Anthropogenic heat release and urban heat island effect in Rotterdam, the Netherlands

R.J. Ronda, G.J. Steeneveld, L.W.A van Hove, and A.A.M. Holtslag

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Knowledge for Climate

Research questions

The Urban Heat Island (UHI) effect critically influences health and comfort of inhabitants in cities. Steeneveld et al. (2011) studied UHI in the Netherlands using observations taken by hobby meteorologists.

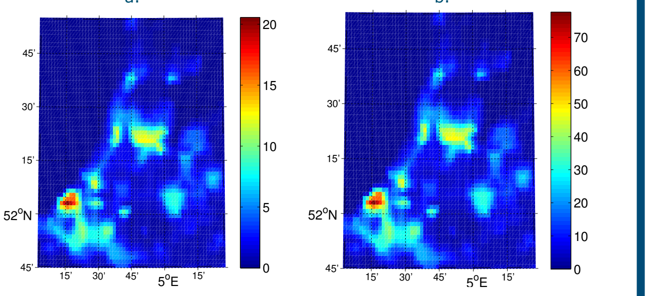

Fig. 1:Anthropogenic heat emissions in the western part of the Netherlands extracted from LUCY 3.1 at 2 hours (a.) and 12 hours (b.) on 6 August 2009.

Heat production by human activities is a major contributor to the UHI in many cities. Recently, Allen et al. (2011) developed the Large scale Urban Consumption of energY model (LUCY) that provides hourly estimates of the Anthropogenic Heat (AH) fluxes on a 2.5 arc-minute scale around the globe. As illustrated in Fig. 1 for the Western Netherlands, AH fluxes (provided by LUCY3.1) are typically low in rural areas, but can peak locally in urban areas to values up to 20 W m^{-2} during nighttime and up to 70 W m^{-2} during daytime. Goal of this study is to assess the impact of AH fluxes on the UHI of Rotterdam and surrounding cities. Because of the high spatial variation of AH fluxes, we have introduced the 2.5 arc-minute AH fluxes extracted from LUCY3.1 as an extra sourceto the grid cell sensible heat flux of urban pixels in the WRF-ARW model. Results of the WRF-ARW model including LUCY3.1 AH fluxes are compared to a traditional setup with spatially uniform AH heat fluxes and a setup of the WRF-ARW model where no AH fluxes are applied.

Methodology

Observations are taken from sites

- KNMI station Zestienhoven: (rural),
- Rijnmond: urban (hobby),
- IJsselmonde: urban (hobby).

WRF 3.3.1 – ARW setup

- Resolution: 41x41, 41x41, 61x61 grids with 25, 5, 1 km resolution and 27 vertical layers;
- NCEP-FNL boundary conditions;
- PBL: YSU scheme;
- Land: NOAH with 4 soil layers;
- Urban: Single Layer Urban Canopy Model (Chen et al. 2011);
- Land use: USGS (see fig. 2);
- Albedo wall, roof and road: 0.2;
- Fraction green: 3 %;
- AH emission scenarios
  - $Q_F = 0$: no AH emissions
  - $Q_F = 38$ W m^{-2} (Klok et al. 2010)
  - $Q_F =$ LUCY3.1 (Allen et al. 2011)

$$SHF_{WRF} = SHF_{SLUCM} + Q_F$$

Other urban parameters according to Chen et al. (2011).

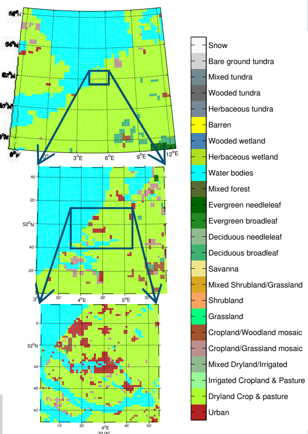

Fig. 2: USGS land surface classification for coarsest grid (upper), first nested grid (middle) and the inner grid (lower).

Results

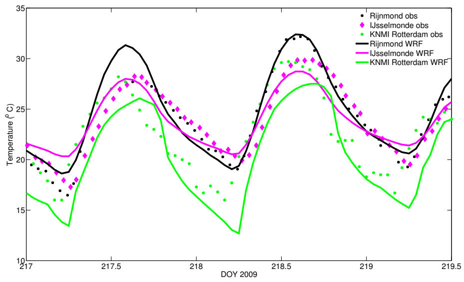

Fig. 3: modelled (Rijnmond and IJsselmonde: urban canyon temperature, KNMI Rotterdam: screen level temperature) and measured temperatures on DOY 2009 217, 218 and 219 (AH emissions from LUCY3.1).

The WRF model is reasonably capable of simulating the observed temperatures for the rural site and the urban site at Rijnmond, especially during the evening transition and during nighttime. For the urban site of IJsselmonde the WRF model tends to overestimate the temperature during the evening transition.

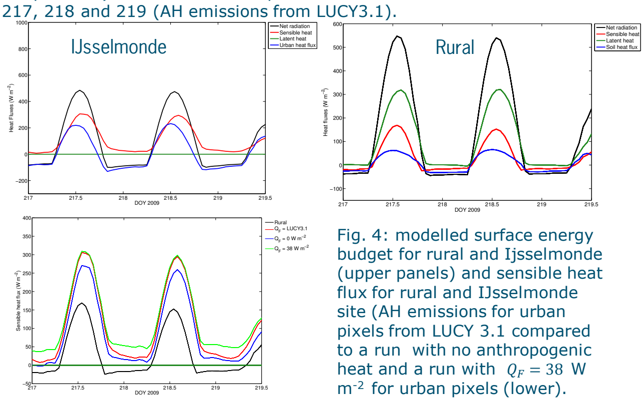

Fig. 4: modelled surface energy budget for rural and Ijsselmonde (upper panels) and sensible heat flux for rural and IJsselmonde site (AH emissions for urban pixels from LUCY 3.1 compared to a run with no anthropogenic heat and a run with $Q_F = 38$ W m^{-2} for urban pixels (lower).

WRF3.3.1 fluxes show that the diurnal cycle of heat flux into and out of the urban fabric is much larger for the soil heat flux of the rural site. Furthermore, the AH emissions contribute significantly to the sensible heat flux of the urban site, especially during daytime. Adopting a constant value for the AH flux leads to values of the sensible heat that are, particularly during nighttime, higher than the AH fluxes taken from LUCY3.1.

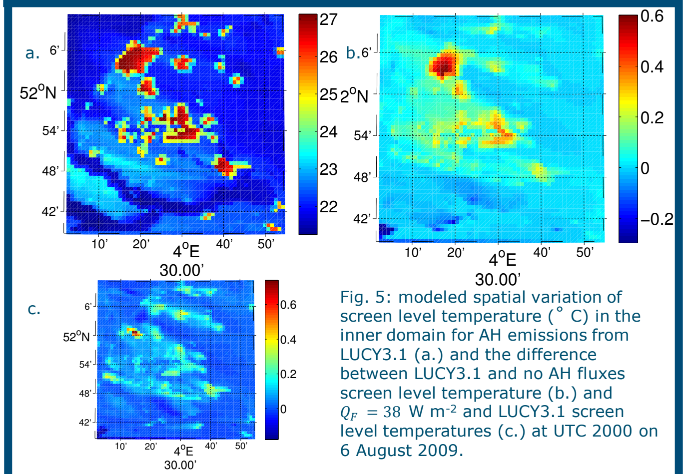

Fig. 5: modeled spatial variation of screen level temperature (° C) in the inner domain for AH emissions from LUCY3.1 (a.) and the difference between LUCY3.1 and no AH fluxes screen level temperature (b.) and $Q_F = 38$ W m^{-2} and LUCY3.1 screen level temperatures (c.) at UTC 2000 on 6 August 2009.

AH emissions from LUCY 3.1 lead to higher modelled screen level temperatures as compared to the scenario without AH emissions, especially in the centre of the urban areas of Rotterdam and The Hague. Adopting a constant value of 38 W m^{-2} for the AH fluxes gives temperatures that are locally up to 0.6 °C higher or up to 0.2 °C lower than screen level temperatures obtained using LUCY3.1 for the AH fluxes.

Conclusion

Anthropogenic Heat emissions of LUCY 3.1 are successfully incorporated in WRF3.3.1 leading to differences of up to 0.6 °C in urban areas as compared to a run without anthropogenic emissions of heat and differences up to 0.6 and 0.2 °C for a scenario with a constant value of 38 W m^{-2} for the AH fluxes.

Allen, L., F. Lindberg, and C.S.B. Grimmond, 2011: Global to city scale urban anthropogenic heat flux: model and variability. *Int. J. Climat.*, **31(13)**, 1990-2005

Chen, F., and Coauthors, 2011: The integrated WRF/urban modeling system: development, evaluation, and applications to urban environmental problems. *Int.. J. Climatol.*, 31(2), 273-288, DOI:10.1002/joc.2158

Klok, E.J., H. ten Broeke, T. van Harmelen, H. Verhagen, H. Kok, S. Zwart, 2010: Ruimtelijke verdeling en oorzaken van het hitte-eiland effect. TNO-rapport, Concept, in Dutch

Steeneveld, G.J., S. Koopman, B.G. Heusinkveld, L.W.A. van Hove, and A.A.M. Holtslag, 2011:Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. *J. Geophys Res.* **116**, D20129