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A Study of Non-Linear Ocean Waves with a Parallel Pseudo-Spectral Model: Applications to Coastal Storm Waves

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The West coast of Ireland is vulnerable to severe flooding and wave events (O'Brien et al. (2013)), most of them caused by violent storms that form over the Atlantic Ocean. It has been shown in (Cox et al.(2012)) that these storm events are powerful enough to create and move large boulder deposits on top of steep cliff tops. These deposits can be regarded as a proxy for storm intensity and tracking their movement over time can give some indication about storm impact and, eventually, help our understanding of storm-induced flooding and boulder movement.

The lack of measurement data of these rare extreme events, however, emphasizes the need for accurate and efficient numerical models. CFD- or finite-element-type simulations of the three-dimensional non-linear evolution of ocean and coastal waves are still widely impractical on today's high performance computers because of the complexity of the underlying equations. A common simplifying assumption is to neglect viscosity. The other assumptions are incompressibility of the fluid, as well as the irrotationality of the flow which leads us to have to solve Laplace equation with boundary conditions at the free surface.

For computational efficiency, we developed a three-dimensional MPI-parallel pseudo-spectral model following the idea presented in (West et al. (1987); Dommermuth and Yue (1987)) to simulate extreme storm waves on the open ocean. The model heavily relies on fast Fourier transform techniques (Cooley and Tukey (1965); Frigo and Johnson (2005)) and solves the free surface boundary up to an arbitrary order of non-linearity. Compared to traditional three-dimensional CFD models, spectral models are computationally more efficient.

We use this model to study non-linear wave amplification during wave events which are triggered by multiple factors including wave interaction, dispersion and influences from non-linear interaction with non-trivial sea bed profiles. It was shown in (Viotti and Dias (2014)) that the latter is significant in the process of generating very large waves. Its numerical treatment in a pseudo-spectral context has been presented in (Liu and Yue (1998)) and is known to add significant complexity to the model. We highlight computational improvements and challenges with respect to its use on supercomputers.

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