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Towards an improved boundary condition for Large-Eddy Simulations with heterogeneous surfaces

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In Large-Eddy Simulations (LES) of atmospheric flows one of the most challenging problems is to prescribe the correct boundary conditions close to the earth's surface. One commonly used approach is to rely on the classical logarithmic law for the mean velocity, which, knowing the velocity and distance from the surface, returns the wall-shear stress. One drawback with this method is that the log-law is defined for the average velocity and not the instantaneous, which is what the simulation solves for. Thus, using it for instantaneous values is not physically correct and it will introduce an error which can be shown to relate to the variance of the fluctuating velocity. To avoid this problem one can spatially filter the velocities over all "first" grid points. However, this will only work if the surface is homogeneous. In order to make LES useful in more realistic situations, with heterogeneous surfaces, a new approach, based on local quantities only, is needed. Bou-Zeid et al. (Physics of Fluids, 2005) developed a hybrid approach where the velocity was filtered over nearby grid points, reducing the error significantly compared to using instantaneous velocities, but still allowing the shear stress to vary over the surface.
Recently a unique experiment, at very high Reynolds numbers, was conducted in the Princeton/ONR Superpipe (Hultmark et al., Physics Review Letters, In press). Measurements of the instantaneous streamwise velocity were acquired with an unprecedented spatial and temporal resolution in order to accurately determine both mean velocity and higher ordering moments. The new data suggests that not only the mean velocities follow a logarithmic behavior, but that the turbulence fluctuations do so too. Furthermore, it was shown that the region in space where the fluctuations exhibit a logarithmic behavior coincides with the classical logarithmic law for the mean velocity. A log-law for turbulence was predicted more than thirty years ago by Townsend (1976), but it has not been observed in experimental data before.
By relating the logarithmic law for the mean velocity to the logarithmic law for the turbulent fluctuations one can reduce the error caused by the variance, thus, improving the LES boundary conditions. This methodology is a first step towards using a completely local formulation suitable also for heterogeneous surfaces.