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Evolution of water wave spectra under a sharp increase of wind

Sergei Annenkov (1), Victor Shrira (1), and Guillemette Caulliez (2)

(1) Keele University, School of Computing and Mathematics, Newcastle-under-Lyme, United Kingdom, (2) Mediterranean Institute of Oceanography, Marseille, France

At present, all modelling of long term spectral evolution of random wind waves is based upon simulations with the kinetic (Hasselmann) equation, or its reductions. The Hasselmann equation is derived under a number of assumptions, including, in particular, quasi-gaussianity, the absence of coherent structures, and quasi-stationarity of the environment. In natural conditions wind is often non-stationary, and a wave field can be subjected to rapid and strong wind increases (gusts). On the basis of direct numerical simulations (DNS) it was suggested that under a sharp increase of wind the timescale of wave increase scales as characteristic amplitude squared and not as amplitude in power four predicted by the kinetic equation (Annenkov & Shrira 2009). Here we revisit the problem and carry out thorough DNS simulations, complementing them by simulations with the kinetic equations and with a laboratory experiment carried out under carefully controlled conditions.

The laboratory experiment was carried out in the large Marseille-Luminy wind-wave facility. We examine evolution of wind waves naturally generated by wind without an initial perturbation. The wind wave field was allowed to develop under a constant wind with speed 4–8 m/s over fetch of 23.6 m, and then an 1.5 times increase of wind was caused by narrowing down the wind tunnel by a false ceiling. Downwind, the increased wind speed was kept constant up to the end of the water tank. The wave field spectral evolution was measured at multiple points before and after the increase by capacitance wave probes.

The DNS simulations were performed using the model based on the Zakharov integrodifferential equation for water waves, with an ensemble averaging over a large number of realisations. The approach does not depend on any statistical assumptions. At present, this is the only DNS algorithm that allows long-term simulations of spectral evolution (exceeding $O(10^3)$ characteristic wave periods). Evolution of wind spectra was simulated with the DNS under constant wind of various speed values into the self-similar regime, and then the wind was instantly increased by different factors. The simulations were compared with the results obtained with the kinetic equation (WRT algorithm) under the same conditions.

An increase of wind leads to the increase of wave steepness, fast growth of the spectral peak and its faster downshift, both in the numerics and in the experiment. Analysis of the spectral growth measured in the experiment shows that normalised growth rates on the spectral front scale as the square of wave steepness. This “dynamical” scaling of growth rates is in sharp contrast with the statistical scaling predicted by the kinetic equation, where normalised growth rates scale with the fourth power of nonlinearity. Thus, the growth rates obtained by the DNS confirm our earlier finding, and the main conclusion is that the observed dynamical scaling is supported by the experiment. A new feature is the phenomenon of strong intermittency of the absolute growth rates near the spectral peak, observed both in the experiment and in the DNS simulations.