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Statistics for long irregular wave run-up on a plane beach from direct numerical simulations

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Very often for global and transoceanic events, due to the initial wave transformation, refraction, diffraction and multiple reflections from coastal topography and underwater bathymetry, the tsunami approaches the beach as a very long wave train, which can be considered as an irregular wave field. The prediction of possible flooding and properties of the water flow on the coast in this case should be done statistically taking into account the formation of extreme (rogue) tsunami wave on a beach.
When it comes to tsunami run-up on a beach, the most used mathematical model is the nonlinear shallow water model. For a beach of constant slope, the nonlinear shallow water equations have rigorous analytical solution, which substantially simplifies the mathematical formulation. In (Didenkulova et al. 2011) we used this solution to study statistical characteristics of the vertical displacement of the moving shoreline and its horizontal velocity. The influence of the wave nonlinearity was approached by considering modifications of probability distribution of the moving shoreline and its horizontal velocity for waves of different amplitudes. It was shown that wave nonlinearity did not affect the probability distribution of the velocity of the moving shoreline, while the vertical displacement of the moving shoreline was affected substantially demonstrating the longer duration of coastal floods with an increase in the wave nonlinearity.
However, this analysis did not take into account the actual transformation of irregular wave field offshore to oscillations of the moving shoreline on a slopping beach. In this study we would like to cover this gap by means of extensive numerical simulations. The modeling is performed in the framework of nonlinear shallow water equations, which are solved using a modern shock-capturing finite volume method. Although the shallow water model does not pursue the wave breaking and bore formation in a general sense (including the water surface overturning), it allows shock-wave formation and propagation with the speed given by Rankine-Hugoniot jump conditions, which to some extent approximates wave breaking. The scheme is second order accurate thanks to the UNO_2 special reconstruction. It was described and validated in (Dutykh et al. 2011a) and has already been successfully used to simulate wave run-up on random beaches (Dutykh et al. 2011b). For simplicity the incident wave field offshore is taken Gaussian in the present study, however, this distribution can be easily changed in the numerical code. Similar to (Didenkulova et al. 2011), in order to study influence of wave nonlinearity during wave propagation to the coast we consider waves of different amplitudes and the corresponding modifications of statistics of the moving shoreline. We also consider wave fields with a different bandwidth, so that we can see the influence of the bandwidth of the incoming wave field on statistics of wave run-up on a beach. In order to validate the numerical results we use the available experimental data of irregular wave run-up on a beach (Denissenko et al. 2011; 2013). For this in our simulations we use the corresponding bathymetry set-up: the flat part of the flume with a water depth of 3.5 m is matched with the beach of constant slope 1:6. The significant wave heights Hs are chosen according to (Denissenko et al. 2013) and are equal to 0.1m, 0.2m, 0.3m, 0.4m and 0.5m, while the bandwidth is selected as 0.1, 0.4 and 0.8, which allows comparison of the behavior of wide-band and narrow-band wave fields on the beach. The characteristic wave period is 20s, as in (Denissenko et al. 2013) that provides long wave condition. All time records contain several weeks of simulations that provides significant amount of data for extreme value statistics.

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