Ground Motion Prediction Equations for the Campi Flegrei volcanic area

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Ground Motion Prediction Equations (GMPEs) are semi-empirical relationships widely used to model ground motion intensity measures, such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and pseudo-Spectral Acceleration (SA) at a specific site, as a function of earthquake parameters like magnitude, source-site distance, and local site amplification effects. GMPEs serve multiple applications in seismology and earthquake engineering, including probabilistic seismic hazard analysis (McGuire 2004), and rapid response tools like ShakeMaps (Worden et al. 2018).

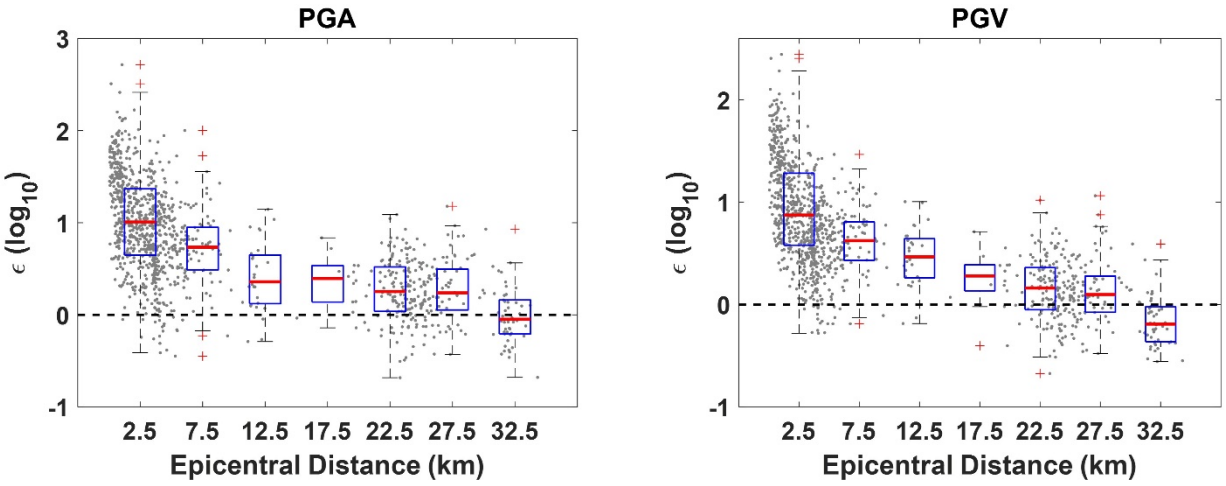

Fig. 1 – Residuals of PGA (on the left) and PGV (on the right). The residuals ϵ are estimated as $\epsilon = log_{10}\left(\frac{PGx_{obs}}{PGx_{pred}}\right)$, with PGx_{obs} being the recorded intensity measure and PGx_{pred} is computed through the GMPEs, valid for seismicity in Italian volcanic areas, proposed by Tusa & Langer (2016).

In the past decade, the densely populated volcanic area of Campi Flegrei in Southern Italy has experienced intense seismic activity, driven by inner-caldera resurgence and ground uplift. Over nine-thousands seismic events have been recorded (Scotto di Uccio et al., 2024). In the last two years, this activity has intensified, with uplift rates and seismicity accelerating, resulting in approximately seventy events with duration magnitudes (M_d) between 2.5 and 4.4. Some of these events have been perceptible to the population and/or had intensity of engineering relevance, with recorded SAs even exceeding 1g at less than 1 km from the epicentre of the $M_d = 4.4$.

Given the substantial discrepancies between observed recorded ground motion data and predictions from existing GMPEs (Fig. 1) and the unprecedented amount of data for Campi Flegrei, this study develops locally calibrated GMPEs for PGA, PGV, and SA at 21 periods $T \in [0.01s, 10s]$. The dataset includes recordings from the 65 largest magnitude events in the past two years, captured by 52 accelerometric and velocimetric stations at epicentral distances $R_{epi} < 40km$. Events were relocated using a probabilistic, non-linear approach (Scotto di Uccio et al., 2024), and moment magnitudes were derived from displacement spectrum amplitudes. Results indicate that the recalibrated GMPEs (Fig. 2a) predict higher PGA and PGV near the source ($R_{epi} < 5km$) and show faster attenuation at larger distances compared to existing attenuation relationships for Italian volcanic regions.

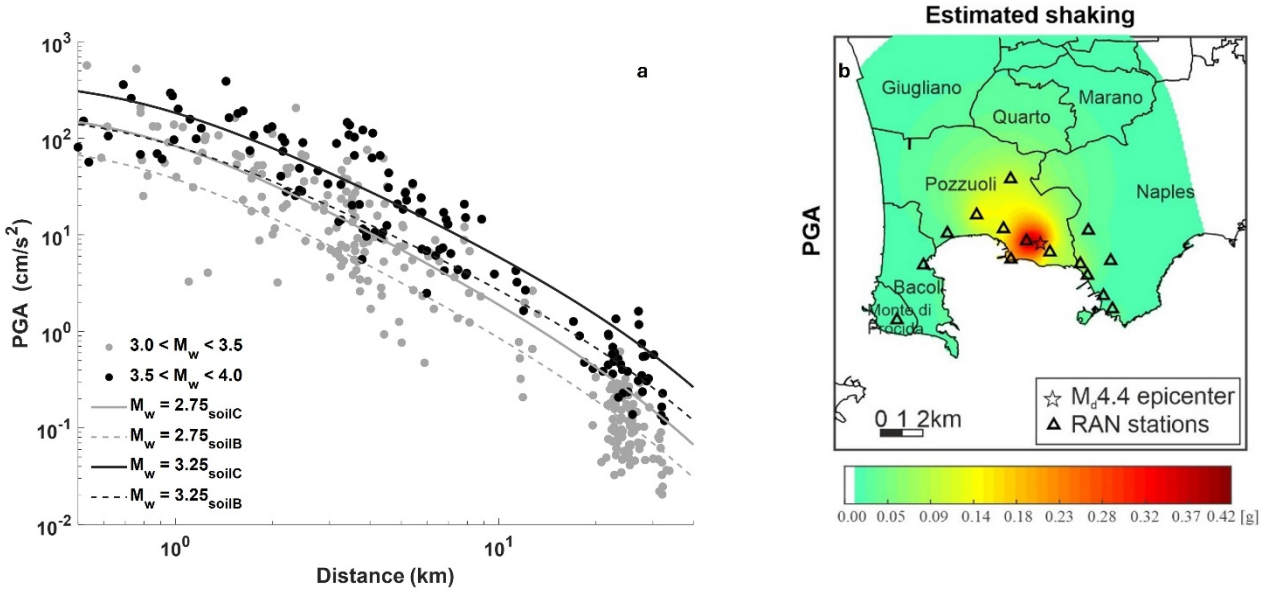

Fig. 2 – (a) Ground Motion calibrated models for PGA along with corresponding data in the range $3.0 < M_w < 3.5$. The models are separated between soil C (solid lines) and soil B (dashed lines). (b) Estimation of the shaking caused by the $M_d = 4.4 (M_w = 4.0)$ earthquake occurred on 20 May 2024, in terms of largest horizontal PGA, through a multivariate normal approach similar to the one implemented in ShakeMap (Worden et al. 2018).

The calibrated GMPEs are deemed to capture the seismic characteristics of the Campi Flegrei area. They were used to compute maps of the estimated PGA in the area due to the largest magnitude event, conditional to event features and observations, similar to ShakeMap approach. They reveal a reduction of the median PGA by more than 25% at epicentral distances lower than

1 km (Fig. 2b), while the same reduction is observed at about 1.5 km according to official Shake-Map data. Additionally, in the framework of a seismic risk mitigation study for Campi Flegrei area (Iervolino et al., 2024), the GMPEs were employed to compare the minimum magnitude of nearby earthquakes expected to exceed code-mandated design (elastic) seismic actions on structures (so-called strong earthquakes; Cito and Iervolino, 2020) with the reference magnitude for the area. It was found that strong earthquakes occurring within 1 km from the site have magnitude larger than 4.1, which is the lower bound of the reference magnitudes.

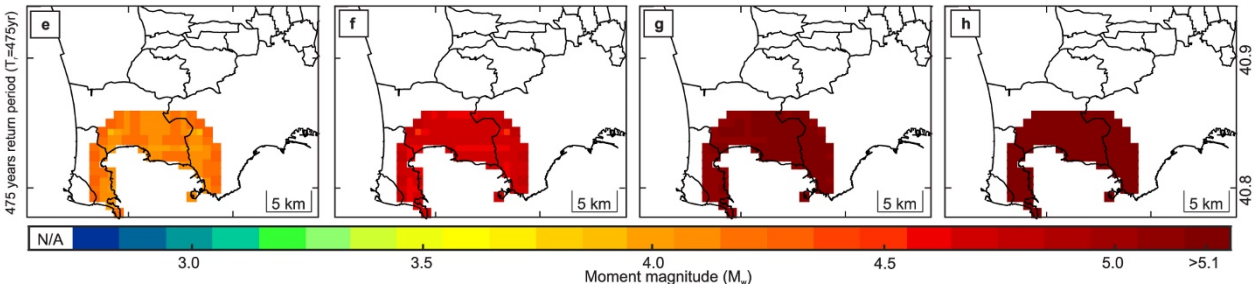

Fig. 3 – Minimum moment magnitude of strong earthquakes if occurring within 1 km from the site. From left to right, values for PGA, and SA (T = 0.3, 1.0 and 1.5 s) are shown. The values are those for an average return period of 475yr (figure by Iervolino et al. 2024).

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