Pyrocko - new open-source software tools for source modelling of earthquakes combining InSAR data and seismic waveforms

Henriette Sudhaus[*1], Sebastian Heimann[2], Andreas Steinberg[1], Marius Isken[1], and Hannes Vasyura-Bathke

[1]Kiel University (CAU) – Otto-Hahn-Platz 1 24118 Kiel, Allemagne
[2]German Reasearch Centre of Geosciences GFZ (GFZ) – Helmholtzstr. 7 14476 Potsdam, Allemagne

Résumé

In the last few years impressive achievements have been made in improving inferences about earthquake sources. Next to an increased data availability also computational resources improve, which greatly benefits more exhaustive data analyses and error propagations.
Furthermore, for earthquake source inferences, more and more regularly InSAR-derived surface displacements and seismological waveforms are combined. This requires finite rupture models instead of point-source approximations and layered medium models instead of homogeneous half-spaces. In other words the disciplinary differences in geodetic and seismological earthquake source modelling shrink towards common source-medium descriptions and a source near-field/far-field data point of view. With the work we present we explore and facilitate the combination of InSAR-derived near-field static surface displacement maps and dynamic far-field seismological waveform data for global earthquake source inferences.

We join in the community efforts with the particular goal to improve crustal earthquake source inferences in generally not well instrumented areas, where often only the global backbone observations of earthquakes are available provided by seismological broadband sensor networks and, since recently, by Sentinel-1 SAR acquisitions. In these general cases automated locations of earthquake hypocenters may be inaccurate and information on location and orientation of the causative faults highly uncertain such that fully non-linear and practically unconstrained source inferences are necessary. We present our work on modelling standards for the combination of static and dynamic surface displacements in the source's near-field and far-field, e.g. on data and prediction error estimations as well as model uncertainty estimation. The data combination is driven by estimations of the data error covariances in space and time. Rectangular dislocations and moment-tensor point sources are exchanged by simple planar finite rupture models. 1d-layered medium models are implemented for both near- and far-field data predictions. Non-linear source optimizations and Bayesian sampling of the model parameter space is carried out to provide quantified source model uncertainties estimations. A highlight of our approach is a weak dependence on earthquake bulletin information: hypocenter locations and source origin times are relatively free source model parameters. The near-field data do well constrain the source location and the higher frequencies of the far-field dynamic waveforms potentially constrain the rupture

---

[*]Intervenant

propagation from a variable nucleation point on the rupture plane.

We present this harmonized source modelling environment based on example earthquake studies. We discuss the benefit of combined-data non-linear modelling on the resolution of first-order rupture parameters, e.g. location, size, orientation, mechanism, moment/slip and rupture propagation.
The presented studies apply our newly developed software tools which build up on the open-source seismological software toolbox pyrocko (www.pyrocko.org) in the form of modules. We aim to facilitate a better exploitation of open global data sets for a wide community studying tectonics, but the tools are applicable also for a large range of regional to local earthquake studies. Our developments therefore ensure a large flexibility in the parametrization of medium models (e.g. 1d to 3d medium models), source models (e.g. explosion sources, full moment tensor sources, heterogeneous slip models, etc) and of the predicted data (e.g. (high-rate) GPS, strong motion, tilt).