Using the Town Energy Balance model (TEB) in regional climate simulations over the Netherlands

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Summary

The Town Energy Balance Model (TEB) is used for modelling the surface-atmosphere exchange processes for urban environments in the Netherlands. Simulations were run with and without TEB using the regional NWP and climate modelling system HARMONIE for a month with relatively clear and calm conditions. The results where compared to urban and rural air temperature measurements from Rotterdam as well as to results reported from observational studies.

The magnitude and diurnal cycle of the urban heat island was realistically simulated with TEB. This indicates that TEB captures important physical properties of the built up environment necessary for modelling the urban climate. Overall the results were promising suggesting that TEB coupled to a regional climate model can be a useful tool for work where realistic representation of urban climate conditions is important.

Introduction

Urban areas have very different physical properties compared to its rural surroundings which influences its hydrological, thermal, radiative and aerodynamic behaviour and thereby the exchange of heat, water and momentum between the urban surface and the atmosphere. This results in the development of an urban climate that deviates from that of its surroundings. Usually urban areas are warmer than their neighbouring areas which have become known as the urban heat island effect. The main factors contributing to the urban heat island effect are efficient drainage, radiation trapping between buildings, increased heat storage in building materials and anthropogenic emissions (see e.g. Arnfield 2003 and Grimmond 2006).

Although the urban heat island is a significant and well documented anthropogenic climate modification it is only recently that physical representations of the urban land surface has been included in atmospheric models. The increase in computer power has allowed regional climate models to operate at resolutions where the land surface of entire grids can be represented as urban areas. Efforts have therefore been made to develop land surface parameterizations that include the representation of urban physical properties and exchange characteristics. This was first done by tuning existing soil-vegetation-atmosphere schemes to better represent urban environments by e.g. reducing water available for evapotranspiration, increasing the roughness length and changing the thermal properties of the soil. However, since about year 2000 several efforts have been made to represent the urban land surface with urban canopy models which aim to realistically represent the energy balance of the 3D urban canyon, i.e. representing roofs, walls and roads (Masson 2006).

In this study we run a regional climate model at 2.5 km resolution for a domain centred over the Netherlands using the Town Energy Balance (TEB) scheme (Masson 2000) to parameterize urban surfaces. Simulations are run with and without TEB with the purpose to elucidate the performance of an urban land surface parameterization and to assess its potential to improve modelling results for urban environments in the Netherlands. We examine the changes in energy balance partitioning and compare to what has been reported from observational studies. For Rotterdam we compared modelled urban and rural air temperatures to observations.

Methods

Model setup and observations

Simulations were conducted using the non-hydrostatic NWP and climate modelling system HARMONIE (HARMONIE documentation). Depending on resolution and purpose HARMONIE can be setup using different model components. In this study we run HARMONIE with AROME at 2.5 km resolution for a 300x300 grid centred over the Netherlands. Boundary conditions at 12 km resolution were downscaled from ERA-Interim using HARMONIE with ALARO.

Simulations were conducted with and without TEB for April 2011. Urban areas were represented as the land surface category "rock" for the simulation without TEB. The time period was selected because relatively clear and calm conditions prevailed, i.e. conditions when we can expect to have pronounced urban-rural climate differences. Air temperature observations from central and rural Rotterdam were compared to model results from the grid box covering the location of the respective measurement station. The central measurement station (51° 55' 24.18'' N, 4° 28' 10.35'' O) was located in an area with high building density and little vegetation and the rural station was located at an agricultural area in the northern part of Rotterdam (51° 58' 55.17'' N, 4° 25' 45.31'' O) (see van Hove et al. 2011 for details).

TEB (Town Energy Balance model)

Surface-atmosphere exchange processes in HARMONIE are simulated by the surface modelling platform SURFEX (Masson et al. 2013) which uses four separate tiles representing land, sea, inland waters and urban areas. Each tile has its own sub-model and the total grid flux is the sum of contributions from each tile according to the fraction they cover.

The urban tile of SURFEX is represented by the Town Energy Balance model TEB. TEB is designed for large horizontal scales and uses the so called canyon approach where the urban geometry is simplified and represented by a road boarded by buildings (Masson 2000). Within a grid all urban canyons are identical (same building height, road width etc.) and all canyon orientations exist with the same likelihood. Separate surfaces are used for roofs, walls and roads where each surface has its own surface temperature, energy budget and heat conduction. The canyon geometry is taken into consideration for radiation processes (shading and reflections) and for the vertical wind profile inside the canyon. Results from offline simulations has been validated against several urban flux observation data sets and TEB has been demonstrated to perform well for a variety of urban environments and climate conditions (see e.g. Masson et al. 2002 for dry districts of Vancouver and Mexico City and Lemonsu et al. 2010 for Montreal during cold and snowy conditions).

Fraction of urban areas as well as necessary parameter values for canyon geometry and urban physical properties are taken from the global land surface database ECOCLIMAP (Champeaux et al. 2005) (Fig. 1). Two urban types, "urban" and "temperate suburban", are dominant within the domain according to ECOCLIMAP of which the former is characterised as dense urban areas often found in city centres with higher buildings and a rougher urban surface compared to the later (Table 1).

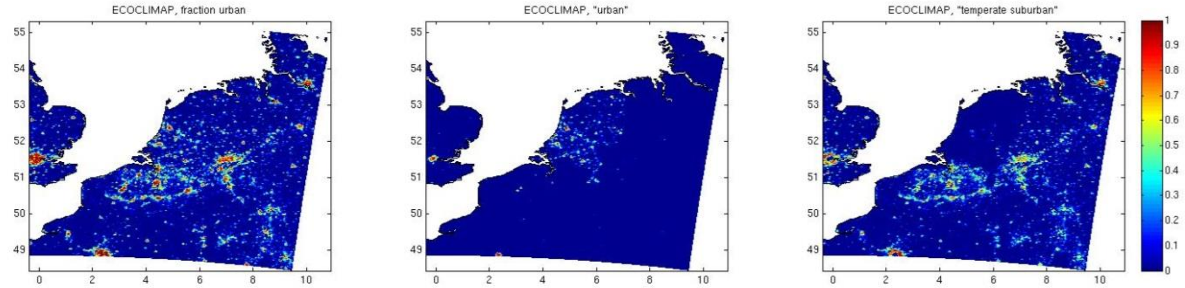

Figure 1. Urban information from the land surface database ECOLIMAP. Total fraction of urban areas (left) and the fraction of the two dominant urban categories "urban" (centre) and "temperate suburban" (right).

Table 1. Urban parameter values according to ECOCLIMAP for the two dominant urban categories within the domain.

	Temperate suburban	Urban
Morphological parameters		
Building fraction	0.3	0.45
Height to width ratio	0.21	0.82
Building height (m)	10	30
Roughness length (m)	1.0	3.0
Radiation parameters		
Albedo roof/wall/road	0.15/0.08/0.25	0.15/0.08/0.25
Emissivity roof/wall/road	0.90/0.94/0.85	0.90/0.94/0.85

Results and discussion

Including TEB has a substantial influence on the simulated climate (Figure 2). The spatial distribution of urban areas is clearly reflected in the 2 m air temperature with a mean temperature during April 2011 being 1-2 K warmer over the built up areas when TEB is included. Similar spatial pattern can be seen for changes in the surface energy budget where the sensible heat flux is increased while the latent heat flux is reduced over the urban areas. This is in line of what has been reported from observational studies from urban areas with no or little vegetation (see e.g. Arnfield 2003 for a review).

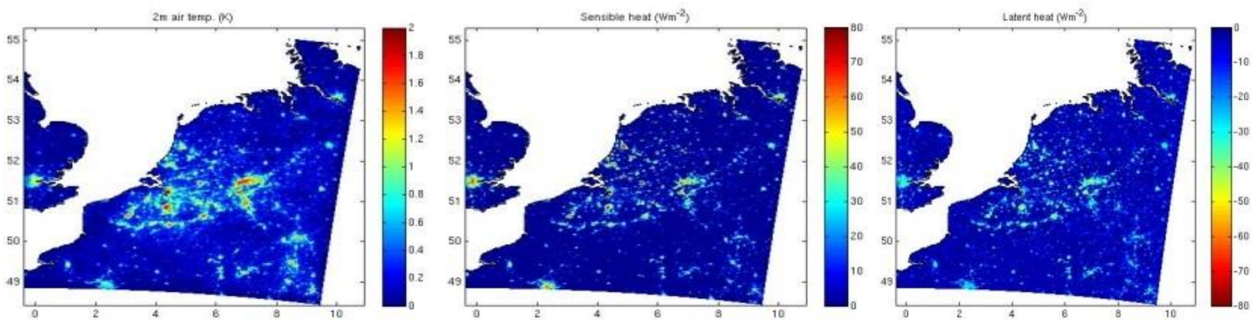

Figure 2. Changes (with-without TEB) in monthly mean 2m air temperature (left), sensible heat (centre) and latent heat (right).

For Rotterdam simulated results are compared to site observations. It should be noted that one has to be careful when comparing model results representing mean grid properties to site observations since they represent different scales. Nevertheless, we do such a comparison here to give an idea if simulations including TEB provide realistic urban-rural temperature differences.

The simulated urban heat island (the urban-rural air temperature difference) was in the range of 1-4 K during clear and relatively calm days (Figure 3) which is in the range of the observations and what has been reported for other cities in the Netherlands (Steenvald 2011). However, the simulated maximum urban heat island effect was lower than the observed and an explanation seems to be a too slow rural temperature decrease during the night in the simulations. The diurnal cycle of the urban heat island is similar between simulations and observations with maximum values occurring around midnight and minimum values in the early mornings. This pattern is often reported from observational studies and explained by heat being released from the urban fabric several hours after sunset providing energy to the surface resulting in an upward sensible heat flux and warmer air temperatures (Grimmod and Oke 1999). This is also reflected in the simulations where more energy is put into storage during the day and more energy is being released during the night for urban compared to rural Rotterdam. During clear and calm conditions the release of stored energy seems to support an upward sensitive heat flux throughout the night and hence preventing stable conditions to occur.

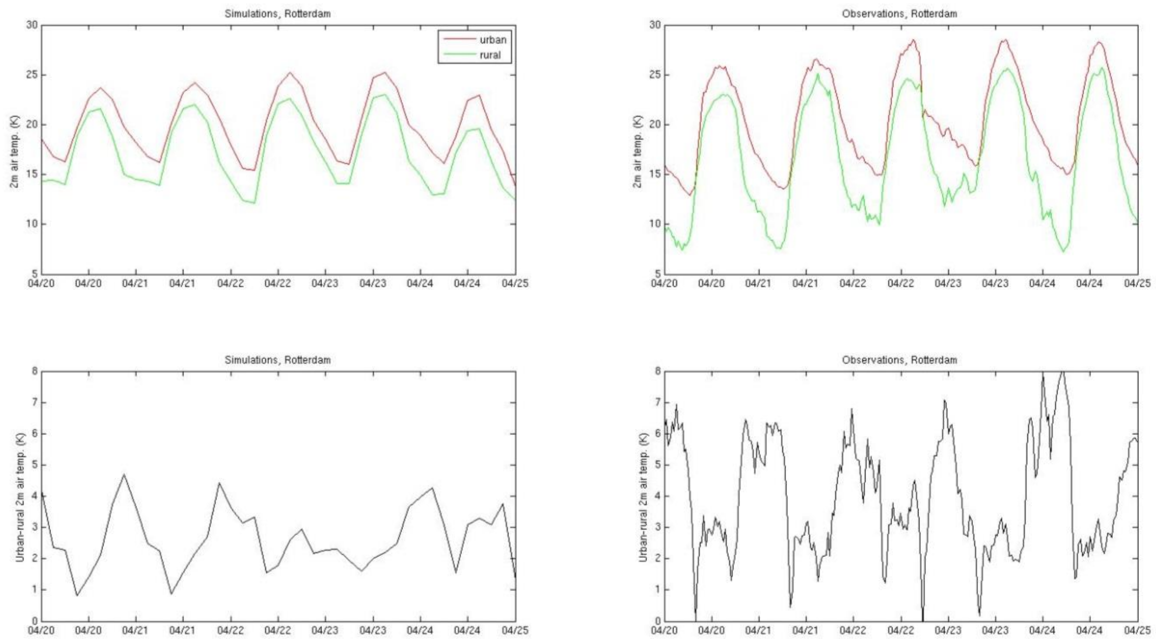

Figure 3. Simulated (left) and observed (right) 2 m air temperatures and urban-rural air temperature differences for Rotterdam during five clear and relatively calm days in April 2011. Modelled data are taken from the grid box covering the urban and rural measurement sites, respectively.

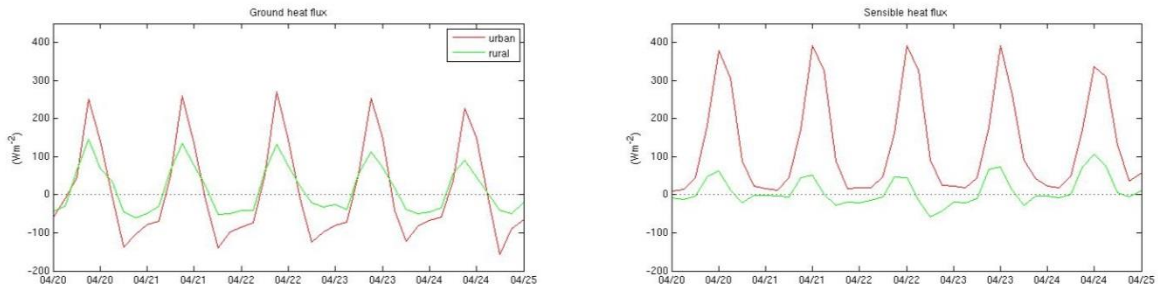

Figure 4. Simulated urban and rural heat storage (left) and sensible heat flux (right) for Rotterdam during five days in April 2011.

Conclusions

This study examines the effect of including the Town Energy Balance model (TEB) in regional climate simulations for a domain centred over the Netherlands. The results are promising with warmer climate over the urban areas when including TEB which agrees with what has been reported from observational studies. Comparing simulated results to observations from Rotterdam during five clear and calm days shows that TEB realistically simulates the magnitude and diurnal variation of the urban heat island effect. This indicates that TEB captures characteristics important for the surface energy balance partitioning in urban environments.

Including TEB in regional climate simulations over the Netherlands will improve the representation of climate influenced by urban environments. Results using TEB will therefore be useful for studies where the local urban climate is important such as work related to e.g. the urban heat island effect, human comfort and urban air quality.

Acknowledgments: This study was part of the Dutch research program Knowledge for Climate. The HARMONIE model is developed and provided by the HIRLAM consortium, Météo France and the LACE countries. We thank Ulf Andrae at SMHI for HARMONIE technical support. Measurements from Rotterdam were kindly provided by Jan Elbers at Wageningen University and Research centre. The authors would like to acknowledge Geert Lenderink at KNMI for coordinating Knowledge for Climate and for providing input to this study.

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