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Michael Hebbert and Vladimir Jankovic

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Abstract

This paper reviews the long tradition of city-scale climatological and meteorological applications prior to the emergence in the 1990s of early work on the urban/global climate change interface. It shows how 'valuing and seeing the urban' came to be achieved within modern scientific meteorology and how in a limited but significant set of cases that science has contributed to urban practice. The paper traces the evolution of urban climatology since 1950 as a distinct research field within physical geography and meteorology, and its transition from observational monographs to process modelling; reviews the precedents, successful or otherwise, of knowledge transfer from science into public action through climatically aware regulation or design of urban environment; and notes the neglect of these precedents in contemporary climate change discourse—a serious omission.

Introduction

It is an indisputable fact that cities were initially overlooked in the IPCC process. The science consisted of climatic forecasts framed at a global scale and the policy stakeholders were international or state actors. Scientists involved in global climate forecasting were slow to engage with the urban phenomenon except as an anomaly, city weather stations being a source of data distortion within the synoptic grid. The initial techniques for calculating national greenhouse gas inventories were based on the sectors of energy, industry, land use, agriculture and waste, making it hard to detect the role of urbanisation. Cities were not mentioned in the Kyoto Protocol. A similar sectoral logic applied to the periodic Global Environmental Outlook published by the United Nations Environment Programme. Governmental actors reinforced this predisposition: it was natural for the process of international negotiation

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to frame the climate change issue in terms of ministerial portfolios. The conventions of intergovernmental diplomacy discouraged consideration of urbanisation as a forcing factor and cities as distinct territorial stakeholders within the IPCC process.

Today, these exclusions are breaking down, bringing a sense of fresh opportunity at the urban level. The increasingly fine resolution of models of the earth's atmosphere (down to 25 km globally) means that cities are for the first time visible within general circulation systems. The environment of the city with its three-dimensional geometry, heat-absorbing materials, impermeable surfaces and pollution concentrations, is beginning to be resolved in weather models. Governmental actors have realised that mayors may be able to maintain progress where international agreement had stalled. Urbanisation entered for the first time as a climate change consideration in the fourth assessment report of 2007 and the fifth report due in 2014 will contain a separate chapter on cities and attempt a full-scale assessment of their role in carbon pollution and their potential adaptability to climate risk. The contemporary literature on cities and climate change—not least this Special Issue of *Urban Studies*—shows cities at last incorporated into global climate policy both as causal agents in greenhouse gas emissions/mitigation and as vulnerable targets.

In thinking about cities and climate change, it is hard to avoid the word 'unprecedented'. Everything hinges on recent scientific discovery and response to projected future threat. The time-frame stretches back no further than 1988, the year of UN General Assembly Resolution 43/53 and the establishment of the Intergovernmental Panel on Climate Change; or 1994 and the United Nations Framework Convention on Climate Change; or 1997, year of the Kyoto Protocol. All the C3 actors are new-born—ICLEI in 1990, the Climate Alliance in 1991, UNCED's Rio Conference in 1992, ICLEI's Climate Change Programme in 1993, *energie-cités* in 1994, the UN's Cities and Climate Change in 2008, the World Bank's Mayors' Task Force on Urban Poverty and Climate Change in 2009. It is often remarked that the discovery of global climate change has coincided with the tipping point to a world in which city-dwellers outnumber rural folk. So UN-Habitat summarises the threat to humanity

> Fuelled by two powerful human-induced forces that have been unleashed by development and manipulation of the environment in the industrial age, the effects of urbanization and climate change are converging in dangerous ways which threaten to have unprecedented negative impacts upon quality of life and economic and social stability (UN-HABITAT, 2011, p. 1).

This paper challenges none of the above except to put a question mark by the word unprecedented. It was at the scale of the urban heat island that anthropogenic effects—many linked to carbon combustion—were first systematically studied. The seminal contribution came from Albert Kratzer whose *Das Stadtklima* (1937) originated as a PhD thesis under the supervision of the geographer Edward Fels. Fels's own work on environmental impacts of economic progress—the businessman as shaper of the earth, *Der wirtshaftende Mensch als Gestalter der Erde* (1954)—stood directly in line between the pioneering conservation science of George Perkins Marsh (1882) *The Earth as Modified by Human Action* or Nathaniel Shaler (1905) *Man and the Earth*, and modern environmental conservation represented by the Wenner-Grenn Foundation's symposium *Man's Role in Changing the Face of the Earth* (Thomas, 1956), Rachel Carson's (1962) *Silent Spring*, Carrol Wilson's

(1971) *Report of the Study of Man's Impact on Climate* and Ward and Dubos's *Only One Earth* (1972). Urban climatology has a long pedigree in the conservation movement.

Since the study of urban weather systems is explicitly a science of anthropogenic cause, it has always challenged cities to assume responsibility for their role as "co-patterners of their climate" (Kratzer, 1956, p. 170). So there is also a prequel in the realm of collective action. Greenhouse gas mitigation is prefigured in municipal energy provision and public health action against soot and smog. The history of modern town planning can be written in terms of a collective response to the externalities of carbon-based industrialisation—as Patrick Geddes defined it in the early 20th century, substituting the clean-energy 'Neotechnic' city for the black pollution and physical concentration of 'Paleotechnic' capitalism (Geddes, 1915). Adaptation strategy has much older antecedents. The design of cities embodies local knowledge of wind, sun, humidity and precipitation, and of what is needed to survive in a given geographical setting against the contingencies of weather and human enemies. The history of urban habitats is not just one of passive adaptation to regional climate but of active transformation to produce microclimates radically unlike their surrounding terrain—hotter, cooler, drier, moister, less windy, more ventilated, or whatever is most conducive to human comfort at a given latitude. City design is the oldest type of anthropogenic climate change (Egli, 1951).

These precedents are explored in order, the next section dealing with the science of cities as climatic singularities, and subsequent sections with antecedents of urban policy response. The purpose of these historical excursions becomes apparent in the final section of the paper where we compare the prequel with the sequel and ask if and how it matters.

The Scientific Precedents

Scientific interest in the atmospheric effect of urbanisation extends more than 200 years. As a nation of pioneers, Americans contributed early research into the effects of deforestation, agriculture and town-building on seasonal change (Fleming, 1998). Thomas Jefferson suggested in 1824 that anthropogenic impact should be monitored through climatic surveys 'repeated once or twice in a century' (Landsberg, 1956). However, it was the great cities of Europe that contained the sites with the longest instrumental measurement series and here that the climatic changes produced by industrialisation, densification and suburban growth were most readily visible. Patterns of urban temperature, precipitation and wind circulation were studied for sites around London by Luke Howard between 1806 and 1830, for Paris in the 1870s by Emilien Renou, and for Berlin and Vienna in the 1890s by Gustav Hellmann and Julius Hahn respectively. The physicist Sir Arthur Schuster set up a University of Manchester observatory that allowed comparison with a municipal weather station two miles north. He commented

> The remarkable differences which appear in the temperature records in different parts of the city furnish an additional proof, if proof were wanted, that observations taken in or near a large town cannot be taken to represent correctly the meteorological character of the surrounding districts, but it by no means follows that these observations are of no value. On the contrary, they may lead to some important conclusions on what may be called town weather as distinguished from country weather (Schuster, 1893, p. 168).

Manchester, of course, epitomised the spectacular environmental contamination achieved by free industrial enterprise in the absence of pollution control. Whatever the season, town weather was foul. Its evil reputation was compounded by the orthodox medical assumption that infection occurred miasmatically—germ theory prevailed only in the final quarter of the century. Some of the 19th century's most detailed urban heat island studies were done by doctors—Barles (1999) for example discusses the work of Pierre Foissac, author of *De l'influence des climats sur l'homme* (1837) and *De la météorologie dans ses rapports avec la science de l'homme et principalement avec la medicine et l'hygiène publique* (1854). Ventilation and sunlight became overriding concerns of the movement for public health and hygiene, and so for early modern town planning.

The literature on the atmospheric environments of cities and their effects on citizens was swelled in the 20th century by a growing number of monographs from regional geographers, for whom the physical environment of the city offered an ideal object of study as a cultural artefact in a natural landscape. An increasing interest in micro-climates amongst meteorologists was pioneered by Gregor Kraus (*Boden und Klima auf kleinstem Raum*, 1911) and Rudolf Geiger (*Klima der bodennahen Luftschicht*, 1927). Much of this research was German, as was Albert Kratzer's earlier-mentioned synoptic text *Das Stadtklima* (1937). Written as a doctoral thesis in the philosophy faculty of the University of Munich by a Benedictine monk and geography teacher from the Ettal Abbey, *Das Stadtklima* was a definitive state-of-the-art review, based on 225 studies and extensive analysis of comparative data, documenting the differences between urban and non-urban climates, and explaining the mechanisms of the urban heat island, wind systems, ventilation and stagnation, precipitation anomalies, pollution and its dispersion, and the downwind effects of urbanisation. By the publication of the second edition in 1956, its reference list had grown to more than double the original size, incorporating a mainly English-language bibliography by the British public meteorologist Charles Brooks (1952).

Subsequent translation of Kratzer's second edition into English by the US Air Force in 1962 confirmed the internationalisation of the science in post-war years. The leading protagonist was the German-born Helmut Landsberg who moved to the US from Germany in 1934 to teach the first graduate course on bioclimatology. A major figure in American meteorology, he served as director of the US Weather Bureau office of climatology from 1954 to 1967 and was a key architect of the modern-day NOAA. As US representative, he became a leading light in the early decades of the World Meteorological Organisation, chairing WMO's Committee for Special Applications of Meteorology and Climatology from 1971 to 1983. Landsberg had a particular interest in the science of urban climates, eventually authoring his own successor volume to Krazter's *Das Stadtklima, The Urban Climate* (1981). One of his most distinctive contributions to the literature was a longitudinal study of the new town of Columbia, Maryland, monitoring for the first time the emergence of an urban heat island as a greenfield site with 200 residents in 1968 was developed into a town of 20,000 population by 1975 (Landsberg, 1979).

Heat island studies at every scale continued to be a central object of research as the field of urban climatology developed in the second half of the 20th century. The geographer Tony Chandler analysed the entire metropolitan climate of Greater London, combining the German technique of automobile-mounted instrumental traverses with a British-style field survey involvement of schools, training colleges and volunteers (Chandler, 1965). The ambitious

$10 million Metropolitan Meteorological Experiment METROMEX monitored an area of more than 4000 square kilometres around St Louis and controversially attributed anomalous patterns of thunderstorms, hailstorms and heavy rain to pollution drift east of the city (Changnon, 1979). Other researchers were tracking the Chicago dust plume 150 miles north-west to Madison Wisconsin (Bryson and Ross 1972, p. 64) and demonstrating the radical impacts of Houston's post-war development boom upon its rainfall pattern (Ferrar, 1976, pp. 60–98).

Belying Patrick Geddes's expectation of the clean technologies of the 20th century, pollution concerns continued to dominate the post-war climate agenda thanks to rapidly rising traffic levels and complex new types of industrial emissions—including lead, asbestos, micro-organisms, NO_x, SO_x, hydrochloric acid, particulates, aerosols and radioactivity—which dispersed under free wind conditions but could be trapped and combined into chemical soups under conditions of thermal inversion. At the conclusion of the second edition of *Das Stadtklima*, Albert Kratzer defined air pollution as the outstanding issue of the urban environment

> Enormous amounts of gases as well as liquid and solid matter are poured into the air every day by urban industry, household heating and traffic. It is not too far-fetched to compare the city to a *volcano* which continuously spews forth clouds of gas, dust and ashes (Kratzer, 1956, p. 166).

London experienced deadly smogs in 1952 and 1955, and New York on Thanksgiving Day of 1966 and in July 1970 (Bach, 1972). The first international conference on air pollution took place in New York in 1955 and Helmut Landsberg convened a major scientific gathering in St Louis in 1961, under the title 'Air over cities' (Landsberg, 1961). In these Cold War years, urban climate research also had the stimulus of the Soviet Union's known use of weather engineering technologies, and military concern for climatic dispersal of chemical and radioactive hazards (Derrick Sewell, 1968; Ferrar, 1976; Fleming, 2010).

One effect was to bring more atmospheric chemistry and physics into the urban arena. New measurement techniques such as constant-height balloons and remote sensing were added to the traditional repertoire of meteorological observation. The focus of analysis shifted towards measurement and modelling of energy fluxes on the meso-scale of the urban boundary layer and the micro-scale of the street canyon. Seminal contributions such as Ted Munn's *Descriptive Micrometeorology* (1966), Werner Terjung's *The energy balance climatology of a city–man system* (1970) and Tim Oke's *Boundary Layer Climates* (1978) laid the basis for progressively more sophisticated numerical modelling of the urban climate as computing power increased (Arnfield, 2003). Urban climatology was enriched by cross-disciplinarity: fluid mechanics contributed the techniques of CFD (computational fluid dynamic) modelling to simulate air flow in the complex three-dimensional urban environment; geography contributed GIS (geographical information system) methodology, allowing datasets on urban land use to be combined with atmospheric variables at high levels of resolution; architecture contributed CAD (computer assisted design), providing the link between urban-scale climatology and the burgeoning fields of environmental engineering and passive and low-energy architecture (PLEA); environmental management contributed modelling software such as the ENVI-met freeware which allows three-dimensional surface–plant–air interactions to be simulated at high levels of resolution. Last but not least, increased computing power and speed within the parent discipline of meteorology brought greater spatial precision to weather modelling so that for the first time urban-scale climatology could begin to be integrated with the synoptic mainstream (Masson, 2000).

The scientific consolidation of urban meteorology was matched at the institutional level. Helmut Landsberg played a key role in establishing urban climatology networks within the World Meteorological Organisation. A meeting on Urban Climates and Building Climatology jointly sponsored with the World Health Organisation in Brussels in 1968 was the first in a regular and continuing series of scientific conferences and state-of-the art reviews, led first by Tony Chandler and then by the Vancouver-based urban meteorologist Tim Oke. Significant features at the international level have been the continuing strength of the German research tradition, the emergence (with direct German links) of an equally vigorous scientific culture in Japan, the linkage to other UN-related agencies such as WHO, UNEP, UN-HABITAT, and the CIB, and the co-sponsorship of non-governmental bodies such as the International Federation for Housing and Planning (IFHP) and the International Society for Biometeorology (ISB). Conscious of the need to establish their group identity, urban climate scientists formed their own International Association for Urban Climatology (IAUC) in 2001 under the leadership of Tim Oke. IAUC's website[1] and three-yearly conferences are the principal focus for urban climatology today. So the organisation is relatively new, but the scientific community has a 200-year track record of work on anthropogenic climate change.

The Policy Precedents—Attempted

Research in urban climatology was never just about 'blue skies' thinking. Scientists knew from the outset that they were studying an anthropogenic system with opportunities for positive feedback. In the words of M. Parry

> the urban climate deserves the interest of climatologists as an element of the physical background of town life, and as an artificial climate which may be modified by suitable planning (Parry, 1956, p. 45).

The duty of knowledge transfer from science to urban practice was a constant theme throughout the influential career of Helmut Landsberg

> The knowledge we have acquired about urban climates should not remain an academic exercise on an interesting aspect of the atmospheric boundary layer. It should be applied to the design of new towns or the reconstruction of old ones. The purpose is, of course, to mitigate or eliminate the undesirable climate modifications brought about by urbanization (Landsberg, 1981, p. 255).

The science-based call to action was given urgency by on-going trends (Douglas, 1983). The motor-car, once regarded as a clean technology, was found to be a significant chemical polluter and a forcing factor in the urban heat island, with each vehicle emitting as much heat as a domestic boiler; rates of stormwater run-off grew in direct relation to post-war highway construction and surface parking; loss of vegetation and permeable surfaces also reduced the moisture available for evaporative cooling in the urban heat island; the growing height and mass of urban buildings increased aerodynamic roughness and complex turbulence effects at ground level, while denser building materials with high thermal admittance, absorbed and retained heat; public health concerns over photochemical smog were compounded by the issues surrounding nuclear power generation. Reid Bryson and John Ross wrote

> The time is at hand to begin planning and redesigning of urban areas with much more attention to climatic considerations (Bryson & Ross, 1972, p. 52).

In terms of recommendations, urban climatology had begun (as in Kratzer, 1937, p. 95) with simple advice about sunshine and shadow, and the need to locate residential districts upwind of industry, in the 'climatically beneficial direction'—*klimatisch begünstigte Luvseite*. In post-war years, it developed a progressively more sophisticated critique of current urbanisation practices. In November 1972, Helmut Landsberg's plenary address to the American Meteorological Society Conference on the Urban Environment in Philadelphia set out an agenda for city-building

> Widely divergent views have come from architects, engineers, economicsts, political scientists and real estate developers. To this chorus of intellectual bricklayers the meteorologist is a Johnny-come-lately … Sound meteorological principles … must begin to penetrate the planning process (Landsberg, 1973, p. 86).

Attacking the fatalistic attitude of decision-makers towards weather effects of their own making, he offered a set of meteorological rules for urbanism that could be reprinted verbatim today: do not build on flood plains; mitigate heat island effects with shade trees; reduce surface parking lots; introduce vegetation into urban surfaces; capture waste heat for district heating; promote natural outdoor ventilation through urban design; promote electric transport and discourage the private automobile in cities; promote energy-efficient housing which makes use of solar power for space and water heating, with reflective external paint to reduce albedo. Since topographic and synoptic conditions vary widely, and with them temperature patterns, wind speeds and ventilation rates, Landsberg emphasised the need for local analysis: the 'air resource' of every city is unique.

As an international science community, urban climatologists tried to reach decision-makers through global intergovernmental networks and NGOs. Urban climate was recognised as an issue quite early in the history of global environmental governance ('world family housekeeping' in the phrase of Max Nicholson, 1987). Under Landsberg's leadership, the World Meteorological Organisation promoted research into cities through its Commission for Climatology, one of eight established at the first WMO Congress in 1951. An international study group on urban climates was set up as early as 1959 in partnership with the International Federation of Housing and Planning (IFHP), the International Society for Biometeorology (ISB) and the UNESCO-funded Conféderation Internationale du Bâtiment (CIB). Subsequent collaborations included the World Health Organisation, which co-sponsored a 1968 Conference on Urban Climates in Brussels and a 1984 Mexico City congress on Urban Climatology and its Applications with Special Regard to Tropical Areas; and the United Nations Environment Programme (UNEP) co-sponsor of a 1992 meeting on Tropical Urban Climates in Dhaka. Helmut Landsberg summarised the anthropogenic effects of urbanisation on climate for the World Meteorological Orgaisation in a Special Environmental Report of 1976. Interestingly, he noted in the same report that WMO was also beginning to study anthropogenic alteration of the global climate of the earth, adding prophetically: "it is to be hoped that this surveillance will give an early warning of untoward happenings" (Landsberg, 1976, p. 26). At the urban scale, of course, evidence of the untoward was already abundant.

All these meetings featured appeals to decision-makers to become aware of anthropogenic climate effects. "The acquisition of more knowledge about the climate of cities", wrote William Lowry in a consciousness-raising feature for *Scientific American*, "may in the long run be one of the key's to man's survival" (Lowry, 1967, p. 24). The international climatological community made repeated efforts to raise awareness through meetings, institutional links, training initiatives and publications. Examples from a single year include two World Meteorological Organisation reports, *Weather, climate and human settlements* (Landsberg, 1976) and *Urban climatology and its relevance to urban design* (Chandler, 1976), as well as published proceedings on *Planning and construction in conformity with the climate* (CIB, 1976) and *The role of local and regional government in improving the environment of human settlements* (IFHP, 1976). Climate experts researched the training of architects and town planners and campaigned to improve the almost non-existent coverage of meteorological factors within the curricula of built environment schools. Remarkably, their lobbying effort extended to an unsolicited mail-out of 1500 copies of the text *Fundamental knowledge in urban and building climatology* to Europe's architecture and planning schools (Frommes, 1980).

The scientific community was repeatedly disappointed by the lack of response to its efforts at knowledge transfer. The political scientist Richard Tobin explained the reasons: urban decision-makers would resist evidence of inadvertent anthropogenic climate change until public opinion forced them to do so (Ferrar, 1976, p. 255). Standards for an optimised built environment could perhaps be applied to new towns (as in Olgyay, 1963) or post-disaster reconstructions but were of little use for actually existing cities. WMO Technical Note No. 149 acknowledged the problem

> Many ancient towns of Europe and elsewhere still retain their basic mediaeval plan in their central areas and this resistance to fundamental change, in spite of urban renewal, imposes a severe constraint upon the successful application of urban climatological principles to city design … Urban climatology is relevant only in cases of major expansion, urban redevelopment, or most obviously, in new town design (Chandler, 1976, p. 39).

The author, Tony Chandler, had compiled the WMO's first comprehensive bibliography of urban climatology (1970). His account of optimised climatic design drew extensively on the meteorological state-of-the-art but, tellingly, contained not a single reference to city planning literature. Even more remarkably, the same was true of a bibliography of 250 entries on *The Urban Environment: A Climatological Anomaly* (Berlin, 1972) compiled specifically for use in planning education and research by the Council of Planning Librarians. The difficulties of translation were compounded as post-war climatology shifted from empirical observation towards more sophisticated mathematical understandings of energy budget, radiation and street canyon properties. Melvin Marcus's presidential address to the AAG in New Orleans in 1979 reproached his physical geography colleagues for their tendency to operate in

> a natural science isolation booth expressing little concern for the relevance their microclimatic fluxes and anomalous precipitation statistics may have to urban planning or quality of life (Marcus, 1979, p. 531).

The problem was two-way. Urban professionals, for their part, had become strangely uninterested in the three-dimensional environment, especially its invisible atmospheric layers (Spirn, 1984). It was not always so—the nexus between human wellbeing and physical setting had been a central concern of early 20th-century planning theory. Planning *meant* a physical shaping of morphology, density, layout, street form and land use pattern. Yet the tendency of planning theory after 1970 was to regard 'environmental determinism' as a fallacy. The mainstream of planning, particularly in the Anglo-Saxon world, was being redefined as a mode of social intervention based upon the methods of social science (Hebbert, 2006). An equally significant shift was occurring at the scale of building design as professional responsibility for many aspects of thermal performance shifted from architects to heating, ventilation and air conditioning engineers. Neither of the two main target audiences for *Fundamental Knowledge on Urban and Building Climatology* was in receptive mode for insights into their climate-shaping role.

Policy Precedents—Achieved

Cities which did incorporate urban climatic analysis into planning were the exception rather than the rule: but some did. The Building Research Station at Haifa Technion provided important climatological support of new settlement design in Israel (Givoni, 1969). The Japanese architect Kenzo Tange undertook wind-tunnel experiments of different layout options for his successful entry for the reconstruction of the Yugoslavian city of Skopje after the earthquake of 1961 (Tange, 1967). Major cities tended to commission climatic investigations episodically in response to critical events. Concern over urban 'dust domes' or 'haze hoods' was a typical trigger (Lowry, 1967). A three-day inversion episode in 1966 caused 168 deaths in New York City. Mayor John Lindsay appointed the public health expert Austin N. Heller as the Commissioner of the Department of Air Pollution Control (DAPC). Heller set up an 'air resource management' (ARM) network of 37 aerometric stations across the five boroughs to measure sulphur dioxide, carbon monoxide, smoke shade, suspended particulates, dust fall, wind direction and air temperature. University partners were also involved in the interests of "cross-fertilization of the academic and operational branches of applied science and basic research". Heller noted that "our department is probably the first city agency in the nation to effect such an arrangement" (DAPC, 1968). For a brief while, New York was a climate-aware city. As Mayor Lindsay commented in a TV broadcast

> A few years ago, it would have taken a meteorologist to tell you what an 'inversion' of the weather was. Now any New Yorker can tell you that it's when the layers of air above us arrange themselves in such a way that our pollution can't float away—and instead just hangs at street level in a stagnant pool … Until [Heller] came, the department never had a meteorologist on its staff. *Imagine that.* No meteorologist in a department whose job is the air around us. Not only do we now have a meteorologist, but a department is already working with Columbia, NYU, and Cooper Union in developing basic studies of our traffic pattern, our weather and air currents, and a host of new devices that may hold down pollution at its source.[2]

With a change of mayor, climate policy went off the agenda in New York City for four decades and the leading urban climatology unit on the Bronx campus of New York

University was disbanded. The city's observation networks and the research partnerships were only revived after 2002 with the election of Mayor Michael Bloomberg, who positioned New York for leadership of the new wave of global climate change awareness (Corburn, 2009; Rosenzweig *et al*., 2011).

For consistent long-term application of climatological principles to urban management, we must look to German-speaking countries, particularly the southern zone of Germany, together with neighbouring Swiss cantons and Austria. This is the only part of Europe which has an extensive literature of urban climatological monographs and where city plans will routinely cite air movement as a basis of planning policies. Both theory and practice having common origins in a national culture of weather sensitivity—*Wetterfüligkeit*—which extends far beyond awareness of *Licht und Luft* and the atmospheric dimension of public health. Factors include a conscious reaction against the negative object-lesson of industrial Britain in Germany's late industrialisation; collective memory that *Stadtluft* has cultural as well as chemical properties; a legal system that clearly allows constraint of private property rights in the environmental interest; and a decentralised constitution which requires the *Deutsches Wetterdeinst* to engage more than most national meteorology agencies with services to state and local governments. Two examples can be mentioned.

Munich has an important place in the history of climatology. Max Joseph v. Pettenkofer, creator of the *Archiv für Hygiene*, founded the first institute for urban hygiene in Munich in 1879. Several of the foundation texts of micro-climatology originate in the city's university, especially the seminal *The Climate Near the Ground* of Rudolf Geiger—first published in 1927 and still in print today (Geiger *et al*., 2009) and the *Das Stadtklima* of his pupil Albert Kratzer.

Planning regulation has been shaped by considerations of light and air ever since the late 18th century, when Prince Elector Karl Theodor declared Munich an 'open city', demolished the 17th-century fortifications, created the Englischer Garten as a public park and instituted building regulations based on separation distance. The 1904 *Staffelbauplan der K.Haupt- und Residenzstadt München* by Theodor Fischer was a remarkable synthesis of enclosed street corridors along principal roads with open layout along side streets—both elements reflecting the climatic principles of his mentor Camillo Sitte (Collins and Collins, 1965). Fischer's plan remained in effect until 1980, Munich having deliberately decided to rebuild the gaps in its ruined street plan after World War II rather than open them up, as Hanover and Berlin did, into a modernist '*stadtlandschaft*'. Under the city's *Stadtentwicklungplan* of 1963 (the Jensen Plan) the built-up extensions of the growing metropolis were to alternate with green environmental fingers. And, coming up to date, the city's present overall strategy *die Perspektive München 1998* is based on a triad of principles—*kompact–urban–grün*—that echo Fischer's early 20th-century synthesis of urbanity and nature (City of Munich, 2010).

Munich's design strategy is underpinned by climate science. In 1986, the Bavarian urban climate unit Stadtklima Bayern undertook a comprehensive measurement and modelling campaign that demonstrated Munich's dependence for summer ventilation on cold night-time air draining off the Alps to the south and daytime flows of fresh air from the Danube plain to the east (Bründl, 1988). Soon afterwards, it was decided to relocate the airport from the east to the north of the city, releasing its huge site for a trade fair and urban extension, the Messestadt Reim, which would be the first demonstration project of the ground-rules set out in the city's 'compact–urban–green' strategic vision (City of Munich, 2010).

The airport redevelopment concept was devised by one of the three climatologists behind the 1986 study of Munich, Professor Helmut Mayer, now of the University of Freiburg. The entire layout is configured to protect the quality of that slow wind that blows from the Danube plain on sticky summer days. A landscaped band 400 metres wide from east to west of the site serves as a 'fresh air glade' (*Frischluftschneise*) to guarantee the ventilation of the city centre from the east. Then, within the residential neighbourhoods, a secondary system of open spaces runs into the housing blocks to pour cool nocturnal alpine air from the south (City of Munich, 1995, pp. 11–12). It is an unusually direct application of climate analysis to urban design.

The seminal example of long-term application of climatology to the practice of urban design is found in Stuttgart, state capital of Baden-Württemberg. As a manufacturing town surrounded by steep hills, Stuttgart has always suffered from air quality problems, exacerbated by exceptionally low wind speeds and weak circulation—locals refer to the city centre as the *Kessel* (cauldron). Its planning history shows a level of awareness of climatic factors exceptional even by German standards. 'Unhindered access of light and air' was the design basis of the first workers' suburb—das Postdörfe—laid out by the Württemberg authorities for postal and railway workers in 1868. The city extension plan devised by Karl Friedrich Kölle in 1897 was based on through-ventilation (*Durchlüftung*) principles with houses spaced along one side only of the new streets along the valley sides (City of Stuttgart, 2007, pp. 16–17). The extension plan approved by Mayor Gauss in 1901 included a technical appendix by Dr Fritz Erk on the natural patterns of wind movement in the city's valleys: this science provided the basis for detailed regulation of building separation and height. As the Daimler-Mercedes works grew along the River Neckar in the first half of the 20th century, so did concern for air-hygeine, to the point where the municipal council decided in 1938 to appoint an in-house meteorologist to ensure that climatic factors were given full weight in the implementation of its 1935 Urban Construction By-law.

Paradoxically, with the outbreak of war, Karl Schwalb's first task was to create a network of rooftop chemical nebulisers and 'fog catapults' that would shroud the entire city and its factories from the view of Allied bombers. Yet the camouflage tactic also provided valuable experimental data on the pattern of air-flows in and around Stuttgart. After the war, Schwalb built up a specialist team which continues today as the Urban Climatology Unit. Dr Jürgen Baumüller succeeded him in 1971 and Dr Ulrich Reuter in 2008. Stuttgart's municipal team of 10 urban climatologists maintains a small number of weather stations, carries out *ad hoc* measurement campaigns—such as an experimental release of tracer-gas SF in the hills above the city in 1981—and operates a comprehensive set of computer models of the city climate. Baumüller and Reuter are both active scientists, well connected not only with research units in German universities but with urban climatologists world-wide (Hebbert *et al*., 2011).

Stuttgart first attracted international attention through a documentary film entitled *Urban Development and Urban Climate: Stuttgart—an example from the Federal Republic of Germany*, presented with voice-over in Chinese, Russian, Japanese and English as the official German contribution to the United Nations Habitat I Conference in Vancouver in June 1976. The film's vivid imagery included long shots of shimmering thermal hazes and three dimensional animations of cold air flows—streams of blue gel pouring down valley sides until blocked by buildings. Above all, the documentary displayed real-life city-scale climate management in the person of Oberbürgermeister Manfred Rommel, pipe-smoking son of the World War II general, scrutinising city maps with his staff of meteorologists and planners. It caused a stir in North America (Spirn, 1984) and yielded extensive long-term links with Japanese scientists and municipalities.

Stuttgart's most significant policy contribution has been a translation device, the *Klimaatlas* or urban climate map, connecting meteorological analysis of the city's 'climatopes' to policy guidelines for planning. High-resolution mapping of air flows and thermal exchanges provides an evidence base for controls over the siting and massing of buildings, the management of open spaces and the reservation of unbuilt zones as catchments and conduits of the strategic ventilation system (Hebbert and Webb, 2012). It is useful equally for the determination of individual sites and for the spatial planning of the metropolitan region of 2.6 million inhabitants (VRS, 2008).

The prosperous Schwabian capital in the Neckar valley, where vineyards co-exist with high-technology car production, might be a special case. Yet under the heading of *Environmental Meteorology Climate and Air Pollution Maps for Cities and Regions*, its methodology has been adopted as national standard VDI 3787-1 by the Verein Deutscher Ingenieure, the German Institute of Engineers, and applied domestically in (for example) Berlin, Kassel, Freibourg, Frankfurt and Bochum. Its success has prompted international interest, led by Japanese cities such as Osaka, Kobe, Yokohama, Fukuoka, Okayama and Sakai, with many others following world-wide (Ren *et al.*, 2011). The *Klimaatlas* focus on topography, roughness and the katabatic and anabatic systems of air circulation has particular appeal in dense hot-humid centres such as Hong Kong, Kaohsiung City, Singapore and Phom Pehn, where even the slightest acceleration of air flows may have significant implications for ventilation and human thermal comfort (Hebbert *et al.*, 2011). So a methodology evolved in the temperate zone has found a following in the southern hemisphere—playing a part, for example, in the Hong Kong government's response to the SARS crisis (McCann and Ward, 2011, ch. 6; Ng, 2012).

Recalling the historical precedents, the potential for knowledge transfer which Richard Tobin doubted in 1976 now seems strong. In a context of widespread awareness of urban climatic factors and their significance, the appeal of climate mapping is obvious. Less so are the institutional requirements that underpin it—the resources to mount high-density weather observation campaigns, expertise and computing power for models, institutional capacity to derive and enforce planning guidelines. It remains to be seen how 'mobile', in McCann and Ward's terms (2011), this technology of urbanism really is.

Conclusion

How might these precedents affect our understanding of urban climate change? First, obviously, they shift the time-frame. The urban heat island appears not as an anomalous discovery of the 1990s but in its true light as the longest-studied category of anthropogenic climate change. Instead of seeing adaptation planning as "still only a novelty" (Rosenzweig *et al.*, 2011, p. 238), we have many decades of experiment to draw upon, and not just the overhyped handful that crop up repeatedly in the urban climate literature, such as Mayor Lee Myung-bak's Cheong-gye stream in Seoul and ARUP's unbuilt master plan for Dongtang, Shanghai.

Secondly, the perspective of urban climatology brings into relief a different set of climate factors. The risk-resilience model highlights high-impact risks such as storm-surge, drought, typhoons and temperature extremes, but has less to say about everyday and localised weather phenomena such as rainfall and wind patterns. Air movement, perhaps the most important micro-climatic variable affecting human thermal comfort, occurs in every city at every hour of day and night and is directly affected by building form and urban layout. Ventilation is not just of interest in heat-waves, it enhances liveability in all weathers.

Thirdly, all the successful examples of urban climate management depend upon fine-grained spatial mapping. The repeating patterns of urban weather (i.e. their climates) are complex and spatially specific, requiring observation and analysis of local particularities. Diurnal patterns of urban wind circulation have an intricate spatial distribution linked to topography, building form and landscape. Solar radiation and shade patterns relate directly to street canyon dimensions and the spacing of buildings. Human comfort levels are highly sensitive to air flows and humidity levels dependent on presence or absence of street trees. So the level of resolution is a vital consideration: the urban climate is a meso-scale phenomenon but it can only be usefully understood in micro. The micro-climatic variables at the centre of VDI 3787-1 methodology cannot be derived from coarse-gridded models derived from IPCC forecasts of annual average temperature, precipitation and sea level rise. Ren *et al*. (2011) show how a city's geographical information system (GIS) base can support the integration of three broad categories of data: analytical maps of climatic elements such as air temperature, atmospheric humidity, wind velocity and direction, precipitation, fog and mist, and air pollution; geographical terrain information derived from topographic, slope/valley and soil type maps; and a third layer of data on land use, landscape and buildings, with associated planning parameters. The climatic analysis map translates into site-specific recommendations—proactive, to improve and maintain desired microclimates, and reactive, to deal with undesirable consequences of development. The methodology reveals potentials that may be missed by a risk-resilience approach: potential to reduce urban thermal loads; to optimise existing urban ventilation paths and chart new air paths where needed; to protect cold air production and drainage areas in the peri-urban landscape; to harness topography, land–sea breezes and the internal thermal circulation of the urban heat island. Again, Stuttgart's climate change adaptation strategy offers a nice example of the global–local coupling in practice (City of Stuttgart, 2010).

Fourthly, urban climatology offers a different perspective on mitigation and adaptation. UN-HABITAT has argued that the surest way to mitigate carbon emissions is by planning for compact, mixed-use urbanism, "delinking high living standards and high quality of life from high consumption and high greenhouse gas emissions" (UN-HABITAT, 2011, p. 61). Yet the same report fails to explain how urbanists are to become climatically informed, except by compiling lists of previous extreme weather events and small disasters (UN-HABITAT, 2011, p. 147). We argue the equal importance of understanding everyday weather. Approximately half the urban heat island is caused by human energy use, and half is solar energy trapped in the urban form. Both aspects can be affected, for better or worse, by physical planning and landscape. This spatial, diagnostic approach is most urgently required in tropical cities where present planning and design practices still aggravate instead of mitigate (Emmanuel, 2005).

And finally, the story of urban climatology has an institutional dimension. It is true that the urban climate awareness campaigns mounted over four decades by the World Meteorological Organisation, UNEP, the World Health Organisation and the International Federation for Housing and Planning had disappointingly little impact: but perhaps they should be remembered precisely because they demonstrate the limits of declaratory international action. For successful examples of applied climate science, look to City Hall. Mayor Bloomberg's strategic vision for New York City, PlaNYC, makes the point: released in 2007, updated in 2011 and put to the test in dramatic fashion by Hurricane Sandy in 2012 (PlaNYC, 2012).

Urban climate management is a classic instance of municipalism in action: it depends upon local capacity, competences and political autonomy—on a pipe-smoking mayor poring over the detailed city map with local expert staff. Cities which understand and manage their local climate have a head start in responding to global climate change. We can almost invert the famous mediaeval German proverb 'city air makes free' to say that a free city can make its air. Which cities can realistically hold out that hope is a topic for another day.

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Notes

1. See: www.urban-climate.org.
2. J. Lindsay speech transcript, 18 July 1967, Department of Air Pollution Control, The City of New York.

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