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Towards Adaptive Simulation of Dispersive Tsunami Propagation from an Asteroid Impact

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Many steps are required in modeling a tsunami arising from an asteroid impact in the ocean. The impact itself forms a crater that drives the eventual tsunami creation. Modeling this requires a complex three-dimensional multi-physics hydrocode, since there are many physical processes and time scales. Once the tsunami has formed, it propagates hundreds or thousands of kilometers across the ocean. When the shoreline is reached, the ultimate goal is modeling the inundation risk to coastal populations and important infrastructure at a much smaller spatial scale.

This work addresses the last two steps, the long-distance propagation and coastal inundation. The goal is a high fidelity model that can accurately determine the inundation risk for particular sites using available bathymetric data sets. Since large scale ocean simulations are so compute-intensive, for many tsunami modeling problems the two-dimensional depth-averaged Shallow Water Equations (SWE) are used for the propagation step. However, in earlier work [1] we found this was often insufficient for short-wavelength asteroid-generated tsunamis, giving inaccurate results for both tsunami travel time and maximum shoreline run-in. Instead we turn to a form of the Boussinesq equations [2, 3] that are still two-dimensional and depth-averaged, but include higher derivative terms to better model dispersive waves. These terms are suppressed in very shallow water and onshore, since the inundation is best modeled with the original nonlinear SWE. We are incorporating these modifications into the software package GeoClaw [4], which implements adaptive mesh refinement for the SWE and is well-validated for earthquake-generated tsunamis.

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Figure 1 shows simulations using the Boussinesq equations for an impact situated roughly 200 km off the coast of Washington State. The initial conditions for the simulation are taken from a hydrocode simulation of the the first 251 seconds after impact[3] This is necessary because depth-averaged equations are unsuitable for computations of an initial crater, since the ensuing large vertical velocity components are not modeled. Adaptive mesh refinement (AMR) is a crucial component in making simulations affordable. Shoaling on the continental shelf leads to a further shortening of wavelengths, and then to model onshore inundation the goal is generally to use 10 m resolution around the community of interest.

The Boussinesq equations involve third-order derivatives, and so explicit time stepping (as used for the SWE) is no longer a good option since it would require very small time steps. An implicit method requires solving a sparse linear system on each grid level that couples grid cells on all patches at this level, and uses boundary data provided by coarser patches. This builds on the work of [5], which did not include AMR. Preliminary results indicate that this will provide a powerful new tool for efficiently modeling trans-oceanic propagation of asteroid-generated tsunamis coupled with high-resolution coastal inundation.

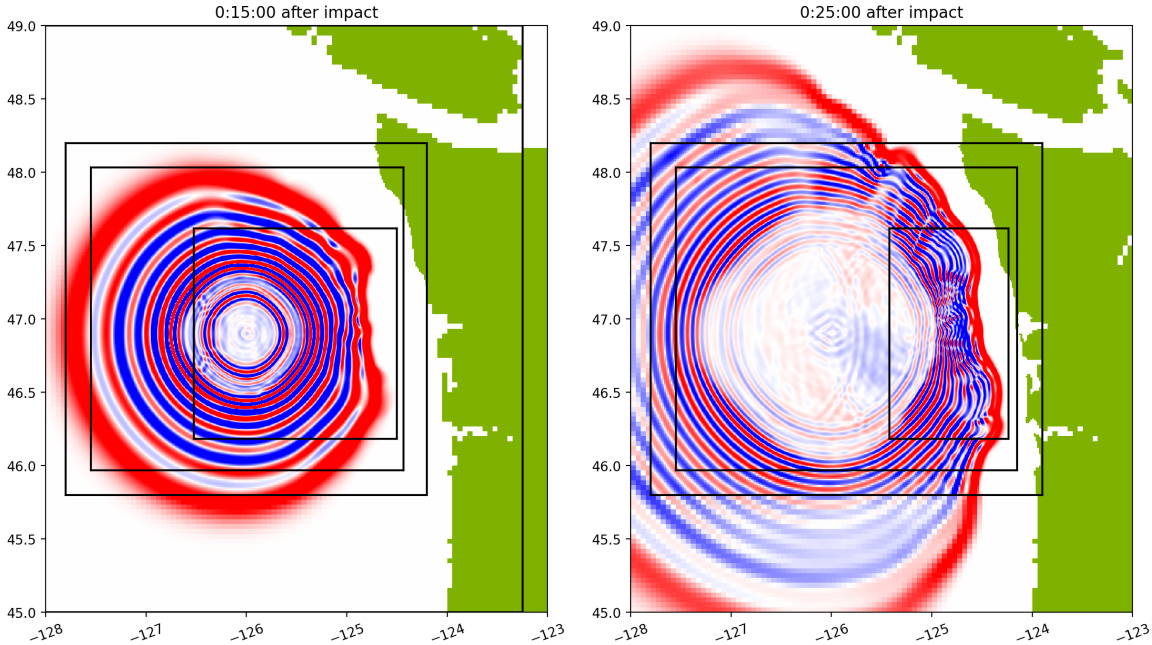

Figure 1: Tsunami propagation 15 and 25 minutes after a simulated asteroid impact, computed using the dispersive Boussinesq equations. Three regions of successively higher mesh refinement are outlined in the colored rectangles. Waves propagating away from the coastal region of interest dissipate as they move onto coarser grids, with little spurious reflection at patch edges. Colors saturate at surface elevations 3 meters above (red) and below (blue) sea level.

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Comments: *(Oral or Poster) Prefer Oral, but Poster is OK.*

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