Measuring earthquakes across the global continents from space and seismological observations

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This exciting project aims to improve our understanding of the nature of shallow continental earthquakes by combining high resolution geodetic (InSAR) measurements of ground deformation with seismological observations for earthquakes across the global land masses.

The quantity and quality of satellite-geodetic measurements of tectonic deformation have increased dramatically over the past two decades improving our ability to observe active tectonic processes. Prior to this, the dominant constraint on earthquakes was from seismological observations. In addition, we now routinely respond to earthquakes using satellites, mapping surface ruptures and estimating the distribution of slip on faults at depth for most continental earthquakes. Studies directly linking earthquakes to their causative faults allow us to calculate how resulting changes in crustal stress can influence future seismic hazard. This revolution in space-based observation is driving advances in models that can explain the time-dependent surface deformation and the long-term evolution of fault zones and tectonic landscapes (Elliott et al., 2016). This project aims to harness both the spatial reach of space-based InSAR observations of earthquake deformation with the time sensitive information contained with seismological observations to better understand shallow continental earthquake locations, fault segmentation and ruptures, spread right across the global land masses.

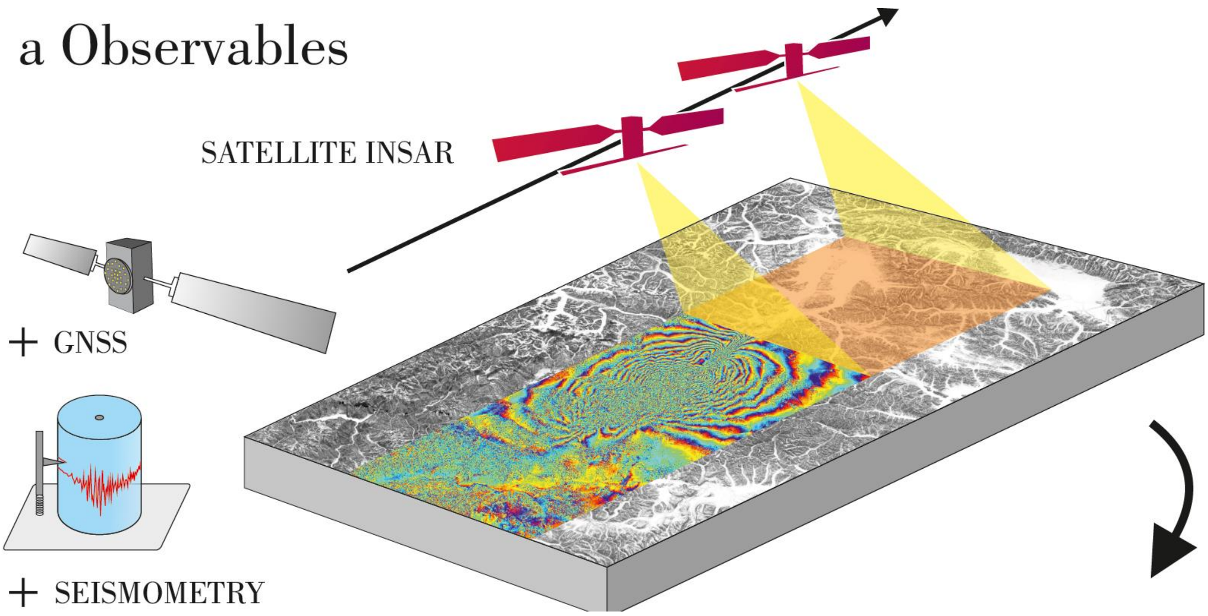

Figure 1: *Earth observations are used to model and interpret earthquake ruptures and the geometries of faults and their slip distributions. Satellite interferometry provides high-resolution measurements of surface displacements by repeated illumination of the ground with radar over wide areas. This captures in its entirety the ground motion due to some of the largest continental earthquakes. These observations can also be augmented with complementary data sets such as GNSS and seismometry to provide a time history of rupture.*

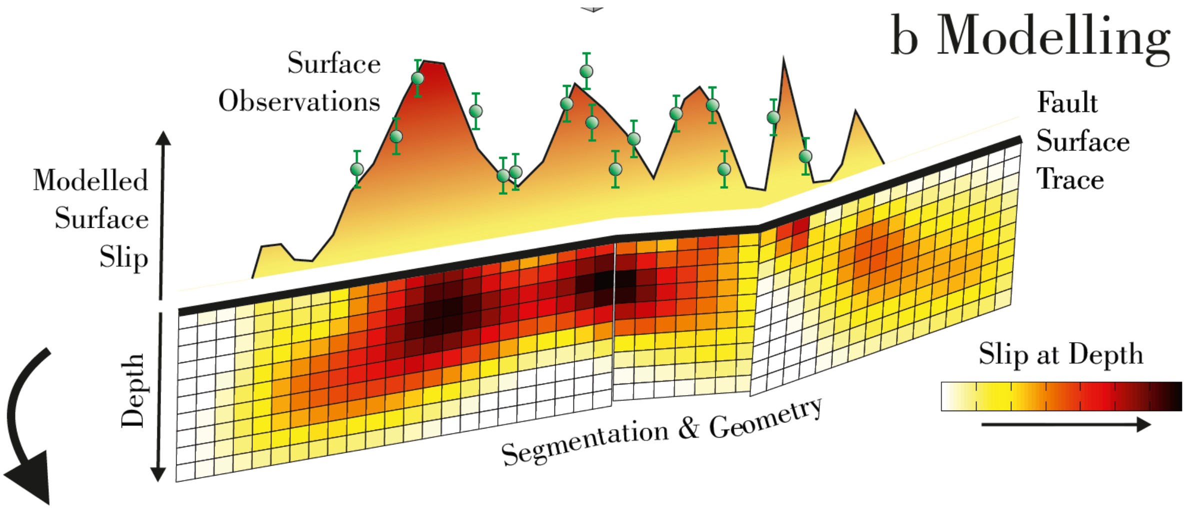

Figure 2: *Based on these data and using elastic dislocation theory, it is possible to infer the slip across the fault at depth, as well as constrain the geometry and segmentation of faulting. The modelled observations of slip in the near-surface can then be compared with field observations of discrete mapped surface offsets (green circles). Determining the geometry of faulting and its relationship with surface geomorphology is important for interpreting the surface fault expression and understanding the segmentation of rupture for estimating potential seismic hazard. Establishing the extent of slip is needed for determining which portion of the fault failed in the earthquake, and also which did not and could fail in future.*

Much of our understanding of active tectonics comes from the study of earthquake sources and relating them to the active fault structures seen at the surface. The sparseness of seismological stations reporting to the international seismological bulletins (GCMT, USGS NEIC) in certain parts of the world and the crustal heterogeneity of various regions, can result in the mislocation of earthquakes in these catalogues due to unmodelled bias in the seismic wave paths. The technique of InSAR allows the accurate positioning of events for moderately sized (Mw 5.5+) and relatively shallow (<20 km) events. With elastic modelling it is also often possible to resolve the ambiguity of the fault slip plane and to determine the fault parameters describing it.

A number of small and shallow earthquakes have occurred beneath the continents in the window of Sentinel-1 radar imaging (Oct 2014-present). It is not clear whether these earthquakes are readily visible in interferograms produced over the epicentral areas or not, as the ground deformation can be masked by atmospheric noise for these small events. This project aims to detect the location of these events by examining an existing automated catalogue of processed interferograms, and also process past data for older earthquakes using the Sentinel-1 spacecraft data to make interferogram observations of the epicentre. In the case that sufficient signal is found, the student will model the signal to improve the source location and depth, as well as potentially constrain the fault geometry (Bagnardi & Hooper, 2018). Potential processes to improve signal to noise ratios could also be implemented including stacking of multiple InSAR images, or more advanced time series analysis.

Once a catalogue of well-constrained InSAR derived locations of moderate-magnitude earthquakes has been compiled, the student will then work on comparing these locations to those derived using a range of seismological techniques, estimating both generic and regional specific uncertainties and biases. As these data allow (or require), it may be possible to use events with well-located InSAR locations to calibrate seismological location routines, allowing the correction and relocation of a more complete seismic dataset.

For a subset of larger or more interesting earthquake ruptures, it will be possible to advance the modelling analysis to the distribution of earthquake slip (Figure 2) using inversion approaches (Amey et al., 2018). The aim would be to constrain the depth extent of faulting and examine the relationship between slip asperities and fault segmentation. There will also be the potential to examine the seismologically constrained time variability of rupture and compare this to the InSAR constrained distributions of slip.

Objectives

In this project, the student will work with leading scientists at Leeds (John Elliott, Tim Craig, Andy Hooper & Tim Wright) to apply the latest techniques in measuring earthquake deformation, seismology, active tectonics, faulting and continental deformation to the continental landmasses. The project will have the following specific objectives:

1. The student will use data from the new Sentinel-1 radar constellation to measure surface deformation associated with moderately sized, shallow continental earthquakes across the global landmasses for the past 5 years and through the lifetime of the project to amass a global catalogue of the location of InSAR events. They will subsequently model the earthquakes to provide basic earthquake fault parameters (Bagnardi & Hooper, 2018).

2. The student will compare the locations of small earthquakes with a range of seismological locations, determining any systematic, potentially region-specific, location biases and generic catalogue uncertainties (Lohman & Simons 2005, Weston et al., 2012). Depending on the interests of the student, the recalculation and relocation of the seismological catalogue, using calibrated events constrained using geodetic data, may then be one avenue for taking this project forward.

3. For a select choice of more interesting earthquakes studied with the above techniques, the candidate will be able to take the earthquake modelling approach further by also performing inversions for fault slip distribution (Amey et al., 2018). They will examine the location of slip asperities and potential correlation with fault segmentation (Figure 2). Potential further interpretations of such models could include the calculation of stress transfer (Figure 3), remote sensing interpretation of inferred active faults, further analysis with past archive data or revisiting prior earthquakes in the region.

We would expect the balance between these components to vary depending on the specific interests of the student.

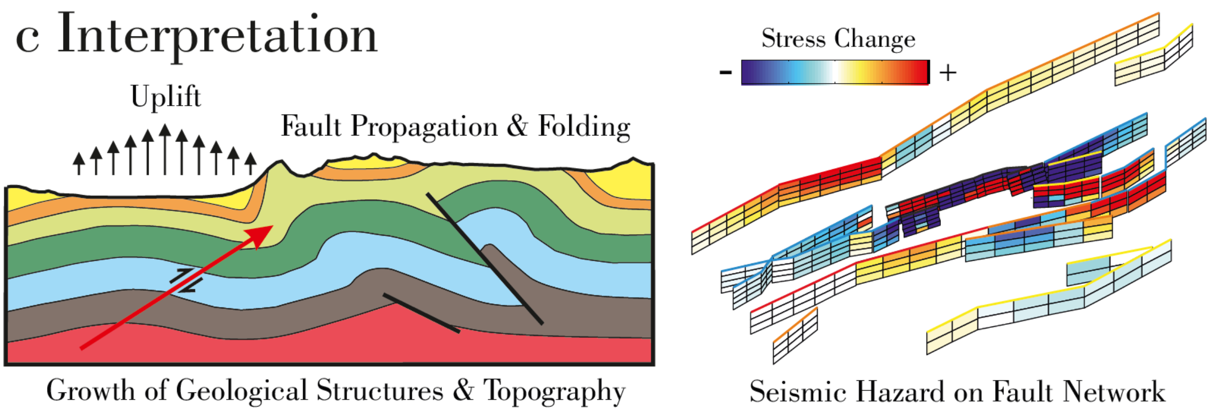

Figure 3: *By establishing the depth range of faulting and combining this with geological mapping and sections, it is possible to constrain the relationship between faulting and the growth of geological structures such as folds and topography, as well as explore the potential control of lithology on both coseismic and postseismic slip. Using the distribution of slip and fault geometry, it is possible to infer the changes of stress on the surrounding network of faults in an attempt to update the estimate of seismic hazard in a region. Portions of faults which have undergone a positive change in stress will an increased seismic hazard, whilst those with negative stress changes will have been brought away from failure.*

Potential for high impact outcome

Active tectonics and earthquake hazard is a pressing issue facing many countries. We are in a unique position at Leeds to bring together a range of observational, modelling and field approaches to answer important unresolved questions about the relative activity of faulting around population centres distributed in major orogenic zones. The research topic has immediate relevance to improving our understanding of the link between faulting and earthquake locations, and has the potential to better inform seismic hazard. We anticipate the project generating several papers. There will be ample opportunities to deliver the results of the project at international conferences in addition to UK meetings.

Training

The student will work under the supervision of Dr. John Elliott, Dr. Tim Craig, Prof. Andy Hooper and Prof. Tim Wright within the Tectonics group of the Institute of Geophysics & Tectonics in the School of Earth & Environment at Leeds. The Institute also hosts the Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET http://comet.nerc.ac.uk/) which provides a large group of researchers engaged in active tectonics research with whom the student can interact. This project provides a high level of specialist scientific training in: (i) Satellite geodesy and remote sensing, (ii) Seismology, (iii) Data processing and Interpretation. The successful PhD student will have access to a broad spectrum of training workshops put on by the Faculty that include an extensive range from scientific computing through to managing your degree, to preparing for your viva (http://www.emeskillstraining.leeds.ac.uk/). The student will also have the opportunity to engage with a wider range of scientists within COMET at a number of other UK institutions who have a broad interest in problems of active tectonics and earthquakes.

Student profile

The student should have a strong interest in active tectonics problems, a strong background in a quantitative science (geophysics, earth sciences, physics), and a familiarity and willingness to develop their skills in scientific computing.

References

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