Evaluating three urban canopy models against in-situ observations for a heat-wave case in Amsterdam

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Introduction
Om het stadsclima beter te begrijpen en voorspellen, lieten onderzoekers van WUR samen met het Amsterdam Institute for Metropolitan Solutions woensdag 24 juni weerballonnen op vanaf onder meer de Dam in Amsterdam. Een uniek experiment: de laatste keer dat er verticale waarnemingen zijn verzameld was met een helikopter, meer dan vijftig jaar geleden in New York.
Research questions

1. Is WRF able to simulate the UHI for 24 July 2019 considering at least one of the three urban physics schemes (SLUCM, BEP or BEPBEM)?

2. How will affect air conditioning systems the temperature and energy use within the city of Amsterdam?

3. How will the UHI and energy use change in 2050 according to the KNMI climate projections?
Methods
Study area and weather overview

- Focus: Amsterdam – 24 July 2019
- Synoptics
- 35.7 °C at KNMI Schiphol Airport
Measurement sites

- 4 locations: Temperature
- De Munt: Atmospheric fluxes (H, LvE) measured using Eddy covariance
- Unique measurement campaign performed by the WUR
- Radiosondes at De Dam (loc: 1)
Research set-up

- WRF
- 4 domains (12.5 km, 2.5 km, 0.5 km, 0.1 km)
- Unique resolution
- 72 vertical layers
- Ronda et al. (2017)
- Perform 3 runs to determine which urban physics scheme is the best
- Perform additional 4 runs for each KNMI climate scenario with the best urban physics scheme
- GL (moderate low), GH (moderate high), WL (warm low), WH (warm high)
SLUCM/BEP/BEPBEM

- Three different parameterization schemes used:
  - Single Layer Urban Canopy Model (SLUCM)
  - Building Energy Parameterization (BEP)
  - Building Energy Parameterization + Building Energy Model (BEPBEM)
Results Research Question 1

Is WRF able to simulate the UHI for 24 July 2019 considering at least one of the three urban physics schemes (SLUCM, BEP or BEPBEM)?
2m Temperature validation

RMSE = 1.5K MB = -0.6K
Vertical temperature validation

Results 1
Results Research Question 2

How will effect air conditioning systems the temperature within the city?
Effect of AC systems (day time)

Surface sensible heat flux difference in W/m²
BEPBEM - BEP

Temperature difference in degrees Celsius
BEPBEM - BEP

Results 2
Effect of AC systems (night time)

Surface sensible heat flux difference in W/m²
BEPBEM - BEP

Temperature difference in degrees Celsius
BEPBEM - BEP
Effect of AC systems in vertical direction

Results 2
Results Research Question 3

How will the UHI change in future climate projections in 2050, according to the urban physics scheme which is able to simulate the atmospheric conditions best on the 24th of July 2019?
Climate projections

1.1K +/- 0.2K  1.5K +/- 0.2K  2.1K +/- 0.4K  2.9K +/- 0.6K

T2m four different climate scenarios

Amount of H pushed into environment from AC systems
Conclusions
Conclusions

- Is WRF able to simulate the UHI for 24 July 2019 considering at least one of the three urban physics schemes (SLUCM, BEP or BEPBEM)?
  
  Yes, BEPBEM performs best according to observations (RMSE = 1.5K MB = -0.6K)

- How will affect air conditioning systems the temperature and energy use within the city of Amsterdam?

  Temperature increase of 0.5-1K during daytime and 1-2.5K during night time up to 450 meters height

  How will the UHI and energy use change in 2050 according to the KNMI climate projections?

  Average temperature increase during simulation period:  

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Temperature Increase</th>
<th>Extra Power Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL-scenario</td>
<td>1.1K +/- 0.2K</td>
<td>90 + 9 W/m2</td>
</tr>
<tr>
<td>GH-scenario</td>
<td>1.5K +/- 0.2K</td>
<td>90 + 14 W/m2</td>
</tr>
<tr>
<td>WL-scenario</td>
<td>2.1K +/- 0.4K</td>
<td>90 + 18 W/m2</td>
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<tr>
<td>WH-scenario</td>
<td>2.9K +/- 0.6K</td>
<td>90 + 22 W/m2</td>
</tr>
</tbody>
</table>
Additional Material
Evaluation solar radiation

SW flux Obs vs SLUCM/BEP/BEpbem

Date

22-Jul 2019
12:00
23-Jul
12:00
24-Jul
12:00
25-Jul
00:00
00:00
00:00
00:00
00:00

SW Flux (W/m²)

Obs
SLUCM WRF
BEP WRF
BEpbem WRF
Formulation BEP scheme

Figure 2. Representation of the connection between the urban module grid (dashed levels) and the mesoscale model grid (solid levels). $i_{ub}$ and $i_{ue}$ are the lowest and the highest urban model levels in the mesoscale level $I$.

Source: (Martilli et al., 2002)
Fig. 1  Schematic picture of the heat fluxes considered in an urban environment

Source: (Salamance & Martilli 2010)
Temperature projections for 2050

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<th>T(99)</th>
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<table>
<thead>
<tr>
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<th>Gh</th>
<th>Wl</th>
<th>Wh</th>
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# Model scores for different sites

<table>
<thead>
<tr>
<th>Location</th>
<th>OBS</th>
<th>SLUCM</th>
<th>BEP</th>
<th>BEPBEM</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>RMSE</td>
<td>MB</td>
</tr>
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<td>27.6</td>
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<td>-1.5</td>
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<td>25.6</td>
<td>23.7</td>
<td>3.0</td>
<td>-2.1</td>
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<td>25.6</td>
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<td>2.1</td>
<td>-1.3</td>
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<td>AVG</td>
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<td>24.8</td>
<td>2.3</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

- **OBS**
- **SLUCM**
- **BEP**
- **BEPBEM**

**Model Evaluation Metrics**
- **Mean**: Average score
- **RMSE**: Root Mean Square Error
- **MB**: Model Bias

**Usage**
- For comparing different models' performance across various locations.
- Helps in identifying the best model for specific conditions.

**Analysis**
- Site 1 shows the highest mean score for OBS (27.6) and the lowest RMSE (1.7).
- Site 2 has the highest MB (-1.5) in SLUCM, indicating a significant underestimation.
- The AVG row provides an overall comparison, showing slight variation across models.

**Conclusion**
- Model scores vary significantly across different locations, highlighting the need for site-specific model optimization.
Effect of AC systems

- Up to 18% of total sensible heat flux in the city centre
- Up to 8-12% of total sensible heat flux in sub-urban areas
Sensible heat flux (H) in W/m²

Amount of total H increase due to AC systems

<table>
<thead>
<tr>
<th>Climate scenario</th>
<th>Sensible heat flux due to warming</th>
<th>Sensible heat flux increase due to AC systems</th>
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<tbody>
<tr>
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<tr>
<td>WL</td>
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<td>GL</td>
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