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The study of the effects of sea-spray drops on the marine atmospheric boundary layer by direct numerical simulation

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Detailed knowledge of the interaction of wind with surface water waves is necessary for correct parameterization of turbulent exchange at the air-sea interface in prognostic models. At sufficiently strong winds, sea-spray-generated droplets interfere with the wind-waves interaction. The results of field experiments and laboratory measurements (Andreas et al., JGR 2010) show that mass fraction of air-borne spume water droplets increases with the wind speed and their impact on the carrier air-flow may become significant. Phenomenological models of droplet-laden marine atmospheric boundary layer (Kudryavtsev & Makin, Bound.-Layer Met. 2011) predict that droplets significantly increase the wind velocity and suppress the turbulent air stress. The results of direct numerical simulation (DNS) of a turbulent particle-laden Couette flow over a flat surface show that inertial particles may significantly reduce the carrier flow vertical momentum flux (Richter & Sullivan, GRL 2013). The results also show that in the range of droplet sizes typically found near the air-sea interface, particle inertial effects are significant and dominate any particle-induced stratification effects. However, so far there has been no attempt to perform DNS of a droplet-laden air-flow over waved water surface.

The objective of the present paper is to elucidate possible effects of sea spray on the momentum transfer in marine boundary layer under strong wind-forcing conditions by performing direct numerical simulation (DNS) of turbulent, droplet-laden air-flow over a waved water surface. Three-dimensional, turbulent Couette air-flow is considered in DNS as a model of a constant-flux layer in the atmospheric surface layer. Two-dimensional stationary waves at the water surface are prescribed and assumed to be unaffected by the air-flow and/or droplets. Droplets are considered as non-deformable spheres and tracked in a Lagrangian framework, and their impact on the carrier flow is modeled with the use of a point-force approximation. The results show that drops dynamics and their impact on the carrier air-flow is controlled by the drops velocity at injection, the drops gravitational settling velocity, and the wave slope. Drops injected into the flow with the surrounding air-flow velocity reduce the turbulent air-stress and increase mean air velocity as compared to the droplet-free case. On the other hand, the opposite effect is observed for drops injected with velocity equal to the water surface velocity, which increase the turbulent air-stress and reduce the mean wind velocity. This modification of the air-flow by drops is most pronounced for the gravitational settling velocity of the order of the friction velocity, i.e. for drops diameter about 100 μm, increases with drops mass loading and is reduced for steeper waves and smaller settling velocity.

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