Tsunami inundation mapping

Stefano Lorito

Fabrizio Romano, Manuela Volpe

INGV, Italy

Pio di Manna

ISPRA, Italy

Nikos Kalligeris

Marinos Charalampa

NOA, Greece

Maria Merino Gonzale

Ignacio Aguirre-Ayerb

IHC, Spain

Tsunami Inundation Mapping and Tsunami Evacuation Planning

Muscat, Oman 21-25 April 2024

STEPS of Tsunami Inundation Mapping

HAZARD CURVES, MAPS

- Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level
- Uncertainty of these estimates

THRESHOLDS

- Validation of the hazard maps
- Selection of the design rate/probability/return period
- Selection of the design model uncertainty level
- Safety factors

Here the desired level of risk reduction is implicitly chosen

INUNDATION MAPS

- Selection of the design inundation as a result of the previous steps
- Validation and refinement of the maps

Levels of Analysis - HAZUS, FEMA, USA

1. **Full consideration of source uncertainty**
2. **High-Resolution (5m) Shallow Water Numerical Simulations**

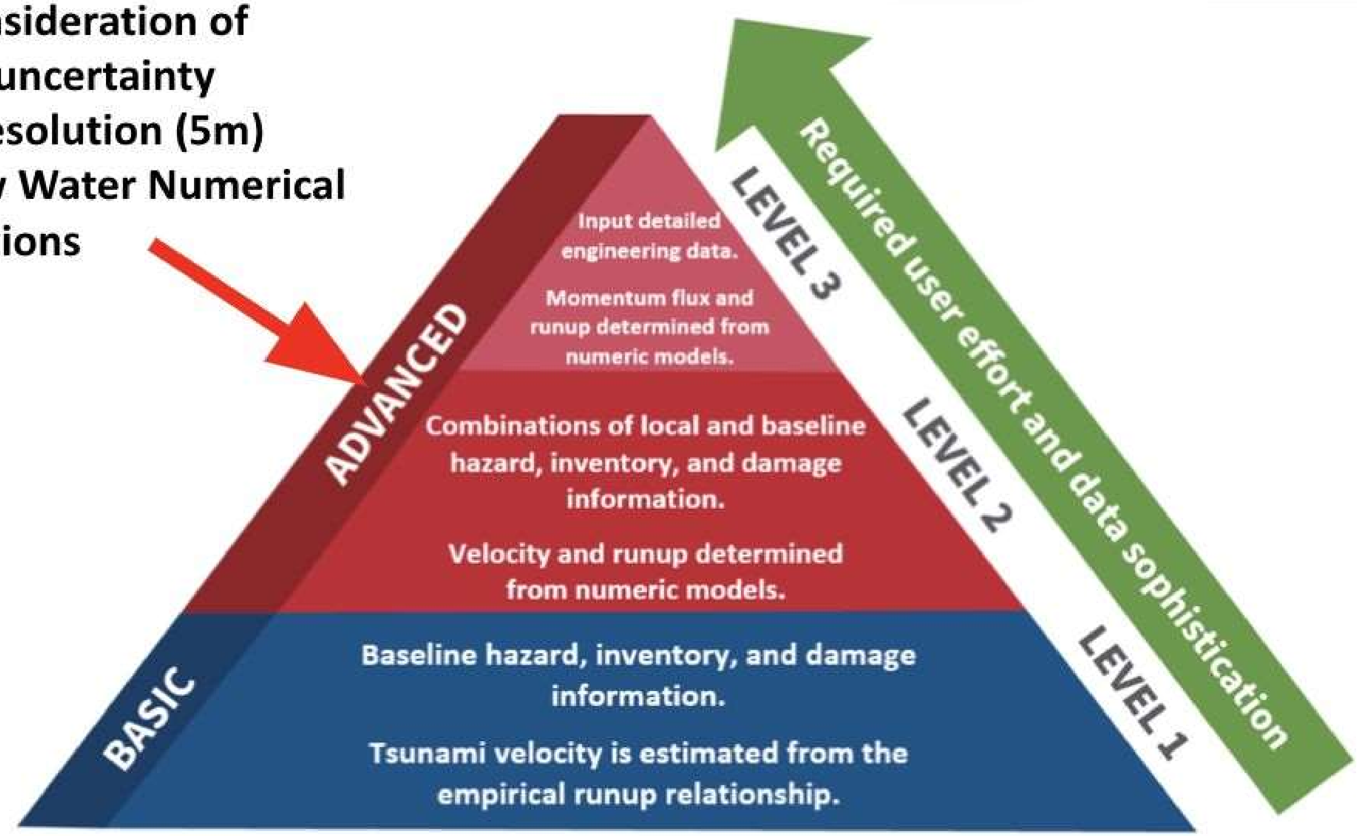
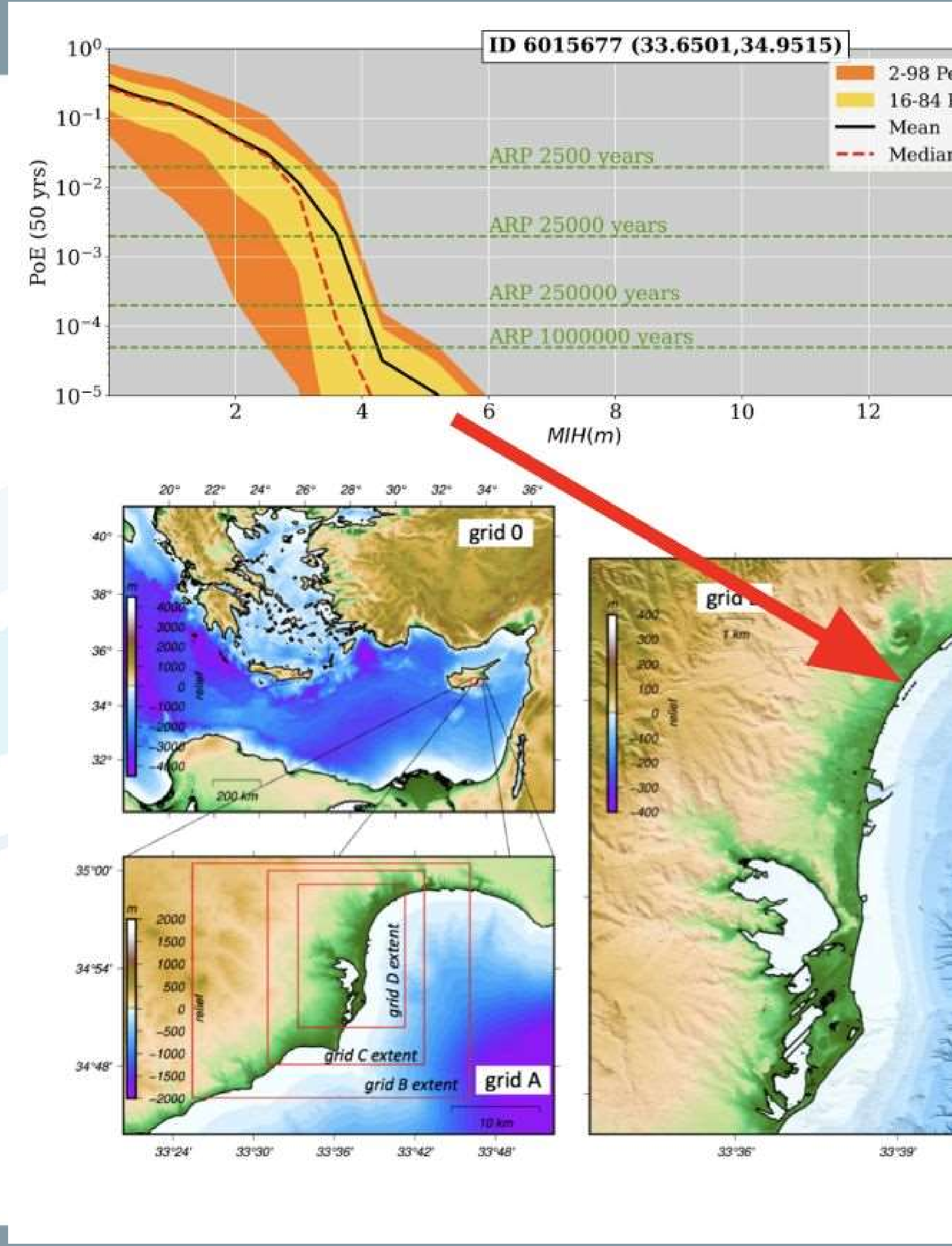


Figure 2-2 Levels of Analysis

Hazard Mapping

HAZARD CURVES, MAPS

- **Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level**
- **Uncertainty of these estimates**

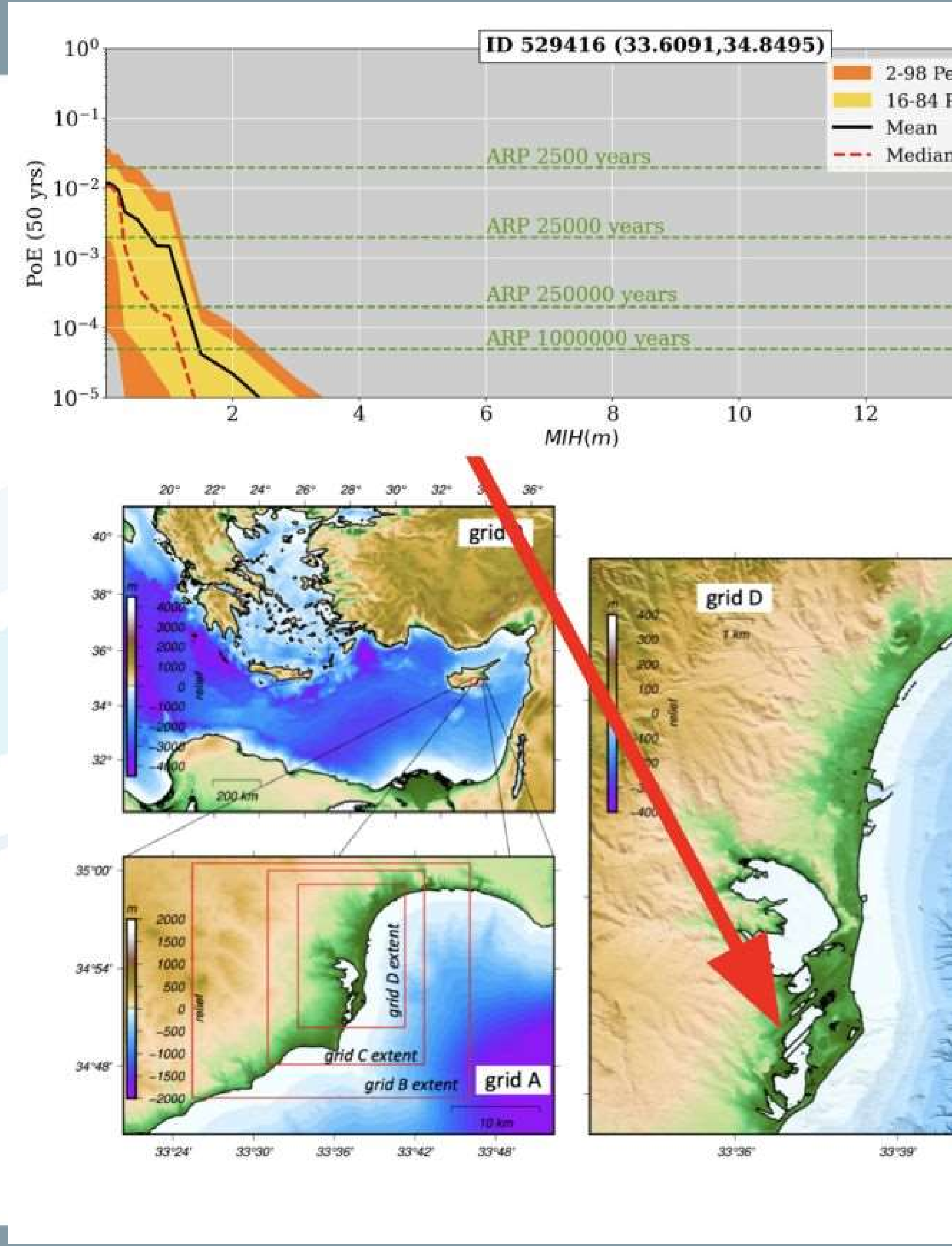


CENTRO ALLERTA TSUNAMI

Hazard Mapping

HAZARD CURVES, MAPS

- **Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level**
- **Uncertainty of these estimates**



CENTRO ALLERTA TSUNAMI

Information flux

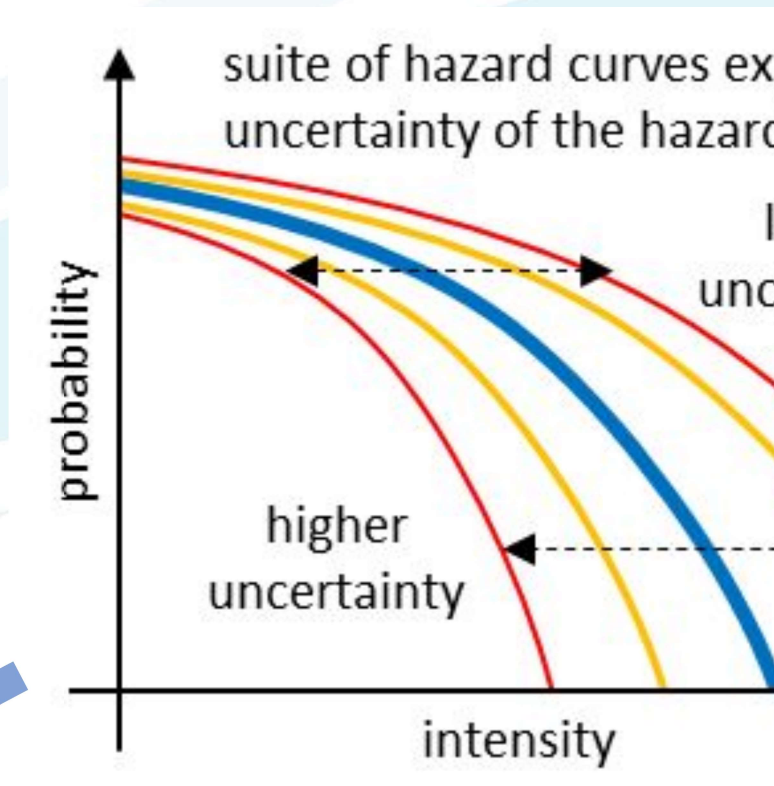
Step-1: Probabilistic earthquake model

Step-2: Tsunami generation & modeling in deep water

Step-3: Shoaling and inundation

Step-4: Hazard aggregation & uncertainty quantification

Hazard Curve



Information flux

Step-1: Probabilistic earthquake model

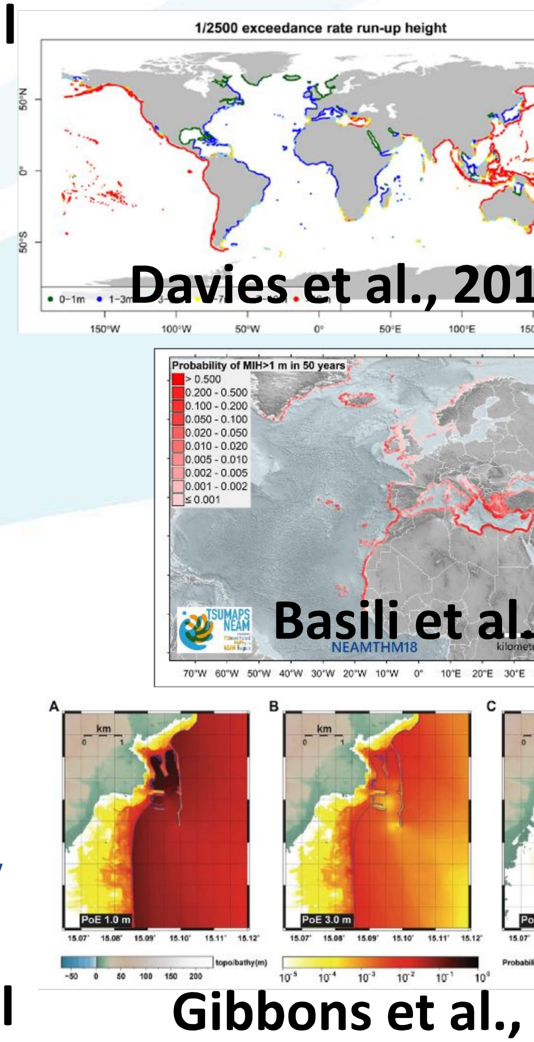
Step-2: Tsunami generation & modeling in deep water

Step-3: Shoaling and inundation

Step-4: Hazard aggregation & uncertainty quantification

Applies to all scales

Global



Local

HAZARD CURVES, MAPS

- Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level
- Uncertainty of these estimates

NEAMTHM18

Basili et al., 2018; 2019; 2021 (Documentation+Data+Paper)

TSUMAPS NEAM
Probabilistic TSUnami Hazard MAPS for the NEAM Region

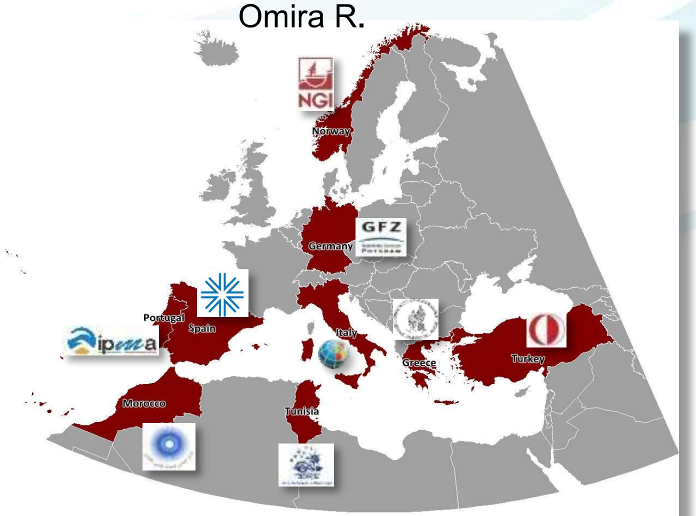
The TSUMAPS-NEAM project at a glance (https://tsumaps-ne

NEAMTHM18 is the main outcome of the TSUMAPS-NEAM project whose objectives

- produce the first region-wide long-term homogenous time-independent **PTHA** from **earthquake sources** for the **NEAM** coastlines;
- trigger a common tsunami risk management strategy in the region.

INGV	NGI	IPMA	GFZ	METU	UB	NOA	CNRST	INM
Italy	Norway	Portugal	Germany	Turkey	Spain	Greece	Morocco	Tunisia
Basili R.	Harbitz C.B.	Baptista M.A.	Babeyko A.	Yalciner A.	Canals M.	Papadopoulos G.	Benchekroun S.	Ben Abdallah S.
Lorito S.	Løvholt F.	Carrilho F.	Hoechner A.	Pekcan O.	Lastras G.	Agalos A.		Agrebi Jaouadi H.
Selva J.	Glimsdal S.	Matias L.		Gurbuz M.		Triantafyllou, I.		Attafi K.
Brizuela B.		Omira R.						Bouallegue A.
Iqbal S.								Hamdi H.
Maesano F.E.								Oueslati F.
Murphy S.								
Perfetti P.								
Romano F.								
Scala A.								
Taroni M.								
Thio H.K.								
Tiberti M.M.								
Tonini R.								
Volpe M.								
Herrero A.								

Dura
(01/



End Users and Advisers

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE
Institute for the Protection and Security of the Citizen
The Director

EPOS

USGS science for a changing world

UNESCO

SRB-RAS

EW

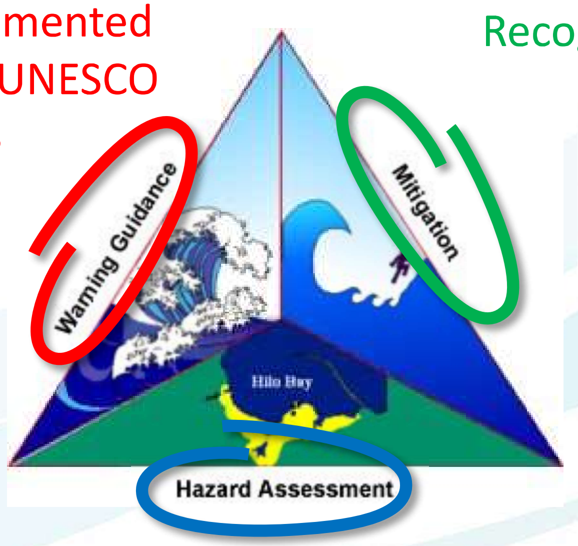
HPC support by

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

NEAM = **N**orth-**E**astern **A**tlantic, the **M**editerranean, and connected Seas

Tsunami Early Warning has been implemented within the IOC UNESCO ICG/NEAMTWS framework

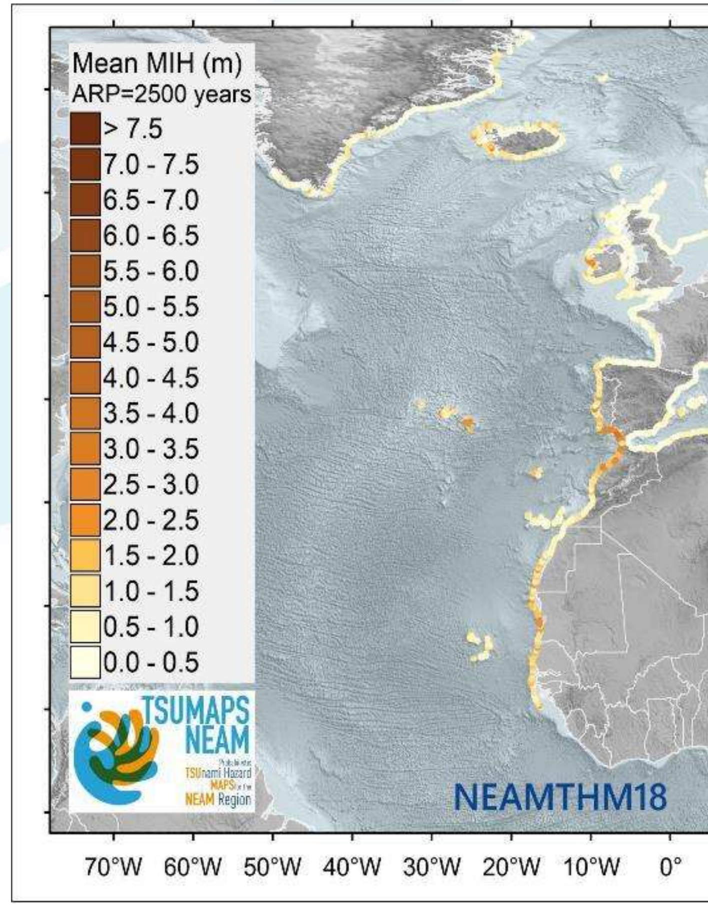


Tsunami Ready Recognition Program

Tsunami Ready

United Nations Educational, Scientific and Cultural Organization · Intergovernmental Oceanographic Commission

NEAM Tsunami Hazard Model 2018 (NEAMTHM18)



https://tsumaps-neam.eu/

Historical tsunami database in the Mediterranean region

(Marama

294 tsunami events from 6150 BC to the present

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

Paleotsunami database in the Mediterranean region

151 sites and 220 tsunami evidence (events)

(De Martini et al., 20

- Conditions for preserving tsunami deposits must exist
- Scientists have to find out, perform analyses, publish results
- Analysts should carry out the hazard estimations

In the most favorable circumstanc
history at a given site cannot exter
more than a few thousand years

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

Local 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

S-PTHA

Limited observation com

Tsunami hazard

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

Scenarios Proba

Tsunami imp

Computation-bas

Local 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

S-PTHA

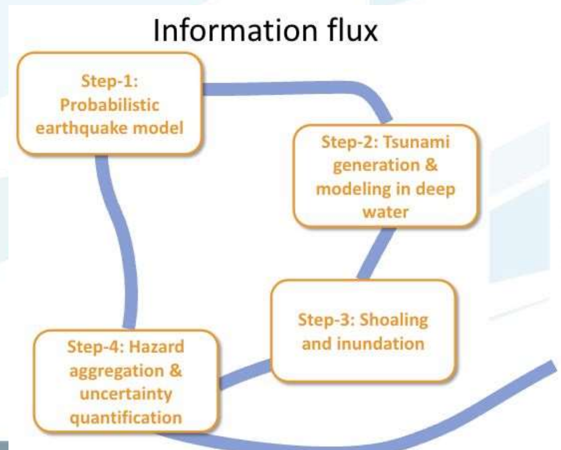
Limited observation com

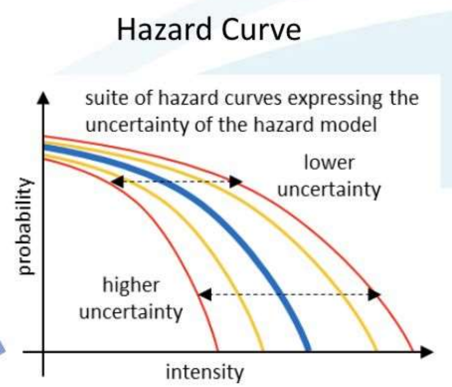
Tsunami hazard
- Potential Tsunamigenic sources (geology)
- Seismological information
- Numerical modeling

Scenarios Proba

Tsunami imp

Computation-bas

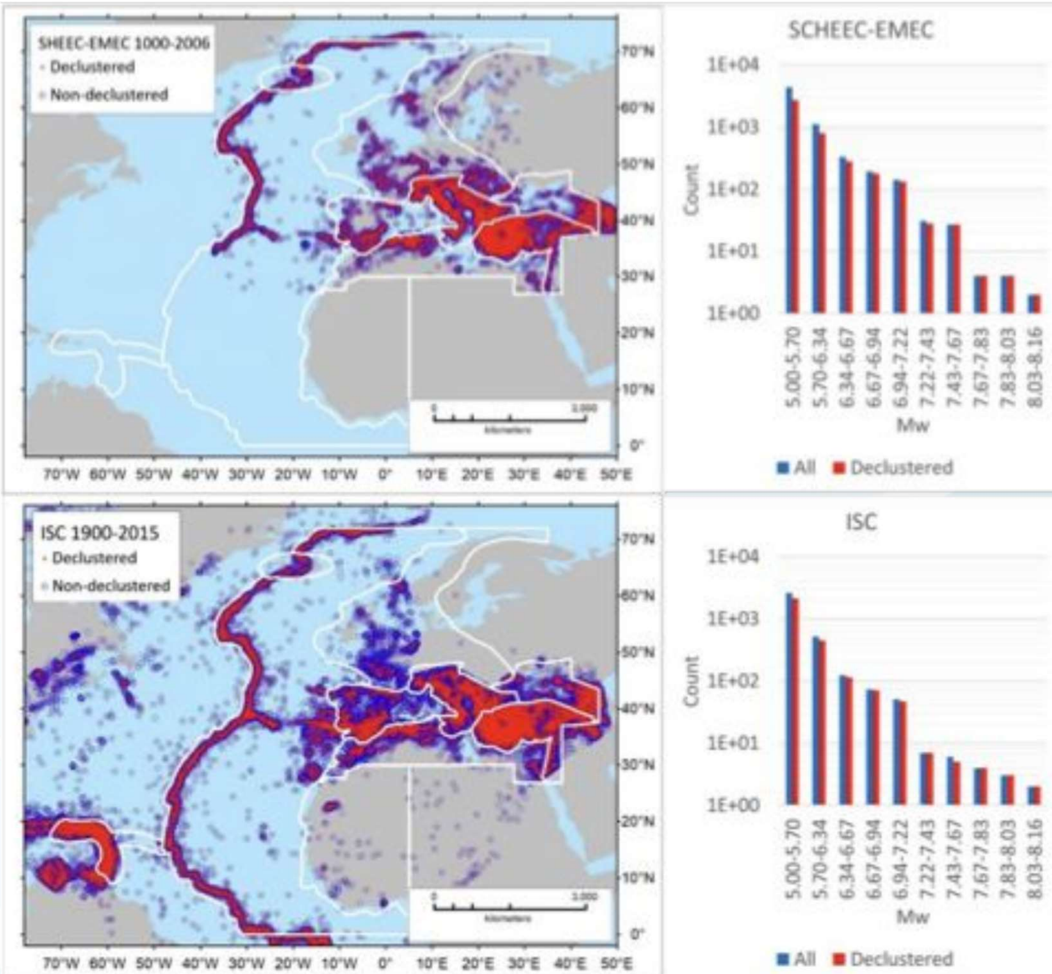


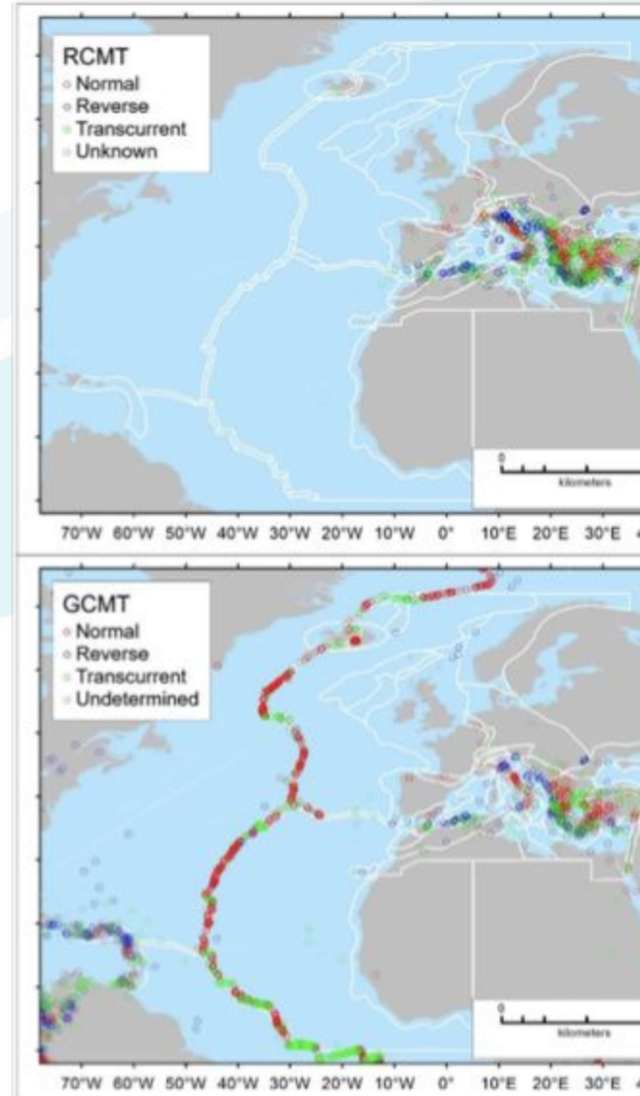


CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

Seismic data

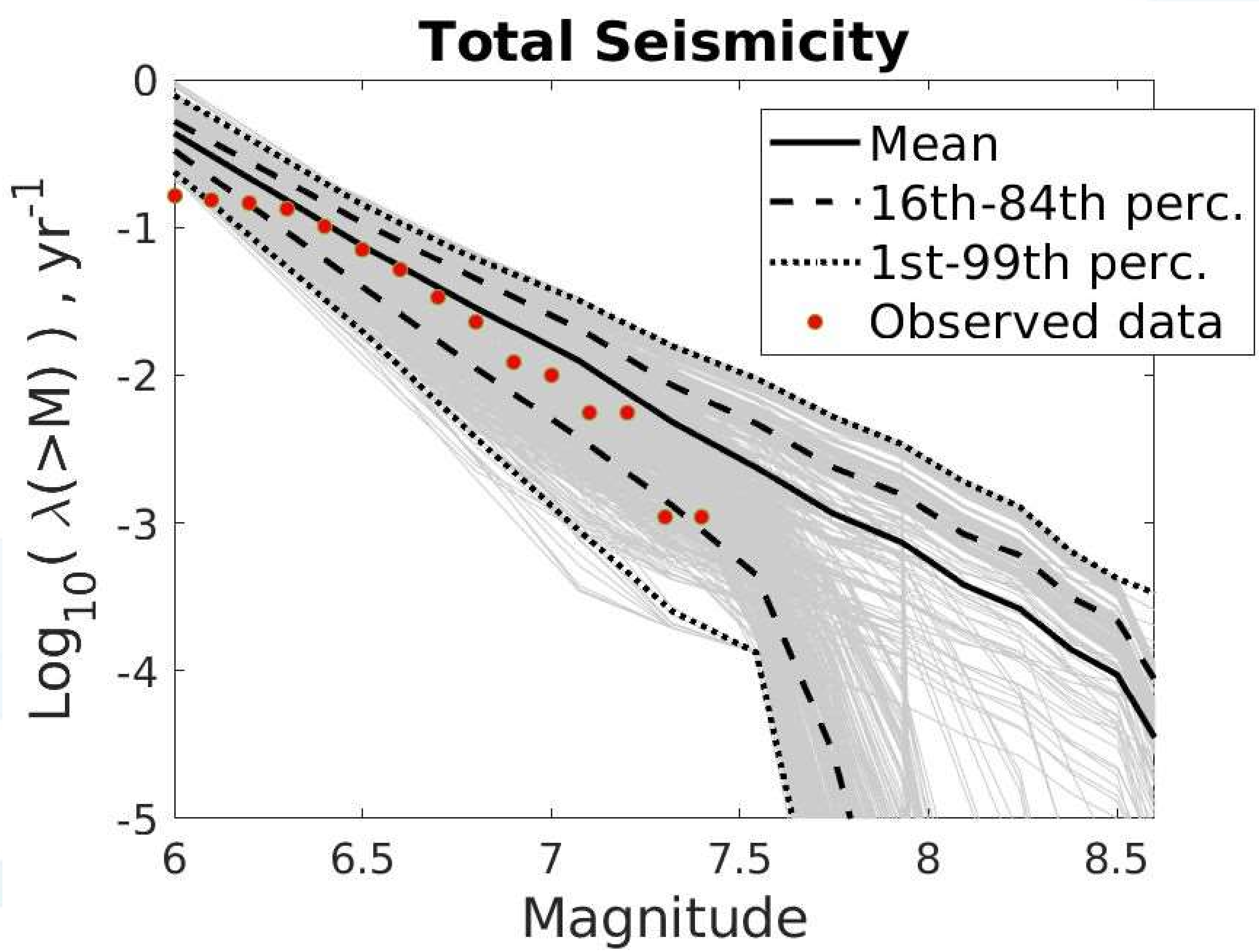




CENTRO
ALLERTA
TSUNAMI

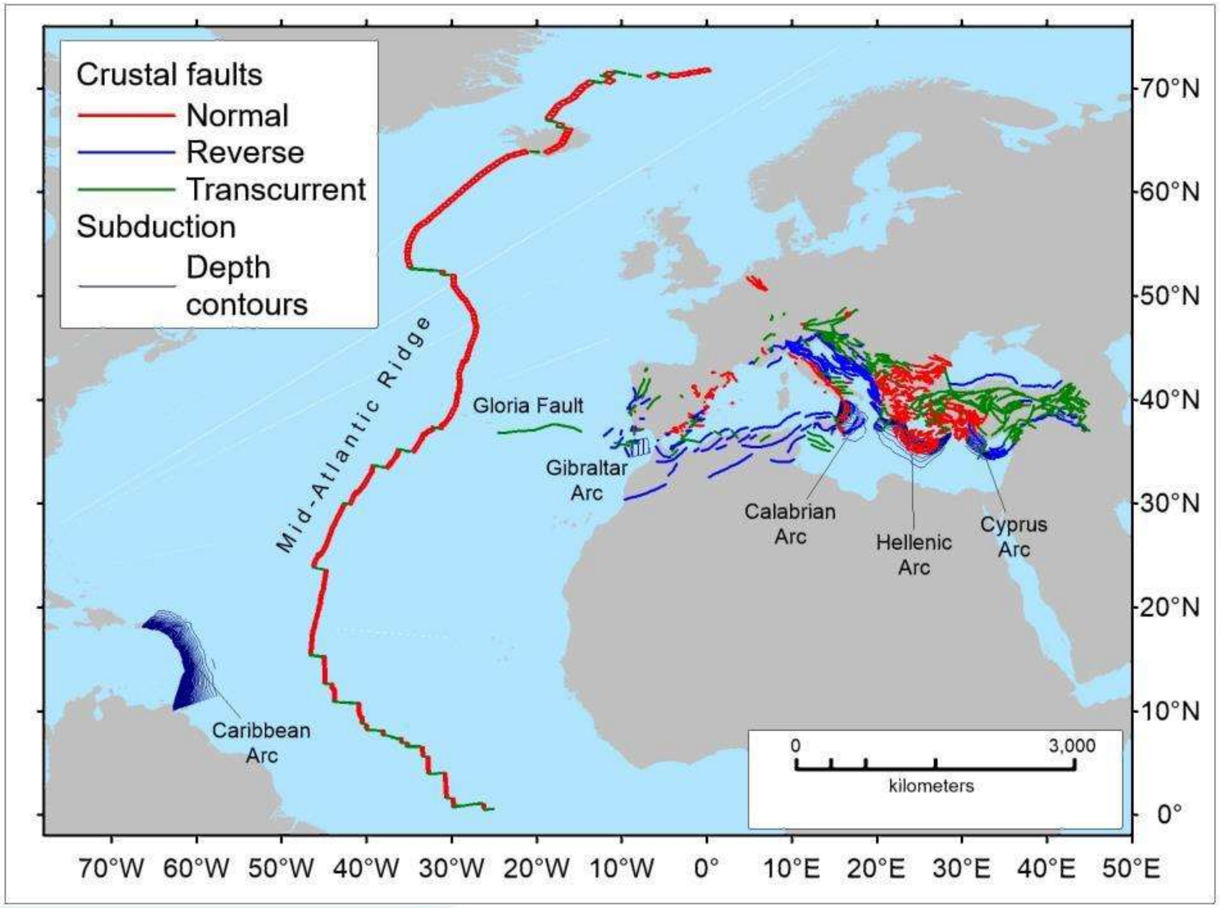
ISTITUTO NAZIONALE DI GEOFISICA E VU

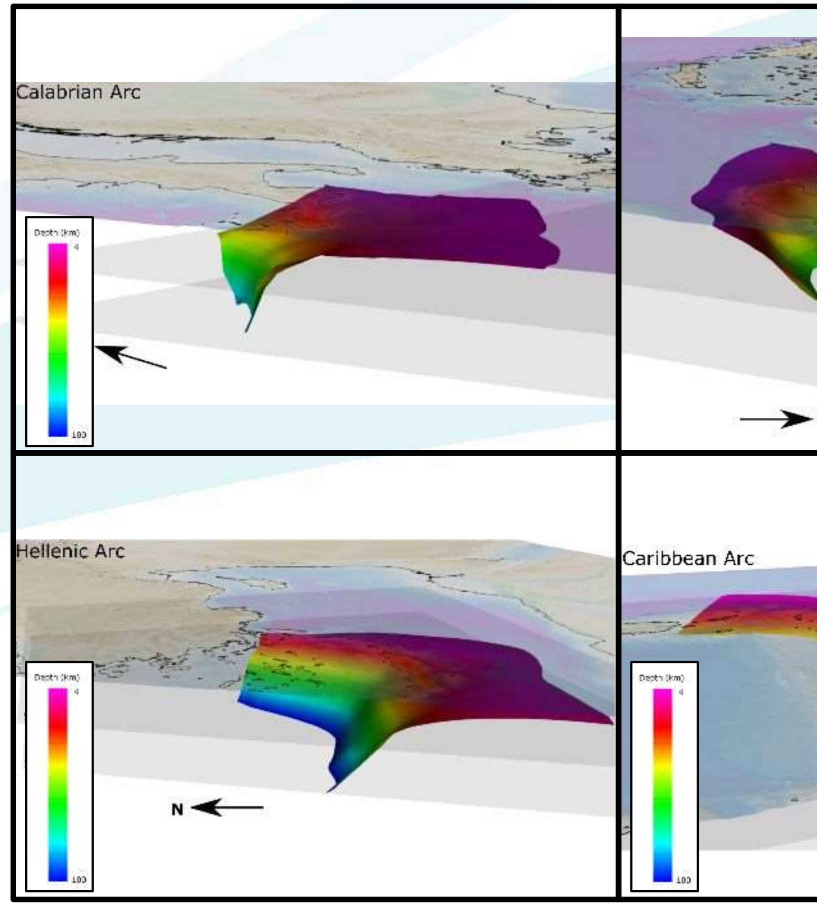
Magnitude-frequency distributions



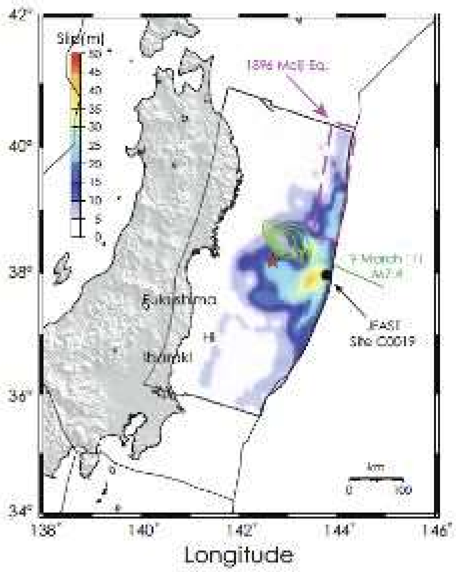
Example of frequency-magnitude distributions for the Kefalonia-Lefkada, Greece region

Crustal faults and subduction interfaces



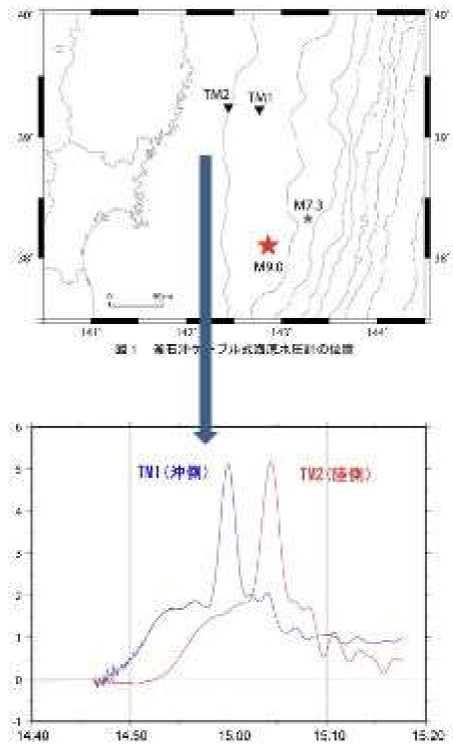


Importance of slip heterogeneity

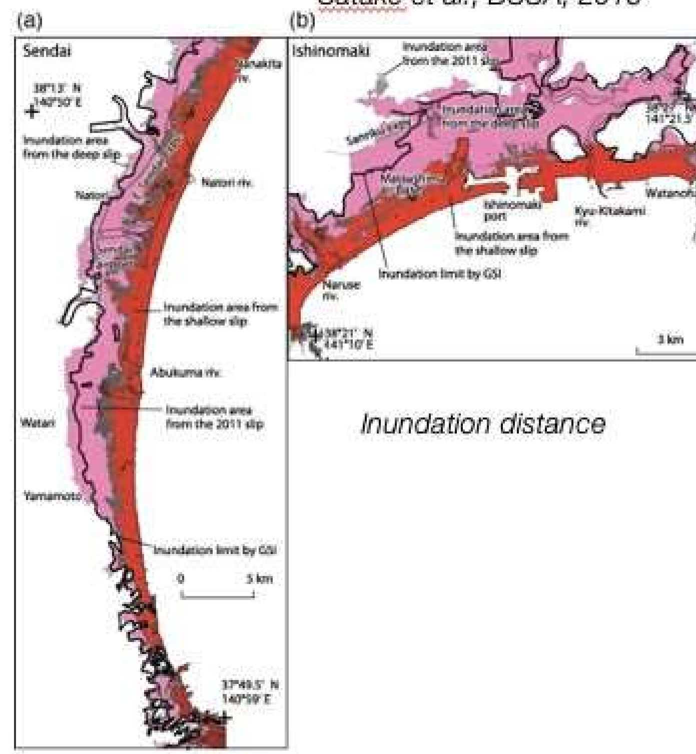


Romano et al., SREP, 2014

Romano et al., SREP, 2014



Satake et al., BSSA, 2013



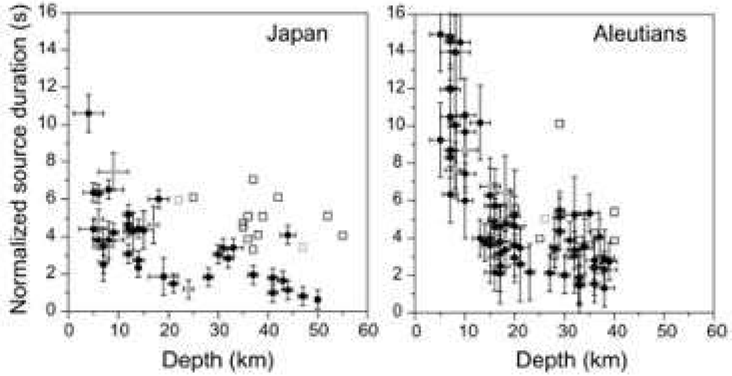
Inundation distance

Shallow slip	➔	Short wavelength	➔	Small inundation distance
Deep slip	➔	Long wavelength	➔	Large inundation distance

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

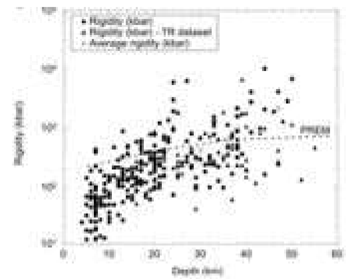
Depth-dependent earthquake features



$$\tau = T\left(\frac{M_0^{ref}}{M_0}\right)^{1/3}$$

To make the observable independent from the size of the event

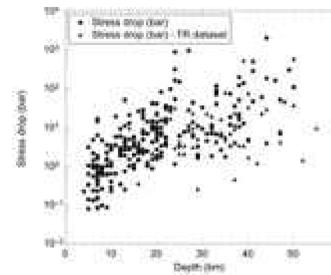
Uniform stress drop

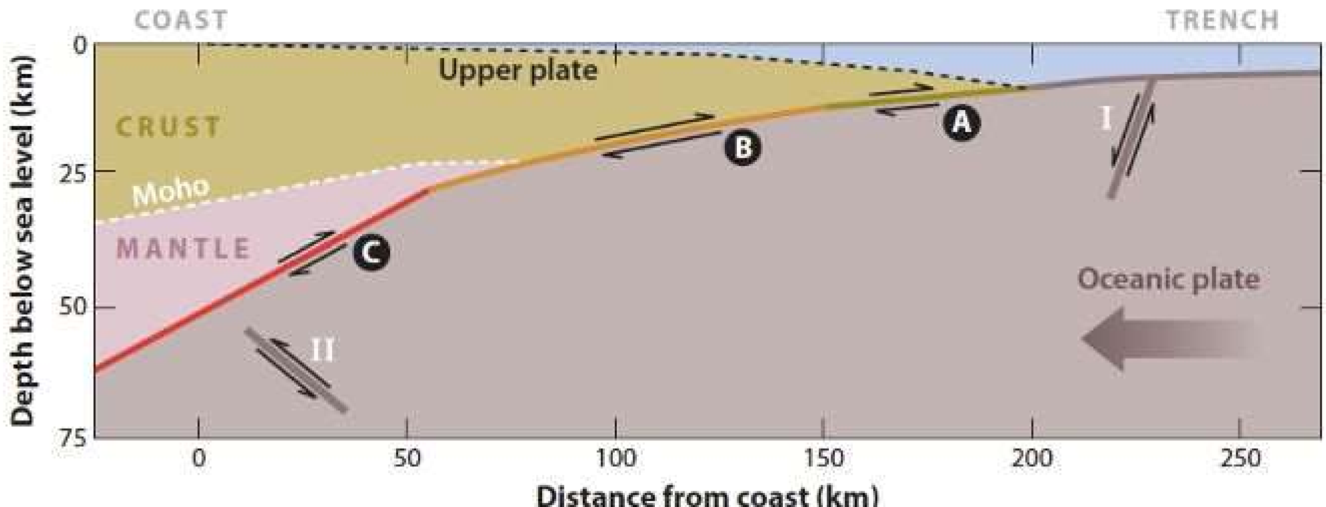


$$\tau \sim \frac{L(\sim\Delta\sigma^{-1/3})}{V_r(\mu^{1/2})}$$

Bilek & Lay 1999 Nature

Uniform rigidity





Lay et al., JGR, 2012
Kanamori, AREPS, 2014

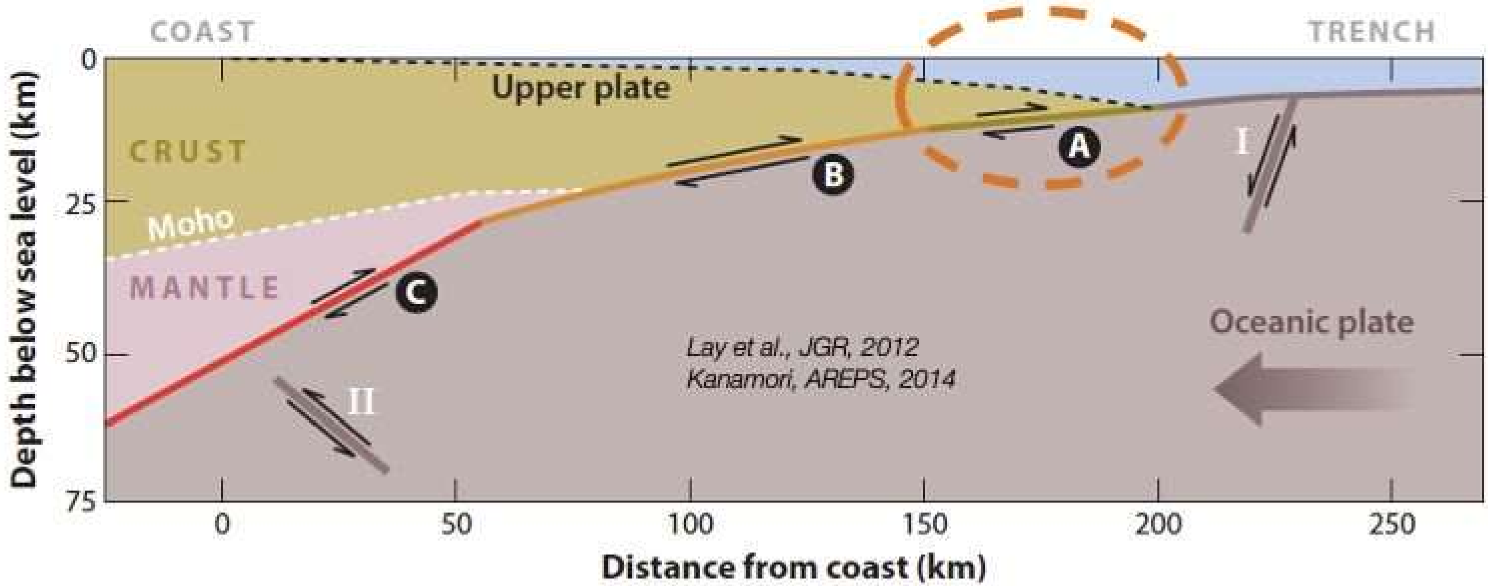
Depth-dependent earthquake features (tsunami earthqu

Earthquakes that directly cause a regional and/or teleseismic tsunami that is greater in amplitude than would be typically expected from their seismic moment magnitude

Polet & Kanamori, 2009

Two families of simplified models:

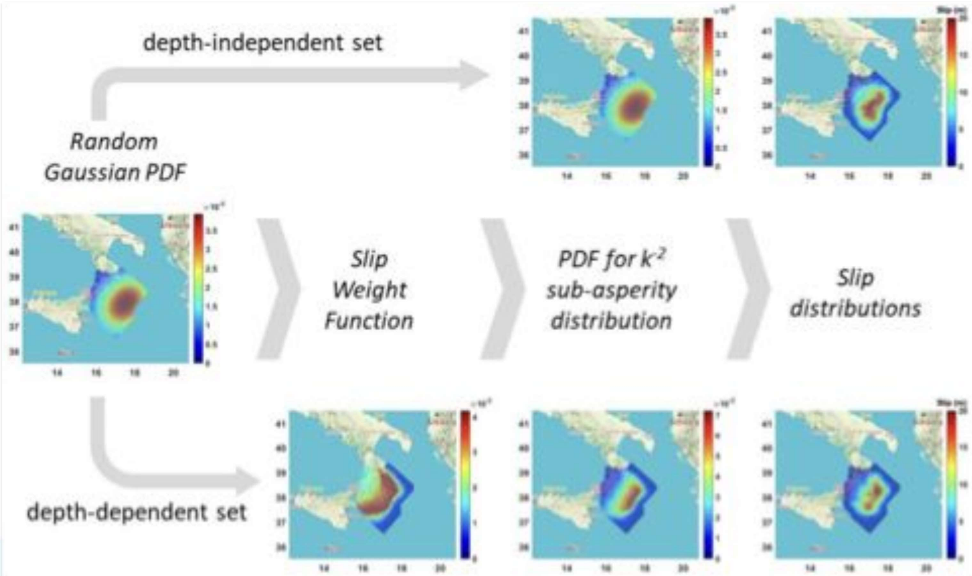
- Slumping-like displacement of accretionary wedge
- Splay fault

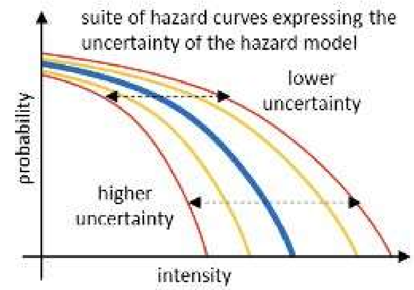


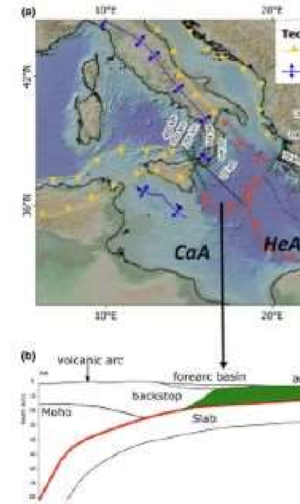
$M_0 = \mu AD$

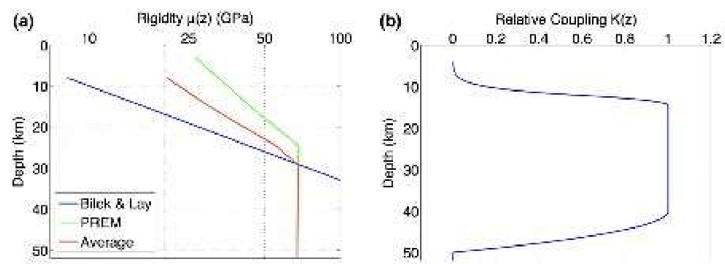
Shallow (i.e. low rigidity μ) → Slip D increases

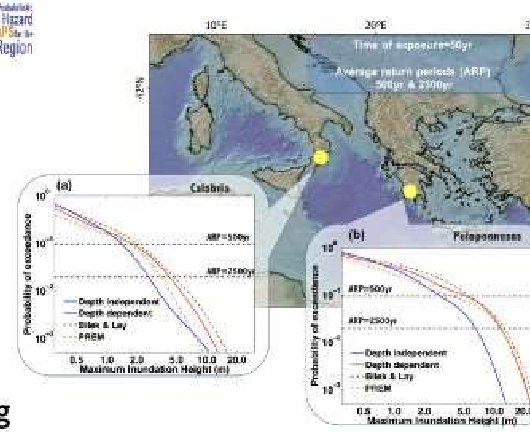
Treatment in NEAMTHM18







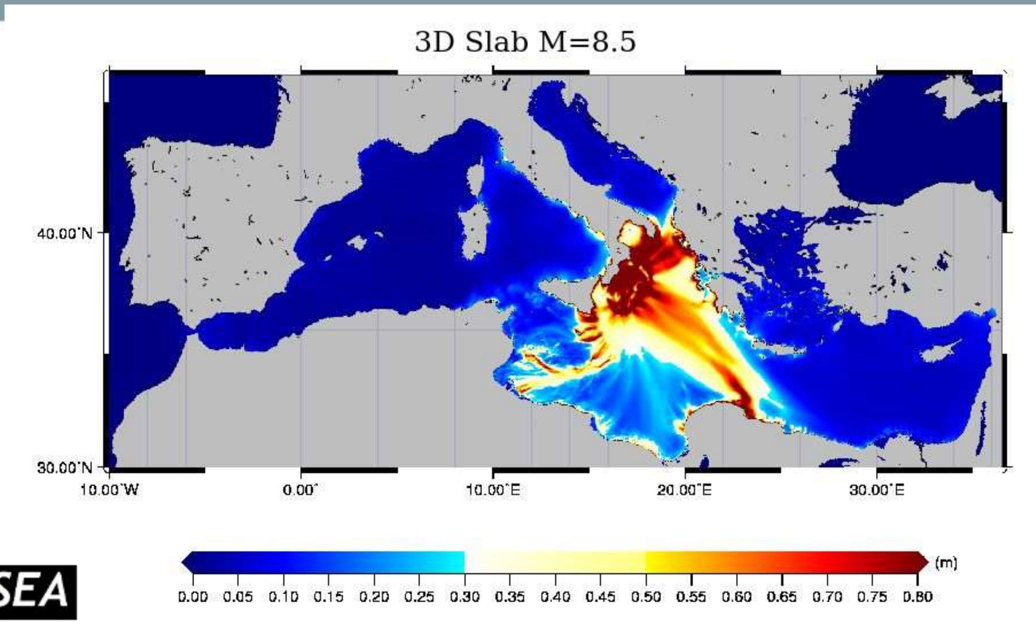




Depth-dependent rigidity and coupling – Long term Rate Balancing
Scala et al., PAGEOPH, 2019

CENTRO
ALLERTA
TSUNAMI

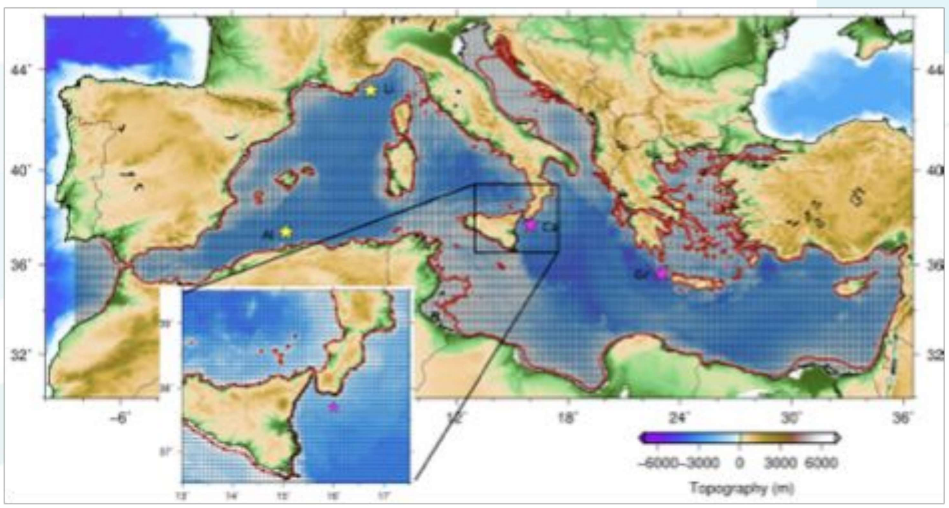
For each seismic source and each point of interest (POI)= Millions of tsunam



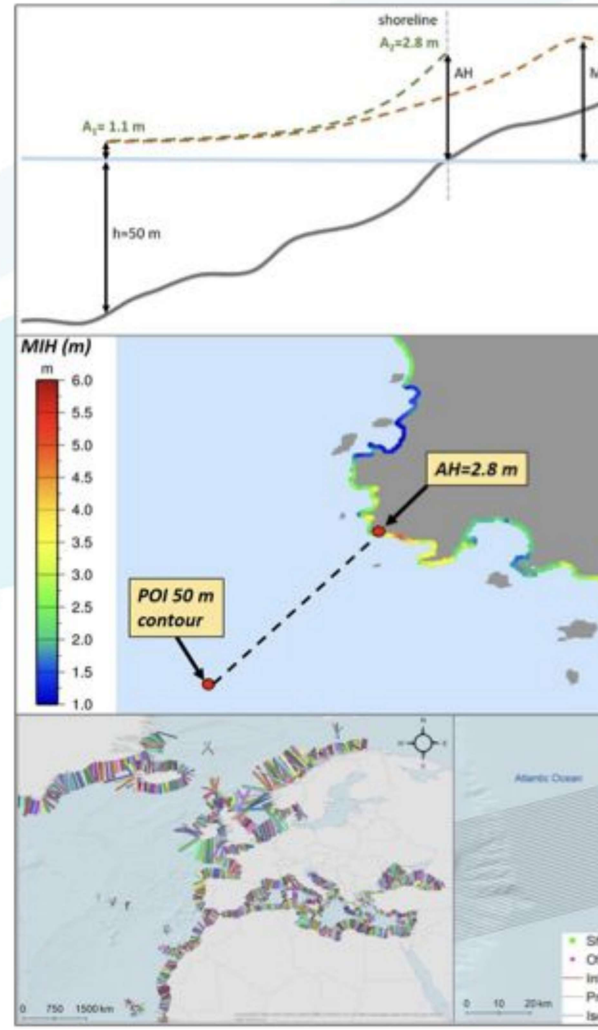
HySEA

CINECA

UNIVERSITAS MALACITANA



Molinari et al., 2016

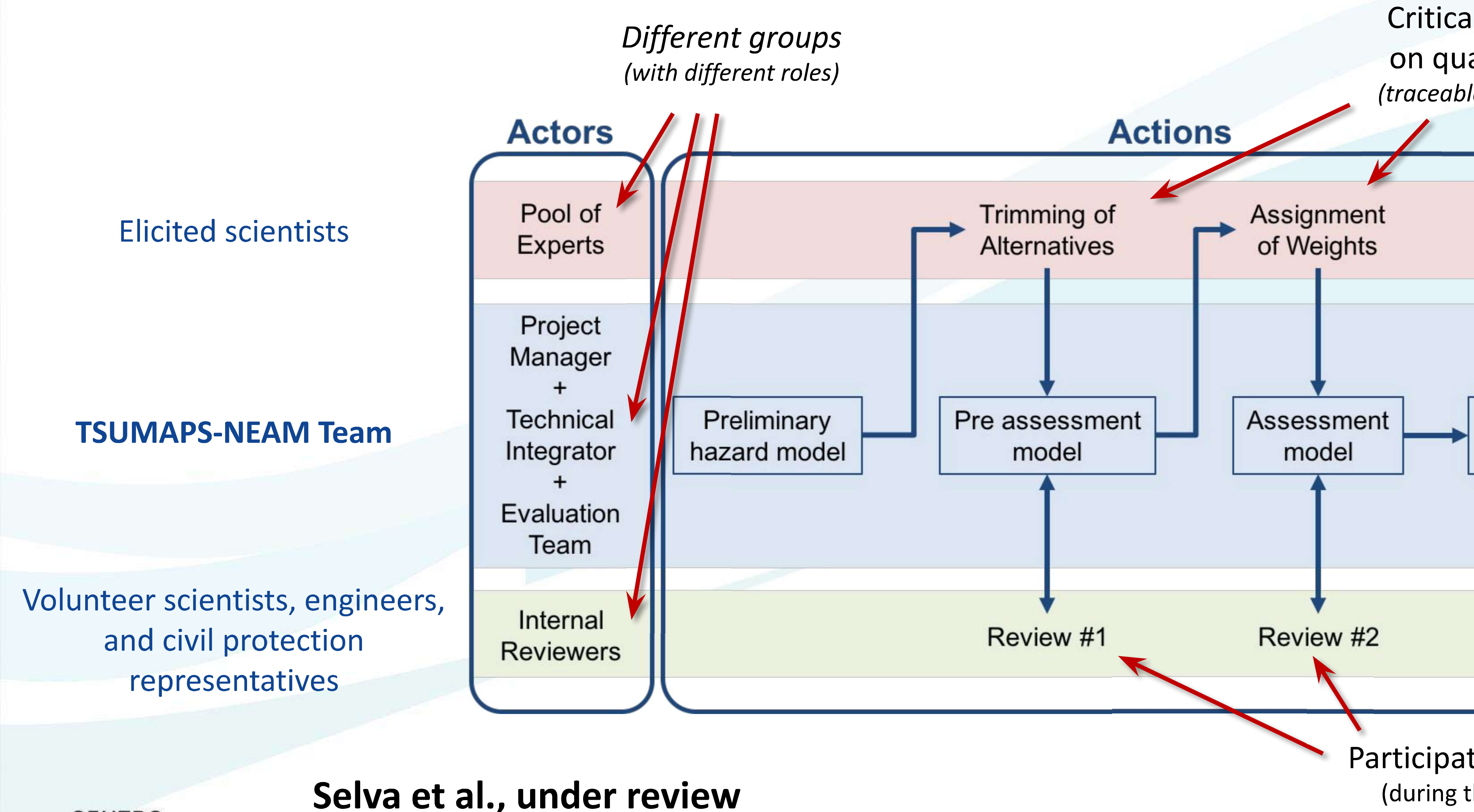


Glimsdal et al., 2019

CENTRO ALLERTA TSUNAMI

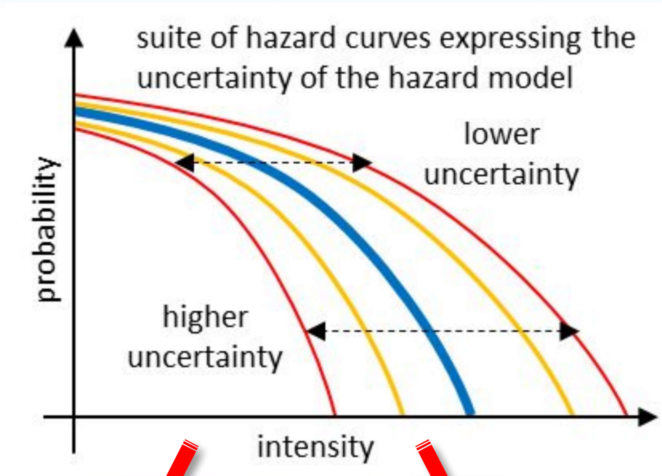
ISTITUTO NAZIONALE DI GEOFISICA E VU

Multiple-Expert Management Protocol



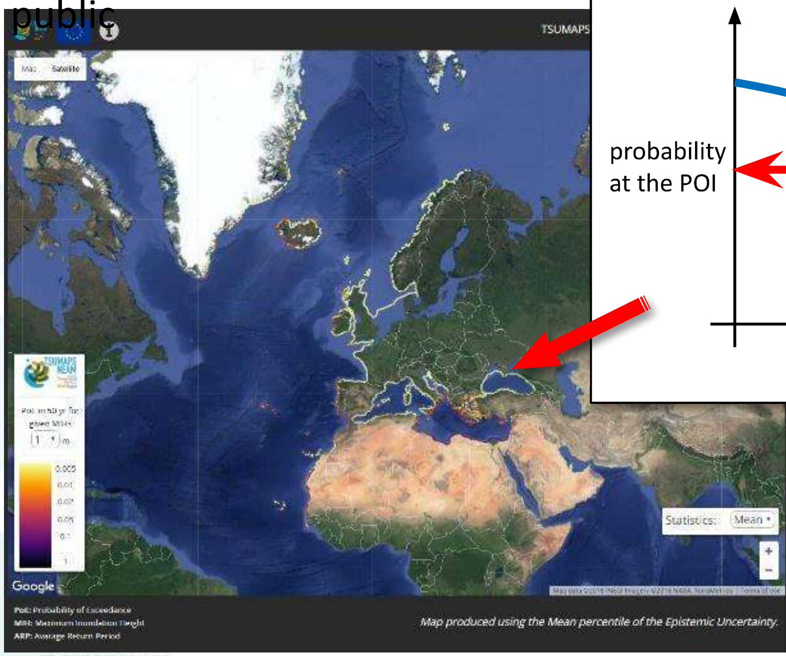
Selva et al., under review

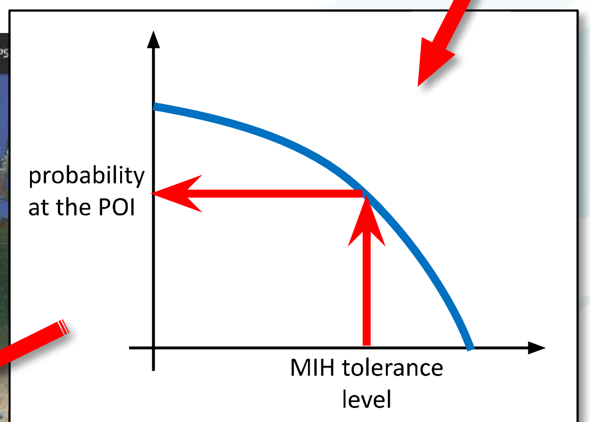
NEAMTHM18 Results: Probability and Hazard Maps

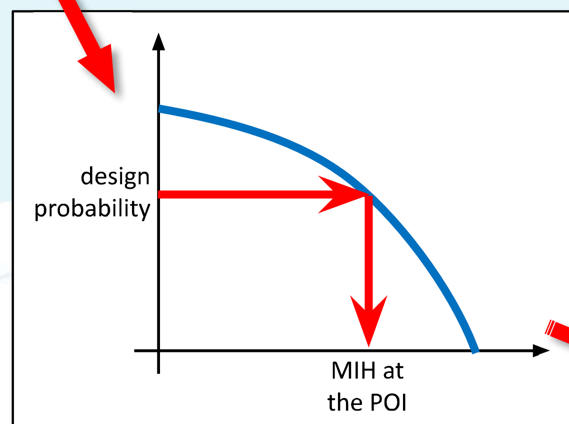


PROBABILITY MAPS

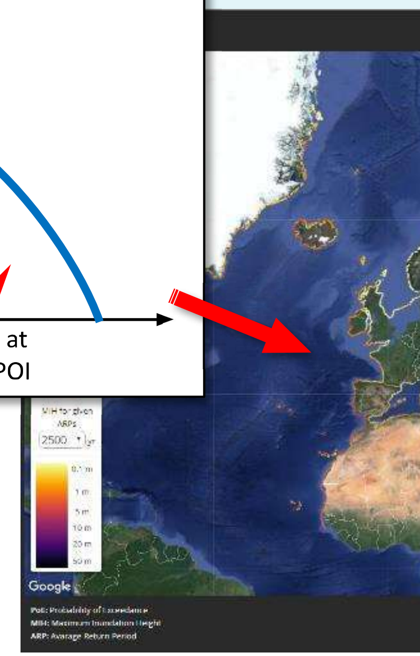
more effective to communicate the hazard to administrators, decision-makers, and the general public







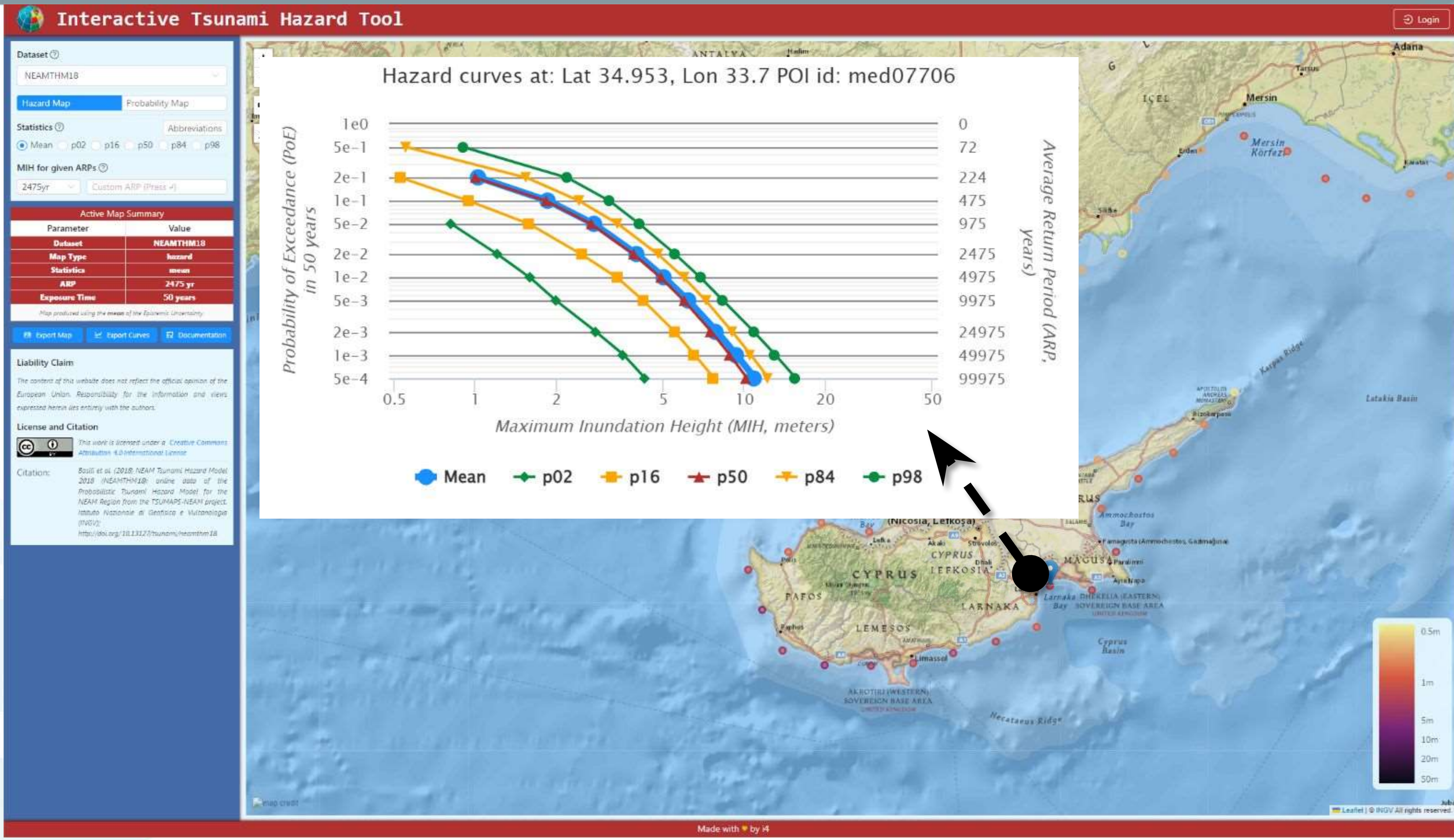
HAZ



CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

NEAMTHM18 sample hazard curves



from NEAMTH18 to inundation mapping in Italy

“Separation” between scientific input and

HAZARD CURVES, MAPS

- Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level
- Uncertainty of these estimates

THRESHOLDS

- Validation of the hazard maps
- Selection of the design rate/probability/return period
- Selection of the design model uncertainty level
- Safety factors

Here the desired level of risk reduction is implicitly chosen

from NEAMTH18 to inundation mapping in Italy

"Separation" between scientific input and

HAZARD CURVES, MAPS

- Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level
- Uncertainty of these estimates

THRESHOLDS

- Validation of the hazard maps
- Selection of the design rate/probability/return period
- Selection of the design model uncertainty level
- Safety factors

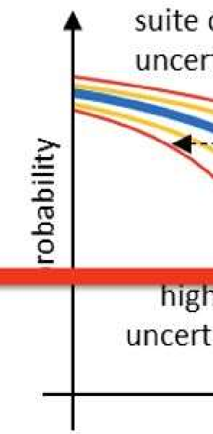
Here the desired level of risk reduction is implicitly chosen

For coastal planning (evacuation maps)

- 2500 yr ARP
- 84th percentile

i.e.

~ 2% in 50 yr



Similar approaches:

- New Zealand inundation mappin
- US ASCE7-16 Building Codes

Tonini et al.,

Alert Levels

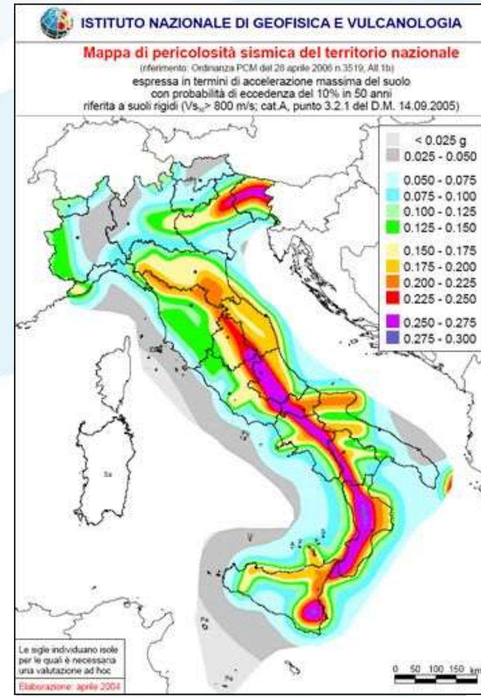
Advisory: run-up up to 1 m

Watch: run-up exceeding 1m

First version of National Coastal Planning is based on TSUMAPS-NEAM

For coastal planning (evacuation maps)

- 2500 yr ARP
- 84th percentile



Seismic Hazard map, by law:
Accelerazione (g) attesa con una probabilità del 10%
in 50 anni, riferiti a suoli con Vs30 > 800 m/s
Incertezza al 16 e 84 percentile

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

from NEAMTH18 to inundation mapping in Italy

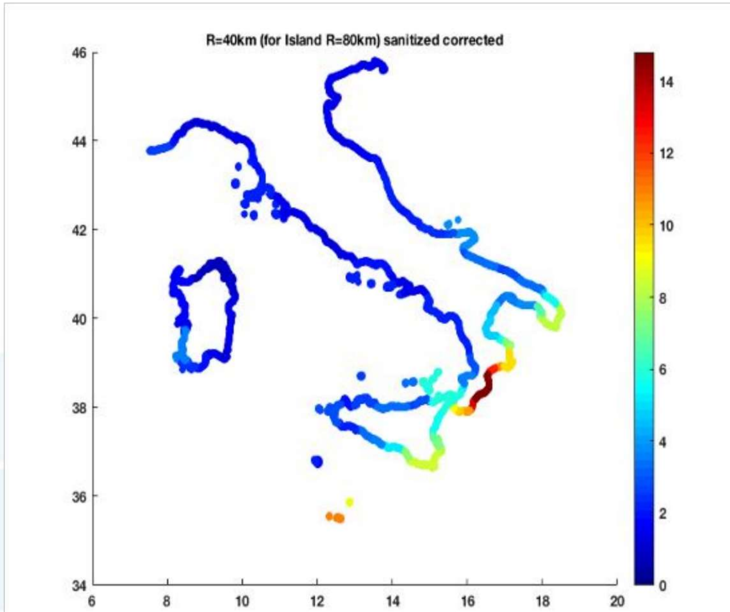
Alert Levels

Advisory: run-up up to 1 m

Watch: run-up exceeding 1m

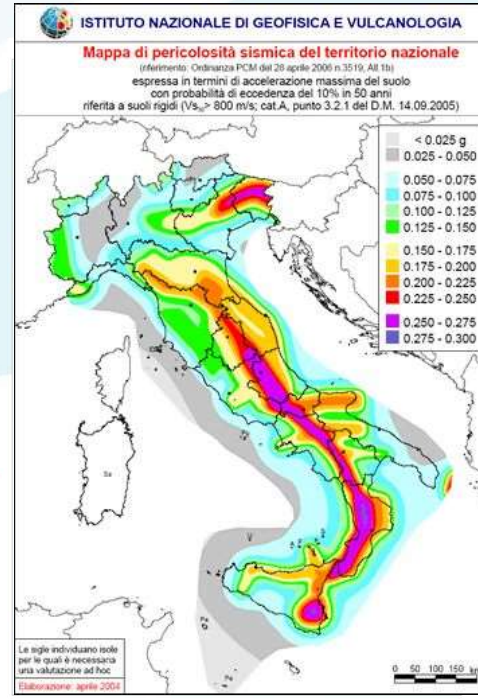
Tonini et al.,

First version of National Coastal Planning is based on TSUMAPS-NEAM



For coastal planning (evacuation maps)

- 2500 yr ARP
- 84th percentile
- Maxima within search radii of 40 to account for relatively low resolution



Seismic Hazard map, by law:
Accelerazione (g) attesa con una probabilità del 10%
in 50 anni, riferiti a suoli con Vs30 > 800 m/s
Incertezza al 16 e 84 percentile

CENTRO ALLERTA TSUNAMI

ISTITUTO NAZIONALE DI GEOFISICA E VU

STEPS of Tsunami Inundation Mapping

HAZARD CURVES, MAPS

- Model for the Exceedance rate/probability for a given time interval of different values for the hazard intensity, typically the flow depth, or the height with respect to the sea level
- Uncertainty of these estimates

THRESHOLDS

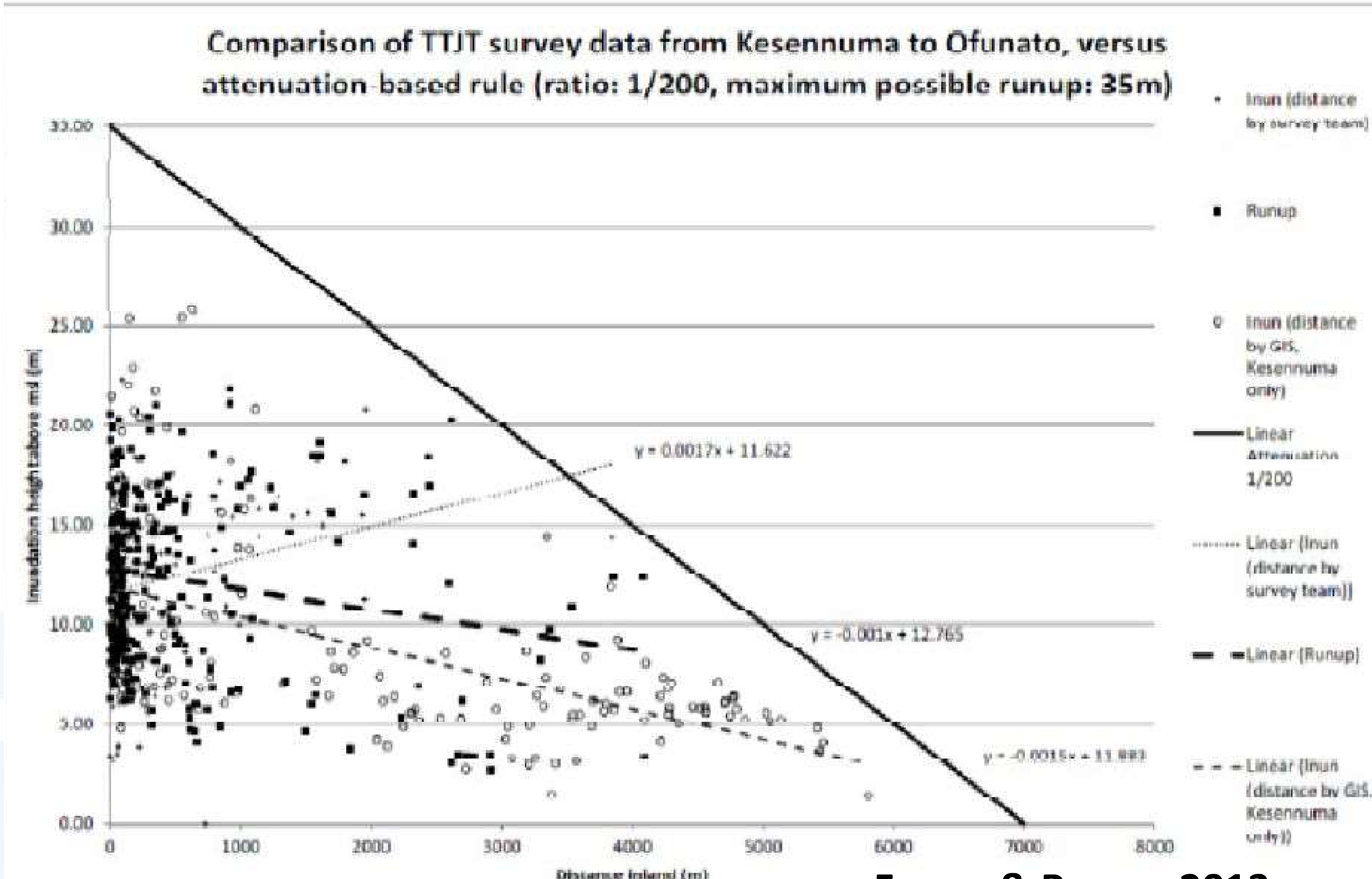
- Validation of the hazard maps
- Selection of the design rate/probability/return period
- Selection of the design model uncertainty level
- Safety factors

Here the desired level of risk reduction is implicitly chosen

INUNDATION MAPS

- Selection of the design inundation as a result of the previous steps
- Validation and refinement of the maps

Methodology: empirical approach for i



Fraser & Power, 2013

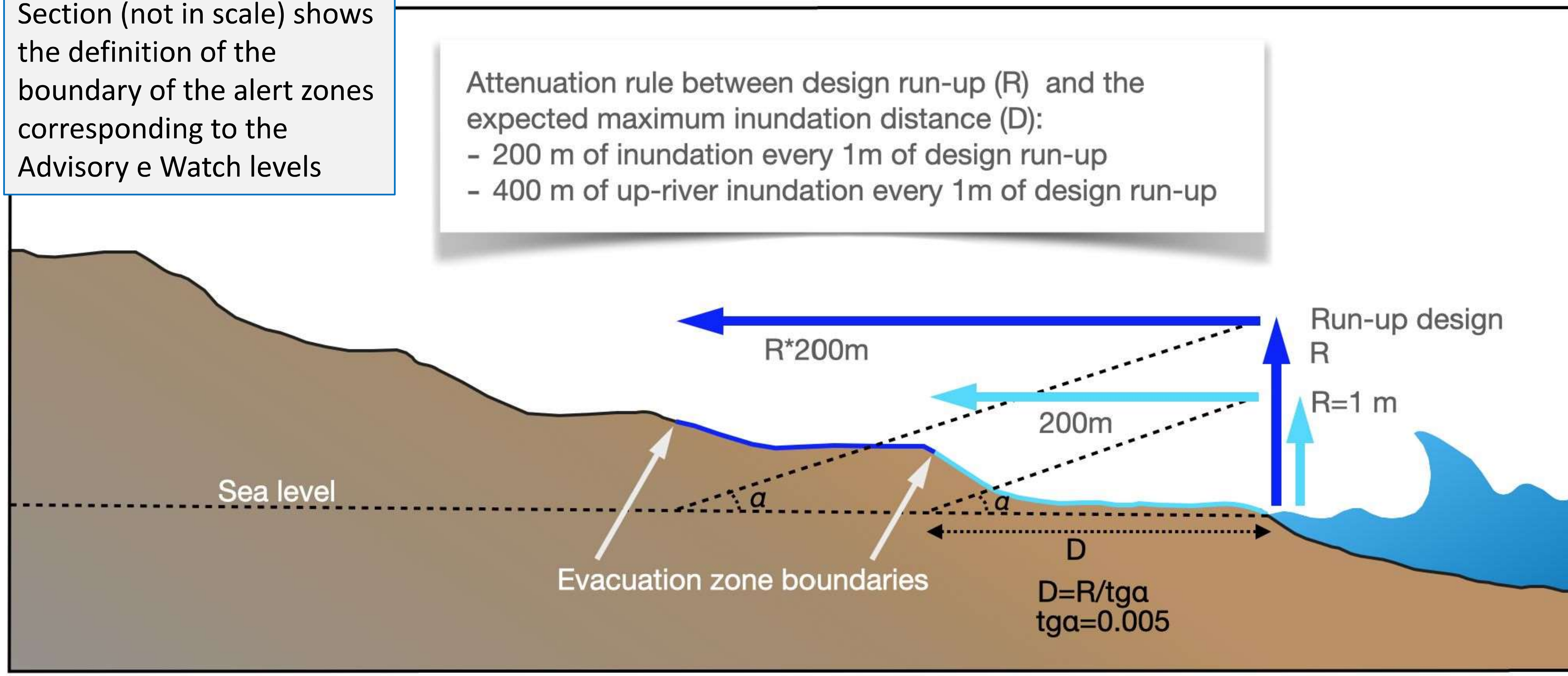
We adopted a GIS- b approach following a empirical model of propagation and inundation.

Following Fraser & P (2013), a linear atten rule between the R (run-up) values and I 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 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

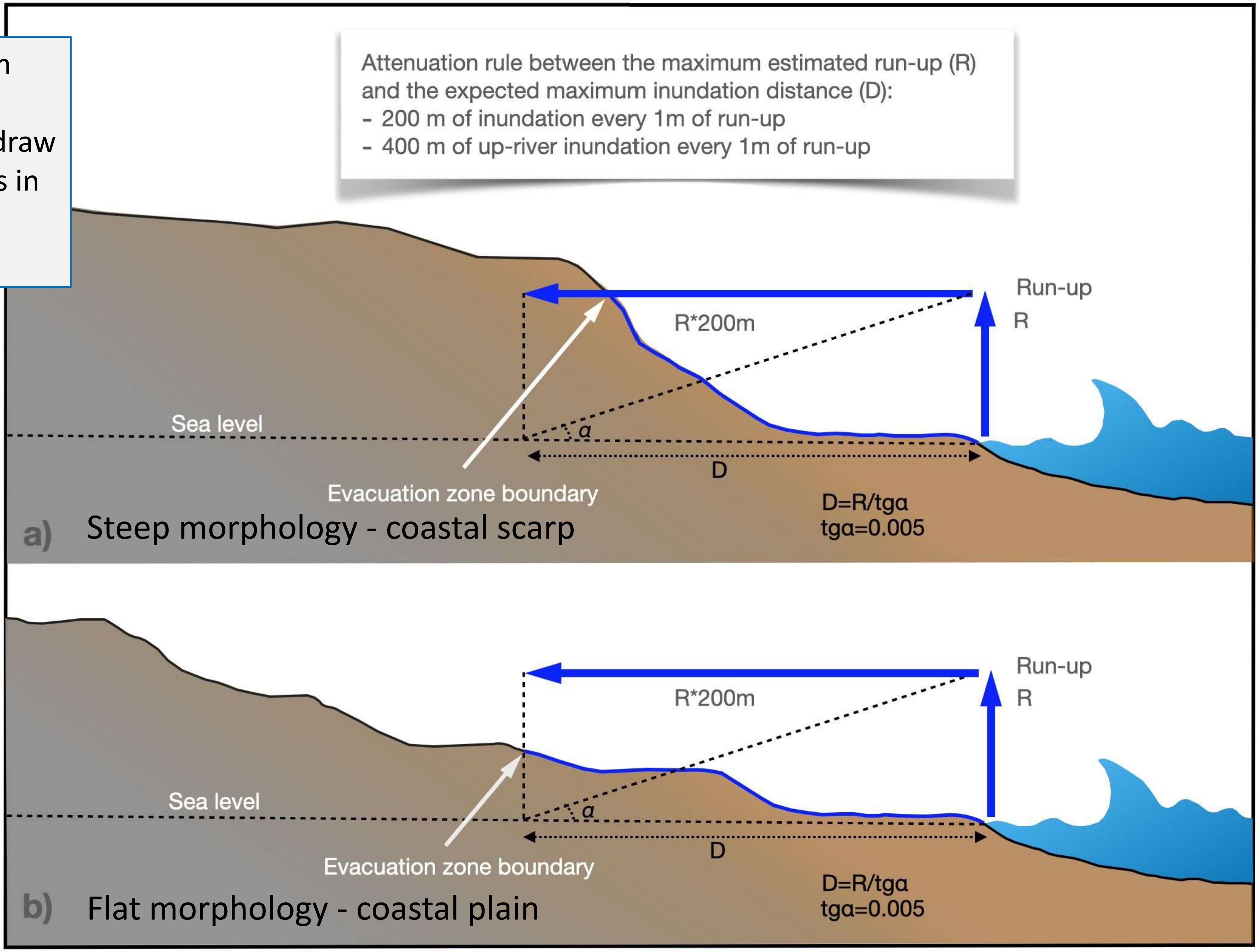
Section (not in scale) shows the definition of the boundary of the alert zones corresponding to the Advisory e Watch levels



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

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

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



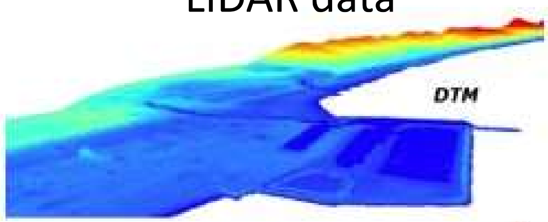
Digital Terrain Model

DEM IGM 20m

DEM tinitaly

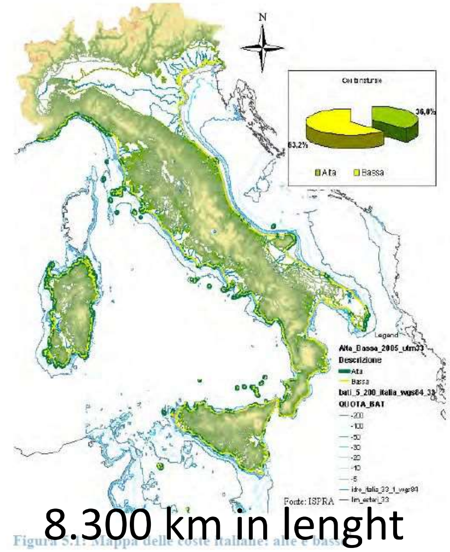
Regional DTMs 1-2-5 metres resolution

High resolution LIDAR data



Elevation accuracy up to 15cm

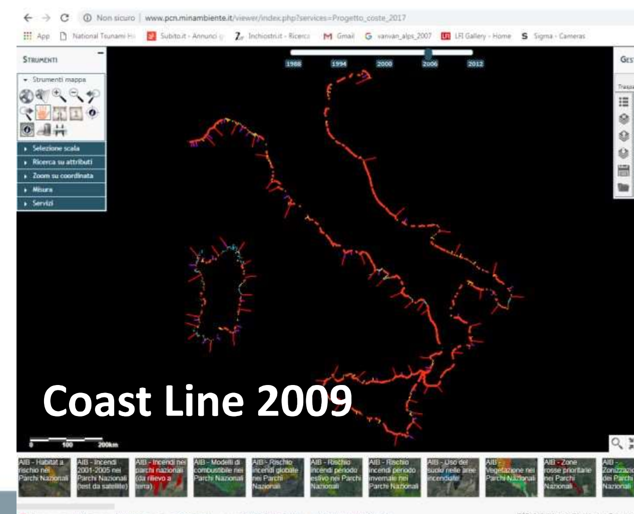
Coast Line data



8.300 km in lenght

[1] Fonte: ISPRA, Elaborazione della copertura territoriale disponibile con le ortofoto del volo IT2006

Coast Line 2006



Coast Line 2009

River r

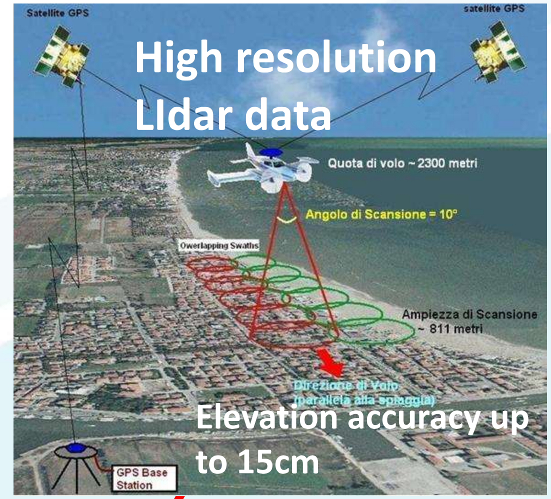
Ri
ISI
at

SICA E VU

Input data: updating, mosaicking an

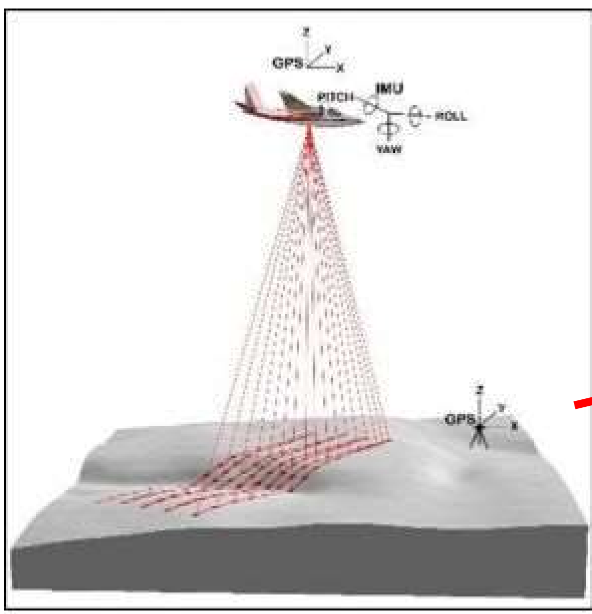
DEM tinitaly

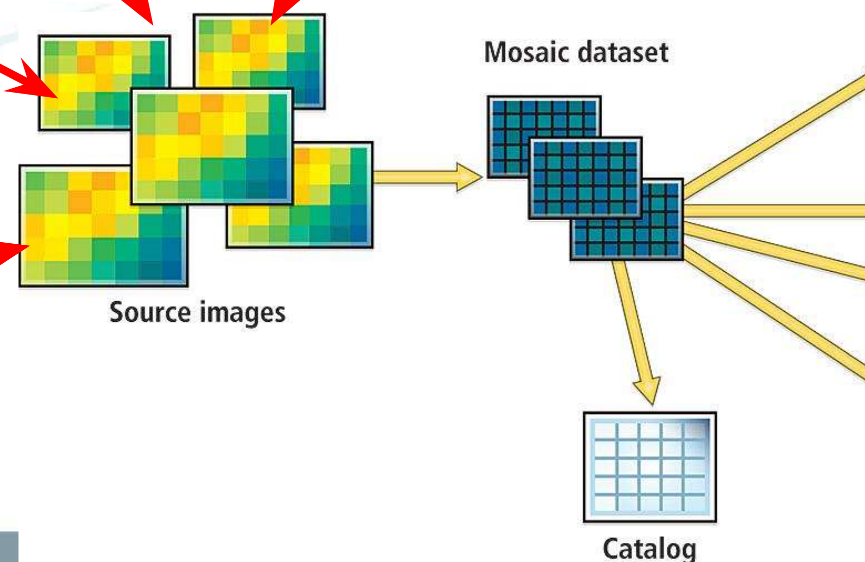
DEM IGM 20m



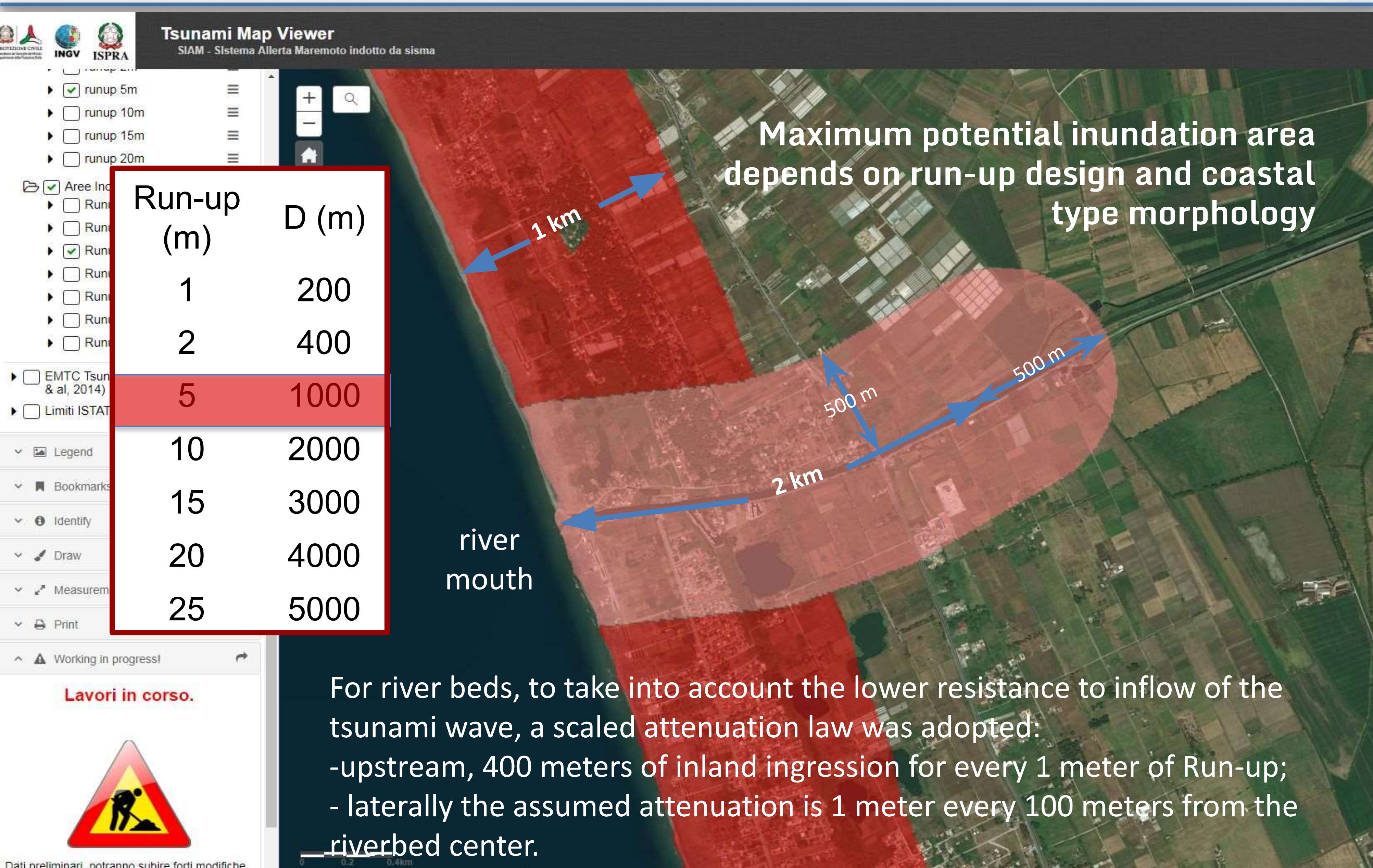
N
h
r
t
i

DTM 1-2-5-10 metres res.





Attenuation rule application and



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

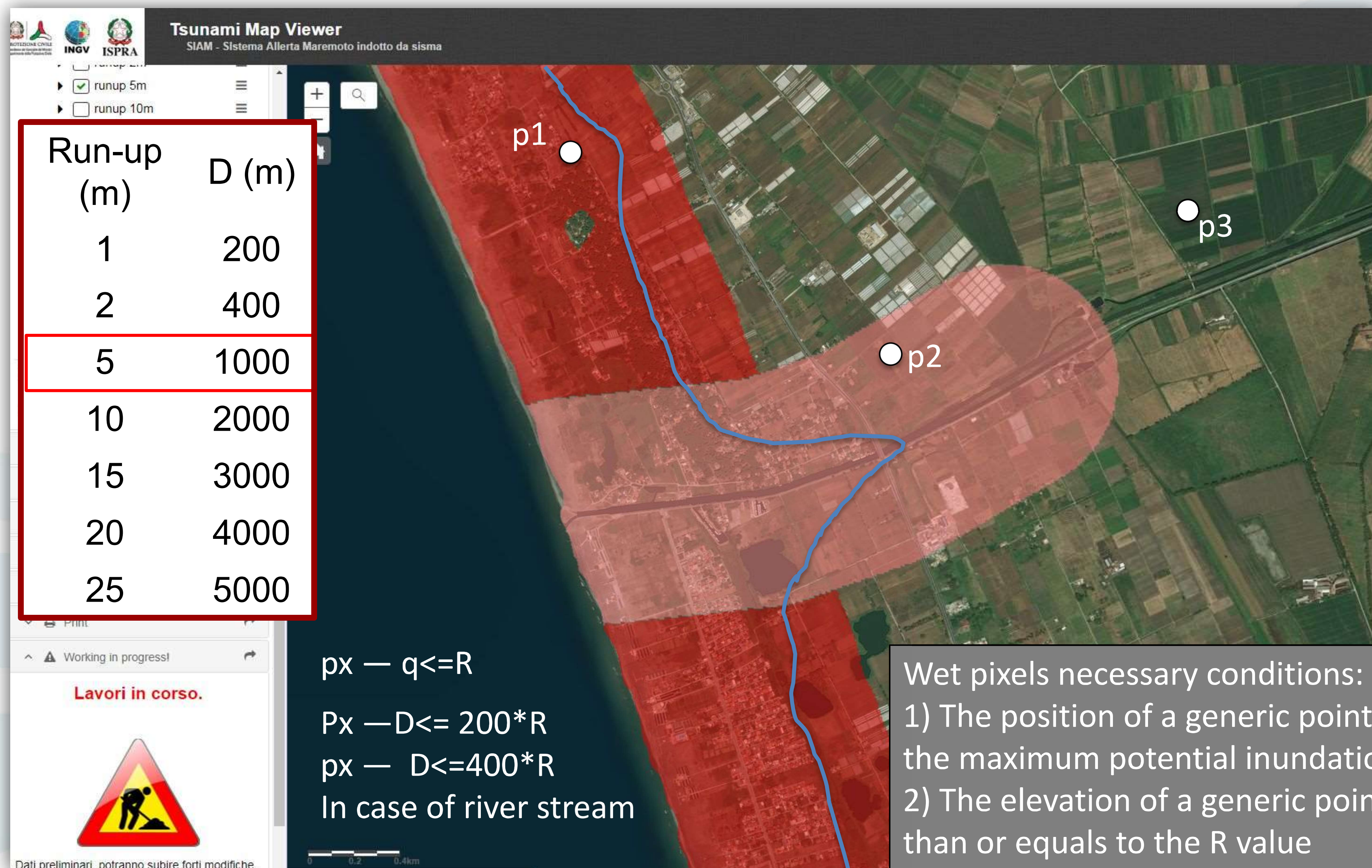
For river beds, to take into account the lower resistance to inflow of the tsunami wave, a scaled attenuation law was adopted:

-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.

Th
ap
ba

E VU



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

Wet pixels necessary conditions:

1) The position of a generic point x is inside the maximum potential inundation area;

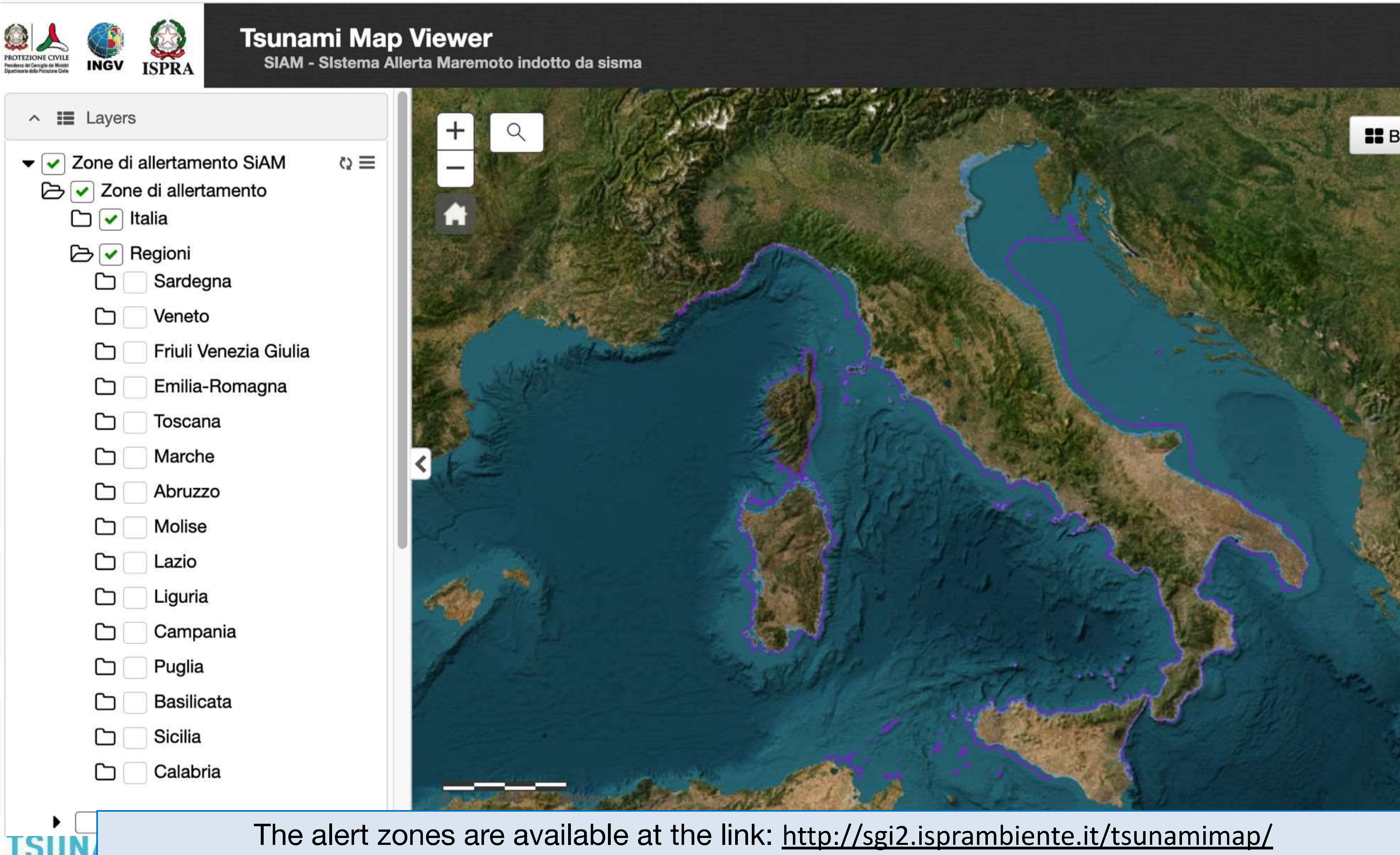
2) The elevation of a generic point x is less than or equals to the R value

Raster
dry/w
tools b
applic
empir

Both t
satisfie
only

The bl
inunda

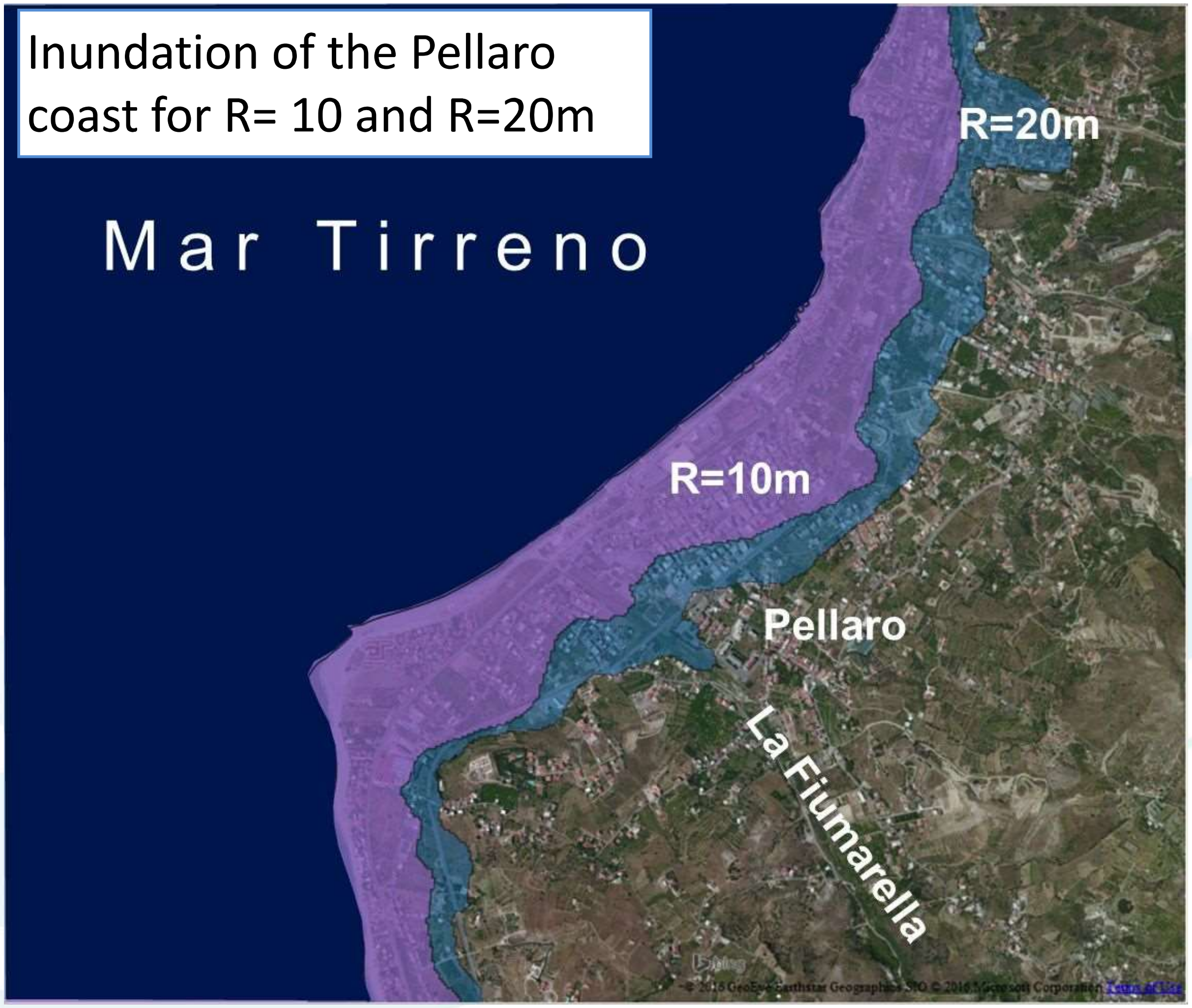
Tsunami Map Viewer – evacuation m



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

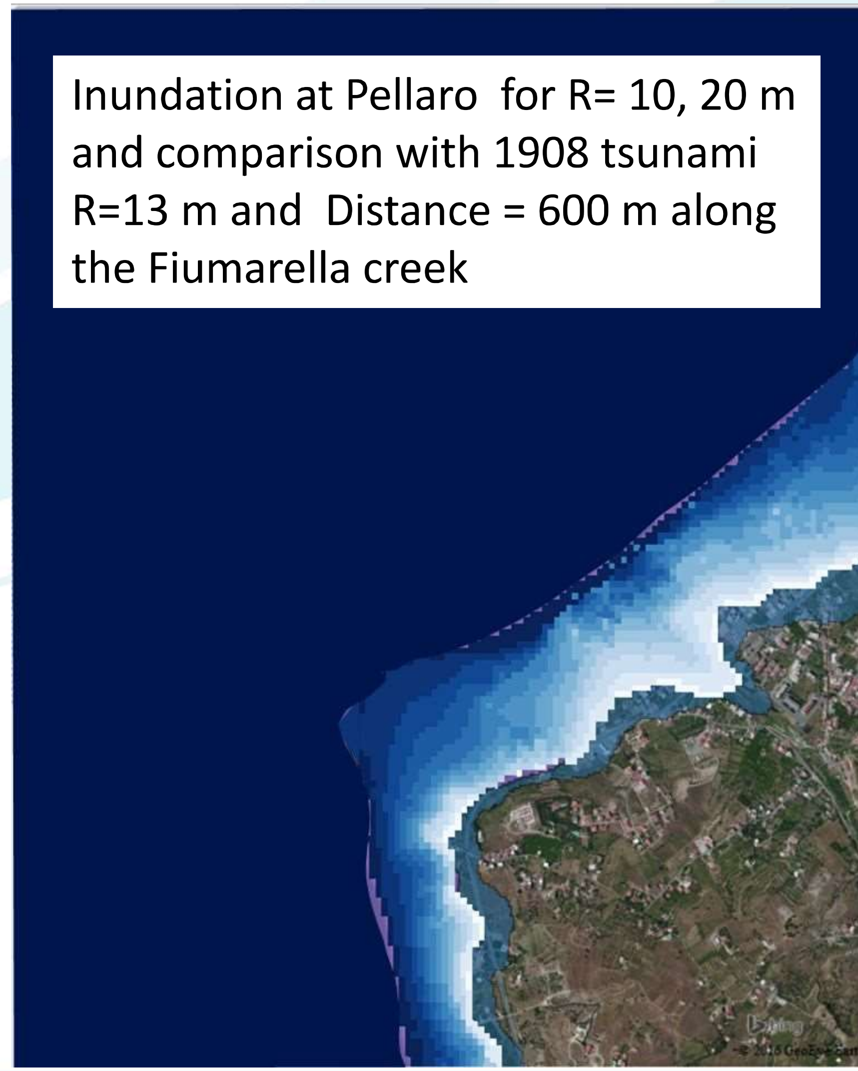
Testing activity: comparison with historical e

Inundation of the Pellaro coast for R= 10 and R=20m



Comparison with 1908 Messina an event inundation scenarios

Inundation at Pellaro for R= 10, 20 m and comparison with 1908 tsunami R=13 m and Distance = 600 m along the Fiumarella creek



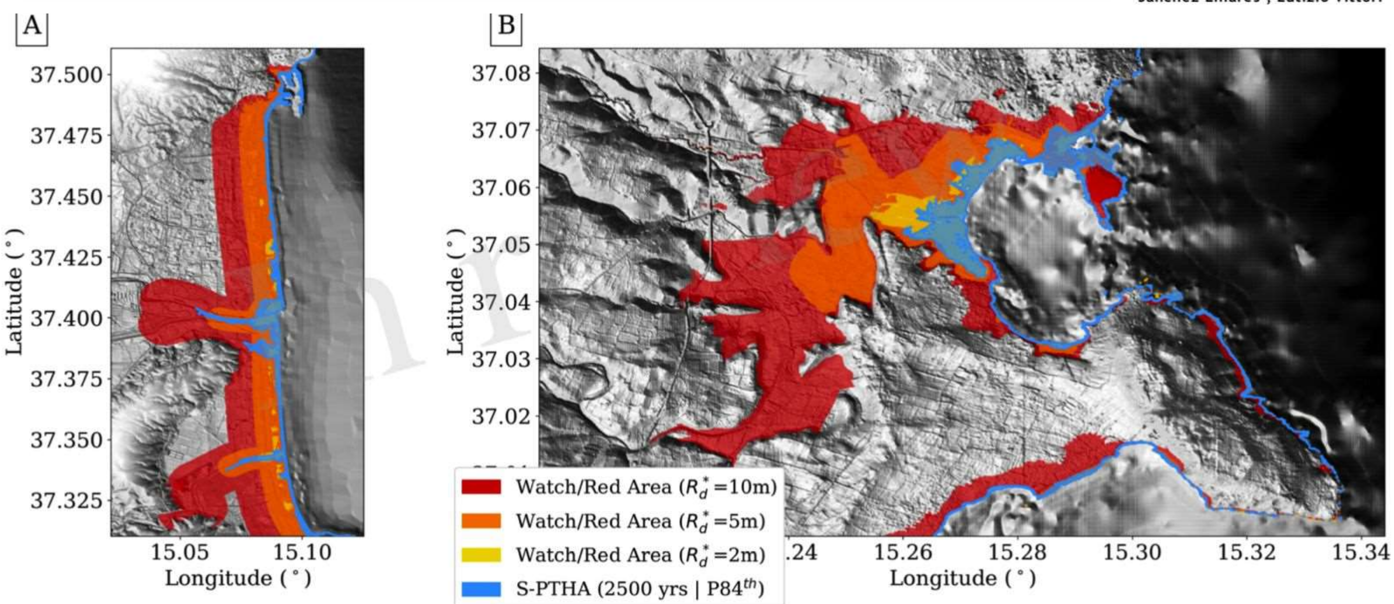
CENTRO ALLERTA TSUNAMI

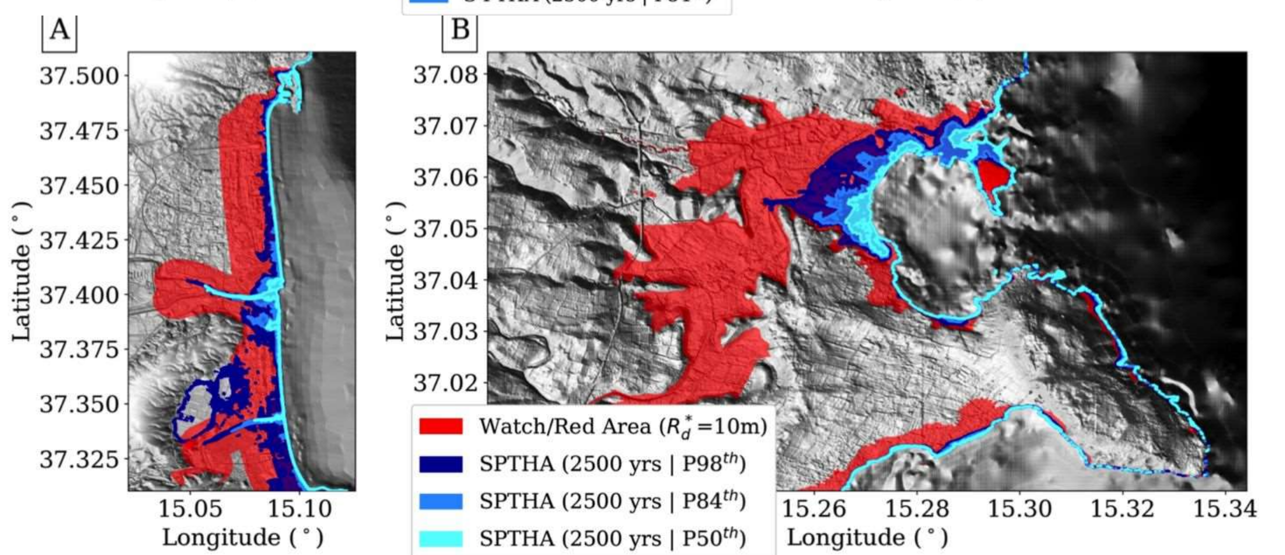
Testing: comparison with nume

frontiers

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

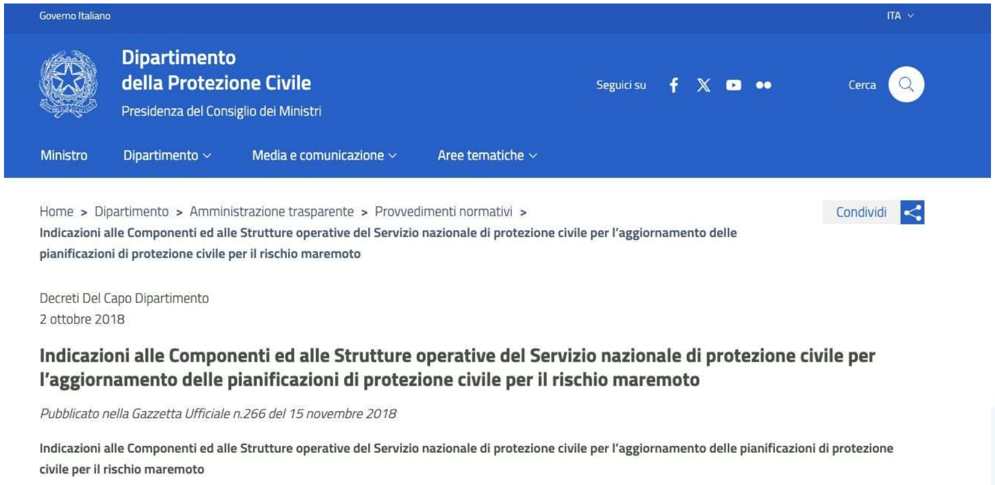
The comparison corroborates reliability and goodness of the methodology used in the definition of the SiAM alert zo

GIS-based inun used for planni conservatively hazard underes local scale

Detailed results i Tonini e

ISTITUTO NAZIONALE DI GEOFIS

Local emergency planning follows



Governo Italiano ITA

Dipartimento della Protezione Civile
Presidenza del Consiglio dei Ministri

Seguici su Cerca

Ministro | Dipartimento | Media e comunicazione | Aree tematiche

Home > Dipartimento > Amministrazione trasparente > Provvedimenti normativi >
Indicazioni alle Componenti ed alle Strutture operative del Servizio nazionale di protezione civile per l'aggiornamento delle pianificazioni di protezione civile per il rischio maremoto

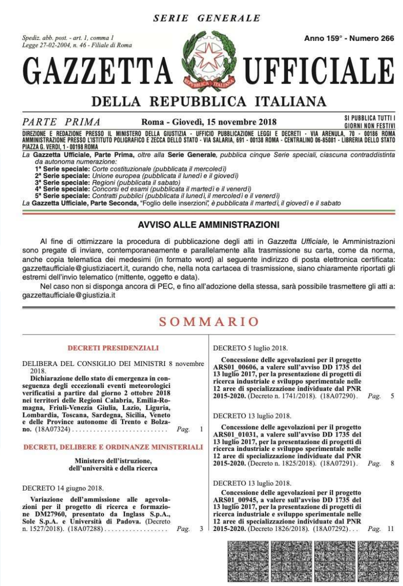
Condividi

Decreti Del Capo Dipartimento
2 ottobre 2018

Indicazioni alle Componenti ed alle Strutture operative del Servizio nazionale di protezione civile per l'aggiornamento delle pianificazioni di protezione civile per il rischio maremoto

Pubblicato nella Gazzetta Ufficiale n.266 del 15 novembre 2018

Indicazioni alle Componenti ed alle Strutture operative del Servizio nazionale di protezione civile per l'aggiornamento delle pianificazioni di protezione civile per il rischio maremoto



SERIE GENERALE

Anno 159° - Numero 266

GAZZETTA UFFICIALE
DELLA REPUBBLICA ITALIANA

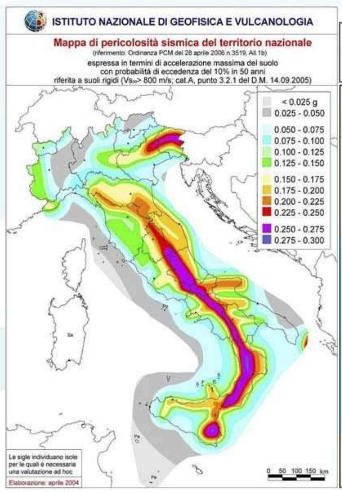
PARTE PRIMA — Roma - Giovedì, 15 novembre 2018

AVVISO ALLE AMMINISTRAZIONI

SOMMARIO

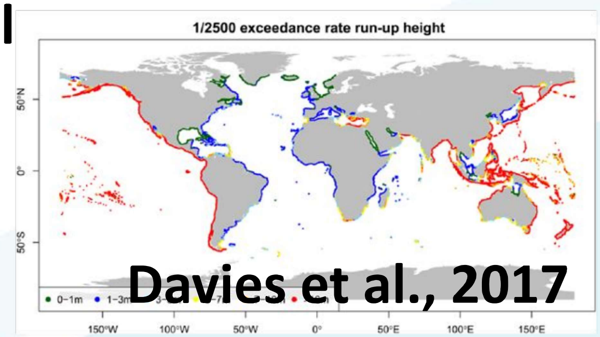
DECRETI PRESIDENZIALI

DECRETI, DELIBERE E ORDINANZE MINISTERIALI

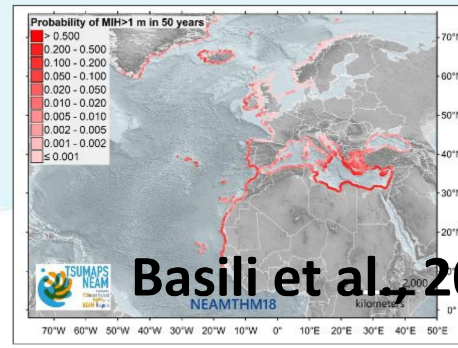


Global

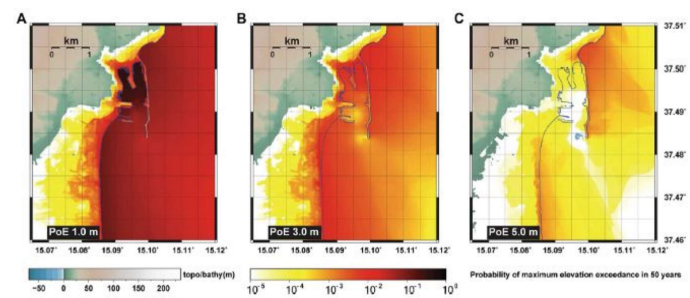
Local



Davies et al., 2017



Basili et al., 2021

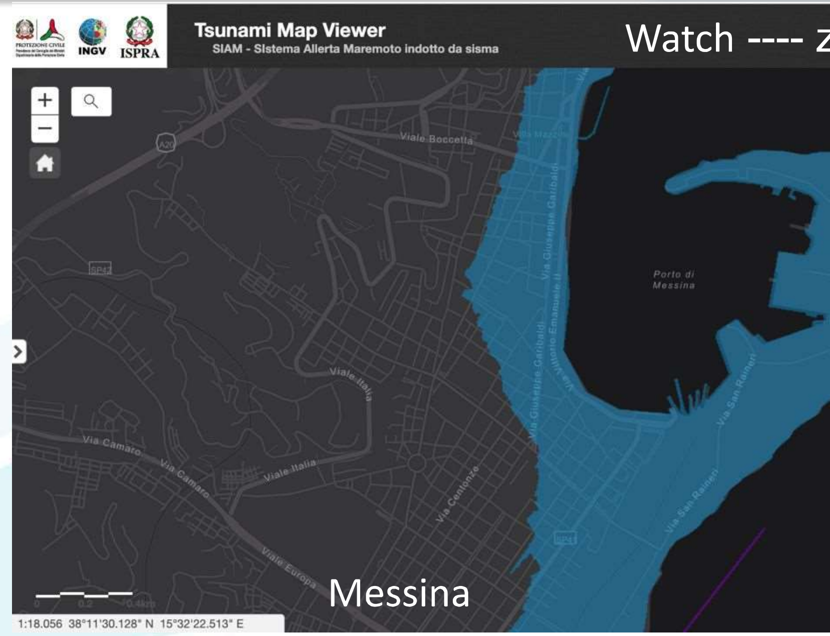


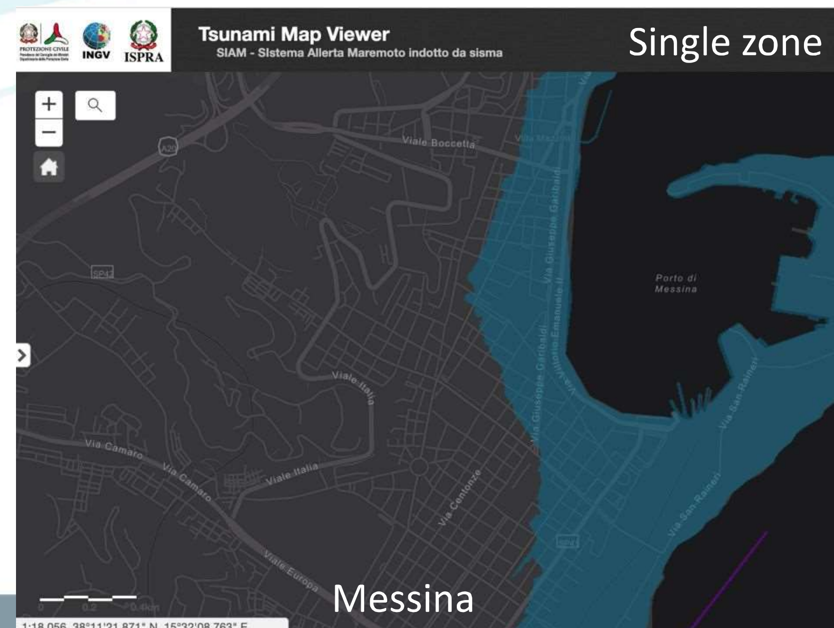
Gibbons et al., 2020

CENTRO ALLERTA TSUNAMI

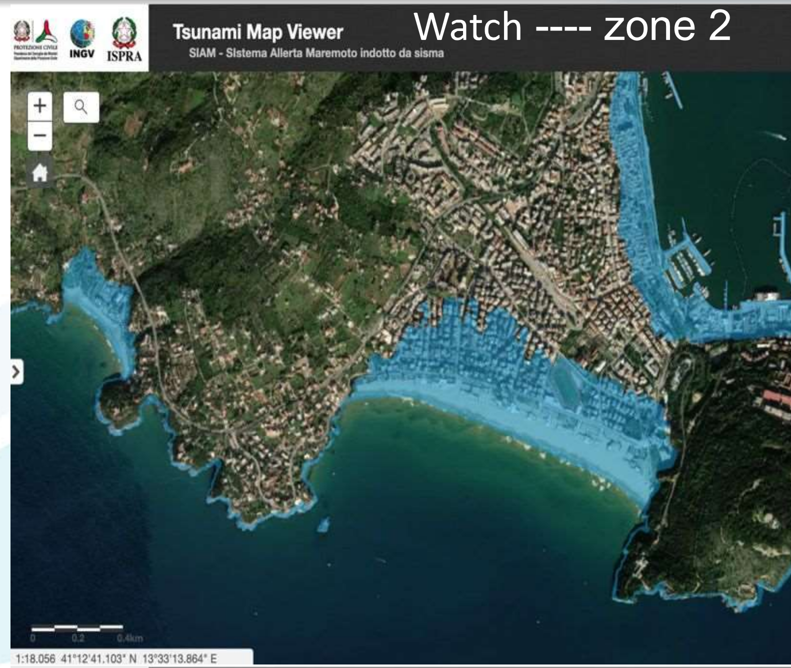
ISTITUTO NAZIONALE DI GEOFISICA E VU

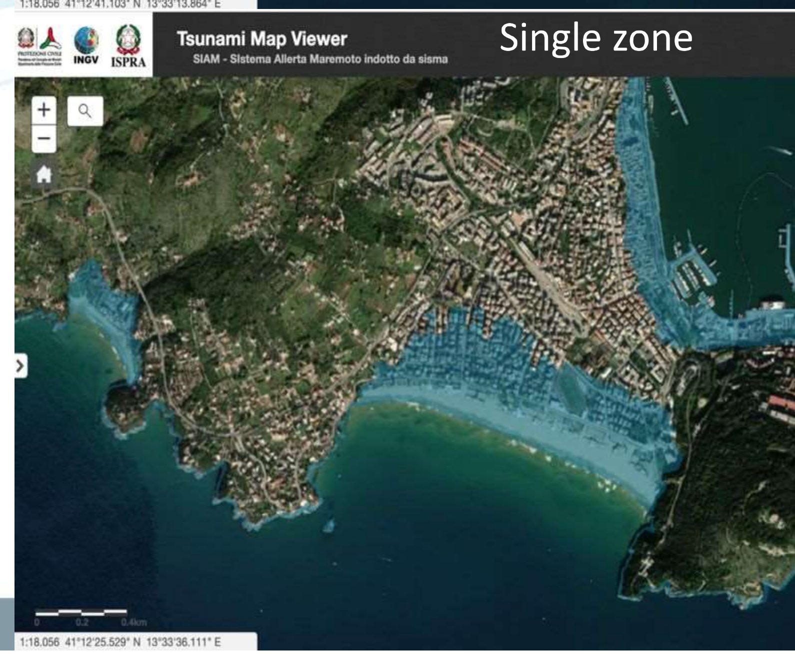
Tsunami Map Viewer – ale





Tsunami Map Viewer –





Thank you

stefano.lorito@ingv.it

CENTRO ALLERTA TSUNAMI

CENTRO ALLERTA TSU

ISTITUTO NAZIONALE DI GEOFISICA E