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Freezing of nonlinear waves over an uneven bottom

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The nonlinear Schrödinger equation (NLS) is a robust model for describing the evolution of narrow-banded wave packets and has been widely applied in different contexts as optics, plasmas, cosmology or hydrodynamics. When the nonlinear interactions between spectral modes are balanced by wave dispersion or diffraction, stable configurations can appear giving rise to solitons or breathers.
We will consider the evolution of surface gravity water wave-packets propagating over an arbitrary bathymetry. In this case, both the dispersive and the nonlinear coefficients turn out to depend on the fluid depth. Its variation along the propagation direction provides a new degree of freedom to tailor the wave-packet evolution, in analogy to what has been obtained in optical fibers with varying dispersion.

We describe how the nonlinear stage of modulation instability can be frozen by varying the water bottom from intermediate to large depth, giving rise to an increase of the magnitude of the nonlinear coefficient. We consider the case of abrupt [1] and smooth [2] bathymetry changes. With the help of a three-wave truncation, we first provide analytical conditions on the occurrence of freezing. Then, we present numerical simulations of the full model, and the experimental confirmation in a water wave flume experiment. We show that the effects of high-order nonlinear terms and dissipation do not dominate the evolution, making the freezing quite a robust phenomenon that can be described using the NLS framework.

Our results help clarify how the breathing evolution of water wave-packets can be dynamically controlled and to understand the impact of bathymetry on extreme-wave lifetimes.

References

[1] Gomel, Chabchoub, Brunetti, Trillo, Kasparian, Armaroli, Stabilization of Unsteady Nonlinear Waves by Phase-Space Manipulation Phys. Rev. Lett. 126, 174501 (2021)
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