Aftershocks' effect on design seismic actions in Italy

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

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Edited post-workshop

Classical-hazard integral (after Cornell, 1968; McGuire, 1974…)

Probability of exceedance in a generic earthquake $P\left[IM > im\right]$

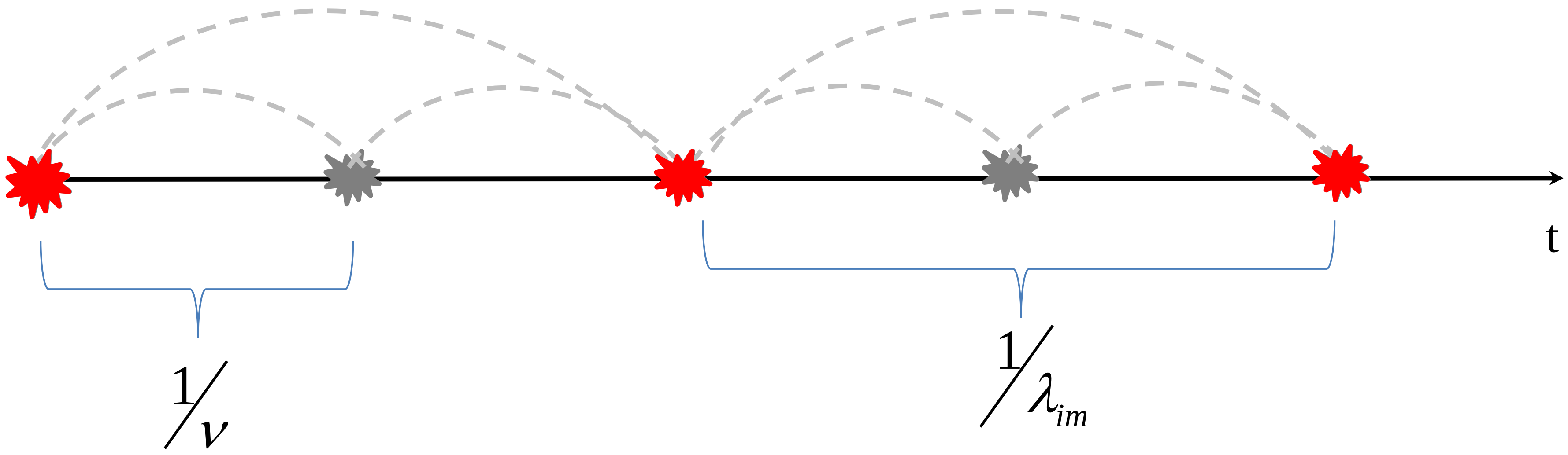
Rate of earthquakes causing exceedance

$$\lambda_{im} = \nu \cdot \int_{r_{\min}}^{r_{\max}} \int_{m_{\min}}^{m_{\max}} P\left[IM > im \mid x, y\right] \cdot f_{M_E, R_E}\left(x, y\right) \cdot dx \cdot dy$$

GMPE

Distribution of source features

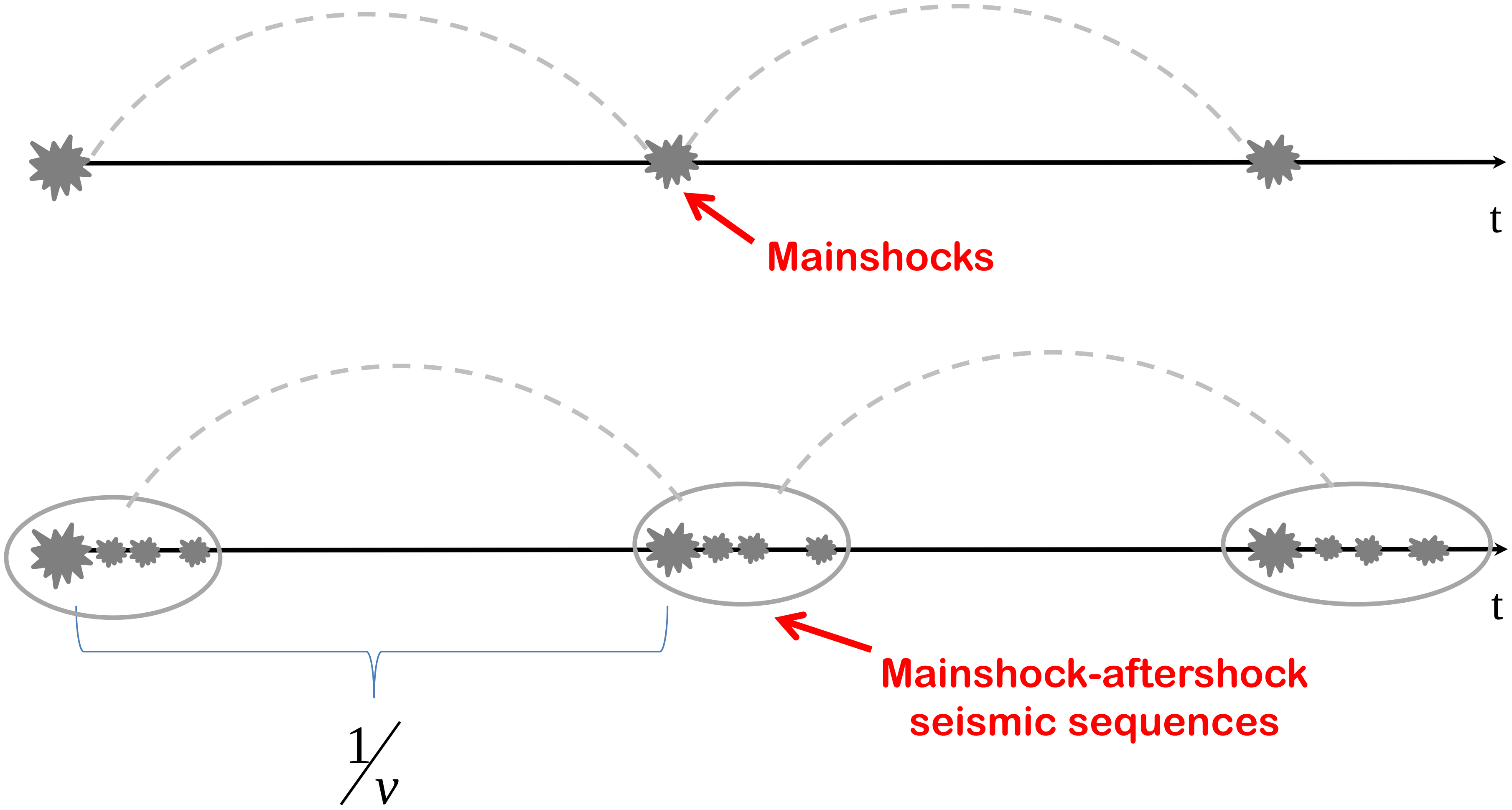
Rate of occurrence from declustered catalog (mainshocks)



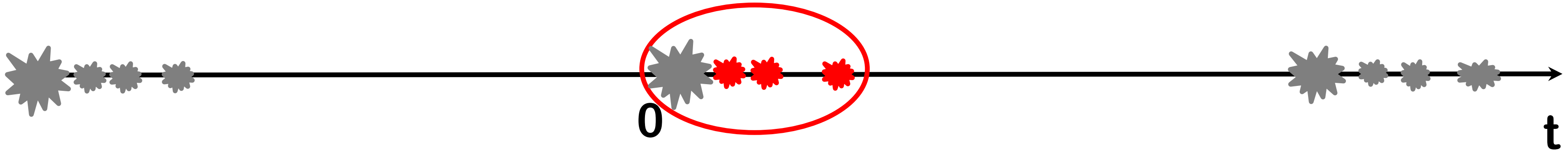
Motivation/Goal

- **PSHA is built on declustered catalogs (it allows to use the homogeneous Poisson process for earthquake occurrence).**
- **It is known that major earthquakes are followed by aftershock sequences.**
- **The exceedance of the *im* can occurr not only in the mainshock but also in the aftershocks.**
- **If the effect of afteshocks on the annual rate of exceedance of the *im* is significant, it may be of engineering interest to include it in hazard analysis so not to underestimate the design risk.**
- **The goal is pursued with the least modifications possible to the hazard integral and still considering a declustered catalog.**

Mainshock-aftershock sequences occur at the same rate of mainshocks (after Toro and Silva, 1996; Boyd, 2012)



Aftershock probabilistic seismic hazard analysis (after Yeo and Cornell 2009)

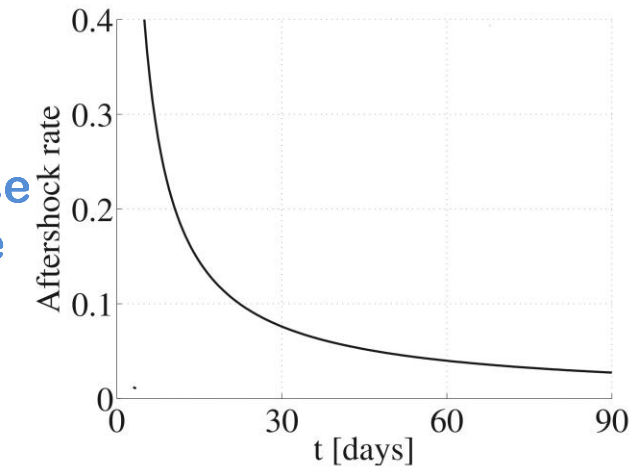


Aftershock rate given the mainshock (Modified Omori law)

$$v_{A|m}(t)=\left(10^{a+b\cdot(m-m_{\min})}-10^{a}\right)\Big/(t+c)^{p}$$

Gutenberg-Richter relationship for aftershocks

Number of elapse days since the mainshock



Aftershock-hazard integral

$$\lambda_{im|m}(\tau)=v_{A|m}(\tau)\cdot\iint_{M,R} P\left[IM>im\,|\,w,z\right]\cdot f_{M,R}(w,z)\cdot dw\cdot dz\cdot d\tau$$

To include aftershocks in classical hazard the probability that the *im* is exceeded in the aftershocks sequence must be accounted for

$$\lambda_{im} = \nu \cdot P\left[IM > im \cup IM_{\cup A} > im \right] =$$

$$= \nu \cdot \left\{ 1 - P\left[IM \le im \cap IM_{\cup A} \le im \right] \right\} =$$

$$= \nu \cdot \left\{ 1 - \iint_{M,R} \underbrace{P\left[IM \le im \mid x,y \right]}_{\text{GMPE}} \cdot \underbrace{P\left[IM_{\cup A} \le im \mid x,y \right]}_{\text{Probability that zero aftershocks exceed IM in the sequence}} \cdot \underbrace{f_{M,R}\left(x,y\right)}_{\text{Distribution of source features (mainshocks)}} \cdot dx \cdot dy \right\} =$$

GMPE

Probability that zero aftershocks exceed IM in the sequence

Distribution of source features (mainshocks)

$$P\left[IM_{\cup A} \le im \mid x,y \right] = e^{-\int_0^{\Delta T_A} \nu_{A|x}(\tau) \cdot \iint_{M,R} P\left[IM \le im | w,z\right] \cdot f_{M,R}\left(w,z | x,y\right) \cdot dw \cdot dz \cdot d\tau}$$

Sequence-based probabilistic seismic hazard analysis (SPSHA)*

$$\lambda_{im} = \nu \cdot \left\{ 1 - \iint_{M,R} P\left[IM \le im \mid x,y\right] \cdot e^{-\int_0^{\Delta T_A} \nu_{A|x}(\tau) \cdot \iint_{M,R} P\left[IM \le im|w,z\right] \cdot f_{M,R}\left(w,z|x,y\right) \cdot dw \cdot dz \cdot d\tau} \cdot f_{M,R}\left(x,y\right) \cdot dx \cdot dy \right\}$$

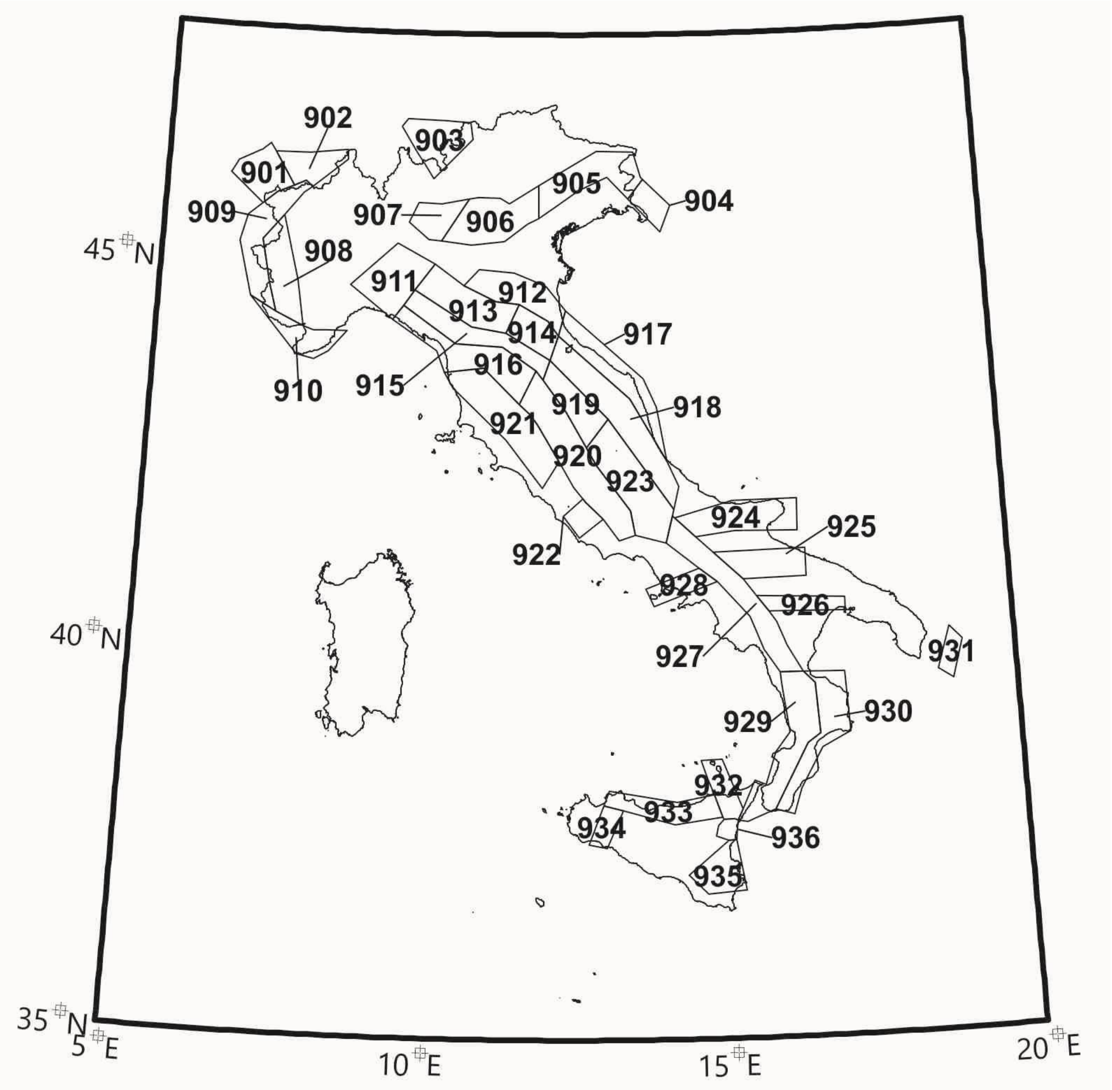
Still rate of mainshocks

GMPE (probability of not exceeding the IM threshold due to the mainshock)

Probability of not exceeding the IM threshold due to aftershocks (nested aftershock hazard integral)

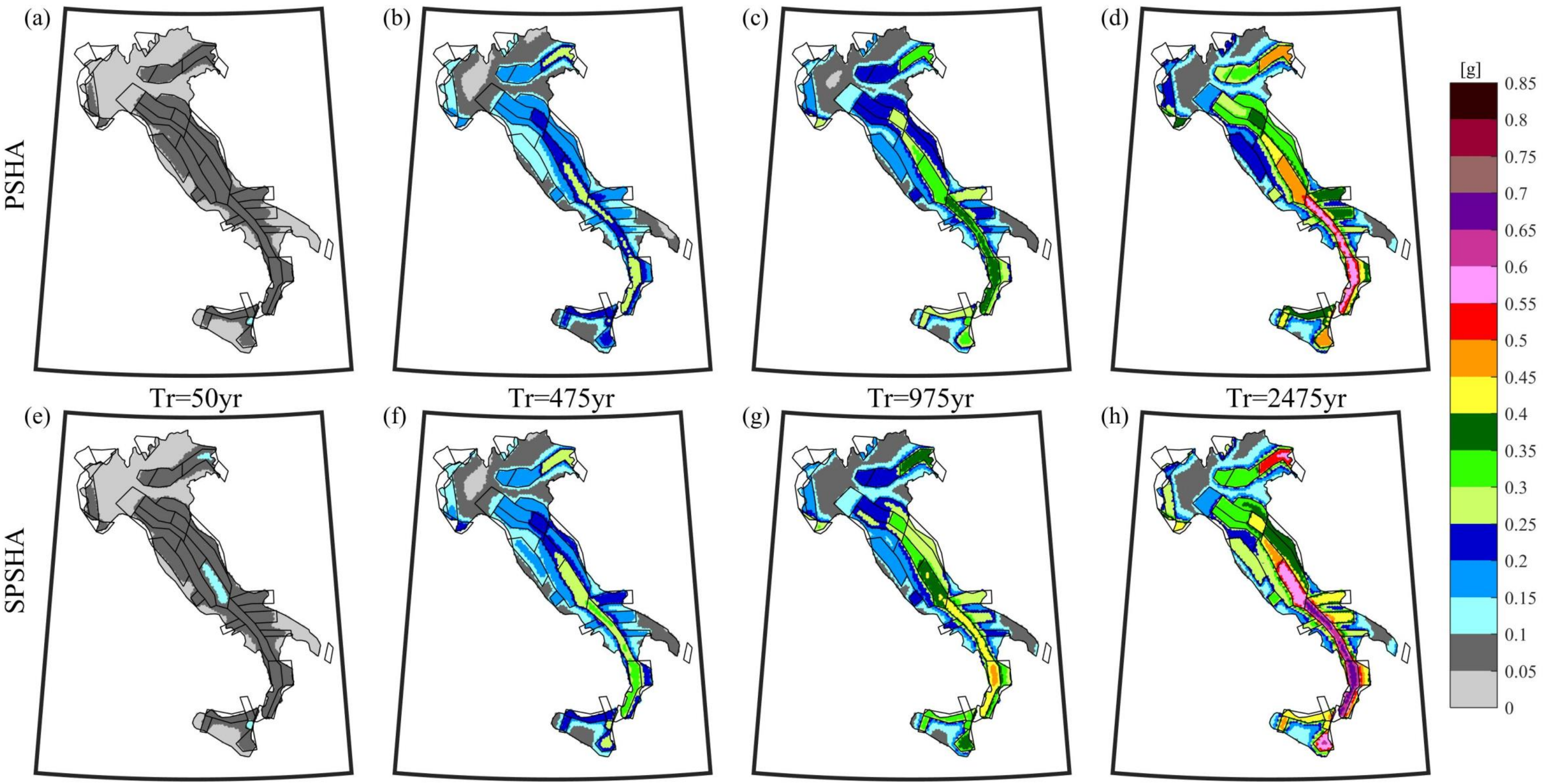
Distribution of source features (mainshocks)

*Iervolino, Giorgio, Polidoro (2014). Sequence-based probabilistic seismic hazard analysis. Bull. Seismol. Soc. Am., 104: 1006-1012.

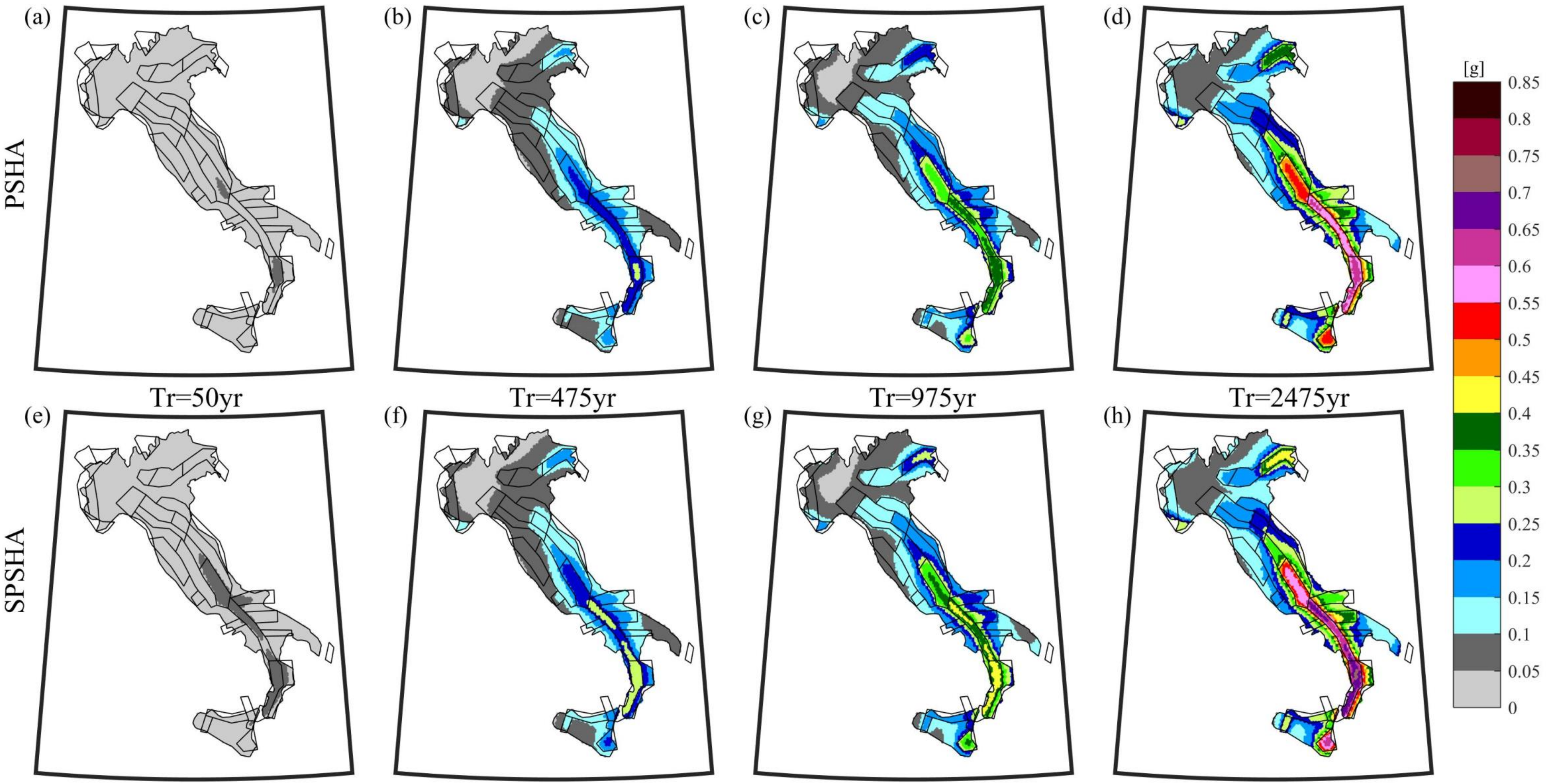


- **Source model of the Italian hazard map (MPS04) branch 921 of the logic tree (Stucchi et al., BSSA, 2011);**
- **The generic aftershock sequence modified Omori law parameters from Lolli and Gasperini (J. Seismol., 2002);**
- **Relationship between earthquake magnitude and aftershock area from Utsu (1970).**

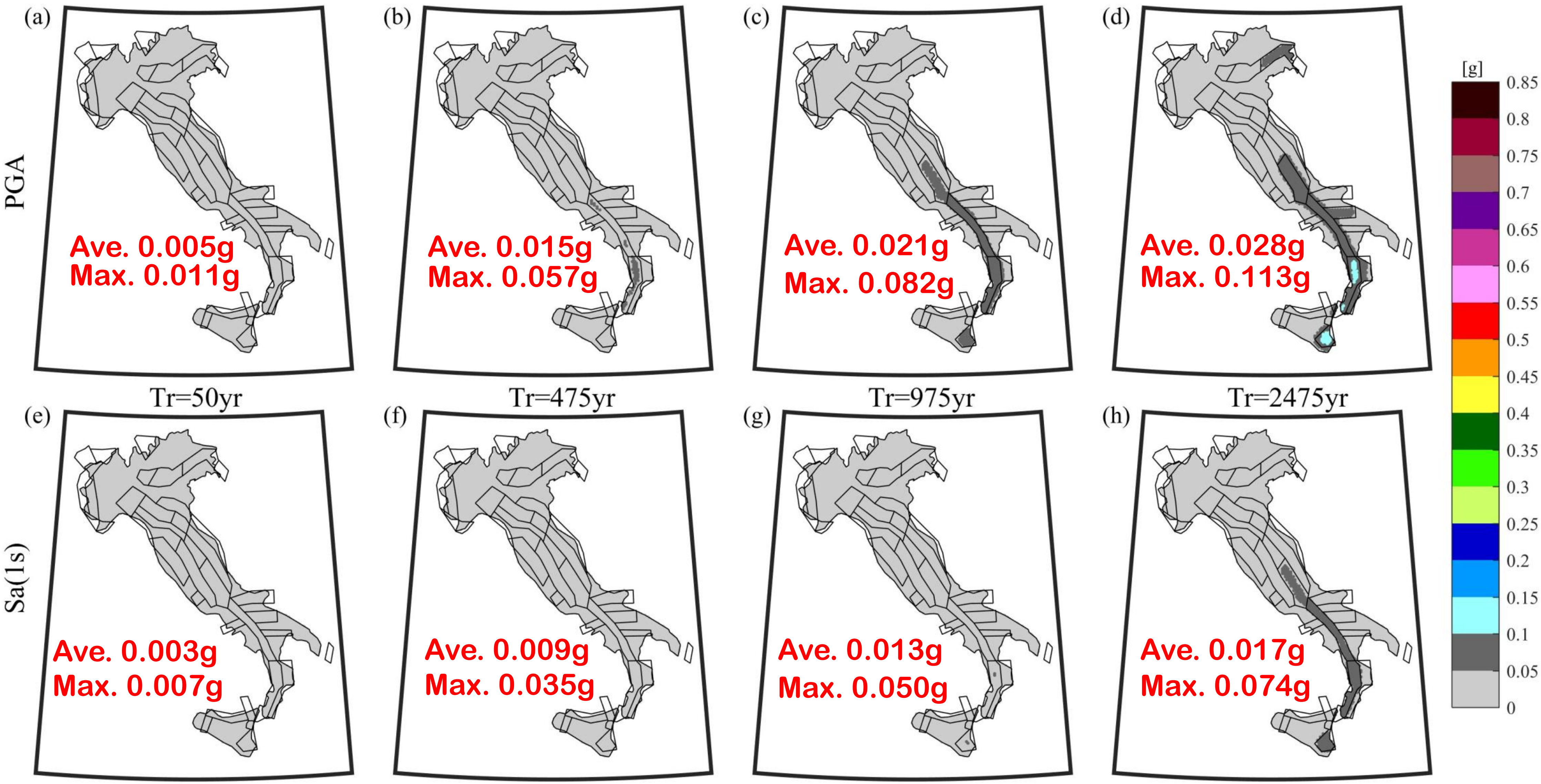
PSHA vs SPSHA in terms of PGA – preliminary results



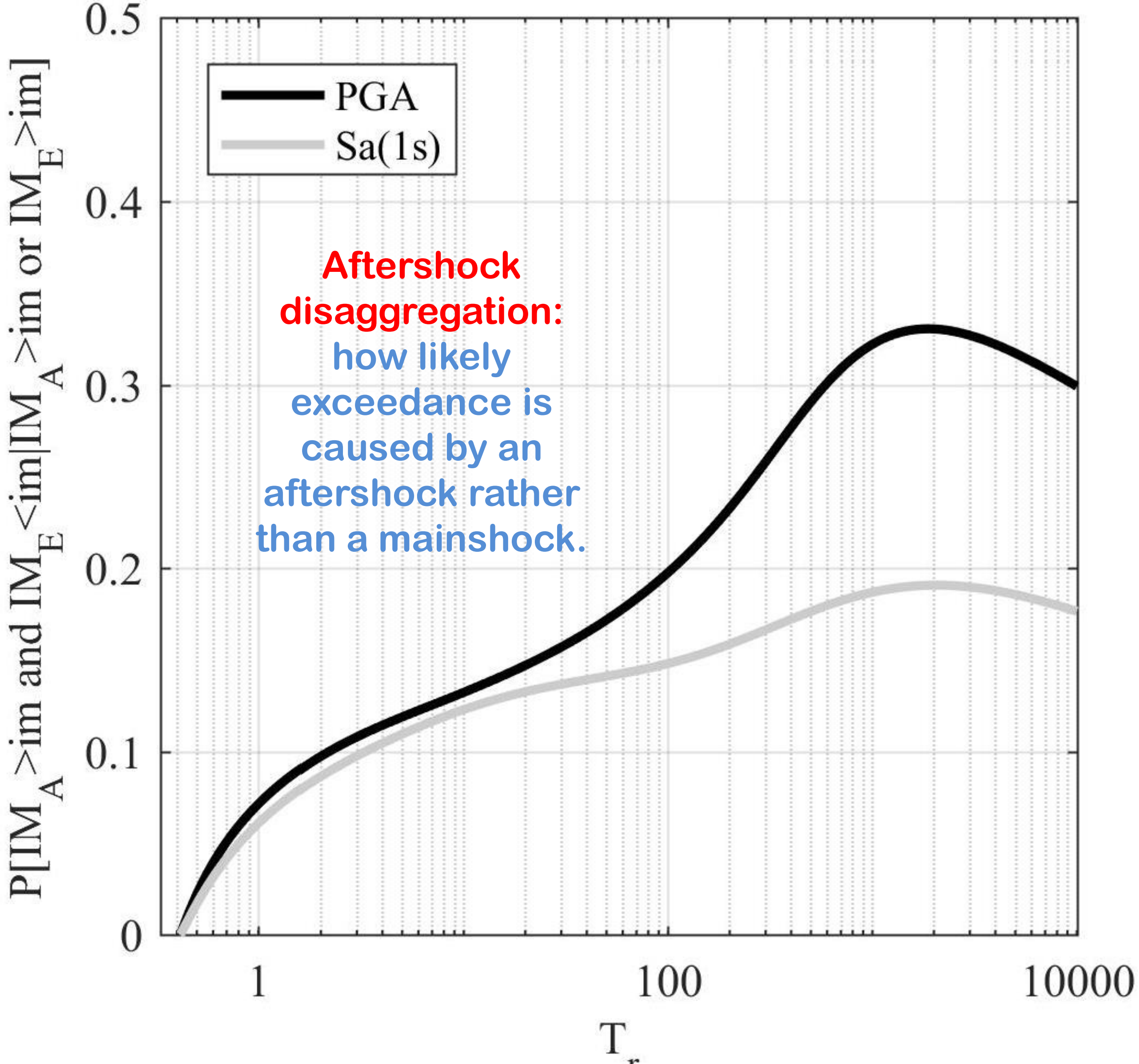
PSHA vs SPSHA in terms of Sa(T1s) – preliminary results



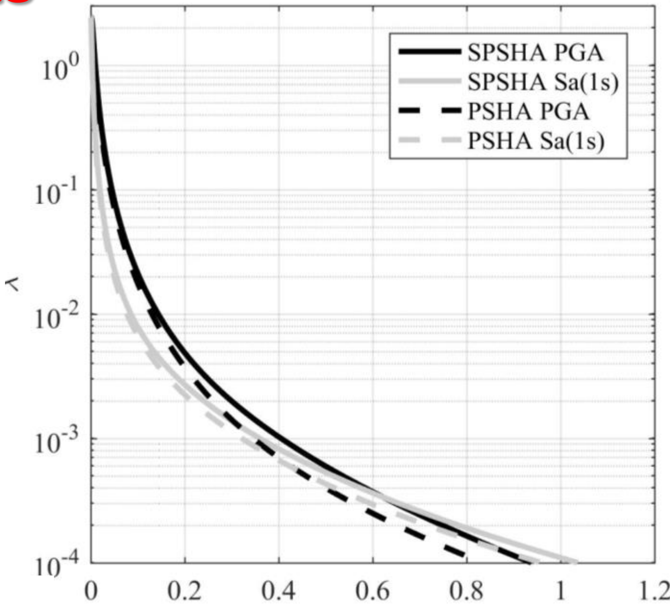
Differences – preliminary results

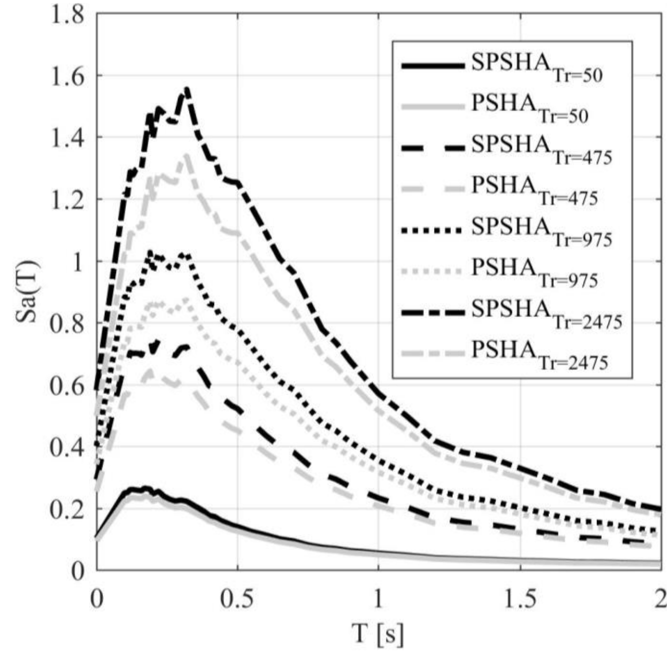


The case of L'Aquila – preliminary results



L'Aquila





Summary

- In 2014 a probabilistically rigorous reformulation of the hazard integral to account for the contribution of aftershocks was published.

- The model is based on the occurrence of sequences with the same rate of mainshocks and the occurrence of aftershocks is modeled via the modified Omori law (combination of PSHA and APSHA).

- The rate of occurrence of a mainshock-aftershocks cluster is the same of the mainshocks, thus the catalog is the same of the classic calculation (declustered).

- SPSHA was applied to Italy based on the source model for the official hazard map, the preliminary results show average increases around 10%, but larger effects in most hazardous areas.

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