Accurate modeling of nonlinear and dispersive waves in the coastal zone

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Accurate modeling of nearshore waves is required to make predictions of nearshore hydrodynamics, morphological evolution, and interactions between waves and structures (e.g. jetties, wave energy conversion devices). It is necessary to be able to model the nonlinear and dispersive properties of irregular, multi-directional waves at a wide range of temporal and spatial scales. A variety of models exist to respond to different demands, ranging from approaches based on the mild-slope equation, Boussinesq approximations, fully nonlinear potential flow theory, to CFD models resolving the Navier-Stokes or Reynolds Averaged Navier-Stokes (RANS) equations. Here, following Bingham and Zhang [2] and Engsig-Karup et al. [4], a nonlinear potential flow model is developed using high-order finite difference schemes. The model is based on the Zakharov equations, which express the evolution of the free surface and the velocity potential at the free surface. To integrate in time, it is necessary to resolve the vertical velocity at the free surface, which is accomplished by discretizing the vertical using a stretched grid, resolving the Laplace equation for the entire domain, and then evaluating the vertical derivative of the velocity potential at the free surface. The model results are compared to a series of reference test cases, including (i) simulations of the transformation of a series of waves on a sloping beach [5], (ii) laboratory experiments of the propagation and dispersion of nonlinear regular waves over a submerged bar [3], and (iii) laboratory experiments with nonlinear, non-breaking irregular waves propagating over a submerged bar [1]. The first test case verifies the ability of the model to simulate shoaling processes for a range of wave heights, from near-linear to near-breaking waves, showing excellent agreement with the reference solutions of Kennedy et al. [5]. For the next two tests, the model simulations are compared to laboratory experiment measurements taken with a series of probes distributed along the wave tanks, comparing the surface elevation for the case with regular waves and the observed spectra, as well as sea state parameters (e.g. significant wave height, mean period), for the case with irregular waves. The comparison to the experiments of Dingemans [3] shows that the model is able to simulate the shoaling of nonlinear waves over a submerged bar, including the wave-wave interactions and the generation of harmonics on and after the bar. Finally, the comparison to the laboratory experiments of Becq-Girard et al. [1] allows an extended validation of the model's capability to simulate wave-wave interactions and the transfer of energy to higher and lower harmonics for irregular waves. The 1DH version of the model shows promising results, and ongoing work includes model validation with additional test cases and extension to 2DH, as well as taking into account additional physical processes such as the effects of currents or the generation of waves due to a deformation of the bottom boundary.

References

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