Multi-wave resonances and formation of high-amplitude waves in the ocean

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Properties of nonlinear resonant interactions are considered in order to propose effective ways of modelling of observed phenomena of ocean giant and freak waves in the framework of weakly nonlinear concepts.

Since dispersion effects do not provide an effective geometric focusing of wave components, nonlinear effects such as fourth- and fifth-order resonant interactions are considered as an effective mechanism of energy exchange between different components of a wave field. High local amplitudes are not possible in the simplest cases of two-dimensional geometry similar to Benjamin-Feir model, Thus, development of more adequate three-dimensional models of wave propagation with five-wave resonances taken into account is needed in order to solve the problem of formation of high-amplitude water waves.

Novel approach to the modelling of weakly nonlinear three-dimensional water wave dynamics, based on the Hamiltonian formulation of water wave equations, has been elaborated in recent works of authors. Wave field is presented as a superposition of relatively small number of 'master' modes obeying a set of ordinary differential equations. These modes are related to primitive variables by the properly constructed canonical transformation. Thus, the solution is split into two stages:

- Solution of the set of ordinary differential equations for "master" modes. Energy exchange between wave harmonics is treated quite naturally in these terms;
- Algebraic transformation to primitive variables, with the reconstruction of spatio-temporal evolution of wave surface. At this stage of analysis, possibility of high local amplitudes is demonstrated.

Water wave dynamics has been studied numerically for various initial wave field states, with spectral characteristics given by conventional wind wave models. It was shown that

- effective energy exchange occurs between different wave field components;
- in the generic case, selection of relatively small number of dynamically active modes is observed;
- cooperative effect of four- and five-wave interactions and intrinsic dispersion of waves can lead to local amplification of wave amplitudes due to the effects of energy pumping to certain harmonics and wave interference (geometric focusing).

Weak generation/dissipation being incorporated in the numerical model does not change qualitatively the results presented above.