<u>Monitoring the Dynamic Earth's Interior using Seismic Interferometry</u>

Ph. D. project supervised by Prof. Andrew Curtis *(University of Edinburgh)*

<u>100% Funded</u>. Part of an International Academic/Industrial Research Collaboration

SUMMARY: A new method known as *seismic interferometry* is revolutionising earthquake and industrial exploration seismology. It allows *virtual (imagined) sources* of energy to be created and recorded inside the *real* Earth, and *virtual (imagined) sensors* to be created that record real seismic waves. Such virtual recordings can be used to image the *real* Earth.

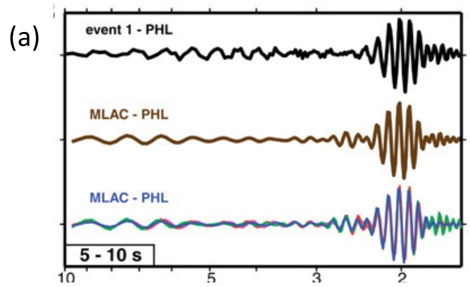
In this Ph. D. project you will use these techniques to create *new academic and industrial imaging methods* to monitor the changing properties of the Earth's subsurface for the purpose of monitoring fluid changes within the pore space of rock during resource extraction (water, hydrocarbon, ores) or subsurface waste disposal (of nuclear waste or carbon dioxide for climate-change mitigation). You will conduct this research in the largest seismological research group in the UK, *Edinburgh Seismic Research* (<u>www.geos.ed.ac.uk/seismic</u>). You will be trained in all relevant theory, be given all necessary computing and other resources, and will collaborate with some of the world's leading seismologists. You will have the opportunity to apply these methods to industrial exploration seismology, to collaborate with international scientists, and to present your research at international conferences.

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 allows us to extract useful information from such 'passive' seismic data. The techniques were only proven in 2003, but already seismograms from large energy sources are often discarded and only noise is analysed; there are now many seismologists researching "seismology without earthquakes"!

Interferometry involves cross-correlating seismic noise data recorded at two seismometers. The result is a "virtual" seismogram – the seismogram that would have been obtained at one of the seismometers if there had been a real earthquake at the other. The virtual seismogram can be treated like a real seismogram and used to image the Earth's interior.



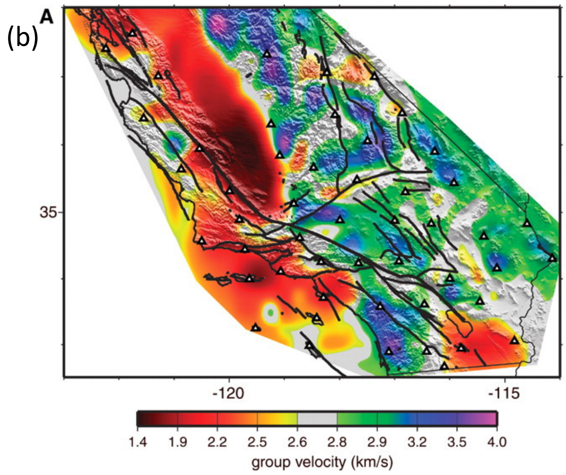


Figure 1: (a) Virtual and real seismograms for Californian seismometers PHL and MLAC at 5-10s period. (b) High resolution seismic speed map for 7.5s period across California. From Shapiro et al. (2005).

The top seismogram in Figure 1(a) shows a seismogram recorded at Californian station PHL due to an earthquake that occurred very close to another station, MLAC. The middle trace in Figure 1(a) shows the virtual seismogram obtained by applying interferometry to 30 days worth of seismic noise recorded at stations MLAC and PHL. Notice the remarkable similarity between both traces. Figure 1(b) shows the result of high resolution, surface wave tomography using seismograms created using purely passive noise interferometry to every station pair in the entire Californian seismometer network. The features of the tomographic map correspond very well with the known regional geology.

Other methods developed recently called "coda-wave interferometry" (CWI) allow tiny changes in the subsurface properties of the Earth to be measured, provided they occur over large volumes of the Earth's subsurface. Changes that can be measured then only represent averaged changes over those large volumes. CWI has previously been used to monitor subsurface stress or property changes associated with volcanic and earthquake activity.

Working as part of a team you will extend these revolutionary techniques to develop new methods for monitoring the Earth's subsurface during periods when its properties are changing (for example, when we extract fluids from, or inject fluids into the Earth). You will develop CWI techniques to monitor tiny changes inside the Earth's crust within imaging algorithms, such that we can identify the location of the changes more accurately in 3-dimensional space. You will apply your methods to perform both industrial and academic seismological monitoring – either passive or man-made energy sources will be used to image subsurface properties during resource (water, hydrocarbon) extraction or (waste, CO_2) injection and disposal. Your methods will also have significant implications for earthquake and volcanic monitoring.

You will develop these methods in a supportive, world-leading environment of other Ph. D. and post-doctoral scientists working in related fields, and will be trained in necessary theory and skills. The results will represent a major advance in our understanding of seismology, and will allow us to develop models both of wave propagation, and of the structure and properties of the Earth's interior. You will publish your research in the top scientific journals, and present your work internationally.

Prerequisites

Candidates must have an excellent degree in a **Mathematical, Physical** or **Geophysical** science, and a good background in **wave theory**. Experience of **computer programming** is also necessary. Prior experience of **seismology, imaging, tomography** or **interferometry** would be advantageous.

Introductory Reading:

Curtis, A., Gerstoft, H., Sato, R., Sneider, R., and Wapenaar, K., 2006, Seismic Interferometry – turning noise into signal, *The Leading Edge*, **25**, 1082 – 1092 (pdf available at: www.geos.ed.ac.uk/homes/acurtis).

Reference used above:

Shapiro, N., Campillo, M., Stehly, L., and Ritzwoller, M., 2005, High-Resolution Surface-Wave Tomography from Ambient Seismic Noise, *Science*, **307** no. 5715, 1615 – 1618.