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INFLUENCE OF EARTHQUAKE MAGNITUDE ON HAZARD RELATED TO INDUCED SEISMICITY

Benjamin EDWARDS[1], John DOUGLAS[2] and Stefan WIEMER[3]

Ground shaking from seismicity associated with stimulation and exploitation of geothermal reservoirs increases risk exposure to the local population. For instance, a project in Basel, Switzerland, triggered an ML3.4 mainshock and thousands of aftershocks (Deichmann and Giardini, 2009), leading to insurance claims of more than $9M (Giardini, 2009). A necessary component of any study that seeks to assess this seismic hazard is a ground-motion model that estimates measures of shaking given earthquake scenarios. Because of the considerable epistemic uncertainty in this, particularly in the near-field, Douglas et al. (2013) presented ground-motion prediction equations (GMPEs) using 36 simulation models based on various M_w, stress-drop, local (κ) and regional (Q) attenuation.

The first problem to address in the prediction of ground motion for induced seismicity is the significant variability of reported earthquake magnitude from agency to agency (Fäh *et al.*, 2011). Edwards and Douglas (in press) homogeneously computed earthquake moment- and local-magnitude for events related to Enhanced Geothermal Systems (EGSs) in Basel (Switzerland), Soultz (France) and Cooper Basin (Australia); natural geothermal fields in Geysers (California) and Hengill (Iceland), and a gas-field in Roswinkel (Netherlands). As shown in previous studies, published catalogue (M_L) magnitudes were shown to differ widely with respect to M_w, with up to a unit of magnitude difference in the scaling relations. Using simple conversions from the catalogue magnitudes (e.g., M_L) to M_w for use in GMPEs would subsequently lead to significant bias. On the other hand, Edwards and Douglas (in press) showed that given a common magnitude definition (and corresponding attenuation corrections), the scaling between moment- and local-magnitude of small earthquakes follows a second-order polynomial (Figure 1), consistent with previous studies of natural seismicity (Goertz-Allmann *et al.*, 2011, Grünthal *et al.*, 2009). Using both the Southern-California M_L scale and M_{equiv} (Bommer *et al.*, 2006) it was found that the analysed datasets fall into two subsets offset by 0.5 magnitude units with well-defined relation to M_w (Figure 1a, 1b). M_{equiv} was shown to correlate 1:1 with M_L, albeit with region-specific offsets.

Even when we have a homogenous magnitude scale, analysis by Douglas et al. (2013) highlighted considerable variation in source and path parameters (e.g., stress-drops, local attenuation) among regions and sites. Therefore, when conducting seismic hazard assessment for a given geothermal project it is not known a priori which GMPEs are most applicable. In Edwards and Douglas (2013) it was shown that as seismograms are recorded at a site, the applicability of particular models becomes quickly evident. Cooper Basin (Australia) was taken as a case study, where a hot-fractured-rock project was established in 2002. To select suitable models two methods were applied. In a first approach, seismograms recorded on the local monitoring network were spectrally analysed to determine characteristic stress and attenuation parameters. In a second approach, residual analysis using the log-likelihood method was used to directly compare recorded and predicted short-period response spectral accelerations.

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[1] Dr., Swiss Seismological Service, Zürich, edwards@sed.ethz.ch
[2] Dr., BRGM, Orléans, j.douglas@brgm.fr
[3] Prof. Dr., Swiss Seismological Service, Zürich, wiemer@sed.ethz.ch

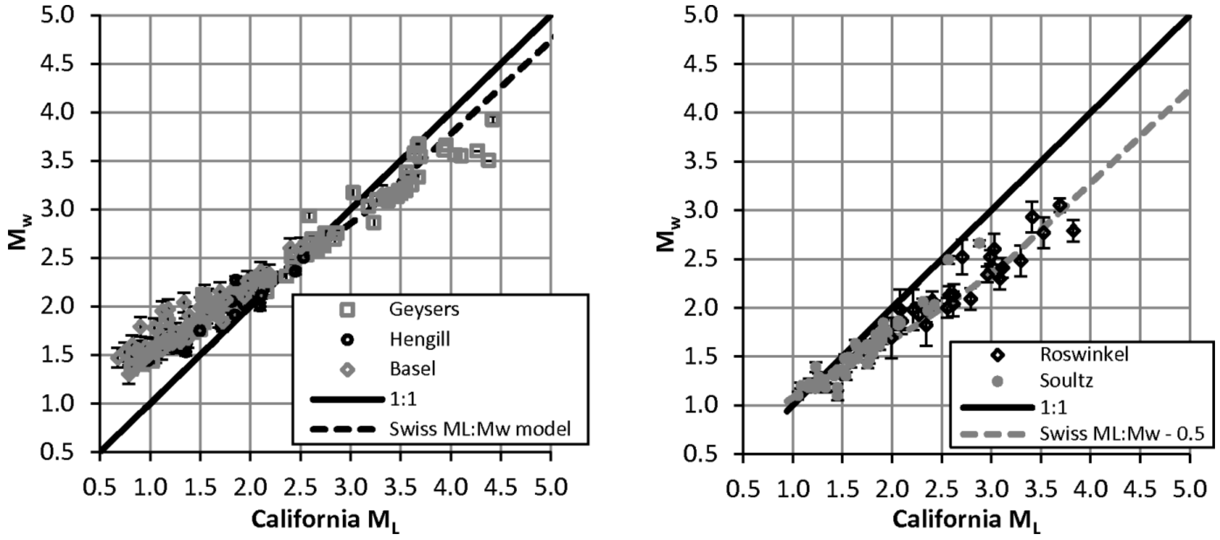
(a)

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Figure 1. Comparison of common ML scale versus inverted Mw for all datasets in the study. (a) Geysers, Hengill and Basel events, along with the Swiss ML:Mw model of (Goertz-Allmann *et al.*, 2011). (b) Roswinkel and Soultz events plotted along with the Swiss M_L:M_w model offset by 0.5 units.

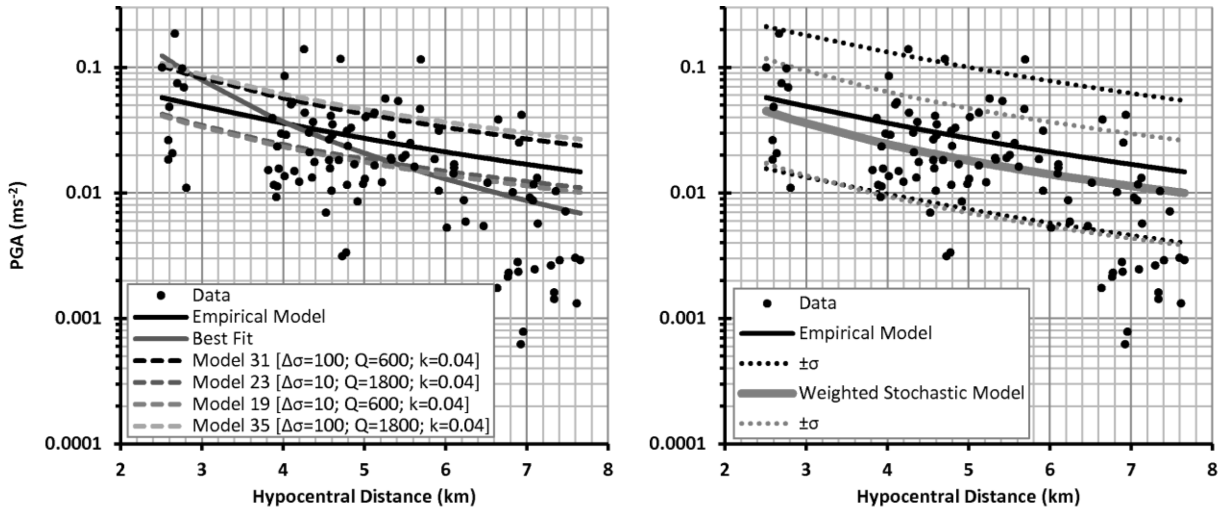
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Figure 2. (a) PGA data for Cooper basin for events with 2.5<M<3.1 and the selected predictions (stochastic and empirical) from Douglas et al. (2013) for M2.8 along with the best fit of the data. (b) The empirical model of Douglas et al. (2013) along with the weighted median stochastic model (from LLH testing) including their variabilities.

Region-specific estimates of variability were then computed, with significantly lower values observed compared to previous studies of small earthquakes. This was consistent with the limited range of stress drops and attenuation observed from spectral analysis. The reduced uncertainty observed in the data allowed the weighted simulation models to reflect this in the final prediction (Figure 2).

Finally we note the impact on the Gutenberg-Richter (G-R) b-value from using different magnitude scales. Using various simulation models (e.g., Edwards *et al.*, 2010) it is apparent that the b-value obtained using M_L is different from that obtained using M_w for the same dataset. The exact difference is driven by the source properties (e.g., stress-drop), the attenuation, and the interaction of the earthquake spectrum and the Wood-Anderson Seismometer used to compute M_L. The range over which the G-R relation is calculated also has a significant impact on the differences. From this analysis it is clearly important for consistent and transparent magnitude determination at various stages of seismic hazard analysis.

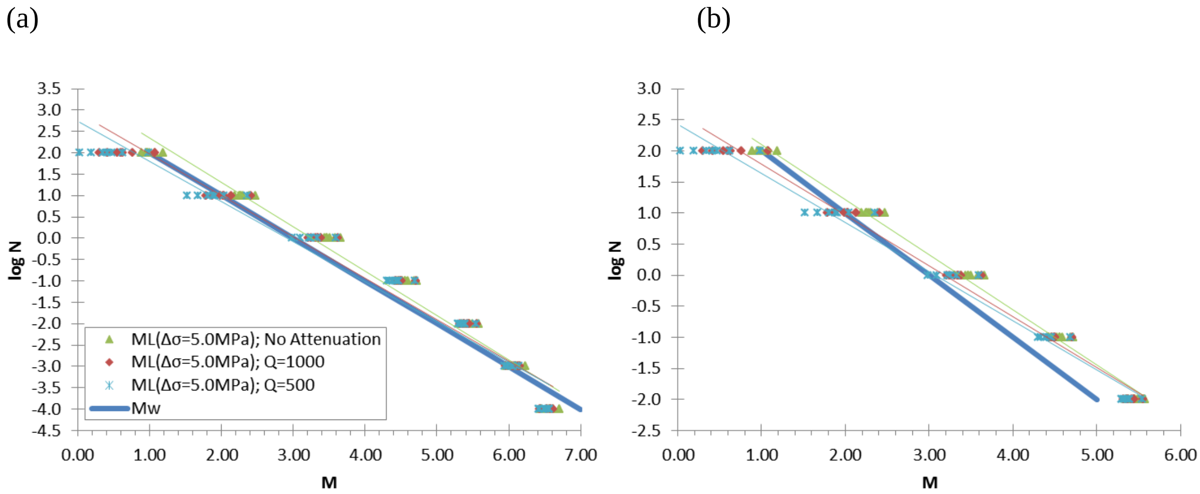

Figure 3. G-R relation using M_w and M_L for synthetic catalogues using $\Delta\sigma$=5MPa and different attenuation. (a) For all events; (b) for events with $\mathbf{M} \leq 5$.

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