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Added-value joint source modelling of seismic and geodetic data

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In tectonically active regions earthquake source studies strongly support the analysis of the current faulting processes as they reveal the location and geometry of active faults, the average slip released or more. For source modelling of shallow, moderate to large earthquakes often a combination of geodetic (GPS, InSAR) and seismic data is used. A truly joint use of these data, however, usually takes place only on a higher modelling level, where some of the first-order characteristics (time, centroid location, fault orientation, moment) have been fixed already. These required basis model parameters have to be given, assumed or inferred in a previous, separate and highly non-linear modelling step using one of the these data sets alone. We present a new earthquake rupture model implementation that realizes a fully combined data integration of surface displacement measurements and seismic data in a non-linear optimization of simple but extended planar ruptures. The model implementation allows for fast forward calculations of full seismograms and surface deformation and therefore enables us to use Monte Carlo global search algorithms. Furthermore, we benefit from the complementary character of seismic and geodetic data, e. g. the high definition of the source location from geodetic data and the sensitivity of the resolution of the seismic data on moment releases at larger depth. These increased constraints from the combined dataset make optimizations efficient, even for larger model parameter spaces and with a very limited amount of a priori assumption on the source.

A vital part of our approach is rigorous data weighting based on the empirically estimated data errors. We construct full data error variance-covariance matrices for geodetic data to account for correlated data noise and also weight the seismic data based on their signal-to-noise ratio. The estimation of the data errors and the fast forward modelling opens the door for Bayesian inferences of the source model parameters. The source model product then features parameter uncertainty estimates and reveals parameter trade-offs that arise from imperfect data coverage and data errors.

We applied our new source modelling approach to the 2010 Haiti earthquake for which a number of apparently different seismic, geodetic and joint source models has been reported already – mostly without any model parameter estimations. We here show that the variability of all these source models seems to arise from inherent model parameter trade-offs and mostly has little statistical significance, e.g. even using a large dataset comprising seismic and geodetic data the confidence interval of the fault dip remains as wide as about 20 degrees.