Dynamically Adaptive Tsunami Simulation on Triangular Grids within the ASCETE project

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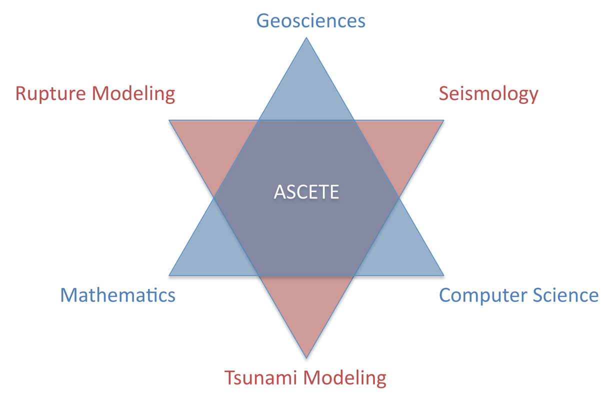
The ASCETE Project

Earthquakes and tsunamis represent the most dangerous natural catastrophes and can cause large numbers of fatalities and severe economic loss in a single and unexpected extreme event as shown in Sumatra in 2004, Samoa in 2009, Haiti in 2010, or Japan in 2011. Both phenomena are consequences of the interactions within the complex system of tectonic stress, fracture mechanics, rock friction, rupture dynamics, fault geometry, ocean bathymetry, and coast line geometry.

The ASCETE project forms an interdisciplinary research consortium that – for the first time – aims at coupling the most advanced simulation technologies for earthquake rupture dynamics and tsunami propagation to understand the fundamental conditions of tsunami generation.



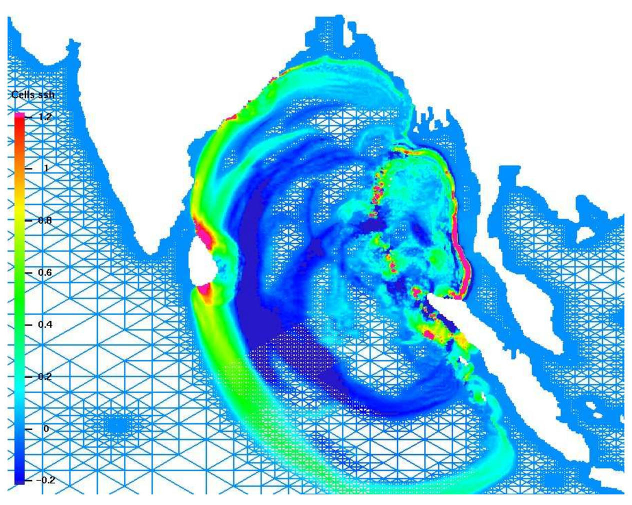
Tsunami Modeling and Simulation

Precise tsunami simulation is currently an active research area and several new methods have been proposed recently. Accurate representation of the scale gap between near shore small-scale wave-topography interaction and global large-scale wave propagation is necessary. The goal of this subproject is to further develop current multi-scale and adaptive mesh numerical techniques for tsunami wave simulation up to operational reliability.

Adaptive Mesh Refinement Using AMATOS

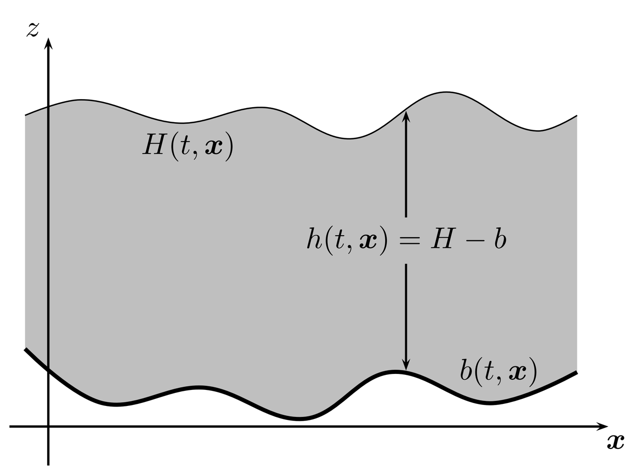
Dynamically adaptive grids with triangular elements [1]

- conforming elements (no hanging nodes)
- refinement by bisection
- space filling curve ordering of elements [4]



$\rightsquigarrow$ computationally efficient representation of multi-scale phenomena (e.g. coastline and small scale solution components)

The Shallow Water Equations



- incompressible, homogeneous fluid with free surface
- small aspect ratio $\rightsquigarrow$ hydrostatic assumption
- non-linear depth-averaged horizontal advection, gravity waves

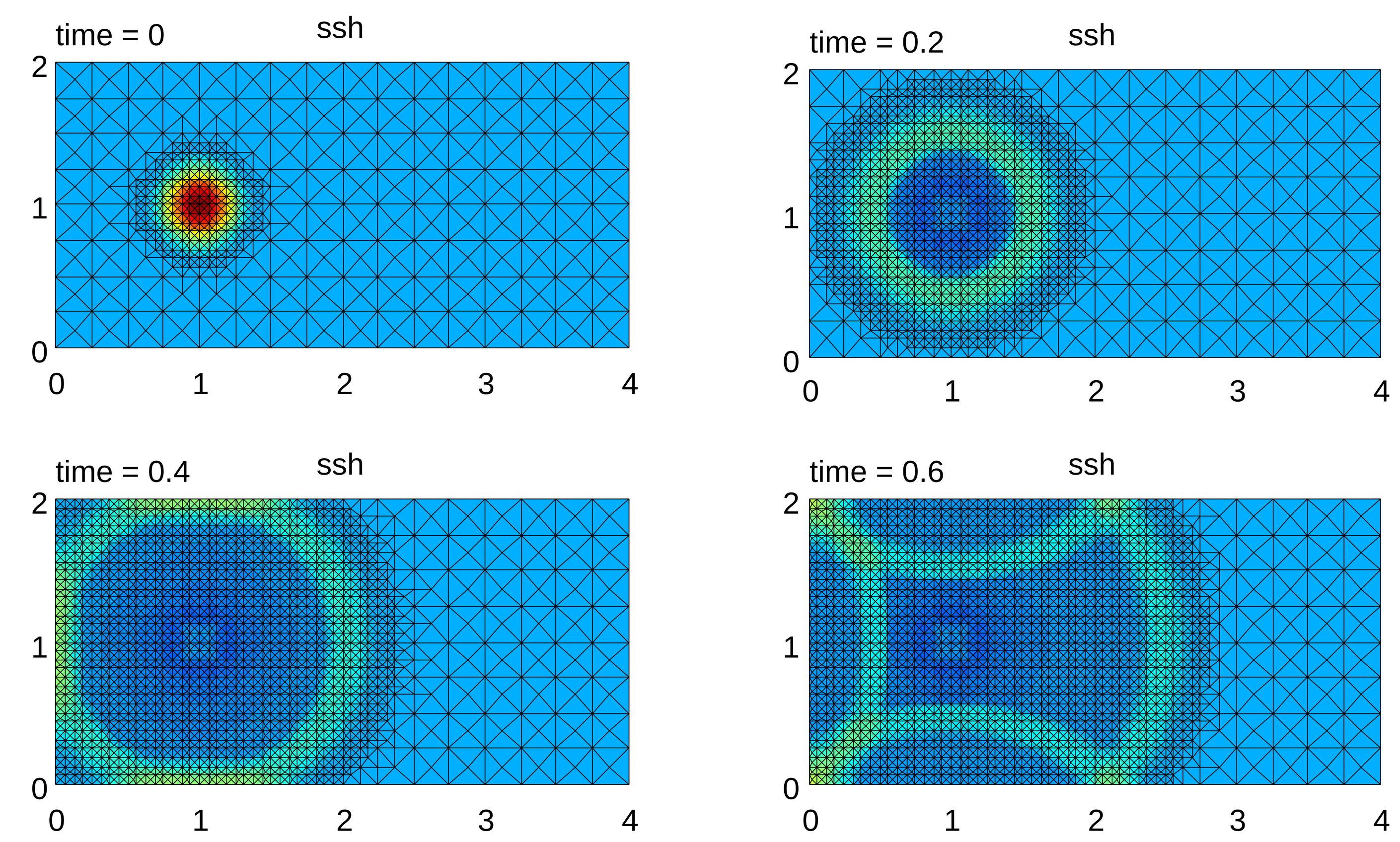
$$
\begin{aligned}
h_t + \nabla \cdot (h\mathbf{v}) &= 0 \\
(h\mathbf{v})_t + \nabla \cdot (h\mathbf{v} \circ \mathbf{v}) + g\, h \nabla (h + b) &= -f(\mathbf{k} \times h\mathbf{v})
\end{aligned}
$$

Adaptive Tsunami Wave Propagation and Inundation Algorithms

- Finite elements with nonconforming velocity elements [3]
  - Leap-frog time-differencing
- Discontinuous Galerkin (DG) finite elements [2]
  - variables approximated by high-order polynomials within each element
  - adjacent elements communicate via fluxes across common interfaces
  - conservation of mass and momentum
  - local character of the scheme leads to efficient parallel performance

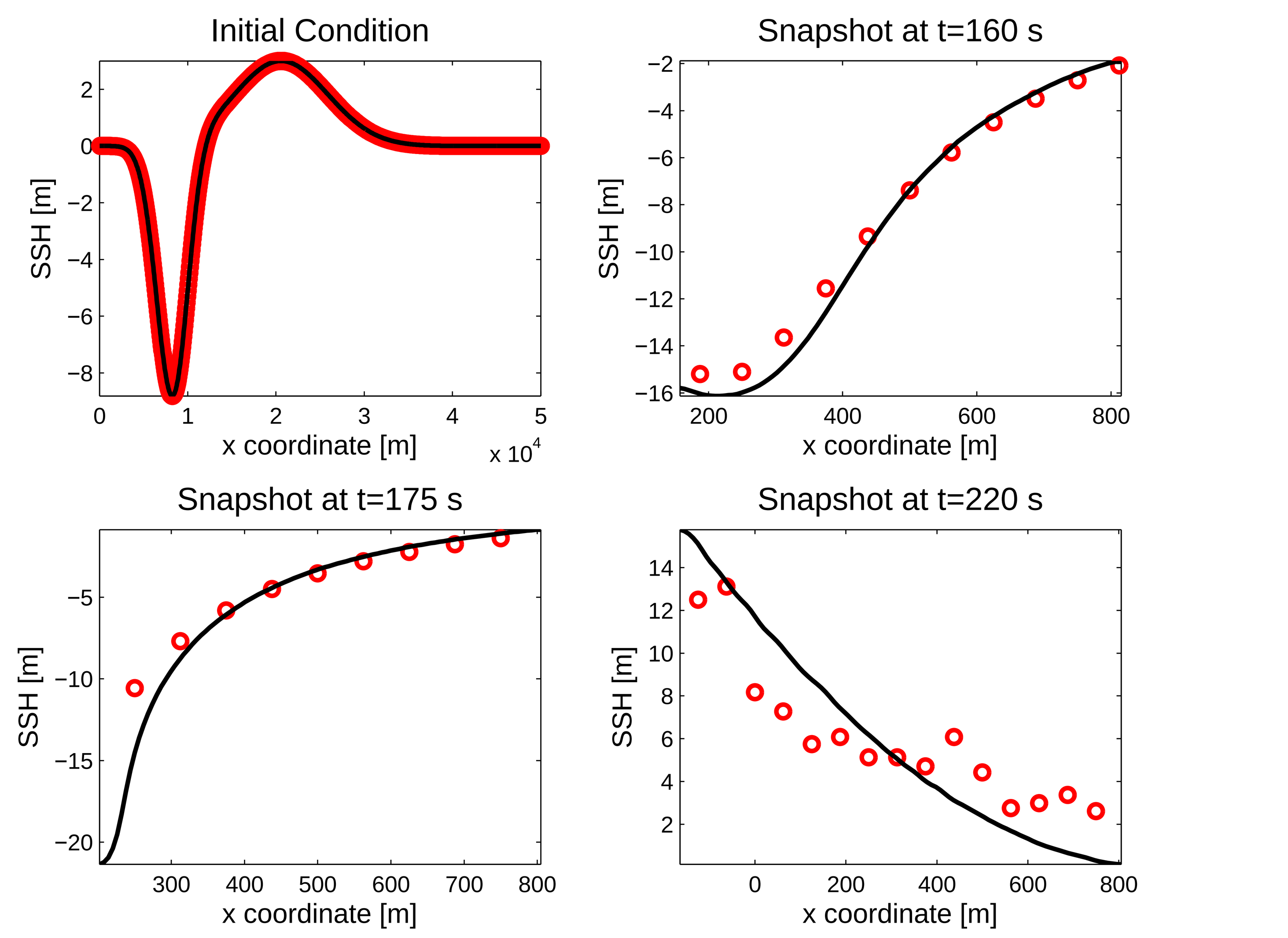
Evolution of an Initial Water hump

- initial water hump in a resting fluid, reflecting b.c.
- test for evolution of gravity waves, adaptive mesh refinement



Tsunami Runup Onto a Plane Beach

- uniformly sloping beach with no variation in the lateral direction
- beach slope fixed at 1/10, initial free surface elevation given (see below)



Future Work

Extension to non-hydrostatic correction terms

- non-hydrostatic effects can play an important role in near and on-shore behavior of tsunami waves
- incorporation by a rederivation of the governing equations
- leads to additional correction terms, multi-layer shallow water model

Earthquake-Tsunami coupling

- study interaction of ocean bottom displacement and wave generation
- dynamical coupling of crust deformation and water wave model

References

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