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Modeling of Tsunami Wave Run-Up over Sloping Bathymetry using Effective Boundary Conditions

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We introduce an effective boundary condition (EBC) as a novel technique to predict tsunami wave run-up along the coast and offshore wave reflections. This method couples the numerical modeling of a tsunami with an analytical run-up theory near the coast. It aims to eliminate high accuracy computations near the shore, which is needed to capture aspects of wave propagation in the shallower area. For example, there are complicated interactions between incoming and reflected waves due to the bathymetry and intrinsic nonlinear phenomena of waves propagation due to shoaling effects. If a fixed wall boundary condition is used at a certain shallow depth contour, the reflection properties can be very unrealistic. Here, we develop the EBC in one spatial dimension. From the deep ocean to a seaward boundary, i.e. in the simulation area, we model wave propagation numerically over real bathymetry using the shallow water equations. We measure the incoming wave at this seaward boundary, and model the wave dynamics towards the shoreline analytically, based on nonlinear theory over sloping bathymetry. We calculate the run-up heights at the shore and the reflection caused by the slope. The reflected wave is then influxed back into the simulation area using the EBC. The coupling between the numerical and analytic dynamics in the two areas is handled using variational principles, which leads to (approximate) conservation of the overall energy in both areas. We verify and validate our approach in a series of numerical test cases of increasing complexity, including a case akin to tsunami propagation to the coastline at Aceh, Sumatra, Indonesia.