Modelling the impact of climate change on heat load increase in Central European cities

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Toulouse, France, July 20-24, 2015
Introduction:

1. **Global surface temperature change**: likely to exceed 1.5°C by the end of the 21st century (IPCC 2013)

2. **Heat load in urban areas**: supposed to increase

3. **Urban areas**: among those most endangered with the potential global climate changes

4. **Studies on the impact of global changes on local climate of cities**: high significance for the urban inhabitants' health and wellbeing

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5. Adaptation actions in particular cities:

- Recognition of the possible range of heat load increase;
- Aspects of the increase: magnitude and spatial extent;
- Both land use and land form influences should be included.

6. Aim:

Evaluation of the expected heat load increase in the Central European cities: Vienna, Brno, Bratislava, Kraków, Szeged

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Methods:

1. **MUKLIMO_3**
   - 3D Mikroskaliges Urbanes KLImaMOdell (*Sievers and Zdunkowski, 1986; Sievers, 1990; Sievers, 1995*)
   - Application for assessment of heat load in urban areas and urban planning
   - Horizontal resolution: 100 m
   - Vertical resolution: 10–100 m, finer resolution near surface
   - Simulation duration: 24 h
   - Input data: orography and land use
   - Initial and boundary conditions: 1D vertical profile of time-varying atmospheric conditions at the referent station

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• Output data: diurnal cycles of air temperature, wind speed and direction, relative humidity and heat fluxes

• Parameterization of buildings and vegetation

• 3-layered vegetation model

• 15-layered soil model

• Calculation of climate indices with “cuboid method” (Früh et al. 2011)

• Application for Frankfurt (Früh et al. 2011) and Vienna (Zuvela-Aloise et al. 2014)

Air temperature and horizontal wind vectors in Frankfurt at 5-m height for flow from the NE initialized with $T_{c,\text{max}} = 25°C$, $\text{rh}_{c,\text{min}} = \ldots$ and $v_{c,\text{min}} = 0.7 \text{ m s}^{-1}$ (Früh et al. 2011)
2. Local Climate Zones

- Mapping procedure: methodology proposed by the World Urban Database and Access Portal Tools (WUDAPT) (Bechtel and Daneke, 2012, Bechtel et al. 2015);
- Several Landsat 7 images were used; obtained from USGS (earthexplorer.usgs.gov);
- LCZ training areas were located using Google Earth;
- Landsat images and vector file: preprocessed in SAGA-GIS;
- The classification was conducted with the built in random forest classifier;
- Input parameters for the model: land use and building height data; thresholds for land use and built-up parameters defined by Stewart and Oke (2012) were applied;
- For each LCZ class, a common value was assigned for all of the necessary input parameters of MUKLIMO for all the cities.
Vienna
Inhabitants: 1 800 000
140-580 m a.s.l.
Grid size: 316x247x39

Krakow
Inhabitants: 760 000
145–460 m a.s.l.
Grid size: 389x275x39

Brno, Inhabitants: 380 000, 200-525 m a.s.l.,
Grid size: 250x250x39

Bratislava
Inhabitants: 500 000
120-450 m a.s.l.
Grid size: 160x160x39

Szeged, Inhabitants: 170 000, 45-145 m a.s.l.,
Grid size: 213x181x25

LCZ classification: Stewart and Oke, 2012
Method: Bechtel and Daneke, 2012
3. Cuboid method

- Conditions potentially leading to heat stress: air temperature (T), relative humidity (rh) and wind speed (v);
- T, rh and v are representing the 3 dimensions of a cuboid structure;
- Limits of the cuboid are chosen to encompass almost all regional climate conditions favorable for the occurrence of urban heat load situations;
- For each cuboid corner, the daily cycle of T, rh and v was simulated with MUKLIMO_3 for each prevailing wind direction;
- Tri-linear interpolation used to assign a value to any data point \( C_i \) (\( T_i, \text{rh}_i, v_i \)) within the cuboid as a weighted average;
- The interpolation weight \( w_i \) is computed from the distance of \( T_i \) to the two fixed points \( T_{c,min} \) and \( T_{c,max} \) and applied to the simulated urban scale MUKLIMO_3 fields to yield the interpolated urban scale fields of \( T_{int}, T_{int,max} \) or \( T_{int,min} \).

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• To identify thermally sensitive areas within the city: idealized simulations of temperature, wind and relative humidity in the urban area, based on the orography and land use data with 100 m resolution;

• Possible climatological changes in urban heat load under future climate conditions expected increase in the number of days with:

  - maximum air temperature $\geq 25^\circ$C (i.e. summer days);
  - maximum air temperature $\geq 30^\circ$C (i.e. hot days);
  - minimum air temperature $\geq 20^\circ$C (i.e. tropical nights);
• To conduct urban scale simulations for several 30-yr time periods would lead to an enormous computational effort;

• Instead, cuboid method is used;

• Future climate signal is based on the data from regional climate projections of the EURO-CORDEX project; 15 different climate predictions were used;

• The model outputs were corrected using orography and the measurement data of 1971-2000 in order to avoid the systematic errors.
EURO-CORDEX - Coordinated Downscaling Experiment - European Domain (EUR-11)

IPCC Scenario RCP8.5

Mean annual number of summer days ($T_{\text{max}} \geq 25^\circ C$), model ensemble average (11 members)

<table>
<thead>
<tr>
<th>City</th>
<th>1971-2000</th>
<th>2021-2050</th>
<th>2071-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vienna, AT</td>
<td>41.7</td>
<td>52.5</td>
<td>78.1</td>
</tr>
<tr>
<td>Brno, CZ</td>
<td>30.6</td>
<td>40.2</td>
<td>63.6</td>
</tr>
<tr>
<td>Bratislava, SK</td>
<td>47.3</td>
<td>58.5</td>
<td>84.3</td>
</tr>
<tr>
<td>Szeged, HU</td>
<td>78.7</td>
<td>91.6</td>
<td>115.6</td>
</tr>
<tr>
<td>Krakow, PL</td>
<td>23.4</td>
<td>31.5</td>
<td>51.4</td>
</tr>
</tbody>
</table>

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Preliminary results

• Modelling air temperatures and wind fields for all cities;

• Idealized case: the same meteorological profiles for all cities;

• Reference conditions: mean daily air temperature: 25°C, mean daily relative humidity: 40%, mean daily wind speed: 3 m·s⁻¹ (i.e. cuboid point 101);

• Upper wind direction: NW, except Krakow (NE).
Idealized simulations for air temperatures and wind fields at h=5 m, at t=1600h MESZ (UTC + 2 h)

Vienna, Austria
Krakow, Poland
Bratislava, Slovakia
Brno, Czech Republic
Szeged, Hungary

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Future climate change impact (preliminary results)

Example:
• changes in the mean annual number of summer days (i.e. max. temp. ≥ 25°C)
• according to scenarios RCP4.5 and RCP8.5
• using ensemble averages from 7 models
• predictions for the periods 2021-2050 and 2071-2100, compared to 1971-2000
Vienna: Scenario RCP4.5

1971-2000
min.: 7.2  max.: 82.8  avg: 45.4  days

2021-2050
min.: 16.0  max.: 99.0  avg: 61.6  days

2071-2100
min.: 21.3  max.: 107.8  avg: 70

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Vienna: Scenario RCP8.5

min.: 7.2  max.: 82.8  avg: 45.4  days

min.: 16.1  max.: 101.9  avg: 63.0  days

min.: 40.0  max.: 128.8  avg: 93.4  days

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Krakow: Scenario RCP4.5

min.: 3.6  max.: 58.8  avg: 17.6  days

min.: 9.3  max.: 76.1  avg: 29.1  days

min.: 13.9  max.: 86.1  avg: 36.2  days

1971-2000

2021-2050

2071-2100

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Krakow: Scenario RCP8.5

min.: 3.6  max.: 58.8  avg: 17.6  days

min.: 9.3  max.: 78.1  avg: 29.9  days

min.: 27.4  max.: 108.1  avg: 57.2  days

1971-2000

2021-2050

2071-2100

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Brno: Scenario RCP4.5

min.: 10.5  max.: 83.4  avg: 37.2  days

min.: 23.9  max.: 93.6  avg: 51.8  days

min.: 27.4  max.: 102.1  avg: 59.3  days

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Brno: Scenario RCP8.5

1971-2000

min.: 10.5  max.: 83.4  avg: 37.2  days

2021-2050

min.: 17.8  max.: 93.2  avg: 52.3  days

2071-2100

min.: 40.7  max.: 123.1  avg: 81.4  days

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Szeged: Scenario RCP4.5

1971-2000

min.: 4.7 max.: 115.1 avg: 46.5 days

2021-2050

min.: 13.7 max.: 129.9 avg: 66.1 days

2071-2100

min.: 19.4 max.: 137.4 avg: 76 days

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Szeged: Scenario RCP8.5

- **1971-2000**
  - min.: 4.7
  - max.: 115.1
  - avg: 46.5 days

- **2021-2050**
  - min.: 14.7
  - max.: 133.9
  - avg: 67.9 days

- **2071-2100**
  - min.: 42.1
  - max.: 153.9
  - avg: 101.7 days

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Further research:

- model evaluation for each city with the available observational data
- comparison of the scenarios between the cities and discussion of the added value from the downscaling method
- evaluation of the predicted changes’ spatial patterns in particular cities, in the context of local conditions (e.g. land forms, land use, land cover)
Thank you for your attention!

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