From PTHA to planning and evacuation maps in Italy

Fabrizio Romano
Istituto Nazionale di Geofisica e Vulcanologia (INGV), Roma, Italy

Pio Di Manna
Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Roma, Italy

NEAMTWS Experts Meeting
Implementing NEAMTWS 2030 Strategy - Opportunities and Actions to Explore
28-30 November 2022, Naples, Italy

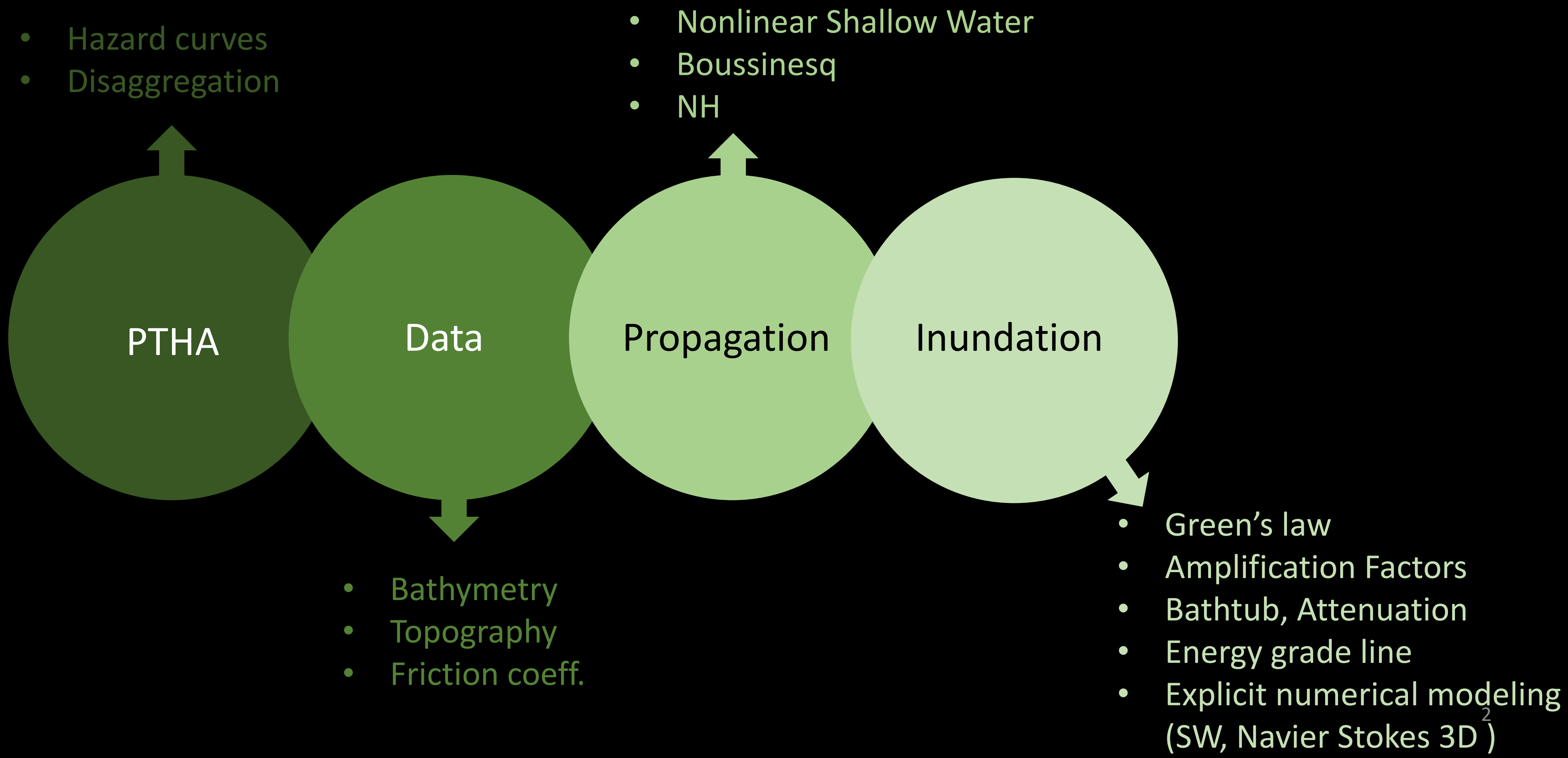
ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

CENTRO ALLERTA TSUNAMI ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

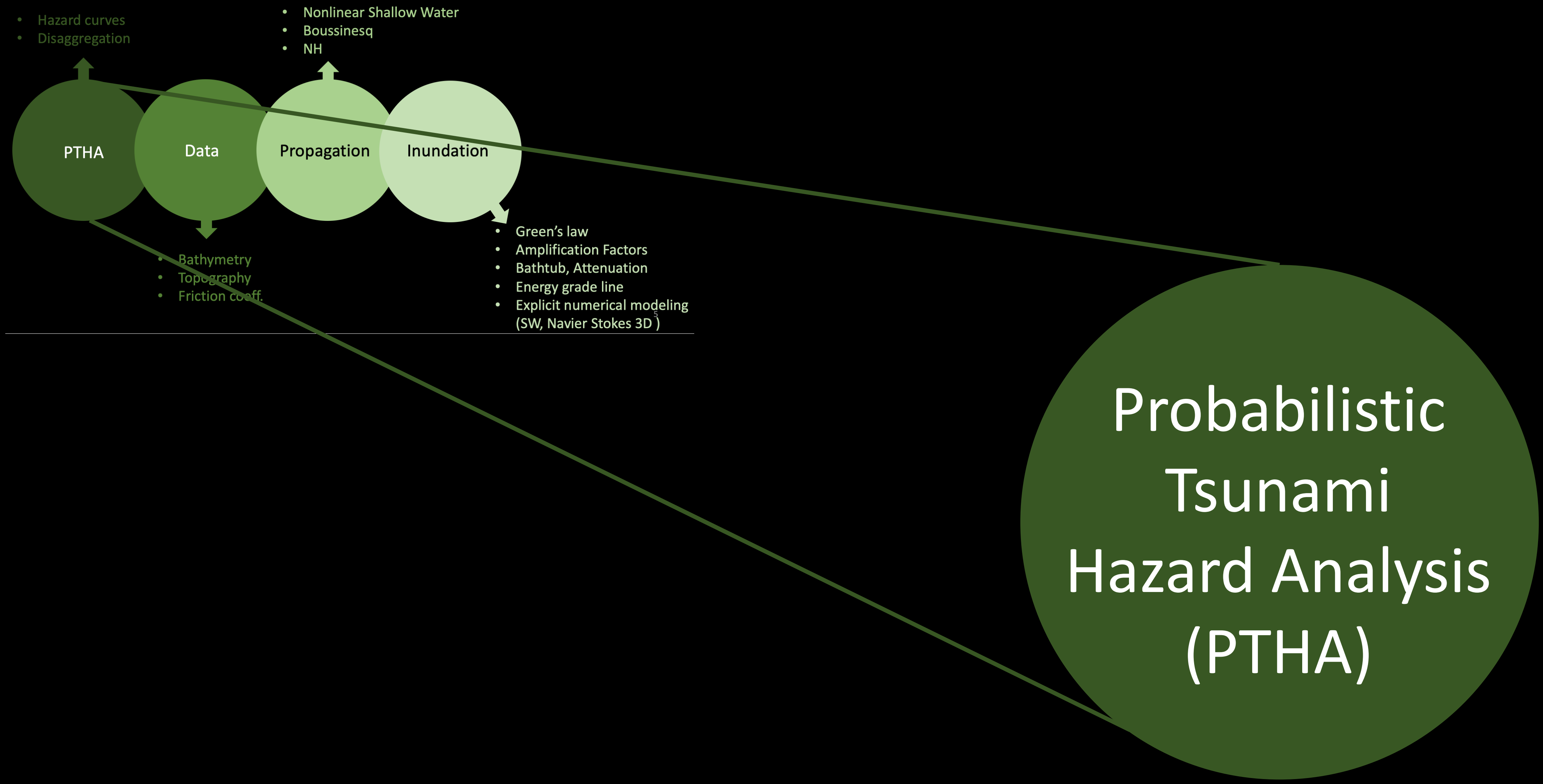
ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

PROTEZIONE CIVILE NAZIONALE

Ingredients for a recipe to inundation mapping



The Italian evacuation and long-term coastal planning



The Italian evacuation and long-term coastal planning

Probabilistic Tsunami Hazard Analysis (PTHA)

Tsunami

- mainly from **seismic** origin (~80% of the events)
- low-frequency/high-impact events
- Sparse observations

Tsunami hazard

- Potential Tsunamigenic sources (geology)
- Seismological information
- Numerical modeling

The Italian evacuation and long-term coastal planning

Probabilistic Tsunami Hazard Analysis (PTHA)

Tsunami
- mainly from **seismic** origin (~80% of the events) → **S**-PTHA
- low-frequency/high-impact events
- Sparse observations

→ Limited observation completeness

Tsunami hazard
- Potential Tsunamigenic sources (geology)
- Seismological information
- Numerical modeling

Scenarios Probability + Tsunami impact

↓

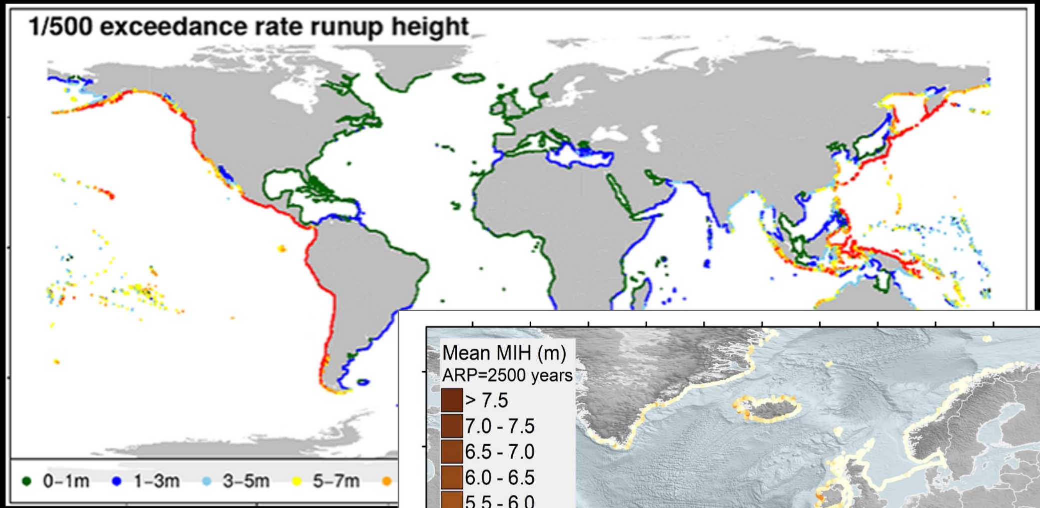
Computation-based S-PTHA

The Italian evacuation and long-term coastal planning

Different scales

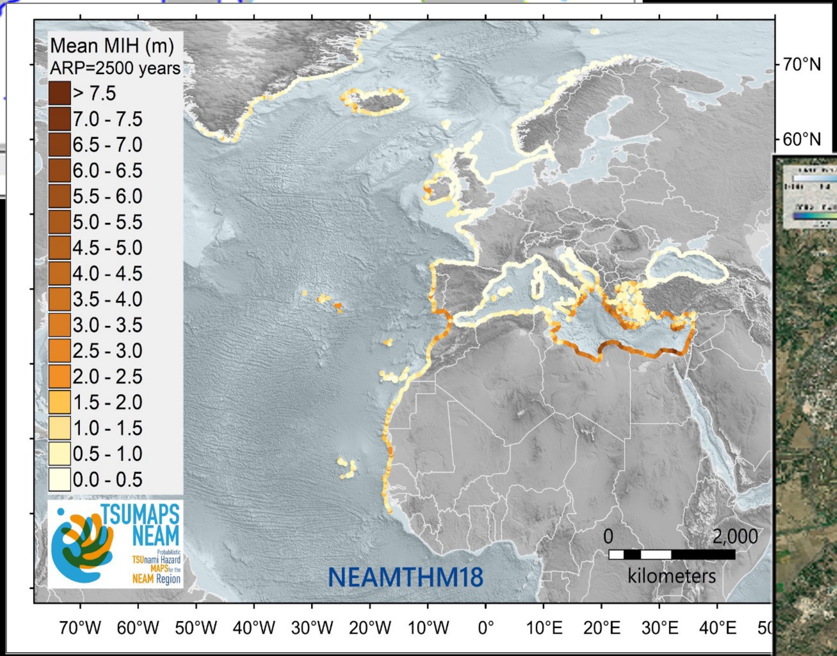
Probabilistic Tsunami Hazard Analysis (PTHA)

Computational & human resources, accuracy, time, cost



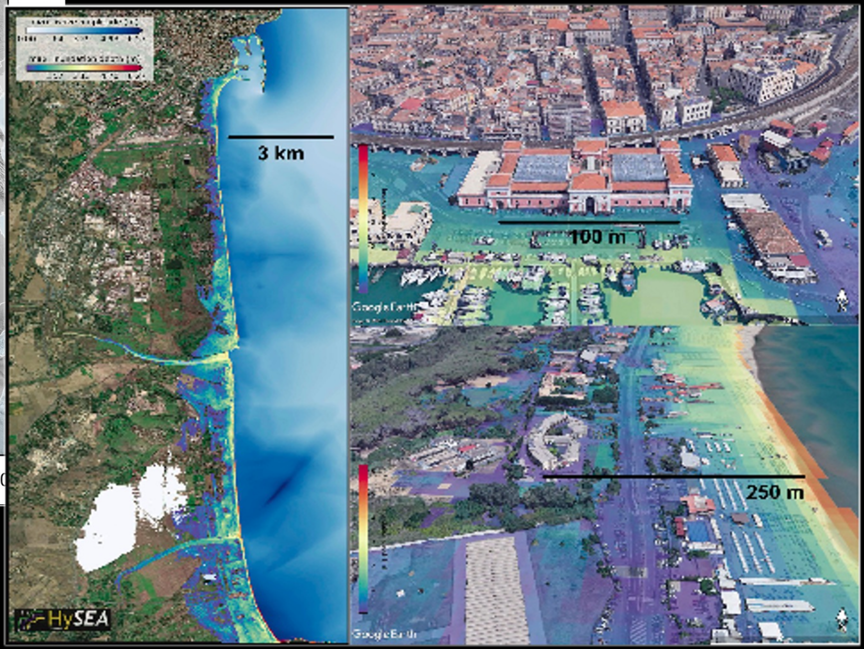
Davies et al., 2018

Global



NEAMTHM18
Basili et al., 2021

Regional



Local

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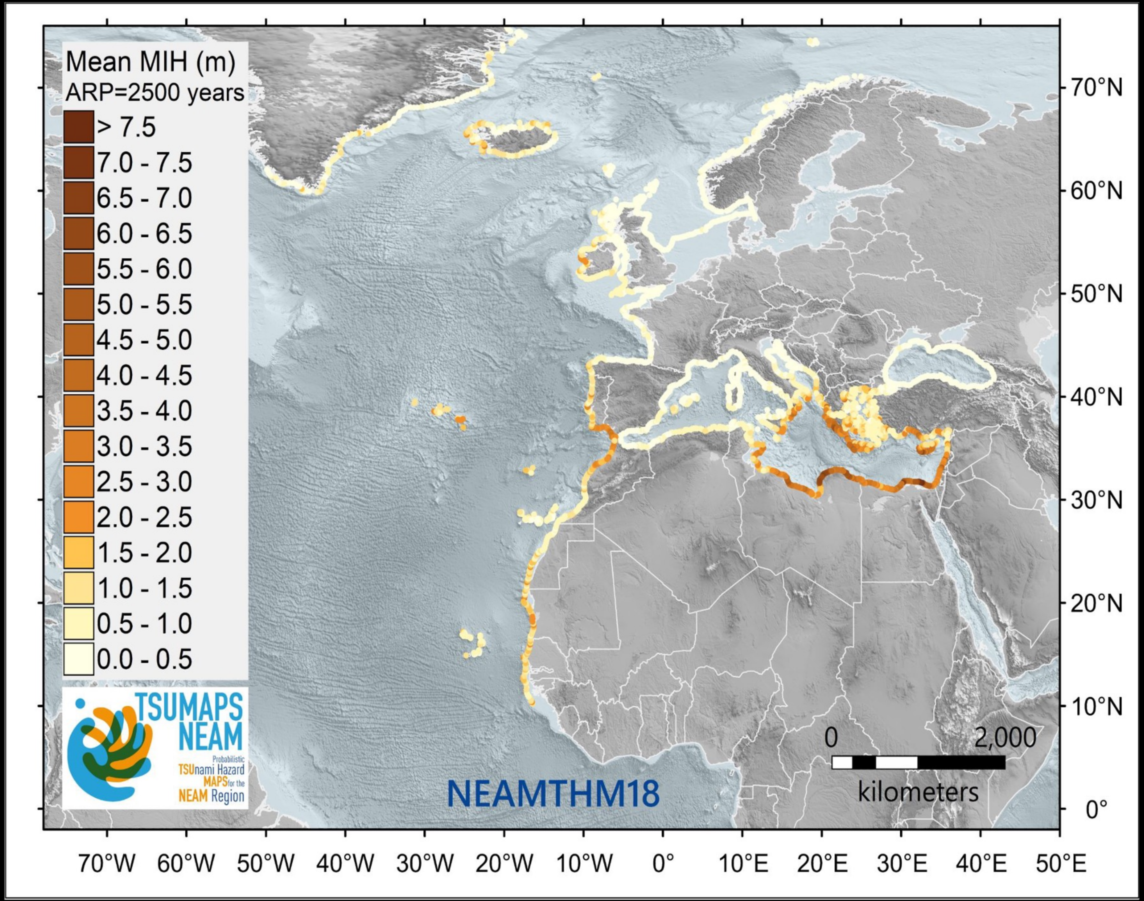
The Long-term Regional Probabilistic Tsunami Hazard Model for NEAM

Probabilistic Tsunami Hazard Analysis (PTHA)



NEAMTHM18
Basili et al., 2021

http://www.tsumaps-neam.eu/

- European Project Networking
- Rigorous Uncertainty treatment
- GTM Pool of Expert (elicitation)
- Revision from external experts

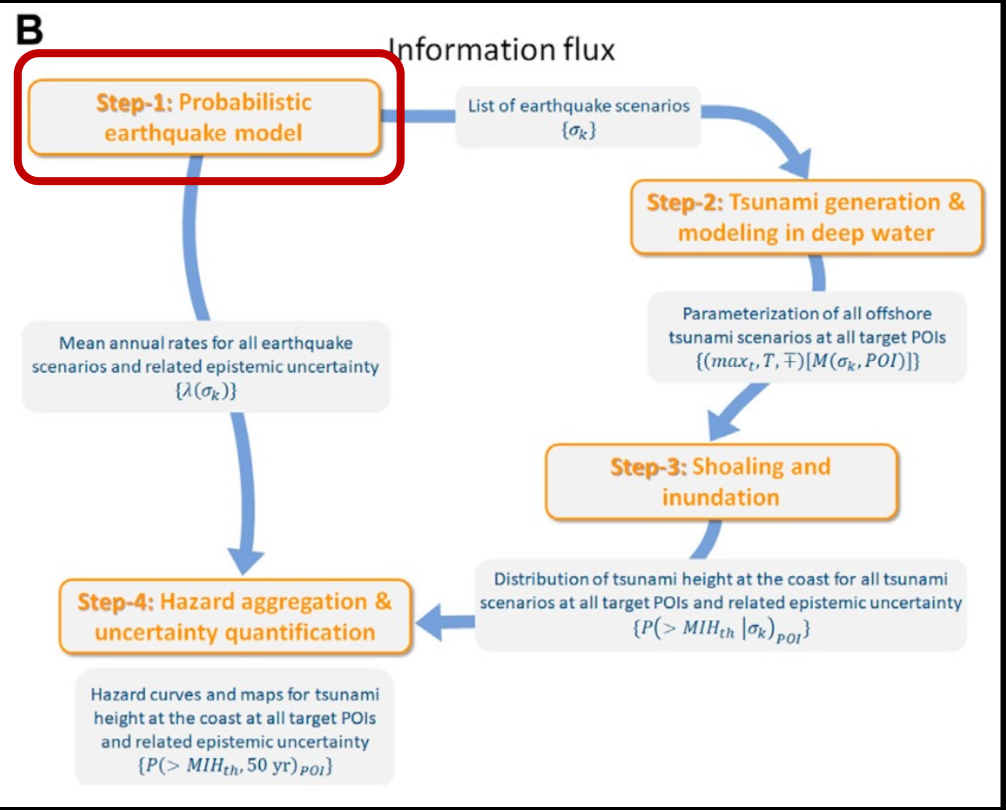
A kind of GTM experiment

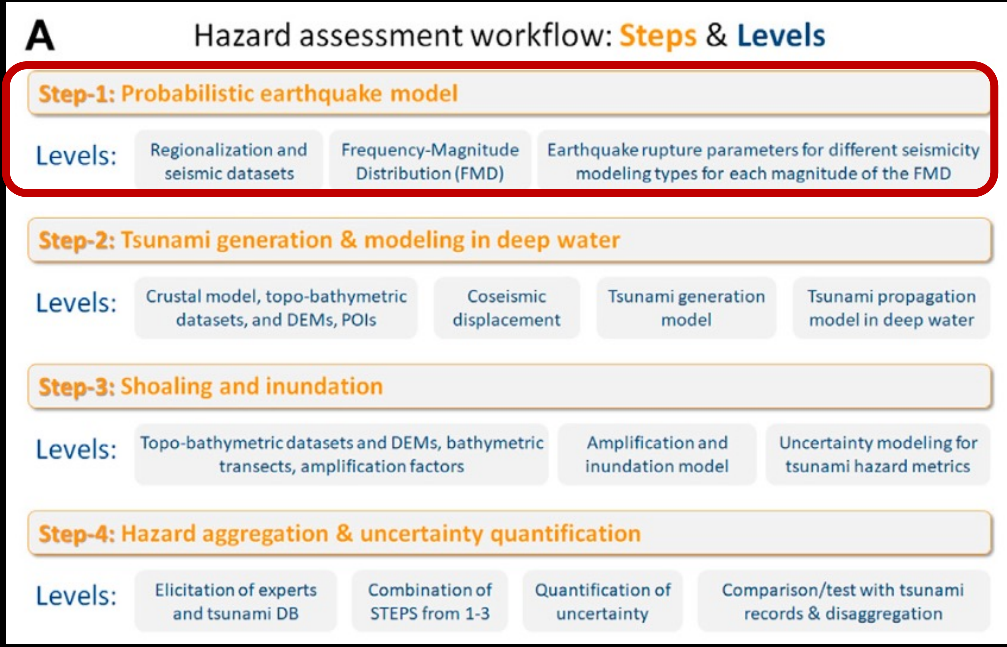
NEAM: *North-East Atlantic, Mediterranean, and connected seas*

The Italian evacuation and long-term coastal planning

The NEAMTHM18 Workflow

Probabilistic Tsunami Hazard Analysis (PTHA)





Output

- List of earthquake scenarios
- Annual rate for earthquake scenarios
- Epistemic Uncertainty

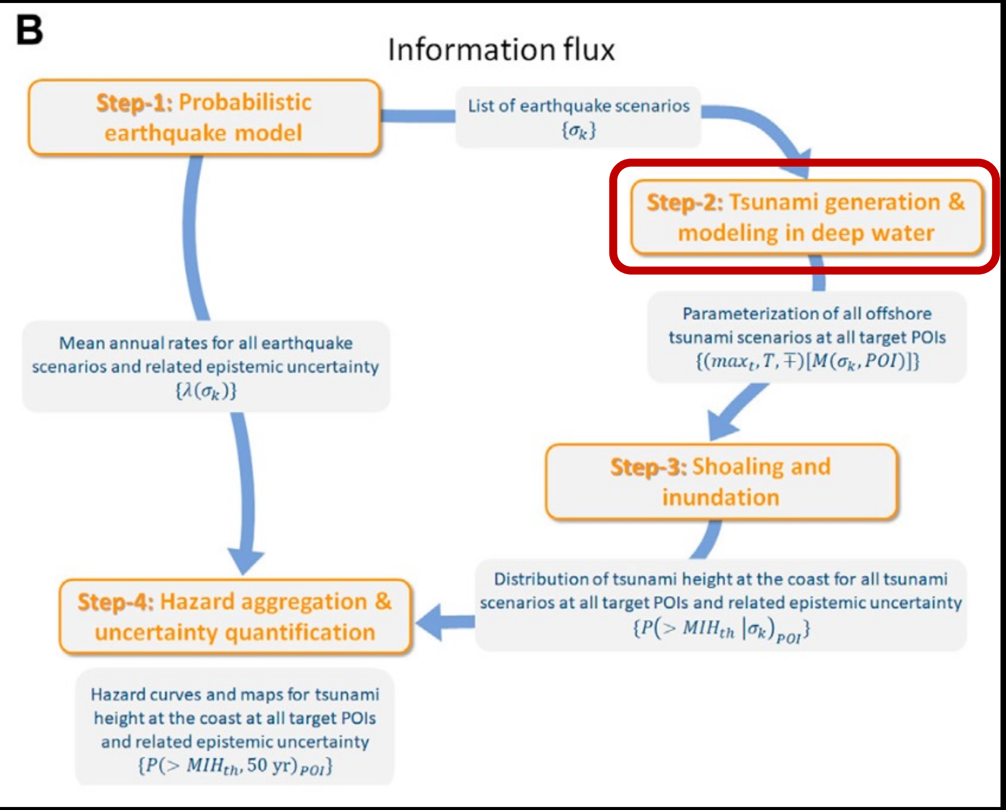
All the details of the methodology in:
NEAMTHM18 documentation, http://doi.org/10.5281/zenodo.3406625

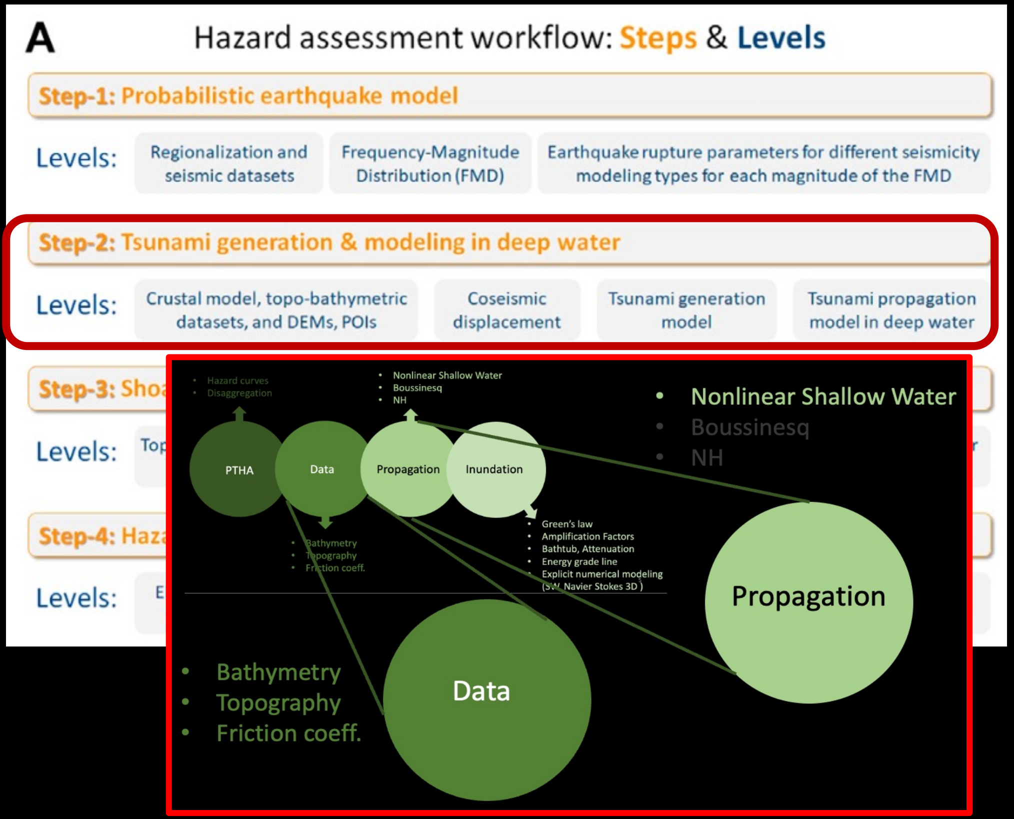
Basili et al., 2021

The Italian evacuation and long-term coastal planning

Probabilistic Tsunami Hazard Analysis (PTHA)

The NEAMTHM18 Workflow





Output

- Offshore tsunami parameters (amplitude, period, polarity)

All the details of the methodology in:
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Basili et al., 2021

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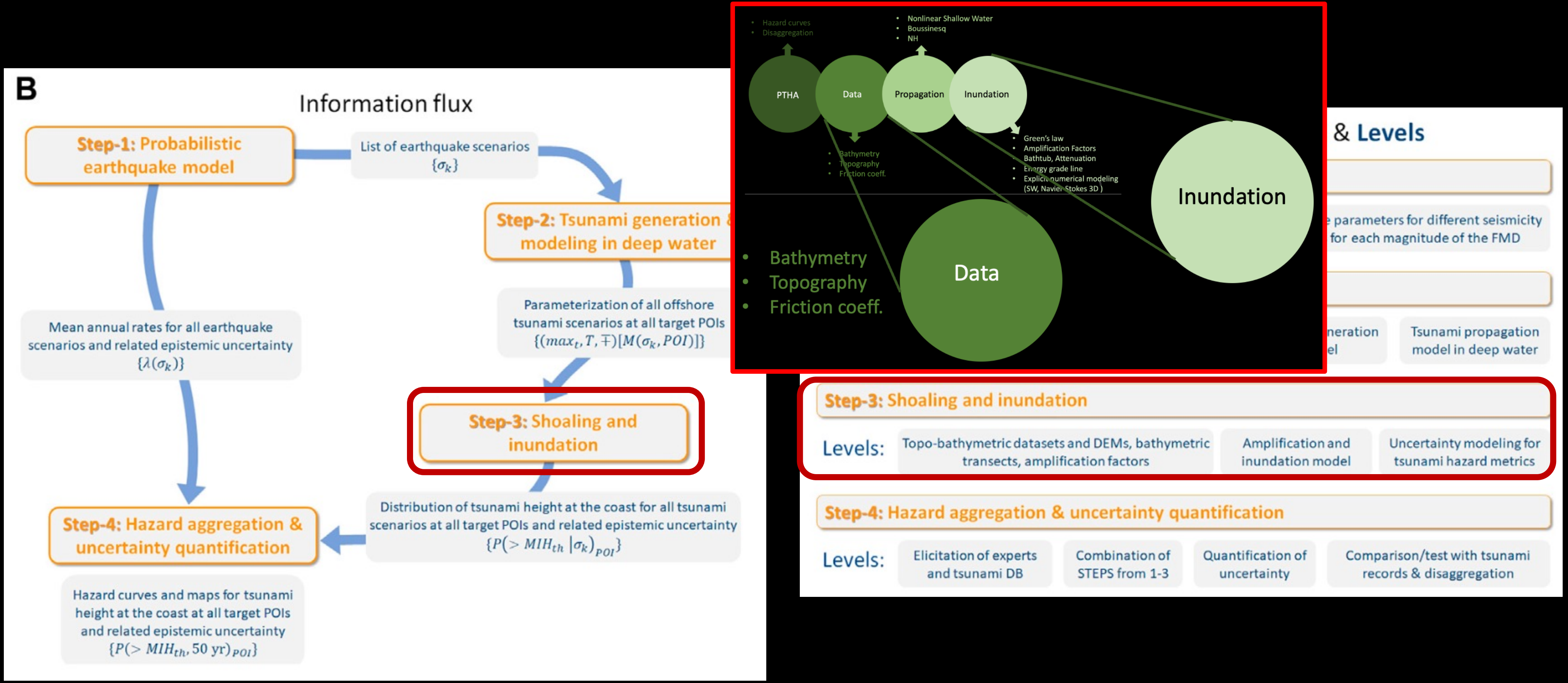
Probabilistic Tsunami Hazard Analysis (PTHA)

The NEAMTHM18 Workflow



Output

- Coastal Tsunami height
- Epistemic Uncertainty

All the details of the methodology in:
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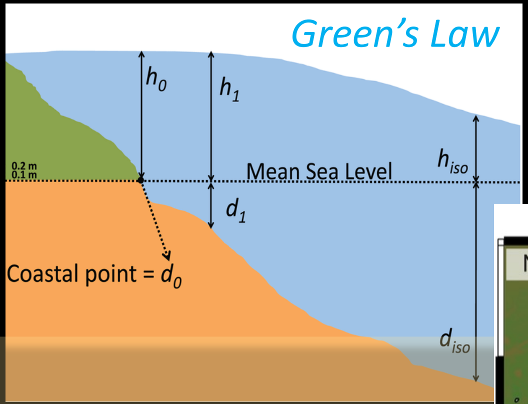
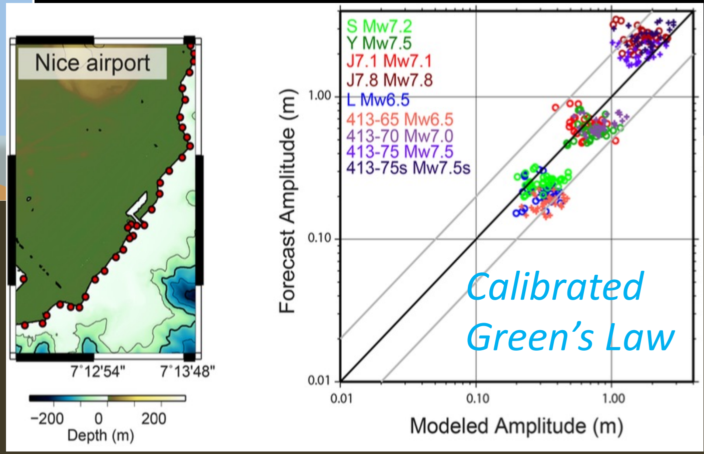
Basili et al., 2021

Different ways to compute/estimate the tsunami inundation

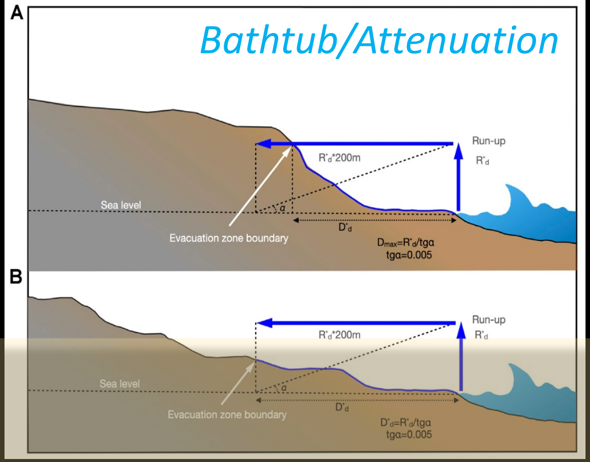
Synolakis, 1991
Kamigaichi, 2014



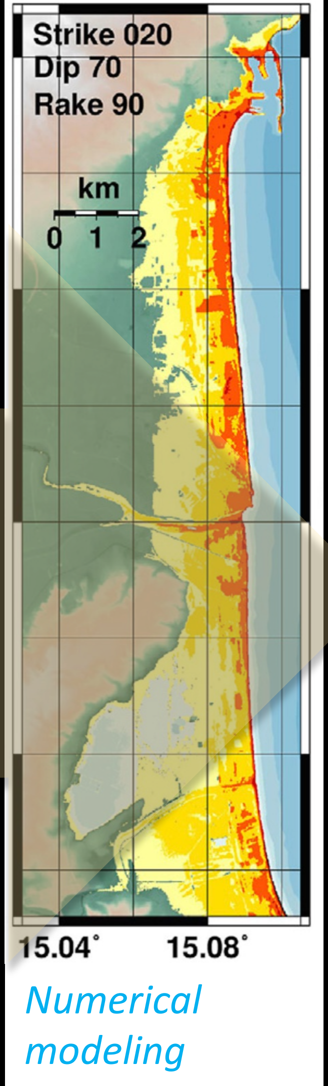
Gailler et al., 2017



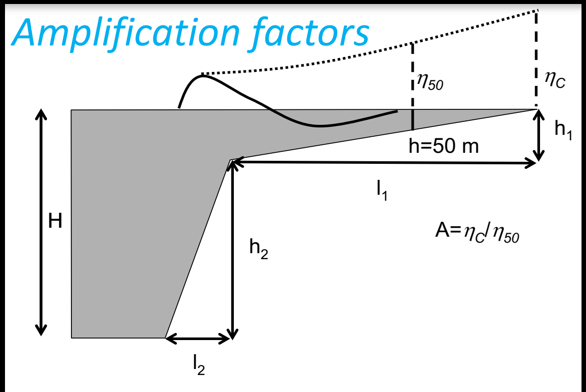
Leonard et al., 2008
Tonini et al., 2021



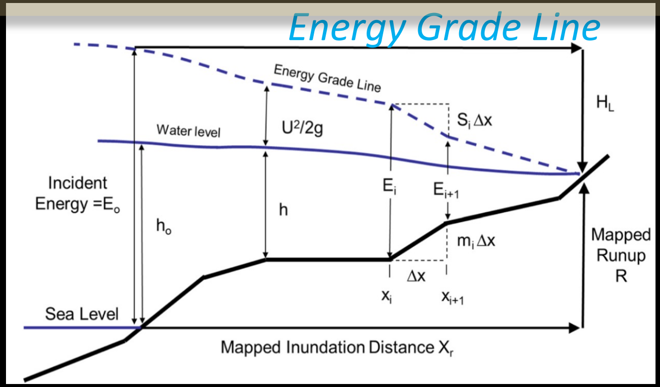
Increasing complexity



Gibbons et al., 2022

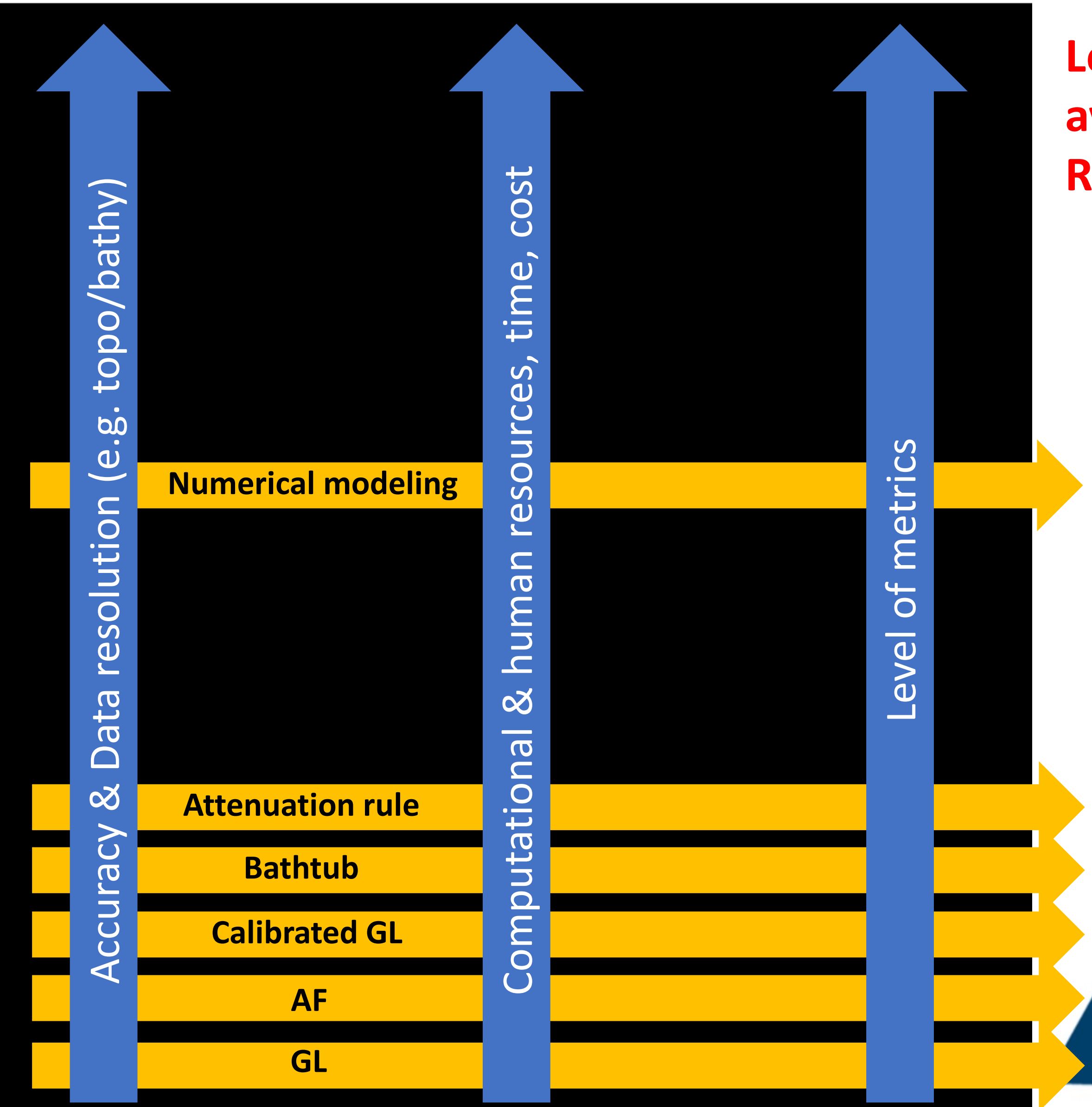


Lovholt et al., 2012
Glimsdal et al., 2019

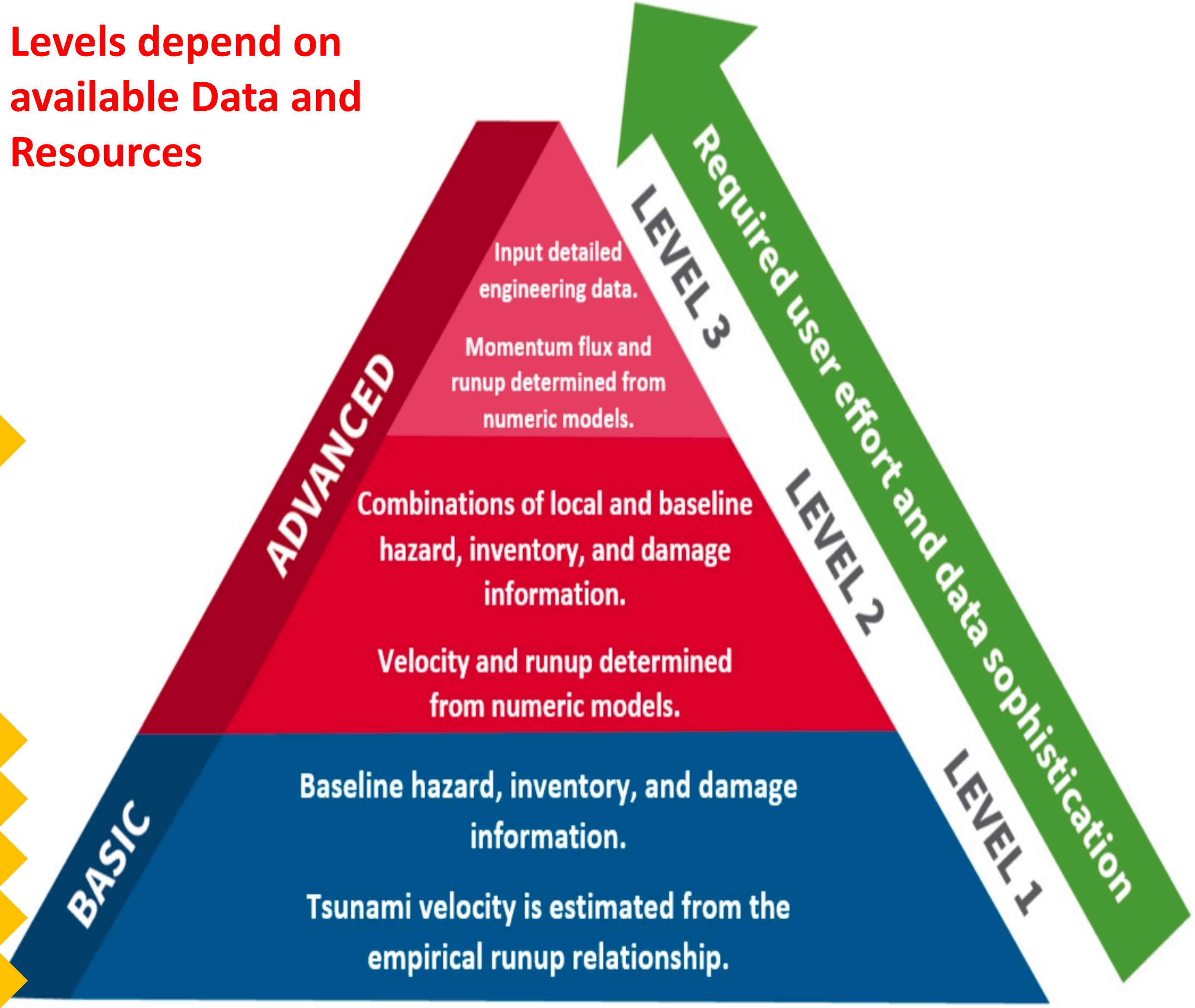


Kriebel et al., 2017
Tada et al., 2018

Level of the analysis for different methods

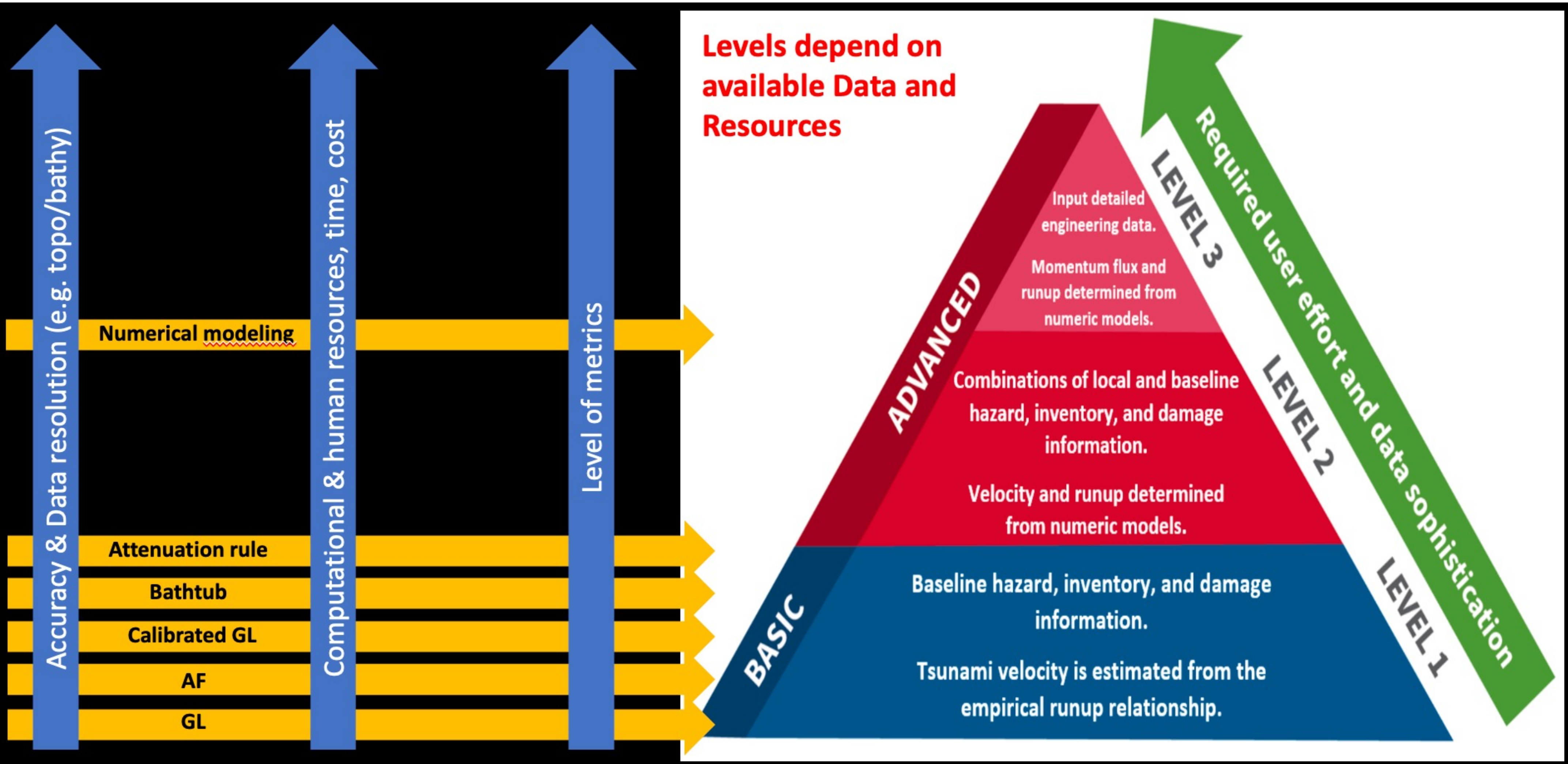


Levels depend on available Data and Resources



https://www.fema.gov/flood-maps/products-tools/hazus

Level of the analysis for different methods



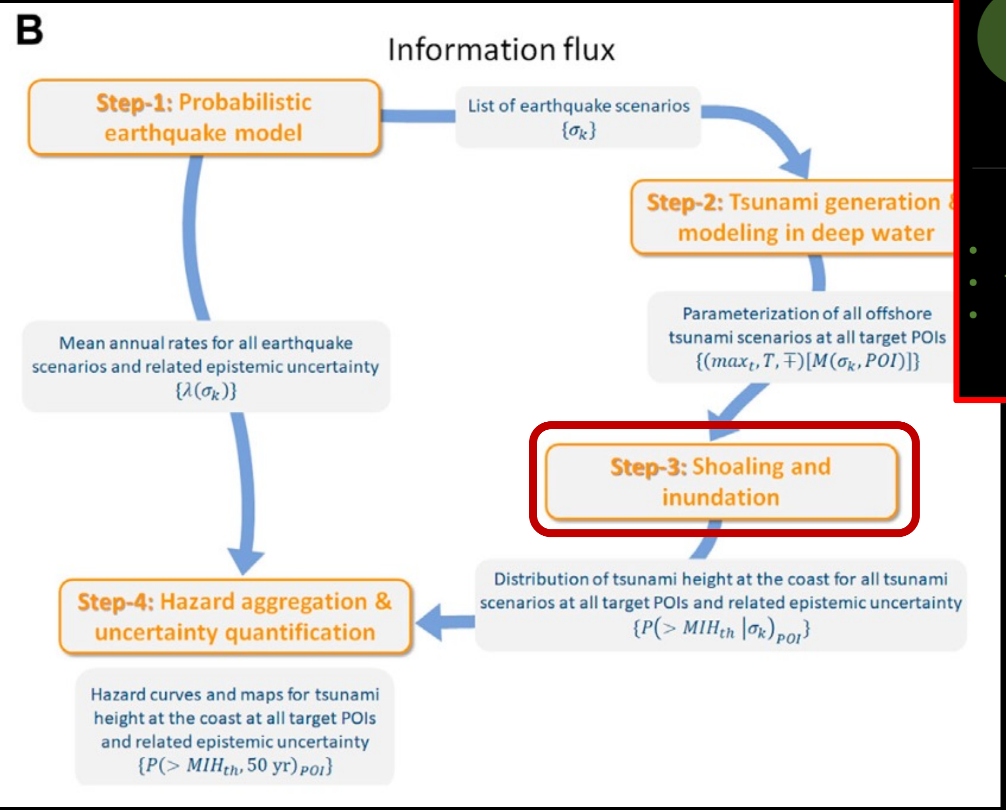
Beyond the ”Pyramid of Levels”

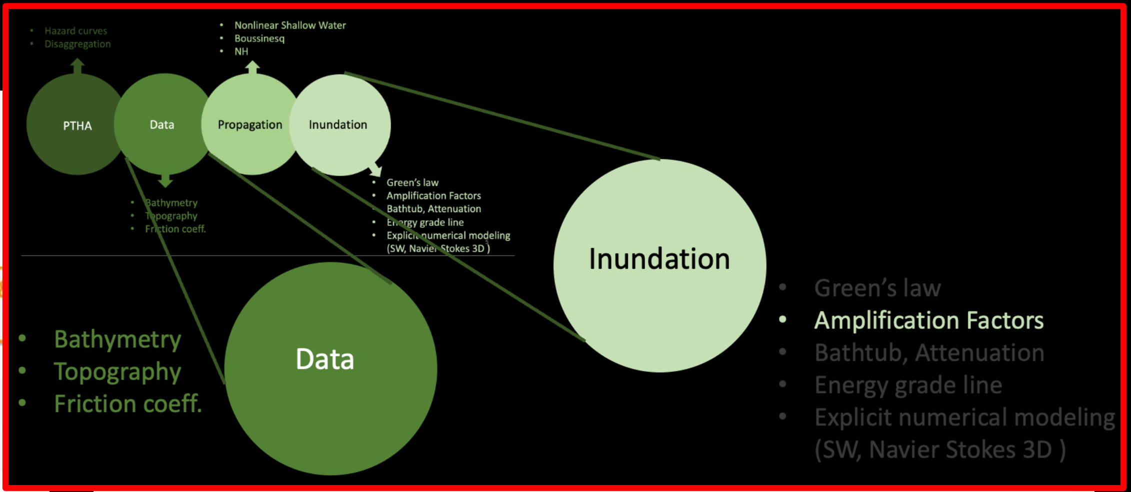
- Considering the uncertainties in the modelling
    - e.g. by adding a log-normal distribution calibrated w/ data or accurate simulations (Davies et al., 2018; NEAMTHM18)

The Italian evacuation and long-term coastal planning

Probabilistic Tsunami Hazard Analysis (PTHA)

The NEAMTHM18 Workflow





Output
- Coastal Tsunami height
- Epistemic Uncertainty

All the details of the methodology in:
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Basili et al., 2021

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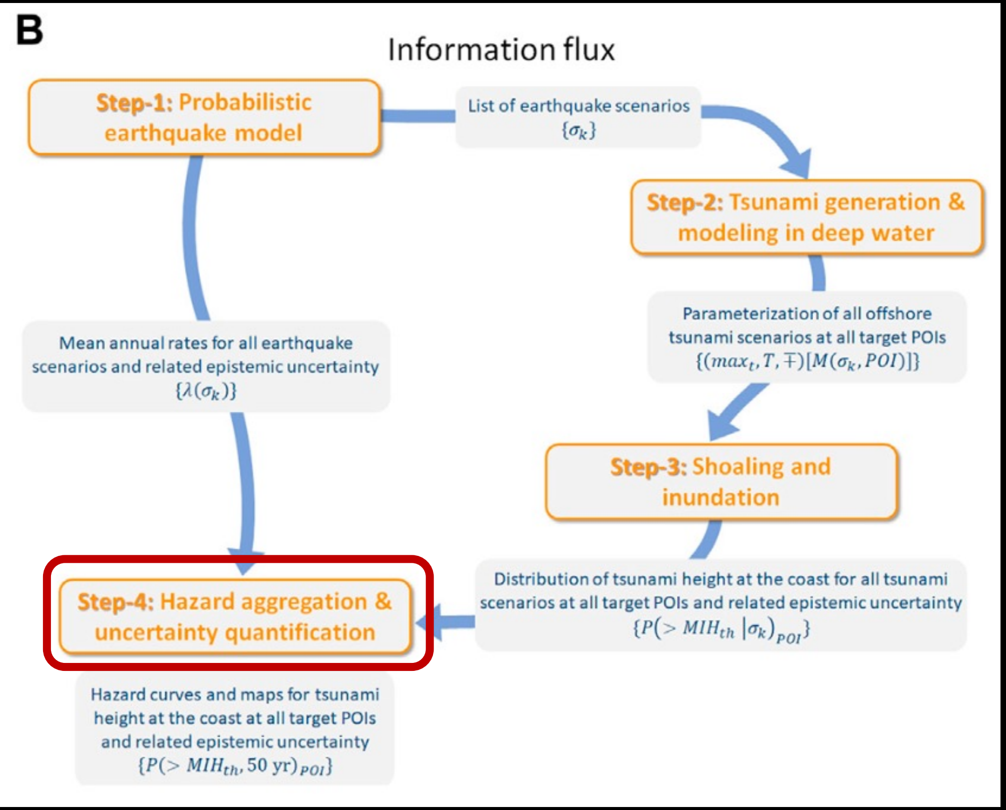

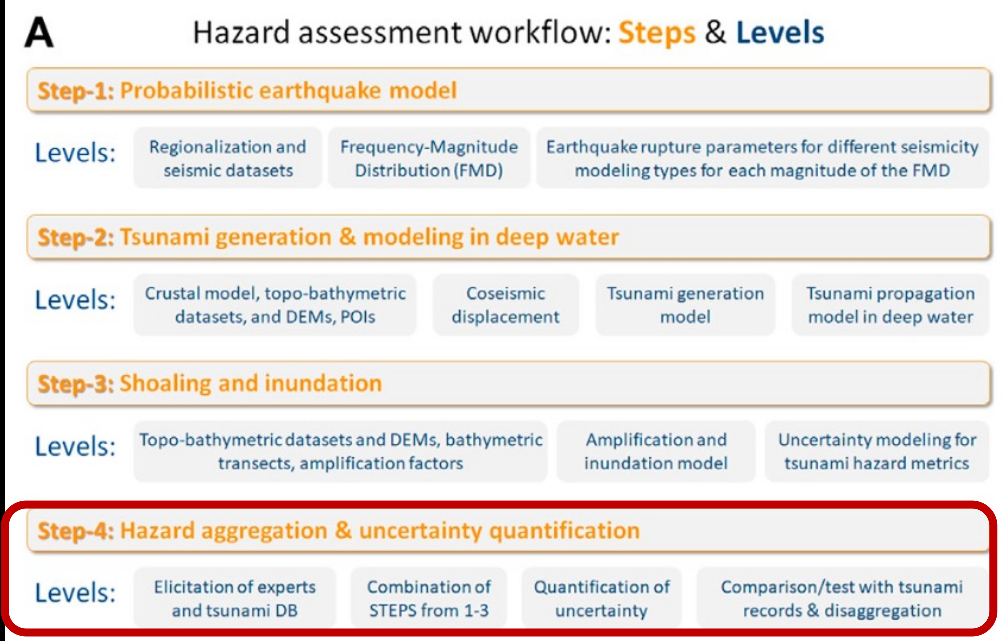

Output
- Hazard curves
- Epistemic Uncertainty

All the details of the methodology in:
NEAMTHM18 documentation, http://doi.org/10.5281/zenodo.3406625

Basili et al., 2021

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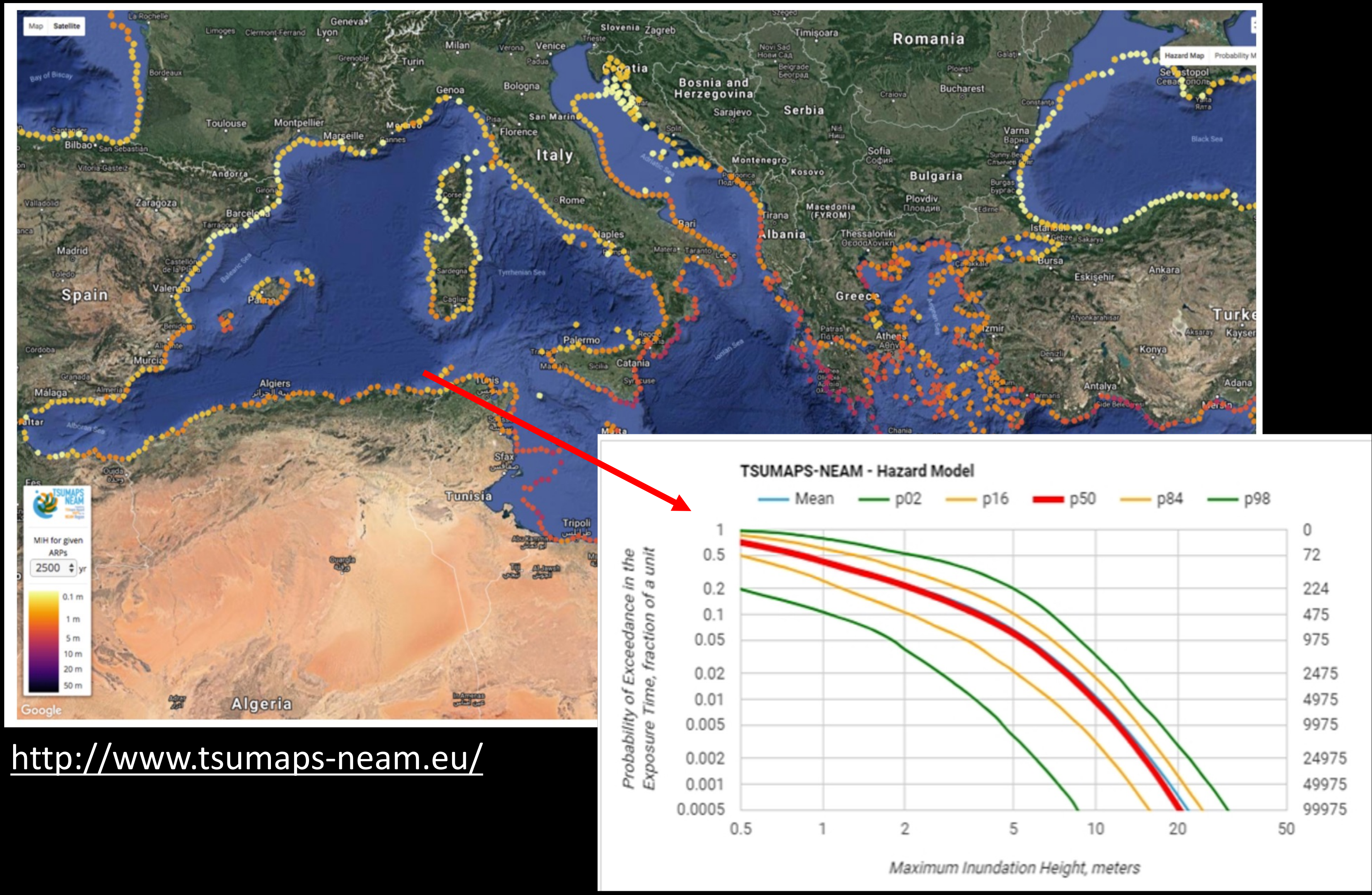
Probabilistic Tsunami Hazard Analysis (PTHA)

The Hazard Curves

The model uncertainty in each POI is estimated by means of a variety of hazard curves, one for each **alternative model** obtained by adopting different assumptions, data, parameters, modelling. The distribution of these curves opportunely weighted describes the epistemic uncertainty associated to the hazard model



http://www.tsumaps-neam.eu/

The Italian evacuation and long-term coastal planning

From Regional to Local scale

Alert Levels

Advisory: runup up to 1m

Watch: runup exceeding 1m

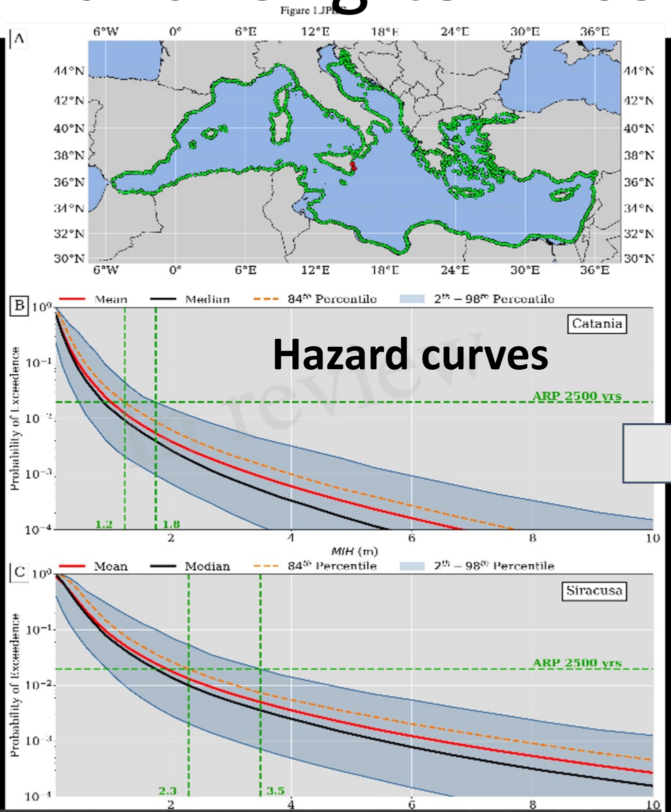
DirPC SiAM; DPC, 2018

Regional Hazard (NEAMTHM18)

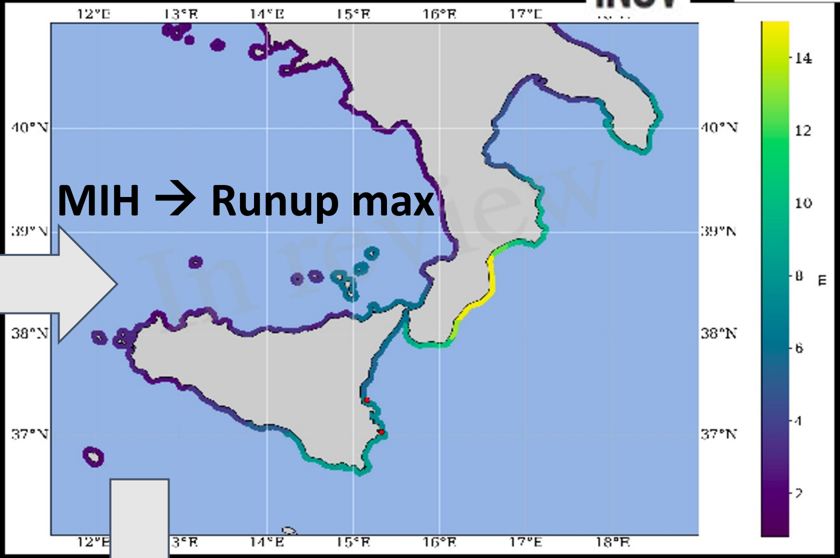
2500 yr ARP + 84th percentile

Safety factors

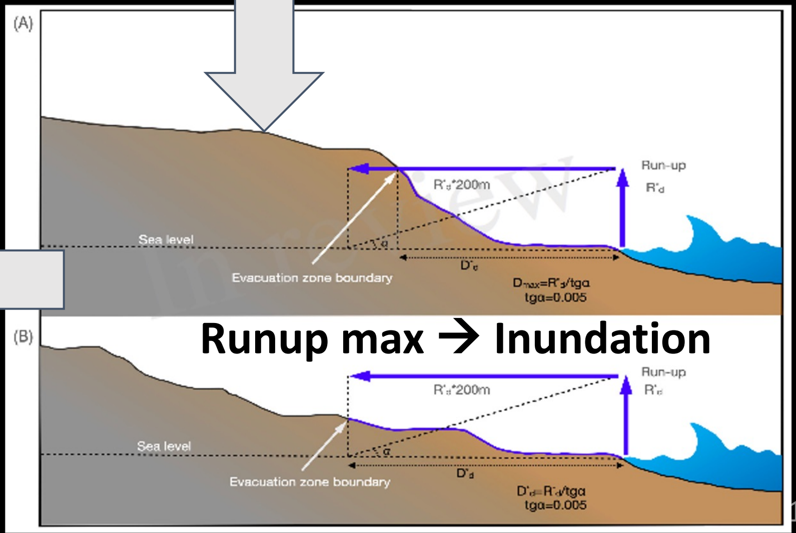
Coastal dissipation



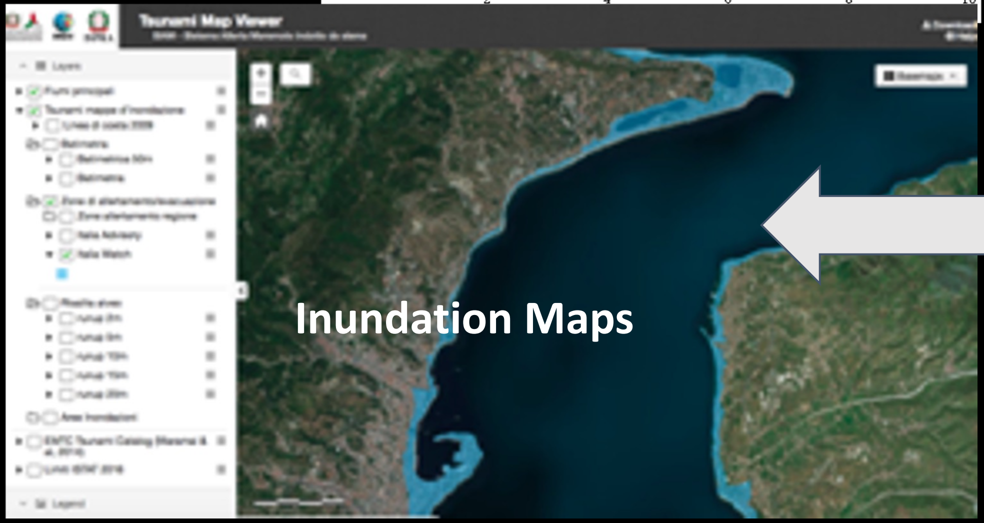
Hazard curves



MIH → Runup max



Runup max → Inundation



Inundation Maps

The Italian evacuation and long-term coastal planning

From Regional to Local scale

Alert Levels
Advisory: runup up to 1m
Watch: runup exceeding 1m

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Depth	M	Epicenter Location	Tsunami Potential	ALERT LEVEL *VS* DISTANCE		
				Δeq ≤ 100 km	100 km < Δeq ≤ 400 km	Δeq > 400 km
< 100 km	5.5 ≤ M ≤ 6.0	Offshore or Inland ≤ 100 km	Nil	Information Bulletin		
	6.0 < M ≤ 6.5	Inland (40 km < Inland ≤ 100 km)	Nil	Information Bulletin		
		Offshore or near the coast (Inland ≤ 40 km)	Potential of weak local tsunami Δeq < 100 km	LOCAL Tsunami ADVISORY	Information	
	6.5 < M ≤ 7.0	Offshore or Inland ≤ 100 km	Potential of destructive local tsunami Δeq < 100 km $\mid$ 400 km	LOCAL Tsunami WATCH	REGIONAL Tsunami ADVISORY	Information
	7.0 < M ≤ 7.5		Potential of destructive regional tsunami Δeq < 400 km $\mid$ basin	REGIONAL Tsunami WATCH		BASIN-WIDE Tsunami ADVISORY
	M > 7.5		Potential of destructive tsunami in the whole basin any Δeq	BASIN-WIDE Tsunami WATCH		
≥100 km	*M ≥5.5*	*Offshore or Inland ≤100 km*	*Nil*	*Information Bulletin*		
any	*any*	*Inland > 100 km*	*Nil*	*Nil*		
				LOCAL	REGIONAL	BASIN-WIDE

Decision Matrix (for M>=5.5):

From earthquake parameters - Magnitude - hypocentral location
to
Alert levels - Watch (land threat), Advisory (coastal and marine threat)

GAPS

- Implicit, simplistic and worst-case oriented uncertainty consideration (prone to false alarms)
- Neglects source and bathymetry tsunami directivity effects (missed alarms are still possible!)
- Mixes tsunami forecasting with tsunami warning (not a transparent balance and confusion of roles)

The Italian evacuation and long-term coastal planning

From Regional to Local scale

Alert Levels
Advisory: runup up to 1m
Watch: runup exceeding 1m

DirPC SiAM; DPC, 2018

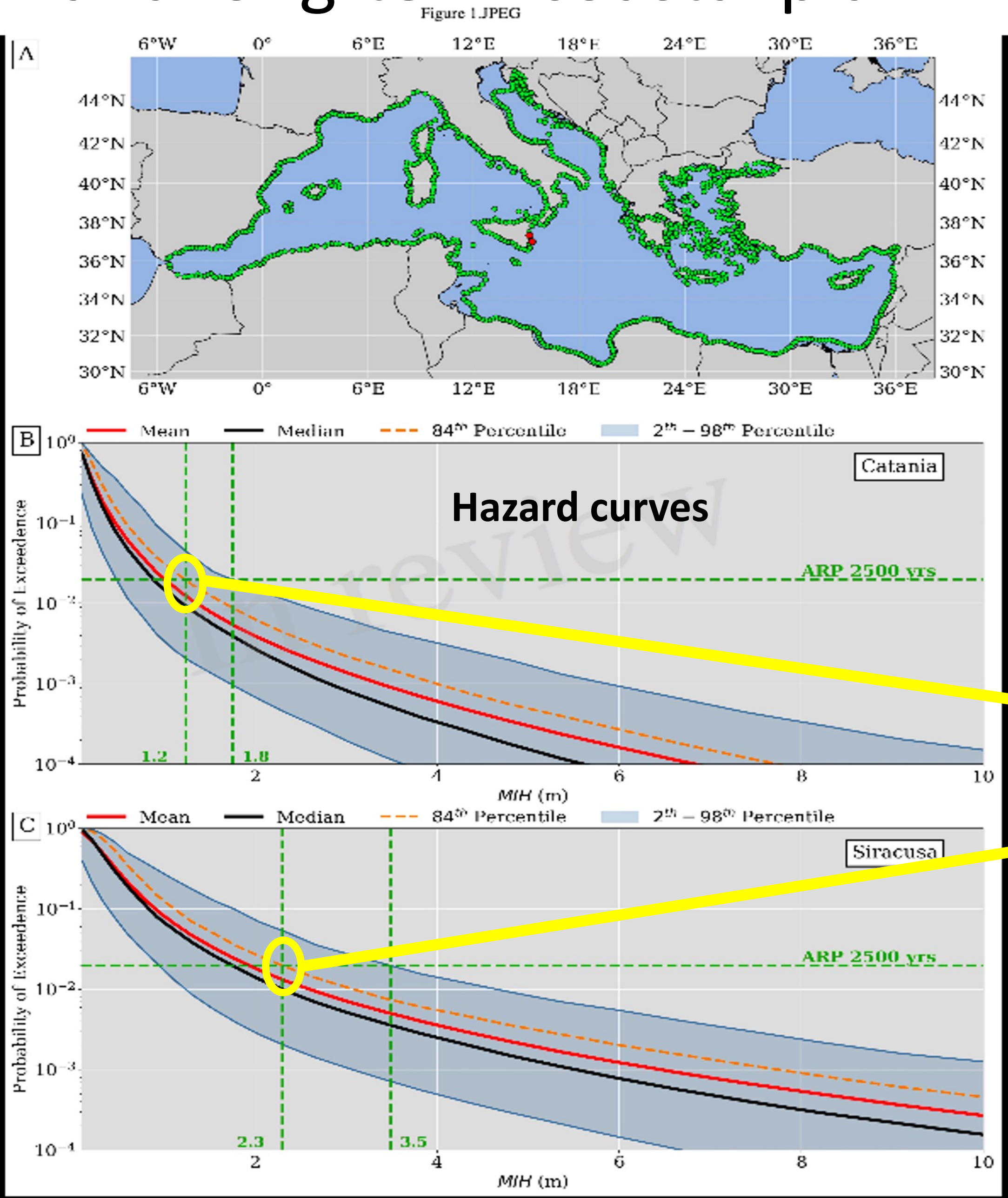
Regional Hazard (NEAMTHM18)

2500 yr ARP + 84th percentile

Safety factors

Coastal dissipation

~2% in 50 yr (design probability)



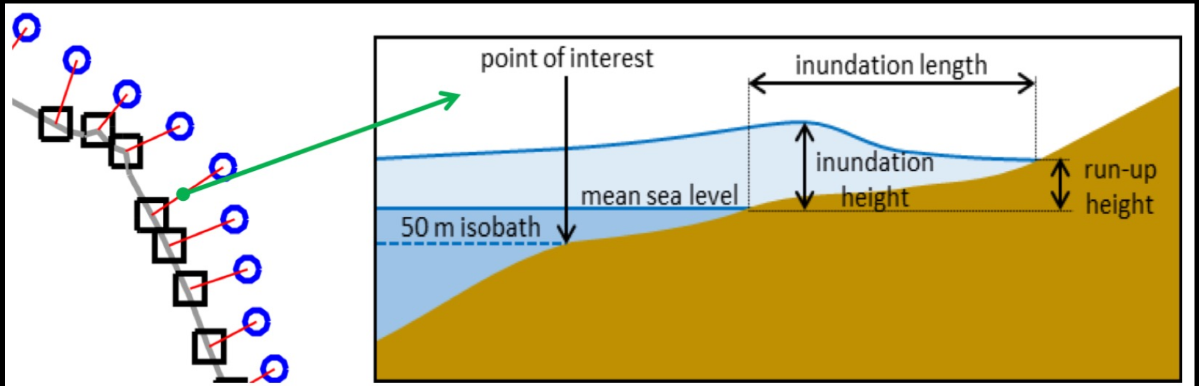
MIH values at POIs

For inundation we need to switch **from MIH at POIs to Max Runup for stretch of coast**

The Italian evacuation and long-term coastal planning

From Regional to Local scale

From MIH at POIs to Max Runup for stretch of coast



Alert Levels

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DirPC SiAM; DPC, 2018

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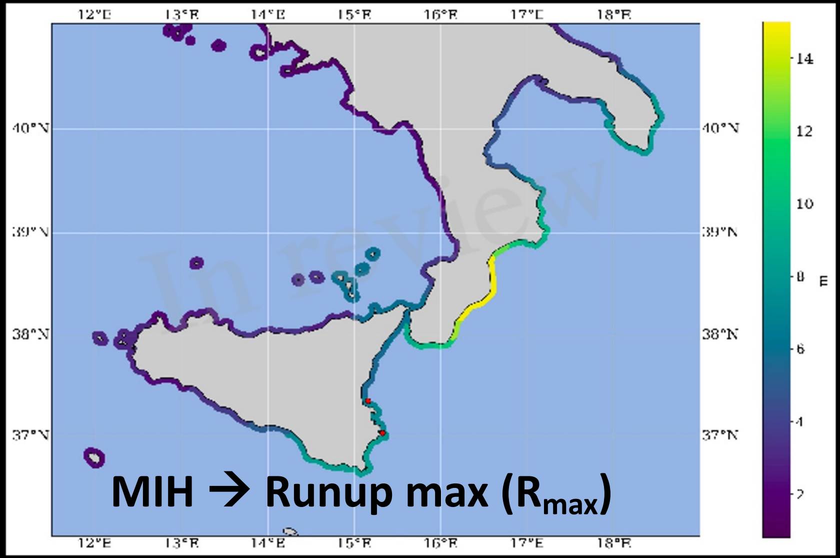
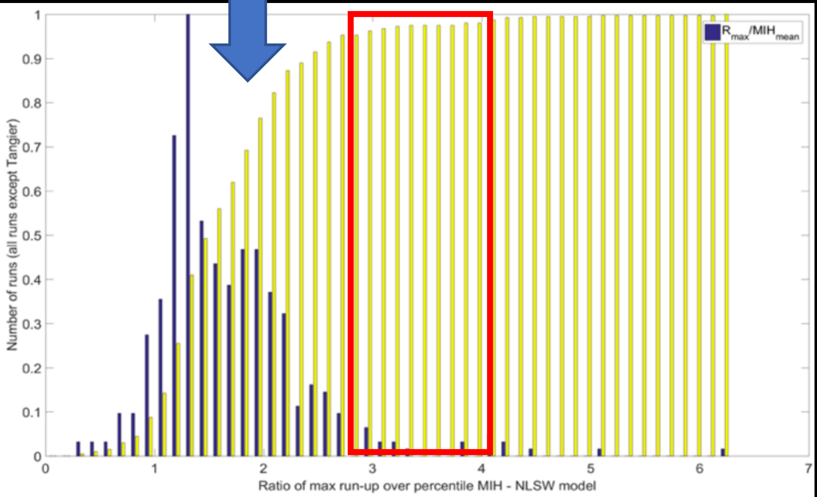


To account the tsunami variability along the coast, R_{max} on the coast is the maximum value within 40 km

MIH is a mean value in the inland area corresponding to a specific POI → **none 2D perspective**

Comparison w/ 2D inundation modeling



MIH can be 3-4x larger!!!

R_{max}=MIH*3

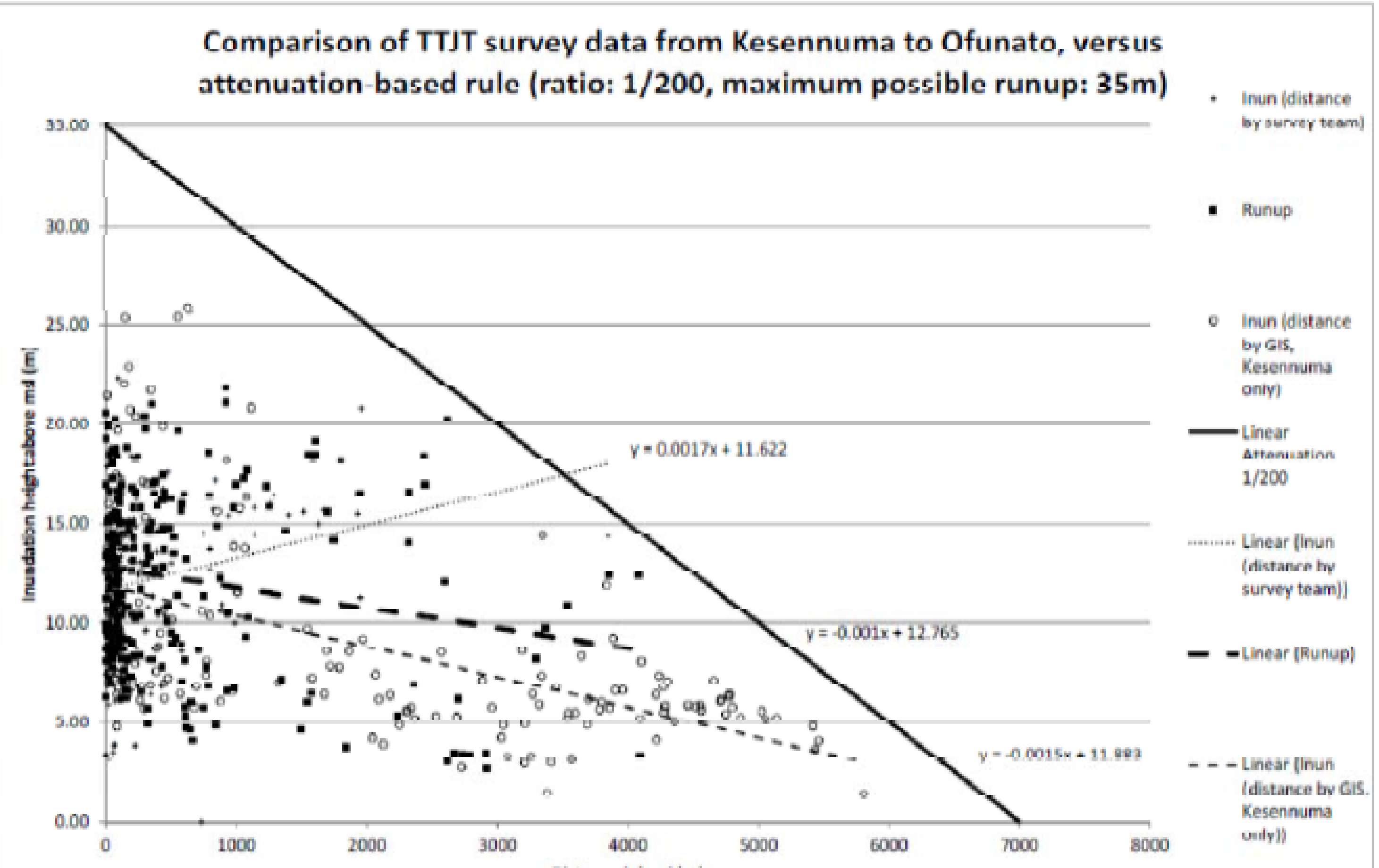
3 is the safety factor

SiAM evacuation zones

Summary of the presentation

- ❑ Methodology: GIS approach and empirical rule application
- ❑ Input data and processing
- ❑ Results: inundation maps/alert zones
- ❑ Tsunami Map Viewer: availability and accessibility of inundation maps
- ❑ Future goals - improving the maps and the methodology

Methodology: empirical approach for inundation maps



Fraser & Power, 2013

We adopted a GIS- based approach following an empirical model of propagation and inundation.

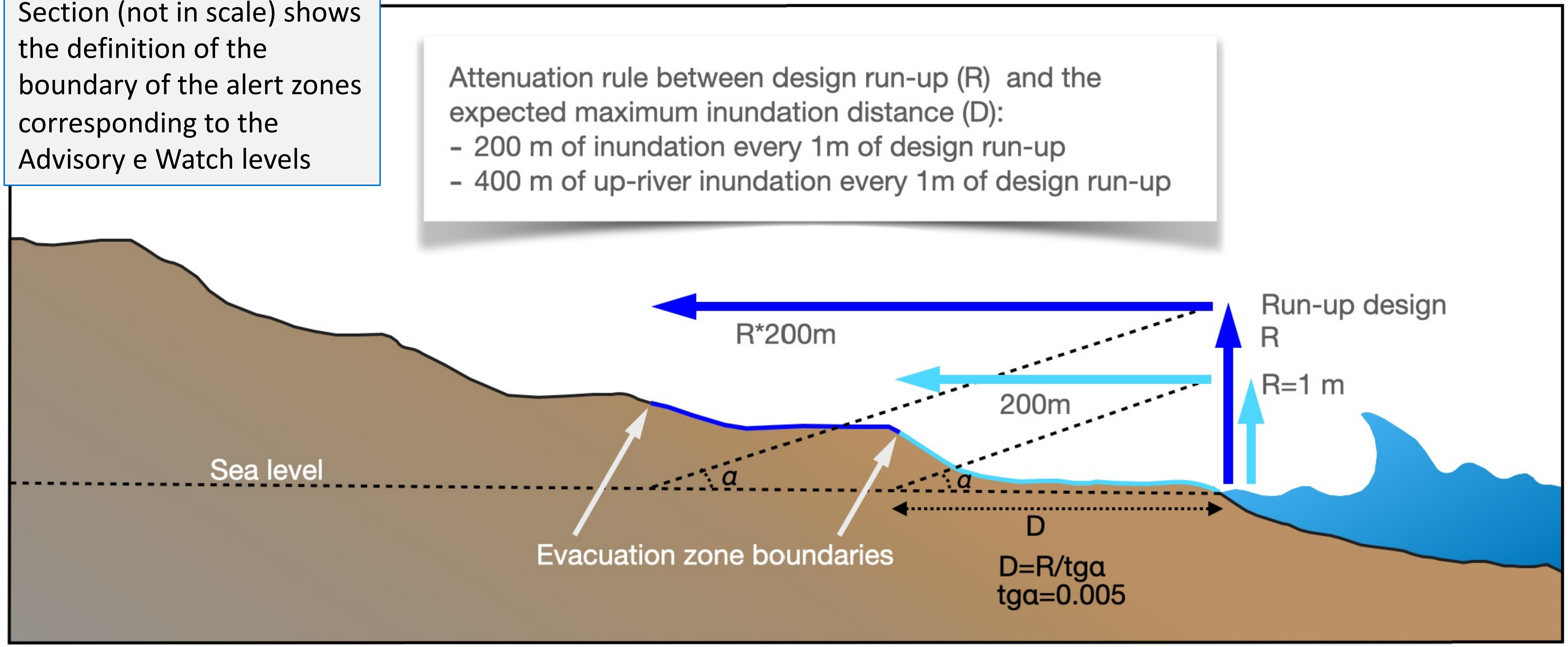
Following Fraser & Power (2013), a linear attenuation rule between the R (run-up) values and D (maximum expected inland inundation distance) is applied.

The empirical relationship between run-up and inland wave penetration is based on the filed surveys and observations following recent and historic tsunami events, especially in the Pacific area, in particular that of Tohoku (Japan) in 2011.

Calculation of dry/wet pixels by GIS tools

Empirical relationship between run-up and inundation distance

Section (not in scale) shows the definition of the boundary of the alert zones corresponding to the Advisory e Watch levels



$D=R*f$

$f=1/tg\alpha$

$D=R*200$

$tg\alpha=0.005$

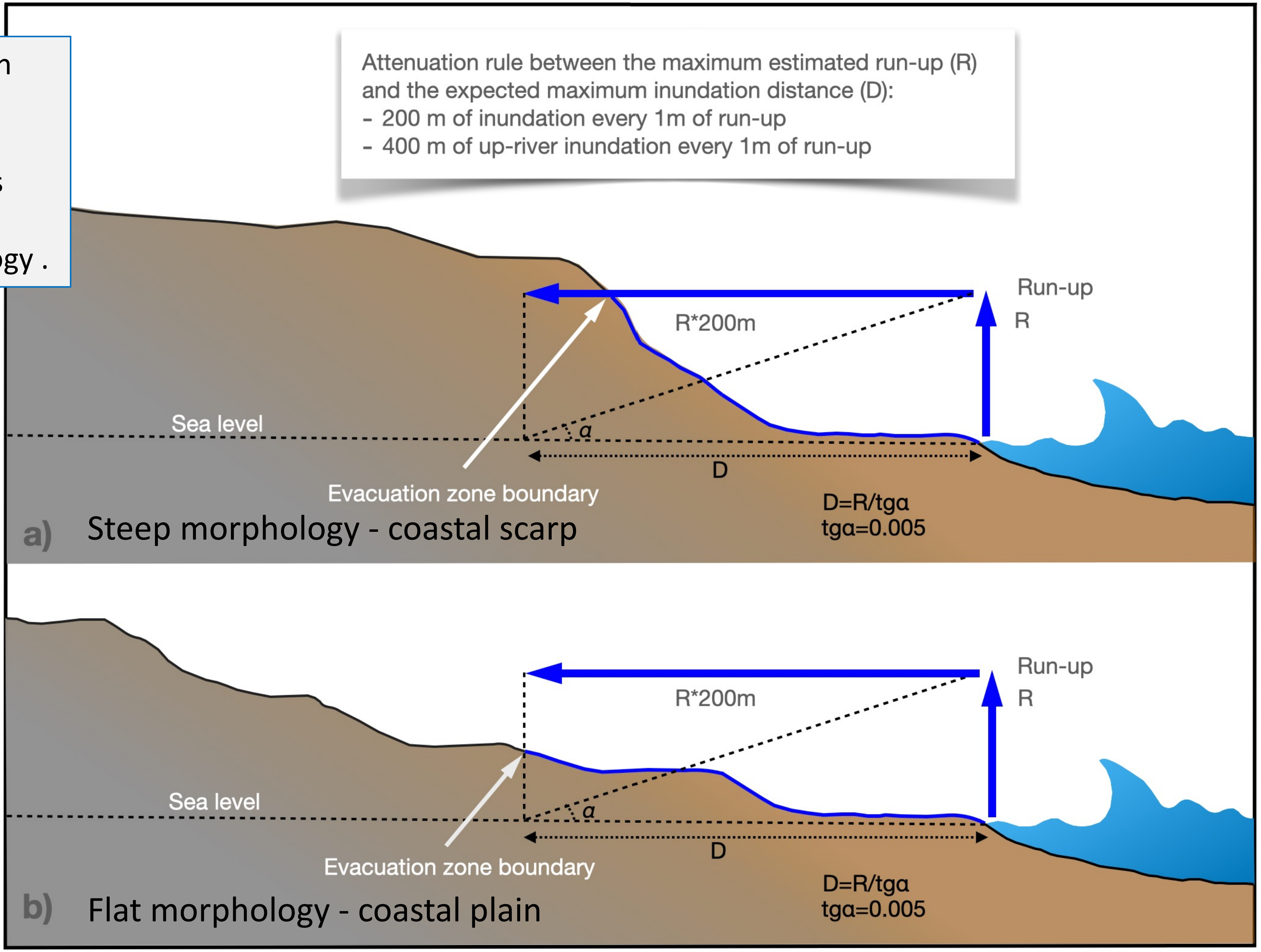
$f=1/tg\alpha=200$

R is the calculated design run-up for each coastal sector

D is the maximum expected inundation distance - D(R)

Evacuation zones boundary and coastal morphology

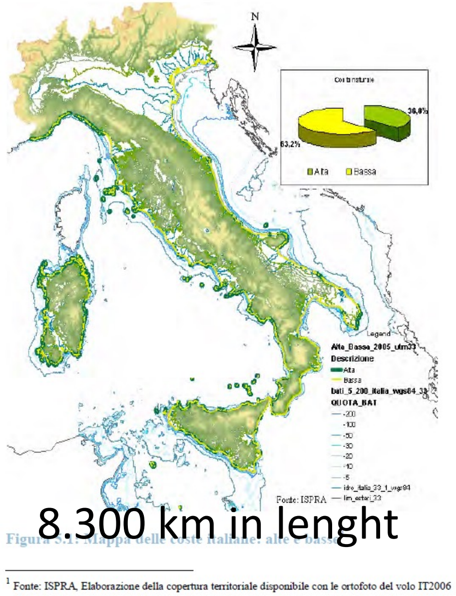
This sketch (not in scale) shows the method used to draw inundations maps in different coastal morphology .



Input data: collected elevation and morphological dataset

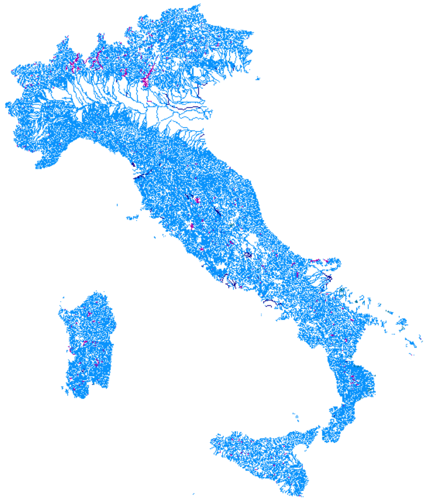
DEM tinitaly

DEM IGM 20m

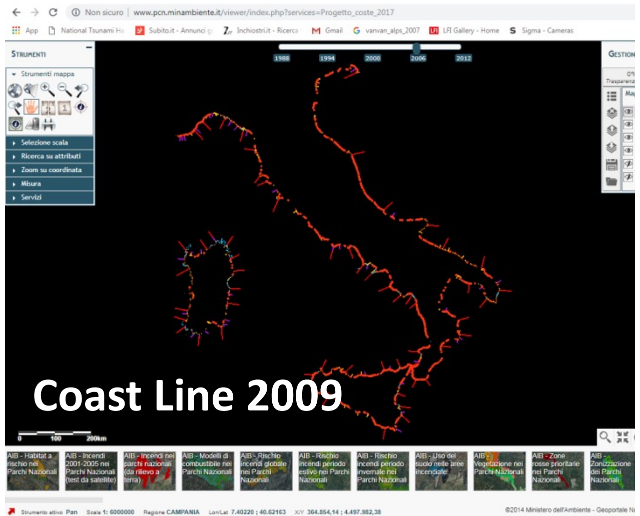


8.300 km in lenght

Coast Line 2006



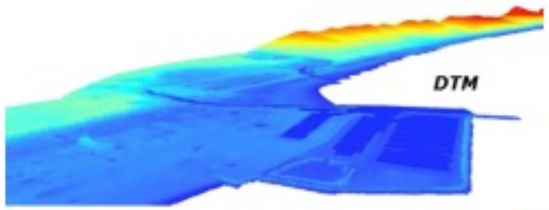
River network
ISPRA – 250k (updated at 10.000 scale)



Coast Line 2009

Regional DTMs 1-2-5 metres resolution

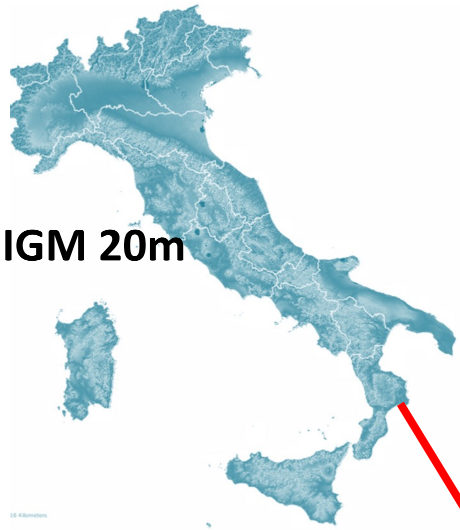
High resolution LIDAR data



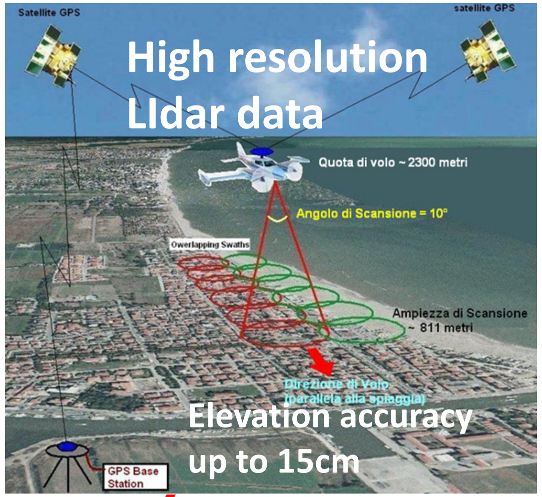
Elevation accuracy up to 15cm

Input data: mosaicking and the harmonization

DEM tinitaly

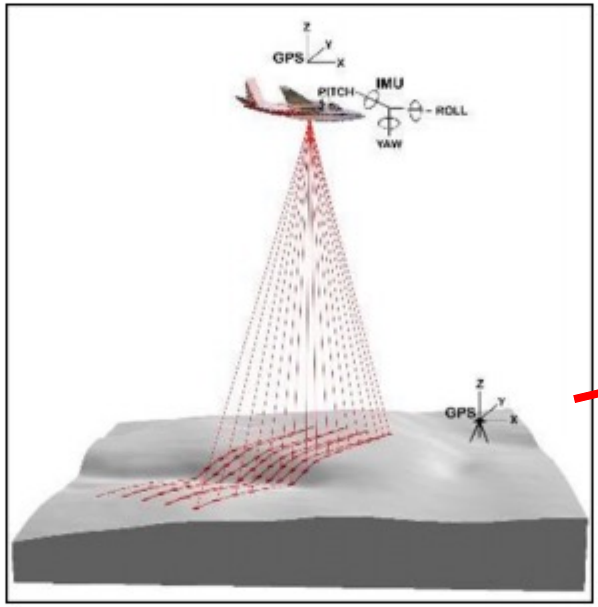


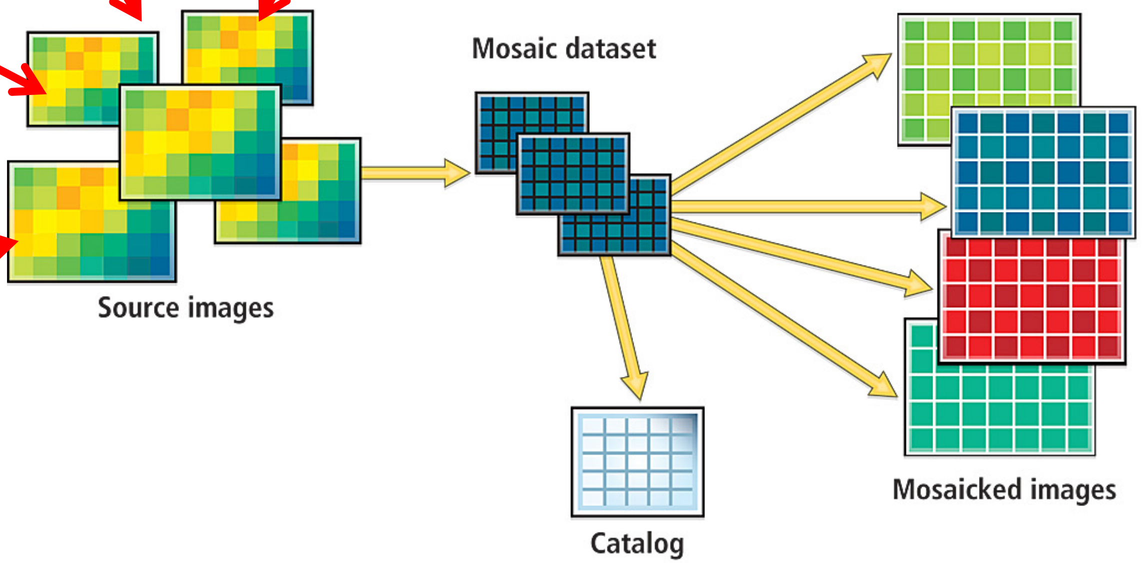
DEM IGM 20m



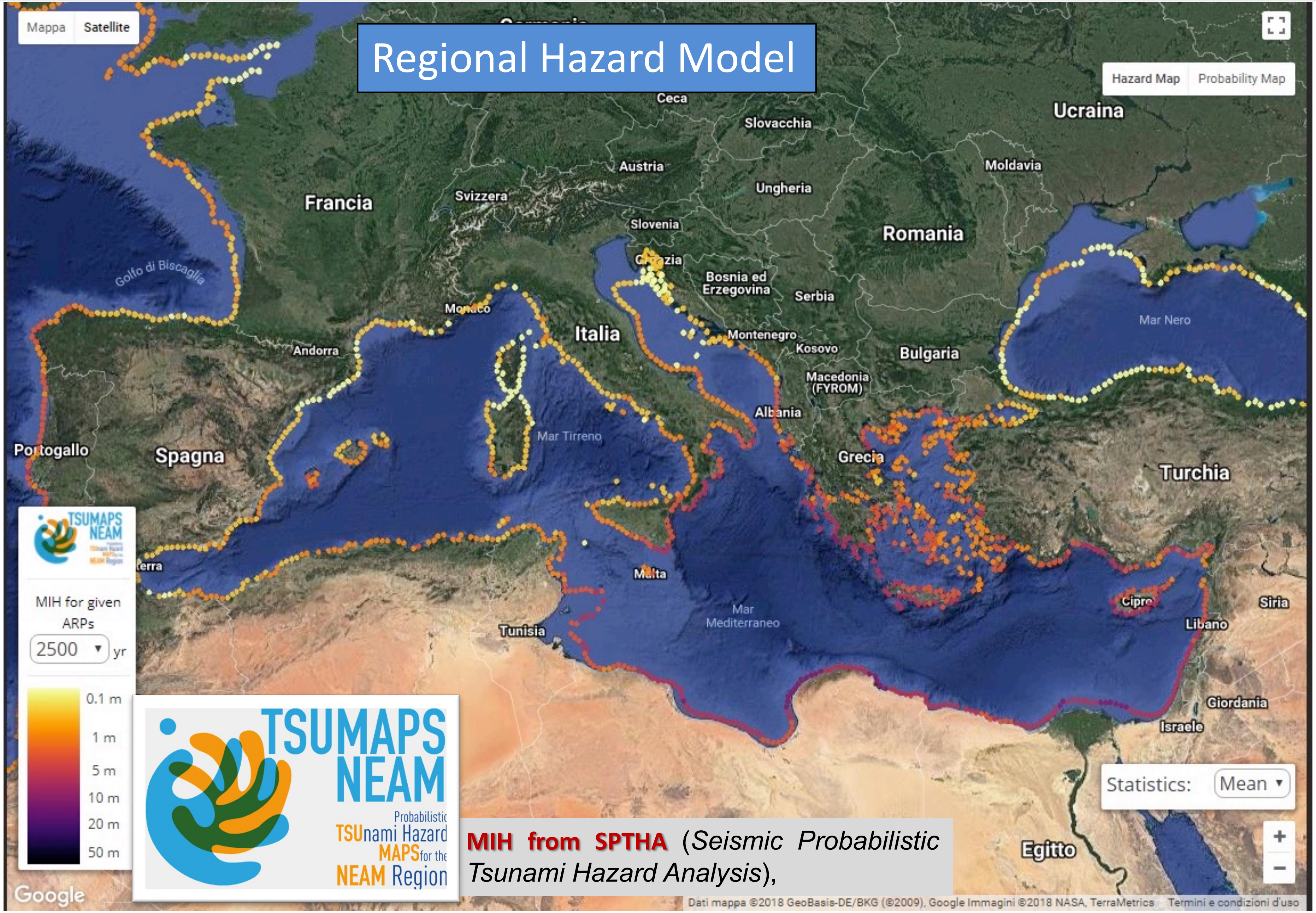
New mosaicked homogeneous raster covering the whole potential inundation area

DTM 1-2-5-10 metres res.



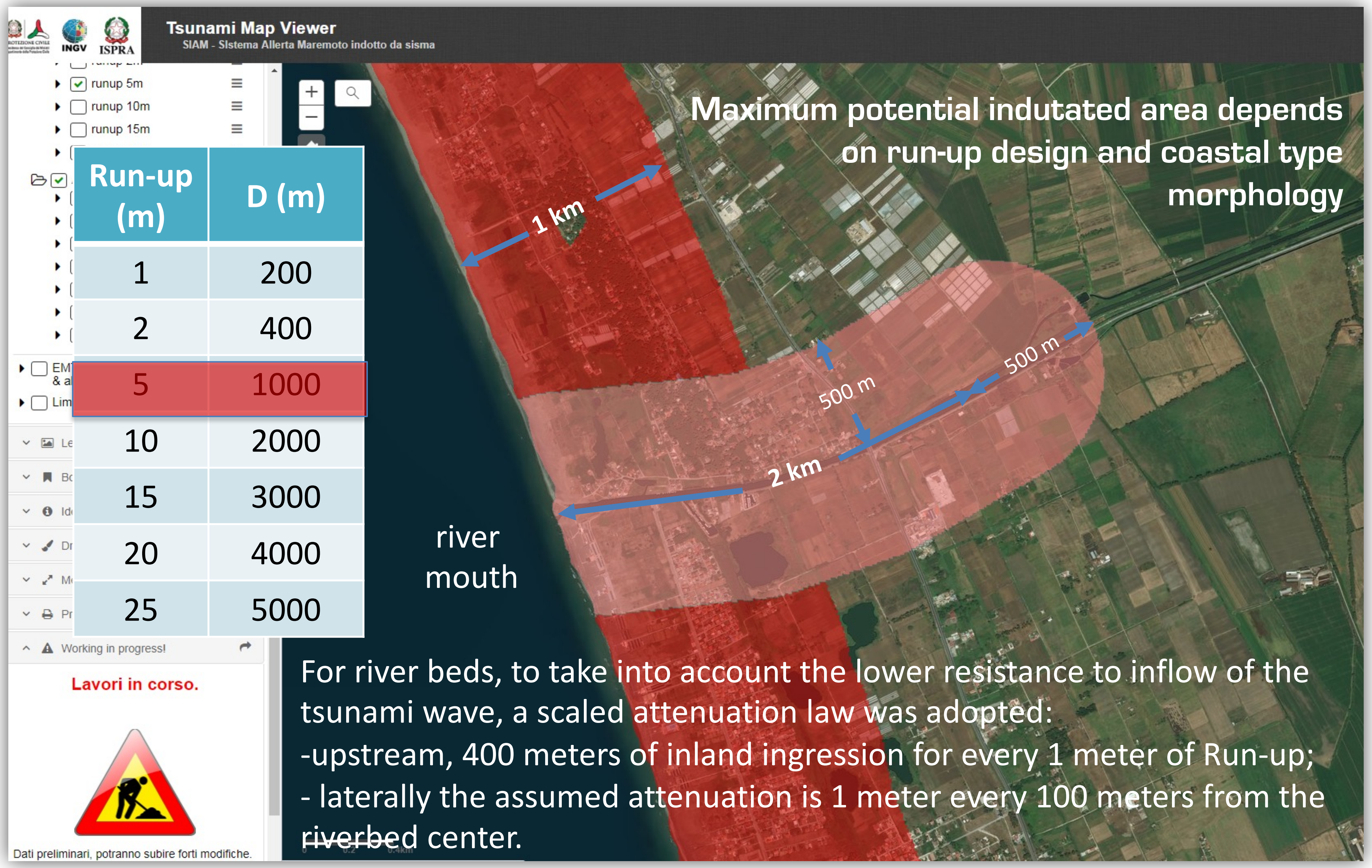


Input data: run-up values



MIH from SPTHA (*Seismic Probabilistic Tsunami Hazard Analysis*),

The Project provides MIH values for POIs. MIH values have been converted in run-up values for every coastal sector and used for the definition of the evacuation zones



Run-up (m)	D (m)
1	200
2	400
5	1000
10	2000
15	3000
20	4000
25	5000

For river beds, to take into account the lower resistance to inflow of the tsunami wave, a scaled attenuation law was adopted:
-upstream, 400 meters of inland ingression for every 1 meter of Run-up;
- laterally the assumed attenuation is 1 meter every 100 meters from the riverbed center.

The empirical rule application is based on GIS tools

Calculation of dry/wet pixels by GIS tools

Run-up (m)	D (m)
1	200
2	400
5	1000
10	2000
15	3000
20	4000
25	5000

px → q<=R

px → D<= 200*R
px → D<=400*R
In case of river stream

Raster calculation of dry/wet pixels by GIS tools based on the application of the D=Rf empirical rule

Both the conditions are satisfied for the point p1 only

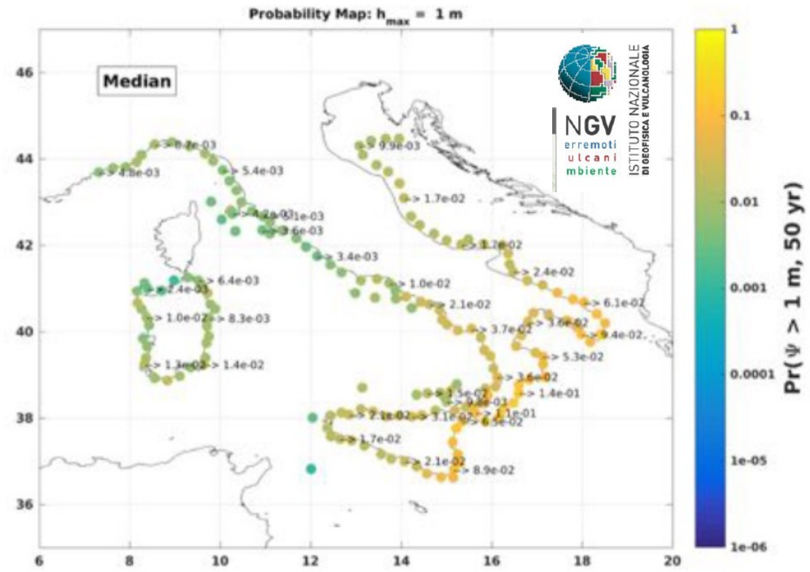
The blue line is the inundation boundary

Wet pixels necessary conditions:
1) The position of a generic point x is inside the maximum potential inundation area;
2) The elevation of a generic point x is less than or equals to the R value

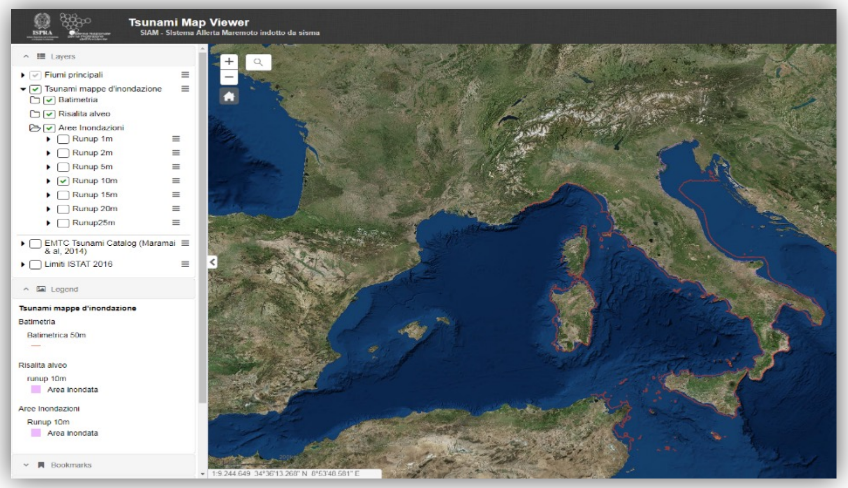
Combining the run-up values and the related inundation maps we elaborated the alert/evacuation zones for the Italian coastal regions

Definition of alert/evacuation zones
based on

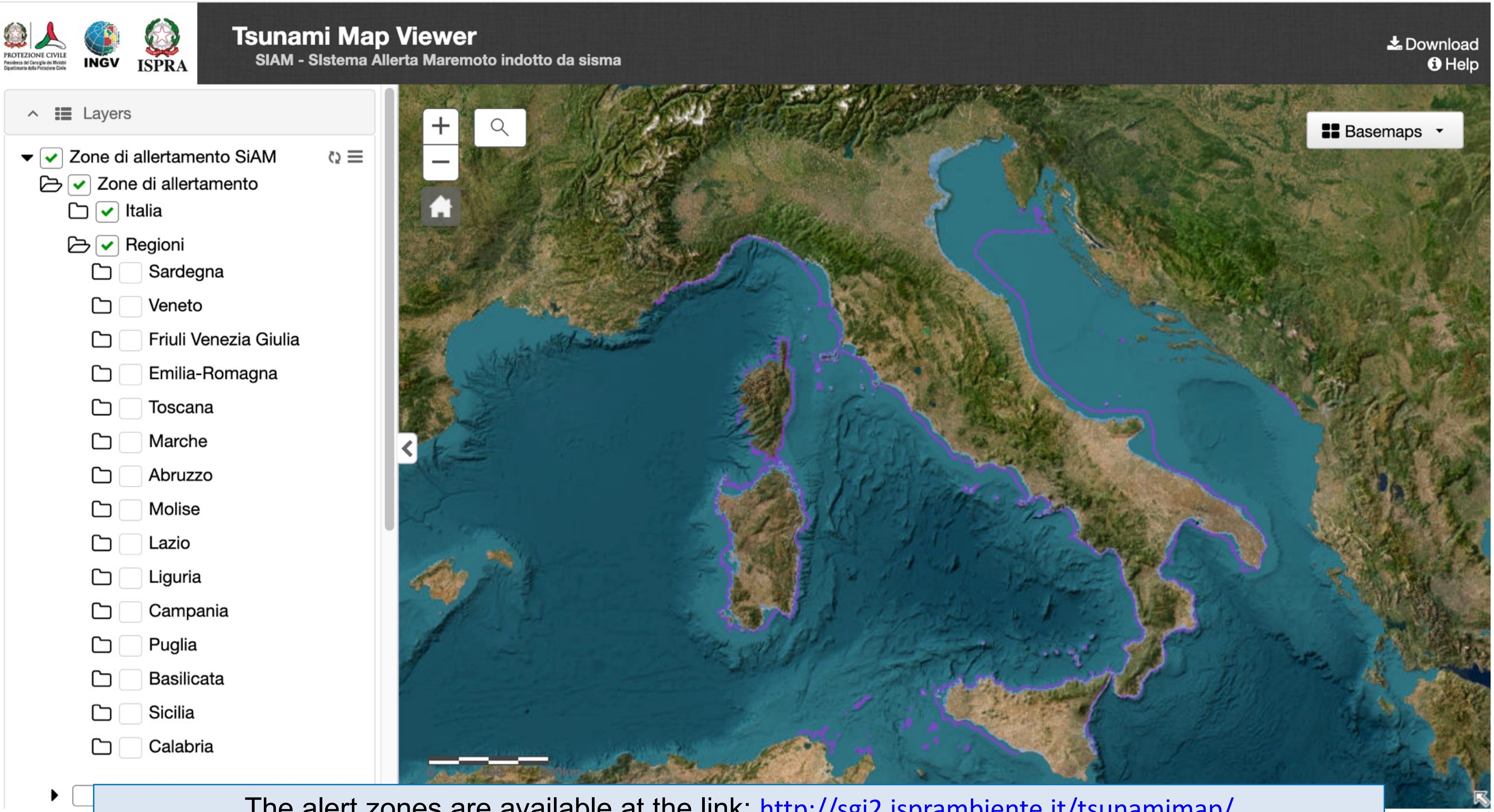
Tsunami hazard model- INGV



Inundations maps - ISPRA

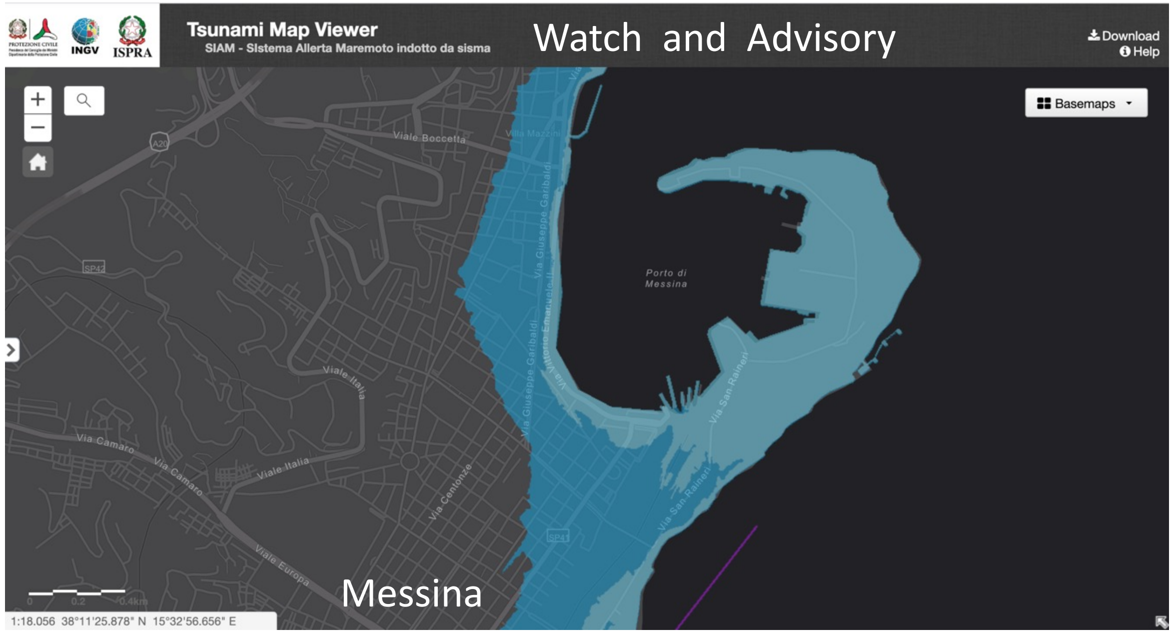


Tsunami Map Viewer – evacuation maps accessibility



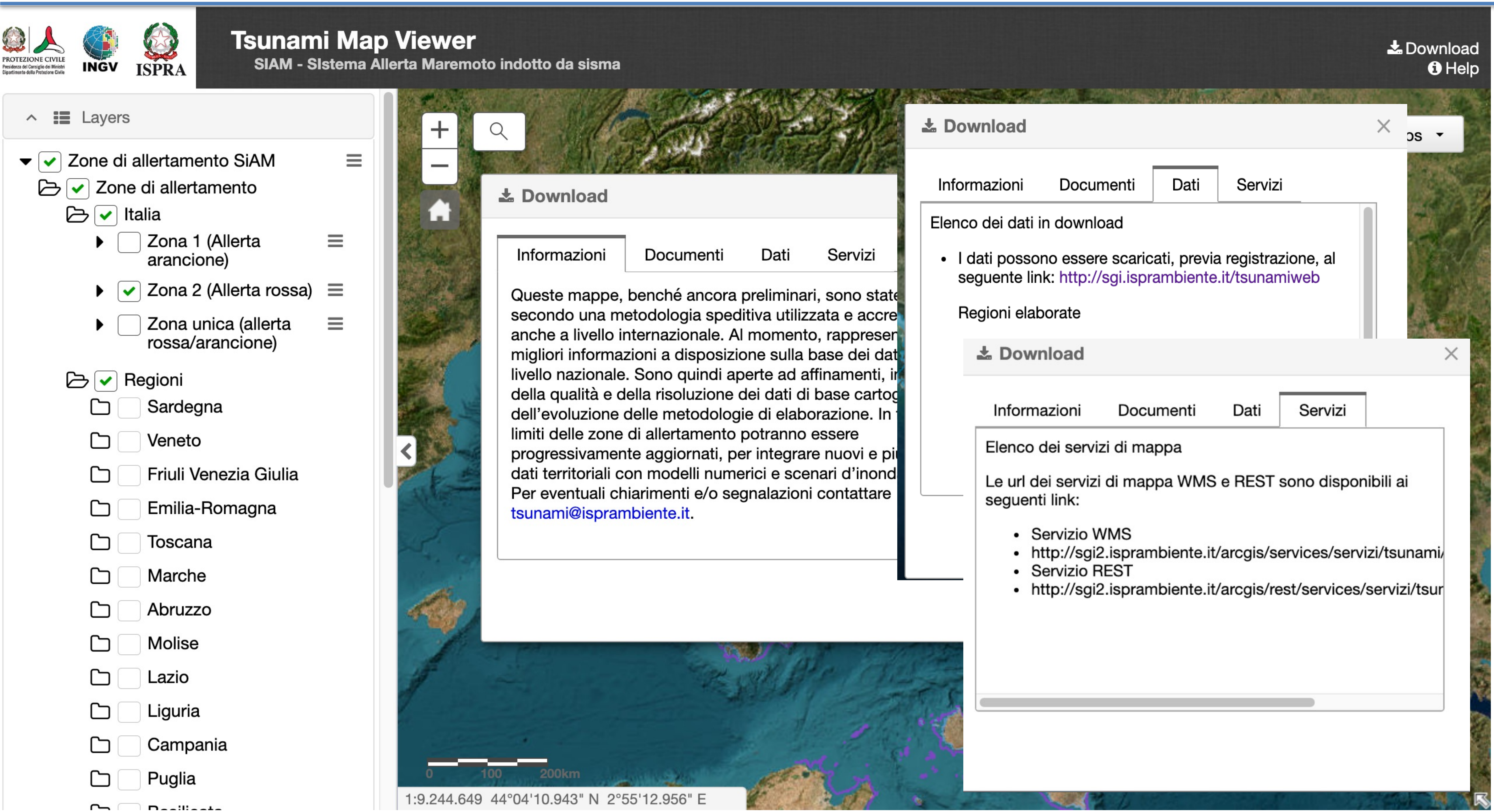
The alert zones are available at the link: http://sgi2.isprambiente.it/tsunamimap/

Tsunami Map Viewer – alert zones of SiAM



Tsunami Map Viewer – SiAM alert zones

Tsunami Map Viewer – information, web services and download



Tsunami Map Viewer – download

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SISTEMA NAZIONALE DI ALLERTA MAREMOTI (S.i.A.M.)

L'ISPRA fa parte del Sistema nazionale di Allerta per i Maremoti indotti da sisma (SiAM), istituito con la Direttiva del Presidente del Consiglio dei Ministri del 17 febbraio 2017, pubblicata nella Gazzetta Ufficiale n. 128 del 5 giugno 2017. Il SiAM è promosso e coordinato dal Dipartimento della Protezione Civile (DPC) e coinvolge anche l'Istituto di Geofisica e Vulcanologia (INGV). L'ISPRA ha il compito di fornire in tempo reale i dati di livello marino rilevati dalla rete mareografica nazionale al Centro per l'Allerta Tsunami (CAT) dell'INGV, che verifica la possibilità che un determinato evento sismico con epicentro nel mare, o in prossimità di aree costiere, possa generare un maremoto, stimando i tempi di arrivo delle onde e i tratti costieri potenzialmente interessati. L'INGV si avvale della collaborazione dell'ISPRA per la conferma di un possibile maremoto e provvede ad informare rapidamente il DPC che detiene la responsabilità di lanciare l'allerta su tutto il territorio nazionale, mobilitando tutte le componenti del sistema di protezione civile e i suoi

Tsunami Map Viewer – download

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Sistema Nazionale per la Protezione dell'Ambiente

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Via Vitaliano Brancati 48-60	http://portalesgi.isprambiente.it	portalesgi@isprambiente.it	

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Queste mappe, benché ancora preliminari, sono state realizzate secondo una metodologia speditiva utilizzata e accreditata anche a livello internazionale. Al momento, rappresentano le migliori informazioni a disposizione sulla base dei dati fruibili a livello nazionale. Sono quindi aperte ad affinamenti, in funzione della qualità e della risoluzione dei dati di base cartografici e dell'evoluzione delle metodologie di elaborazione. In futuro, i limiti delle zone di allertamento potranno essere progressivamente aggiornati, per integrare nuovi e più definiti dati territoriali con modelli numerici e scenari d'inondazione. Per eventuali chiarimenti e/o segnalazioni contattare tsunami@isprambiente.it.

Aree elaborate:

	ZONA 1	ZONA 2	ZONA UNICA
SICILIA	advisory	watch	unica
CALABRIA	advisory	watch	unica
BASILICATA	advisory	watch	unica
PUGLIA	advisory	watch	unica
CAMPANIA	advisory	watch	unica
LIGURIA	advisory	watch	unica
LAZIO	advisory	watch	unica
MOLISE	advisory	watch	unica
ABRUZZO	advisory	watch	unica
MARCHE	advisory	watch	unica
TOSCANA	advisory	watch	unica

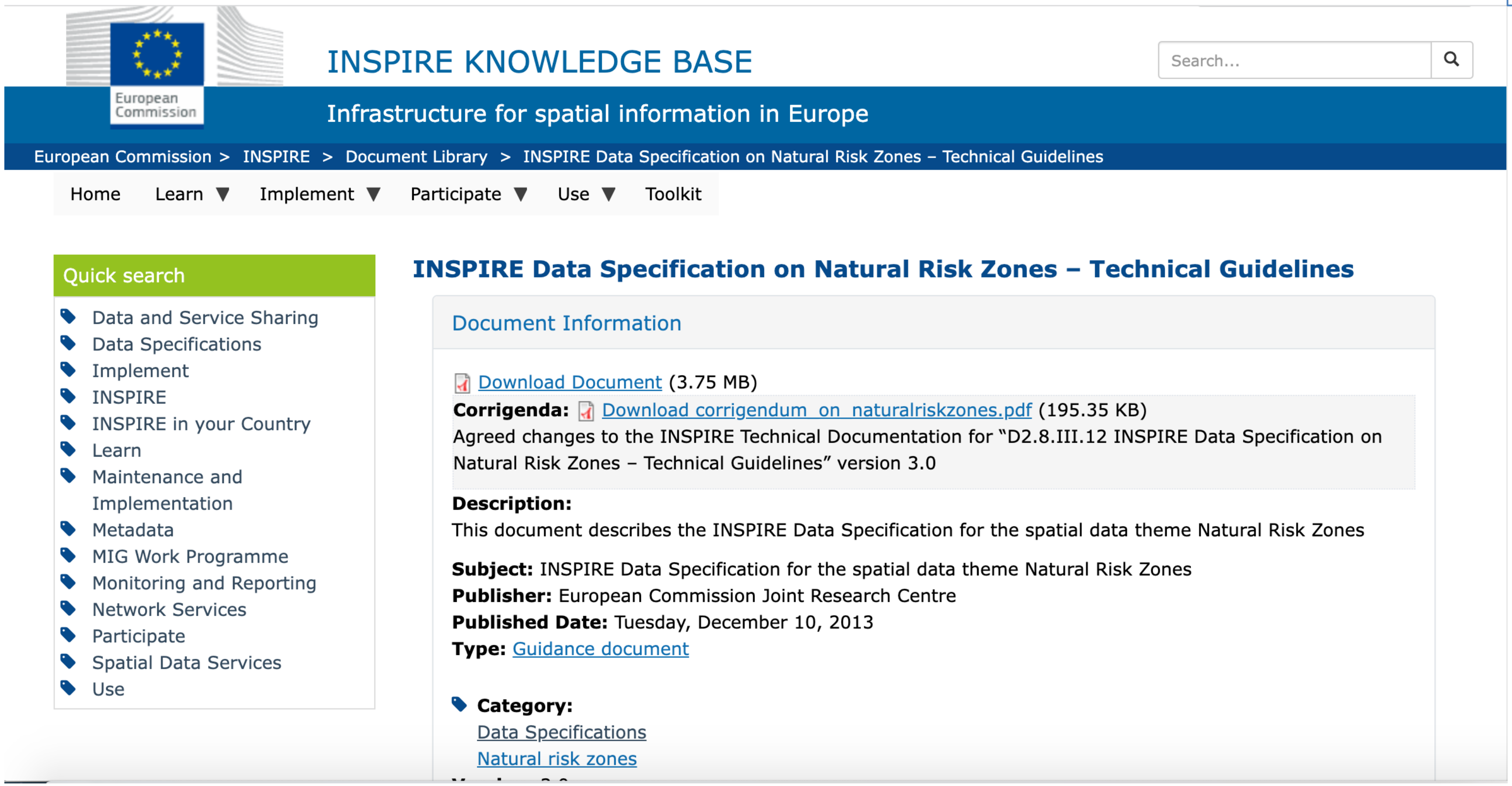
metadati

As for all the datasets of the Geological Survey of Italy, the Tsunami Map Viewer dataset is provided with specific metadata

The Tsunami Map Viewer dataset is INSPIRE compliant, following the INSPIRE *application schema* for Natural Risk Zones (NZ- https://inspire.ec.europa.eu/id/document/tg/nz).

INSPIRE compliant

The dataset go with specific metadata



European Commission

INSPIRE KNOWLEDGE BASE

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European Commission > INSPIRE > Document Library > INSPIRE Data Specification on Natural Risk Zones – Technical Guidelines

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INSPIRE Data Specification on Natural Risk Zones – Technical Guidelines

Document Information

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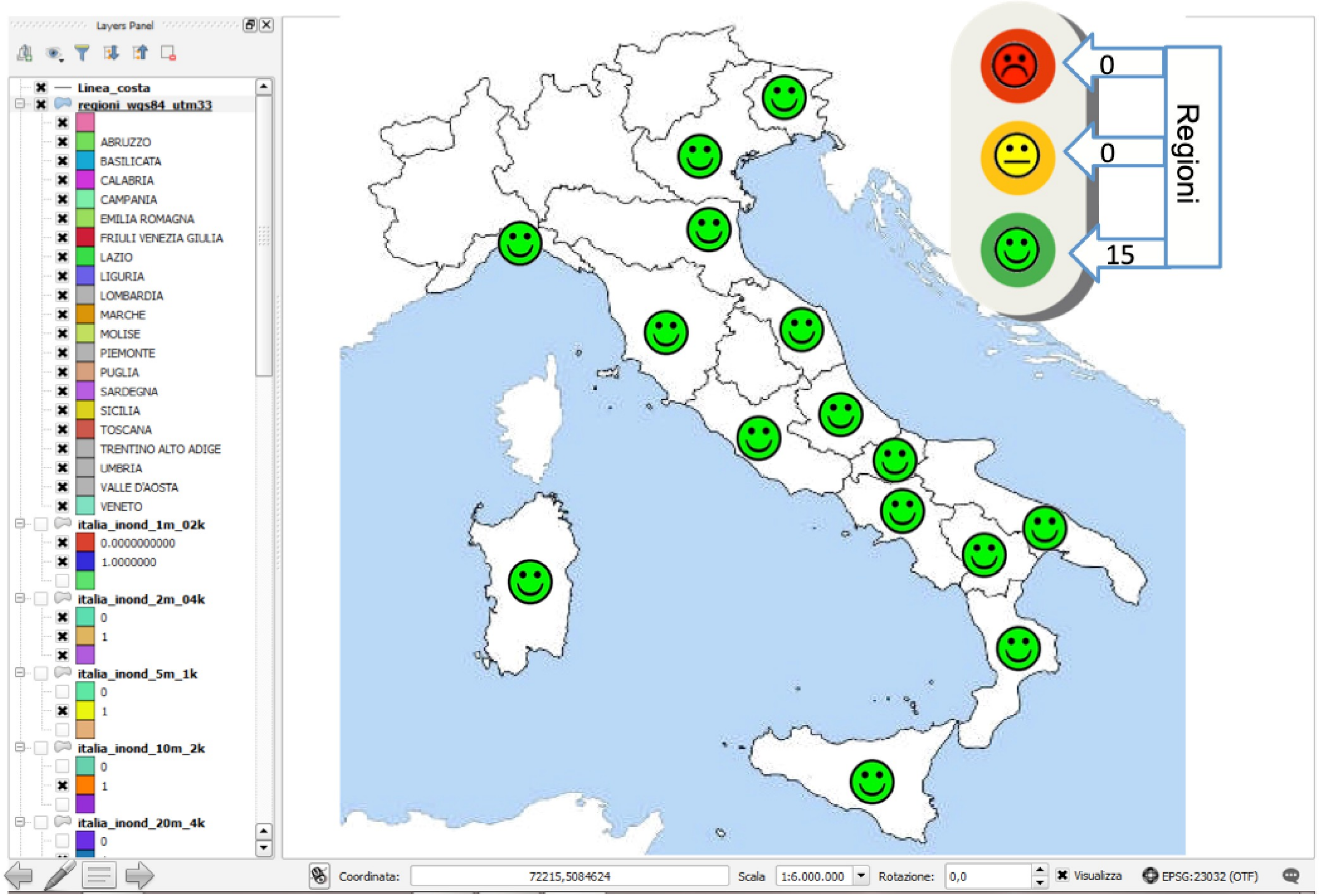
Corrigenda: Download corrigendum_on_naturalriskzones.pdf (195.35 KB)
Agreed changes to the INSPIRE Technical Documentation for "D2.8.III.12 INSPIRE Data Specification on Natural Risk Zones – Technical Guidelines" version 3.0

Description:
This document describes the INSPIRE Data Specification for the spatial data theme Natural Risk Zones

Subject: INSPIRE Data Specification for the spatial data theme Natural Risk Zones
Publisher: European Commission Joint Research Centre
Published Date: Tuesday, December 10, 2013
Type: Guidance document

Category:
Data Specifications
Natural risk zones

SiAM – evacuation maps availability



The evacuation maps have been elaborated for all the Italian coastal regions.
We completed the elaboration at the end of 2021.
The SiAM is fully operational

Future goals: improving inundation maps

The now available SiAM evacuation maps could be considered as a preliminary version, subject to improvement and periodical updates and changes

New version and release based on

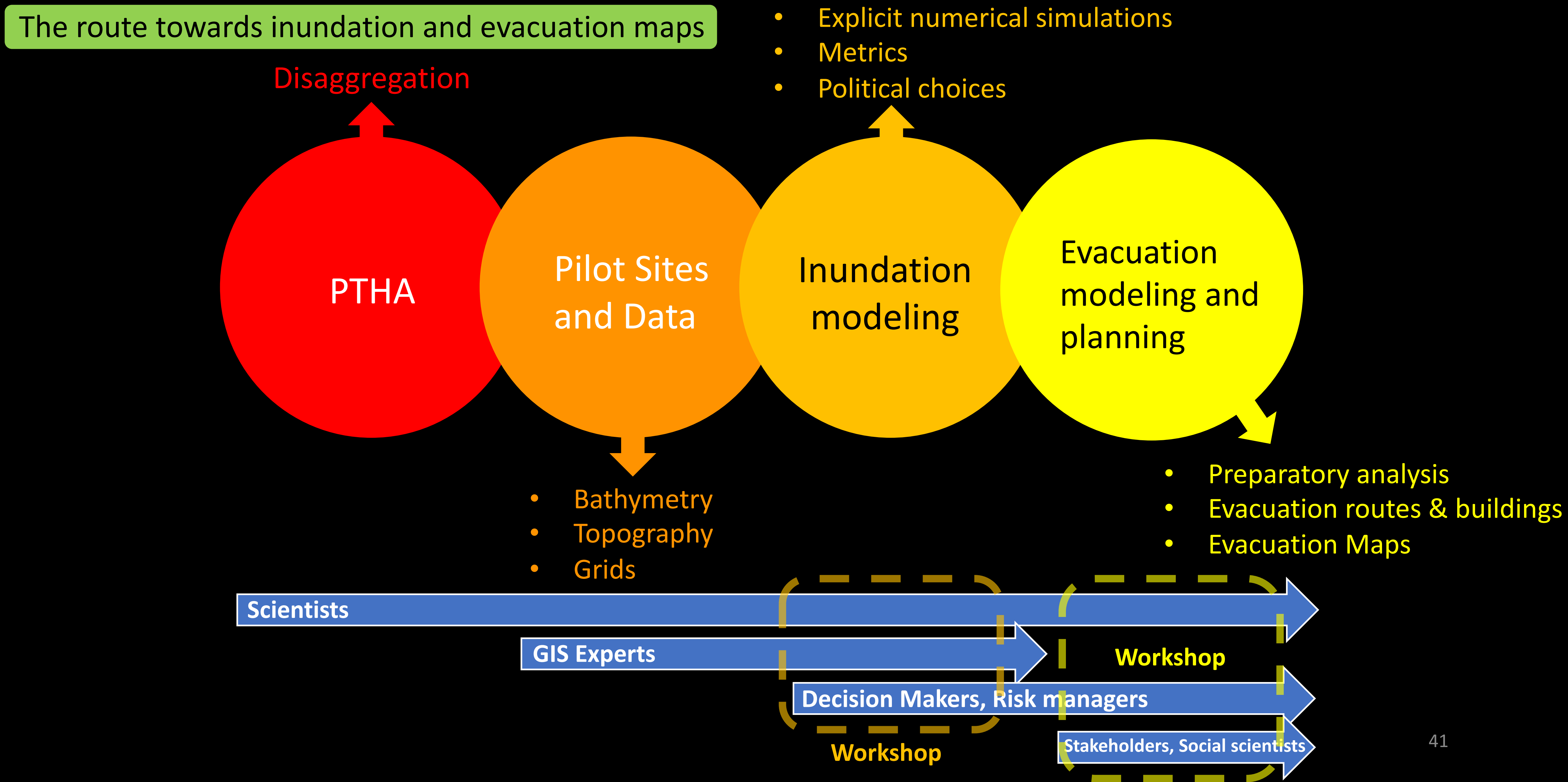
Availability of new input data

- High resolution DTM coverage
- Increase of LIDAR data coverage through new acquisition
- Updating data on coast line and river network
- Detailed coastal bathymetry data
- Detailed 3D data on coastal protection works, easy to flow ways, etc.

Progress in the methodology

- Use of specific factors as function of the morphology and of the land use
- Use of attenuation factors associated with protective structures/barriers
- Contextualization of the analyses, considering local conditions (barriers and easy to flow ways, typical in urbanized areas)
- Integration with the results of numerical modelling for relevant coastal sectors
- Uncertainty estimation improvement

What we need for inundation and evacuation maps



Thank you

fabrizio.romano@ingv.it
pio.dimanna@isprambiente.it

Additional contributions from: S. Lorito, M. Volpe, R. Tonini, B. Brizuela, J. Selva, R. Basili, M. Taroni (INGV), M.P. Congi, R. Ventura, E. Vittori (ISPRA), F. Løvholt, S. Gibbons (NGI), A. Babeyko (GFZ)

Green's Law (GL)

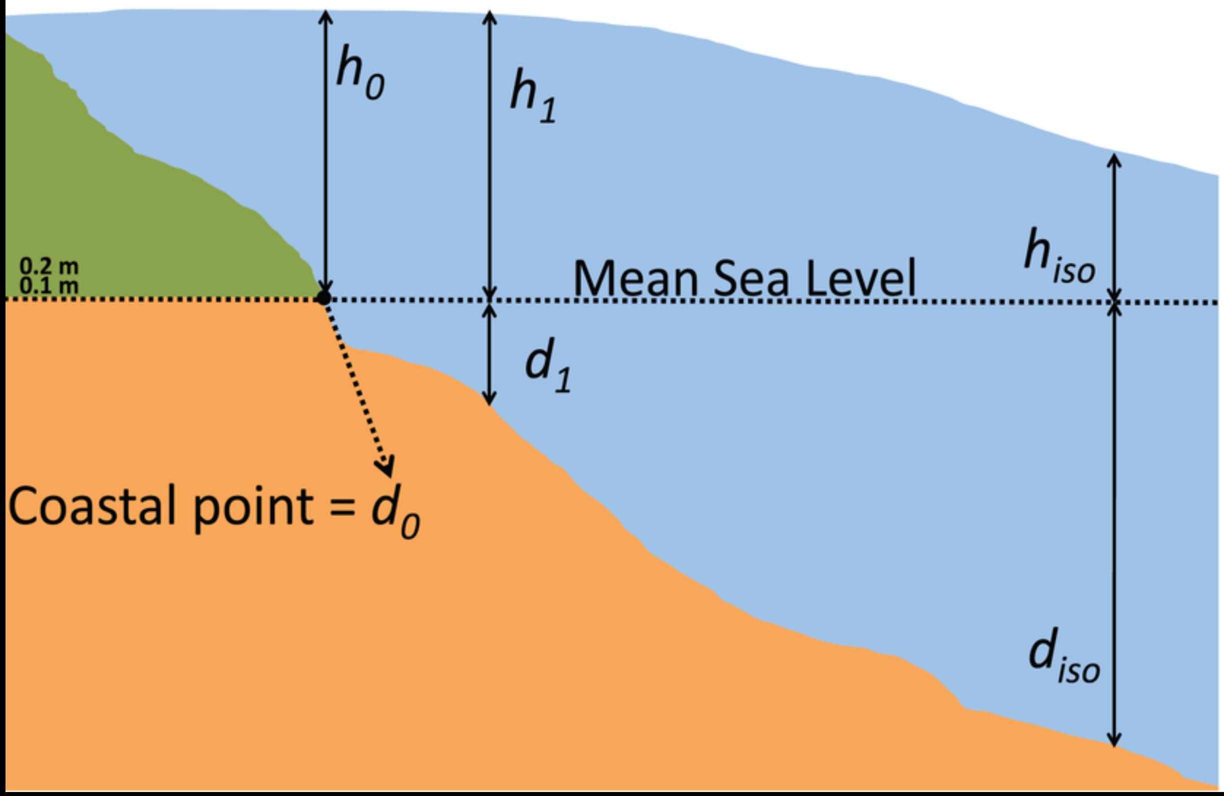
- Compute the tsunami wave shoaling
- Assumptions: Long non-breaking waves, gentle slopes

Used to estimate the maximum runup (e.g. *Sørensen et al. 2012*) when:

- Lack of hi-res bathy/topo models
- Reduced computational resources

Limitations:

- 1D
- Wave amplification must be evaluated at depth > 1m (avoid instabilities)
- Does not take into account coastal nonlinear effects
- Does not take into account wave period/polarity



Synolakis, 1991
Grezio et al., 2020

$$h_1 = h_{iso} \sqrt[4]{\frac{d_{iso}}{d_1}}$$

Amplification Factors (AF)

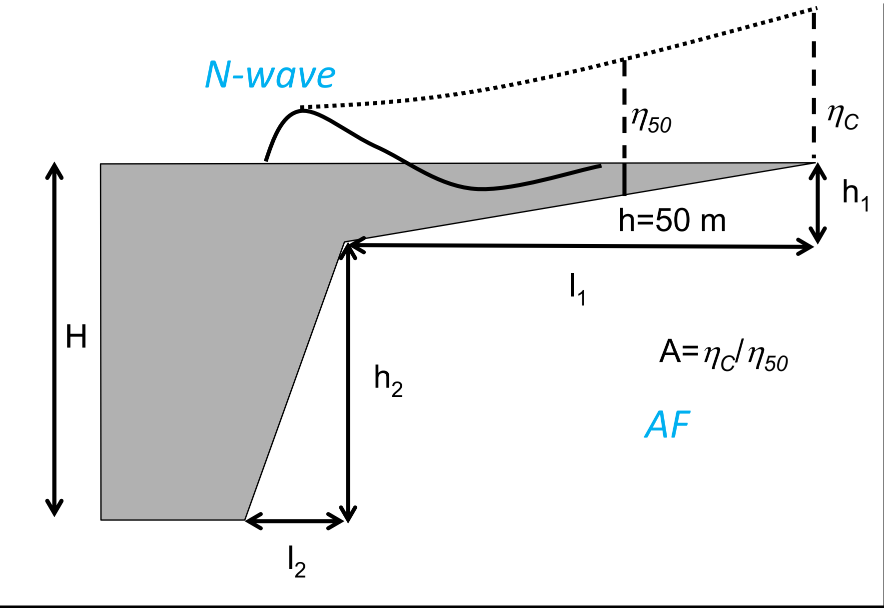
- Estimate the tsunami amplitude at the shoreline → an approximation for the Maximum Inundation Height (MIH)
- Assumptions: Linear hydrostatic non-breaking waves; N-wave (sin shaped) as input; tsunami offshore at 50m

W/ respect to GL:

- Account for several wave periods and polarity combinations
- More computational demanding (but still feasible)

Limitations:

- 1D
- Does not take into account coastal nonlinear effects
- Site-dependent
- MIH represents a stretch of coast → coarser resolution than explicit numerical simulations



Lovholt et al., 2012

MIH: Flow-depth + topography

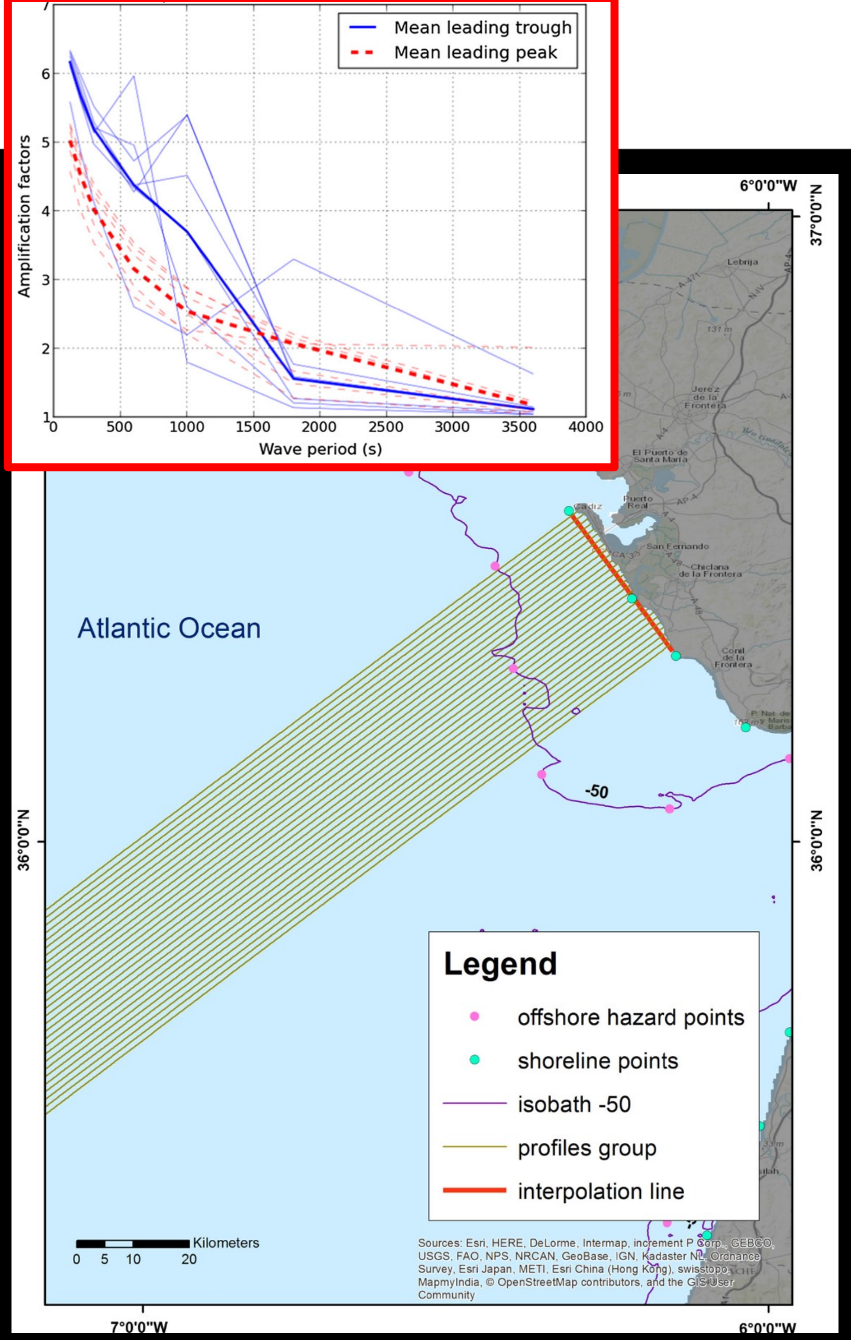
Amplification Factors (AF)

How it works:

- Select a stretch of coast
- Extract a set of topographic (mid-to-hi resolution) profiles orthogonal to the coast (1 km spaced)
- Simulate N-waves w/ different period (120-3600s) & polarity (*Løvholt et al., 2012*)
    - 1m amplitude in deep water (50m)
    - Resolution grid variable based on both depth and wave period
    - Courant constant = 0.9
    - No-flux B.C. at shoreline
- Compute AF (offshore to shoreline amplitudes ratio)
- Lookup table (AF vs Period)
    - One for each polarity
    - Median (?) value among the profiles to avoid unrealistic fluctuations along the coast

Specific issues

- Automatic procedure except for small islands and/or narrow bays (e.g. fjords)

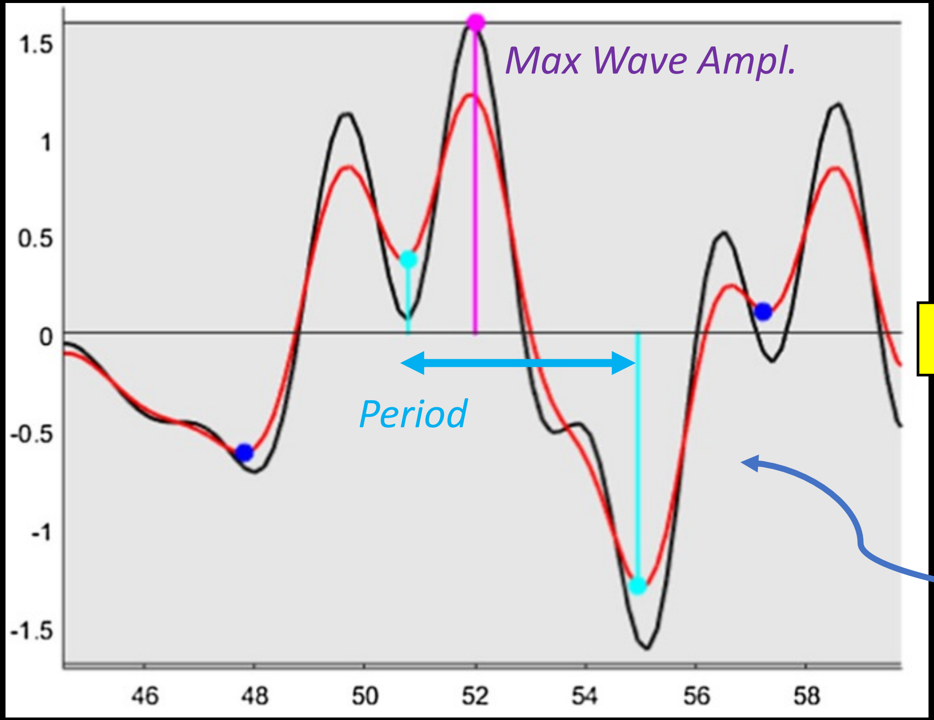


Glimsdal et al., 2019

Amplification Factors (AF)

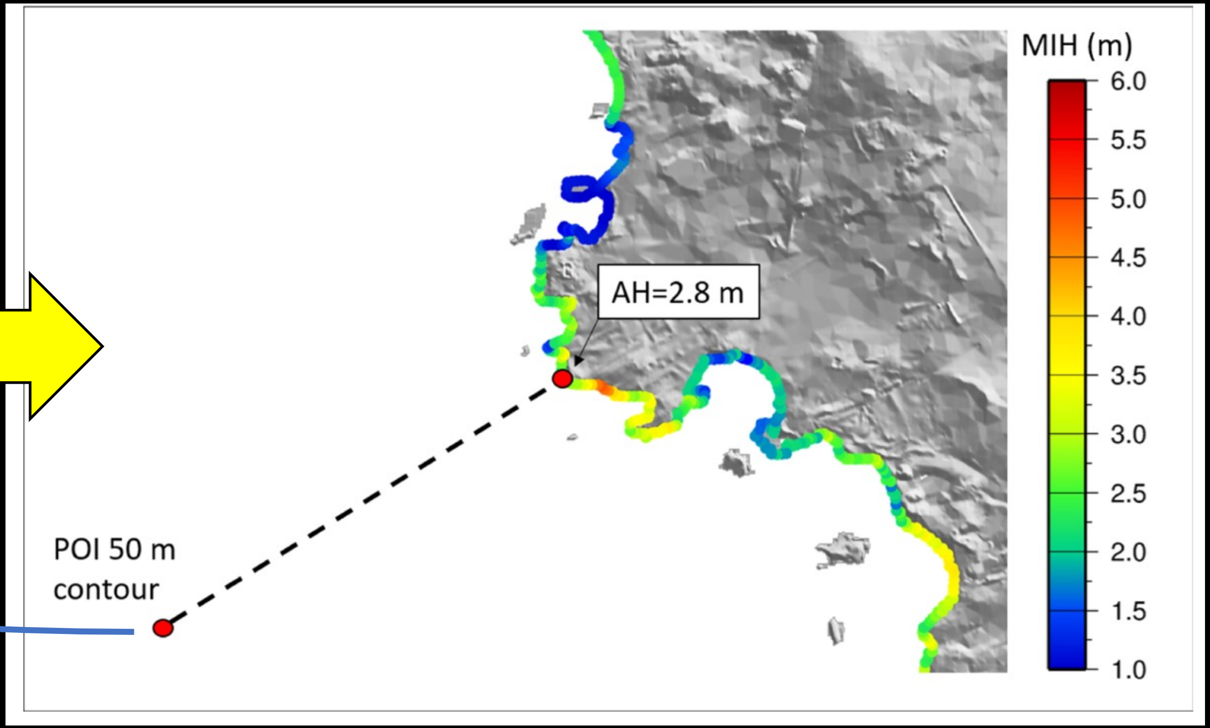
From AF to MIH for a given scenario:

- for selected Points of Interest (POI) located at 50m depth and for each scenario
    - Analysis of the time series to extract Maximum Wave amplitude, Dominant Period, and Polarity
    - MIH from the Lookup table



Lookup table

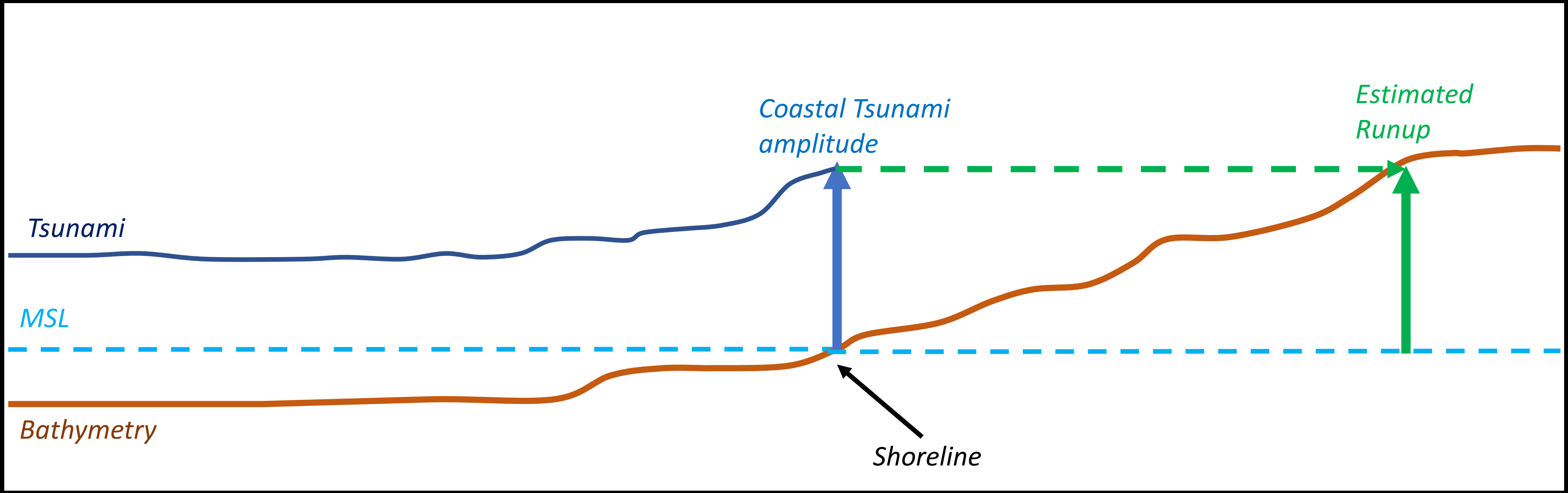
Glimsdal et al., 2019



Bathtub

How it works:

- Consider the tsunami amplitude at the coast
  - GL or AF methods can me adopted
- Identify (w/ a GIS) all the areas inland below this height to determine an inundation footprint.



Benefits:

- Computationally efficient
- Easy to implement

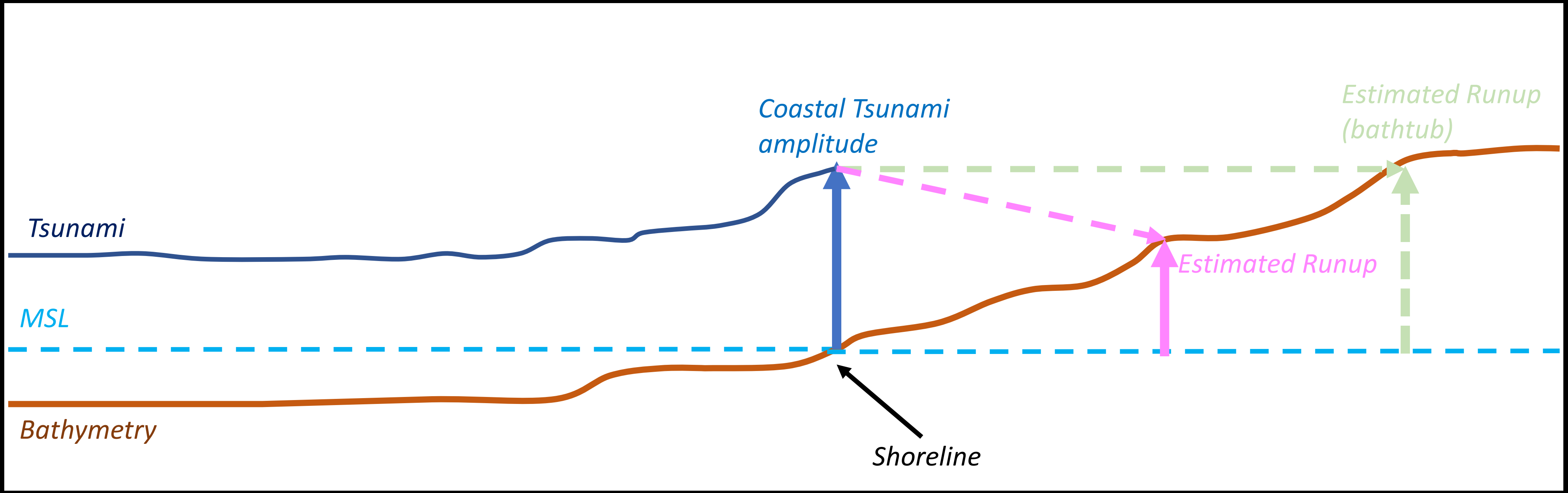
Limitations:

- Flow dynamics not considered
- Unlikely results in low-lying areas

Attenuation rule

How it works:

- Consider the tsunami amplitude at the coast (similar to Bathtub method)
  - GL or AF methods can me adopted
- Apply an attenuation rule (w/ a GIS) to estimate the maximum inundation distance (and runup)



Benefits:

- More realistic inundation (decrease w/ distance)
- Easy to implement

Limitations:

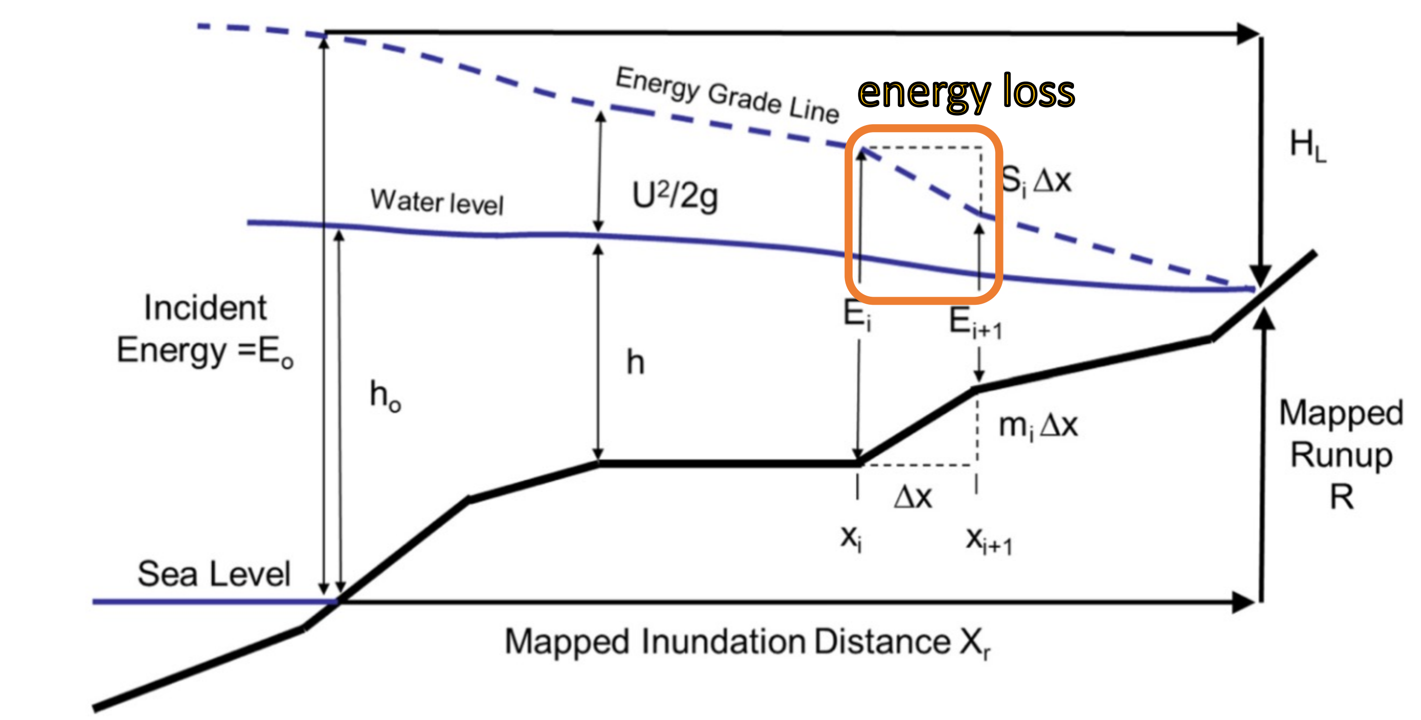
- Flow dynamics not considered
- Attenuation (friction) rule depends on site

Energy Grade Line (EGL)

- The method considers the energy balance (kinetic + potential) of the tsunami and the dissipation due to the ground friction
- **Used by engineers to evaluate the potential tsunami impact on the structures**
- Can be used provided having a hi-res topographic model and knowing the 1) tsunami amplitude at the shoreline or the 2) maximum inundation distance
  - 1) forward modelling
  - 2) backward modelling

How it works:

- define a topographic profile crossing the inundation line and orthogonal to the coast
- Compute the energy loss along the profile (as the contribution of ground friction and topographic gradient)
  - Set a Manning friction coefficient
  - Set a decay law for the Froude number w/ the distance



Kriebel et al., 2017

Numerical Modeling

Tsunami inundation is preceded by the shoaling phase → Shorter wavelengths and higher spatial resolution is needed to properly model the flow

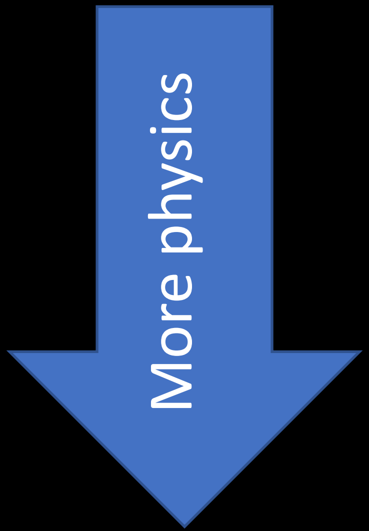
The more accurate way to compute tsunami inundation is the numerical modelling because takes into account:

- Dynamic of the flow
- Topo/Bathymetric features
- Dissipation of the wave inland

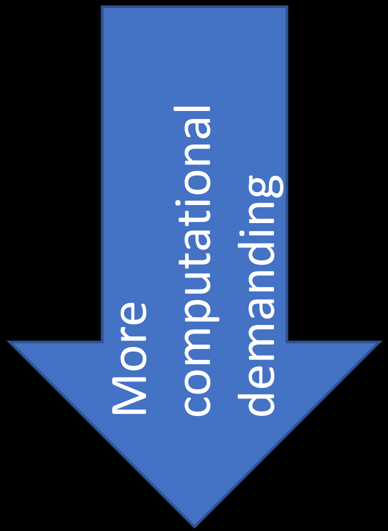
We need hi-resolution topo-bathymetric models and high performance computational resources

Numerical Modeling

Different models



- 2D NonLinear Shallow Water
- Boussinesq
- 3D Navier Stokes
- …



Numerical Modeling

Different models

More physics

- 2D NonLinear Shallow Water
- Boussinesq
- 3D Navier Stokes
- …

More computational demanding

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0,$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial}{\partial x}\left(hu^2 + \frac{1}{2}gh^2\right) + \frac{\partial (huv)}{\partial y} = gh\frac{\partial H}{\partial x} + S_x,$$

$$\frac{\partial (hv)}{\partial t} + \frac{\partial}{\partial y}\left(hv^2 + \frac{1}{2}gh^2\right) + \frac{\partial (huv)}{\partial x} = gh\frac{\partial H}{\partial y} + S_y.$$

- NLSW are typically enough to model the tsunami inundation stage
- Some limitations to model the vertical details of many coastal effects (being depth-integrated)

Lynett, 2009

Numerical Modeling

However, what we need is:

- Accurate topographic/bathymetric data
- Computational resources

Numerical Modeling

However, what we need are:

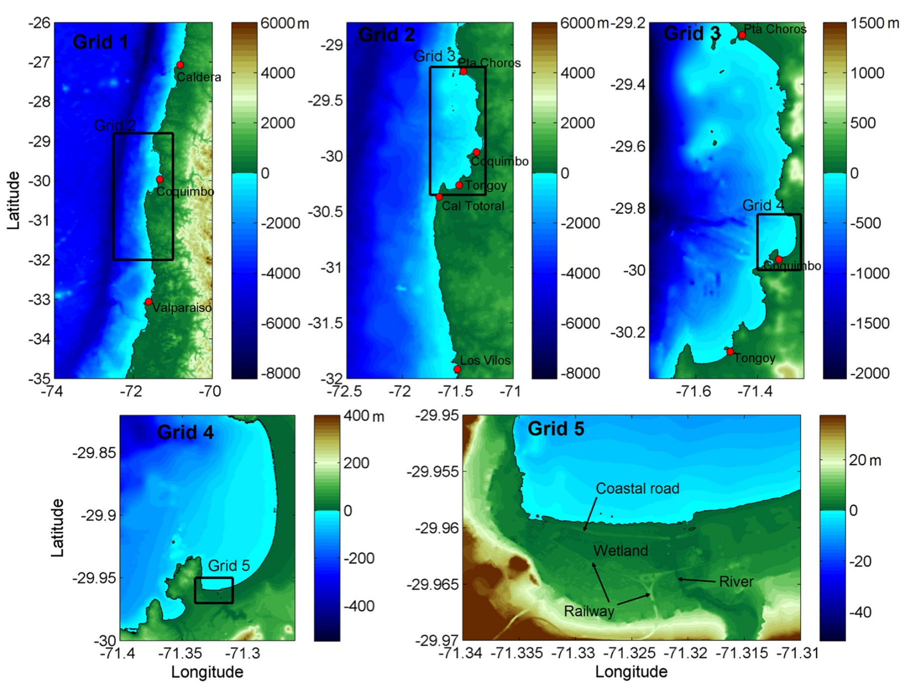
- Accurate topographic/bathymetric data
- Computational resources

Optimise the resources by using Telescopic nested grids:

- Up to 5-10 m resolution
- Spatial ratio of 3,4 between grids

Try to limit numerical instabilities

- by making topo/bathy features coherent between grids
- No grid corners in the sea (if possible) or within a strong bathymetric gradient



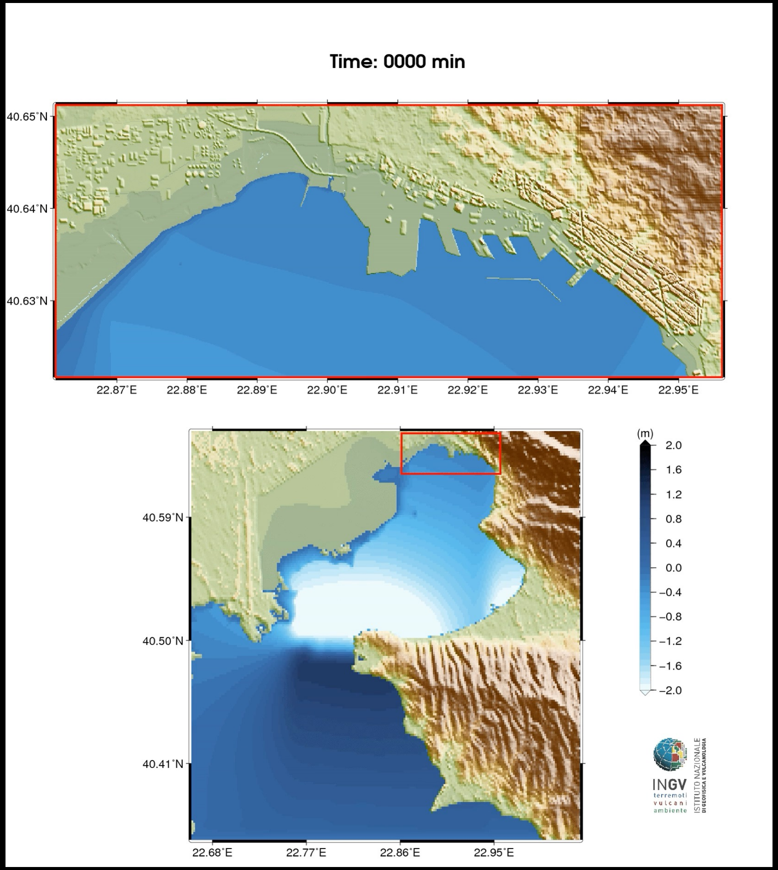
Aranguiz et al., 2017

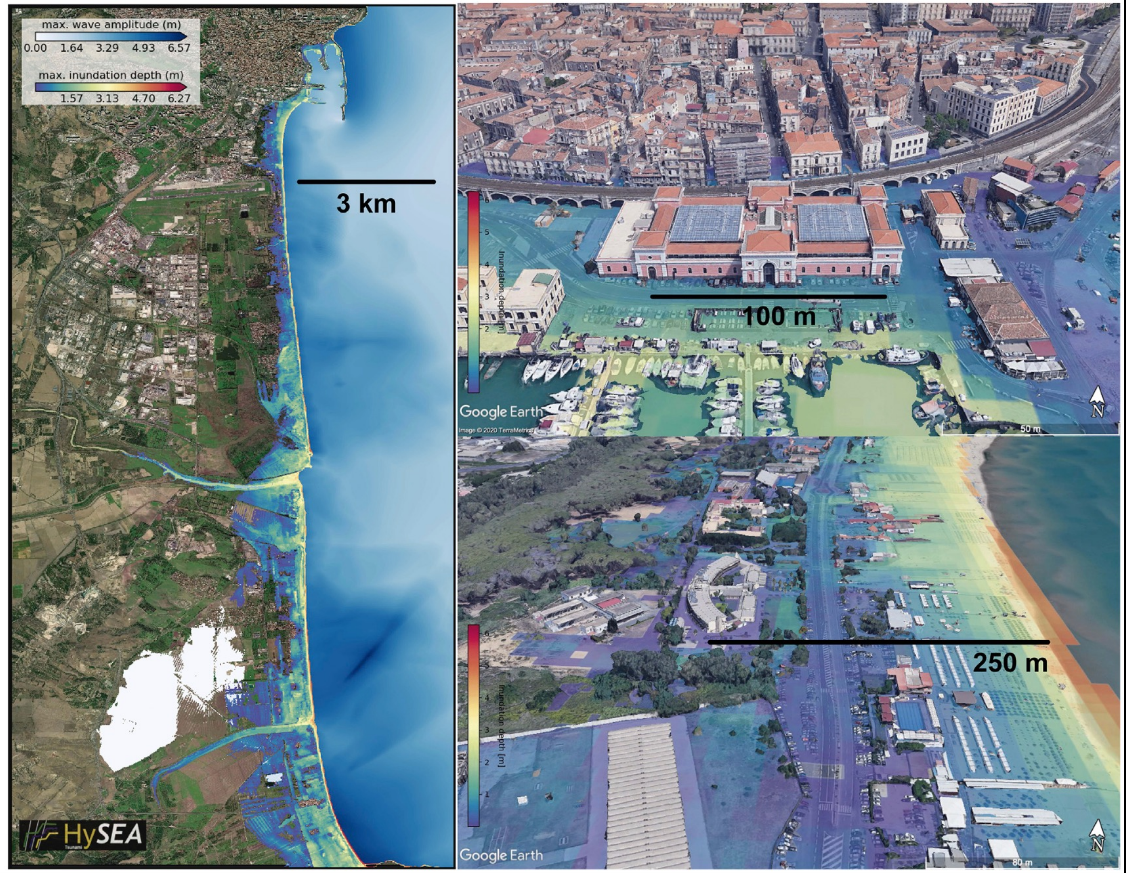
Numerical Modeling

However, what we need are:

- Accurate topographic/bathymetric data
- Computational resources

- HPC resources
- GPU codes





Tsunami HySEA, Univ. of Malaga

Macias et al., 2017

Energy Grade Line (EGL)

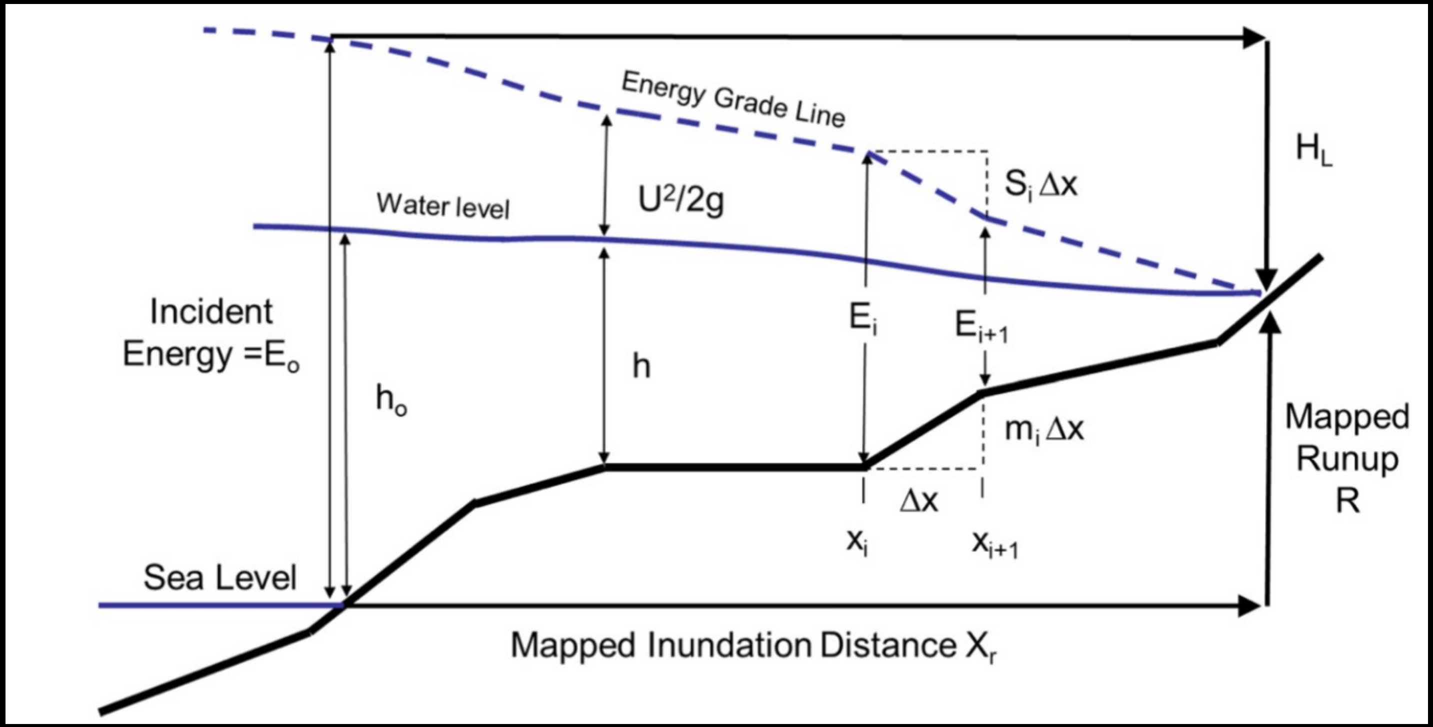
Backward modelling

- Inundation distance (i.e. runup) well known
    - Wave amplitude = 0
    - Froude number (~velocity) = 0

Forward modelling

Wave amplitude at shoreline known (or estimated by GL, AF)

- Wave amplitude ~= 0
- Froude number (~velocity) ~= 0 (and unknown)



Kriebel et al., 2017

While EGL Backward modelling is fairly well constrained, EGL Forward modelling intrinsically not.

→ Specific issues must be taken into account

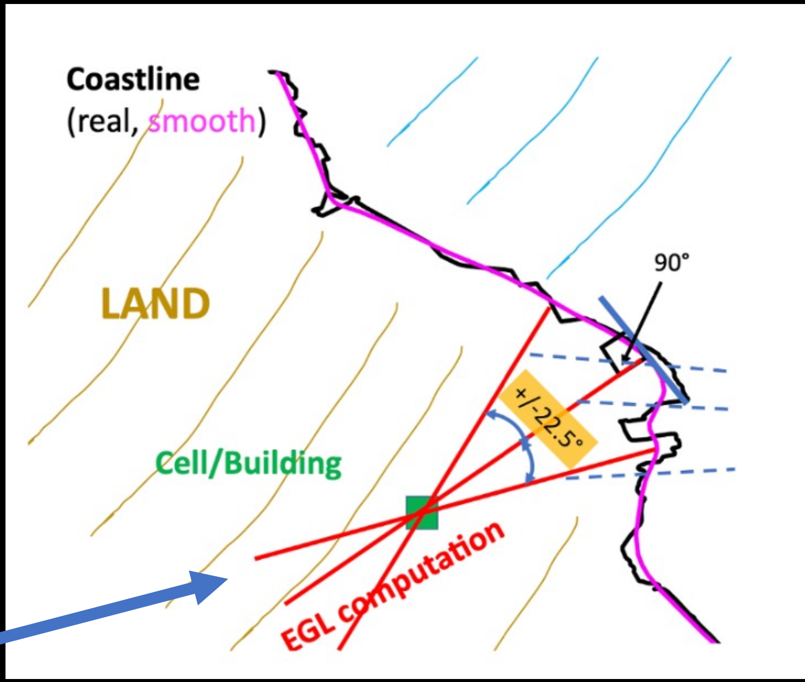
Energy Grade Line (EGL)

Specific issues #1

EGL is applied along a 1D topographic profile

2D dynamic of the flow is not considered (e.g. wall, topographic high, obstacles)

A set of 3 profiles is adopted to try and capture the inundation



Energy Grade Line (EGL)

Specific issues #2

Using EGL forward modelling also means we don't have hi-res simulation nearshore

↓

We must use approximate methods (e.g. GL or AF) to estimate the tsunami in front of the coast

↓

The coastline in the topography might be affected (in position) due to the coseismic deformation

↓

Specific treatment of the topography or the input wave amplitude is carried out depending whether there is subsidence or uplift

Energy Grade Line (EGL)

Specific issues #3

Using EGL forward modelling the Froude number is unknown at the shoreline

↓

We must use a predefined value or try and follow an iterative approach to estimate the Froude number

IMPORTANT difference w/ other approximate methods:

- With EGL, the relation between Froude number and wave amplitude allows to compute in land also velocity and momentum flux.

The Italian evacuation and long-term coastal planning

From Regional to Local scale

Alert Levels
Advisory: runup up to 1m
Watch: runup exceeding 1m

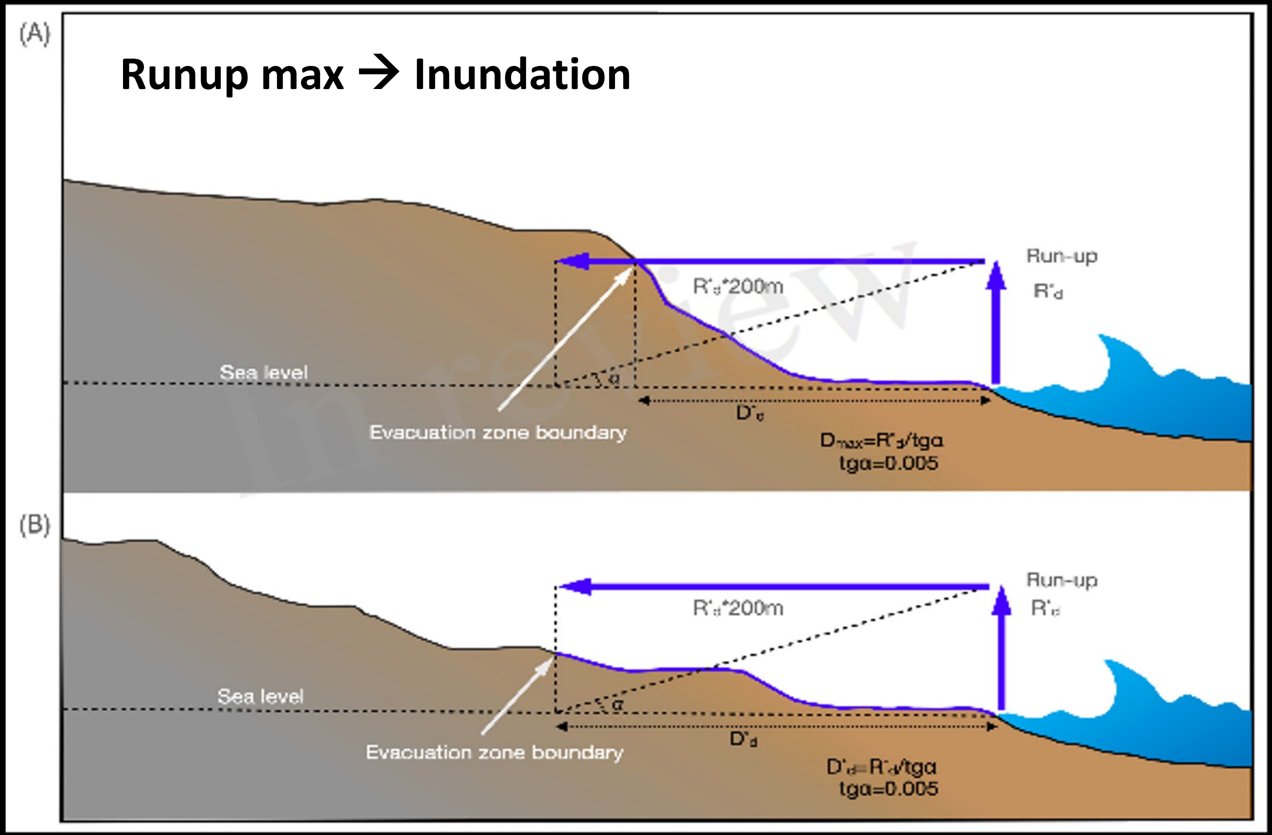
DirPC SiAM; DPC, 2018

Regional Hazard (NEAMTHM18)

2500 yr ARP + 84th percentile

Safety factors

Coastal dissipation



Leonard et al., 2008

Max inundation distance **WITH** obstacles

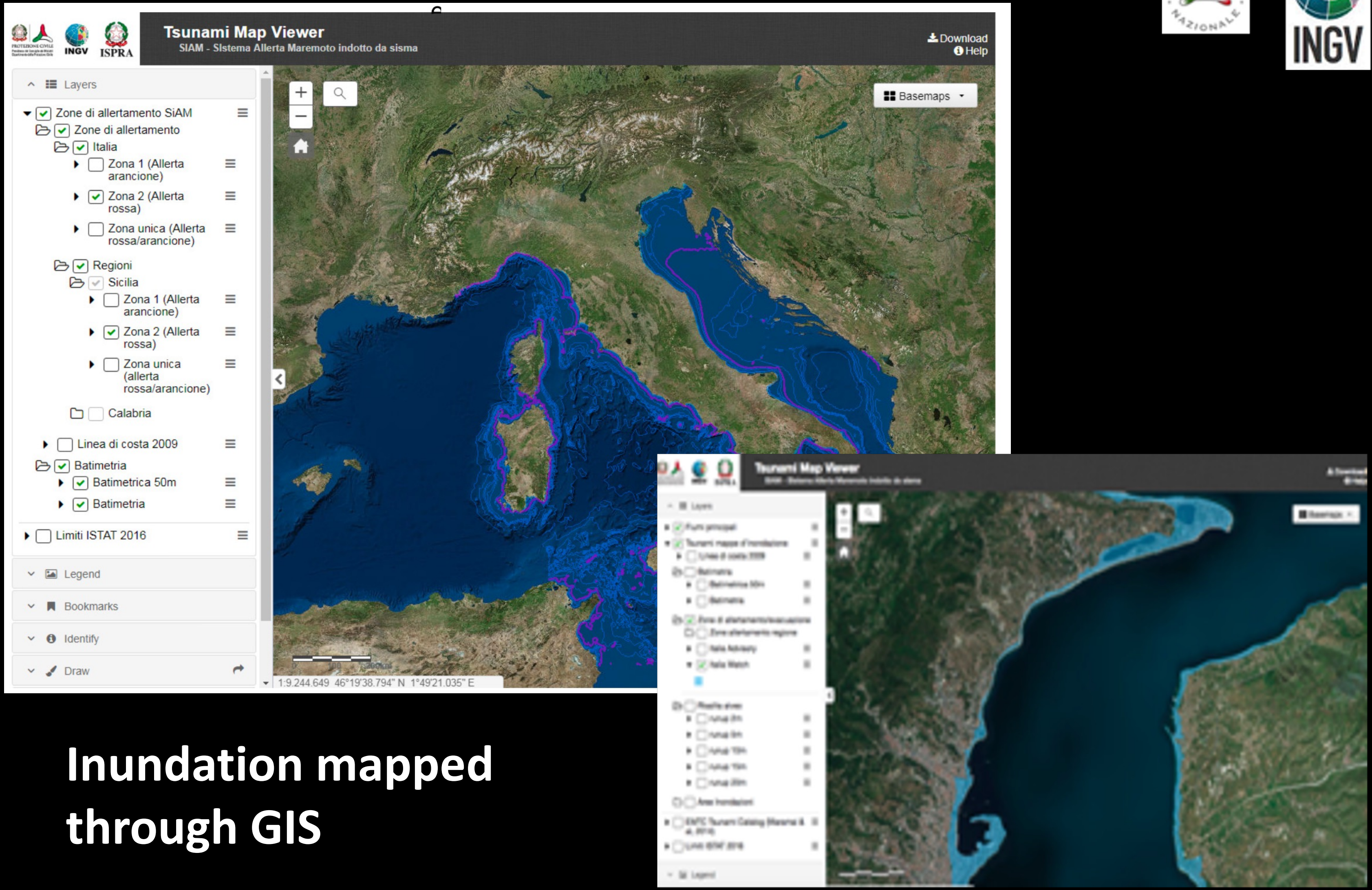
Max inundation distance **WITHOUT** obstacles

Attenuation rate: 1m every 200m (1m every 400m for rivers)

The Italian evacuation and long-term coastal planning

From Regional to Local scale

http://sgi2.isprambiente.it/tsunamimap/



Alert Levels

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DirPC SiAM; DPC, 2018

Regional Hazard (NEAMTHM18)

2500 yr ARP + 84th percentile

Safety factors

Coastal dissipation

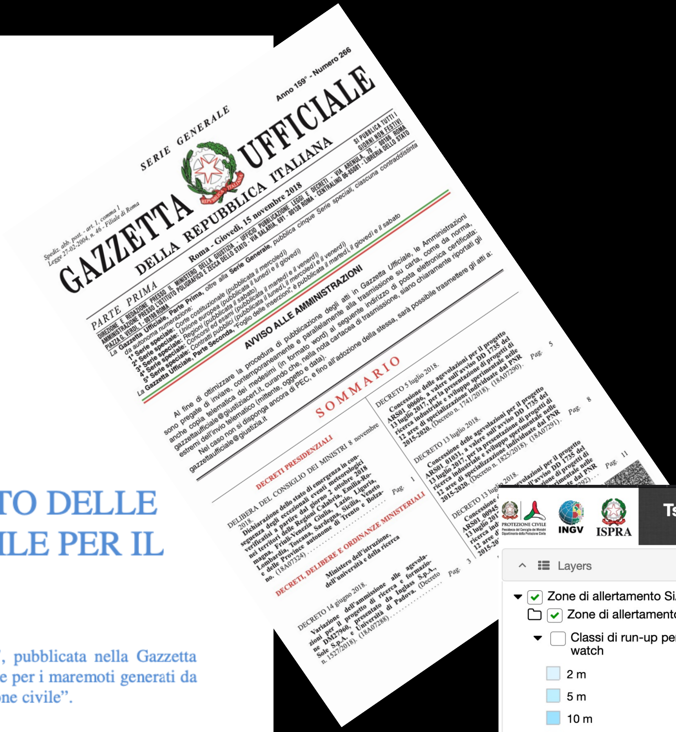
Inundation mapped through GIS

The Italian evacuation and long-term coastal planning

Civil Protection indications to local authorities for local planning

INDICAZIONI PER L'AGGIORNAMENTO DELLE PIANIFICAZIONI DI PROTEZIONE CIVILE PER IL RISCHIO MAREMOTO

Ai sensi della Direttiva del Presidente del Consiglio dei Ministri del 17 febbraio 2017, pubblicata nella Gazzetta Ufficiale n. 128 del 5 giugno 2017 recante "Istituzione del Sistema d'Allertamento nazionale per i maremoti generati da sisma- SiAM" e del Decreto Legislativo 2 gennaio 2018, n.1del 2018 "Codice della protezione civile".

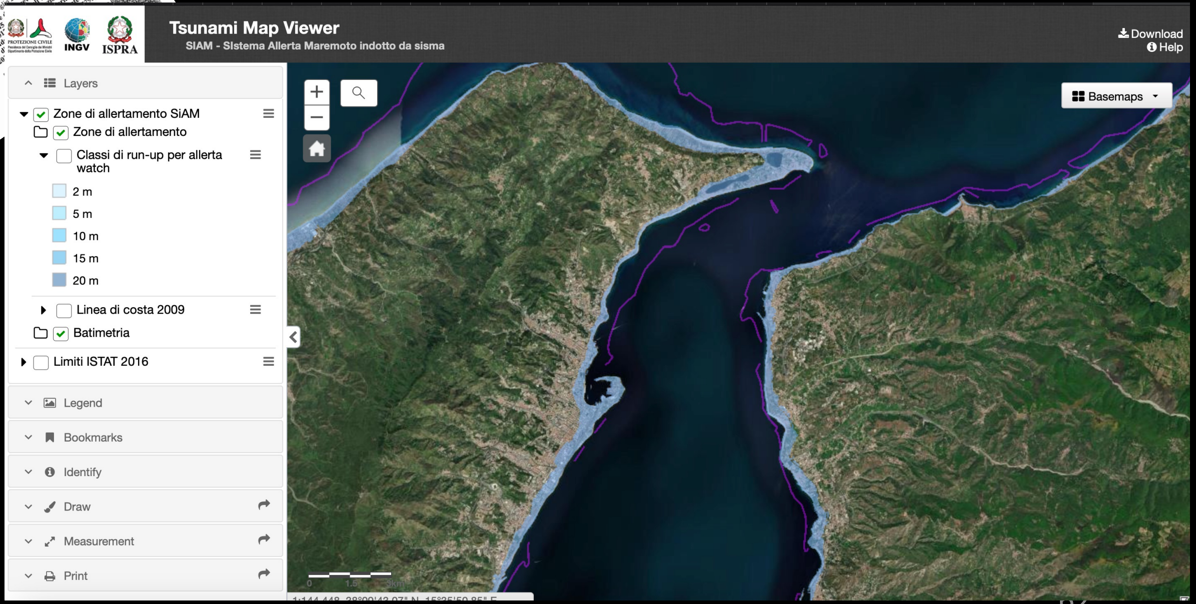


Tsunami Ready

\+

Several Annexes

- Alert zones definition
- Alert messages distribution
- Vertical evacuation guidelines
- Emergency signs



http://sgi2.isprambiente.it/tsunamimap/

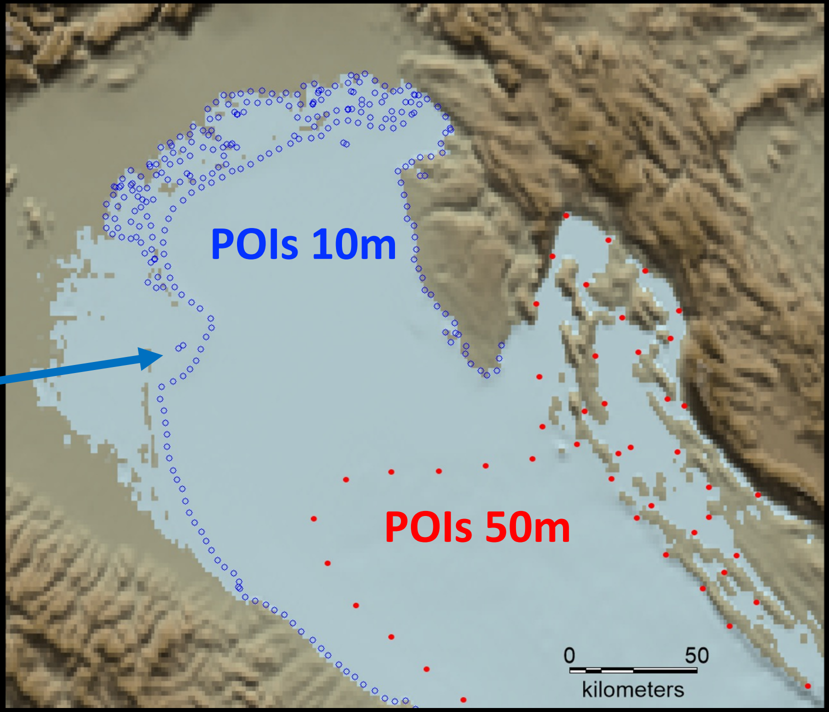
The Italian evacuation and long-term coastal planning

How to improve the current ”picture”

- **Replace Green’s functions w/ direct numerical simulations**

Why?

- We can deal with the propagations nonlinear effects
  - POIs at 10m depth → new amp factors



But….

- 1M+ scenarios to be simulated

HPC

The Italian evacuation and long-term coastal planning

…and the Probabilistic Tsunami inundation maps?

Hi-res (5-10m) topography/bathymetry models →

- Computationally demanding to be designed for all the Italian coasts
- Building hi-res models is a long (demanding and expensive) process

But, due to these limitations, the analysis can be faced for specific test sites, which?

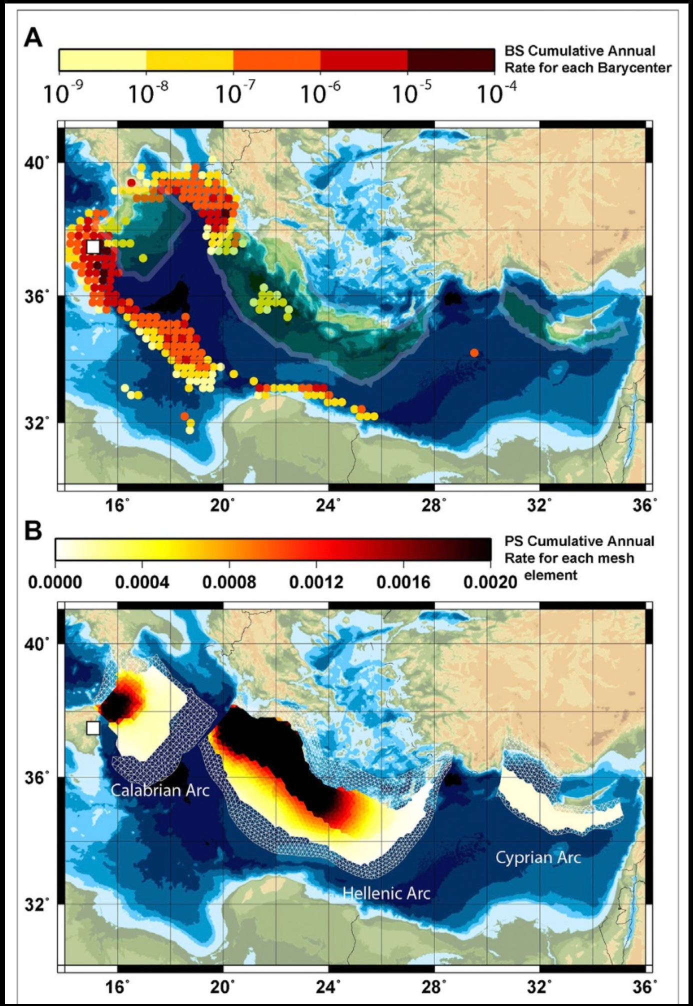
- They can be selected based on available data and the probabilistic hazard model

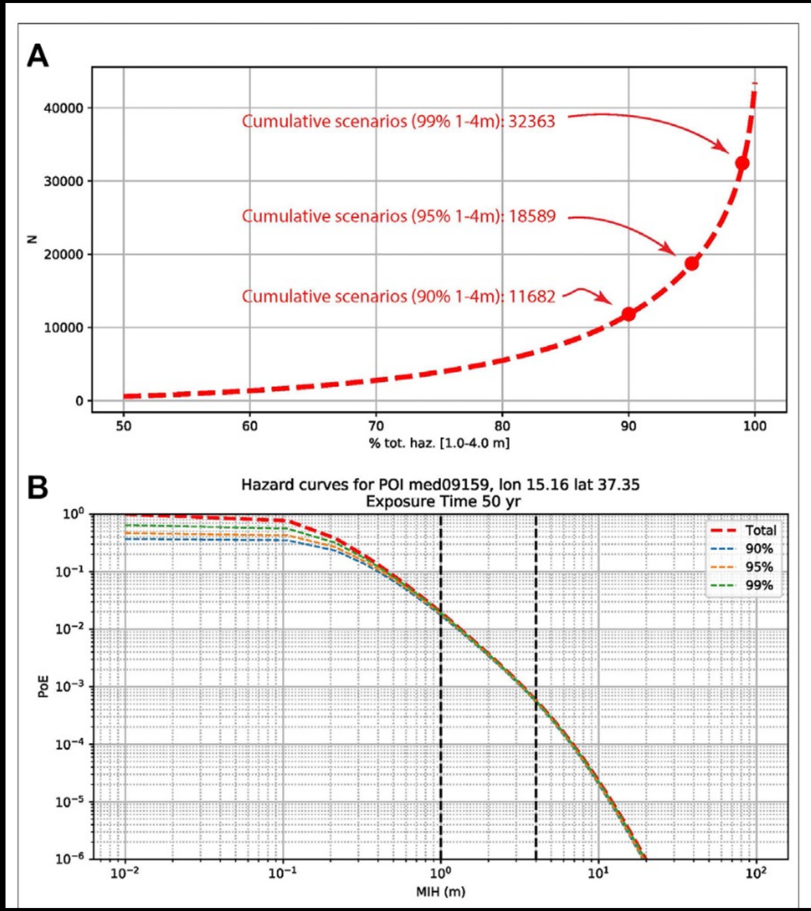
→ disaggregation

The Italian evacuation and long-term coastal planning

Disaggregation:

- Used to individuate only the scenarios that significantly contribute to the hazard for a specific POI (namely the one representing the target area for the inundation)

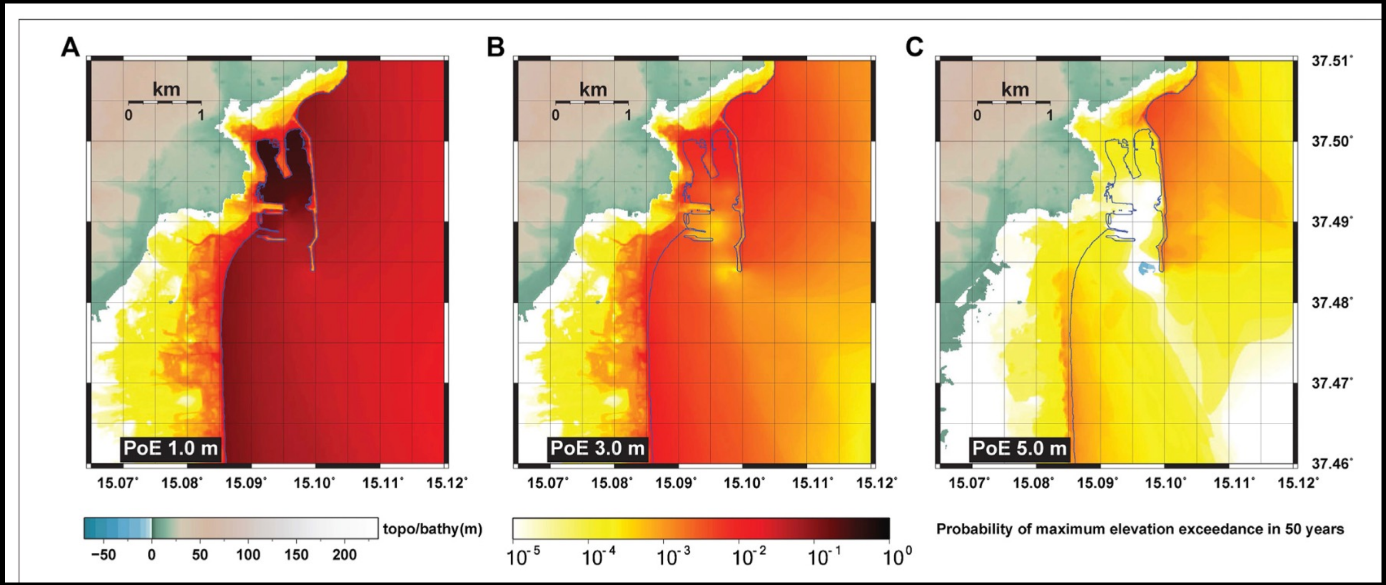




Gibbons et al., 2020

Selected scenarios to be explicitly simulated

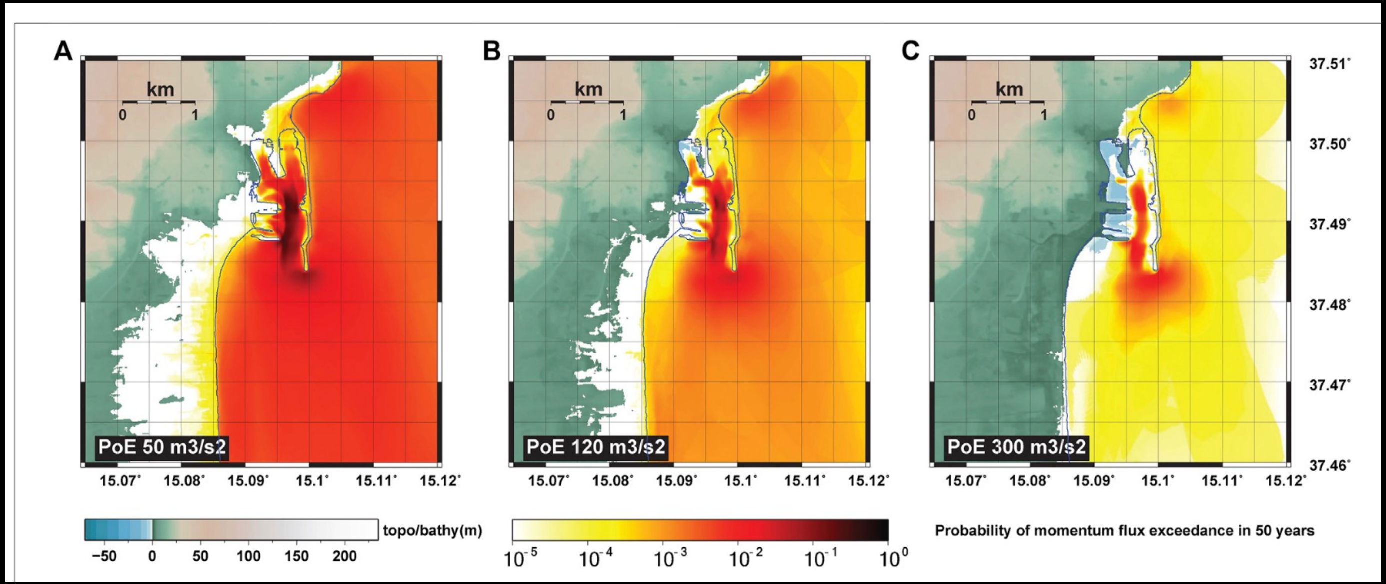
The Italian evacuation and long-term coastal planning



Inundation maps

Gibbons et al., 2020

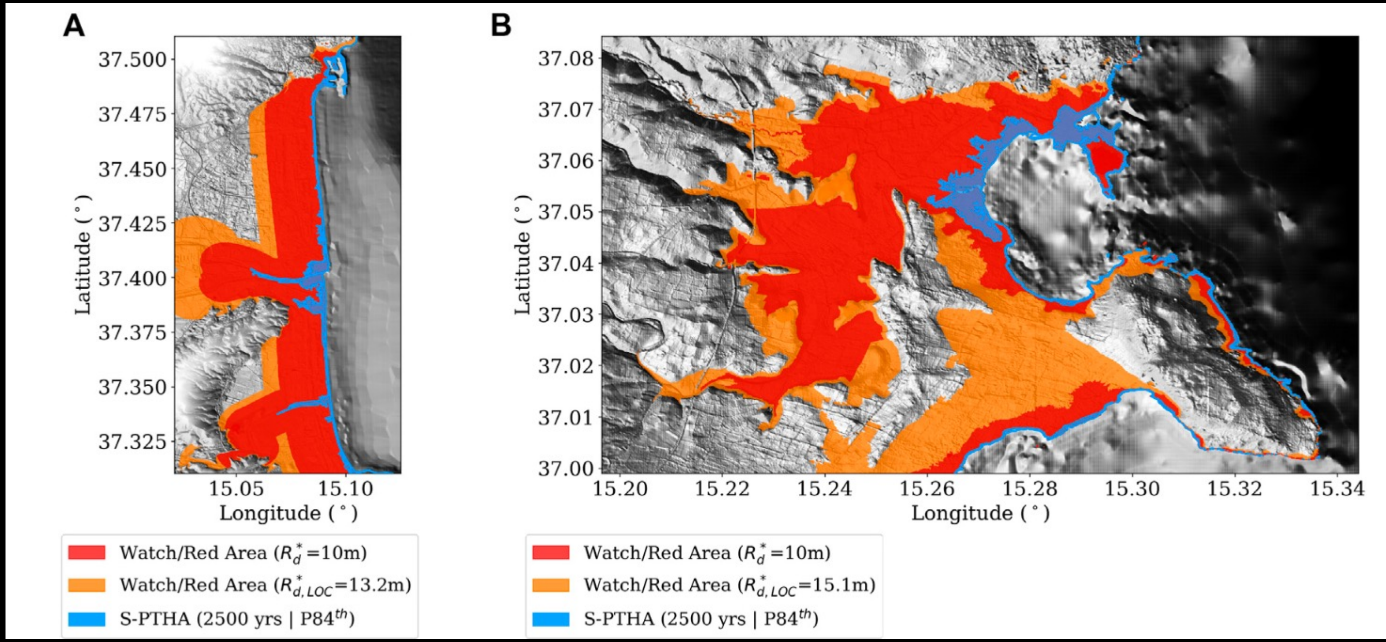
And also additional metrics (e.g. Maximum Momentum Flux)



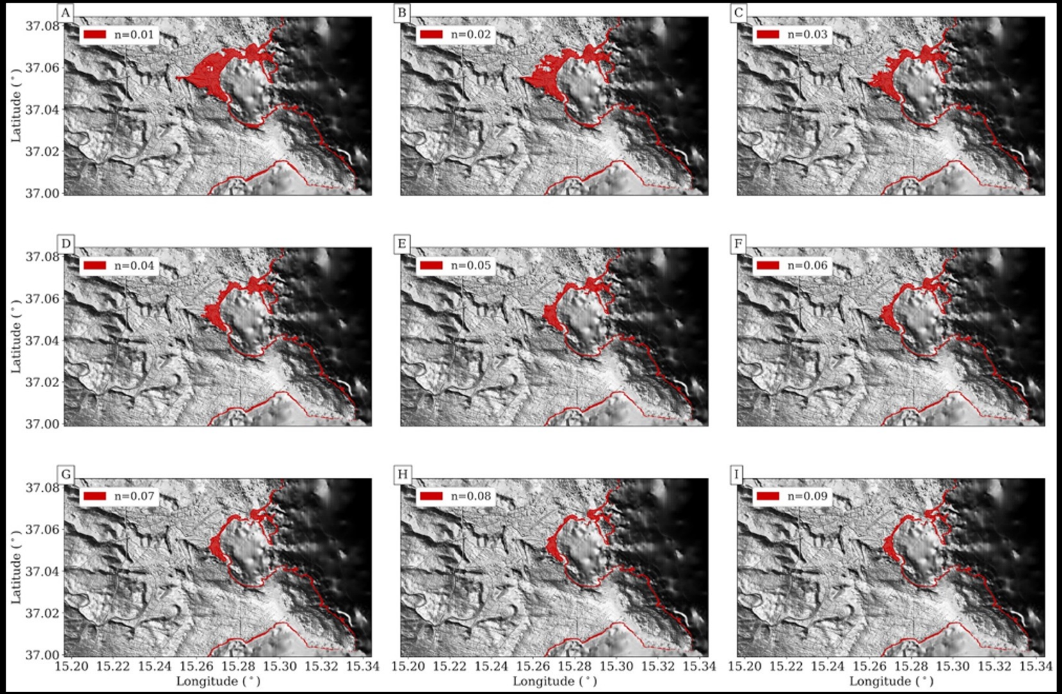
The Italian evacuation and long-term coastal planning

Next steps: taking into account the uncertainties about

- Source modeling and tsunami generation
- Topo-bathymetric model
- Numerical Inundation modeling
- Friction

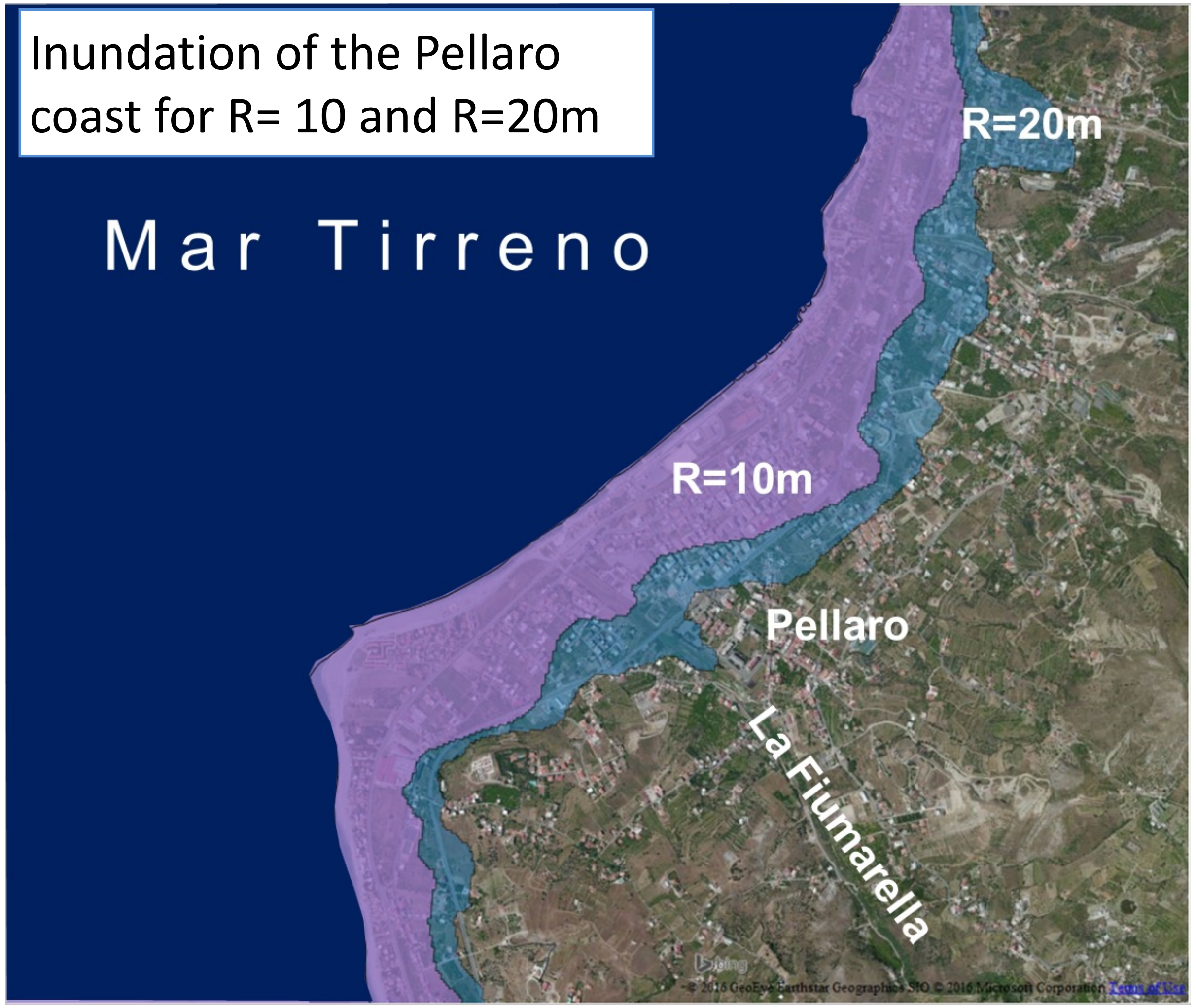


Tonini et al., 2021

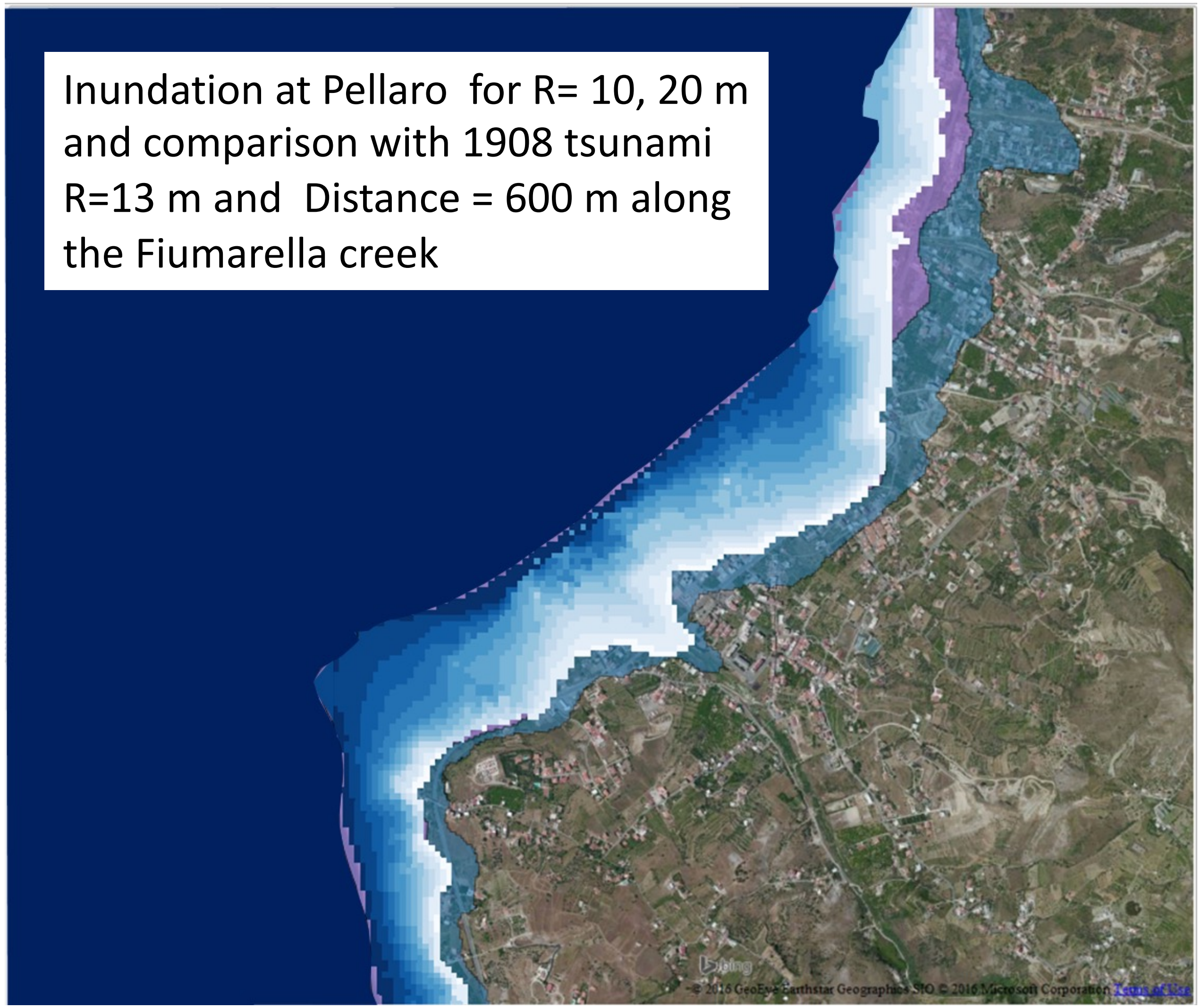


Gibbons et al., 2022

Testing activity: comparison with historical events scenarios

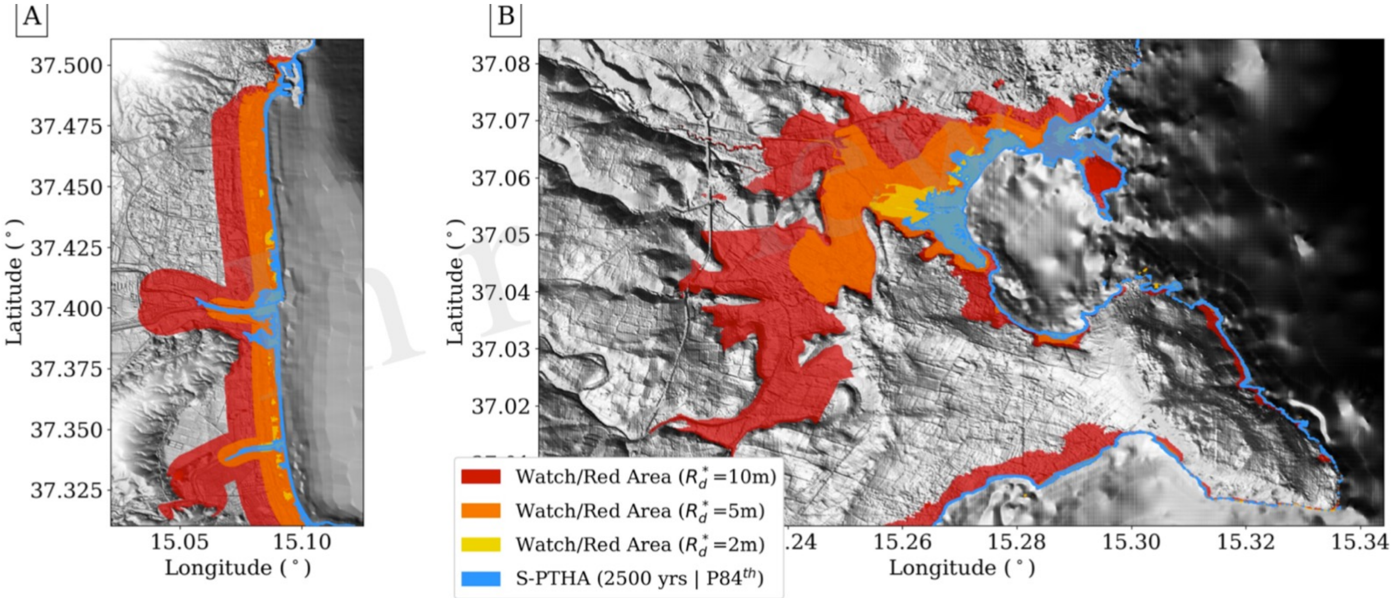


Comparison with 1908 Messina and Reggio tsunami event inundation scenarios

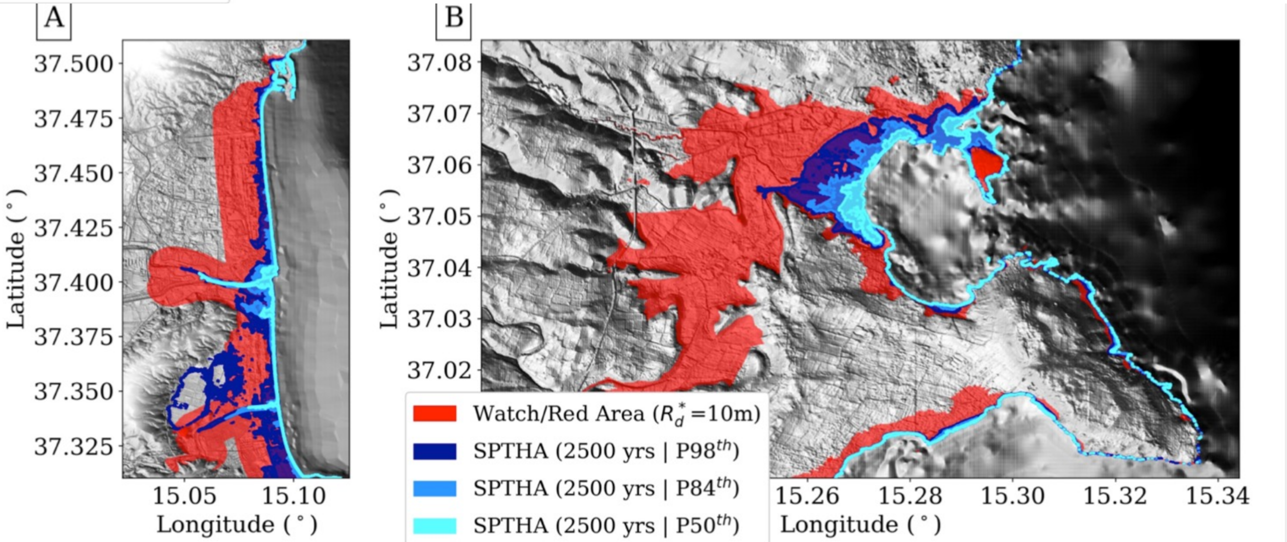


Testing inundation maps for evacuation planning in Italy Tonini et al., 2021

Roberto Tonini[1*], Pio Di Manna[2], Stefano Lorito[1], Jacopo Selva[3], Manuela Volpe[1], Fabrizio Romano[1], Roberto Basili[1], Beatriz Brizuela[1], Manuel J. Castro[4], Marc de la Asuncion[4], Daniela Di Bucci[5], Mauro Dolce[5], Alexander Garcia[6], Steven J. Gibbons[7], Sylfest Glimsdal[7], Josè M. González-Vida[8], Finn Løvholt[7], Jorge Macías[4], Alessio Piatanesi[1], Luca Pizzimenti[1], Carlos Sánchez Linares[4], Eutizio Vittori[2]

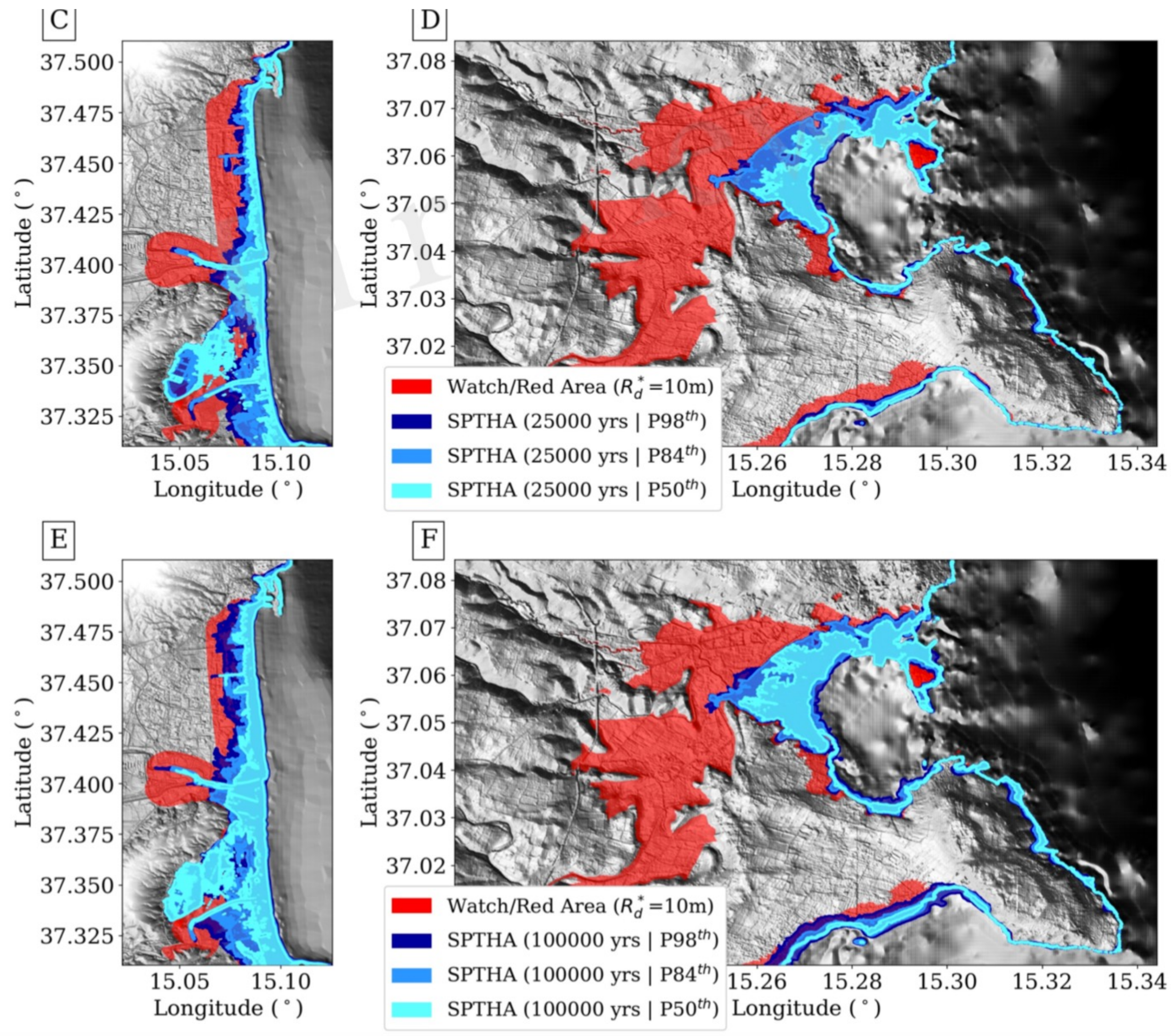


We compared the SiAM indutation maps with numerical modelling results for two site in eastern Sicily: Catania Plain and Syracuse Bay



Testing: comparison with numerical modelling

Testing inundation maps for evacuation planning in Italy Tonini et al., 2021



The comparison corroborates the reliability and goodness of the methodology used in the definition of the SiAM alert zones.

GIS-based inundation maps used for planning deal conservatively with potential hazard underestimation at the local scale

Detailed discussion of the results is available in the paper Tonini et al., 2021