Simulation of wave effects on turbulence

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Abstract

Turbulence in the wind-wave-ocean system is a complex interactive process. Waves can substantially modify the turbulent flows, resulting in many distinct features, for example, Langmuir cells on the ocean side and critical layer on the air side. Despite its importance, the dynamics of turbulence in the wave environment has largely been elusive due to the complexity of the physical problem. Recently, using advanced simulation methods, we have been able to directly couple turbulence with phase-resolved waves using high-performance computing on supercomputers. To capture the sea-surface boundary effects and wave nonlinearity, we simulate the Navier-Stokes equations on a wave-surface-fitted curvilinear grid that moves with the dynamically-evolving wave surface subject to fully nonlinear kinematic and dynamic free-surface boundary conditions. As a result, the wave profile and orbital motions are explicitly resolved, in contrast to the rigid-lid approximation and Stokes drift and sea-surface roughness treatment used in previous studies. Fourier-based pseudo-spectral method in the horizontal directions and finite-difference method in the vertical direction are used for spatial discretization, and a second-order fractional-step scheme is used for temporal integration. Based on the high-fidelity and high-resolution data from simulations, we obtain valuable information on the fundamental mechanisms of the effects of waves on the wind and ocean turbulence.

Keywords: Surface waves; turbulence; direct numerical simulation; large-eddy simulation; free-surface flows; wave-turbulence interaction.