A multi-model and -namelist ensemble for a tropical urban energy balance

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Key Findings

The main (preliminary) findings of this work can be summarized as follows:

• Overall, the skill of each model depends on the flux of interest, the namelist used and the prevailing atmospheric conditions. No model performs better overall compared to any other model, and all models generally perform best for Q* and worst for Qe.

• CLM and SURFEX almost behave identical when the same namelist is used. And while TERRA-URB is the most simple scheme, its performance is as good compared to the more complex schemes.

• During the exceptional dry period, some models' behavior changes compared to the other models (eg. the modelled outgoing long-wave by SUEWS during the dry period). For most models, the normalized bias for upward long-wave radiation (latent heat flux) increases (decreases) as a function of "hours after a rainfall event" (not shown).

• The inter-model and inter-namelist variability often depict a similar magnitude in interquartile range. Also here, no model or namelist combination outperforms the other on all accounts. Thus results very much depend on the choice of model and namelist used, and the flux being considered.

Context

Impervious (urban) surfaces only cover a small percentage of the Earth's land surface, but their representation in land-surface (LS) models and numerical weather prediction / climate models is nevertheless of great importance. Where the range of available LS schemes is high, the number of available urban parameterizations embedded in those schemes - as revealed by the intercomparison study by e.g. *Grimmond et al. (2010, 2011)* – might be even higher. The intercomparison study also outlined that models with various complexities have various strengths and weaknesses, while all models have a varying performance across the energy balance components. Besides the varying model complexities (physics), LS schemes also differ in the amount and characteristics of their external parameters describing the surface characteristics. The amount of parameters is generally associated with a models' complexity.

Against this background, this study aims at 1) a **general evaluation of the capacity of 4 urban canopy models** (see 2. Methods) **in simulating a tropical urban surface energy balance** (see 1. Site & data) and 2) performing a **multi-namelist and -model mini-ensemble indicating the role of and interaction between the models' complexity and the external parameter settings** (See 2. Methods and 3. Preliminary results).

1. Site & data

The climate and flux data used to force and evaluate the models were measured at a flux tower located in the suburban area Telok Kurau (TK) of Singapore. TK is a low-density residential neighborhood located about 3 km north of Singapore's south-eastern coastline. The study area is flat and characterized by low-rise buildings (2-3 story row and semi-detached houses and a few 5 story condominiums). Surface cover in the same area is 85% impervious (39% buildings, 12% roads, 34% parking lots, etc) and 15% pervious (11% tree crowns, 4% grass) (See **Figure 1.**). The area corresponds to local climate zone (LCZ) 3 or "compact low rise" (*Stewart and Oke, 2012*). This site was chosen because of its directional homogeneity in surface cover and the data used here extends from June 2013 to April 2014.
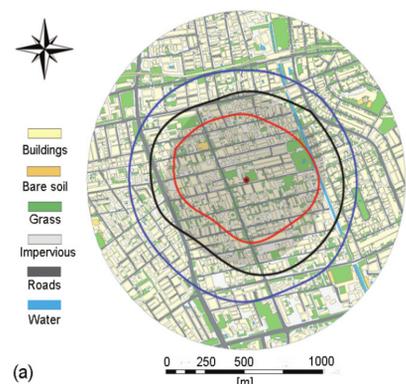
The micro-meteorological tower supported various meteorological sensors at a height of 23.7 m above the surface: radiative fluxes (CNR1), turbulent fluxes of sensible and latent heat (CSAT3/LI-7500), temperature & humidity probe (HMP45C) and rain gauge (HOBO RG3; Onset Computer Corporation, Bourne, MA, USA) .

Legend: Buildings, Bare soil, Grass, Impervious, Roads, Water

(a)   0   250   500   1000   [m]

Figure 1: Footprints encompassing 80 % of the EC flux source area overlaid on a land cover map centered on the EC tower location (red dot). Red, blue and black contours are average footprints for each wind direction during Day (08:00–18:00 h), Night (20:00–06:00 h) and the complete diurnal course, respectively. Shaded area represents the 500 m radius domain used for estimating the bottom-up emissions. Figure from *Velasco et al. (2013).*

2. Methods

Four land-surface models are used in the current study, with a focus on their urban parameterizations. All models are forced with atmospheric data observed above the canopy layer (see 1. Site & Data), hereby removing a potential source of error produced by the atmospheric model.

Four different models are used, each characterized by a varying degree of complexity: **CLM** (*Oleson et al., 2008*)**, SURFEX** (*Masson et al., 2013*), **SUEWS** (*Järvi et al., 2011*) and **TERRA-URB** (*Wouters et al., 2015*). The latter – probably least know model – is a recent development within TERRA-ML, the default land-surface scheme of the numerical weather prediction and regional climate model COSMO-CLM. TERRA-URB is a simple bulk scheme in which urban land cover is characterized by a specific thermal inertia, roughness length, albedo and emissivity and accounts for surface layer stability and the roughness sub-layer (*Demuzere et al., 2008; Wouters et al., 2015*).

While all models are forced with the same meteorological boundary conditions, each LS generally has a native set of external parameter values. E.g. SURFEX used the ECOCLIMAP database (nMA03, *Masson et al., 2003*), while CLM uses the *Jackson et al. (2010)(*nJA10*)* database for its urban parameters. For this study, all models are run with **three namelists (REF, nMA03 and nJA10)**, with varying values for the land cover fractions and the thermal, radiative and morphological properties (see Table 1).

Table 1: Overview of the surface fractions and morphological characteristics describing the residential area of Telok Kurau. H/W refers to to the canyon height to width ratio while W pond,max refers to the maximum water storage on impervious surfaces (roof and impervious road).

		REF	nMA03	nJA10
Coordinates		1°18' 51.46" N, 103°54' 40.31" E		
Urban fraction [%]:		85	60	30.8
	Buildings	39	30	18.5
	Pervious roads	-	-	4.6
	Impervious roads	46	30	7.73
Vegetation fraction [%]:		15	40	69.2
	Broadleaf evergreen tropical tree	11	20	36.55
	Broadleaf deducious tropical tree			9.33
	C3 grass	4	20	17.11
	C3 crop			6.21
Height of roof [m]		9.86	10	30
H/W [unitless]		0.61	0.21	1.2
$W_{pond,max}$ [kg m^{-2}]		1	1	1

3. Preliminary results

The **Phase I general evaluation** uses **all four models with the reference namelist REF**. All performance metrics are based on the hourly output for the whole period (as in Figure 3) or further sub-divided sub-periods (eg. day and night in Figure 4). A temporal evolution of the normalized bias is shown in Figure 5.
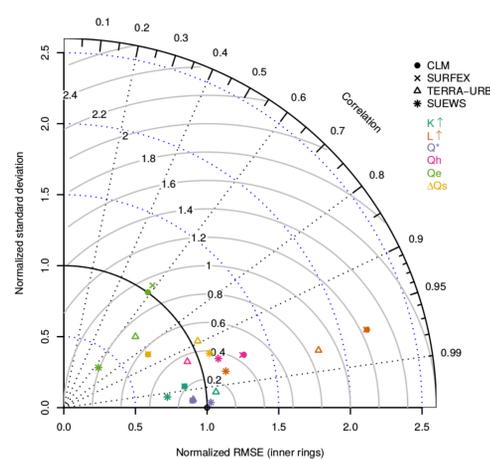
Figure 3 : *N*ormalized Taylor diagram for all models with the REF namelist (symbols) and fluxes (colors) for the full period.
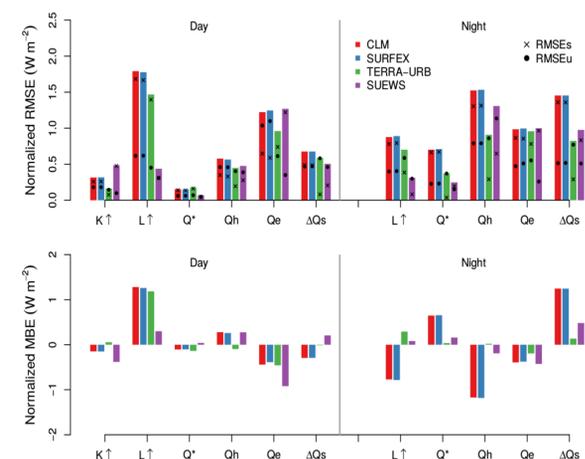
Figure 4 : Normalized RMSE (top row) and MBE (bottom row) for modelled daytime (left panels) and nighttime (right panels) fluxes. All models simulations are performed using the REF namelist. The systematic and unsystematic normalized RMSE are depicted with respectively crosses and dots (top panels).

A first result on the **Phase II multi-namelist and -model experiment** is shown in Figure 5. Here one can clearly see the sensitivity of using one model with different namelists or one namelist for all different models.

Figure 4: Temporal evolution of the daily mean normalized bias (W m^{-2}) for all model realisations with the REF namelist and for all fluxes (panels a to f). Daily precipitation sum (mm day^{-1}) is shown in blue in the top panels only while the exceptional dry spell is indicated by the light grey polygon in all panels. The zero nMBE line is indicated in black. For clarity, a five day moving average is applied to all flux time series and y-axis labels are different per flux. White breaks in the time series refer to time periods with missing data.

Figure 5: Median (dark coloured lines) and IQR (light coloured boxes) of the hourly model bias shown for each flux, grouped according to namelists (A. and C.) and models (B. and D.) and for day and night (left and right panels respectively). The zero bias level is indicated by the black horizontal dotted line.
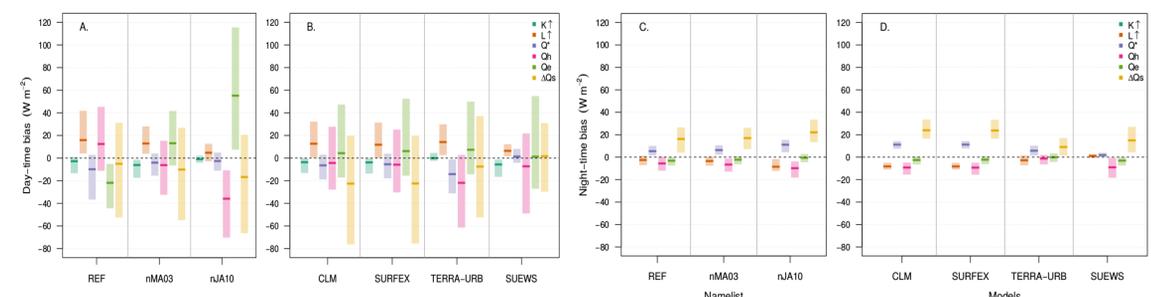
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