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Direct Numerical Simulation of the Aerodynamically Rough Atmospheric Boundary Layer – Implementation of an Immersed Boundary Method for Turbulent Ekman Flow

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Direct numerical simulation (DNS) of the atmospheric boundary layer (ABL) is becoming more and more popular for its conceptual simplicity and increasing degree of realism: domain sizes and simulation durations can be attained that allow for extrapolation of results to the geophysical limit. Geophysical flows predominantly occur over rough surfaces, which significantly affects drag, mixing and transport properties of the flow. For such flows, a method is needed that allows one to impose the intricate mechanical boundary condition resulting from a rough wall, while maintaining the efficient and tuned numerical methods for Cartesian meshes. This is achieved by an immersed boundary method (IBM), where three-dimensional roughness elements are fully resolved at the bottom wall of the simulation domain. Based on the work by Laizet and Lamballais (J. Comp. Phys 2009, Vol 228, p.5989-6015), we develop an IBM for efficient use in a stratified environment. First, a spline interpolation method is used to reduce oscillations in the artificial part of the velocity field. Second, a partially staggered arrangement is introduced to avoid spurious pressure oscillations, as is the case with collocated grids for pressure and velocity. Third, the thermal boundary conditions need to be adjusted to account for background gradients across the height of roughness elements. Based on this implementation, the effect of roughness is investigated in terms of fully resolved three-dimensional roughness elements located on the bottom wall of the simulation domain for neutral and stably stratified turbulent Ekman layer flows.

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