Geophysical Research Abstracts
Vol. 14, EGU2012-14031, 2012
EGU General Assembly 2012

A new boundary condition for large-eddy simulation of turbulent boundary layer flow over heterogeneous surfaces

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Predicting the spatial distribution of surface fluxes over heterogeneous terrains remains a basic challenge in hydrology and the atmospheric sciences. The complexity of such flow, makes it difficult to obtain all the needed information through field experiments alone, and often necessitates high-resolution eddy-resolving numerical tools such as large-eddy simulation (LES). One of the outstanding issues that affect LES performance is the treatment of the surface boundary conditions. Monin-Obukhov similarity (MOS) theory has provided the most common boundary condition formulations for LES of ABL flows. Despite the fact that MOS theory was proposed for homogeneous flat surfaces and applies strictly only to mean quantities, in LES it is used in a wide range of conditions, (including over heterogeneous surfaces and over topography) to compute the fluctuating surface fluxes. Recently, Chamorro and Porté-Agel (2009 and 2010) used wind velocity and surface shear stress data collected in a wind-tunnel experiment and showed direct application of MOS theory over heterogeneous surfaces causes large errors which affect both the average value as well as higher order statistics of the predicted surface shear stress.

In this study, Large-eddy simulations are performed to evaluate the performance of the surface boundary condition downwind of a rough-to-smooth surface transition. Two types of boundary conditions are tested: (i) the standard formulation based on local application of Monin-Obukhov similarity (MOS) theory, and (ii) a new model based on a modification of the recently proposed model of Chamorro and Porte-Agel (2009). The new model assumes that the wind velocity downwind of a rough-to-smooth transition can be estimated as a weighted average of two logarithmic profiles. The first log law is recovered above the internal boundary layer height and corresponds to the upwind velocity profile. The second log law is adjusted to the downwind aerodynamic roughness and it is recovered near the surface in the equilibrium sublayer. The performance of the new model is tested with available wind-tunnel measurements and shows improved predictions of surface shear stress and velocity distribution at different positions downwind of the transition. In addition, the prediction of the new model shows very small dependence on the height at which it is applied.