

## COURSE OUTLINE: GEOG 9224a Urban Climatology

**Instructor:** James Voogt, Ph.D., Associate Professor  
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**Room:** SSC 2401  
**Phone:** 661-2111 x 85018

**Course Meeting Times:** 9:30 – 11:30 Wednesdays (Fall term)

**Location:** SSC 2240

**Course Website:** We will use a course OWL site.

**Office hours:** Wednesdays, 2-3 pm or by appointment

### Course Description and Objectives:

This course examines the field of urban climatology – the climates of cities – and how urbanization leads to a distinctly urban climate. It develops the physical basis of urban climates through an examination of the surface radiation, energy, water and mass balances in cities on scales that range from an individual component of the urban surface, such as a roof, to the scale of an entire city. The principles of urban climate will be illustrated with examples drawn from observational, modelling, conceptual and applied studies in urban climate. Students will have the opportunity to focus on select aspects of urban climatology related to their own research. Students should have some previous background in boundary layer climatology and/or micrometeorology. The course can be related to student interests in remote sensing, field observation or numerical modeling.

### Format:

Instruction is through one two-hour lecture per week.

### Course Prerequisites:

The official course prerequisite is a senior undergraduate course in micrometeorology or boundary layer climatology or meteorology. Students who have less background may take the course with the instructor's permission and with the understanding they may need to do extra work.

### Course Materials:

We will use select chapters from:

Oke, T.R., G. Mills, A. Christen, J.A. Voogt, 2017: *Urban Climates*, Cambridge University Press.

The chapters will be provided via OWL and are intended only for personal use by the students, no further distribution or use is permitted.

In addition, this course outline provides an extended list of readings for different parts of the course. The intent is to sample readings from most sections to provide an adequate overview of urban climatology and to give a focus to sections that are of particular research relevance to individual students. Emphasis and sections covered will be adjusted to reflect student interest.

### Evaluation<sup>1</sup>:

Assignment #1	20%
Assignment #2	25%
Project	40%
Participation	15%

### Notes:

1. Marks as posted by the course instructor are considered provisional until approved by the Department Chair. Final marks are received from the Registrar; errors may be corrected through use of a Marks Revision Form.

**Details:**

Assignment #1: Choose a paper from the urban climate literature that describes an 'urban effect' and critique it in the context of the Lowry method of identifying urban climates.

Assignment #2: Choose two papers that use different methodologies to explore the same general question on some aspect of urban climate and provide a review and critique of the approach and results. As part of this assignment provide a short (15-20 min) presentation to the class.

Project: In consultation with the course instructor, undertake a project related to your own interests in urban climate. This might involve a written review of urban climate literature that relates to an aspect of your own research, use of a numerical urban model to test a simple question, or the collection and/or use of existing urban climate data that can provide an answer to a research problem. For students who have not already done so, undertaking a traverse or traverses to measure the London UHI may be selected as a project.

Participation: this component includes attendance, contributions (amount and/or quality) to class discussions, and short in-class presentations related to the lecture topic (e.g. students to present select graphics from readings and describe their importance/relevance to the lecture topic of the day – these are intended to encourage reading of the text and scientific literature – not be a major assignment).

**Penalties:**

*Assignments/Projects:* Late assignments have a penalty of 10% per day (including weekend days) without prior approval of the instructor. Exceptions can be made for documented medical and other significant reasons beyond your control (see subsequent sections).

**Non-medical Absences:**

Non-medical absences require approval of the instructor.

**Medical Absences:**

Students seeking academic accommodation on medical grounds for any missed tests, exams, participation components and/or assignments worth **10% or more** of their final grade must apply to the Academic Counselling office of their home Faculty and provide documentation. Academic accommodation cannot be granted by the instructor or department.

For UWO Policy on Accommodation for Medical Illness and a downloadable SMC see:

[http://www.uwo.ca/univsec/pdf/academic\\_policies/appeals/accommodation\\_medical.pdf](http://www.uwo.ca/univsec/pdf/academic_policies/appeals/accommodation_medical.pdf)

Downloadable Student Medical Certificate (SMC):

[http://www.uwo.ca/univsec/pdf/academic\\_policies/appeals/medicalform.pdf](http://www.uwo.ca/univsec/pdf/academic_policies/appeals/medicalform.pdf)

When medical illness affects work worth **less than 10%** of the total course grade (i.e. a lab assignment), please contact the course instructor for academic accommodation (documentation not required).

**Academic Offences:**

Scholastic offences are taken seriously and students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence, at the following Web site:

[http://www.uwo.ca/univsec/pdf/academic\\_policies/appeals/scholastic\\_discipline\\_undergrad.pdf](http://www.uwo.ca/univsec/pdf/academic_policies/appeals/scholastic_discipline_undergrad.pdf)

**Mental Health:**

Students who are in emotional/mental distress should refer to Mental Health@Western

<http://www.uwo.ca/uwocom/mentalhealth/> for a complete list of options about how to obtain help

**Western's Commitment to Accessibility:**

The University of Western Ontario is committed to achieving barrier free accessibility for persons studying, visiting and working at Western.

Please contact the course instructor if you require material in an alternate format or if you require any other arrangements to make this course more accessible to you. You may also wish to contact Services for Students with Disabilities (SSD) at 661-2111 x 82147 for any specific question regarding an accommodation.

**Support Services:**

Registrar: <http://www.registrar.uwo.ca/>

Student Development Services: <http://www.sdc.uwo.ca/>

SDC's Learning Skills Services, Rm 4100 WSS, [www.sdc.uwo.ca/learning](http://www.sdc.uwo.ca/learning)

They offer presentations on strategies for improving time management, multiple-choice exam preparation/writing, textbook reading, and more. Individual support is offered throughout the Fall/Winter terms in the drop-in Learning Help Centre, and year-round through individual counselling.

**Fire Drills:**

Students are required to evacuate the building when the fire alarm is activated.

For students who require reading to provide background preparation the following list could be useful:

Arya, S.P. 2001. *Introduction to Micrometeorology*, 2<sup>nd</sup> Edition, Academic Press, San Diego.

Bailey, W.G., T.R. Oke and W.R. Rouse 1997. *The Surface Climates of Canada*, McGill-Queen's University Press, Montréal & Kingston.

Campbell, G.S. and J.M. Norman. 1998. *An Introduction to Environmental Biophysics*, Springer-Verlag, New York.

Foken, T. 2008. *Micrometeorology*, Springer.

Garratt, J.R. 1992. *The Atmospheric Boundary Layer*, Cambridge Univ. Press, Cambridge.

Lowry, W.P. and P.P.II Lowry. 1989. *Fundamentals of Biometeorology*, Vol. 1, Peavine, Press, McMinnville.

Monteith, J.L. and M.H. Unsworth. 1990. *Principles of Environmental Physics*, 2nd ed., Arnold, London.

Oke, T. R., 1987. *Boundary Layer Climates*, 2<sup>nd</sup> edition., Methuen, London.

Rosenberg, N.J., B. Blad and S. Verma. 1983. *Microclimate: The Biological Environment*, Wiley-Interscience, New York.

Stull, R.B. 1988. *An Introduction to Boundary Layer Meteorology*, Kluwer Academic, Dordrecht.

## Course Outline

Week	Dates	Topic	Text Reference	
1	Sep 14	Introduction to urban climatology and meteorology	Chapter 1	
2	Sep 21	Concepts in urban climatology	Chapter 2	
3	Sep 28	Methods in urban climatology: Measurements for identifying urban effects	Chapter 3	
4	Oct 5	The urban radiation budget	Chapter 5	
5	Oct 12	Urban winds	Chapter 4	Assignment #1 Due
6	Oct 19	Urban energy balance: Anthropogenic heat flux and storage heat flux Urban energy balance: Convective turbulent sensible and latent heat fluxes in urban areas.	Chapter 6	
7	Oct 26	Urban Heat Island	Chapter 7	
8	Nov 2	Urban Weather – Clouds, Precipitation and Storms	Chapter 10	
9	Nov 9	Geographical Controls	Chapter 12	
10	Nov 16	Assignment #2 presentations		Assignment #2 Due
11	Nov 23	Flex topic 1	Text/OWL	
12	Nov 30	Flex topic 2	Text/OWL	
13	Dec 7*	Urban Areas and Larger Scale Climates	Chapter 13	Project Due

Flex topics: to be selected from any of the chapters in the text not yet covered, or an expansion of previous topics (e.g. a focus on the surface urban heat island), or other urban-related topics, based on the interest of course participants. Examples: Climate sensitive design, Climates of humans in cities, Urban air pollution, Urban humidity.

## Course Reading List Sorted by Topic

Readings marked with an asterisk provide a good overview of this course component. Specific readings will be selected in consultation with the course instructor on a weekly basis. The intent is not to read everything on the list, but rather to select some from within each category. The list is somewhat biased towards recent papers, so there may be instances of older references contained within these papers that may be necessary to consult

### General / Reviews

- \*Arnfield A. J. 2003: Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *Int. J. Climatol.*, **23**, 1–26.
- \*Grimmond, C.S.B., M. Roth, T.R. Oke, Y.C. Au, M. Best, R. Betts, G. Carmichael, H. Cleugh, W. Dabberdt, R. Emmanuel, E. Freitas, K. Fortuniak, S. Hanna, P. Klein, L.S. Kalkstein, C.H. Liu, A. Nickson, D. Pearlmutter, D. Sailor and J. Voogt. 2010. Climate and More Sustainable Cities: Climate Information for improved planning and management of cities (Producers/Capabilities Perspective). *Procedia Environmental Sciences*, **1**, 247–274
- \*Mills, G., H. Cleugh, R. Emmanuel, W. Endlicher, E. Erell, G. McGranahan, E. Ng, A. Nickson, J. Rosenthal and K. Steemer 2010. Climate information for improved planning and management of mega cities (Needs perspective). *Procedia Environmental Sciences*, **1**, 228–246.
- \*Pearlmutter, D. 2007: Architecture and climate: the environmental continuum. *Geography Compass*, **1**, 752–778.
- Santamouris, M. 2001: *Energy and Climate in the Urban Built Environment*. London: James & James.
- Souch, C. and Grimmond, S. 2006: Applied climatology: urban climate. *Progress in Physical Geography*, **30** (2), 270-279.
- Stewart, I. & Oke, T.R. 2012: A new classification system for urban climate sites, *Bulletin of the American Meteorological Society*, **90**(7), 922-923.

### Scales and Methodological Considerations for Urban Climatology

- \*Lowry, W.P. 1977: Empirical estimation of urban effects on climate: A problem analysis. *Journal of Appl. Meteorol.* **16**, 129-135.
- Oke, T.R. 2006: Towards better scientific communication in urban climate. *Theor. Appl. Climatol.* **84**, 179-190.
- \*Oke, T.R. 2006: World Meteorological Organization Instruments and Observing Methods Report No. 81 Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites. WMO/TD-No. 1250.
- Schmid, H-P. 1997: Experimental design for flux measurements: matching scales of observations and fluxes. *Agric. Forest Meteorol.* **87**, 179-200.
- \*Stewart, I. & Oke, T.R. 2012: Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, **93**(12), 1879-1900.
- Voogt, J.A. and Oke, T.R. 1997: Complete urban surface temperatures. *J. Appl. Meteorol.* **36**, 1117-1132.

### Radiation Balance

- \*Arnfield, A.J. 1982. An approach to the estimation of the surface radiative properties and radiation budgets of cities (Columbus, Ohio). *Physical Geography* **3**(2), 97-122.
- \*Christen, A. and Vogt, R. 2004: Energy and radiation balance of a central European City. *Int. J. Climatol.* **24**, 1395–1421.

- Harman *et al.* 2004: Radiative exchange in an urban street canyon. *Bound.-Layer Meteorol.* **110**, 301–316.
- Kanda, M. 2005: A simple theoretical radiation scheme for regular building arrays. *Boundary-Layer Meteorol.* **114**, 71-90.
- Kondo, A. *et al.* 2001: The influence of urban canopy configuration on urban albedo. *Boundary-Layer Meteorol.* **100**, 225–242, 2001.
- Nunez, M., I. Eliasson, and J. Lindgren 2000: Spatial variations of incoming longwave radiation in Göteborg, Sweden. *Theor. Appl. Climatol.* **67**, 181-192.
- \*Offerle, B. and C.S.B Grimmond 2003: Parameterization of net all-wave radiation for urban areas. *J. Appl. Meteorol.* **42**, 1157-1173.
- Sailor, D.J. and Fan, H. 2002: Modeling the diurnal variability of effective albedo for cities. *Atmos. Environ.* **36**, 713-725.
- Small, C. 2005: A global analysis of urban reflectance. *Int. J. Rem. Sens.* **26**, 661-681.
- \*Voogt, J.A. and Oke, T.R. 2003: Thermal remote sensing of urban climates. *Rem. Sens. Environ.* **86**, 370-384.
- Xu, W., M.J. Wooster, and C.S.B. Grimmond 2008: Modelling of urban sensible heat flux at multiple spatial scales: A demonstration using airborne hyperspectral imagery of Shanghai and a temperature-emissivity separation approach. *Rem. Sens. of Environ.* **112**, 3493–3510.

### Energy Balance

- \*Christen, A. and Vogt, R. 2004: Energy and radiation balance of a central European City. *Int. J. Climatol.* **24**, 1395–1421.
- \*Grimmond C. S. B. 2006: Progress in measuring and observing the urban atmosphere. *Theor. Appl. Climatol.* **84**, 3-22.
- Grimmond *et al.* 2004: Flux and turbulence measurements at a densely built-up site in Marseille: Heat, mass (water and carbon dioxide), and momentum. *J. Geophys. Res.* **109**, D24101, doi:10.1029/2004JD004936.
- \*Grimmond, C.S.B.; Oke, T.R., 1995: Comparison of heat fluxes from summertime observations in the suburbs of four North American cities. *J. Appl. Meteorol.*, **34**, 873-889.
- \*Harman, I.N. Belcher, S.E. 2006: The surface energy balance and boundary layer over urban street canyons. *QJRMS*, **132**, 2749-2768
- Lagouarde, J. –P *et al.* 2006: Monitoring the sensible heat flux over urban areas using large aperture scintillometry: Case study of Marseille city during the ESCOMPTE experiment. *Boundary-Layer Meteorol.* **118(3)**, 449 – 476.
- Moriwaki, R. and M. Kanda 2006: Flux-gradient profiles for momentum and heat over an urban surface. *Theor. Appl. Climatol.* **84**, 127-135.
- Offerle, B., C.S.B. Grimmond and K. Fortuniak 2005: Heat storage and anthropogenic heat flux in relation to the energy balance of a central European city centre. *Int. J. Climatol.* **25**, 1405–1419.
- Offerle, B. C.S.B. Grimmond, K. Fortuniak, K. Klysiak, and T.R. Oke 2006: Temporal variations in heat fluxes over a central European city centre. *Theor. Appl. Climatol.* **84**, 103–115.
- Oke, T.R., 1988: The surface energy budget of urban areas. *Progress in Phys. Geog.* **12**, 471-508.
- Piringer, M. *et al.* 2002: Investigating the surface energy balance in urban areas – recent advances and future needs. *Water, Air, and Soil Pollution: Focus* **2**: 1–16.
- Rotach, M. *et al.* 2005: BUBBLE – an Urban Boundary Layer Meteorology Project. *Theor. Appl. Climatol.* **81**, 231–261.

- \*Schmid, H-P. *et al.* 1991: Spatial variability of energy fluxes in suburban terrain. *Boundary-Layer Meteorol.*
- \*Spronken-Smith, R.A.; M. Kossmann, and P. Zawar-Reza 2006: Where does all the energy go? Surface energy partitioning in suburban Christchurch under stable wintertime conditions. *Theor. Appl. Climatol.* **84**, 137–149.
- \*Roberts, S.M., T.R. Oke, C.S.B. Grimmond, and J.A. Voogt 2006. Comparison of four methods to estimate urban heat storage. *J. Appl. Meteorol. Climatol.* **45**(12), 1766–1781.

### **Anthropogenic Heat**

- Heiple, S., Sailor, D.J. 2008: Using building energy simulation and geospatial modeling techniques to determine high resolution building sector energy consumption profiles. *Energy Build.* **40**, 1426-1436.
- Ichinose, T., Shimodozono, K., Hanaki, K. 1999: Impact of anthropogenic heat on urban climate in Tokyo. *Atmos. Environ.* **33**, 3897–3909.
- Pigeon, G. *et al.* 2007: Anthropogenic heat release in an old European agglomeration (Toulouse, France) *Int. J. Climatol.* **27**, 1969-1981.
- \*Sailor, D. J. 2010. A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. *International Journal of Climatology*, n/a. doi: 10.1002/joc.2106
- Sailor, D.J. and Lu Lu 2004: A top–down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas. *Atmos. Environ.* **38**, 2737–2748.

### **Winds**

- Eliasson, I.; Offerle, B.; Grimmond, C.S.B.; Lindqvist, S. 2006. Wind fields and turbulence statistics in an urban street canyon. *Atmospheric Environment* **40**(1), 1-16.
- Kim J.-J, Baik J-J 1999: A numerical study of thermal effects on flow and pollutant dispersion in urban street canyons. *J Appl Meteorol.*, **38**, 1249–1261.
- Offerle, B.; Eliasson, I., Grimmond, C.S.B., Holmer, B. 2007: Surface heating in relation to air temperature, wind and turbulence in an urban street canyon. *Bound.-Layer Meteorol.*, **122**, 273-292.
- \*Pearlmutter, D., P. Berliner, and E. Shaviv, 2006: Physical modeling of pedestrian energy exchange within the urban canopy. *Building and Environment* **41**(6), 783-795
- Shashua-Bar, L. Y. Tzmir, and M.E. Hoffman, 2004: Thermal effects of building geometry and spacing on the urban canopy layer microclimate in a hot-humid climate in summer. *International Journal of Climatology*, **24**(13), 1729-1742

### **Urban Heat Island**

- Basara, J.B, P.K. Hall Jr., A. J. Schroeder, B.G. Illston, and K. L. Nemunaitis 2008: Diurnal cycle of the Oklahoma City urban heat island. *J. Geophysical Research* **113** D20109. doi:10.1029/2008JD010311.
- \*Basara, J.B. H. G. Basara, B. G. Illston, and K. C. Crawford. 2010. The impact of the urban heat island during an intense heat wave in Oklahoma City,” *Advances in Meteorology*, 2010, Article ID 230365, 10 pages, 2010. doi:10.1155/2010/230365
- Ferguson, G. and A.D. Woodbury, 2007: Urban heat island in the subsurface. *Geophysical Research Letters* **34**, L23713.
- \*Fortuniak, K.; Klysik, K.; Wibig, J. 2006: Urban - rural contrasts of meteorological parameters in Lodz. *Theoretical and Applied Climatology* **84**(1-3), 91-101.

- Gallo, K.P. and Owen, T.W. 1998: Assessment of urban heat islands: a multi-sensor perspective for the Dallas-Ft.Worth USA Region. *Geocarto International* **13(4)**, 35-41.
- \*Hamdi, R., and G. Schayes, 2008: Sensitivity study of the urban heat island intensity to urban characteristics. *Int. J. Climatol.*, **28**, 973-982.
- Hinkel K.M., Nelson F.E., Klene A.E., Bell J.H. 2003a: The urban heat island in winter at Barrow, Alaska. *International Journal of Climatology* **23**, 1889–1905. DOI: 10.1002/joc.971.
- Kłysik K, Fortuniak K. 1999: Temporal and spatial characteristics of the urban heat island of Łódź, Poland. *Atmospheric Environment* **33**, 3885-3895.
- Morris C.J.G. and Simmonds I. 2000: Associations between varying magnitudes of the urban heat island and the synoptic climatology in Melbourne, Australia. *Int. J. Climatol.* **20**, 1931–1954.
- \*Nakamura, Y. Oke, T.R. 1988: Wind, temperature and stability conditions in an east-west oriented urban canyon. *Atmos. Environ.* **22(12)**, 2691-2700.
- Oke, T.R., 2009: The need to establish protocols in urban heat island work. Timothy R. Oke Symposium, American Meteorological Society Annual Meeting, Phoenix AZ.  
[http://ams.confex.com/ams/89annual/techprogram/paper\\_150552.htm](http://ams.confex.com/ams/89annual/techprogram/paper_150552.htm)
- Oke, T.R. 1995: The heat island of the urban boundary layer: characteristics, causes and effects. In. Cermak, J.E. et al. (eds). *Wind Climate in Cities*, pp 81-107. Kluwer Academic.
- \*Oke, T.R. *et al.* 1991: Simulation of surface urban heat islands under ‘ideal’ conditions at night Part 2: Diagnosis of causation. *Boundary-Layer Meteorol.* **56**, 339-358.
- \*Oke, T.R. 1982: The energetic basis of the urban heat island. *QJRM* **108**, 1-24.
- Oke, T.R., 1981: Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *J. Climatol.* **1**, 237- 254.
- Oke, T.R., 1973: City size and the urban heat island. *Atmos. Environ.* **7**, 769- 779.
- Pigeon, G. A. Lemonsu, N. Long, J. Barrie, V. Masson, and P. Durand 2006: Urban thermodynamic island in a coastal city analysed from an optimized surface network. *Boundary-Layer Meteorology* **120**, 315–351.
- \*Roth, M. 1989: Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *Int. J. Rem. Sens.* **10(11)**, 1699-1720.
- \*Runnalls, K. and Oke, T.R. 2000: Dynamics and controls of the near-surface heat island of Vancouver BC. *Physical Geography* **21**, 283-304.
- Stewart, I. and T.R. Oke, 2009: Newly developed “Thermal climate zones” for defining and measuring urban heat island magnitude in the canopy layer. The Timothy R. Oke Symposium, American Meteorological Society Annual Meeting Phoenix AZ.  
<http://ams.confex.com/ams/pdfpapers/150476.pdf>
- \*Stewart, I.D. 2010. A systematic review and scientific critique of methodology in modern urban heat island literature. *Int. J. Climatol.* DOI: 10.1002/joc.2141
- Taha, H. 1997: Urban climate and heat islands: albedo, evapotranspiration and anthropogenic heat. *Energy and Buildings* **25**, 99-103.
- \*Yow, D.M., 2007. Urban heat islands: Observations, impacts and adaptation. *Geography Compass* **1(6)**, 1227–1251.

## Urban Weather

- \*Best, M.J. 2005: Progress towards better weather forecasts for city dwellers: from short range to climate change. *Theor. Appl. Climatol.* 47-55.
- Bornstein, R. and Lin, Q. 2000: Urban heat islands and summertime convective thunderstorms in Atlanta: three case studies. *Atmos. Environ.* **34(3)**, 507-516.



- Burian, S.J. and J.M. Shepherd 2005: Effect of urbanization on the diurnal rainfall pattern in Houston. *Hydrological Processes* **19(5)**, 1089-1103
- Childs, P.P. and S. Raman 2005: Observations and numerical simulations of urban heat island and sea breeze circulations over New York City. *Pure and Applied Geophysics* **162 (10)**, 1955-1980.
- Collier, C.G. 2006. The impact of urban areas on weather. *Quarterly Journal of the Royal Meteorological Society* **132(614)**, 1-25.
- Dabberdt, W.F. *et al.* 2000. Forecast issues in the urban zone. *BAMS* **81 (9)**, 2047-2064.
- Dixon, P.G. and T.L. Mote, 2003: Patterns and causes of Atlanta's urban heat island-initiated precipitation. *J. Appl. Meteorol.* **42(9)**, 1273-1284.
- \*Han, J.-Y., J.-J. Baik, H. Lee 2014. Urban impacts on precipitation. *Asia-Pac. J. Atmos. Sci.* **50(1)**, 17-30.
- Hildebrand, P.H. and B. Ackerman, 1984: Urban effects on the convective boundary layer, *J. Atmos. Sci.* **41**, 76-91.
- Loose, T. and R.D. Bornstein, 1977: Observations of mesoscale effects on frontal movement through an urban area. *Month. Weath. Rev.* **105**, 563-571.
- Lowry, W.P. 1998: Urban effects on precipitation amount. *Progress in Physical Geography* **22 (4)**, 477-520.
- Sachweh, M. & P. Koepke, 1995: Radiation fog and urban climate. *Geophys. Res. Letters* **22**, 1073-1076.
- \*Shepherd, J.M., 2005. A review of current investigations of urban-induced rainfall and recommendations for the future. *Earth Interactions*, **9**, 1.
- Shepherd, J.M. 2013. Impacts of urbanization on precipitation and storms: Physical insights and vulnerabilities. In: *Climate Vulnerability: Understanding and Addressing Threats to Essential Resources*. pp. 109–125, Elsevier Inc., Academic Press
- Shepherd, J. M. Carter, M. Manyin, D. Messen, S. Burian, 2010. The impact of urbanization on current and future coastal precipitation: A case study for Houston. *Environment and Planning B: Planning and Design*, v 37, n 2, p 284-304, 2010

## Modelling

- \*Baklanov *et al.* 2009. Model Urbanization Strategy: Summaries, Recommendations and Requirements. In: A. Baklanov *et al.* (eds.), *Meteorological and Air Quality Models for Urban Areas*, Springer-Verlag Berlin Heidelberg.
- Best, M.J. 1998: A model to predict surface temperatures. *Boundary-Layer Meteorol.* **88**, 279-306.
- \*Best, M.J., C.S.B. Grimmond 2015: Key conclusions of the first International Urban Land Surface Model Intercomparison project. *Bulletin of the American Meteorological Society*, DOI: <http://dx.doi.org/10.1175/BAMS-D-14-00122.1>
- Grimmond C.S.B. and Oke T.R. 2002: Turbulent heat fluxes in urban areas: observations and a local-scale urban meteorological parametrization scheme (LUMPS). *J. Appl. Meteorol.* **41**, 792-810.
- Grimmond *et al.* 2010. The International Urban Energy Balance Models Comparison Project: First Results from Phase 1. *Journal of Applied Meteorology and Climatology* **49**, 1268-1292.
- Grimmond *et al.* 2011. Initial results from Phase 2 of the international urban energy balance model comparison. *Int. J. Climatol.* **31**, 244–272. DOI: 10.1002/joc.2227
- Kanda, M. 2006: Progress in the scale modeling of urban climate: Review. *Theor. Appl. Climatol.* **84**, 23-33.
- Kawai *et al.* 2007: Validation of a numerical model for urban energy-exchange using outdoor scale-model measurements. *Int. J. Climatol.* **27**, 1931-1942.

- \*Martilli 2007. Current research and future challenges in urban mesoscale modelling. *Int. J. Climatol.* **27**, 1909–1918.
- \*Masson, V. 2006: Urban surface modeling and the meso-scale impact of cities. *Theor. Appl. Climatol.* **84**, 35-45.
- Masson V. *et al.* 2002: Evaluation of the Town Energy Balance (TEB) Scheme with Direct Measurements from Dry Districts in Two Cities. *J. Appl. Meteorol.* **41**, 1011-1026.
- Masson, V. 2000: A physically-based scheme for the urban energy budget in atmospheric models. *Boundary-Layer Meteorol.* **94**, 357–397.
- \*Myrup, L.O 1969: A numerical model of the urban heat island. *J. Appl. Meteorol.* **8**, 908-918.

### Applied Urban Climates

- Givoni, B. 1998. *Climate considerations in Building and Urban Design*. Van Nostrand Reinhold ITP: New York.
- \*Mills, G. 2006: Progress toward sustainable settlements: a role for urban climatology. *Theor. Appl. Climatol.* **84**, 69–76.
- Shashua-Bar, L. & M.E. Hoffman, 2000: Vegetation as a component in the design of an urban street. *Energy and Buildings* **31**, 221-235.
- Stone Jr., Brian 2005: Urban heat and air pollution: An emerging role for planners in the climate change debate. *Journal of the American Planning Association* **71(1)**, 13-25

### Urban Areas and Larger Scale Climates

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