EGU21-10435
https://doi.org/10.5194/egusphere-egu21-10435
EGU General Assembly 2021

Long-term evolution of directional spectra of wind waves modelled by DNS and kinetic equations, and comparison with airborne measurements

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We consider the evolution of directional spectra of waves generated by constant and changing wind, modelling it by direct numerical simulation (DNS), based on the Zakharov equation. Results are compared with numerical simulations performed with the Hasselmann kinetic equation and the generalised kinetic equation, and with airborne measurements of waves generated by offshore wind, collected during the GOTEX experiment off the coast of Mexico. Modelling is performed with wind measured during the experiment, and the initial conditions are taken as the observed spectrum at the moment when wind waves prevail over swell after the initial part of the evolution.

Directional spreading is characterised by the second moment of the normalised angular distribution function, taken at selected wavenumbers relative to the spectral peak. We show that for scales longer than the spectral peak the angular spread predicted by the DNS is close to that predicted by both kinetic equations, but it underestimates the corresponding measured value, apparently due to the presence of swell. For the spectral peak and shorter waves, the DNS shows good agreement with the data. A notable feature is the steady growth of angular width at the spectral peak with time/fetch, in contrast to nearly constant width in the kinetic equations modelling. Dependence of angular width on wavenumber is shown to be much weaker than predicted by the kinetic equations. A more detailed consideration of the angular structure at the spectral peak at large fetches shows that the kinetic equations predict an angular distribution with a well-defined peak at the central angle, while the DNS reproduces the observed angular structure, with a flat peak over a range of angles.

In order to study in detail the differences between the predictions of the DNS and the kinetic equations modelling under idealised conditions, we also perform numerical simulations for the case of constant wind forcing. As in the previous case of forcing by real wind, the most striking difference between the kinetic equations and the DNS is the steady growth with time of angular width at the spectral peak, which is demonstrated by the DNS, but is not present in the modelling with the kinetic equations. We show that while the kinetic theory, both in the case of the Hasselmann equation and the generalised kinetic equation, predicts a relatively simple shape of the spectral peak, the DNS shows a more complicated structure, with a flat top and dependence of the peak position on angle. We discuss the approximations employed in the derivation of the kinetic theory and the possible causes of the found differences of directional structure.