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A 3D PBL scheme for high resolutions mesoscale simulations over heterogeneous surfaces: new length scale formulation and evaluation against idealized LES simulations.

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The presence of spatial heterogeneities in scalar and momentum surface fluxes at the scale of few kilometers induces spatial heterogeneities at the same scale in horizontal turbulent fluxes within the planetary boundary layer. The divergence of such horizontal turbulent fluxes impacts the spatial distribution of mean variables like potential temperature, humidity and wind. The continuous increase in computational power is making possible to run mesoscale simulations at sub-kilometer resolution, so that such spatial heterogeneities can be resolved. However, PBL parametrizations traditionally used in mesoscale models are 1D in the vertical because they are based on the assumption of horizontal homogeneity, which is clearly violated in these cases. In this work, we build on the classical Mellor and Yamada level 2 (MY2, Mellor and Yamada, 1982) scheme, without the assumption of horizontal homogeneity, to derive an expression for vertical and horizontal turbulent fluxes (Jimenez and Kosović, 2016). This approach has been implemented in the Weather Research and Forecasting model (WRF), tested over idealized flat terrain, and compared against LES. The main results of the study are:
1) Simulations over flat terrain with homogeneous surface fluxes. At 500m resolution the original MY2 scheme presented spurious structures, similar to those described in Ching et al. (2014). This issue was eliminated thanks to the development of a new formulation for the length scale, a new set of numerical constants derived from LES data, and the adoption of a 6th order horizontal filter to eliminate 2DX features.
2) Simulations over flat terrain with 2 km wide stripes alternating high (320 W/m2) and low (160 W/m2) surface heat fluxes. At 200m resolution the modified MY2 scheme is able to reproduce the horizontal homogeneity in the direction parallel to the discontinuity in the surface fluxes, and the mean flow structure (wind, potential temperature) is similar to the one derived from LES simulations at 20m resolution. However, larger differences were found for variances and co-variances. On the other hand, if the horizontal turbulent fluxes are neglected (e. g. if the PBL scheme is 1D), the model is not able to ensure the horizontal homogeneity in the direction parallel to the surface flux discontinuity.

These results are significant because they indicate that to perform high resolution (sub-kilometer) mesoscale simulations correctly it is necessary to take into account horizontal turbulent fluxes and improve the representation of vertical ones. Failing to introduce these modifications, may generate non-realistic flow structures.

References:
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