# 1. Approximated multi-site PSHA based on conditional hazard

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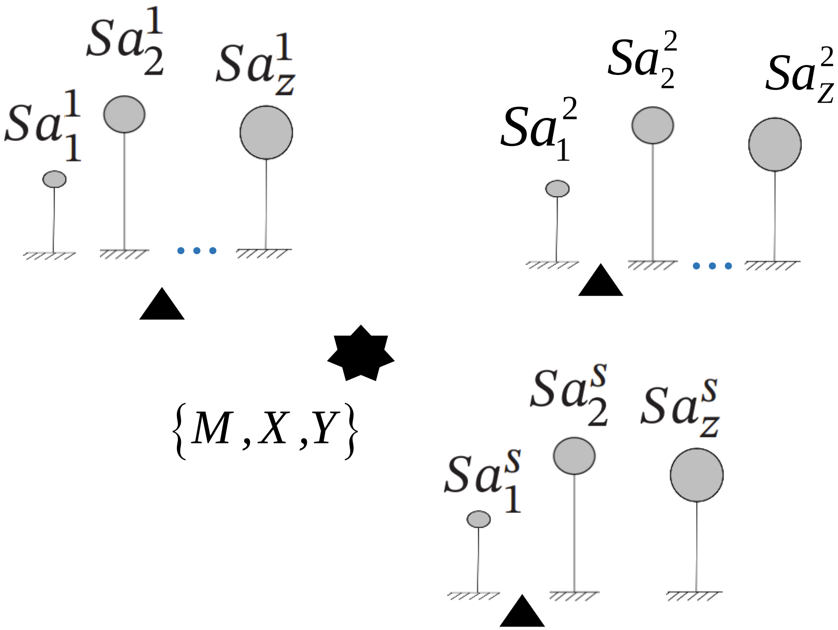



Giorgio and Iervolino
BSSA (2016)

**MSPSHA is when one is interested in the exceedance of various intensity measures at multiple sites in time.**

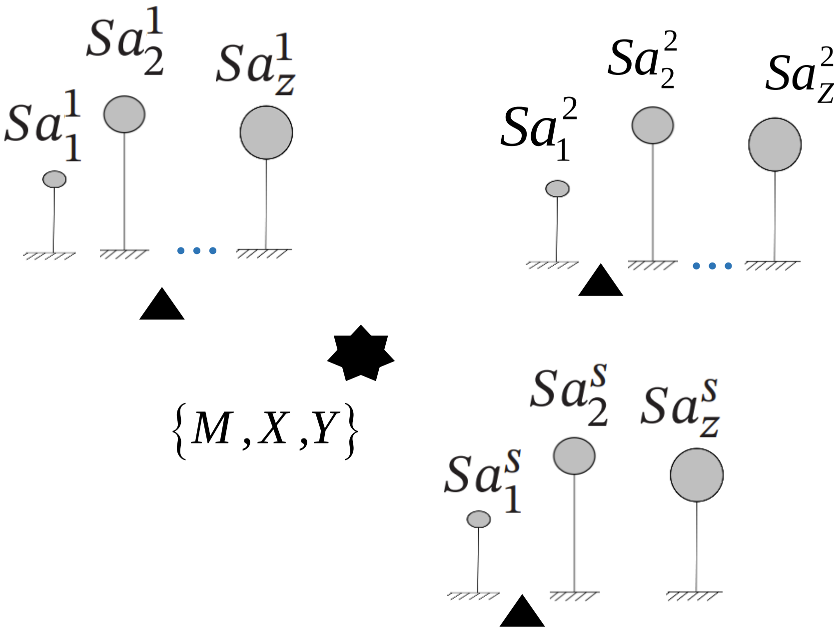
**MSPSHA: *z* IMs at *s* sites.**

$Sa_i^j$

- $j$-th site, $j$=1,...,s
- $i$-th intensity, $i$=1,...,$z$

**Actually, what is needed is the joint distribution of all Sa' at all sites conditional to magnitude and location of the earthquake**

$$f_{Sa_1^1,\ldots,Sa_z^s|M,X,Y}\left(sa_1^1,\ldots,sa_z^s\,|\,m,x,y\right)$$



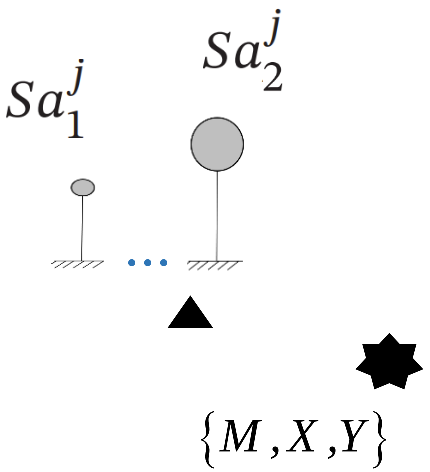

**One Sa (*i*-th) at one site (*j*-th)**

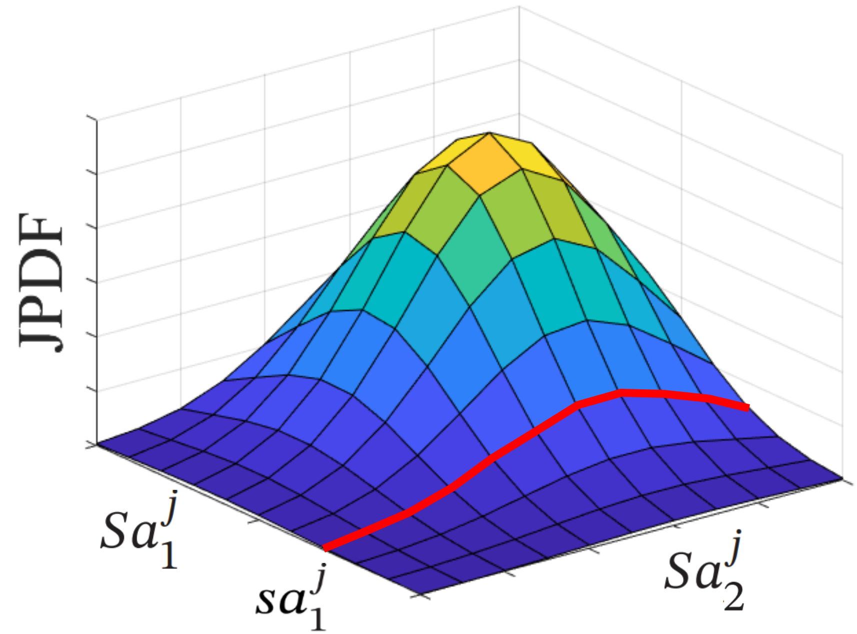
$$\log\left(Sa_i^j\right) = \mu_i^j\left(m, x, y, \underline{\theta}\right) + \sigma_i \cdot \varepsilon_i^j$$

$$\sigma_i \cdot \varepsilon_i^j = \phi_i \cdot \varepsilon_{i,inter}^j + \gamma_i \cdot \varepsilon_{i,intra}^j$$

**Gaussian Random Field (GRF) assumption conditional to magnitude and location: the covariance matrix of the spectral ordinates at the sites is needed.**

$$\underline{\underline{\Sigma}} = \begin{bmatrix} (\sigma_1)^2 & \cdots & \rho_{1,1}^{1,s} \cdot (\sigma_1)^2 & \cdots & \rho_{1,z}^{1,1} \cdot \sigma_1 \cdot \sigma_z & \cdots & \rho_{1,z}^{1,s} \cdot \sigma_1 \cdot \sigma_z \\ \ddots & & \vdots & \cdots & & \cdots & \vdots \\ & & (\sigma_1)^2 & \cdots & \rho_{1,z}^{s,1} \cdot \sigma_1 \cdot \sigma_z & \cdots & \rho_{1,z}^{s,s} \cdot \sigma_1 \cdot \sigma_z \\ & & & & & \cdots & \vdots \\ & & & \ddots & (\sigma_z)^2 & \cdots & \rho_{z,z}^{1,s} \cdot (\sigma_z)^2 \\ & & & & & \ddots & \vdots \\ & sym & & & & & (\sigma_z)^2 \end{bmatrix}$$




## Conditional hazard

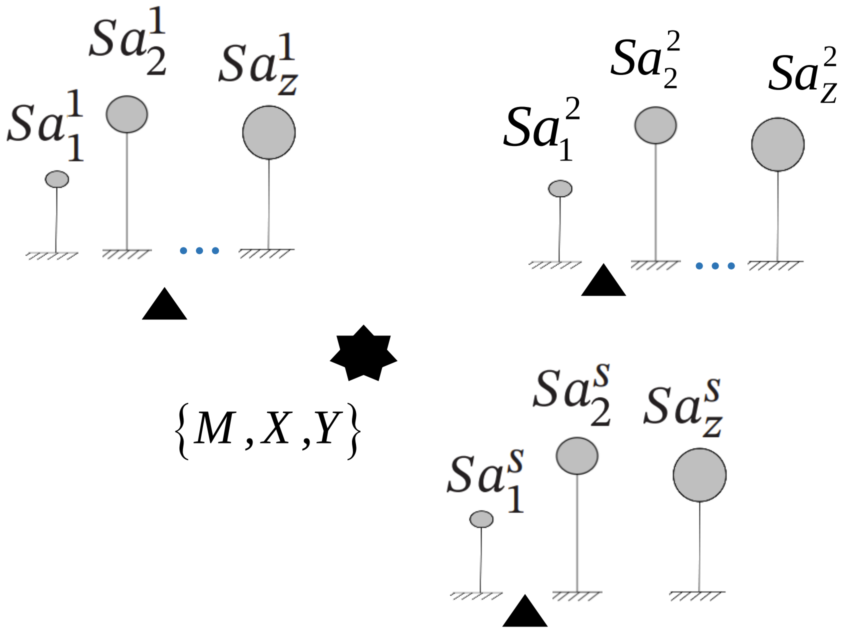
$$\begin{cases} \mu_2^j\left(m, x, y, sa_1^j\right) = \mu_2^j(m, x, y) + \sigma_2 \cdot \rho_{1,2}^{j,j} \cdot \dfrac{\log\left(sa_1^j\right) - \mu_1^j(m,x,y)}{\sigma_1} \\ \sigma_2\left(sa_1^j\right) = \sigma_2 \cdot \sqrt{1 - \left(\rho_{1,2}^{j,j}\right)^2} \end{cases}$$

Cross-correlation coefficient for total residuals

Iervolino et al. BSSA (2010)

$$\rho_{1,2}^{j,j} = \frac{\tau_{1,2}^{j,j} \cdot \phi_1 \cdot \phi_2 + \varsigma_{1,2}^{j,j} \cdot \gamma_1 \cdot \gamma_2}{\sqrt{\left(\phi_1 \cdot \phi_2\right)^2 + \left(\phi_1 \cdot \gamma_2\right)^2 + \left(\gamma_1 \cdot \phi_2\right)^2 + \left(\gamma_1 \cdot \gamma_2\right)^2}}$$

**What happens using contidional hazard + a spatial correlation model for the primary Sa to run MSPSHA?**




1. The GRF of the primary *Sa* (the same) at all the sites is known via a GMPE and a spatial correlation model of residuals.

$$f_{Sa_1^1,\dots,Sa_1^s|M,X,Y}$$

2. At each site, the distribution of all secondary *Sa'* conditional the primary *Sa* and magnitude and location is known.

$$f_{Sa_2^j,\dots,Sa_z^j|Sa_1^j,M,X,Y}\left(sa_2^j,\dots,sa_z^j\,\middle|\,sa_1^j,m,x,y\right)=$$
$$=\prod_{i=2}^{z} f_{Sa_i^j|Sa_1^j,M,X,Y}\left(sa_i^j\,\middle|\,sa_1^j,m,x,y\right)$$

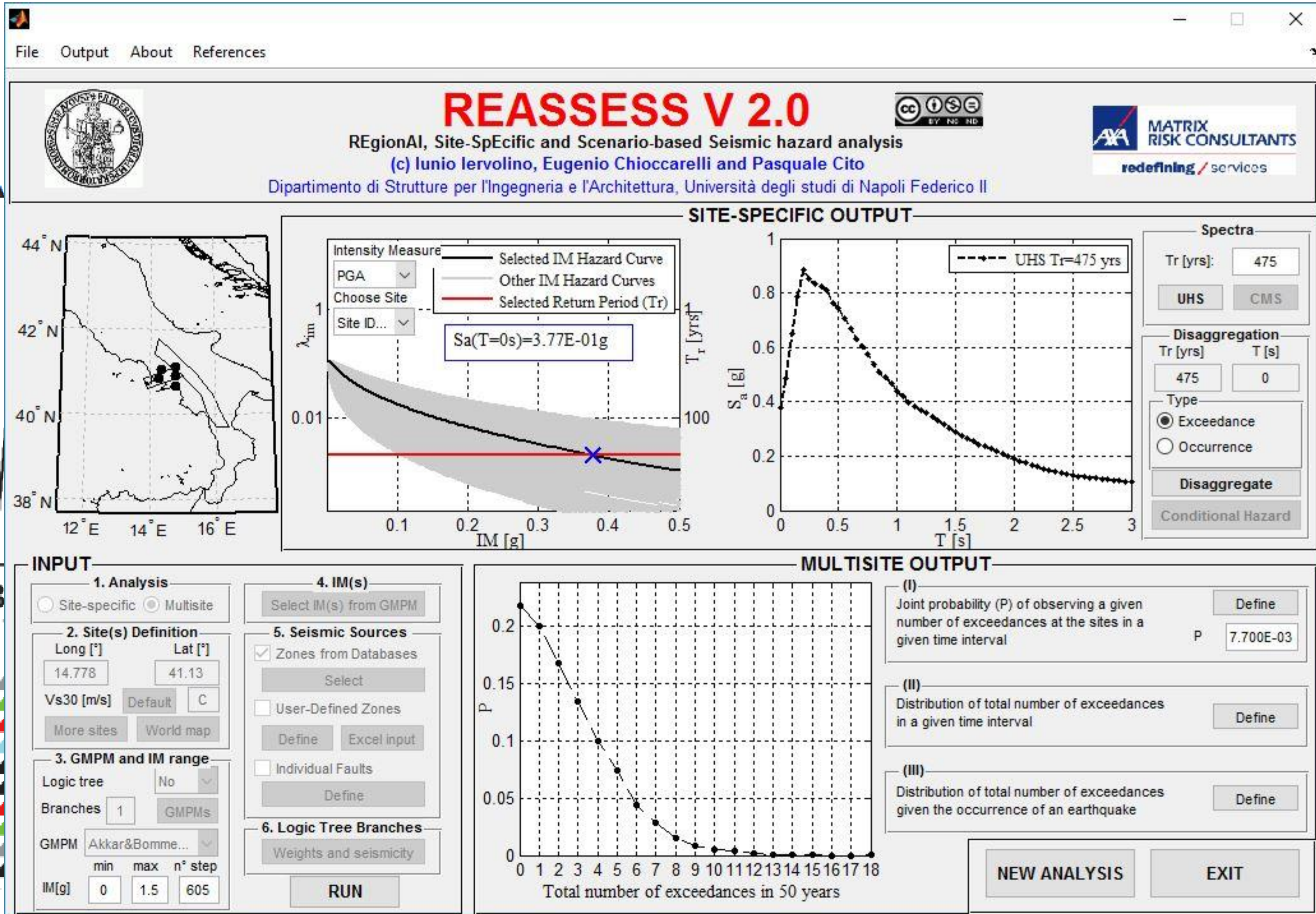
3. The joint distribution of all secondary *Sa'* at all the sites, conditional to the primary Sa' and magnitude and location is known.

$$f_{Sa_2^1,\dots,Sa_z^s|Sa_1^1,\dots,Sa_1^s,M,X,Y}\left(sa_2^1,\dots,sa_z^s\,\middle|\,sa_1^1,\dots,sa_1^s,m,x,y\right)=\prod_{j=1}^{s} f_{Sa_2^j,\dots,Sa_z^j|Sa_1^j,M,X,Y}\left(sa_2^j,\dots,sa_z^j\,\middle|\,sa_1^j,m,x,y\right)$$

3. The joint distribution of all *Sa'* at all sites is known.

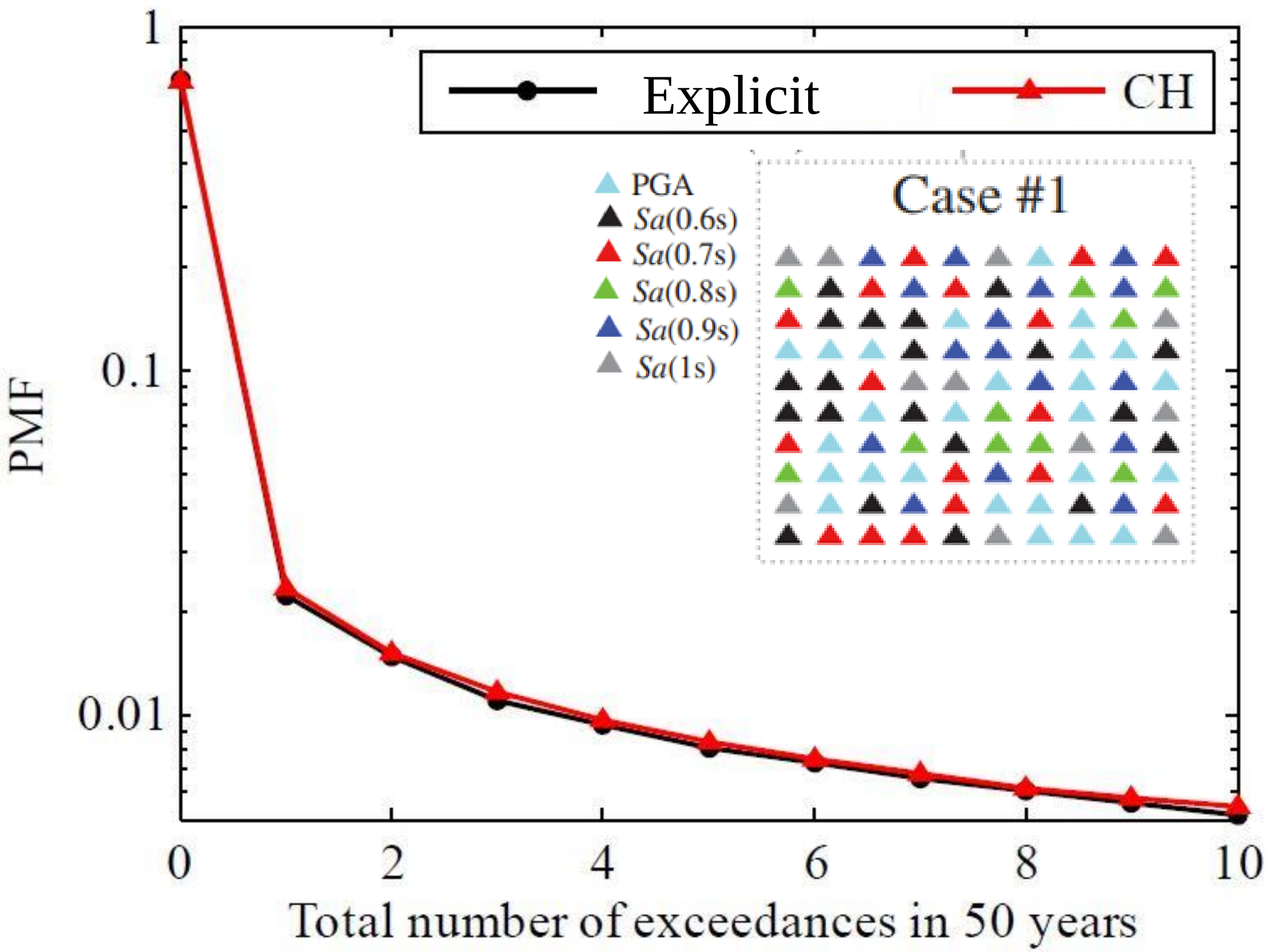
$$f_{Sa_1^1,\dots,Sa_z^s|M,X,Y}\left(sa_1^1,\dots,sa_z^s\,\middle|\,m,x,y\right)=$$
$$=f_{Sa_2^1,\dots,Sa_z^s|Sa_1^1,\dots,Sa_1^s,M,X,Y}\left(sa_2^1,\dots,sa_z^s\,\middle|\,sa_1^1,\dots,sa_1^s,m,x,y\right)\cdot f_{Sa_1^1,\dots,Sa_1^s|M,X,Y}\left(sa_1^1,\dots,sa_1^s\,\middle|\,m,x,y\right)$$

$$\underline{\underline{\Sigma}} = \begin{bmatrix} (\sigma_1)^2 & \cdots & \rho_{1,1}^{1,s} \cdot (\sigma_1)^2 & \cdots & \rho_{1,z}^{1,1} \cdot \sigma_1 \cdot \sigma_z & \cdots & \rho_{1,z}^{1,s} \cdot \sigma_1 \cdot \sigma_z \\ \ddots & & \vdots & \cdots & & \cdots & \vdots \\ & & (\sigma_1)^2 & \cdots & \rho_{1,z}^{s,1} \cdot \sigma_1 \cdot \sigma_z & \cdots & \rho_{1,z}^{s,s} \cdot \sigma_1 \cdot \sigma_z \\ & & & & & \cdots & \vdots \\ & & & \ddots & (\sigma_z)^2 & \cdots & \rho_{z,z}^{1,s} \cdot (\sigma_z)^2 \\ & & & & & \ddots & \vdots \\ & sym & & & & & (\sigma_z)^2 \end{bmatrix}$$




Chioccarelli et al. BEE (2019)

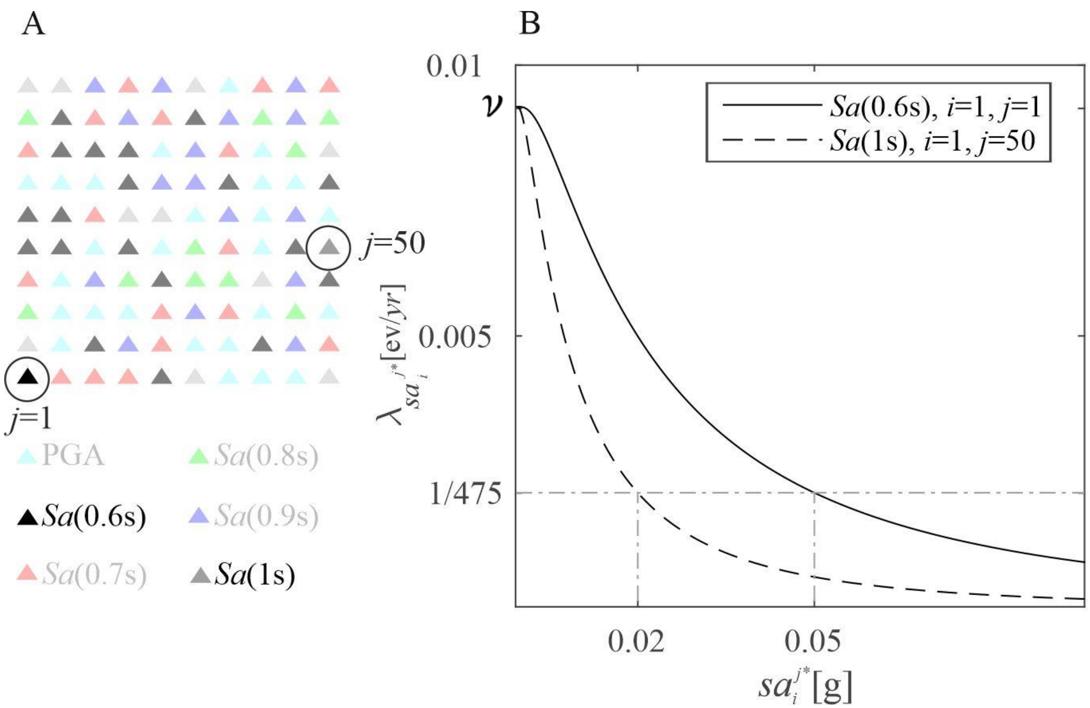
## MSPSHA result: distribution of the total number of exceedances of Sa thresholds at the sites in a time interval.




The two distributions have the same mean (as expected).

To replace the explicit approach with CH underestimates the variance.

The variances of the exceedances were compared considering the thresholds at the site with the same probability of being not exceeded in one generic earthquake (*p*).

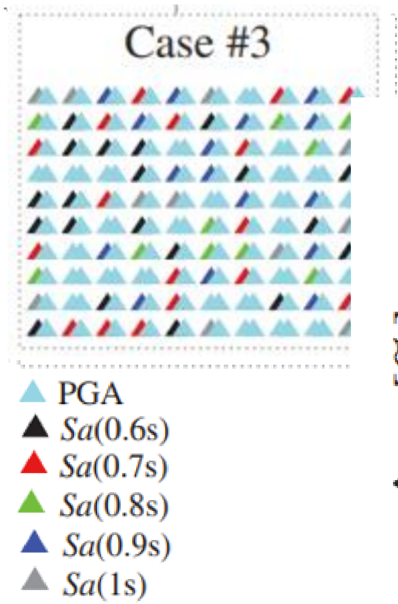


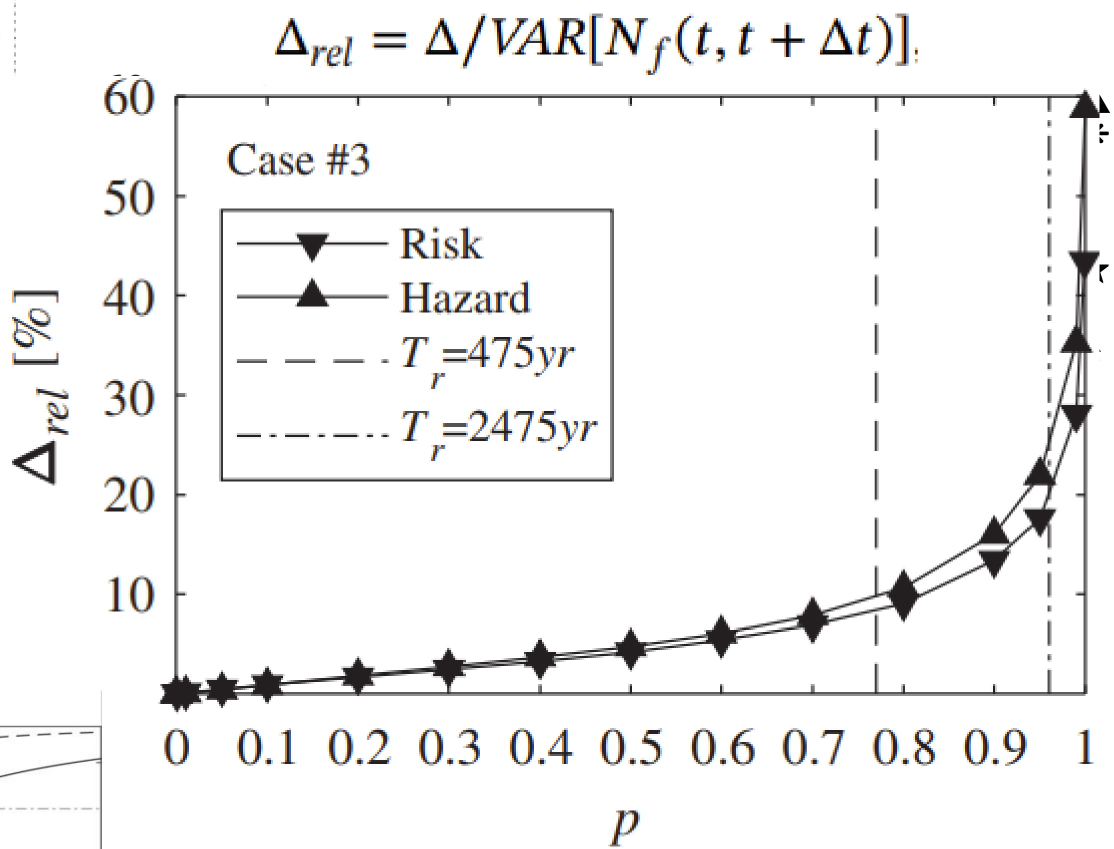

Thresholds at the sites with Tr=475yr

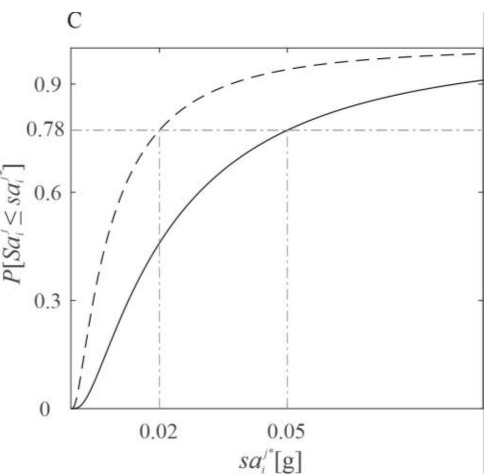
Iunio Strutc. Saf. (2023)

## The variances of the exceedances were compared considering the thresholds at the site with the same probability of being not exceeded in one generic earthquake ($p$).

Cito et al.
EESD (2023)



**Conditional hazard allows to approximate MSPSHA defining only part of the whole covariance matrix of the IMs. The other terms not directly assigned are approximated in a known manner.**

**With respect to the explicit approach, CH causes an underestimation of the variance of the number of exceedance of *Sa* thresholds at multiple sites. In relative terms, it does not exceed 20%, at least in the considered MSPSHA cases.**

**The amount of underestimation depends on the percentiles the thresholds represent in the distribution of Sa in one generic (i.e., unspecified magnitude and location) earthquake from site-specific PSHA.**

**Going all the way down to the risk (i.e., counting the number of failures) the underestimation of the variances reduces.**

# 2. Use and misuse of ShakeMap in (semi-) empirical fragility fitting

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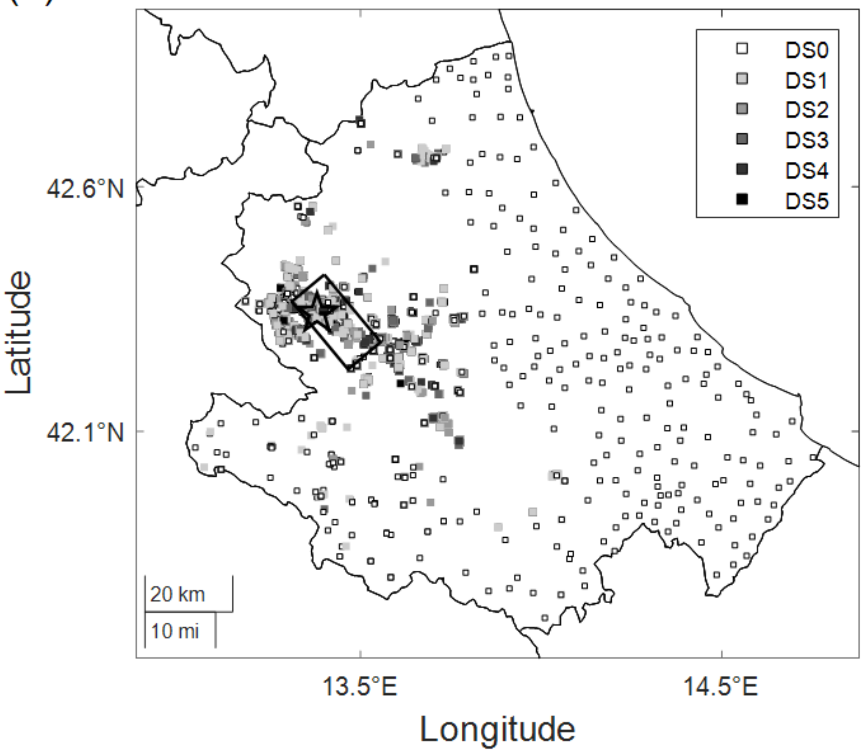
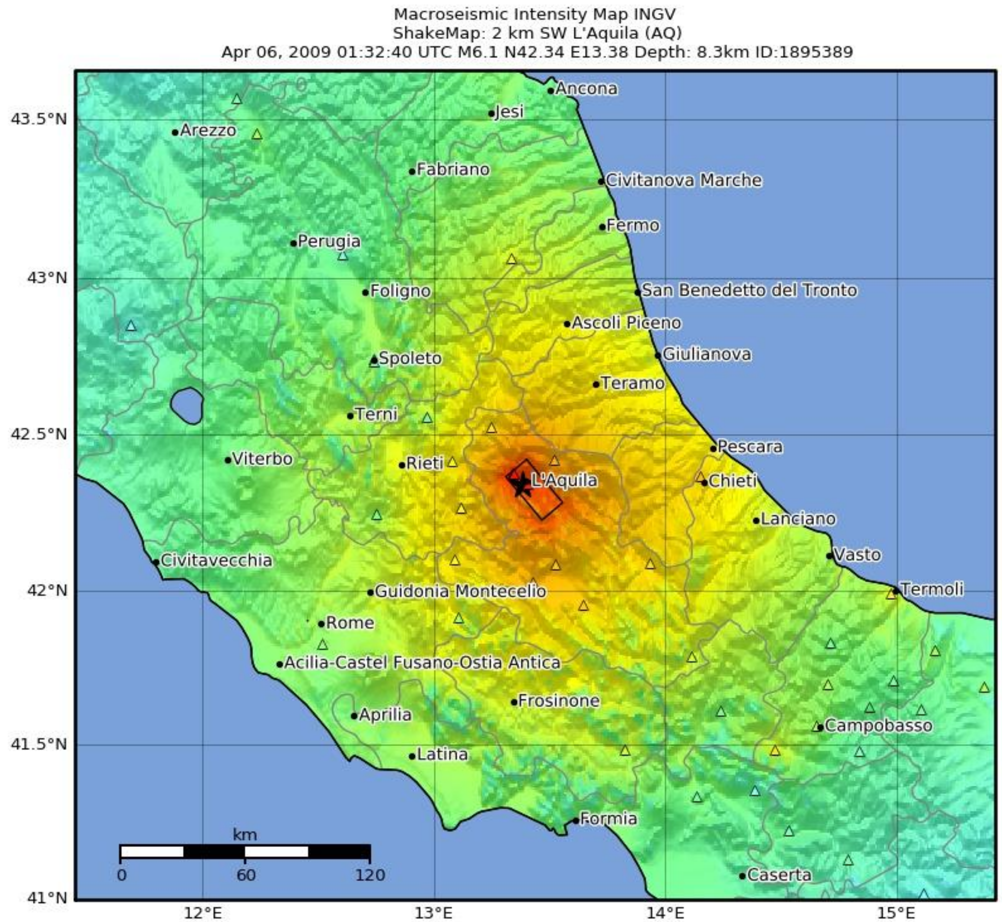
*IUSS - Scuola Universitaria Superiore di Pavia*

# Fitting of a semi-empirical models starts with a database of assessed damages for a typology  damages and a ShakeMap.

## Damages to some RC structures in the 2008 L'Aquila earthquake (M<6.1)

(a)



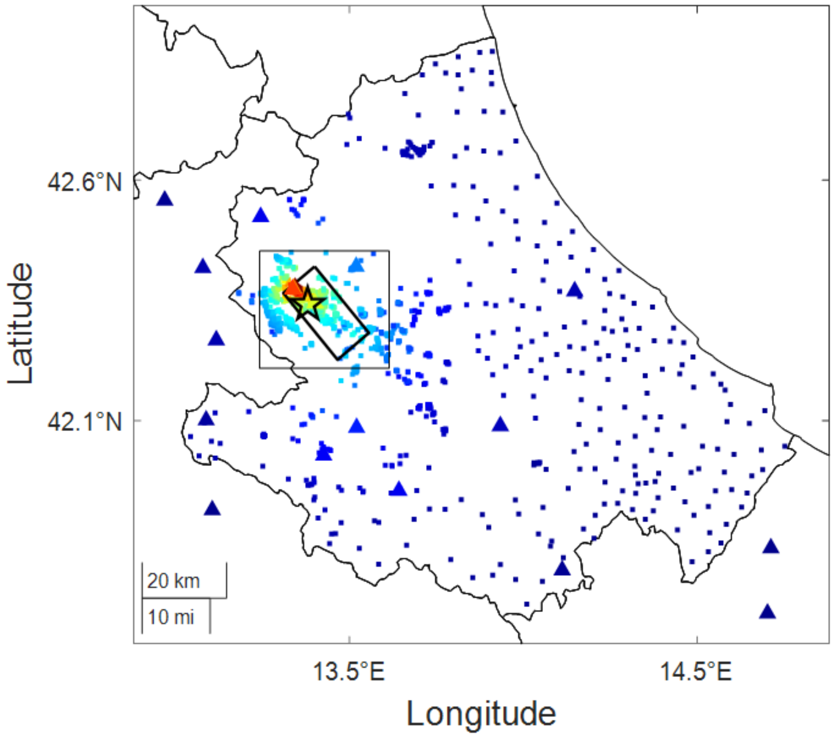

| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0556 | 0.212 | 0.808 | 1.97 | 4.82 | 11.8 | 28.7 | 70.1 | >171 |
| PGV(cm/s) | <0.0178 | 0.0775 | 0.337 | 0.898 | 2.39 | 6.37 | 17 | 45.2 | >120 |
| INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

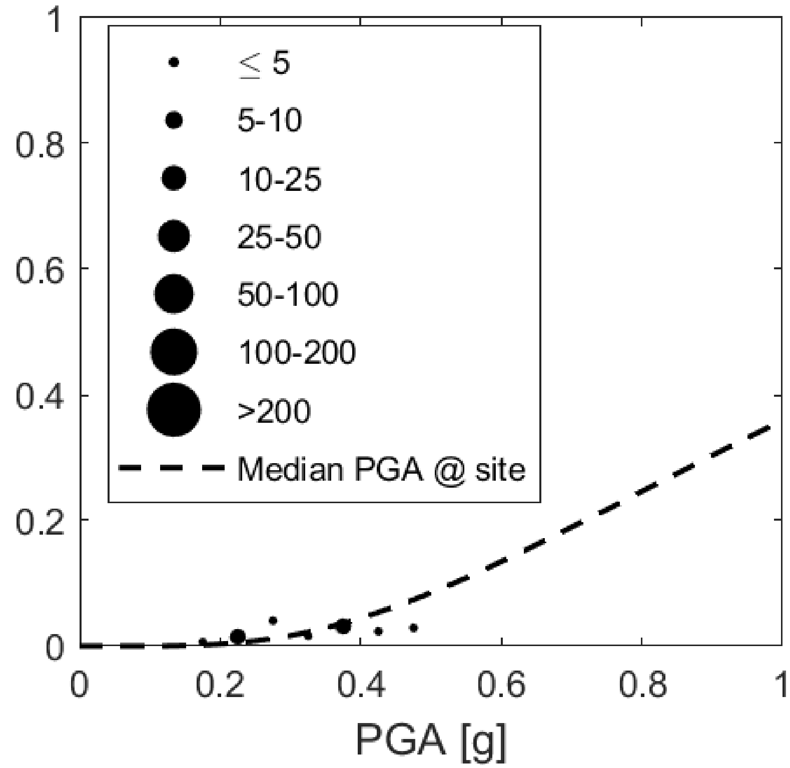
Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2020-07-14T11:10:39Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

## ShakeMap represents median intensities at the sites

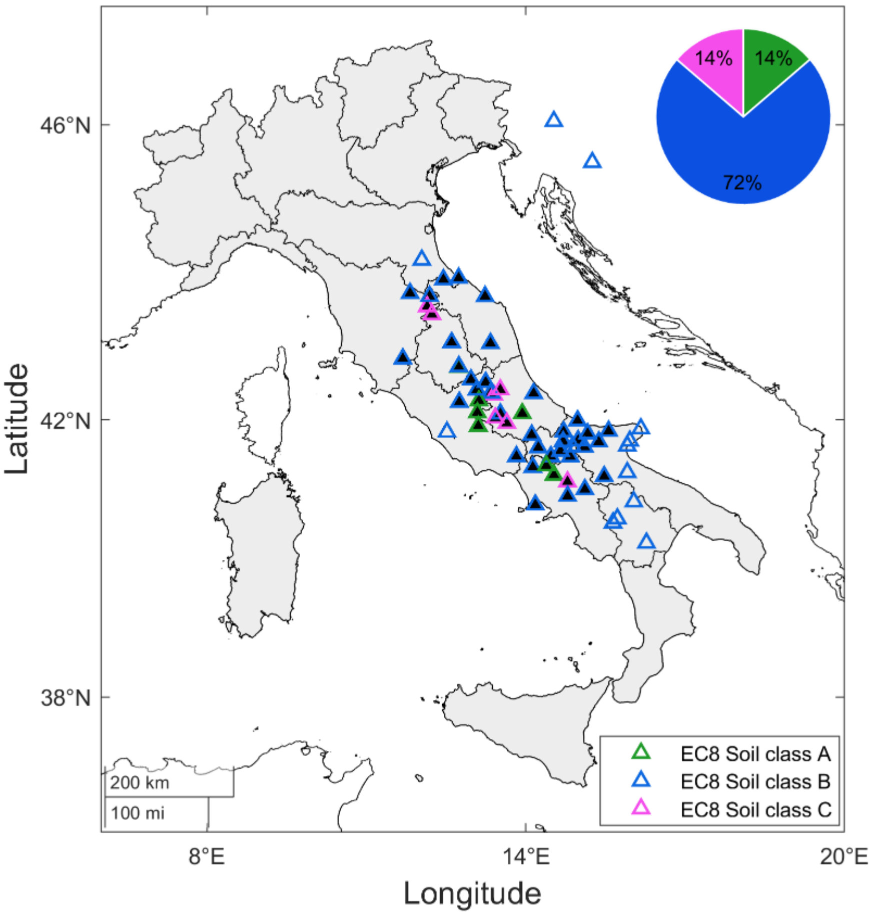
**Using the ShakeMap to get information about the shaking intensity at the sites of the damages can be used to develop a vulnerability model (e.g., lognormal).**

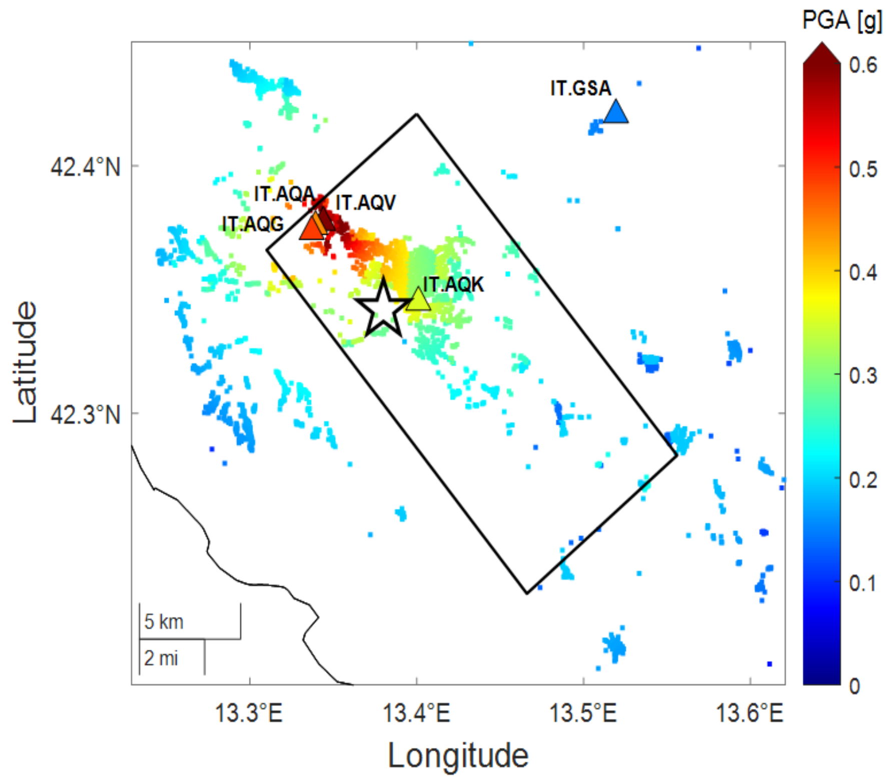


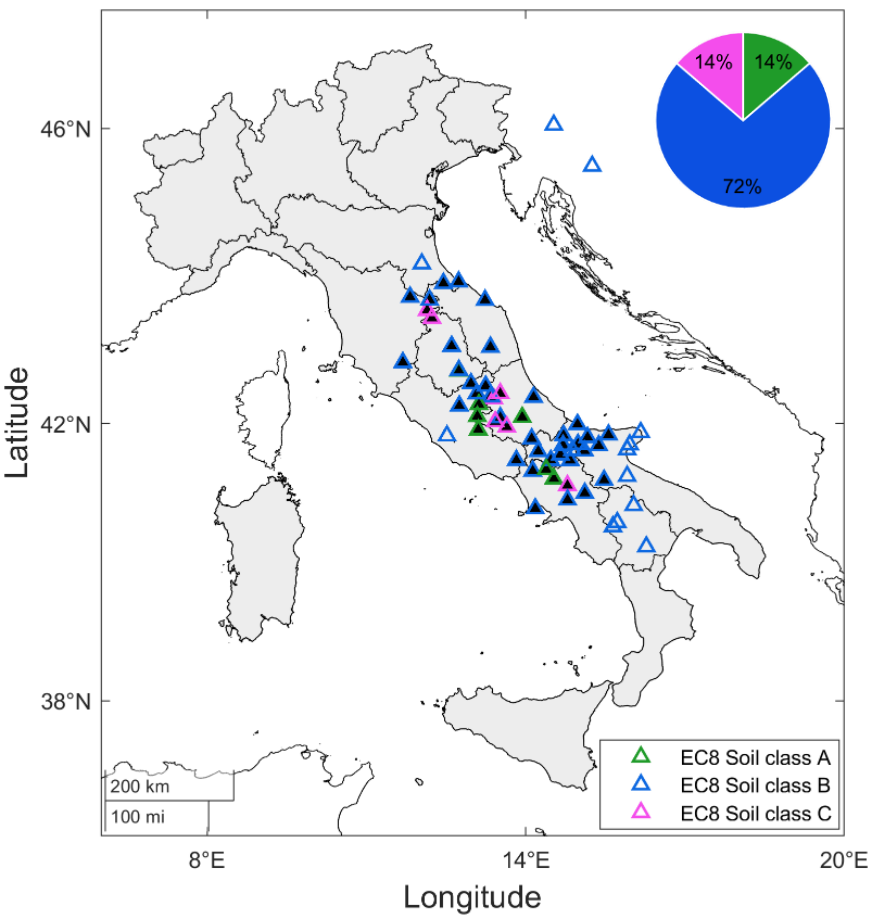



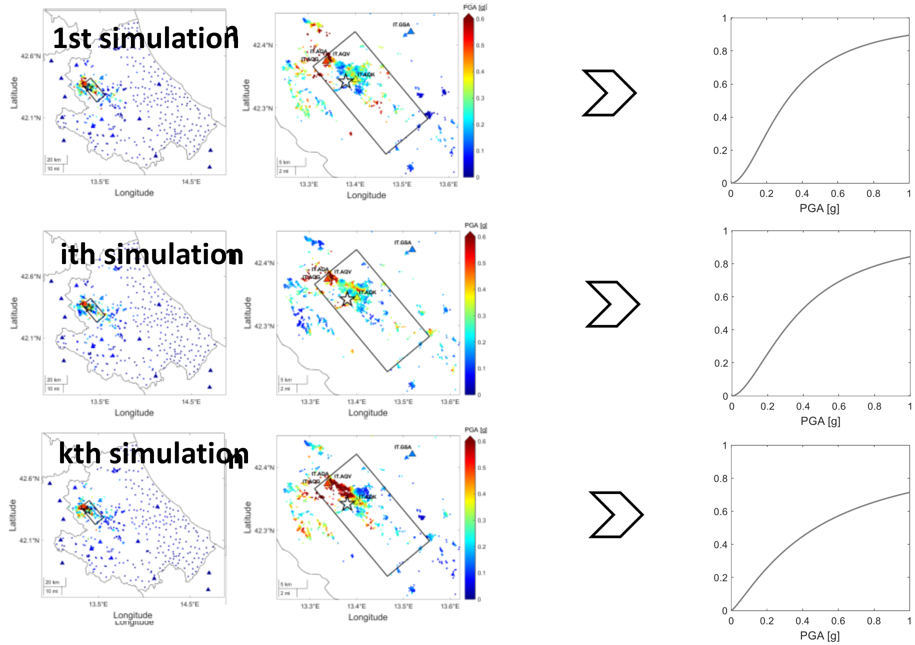

$(\theta, \beta)$

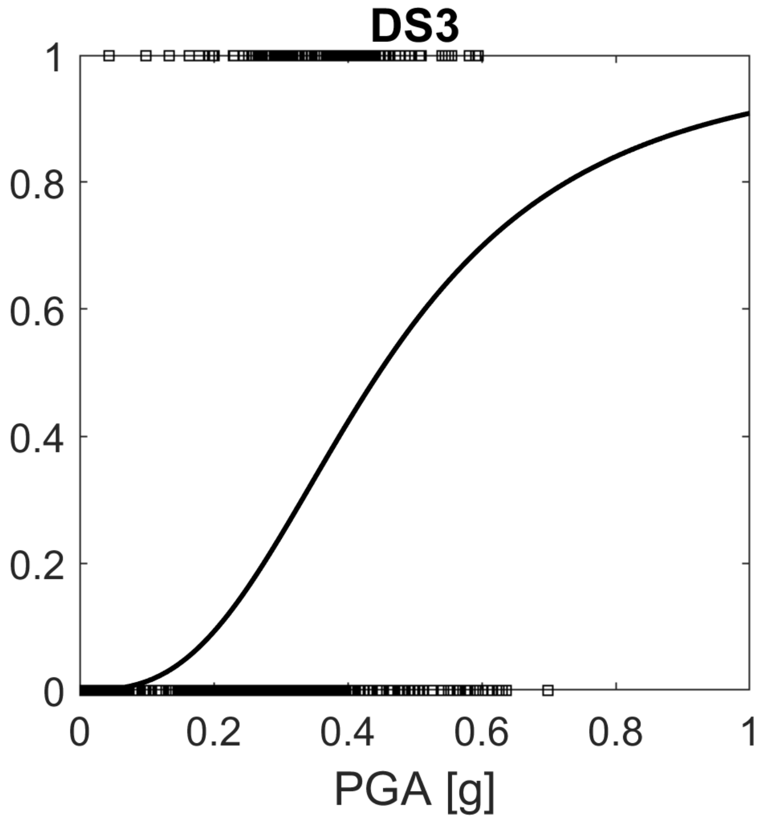
**Not that easy!** **This is a missing data problem: the intensity at the sites are not known except for a few, they are a random field. In addition, damages affect unknown PGAs.**



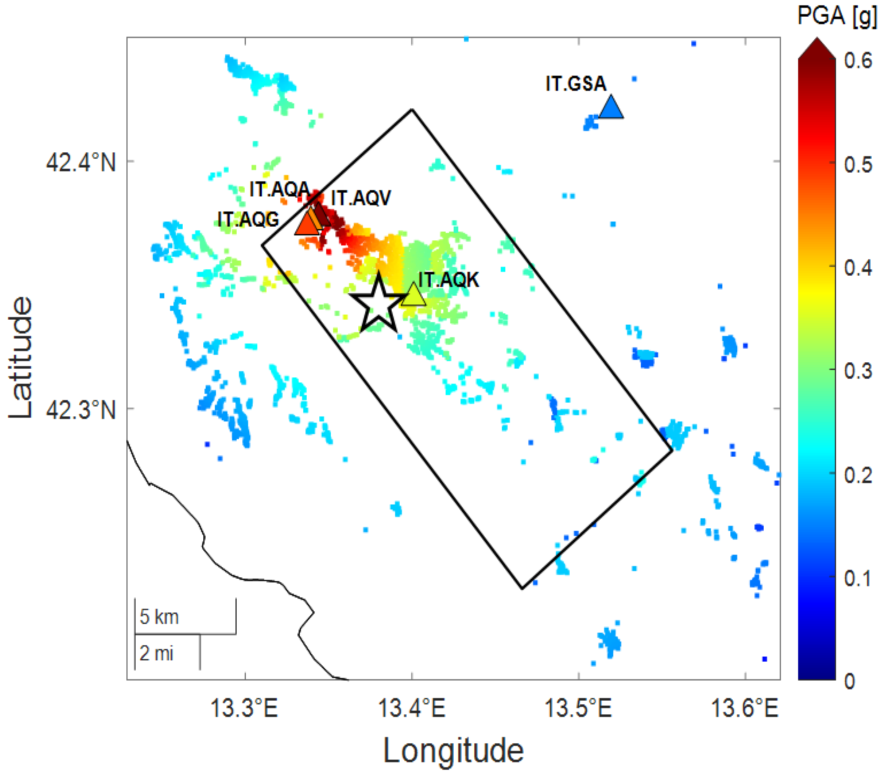




14%
14%
72%
46°N
42°N
38°N
Latitude
8°E
14°E
20°E
Longitude
200 km
100 mi
EC8 Soil class A
EC8 Soil class B
EC8 Soil class C


1st simulation
ith simulation
kth simulation
Longitude
Latitude
PGA [g]

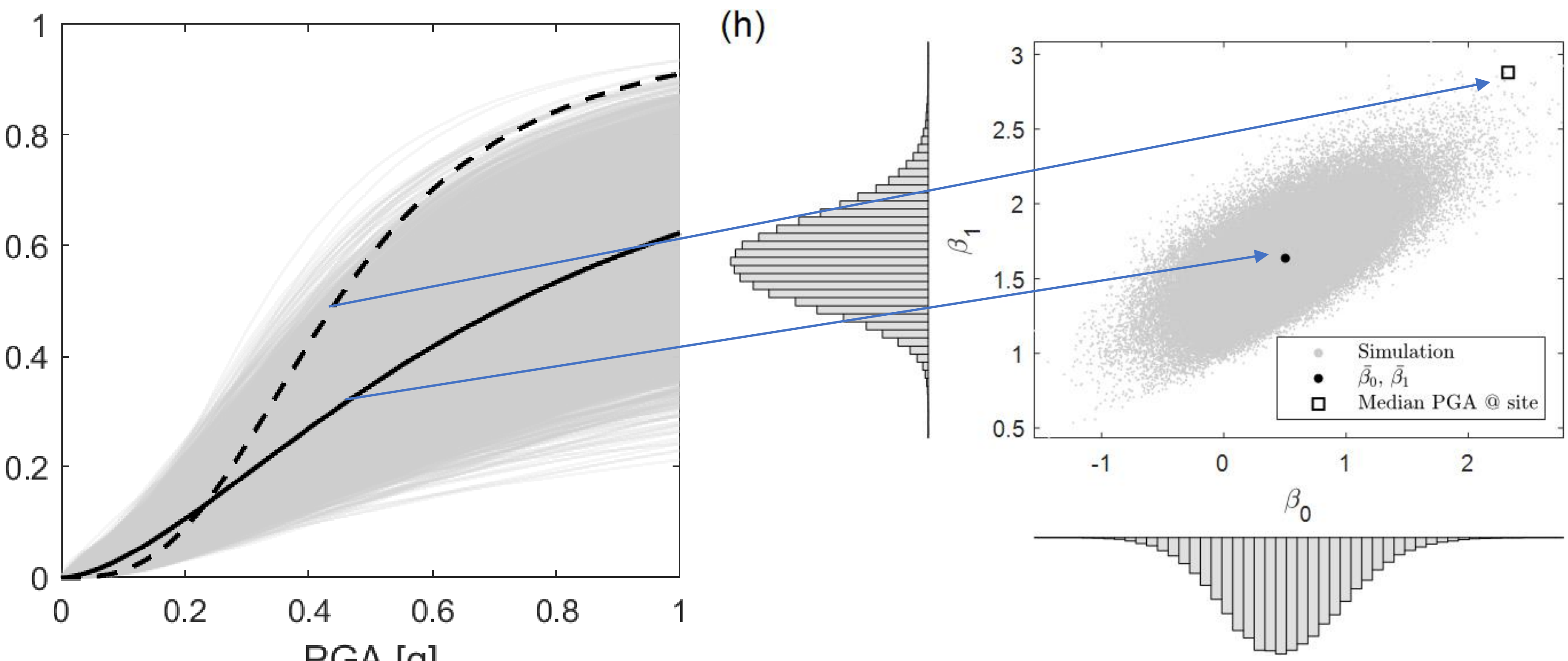


DS3
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
PGA [g]

PGA [g]
0.6
0.5
0.4
0.3
0.2
0.1
0
IT.GSA
IT.AQA
IT.AQV
IT.AQG
IT.AQK
42.4°N
42.3°N
Latitude
5 km
2 mi
13.3°E
13.4°E
13.5°E
13.6°E
Longitude

**Very preliminary and incomplete!**




**Distribution of the fragility parameters due to ShakeMap uncertainty $\{\widehat{\beta_0}, \widehat{\beta_1}\}$**

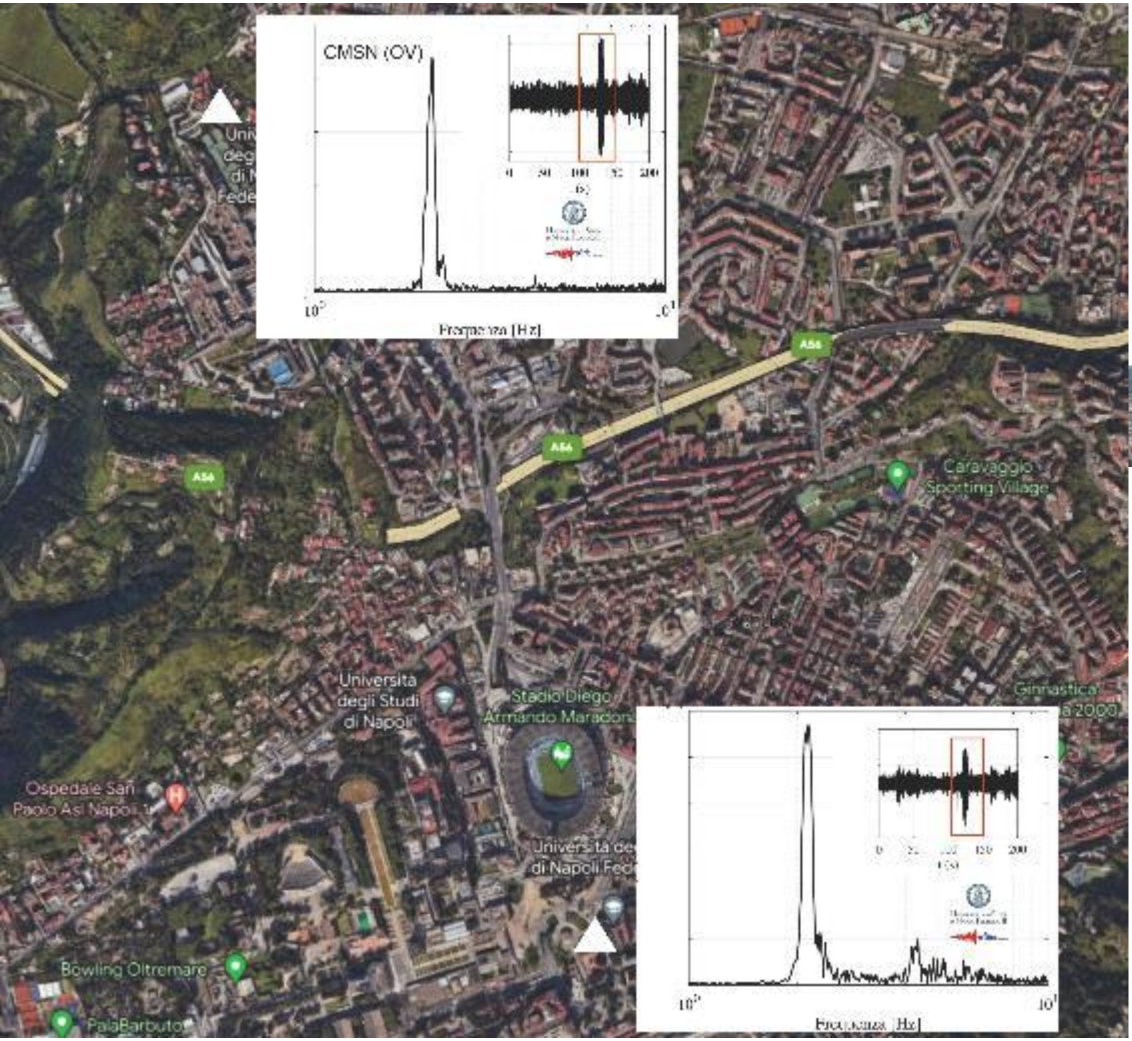
**Semi-empirical vulnerability models are attractive, but the use of damage data in conjunction with ShakeMap requires not neglecting the source of uncertainty in the latter, which is derived from that of GMPEs.**

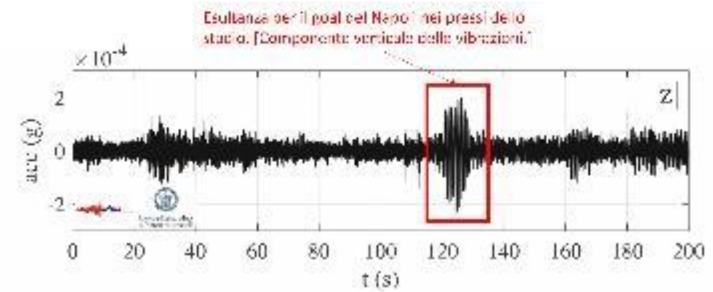
**Fortunately, the uncertainty model at the basis of ShakeMap is the same GRF as in MSPSHA, so fully specified.**

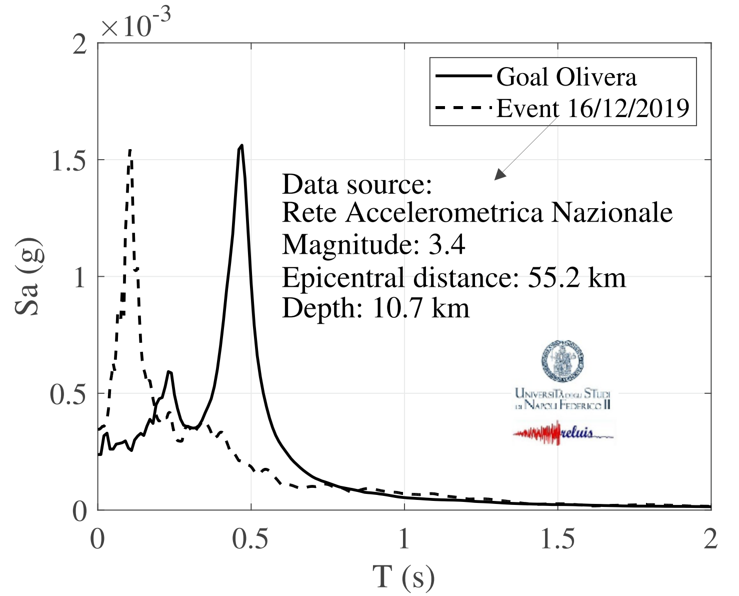
**It is a missing data problem that is practically equivalent to an estimation uncertainty problem with respect to the fragility parameters.**

**To account for such an uncertainty in (two-parameter) (semi-empirical) fragility fitting shows not only a variance underestimation but also a bias that reflects to the loss.**

# Napoli-Salernitana 30/04/2023

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