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Investigation of statistical parameters of turbulent air flow over waved water surface by direct numerical simulation

Yuliya Troitskaya and Oleg Druzhinin

Institute of Applied Physics, Nonlinear Oscillations and waves, Nizhny Novgorod, Russian Federation (yuliya@hydro.appl.sci-nnov.ru)

Interaction of surface water waves with the wind flow is of primary importance for the wave modeling. The most difficult case for modeling is that of steep waves, when the strongly non-linear effects (e.g. sheltering, flow separation, vortex formation etc.) are encountered in the airflow over waves. Of special interest is also the influence of the wind flow stratification on the wind-wave interaction. In this work the preliminary results of direct numerical simulation (DNS)of structure and statistical characteristics of a turbulent, stably stratified atmospheric boundary layer over waved water surface are presented. In the experiments two-dimensional water waves with different wave age parameters (c/u* = 0-10, where u* is the friction velocity and c is the wave celerity), wave slope ka = 0-0.2 and at a bulk Reynolds number Re = 15000 and different values of the bulk Richardson number Ri (based on the buoyancy jump, bulk velocity and the surface wave length) are considered. The shape of the water wave is prescribed and does not evolve under the action of the wind. The full, 3D Navier-Stokes equations under the Boussinesq approximation are solved in curvilinear coordinates in a frame of reference moving the phase velocity of the wave. The shear driving the flow is created by an upper plane boundary moving horizontally with a bulk velocity in the x-direction. Periodic boundary conditions are considered in the horizontal (x) and lateral (y) directions, and no-slip boundary condition is considered in the vertical z-direction. The grid of nodes in the x, y, and z directions is used. The Adams-Bashforth method is employed to advance the integration in time and the equation for the pressure is solved iteratively by using FFT in the x and y directions and the Gauss method in the z-direction. Ensemble-averaged velocity and pressure fields are evaluated by averaging over time and the spanwise coordinate. Profiles of the mean velocity and turbulent stresses are obtained by averaging over wavelength.
The preliminary DNS results show that the wind flow is significantly affected by the stratification. If the Richardson number is sufficiently small, the instantaneous vector velocity fields manifest considerable airflow separation at the crests of the surface waves similar to that observed in physical experiments by PIV-technique. Alternatively the ensemble averaged velocity fields are non-separating and have typical structures similar to those observed in shear flows near critical levels, where the phase velocity of the disturbance coincides with the flow velocity. On the other hand, for large Richardson numbers the wind flow turbulence is superseded by internal lee waves radiated from the wave crests and dissipating at a critical level, at some distance above the crests.
The DNS results are compared with the prediction of a theoretical model of a turbulent boundary layer, based on the system of Reynolds-averaged equations with the first-order closure hypothesis. The wind-wave interaction is considered within the quasi-linear approximation, i.e. wave-induced disturbances in the air flow are considered in the linear approximation, but the resistive effect of the wave momentum flux on the mean flow velocity profile is taken into account.
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