PSHA Workshop

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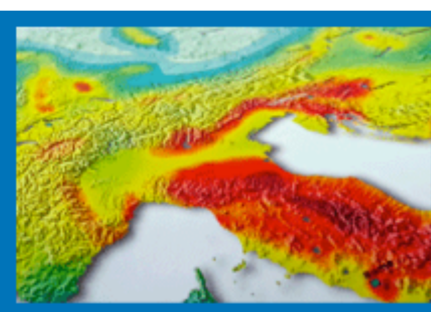

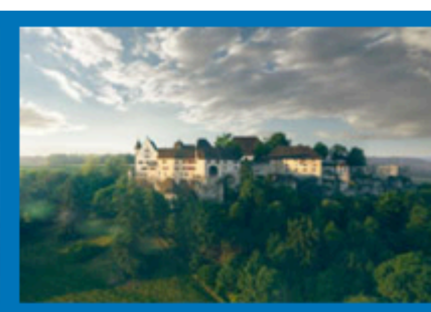

Future directions for probabilistic seismic hazard assessment at a local, national, and transnational scale

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INVESTIGATING DIRECTIVITY EFFECTS IN PSHA THROUGH DETERMINISTIC-STOCHASTIC SIMULATIONS

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The median and standard deviation of empirical ground-motion prediction equations (GMPEs) are usually poorly constrained close to the seismogenic source due to the general lack of strong-motion records. In addition, the ground-motion variability associated with a single fault is even more difficult to assess because multiple records of earthquakes generated by the same fault rarely exist. Finite-fault simulations can represent a valid alternative to overcome the limitations of GMPEs, especially in the near-source region, where effects due to the finiteness of the source dominate the ground motion. Directivity effects, in particular, have the largest impact on the ground-motion variability at low and intermediate frequencies, causing amplification at sites in the forward direction of the rupture. Therefore we explore the use of a deterministic–stochastic method (DSM, Pacor et al., 2005) to predict the ground motion close to the source, assess its variability, and calibrate synthetic attenuation models including directivity effects to be incorporated into Probabilistic Seismic Hazard Analysis (PSHA). Our results show that, for specific source-to-site configurations, the non-ergodic PSHA is very sensitive to the additional epistemic uncertainty that may augment the exceedance probabilities when directivity effects are maximized. The proposed approach may represent a suitable way to develop novel ground-shaking models for computing more accurate hazard estimates.

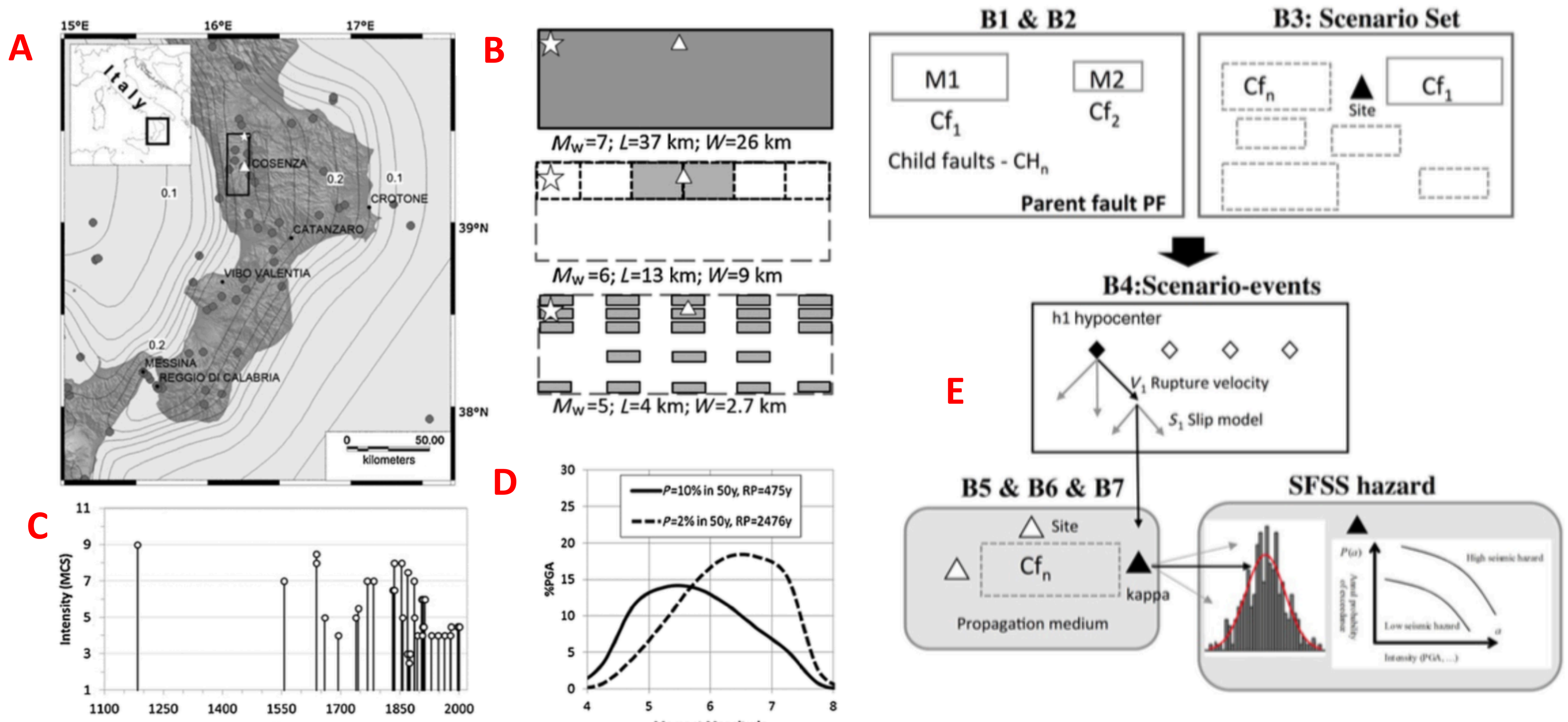
Aleatory Variability of Single-Fault Single-Site scenarios

We set up a case study for the city of Cosenza (CSZ), southern Italy, a densely populated city with a rich heritage of historic buildings, located in one of the Italian regions characterized by the highest seismic hazard (**A**: official Italian hazard map MPS04), a long history of damaging earthquakes (**C**), and where only few strong-motion data are available (http://itaca.mi.ingv.it/).

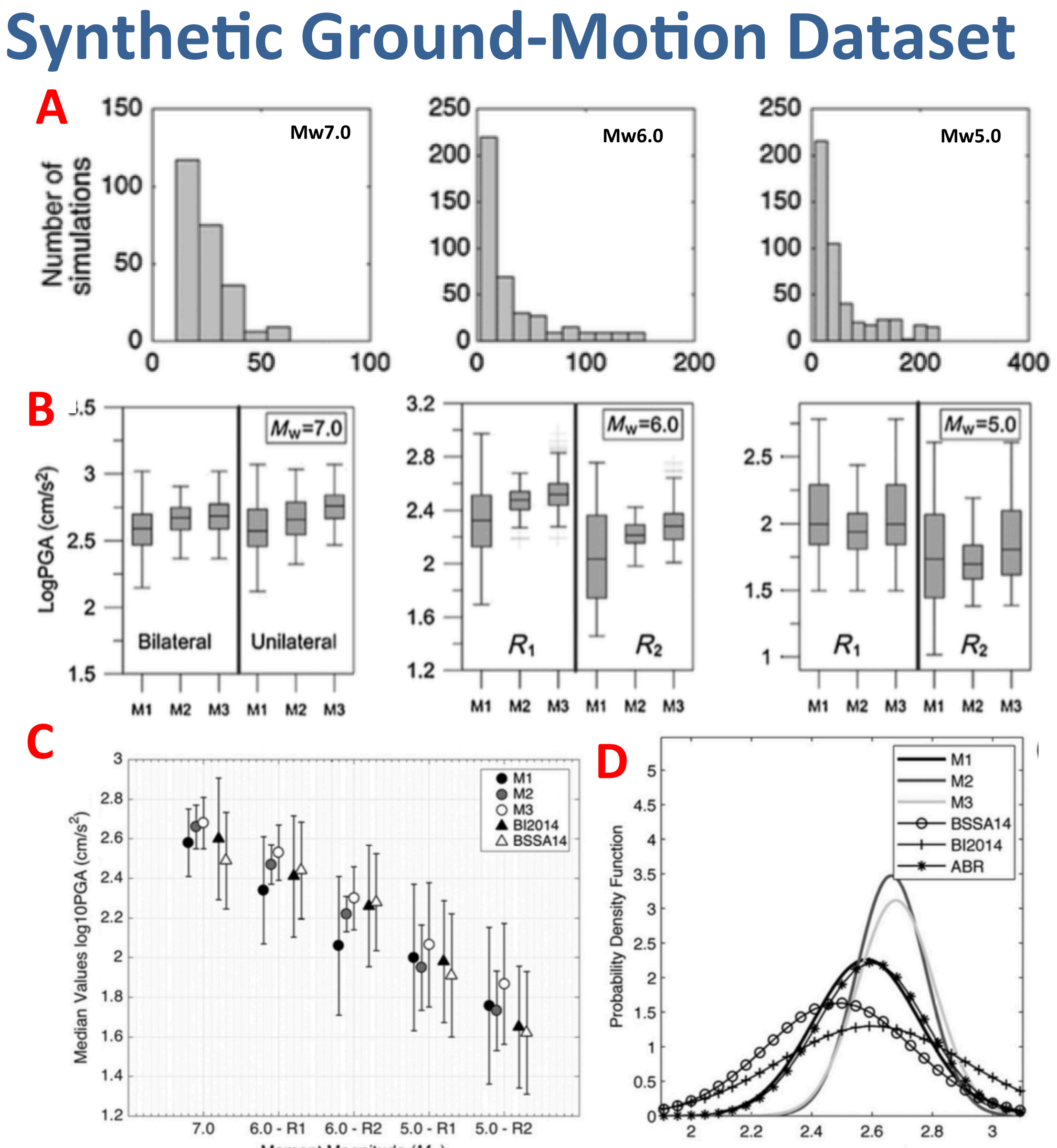
The ground motion is simulated for bedrock and free-field conditions at a single target site located in the proximity of a single fault (single-fault single-site scenarios SFSS), assumed as capable of generating from moderate to strong earthquakes .

We generate a large number of SFSS scenarios by varying both the location and kinematic parameters of individual ruptures. We simulated earthquakes of three magnitude values, Mw7.0, 6.0, and 5.0, as well as source-to-site distances of 0-10 km (**B**), thereby exploring the range of the major contribution to PSHA at CSZ resulting from MPS04 disaggregation (**D**).

To sampling the aleatory uncertainty of the simulation parameters we adopt an Event Three (ET) scheme (**E**) in which each branch represents possible realizations of earthquake rupture models exploring various characteristic of earthquake source and target site.



Synthetic Ground-Motion Dataset



Directivity effects are included in the simulations by means of the apparent corner frequency, from which we estimate the apparent stress Δ_{app}. These parameters depend on: rupture velocity, nucleation point, site-source geometry.

We consider three setups of the simulation method to differently weighting the directivity effects:

M1-maximum Δ_{app} variable from site to site; *M2-minimum* stress drop fixed to 30 bars; *M3-medium* backward effects are minimized introducing a minimum threshold for Δ_{app}.

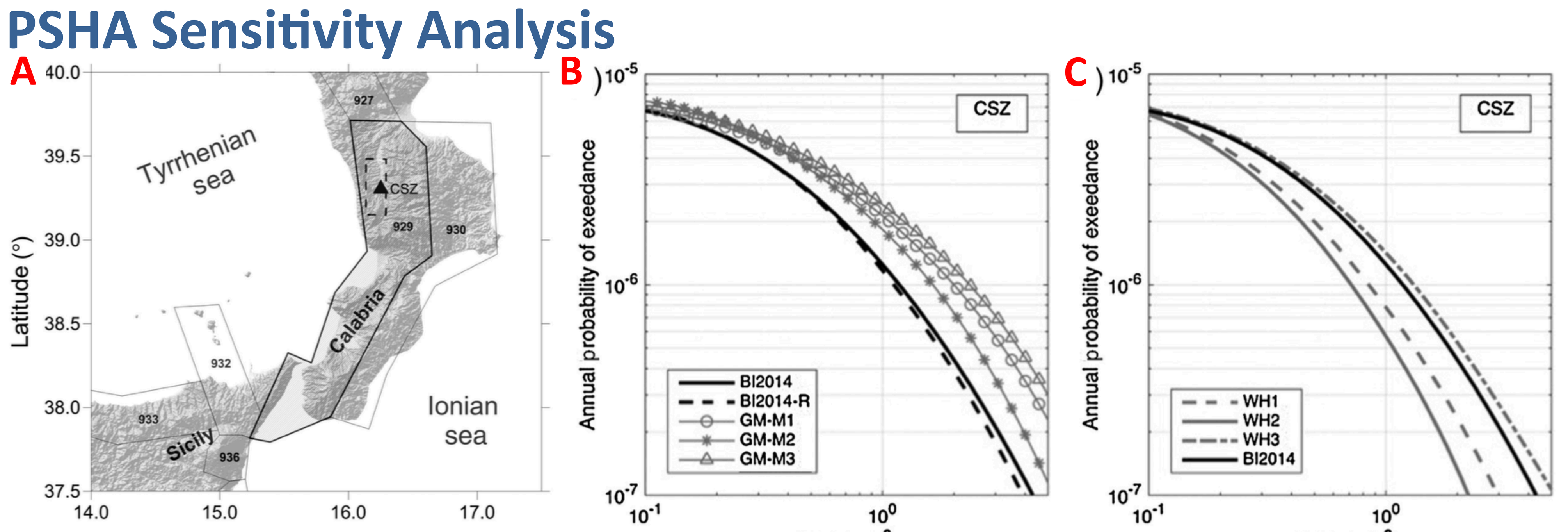
A range of variability of the Δ_{app} for M1

B Box plots of the synthetic PGA. The set of synthetics are grouped by distance (R_1 = 0 and R_2 = 5 km for Mw6.0 and R_1 = 5 and R_2 = 10 km for Mw5.0).

C Comparison among simulated PGA (median and standard deviations) and median GMPEs (BI2014, Bindi et al., 2014; BSSA14, Boore et al., 2014).

D Probability density function (PDF) for M1, M2 and M3 setups compared with empirical PDFs. Empirical PDFs are plotted considering the fault variance $\tau^2/2$ (Yagoda-Biran et al., 2015) instead of the between-event variance; the sigma estimated for a single seismic source (ABR) by Luzi et al., 2014 is also considered.

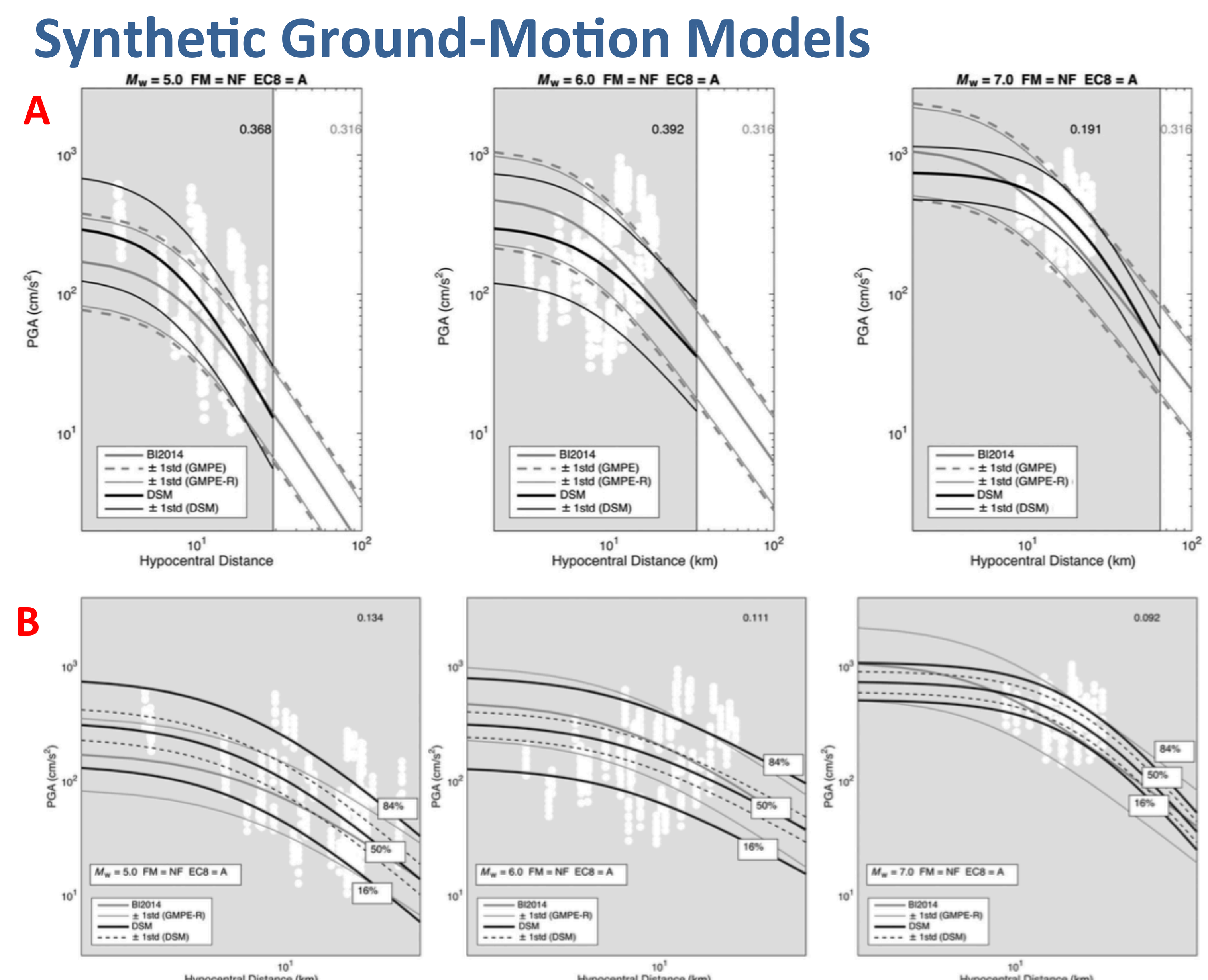
PSHA Sensitivity Analysis



The synthetic attenuation models are employed to perform a simplified PSHA sensitivity analysis accounting for the 929 seismogenic zone of the ZS9 model (Meletti et al., 2008 in **A**). The annual probability of exceedance (APEs) for PGA is calculated at the CSZ site using empirical (black line) or hybrid ground-motion models (gray lines) without accounting for the directivity term B. Conversely, the hazard curves in **C** are for a set of logic-tree weights that differently combine directivity effects after introducing the directivity term into M1 setup. Attenuation curves are weighted so that WH2 implies the same likelihood of occurrence for each model, while WH1 and WH3 consider an higher weight by the 16th or the 84th percentile of the Δ_{app}.

In case of models depending on distance, we observe increased APEs due to the overall enhancement of the median ground motion produced by the synthetic models (**B**). Regarding to the APEs obtained by introducing the directivity term (**C**) we observe how the global effect of the sigma reduction leads to a decrease of APEs with respect to the ergodic assumption (BI2014). The only exception is due to the increase in the epistemic uncertainty of the median when forward-directivity effects are accounted for.

Synthetic Ground-Motion Models



$$[1] \quad \log(PGA) = c_1 + c_2 log\frac{\sqrt{R_{hypo}^2+h_{eff}^2}}{d} + \boxed{c_3\log(\Delta_{app})} \quad \text{Directivity term}$$

We calibrate SFSS ground-motion equations for PGA and hypocentral distance (R_{hypo}) that account for directivity effects by means of Δ_{app}. In this way source-specific and path-specific effects are accounted for. In equation [1], the empirical model BI2014 describes the attenuation at distances larger than those covered by simulations. For each magnitude class, we fit the simulated PGAs using the functional form [1] where h_{eff} is the effective depth parameter that includes near-source saturation effects and d is the joint distance between synthetic and BI2014 median values.

A synthetic models for the M1 setup, using only the hypocentral distance; **B** synthetic models corrected for the directivity term (16th, 50th, and 84th percentile of the Δ_{app} distribution) compared to BI2014. The aleatory variability of the synthetic GMPEs is reduced (~50%) by including the predictive directivity term.

Conclusions

DSM simulations are accurate enough to be used in seismic-hazard applications and, although they have a higher computational cost than the GMPEs, they provide an added value represented by (1) one-to-one association between seismic source characteristics and their calculated effects; (2) the possibility to supply results in any hazard ground-motion parameters directly derived from synthetic waveforms; (3) the possibility to explore the ground-motion variability due to several fault kinematic parameters, directivity, and short source-to-site distances; (4) integration with empirical ground-motion models, especially for moderate-to-large magnitudes in the near-source region where recorded data are usually poor or nonexistent; (5) PSHA accounting for heteroscedastic features of the ground motion; and (6) total removal of the ergodic assumption for prevailing path-specific effects.

References: Pacor, F., G. Cultrera, A. Mendez, and M. Cocco (2005). Finite fault modeling of strong ground motions using a hybrid deterministic–stochastic approach, Bull. Seismol. Soc. Am. 95, 225–240, doi:10.1785/0120030163; Bindi, D., M. Massa, L. Luzi, G. Ameri, F. Pacor, R. Puglia, and P. Augliera (2014). Pan-European ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods up to 3.0 s using the RESORCE dataset, Bull. Earthq. Eng. 12, 391–430, doi: 10.1007/s10518-013-9525-5; Boore, D. M., J. P. Stewart, E. Seyhan, and G. M. Atkinson (2014). NGA- West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes, Earthq. Spectra 30, 1057–1085, doi: 10.1193/070113eqs184m; Yagoda-Biran, G., J. G. Anderson, H. Miyake, and K. Koketsu (2015). Between-event variance for large repeating earthquakes, Bull. Seismol. Soc. Am. 105, 2023–2040, doi: 10.1785/0120140196; Luzi, L., D. Bindi, R. Puglia, F. Pacor, and A. Oth (2014). Single-station sigma for Italian strong-motion stations, Bull. Seismol. Soc. Am. 104, no. 1, 467–483, doi: 10.1785/0120130089; Meletti, C., F. Galadini, G. Valensise, M. Stucchi, R. Basili, S. Barba, G. Vannucci, and E. Boschi (2008). A seismic source zone model for the seismic hazard assessment of the Italian territory, Tectonophysics 450, 85–108, doi: 10.1016/j.tecto.2008.01.003.

For further details about this work please refer to

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Ground-Motion Variability for Single Site and Single Source through Deterministic Stochastic Method Simulations: Implications for PSHA

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