The relative impact of climate change and urban land-use change on the heat stress in Belgium

Hendrik Wouters, Nicole van Lipzig, Lien Poelmans, Patrick Willems, Koen De Ridder, Erwan Brisson, Matthias Demuzere
Changes in global society

- Technological and scientific advancements
- Industrialisation, trading, and business

-> growth in assets, services and population

1800 -> 2014: 1 -> 7 Billion
Climate change

Figure from Knutti and Sedláček (2012).
Urban expansion
Objectives

- To reconstruct the present-day heat stress for an extended period and for an extended area (Belgium) based on high-resolution urban climate modelling
- To quantify the impact of climate change and urban land-use change on the heat stress in Belgium
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Heat stress index

• Definition by the Federal Agency Public Health of Belgium:
  - Heat wave day ($h_i$): this is 1 for the days for which the 3-day averaged minimum screen-level temperature exceeds 18.2 °C and averaged maximum exceeds 29.6 °C. Otherwise it is 0.
  - Heat-wave Degree Days (HWDD): sum over $h_i$ multiplied with the degrees of positive threshold exceedances at each day:

\[
HWDD = \sum_i \left[ \left( T_{\text{min},i} - 18.2 \; ^\circ\text{C} \right)^+ + \left( T_{\text{max},i} - 29.6 \; ^\circ\text{C} \right)^+ \right] h_i ,
\]
Scenario's

**Land-use change**

**Climate change**

Adaptation
- vegetation
- water management
- energy use
- building characteristics

**Urban risk assessment**

City-level impact and extremes:
- temperature
- precipitation

Local impact models:
- Heat stress
- Air quality modelling (ozone peaks)
- River and sewage models (floods)
Scenario's

- Land-use change
- Climate change
  - Adaptation
  - Vegetation
  - Water management
  - Energy use
  - Building characteristics

Regional climate model

COSMO-CLM

TERRA-URB

Urban risk assessment

City-level impact and extremes:
  - Temperature
  - Precipitation

Local impact models:
  - Heat stress
  - Air quality modelling (ozone peaks)
  - River and sewerage models (floods)

See Poster 25: NOMTM - Urban canopy parameterizations on Thursday, 23 Jul 2015: 3:00pm - 4:00pm
COSMO-CLM + TERRA-URB model setup for Belgium

- 2.8km horizontal resolution; 40 vertical layers
- Default external parameters in COSMO-CLM (EXTPAR) + Impervious Surface Area extracted from a state-of-the-art land-use model ('Ruimtemodel Vlaanderen')

Period:
- Evaluation period: 2012 (nested in ECMWF)
- Long-term hindcast (2000 – 2010); cascade-nested in ERA-INTERIM
Evaluation daily minimum air temperatures Antwerp
Evaluation daily minimum air temperatures Antwerp
Evaluation daily minimum air temperatures Antwerp

urban

rural
Evaluation daily minimum air temperatures Antwerp
Evaluation daily minimum air temperatures Antwerp
Evaluation daily minimum air temperatures Antwerp

HWDD for Antwerp in 2012 [°C x day]

<table>
<thead>
<tr>
<th></th>
<th>ISM</th>
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<tbody>
<tr>
<td>URBAN</td>
<td>18.8</td>
<td>53.1</td>
</tr>
<tr>
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<td>19.9</td>
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urban - rural (UHI)

ΔT_min
Evaluation daily minimum air temperatures Antwerp
Evaluation daily minimum air temperatures Antwerp

urban

rural

urban - rural (UHI)

\[ T_{\text{min}} \]

\[ \Delta T_{\text{min}} \]

day in 2012
Evaluation daily minimum air temperatures Antwerp

HWDD for Antwerp in 2012 [°C x day]

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Evaluation daily minimum air temperatures Antwerp

urban

- ISM
- UCM
- EOBS

rural

urban - rural (UHI)

ΔT_min

day in 2012
Scale composition: combining small-scale information from UCM with Large-scale information from EOBS

\[ T_{\text{COMP}}^{i,j} = T_{\text{UCM}}^{i,j} - \frac{[T_{n}^{\text{UCM}}*G]_{i,j}}{[1_n*K]_{i,j}} + \frac{[T_{n}^{\text{EOBS}}*G]_{i,j}}{[1_n*K]_{i,j}} \]

→ UHI correction factor
Evaluation daily minimum air temperatures Antwerp

urban

rural

urban - rural (UHI)

da in 2012
Evaluation daily minimum air temperatures Antwerp

urban

rural

urban - rural (UHI)

day in 2012
Evaluation daily minimum air temperatures Antwerp

HWDD for Antwerp in 2012 [°C x day]

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Reconstruction heat-stress index for 2000-2010

COSMO-CLM + TERRA-URB (composite) cascade-nested in ERA-INTERIM
Reconstruction heat-stress index for 2000-2010

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COSMO-CLM + TERRA-URB (composite) cascade-nested in ERA-INTERIM

Bruges

- Red: Bruges centre
- Blue: Moerkerke

HWDD [°C-days]

Year

- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
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Urban expansion

Output from Ruimtemodel Vlaanderen

Impervious surface area (%)
Urban expansion

Output from Ruimtemodel Vlaanderen

BAU Urban expansion 2060

Impervious surface area (%)
Climate change and uncertainty for Belgium (2000 → 2060)

$\Delta T$ approach → add monthly-mean temperature change to the high-resolution composites
Heat stress scenarios
Heat stress scenarios
Heat stress scenarios

[Map and graph showing heat stress scenarios for urban, semi-urban, and rural areas, with a spread indicating average values.]
Heat stress scenarios
Heat stress scenarios

urban

semi-urban

rural

spread

average
Heat stress scenarios

urban
semi-urban
rural
spread
average
Heat stress scenarios

- Urban
- Semi-urban
- Rural

Average spread

HWD [°C, day]
Conclusions

- Present-day heat stress in Belgium is primarily occurring in cities
- Increment of heat stress mainly originates from global climate change
- Cities are the hotspots of climate change: increment of heat stress is the largest in cities where it is already warmer
- Heat stress in city centres is further intensified by urban expansion