Ground Motion Analysis for the Einstein Telescope: ShakeMap, Seismic Hazard, and Case Studies

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INGV

Overview

Seismic Hazard Perspective

Historical and Instrumental seismicity

ShakeMap Scenario test example

Ground Motion at the depth the the ET

What Is Probabilistic Seismic Hazard Analysis (PSHA)?

PSHA estimates the likelihood of different levels of ground shaking occurring at a site over a given time period.

It considers:

- All possible earthquake sources (faults and regions)
- A range of magnitudes and distances
- Uncertainty in seismic activity and ground motion

Importance:

- Provides a scientific basis for seismic design codes
- Supports decision-making for critical infrastructure
- Enables risk-based comparison across sites and regions
- Fundamental input for seismic risk analysis

Probabilistic Seismic Hazard Models

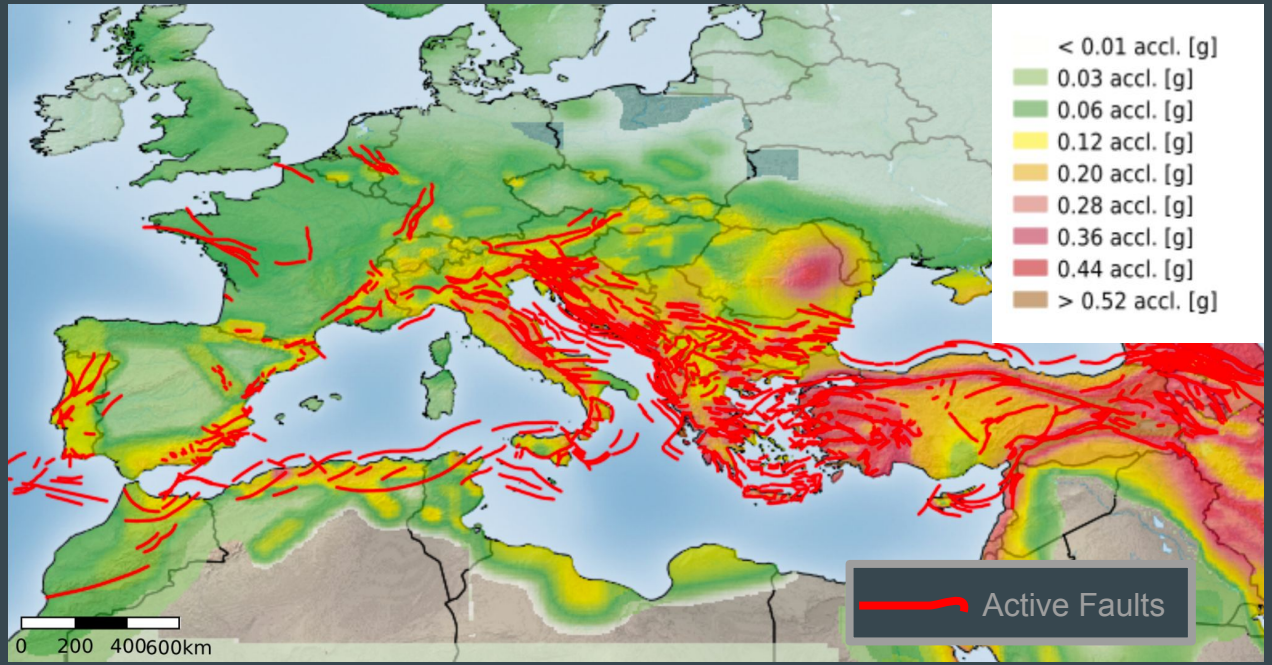
ESHM20 : European model (Danciu et al., 2024)

- Continental-scale
- Unified earthquake catalog
- Fault and distributed sources
- Spectral accelerations for multiple return periods
- Used as reference for risk analysis at European level

MPS19 : Italian national model (Meletti et al., 2019)

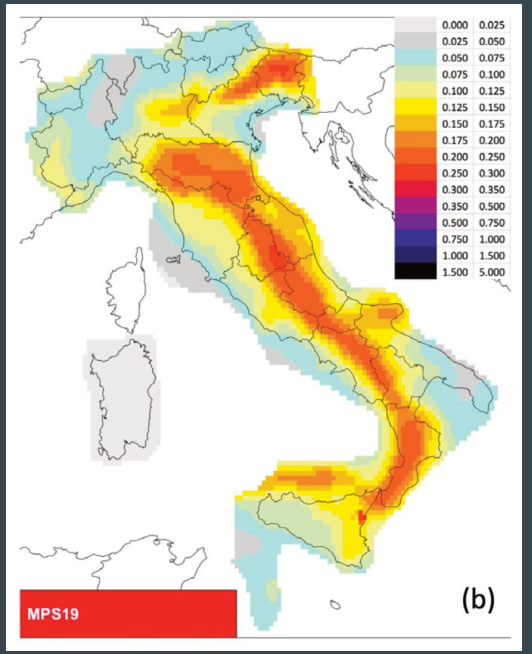
- High-resolution model tailored to Italy
- Based on CPTI15 catalog and Italian fault database
- Region-specific GMMs
- Spectral accelerations for multiple return periods
- Updated hazard model for Italy

Both developed with **broad expert consensus** and **collaborative efforts** by **leading experts** in the field of seismic hazard assessment across **Europe and Italy** .



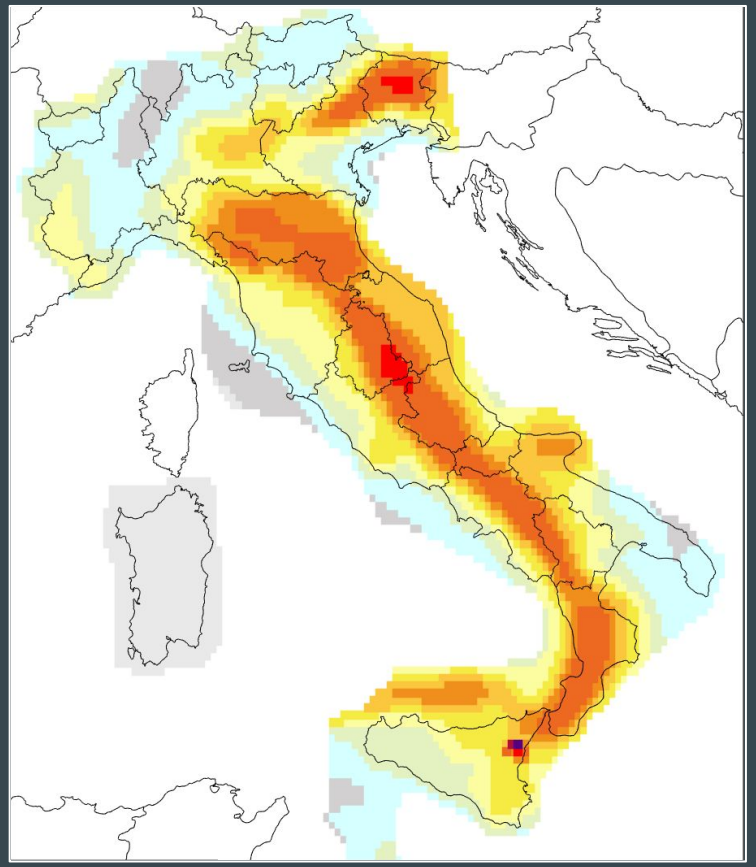
ESHM20

http://www.hazard.efehr.org/en/home/

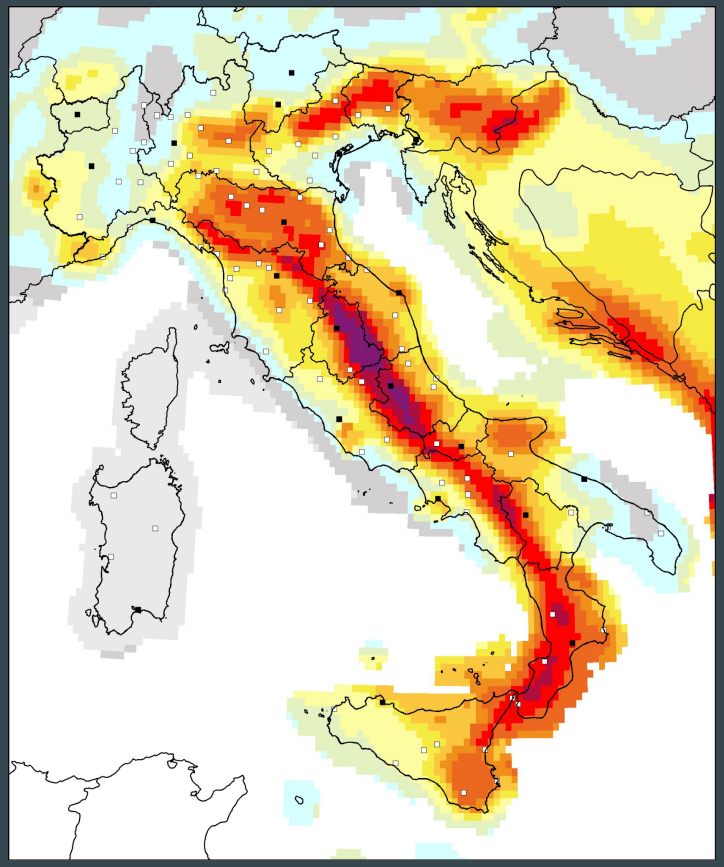


MPS19

Seismic Hazard Map 10% in 50 years (statistical return period of 475 years) on **rock soil**



< 0.025 g
0.025 - 0.050
0.050 - 0.075
0.075 - 0.100
0.100 - 0.125
0.125 - 0.150
0.150 - 0.175
0.175 - 0.200
0.200 - 0.250
0.250 - 0.300
0.300 - 0.350
0.350 - 0.500
0.500 - 0.750
0.750 - 1.000
1.000 - 1.500
> 1.500 g



MPS19
PGA 10% prob. exc. in 50 years
Return period 475 years – rock soil

ESHM20
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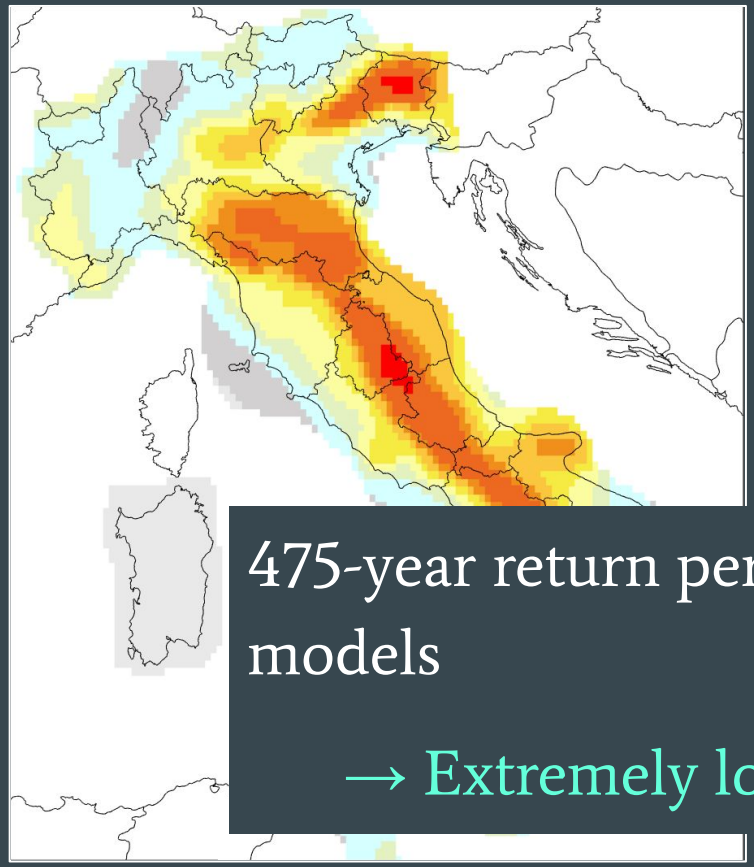

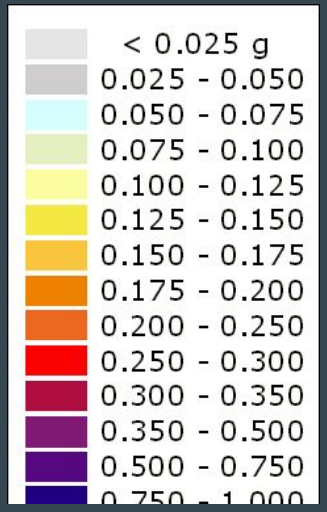

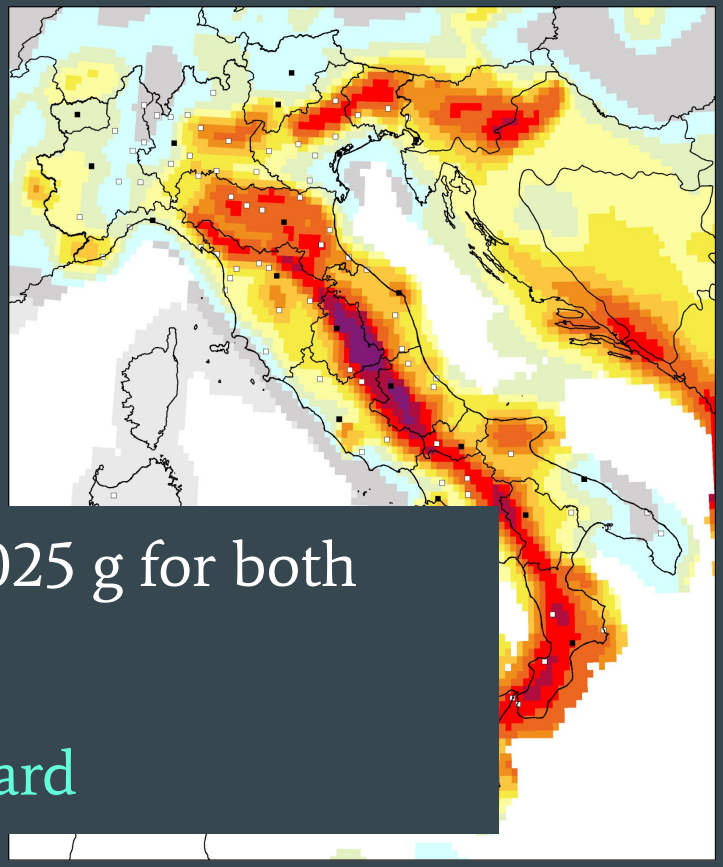

475-year return period: PGA < 0.025 g for both models

→ Extremely low seismic hazard

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Return period 475 years – rock soil

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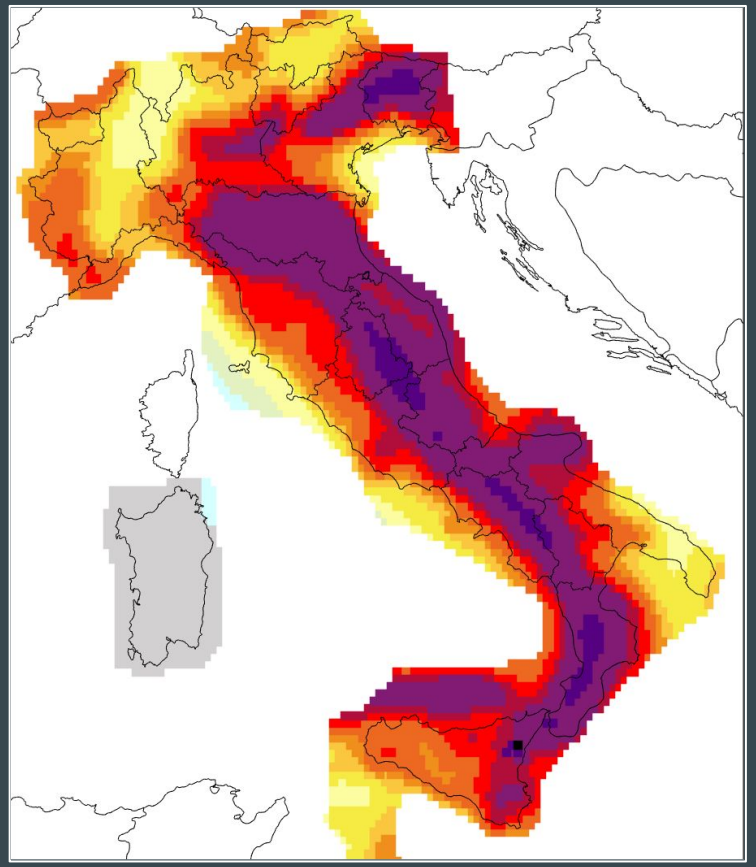

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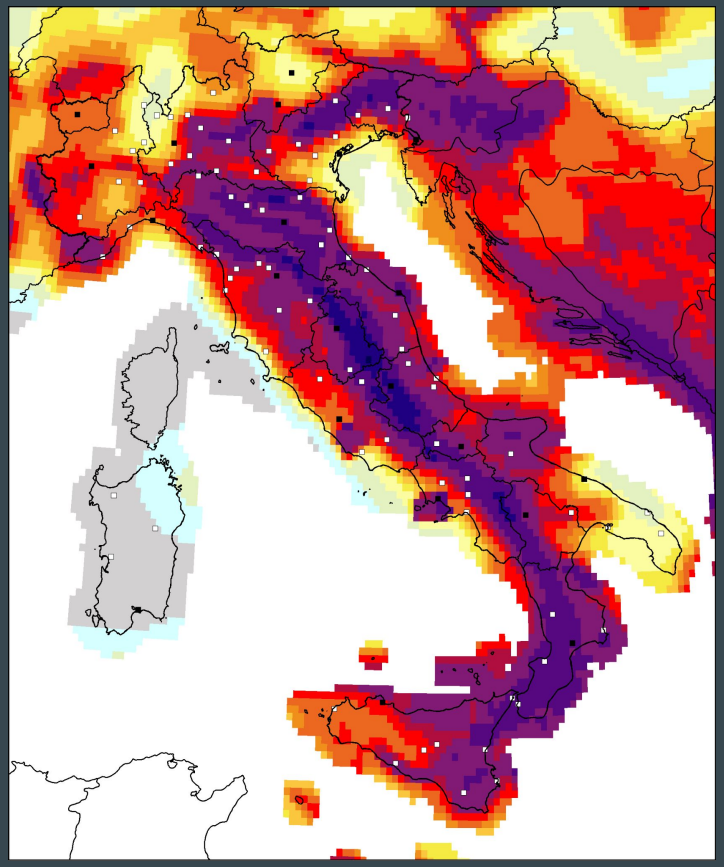

MPS19

PGA 2% prob. exc. in 50 years
Return period 2475 years – rock soil

ESHM20

PGA 2% prob. exc. in 50 years
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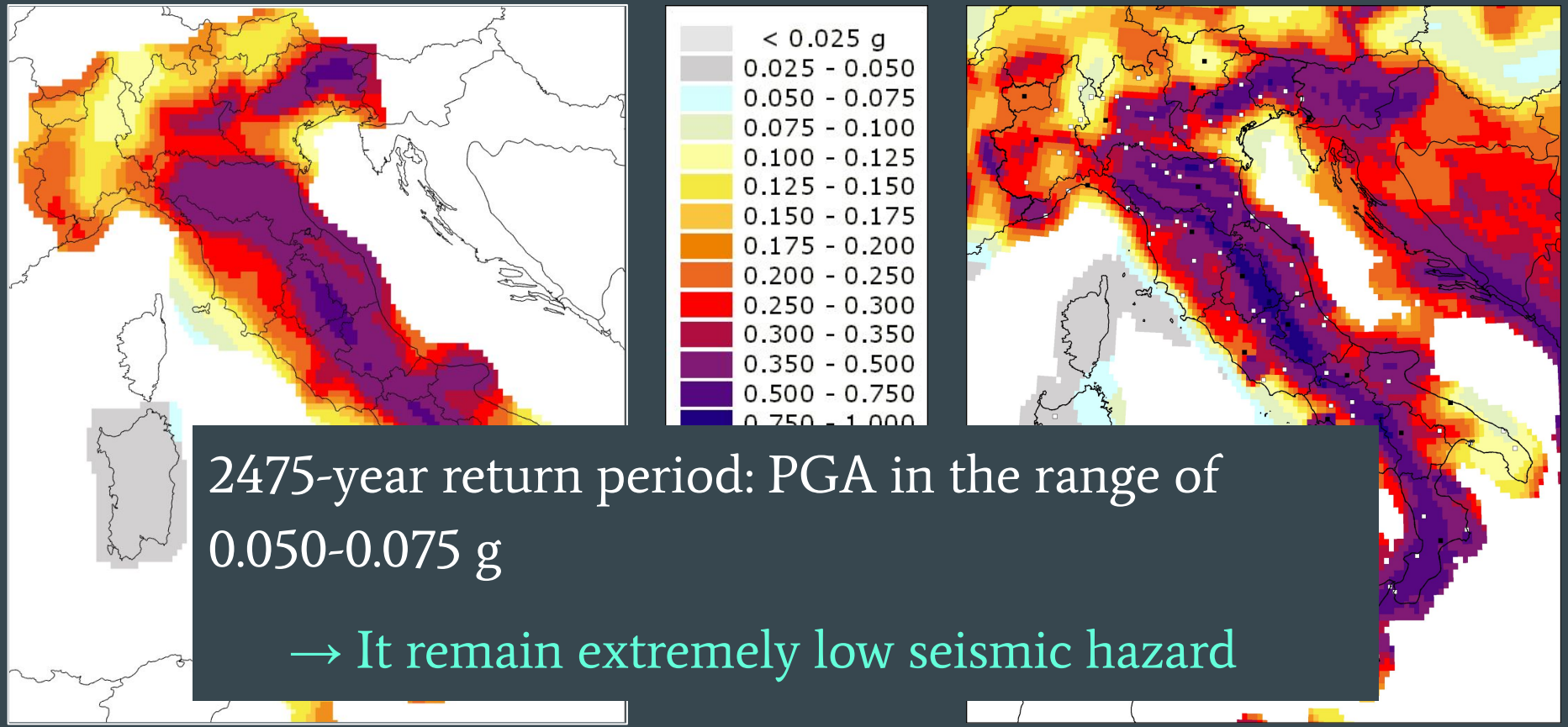

2475-year return period: PGA in the range of 0.050-0.075 g

→ It remain extremely low seismic hazard

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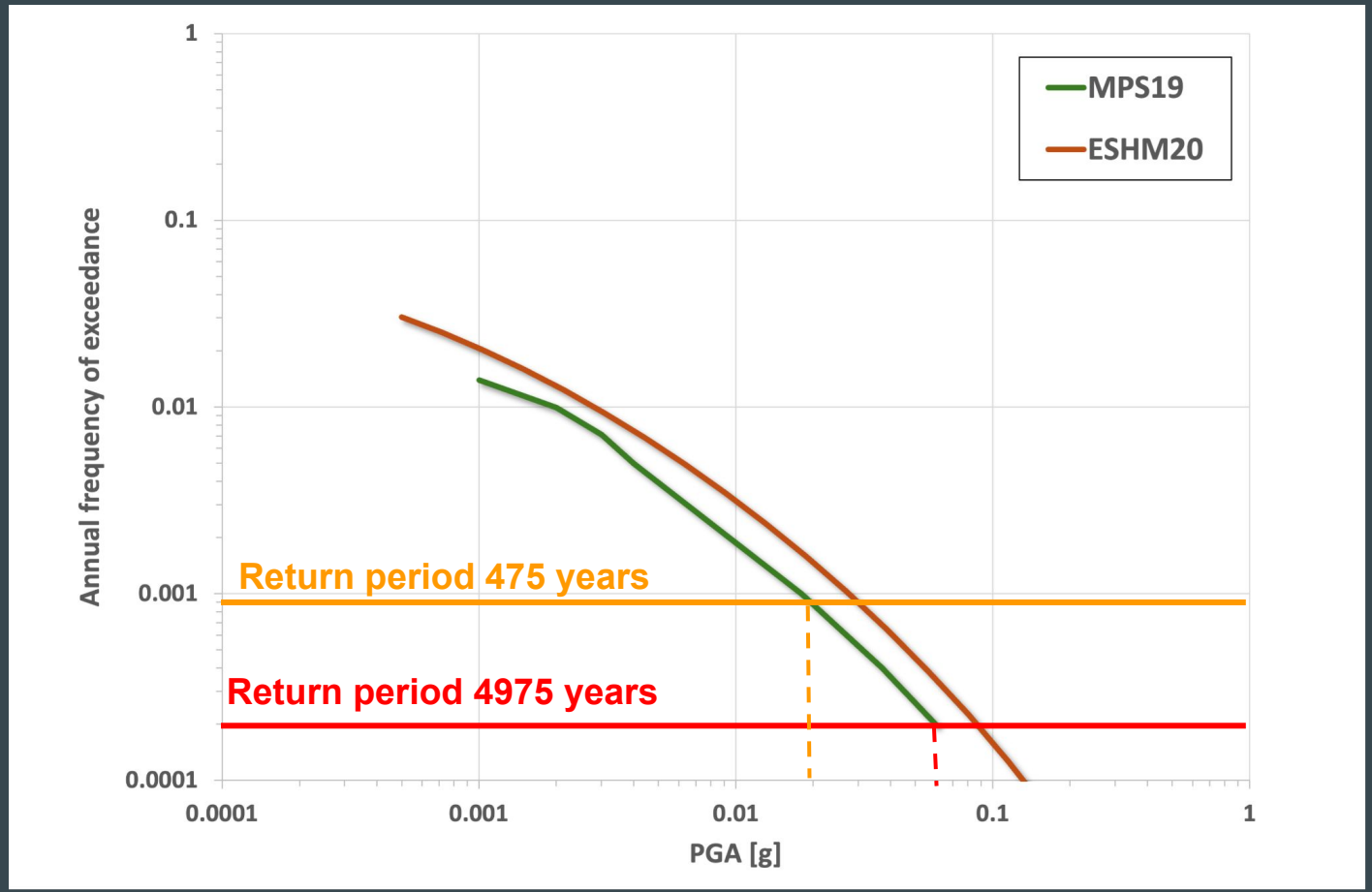
HAZARD CURVE



Probabilistic Seismic Hazard Models

Interpretation:

- This is considered very low shaking
- Comparable to barely perceptible motion for humans
- Far below design thresholds for structural safety

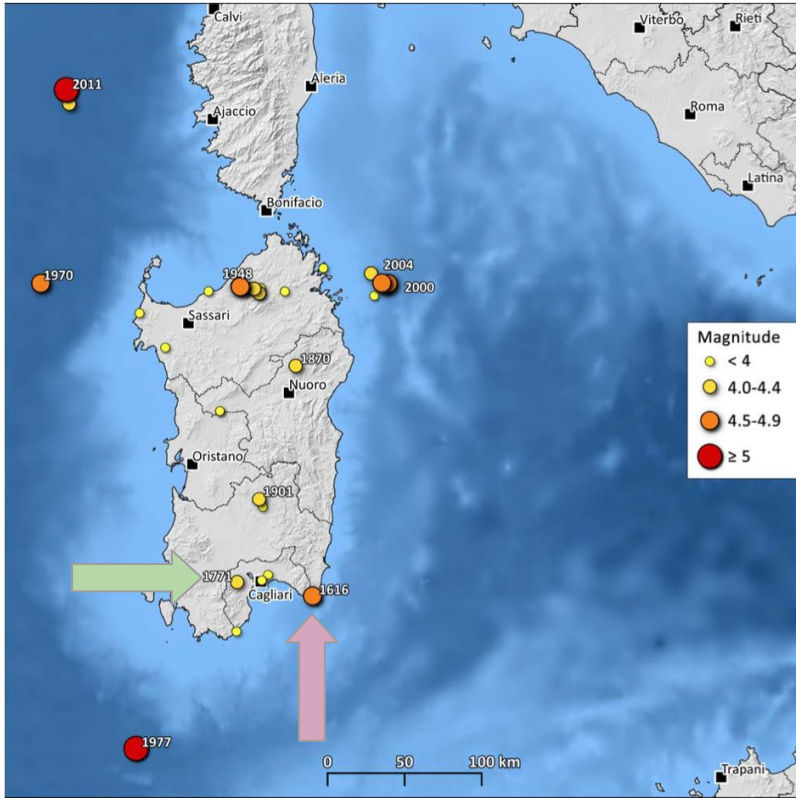
Why it matters:

- Guarantees a seismically quiet environment
- Ensures minimal vibrational noise for operations

Historical Seismicity Reassessment of Sardinia (Meletti et al., 2020)

Two most significant confirmed events:

- 1616 (South-East Sardinia, M ~4.9)
- 1771 (Cagliari area, moderate magnitude)



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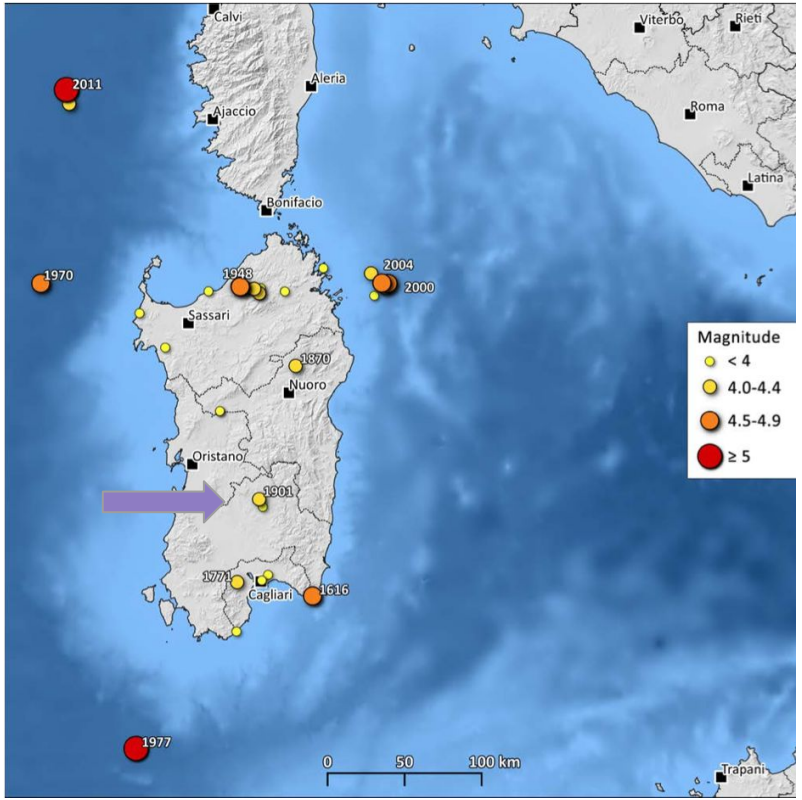

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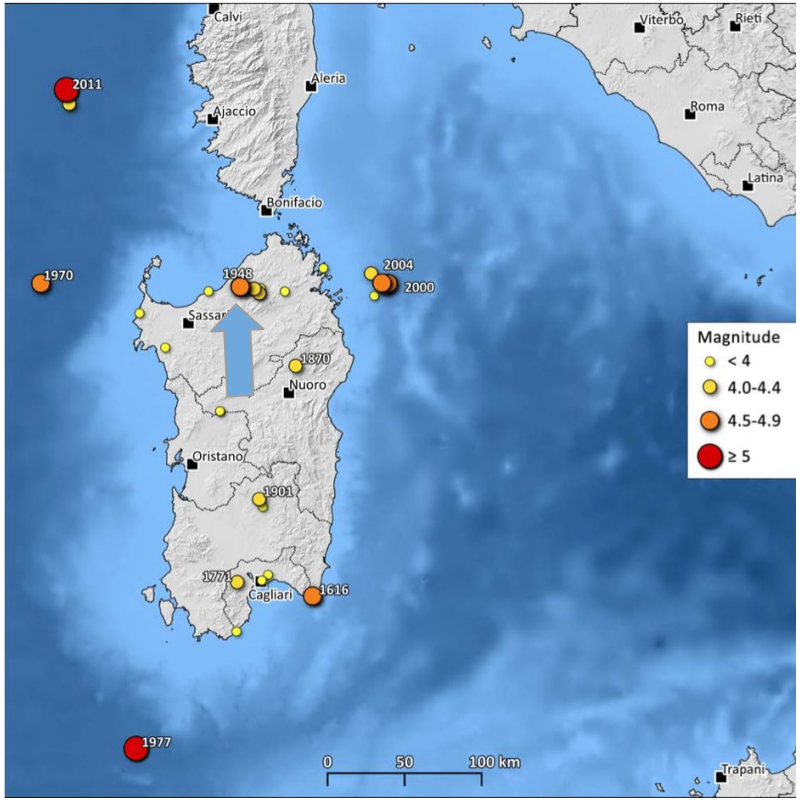

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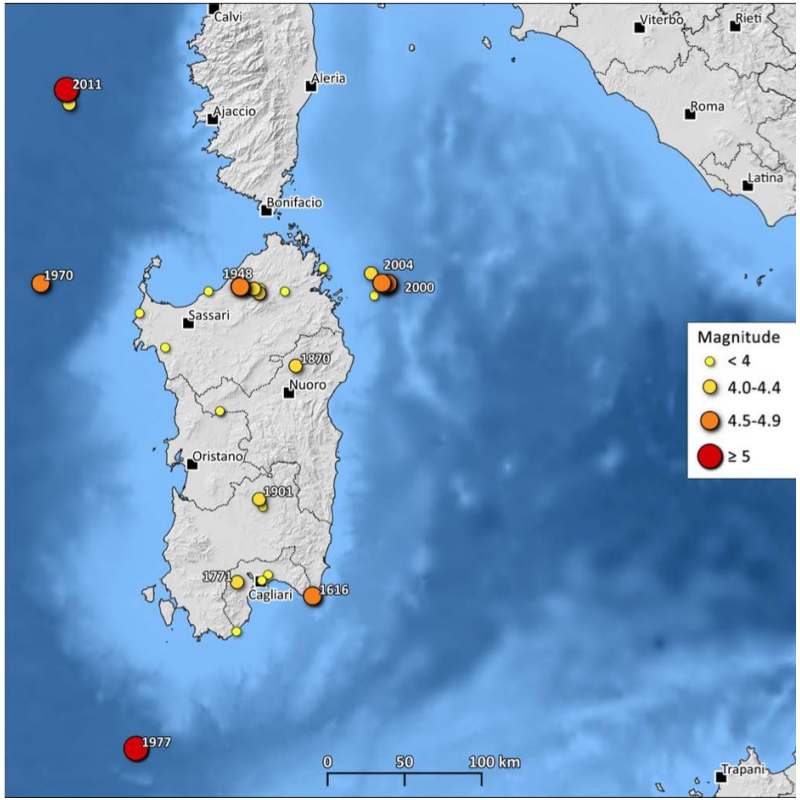
Clarification of doubtful events:

- 1835: Possibly real, but minor
- 1838, 1855, 1898: Proven non-existent

Other 19th–20th century events (1870, 1906, 1922, 1924):

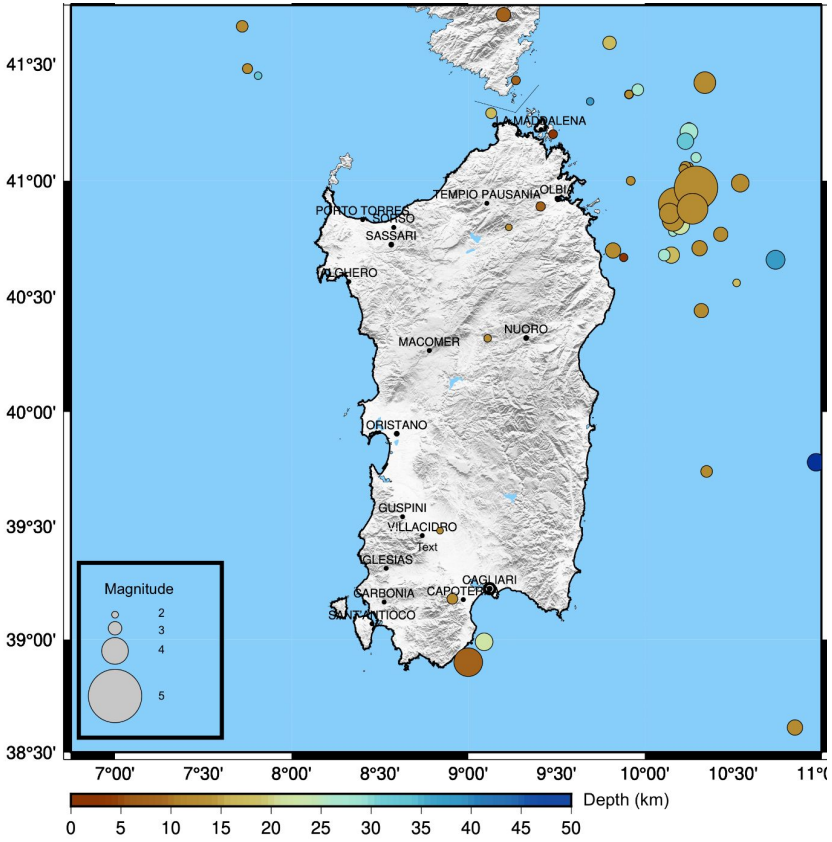
- Low magnitude, no macroseismic effects



Instrumental Seismicity of Sardinia (from 1985 to the present day)

A few dozen earthquakes were recorded, in four magnitude 4 was exceeded (all off shore)

- in the north-east there were two earthquakes on **26 April 2000** (magnitude **4.2** at 13:28 and magnitude **4.7** at 13:37)
- in the north-east the magnitude **4.3** earthquake of **18 December 2004.**
- South of Sardinia was the magnitude **4.1** earthquake of **24 March 2006.**

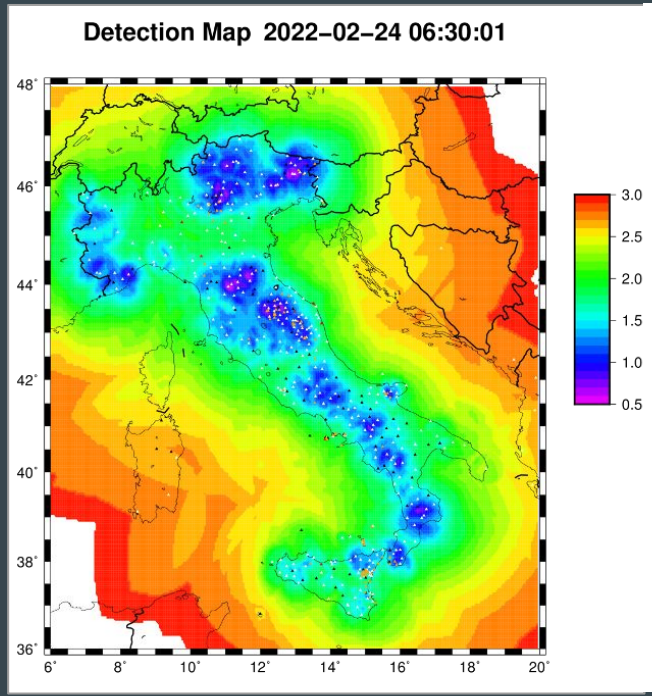


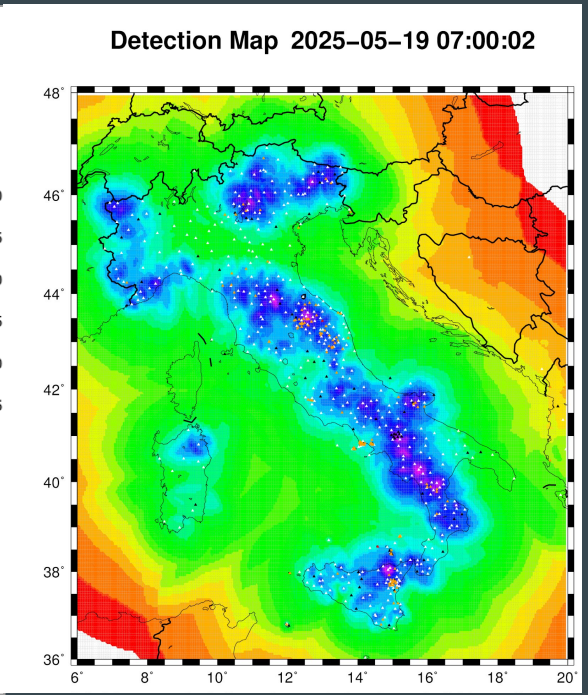
Instrumental Seismicity of Sardinia (from 1985 to the present day)

Improvement of the minimum detected magnitude of the Italian National Network

Based on

- the number of stations
- the geometry of the network
- the background noise level

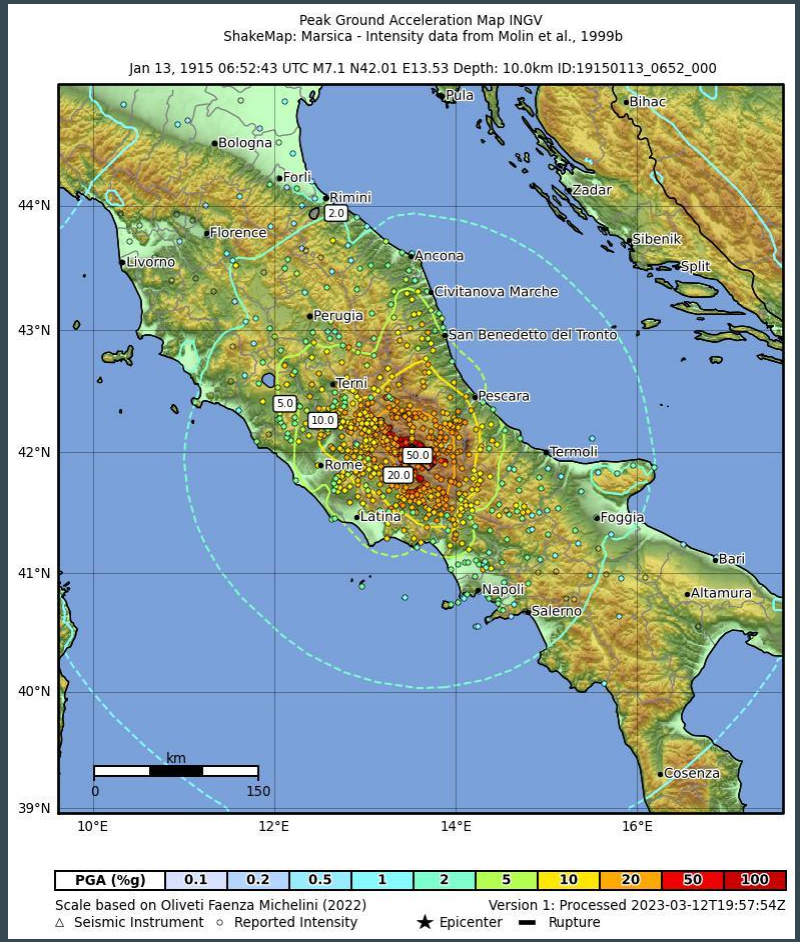




Earthquake Scenario Modelling

- Italy has an exceptionally detailed knowledge of seismicity, with historical records extending several centuries into the past.
- In the absence of known active faults in Sardinia, we relied on the Italian historical earthquake catalogue to develop scenario-based models.
- A strong historical earthquake from Central Italy was selected as a conservative scenario, representing one of the largest events in the national catalogue, able to be felt in Sardinia

Earthquake Scenario Modelling

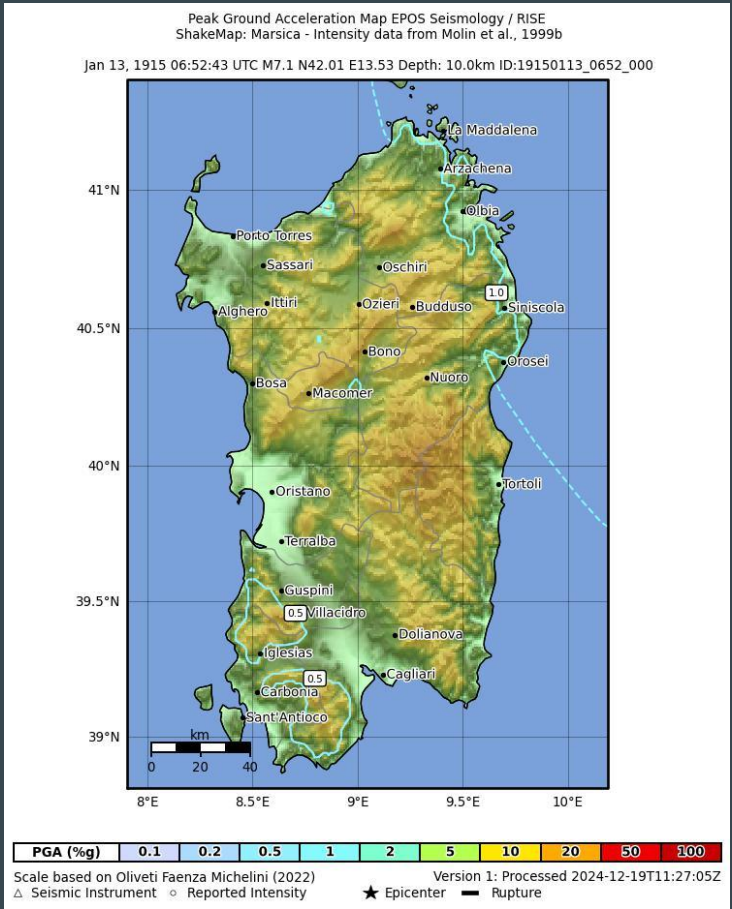


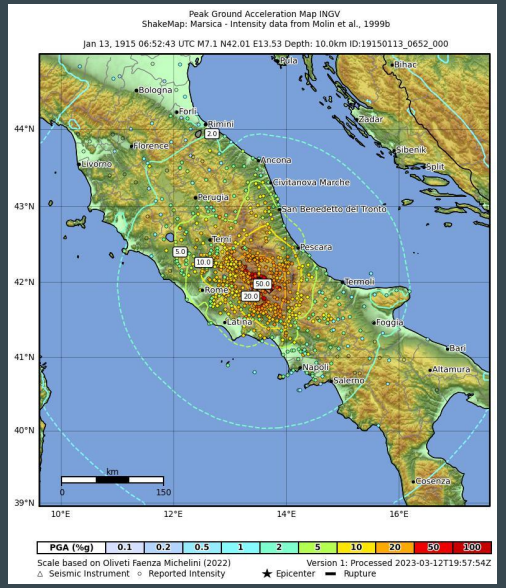
https://shakemap.ingv.it/

Earthquake Scenario Modelling

SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0555	0.232	1.21	3.38	7.46	14.5	26.1	44.4	>72.3
PGV(cm/s)	<0.0178	0.0939	0.686	2.08	5.06	10.9	21.6	40.3	>71.7
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Oliveti Faenza Michelini (2022) Version 1: Processed 2023-03-12T19:57:54Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture





https://shakemap.ingv.it/

Estimating Ground Motion at Depth

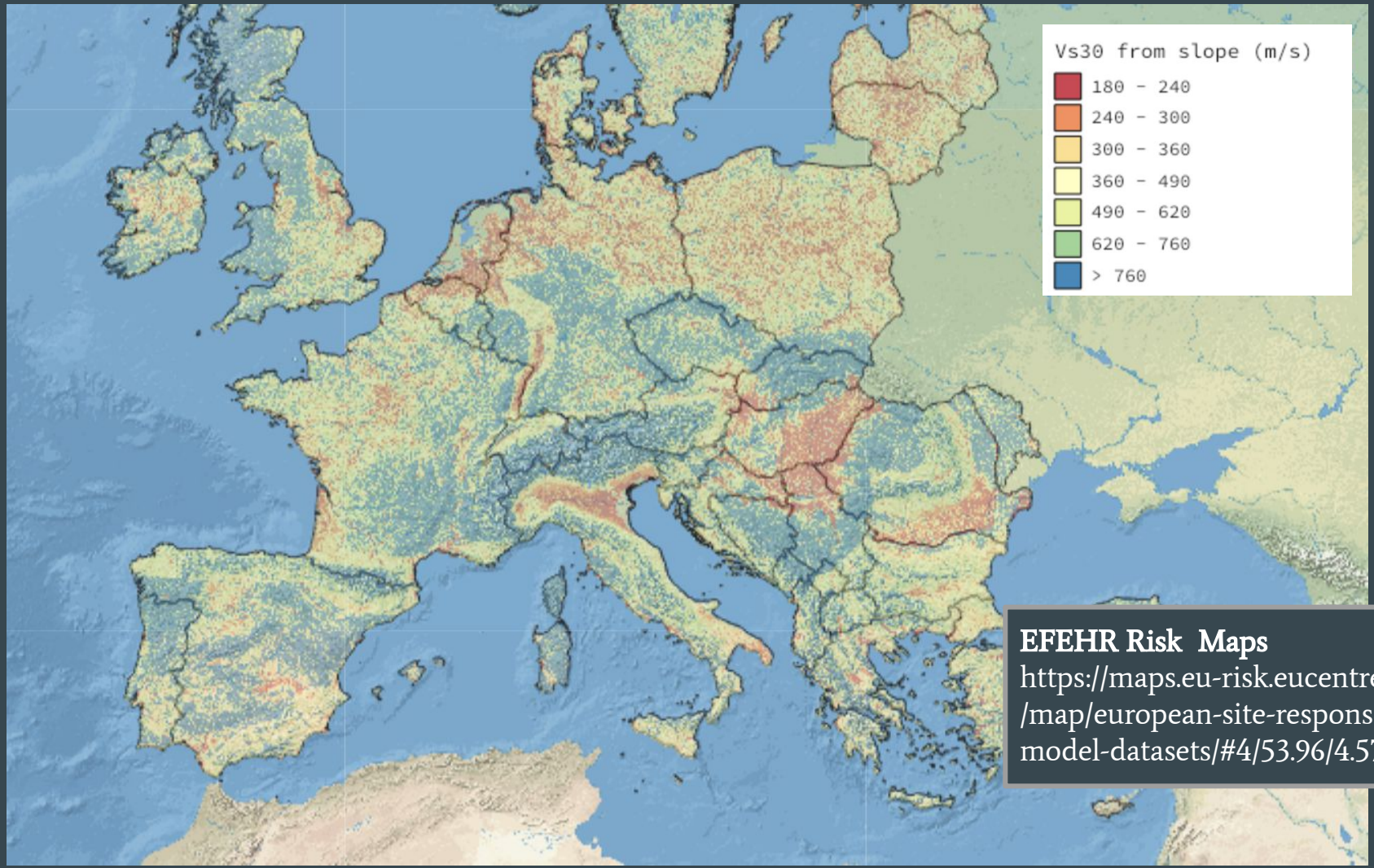
Accurate ground motion estimation at depth requires multiple borehole recordings to calibrate a site-specific model (GMM)

→ Not available for Sardinia (borehole stations installed in the last 2 years)

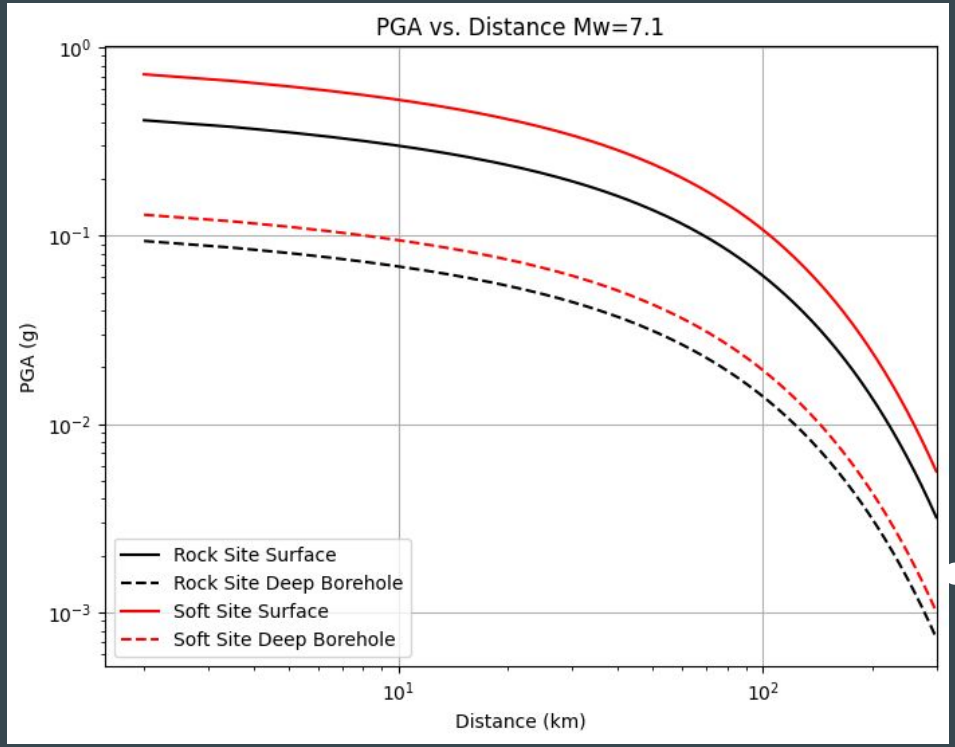
→ Japanese KiK-net network

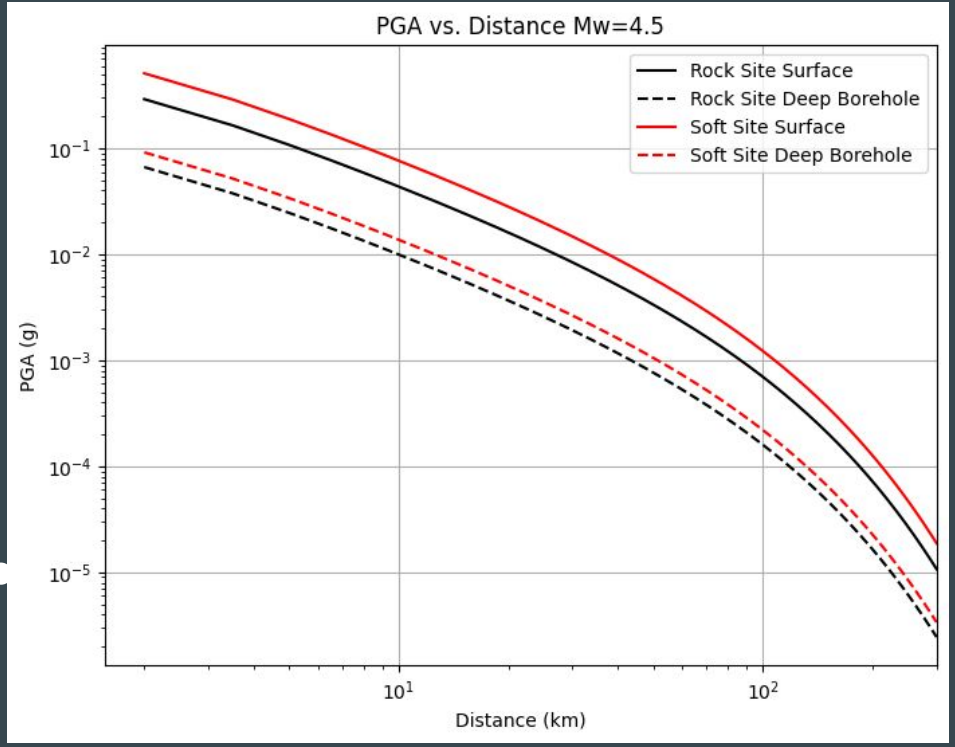
Rodriguez-Marek et al. (2011) developed a GMM that quantifies ground motion both at the surface and at borehole depth:

- Deep Borehole (>150m)
- Depth where shear-wave velocity reaches rock values
- Shear-wave velocity at the bedrock
- Vs30



EFEHR Risk Maps
https://maps.eu-risk.eucentre.it/map/european-site-response-model-datasets/#4/53.96/4.57





Decrease of 23% for ROCK SITE and 18% for SOFT SOIL

Summary of Key Findings

Exceptionally low seismic hazard

- PGA consistently < 0.03 g for return periods up to 475 years
- Even at 2,475 years: values remain < 0.075 g
- Far below critical design thresholds for sensitive facilities

Stable continental region

- Rock conditions confirmed at ET tunnel depth
- Ground motion at depth significantly lower than at the surface

Comprehensive historical and instrumental data

- Centuries of documented seismicity
- No active faults in the region

Summary of Key Findings

Exceptionally low seismic hazard

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- Centuries of documented seismicity
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Why It Matters for Einstein Telescope

- Guarantees a **seismically quiet environment**
- Ensures **minimal vibrational noise** at operating depth
- Meets the **highest scientific and engineering standards** for site selection