INCLUSION OF A DRAG APPROACH IN THE TOWN ENERGY BALANCE (TEB) SCHEME: OFFLINE 1-D EVALUATION IN A STREET CANYON

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Abstract
To improve prediction of the meteorological fields inside the street canyon with TEB, a new version has been developed, following the methodology described in a companion paper (Masson et al. 2009). It resolves the surface boundary layer inside and above urban canopy by introducing a drag force approach. This new version is tested offline in a street canyon. Results are compared with the original single-layer version of TEB and with measurements within and above the street canyon. Results show that this new version produces profiles of wind speed, friction velocity, turbulent kinetic energy, turbulent heat flux, and potential temperature that are more consistent with observations. Furthermore, this new version can still be easily coupled to mesoscale meteorological models.

Key words: BUBBLE, TEB, Drag approach

1. INTRODUCTION
The Town Energy Balance (TEB, Masson 2000) single-layer module, is essentially designed to provide canopy heat fluxes for the lower boundary condition of mesoscale meteorological models (MMMs). TEB is forced with literature-based surface thermal parameters and observed or simulated atmospheric and radiation data from above roof level. Despite the simplification hypotheses, offline simulations of TEB have been shown to accurately reproduce surface energy balance, canyon air temperature, and surface temperatures observed in dense urban areas (Masson et al. 2002; Lemonsu et al. 2004). However, since TEB is a single-layer module, then characteristics of air inside the canyon space must be specified. In fact, the logarithmic law for wind is assumed to apply down to the layer around roof top, and an exponential decay law is used below. Air temperature and humidity are assumed to be uniform inside the street canyon. So, in order to improve meteorological fields prediction inside street canyon a new version of TEB has been developed. It resolves the surface boundary layer (SBL) inside and above urban canyon by including a drag force approach to account for the vertical effects of buildings as it is done in Martilli's parameterization except that only one surface energy balance per wall is resolved. Thus, calculation of heat fluxes is not required at each level inside the urban canopy.

2. INCLUSION OF A DRAG APPROACH IN TEB

Fig. 1. Configuration of the 1D TEB_SBL, with forcing from the top (*), and calculation down to the ground in the street canyon (x), and schematic representation of the city (street and buildings).
Lemonsu et al. (2004) single-layer version of TEB (here referred to as TEB_REF), simulates the exchanges between surface and atmospheric forcing level using an aerodynamical resistances network. In the present version of TEB, (here referred to as TEB_SBL) several prognostic air layers are added within and above urban canopy, up to the forcing level. That way, the single-layer version of TEB will gain by the explicit physical representation of surface boundary layer thanks to additional air layers, and still be coupled to MMMs through only one layer (see Masson et al. 2009; Hamdi and Masson 2008 for more details). Thus, with TEB_SBL the exchanges with SBL air occur at ground level and at the SBL scheme levels in contact with buildings. So, in order to improve the computation of meteorological fields inside the urban canopy, drag force approach that was used for vegetation canopy and has been recently extended to urban canopy (Martilli et al. 2002) is applied in this study to represent thermal and dynamical effects of buildings.

3. SIMULATIONS

3.1. Measurements site

As a part of the BUBBLE (Basel urban boundary layer experiment) measurements in 2001-02 carried out in the city of Basel, Switzerland, a micro-meteorological tower was operated in dense urban areas for 9 months: Basel-Sperrstrasse. This site is located in a heavily built-up part of the city. Measurement set-up consists of a tower inside a street canyon reaching up to 32 m Above Ground Level (AGL), i.e., a little more than two times the local building height (2.2 zH), instrumented with six ultrasonic anemometer-thermometers and full radiation component measurements. The instruments installed at the highest level were mounted sufficiently far above the surface to ensure that the measurements are representative of the local scale. Instrumentation was heavily extended during the intense observational period (IOP) between 15 June and 15 July 2002, with additional measurements of turbulent fluxes. More complete details are available in Christen (2005).

3.2. The 1-D configuration

In this study, TEB_SBL is run offline on a vertical column (SBL levels are chosen at 3 m, 4 m, 6 m, 10 m, 12 m, 14 m, 16 m, 20 m and 25 m AGL) using measurements recorded at tower top (31.7 m AGL) as forcing. Integration time step is 300s. TEB_SBL calculates the meteorological variables from this forcing level down to the ground (Fig. 1). The surface energy balance for the fraction of vegetation contained in the Basel's city center is calculated using the ISBA scheme (Noilhan and Planton 1989). Forcing is applied with a 600s time step to wind, temperature, humidity, and downward global short- and long-wave radiation. The period of simulations extends from 16 June to 30 June 2002 (15 days in the first half of the IOP). Both TEB_SBL and TEB_REF versions are run to study the impact of modifications and the results are compared with measurements from the tower.

4. RESULTS AND DISCUSSIONS

4.1. Wind speed

Results in Fig. 2 show that the observed average profile can be conceptually divided into three layers (Christen 2005): (i) at the bottom there is the canyon layer, where winds are greatly reduced resulting from the presence of obstacles. (ii) The roof layer around roof top is characterized by highest gradients due to the skimming flow over the street canyon. Similarity to profiles measured over and within plant canopies, an upper inflection point, where curvature changes from negative to positive, is found around canopy top. (iii) Finally, the above-roof layer is expected to approximate the well known log-type profile of the inertial sub-layer. The TEB_SBL is able to represent the overall shape of the observed profile. The reason for that arises from the fact that this new canopy parameterization takes into account the repartition of drag force in the momentum equation along the vertical, from the ground up to roof height. The TEB_SBL is able to simulate also the inflection point which appears just above roof level between 1 and 1.2 zH (Christen 2005). And, the height of the inflection point is in agreement with observations. However, it appears that simulated drag force is underestimated in the upper part of the street canyon. This is due to the fact that in TEB_SBL, which takes the local characteristics as an input, the mean building height is small in comparison with that in some sections of the upwind area of influence.
Fig. 2. The average vertical profile of wind speed, normalized by $u(z_{ref})$ at the tower top during the first half of the IOP in the frame of BUBBLE, for measurements and TEB_SBL. Data source: Sonic, 600s time step, neutral stability at tower top, and calm situations with a mean wind speed lower than 1 m s$^{-1}$ at top level are excluded. The bars present the standard deviation of the observations.

The observations, in turn, are influenced by a fetch that may include larger, higher, and more complicated structures (the standard deviation of building height inside 250 m circle around the site is about 6.9 m, Christen (2005)).

4.2 Temperature
Vertical profile of potential temperature shows similar behavior to the observations for the simulated period. Therefore, in Fig. 3, we present averaged vertical profile, from 16 to 19 June 2002, of the observed and simulated potential temperature at 0200, 0800, 1600, and 2200 LT. Observed vertical profile of potential temperature at daytime (Fig. 2b, 2c) shows a pronounced gradient around roof level and small gradient above. TEB_SBL is able to reproduce this shape, but underestimates the temperature inside the street canyon by 0.3$^\circ$C and computes a gradient that is too large above roof level. TEB_SBL calculates heat fluxes from the street, roof, and walls. Heat sources are then distributed along the vertical up to roof level. The nocturnal urban canopy computed with TEB_SBL (Fig. 2a, 2d) shows a slightly unstable layer which is in agreement with the results, of the detailed multi-layer urban surface exchange parameterization of Martilli et al. (2002), found in Hamdi and Schayes (2007), but underestimates the temperature inside the street canyon by 1$^\circ$C.

5. CONCLUSION
The results of the comparison are summarized below: **Wind speed**: TEB_SBL fits better to the observations at 11.3 m AGL than TEB_REF, which overestimates the wind speed inside the street canyon. However, it appears that the simulated drag force is underestimated in the upper part of the street canyon. **Canyon temperature**: Near the ground, both TEB_SBL and TEB_REF versions are in good agreement with measurements. The results near roof level indicate that during daytime TEB_SBL performs better than TEB_REF which tends to overestimate the canyon temperature. **Turbulent exchange of heat**: Near the ground, TEB_SBL clearly underestimates the vertical heat flux, but observed values of the fluxes are very small. Above roof level, the values calculated by TEB_SBL correspond very well to the measurements. Inside street canyon, as well as above roof level, TEB_SBL succeeds in producing a positive turbulent heat flux at night, and thus, the nocturnal profile remains neutral and
Fig. 3. Averaged vertical profile, from 16 to 19 June 2002, of the observed and simulated potential temperature in the street canyon at 0200, 0800, 1600, and 2200 LT.

never becomes stable. Vertical profiles in the street canyon suggest that strongest gradients are found around roof top. This feature is well captured by TEB_SBL. Friction velocity: TEB_SBL is able to represent in broad terms the increase of the local friction velocity occurring with increasing height inside the urban canopy. But, the level of the maximum value is somewhat lower than the one shown by measurements. In our configuration, we do not take into account the horizontal variability of the height distribution of buildings. However, the observations are influenced by a fetch of somewhat larger height variability. The analysis of time series shows that near the ground, although TEB_SBL underestimates the local friction velocity especially during daytime, it fits, in general, better to measurements than does the single-layer version above the canyon.

References