197: Mitigation of the urban heat island effect using vegetation and water bodies

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Abstract

This paper gives a summary of research studying the impact of green vegetation and water surfaces on the urban heat island effect in Dutch cities. It appears that observations from both hobby meteorological stations, bike traverses and model results from 1D and a 3D WRF mesoscale model consistently estimate the cooling effect of urban green vegetation by 0.06 K/% vegetation cover. Surprisingly, enhanced water surface cover appears to *increase* the maximum urban heat island effect.

Keywords: urban heat island; vegetation; water, WRF, bike traverse, weather amateurs, Netherlands.

1. Introduction

Quantification of the canopy layer urban heat island (UHI) has substantially gained research attention in the recent years. Enhanced urban temperatures affect human comfort, health and labor productivity. Moreover, urbanization is projected to increase in the coming decades. In terms of urban planning and the foreseen climate change, the introduction of green vegetation and open water areas have been hypothesized as effective counter measures against adverse human comfort in cities (Wilmers, 1988; Dimoudi and Nikolopoulou, 2003; Synnefa et al., 2008; Takebayashi and Moriyama, 2009; Xua et al., 2010). It is also clear that urban evaporation appears to be the most difficult energy budget component to model (Grimmond et al., 2011). However, the effectiveness of these measures needs to be further quantified, and consistency from different methods should be assessed. In this paper we study these hypotheses within the context of the Rotterdam metropolis (Netherlands), by formulating the following research questions:

- To what extent does urban green indeed reduce UHI?
- Do bike traverse observations, fixed station observation and model estimates quantitatively reveal similar efficiency of green vegetation in reducing the UHI?
- Does urban water cover reduce or enhance UHI?

2. Methodology

We bring together the results three experimental approaches.

A. Observations by fixed stations.

Since long-term observational records in cities are scarce, we explore the possibility to use long observational records from hobby meteorologists (Steeneveld et al., 2011). After careful selection and classification of these observations in terms of measurement height, urban architecture, and filtering for time slots with fog and rain, we found that in the Netherlands the mean daily maximum UHI amounts 2.3 K and the 95 percentile amounts 5.3 K. The studied sites differ substantially in green vegetation cover. Moreover, with the many canals, the Netherlands is an excellent testbed for unravelling the relation between UHI and water cover (see below). The green and water cover were determined using GoogleMaps images in an area of 600 x 600 m around the observational site.

B. Bike traverse observations in Rotterdam (Netherlands).

On August 6, 2009, two tricycles equipped with measurement of temperature, humidity, wind speed, and 3D radiation components made 3 traverses through Rotterdam, 20 km each, covering a variety of urban climate zones (Heusinkveld et al., 2009 & 2012Fig. 1 & 2). The observations reveal a substantial UHI of about 6 K in the city center and smaller UHI in the outskirts. The nocturnal UHI measurements have been related to the green vegetation cover in a 600 m radius from each measurement point (Heusinkveld et al., 2012).

Fig 1: Instrumented tricycle (measuring temperature, humidity, wind speed, radiation components) .

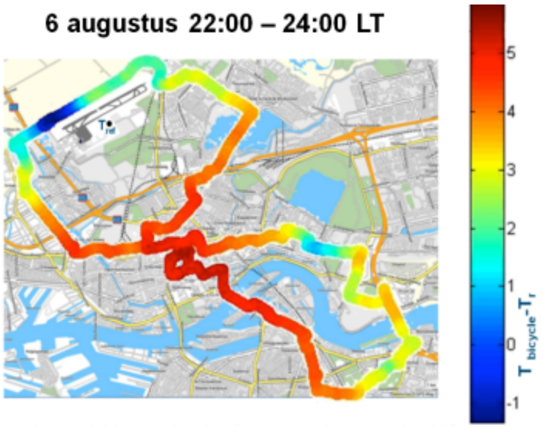

Fig 2: Measured (bike traverses) urban heat island effect in Rotterdam, 22:00-24:00h, August 6, 2009.

C. WRF single column model

In this approach the WRF (version 3.2.1) single column model is run for an idealized case with a geostrophic wind speed of 3 m/s, for two independent columns, i.e. a rural and an urban column. For the urban column, the model has been equipped with the Single Layer Urban Canopy Model, using urban parameters determined for Rotterdam with a varied vegetation fraction as a separate tile (Theeuwes et al, 2012). The rural column is located and evaluated for the Cabauw tower site, with a grassland surface (Fig. 3).

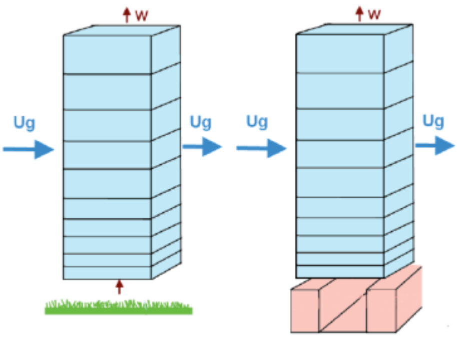

Fig 3: WRF 1D model set up: rural column (left), urban column (right).

D. WRF full 3D model

In this approach, the experiment under C. has been repeated for the city of Rotterdam, but then with the full 3D WRF model (version 3.3.1). With this approach we introduce advection and mesoscale circulations as additional processes. Similar to the single column model approach, this experiment utilizes the YSU boundary layer scheme (Hong et al., 2006) and the NOAH land surface scheme (Ek et al. 2003) equipped with the single layer urban canyon model (SLUCM), using an aspect ratio of H/W ~ 1, and an anthropogenic heat flux of 38 Wm^{-2}. Other parameters are similar to Chen et al. (2011).

3. Preliminary Results

a) Results 1: UHI and Water Cover

Physical intuition and some empirical results (Robitu et al., 2006; Pearlmutter et al., 2009) suggest that water bodies cool urban areas due to their evaporative power, and enhanced wind speed due to reduced surface friction. On the contrary, our results from the hobby meteorological dataset (Steeneveld et al., 2011) indicate that both the mean and the 95 percentile of the UHI *increase* significantly with water cover (Fig. 4). Bike traverse observations support these findings: the observed air temperature nearby water bodies is not lower than its surroundings (Fig. 2). Possibly, the high thermal inertia limits nocturnal cooling once the waters are warm. Also, nocturnal stable conditions limit the wind speed over water in case the water is cold in spring. This inhibits the exchange with the colder surface.

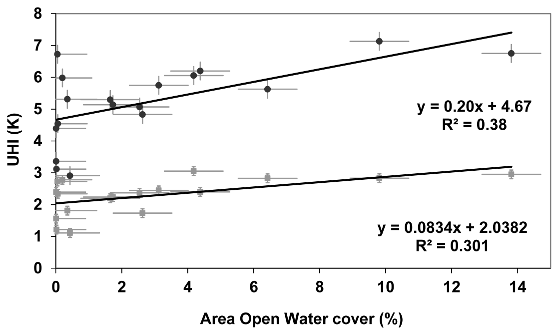

Fig 4: Measured median and 95 percentile UHI as function of surface water cover.

b) Results 2: UHI and Green Vegetation Cover

Green vegetation strongly reduces the UHI, as found in earlier observational studies by hobby meteorological data (Steeneveld et al, 2011) is supported by bike traverse observations (Heusinkveld et al., 2012; Fig. 5). However, it appears that our observational results for Dutch cities are also supported by the WRF single column model, and by the 3D WRF model. Moreover it is surprising that the sensitivity of the UHI to green vegetation is approximately similar in all approaches, i.e. typically 0.6 K decrease for each 10% vegetation cover increase.

The fact that the bike traverse data show an offset compared to the other sources is due to the fact that the traverse data cover only a single warm day, while the points from the fixed stations represent the 95 percentile of the daily maximum UHI, based on multiple years of data. In addition, for traverse data the KNMI station at Rotterdam airport has been taken as the rural reference. However, a later study (Heusinkveld et al., 2012) showed that this station could be influenced by nearby urban areas as well, because temperatures at a more rural location appeared to be >1.5 K colder than at the KNMI station for analogue nights (and is also visible in Fig. 2). Most importantly, in this paper our focus is on the slope of the graph rather than on the absolute values.

It is important to note that the UHI in WRF is based on the difference in minimum temperature between rural and urban sites, while the bike traverse data represent instantaneous UHI values, and the fixed station data (Steeneveld et al., 2011) use the maximum urban-rural temperature difference. The different UHI definitions hamper one to one comparison, but can also partly explain the difference in the offsets.

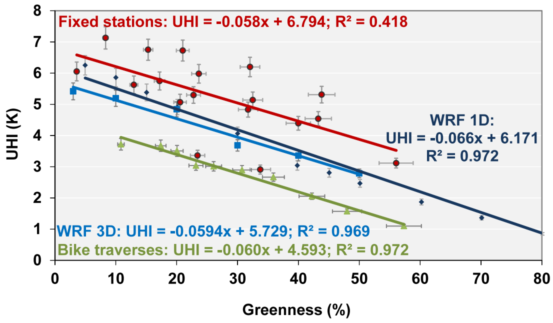

Fig 5: Estimated dependence of UHI versus green vegetation fraction for the Netherlands as extracted from different research strategies.

4. Conclusion

This paper studies the role of vegetation and surface water cover in mitigating the urban heat island effect in the city of Rotterdam (Netherlands), based on different research strategies. Model results from 1D and 3D WRF indicate a substantially reduced UHI for high green vegetation. Field observations by both hobby weather stations and bike traverses indicate a smaller UHI for high green vegetation. Model and observational results are surprisingly consistent from a quantitative perspective, and amounts about 0.6 K per 10% vegetation cover. Surprisingly, a larger water surface cover *enhances* the maximum urban heat island effect.

5. Acknowledgements

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