URBAN CLIMATOLOGY

4. Urban heat Island, UHI types, atmospheric UHI, UHI intensity

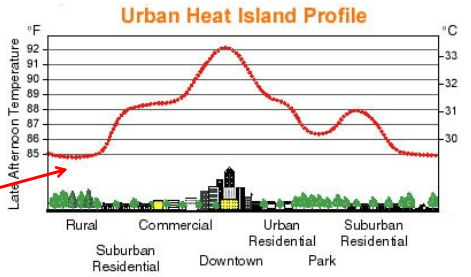
Paper to read

https://is.muni.cz/auth/el/sci/podzim2022/ZX601/um/67875456/04_UHI_BasicsCompendium.pdf

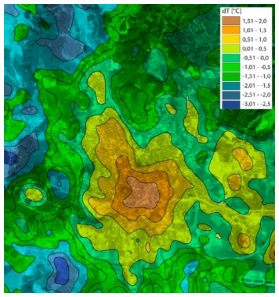
4.1 Urban Heat Island (UHI) concept

Table U2 Urban climate effects for a mid-latitude city with about 1 million inhabitants (values for summer unless otherwise noted)

Variable	Change	Magnitude/comments
Turbulence intensity	Greater	10–50%
Wind speed	Decreased	5–30% at 10 m in strong flow
	Increased	In weak flow with heat island
Wind direction	Altered	1–10 degrees
UV radiation	Much less	25–90%
Solar radiation	Less	1–25%
Infrared input	Greater	5–40%
Visibility	Reduced	
Evaporation	Less	About 50%
Convective heat flux	Greater	About 50%
Heat storage	Greater	About 200%
Air temperature	Warmer	1–3°C per 100 years; 1–3°C annual mean up to 12°C hourly mean
Humidity	Drier	Summer daytime
	More moist	Summer night, all day winter
Cloud	More haze	In and downwind of city
	More cloud	Especially in lee of city
Fog	More or less	Depends on aerosol and surroundings
Precipitation		
Snow	Less	Some turns to rain
Total	More?	To the lee of rather than in city
Thunderstorms	More	



http://weather.msfc.nasa.gov/urban/urban_heat_island.html

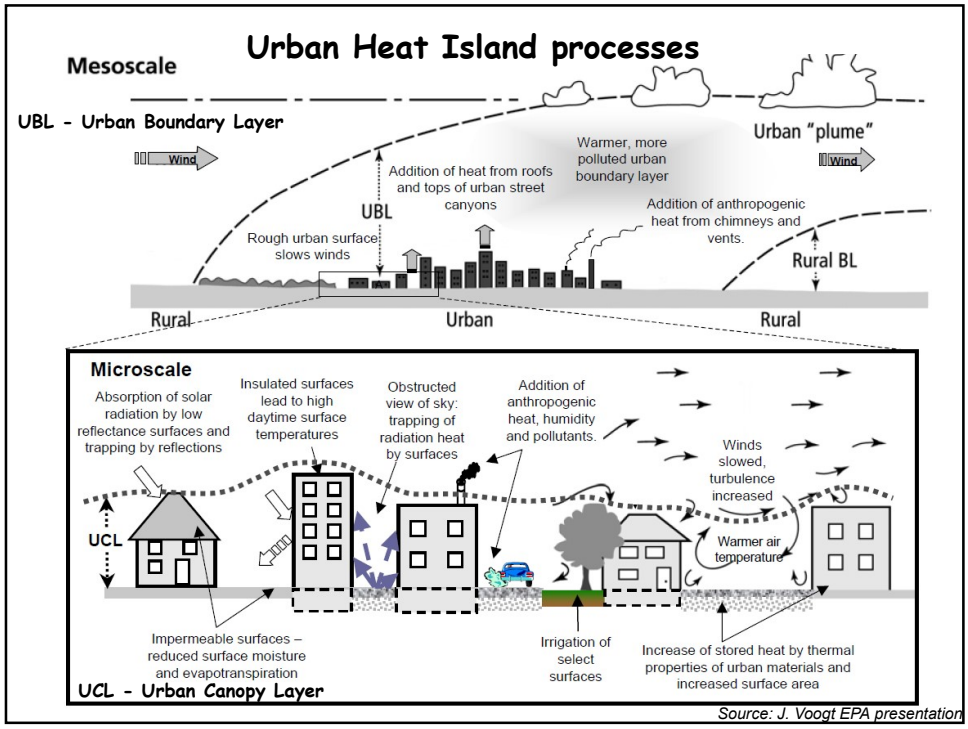


Simplified model because numerous natural and anthropogenic factors cause considerable spatial and temporal variability in the UHI

Urban Heat Island (UHI) concept

- UHI – closed isotherms indicating an area of the surface that is relatively warm; most commonly associated areas of human disturbance such as towns and cities.
- The physiographic analogy derives from the similarity between the pattern of isotherms and height contours of an island on a topographic map.
- The annual mean temperature of a large city (say 10^6 inhabitants) may be 1°–2°C warmer than before development, and on individual calm, clear nights may be up to 12°C warmer.
- This difference is called the **UHI intensity (UHI magnitude)**
- The warmth **extends vertically** to form an urban heat dome in near calm, and an urban heat plume in more windy conditions.

AMS Glossary of Meteorology, 2nd Edition (2000)



Source: J. Voogt EPA presentation

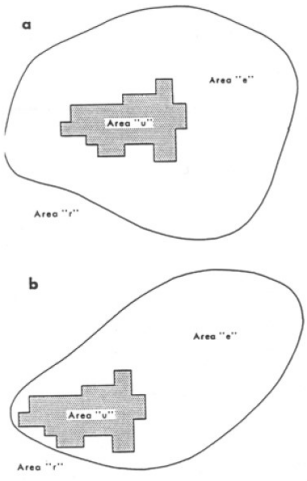
A Conceptual Model for Urban Climate Measurements

$$M_{itx} = C_{itx} + L_{itx} + U_{itx}$$

M - measured value of a weather element
C - background ("flat-plane") climate
L - departure from C due to topography
U - departure from C due to urban effects

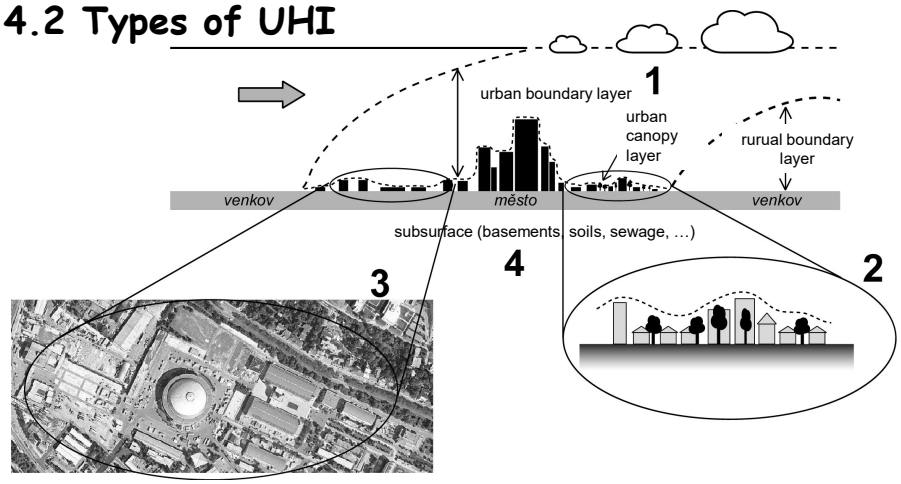
Subscripts:
i - weather type
t - time period
x - station location (urban, environs, rural)

Recognizes that a measured element is impacted by influences at a number of different scales – the trick is to try and *isolate urban influences*.



Lowry (1977)

4.2 Types of UHI

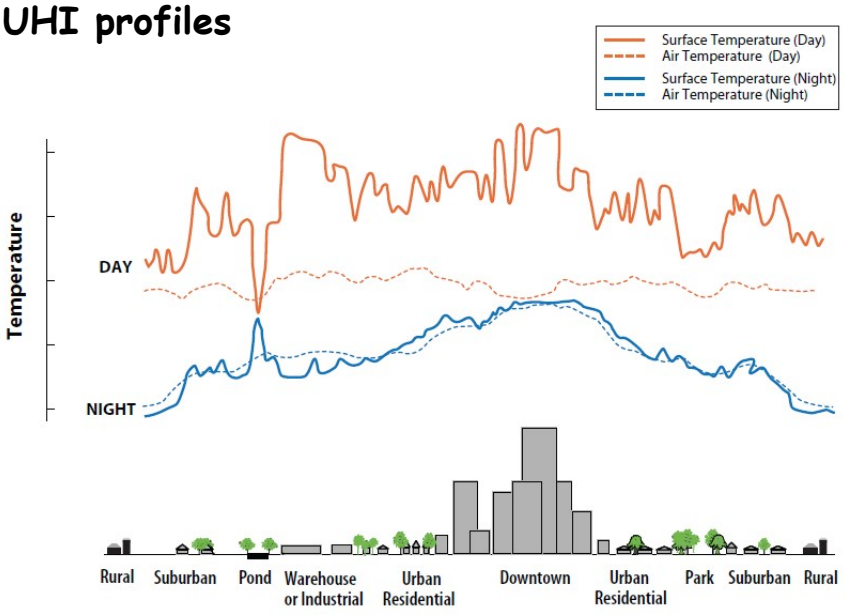


1. Atmospheric Boundary layer Urban Heat Island
2. Atmospheric Canopy Layer Urban Heat Island
3. Surface Urban Heat Island
4. Subsurface Urban Heat Island

What variables are measured?

(Oke et al., 2017)

UHI profiles



Reducing Urban Heat Islands: Compendium of Strategies and (Voogt 2000)

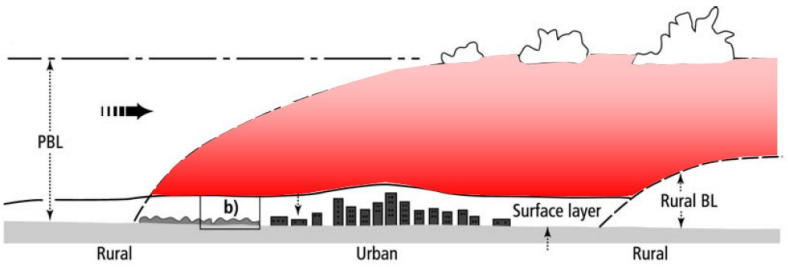
UHI types characteristic

Table 1: Basic Characteristics of Surface and Atmospheric Urban Heat Islands (UHIs)[4]

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	• More spatial and temporal variation: ▪ Day: 18 to 27°F (10 to 15°C) ▪ Night: 9 to 18°F (5 to 10°C)	• Less variation: ▪ Day: -1.8 to 5.4°F (-1 to 3°C) ▪ Night: 12.6 to 21.6°F (7 to 12°C)
Typical Identification Method	• Indirect measurement: ▪ Remote sensing	• Direct measurement: ▪ Fixed weather stations ▪ Mobile traverses
Typical Depiction	• Thermal image	• Isotherm map • Temperature graph

Reducing Urban Heat Islands: Compendium of Strategies and (Voogt 2000)

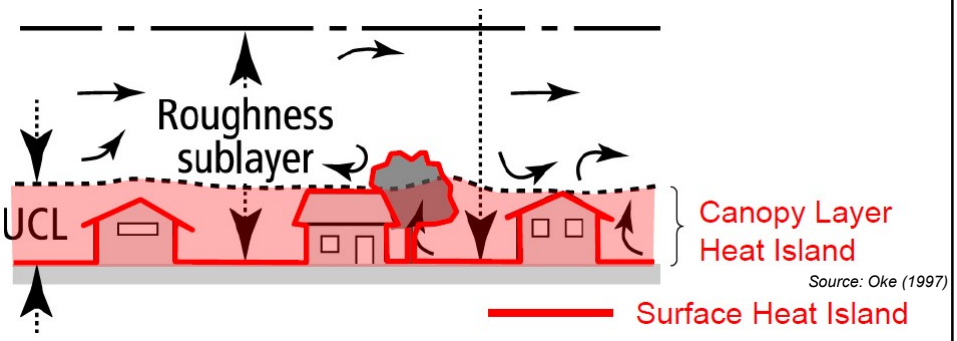
Atmospheric Boundary layer UHI



Source: Oke (1997)

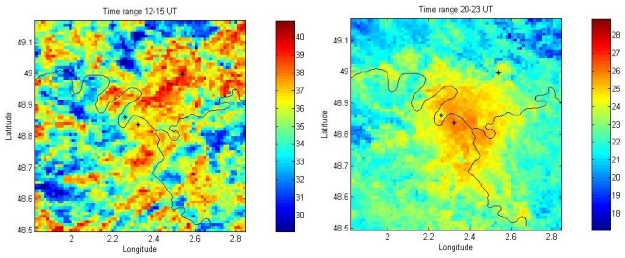
- Forms either a dome or a plume in UBL
- Measured by temperature sensors mounted on tall towers in urban and rural regions,
- Use of balloons, radiosondes, aircraft flown across the area
- Maintained by enhanced heat flux from city structures
- Higher turbulence especially during day – higher air temperatures compared to rural BL at all levels

Atmospheric Canopy layer UHI



- Measured at networks of sensors at standard (2 m) or screen-level (~1.3 m); sensors must be adequately shaded and ventilated
- Sensor location is critical in urban environments:
  - What are the measurements trying to represent?
  - What is the sensor source area – the surface type upwind of the site?
  - Are there multiple rural – non-urban types surrounding the city?
- Maximum at night, under calm and clear conditions, may be small or even negative during the day.

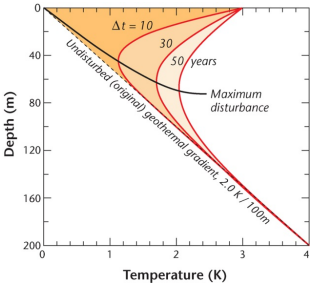
Surface UHI



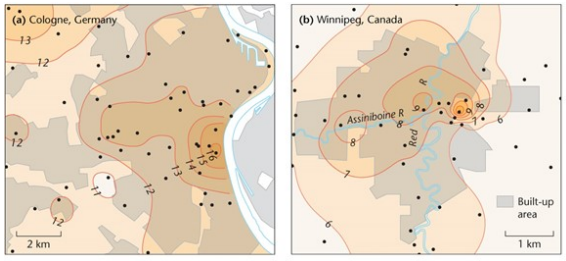
Average Land Surface Temperature in Paris, France over the heat wave event of August 4 to 13, 2003 (Dousset et al. 2007)

- Uses thermal remote sensing technology from different platforms (see next lecture)
- Surface temperature is different from air temperature
- Weather type limitation, atmospheric effects, viewing geometry,
- Mostly used as a relative surface temperature differences
- Very spatially variable especially during the day as the surface temperature of every facet depends on numerous factors (see lecture 2)
- SUHI is well expressed both day and night

Surface Urban Heat Island



Generalized form of sub surface temperature profiles

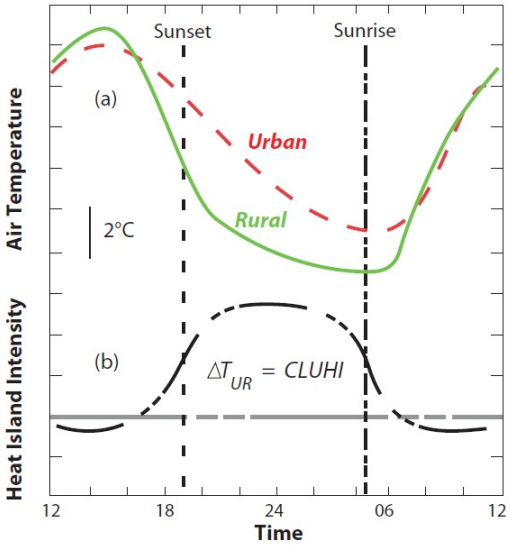


Isotherms representing sub surface UHI at Cologne, Germany at 15 m depth and in Winnipeg, Canada in 20 m depth

Oke *et al.*, 2017, *Urban Climates*
© Cambridge University Press 2017

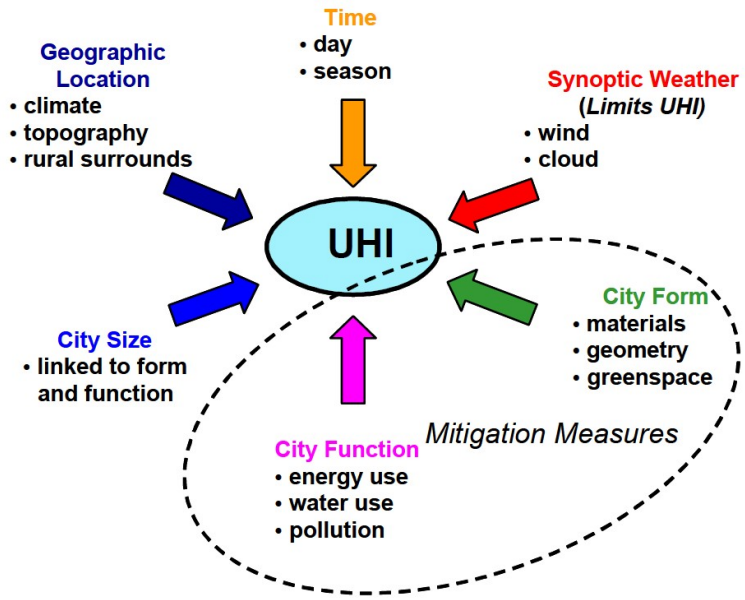
- Measured in bore holes
- Forms due to transfer of sensible heat from the urban surface to the ground
- Accumulates for a long time period
- Responds to natural (climatic) and anthropogenic processes on long time scale (monthly to decadal)

UHI intensity (ΔT_{u-r})



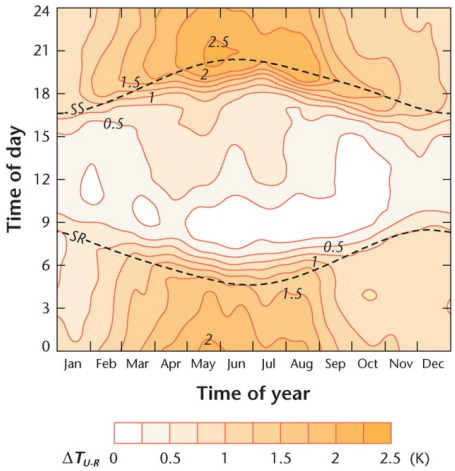
Conceptual Drawing of the Diurnal Evolution of the Urban Heat Island during Calm and Clear Conditions (modified from Oke, 1982)

Factors Affecting Urban Heat Islands



Source: J. Voogt EPA presentation

Daily and seasonal variation of the canopy UHI intensity



The canopy UHI intensity for Basel (Switzerland) calculated as a difference between urban and rural station (average over the 10 year period, SR and SS are times of the sunrise and sunset respectively.

Oke *et al.*, 2017, *Urban Climates*

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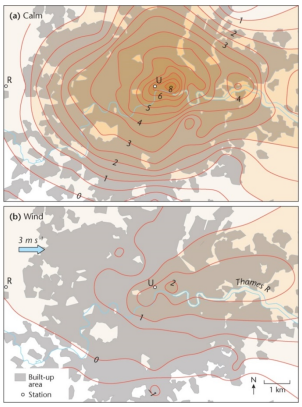
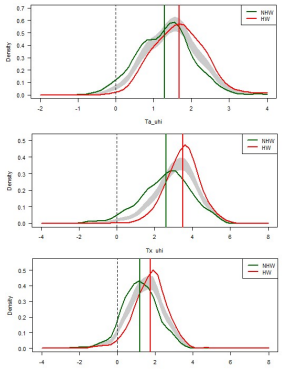
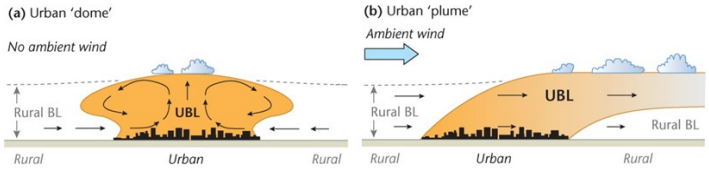
UHI intensity and weather types



Nocturnal UHI intensity in London during the radiation-driven (a) and advection-driven (b) weather



UHI intensity for heat wave days (HW) and non-HW days (NHW) during the summer months (JJA season) of the 2011-2020 period at Brno BISK station. Vertical lines are mean UHIIs, and their differences express the heat magnitude (HM).



Oke *et al.*, 2017, *Urban Climates*
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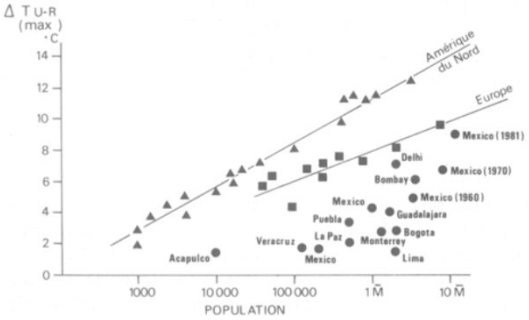
UHI intensity and city size (parametrs)



Relationship of the maximum heat island intensity with urban population in European, North American and tropical cities (Escourrou, 1991) are different.

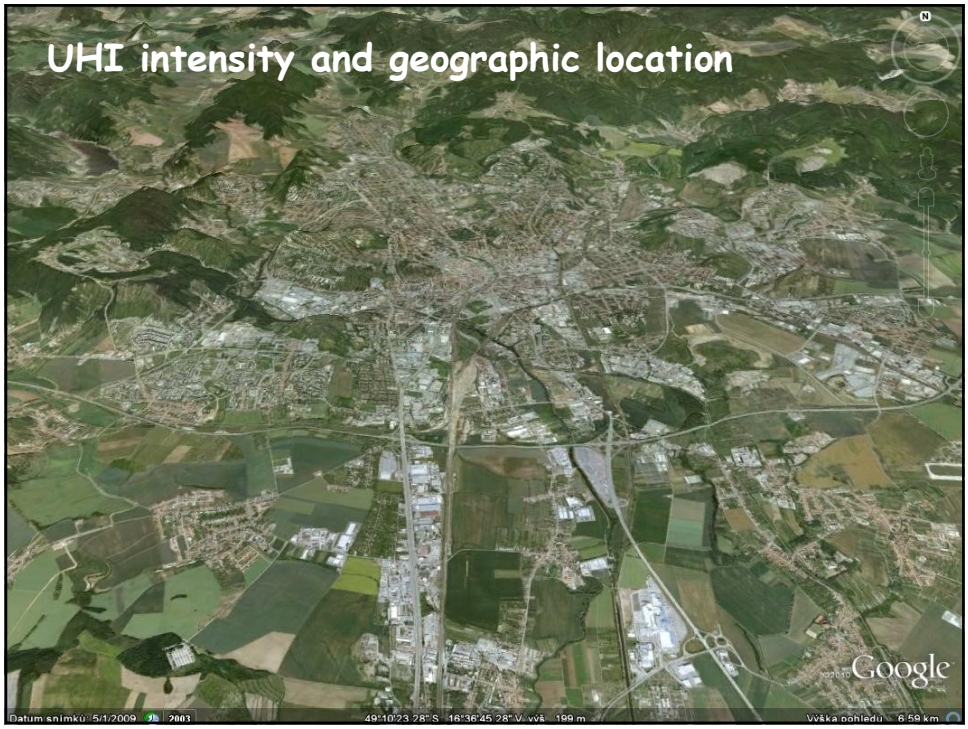
The size of the city can be characterized via **number of inhabitants**

There is a relation between maximum UHI intensity (*UHImax*) and number of dwellers (*P*) (van Hove et al. 2011):

$$UHImax = 2{,}93 \log P - 11{,}95$$

For Brno (P = 380 ths.) UHImax = 4,4 °C

What **other city parameters** can influence UHI intensity?



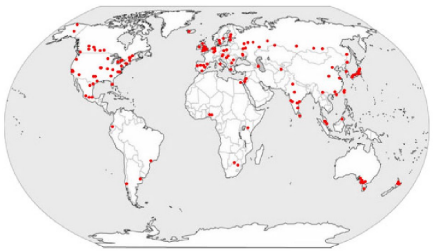
Problems with UHI definition and UHI intensity evaluation

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **31**: 200–217 (2011)
Published online 15 April 2010 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.2141

RMetS
Royal Meteorological Society

A systematic review and scientific critique of methodology in modern urban heat island literature

I. D. Stewart*
Department of Geography, University of British Columbia, Vancouver, BC Canada



Two areas of universal weakness in the literature sample are
1) **controlled measurement** and
2) **openness of method**

4.3 Measuring the UHI effect

How we can estimate UHI intensity depending on available data?

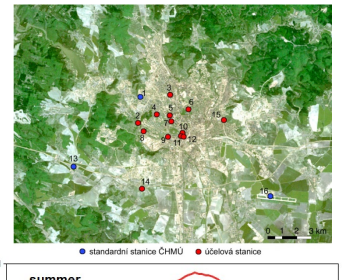
- „Point" measurements – standard meteorological stations
- „Point" measurements – special-purpose automatic stations
- Mobile measurements
- Urban remote sensing
- Urban climate and UHI intensity modelling

All types of measurements also involve three different components that are hardly to quantify (Lowry 1977):

1. the „backgound" climate
2. the effects of local climate (topoclimate)
3. the effect of local urbanization

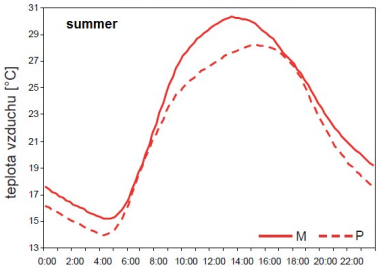
Where are the spatial limits of the urban effect?

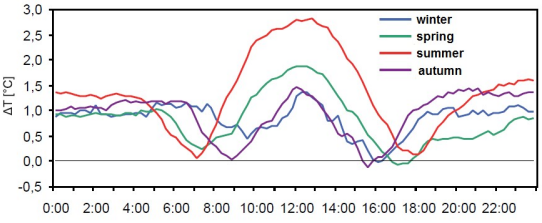
UHI Intensity in Brno from statinos



stanice	NV	NDVI	DENS
MEND	210	0,29	20
BOTA	242	0,18	27
FILO	232	0,21	39
UKZU	218	0,34	14
GEON	226	0,31	17
KRAV	297	0,35	16
VERO	222	0,02	46
BISK	245	0,11	41
KAPU	221	0,05	43
VETE	237	0,26	25
ZIDE	215	0,31	19
ZABO	236	0,40	20
JUND	257	0,55	7
TROU	277	0,36	9
LISK	238	0,52	1
TURA	241	0,24	5

Spatial distribution of meteorological stations in Brno area (left) and their characteristics (right): Elevation (NV), density of buildings (DENS), and amount of vegetation (NDVI) (b)





Mean daily variations of summer air temperature at urban (M) and rural (P) stations **during clear and calm days** in Brno region (left) and daily variation of urban heat island intensity (ΔT). UHI intensity is expressed as a difference between mean air temperature at urban and rural stations (right)

AUHI – from „point" measurements to maps

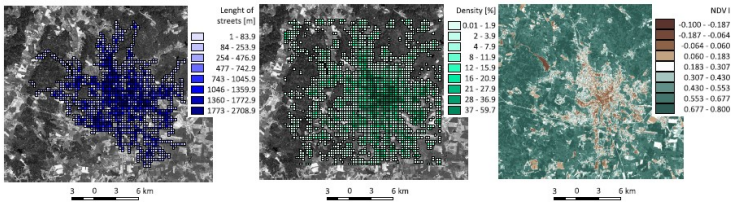
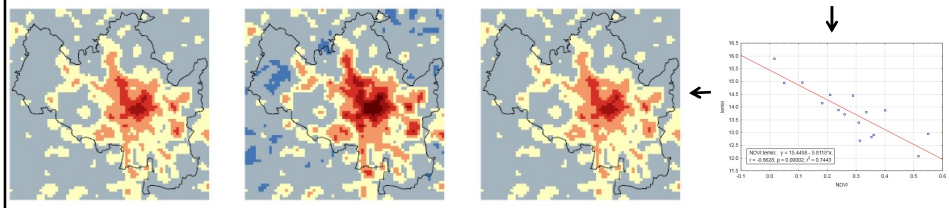


Figure 2 Total length of streets (further TLoS) calculated for a regular grid (300 x 300 m) in the study area.

Figure 3 Density of buildings (%) (further DENS) calculated for a regular grid (300 x 300 m) in the study area.

Figure 4 Normalized Difference Vegetation Index (further NDVI) as an indicator of vegetation amount and vigor in Brno area.



Temperature deviation [°C]

-1 -0,5 0 0,5 1 1,5 2 2,5

hranice katastrálního území města Brna

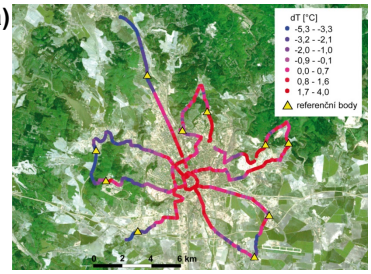
0 5 10 15 km

T = f(NDVI)

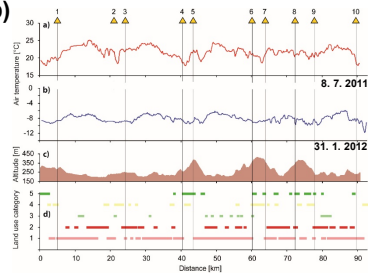
Spatial distribution of mean daily air temperature (Tavg), temperature minimum (Tmin) and intensity of UHI (ΔT) in Brno area during clear and calm days in summer; air temperatures are expressed as deviations from mean temperature of the study area (c)

AUHI – mobile measurements

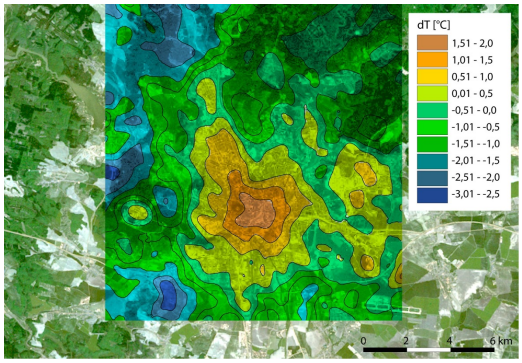
a)



b)



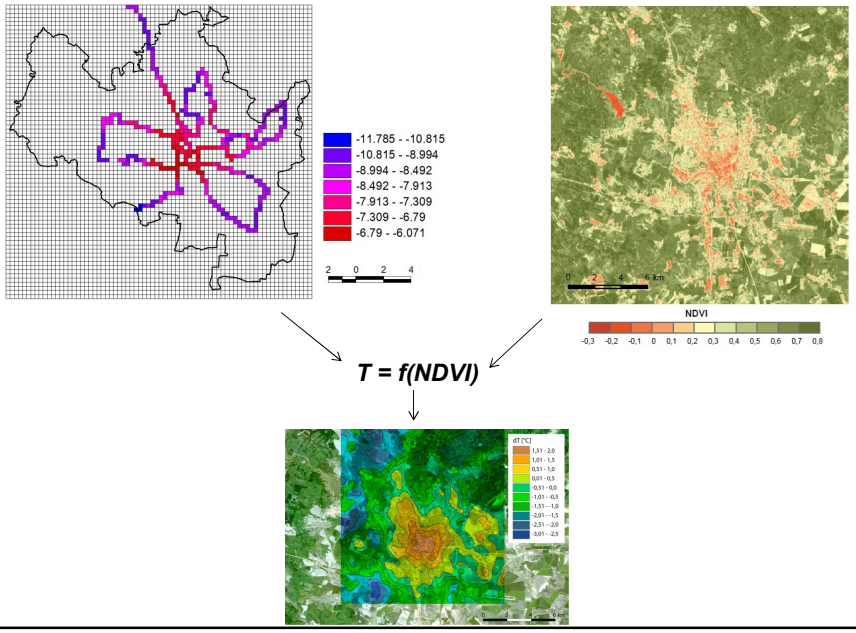
c)



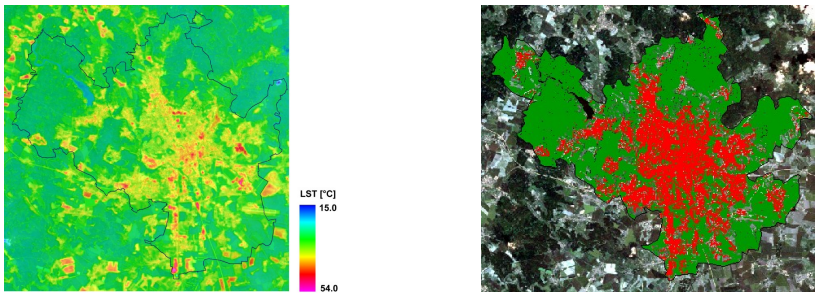
Design of measuring routes (**a**), air temperature profile along measurement routes (**b**) and typical spatial distribution of air temperature in central part of Brno in early night hours; air temperature is expressed as deviation (dT) from mean value of the study area and is typical for clear and calm weather during summer (**c**)

Corrections required for temperature changes during the time of the traverse

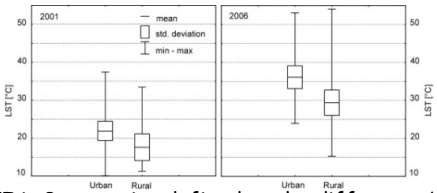
AUHI – from mobile measurements to maps



SUHI – remote sensing



Spatial variability of LST values within the Brno region; LST derived from Landsat thermal imagery acquired on 15 June 2006.



Intensity of surface UHI in Brno region defined as the difference between urban (M) and rural areas (P)

4.4 UHI consequences

- UHI impacts may be direct and indirect, negative effects prevail in general
- Diurnal Temperature Range is smaller in cities
- Increased temperatures during summer in cities amplify energy demand for air conditioning.
- Peak electricity demand increases 1.5 to 2% for every 1°C increase in summer temperatures.
- Higher surface temperatures can heat storm water runoff with negative effect of various water ecosystems (**thermal pollution**)
- Impacts to plants through changes in phenology may be ambiguous (beginning and end of individual phases of the growing cycle

UHI consequences

- Higher air pollution reduce nighttime cooling, both factors increase a discomfort for city dwellers
- Higher temperatures enhance urban ozone formation.
- Higher temperatures increase evaporative emissions, adding volatile organic compounds (VOCs) to the air.
- Higher daytime and nighttime temperatures affect human health, including general discomfort, respiratory difficulties, heat cramps, heat strokes, and heat related mortality.
- Urban heat islands make extended heat waves more damaging, particularly to sensitive populations such as children and older adults.

How to Reduce UHIs negative impacts?

(see special lecture on adapatation and mitigation measures)

4.5 Final remarks and questions

- How do Urban Heat Islands form?
- What are the UHI types?
- How we can estimate UHI intensity depending on available data?
- What are the main problems related to UHI?
- What is a relation between heat waves and UHI?
- Can be there any benefits of UHI?