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Robust Inversion for Earthquake Mechanisms from Geodetic Surface Displacements (Ref IAP-17-114)

Newcastle University, Geomatics, School of Engineering
In partnership with Durham University, Deptartment of Earth Sciences

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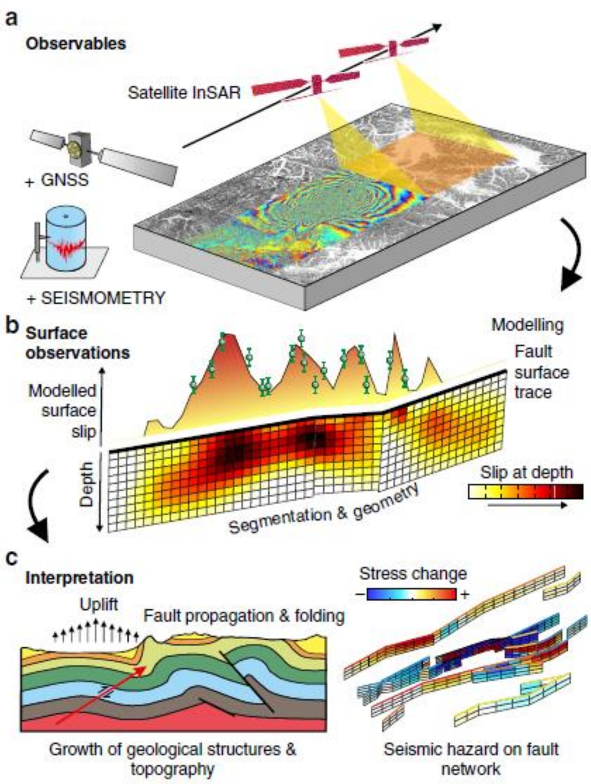
Key Words	**Fault slip, geophysical inverse theory, GNSS / InSAR geodesy, geohazards**

Overview

Geodetic measurements of the way in which the Earth's surface is permanently displaced during an earthquake can nowadays be made semi-automatically across wide areas using spaceborne synthetic aperture radar interferometry (InSAR), with delays of only a few days, or in near real time at large numbers of nearby individual sites using continuous GPS / global navigation satellite systems (GNSS). A challenge for geophysicists trying to understand the earthquake source is to interpret these surface measurements in terms of a simple but realistic geometric arrangement of fault patches on which slip takes place (e.g. Wright *et al.*, 1999; Feng *et al.*, 2014). Even with perfect and well-distributed data, this is a nonlinear and non-unique inverse problem requiring some level of constraint (e.g. uniform slip or smooth, non-negative slip on a bounded planar fault); for real data with errors and gaps, there may be many apparently valid solutions in addition to the global optimum (Clarke *et al.*, 1997). Yet more complication arises if the inversion scheme permits multiple fault segments or an Earth model composed of layers with differing elastic properties.

To bypass these difficulties, geophysicists typically solve for the fault geometry in one step (assuming uniform slip on each segment), and then estimate the slip distribution in a second, linear step. However, this procedure will rarely achieve the global optimum solution. In this project, we aim to remove this difficulty by developing a single-step inversion procedure allowing direct inversion for all earthquake parameters in a variable-slip layered-Earth model. We will then establish the robustness of this scheme by estimating realistic confidence limits for the inverted parameters, allowing comparison to be made with other geological and geophysical information.



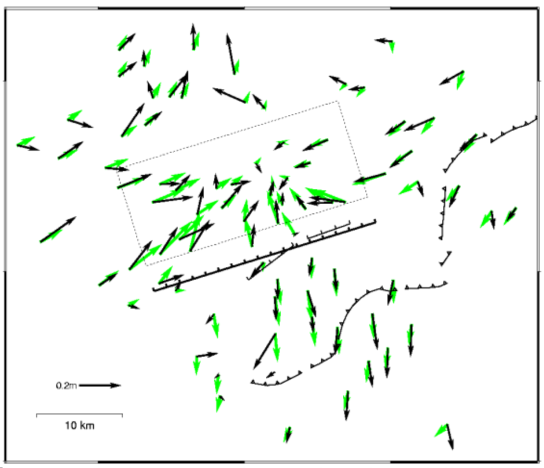
Observing and interpreting earthquake faulting using satellite data (from Elliott et al., 2016).

Methodology

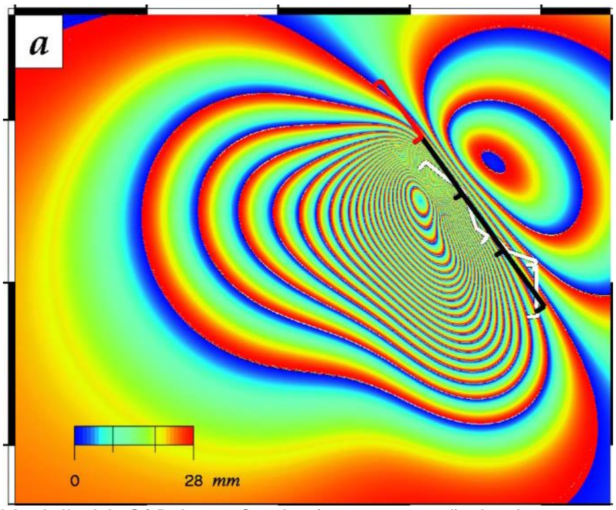
This project will be largely computer-based, although there may be the possibility to take part in fieldwork if a suitable earthquake occurs during the project timeframe. Starting from existing geodetic inversion software written in-house (OKINV and PSOKINV), the student will adapt the code to solve for variable-slip models simultaneously with the fault geometry, given an appropriate slip smoothness constraint. This scheme can then be adapted further to incorporate analytical models with a fixed distribution of slip on the fault plane, which are combined and scaled to model the overall deformation.

The model will be further refined by incorporating a layered elastic structure for the Earth, rather than a simple half-space model. In practice, the structure and contrasts in elastic moduli are not usually well known and must be estimated from real data, which introduces additional complexity into what is already a nonlinear and highly non-unique problem. Through numerical tests using the Newcastle high performance computing cluster, the student will investigate the sensitivity of the inversion to these additional parameters and the degree to which they can be constrained in the presence of realistic observational errors. It is expected that a substantive journal article will result from this part of the work.

Finally, the improved methodology will be applied to suitable real earthquakes. Depending on the student's interests and on circumstance, the application may be directed towards the near-real-time estimation of the earthquake mechanism using kinematically-processed GNSS data, and/or the final estimate using Sentinel-1 InSAR data from within a few days of the event. The student will learn to use the established processing chains for these datasets at Newcastle, and apply the new inversion scheme suitably. Again, it is expected that at least one journal publication will result from this part of the work.



Comparison between observed and modelled horizontal surface displacements for a simple uniform slip fault model (from Clarke et al., 1997).



Modelled InSAR line-of-sight (near-vertical) displacements for a 3-fault model (from Wright et al., 1999).

Timeline

Year 1: introduction to geodesy, geophysical inverse theory, programming; development of analytical and stochastic variable-slip fault models and their use in a single-step inversion for both fault geometry and slip in an elastic half-space (journal article).

Year 2: extension to layered Earth models, and investigation of confidence limits of inverted parameters in the presence of uncertain layering, variable slip, and realistic observational error (journal article).

Year 3: geodetic data processing; application of inverse methodology to static and kinematic case studies of topical earthquakes (journal article).

Year 3.5: combination of published outputs and associated material into PhD thesis; submission and examination.

Training & Skills

This project will suit a numerate graduate in Earth Sciences (including geophysics, geomatics / surveying, physical geography) or a graduate in physics, computing, engineering, or maths / statistics with a keen interest in geosciences and geohazards. Some prior experience in programming is a distinct advantage.

The student will gain highly-transferable skills in geophysical inverse theory, programming, high-performance computing, management and analysis of large datasets, and geodetic Earth observation. Much of this will be through "on the job" training within the project and the high-supportive geodesy research team at Newcastle, supplemented with subject-specific and generic postgraduate training courses provided by Newcastle University and the IAPETUS consortium.

The student will become a member of the NERC COMET consortium, benefitting from the shared expertise of staff in several universities, and attending regular meetings where the research of these various groups is discussed. Following the PhD, the student will be well equipped for a career in academia or a variety of industry sectors.

References & Further Reading

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Further Information

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