1. Introduction

We present a modular open-source software framework - kite (http://pyrocko.org; Isken et al., 2017) - for rapid post-processing of space-borne InSAR-derived surface displacement maps. The software enables swift parameterisation and sub-sampling of the displacement measurements. Through this approach we aim to ease and streamline the joint optimisation of earthquake parameters from InSAR and GPS data together with seismological waveforms. This will improve the determination of rupture parameters and processes. Using the pyrocko framework we want to provide finite models of earthquake ruptures from near- and far-field observations and contribute to a timely and better understanding of earthquake kinematics.

Further we introduce an interactive deformation modelling sandbox for handling and manipulating various kinds of tectonic and volcanic deformation source types, interacting in elastic full- and layered half-space.

The current development of software packages comprehends:

- Post-processing InSAR surface displacements and model input parameterisation.
- Green’s functions databases for static surface deformation, implemented in the pyrocko. gf software framework.
- Earthquake source inversion from heterogeneous datasets.
- Sandbox earthquake modelling handling various types of deformation sources.

2. Post-processing InSAR Surface Displacements

kite is based on a modular concept, this allows to extend to the software with great ease and also enables flexible utilisation of the provided tools. Data from different SAR processors can be imported: GAMMA, ROJUAC, ISCE and GMT5SAR.

The framework enables interactive inspection of the displacement data and swift and transparent manipulation of derived features, such as sub-sampled surface tilts and covariance/weight matrices.

Below we present optimisation results for a rectangular fault plane in layered media inferred from observed InSAR-derived surface displacement data. The modularity of the frameworks (pyrocko and kite) enables quick ignition and customisation of the optimisation workflow once the space-borne surface displacements are received.

3. Earthquake Source Inversion

The joint inversion of an earthquake source model from geodetic and seismic observations is a highly non-linear problem. With the software package kite we develop a modular inversion framework which is capable of handling heterogeneous databases. We concentrate on point and finite source earthquake models (Heimann et al., 2017).

The joint forward modelling part of seismic waveforms and static displacement is solved through the pyrocko. gf module, which uses pre-computed Green’s function databases to simultaneously model waveforms and static displacement of earthquake sources in layered media (see poster: Pyrocko - A Versatile Software Framework for Seismology). Data handling of seismic traces is provided through pyrocko and displacement scenes are delivered through kite. These are the essential building blocks which fuel the exchangeable solvers and inversion engine of the kite software package.

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4. Sandbox Earthquake Modelling

Fault ruptures and volcanic plumbing systems are complex and highly interactive processes which take place in heterogeneous composition of the Earth’s crust. To intuitively study the complexities we developed the graphical tool talpa to interact and link observed surface displacement data to a selection of synthetic, kinematic deformation models. This might serve as a first measure and constrain future numerical optimisation. talpa, the model, provides interfaces to different medium and source model types:

- Point and finite pyrocko. gf sources; layered half-space
- Rectangular dislocation source (Okada); homogeneous elastic half-space (Okada, 1985)
- Triaxial ellipsoidial source, compound dislocation model, homogeneous elastic half-space (Nikkhoo et al., 2017)

The open-source software framework kite is developed and is developed in a cooperation of Kiel University and GFZ Potsdam, Germany; it is written in Python and C programming languages. The toolbox architecture is modular and independent and can be utilised flexibly for a variety of geophysical problems. The next step is to establish a robust joint optimisation of InSAR observations together with teleseismic waveform data. This work is conducted within the BridGeS project (http://www.bridges.uni-kiel.de) funded by the German Research Foundation DFG through an Emmy-Noether grant. The ALOS data are kindly provided by JAXA through the R4A project 1349.

References


Isken, M., Sudhaus, H., Heinemann, S., Sudhaus, A., and et al. (2017). Kite - software for rapid earthquake source optimisation from InSAR surface displacement. Sudhaus, H. and Gomba, G. (2016). Influences of ionospheric disturbances in l-band insar data and displacement scenes are delivered through kite. These are the essential building blocks which fuel the exchangeable solvers and inversion engine of the kite software package.

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Figure 4: Conceptual architecture of the ground earthquake source optimisation framework.

The modular design allows to flexibly plug-in different source models (Problems), observed data (such as waveforms, InSAR or CMS-displacements) as well as the optimisation strategy (Solver).

Our results differ from other SAR studies investigating the same rupture, as compared to Feng et al. (2013). This is likely influenced by the simplified extended, rectangular source. However we can proof the interplay of the developed frameworks.

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Figure 5: Observed LOS displacement (ascending track; ALOS-1 PALSAR) and model results from the 2011 Miyake earthquake (Mu 6.8). A flow-strike slip rupture extending ~20 km in length and ~6 km in depth, with a maximum slip of 3.9 m. Our forward model optimisation shows good alignment with the observed surface displacements.

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Figure 6: Sequence plots of the converging optimisation process. The figure shows basic parameters of the finite fault model, running towards an optimal solution.

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