CL2.1/AS1.21: Urban Climate, urban heat island and urban biometeorology

Interaction between Cities and Climate Change: Modelling Urban Morphology and Local Urban Planning Scenarios from Open Datasets across European Cities

Bart Thomas, Catherine Stevens, Mart Grommen
NAACLIM fact sheet

• **ECOMS** = European initiative for climate service observation and modelling
  - **NAACLIM**
  - SPECS
  - EUPORIAS
• **NAACLIM** = North Atlantic Climate
• FP7 Collaborative Project
• Project lifetime: 11/2012 – 02/2017
• Research focus:
  - Assessment of decadal climate forecasts
  - North Atlantic / European sector
• 19 research institutes / 10 European countries
• 5 Core themes / 12 work packages

• **WP4.2: Impact on European urban societies** of predicted North Atlantic/Arctic Ocean variability
• Case Cities: Antwerp (BE), Berlin (DE), Almada (PT)
WP4.2: Impact on urban societies
Previous work

• Calculation of Planar Area Index (PAI) and Frontal Area Index (FAI) on 250x250m grid

• **Relationship** between:
  • Surface Soil Sealing (EEA SSL) and PAI ($R^2 \sim 75\%$)
  • EEA SSL and FAI ($R^2 \sim 65\%$)

• PAI: Stable relationship (all cities)
• FAI: More variation in relation across cities
• Flexible approach:
  • **Exact calculation** when 3D city models are available
    > calibration on local data
  • **Extrapolation** for other regions (outside AOI)
  • Possibility of **downscaling** urban climate simulations to higher resolution
Present work

1. Increase $R^2$ of the relationships between generic / open EU-datasets and urban morphology indices by combining EEA SSL and population data in the regression analysis.

2. Extract other urban morphology indices.

3. Estimate the UHI for local urban planning scenarios by updating urban morphology.
Regression using EEA SSL and population

Antwerp

<table>
<thead>
<tr>
<th></th>
<th>PAI (y) - EEA SSL (x)</th>
<th>PAI (y) - POP DENS (z)</th>
<th>PAI (y) - EEA SSL (x) - POP DENS (z)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equation</strong></td>
<td>y = 0.00033x</td>
<td>y = 0.0038z + 0.0479</td>
<td>y = 0.0022x + 0.0025z + 0.0018</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.64</td>
<td>0.61</td>
<td>0.82</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>FAI (y) - EEA SSL (x)</th>
<th>FAI (y) - POP DENS (z)</th>
<th>FAI (y) - EEA SSL (x) - POP DENS (z)</th>
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</thead>
<tbody>
<tr>
<td><strong>Equation</strong></td>
<td>y = 0.00008x</td>
<td>y = 0.0011z + 0.0131</td>
<td>y = 0.00028x + 0.00091z + 0.0071</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.42</td>
<td>0.74</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Source used datasets
Other urban morphology indices

Considered land surface parameters:

- Planar area index (PAI)
- Frontal area index (FAI)
- Average building height (AVG_H)
- Standard deviation building height (STD_H)
- Sky view factor (SVF)
- Fraction vegetation cover (F_VEG)
- Fraction urban land use (F_ULU)
- Vegetation type (LULC)
- ...

Relationship between morphology indices and EEA SSL on 1x1km grid
Other morphology indices

<table>
<thead>
<tr>
<th></th>
<th>PAI</th>
<th></th>
<th>FAI</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>$R^2$</td>
<td>Equation</td>
<td>$R^2$</td>
</tr>
<tr>
<td>Berlin</td>
<td>$y=0.003x$</td>
<td>0.81</td>
<td>$y=0.0018x$</td>
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<td>Antwerp</td>
<td>$y=0.0033x$</td>
<td>0.64</td>
<td>$y=0.0008x$</td>
<td>0.42</td>
</tr>
<tr>
<td>Almada</td>
<td>$y=0.0027x$</td>
<td>0.77</td>
<td>$y=0.0016x$</td>
<td>0.81</td>
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</table>

<table>
<thead>
<tr>
<th>AVG_H</th>
<th></th>
<th>STD_H</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>$R^2$</td>
<td>Equation</td>
</tr>
<tr>
<td>Berlin</td>
<td>$y=0.1432x+4.2573$</td>
<td>0.51</td>
<td>$y=0.1437x+4.2394$</td>
</tr>
<tr>
<td>Antwerp</td>
<td>$y=0.0533x+4.5515$</td>
<td>0.34</td>
<td>$y=0.0285x+2.4538$</td>
</tr>
<tr>
<td>Almada</td>
<td>$y=0.0738x+4.9585$</td>
<td>0.41</td>
<td>$y=0.0617x+1.7292$</td>
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</table>

<table>
<thead>
<tr>
<th>F_VEG</th>
<th></th>
<th>F_ULU</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>$R^2$</td>
<td>Equation</td>
</tr>
<tr>
<td>Berlin</td>
<td>$y=-0.0073x+0.8739$</td>
<td>0.79</td>
<td>$y=0.0098x$</td>
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<tr>
<td>Antwerp</td>
<td>$y=-0.0059x+0.6802$</td>
<td>0.9</td>
<td>$y=0.0096x$</td>
</tr>
<tr>
<td>Almada</td>
<td>$y=-0.0078x+0.8249$</td>
<td>0.74</td>
<td>$y=0.0093x$</td>
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</table>

<table>
<thead>
<tr>
<th>SVF</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
</tr>
<tr>
<td>Berlin</td>
<td>$y=-3E-05x^2-0.0013x+0.9936$</td>
</tr>
<tr>
<td>Antwerp</td>
<td>$y=-2E-05x^2-0.0005x+0.9825$</td>
</tr>
<tr>
<td>Almada</td>
<td>$y=-2E-05x^2-0.0006x+0.9692$</td>
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</table>

$x = \text{EEA SSL}$
Other morphology indices

Trendlines Relation Surface Soil Sealing and Average Building Height for 3 use case cities

- Berlin
- Antwerp
- Almada

Trendlines Relation Surface Soil Sealing and Sky View Factor for 3 use case cities

- Berlin
- Antwerp
- Almada
Urban plans – future urban morphology

Relationships for present situation

SSL - Morphology Index

SSL – Pop Dens

City data

Urban plan city development (future)

Socio-economic prospects (future)

Future Urban morphology

UrbClim

UHI prediction future

FUTURE HEAT STRESS EXPOSURE MAPS
3. Urban plans – future urban morphology
Urban plans – future urban morphology

Methodology

• Assign future LULC to urban plans
• Overlap with analysis grid (250x250m)
• Calculate future SSL for grid cells covered by urban plans
  • As average EEA SSL of the current grid cells with similar LULC
  • *Or if future population data available*: use relation between EEA SSL and population density (current situation)
Urban plans – future urban morphology

Methodology

- Estimate the future morphology index value
  - From the established relationship with the EEA SSL
  - Or if future population data available: estimate an evolution factor \( r \) for each index based on the changes in population density (and hence soil sealing) and apply this factor to the present index value

\[
r = \frac{PAI^*_{\text{future}}}{PAI^*_{\text{present}}}
\]

\[
PAI_{\text{future}} = r \times PAI_{\text{present}}
\]
Current situation vs future situation

e.g. Berlin, urban plan Airport Berlin - Tegel

PAI, current situation

PAI, 2030

FAI, current situation

FAI, 2030
Conclusions

Regression analysis
• Considerable increase in $R^2$ when including population data in the regression analyses together with EEA SSL

Morphology indices
• Significant relationships between variables and EEA SSL
  • Depending on urban morphology index (e.g. AVG_H lower than F_VEG)
  • Depending on the city (e.g. higher $R^2$ for Berlin than for Antwerp)

Urban Plans
• Limited changes on UHI effect on 250m grid → local effects are however significant but not captured at this resolution
• Resolution independent methodology – flexibility
Future work

- Integration of the **population density** in the relationships for all urban morphology indices
- **Higher resolution** modelling
  - Individual buildings or blocks?
  - Complexity versus performance
  - Take high resolution effects into consideration (shadow, radiation from buildings, ...)
  - Resolution → meter(s)?
  - Applicability relationships at meter scale?
- **Other** indices / use of **satellite** imagery?
- Combination of **heat stress parameters** (UHI, # heatwave days) with **socio-economic** data to produce heat stress **exposure** maps
Questions?

Thank you for your attention!
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