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# On the Sensitivity of Earthquake Hazard in North Iceland Using a New Set of Ground Motion Models

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## ABSTRACT

In this study, we address several GMMs that have been proposed in the literature for the application of earthquake hazard assessment in Iceland. We show that they are dramatically inconsistent with the existing strong-motion data which brings their suitability for application in hazard analyses in Iceland in question. However, their different functional forms may have useful applications, and therefore we recalibrate the models to the Icelandic dataset. A Bayesian random effects model that uses a Markov Chain Monte Carlo algorithm for inference is presented to account for uneven sampling of the different earthquakes and correlations of the recorded ground-motion from a single event by partitioning the aleatory variability into inter-event and intra-event components. The results reveal that the recalibrated models seem to fit the recorded data very well in the magnitude and distance range where data is available. The residual behaviour shows that the recalibrated GMMs are unbiased and thus explicitly account for the prevailing uncertainties in a satisfactory manner. As a result, our confidence in the application of the recalibrated GMMs in Iceland is greatly improved. We revisit therefore the probabilistic seismic hazard assessment (PSHA) and explore it in terms of its sensitivity to the selected GMMs for North Iceland where due to large uncertainties in the earthquake catalogue the hazard needs to be updated. The results indicate that the recalibrated models are promising candidates to be applied for future hazard studies in Iceland, but more importantly they show how to what extent and how the epistemic uncertainty of the GMMs contribute to patches of heightened hazard uncertainties, especially at near- and far-fault distances where there is a particular lack of data.

## RECORDED EARTHQUAKES IN ICELAND

Earthquake strong-motion acceleration time histories recorded on the Icelandic Strong-Motion Network and ICEARRAY I, a small-aperture strong-motion array, of the Earthquake Engineering Research Centre of the University of Iceland. The parametric properties of the dataset are shown in Figure 1. The recording stations were classified into rock and stiff soil, respectively. In total, 83 records were used for the analysis from the 62 and 21 stations for rock and stiff soil site classes, respectively.

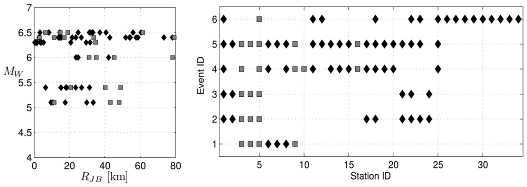

Figure 1. left: Magnitude-distance distribution; Right: Distribution of records indicating which station has accepted data for a given event (rock sites are in black diamonds and soil sites are in grey squares.

## SELECTED GMMs

In the SHARE project four GMMs were proposed to apply and were used in the PSHA for Iceland. We additionally select several other GMMs for other regions that have desireable functional forms. All the GMMs satisfy the minimum requirements proposed by Cotton et al. (2006) and Bommer et al. (2010) for recalibration to the Icelandic earthquakes. Table 1 shows the functional form, magnitude and distance ranges, used period, site classification and region of origin of the selected GMMs.

Table 1. Description of the selected Ground-motion models.

| GMM | Functional Form | Mw Range | R Range | Period (s) | Site class | Main Region(s) |
|---|---|---|---|---|---|---|
| RS09 (Rupakhety and Sigbjörnsson, 2009) | $\log_{10}(PGA) = C_1 + C_2 M_w + C_3 \log_{10}\sqrt{(C_4^2 + R^2)} + C_5 S + \sigma$ | 5.0-7.7 | 1-97 | PGA, 0.04-2.5 | 2 | Iceland, Greece, Turkey |
| Am05 (Ambraseys et al., 2005) | $\log_{10}(PGA) = C_1 + C_2 M_w + (C_3 + C_4 M_w).\log_{10}\sqrt{(C_5^2 + R^2)} + C_6 S + \sigma$ | 5.0-7.6 | 0-100 | PGA, 0.05-2.5 | 3 | Europe and Middle East |
| AB10 (Akkar and Bommer, 2010) | $\log_{10}(PGA) = C_1 + C_2 M_w + C_3 M_w^2 + (C_4 + C_5 M_w)\log_{10}\sqrt{(C_6^2 + R^2)} + C_7 S + \sigma$ | 5.0-7.6 | 0-100 | PGA, 0.05-3.0 | 3 | Europe and Middle East |
| DT07 (Danciu and Tselentis, 2007) | $\log_{10}(PGA) = C_1 + C_2 M_w + C_3 \log_{10}\sqrt{(C_4^2 + R^2)} + C_5 S + C_6 F + \sigma$ | 4.5-6.9 | 0-136 | PGA, 0.1-4.0 | 3 | Greece |
| Zh06 (Zhao et al., 2006) | $\ln(PGA) = C_1 M_w + C_2 R - \ln(R + C_3 e^{C_4 M_w}) + C_5(\min(\max(H,15),125) - 15) + C_6 S_I + C_7 S_{II} + \sigma$ | 5.0-8.3 | 0-300 | PGA, 0.05-5.0 | 5 | Japan |
| LL08 (Lin and Lee, 2008) | $\ln(PGA) = C_1 + C_2 M_w + C_3 \ln(R + C_4 e^{C_5 M_w}) + C_6 H + \sigma$ | 4.1-8.1 | 15-630 | PGA, 0.01-5.0 | 2 | Northern Taiwan |

## RESIDUALS

Figure 2 shows the residual plots (in log-10 units) versus distance and magnitude for the original and recalibrated Am05 model. For the sake of space only the residuals for model Am05 are shown but their behavior is quite representative of the overall residual behavior of the other models considered in this study.

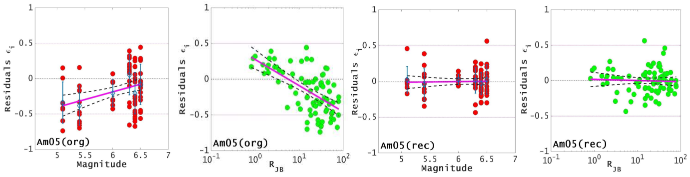

Figure 2. The residual plots (in log-10 units) of magnitude (in red) and distance (in green) for the original (left) and recalibrated (right) Am05 model. The solid line is the least-squares linear regression line and the dashed lines are the 95% confidence limits.

## GROUND-MOTION VARIABILITY

The model-to-model variability in the median predictions is obtained for estimating the minimum epistemic uncertainty (Al Atik and Youngs, 2014). The variability among the median ground-motion estimates of the original and recalibrated models for different magnitudes at two site classes is compared and shown in Fig 3. The thick line and the gray shaded area represent the mean and the standard deviation, respectively. The red solid line shows the epistemic uncertainty proposed by Atkinson and Adams (2013).

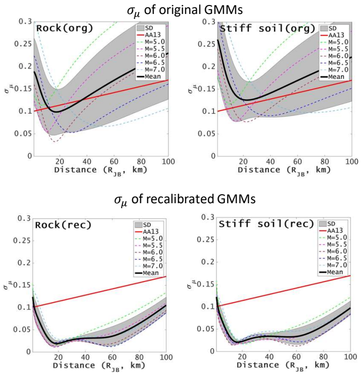

Figure 3. Variability among the median ground motion estimates of the original (top) and the recalibrated (bottom) GMMs for two site classes.

## HAZARD MAPS USING A MONTE CARLO PSHA

A Monte Carlo basis approach is used to provide probabilistic seismic hazard maps for North Iceland. The seismic source zones and associated seismicity parameters proposed in the simplified source model of Sigbjörnsson and Snaebjornsson (2007) are used to illustrate the hazard variability. To show how the GMM variability manifests as uncertainy of the earthquake hazard, the standard deviation and coefficient of variation of PGA for two hazard levels based on the original and recalibrated GMMs have been calculated over a dense grid over North Iceland.

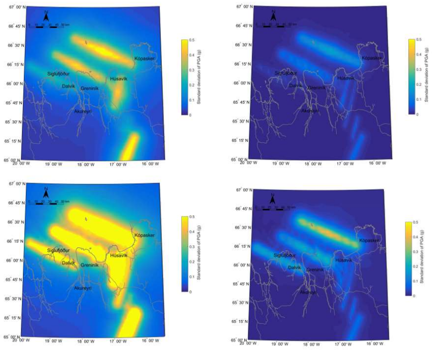

Figure 4. Maps of standard deviation of the earthquake hazard in North Iceland calculated for PGA corresponding to 10% PE of in 50 years (top row) and 2% PE in 50 years (bottom row). The figures at left show the standard deviation of hazard when using the original recalibrated (right) GMMs.

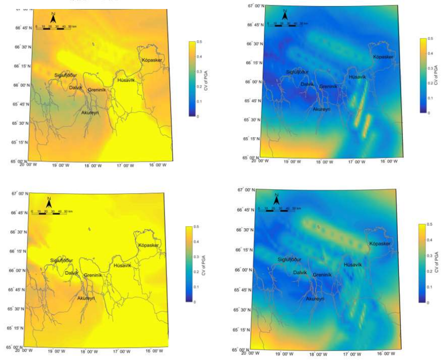

Figure 5. Maps of the coefficient of variance for earthquake hazard in terms of PGA with a 10% in 50 years (top row) and 2% in 50 years (bottom row) in North Iceland. The figures at left and right show the CV based on the original and recalibrated GMMs, respectively.

## CONCLUSIONS

- Many of the GMMs in previous PSHA studies for Iceland may not necessarily be appropriate. Therefore, the GMMs have been recalibrated to Icelandic strong-motion data.
- The residuals versus magnitude and distance have been centered on zero throughout the range of fitted values which indicate the recalibrated GMMs are unbiased over the magnitude and distance range of the data.
- The the spatial variation of hazard uncertainty and coefficient of variance shows how the epistemic uncertainty of the GMMs is translated into the hazard, espicially at near- and far-fault regions where data is sparse.
- The case-study for North Iceland shows how, and to what extent, important assumptions of the selected GMMs affect the hazard levels and its uncertainty, and directly also affects our level of confidence in the final result.
- The findings have direct implications on the reassessment of the earthquake hazard in Iceland which is the basis of earthquake resistant design in the country.

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