Seasonal comparison of three urban land surface schemes in a high-latitude city of Helsinki

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1. Introduction

Due to the growing number of people living in urban areas, the ability to forecast the local climate by means of weather, climate and air quality is important. The interaction between the surface and the atmosphere in atmospheric models is presented using land-surface (LS) models, which parameterize the surface-atmosphere exchanges. There is a range of different land surface models for urban areas, but their ability to correctly simulate the surface exchange have a large variability (Grimmond et al. 2010, 2011). The comparisons are however made in mid-latitude cities and little is known on their performance in high-latitude cities despite the largest climate change is expected at the area.

The purpose of the current study was to compare three urban LS models (CLM, SUEWS and SURFEX) at two sites in Helsinki, Finland. The modeled net all-wave radiation, turbulent fluxes of sensible and latent heat and snow depth were compared against observations. The model evaluation particularly focused on seasonality and snow, which is a frequent feature of cold climate cities.

2. Methods

2.1 Study sites

The model evaluation was done at two sites representative for different surface covers in Helsinki, Finland. Hotel Torni site is located in the Helsinki city center and it is representative for highly built-up surface cover with 22 % of the surface covered with vegetation. The mean building height in the area is 18 meters and the site belongs to the local climate zone (LCZ) 2 (Steward and Oke, 2012). The second site is the semi-urban Kumpula located 4 km north-east from the city center. In Kumpula over 50% of the surface is covered with vegetation as the University Botanical garden and city allotment garden are located in the area. Kumpula belongs to LCZ 6.

2.2 Modeling

The surface energy exchange and snow was simulated using three models: the Community land model version 4 (CLM4, Lawrence et al. 2011), the Surface Urban Energy and Water balance Scheme (SUEWS V2014b, Järvi et al. (2014)) and SURFEX (Surface Externalisée, Masson et al. 2013). All three models have slightly different methods to simulate the different surface energy balance components (Table 1). The models were run for 1 km radius circular areas centred on the measurement masts to approximate the measured surface fluxes. The models used the same forcing data obtained from the measurements and surface cover information including surface cover fractions, building and tree heights and the initial conditions for the runs. For the other model parameters, CLM used the Jackson et al. (2010) database, SURFEX the ECOCLIMAP (Masson et al. 2003; Faroux et al. 2013) and SUEWS its own values (Järvi et al., 2011). The models were run for 1 July 2011 to 31 December 2012 where the first six months are used to spin-up the models leaving the remaining 12 months for the actual model comparisons.

Table 1. Model specific methods to define the components of the surface energy balance and melt of snow. Q^* *= net all-wave radiation* (W m^{-2})*,* Q_H *= sensible heat flux* (W m^{-2})*,* Q_E *= latent heat flux* (W m^{-2})*,* Q_F *= anthropogenic heat flux* (W m^{-2})*,* ΔQ_S *= storage heat flux* (W m^{-2}) *and M = snow melt (mm h^{-1}).*

	CLM	SURFEX	SUEWS
Q^*	α + T_{surf}	α + T_{surf}	NARP (α + T_{surf})
Q_H	As a resistance from (T_{air} - T_{surf})	As a resistance from (T_{air} - T_{surf}) + building and traffic Q_F	As a residual
Q_E	As a resistance from (q_{air} - q_{surf})	As a resistance from (q_{air} - q_{surf})	Penman-Monteith equation
Q_F	Building heating	Building heating+ industrial activities + traffic	Building heating and cooling + traffic
ΔQ_S	As a residual	As a residual, driven by heat conduction through surfaces	OHM
M	Energy balance of snow (up to 5 layers)	Energy balance of snow (1 layer)	Degree day method based on Q^* and T_{air}

2.3 Measurements

At both study sites the turbulent fluxes of sensible and latent heat were measured using the EC technique. The wind components and sonic temperature were measured with an ultrasonic anemometer (USA-1, Metek GmbH, Germany) and in Kumpula the water vapour mixing ratio was measured with a closed-path infrared gas analyser (LI-7000, LI-COR, Lincoln, Nebraska, USA) and in Hotel Torni using an enclosed path analyser (LI-7200, LI-COR). The 10 Hz measurements were analysed using commonly accepted methods (Nordbo et al. 2012). The EC measurements were carried out at a sufficient height above the surrounding buildings at both sites (31 m Kumpula, 60 m Torni). Meteorological data needed to force and evaluate the models were mainly measured at Kumpula, where air temperature, wind speed and incoming and outgoing short- and long-wave radiation were measured at the EC measurement mast and relative humidity and precipitation from the roof of a nearby building at 24 m. In the centre, air temperature and outgoing short- and long-wave radiation were measured 550 m southeast of the Torni site at a height of 53 m. Snow depth was measured near the Kumpula mast and in a park in city centre by the Finnish Meteorological Institute.

3. Results

All models simulated the net all-wave radiation well and the largest uncertainties were related to the snow-melting period in spring when the fraction of snow on surfaces causes a bias to the outgoing short- and long-wave radiation. The largest uncertainties in the sensible heat flux seemed to relate to the modeling of the anthropogenic and storage heat fluxes particularly at the more densely built Hotel Torni site. Similarly to previous studies from mid-latitude cities, the latent heat flux performance was most problematic for all models with a clear underestimation at both sites particularly in summer. Energy partitioning of the turbulent fluxes was better during the growing season than outside it (Fig. 1).

Models simulated the snow depth well. However SUEWS and SURFEX delayed the complete snowmelt for Torni (> ten days) longer than for a vegetated surface. This had only a minor impact on the turbulent fluxes given the small fraction of vegetated surfaces at the site. No models outperformed the others, but rather the performances were season, site and flux dependent.

Atmospheric stability, an important parameter in applications such as air quality forecasts, was compared against observations. Wintertime stability classes varied between the models. However, they were better simulated at the suburban site than at downtown. There, CLM was unable to simulate stable atmosphere whereas SUEWS and SURFEX simulate more stable and neutral cases than the observations indicate. Thus, the parameters in the Jacks*on et a*l. (2010) database used n CLM should be revisited for high-latitude cities.

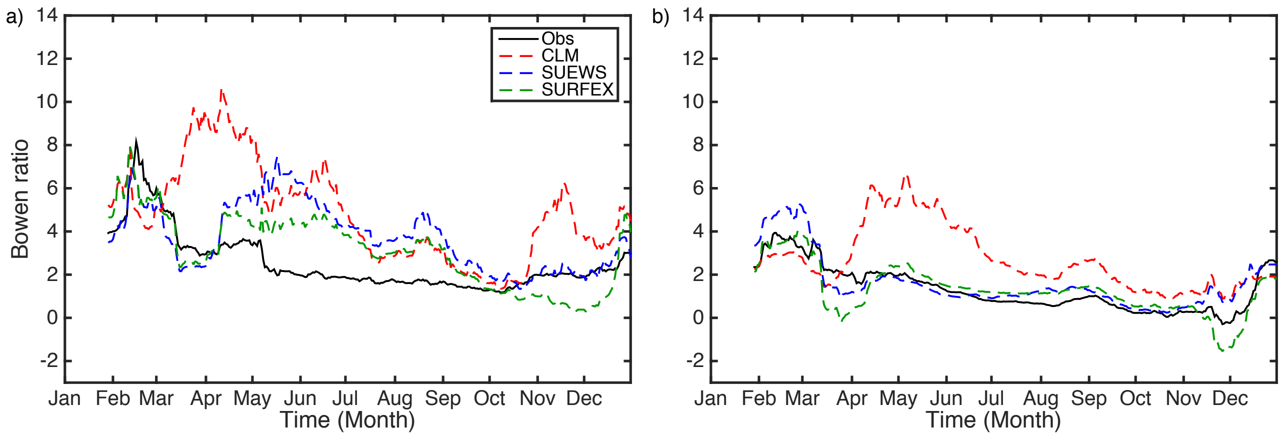

Fig. 1 28-day running mean of Bowen ratio in a) Torni and b) Kumpula.

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