Comparing the 2020 European Seismic Hazard Model (ESHM20) with ShakeMap Footprints: application in Greece

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Abstract: Probabilistic Seismic Hazard Assessment (PSHA) maps estimate the likelihood and intensity of ground shaking, usually expressed in terms of Peak Ground Acceleration (PGA) or Spectral Acceleration (Sa) at different periods, over a given time frame. This study evaluates the performance of the 2020 European Seismic Hazard Model (ESHM20; Danciu et al., 2021), by comparing its predictions with observed ground motion from ShakeMap footprints. We generated a total of 2.617 ShakeMaps, using the United States Geological Survey (USGS) software (Worden et al., 2018), corresponding to earthquakes in Greece with a minimum potency magnitude of 4.5. Earthquake parameter data were derived from the USGS Comprehensive Catalog (ComCat). The earthquake catalog was homogenized following a standardized approach to ensure consistency (Trugman and Ben-Zion, 2024). We analyzed intensity measures (IMs) including PGA and spectral accelerations at 0.3s and 1.0s, as derived from the ShakeMaps, for events spanning January 1973 to December 2022. Sites where observed IMs exceeded those predicted by the ESHM20 were identified, and fractional exceedance areas were calculated (Allen et al., 2023; Cito et al., 2024; Pothon et al., 2020) to compare these exceedances against the probability targets for return periods of 475 and 50 years across four aggregation levels (mean, 16th, 50th, and 84th quantiles). Overall, ESHM20 showed a good correlation with ShakeMap-derived observations with the mean and 50th quantile values closer to the predicted targets. It is critical to note that exceedance at a site does not inherently indicate severe ground shaking. As anticipated, exceedance sites were predominantly located near the epicenters of significant seismic events. Our findings highlight regions where observed ground motions significantly exceeded model predictions and provide insights into the strengths and limitations of ESHM20 in Greece.

Method

Catalogue compilation of 43,196 Earthquakes occurred in Greece and the surrounding area (100-km radius) **from January 1973 to December 2022** (50 years), USGS ComCat.

Magnitude homogenization to Potency Magnitude, Mp derived from seismic potency, P_O (Trugman & Ben-Zion, 2024)

ShakeMap calculation using the USGS v4 software (Worden et al., 2018) for all earthquakes with potency magnitude Mp 4.5 and greater (**2,617 ShakeMaps**; Fig. 1) applying three different combinations of GMPEs for three different tectonic environments: active crustal, subduction interface, and subduction slab.

Retrieval of the maximum Intensity Measure (*IM*) ever observed at each spatial grid cell over the observational timeframe across a rectangular 0.01°x0.01° base grid, which corresponds to 1 km^2 resolution (Fig. 2a). Adjustment of the observed max *IMs* to rock site conditions using the European Seismic Risk Model (ESRM20) amplification factors (Fig. 2b).

Comparison of ShakeMap obtained *IMs* to expected-by-ESHM20 IMs, and calculation of the corresponding fractional exceedance area, considering also the uncertainty in ground shaking estimation from the ShakeMaps for the chosen observation period. **Both ShakeMaps and ESHM20 are valid to RotD50**.

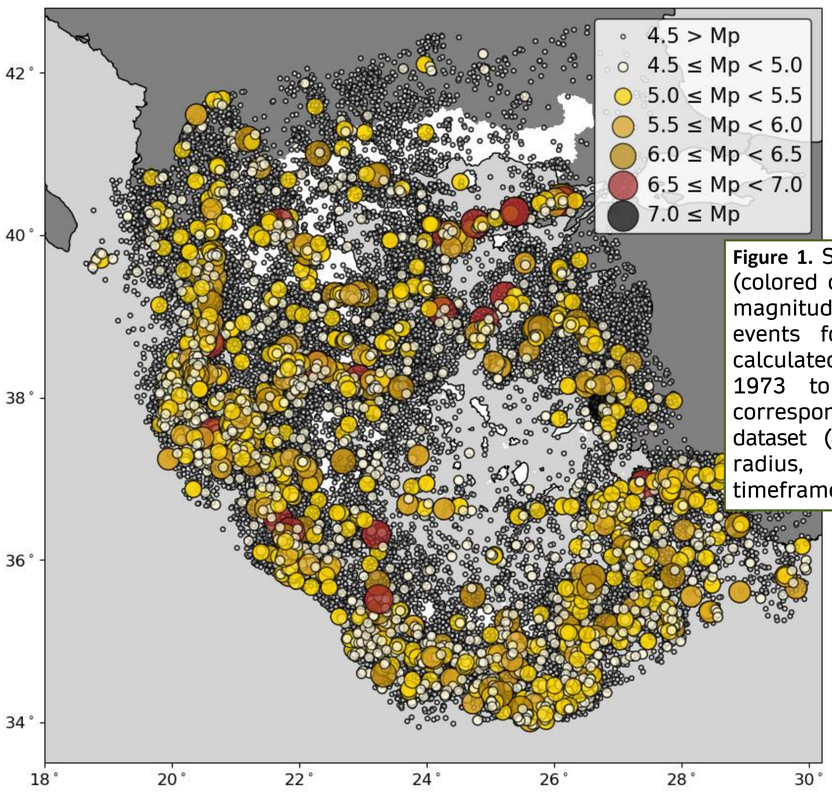

Figure 1. Spatial distribution of the epicenters (colored circles, scaled according to potency magnitude, Mp) of the final dataset of 2,617 events for which ShakeMaps are herein calculated, over a 50-year period (January 1973 to December 2022). Gray circles correspond to the epicenters of the initial dataset (43,169 events) across a 100-km radius, for the same observational timeframe.

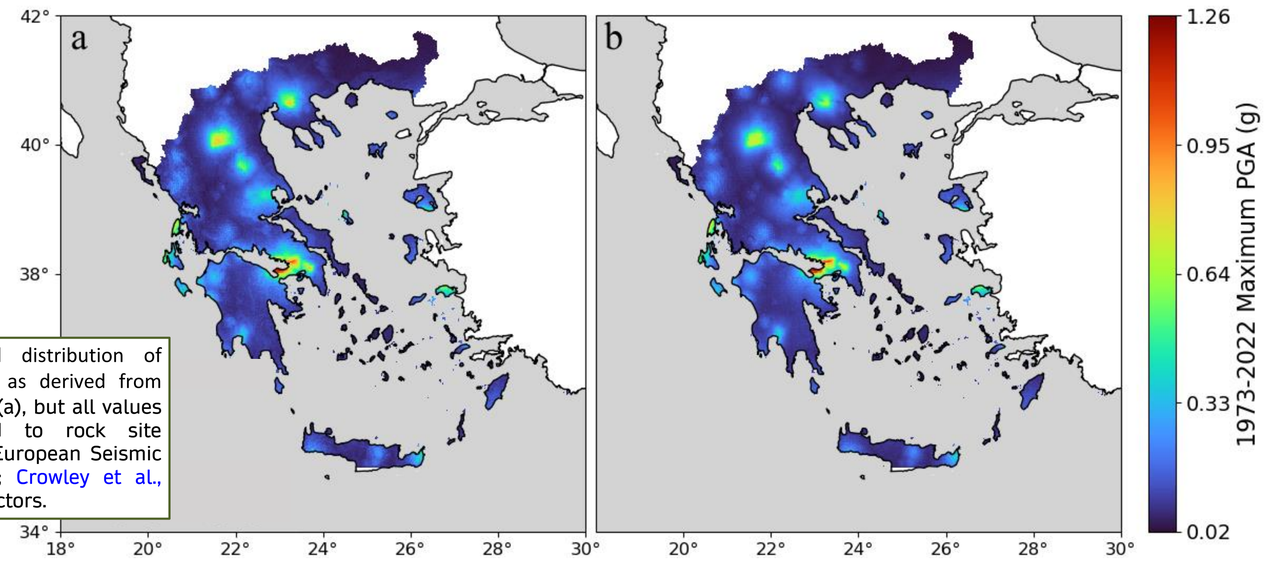

Figure 2. (a) Spatial distribution of maximum PGA values as derived from ShakeMaps; (b) as in (a), but all values have been adjusted to rock site conditions using the European Seismic Risk Model (ESRM20; Crowley et al., 2021] amplification factors.

Results

- Fractional Exceedance area (exceeded sites / total sites)[**Figure 3**].
- Overlapping Coefficient (OVL) for quantitative comparison. Values equals to 1 correspond to a perfect fit [**Figure 4**].

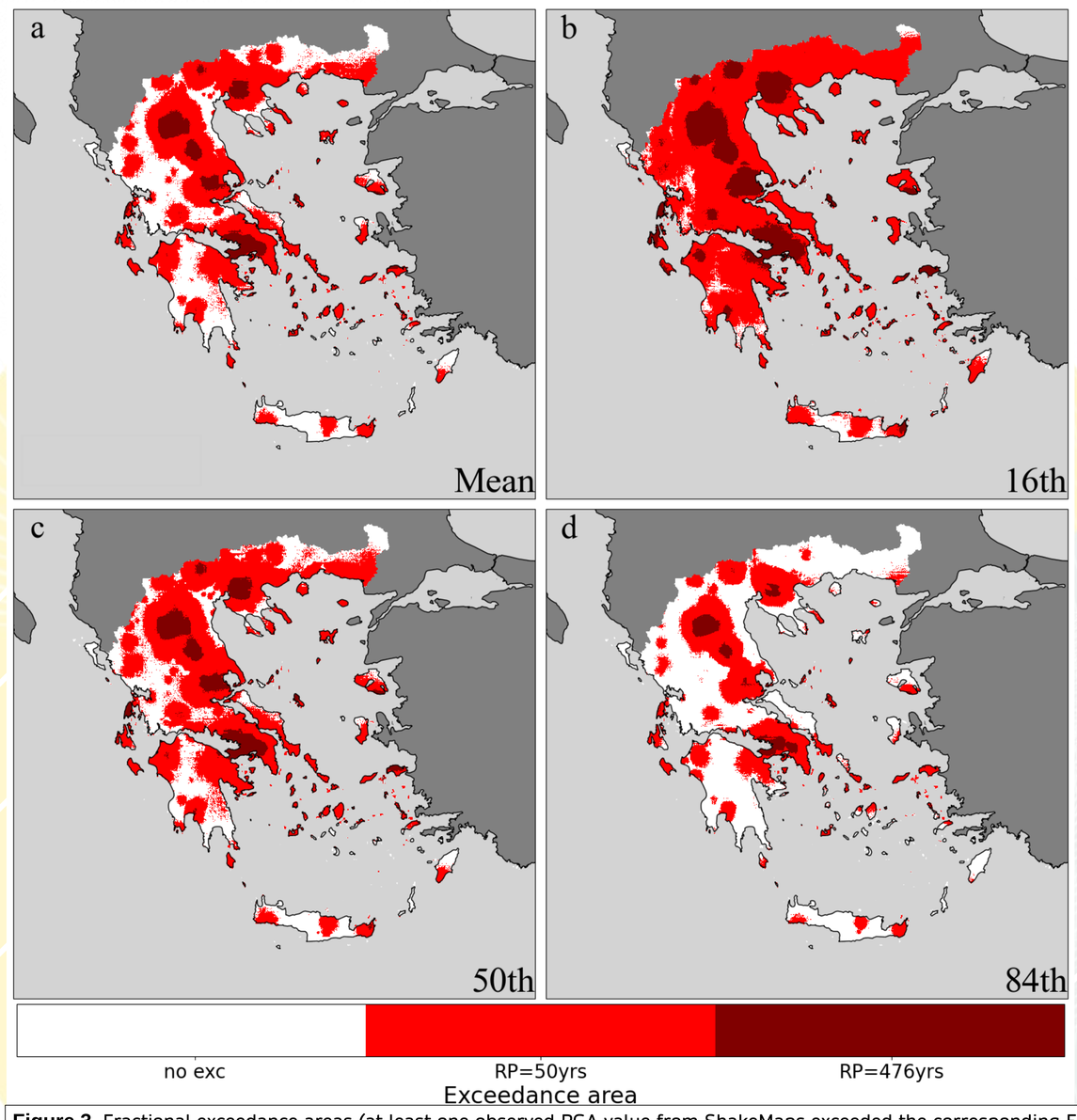

Figure 3. Fractional exceedance areas (at least one observed PGA value from ShakeMaps exceeded the corresponding ESHM20 hazard thresholds), for earthquakes of minimum potency magnitude 4.5 for a 50yrs timeframe (1973—2022) across the study region. The colors (white/red/maroon) correspond to the return period (RP) for which the exceedance area is estimated. Red for RP=50 years (i.e., 63.2% probability of exceedance in 50 yrs), maroon for RP=475 years (i.e., 10% probability of exceedance in 50 yrs), white denotes no exceedance. Panels compare the observed PGA exceedances against the different percentiles of the ESHM20 hazard thresholds: (a) mean, (b) 16th percentile, (c) 50th percentile (median), and (d) 84th percentile.

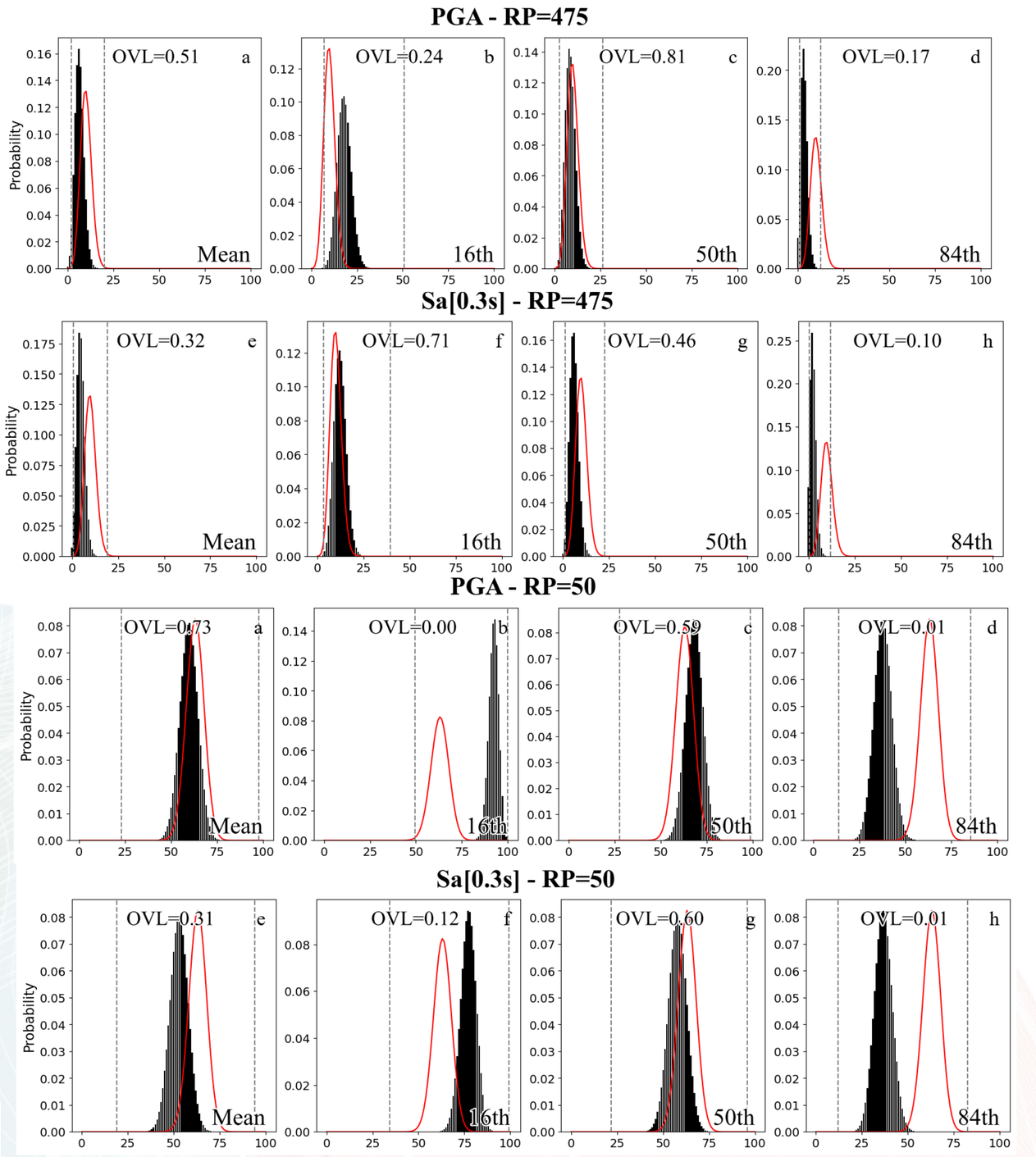

Figure 4. Binomial distribution of empirical exceedance area for IMs (black bars) and theoretical exceedance area (red line). The effect of ShakeMap uncertainty is given for ± one standard deviation (grey dashed line). Each row corresponds to a specific IM (PGA and Sa[0.3s]) and each column to a specific aggregation Level (mean, 16th, 50th, and 84th quantiles).

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