Particle-resolved simulations of positively-buoyant particles in the open channel flow

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We study the dynamics of turbulent open channel flow laden with finite-sized positively-buoyant spheres. The turbulent transport of buoyant matter near free surfaces of water bodies about in nature (e.g., phytoplankton, or pollutants such as microplastics), and this configuration aims at representing the case where surface waves and ripples are smooth or absent. We performed particle-resolved direct numerical simulation of turbulent open channel flow coupled with Lagrangian particle tracking, at friction Reynolds number ($Re_\tau \approx 550$), constant volume fraction ($\Phi = 1\%$) and Galileo number ($Ga = 30$). The ratio between the particle diameter (d) and channel depth (h) is varied from $d/h = 1/9$ (large), 1/18 (medium) and 1/36 (small). We qualify the effect of particle size on the turbulence and particle statistics with/without the positive buoyancy effects. The results show that particle buoyancy induces particle clustering beneath the free surface, which becomes stronger with decreasing particle size (see Fig. 1 for the case with medium particles). We compare the results with the gravity-free baseline ($Ga = 0$), and quantify cluster dynamics, which is crucial when modeling dispersion in free-surface flow turbulence. Furthermore, the modulation of large-scale motions (LSMs) near the wall seems to follow the "top-down" mechanism, i.e., the floating particles modulate the very-large-scale motions (VLSMs) in the outer layer, which sustainably modulate the near-wall turbulent structures even if the gravity is absent.

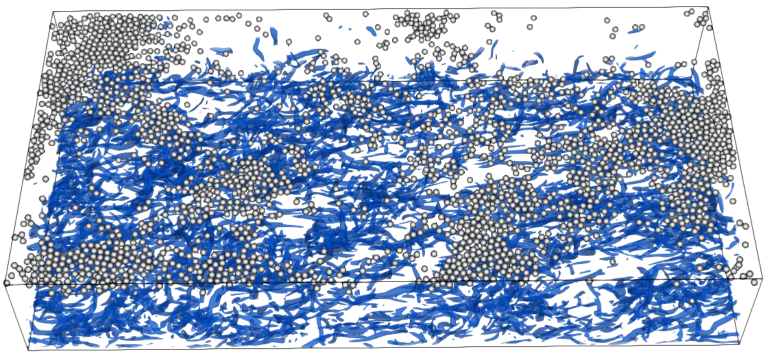

Figure 1: Visualization of the small-scale coherent structures depicted as isosurfaces of the Q-criterion (colored in blue) along with the solid particles (colored in gray), for a particle-laden turbulent open channel flow at $Re_\tau \approx 550$, with a ratio of channel height–particle diameter $h/d = 18$, under gravity at a Galileo number $Ga = 30$.

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