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Rogue waves on jet currents caused by nonlinear evolution of trapped modes

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From seamen accounts and insurer records it has been known for long time that rogue waves events are much more frequent on certain currents (e.g. Aghulas current) than in the ocean devoid of strong circulation patterns. The theoretical explanation of this fact is still lacking.
We address this problem by exploring the following idea. It has been established recently that from the perspective of rogue wave occurrence there is a crucial difference between the situations of strictly or almost unidirectional wave propagation (long-crested waves) and realistic sea situations characterized by finite width of the angular spectra. The dramatic increase in the probability of rogue wave in case of almost unidirectional wave propagation is particularly pronounced for wave fields with sufficiently narrow frequency spectra since then nonlinear effects due to the Benjamin-Feir instability lead to dangerously strong modulation of wave field.
It is known that water waves on jet currents against the current may be trapped by the current lateral inhomogeneity although a theory of such waves is still lacking. We examine nonlinear evolution of trapped modes, which is of interest in rogue wave context since their dynamics is effectively one dimensional even if the angular distribution is broad and waves are short-crested. This mechanism of increase of probability of rogue wave on currents is investigated in the present paper.
First we develop linear theory for trapped modes on a jet current with an arbitrary lateral profile. Analytical condition for the existence of trapped modes is obtained, the modal structure for the trapped waves is analysed for some shapes of the current profile. Then a general weakly nonlinear theory of trapped mode evolution is developed. In particular, for a narrow band wave packet wave field is found to be described by the one-dimensional nonlinear Schrodinger equation (NLS).
Although the wave is three-dimensional, the derived NLS contains only one spatial coordinate along the jet current, while the lateral distribution of the wave field is given by the mode structure prescribed by the linear eigenvalue problem. The coefficients and in the one-dimensional NLS depend on the current profile, we show that the derived NLS is of the focusing type. Thus, at least for narrow band wave fields nonlinear self-modulation increases rogue wave probability on jet-currents. In contrast to alternative linear mechanisms of rogue wave enhancement on currents (blocking, caustics) discussed in the literature, for this mechanism to operate there is no threshold condition on the strength of the opposing current.