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Estimates of Local Stress Drop for Strong Earthquakes in the South Iceland Seismic Zone

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Lacking sufficient earthquake strong-motion data for a specific region, the corresponding seismological models are typically calibrated to earthquake data collected from regions of similar tectonic characteristics. If the physical parameters of the seismological model can be obtained, reasonable strong motion simulations can be carried out and their use justified in the given region even when not directly supported by local data, as the underlying process is being simulated instead of extrapolating a narrowly defined set of frequency and distance dependent ground motion prediction equations (GMPEs). While we do not possess perfect knowledge about the physical processes, we can attempt to use our data to infer the parameters of simplified but appropriate source, path and site models with the corresponding uncertainties in order to predict strong ground motion in comparable areas. In the case of the Húsavík-Flatey fault (HFF) in the Tjörnes Fracture Zone (TFZ) of North Iceland for which strong-motion data from even moderate earthquakes is essentially nonexistent, we propose using a seismological model calibrated to data from several strong earthquakes in the South Iceland Seismic Zone (SISZ).

A stochastic model can yield both strong motion waveforms and also mean estimates of peak values such as peak ground acceleration and response spectral acceleration (SA). It is based on random noise with an envelope function applied in the time domain and then modulated in the frequency domain by a source model Fourier amplitude spectrum. Typically, point sources are assumed and only incoherent high-frequency energy (> 1 Hz) can be simulated. We have chosen the Specific Barrier Model (SBM) by *Papageorgiou and Aki* (1983) to represent the earthquake source model, as it a simple model which yet provides a near complete, efficient and self-consistent description of the faulting processes that are responsible for the generation of high-frequency waves. A key source parameter of the SBM is the local stress drop which drives the slip on the fault. The seismological model is that used by *Halldórsson et al.* (2007), which mainly follows the approach of *Boore* (1983, 2003) while using the SBM as source model. The path model contains a two-segment geometric spreading function and frequency dependent anelastic attenuation. The site model is based on independent high-frequency decay measurements using the Kappa parameter by *Anderson and Hough* (1984) and two different soil amplification functions for rock and stiff soil based on the quite limited site information available. Optimal values for global and local stress drop as well as attenuation parameters have been found through regression by *Halldórsson et al.* (2007), but a limitation of their approach is that all uncertainties of model parameters were not further quantified. This current study investigates the possible variability of the local stress drop parameter and a number of other seismological parameters by simulating the spectral acceleration response amplitudes of a lightly damped single-degree-of-freedom oscillator in a Bayesian inference through the Markov chain Monte Carlo (MCMC) method. The predictions of the seismological model are compared to data in the context of the random effects model which separates the model error into an intra-event random effect and an inter-event error term, respectively. The marginal probability distributions for the model and covariance parameters are inferred based on the strong ground motion recordings of seven earthquakes from the SISZ with 79 station records in total.

The results as shown in *Figure 1* indicate the posterior distributions of eight model parameters and are given numerically in *Table 1*. These value ranges are mostly well-constrained, except for the depth parameter *h*, which tends towards zero. There may be different reasons for that, for example the fact that depth is mostly constrained by near-fault measurements and as we are using a point source originated far-field representation the near-fault region is not accurately described. In this model configuration, the Kappa parameter has been fixed to 0.035 s, but the result changes again somewhat when fixing the depth to 3 km as estimate of an upper seismogenic depth with significant rupture activity. In that latter case, the maximum likelihood estimates (MLE) for the remaining parameters would be a global stress drop of 25 bar, local stress drop about 97 bar, anelastic attenuation of $Q(f) = 46.8f^{0.88}$ and geometric spreading intermediate distance $R_x = 29$ km. The intra-event covariance term is $\tau = 0.137$ (relating to the decadic logarithm of SA values) while the inter-event error term is $\sigma = 0.224$, which results in a total standard deviation of $\sigma_T = 0.264$ (compared to 0.20-0.22 for the more flexible, but less physically consistent, GMPEs). Parameter trade-off is well known in the stochastic approach, and as expected we observe that some parameters are more correlated to others, for example Q_0 and R_x are positively correlated while γ and Q_0 are negatively correlated. The model fit is measured via bias plots, with the frequency-dependent bias and slope values with respect to distance and magnitude in *Figure 2* show a good model fit for frequencies above 1 Hz up to 24 Hz and the bias is largest for the two lowest frequencies (0.56 to 0.75 Hz), as can be expected from a point-source model. The event-dependent random effect η_j appears to increase with magnitude, which is subject to further modeling and interpretation.

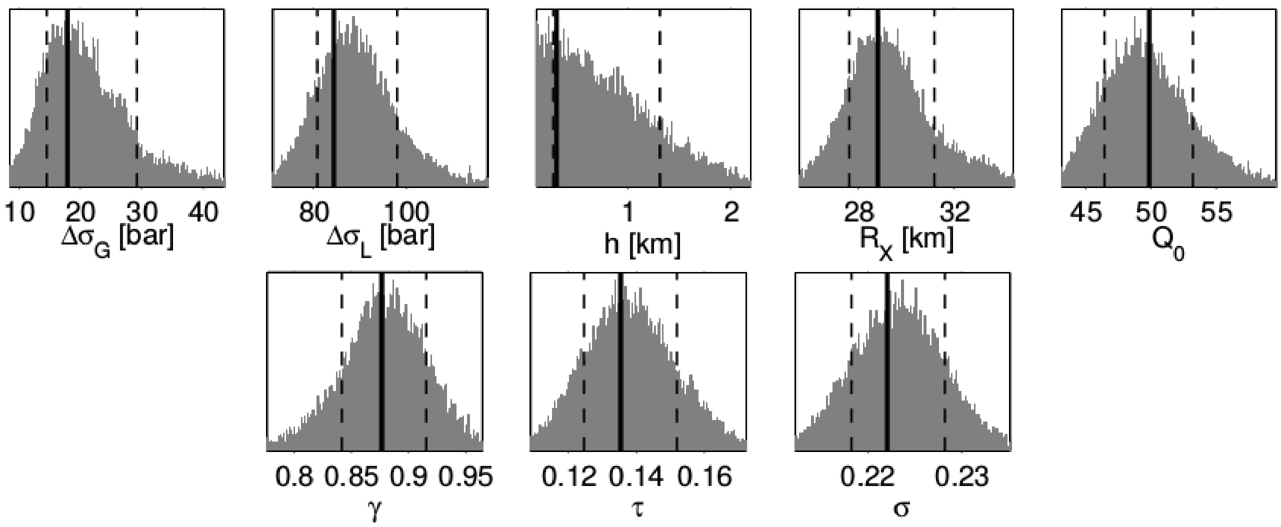

Figure 1. *Histograms representing marginal posterior distributions of the seismological model parameters. The black line indicates the maximum likelihood estimate, while the dashed lines indicate the 16-84% credibility interval.*

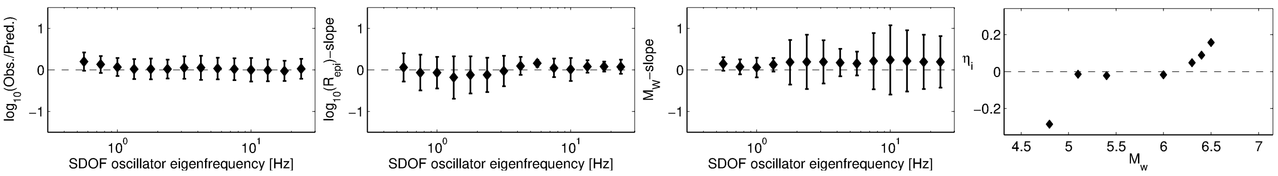

Figure 2. *Model bias when using the maximum likelihood estimate parameter values. Mean and one standard deviation of bias (left), slope of bias with* $\log_{10}(R_{epi})$ *(mid-left) and slope of bias with magnitude (mid-right), all for each oscillator frequency [0.56 to 23.71 Hz]. Right: Inter-event residuals (random effect) versus magnitude.*

Table 1: *Inferred model parameters. Optimal parameter values with 2.5th and 97.5th percentile estimates in subscript and superscript respectively, while * indicates fixed parameters.*

β [km/s]	ρ [g/cm^3]	$\Delta\sigma_G$ [bar]	$\Delta\sigma_L$ [bar]	κ [s]	h [km]	R_x [km]	Q_0	γ	τ	σ
3.20*	2.80*	$17.9_{10.1}^{39.4}$	$84.3_{73.7}^{110.8}$	0.035*	$0.3_{0.1}^{2.0}$	$28.8_{26.1}^{33.7}$	$49.9_{44.0}^{57.7}$	$0.877_{0.796}^{0.950}$	$0.135_{0.113}^{0.167}$	$0.222_{0.214}^{0.233}$

Seismological parameters, inter-event variability of local stress drop $\Delta\sigma_L$ and intra-event variability of simulations all together with their respective uncertainties have been estimated for earthquakes in the SISZ, but the results need to be understood in the context of their parametrization. Different prior assumptions and choices of fixed or free parameters can put these results into perspective. We hope to apply the parameter estimates based on data of the SISZ in the future for stochastic models for the TFZ in the north of Iceland. The low frequencies (< 1 Hz) and the near-fault region remain the target of other models, which need to be explored for Iceland and eentually combined to calibrated hybrid approaches.

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