Global Earthquake Source Modelling
New developments in open-source tools to combine geodetic data and seismic waveforms

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1) Motivation

Near-field and far-field as well as static and dynamic surface displacements cause by earthquakes carry different source information contents. Therefore joined near-field and far-field data optimisations are very beneficial (Fig. 1).

Openly available static near-field data of shallow crustal earthquakes are provided by ESA for all their past SAR (Synthetic Aperture Radar) satellite missions ERS and Envisat, and for the ongoing mission Sentinel-1. New services nowadays provide higher level InSAR data products, like the Thematic Exploitation Platform (TEP) for Geohazards by ESA and the COMET-LiCS Sentinel-1 InSAR portal. At the latter even displacement maps are published. Dynamic surface displacements are measured and broadcasted in real-time at several thousand seismological stations worldwide. Still, these data are not fully exploited.

With our software codes we use a common representation of static near-field (e.g. interferometric SAR data) and far-field dynamic displacements (e.g. seismological waveform data) based on finite earthquake rupture models (Fig.2).

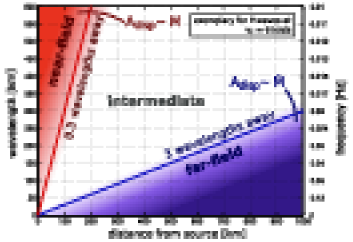

Figure 1. Definition of earthquake near- and far-fields.

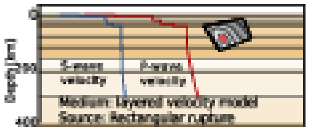

Figure 2. Rectangular, uniform-slip and constant velocity rupture representation for near- and far-field data.

2) Concepts and tools for source optimisations

Our toolbox is easy to illustrate taking the simplified representation theorem of faulting processes. We are developing a harmonized source modelling framework for static near-field data and dynamic waveforms building up on the open-source seismology toolbox pyrocko (see www.pyrocko.org). Using the same medium and source representations for the data we are enabling consistent and flexible, fully non-linear and joined-data source optimisations.

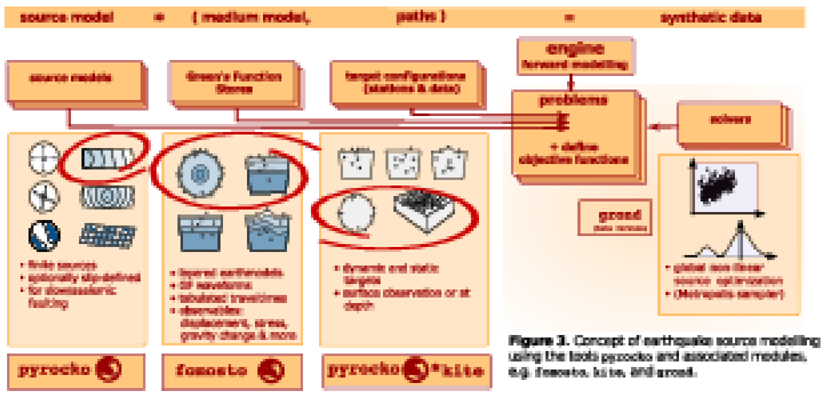

Figure 3. Concept of earthquake source modelling using the tools pyrocko and associated modules, e.g. fomosto, kite, and grond.

pyrocko(doi:10.5880/GFZ.2.1.2017.001):
Seismology toolbox, e.g. waveform data downloading, browsing and processing. It includes fomosto for creating customized Green's function databases (Fig. 3).
Synthetic data can be derived using pyrocko alone.

kite (doi:10.5880/GFZ.2.1.2017.002):
Post-processing InSAR-derived displacement maps and data error estimation. Kite prepares InSAR data for optimisations using preparation (Fig. 3).

grond (beta version):
Misfit-handler and model-space sampler for static and dynamic displacement data and joint optimisations of various source models (Fig.3). grond is under development, but could be used as a basis for your own model-space sampler.

Cesca, S., Heimann, S., Stammler, K., Dahm, T., Automated procedure for point and kinematic source inversion at regional distances. DOI: 10.1029/2009JB006450, 2010

QSSP Green's function code: Wang, R., F. Lorenzo-Martín and F. Roth (2006), PSGRN/PSCMP - a new code for calculating co- and post-seismic deformation, geoid and gravity changes based on the viscoelastic-gravitational dislocation theory, doi:10.1016/j.cageo.2005.08.006

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3) Toolbox application: Source of the 2009 L'Aquila earthquake (M_W6.3, Italy)

Here we show an example of an earthquake source optimization applying our toolbox. We show results of a fully non-linear source optimisation combining near-field static displacements and teleseismic waveforms from the start (Fig. 4 & 5).
We optimise the parameters of a simple rectangular rupture model with constant slip. Simultaneously we solve for fault location, mechanism, fault dimensions and moment (Fig. 3 & 6). Additional parameters are ramp corrections for the displacement maps and the nucleation point on the rupture plane and time (Fig. 6).

The medium is represented through elastic, layered local and global velocity models. Gridded corresponding Green's functions for ranges of receiver-source configurations are precalculated and stored in a database for speedy pick-up during the optimisation (Fig. 3).

The "targets" are (1) subsampled displacement data derived from unwrapped Envisat InSAR data in ascending and descending viewing geometries (Fig. 4) and (2) teleseismic broadband recordings of the Global seismological Network (Fig. 5). For the latter we model full P and S body waveforms in time-domain, using Z and R, and Z and T components, respectively.

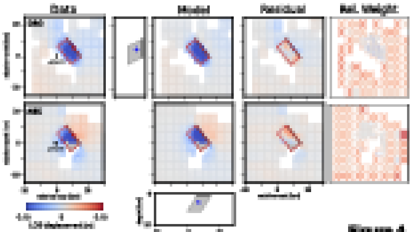

Figure 4. Examples of static displacement data, synthetics, residuals and relative weights based on error covariances.

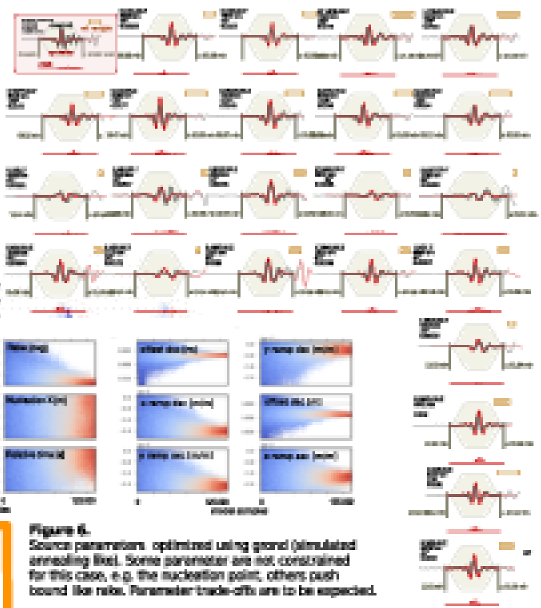

Figure 5. Examples of full waveforms and fits (gray - data, red - synthetics), together with the relative weights (brown bars).

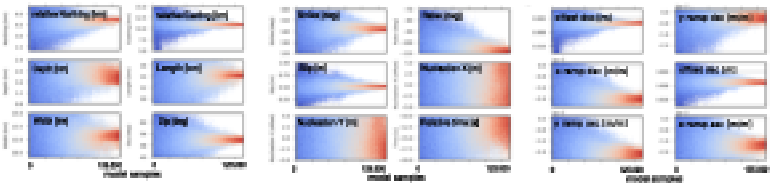

Figure 6. Source parameters optimized using grond (simulated annealing like). Some parameter are not constrained for this case, e.g. the nucleation point, others push bound like rake. Parameter trade-offs are to be expected.

4) Outlook

- **Further development of the target-specific error data error estimations and corresponding target weighting**
- **Include handling of slow, aseismic fault movements**
- **Exploitation of GF methods* to more data synthetics and smooth handling for source optimizations optimizations**

***) including more types observables, e.g. gravity, and visco-elastic material**

Acknowledgements

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