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Dynamic surface roughness model for LES of atmospheric boundary layer flow over multi-scale terrain with power-law height spectra

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Multiscale atmospheric turbulence most often develops over rough terrain which itself has multiscale height distribution. For large eddy simulations (LES) in which the filter scale is such that some large-scale portion of the roughness elements of the surface can be resolved explicitly, new techniques need to be developed to parameterize the roughness associated with unresolved roughness elements. Here we review a recent model that determines a roughness parameter dynamically using first-principles based constraint that the total momentum flux must be independent on grid-filter scale. This dynamic surface roughness model is inspired by the Germano identity traditionally used to determine model parameters for closing subgrid-scale stresses in the bulk of a turbulent flow. We consider LES of flows over rough surfaces with power-law height spectra, as often encountered in natural terrains. A series of LES of fully developed flow over rough surfaces are performed. We firstly review our initial results for isotropic stochastic surfaces built using random-phase Fourier modes with prescribed power-law spectra. Results show that the approach yields well-defined, rapidly converging, values of the roughness parameter. Effects of spatial resolution and landscape spectral exponent are summarized. We also consider the case of a fluvial-like anisotropic landscape obtained from the U.S. National Elevation Dataset (drainage from the Edwards plateau in Texas). This landscape is dominated by anisotropic modes that have emerged through geomorphological erosion processes. We find that the dynamic approach finds stable solutions also for surfaces with such anisotropies. Results comparing various eroded surfaces generated as solutions to the KPZ equation (Passalacqua and Porte-Agel) had shown results are most accurate for cases where the LES grid- and test-filter width are within the landscape 'self-similar' range. We present detailed analysis of the breakdown of momentum fluxes into resolved and subgrid contributions as function of grid resolution.

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