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New Developments in Open-source Tools to Combine Geodetic Data and Seismic Waveforms

Henriette Sudhaus (1), Marius Isken (1), Sebastian Heimann (2), Andreas Steinberg (1), Simon Daout (1), and Hannes Vasyura-Bathke (3)

(1) Christian-Albrechts-University Kiel, Institute of Geosciences, Kiel, Germany (henriette.sudhaus@ifg.uni-kiel.de), (2) German Research Centre for Geosciences GFZ, Potsdam, Germany, (3) University of Potsdam, Institute of Geosciences, Potsdam, Germany

We present the latest implementations in our open-source and python-based software toolbox for the inverse modelling of earthquake rupture characteristics by using different data sets, mainly static and dynamic surface displacements measured by InSAR, seismic sensors and GNSS receivers. With these tools we aim to facilitate a better exploitation of open global data sets for a wide scientific community studying tectonics.
In our seismological community remarkable improvements have been made in earthquake source inferences during the last years. More and more data are recorded and timely available for increasingly robust and detailed earthquake source studies. We join in the community efforts exploring and facilitating the combination of InSAR-derived near-field static surface displacement maps and dynamic far-field seismological waveform data for global earthquake source inferences.
Our particular goal is 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 introduce our harmonized source modelling environment for the combination of static and dynamic surface displacements in the source's near-field and far-field. Here, the data combination is driven by estimations of the data error covariances in space and time. The model consists of rectangular finite rupture models in 1d-layered media for which we synthesize both static near- and dynamic far-field surface displacements. We carry out non-linear source optimizations and Bayesian sampling of the model parameter space, which provides 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 free source model parameters. Stable model results are achieved, because the near-field data do well constrain the source location. Potentially, higher frequencies of the far-field dynamic waveforms can constrain the rupture propagation from a variable nucleation point on the rupture plane.
We demonstrate the abilities of this harmonized source modelling environment with example earthquake studies, e.g. the 1994 Northridge earthquake, the 2009 L'Aquila earthquake and the 2010 Haiti earthquake. 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 tools build up on the open-source modular seismological software toolbox pyrocko (www.pyrocko.org). Our tools are well applicable also for a large range of regional to local earthquake studies. They ensure a large flexibility in the parametrization of medium models (e.g. 1d to 3d media), source models (e.g. explosion sources, full moment tensor sources, heterogeneous slip models, etc) and of the predicted data (e.g. GNSS, strong motion, tilt).
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