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Wave boundary layer turbulence over surface waves in a strongly forced condition – LES and observation

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Accurate predictions of the sea state dependent air-sea fluxes require a thorough understanding of the wave boundary layer turbulence over surface waves. A set of momentum and energy equations is derived to formulate and analyze wave boundary layer turbulence. The equations are written in wave following coordinates and all variables are decomposed into wave mean, wave fluctuation, and turbulent fluctuation. The formulation defines the wave induced stress as a sum of the wave fluctuation stress (due to fluctuating velocity components) and a pressure stress (pressure acting on a tilted surface). Large eddy simulations (LESs) and laboratory observations of wind over a wave train under strongly forced conditions are analyzed using the proposed formulation. Both LESs and observations show that the enhanced wave induced stress very close to the water surface reduces the turbulent stress (satisfying the momentum budget). The reduced turbulent stress is correlated with the reduced viscous dissipation rate of the turbulent kinetic energy. The latter is balanced by the reduced mean wind shear (satisfying the energy budget), which causes the equivalent surface roughness to increase. Interestingly, there is a region further above where the turbulent stress, the dissipation rate, and the mean wind shear are all enhanced. This appears to be due to airflow separation like patterns that occur intermittently.