Nonlinear effects and extreme wave statistics induced by an abrupt variation of water depth in coastal area

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When ocean waves propagate over an abrupt reduction of water depth, a non-equilibrium dynamics (NED) of the wave train takes place. This NED is induced by the adaptation of the incident quasi-equilibrium sea-state to a new shallow-water equilibrium state after the depth variation. The dynamical process lasts in a longer spatial extent than that of the depth variation. Over a distance of several wavelengths after the depth variation the NED can result in strong non-Gaussian behaviour of the sea-state, which manifests by local sharp variations of the statistical parameters of surface elevation (skewness and kurtosis) and a local enhancement of higher-order harmonics. The probability of extreme wave heights is also enhanced, with an increased occurrence of large waves meeting the usual freak wave criterion, i.e. $H > 2H_s$, where H_s denotes the significant wave height.

To study the NED induced by a submerged trapezoidal bar, case 3 of the experiments in [1] with irregular waves has been simulated with a fully nonlinear and dispersive wave model by [2], showing excellent agreement with the measurements. The analysis of NED effects is then extended to a longer spatial scale in the shallow water area, from $O(L_p)$ to $O(10L_p)$, where L_p is the spectral peak wavelength. With the numerical model validated in [2], a series of tests have been performed as variations of the experimental case, in which the shallower area after the slope is extended by approximately $40L_p$. The results are analyzed and interpreted using spectral, cross-spectral, and statistical analysis approaches.

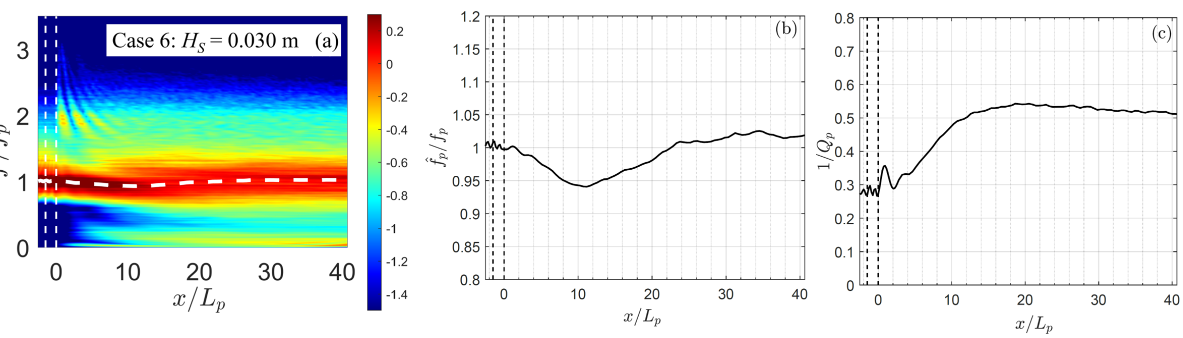

Figure 1. Spatial evolution of normalized wave spectrum after a bottom step (outlined by vertical dash lines)

We show the NED affects the shallow water wave evolution in a long-standing way. The relatively fast and significant effects appear a few L_p after the shoal, while the milder yet important effects remain in a longer scale (cf. Fig. 1.a). In particular, it is found that the spectral shape is subject to significant changes in the longer spatial scale, with spectral downshift/upshift (Fig 1.b) and broadening (Fig 1.c).

References

1. K. Trulsen, A. Raustøl, S. Jorde & L.B. Rye, Extreme wave statistics of long-crested irregular waves over a shoal, *J. Fluid Mech.*, **882**, R2 (2020).
2. J. Zhang & M. Benoit, Wave-bottom interaction and extreme wave statistics due to shoaling and de-shoaling of irregular long-crested wave trains over steep seabed changes, *J. Fluid Mech.*, **912**, A28 (2021).