Cities as urban clusters: an empirical and large sample study of urban heat island intensity

Bin Zhou, Diego Rybski, Jürgen P. Kropp

Potsdam Institute for Climate Impact Research

Toulouse

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Status quo of empirical Urban Heat Island (UHI) study

- Inconsistency and instability with regard to urban-rural definition
- Based on individual or a few case study cities.
- Lack of systematic analyses
- ...
Introduction

Status quo of empirical Urban Heat Island (UHI) study

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Questions addressed in this study

- **Question 1**: Whether and to what extent the city size determines the UHI intensity?
- **Question 2**: Seasonal variations of surface UHI.
- **Question 3**: Whether similar patterns exist in site-specific UHI characteristics? How are they geographically distributed?
Introduction

Theoretic basis

- Land Surface Temperature (LST)
- Urban cluster identification
- Land Use
- Reality

MODIS, CORINE
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Data & Methods

CORINE Land Cover & Urban Morphological Zones 2006
- 38 European countries at 250 m
- 44 land cover types are reclassified into binary urban/non-urban ones.

MODIS Land Surface Temperature (LST)
MYD11A2 data: 8-day mean at local time
~ 13:30 & ~ 01:30
Spatial resolution: ~1 km
Temporal coverage: 2006-12
Data & Methods

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(a) Urban cluster identified by the City Clustering Algorithm (CCA) for the Greater London Area.
(b) LST for the same area as in (a) captured by the MODIS Aqua at 13:30 (02/07/2006 – 09/07/2006).

\[
\Delta T = T_C - T_B \quad (\text{coverage} \geq 50\%)
\]

B. Zhou, D. Rybski, J. P. Kropp (PIK) Zhou@pik-potsdam.de
**Data & Methods**

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- 38 European countries at 250 m
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**MODIS Land Surface Temperature (LST)**
- MYD11A2 data: 8-day mean at local time \( \sim 13:30 \& \sim 01:30 \)
- Spatial resolution: \( \sim 1 \) km
- Temporal coverage: 2006-12

**Definition of UHI intensity**
\[
\Delta T = \overline{T_C} - \overline{T_B} \quad (\text{coverage} \geq 50\%)
\]
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   - UHI Intensity and City Size
   - UHI intensity and Surrounding Temperature
   - Observed and modelled seasonality
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UHI Intensity ($\Delta T$) and City Size ($S_C$)

(UHII as a function of $S_C$ and seasonal variability. Typical dependence for (a) summer days and (b) winter days.)
UHI Intensity ($\Delta T$) and City Size ($S_C$)

UHI as a function of $S_C$ and seasonal variability. Typical dependence for (a) summer days and (b) winter days.

Logistic model:

$$\Delta T = \frac{a}{1 + \left( \frac{S_C}{b} \right)^{-c}}$$

Asymptote $\circ$
Inflection $\circ$
Steepness $\circ$

• positive correlation both in summer and winter
• more pronounced UHI in summer, which can be well fitted by the empirical logistic model.
• max. up to 3 $^\circ$C in summer (Jun-Aug) and down to 0.5 $^\circ$C in winter (Dec-Feb).
UHI Intensity ($\Delta T$) and City Size ($S_C$)

UHI as a function of $S_C$ and seasonal variability. Typical dependence for (a) summer days and (b) winter days.

Logistic model:

$$\Delta T = \frac{a}{1 + \left( \frac{S_C}{b} \right)^c}$$

- Asymptote $\bigcirc$
- Inflection $\bigcirc$
- Steepness $\bigcirc$
- $95\%$ CI
- Binned average $\pm \sigma$

- positive correlation both in summer and winter
- more pronounced UHI in summer, which can be well fitted by the empirical logistic model.
- max. up to 3 °C in summer (Jun-Aug) and down to 0.5 °C in winter (Dec-Feb).

Time series of the parameter $a$. 

B. Zhou, D. Rybski, J. P. Kropp (PIK)  
zhou@pik-potsdam.de  
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Diversity in urban climate: UHI versus Urban Oasis Effect

UHI characteristics of individual city clusters and hysteresis-like curves:

(a) Paris
(b) Milan
(c) Madrid
(d) Nicosia

UHI intensity ($\Delta T$) and surrounding temperature ($T_B$)
Observed and modelled seasonality

Is the seasonality of UHI intensity based on 2 m air temperature (T2m) consistent with that in LST?
– Greater London Area as a case study

Combination of observation and simulation

• Observed weather stations
  – St. James Park (urban), Charlwood (rural)
• Urban boundary layer climate model - UrbClim [De Ridder et al., 2015]
  – A simple and time fairly alternative for computation-intensive urbanized mesoscale climate models.
  – Bulk parameterization of the urban surface energy balance, coupled to a 3-D atmospheric boundary layer scheme
  – Validated in Toulouse, Ghent, Antwerp, and Bilbao

More details of UrbClim in:

Koen De Ridder, Dirk Lauwaet, Bino Maiheu (2015),

Observed and modelled seasonality

* The inset icons denote how $\Delta T$ is calculated: areal average versus station-based.
Observed and modelled seasonality

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Conclusion

- A general framework to conduct systematic statistical assessment of UHI via an automatic urban cluster identification algorithm.

- Logistic relationship between UHII and city size (more pronounced in summer than in winter)

- Urban boundary layer model (UrbClim) can reproduce the hysteresis in the surface UHI intensities, while in the observed and modeled 2 m air temperature, the phenomenon is absent.

- Various UHI characteristics across Europe. Efforts to identify regional patterns of UHI, based on Hysteresis-like curves, suggest a climatological basis.
Thank you for your attention!

More details in:


Methods

City cluster identification – City Clustering Algorithm (CCA)

CCA with threshold distance $l = 2c$.

<table>
<thead>
<tr>
<th>total No. of city clusters</th>
<th>$&gt;130,000$</th>
</tr>
</thead>
<tbody>
<tr>
<td>area $&gt;13$ km$^2$ (=200 cells)</td>
<td>$&gt;2,000$</td>
</tr>
</tbody>
</table>

large city clusters

- Flemish Diamond
- Paris
- London
- Milan
- Ruhr
- Berlin...

Boundary identification: Boundary area ($S_B$) $\approx 1.0$ Cluster area ($S_C$)
Hysteresis of UHI intensity for the London city cluster comparing the empirical MODIS values with the ones obtained from the constant short-wave radiation (SR) experiment.
Influence of Boundary/Cluster ratio on the UHI intensity

The larger the ratio, the smaller the UHI intensity.
Summertime (June-July-August) mean LST averaged over 6 years (2006-2011) for the Greater London Area.
Classification of city clusters

**Step 1: Fourier approximation**

- $\Delta T$
- $T_B$
- AIC

**Step 2: K-means clustering**

- Fourier coefficients
- Z-score
- $\Delta T: g_0 g_1 h_1$
- $T_B: g_0 g_1 h_1$

- 7 Groups
- Silhouette