Towards Faster Than Real Time Simulations in tsunami modelling

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Tsunami simulation within the framework of Tsunami Early Warning Systems (TEWS) is a fairly recent achievement, but still limited by the size of the problem and restricted to tsunami wave propagation. Using the resources made available by the High Performance Computing centers makes it possible to run from hundreds to thousands of simulations instead of a single deterministic simulation and still in just few minutes [2, 3]. This broadens the horizon when studying how the uncertainty of this type of events influences the final result, further enriching the quick response of the warning system [6]. In this work, we present the use of the Tsunami-HySEA model [4], which approximate the nonlinear 2D equations for shallow waters in lat-lon coordinates:

$$
\left\{
\begin{array}{l}
\partial_t h + \dfrac{1}{R\cos(\varphi)}\Big(\partial_\theta q_\theta + \partial_\varphi (q_\varphi \cos(\varphi))\Big) = 0, \\
\partial_t q_\theta + \dfrac{1}{R\cos(\varphi)}\partial_\theta \left(\dfrac{q_\theta^2}{h}\right) + \dfrac{1}{R}\partial_\varphi \left(\dfrac{q_\theta q_\varphi}{h}\right) - 2\dfrac{q_\theta q_\varphi}{Rh}\tan(\varphi) + \dfrac{gh}{R\cos(\varphi)}\partial_\theta h = \dfrac{gh}{R\cos(\varphi)}\partial_\theta H, \\
\partial_t q_\varphi + \dfrac{1}{R\cos(\varphi)}\partial_\theta \left(\dfrac{q_\varphi q_\theta}{h}\right) + \dfrac{1}{R}\partial_\varphi \left(\dfrac{q_\varphi^2}{h}\right) + \dfrac{(q_\theta^2 - q_\varphi^2)}{hR}\tan(\varphi) + \dfrac{gh}{R}\partial_\varphi h = \dfrac{gh}{R}\partial_\varphi H,
\end{array}
\right.
\tag{1}
$$

where R is the radius; (θ, φ), the longitude and latitude; g, the gravity; h, the thickness of the water layer; H, the bottom depth; $q_\theta = hu_\theta$ and $q_\varphi = hu_\varphi$, with u_θ and u_φ the longitudinal and latitudinal velocities averaged in the normal direction.

Tsunami-HySEA uses a discretization of the nonlinear 2D shallow-water system with a second-order Finite Volume method that is well-balanced for water at rest on the sphere. The use of lat-lon coordinates introduces an extra difficulty in the design of the well-balanced method due to the new geometry terms[1]. The seafloor deformation generated by the earthquake is computed using the Okada model ([5]). Thus, Tsunami-HySEA is specifically designed for simulations of earthquake-generated tsunamis on the real earth, as the main computational ingredient on which the operational TEWS is based.

We present a workflow that aims to address two main issues that we consider critical for TEWS; the first one for now-a-day systems, the second one for forthcoming (near-future) systems, both with the support of HPC environments:

1. Compute a large number of FTRT simulations, which is critical to quantify uncertainty in the tsunami impact assessment, using all available evidence, and rapidly characterize the complex tsunami propagation;

2. Increase the resolution of the local domains with the aim of simulating the most probable flooding areas with the novelty of doing it Faster Than Real Time.

We apply this workflow to a hypothetical event in the Gulf of Cadiz with the realization of hundreds of simulations in less than one minute, we analyze the time series of all these simulations in virtual gauges along the coast, and then, we compute the high-resolution inundation simulations using nested meshes to study the areas most likely to be flooded according to propagation simulations and time series at gauges.

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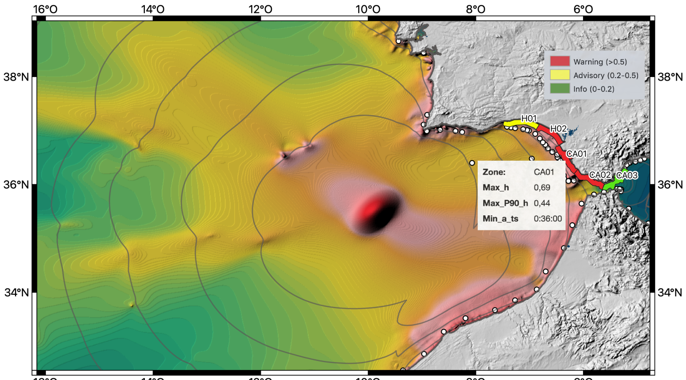

Figure 1: Tsunami warning map obtained from the results of the 135 simulations performed by including variability in the parameters of the seismic source model from the reference scenario. Forecast points and target areas are colored by alert level.

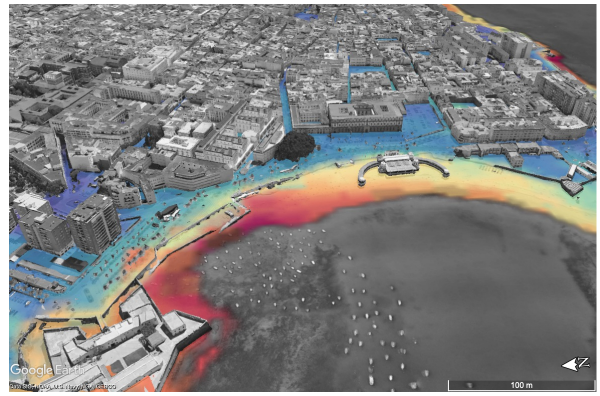

Figure 2: Inundation area at high resolution target area. (Cádiz, Spain)

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