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Numerical investigation of turbulence generation in non-breaking potential waves

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Theoreticaly, potential waves cannot generate the vortex motion, but the scale considerations (Babanin, 2006) indicate that if the steepness of waves is not too small, the Reynolds number can exceed the critical values. This means that in presence of initial non-potential disturbances the orbital velocities can generate the vortex motion and turbulence. This problem was investigated by means of linear-instability theory (Benilov et al, 1993). It was shown that pure two-dimensional motion always remains potential because one-dimensional vortex (in vertical plane) does not interact with the orbital motion. The waves can generate the vortex in horizontal plane, and further development of vorticity occurs due exchange of energy between the components of vorticity. Then, due to non-linearity, motion at smaller scales and more or less developed turbulent regime arises.

This problem was investigated numerically on basis of full two-dimensional (x-z) equations of potential motion with the free surface in cylindrical conformal coordinates. It was assumed that all variables are a sum of the 2D potential orbital velocities and 3D non-potential disturbances. Because the energy of waves is much larger than energy of turbulence, currently it was assumed that only one-way interaction exists: non-potential motion takes the energy from potential waves. The non-potential motion is described directly with 3D Euler equations, with very high resolution. The interaction between potential orbital velocities and non-potential components is accounted through additional terms which include the components of vorticity. The effects of turbulence are incorporated with a use of subgrid turbulent energy evolution equation. The turbulent scale is assumed to be proportional to grid resolution (LES technique). For small waves, the approach turns into a direct simulation method. Numerical scheme is based on 2D Fourier Transform method in ‘horizontal’ (in conformal coordinates) plane and on second-order approximation in the ‘vertical’. The pressure is calculated by means of Poisson equation in cylindrical conformal coordinates derived through covariant components of velocity. Poisson equation was solved with Three Diagonal Matrix Algorithm (TDMA). Initial conditions for the elevations and the surface potential for waves were assigned according to the linear theory, and 3D non-potential velocity components were inserted as a small-amplitude noise.

Long-term numerical integration of the system of equations was done for different wave steepnesses. The vorticity and turbulence usually occurred in vicinity of wave crests (where the velocity gradients reach their maximum) and then spreads over upwind slope and downward. Specific feature of the wave turbulence is its strong intermittency: the turbulent patches are mostly isolated and intermittency grows with decrease of the wave amplitude. The maximum values of energy of turbulence are in qualitative agreement with experimental data.

The results suggest that even non-breaking potential waves can generate the turbulence, which thus enhance the turbulence created by the shear current. Further investigation of this process will include the effect of tangential stress on a sea surface and flux of turbulent energy from the surface generated by breaking waves.

References

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