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Towards a Hybrid Earthquake Strong-motion Simulation Model for South Iceland

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This study is motivated by the need for accurate ground motion estimates by engineers involved in earthquake resistant building design. While several approaches to this already exist in the form of ground motion prediction equations for scalar intensity measures and re-using the waveforms of recorded past earthquakes, these standard procedures are less appropriate for large and complex structures and regions with few recorded data, especially in the near-fault region of past strong earthquakes. For more realistic nonlinear structural dynamic analyses, ground-motion time series are required and only using existing recordings does not account for the many still possible earthquake scenarios. Broadband (0-25 Hz) strong-motion simulation models can serve well for this purpose and we propose a hybrid approach combining a deterministic low-frequency (LF) method with a stochastic high-frequency (HF) model.

The LF simulations are based on a kinematic description of the rupture process. A discrete wavenumber finite-element implementation (*Olson et al.*, 1984; *Spudich and Archuleta*, 1987) which uses a 1D velocity-density model is employed to calculate deterministic waveforms based on a set of source parameters, which are the fault dimensions and geometry, seismic moment, hypocenter location and distributions of final slip, rupture onset time, rise time and acceleration time. A validation using static slip distributions derived from inversions of GPS and InSAR data for several earthquakes has been carried out (see example rupture model in *Figure 1*). We follow *Mai and Beroza* (2002) and *Schmedes et al.* (2010) in generating random rupture models with established correlations between their parameters, but also calibrate these parameters to satisfy the observed records of medium to strong earthquakes in the South Iceland Seismic Zone (SISZ). This is done by minimizing the model bias to observed metrics such as response spectral acceleration in the LF range of three major earthquakes through running suites of randomly generated rupture models with different statistical properties and parameters.

The HF synthetics are generated through a stochastic seismological model following the form suggested by *Boore* (1983) but using the Specific Barrier Model (SBM, *Papageorgiou and Aki*, 1983) as source representation. Its parameters and their marginal distributions have already been inferred through Bayesian methods using strong-motion records of seven SISZ earthquakes (see *Figure 2*). The combination of LF and HF simulations to broadband synthetics needs to be done with care as pointed out and described by *Mai and Beroza* (2003) by matching both frequency domain phase and amplitude spectra within the LF-HF crossover band.

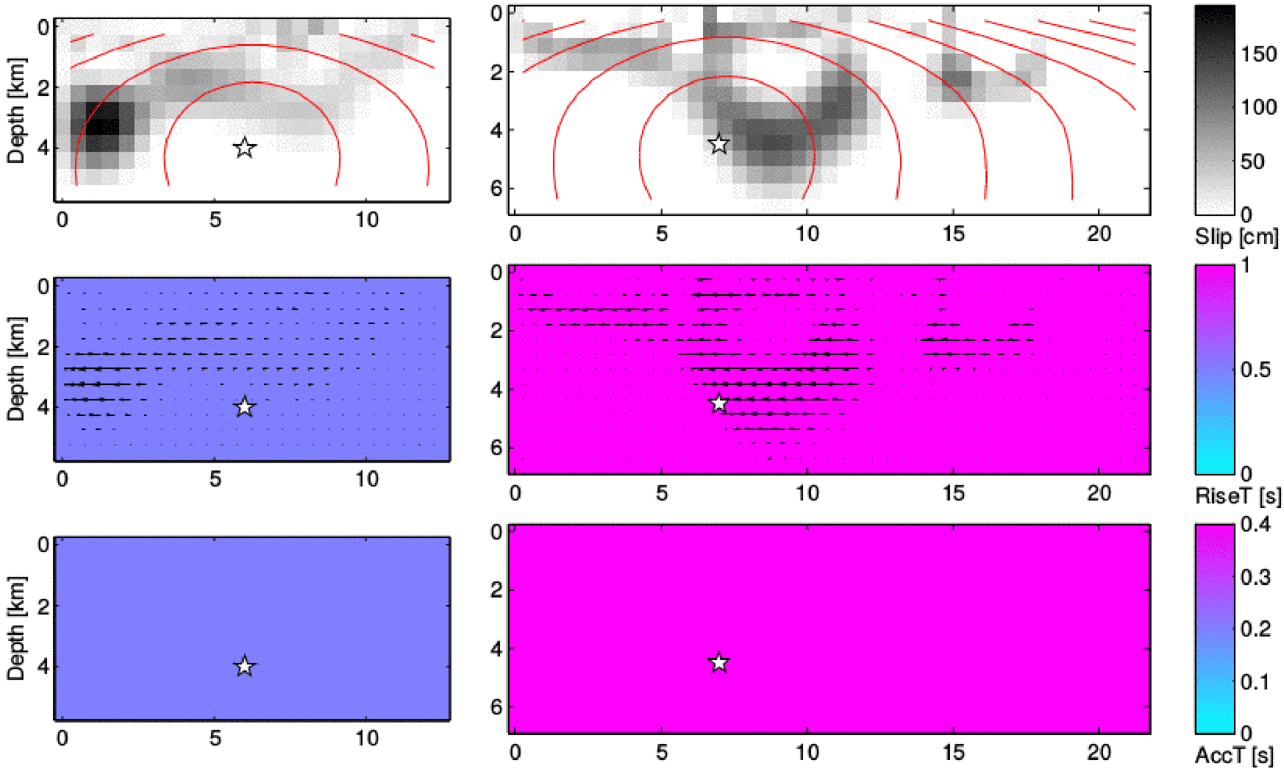

Figure 1. Kinematic rupture model derived from static slip distribution (Decriem et al., 2010) for the 29 May 2008 earthquake doublet between Hveragerði and Selfoss. Top: Slip distribution and contours in 1 sec interval of rupture onset time. The rupture initiation point is indicated by a star symbol on each fault segment. Center: Rise time and arrows indicating the rake at each discrete fault location. Bottom: Acceleration time of the source time function. In this case, no randomization has been applied.

Results from the stochastic model calibration can be used to influence parameter choices of the kinematic model. A point of discussion is the exact implementation of the SBM to match the finite fault description of the deterministic model, which can be done for example with regularly spaced subevents of equal size or varied positions and sizes that could be informed by the slip distribution as well. We note however that such regular distribution of the seismic moment on the fault plane represents an idealization, and more irregular distribution is generally observed. However, the SBM in terms of its variations can still be used to model more complex earthquake sources, without the loss of consistency or physical nature. Further, the kinematic model could be updated to a 3D implementation (finite difference or spectral element), especially if more knowledge about lateral velocity heterogeneity becomes available. This would then better account for path effects and possible basin reflection effects. The 1D implementation is convenient for testing and calibrations, but increasing computing power is available. A more detailed site response definition would be another important contribution to the full broadband model. After these model setups and calibrations have been finished, simulations for a number of scenario cases on known active faults in North Iceland will be carried out and their results will be presented.

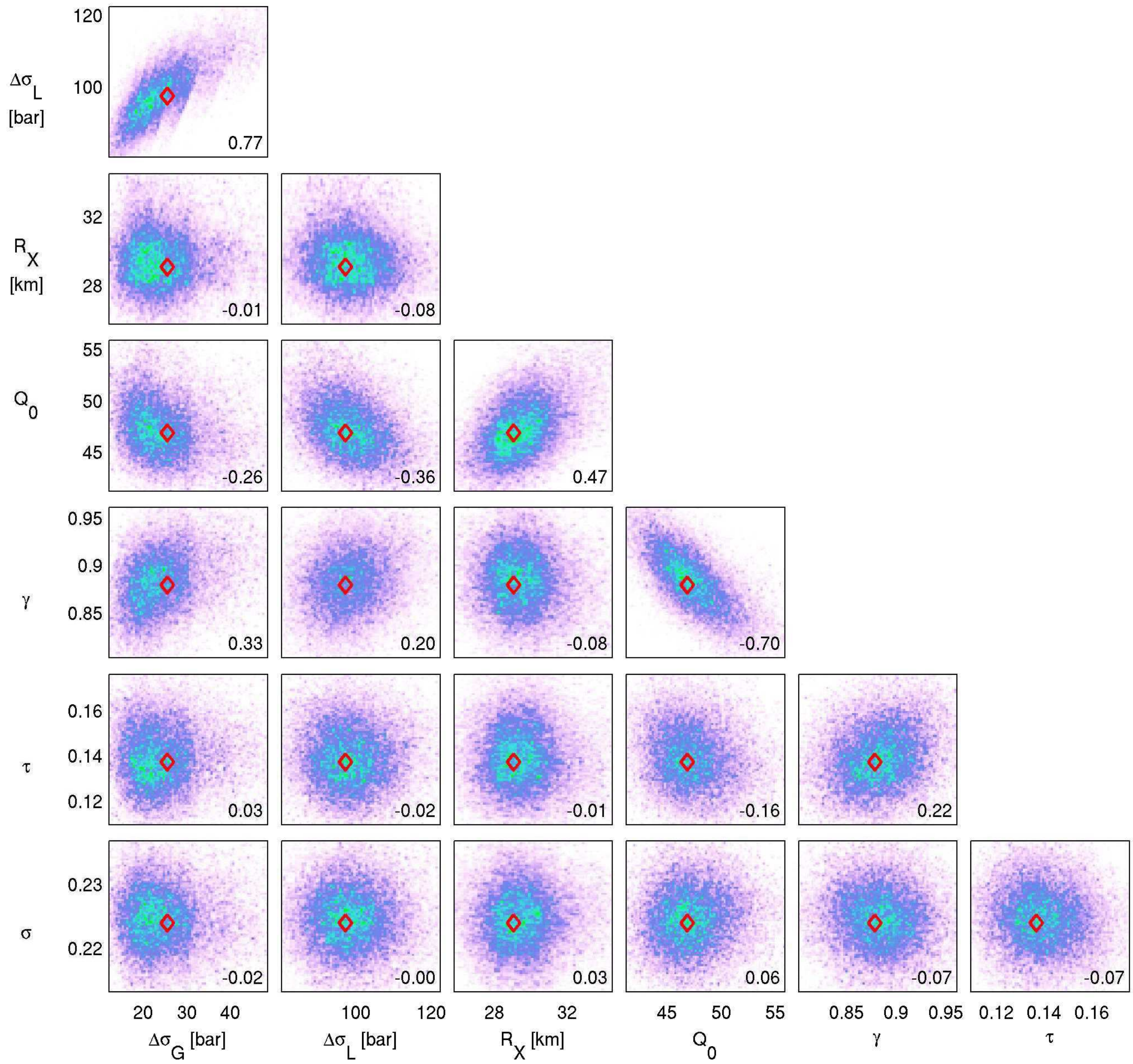

Figure 2. Joint posterior distributions of stochastic model parameters based on earthquake recordings of the SISZ, indicating parameter correlations as Spearman's correlation coefficient in the lower right corner of each plot. The red diamonds represent the maximum likelihood estimate values.

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