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To introduce new surface-layer exchange coefficients, a parametrization of the thermal roughness length and a new urban surface type into TERRA-ML (SVAT)

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Outline and motivation of the work

There exists a large discrepancy between rural and urban land cover types in terms of water-, aerodynamical, thermal and radiative characteristics and anthropogenic heat. This results in urban-scale meteorological features like the urban heat island (UHI), reduced wind speed and 'city breeze'. Some of these effects have a considerable impact human health in cities when the nightly cooling is reduced during heat waves or when air quality is reduced during smog episodes. It also has an impact on energy consumption (refrigerators and airconditioning) and stresses water eco-systems. To predict and mitigate these effects, a regional meteorological model (COSMO-CLM) and air quality model (AURORA developed by VITO) will be applied at an urban scale (horizontal resolution of 1km). However, the difference in characteristics between rural and urban land-cover types in the meteorological model, more specifically in its surface module TERRA-ML, have to be represented well first.

Correct representation of the aerodynamical characteristics

Surface fluxes for momentum heat and evaporation between the surface and the first model layer in meteorological models are important to simulate the wind speed, temperature and humidity near the surface. At first, for a correct representation of these aerodynamical effects over both rural and urban terrains, new analytical exchange coefficients momentum and heat have been developed similar to the Louis scheme which avoids an iterative procedure (see left bottom). At second, a correct thermal roughness lengths have to be prescribed for each surface type. For natural land covers, kB^{-1} is set to 2 (Garratt, 1992) and for urban land covers a bluff-rough parametrization for kB^{-1} is used according to Zilitinkevich (1970).

Correct representation of the water, thermal and radiative characteristics

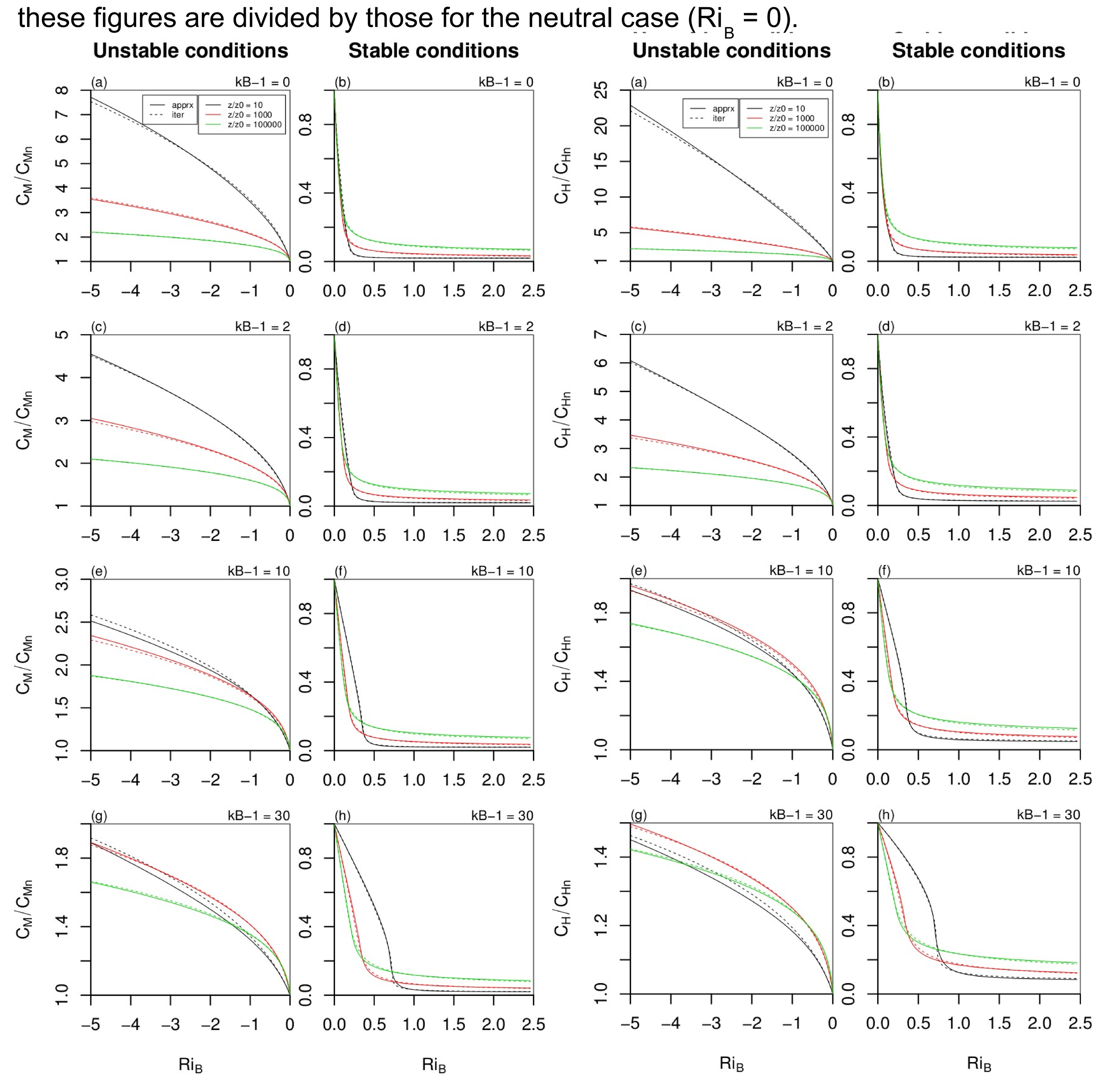
The values for albedo, emissivity, specific heat and conductivity for rural and urban land covers will be adopted from several sources (e.g. Demuzere et al, 2008). For urban land-cover types the soil-water content and evaporation will be ignored. A tile approach will be used in the meteorological model to both represent the natural and urban fraction in cities.

Results for the approximate analytical solution for the exchange coefficients

For unstable situations ($Ri_B < 0$), we found an approximate solution inspired by Yang et al, 2001[1], but with a correct limit behaviour for Ri_B approaching to 0. For stable situations ($Ri_B > 0$), we present a 'coupling' of the exact solution for linear stability functions for a weakly stable surface layer (Yang et al, 2001) and an approximate linear relation between ζ and Ri_B for a very stable surface layer (Li et Al, 2010). The analytical approximation compares well with the iterative approach for a wide range of z/z_0(*) and kB^{-1} (= $[\ln(z_0/z_{0h})]$) values. As a consequence, these analytical exchange coefficients are applicable both for rural surfaces and urban surfaces.

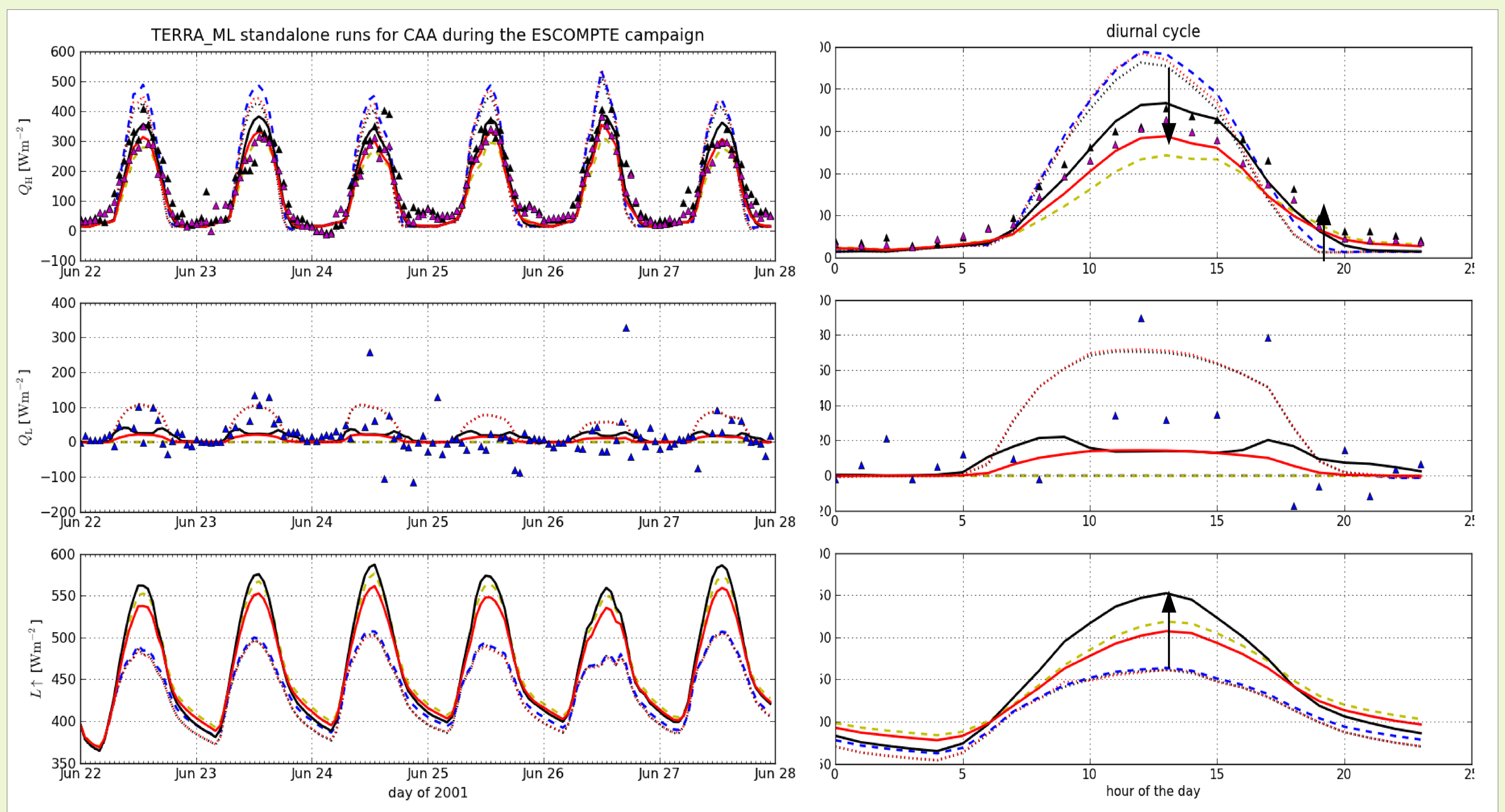
(*) z, z_0 and z_{0h} are resp. the first model layer, the thermal and aerodynamical roughness length.

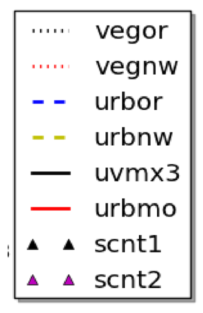
The figures show both the iterative solution (dashed line) and analytical approximation (full line) of the exchange coefficients for momentum (left) and heat (right) as a function of the Richardson Bulk number ($Ri_B = 0$). For simplicity, the exchange coefficients in these figures are divided by those for the neutral case ($Ri_B = 0$).



Results of 'offline' runs with an updated TERRA-ML

A new urban surface type, a parametrization of z_{0h} and the new exchange coefficients for momentum and heat have been implemented in TERRA-ML, the SVAT (Soil-Vegetation Atmosphere Transfer model) of COSMO(-CLM). These changes are currently tested in "offline" mode, which means that TERRA-ML is forced with meteorological data from tower observations instead of being "online" coupled to COSMO(-CLM). Both a rural site at Lindenberg (Falkenberg) and ESCOMPTE measurements over Marseille city centre (ESCOMPTE campaign; Grimmond et al, 2004) have been used to force and validate TERRA-ML. As expected, the new stability functions have a minor impact on the output for the rural site for which $kB^{-1} = 2$. However, the sensible heat and outgoing longwave radiaton, changes dramatically for the urban site because of the very high kB^{-1}-values in that area.





Several TERRA-ML offline runs with different configurations are shown. Firstly, '**vegor**' represents the run for which the surface has 100% of natural claycover with 80% **veg**etation for an original unmodified TERRA-ML version with the **or**iginal exchange coefficients. Secondly, '**vegnw**' represents the same, but using the new exchange coefficients. Thirdly, '**urbor**' uses the new **urb**an surface type with 0% vegetation in which the **or**iginal exchange coefficients are used. Fourthly, '**urbnw**' is the same as 'urbor' but using the **new** exchange coefficients. For the diurnal cycle, the high impact of using the bluff-rough thermal roughness parametrization with the new stability functions is indicated with the arrows. Lastly, '**urbmo**' represents the **mo**saic/tile approach in which we make a weighted average of the urban ('urbnw'; 80%) and natural ('vegnw'; 20%) fraction. Note that for the 'urbnw' and 'urbmo', a strong reduction of sensible heat occurs, which is compensated by an increase of outgoing long-wave radiation. The increase of sensible heat in the evening results from an increased storage heat release originally stored during the day.

Conclusions

New analytical exchange coefficients for momentum and heat are presented which can be used for both natural and urban surface types. These coefficients, together with a thermal roughness length parametrization and a new urban Surface type, are implemented into TERRA-ML. From the results of offline runs, it is shown that the extremly small thermal roughness lengths for urban areas have a great impact on the sensible heat flux. It is also found that a tile approach is needed to represent both natural and urban fraction in cities.

Perspectives

We will perform COSMO-CLM simulation runs using the updated TERRA-ML over Marseille during the ESCOMPTE campaign of 2001. A tile-approach will be implemented to represent both the urban and natural fraction within a $1x1km^2$ grid-cell. Later on, sensitivity tests are planned to estimate the impact of small-scale vs. large-scale meteorology around urban cities on air quality modeling with the regional-scale air quality model AURORA developed at VITO. The latter will be forced with meteorological output from COSMO-CLM.

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