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A dynamic subgrid-scale parameterization of the effective wall stress in atmospheric boundary layer flows over multiscale, fractal-like surfaces

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A dynamic subgrid-scale (SGS) parameterization for hydrodynamic surface roughness is developed for large-eddy simulation (LES) of atmospheric boundary layer (ABL) flow over multiscale, fractal-like surfaces. The model consists of two parts. First, a baseline model represents surface roughness at horizontal length-scales that can be resolved in the LES. This model takes the form of a force using a prescribed drag coefficient. This approach is tested in LES of flow over cubes, wavy surfaces, and ellipsoidal roughness elements for which there are detailed experimental data available. Secondly, a dynamic roughness model is built, accounting for SGS surface details of finer resolution than the LES grid width. The SGS boundary condition is based on the logarithmic law of the wall, where the unresolved roughness of the surface is modeled as the product of local root-mean-square (RMS) of the unresolved surface height and an unknown dimensionless model coefficient. This coefficient is evaluated dynamically by comparing the plane-average hydrodynamic drag at two resolutions (grid- and test-filter scale, Germano et al., 1991). The new model is tested on surfaces generated through superposition of random-phase Fourier modes with prescribed, power-law surface-height spectra. The results show that the method yields convergent results and correct trends. Limitations and further challenges are highlighted.

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