Long-period soil amplification in the Po Plain (Italy) to account for site effects in regional PSHA

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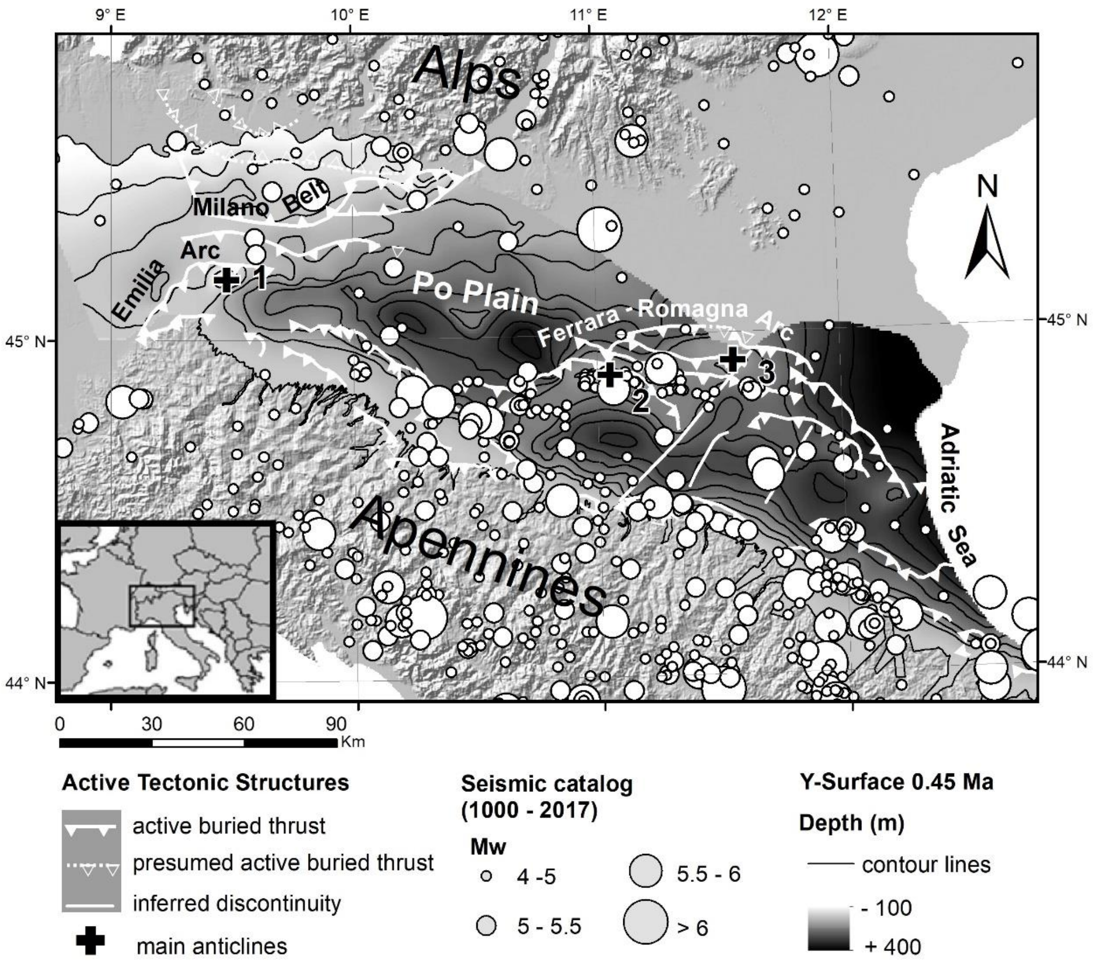
TOPIC & GOALS

- The **Po Plain** is one of the deepest and widest sedimentary basin worldwide
- susceptible to **long-period (>1s) resonance phenomena**
- that impact on **large-scale structures**, such as tall buildings, long-span bridges, and large storage tanks.
- High density of both population and infrastructure makes this basin a **high seismic risk zone**.



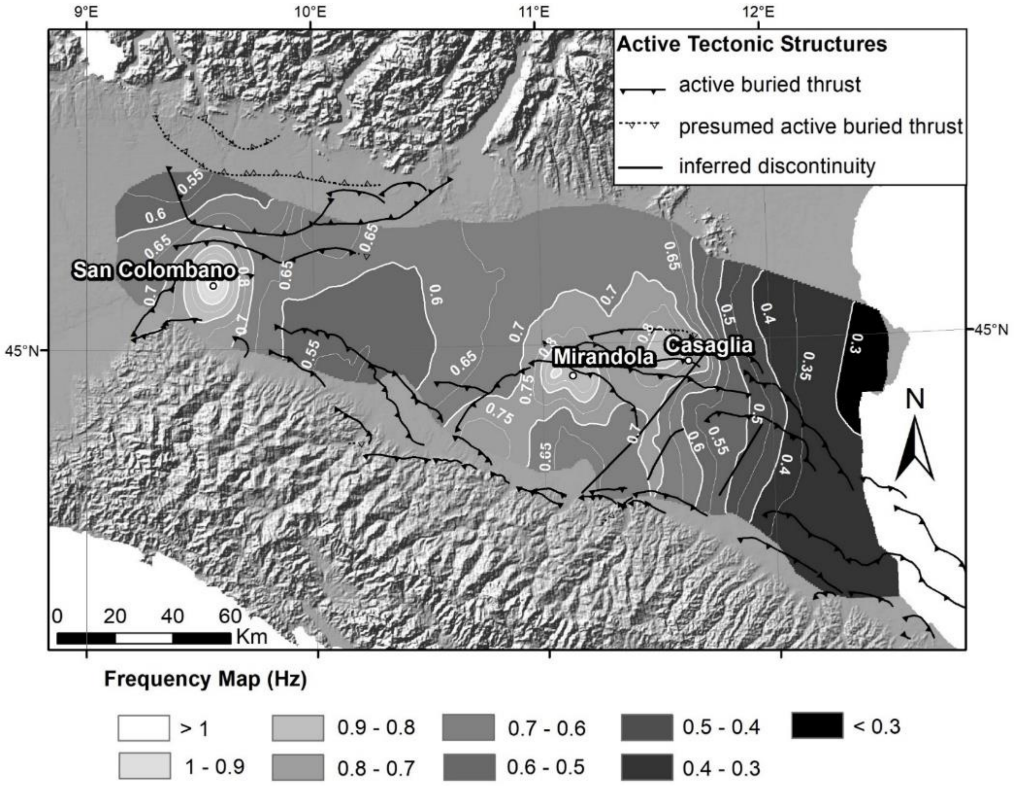
Goals:

1. **Seismo-stratigraphic** model of the Po Plain;
2. Long-period **soil amplification** factors;
3. Soil-specific, partially non-ergodic probabilistic seismic **hazard** maps.

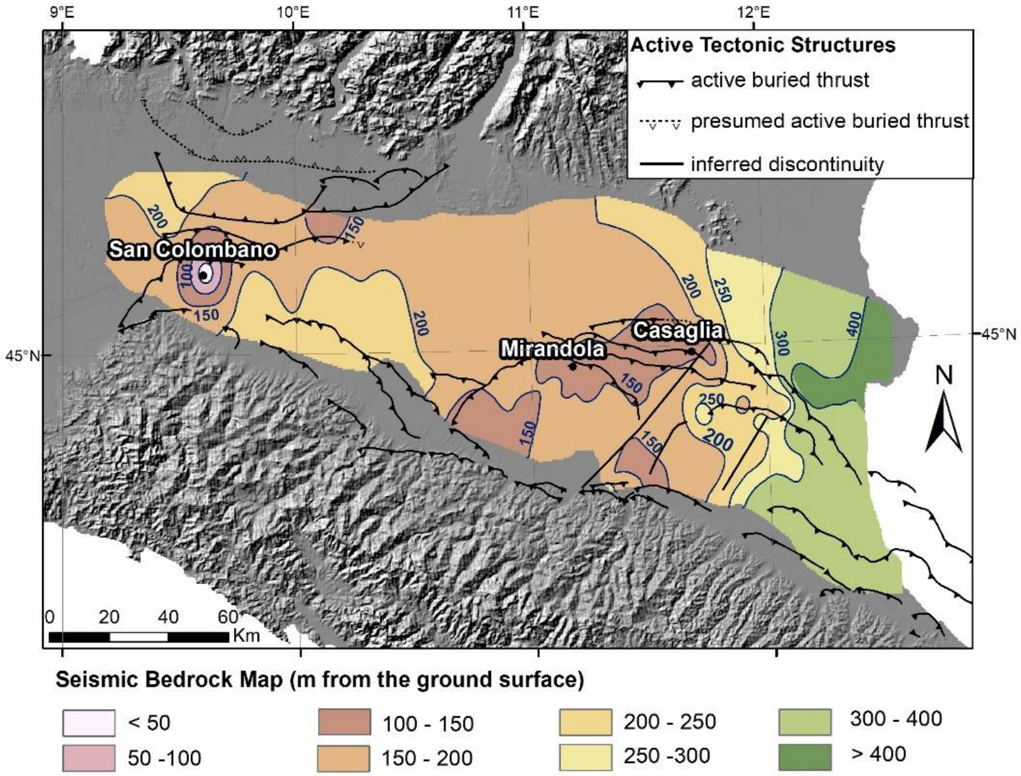
Task 1: seismo-stratigraphic model

➡ a) Map of Seismic bedrock depth

b) 3D Shear-wave velocity model of soft sediments above seismic bedrock



Resonance frequency of soft sediments above seismic bedrock



Seismic bedrock depth

Mascandola et al. (2019). *Mapping the Seismic Bedrock of the Po Plain (Italy) through Ambient-Vibration Monitoring,* **Bull. Seismol. Soc. Am., 109(1),** 164-177.

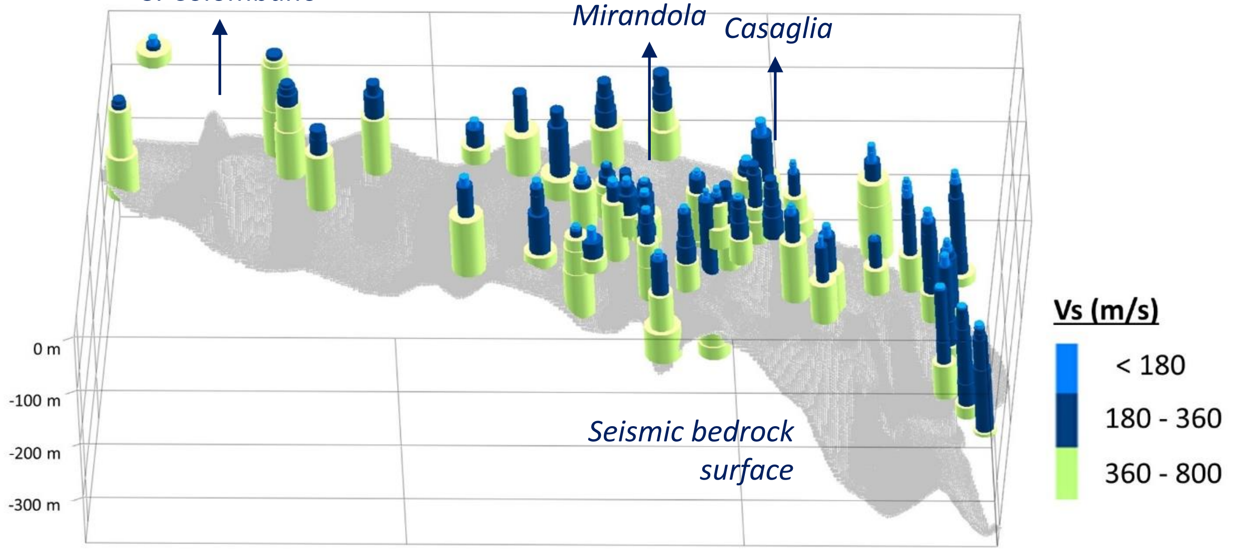
Task 1: seismo-stratigraphic model

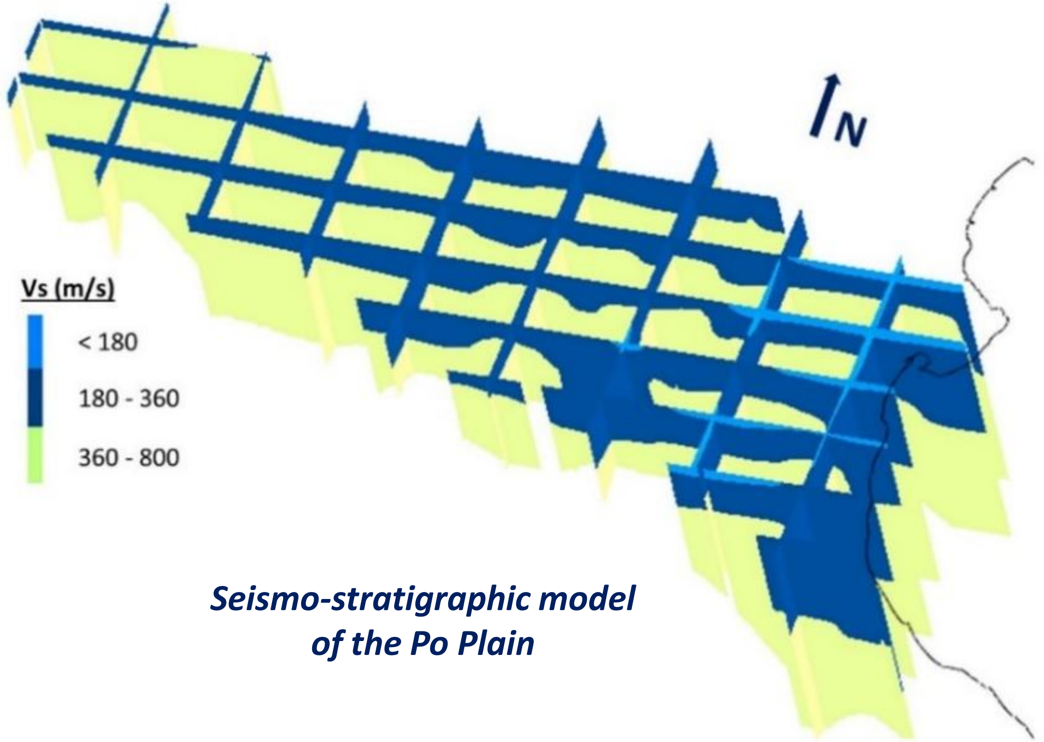
a) Map of Seismic bedrock depth

➡ b) 3D Shear-wave velocity model of soft sediments above seismic bedrock

Input data

- Seismic bedrock surface
- *54 1D V_S* profiles from array measurements (selected – quality check)





Seismo-stratigraphic model of the Po Plain

Distance range: 3 -30 km

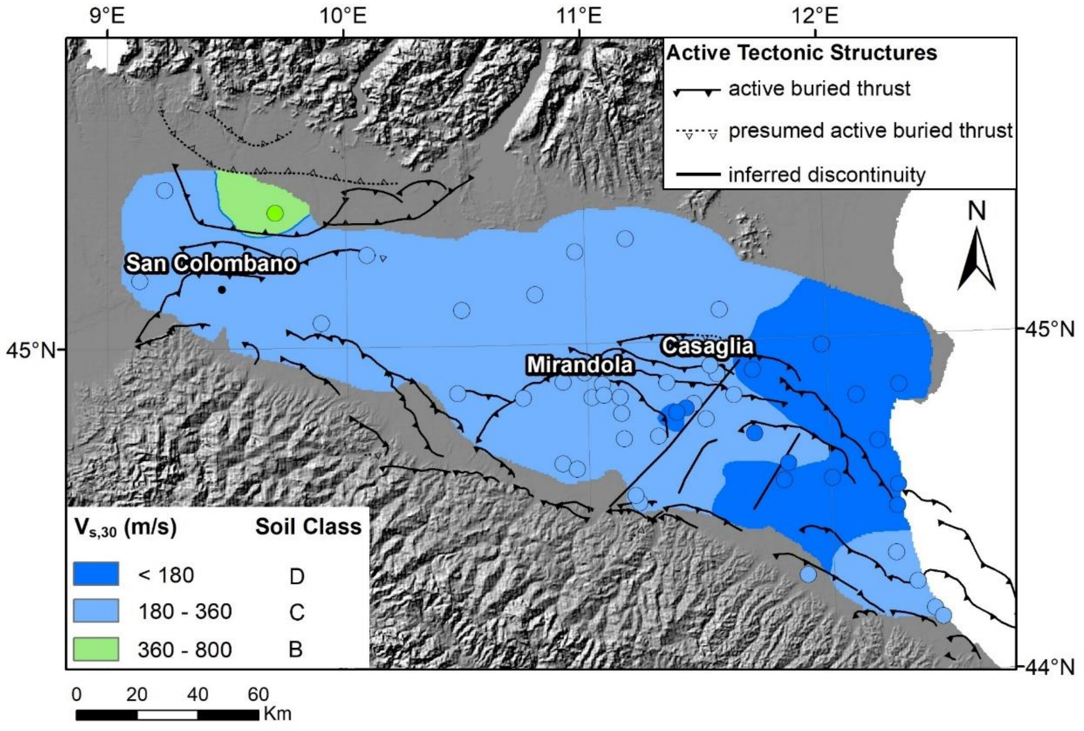
***3D* Interpolation algorithm:** Inverse-Distance (IDW) Anisotropic

Task 1: seismo-stratigraphic model

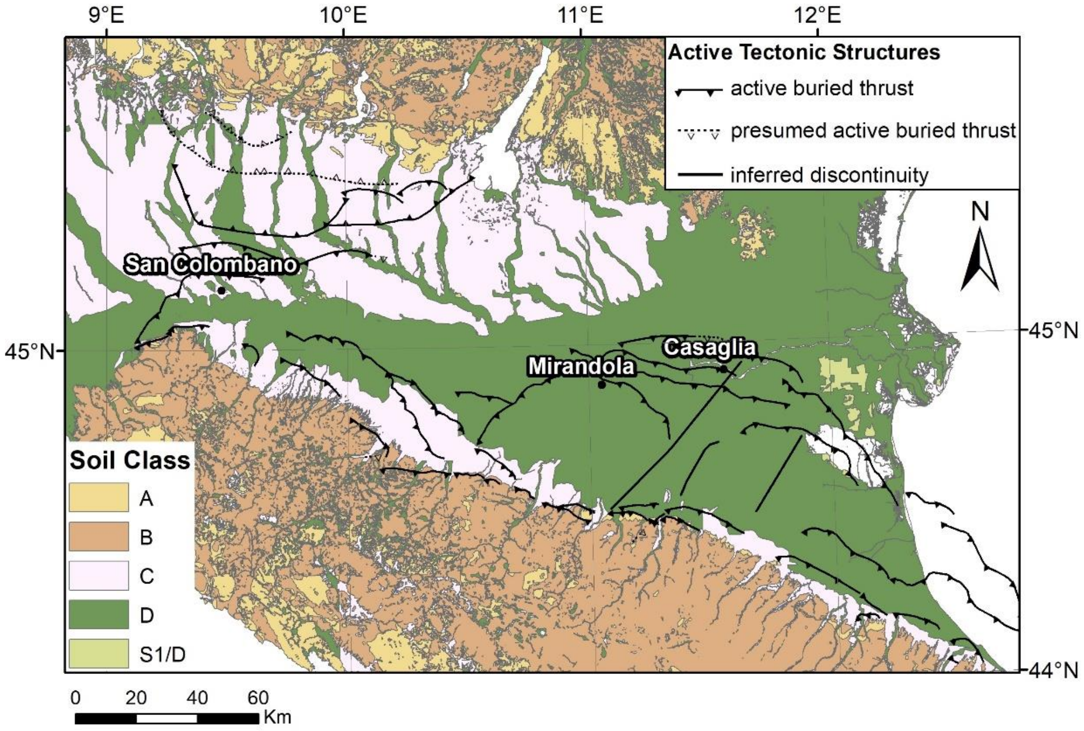
a) Map of Seismic bedrock depth

➡ <u>b) 3D Shear-wave velocity model of soft sediments above seismic bedrock</u>

$V_{S,30}$



This study



Di Capua et al., 2011

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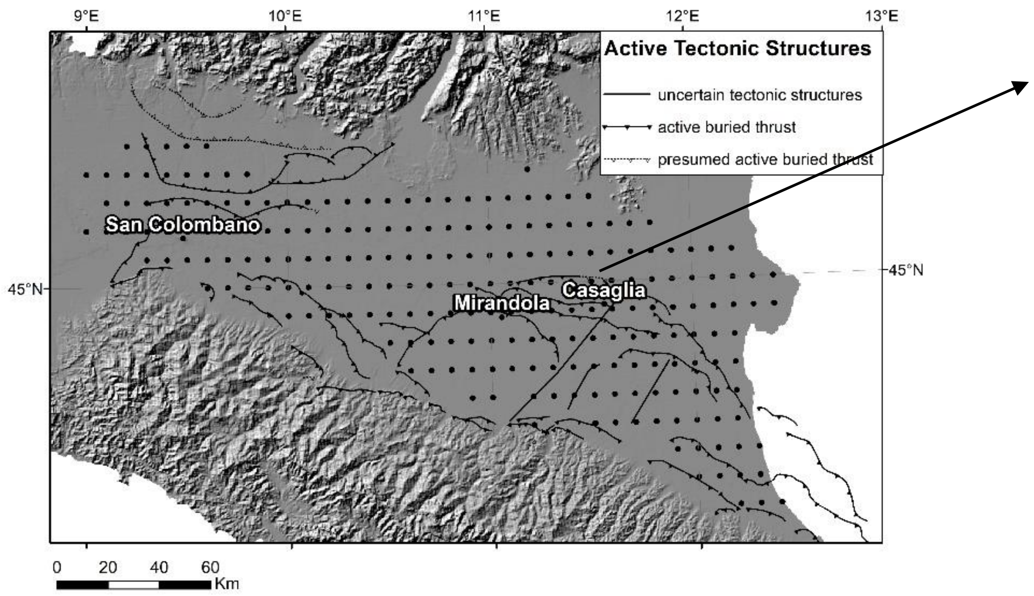
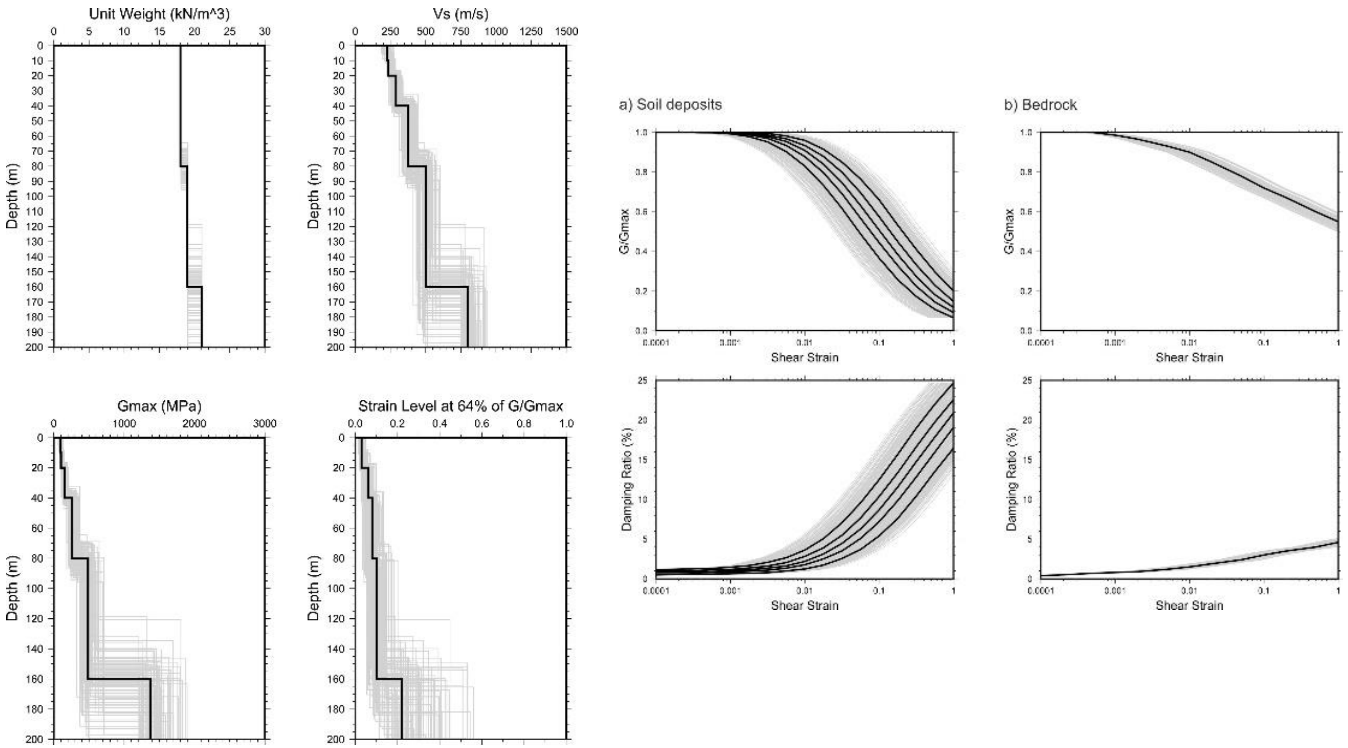
Task 2: long-period soil amplification model

- a) <u>Soil modelling parametrization</u>
- b) Selection of input motion
- c) Regional amplification factors
- d) Comparison with the Site Coefficient of NTC18

The study area is discretized into a **0.1° x 0.1° grid** (8 km x 11 km). A soil column corresponds to each grid node.





The numerical characterization of the soil columns is the **randomized model** that allows for the uncertainty in the soil parameters through a Monte Carlo approach.

Degradation curves: EPRI 1993 (soil), Schnabel et al. 1972 (bedrock).

Random variables (RV): *Vs* (σ_{lnVs} = 0.1), *h* (σ_{lnh} = 0.13), , $\varepsilon_{64\%}$ ($\sigma_{ln\varepsilon 64\%}$= 0.35). γ is estimated from *Vs* (Mayne 2001) and not randomized.

Randomizations: 100 representations of the soil column for each grid node.

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New methodology for selection of accelerometric recordings over wide areas *(Mascandola et al., BEE submitted)*

Definition of zones for which the same set of earthquake recordings can be reasonably used.

⬇

Clustering analysis (K-means)

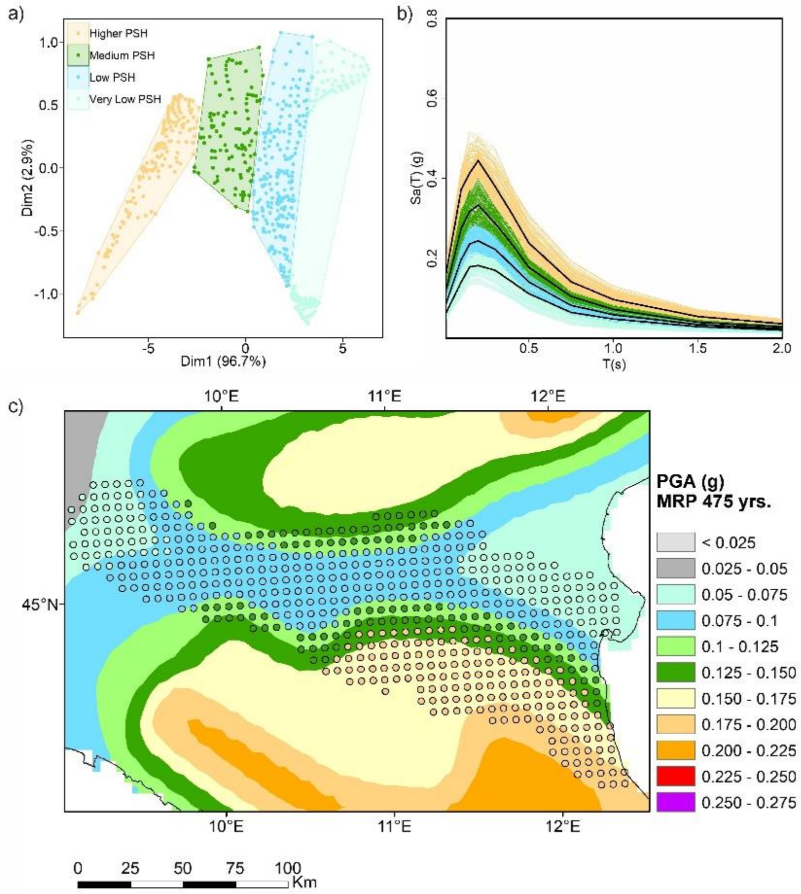
to define clusters of sites with similar ground motion hazard (i.e., similar UHS).

K-means algorithm needs the number of cluster K. To define K:

- analysis of seismic hazard maps and hazard disaggregation results;
- statistical techniques aimed at defining the optimal value of K.

***K* = 4**

K-means (*K* = 4)



4 Zones are clearly identified:

- one, with higher seismic hazard, corresponding to the southern Po Plain sector;
- one, with moderate seismic hazard, at the transition between the central Po Plain and the Alpine (to the north) and Apennines (to the south) foothills;
- one, with low hazard, encompassing the central plain;
- one, with very low hazard, including the marginal plain sectors near Milan and the Adriatic coast.

⬇

For each zone, a **target uniform hazard spectrum (UHS)** is identified.

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Strong-motion dataset

for selection of input motion

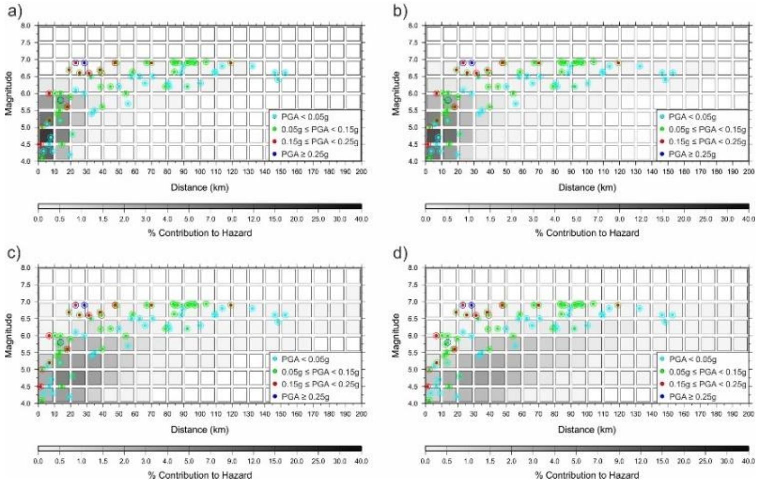
To account for the different **M-R scenarios** contributing to the hazard of each zone, the analyst can group together (by stacking and normalizing) the magnitude-distance contributions obtained from the disaggregation of the seismic hazard at all computation nodes belonging to that zone, and select the time histories accordingly.

PGA: representative of the M-R contributions at short-to-medium periods.

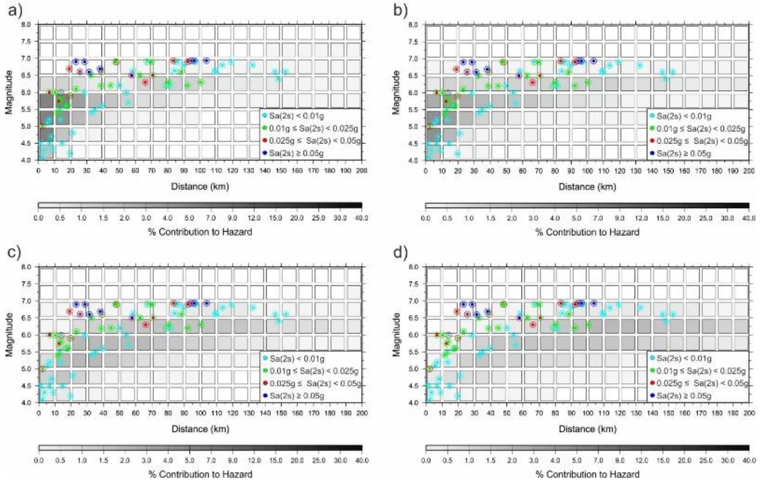
Sa(2s): representative of the M-R contributions at medium-to-long periods.

(Barani et al., 2009)

PGA

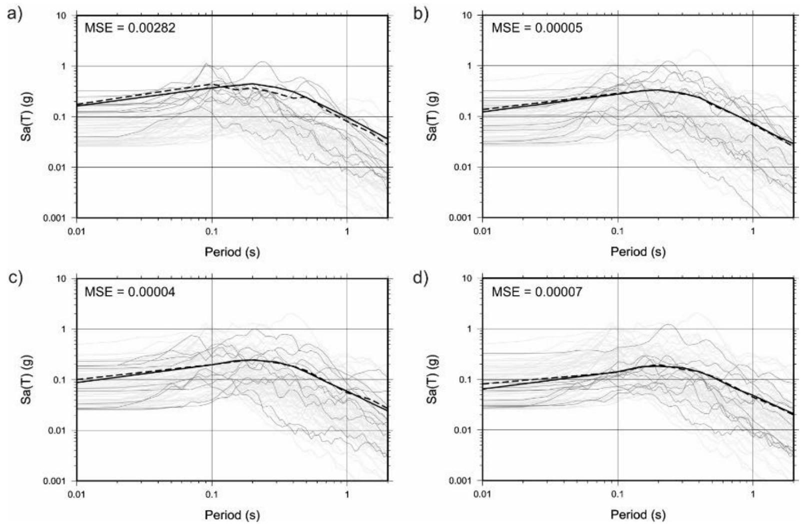


Sa(2s)



Time history selection

(spectrum-compatibility requirement NTC18)



(Mascandola et al., BEE submitted)

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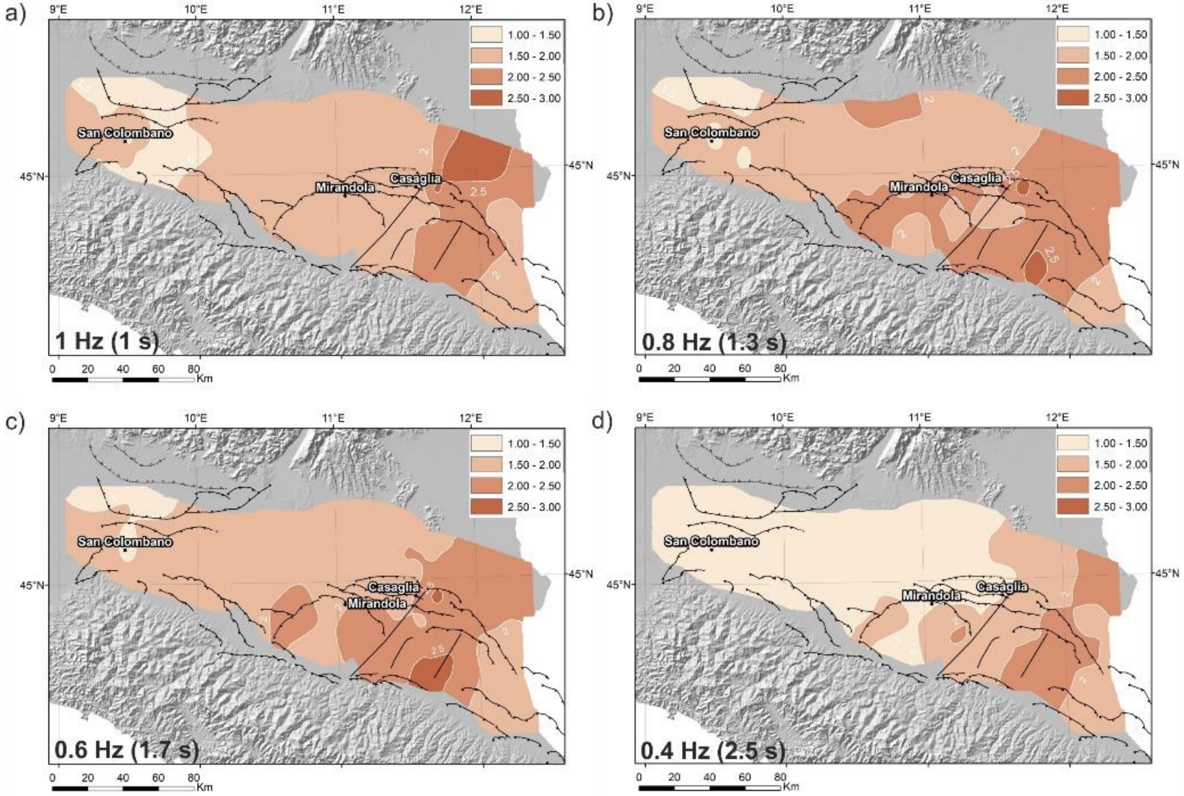
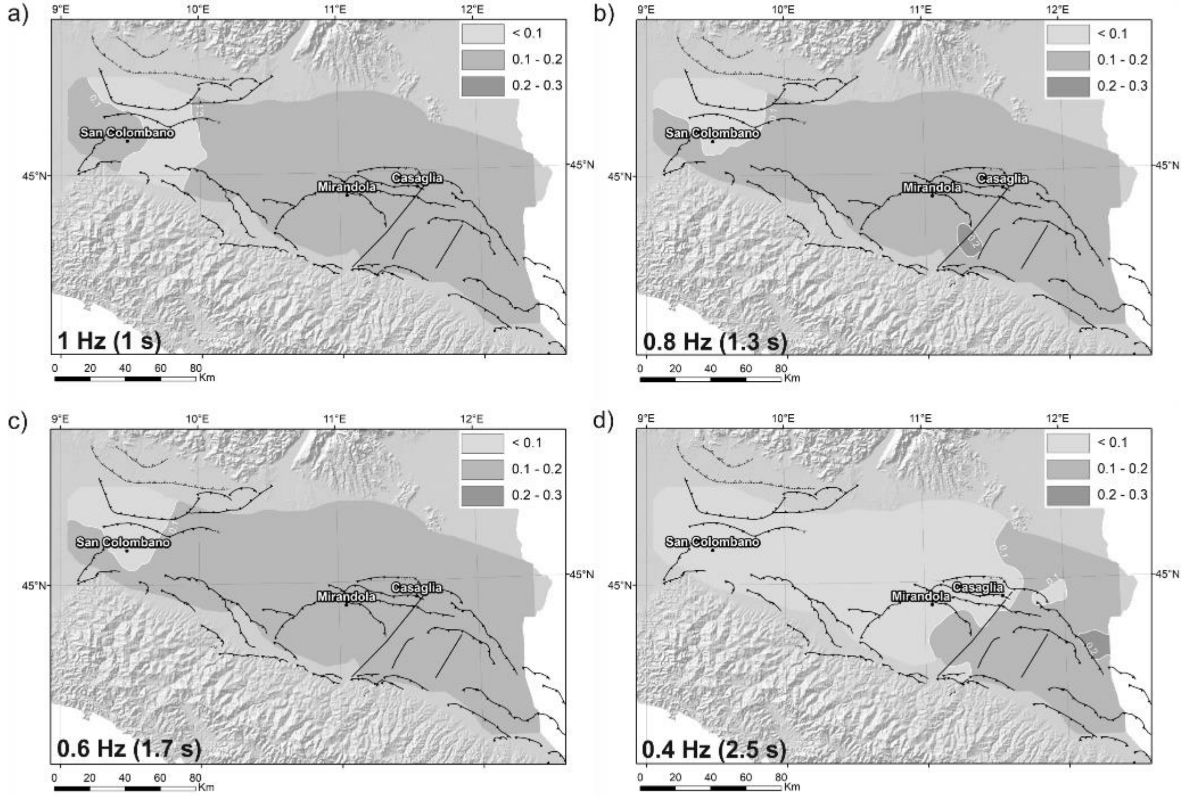
Task 2: long-period soil amplification model

a) Soil modelling parametrization
b) Selection of input motion
→ c) <u>Regional amplification factors</u>
d) Comparison with the Site Coefficient of NTC18

AF(f)



$\sigma_{AF(f)}$



AF(f): ratio of the surface-level to the (outcropping) rock-level damped spectral accelerations for a specific value of *f*.
Method: Equivalent linear approach
Code: Shake91

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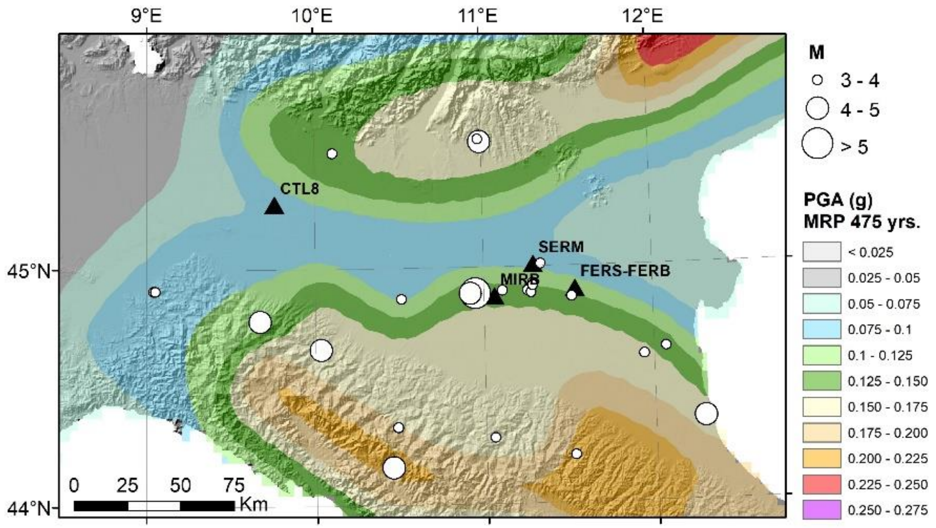
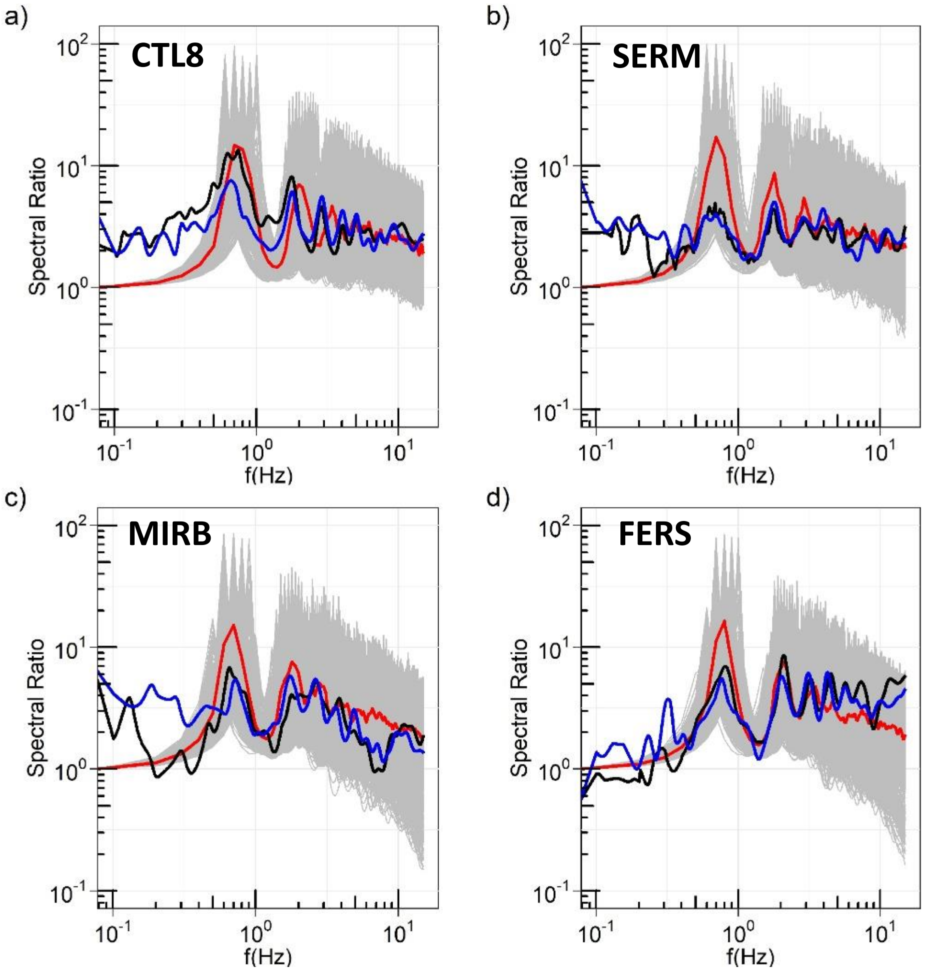
Local Test sites

Station	Surface	Borehole	Depth
CTL8	EPISENSOR-2G	MALIN S-2	-162 m
SERM	EPISENSOR-2G	LE3D-1S	-135 m
MIRB	SARA - SA10	SARA-SA10BH	-126 m
FERS	EPISENSOR-2G	GURALP-CMG-3T	-135 m





Experimental function

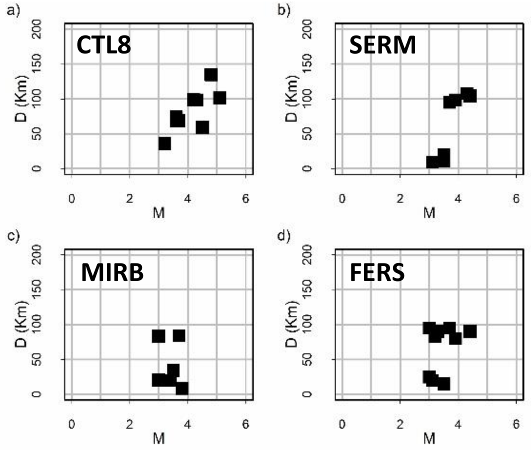
NS component (av.)

EW component (av.)

Numerical function

Average

Randomized models



Task 2: long-period soil amplification model

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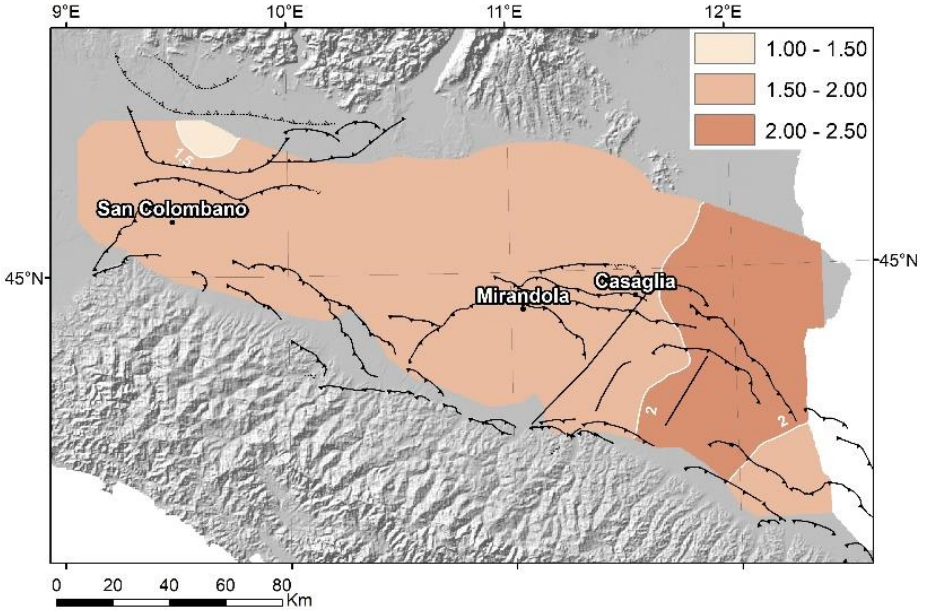
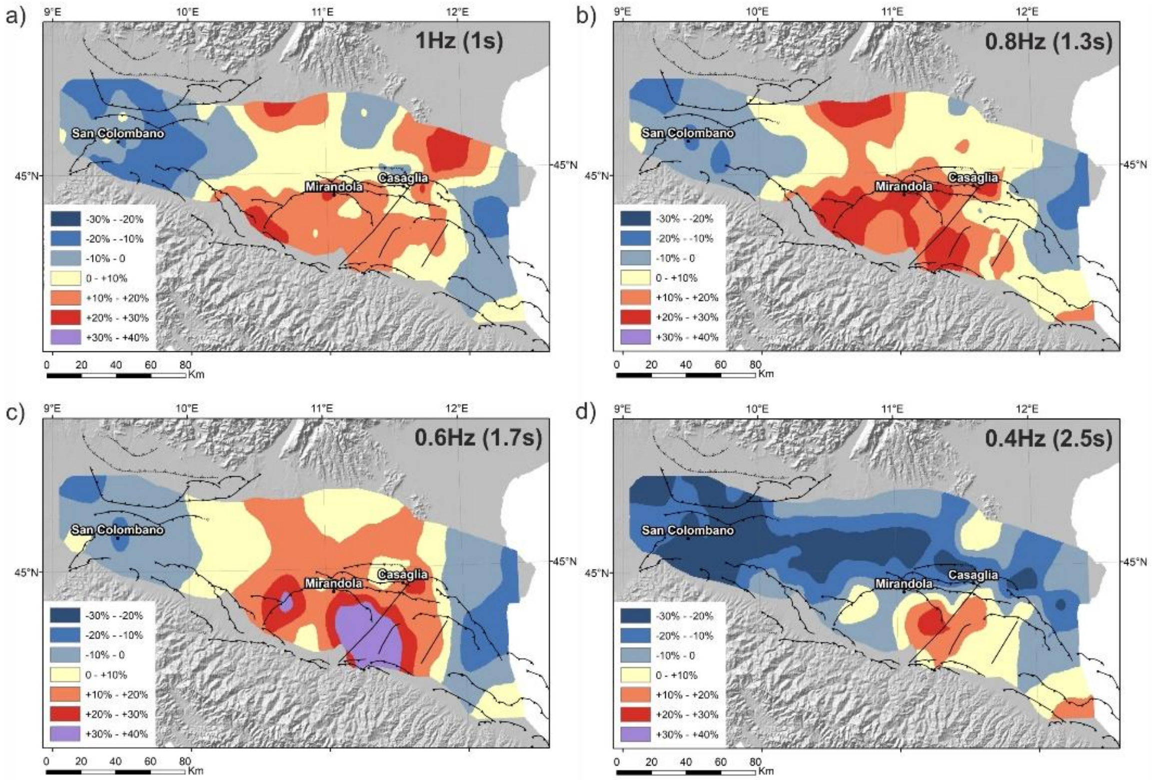
➡ d) <u>Comparison with the Site Coefficient of NTC18</u>

<u>Site coefficient *S* *(NTC 2018)*</u>



- Frequency-independent site coefficient
- Based on the soil classification defined from the seismo-stratigraphic model provided in this study

Percentage Change of *AF(f)* with respect to *S*



$AF(f) > S$ *positive percentage*

$AF(f) < S$ *negative percentage*

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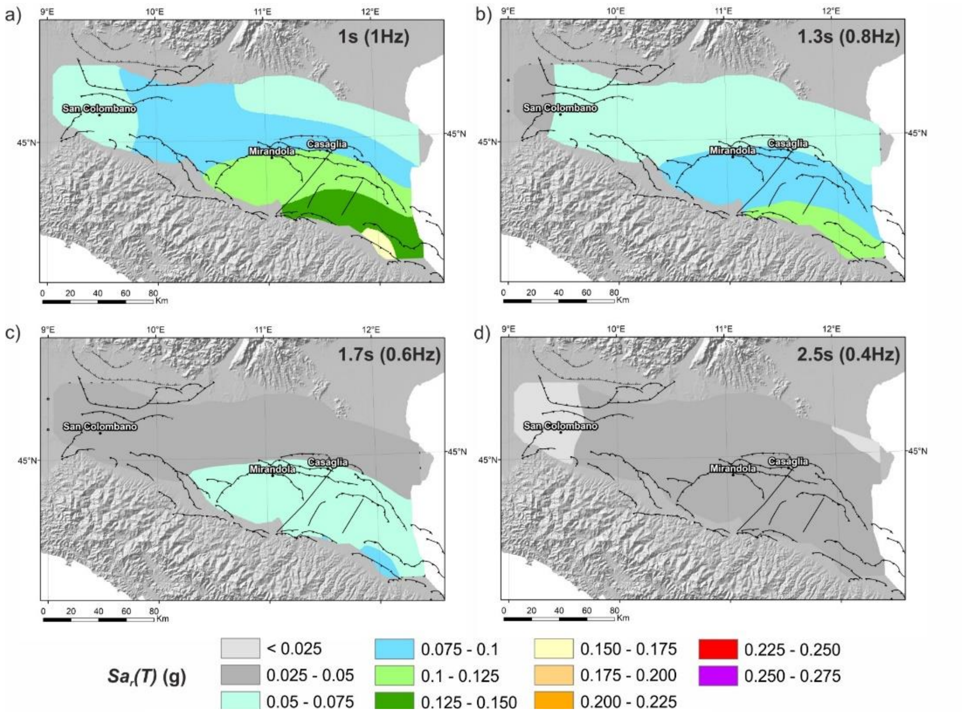
Task 3: impact of soil amplification on PSHA

- a) Soil-specific, partially non-ergodic PSHA
- b) Comparison with reference Italian seismic hazard maps (MPS04)

Conventional ergodic PSHA



MA1 — GR-ML — M_{max1} — BND14

SZ: Santulin et al. (2017)

Parametrization with highest weights

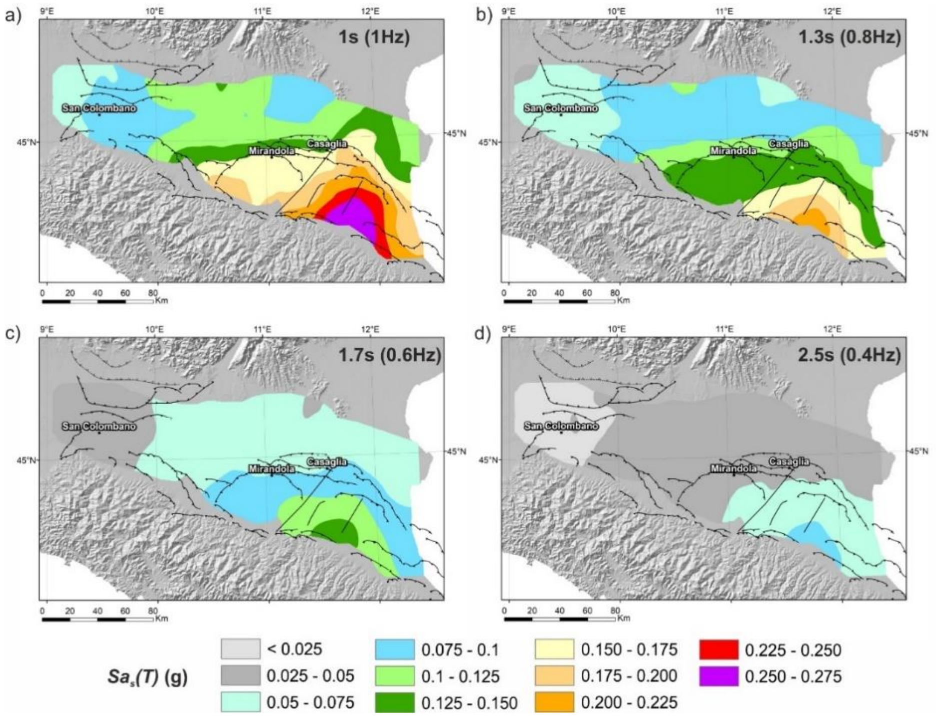
GMPE: Bindi et al. 2014

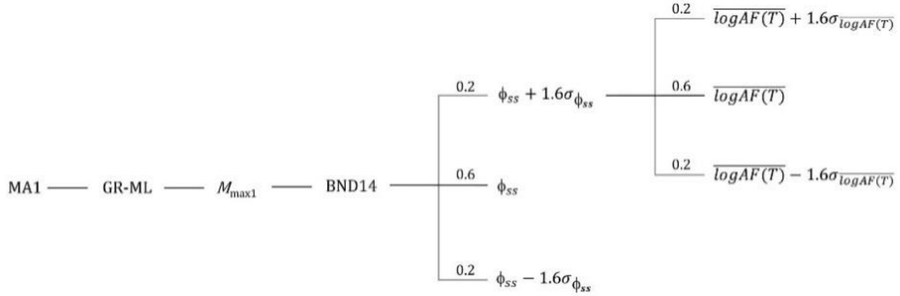
Soil Amplification AF(f)

Soil-specific, partially non-ergodic seismic hazard maps

MRP 475 yr.

At the Surface



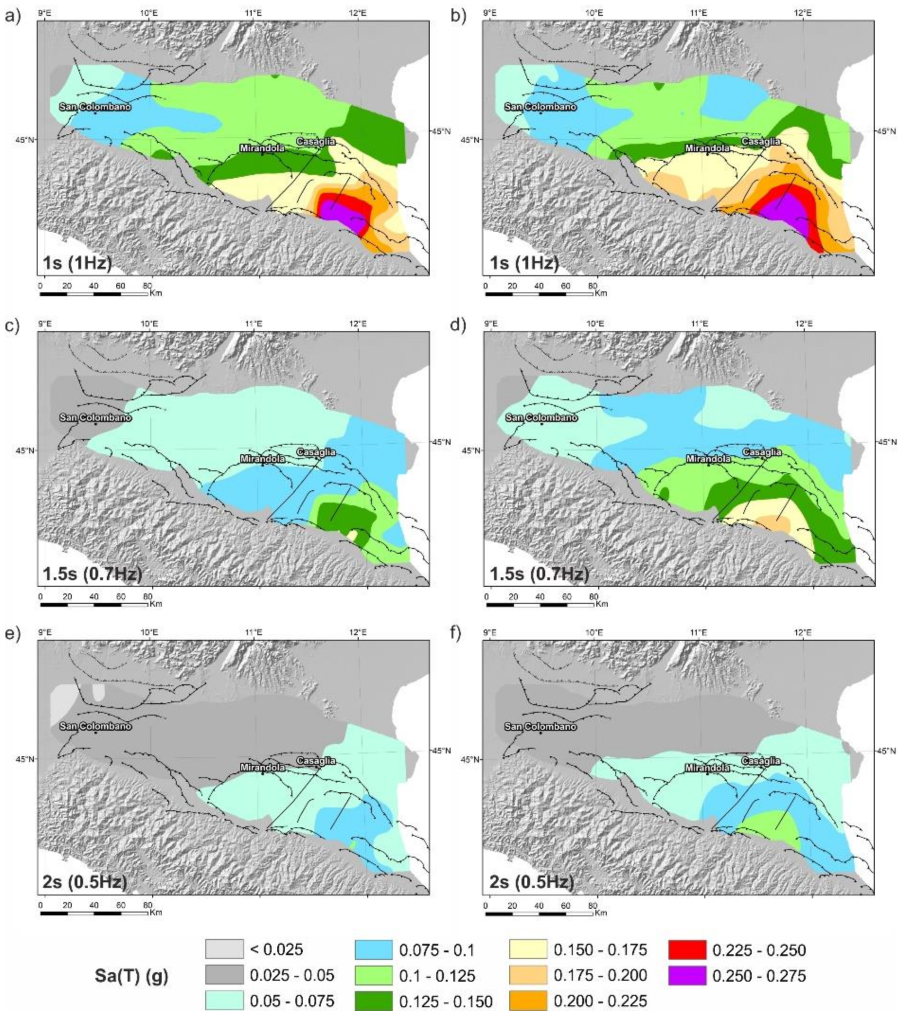


Task 3: impact of soil amplification on PSHA

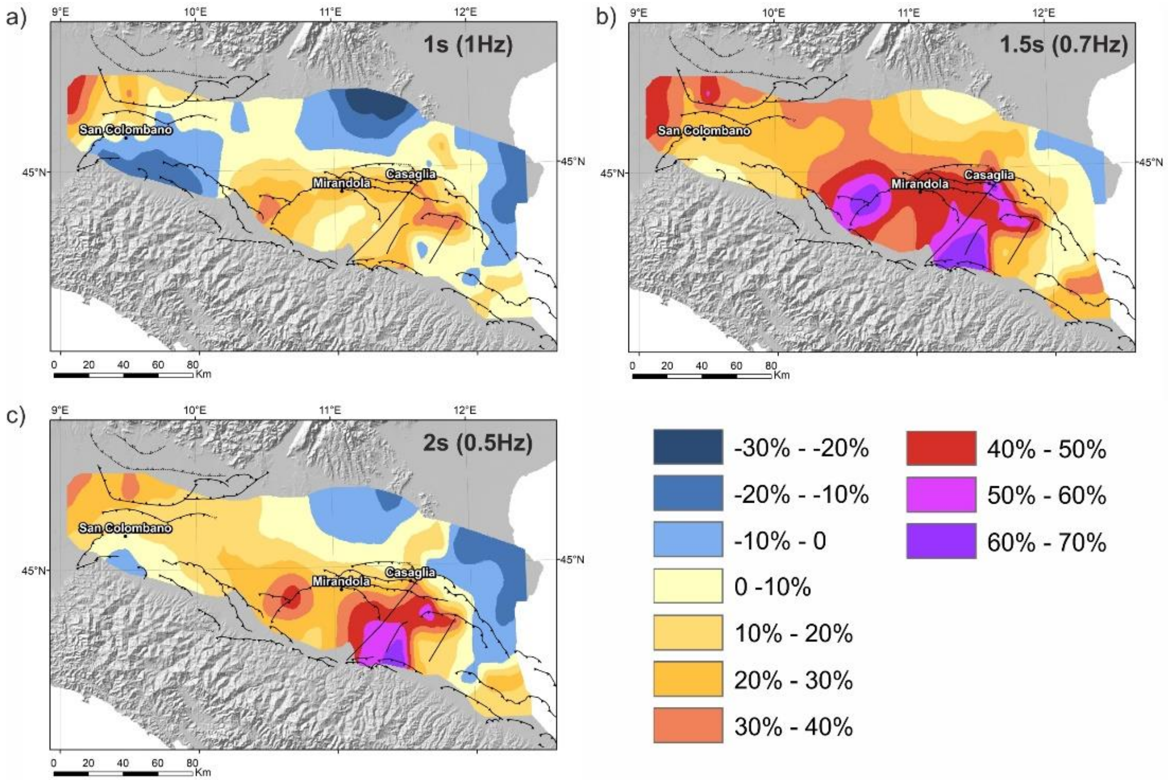
a) Soil-specific, partially non-ergodic PSHA

➡ b) Comparison with reference Italian seismic hazard maps (MPS04)

MPS04 *S   This Study



Percentage Change of the new results with respect to MPS04*S



new PSHA > MPS04: positive percentage

new PSHA < MPS04: negative percentage

Conclusions

- The amplification factors ***AF(f)* range between 1 and 3**, with values that **increase from West to East** at all the considered frequencies (< 1 Hz). On the other hand, **the maximum amplification** takes place in different part of the basin **based on frequency**.

- The comparison between ***AF(f)* and *S*** highlights a percentage change up to **+ 40%** at 0.6 Hz (1.7 s) and down to **- 30%** at 0.4 Hz (2.5 s).

- The **soil hazard maps** obtained in this study goes beyond conventional seismic hazard maps on rock, or adjusted through the application of generic site coefficients, as they have the clear advantage of providing the final user with a comprehensive picture of the **actual (i.e., specific) seismic hazard** in a region.

- The results give some indication on the **different resolution to be expected in hazard maps** resulting from the use of a site response model; as opposed to the more conventional model, that includes only frequency independent site coefficients.

- This study provides new insights on the long-period site effects in the Po Plain sedimentary basin that can be useful for **risk mitigation strategies at regional scale**, in particular for **large-scale structures**, such as tall buildings, long-span bridges, and large storage tanks. These results can provide a substantial improvement in the assessment of the seismic hazard of the Po Plain, but further work can be done in order to test the proposed models and eventually increase the resolution at short periods.

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Thank you for your attention!