

PROBABILISTIC TSUNAMI HAZARD ANALYSIS FROM SUBMARINE MASS FAILURE: A MONTE CARLO APPROACH TO A CASE STUDY IN ITALY

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Tsunamis, although of rare occurrence compared to other natural disasters, can have devastating consequences for society's increasingly populated coastal areas. In order to manage the associated risk, coastal tsunami hazard can be assessed by performing a Probabilistic Tsunami Hazard Analysis (PTHA). Typically, PTHAs have mainly focused on coseismic tsunami sources, however, some probabilistic investigations have been carried out for subaerial or submarine landslide sources (e.g., Grilli et al 2009; Grezio et al 2012).

One potential approach for performing a PTHA for landslide tsunamis, which is illustrated in this work, is to develop and parameterize probability distribution functions for key source parameters (e.g., landslide volume, velocity, submergence depth, etc.), and then perform Monte Carlo simulations (MCS) of tsunami generation for a large number of randomly generated landslide scenarios. Simulating potentially thousands of landslide tsunamis, however, requires using an efficient wave propagation model that features relevant physics.

Here, to perform such hazard analyses, we use the efficient model developed by Iorio et al. (2021), based on solving the linear mild-slope equation (MSE) in the frequency domain, with a time-dependent source term representing the seafloor motion caused by the landslide. Away from shore, tsunami waves are of small steepness and, hence, well represented by a linear model. The MSE features full frequency dispersion, which is necessary for an accurate modeling, since landslide tsunamis are typically made of shorter waves than coseismic tsunamis.

The MSE model was first validated based on results of physical model experiments for: (i) landslide tsunamis generated along a straight coastline by a submerged streamlined rigid body moving down a plane slope (Enet and Grilli, 2007); and (ii) the case of subaerial landslide tsunamis generated around a conical island by moving bodies of similar shape (Di Risio et al., 2009; e.g., Fig. 1).

Since the MSE model is linear for a single frequency, a broad spectrum wave fields can be reproduced by superposing solutions in a Fourier sense. Based on this principle, to speed-up landslide tsunami simulations, Cecioni et al. (2023) developed a database of elementary landslide solutions, representing unit amplitude motions over a small seafloor area, within the footprint of all landslides considered in the MCS. For each unit source, the resulting tsunami elevations (elementary solutions; ES) were computed with the MSE model at a series of save points of interest located along a nearshore isobath of moderate depth (e.g., 50 m); tsunami runups were then

estimated based on the latter. The tsunami generated by each landslide scenario in the MCS was then constructed as a weighed linear superposition of the ES. Figure 1a shows the computational domain used to simulate the laboratory experiments of Di Risio et al. (2009); the rectangular gray area encloses the possible landslide footprints, and is divided in small sub-areas, each representing a unit landslide source, for which the tsunami surface elevations are pre-computed at save points (numbered locations marked in Fig. 1a).

In standard MCS, a large number of landslide scenarios are generated by randomly selecting geometric and location parameters within their statistical distributions. The corresponding tsunami elevations are then efficiently simulated at save points, as a linear combination of the pre-computed ES, weighed by coefficients resulting from the Fourier transform of each landslide's specific bottom motion. The latter are simply obtained based on a balance of forces (e.g., Grilli and Watts, 2005). Figure 1b shows MCS results, in terms of percentile bands, computed at one save point located at gauge 22S.

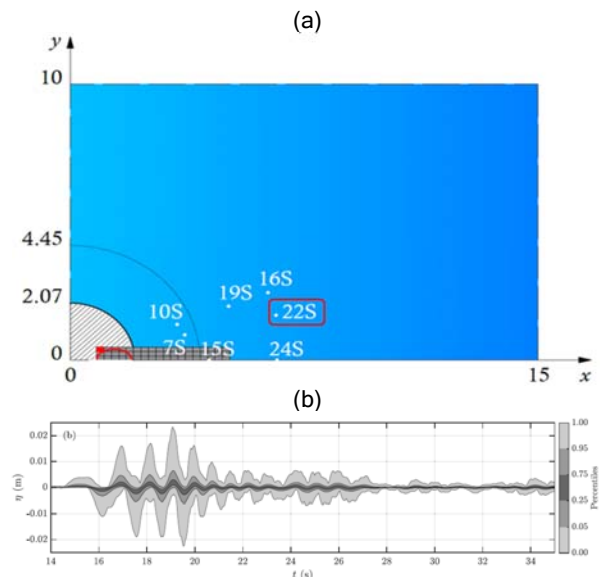


Figure 1: (a) Sketch of numerical domain used to simulate Di Risio et al. (2009) laboratory experiments; (b) Percentile bands of free surface elevations computed at gauge 22S for MCS of 1,000 landslide tsunami scenarios.

The PTHA model developed based on the ES approach can be used for two different purposes: (i) assessing and dealing with the uncertainty in source parameters for a tsunami event that has already occurred; (ii) performing a

PTHA for future tsunamis triggered by submarine mass failures, in a large geographic area.

Regarding (i), Cecioni et al. (2023) computed MCS results to assess source uncertainty effects on tsunami runup in Palu Bay, for the 2018 Palu event. Regarding (ii), in a companion paper submitted to the conference (Grilli et al., 2024), we detail a new modeling framework developed for performing a PTHA for submarine mass failures triggered by earthquakes. In the latter, probabilistic (MCS) slope stability analyses are first performed, which extend Grilli et al.'s (2009) approach, for underwater slides and slumps triggered by seismicity, based on site specific data; in particular, bathymetry, seismicity, and seafloor and sub-bottom sediment properties. This allows defining a large data base of randomly generated potential submarine mass failures, and their kinematics/footprint on the seafloor. This footprint is then divided into many unit areas/sources, to which the MSE model is applied, over a range of relevant frequencies, thus computing a data base of ES at many nearshore save points. Tsunami elevations are finally computed for each landslide tsunami scenario at the save points by linear superposition of the ES.

In this work, after reporting on the experimental validation of the ES-MSE model, the new PTHA modeling framework for landslide tsunamis is applied to the eastern coast of Sicily (numerical domain shown in Fig. 2), an area prone to tsunami events, triggered by both seismicity and related submarine mass failures (e.g., Schambach et al., 2020).

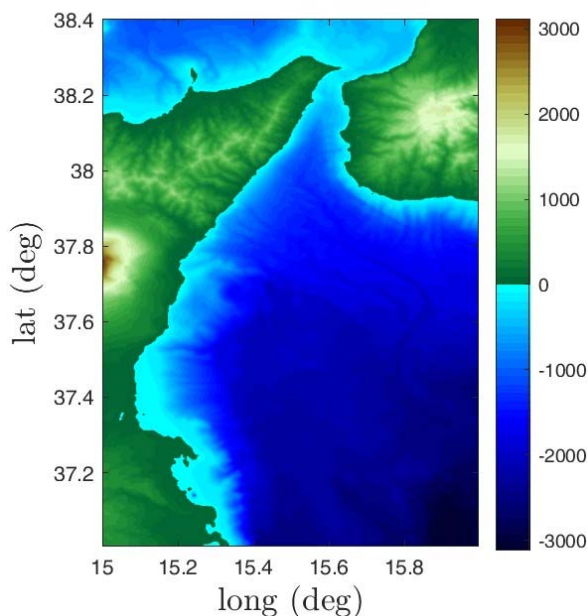


Figure 2 Topo- and Bathy-data of the area of the PTHA case study performed in the Ionian Sea (central Mediterranean Sea), along the eastern coast of Sicily.

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