Assess-1: Tsunami hazard zones are mapped and designated

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UNESCO-IOC EU DG ECHO CoastWAVE 2.0 Project
IOC-UNESCO Regional Tsunami Ready Recognition Programme (TRRP)
Workshop
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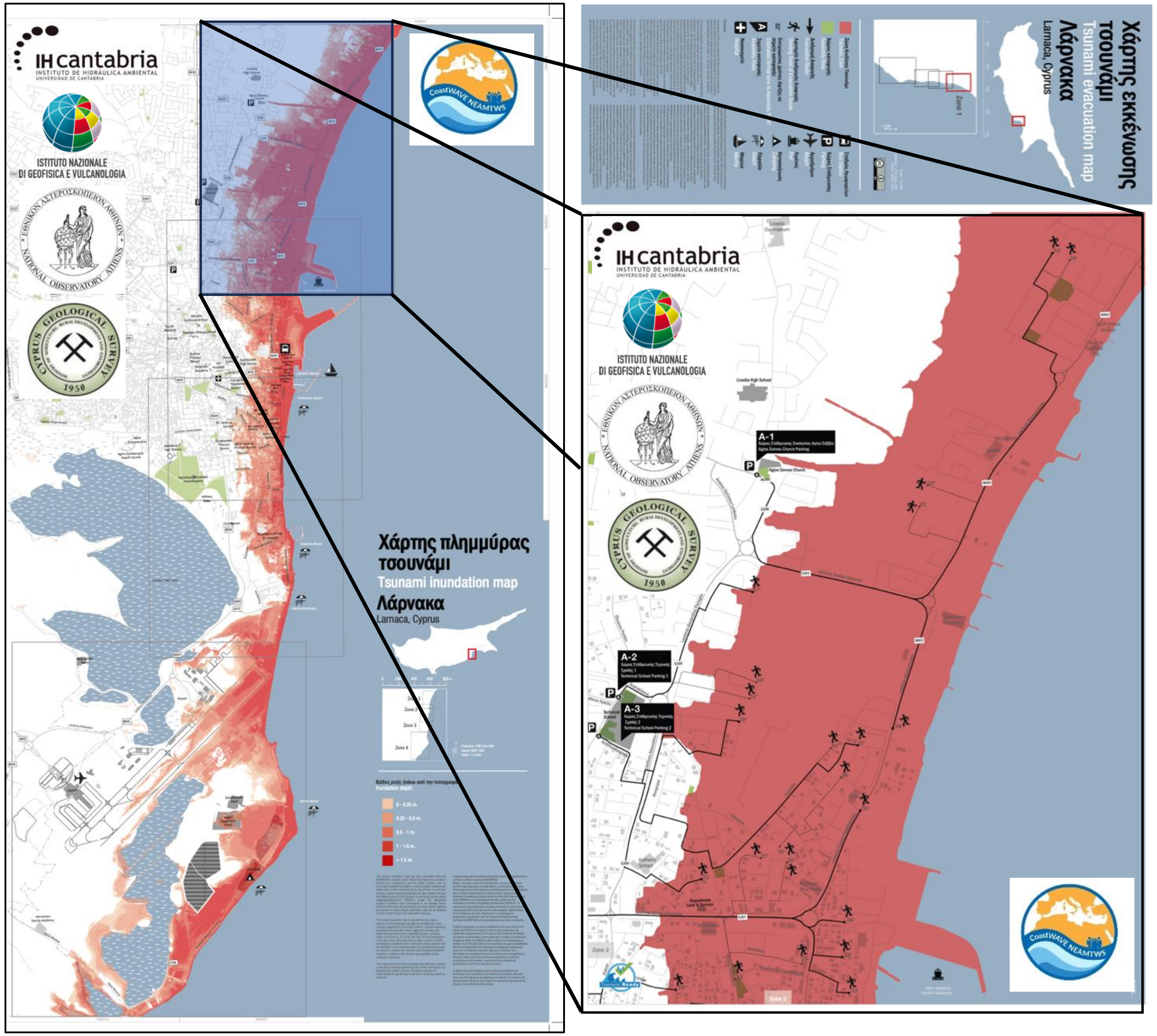
A tsunami inundation map:

- Identifies areas expected to be flooded by tsunamis based on available historical evidence and/or modelling.
- Provides awareness of tsunami hazard and assists communities and local/national government in developing evacuation plans and mitigation measures to minimize the impact of the tsunami.



Example of inundation map for the Municipality of Larnaca, Cyprus; collaborative work between IHCantabria, INGV, NOA & GSD within the framework of the CW1 project.

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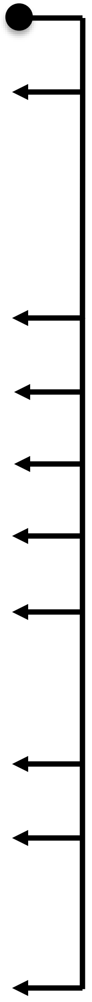

I	**ASSESSMENT (ASSESS)**
1	**ASSESS-1.** Tsunami hazard zones are mapped and designated.
2	**ASSESS-2.** The number of people at risk in the tsunami hazard zone is estimated.
3	**ASSESS-3.** Economic, infrastructural, political and social resources are identified.
II	**PREPAREDNESS (PREP)**
4	**PREP-1.** Easily understood tsunami evacuation maps are approved.
5	**PREP-2.** Tsunami information including signage is publicaly displayed.
6	**PREP-3.** Outreach and public awareness and education resources are available and distributed.
7	**PREP-4.** Outreach or educational activities are held at least three times a year.
8	**PREP-5.** A community tsunami exercise is conducted at least every two years.
III	**RESPONSE (RESP)**
9	**RESP-1.** A community tsunami emergency response plan is approved.
10	**RESP-2.** The capacity to manage emergency response operations during a tsunami is in place.
11	**RESP-3.** Redundant and reliable means to timely receive 24-hour official tsunami alerts are in place.
12	**RESP-4.** Redundant and reliable means to timely disseminate 24-hour official tsunami alerts to the public are in place.

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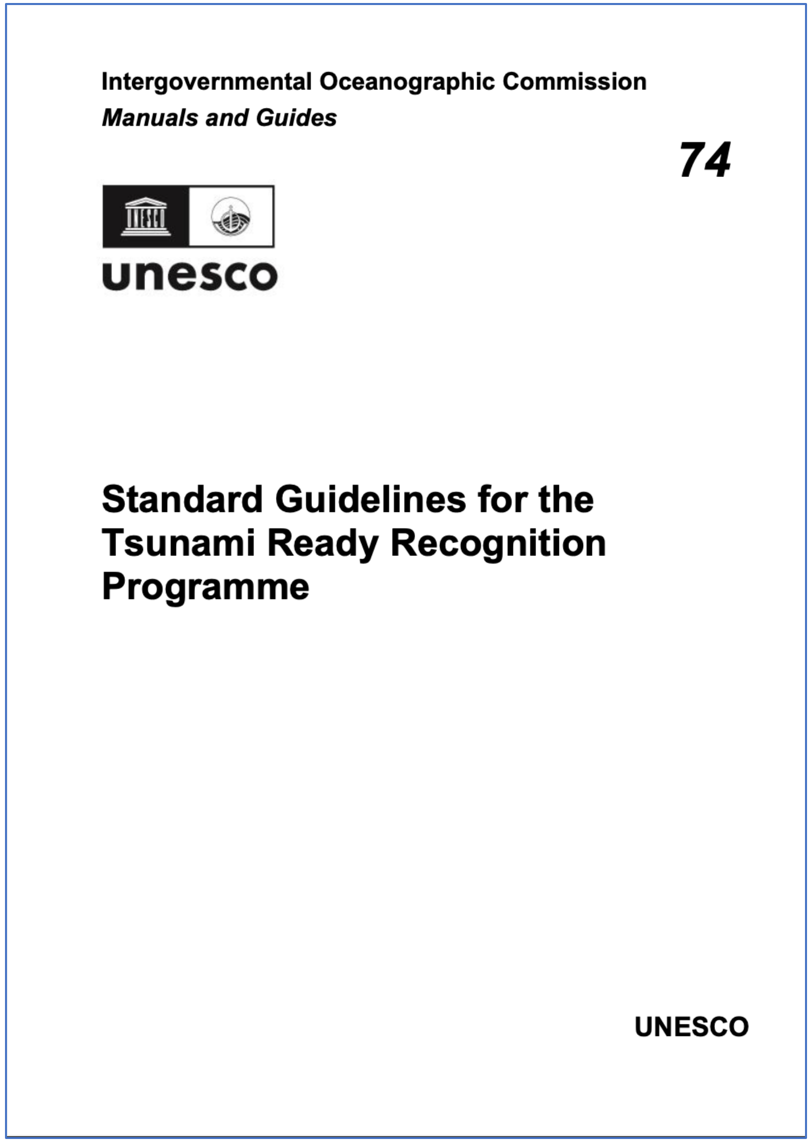
UNESCO-IOC references used for

ASSESS-1 TRRP indicator presentation:



Intergovernmental Oceanographic Commission
Manuals and Guides

74

Standard Guidelines for the Tsunami Ready Recognition Programme

UNESCO

Intergovernmental Oceanographic Commission
Manuals and Guides 82

PREPARING FOR COMMUNITY TSUNAMI EVACUATIONS

From Inundation to Evacuation Maps, Response Plans, and Exercises

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Flow chart for development of tsunami inundation maps

1
Acquire required information

2
Learn basics of tsunami science and numerical modelling

3
Conduct tsunami modelling or no modelling

4
Create Inundation Map

Collect:

- Tsunami scenarios;
- Topo/bathy DEMs.

Learn:

- Basics on tsunami science;
- Tsunami numerical modelling background.

- Define the tsunami source parameters and create ICs;
- Run numerical simulations.

OR

- Follow guidelines for defining the inundation zone without numerical modelling.

- Post-process collected information;
- Create inundation map.

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Step 1: acquire required information

Topographic/bathymetric information (Digital Elevation Models, DEMs)

- Tsunami inundation (numerical) modelling requires a series of telescopic numerical grids of combined topography & bathymetry;
- Coarsest (propagation grid, encompassing all tsunami sources and computational domain) -> finest (inundation) grid;
- Start from the highest resolution grid (inner grid), which encompasses the study area - resolution of inner grids depends on scope and data availability; preferable to be <= 10 m;
- Consult manual of used numerical model for file formatting and other grid design recommendations. Also read US National Tsunami Hazard Mitigation Program guidelines and best practices for tsunami inundation DEM development.

Some sources for topographic/bathymetric information:

- GEBCO (www.gebco.net) - 15 arc-second global relief;
- EMODnet (https://emodnet.ec.europa.eu/en) – 1/16 arc-minute bathymetry for European sea regions.

For inundation grids:

- LiDAR (topography) and multibeam (bathymetry) data preferred;
- If such data not available, search for most accurate and high-resolution topo/bathy data available for study area, including nautical charts, etc.

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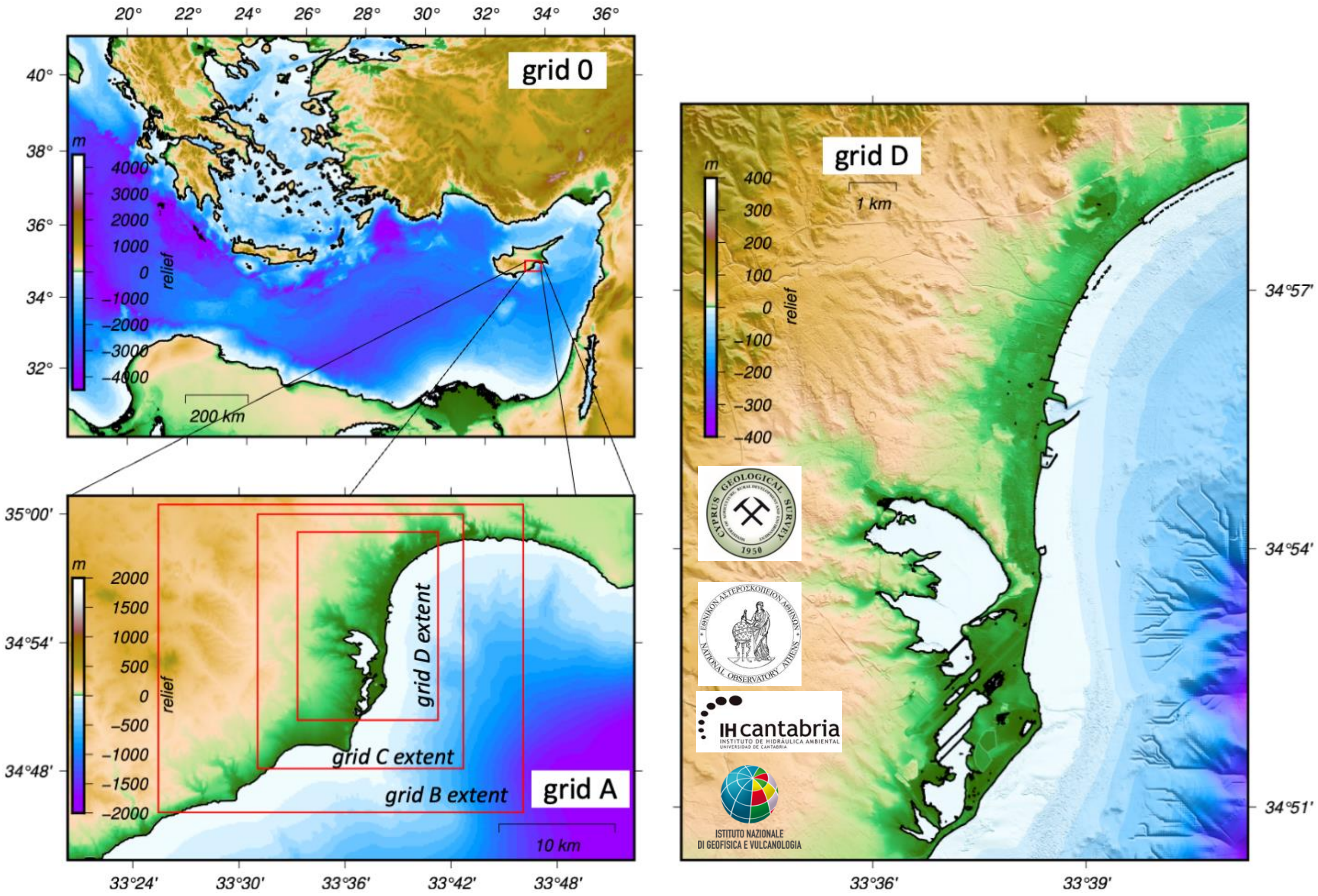
Step 1: acquire required information

Name	Grid size	Cell size (m)	Data source
grid 0	5425x3813	320	SRTM15+
grid A	306x198	160	DLS/EMODnet
grid B	394x334	80	DLS/EMODnet
grid C	888x1100	20	DLS/EMODnet
grid D	2424x3248	5	DLS/EMODnet



Example of nested numerical grids for tsunami inundation modelling; collaborative work between NOA , INGV, IHCantabria & GSD within the framework of the CW1 project.

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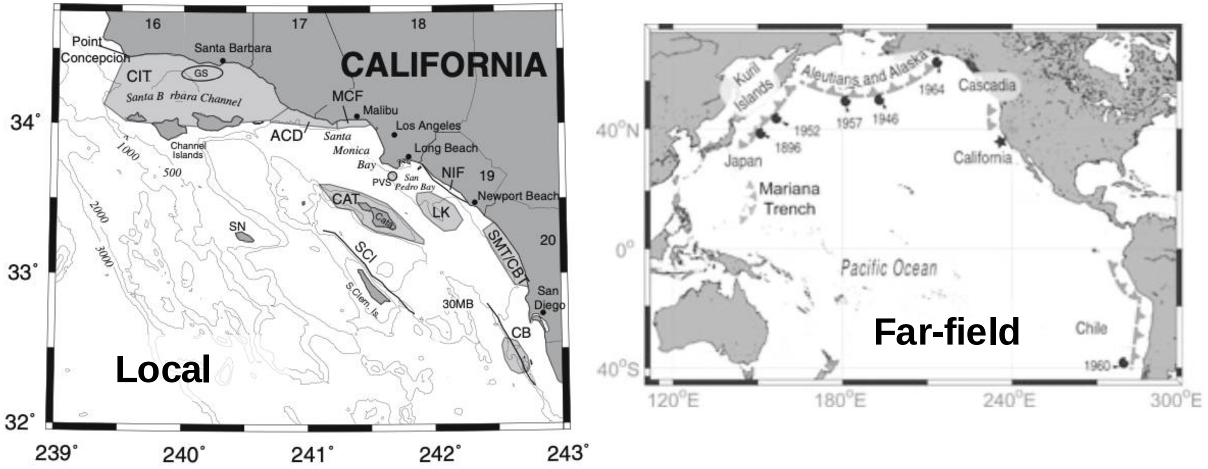
Step 1: acquire required information

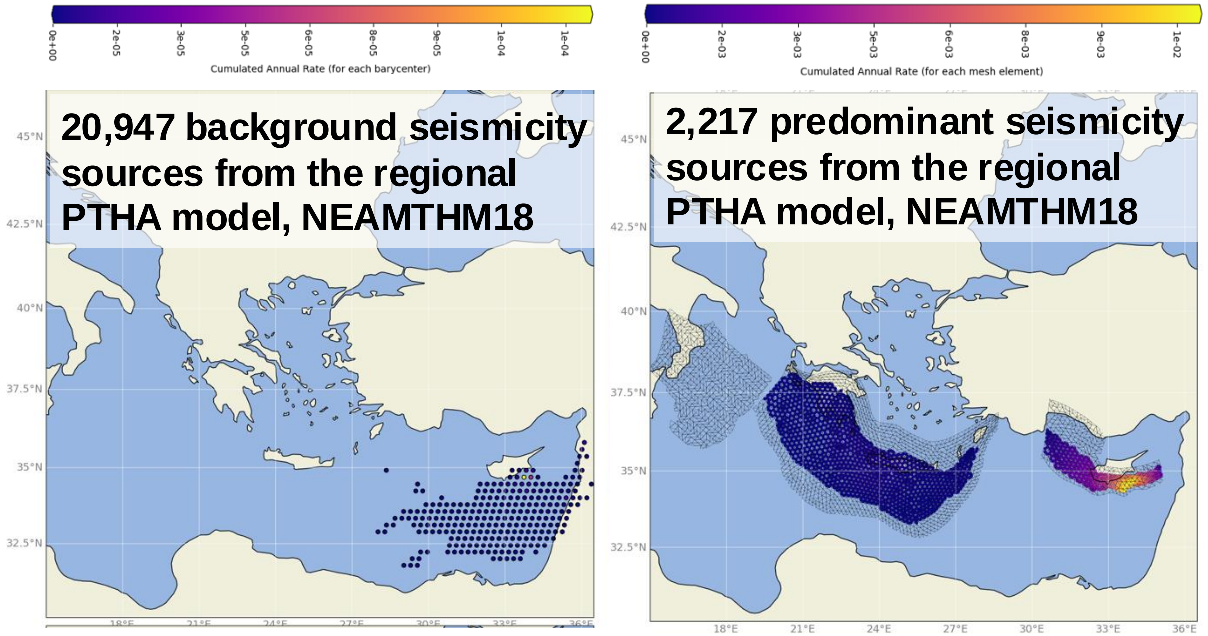
Tsunami sources

- Determining the maximum credible, worst-case, or a wide range of realistic tsunami scenarios, depending on hazard assessment methodology (deterministic VS probabilistic);
- Ideally, the most credible and realistic earthquake or other source(s) defined at regional/national/local level;
- Otherwise, every effort should be made to consult with national/international experts;
- In addition to local sources, consider far-field source regions which pose a threat to the coastal region of interest;
- Local earthquake scientists should be consulted to identify credible scenarios to be used for inundation modelling.
- Also read guidelines and best practices for tsunami sources from US National Tsunami Hazard Mitigation Program.

Step 1: acquire required information: tsunami sources



Total number of distant sources	12
Total number of local sources	23
Total number of local earthquake sources	16
Total number of landslide sources	7



20,947 background seismicity sources from the regional PTHA model, NEAMTHM18

2,217 predominant seismicity sources from the regional PTHA model, NEAMTHM18

Example of some of the locations of earthquake and landslide sources used for tsunami inundation mapping of California, USA, using a deterministic approach; Barberopoulou et al. (2011), Pure Appl. Geophys. 168, 2133–2146

Example of earthquake sources considered for tsunami inundation mapping in Larnaca, Cyprus, using the PTHA methodology; collaborative work between INGV, NOA, IHCantabria & GSD within the framework of the CW1 project.

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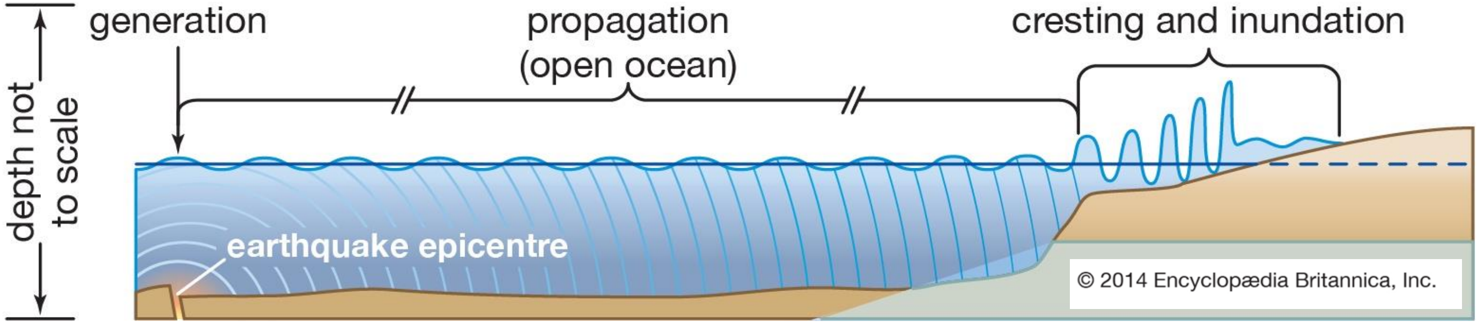
Step 2: learn basics of tsunami science and numerical modelling

- Gain understanding on the process of how tsunamis are generated, how they propagates in the deep ocean, and why they become destructive as they reach a coastline;
- Learn background on the development of a tsunami numerical model and get acquainted with its use – training needed.



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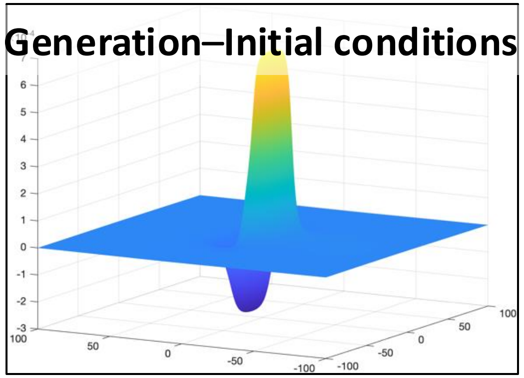
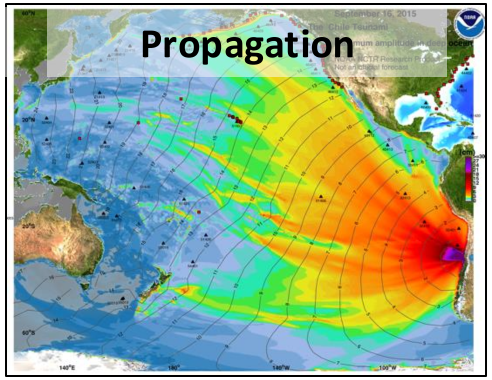
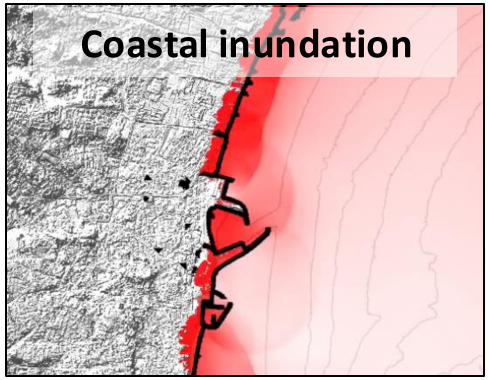


Generation–Initial conditions



Propagation



Coastal inundation

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Step 3: conduct tsunami modelling (or no modelling)

Governing equations used in tsunami numerical models

- Linear or non-linear shallow water equations (SWE);
- Boussinesq-type, or non-hydrostatic SWE which include dispersive properties – frequently used to model non-seismic tsunamis;
- Other higher order models, e.g., 3D (CFD) models based on Navier-Stokes equations – typically used to model complex tsunami generation processes and are coupled to less computationally expensive models to simulate wave propagation and inundation.

Numerical model schemes

- Finite difference;
- Finite volume;
- Finite element;
- Others, e.g., Smooth-Particle Hydrodynamics (SPH).

Use suitable BENCHMARKED model to numerically simulate tsunamis depending on the case study

See *Synolakis et al. (2007) NOAA Technical Memorandum, OAR PMEL-135*

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Step 3: conduct tsunami modelling (or no modelling)

Selected guidelines and best practices on tsunami modeling for tsunami inundation mapping from US NTHMP:

- Numerical models should be used appropriately with respect to domain of applicability (as identified by benchmarks);
- Model outputs should be compared against tsunami event measurements and other local information where available;
- Inundation modeling should use the best available data and appropriate modeling techniques and described in a technical report;
- Model runtime should be sufficient to capture the maximum inundation of the tsunami simulation and to estimate a time period when hazardous waves are present;
- To capture the contribution of high tidal conditions, inundation models should be run at a minimum of MHW level conditions for a specific region;
- A bottom “Manning’s n” friction coefficient which best represents the overall terrain and product use should be used.

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Step 3: conduct tsunami modelling (or no modelling)

M&G 82 guidelines in case of no numerical modelling:

- Consult regional, local, or national experts in seismology or tsunamis;
- Verify if markers of historical events are available;
- Check regional, local, or national newspaper archives and town bulletins reporting about tsunamis;
- Check local folklores or stories passed down through elders about the ocean attacking the coast;
- Search tsunami catalogues, such as NCEI/WDS & SB RAS

- If historical evidence of past tsunamis is available, recommended to add buffer zones to the maximum inundation evidence and also account for storm surge and maximum tidal level.
- For added safety, US NTHMP Guidelines recommend adding extra 1/3 of the area corresponding to the maximum historical run-up.
- The US guidelines suggest that at 3 km inland from the shoreline, most local tsunamis are no longer destructive, while for a distant tsunami the distance is about more than 1.6 km. However, as was documented in Japan in 2011, a local tsunami could far exceed 'recommended' levels and also vary from one location to the next.

If there is no reference information available

- US NTHMP Guidelines recommended safe elevation is 10 meters or higher.

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Step 4: create inundation map

Deterministic methodology

- Define worst-case (scientifically sound) tsunami generation scenarios;
- Run tsunami numerical simulations for all scenarios;
- Define inundation zone as the maximum extent of flooding from all credible tsunami scenarios.
- Optionally, inundation zones for local and far-field sources, or advisory/watch, can be designated.

Some references:

Barberopoulou et al. (2011), *Pure Appl. Geophys*. 168, 2133–2146

Dilmen et al. (2014), *Pure Appl. Geophys*. 172, 921–929

Probabilistic Tsunami Hazard Assessment (PTHA)

- Define tsunami source catalogue coupled with scenario recurrence rates;
- Run (larger number of) numerical simulations for all scenarios;
- Build tsunami hazard curves and compute inundation height (and zone) based on design ARP and uncertainty.
- Optionally, inundation zones for local and far-field events, or advisory/watch can be designated.

Some references:

Geist and Parsons (2006), *Nat Hazards* 37, 277–314

González et al. (2009), *J. Geophys. Res.: Oceans* 114(C11)

Gibbons et al. (2020), *Front. Earth Sci.* 8:591549

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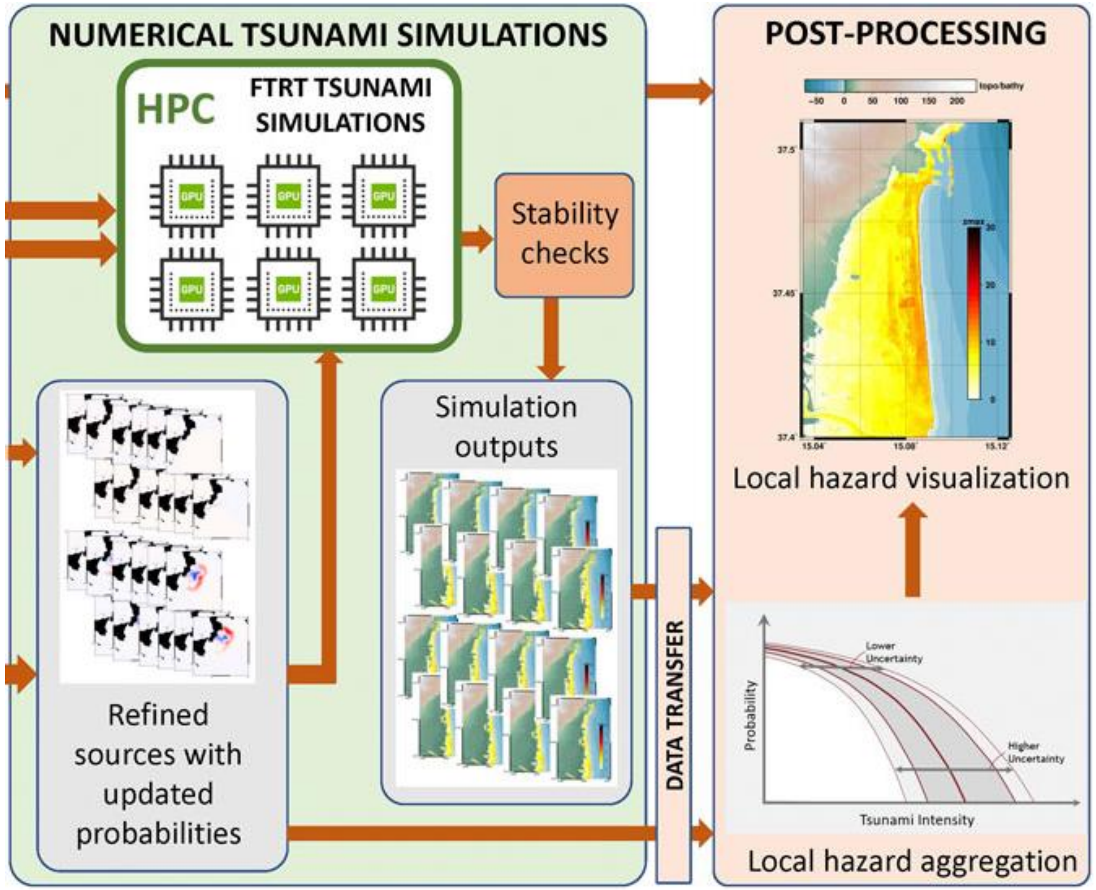
Step 4: create inundation map



Last steps of PTHA; Gibbons et al. (2020), Front. Earth Sci. 8:591549

Probabilistic Tsunami Hazard Assessment (PTHA)

- Define tsunami source catalogue coupled with scenario recurrence rates and uncertainties;
- Run numerical simulations for all scenarios;
- Local hazard aggregation: build hazard curves for each inland grid point;
- The inundation height (flow depth) at each cell is computed based on input (from decision-makers) on ARP and accepted uncertainty level;
- The inundation zone is defined based on all connected cells with inundation height > threshold (e.g., 1 cm).

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SiAM - Italian Tsunami Early Warning System

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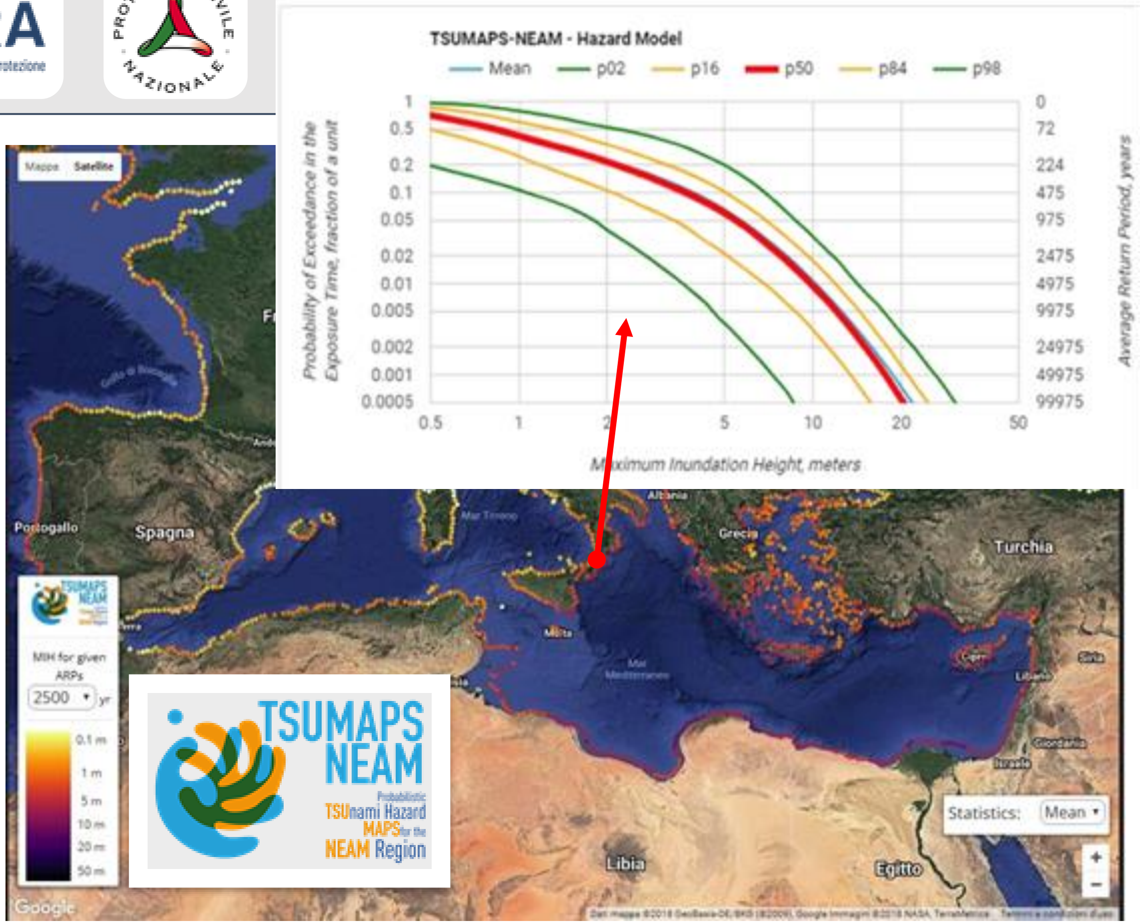
PROTEZIONE CIVILE NAZIONALE

Development of national tsunami inundation maps in Italy:

- Utilize offshore tsunami hazard curves from regional probabilistic tsunami hazard model (NEAMTHM18) to obtain Maximum Inundation Height (MIH) along the coast for combination of ARP and uncertainty level;



NEAMTHM18 available at the link: https://tsumaps-neam.eu

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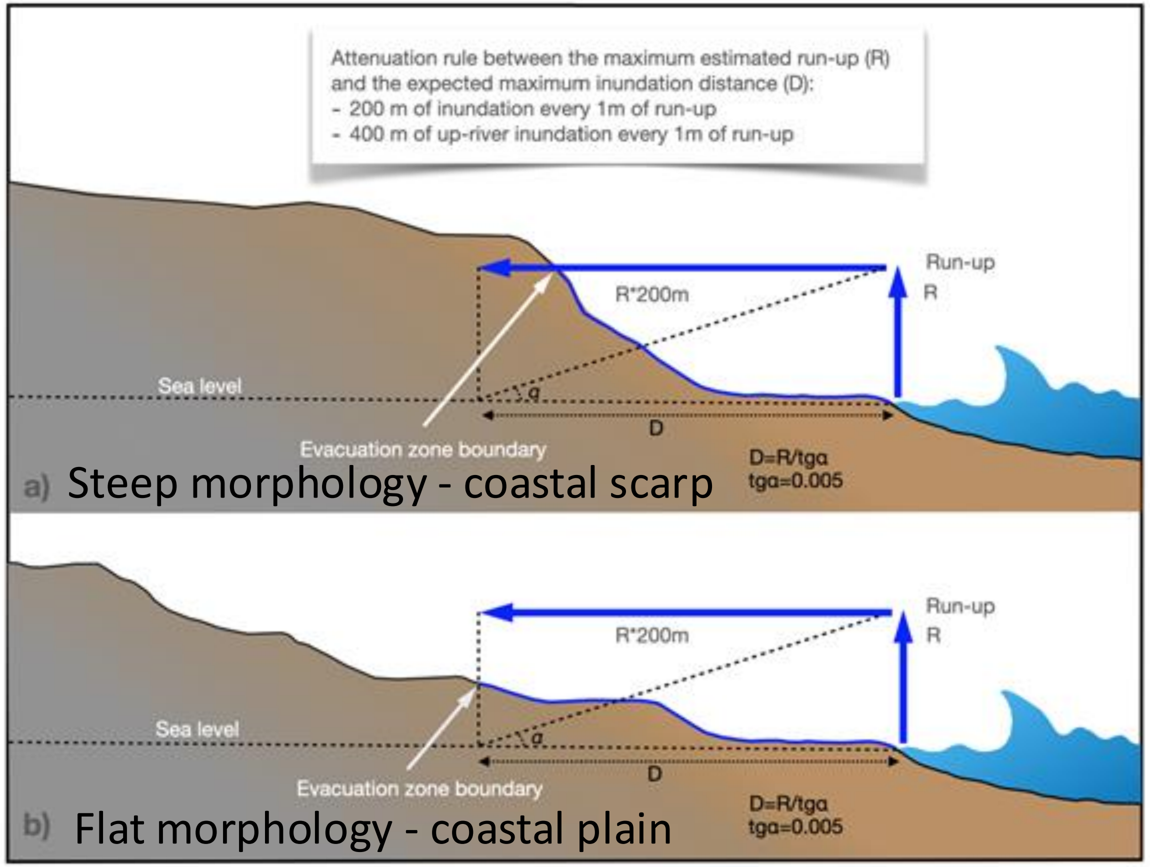
PROTEZIONE CIVILE NAZIONALE

<u>Development of national tsunami inundation maps in Italy:</u>

- Utilize offshore tsunami hazard curves from NEAM probabilistic tsunami hazard model (NEAMTHM18) to obtain Maximum Inundation Height (MIH) along the coast for combination of ARP and uncertainty level;
- MIH (after scaling) is projected onshore using best-available DEMs and GIS tools to infer inundation zone;



Attenuation rule between the maximum estimated run-up (R) and the expected maximum inundation distance (D):
- 200 m of inundation every 1m of run-up
- 400 m of up-river inundation every 1m of run-up

a) Steep morphology - coastal scarp

b) Flat morphology - coastal plain

Sketch of the method used to draw Italy's national inundation maps; Tonini et al. (2021), Front. Earth Sci. 9:628061.

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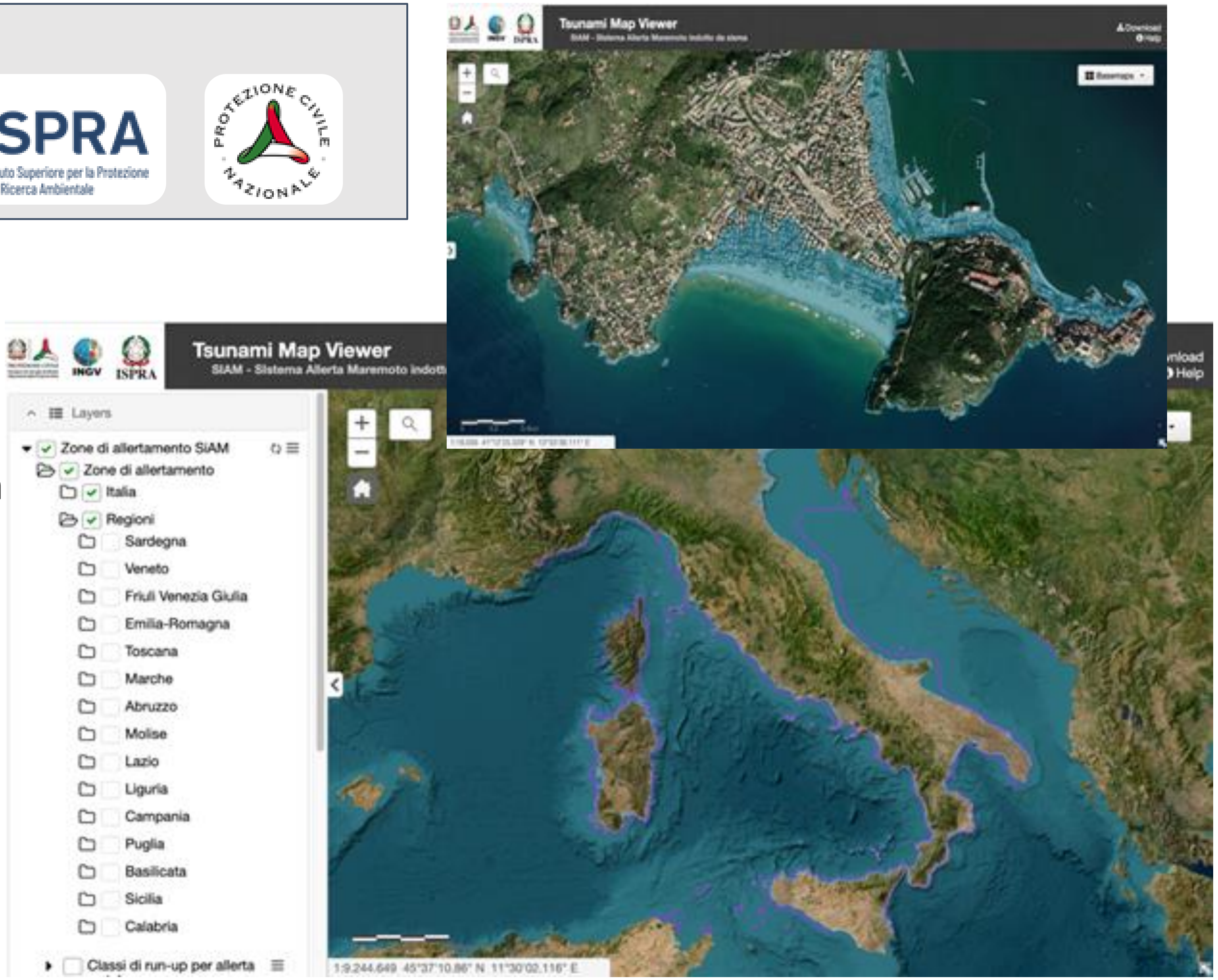

<u>Development of national tsunami inundation maps in Italy:</u>

- Utilize offshore tsunami hazard curves from NEAM probabilistic tsunami hazard model (NEAMTHM18) to obtain Maximum Inundation Height (MIH) along the coast for combination of ARP and uncertainty level;
- MIH (after scaling) is projected onshore using best-available DEMs and GIS tools to infer inundation zone;
- The methodology can be applied to develop tsunami inundation maps over large stretches of coastline – example shown here for the Italian coastline.

Reference:

Tonini et al. (2021), *Front. Earth Sci.* 9:628061

The alert zones are available at the link:
<u>http://sgi2.isprambiente.it/tsunamimap/</u>

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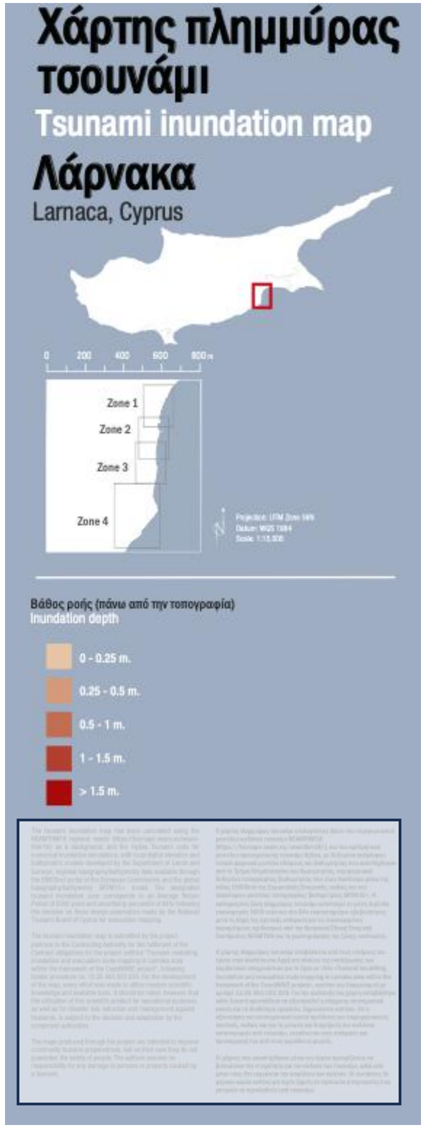
Selected tsunami inundation mapping guidelines and best practices

from US National Tsunami Hazard Mitigation Program:

- Tsunami inundation maps (TIMs) should include a title, scale, geographic location (coordinates), intended use, and appropriate explanatory information;
- TIMs should be accompanied by technical documentation on how modeled results were transferred onto the tsunami inundation maps. Intended use and/or limitations should be included;
- TIMs should be reviewed and field checked for consistency with existing topography before publication;
- Digital maps should include appropriate scale limitations and be displayed on a suitable base map, as determined by state emergency management or scientific personnel.



Title

Location description

Map inset

Map scale

Map inset for separate (zoom-in) maps and projection/datum info

Inundation depth (flow depth) color legend

Information on map development and disclaimer

Example of inundation map legend for the Municipality of Larnaca, Cyprus; collaborative work between IHCantabria, INGV, NOA & GSD within the framework of the CW1 project.

Thank you

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