Modeling of the Urban Heat Island:
Assessment of mitigation strategies for the City of Stuttgart

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Overview

- **CENTRAL Europe Project:**
  "Development and application of mitigation and adaptation strategies counteracting the Urban Heat Island (UHI)." (European Territorial Cooperation Objective CENTRAL EUROPE Programme - 3CE292P3)

- **Mesoscale numerical modeling (WRF)** of the UHI for selected Region:
  - Urbanization of WRF → Selection of most suited urbanization scheme

- **Validation** of modeling results through measurement data

- **Simulation** of simple mitigation strategies
  - Change of land surface properties

- UHI triggers **secondary circulation**
  - Urban-Rural interaction
  - Air Quality assessment

- **Assistance to Urban Planning** (local stakeholders, City of Stuttgart)
Model approach

- Choosing the WRF/urban parameterization scheme suitable for the modeling approach (coupled with Noah LSM)
  - Single Layer Urban Canopy Model SLUCM (KUSAKA, 2001)
  - Building Energy Parameterization BEP (MARTILLI, 2002)
- Replace urban land use classes by natural vegetation
- Change albedo of urban surfaces, building densities etc.
- Comparing temperature development under different scenarios

*Fig. 1: Schematic of SLUCM (left) and multi-layer-BEP (right) (CHEN, 2011)*
WRF Configuration

Meteorological driver:
ERA Interim 0.5° Reanalysis Data

Fig. 2: Schematic and setup of model domains (Source: EEA)

<table>
<thead>
<tr>
<th>Domain</th>
<th>D01</th>
<th>D02</th>
<th>D03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographical input data</td>
<td>1km</td>
<td>1km</td>
<td>1km</td>
</tr>
<tr>
<td>dx, dy</td>
<td>15</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>West-east [km]</td>
<td>645</td>
<td>228</td>
<td>61</td>
</tr>
<tr>
<td>North-south [km]</td>
<td>510</td>
<td>168</td>
<td>49</td>
</tr>
<tr>
<td>Total [km²]</td>
<td>328950</td>
<td>38304</td>
<td>2989</td>
</tr>
</tbody>
</table>
WRF Configuration

- WRF Single Moment 6-class scheme
- RRTM long wave radiation
- Dudhia short wave radiation
- Eta similarity surface layer
- NOAH Land Surface Model
- Mellor-Yamada-Janjic (MYJ) boundary layer scheme
- Kain-Fritsch scheme for cumulus parameterization (1st domain)
- Building-Energy parameterization (BEP) / Single Layer Urban Canopy Model (SLUCM)
Validation

**Fig. 3:** Simulated 2m air temperature for **SLUCM** (left) and **BEP** (right) – Comparison with data from measurement station Bad Cannstadt visible through correlation plots (right)
Land use change to test urban effects

**Fig. 4:** Changed land use type in between the urban area of Stuttgart for 3rd domain

**Fig. 5:** Potential 2m air temperature – early evening in summer – Snapshot for Aug 13th 2003 18:00

**Fig. 6:** Characteristic circulation patterns through urban-rural interaction

Urban = ‘on’ | Urban = ‘off’
Urban planning mitigation scenarios - area

Fig. 7: Effect of urban planning strategy on WRF potential air temperature – scenario case compared to ‘real’ case (WRF-BEP) for Aug 13th 2003 18:00; up to 6% temperature reduction on average

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Albedo</th>
<th>Density</th>
<th>Many Parks</th>
<th>Big Park</th>
<th>Real Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>T mean urban [°C]</td>
<td>32</td>
<td>32.4</td>
<td>32.46</td>
<td>32.34</td>
<td>33.1</td>
</tr>
<tr>
<td>T max [°C]</td>
<td>32.7</td>
<td>33</td>
<td>33.5</td>
<td>33.3</td>
<td>34.3</td>
</tr>
<tr>
<td>Std dev. [°C]</td>
<td>0.32</td>
<td>0.48</td>
<td>0.52</td>
<td>0.42</td>
<td>0.5</td>
</tr>
<tr>
<td>UHI; ΔT [°C]</td>
<td><strong>0.84</strong></td>
<td><strong>1.32</strong></td>
<td><strong>1.47</strong></td>
<td><strong>1.19</strong></td>
<td><strong>2.52</strong></td>
</tr>
</tbody>
</table>

Tab. 1: Effect of mitigation strategy on averaged temperature over the urban area and UHI intensity
Urban planning mitigation scenarios - transect

![Graph showing temperature changes over distance]

**Fig. 8:** Development of potential 2m air temperature for west-east transect after applying mitigation strategy – Aug 13th 2003 00:00
Urban planning mitigation scenarios - transect

Fig. 9: Development of potential temperature for west-east transect after applying mitigation strategy – Aug 13th 2003 12:00
Urban planning mitigation scenarios - transect

Fig. 10: Development of potential temperature for west-east transect after applying mitigation strategy – Aug 13th 2003 18:00
The need for air quality modelling...

UV - Radiation

1) $\text{NO}_2 \rightarrow \text{NO} + \text{O}$

2) $\text{O} + \text{O}_2 \rightarrow \text{O}_3$
Thank you for your attention

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