially the fundamental shift from a descriptive science to an explanatory body of work based on increasingly sophisticated modelling and less on measurements and monographs. We will also see how progress in technology has allowed a move towards an ever finer description of the urban environment, as opposed to the 'parametrization' of the city which prevailed in meteorological models. Another salient aspect of research into urban climate over the period is the status of the urban heat island as the most well documented effect of anthropogenic climate change.

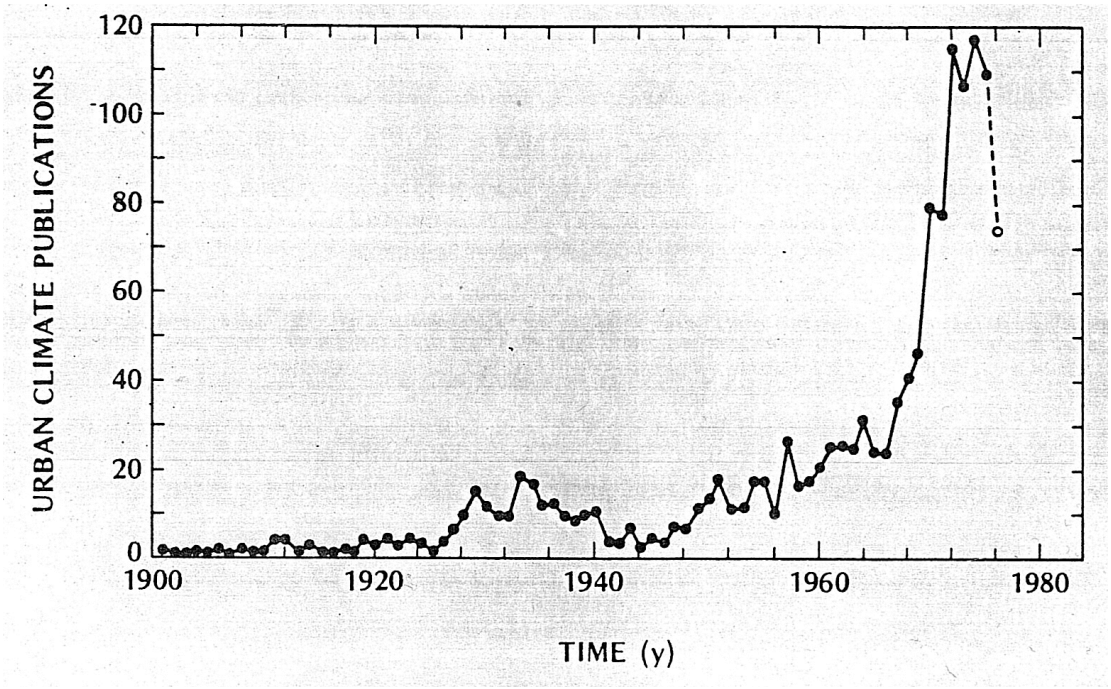
Kratzer's *Stadtklima*, translated into English by the US Air Force in 1956, was based on the first investigations of urban climate conducted in Berlin at the end of the 19th century. Although Luke Howard's work in 1818 first identified and described London's urban heat island, and early in the 20th century several European studies demonstrated further effects on climate, *Stadtklima* is arguably the first modern description of the state of the art in urban climatology. Father Kratzer (1905-1975), a Benedictine monk, gave a summary on all literature on city climate published prior to that time, with an exhaustive description of all research results achieved, in addition to a bibliography of 250 titles. Kratzer's book provides a definitive overview of the descriptive age of the science.
Main topics: observation methods/ tools; UHI?? (I believe you guys took notes on the Kratzer book in Stuttgart? I have not been able to get my hands on it for a detailed perusal).

Chandler (1970) offered the second major summary of work in the field since Kratzer's seminal work. This is not to say that no significant research was carried out in the 30 years between Kratzer and Chandler. On the contrary, a significant body of work on air pollution for instance was produced. Chandler was appointed rapporteur on urban climate at the WMO Commission for Climatology's 4th session in Stockholm in 1965, and this bibliography was his first task. It contains 2,000 references, a ten-fold increase compared to Kratzer, and was presented at the 1968 WMO-WHO symposium on the urban climate,

[1] Full publication and event details are in the datasets entitled 'bibliography' and 'events and organizations'.

itself a major milestone in the history of the discipline. An analysis of the headings reveals a massive predominance of studies on 'air pollution' (121 pages), followed by 'temperature, heat islands, inversions' (40), then by 'case studies' (33), 'general urban climatology' (24), 'radiation and insolation' (22). 'Climate and planning' totals 18 pages of references, 'wind' 16, 'methods of study' 12, while the other topics ('buildings-effect on climate', 'conditions of buildings (inside-outside)', 'clouds', 'health' and others) are in the single digits.

The 1970s were, generally speaking, rich in reviews of the field. We can mention works by Bergstrom (1976), Landsberg (1974, 1976), Terjung (1974), Lowry (1975). Several textbooks were also published in the decade, including Kawamura (1977), Smith (1975), Yoshino (1975), as well as Lowry's (1977) important analysis of methodological approaches to estimating the 'urban effect' on climate. Of particular importance for the field were Oke's (1974 and 1979) reviews of urban climatology. In these reviews, published by WMO as Technical Notes, Oke thoroughly summarized the major advances in urban climatology that occurred in the 1960s and 1970s. Research in this period, as is also evident in Chandler's (1970) review, mainly focused on air pollution problems, which demanded detailed knowledge of urban atmospheric processes. A major shift in urban climate research was of course attributable to Oke himself, with his distinction between urban boundary layer and urban canopy layer (Oke 1976), allowing differentiation between processes operating at the microscale, below building height, and those at the mesoscale, generally above building height. In Oke (1979), published as an addendum to WMO Technical Note 134, the author reviews urban climatology between 1973 and 1976. Studies are divided in two parts: on the one hand, 'observational studies' (pages 6 to 61), which itself is subdivided into 'radiation budget', 'energy balance', 'water balance, cloud, precipitation', 'wind field', 'humidity', 'other', and on the other hand 'modelling studies' (pages 61 to 80), subdivided into 'canopy layer' and 'boundary layer'. Oke also supplies the following graph on the trend of publications in urban climatology (except air pollution studies) in the twentieth century, compiled from Chandler (1970) and Oke (1974).



As we see, publications in the field increased significantly from the 1960s onwards. The spike after 1968 is related to the WMO-WHO symposium on urban climates held that year, and other spikes are evident in the wake of similar events (the 1972 Asheville symposium organized by WMO for instance).

With *The Urban Climate* (1981), H.E. Landsberg delivered the second monographic treatment after Kratzer's seminal work. In between these two reviews, the increase in studies on the urban climate was enormous (see graph above). Landsberg describes the shift from a descriptive discipline to a more scientific, explanatory endeavour, focusing on physical processes, as illustrated by the rise of numerical boundary layer modelling in that period. The book includes a brief historical review and state-of-the art summary (chapter 1), followed by a treatment of technical foundations, including air pollution (chapters 2,3 and 4). Research results concerning temperature and wind (5, 6, 7), and atmospheric moisture and surface hydrology (8 and 9), are followed by brief chapters on impacts and applications (chapters 10 and 11). Among the topics given particular focus are the issues of scale in the studies of urban climate; the then budding science of urban energy fluxes; and urban wind modelling. Intended for a wide audience, from neophytes to boundary layer meteorologists and city planners, the book falls short as a textbook due to a lack of clarity in who is being addressed and when, but provides a useful research review. One salient conclusion was that Landsberg felt that urban climatology had reached a 'plateau' in its methods and knowledge.

-Oke, T. R., 1983: "Bibliography of Urban Climate, 1977-1980," WCP-**45**, World Climate Programme. World Meteorological Organization, Geneva, 39 pages. (Could not find it)

-Oke, T. R., 1990: "Bibliography of Urban Climate, 1981-1988," WCAP-**15**, World Climate Programme. World Meteorological Organization, Geneva, 62 pages (awaiting delivery from JRUL)

The mid-1980s saw the beginning of a rise in the number of studies focusing on urban climate in the subtropical and tropical worlds. Urban climatology had from the beginning been biased towards the mid latitudes, excepting maybe a certain number of studies on arctic settlements conducted by the Soviets, the Norwegians and the Swedes (see Berlyand, Kondrat'yev 1972), and studies carried out by the Israelis for settlement purposes in arid climates. The WMO symposia on the urban environment held in Mexico City (1984) and Dhaka (1993) saw a call, especially from figures such as Tim Oke, for more focus on the tropical, developing world, where the major challenges lie. Ernesto Jauregui, an Argentinian researcher, charted this evolution in two major reviews of urban climatology.

Jauregui's *Bibliography of urban climate in Tropical/Sub Tropical areas, 1981-1991* (Jauregui 1993) was part of the first phase of WMO's 'TRUCE' (Tropical Urban Climate Experiment) programme. While Oke (1990) listed 71 papers on urban climatology in tropical areas out of a total of 670 entries for the 1970s, the period 1981-1991 studied by Jauregui saw the publication of 169 papers on tropical urban climate out of a total of 696, as illustrated in the following graph. Peaks in 1991 and 1994 were attributed by the author to the Kyoto and Dhaka conferences (there was double the amount of papers presented at ICUC 1996 in Essen compared to Dhaka, for instance).

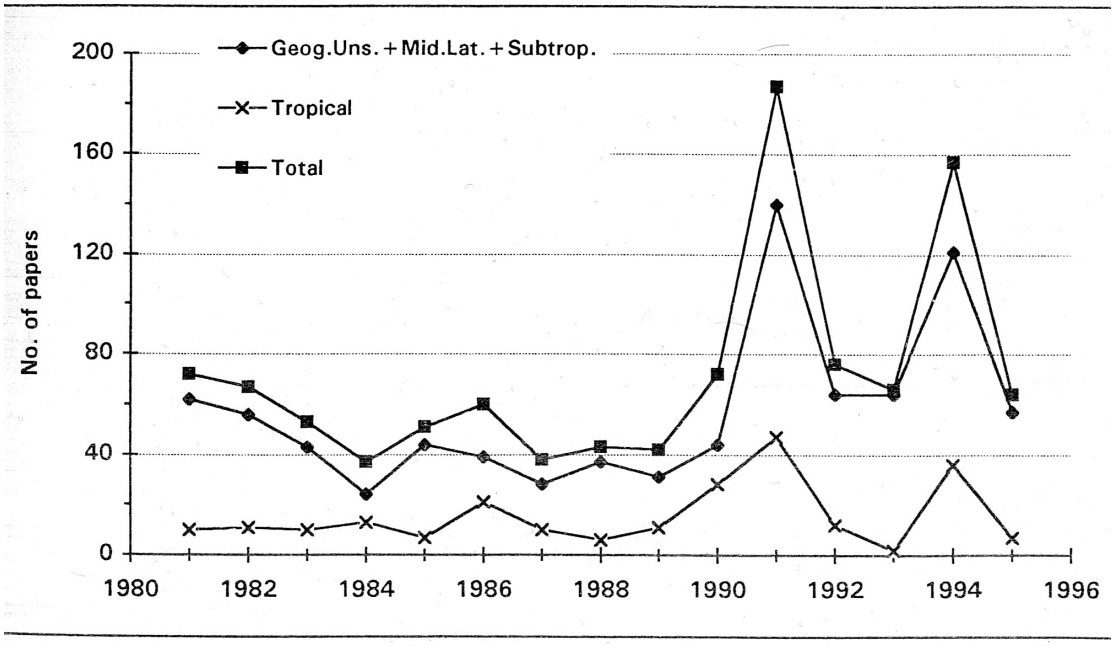


Fig. 1 Annual totals of publications in urban climatology for specifically the tropics (Trop.), other climate regions (Geophysically unspecified, mid-latitude and subtropics) and a global total (Total).

The headings in this study run as follows: 'physical urban climate', 'general, descriptive urban climatology', 'urban humidity and hydrology', 'urban planning', 'air pollution', 'energy and urban climate', 'urban bioclimate', and 'physical modelling of the climate'. Air pollution studies were the major focus, followed by physical modelling.

This bibliography was followed by Jauregui's *Bibliography of urban climatology for the period 1992-1995 including a section on Urban Climate in Tropical/sub-Tropical areas* (Jauregui 1996) which offered a wealth of useful information on the state of the discipline. Overall, activity in urban climatology had seen a rise from 63 published papers per year in the period 1980-1990, to 85 papers/year over the first half of the 1990s. Papers on urban air pollution made up 16% of publications in the 1980s, and 35% in the 1990s. A more detailed breakdown of published papers by specific subject is given in the following graph, showing the papers published between 1992 and 1995 according to topic. Again, air pollution studies dominate (QUA=122), but we note a rising focus on energy use and climate change (EUC=53). Moreover, another interesting tendency illustrated here is the focus on physical modelling of the climate (PhMUC, 37 publications). Geographically speaking, the focus is still very much on the mid latitudes, but the sub/tropical worlds made up a third of all publications.

SUBJECT / REGION	GU	HL	ML	ST	T	TOTAL
PhMUC	20	1	14	2	0	37
EUC	5	0	28	8	12	53
GUC	4	2	21	7	9	43
PhUC	6	0	16	4	4	30
QUA	10	8	57	35	12	122
RSUC	7	0	13	3	0	23
UBCL	7	1	5	5	6	24
UH	2	0	3	1	2	8
UP	9	2	15	2	9	37
TOTAL	70	14	172	67	54	377

Subjects:

PhMUC -	Physical modeling urban climate.
EUC	Energy consumption and urban climate
GUC	General, descriptive urban climate e.g. description of near surface fields of temperature, wind, rainfall, humidity, etc.
PhUC	Physical urban climate.
QUA	Quality of urban atmosphere.
RSUC	Remote sensing and urban climate.
UBCL	Urban bioclimatology
UH	Urban hidrology.
UP	Urban planning.

REGIONS:

GU -	*GEOGRAPHICALLY UNSPECIFIED*
HL -	*HIGH LATITUDES*
ML -	*MIDDLE LATITUDES*
ST -	*SUBTROPICAL*
T -	*TROPICAL*

The end of the 1990s saw the emergence, under Tim Oke's and Sue Grimmond's leadership, of the International Association of Urban Climatology (IAUC). The association has been active since then in producing bibliographies of urban climatology. The first such one was Salmond, J, *Bibliography of urban climate 1996-1999*, available online at www.urban-climate.org.

Out of 227 papers published in this period, 78 were in the category Air pollution, aerosols, fog, urban odours, noise; 42 in the category Urban boundary layer physics, dispersion modelling, wind tunnel; 39 in Pollution / instrument focus with implications for urban measurement; 24 on Energy Balance, heat fluxes, turbulence, radiation; 15 were on Urban bioclimatology, impact on health/vegetation and Climate Change, variability and urban climate respectively. Only 6 covered the topics of urban planning, urban parks, building climatology. Again, air pollution was the main topic of investigation, followed closely by modelling.

IAUC has recently published another bibliography, covering the beginning of the 21st century. Salmond, J, *Bibliography of urban climate 2000-2004* (also available at www.urban-climate.org) lists 559 published papers for this period, more than double the amount published between 1996 and 1999. Of these, 255 dealt with 'air pollution, aerosols, fog, urban odours, noise', 104 with 'urban boundary layer physics, dispersion modelling, wind tunnel', 66 focused on 'energy Balance, heat fluxes, turbulence, radiation', 48 on 'pollution / instrument focus with implications for urban measurement', 26 on 'urban bioclimatology, impact on health/vegetation'. 'Climate change and variability', together with 'urban climate', totaled 24 publications. 'Descriptive urban effects on temperature, wind, rain, etc.' was the focus of 19 papers, 'urban planning, urban parks, building climatology' came in before last with 13 papers, while 'urban hydrology' closed the list with 4. The majority of papers still dealt with the 'air pollution, aerosols, fog, urban odours, noise' category, their proportion increasing from one third of the total, to nearly a half. The category 'Urban boundary layer physics, dispersion modelling, wind tunnel' stayed the same, with about one-fifth of all publications. The proportion of papers dealing with Urban bioclimatology, impact on health/vegetation actually decreased by around a third, as did the number of papers focusing on Climate change and variability, while urban planning, urban parks, building climatology remained around a lowly 2% of publications.

The last documents we review here in this state of the art of urban climate research are of a slightly different nature. Instead of a commented bibliography, it is a statement of the problems facing the urban climate community and the requirements, both in terms of knowledge and practice, in order to rise up to these challenges. 'Climate and More Sustainable Cities' (Grimmond et al 2009) was produced as a white paper for WMO. Six areas where 'improvements in our capabilities are needed' are identified (Observations, data, understanding, modelling, tools, education). These areas are detailed through a review of topics: 'sensitivity of cities to climate variability and change'; 'applications'; 'urban processes and observational capabilities'; 'prediction and modelling capabilities'. Overall, a call for more mutual education of planners and meteorologists, to establish strong networks of urban climate practitioners, emerges from this document. Also, the need to focus on (tropical) megacities (the subject of a related WMO white paper, Cleugh et al 2009) is emphasised in a now mainly urbanised world, where the negative effects of urban climate often combine with those of poverty. A series of 'impediments to knowledge transfer', both between planning and development communities, and between developed and developing world are identified in this document, as well as 'gaps in knowledge and the ability to apply this knowledge' (of a 'theoretical', 'science', 'communication', 'application' and 'addressing sustainability' nature).

Conclusions

This review of 70 years of the 'state of the art' in urban climate research shows several significant evolutions in the science. Firstly, an overall evolution from a descriptive discipline based on (ever more thorough and detailed) monographs,

in keeping with the pioneering work of Luke Howard in the early 19th century, to more and more sophisticated models. The monographic approach was refined with innovative measuring campaigns, illustrated by Chandler's clever use of the family Land Rover in London to obtain transversal measures; likewise, bicycles, balloons etc are now regularly used to obtain specific data. Landsberg's Urban Climate summed up this descriptive approach, whilst underlining the fact that the discipline had reached a 'plateau'. The emergence of information technology, pioneered in the field by figures such as Werner Terjung in the 1970s, permitted a gradual move away from the monographic to simulation, paving the way for a more predictive science, and reducing the need for costly and time-consuming measurement campaigns. However, this is not to say that the latter have disappeared, nor that that urban climate research can do without them. On the one hand, there is a lack of empirical information about cities in the tropical world; on the other hand, some computer models are too simplistic and add up to a 'parametrization' of the urban, evident in weather forecasting departments (the city of Birmingham in the UK is represented in climate models as a particularly large grassy valley). The current challenge is therefore clear: it is about the scales of the models used in urban climate research, and the ability to define finer models that fully represent the 3-dimensional nature of the urban environment, and the immensely complex air and temperature effects of building surfaces, shapes and locations, and the interaction of these parameters.

The second big evolution we see in this 'review of reviews' is the shift towards greater research focus on cities of the developing world, in particular in the tropical world. Tim Oke had long called for such an evolution, required by the compounded challenges facing this part of the world: crowded megacities in climates that foster increased pollution (tropical climates are conducive to high ozone concentrations, and fuel used in cities provides the 'spark' for this), with particularly dire consequences for the poorest (makeshift housing bears the brunt of extreme climate events such as heatwaves and floods for instance). This shift is welcome, as urban climate research can make clear contributions to wellbeing in these cities, especially in the context of climate change.

And this is the third big shift in the discipline over these 7 decades, the contribution to proving scientifically that cities are major weather producers, as their heat and other emissions mix with global air flows, as well as potential victims of the changes wrought in the climate. It is to be hoped that urban climate research will make a significant contribution to debates over mitigation and adaptation measures, based on the long, thorough intellectual heritage reviewed here.

Table I. Reviews, bibliographies and summaries on urban climatology published during the review period

Reference	Topic
Oke (1979b)	Review of urban climatology, 1973–76
Changnon (1980)	The La Porte precipitation anomaly
Oke (1980)	Bibliography of urban climate literature, 1977–80
Landsberg (1981a)	Multiple topics in urban climatology
Changnon (1981)	A review and summary of the METROMEX project
Landsburg (1981b)	Multiple topics in urban climatology
Oke (1982)	Urban energy balance
Douglas (1983)	Urban physical environment in general with one chapter on urban climate
Lockerby (1983)	Bibliography on the climate of cities
Lee (1984)	Multiple topics in urban climatology
Oke (1986)	Urban climatology with special emphasis on tropical areas
Oke (1988b)	Urban energy balance
Smithson (1989)	Progress report (includes 'urban climates')
Oke (1989)	Trees in cities
Smithson (1990a)	Progress report (includes 'urban climates')
Smithson (1990b)	Progress report (includes 'urban climates')
Yoshino (1990–91)	Emphasis on Japanese urban climate work
Oke *et al*. (1990–91)	TRUCE (Tropical Urban Climate Experiment)
Brazel *et al*. (1991)	Includes section on urban climatology
Changnon (1992)	Inadvertent climate change in urban areas and lessons for global climate work
Steyn (1992)	Integrated studies of air pollution meteorology
Cermak *et al*. (1995)	Wind climates in cities
Goldreich (1995)	Review of Israeli urban climate work
Arnfield (1998a)	Review of urban climate work published in 1996
Arnfield (1998b)	Review of urban climate work published in 1997
Sturman (1998)	Urban climate processes, mitigation of urban climate effects and implications for urban design
Lowry (1998)	Urban effects on precipitation amount including a critique of experimental design
Arnfield (2000a)	Review of urban climate work published in 1998
Roth (2000)	Atmospheric turbulence in urban environments
Arnfield (2001a)	Review of urban climate work ('urban canyon studies' and 'urban climates outside the mid-latitudes') published in 1999
Arnfield (2001b)	Review of urban climate work published in 2000

Table from Arnfield (2003), could be used here as helpful summary for reader.

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