Direct numerical simulation of deep-water waves in rotating frame

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The ratio of the periods of oceanic surface waves (wind waves and swells) and the inertial period is about 10^{-4}, and the earth's rotation does not greatly affect the orbital motion of fluid particles. Waves, however, do modify mean flow under the influence of Coriolis force. This is because the slight tilt of the orbital plane of fluid particle generates Reynolds stress. Hasselmann (1970) and Huang (1979) demonstrated that this Reynolds stress induced by waves can be expressed as the Coriolis force acting on the Stokes drift. The latter expression is called Coriolis-Stokes forcing. In ocean surface layer studies, Coriolis-Stokes forcing has been used as a standard formulation to incorporate the wave-stress effect. However, Coriolis-Stokes forcing is derived under several assumptions, and there has been no research that directly examined the appropriateness of the forcing.
Here we investigated the Coriolis-Stokes forcing, by performing direct numerical simulations of deep-water waves using a recently developed free-surface nonhydrostatic numerical model. The new scheme that this model adopts allows for the accurate simulation of the orbital motion and the dispersion relation of deep water waves, which could not be achieved by the conventional mode-splitting scheme.
Simulations were carried out under idealized conditions of x-z two dimensional domain with periodic horizontal boundaries. Waves were maintained by surface pressure perturbation. Reynolds stress was obtained from the velocity field, and the Coriolis-Stokes forcing was calculated using the Stokes drift, which we obtained from the on-line particle tracking.
Comparison of the two forces tells us that the Coriolis-Stokes forcing is nearly identical to the wave stress under the idealized condition. These forces induce a Eulerian response to the Stokes drift. In the existence of viscosity, this Eulerian flow generates the spiral current throughout the Ekman depth, even there is no net momentum input from the surface. By imposing a uniform stress on the surface, we also find that the mean current profile is described by Ekman-Stokes solution (Polton et al., 2005), which is obtained by considering Coriolis-Stokes forcing, rather than the classical Ekman solution. We will be presenting the results of further simulations under various conditions.

Keywords: wave-mean flow interaction, Coriolis-Stokes forcing, free-surface nonhydrostatic numerical model

