ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

NEAM·COMMITMENT
NEAM Collaboration fOr iMproved tsunaMi rIsk miTigation and manageMENT

NEAMTWS webinar on Non-seismic tsunami sources

27 November 2025

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The results does not necessarily represent official views of the Dipartimento della Protezione Civile (Italy).

The NEAM-COMMITTMENT project on multi-hazard assessment and the Stromboli volcano test site for tsunami evacuation planning

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IHcantabria INSTITUTO DE HIDRÁULICA AMBIENTAL UNIVERSIDAD DE CANTABRIA
ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale
GEM GLOBAL EARTHQUAKE MODEL working together to assess risk
UNIVERSIDAD DE MÁLAGA
GENERAL SECRETARIAT FOR CIVIL PROTECTION
PROTEZIONE CIVILE Presidenza del Consiglio dei Ministri Dipartimento della Protezione Civile
INSTITUTO GEOGRÁFICO NACIONAL cnig

Co-funded by the European Union

The NEAM-COMMITMENT project

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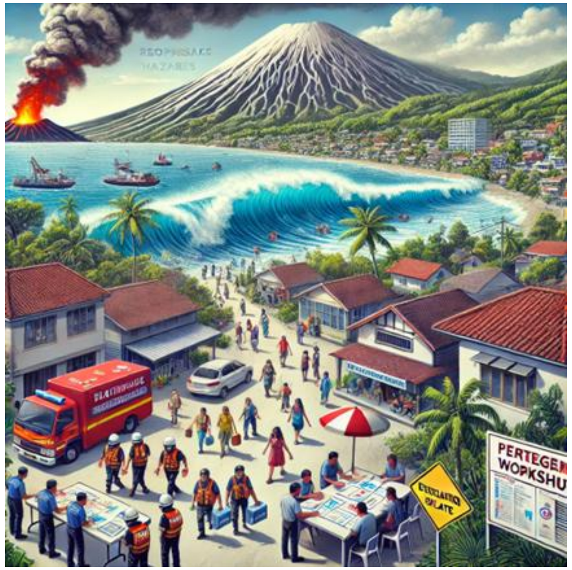

✓***Aim:*** Improve tsunami preparedness in the NEAM region, at different scales, for effective risk, evacuation and emergency management.

✓**Objectives** are spanning from the national to local levels, addressing needs for national tsunami risk planning and for enhancing multi-hazard preparedness in coastal communities at risk.

- **National level:**
  - National-level tsunami inundation maps are crucial for coastal planning and risk management.
  - Support local tsunami hazard assessment and evacuation planning.
  - Contribute to important global tsunami initiatives like IOC-UNESCO's Tsunami Ready Recognition Programme (TRRP) and Ocean Decade Tsunami Programme (ODTP) by scaling hazard assessment nationally.
- **Local level:**
  - Tsunamis from earthquakes and volcanic activity pose significant risks for coastal communities in the NEAM region.
  - A multi-hazard approach considering cascading effects is needed for effective tsunami evacuation and emergency management.
  - Emphasis on science-informed participatory and decision-making workshops to improve local planning and implementation effectiveness.

2021–2030 United Nations Decade of Ocean Science for Sustainable Development

Duration: 24 months, started on 01 February 2025
Call: European Union Civil Protection Mechanism-2024-Knowledge for Action in Prevention & Preparedness
Title: NEAM Collaboration f**O**r i**M**proved tsuna**M**i r**I**sk mi**T**igation and manage**MENT**
Estimated Project Cost: €985 629.70

Co-funded by the European Union

Expected project's outcomes

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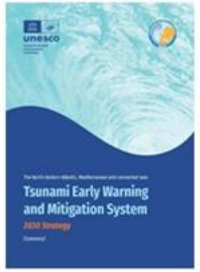
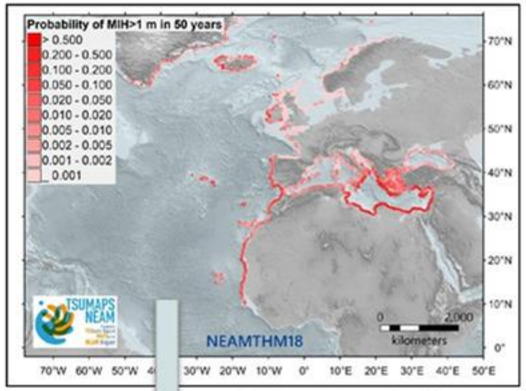
Objective 1 – common national maps across NEAM countries





TSUMAPS NEAM – Probabilistic TSUnami Hazard MAPS for the NEAM Region

European Union Civil Protection and Humanitarian Aid

GTM global tsunami model

EPOS EUROPEAN PLATE OBSERVING SYSTEM

National inundation maps

➔ **National level**

- Development of national tsunami Inundation maps (CY, GR, ES)
- Development of guidelines and tools for implementation in other countries/regions
- Dissemination of results across relevant national stakeholders
- Dissemination of methodological approach at the international level

➔ **Local level**

- Application @ two pilot sites in **Greece** and **Italy**
- Local evacuation mapping through science-informed and participatory decision-making, considering multi-hazard cascading effects, i.e. earthquakes and **<u>volcanic activity</u>**
- Development of guidelines
- Awareness raising activities

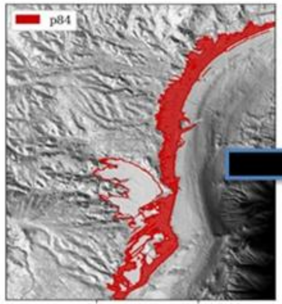
Objective 2 – location-specific multi-hazard risk management

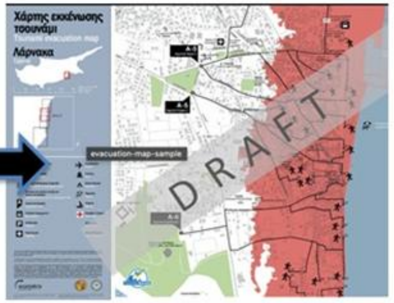
Earthquake + tsunami

Volcanic activity + tsunami

Tsunami Ready

TSUNAMI EVACUATION ROUTE





Stromboli volcano

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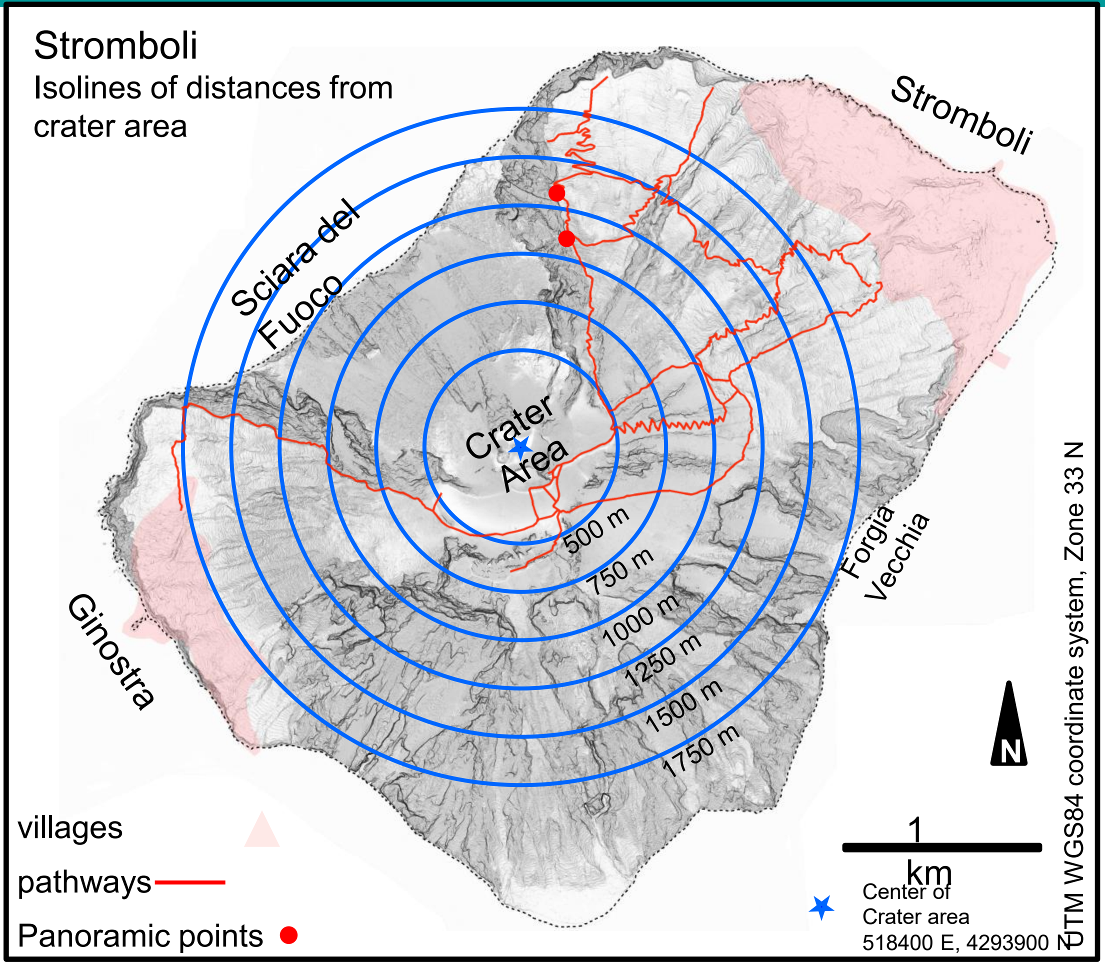
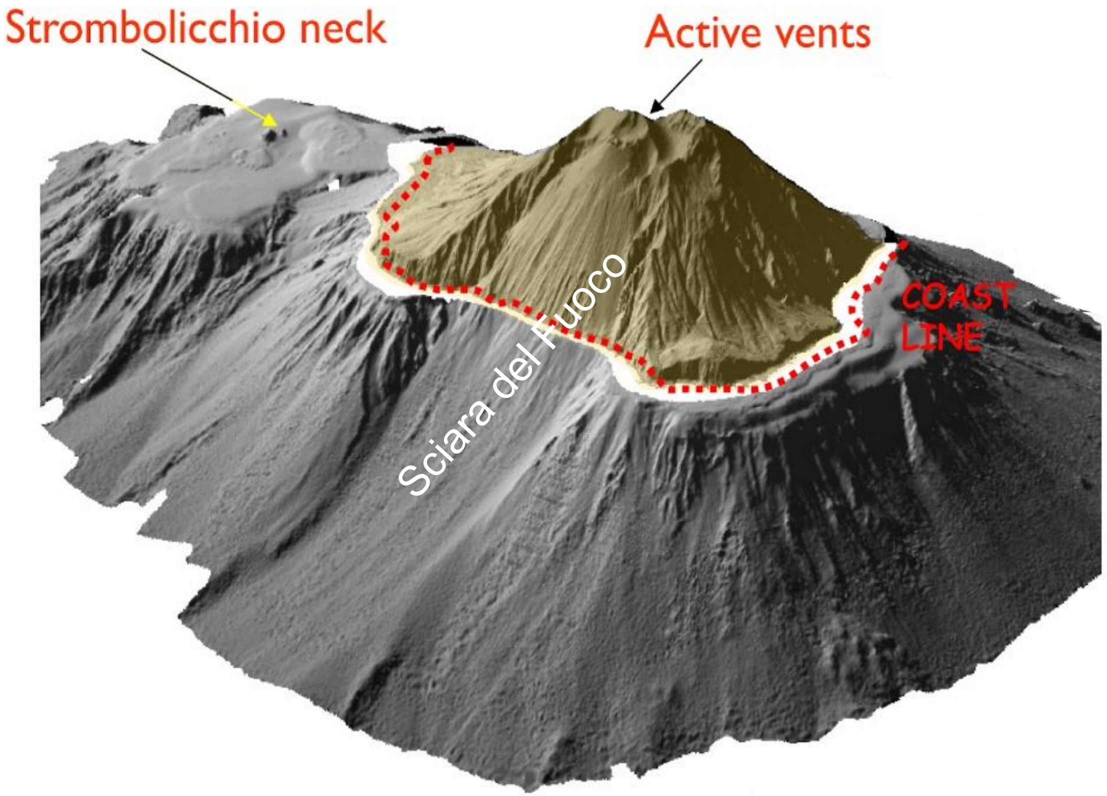
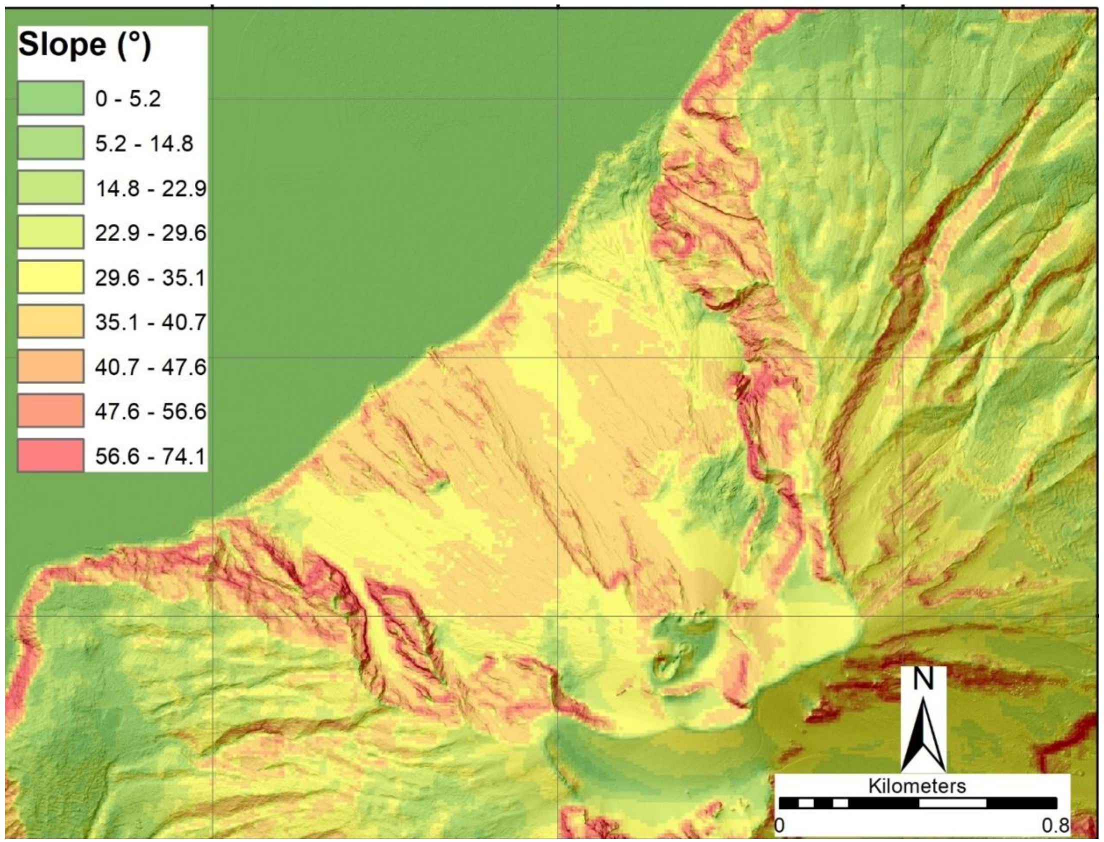


- Stromboli is the Northernmost Aeolian island – its activity is an expression of arc volcanism;
- Its total surface is 12.6 km^2 with two villages (Stromboli and Ginostra) with < 500 permanent inhabitants.
- Important touristic center, with daily arrival of > 2,000 tourists during summer season

Stromboli volcano

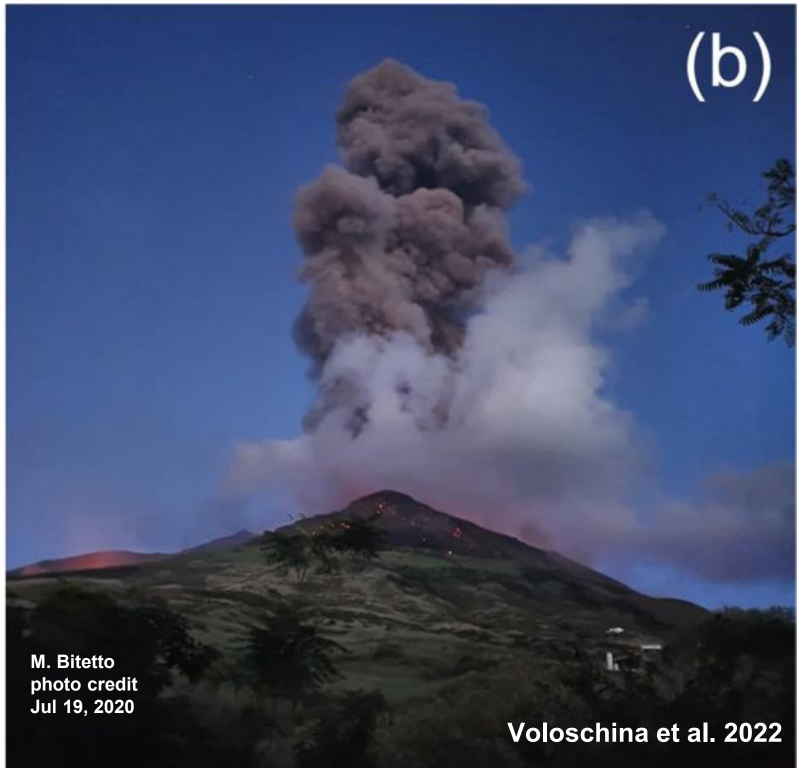




- Stromboli is characterized by frequent explosive and effusive activity;
- Current type of activity has not changed significantly starting since VIII century CE (Bertagnini et al. 2008; Rosi et al. 2013).
- Large structure to the NW of the volcano («Sciara del Fuoco») with subaerial and submarine part, characterized by steep slopes made of both unconsolidated material and lava flows. Volcanic products from Stromboli activity tend to concentrate here.

Overview of explosive activity

Normal activity



Major explosions

Paroxysms

Total duration	4-30 s	< 2 min	5-10 min
Fallout volume	1-10 m^3	10^2-10^3 m^3	10^4-10^5 m^3
Ballistic range/size	200-250 m / centimetric	1000 m / decimetric	Entire island / metric
Column height	50-400 m	1000 m	3000-4000 m
Involved vents	1	Multiple	All

Source: Rosi et al. 2006; 2013

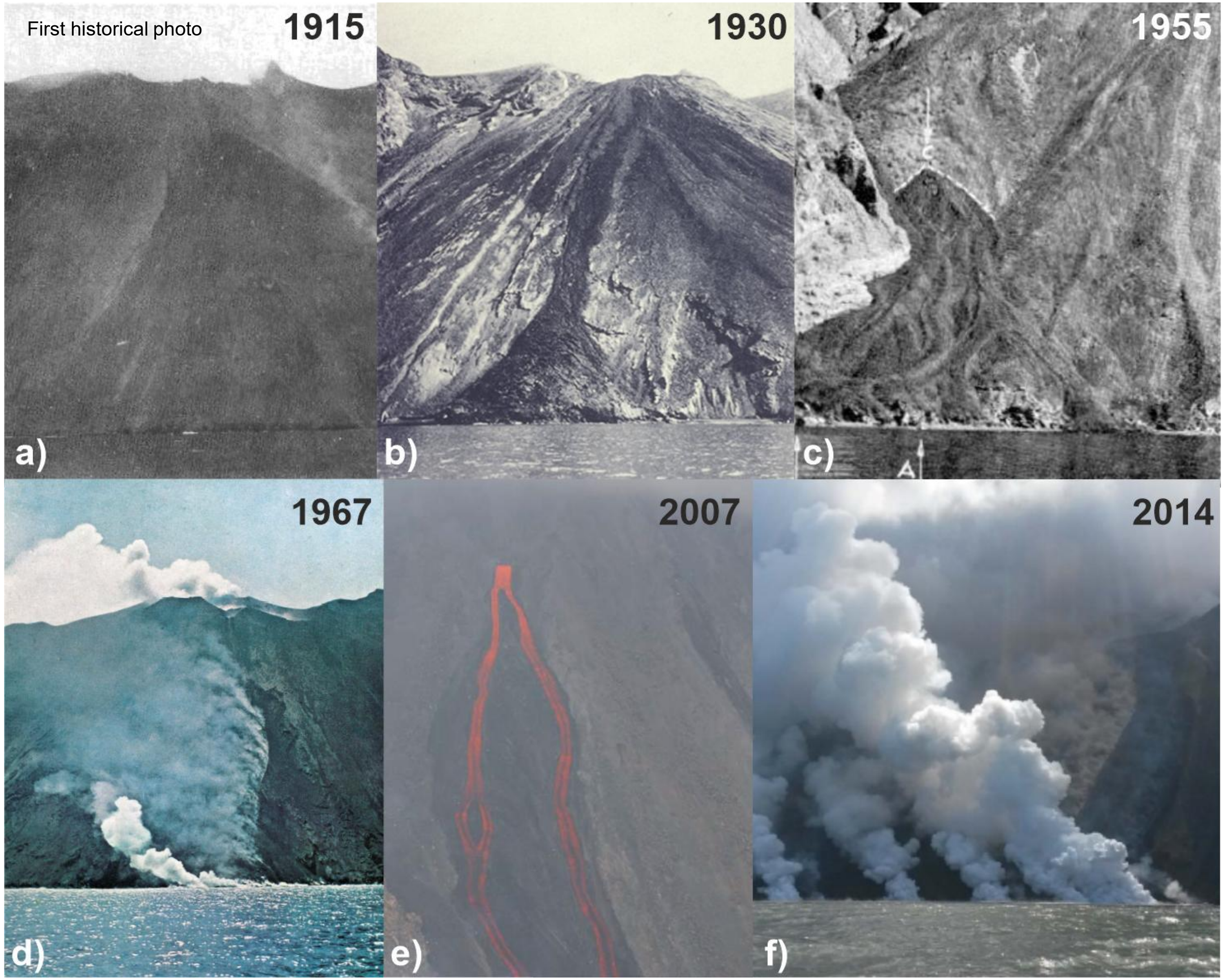
Increasing magnitude/explosivity

Overview of effusive activity

- Effusive activity could span from small, short-lived overflows that are confined to the crater area up to large lava emission that could interests the whole SdF with durations > 1 month;

- In between these two end-members, there is a continuous range of effusive phenomena with variable durations. There is a correlation with explosive activity but there are also isolated effusive phenomena;

- Effusive products of the current activity are almost entirely located within the crater area and the SdF. Lava effusion (both from crater overflows or from new vents/fissures at lower elevation) along the SdF can affect its stability.



Historical photographs of some of the most significant lava flows in the last century. For more details see Marsella et al. (2011).

Tsunami hazard from tsunamigenic landslides/1

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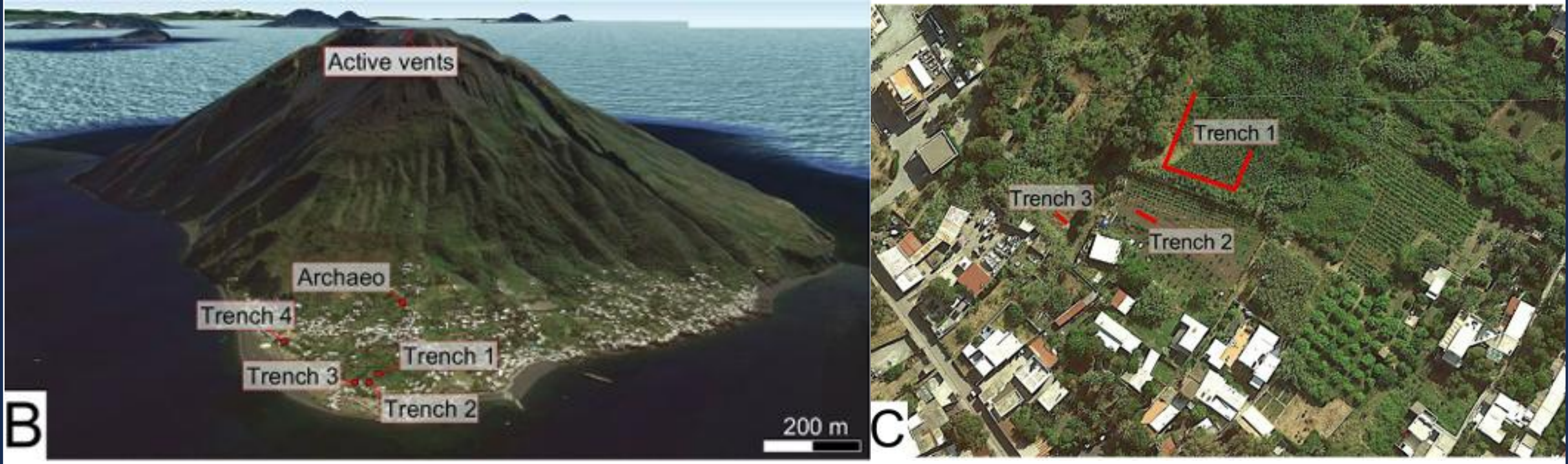
With the term “**tsunamigenic landslide**” (TL) we refer to any tsunamigenic sub-aerial or submarine mass flow, including pyroclastic avalanches and primary PDCs.

At Stromboli TL with associated tsunamis caused on Stromboli:	*TL estimated volumes*
• Extremely large inundation (at least three times in medieval times); →	~$180x10^6$ m^3 (cumulative)
• Medium to large inundation (1916, 1919, 1930, 1944 and 2002); →	~$1\text{-}30x10^6$ m^3
• Little or no inundation (1921, 1959, 2019, 2021, 2022 and 2024). →	≤ 10^6 m^3

30/12/2002 tsunami wave in front of Stromboli village

Photo by G. Cincotta (INGVvulcani)

MEDIEVAL TSUNAMI



Rosi et al. 2019

Tsunami deposit thickenss: ~30 cm in trench 2 gradually diminishing at <5 cm in trench 1 (230 m from coastline; 2.8 m a.s.l.).

Tsunami hazard from tsunamigenic landslides/2

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In the last ca. 150 years, there were 41 Strombolian paroxysms and 5 major tsunamis, i.e. characterized by tens to hundreds of meters water ingression in the inhabited areas. In total, 80% of the major tsunamis, all except 2002, were associated to paroxysms, whereas only 10% of the historical paroxysms were associated to a major tsunami.

4 additional paroxysms before 1960 are reported to be associated to great waves, agitated seawater and limited inundations, possibly indicating smaller tsunamis, similar to those occurred in 2019-2024. Such minor phenomena are likely to be historically under recorded, particularly when they were not associated to a paroxysm.

SEA INGRESSION CHRONICLES – tsunamis reported at about the same time of the main explosions
1916 - tsunami wave of ca. 20 m ingression on the North shore (Spiaggia Lunga?), while at Scari only agitated sea.
1919 - water retreats of 200 m and then inundates 300 m (Pta. Lena?).
1930 - water retreats of 100 m and then inundates 200 m (Pta. Lena).
1944 - water inundates 200-300 m (Pta. Lena).

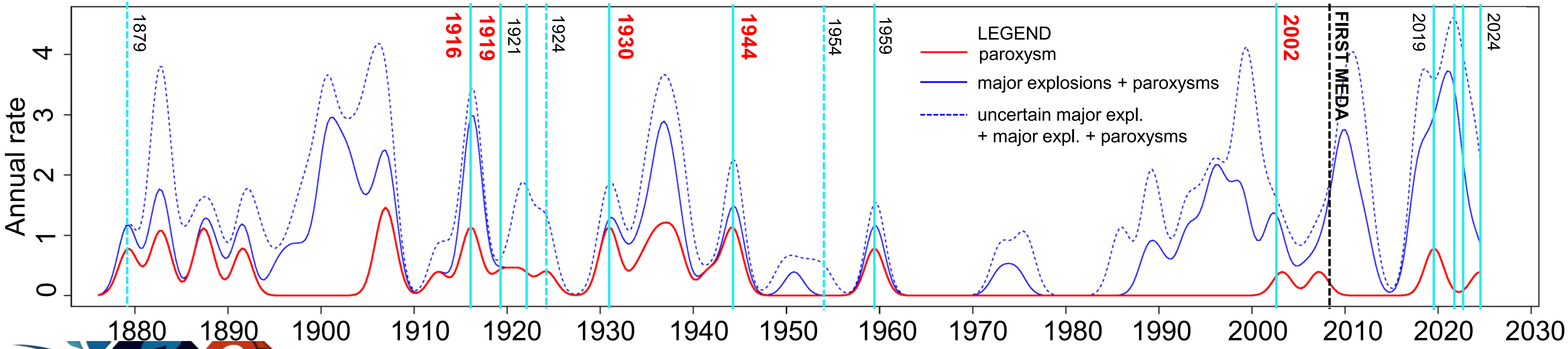

Figure. Kernel density estimation of the annual rate of paroxysms, major explosions, and uncertain major explosions. Historical tsunamis are marked by cyan vertical lines; those not characterized by significant water ingression in the village are marked by dashed lines.

Approach to develop preliminary probabilisitc tsunami hazard maps

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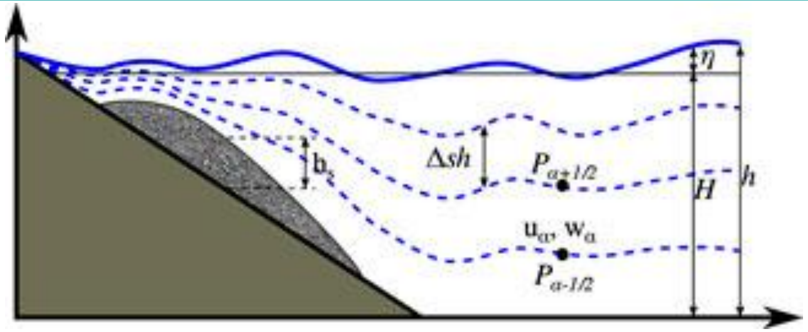
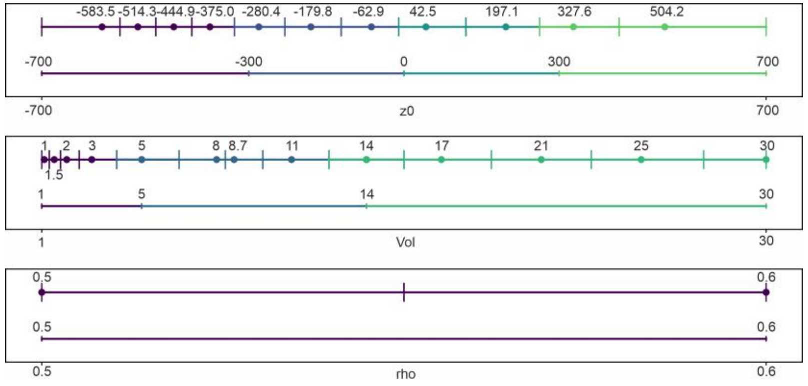
1. Numerical simulations with the Multilayer-HYSea model (Macías et al. 2020) to get inundation maps



2. Expert elicitation to assign probabilities at different scenarios and to create a temporal model

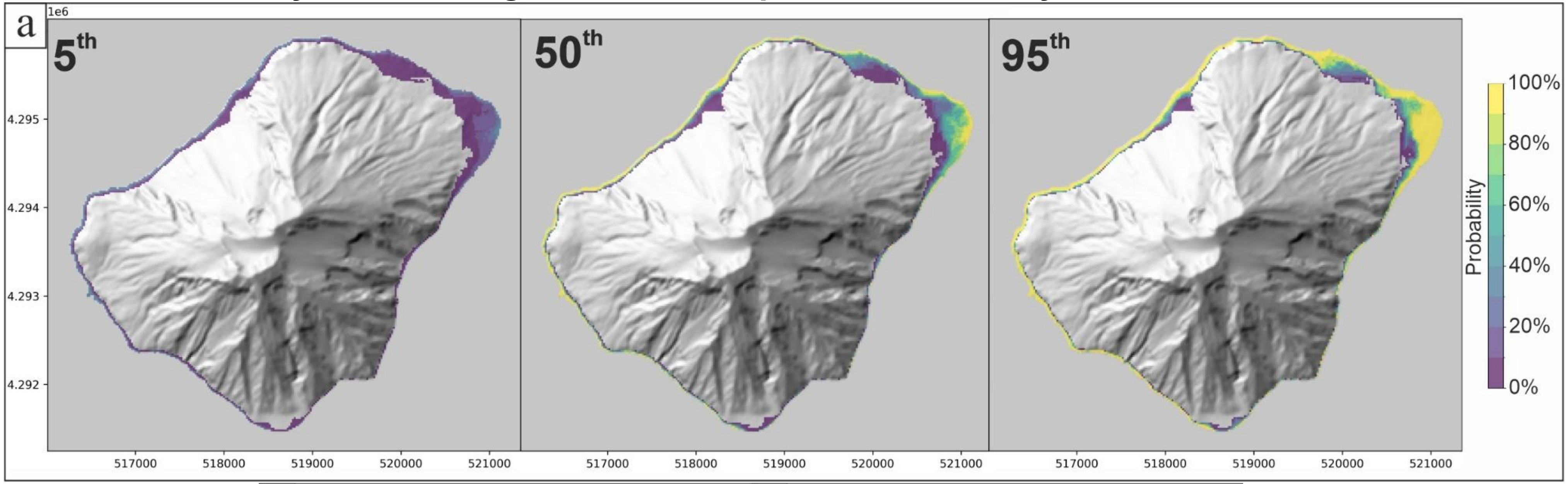
3. Procedur to combine inundation maps with probabilities from elicitation



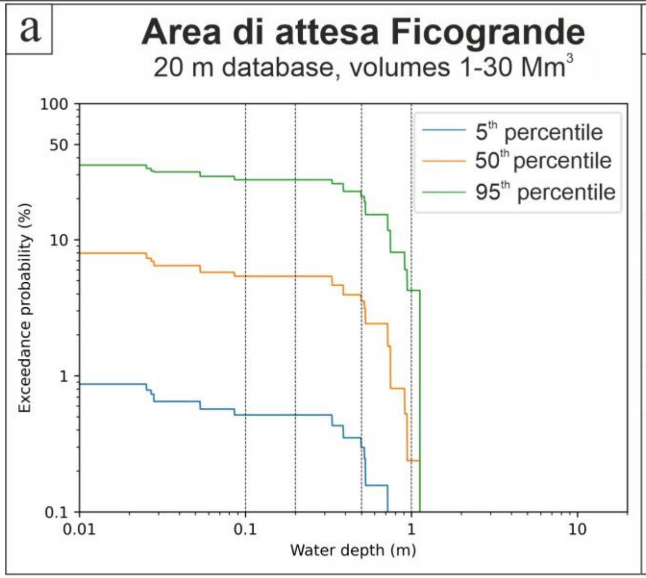
Results

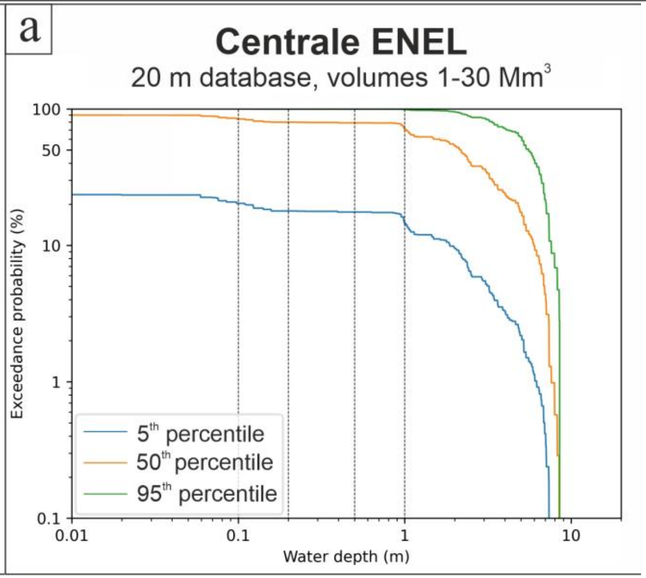
Probability of exceeding 0.5 m water depth in the next 50 years

Hazard maps



Hazard curves





Comparison hazard maps/existing escape routes

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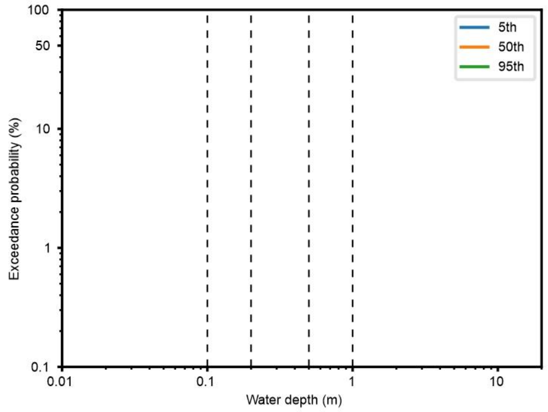
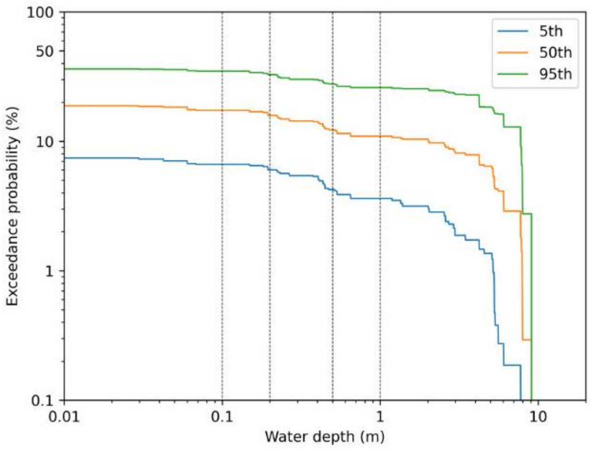
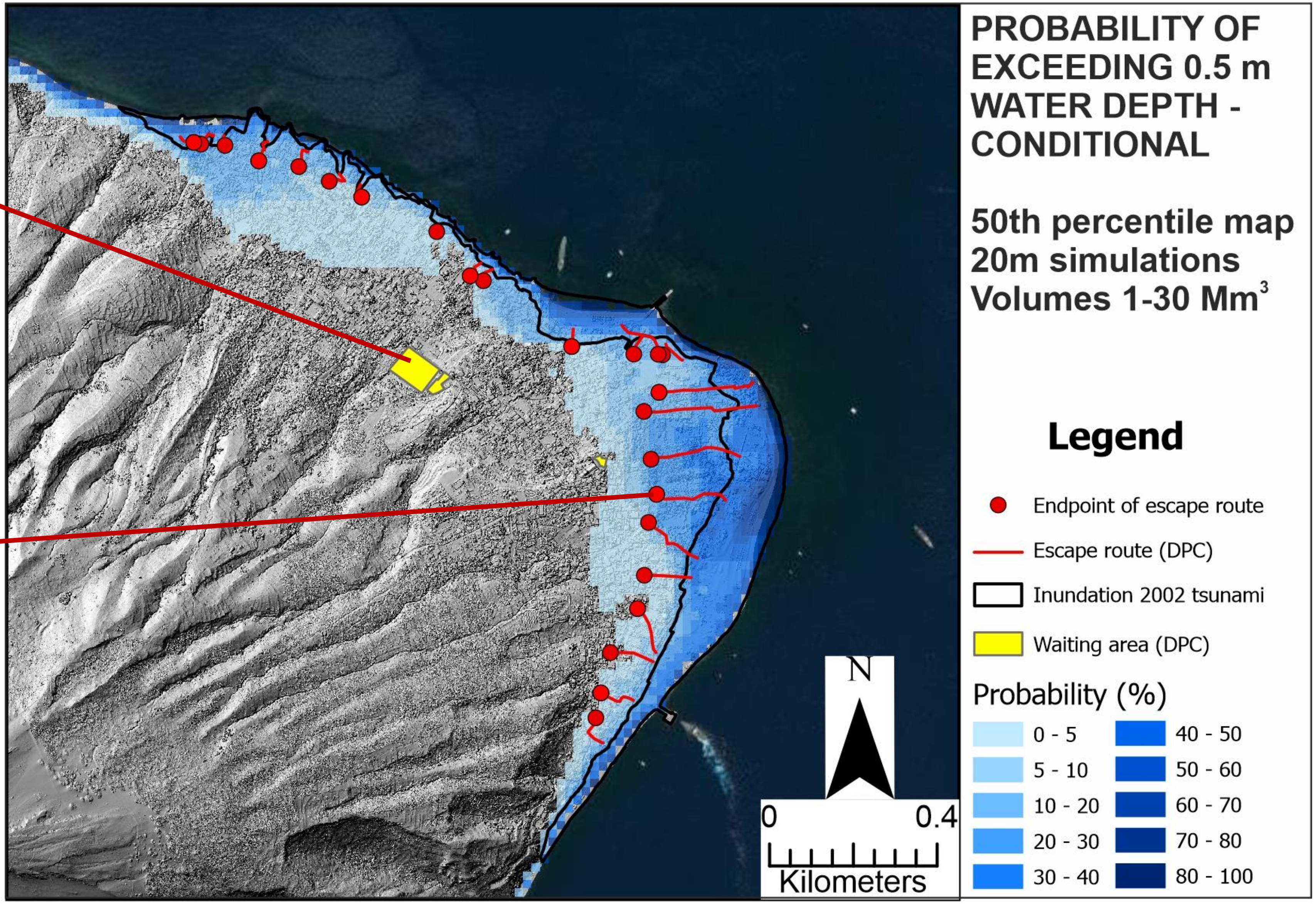
Limoneto Nuova Scuola



Centrale Enel (520809.0641,4294868.8569)





Preliminary assessments of areas affected by ballistic projectile fallout from paroxysms at the endpoints of tsunami escape routes

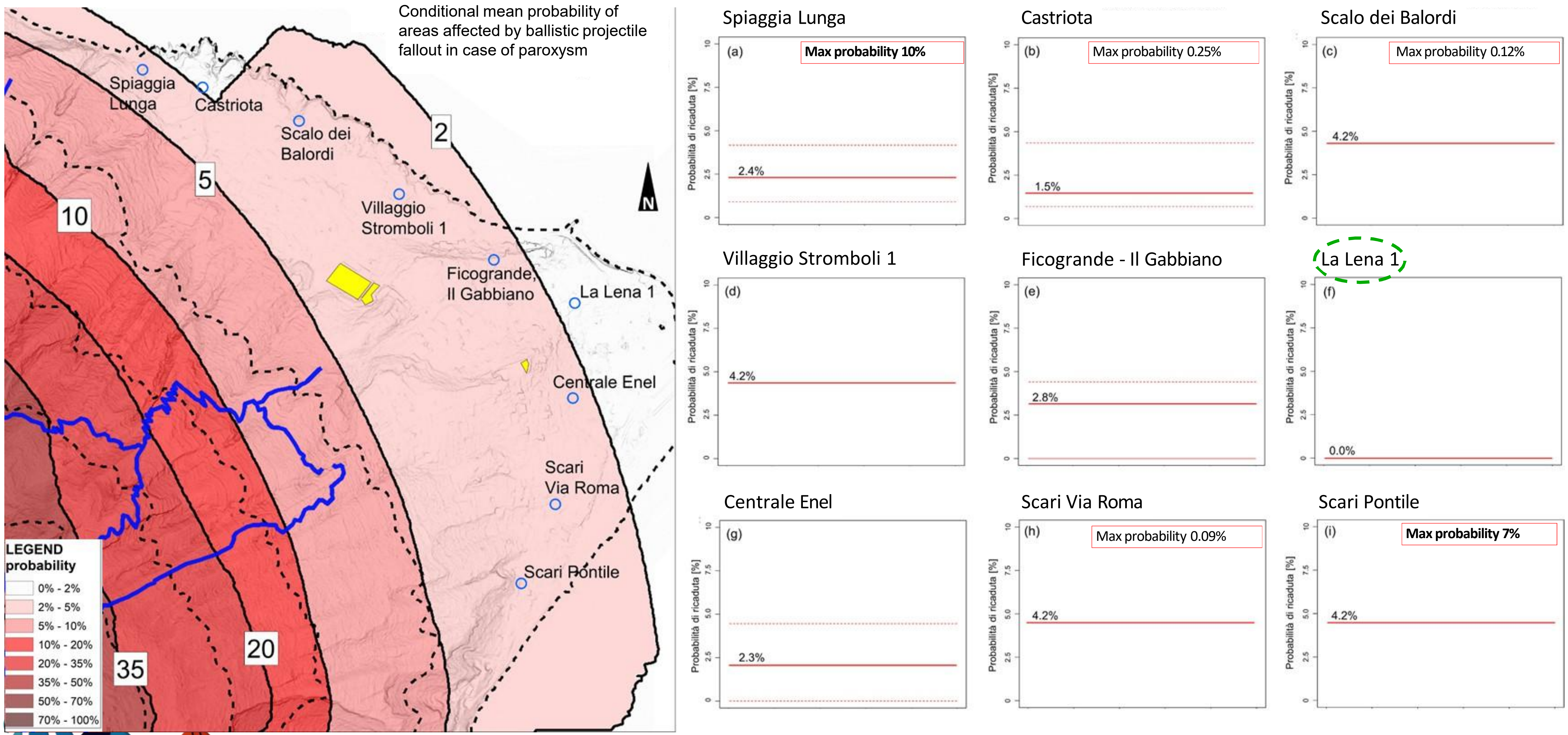
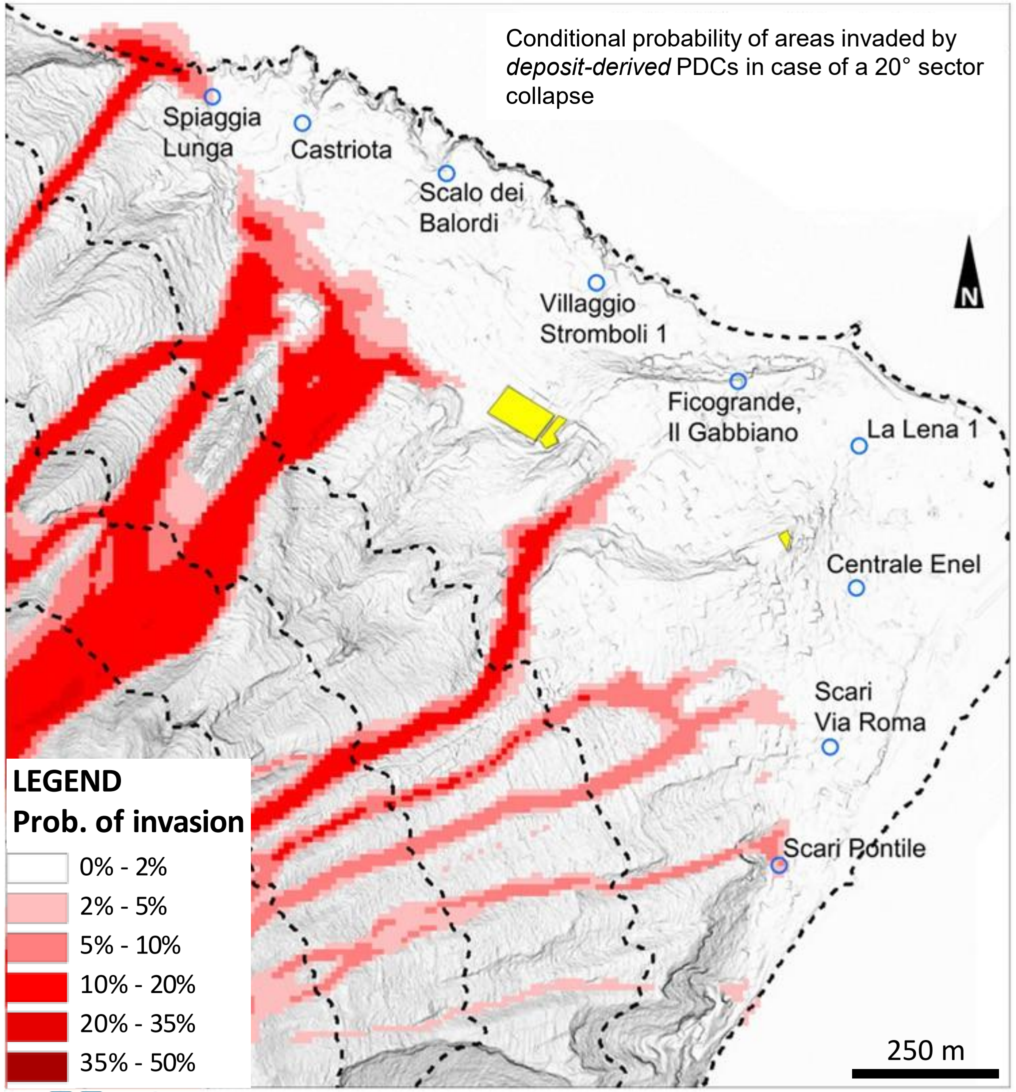


Figure. Probability of ballistic projectile fallout conditional on the occurrence of a paroxysm, and examples of probability estimates at the endpoints of tsunami escape routes. The red lines are the mean value; the pink lines refer to any uncertainty in the estimate.

Preliminary assessments of the hazard from deposit-derived PDCs at the endpoints of tsunami escape routes



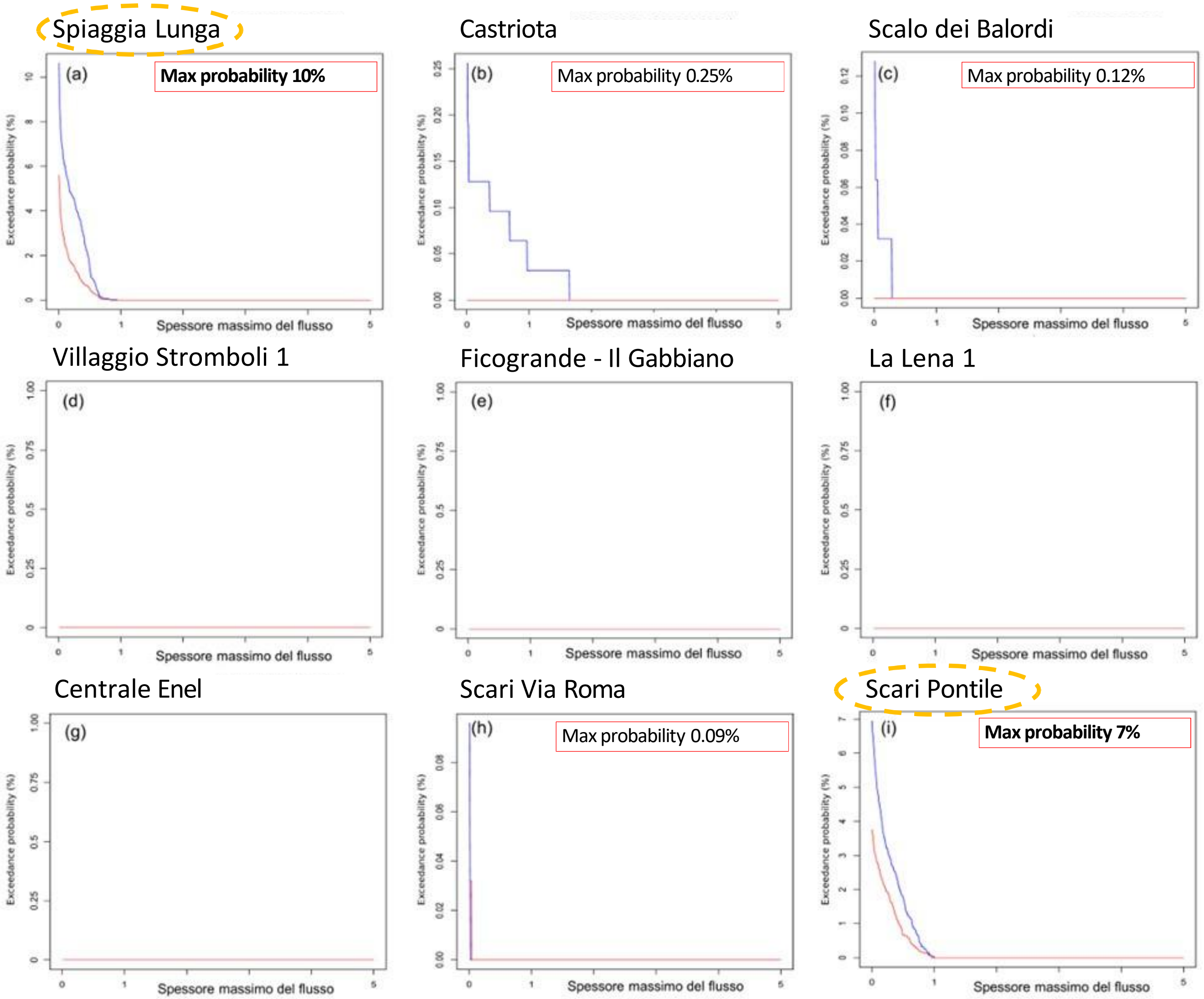


Figure. (left) Probability of invasion by remobilization pyroclastic flows conditional on the collapse of a **random 20° circular sector,** with respect to a maximum flow thickness threshold of 0.1 m. (right) Hazard curves at the endpoints of tsunami escape routes with respect to variable thickness thresholds and circular sectors of 20° (red) and 45° (blue).

Conclusions

- The NEAM-COMMITTMENT project, among its tasks, include the update of tsunami escape routes at Stromboli volcano through science-informed and participatory decision-making
- At Stromboli, inabited areas have been affected (and could be affected in the future) by volcanic-induced tsunamis.
- In addition, ballistics, deposit-derived pyroclastic density currents and wildfires could be source of hazard interfering with tsunami escape routes.
- Within the framework of the DPC-INGV agreement, various research groups of INGV are finalizing preliminary probabilistic hazard maps of the above-mentioned hazards.
- Regarding the tsunami hazard at Stromboli, as part of the DPC-INGV agreement, preliminary probabilistic tsunami inundation maps and hazard curves for selected sites of interest are being finalized and delivered.
- These maps and curves were produced using an innovative process that combines numerical modeling, expert elicitation, and statistical approaches. The products include explicit uncertainty quantification, are available for various databases, and have a 50-year validity period.

- As part of the NEAM-COMMITTMENT project, we proposed several comparisons:
  - Between selected maps and current escape routes and waiting areas
  - Between different hazard curves developed for the end points of escape routes and waiting areas (this latter done for tsunami, ballistic and PDC hazard)

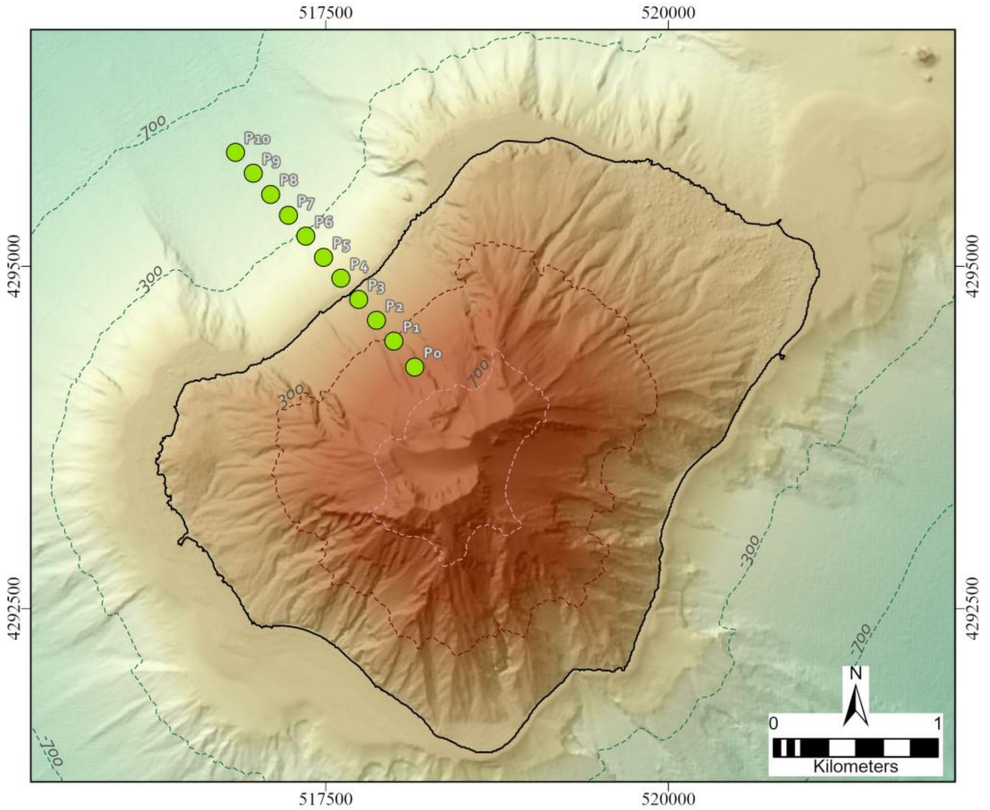
Significant work still needs to be done by INGV with respect to:

- Study the occurrence probabilities of the various phenomena
- Start developing multi-hazard evaluations (e.g., tsunami + other hazards)
- Harmonize (where possible) the format with the PTHA of NEAM-COMM.

ADDITIONAL SLIDES

Approach to develop tsunami probabilistic invasion maps

1. Numerical simulations (Multilayer-HySEA) along the SdF, varying initial positions, volume and landslide density



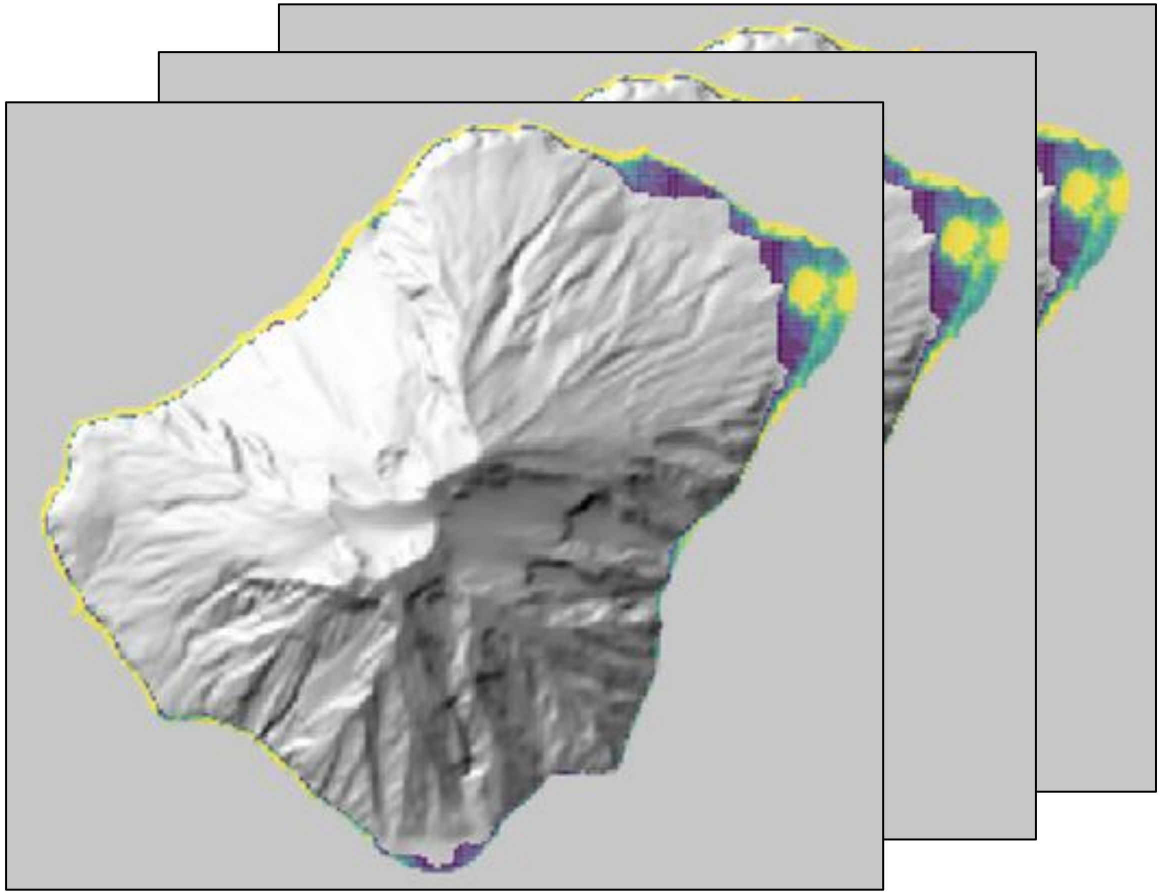
11 positions (P0-P10) along the Sciara del Fuoco centerline

- 48 at elevations +300/+700 (P00,P01)
- 48 at elevations 0/+300 (P02, P03)
- 72 at depths 0/-300 (P04, P05, P06)
- 96 at depths -300/-700 (P07, P08, P09, P10)

12 volumes (1, 2, 3, 5, 8, 8.7, 11, 14, 17, 21, 25, 30 Mm^3)

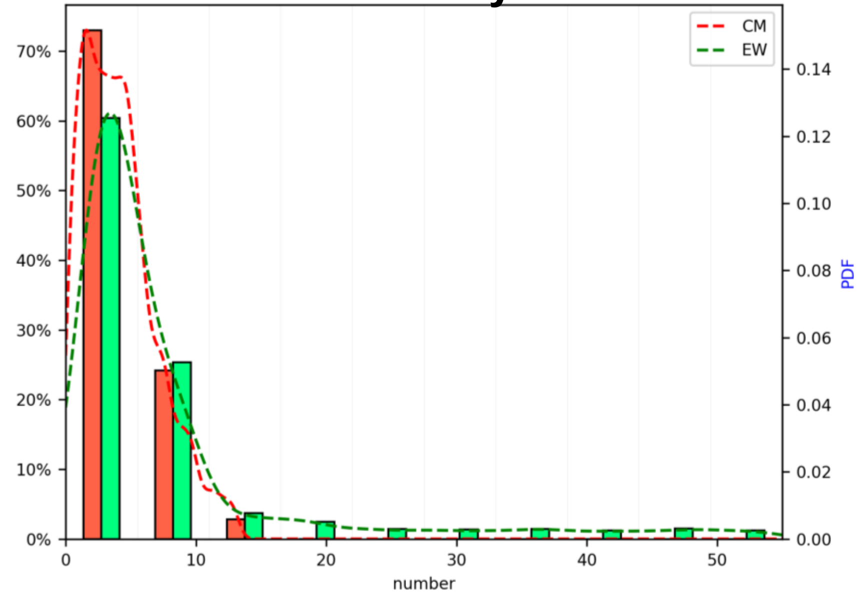
2 landslide densities (2000, 1670 kg/m^3)

286 simulations
286 inundation maps (water depth)

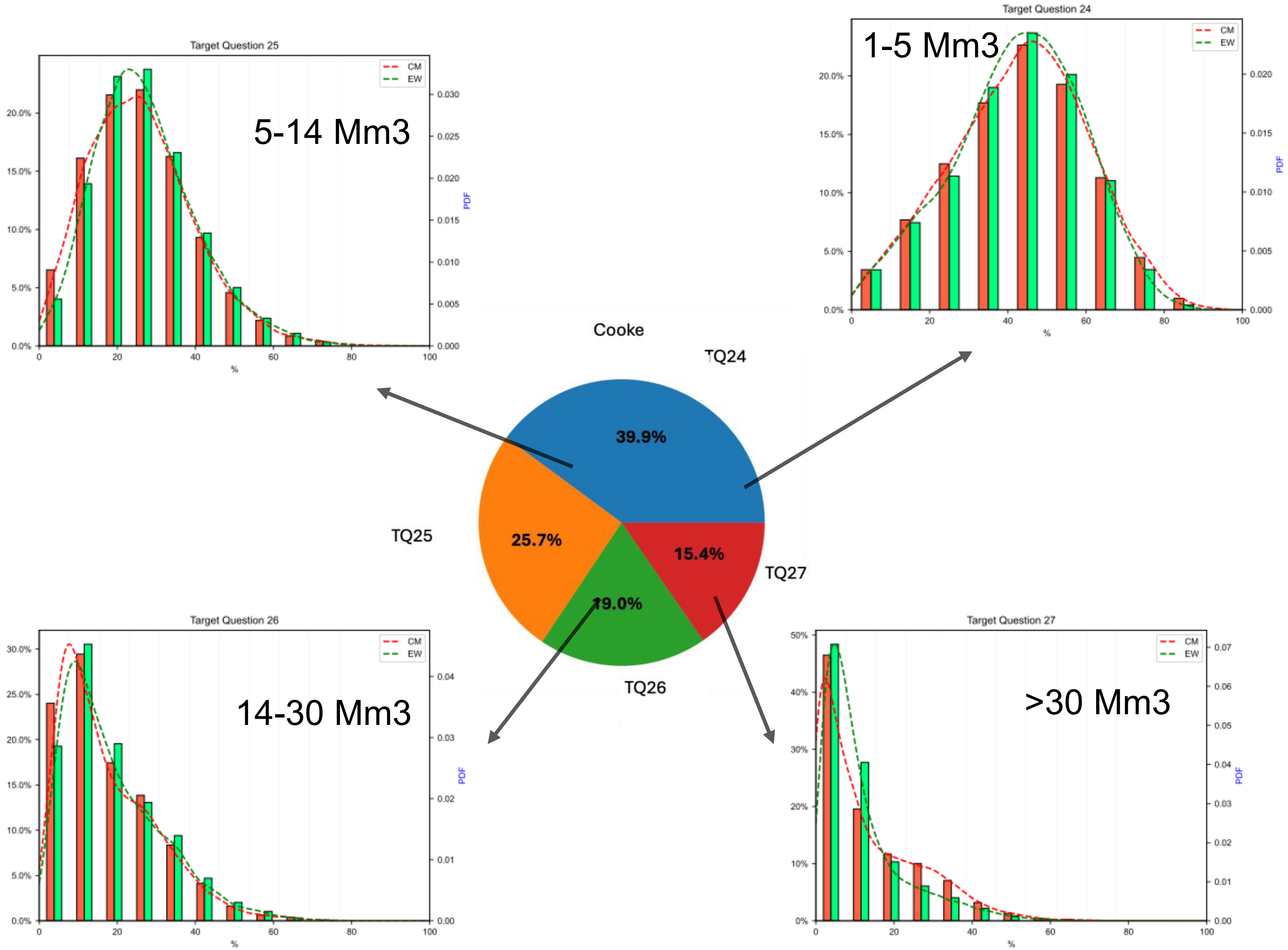


2. Expert elicitation to assign weights to different simulations and to develop a temporal model for the next 50 years (with uncertainty quantification)

TQ3: n° of Tsunamigenic Landslides in the next 50 years

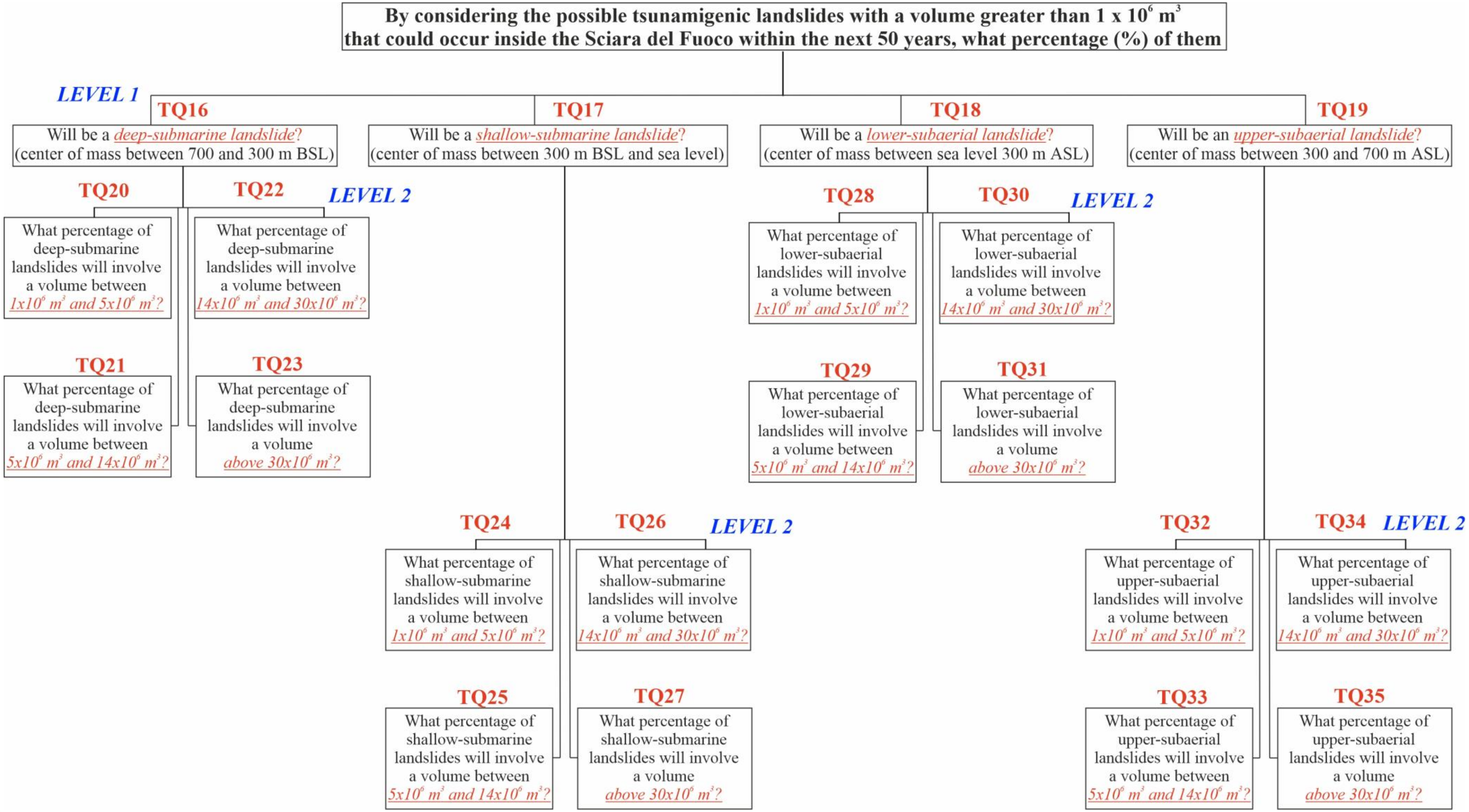


TQ24: Shallow Submarine position, 1-5 Mm3
TQ25: Shallow Submarine position, 5-14 Mm3
TQ26: Shallow Submarine position, 14-30 Mm3
TQ27: Shallow Submarine position, >30 Mm3



Approach to develop tsunami probabilistic invasion maps

2. Expert elicitation to assign weights to different simulations and to develop a temporal model for the next 50 years (with uncertainty quantification)



Approach to develop tsunami probabilistic invasion maps

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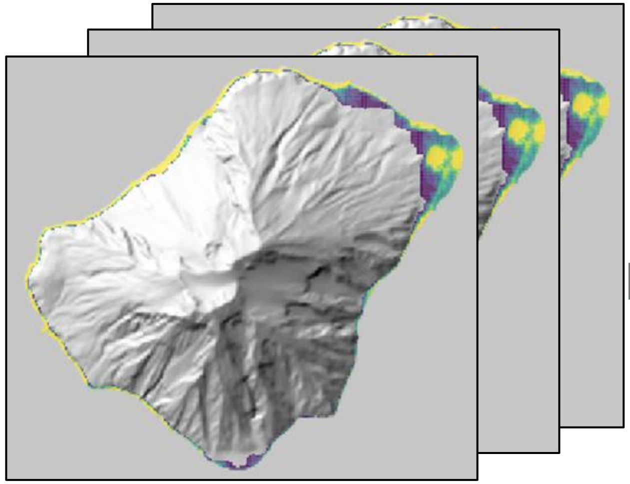
3. Combination of inundation maps with weights from elicitation, in order to produce probabilistic maps for fixed water depth thresholds, maps for fixed probability and hazard curves for specific sites of interest

For each chosen inundation threshold (e.g. 0.5 m) and for volumes between 1 and 30 Mm^3



286 binary maps

0 if < thresh.
1 if >= thresh.

12 sampling of weights (3 V and 4 P <u>intervals</u>)

target_20	target_21	target_22	target_23	target_24	target_25	target_26	target_27	target_28	target_29	target_30	target_31
2.71E+01	4.15E+01	5.98E+00	2.50E+01	3.31E+01	4.78E+01	1.83E+01	1.52E+01	4.06E+01	2.65E+01	1.40E+01	1.10E+01
4.56E+01	1.37E+01	1.18E+01	3.22E+01	9.66E+01	3.82E+01	3.14E+01	3.40E+01	4.61E+01	2.09E+01	6.99E+00	2.74E+01
9.47E+01	1.71E+01	4.17E-01	6.87E+01	4.71E+01	1.94E+01	3.26E-01	6.73E+01	2.97E+01	8.76E-01	1.63E-02	6.56E+01
2.93E+01	4.47E+00	1.86E+00	5.76E+01	6.49E+00	1.51E+01	5.58E+01	6.60E+01	1.73E+01	3.00E+00	2.86E-02	6.41E+01
1.12E+01	3.67E+01	6.68E+00	5.16E+01	1.11E+01	3.12E+01	6.77E+00	5.70E+01	2.36E+01	1.04E+01	6.18E+00	4.93E+01
1.70E+01	2.22E+01	3.69E+01	1.05E+01	4.88E+01	2.74E+01	1.10E+01	7.03E+00	5.12E+01	3.94E+01	3.01E+01	3.63E+01
1.75E+01	5.68E+00	1.29E-01	7.43E+01	1.15E+01	1.06E+01	4.32E+01	7.57E+01	6.62E+00	1.38E+00	2.06E+00	9.24E+01
1.13E+01	1.02E+01	2.53E+01	3.53E+01	1.25E+01	7.49E+01	1.70E+01	3.07E+01	5.53E+01	3.13E+01	3.38E+01	1.72E+01
6.10E+01	6.61E+00	4.42E-01	8.79E+01	3.34E+01	9.56E+00	4.17E+00	6.92E+01	1.93E+01	2.35E+00	4.96E-02	9.18E+01
5.50E+00	4.21E+01	3.84E+01	4.01E+01	2.72E+01	2.86E+01	4.79E+01	2.18E+01	9.45E+00	8.81E+00	2.93E+01	6.58E+01

10000 samples
for each question

Normalization
and
distribution

10000 arrays of 286 weights

10000 hazard curves
For each point of interest

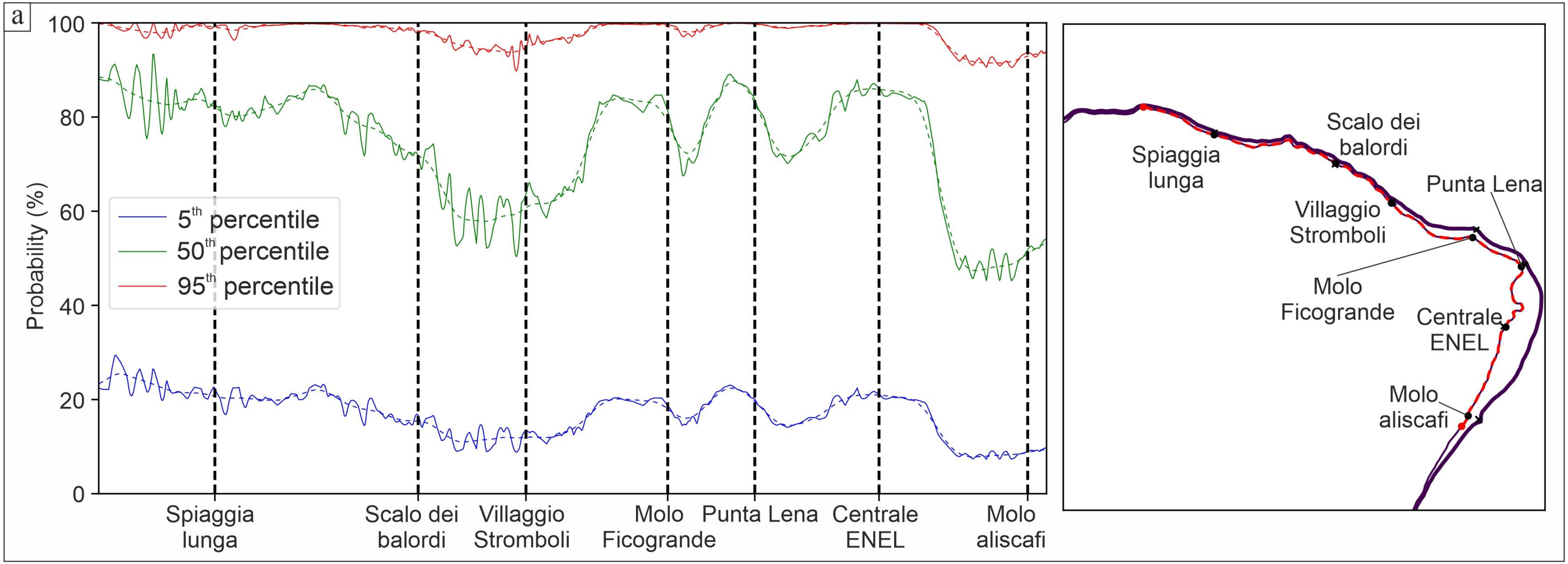
10000 maps

Maps/curvs representing the 5°, 50° and 95° percentiles (for visualization purposes only)

N.B.: these maps/curves describe the elicited uncertainty

Probability variation along isoline

Probability of exceeding 0.5 m water depth within the next 50 years along the 5 m a.s.l. isoline



Preliminary study on escape routes in case of tsunami at Stromboli

Within the DPC-INGV agreement, it has been produced a first evaluation on escape routes and evacuation times at Stromboli, and the material has been published in two papers on NHESS and Annals of Geophysics (Bonilauri et al., 2024a,b).

Figure. Example of escape routes and evacuation times within Ficogrande beach, Stromboli.

Modified from Bonilauri et al., 2024.