NERC CASE project: Interferometric Monitoring of the Earth's Interior

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SUMMARY: A new method known as *seismic interferometry* is revolutionising earthquake and industrial seismology. It allows real seismograms to be obtained from *virtual (imagined) sources* of energy, and *virtual sensors* to be created inside the Earth which record real energy from anthropogenic, wind or oceanic noise, or from earthquakes. This Ph. D. project will develop new methods to monitor changes in the Earth's subsurface using *virtual sources and receivers*, and develop methods to calibrate the sensors to record strain and potentially stress-change. The methods will be tested in regional seismological applications (e.g., monitoring stress around faults and volcanoes) and applied to industrial geophysics (subsurface reservoir monitoring).

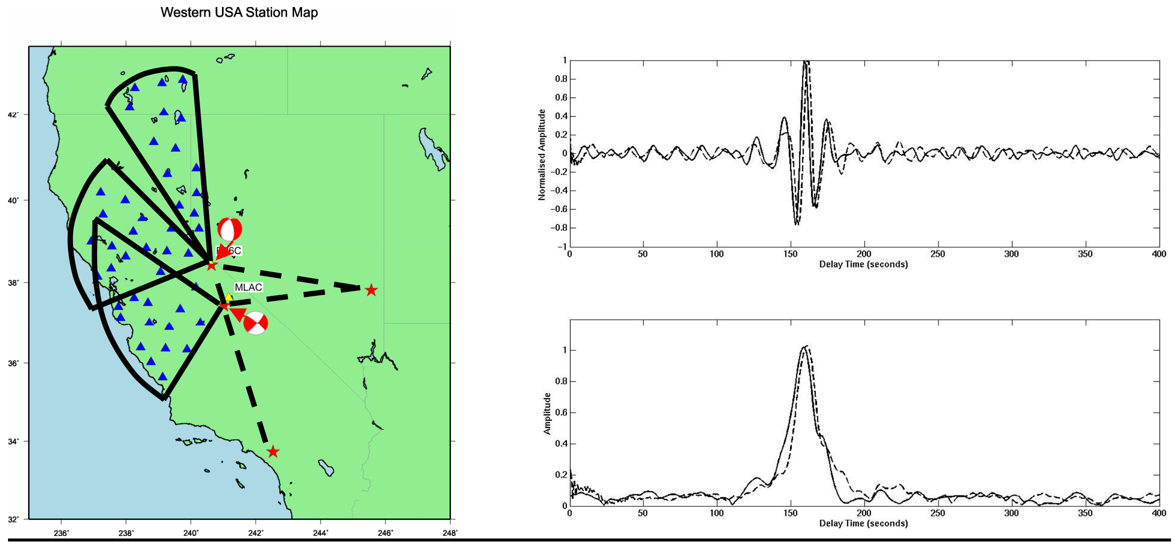
You will conduct this research in the largest academic seismological research group in the UK, *Edinburgh Seismic Research* (www.geos.ed.ac.uk/seismic), in close collaboration with one of Europe's leading industrial geophysical research lab's, Schlumberger Cambridge Research. You will be trained in all relevant theory, be given all necessary computing and other resources, and will spend time in Schlumberger with some of the world's leading seismologists.

DETAIL: Traditionally, seismologists must wait for an earthquake to occur, or detonate an artificial energy source, before they can record wave energy propagating inside the Earth (seismograms). These seismograms are analysed to create images of the Earth's subsurface.

However, naturally occurring seismic waves (for example those caused by passive sources such as wind, anthropogenic disturbances and oceanic swell) are travelling through the Earth constantly. These propagate through the same subsurface structure as the energy from earthquakes and explosions, and so contain similar information about the Earth's interior. These naturally occurring waves are usually regarded as 'noise' and traditionally much time and energy is spent trying to remove them from seismic data.

Seismic interferometry has turned seismology on its head: it allow us to extract useful information from such 'passive' seismic data. Even though the techniques were only proven in 2003, in much current work seismograms from real energy sources are discarded and only noise is analysed; there is now a huge field of "seismology without earthquakes"!

The interferometry technique involves cross-correlating seismic noise data recorded at two seismometers. The result is the "virtual" seismogram – the seismogram that *would have been* obtained at one of the seismometers if there had been an earthquake at the other. The virtual seismogram is therefore just like a real seismogram except that it was generated by a virtual (imagined) earthquake at a known location. Nevertheless, it can be treated just like a seismogram from a real earthquake, and used to image the Earth's interior.



The picture shows a map of earthquakes (stars) with different source mechanisms (beach balls) in the western U.S.A., recorded on different sets of real seismometers (triangles). Top-right is overlain the seismogram from a virtual seismometer, constructed from the normal-faulting earthquake, and the seismogram from a real seismometer located close by on the surface for comparison. Below is the amplitude (envelope) of each. The close match shows that the virtual seismometer works.

Recently, Curtis et al. (2009) showed that related theory can be used to turn *interferometry* on its head: instead of turning a real seismometer into a virtual earthquake, it was possible to turn a real earthquake into a *virtual seismometer*. This seismometer can be used to measure seismograms from other earthquakes, from background noise, or from any other source of energy of sufficient magnitude. The images above show the method in action.

The important point is that the virtual seismometers are co-located with the earthquakes, and hence are by definition within the Earth's subsurface. Also, it can be shown that they are in fact strain sensors (rather than displacement sensors like normal seismometers). What is more, in certain situations they can be calibrated to estimate dynamic stress within the solid rock. Stress changes are of critical interest to earthquake seismologists to predict future earthquake hazard, and to industrial seismologists to identify fluid pressure changes. This Ph.D. will test and develop these techniques in both earthquake and industrial settings, to create the first strain and stress sensors located non-invasively (without the need to drill a well) in the interior of solid rock, with significant implications in industry and academia.

<u>Introductory Reading:</u>

Curtis, A., Gerstoft, H., Sato, R., Sneider, R., and Wapenaar, K., 2006, Seismic Interferometry – turning noise into signal, *The Leading Edge*, **25**, 1082 – 1092.

Curtis, A. et al., 2009. Virtual seismometers in the subsurface of the Earth from seismic interferometry. Nature Geoscience, DOI: 10.1038/NGEO615

Pdf's available at: www.geos.ed.ac.uk/homes/acurtis