Geo-INQUIRE Earthquake and Landslide Induced Tsunami Simulations in northern Adriatic using Tsunami-HySEA

Geo-INQUIRE installation: HySEA - Earthquake and landslide generated tsunami simulations (TA2-531-3)

Project title: Earthquake and Landslide Induced Tsunami Simulations in northern Adriatic using Ch-HySEA

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Project acronym: ELITS-SEA

Project report ID: C3_TA2-531-3-ELITS-SEA

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Date of visit: NA

Geo-INQUIRE Virtual Access: YES

Data/Products: Multi-Scenario Tsunami Simululation Data

Coordinator:

Project report: Sergio Ortega Acosta

1. Introduction

The coastal region of Friuli-Venezia Giulia (FVG, Figure 1) faces multiple natural hazards, including earthquakes and tsunamis. While strong tsunamigenic earthquakes are infrequent in the Adriatic Sea, the high exposure of coastal municipalities, characterized by historical/cultural/touristic sites and fragile ecosystems (lagoons, river deltas), makes even moderate tsunamis potentially impactful. The DISS-3.3.1 database identifies two seismogenic sources (ITCS100 and ITCS101 shown in Figure 2) in the Gulf of Trieste with M_{max}=6.5-6.9, considered tsunamigenic based on their magnitude and source parameters.

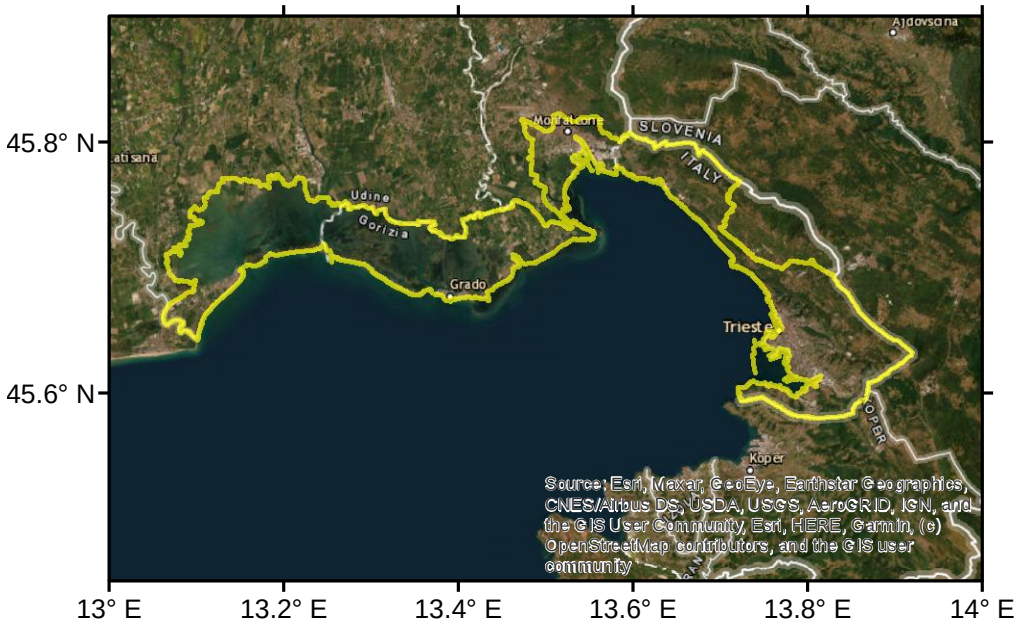


Figure 1 : Regional and zoomed maps of the study region: map of Northeast Adriatic Sea and photos of the areas of interest, AOI.

This project aims to create a comprehensive database of earthquake-induced tsunami scenarios for local seismogenic sources in the NE Adriatic. The specific objectives are: (1) implementing stochastic k^{-2} slip distributions following Ruiz et al. (2015) methodology, (2) producing .par files compatible with Tsunami-HySEA code (Macías et al. 2017) for nested grid simulations, and (3) generating visualization tools for scenario analysis and comparison. The resulting database could support tsunami hazard and risk assessment for coastal municipalities including Lignano, Grado, Monfalcone, and Trieste (Figure 1). Also, we introduce a preliminary scenario that compound earthquake induced tsunami scenario with a rockfall scenario

2. Input Data

2.1 Seismogenic Sources

The study focuses on two local seismogenic sources from the DISS 3.3.1 database:

Source ID	Location	M_{max}	Depth (km)	Strike (°)	Dip (°)	Rake (°)
ITCS100	Gulf of Trieste	6.9	1-10	320-350	50-60	130-160
ITCS101	Gulf of Trieste	6.5	1.5-8	290-330	30-45	100-120

The source parameters were extracted directly from shapefile attributes, which contain complete fault geometry information including minimum and maximum values for strike, dip, rake, and depth ranges. Also, we introduce a preliminary scenario that compound earthquake induced tsunami scenario with a rockfall scenario of 1km long, 0.5km width and 5m wave height with a delay in trigger time, as a test to be further investigated more in future work.

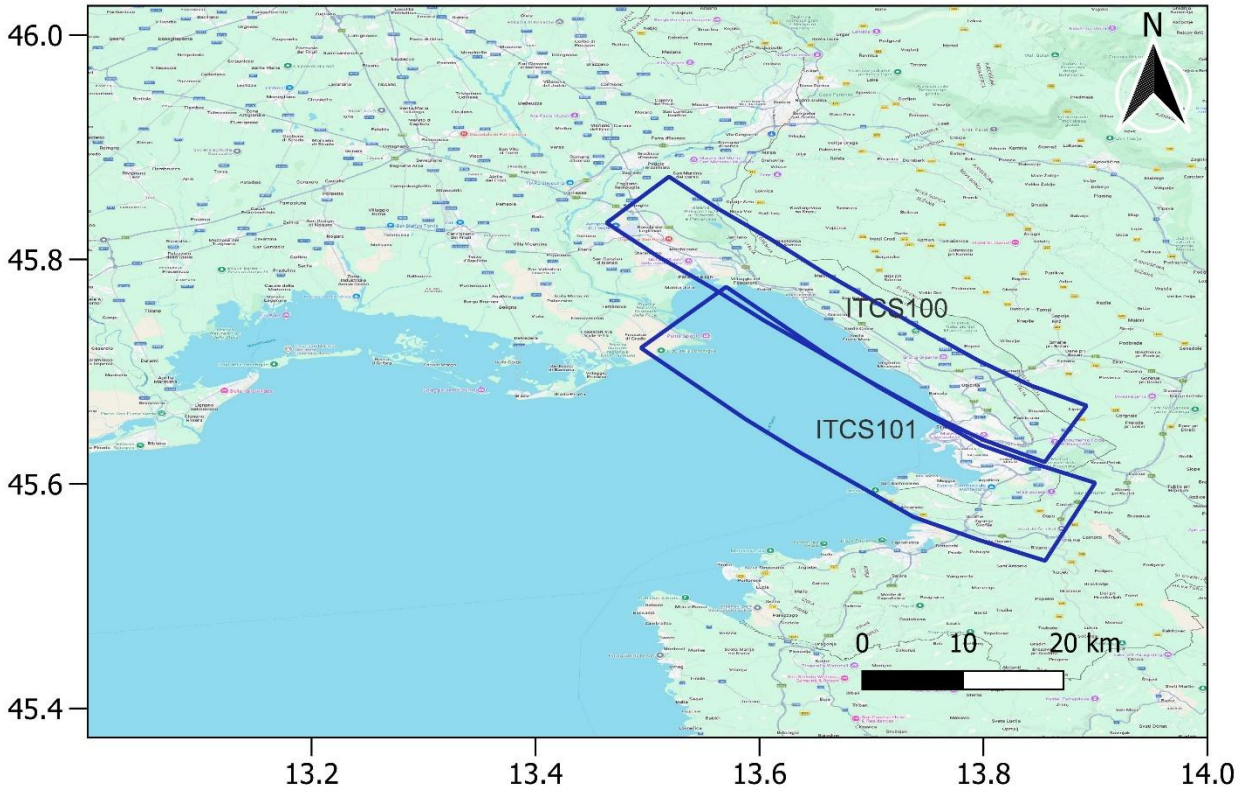


Figure 2: Local Seismogenic sources i.e. ITCS100 and ITCS101, from Database of Individual Seismogenic Sources (DISS-3.3.1) listed in Table 1.

2.2 Reference Simulation File

The reference files were provided by the EDANYA Group (University of Málaga) containing simulation settings for Tsunami-HySEA. This file includes:

- Bathymetry grid specifications (level0.grd, level1.grd, level2.grd)

In this work 3 nested grids were used. level0.grd was extracted GEBCO bathymetry of 460-meter resolution, while level1.grd was adopted from EMODnet bathymetry (115 m resolution) to local relatively higher-resolution data (level2.grd). The relatively high-resolution grid adopted for the FVG coastal region has been developed by integrating three data sources EMODnet (115 m), the Gulf of Trieste local model (Trobec et al., 2018), and Tinitaly-DEM (10 m for onshore topography), with a consistent interpolation scheme that eliminates these artifacts. The improvement is evident in Figure 4, where inundation patterns follow natural topographic controls (drainage channels, the elevated central ridge) rather than grid-induced anomalies.

- Manning coefficients for different grid resolutions (0.03-0.1)
- Simulation time (5000 seconds)

Three scaling laws were implemented to calculate fault dimensions from earthquake magnitude (i.e. Blaser et al. 2010; Wells and Coppersmith 1994; Leonard 2010, 2014). The reference file

serves as a template, with only the fault/subsources section being replaced for each generated scenario while preserving all simulation parameters.

3. Methods and Code Implementation

3.1 Workflow Overview

The tsunami source generation follows a systematic workflow. Input parameters are extracted from shapefile attributes for each seismogenic source. The scaling law is then applied to calculate fault length and width based on magnitude. A stochastic k^{-2} slip distribution is generated using the Ruiz et al. (2015) methodology, which produces realistic heterogeneous slip patterns. The slip distribution is then optionally modified to represent unilateral or bilateral rupture styles. Subfaults are created by discretizing the fault plane into a grid, with geographic coordinates computed for each subfault. Finally, .par files compatible with Tsunami-HySEA are exported, along with NetCDF files and visualization plots.

3.2 Slip Distribution Generation

The stochastic k^{-2} slip distribution follows Ruiz et al. (2015) methodology. Gaussian random noise is generated, and a 2D Fast Fourier Transform (FFT) is applied. A k^{-2} filter is then applied to produce the characteristic spectral shape observed in real earthquake slip distributions. Edge tapering reduces artifacts at fault boundaries. The slip distribution is scaled to match the average slip computed from the seismic moment, ensuring physical consistency. Three rupture styles were implemented. The original style applies no modification to the slip distribution. The unilateral and bilateral styles were applied along the fault length. After applying rupture styles, the slip distribution is renormalized to conserve the average slip. The fault plane is discretized into a grid of subfaults based on the chosen subsource spacing (typically 2.0 km). Each subfault is assigned a slip value from the slip distribution, along with fault geometry parameters (strike, dip, rake, depth). Geographic coordinates for each subfault are computed by transforming local coordinates to geographic coordinates using WGS84 ellipsoid parameters.

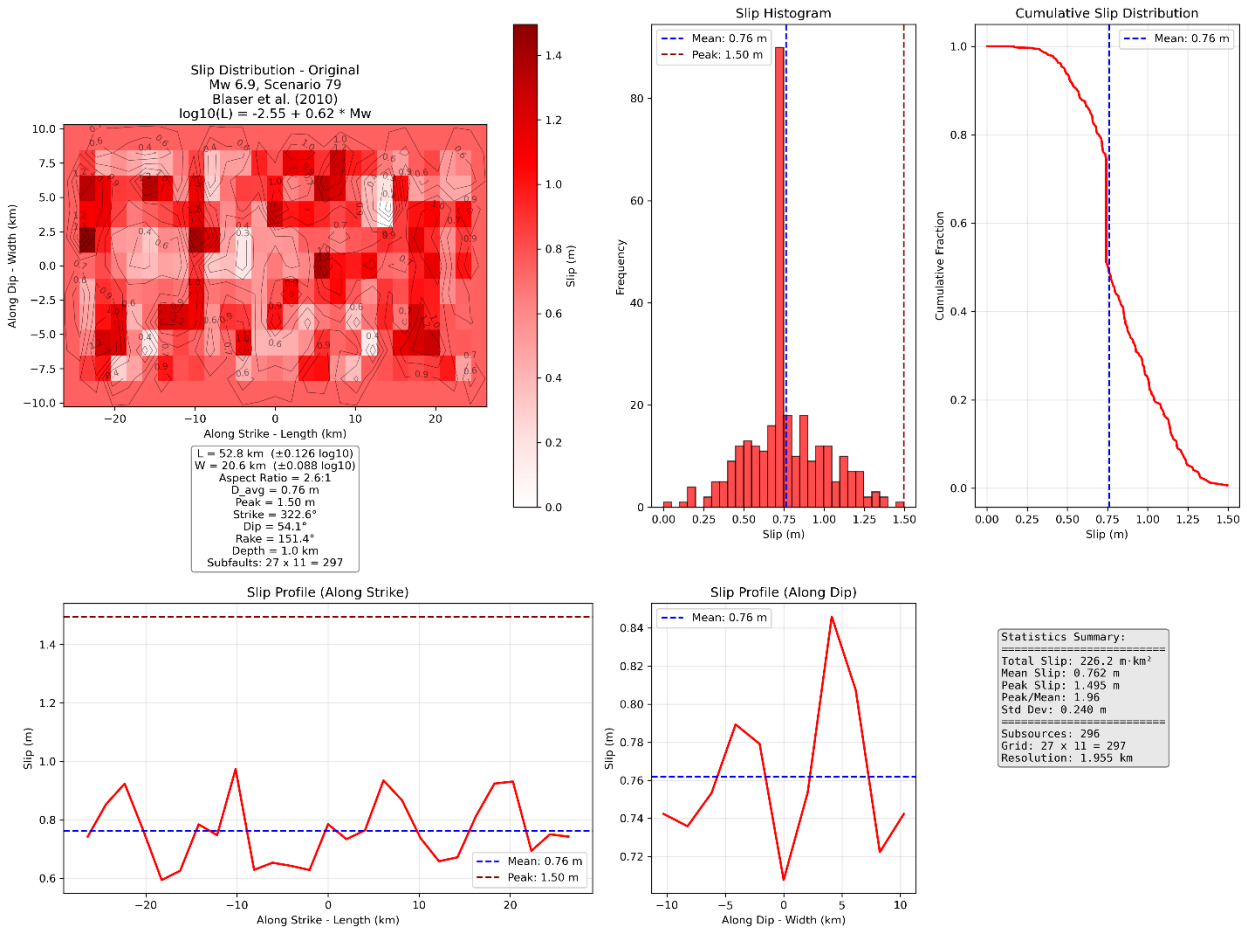


Figure 3: an example of developed slip distribution scenarios for ITCS101 seismogenic source and related statistics.

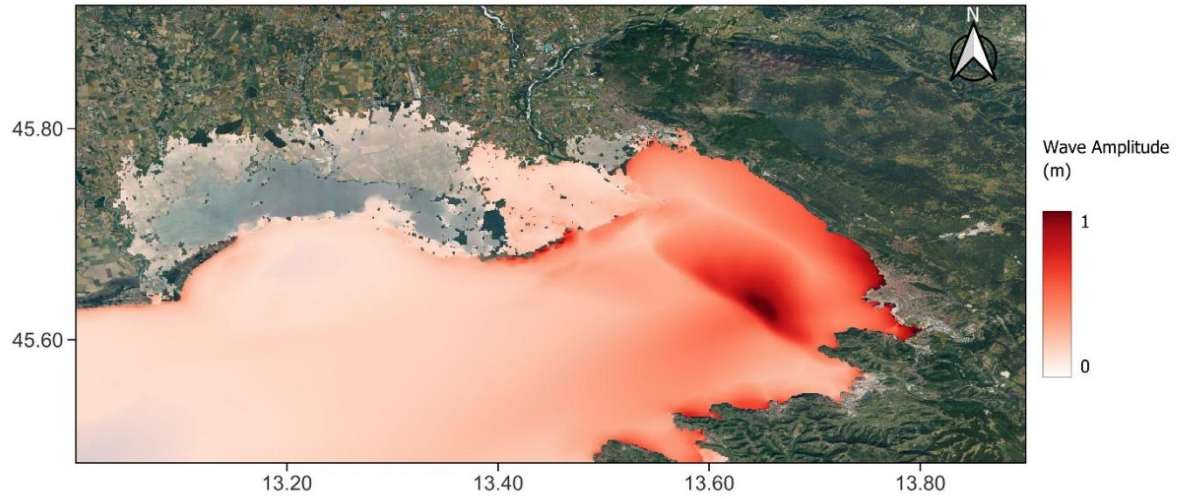
3.3 Tsunami HySEA .par Files Generation

The .par file generation preserves the simulation settings from the reference file while replacing the fault/subsources section. Each .par file contains the experiment identification, grid specifications, and for each subfault: longitude, latitude, depth, subfault length, subfault width, strike, dip, rake, and slip. This format is directly compatible with Tsunami-HySEA for multiscenario runs with nested grids. The rockfall scenario was developed in the comcot code.

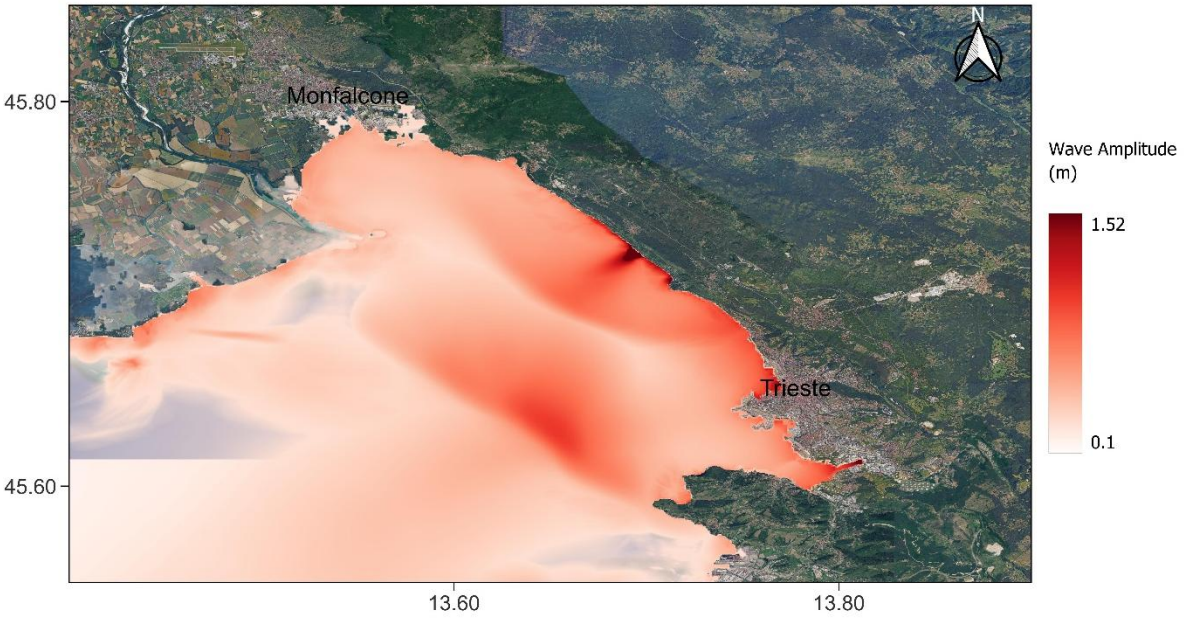
4. Results: ITCS100 Experiment

4.1 Experimental Setup

An experiment was conducted for source ITCS100 to generate 100 scenarios with all three rupture styles (original, unilateral, bilateral), resulting in 300 total outputs. The Adriatic Sea scaling law was selected for region-specific fault dimensions, with a subsource spacing of 2.0 km and rigidity of 30 GPa. The reference .par file provided simulation settings for the Gulf of Trieste region. The experiment produced 300 .par files, 300 NetCDF files containing slip grids, and 300 visualization plots. A comprehensive scenario summary was also generated. The .par files are directly compatible with Tsunami-HySEA and can be used for wave propagation simulations with nested grids (Figure 4a). While Figure 4b, shows a preliminary result for compound scenario of earthquake induced tsunami plus rockfall scenario described in section 2.



a)



b)

Figure 4: a) Selected tsunami scenario experiment for ITCS100 seismogenic sources. b) a preliminary earthquake induced tsunami compound with a rockfall scenario for the coastal part of Adriatic, between Monfalcone and Trieste

5. Conclusions and Recommendations

5.1 Conclusions

This work successfully developed a comprehensive database of earthquake-induced tsunami scenarios for the Northeastern Adriatic Sea. Multiple earthquakes induced tsunami scenarios were generated across local seismogenic sources to the area of interest (ITCS100, ITCS101) from the DISS 3.3.1 database. The implementation incorporates four scaling laws (Blaser et al., 2010; Wells and Coppersmith, 1994, Leonard, 2010&2014) and three rupture styles (original, unilateral, and bilateral). The generated .par files are compatible with Tsunami-HySEA for multi-scenario runs with nested grids. Also, we introduce a preliminary scenario that compound earthquake induced tsunami scenario with a rockfall scenario.

The stochastic k^{-2} slip distributions exhibit realistic heterogeneity and spectral characteristics following Ruiz et al. (2015). The average slip and peak slip values are physically consistent with the seismic moment for the specified magnitudes. The regional Adriatic Sea scaling law provides region-specific fault dimensions that may better represent the local tectonic setting compared to global scaling laws.

The resulting database provides a foundation for tsunami hazard assessment in the FVG coastal region. The scenarios can be used to evaluate tsunami wave heights, arrival times, and inundation areas for different source locations and rupture characteristics. This information is essential for developing effective tsunami warning systems, evacuation plans, and mitigation strategies.

5.2 Recommendations

1- earthquake-induced tsunamis, the methodology could be extended to include landslide-induced tsunamis using the Landslide-HySEA code. The near-shore rock instabilities in the Gulf of Trieste region could generate local tsunamis with different characteristics than earthquake-induced events.

2- A systematic sensitivity analysis should be conducted to evaluate the impact of scaling law selection, subsource spacing, and rupture styles on tsunami wave heights and inundation areas. This will help to identify the most influential parameters and reduce uncertainty in hazard estimates.

Dissimination

As part of the dissemination activities arising from this TA visit, one dataset/experiment resulting from the project has been made publicly available via the Zenodo data repository under an open-access license.

Experiment details:

- **DOI: 10.5281/zenodo.21487000**
- **UUID: c084bd54-83bf-4ec0-8cc8-b8b121699dbb**
- **Repository:** Zenodo (https://zenodo.org/records/21487001)
  DOI: 10.5281/zenodo.21487000

Aknowledgment

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