Geophysical Research Abstracts
Vol. 21, EGU2019-13894, 2019
EGU General Assembly 2019

Common-model framework for the joint optimization of static and dynamic surface displacements in Bayesian source inferences of crustal earthquakes

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In recent years one of the main foci in kinematic earthquake source modelling has been the estimation of model uncertainties. Through method developments of Bayesian inferences and software implementation, moment tensor analyses and highly-resolved heterogeneous slip solutions on finite faults can be well validated these days. It is almost standard to report parameter uncertainties, which prove the robustness of presented source inversions and make model interpretations more easy. Furthermore, data combinations are getting more common that improve the resolution of source parameters, such as geodetic surface displacement data combined with seismic waveforms for the modelling of shallow crustal earthquakes.

Still, some problems remain that need our attention now. (1) Uncertainties in the source geometry that are estimated in non-linear inferences are very often not propagated in the finite-source estimations of distributed slip, even though it has been shown that already small changes in the assumed geometry have significant effects on the slip results. (2) While using the Bayesian theorem allows for the propagation of data and modelling errors, the estimation of these errors is challenging. Particularly modelling errors are hard to quantify. (3) The combination of geodetic data and seismic waveforms is rarely done in the beginning non-linear part of the inferences, despite their very complementary sensitivity to the first-order source parameters. (4) When estimating shallow slip based on InSAR and GNSS data, we often stick to the analytical solutions in homogeneous media. These are often based on strong simplifications and are inconsistent with seismic modelling that are commonly done in layered media. This is far from optimal when data misfits from geodetic and seismic analyses are combined and when models are otherwise compared and interpreted. In our recent work we approach these obstacles and propose new ways.

We present the application of our open-source toolkit for non-linear earthquake source modelling, where we combine near-field InSAR and GNSS surface displacement data with seismic waveforms from the beginning to solve for the first-order rupture parameters of the 2010 Haiti earthquake. The used software module Grond is part of the pyrocko.org project. We use a simple rectangular fault plane with constant slip and rupture velocity. We use a direct search sampling method to simultaneously optimize for the fault location, which includes the fault geometry, rupture dimension, rake and slip magnitude, and the time and origin of nucleation. We use pre-calculated Green's function databases of layered-earth models for data predictions. We include data error variances and covariances in data weighting. We propagate effects of data and modelling errors on the source solution using an innovative and efficient Bayesian bootstrapping implementation.
Our results show that the true data combination of static near-field and dynamic far-field data has a large positive influence on the rupture model resolution. Differences in the published models can be attributed to different model assumptions, e. g. on the medium model. Our optimization approach combined with Bayesian bootstrapping provides an efficient and robust alternative to Markov Chain Monte Carlo sampling methods.