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Numerical investigation of breaking waves in spectral environment

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Mechanism of wave breaking obtains clear interpretation when number of wave modes is small. Most typical configuration investigated numerically referred to case of single wave with two superimposed disturbances. It seems that in such situation the main reason of breaking is the modulational-instability type of Benjamin-Feir instability, when the main mode is growing taking the energy from disturbances, which should carry enough energy. In the model, development of wave breaking is usually recognized by numerical instability, which develops when some threshold reaches a critical value. This is definitely incorrect, since such threshold often depends on correctness of numerical scheme rather than on physical reasons.

Much more complicated and precise method can be based on 1-D numerical models derived in conformal coordinates. Between many advantages of this approach (for example – very high accuracy) the main advantage is that model is able to predict the situation when part of surface becomes vertical. After this moment, the situation never returns back to stability. This moment can be recognized as a point of instability with good accuracy. Second advantage of the conformal model is that its initial condition can account for a large number of modes, thus allowing to simulate the wave fields which correspond to realistic wave spectra.

An onset of the breaking depends on many poorly controlled factors. Even if the wave spectrum in initial conditions is fixed, the time up to occurrence of breaking is different for different initial set of phasesϑ_k. Therefore, the statistics of breaking can be investigated in the course of large number of numerical experiments.

All calculations were done for number of modes $M = 1,000$and number of grid points $N = 4,000$. Wavenumber at the peak of spectrum k_p is equal to 10, number of modes assigned in initial conditions is equal 100. To accelerate the approach to breaking, the initial conditions were generated for JONSWAP spectrum at $\Omega_p = 2$ (inverse wave age). Hence, the wind was twice the phase velocity at the peak that corresponds to the case of developing waves. Time step Δt was equal 0.0001. As many as 5,000 runs with random set of phases were performed up to termination due to breaking. The limiting time $t = 1,000$ (503 periods of peak wave) was reached just in several runs, and these cases were excluded from consideration.

All considered cases can be attributed to situations of strong nonlinearity: the probability of extreme waves exceeding two significant wave height was as high as 0.01%, and crest-to-trough wave height reached as large values as $2.5H_s$. Contrary to previous suggestions, it was found that rate of growth of wave energy is not a criterion of breaking. Breaking waves in spectral environment do not reach the Stokes limit either. More reliable indications of breaking are: (1) increase of horizontal asymmetry, when downwind slope becomes much steeper than that upwind; (2) increase of negative vertical particle acceleration; (3) growth of local skewness; and some others. However, it should be emphasized that all these criteria have very large scatter. For example, the overall steepness of wave (the ratio of trough-to-crest height of main mode to its wavelength cannot be a criterion of breaking, since in the spectral environment the breaking can develop at such low steepness as 0.1. Contrary to the modulational instability, development of wave breaking occurs very rapidly: it goes through all phases of breaking just over a half of dominant period in the wave field. It was found that, contrary to breaking in idealized conditions, the breaking in a multi-mode wave field is an essentially random phenomenon, which depends on local conditions at very short time scales.

From practical point of view, the probability of breaking and its severity as a function of wave spectrum is more important than understanding of the intimate mechanism of breaking itself. This problem can be also investigated with the direct wave model. When the model is set for simulation of long-time development of spectrum, the termination of run due to breaking can be prevented by introducing the algorithm of breaking parameterization, based on selective high-frequency smoothing of the interface and the surface potential profile in a physical space. This approach allows to investigate the spectral properties of dissipation and its dependence on the wave spectrum.