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Spatial Distribution Model of Earthquake Strong-motion Peak Ground Acceleration on ICEARRAY using Bayesian Hierarchical Model

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Iceland, the largest subaerial part of the Mid-Atlantic Ridge, is the most seismically region in northern Europe. The South Iceland Fracture Zone (SIFZ) located in the populated and cultivated farmlands in the south is one of two major fracture zones in the country where earthquake hazard is the highest and the exposure of the population to destructive near-fault earthquake strong-motion is the greatest. For the earthquake resistant design of structures in Iceland residential buildings are assumed to have relatively uniform form-factors (mostly 1-story houses or low-rise apartment buildings), consist of similar materials (mostly reinforced concrete), and constructed on rock (young lava or ancient bedrock), for which site effects are typically assumed to be negligible. However, recent strong-motion data recorded during the M_w6.3 Ölfus earthquake by twelve strong-motion stations of a new small-aperture strong-motion array, the ICEARRAY I in the town of Hveragerði in the SIFZ (*Halldorsson & Sigbjörnsson, 2009*), provides the first ever opportunity in Iceland to quantify the spatial distribution of ground motion amplitudes and their frequency variation on lava rock. This case is of particular interest since geological strata of Iceland is generally described as a recurring piles of basaltic lavas often with intermediate layers of sediments which leads to strong velocity reversals with depth. This is the case in Hveragerði and large parts of the SIFZ where in addition the topography is roughly flat but covered by lava flows. The data shows 100% difference in Peak Ground Acceleration (PGA) values over the small array during the main shock. Moreover, similar differences are observed in data from more than 1700 aftershocks recorded over nearly one year after the main shock. The aftershocks dataset is characterized by strong-motion with geometric mean of the horizontal PGA in the range of

3.5~38% of the acceleration of gravity (g) from earthquakes of local magnitudes of 0.42~4.75 and epicentral distances 1.6~15 km that occurred between May 2008 and May 2009.

In this study, we propose a spatial distribution model using Bayesian Hierarchical Model (BHM) in order to model the variation of the strong-motion amplitude as well as uncertainties across the ICEARRAY I. The BHM offers a flexible probabilistic framework for spatial modeling of physical phenomena and quantifying uncertainty of the latent physical process. The key question that the Bayesian framework addresses is how to statistically update data and make inferences in the light of observations and presents a systematic modeling methodology to capture the latent dependence structure of the observations (*Banerjee, Carlin, & Gelfand, 2014*). In our proposed model, the BHM involving several parameters which are related or dependent in a systematic manner. The dynamic model consists of event effects (γ_t as a function of moment magnitude, source to site distance, source location, etc.) and site effects (α_j) which imposed on all of the parameters of the data density, to model the spatial variation of the underlying process, event-site effects (ϵ_{jt}), and error measurements (u_{jt}) as Eq. (1).

$$\log_{10} PGA_{jt} = \log_{10} \gamma_t + \alpha_j + \epsilon_{jt} + u_{jt} \qquad j = 1, \dots, J \; and \; t = 1, \dots, T. \qquad \text{Eq. (1)}$$

The total uncertainty obtained by hyperparameters inference from our analysis (see Figure 1), indicates a higher standard deviation ($\sigma_{\log_{10} PGA} = \sqrt{\sigma_u^2 + \sigma_v^2 + \sigma_\epsilon^2 + \sigma_\alpha^2} = 0.27$) in comparison to the local GMPEs' standard deviation ($\sigma_{GMPEs} \approx 0.20 - 0.22$). This highlights the importance of detailed studies in micro scale for seismic zone for dense urban areas in seismic zones, especially if local geology is complicated and/or varies considerably across relatively short distances.

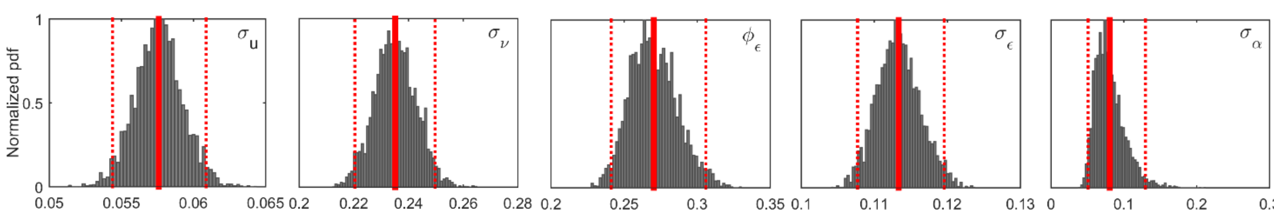

Figure 1. Histograms of the inferred hyperparameters using MCMC approach, the solid red line indicates the maximum likelihood estimates, while the red dashed line indicate the 2.5-97.5% credibility interval.

In particular, the local site conditions and geological setting is found to account for the strong spatial variation of ground motion peak parameters. As can be seen in Figure 2, the obtained inference of the site effects and mapping the spatial distribution of event term show a very good compatibility with the observed strong-motion amplitude. This way new maps showing the spatial variation of PGA have been produced for the town of Hveragerði.

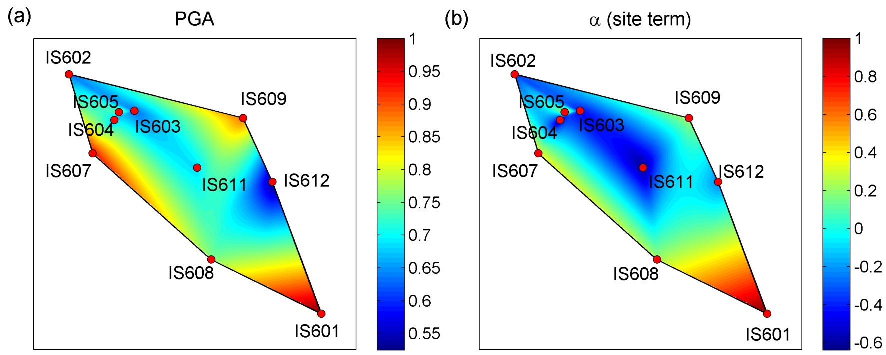

Figure 2. Spatial distribution of (a) PGA, (b) posterior mean of site term across ICEARRAY I stations.

The results may have direct practical implications and importance for improved microzonation of earthquake hazard for the town which now can be accounted for. Furthermore, a new hazard estimate will enable a more optimal earthquake resistant design of structures as well as urban planning. The proposed model will add to the understanding of the source parameters as well as provide quantitative information about site and geological effects. Finally, the results are expected to apply in other urban areas in Iceland with similar geology.

References

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