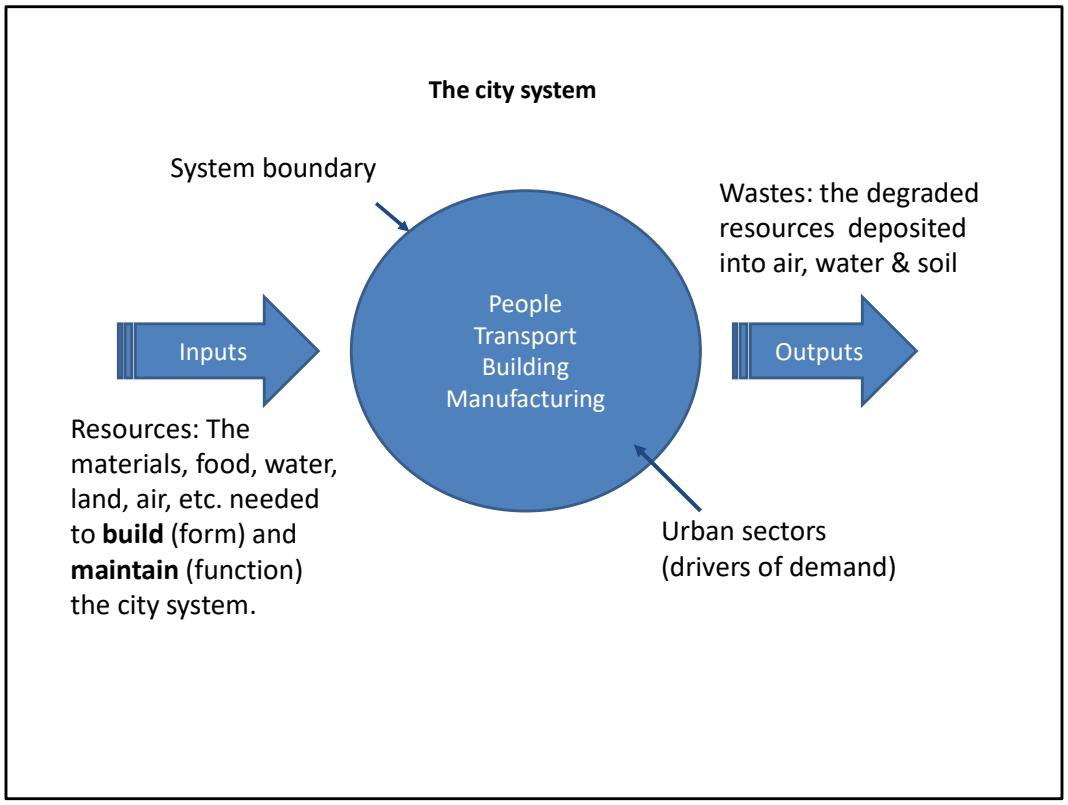
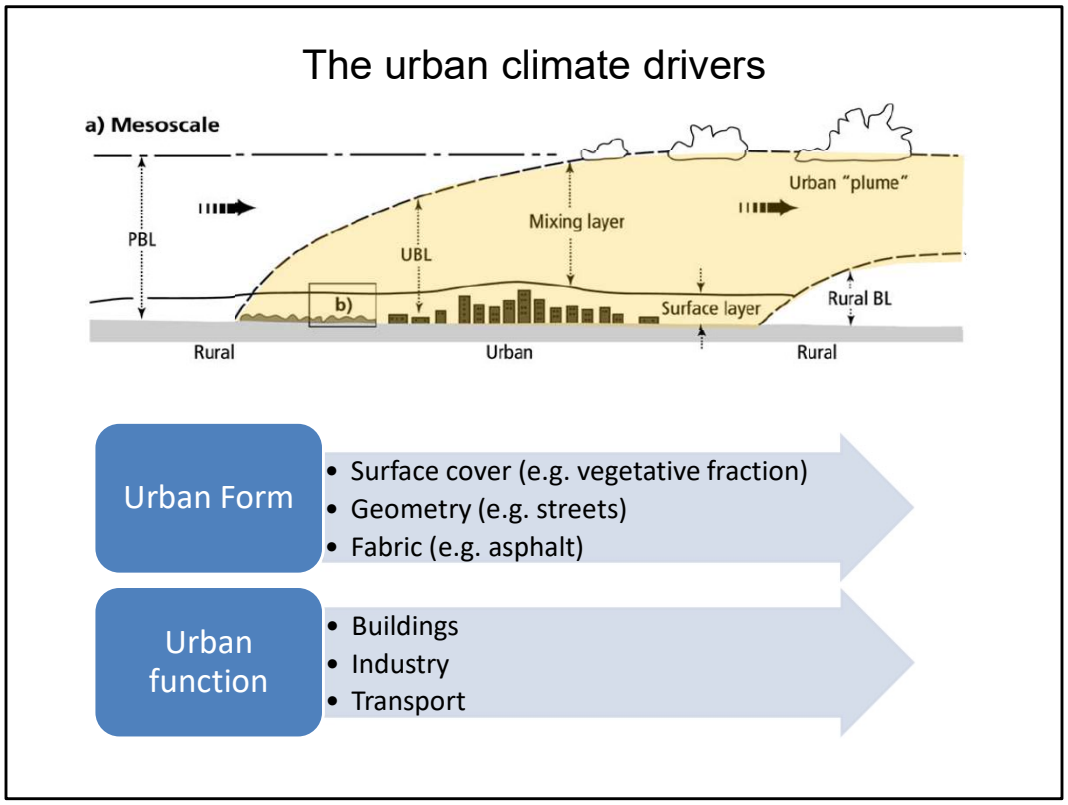
Urban climate is concerned with the impacts that cities have on the overlying atmosphere (at all scales) and the impact of climate on cities. This image of a suburb of Mexico city shows the complete landscape transformation associated with urbanisation as the vegetation is removed and replaced with buildings and paving. What is not visible here is the subterranean infrastructure (pipes) that carry water and waste, electrical cables, etc. Note that this urbanised landscape is draped over a hilly topography, which also has and effect on the climate near the ground. The challenges in urban climate science are to identify (measure) and understand (model) the urban effect in the context of global, regional, urban, local and micro-scale climate changes and develop actions (policy) to ameliorate undesirable outcomes.



This diagram show the city as a defined entity with clear boundaries (identifying this boundary is not simple and is a major decision when formulating the 'problem') A constant flow of resources is needed to sustain the city (its economy and inhabitants): on the left these raw and processed resources enter and on the right degraded (and processed) resources leave. There may be a net accumulation of resources in the city as it grows (horizontally and vertically) and increases the stock of materials, but most resources (left) become waste (right) that enters the air, water and soil where it degrades the natural resources. The demand for resources is linked to drivers within the urban system often identified by economic sector. Of course, these sectors for the geography of the city, described by land-use (function) and land-cover (form).



This diagram shows a cross-section of the city and the impact on the overlying air. The diagram shows the formation of an urban boundary layer (UBL) that eventually occupies the Planetary Boundary Layer (PBL). This layer will be 1-2k thick during the daytime and the UBL has properties that can be linked to the underlying city surface. Note that the UBL has a shape that is regulated by the regional wind that displaces the UBL downwind. On the leeward side of the city, a new PBL linked to the changed lower surface develops, leaving the UBL as a plume that is advected and mixed beyond the urban footprint. The UBL can be divided into two parts: a surface (SL) and mixing (ML) layers. The SL occupies the lowest 10% of the UBL and is strongly linked to the city surface – the ML above combines the contribution of the city with the properties of the air that has advected from upwind surfaces. These layers have an urban 'signal' that is the result of two aspects of cities, divided here into form and function; together these alter natural exchanges (form) and add anthropogenic exchanges (function). These effects extend upward over the city and downwind.

Urban form

The physical imposition of human design onto the natural landscape.

Surface cover – vegetated/built

Fabric – glass, asphalt, concrete

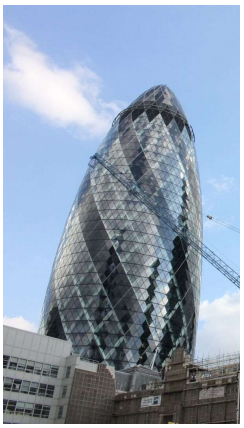
Geometry – street canyons

Urban form has three components: surface cover, materials and geometry. Surface cover describes the extent of urbanised/natural landscape; the latter is generally impervious and seals the underlying soil. Materials describe the construction materials that comprise this landscape, that is the concrete, asphalt, glass etc. The geometry of the city refers to the 3D elements (height, width, depth and orientation) and their layout. The form alters the receipt of solar radiation at the surface (shadows), reflection of sunlight and the gain/loss of radiation to/from surfaces; it also changes the airflow near the surface, creating areas of calm and exposure. The urban form is

Urban functions

The flow of energy, materials, people into/out of cities that is needed to sustain its activities.

Traffic



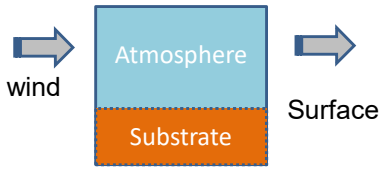
Buildings

Industry

Urban functions describe all of the human activities that demand resources in the city. These demands are often categorised into sectors (such as industry, transport and buildings), which have distinct temporal needs associated with manufacturing, lighting, heating/cooling, mobility, etc. Moreover, these sectors may dominate in different parts of the city creating distinct land uses. The wastes associated with the sectors are deposited into the air, water and soil, inside and outside the city. The emissions may be spatially disconnected from the demand – for example, energy production to generate electricity creates waste at the source of production and at the source of use – the latter is often in the form of heat that is added to the environment.

The urban energy budget

Net Radiation (Q^*) + Anthropogenic heat flux (Q_F) = Sensible heat flux (Q_H) + Latent heat flux (Q_E) + Heat Storage (ΔQ_S) + Advection (ΔQ_A)



The energy budget is an application of the principle of conservation of energy to the Earth's surface. It describes the partitioning of available energy into turbulent fluxes with the overlying air, heat transferred by conduction into the substrate and advection (horizontal transfer).

This budget can be applied to any surface, including urban surfaces once the surface is defined. The urban contributions to consider are:

1. The addition of the anthropogenic heat flux (functions) which adds heat.
2. The impacts of impervious surface cover (form) – enhanced heating over evaporation.
3. The character of the urban fabric (form) enhanced heat storage on the substrate and,
4. The effects of geometry (form) which alters the gain/loss of radiation at the 'surface' and reduces mixing close to the ground.

The urban influence on climate near the ground is often explored using the energy budget. Measuring and modelling these exchanges and the variations across the urban landscape is at the heart of urban climate science, which captures the urban effect.

The components of a climate science

Science infrastructure
- Coherent and consistent observations
- A comprehensive framework for analysis
- An understanding of processes
- A means of simulation and prediction

Communication
- Effective exchange of knowledge
- Agreed lexicon of terms

Application
- Modification of behavior and actions in response to knowledge

Evaluation
- An examination of the effectiveness of application

A ‘science’ of urban climates would generate knowledge that is based on an understanding of the urban effect, communicate this effectively such that this knowledge can be transferred from place to place.

The development of the field is not straight-forward and parts are still under-researched and there are ‘gaps’.

Urban climate science: A brief history

Time	
<1960	Few researchers, rudimentary equipment, measurement of effects (UHI), case studies.
1970-	Few researchers, often working in isolation (few conferences). Shift to process-based understanding using simple models.
1980-	More researchers, development of flux measurement techniques.
1990-	Greater links between models and measurements. Improved descriptions of urban surfaces and the relevant parameters. Emergence of satellite-based urban studies
2000-	Formation of IAUC. Internationalisation of subject. More comprehensive team-based studies. Human thermal comfort as a core subject.
2010-	Links between urban-regional-global models – need for integration. Emergence of IoT and amateur weather station information to overcome data gap.
2020-	Machine learning as a way of processing very large datasets from multiple sources.

This is a brief history of the development of the UC field, broken down by decades for convenience. The path shows a transition from the dominance of observations to modelling, from response variables (temperature, wind, humidity) to process variables (fluxes of energy). The path has been driven by advances in technology (computer, satellites, low-cost sensors), better understanding of the urban surface and improved analytical capabilities. Of course, this has occurred within a context of changing scientific questions. For example, in the last two decades, urban climate science has been increasingly been integrated into regional and global climate sciences as it has become clear that climate change challenges have to studied across the scales.

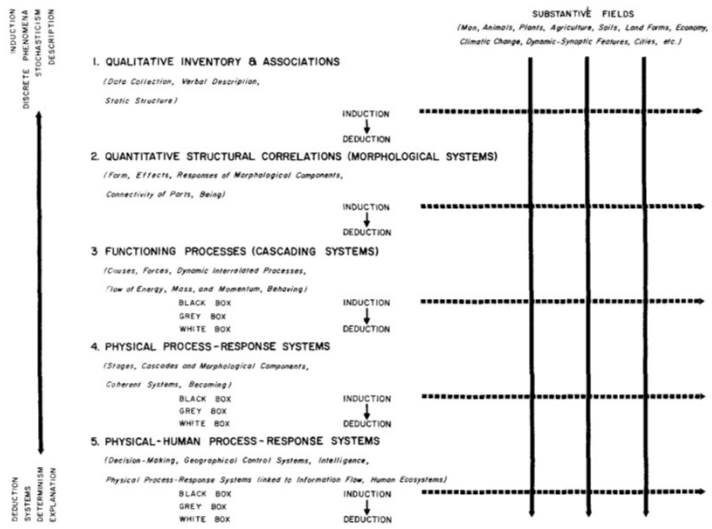


FIG. 2. Possible levels of methodology in physical geography. See text for further explanations.

Ideally an emphasis on man's role in intervening in the natural process-response systems to change the face of the earth should be the most important strategy of geographic research. Such systems deal with the throughput of energy, mass, momentum, and information.

Terjung, W.H., 1976. Climatology for geographers. Annals of the Association of American Geographers, 66(2), pp.199-220.

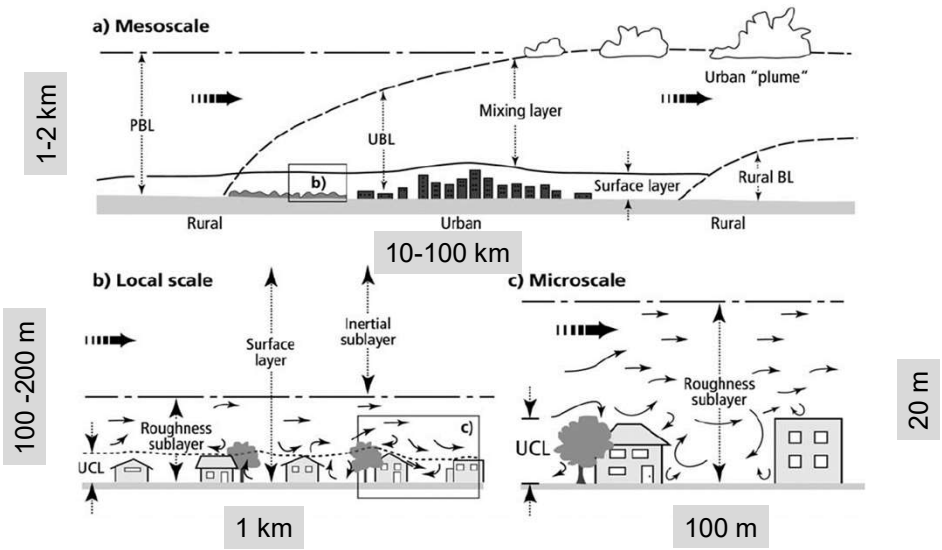
The ideas that underpin much of what we do today were established in the past. Much of the body of literature on urban climates was written in the late 20th century and many of those now teaching the subject would have had their ideas formed by key papers. There is considerable value in reading these papers if only to understand why the research field has taken specific paths. The above diagram comes from an important paper (rarely cited) by a pre-eminent urban climatologist Werner Terjung who argued that the essential task for the climatologist as geographer was to develop models to understand the human environment in the context of 'process-response' systems. He is the first to apply a model to the study of the radiation exchanges within a city street (part of the urban canopy).

History of UC through its developers
Tim R. Oke

TR Oke	1988	Boundary layer climates, 2nd edn.	Routledge, London	10402*
TR Oke	1982	The energetic basis of the urban heat island	Quarterly Journal of	4621
JA Voogt, TR Oke	2003	Thermal remote sensing of urban climates	Remote Sensing of E	2862
TR Oke	1973	City size and the urban heat island	Atmospheric Environ	2696
ID Stewart, TR Oke	2012	Local Climate Zones for urban temperature studies	Bulletin of the Ameri	2634
TR Oke	1988	Street design and urban canopy layer climate	Energy and Buildings	1995
TR Oke	1981	Canyon geometry and the nocturnal urban heat island: comparis	Journal of Climatolog	1484
CSB Grimmond, TR Oke	1999	Aerodynamic properties of urban areas derived from analysis of	Journal of Applied M	1376
TR Oke, G Mills, A Christen, JA Voogt	2017	Urban climates	Cambridge Universit	1128
TR Oke	1988	The urban energy balance	Progress in Physical g	1053
TR Oke	2004	Initial guidance to obtain representative meteorological observat	World Meteorologica	1010
M Roth, TR Oke, WJ Emery	1989	Satellite-derived urban heat islands from three coastal cities and	International Journal	975
TR Oke, GT Johnson, DG Steyn, ID Watson	1991	Simulation of surface urban heat islands under 'ideal'conditions a	Boundary-Layer Met	875
TR Oke	1989	The micrometeorology of the urban forest	Philosophical Transa	788
TR Oke	1976	The distinction between canopy and boundary-layer urban heat i	Atmosphere 14 (4), 2	700
RA Spronken-Smith, TR Oke	1998	The thermal regime of urban parks in two cities with different su	International Journal	616
TR Oke	1995	The heat island of the urban boundary layer: characteristics, caus	NATO ASI Series E Ap	608
Y Nakamura, TR Oke	1988	Wind, temperature and stability conditions in an east-west orient	Atmospheric Environ	602
CSB Grimmond, TR Oke	2002	Turbulent heat fluxes in urban areas: Observations and a local-sc	Journal of Applied M	554
M Nunez, TR Oke	1977	Energy balance of an urban canyon.	Journal of Applied M	529
CSB Grimmond, TR Oke	1999	Heat storage in urban areas: Local-scale observations and evalua	Journal of applied m	523
TR Oke	2006	Towards better scientific communication in urban climate	Theoretical and Appl	477
JA Voogt, TR Oke	1997	Complete urban surface temperatures	Journal of Applied M	457
MW Rotach, R Vogt, C Bernhofer, E Batchvarova, A Chris	2005	BUBBLE–an urban boundary layer meteorology project	Theoretical and Appl	451
ID Stewart, TR Oke, ES Krayenhoff	2014	Evaluation of the 'local climate zone'scheme using temperature o	International journal	443
TR Oke	1979	Review of Urban Climatology, 1973-1976	Technical Note, Worl	382*
CSB Grimmond, TR Oke	1991	Evapotranspiration-Interception Model for Urban Areas.	American Geophysic	373
TR Oke, RA Spronken-Smith, E Jauregui, CSB Grimmond	1999	The energy balance of central Mexico City during the dry season	Atmospheric Environ	360
V Masson, CSB Grimmond, TR Oke	2002	Evaluation of the Town Energy Balance (TEB) scheme with direct	Journal of Applied M	356
TR Oke, GB Maxwell	1975	Urban heat island dynamics in Montreal and Vancouver	Atmospheric Environ	352
CSB Grimmond, M Roth, TR Oke, YC Au, M Best, R Betts,	2010	Climate and more sustainable cities: Climate information for imp	Procedia Environmen	340
CSB Grimmond, HA Cleugh, TR Oke	1991	An objective urban heat storage model and its comparison with c	Atmospheric Environ	322
JA Voogt, TR Oke	1998	Effects of urban surface geometry on remotely-sensed surface te	International Journal	314
RT Oke	1997	Urban climate and global environmental change	Applied climatology,	305
CSB Grimmond, JA Salmond, TR Oke, B Offerle, A Lemon	2004	Flux and turbulence measurements at a densely built-up site in N	J. Geophys. Res 109	299
CSB Grimmond, TR Oke	1995	Comparison of heat fluxes from summertime observations in the	Journal of Applied M	275

There is no person who has exerted as strong an influence on the development of the modern field as Tim Oke. Work that he has completed has often set the path for the field and a judicious reading of his publication will tell you a great deal about UC up to 2010 or so. The influence of the Vancouver 'school' is remarkable. In the table above the most cited publication of this school are listed. Among the key papers that any student should read are: Oke (1973) which is the first paper to collate urban heat island studies around the word and present a statistical analysis; Oke (1976) which makes an important distinction between the canopy layer (below roof level) and boundary layers; Nunez and Oke (1978) which provides the first experiment on flux measurements in a street; Oke (1981) that examines the canopy-level urban heat island using a physical modelling experiment…. And I could go on. The list is like a 'map' of developments in the field, especially as it relates to observations, the urban surface and rigor in climate research.

The scale problem



The urban effect occurs at different scales (horizontal and vertical) and at each scale different processes dominate.

Source: Oke et al. (2017) Urban Climates. CUP

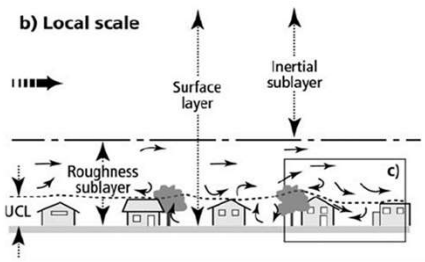
One of the most difficult aspects of urban climate is to deal with processes that produce effects at different scales. A critical part of any study is to be absolutely clear about the scale of the effect under study; this affects how you make observations and apply models, which must be appropriate to the scale. In the above the Urban boundary layer is divided into three distinct scales.

Urban atmospheric scales

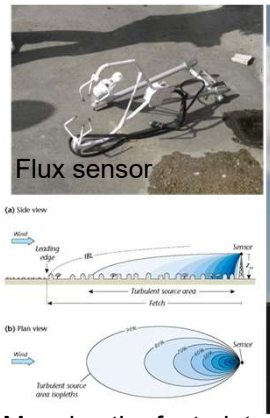
Scale	Dimensions	Sub-layers
Urban City	Horizontal: 10-100km, depending on the size (footprint) of the urbanized landscape. Vertical: 1-2km during daytime and <500 m at night	**Surface layer**: About the lowest 10% of the urban boundary layer. **Mixed layer**: The upper layer which is affected by fluxes from the surface and air from upwid surfaces.
Local Neighbourhood	Horizontal: About 1 km describing a distinct urban landscape with similar buildings and layout and similar functions. Vertical: From 10-100m depending on the heights of buildings/trees	**Roughness sub-layer**: Between 2-4 time the heights of buildings and dominated by turbulence, with each eddy linked to surface features (walls, trees, roofs, etc.). **Inertial sub-layer**: Extends from the top of the RSL to the ML. Here, all of the contributions from the surface features are thoroughly blended to represent the neighbourhood as a whole.
Micro Building/street	Horizontal: Less than 1km and often less than 100m. Vertical: Up to the heights of the roughness elements (trees & buildings).	**Urban canopy layer**: Extends to the tops of buildings. In this layer the radiation exchanges are affected by the 3D layout of buildings and airflow is greatly disturbed.

Scale is critical to urban climate study. Note that the local scale implies a degree of homogeneity that allows the Inertial Sub-Layer to form. It is in this layer that instruments must be placed to record the impact of the neighbourhood. Instruments within the UCL record the micro-scale environment only. This distinction is critical to modelling also.

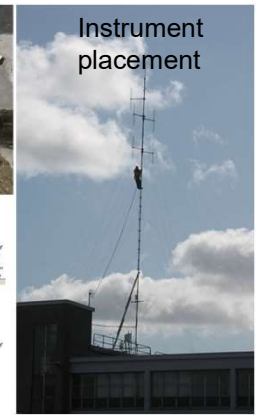
The surface heterogeneity problem



To capture the neighbourhood signal means that sensors need to be placed above the RSL. To link the observations to the underlying surface, the 'footprint' of the signal needs to be mapped.



Mapping the footprint.

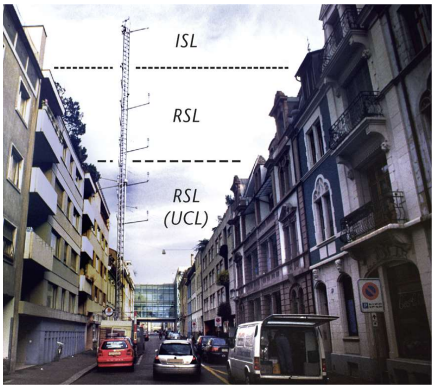


To study the city and how the UBL forms we examine its (local) parts through sampling (chose neighbourhoods). To study the micro-scale we sample types of UCL, such as streets.

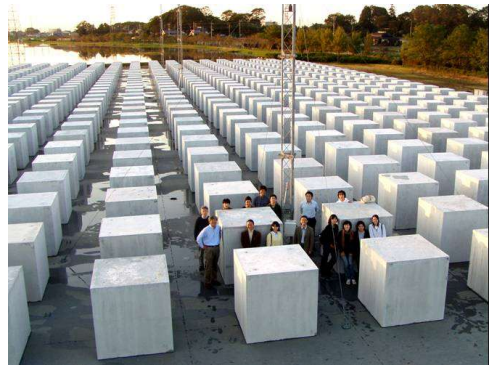
Related to the scale problem, the heterogeneity of the urban surface poses problems. This causes the structure of the urban atmosphere to constantly adjust over short distances; to obtain results that can be generalized we need to select sites carefully based on the surface properties.

Simplifying the urban surface

BUBBLE experiment



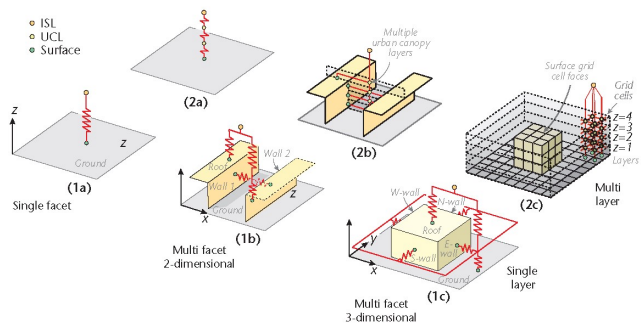
Source: Kanda Lab, Tokyo



A common methodology in urban climate science is to simplify the surface and control for scale and heterogeneity through careful site selection and/or modelling. On the left is a mast in a Zurich street; on the left is a physical (scaled) model of a ‘neighbourhood’.

Note the mast for instruments extends from the ground through the urban layers.

‘Embodied’ urban climate knowledge (models)



There are now a suite of models of varying sophistication available that can simulate aspects of the urban climate effect. Different models make different assumptions to

- Simplify the urban surface
- Reduce the dimensions
- Focus on particular processes.

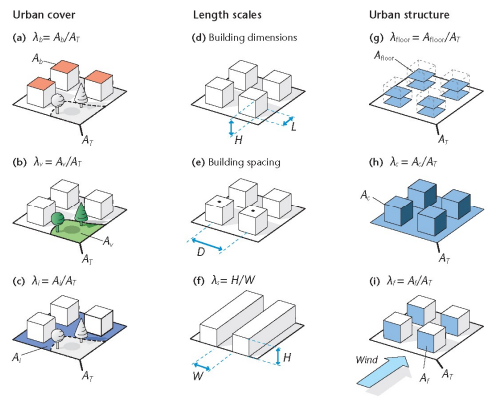
Models are selected to suit distinct needs. Very complex models require a great deal of information on the surface and considerable computation resources.

Source: Oke et al. (2017) Urban Climates. CUP

Numerical models represent ‘embodied’ knowledge of the urban climate as they store the numerical relationships between processes that link the surface to climate effects. It is important to be aware of the assumptions that are made by the selected model and the appropriate use.

Describing the urban surface

Property	Effect
Building plan area (λ_b)	Seen from above, the areas occupied by buildings, vegetation and impervious surface cover (all total to 1). This represents surface cover and are used in 2D models that do not explicitly consider the UCL.
Vegetation plan area (λ_v)	
Impervious plan area (λ_i)	
Building dimensions (H/L)	These describe the geometry of buildings and their position relative to one another. The street geometry is especially relevant as a description of the UCL and is an indicator of daytime energy gain and nighttime energy loss.
Building layout (D)	
Street geometry (λ_s)	
Floor ratio (λ_{floor})	This describes the layering of the indoor spaces within the UCL
Complete surface area (λ_c)	This describes the ration of the total surface area to the plan surface area. In densely built cities, this is often much greater than 1.
Frontal area (λ_f)	This is the area 'exposed' to the wind and indicates the disturbance to airflow generated by 3D obstacles.



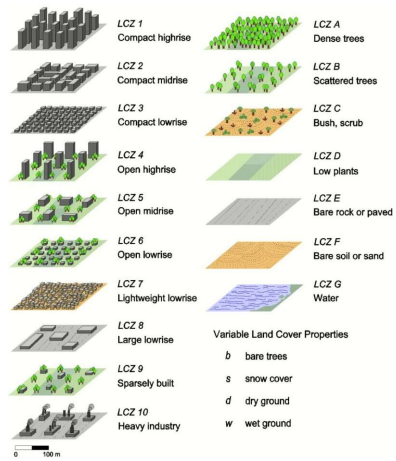
Observations and models have identified key **urban canopy parameters** (UCPs) that describe aspects of the landscape which modulate urban climate effects. This diagram shows UCPs related to aspects of urban form.

Source: Oke et al. (2017) Urban Climates. CUP

Each urban climate model requires numerical details (parameters) that describe the varying nature of the urban landscape. Typically, these UCPs are calculated for grid cells of a given dimension that extend across the built landscape, with each grid representing an area of 1-10 sq. km.

Simplifying the urban landscape
LCZ to UCPs

LCZ Type	Mean building Height (m)	Building Surface Fraction	Impervious Surface Fraction	QF (Wm^{-2})
1	>25	40-60%	40-60%	50-300
2	10-25	40-70%	30-50%	<75
3	3-10	40-70%	20-50%	<75
4	>25	20-40%	30-40%	<50
5	10-25	20-40%	30-50%	<25
6	3-10	20-40%	20-50%	<25
7	2-4	60-90%	<20%	<35
8	3-10	30-50%	40-50%	<50
9	3-10	10-20%	<20%	<10
10	5-15	20-30%	20-40%	>300



The **Local Climate Zone** approach developed by Stewart and Oke builds on other approaches and provides a classification scheme for urbanised and natural landscapes that can be used to describe **neighbourhoods** within cities.

In other words, a map of LCZ types is also a map of many UCPs.

Local Climate Zones were developed for the study of the canopy-level urban heat island (CUHI). Its purpose was to shift the analysis away from a simple urban-rural dichotomy to a richer understanding of the thermal effects of different urban landscapes. In future, communication would be improved by identifying the variations in the CUHI across the urbanized landscape. However, as the thermal response of the near-surface air is closely tied to other urban effects, the LCZ scheme can be used as a template for describing (in types and UCPs) the make-up of a city.

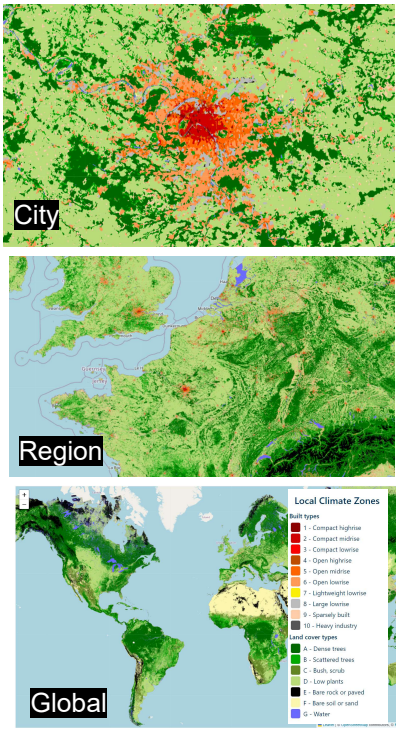
WUDAPT

Creating a global urban climate infrastructure

The World Database Access and Portal Tools (WUDAPT) was initiated to acquire climate relevant data on cities worldwide. These data should be gathered using consistent methods and quality-controlled. Achieving these data would overcome a major obstacle to progress in urban climate science by:

- Providing data on cities that have little or none;
- Allowing the application of some urban models to city applications;
- Linking climate sciences across the scales from global to local.

The global LCZ map is the outcome of a decade of work in the application of urban knowledge within the framework of large-scale geospatial modelling using satellite data. The data provides a first-order description of cities at a 100m resolution that can be used to support urban climate studies.



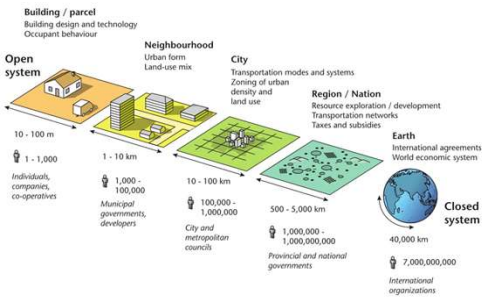
The LCZ generator (https://lcz-generator.rub.de/global-lcz-map) is a major achievement in the development of urban climate science as it provides a first-order description of the urban landscape globally. See: Demuzere, M., Kittner, J., Martilli, A., Mills, G., Moede, C., Stewart, I.D., van Vliet, J. and Bechtel, B., 2022. A global map of local climate zones to support earth system modelling and urban-scale environmental science. Earth System Science Data, 14(8), pp.3835-3873.

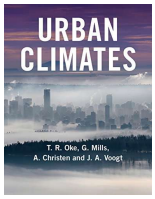
The scope of the subject

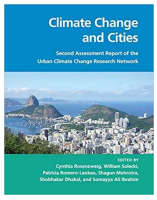
Modes of investigation or practice	
Conceptualization	X
Theorization	X
Field observation	X
Modelling (statistical, scale and numerical)	X
Validation of models	X
Application in urban design and planning	?
Impact assessment (post-implementation)	?
Policy development and modification	?

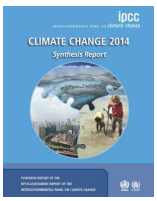
Oke, T.R., 2006. Towards better scientific communication in urban climate. *Theoretical and Applied Climatology*, *84*(1), pp.179-190.

Future: city climates to global climates









The literature on climate at each scale is growing but there is a need for better integration.

The next evolution of urban climate must overcome the challenge of integrating global with local processes. This is important because cities:

1. Modify local climates often making them worse (air quality, heat stress),
2. Alter regional and global climates contributing to climate change,
3. Are exposed to current and future hazards placing them at elevated risks from storms, intense precipitation, heatwaves, etc. and,
4. Have governance structures that can be used to modify aspects of form and function.

In general, urban form is responsible for creating the distinctive micro-climates in cities and urban functions are responsible for driving global climate changes.

The challenge is to modify both form and functions to create live-able microclimates (adapt) AND reduce drivers of large-scale climate change (mitigate).

Cities are a spatial nexus for all of the anthropogenic drivers of climate change.

Building a community

The International Association for Urban Climate (IAUC) is an organization seeking membership from those with scientific, scholarly and technical interests and responsibilities in:

- the climatology and meteorology of built-up areas,
- exchange processes between the urban "surface" and the overlying boundary layer,
- urban air quality,
- wind and turbulence in the city,
- measurement, modeling and remote sensing of urban atmospheric and surface characteristics at all scales,
- micro-scale processes and patterns associated with urban landscape elements (buildings, canyons, parks, roads etc),
- building climatology,
- biometeorology and bioclimatology within urban ecosystems, including human comfort and hazards,
- the inclusion of urban atmospheric processes into design and planning and the modelling of weather, and
- the representation of urban landscapes in models of climate at meso-scales

An important part of any scientific endeavour is the creation of a community that can share ideas and co-operate on projects. For urban climate, the IAUC is the community.

www.urban-climate.org

The IAUC was established in 2000 following an international conference at which several leading urban climatologists decided that the time was right for the creation of an organisation to promote urban climate studies with focussed conferences – the International Conference on Urban Climates. At ICUC5, the first following the establishment of the IAUC, Tim Oke (in his keynote delivered at ICUC5) described the recent history of the field of urban climatology (UC) as 'overcoming the solitudes' by which he meant that the field, which had been characterised by work carried out by small groups of researchers had developed significantly such that the groups were larger, more numerous and the work was co-ordinated.

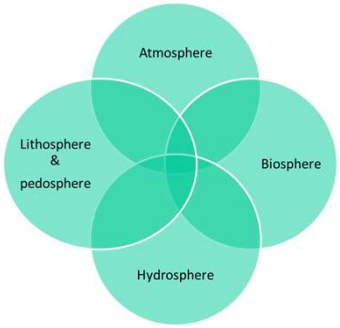
See: Oke T.R., 2006. Towards better scientific communication in urban climate. Theoretical and Applied Climatology, 84(1), pp.179-190.

Personal perspective

1. Need for integration across the urban physical and social science sciences. New curricula to support an urban science.

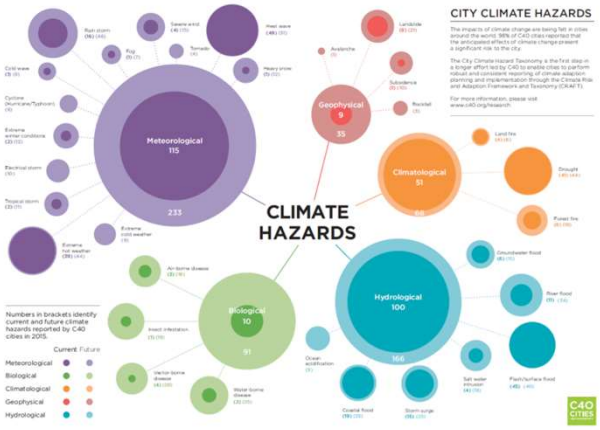
2. Re-think some aspects of urban climate science to facilitate improved understanding of links between climate scientists/managers

3. More effective knowledge transfer between places – more 'bespoke' solutions to city problems.



I would like to see climate science as part of a larger field of urban science that accounts for the integrated urban environment and its components. In this respect, humans are part of the biosphere and alter the atmosphere, hydrosphere and lithosphere.

City organizations and climate

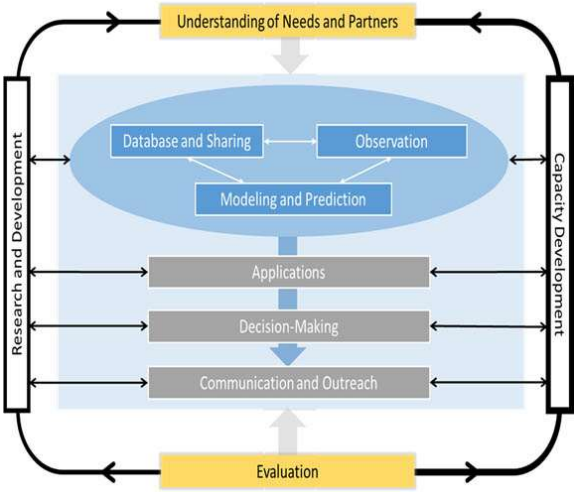


There are now several of organisations that focus on cities and climate. These include C40, ICLEI (local governments for sustainability), and GCoM (Global Covenant of Mayors). These groups focus on climate adaptation and mitigation in the context of hazard management and climate change. We need to integrate climate knowledge into the decision-making process.

Source: www.C40.org

This diagram is the result of a survey (CDP-ICLEI) on the hazards faced by cities globally, categorized by type into meteorological, climatological, hydrological, biological and geophysical. Many of these hazards are linked (heavy rain and flooding) and failures in one part of the urban system can affect other parts (domino effect), enhancing risks. Dealing with these urban risks must entail managing aspects of urban form and function at different time/space scales – it also means mapping risks across city landscapes.

Developing Integrated Urban Services

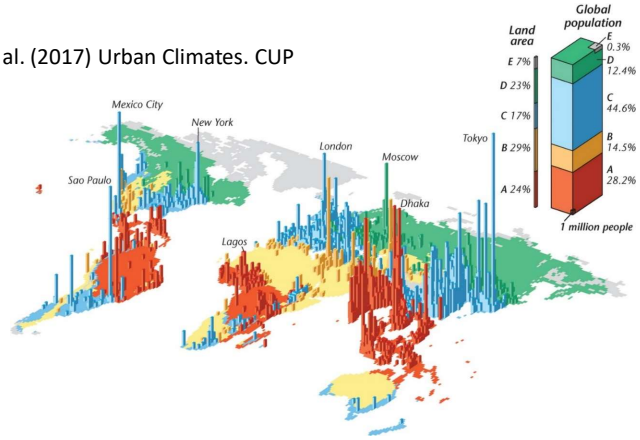


Study Group on Integrated Urban Services (SG-URB)
https://community.wmo.int/activity-areas/sercom/sg-urb

A major initiative of the WMO is to generate services for cities that integrates the scientific infrastructure (observations and models) to provide services for cities. In many national systems the infrastructure for climate, air quality, weather and water are managed by different bodies using different models and observational systems. The IUS provides the context for linking these systems together to create services for cities. The framework places the services in the context of urban needs as articulated by stakeholders (emergency services, energy producers, transport planners, etc). The development of IUS does require capacity development and investment in research and represents a major step in the development of an applied urban climate science.

Meeting emerging city climate needs

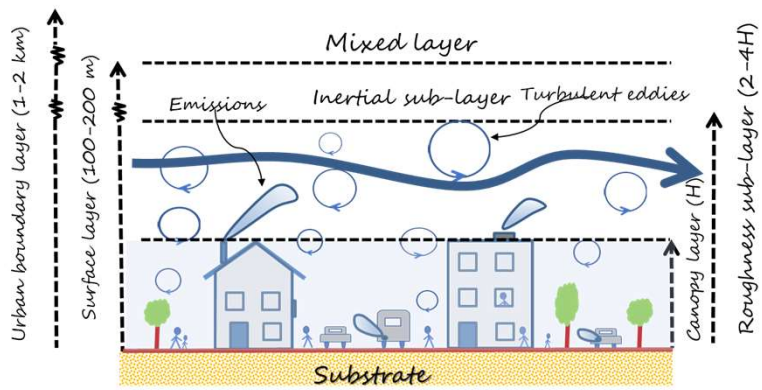
Source: Oke et al. (2017) Urban Climates. CUP



The global distribution of population (and of the urban population) is shifting to hotter climates (A climates rather than C climates), which means that urban climate science needs:

1. Improved understanding of the influence of cities on background Tropical climates and,
2. Better knowledge of emerging city landscapes (form and functions) in the Tropics.

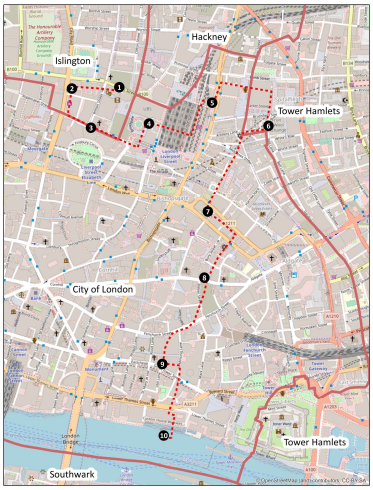
Rethinking the urban canopy layer

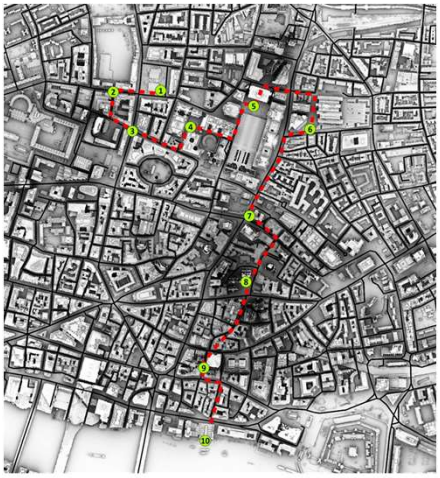


The urban canopy layer (UCL) is the zone of human occupation and is conventionally considered to be the outdoor part of the airspace at, and below, roof level. The indoor space is treated separately and is studied by architects and building engineers. However, the indoor and outdoor is separated by just the building envelope, across which energy is exchanged.

There is value in reconsidering the UCL to include both indoor and outdoor spaces as it is the occupied space, and the climates are either strongly (indoor) or weakly (outdoor) managed. Reframing the UCL in this way provides a structure for linking two fields, gathering data that meet the needs of both and linking urban with building models. It also means redefining the surface for energy studies at the microscale.

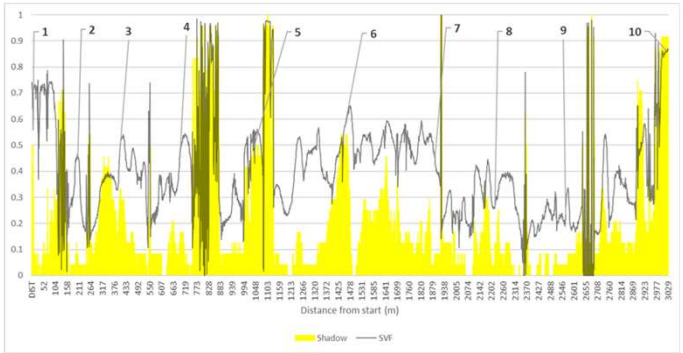
Field exposure





The London urban climate walk (with Julie Futcher) was designed to expose participants to urban microclimates and to provide a basis for understanding how cities create these climates. The path of the walk is designed to maximise the diversity of microclimates. On the right is the daylight availability on March 21st (darkest indicating greatest loss) generated using SOLWEIG within the UMEP package.

While progress in urban climate science has been achieved by isolating urban effects (on temperature, on wind, etc.) and then measuring and modelling processes and responses, there is value in training/teaching people to simply experience microclimates through using their senses.



These images show the variations in potential sunshine (yellow) and the sky view factor along the path shown in the previous slide. The bottom row shows the elements of urban form along the path.

The goal of urban climate science is to understand the processes responsible climate outcomes so that cities can be better designed and managed for their citizens. It is a vigorous science that is still developing and needs diverse inputs and the application of new ideas and concepts.

https://www.nytimes.com/2016/11/18/nyregion/new-york-today-our-city-that-never-was.html

This image

The Dome over Manhattan was a 1959 proposal for a 3-kilometer-diameter geodesic domed city covering Midtown Manhattan by the architects Buckminster Fuller and Thomas C. Howard of Synergetics,inc. Fuller expanded on his earlier work designing geodesic domes and advocating for decreased use of resources, and made a variety of claims to support the "Dome Over Manhattan," such as that it would reduce energy usage in NYC to 20% of what it was in 1960. Source: https://en.wikipedia.org/wiki/Dome_over_Manhattan