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Evolution of random wind wave fields under rapidly changing wind

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Modelling of evolution of nonlinear random wave fields in nature (and, in particular, their most common example – wind waves in the ocean) is based on the kinetic equation paradigm that assumes a proximity to stationarity and homogeneity. In the case of wind waves these assumptions are often violated due the variability of wind, which is present at all timescales. In a recent study, we have found that a single strong instant change of wind leads to a rapid adjustment of a wave field, which occurs on a dynamic $O(\varepsilon^{-2})$ timescale, ε being the measure of nonlinearity, which is much faster than the $O(\varepsilon^{-4})$ timescale predicted by the Hasselmann equation. However, even when wind is nearly constant on average, it is often characterised by a considerable level of gustiness, which formally violates the applicability of the existing statistical theory at every instant of time. At present, this problem is commonly ignored, and the existing wave forecasting models based on the kinetic equation are used beyond the limits of their applicability, due to the lack of alternatives. In this study we consider, by direct numerical simulation (DNS), a random wave field generated by a non-stationary wind with constant mean and constant direction. Three different models of changing wind are considered: (i) wind instantly alternating between two fixed values, at regular intervals, (ii) sinusoidal wind, (iii) realistic gusty wind. The results are compared with constant forcing experiments. We use a DNS algorithm based on the Zakharov integrodifferential equation for water waves.

It is now well-known that the evolution of a random wave field generated by constant forcing is self-similar at large durations or fetches. We show that this self-similarity survives under changing forcing, with averaged statistical characteristics of the wave field corresponding to a field generated by a certain ‘effective’ wind, which in our examples is slightly above the average of the changing forcing. In particular, the total wave energy is shown to oscillate around its ‘effective wind value’, that is following on average the powerlike dependence on time predicted by self-similarity, while the dispersion of these oscillations is slowly decreasing. To summarise: The simulations show that the nonlinear adjustment of a random wave field to changing forcing occurs on fast dynamic timescale and does not break the averaged self-similarity properties, which justifies the use of wave forecasting models based on slowly varying forcing for realistic winds. However, the link between the ‘true’ gusty wind and smoothed ‘effective’ one needs further investigation.