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Mode composition and fine spectrum of fully nonlinear simulated waves trapped by an opposing current

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The modal approach for efficient description of nonlinear wave patterns on opposing jet currents suggested in [1] allows one to derive nonlinear evolution equations for interacting modes from the primitive Euler equations. In many important situations the resulting theory enables simplified description (even exact solutions are available). In particular, for a single trapped mode its evolution on a realistically weak current is governed by the nonlinear Schrodinger equation. Strongly nonlinear simulations within the primitive Euler equations of the representative solutions (uniform trapped waves, modulational instability of trapped waves, envelope solitons of trapped waves) reported in [2] confirm adequacy of the developed weakly nonlinear modal theory.

In this paper to understand better the range of validity of modal description we consider in detail the mode composition of solutions presented in [2], making use of the vast amount of data available in numerical simulations. We compute numerically the spectra of trapped modes (the spectrum in longitudinal wavenumbers, frequencies, and $\omega - k$ spectrum), including the fine comb-shaped structure of the spectrum due to the discrete character of trapped mode frequencies. Thus, we explicitly confirm the existence and observability of localized modes trapped by jet currents. The analysis reveals that in the simulations of single modes and envelope solitons the excited modes hold energy for long time even when waves are steep; there is no evidence of noticeable energy leakage from the energetic mode. In the situation of modulationally unstable trapped mode train, only at the final stage of the evolution, when waves start to break, the energy is being transferred to many trapped modes. Thus only for breaking waves the unimodal regime becomes invalid.

[1] Shrira, V.I., Slunyaev, A.V. Trapped waves on jet currents: asymptotic modal approach. J. Fluid Mech. 738, 65-104 (2014).

[2] Shrira, V.I., Slunyaev, A.V. Nonlinear dynamics of trapped waves on jet currents and rogue waves. Phys. Rev. E. 89, 041002(R) 1–5 (2014).