Geophysics/Meteorology Honours Projects 2015-2016

Course organiser: David Stevenson (dstevens@staffmail.ed.ac.uk), Crew 314
Course secretary: Casey Hollway (casey.hollway@ed.ac.uk), Grant 332

This document lists the projects on offer for senior honours (4th year) students registered on the Geophysics/Geophysics and Geology/Geophysics and Meteorology programs. The meteorology projects (and potentially some of the others too) are also on offer to Physics with Meteorology students (if Physics with Met students are unsure whether projects are suitable, they should contact the course organiser (CO)/primary supervisor).

If you are interested in a particular project, please contact the main supervisor to discuss what is involved in more detail. You need to choose a project and also a second choice (and third choice, etc., if possible), for each semester (Semester two (S2) choices can be revised later). In some cases you won’t be able to do your first choice (for example if it is chosen by multiple people, and the supervisor cannot run several variants of the same project). If you don’t get your first choice, we will try and make sure you do get your first choice in the other semester. Where projects are over-subscribed, the decision of the CO (generally in consultation with the supervisor) will be final.

Any projects/combinations of projects can be taken, irrespective of whether you are a Geophysics or a Geophysics and Meteorology/Geology student. Project choices for S1 (and provisional choices for S2) should be emailed to the CO (email address above) by Tuesday in Week one (22nd Sept), and finalised allocations will be made by the end of Week one (25th Sept) so that you have sufficient time to fully tackle projects.

Students can propose their own projects, but will need to identify a suitable supervisor (normally amongst the geophysics/meteorology staff), and convince that supervisor and the CO that the project is sensible and feasible. Students should do this as soon as possible, to fit with the above timetable.

Projects listed here are a mixture of one semester, 20-credit projects, and two semester, 40-credit projects. In some cases, 20-credit semester one projects can be extended to be 40-credit projects. If students wish to extend their semester one project, they will need to get the supervisor’s and the CO’s agreement, before week seven of S1. Single semester projects should typically be 20-25 pages A4 (and a maximum of 30 pages - including all diagrams, references and appendices; 12 point font, 2.5cm margins, 1.0 line spacing, space between paragraphs); Two semester projects should typically be 40-50 pages (maximum 60 pages). Projects should be spiral bound (e.g., at JCMB copy shop).

Students doing 40-credit projects also need to hand in an interim report – this will be marked and you will be given feedback, as for 20-credit projects. The mark for the interim report makes up 25% of the overall mark. Projects are independently marked by the primary supervisor and one other staff member, using the criteria laid out on the mark sheets, see:

Hand in S1 project reports and 40-credit interim reports by 12 noon on Tuesday January 12th 2016.
Hand in S2 project reports and 40-credit final reports by 12 noon on Friday April 1st 2016.

As part of the introduction to year four (S1, Week 0) projects will be introduced by the CO, along with examples of good (and bad) practice in how students should tackle their projects, including writing them up. It is up to students to contact potential project supervisors to discuss projects (supervisor’s contact details should be included in the project descriptions). If supervisors cannot be contacted, please let the CO know.
In the middle of S2 (during ‘Innovative Learning Week’), students will be expected to give a short presentation on their semester one project, or, if they are doing a single 40-credit project, on that. This presentation will not count towards your final project mark, but does contribute 20% towards the final mark on the ‘Transferable Skills for Geophysicists’ course.
Determining Locations, Magnitudes and Mechanisms for Mining Induced Earthquakes near New Ollerton, Nottinghamshire

Brian Baptie (BGS), Youqian Zhao & Andrew Curtis (Univ. of Ed.)

The coalfields of Britain are frequently the source areas of small to moderate earthquakes and tremors in these areas have been reported for at least the last hundred years, for example the Stafford earthquake of 1916 (Davison, 1919). In the 1980’s and 1990’s mining events accounted for approximately 25% of all the earthquakes recorded in the UK (Browitt et al, 1985). Since the rapid decline of mining activity in the UK there has been a general decrease in the number of these events.

Between December 2013 and October 2014, over 300 small earthquakes were detected in and around New Ollerton, Nottinghamshire. Many of these were felt locally. This is an area with a history of seismic activity related to coal mining and the occurrence of these events coincided with the resumption of deep mining operations at the nearby Thorseby Colliery. A temporary network of seven seismometers was deployed to allow detailed analysis of these events. You will use this data to determine locations for the earthquakes.

The clustering of initial locations events suggests that the relative locations of the events could be improved using multiple event location techniques. You will apply the double difference location
method (Waldhauser and Ellsworth, 2000) to determine precise relative locations for these earthquakes.

The method minimises the difference between the travel time residuals of earthquake pairs and since the velocities along a path for neighbouring earthquakes recorded on one station are nearly identical, no station- or source-specific corrections are required. The method allows combination of catalogue readings with precise relative travel time differences.

The high degree of similarity between the individual events (Figure 3) will also allow you to use waveform cross-correlation (Schaff and Richards, 2004) to obtain accurate and consistent phase arrival time differences that can be used with the double difference algorithm.

The resulting event location estimates will be interpreted in relation to the locus of the mining activity and allow you to study the temporal evolution of the sequence of events. In a further phase of the project you will also determine magnitudes and source mechanisms for these events that will allow the moment release and type of faulting to be evaluated.

References


Is there any correlation between M8+ earthquakes and Solar Polar coronal holes?

Ciarán Beggan (British Geological Survey) [ciar@bgs.ac.uk] and Andrew Bell (School of GeoSciences)

At the northern and southern poles of the Sun lie large open coronal holes whose field lines close out at the edge of the solar system. The strength of the magnetic field within these regions can be measured on Earth by observing the variation of a particular spectral line, and has been routinely monitored by the Wilcox Solar Observatory since 1976 (Figure 1). As the Sun’s field reverses approximately every 11 years the field strength of the coronal holes waxes and wanes. In addition, an annual variation is observed, generated by the passage of the Earth through the plane of the solar ecliptic and the relative view of the Sun’s polar regions (Svalgaard et al., 1978).

Recent unpublished work has suggested there may be a link between the strength of the solar coronal holes and the occurrence of earthquakes with magnitudes larger than M8 (Davidson et al., 2015). The authors have proposed a set of conditions related to the strength of the field (i.e. high or null during reversal) and the pre-conditioning of the Earth itself (e.g. if there have not been recent M7+ earthquakes). The authors claim that their conditions cover 41% of the time period but account for 79% of the occurrences, suggesting that they are doing much better than random chance. The authors’ suggested explanation for the relationship is the interaction of the open magnetic field lines with the Earth’s magnetic field and the injection of energy into the lithosphere-ionosphere system. This has been suggested by other researchers, though see Lui and Chen (2009) or Kamogawa and Kakinami (2013) for the current view of such ideas.

These types of claims about earthquake prediction and/or precursors appear regularly in the literature and on the Internet. BGS are constantly asked about such mechanisms. In this case, it is possible from the unpublished paper and code given by Davidson et al. (2015) to recreate the results they give.

The goal will be to recreate the work and analysis of Davidson et al. (2015). A major outcome of the project would be to provide support or refutation of the suggested correlation. In addition other geomagnetic and space weather indices could be checked to see if any other correlations appear. Existing Matlab and R code is available to do some of the analysis, but additional coding to read in and plot data will be required. All data and indices are freely available on the Internet.

This is a one semester project for the Sep-Dec 2015 term only.

References:
Identifying families of repeating volcanic earthquakes

Supervisors: Andrew Bell & Ian Main (a.bell@ed.ac.uk)
Single semester project, potentially extendible to two semesters

At some volcanoes, seismic activity involves sequences of ‘repeating earthquakes’ – events that have very similar waveforms that re-occur over periods of hours or days. The implication of repeating earthquakes is that there must be persistent sources that can generate earthquakes time and time again. Repeating earthquakes can be classified into ‘families’, each with similar waveforms, and the activity rate of different families can tell us about the changing activity of the volcano and play a role in eruption forecasting. However, there are a range of methods for defining earthquake families, each of which can produce quite different results.

This project will compare the outputs of family classification methods for an episode of repeating earthquakes occurring at Tungurahua volcano, Ecuador, in April 2015, and try to develop new ‘optimal’ methods. The work will use Python, including the ObsPy seismic data analysis library.

![Figure 1: Repeating ‘drumbeat’ low frequency earthquakes at Tungurahua volcano, Ecuador, April 2015](image)

References:

Footprint of the South Asian monsoon on African climate

Supervisor: Massimo Bollasina (massimo.bollasina@ed.ac.uk)

20 credits semester 1 or 2, or extendable to 40 credits across 2 semesters

South Asia is home to the immense South Asian monsoon, a key component of the global water and energy cycles with profound worldwide influences. Its remarkable seasonal shift of precipitation is the life-blood of more than 30% of the world’s population and their agrarian societies.

A link between the S. Asian monsoon and African climate is expected based on the underlying dynamics: at lower levels, the African southwesterlies over the S. Atlantic reach the Horn of Africa converging with the Somali jet in the western Indian Ocean. At upper levels, the tropical easterly jet resulting from regional heating is one of the main characteristics of the African monsoon.

Many features of the above link are however still unclear, especially at subseasonal time scale. How the link works in current and future climate, with rapidly varying emissions of greenhouse gases and aerosols, has important implications for regional climate projections over Africa. In tackling this question, a significant source of uncertainty is represented by internal climate variability, which is the unforced component arising from internal processes.

This project will use data from the novel NCAR CESM Large Ensemble (LE) project to explicitly identify the role of internal climate variability in the link between the S. Asian monsoon and African climate for the recent past and the near future. The data consists of a 30-member ensemble of 1920-2080 experiments with a state-of-the-art global climate model.

This project involves data analyses and plotting, hence knowledge of programming in IDL, Matlab or Python is highly desirable. More sophisticated utilities for reading, analysing and plotting the data will be provided.

Figure 1: Difference in standardized rainfall anomalies between post- and pre- S. Asian monsoon onset pentads. Positive anomalies are shaded. Figure from Camberlin et al. (2010).

Background reading:


Long-term global climate variability modulated by the Southern Ocean

Supervisor: Massimo Bollasina (massimo.bollasina@ed.ac.uk)

20 credits semester 1 or 2, or extendable to 40 credits across 2 semesters

The ocean plays a major role in driving climate variability on decadal to centennial time scales. Due to its much larger heat capacity and dynamical inertia, the ocean’s memory greatly exceeds that of the atmosphere, making it a pacemaker for long-term variability in the climate system.

Natural decadal to centennial timescale variability has the potential to mask global warming signals arising from anthropogenic greenhouse gas emissions in observational data records. Hence, it is important to identify the sources and mechanisms of long-term natural climate variability.

It is however difficult to obtain an estimate of long-term internal (i.e., due to feedback processes within the climate system) variability purely from observations. A further perspective is provided by long control (i.e., with no changes in external forcing agents) simulations of climate models.

The Southern Ocean has been identified as a driver of enhanced centennial variability through regional sea ice-oceanic heating coupled feedbacks. A footprint of the Southern Ocean on global quantities such as surface temperature has also been found (Figure 1).

This project will analyse the output from a 5000-year control simulation of a state-of-the-art climate model, the US NOAA/GFDL CM3.0 model, to assess decadal to centennial simulated internal climate variability in the coupled climate system.

This project involves data analyses and plotting, hence knowledge of programming in IDL, Matlab or Python is highly desirable. More sophisticated utilities for reading, analysing and plotting the data will be provided.

Figure 1: (Left): Time series of annual mean sea surface temperature (SST) over the Southern Ocean. (Right): Pattern of global SST corresponding to high minus low index shown to the left. Figure from Latif et al. (2013).

Background reading:


Relating rain composition to rainfall temporal profiles

Supervisors: Christine Braban (chri2@ceh.ac.uk) and David Stevenson
Single semester project, potentially extendible to two semesters (best done in conjunction with/after Atmospheric Physics course)

Daily rainfall chemical composition has been measured at Auchencorth Moss for 9 years. The rainfall collector is called a daily- wet-only collector and has moisture sensitive trigger for opening the lid to allow rain to be collected. From the instrument there is also information about the duration and time of day the lid is open. There is evidence that volume weighted deposition of chemical is higher during events with low amounts of rainfall, however there are very few published studies. This comprehensive dataset may allow the frequency distribution of rainfall to be studied alongside other co-located measurements.

In this project, you will collate the DWOC lid dataset and build up a spreadsheet with both the meteorological data and the DWOC chemical data. Using the dataset, the patterns of chemical deposition and rainfall events will be studied. You will investigate how different parameters affect the resultant deposition. For example, how important is the time of year and season on chemical deposition? Is deposition dominated by short events or larger events such as Atlantic westerly storms? Can correlations between the precursor gas and aerosol concentrations be used to predict nutrient deposition?

The project will involve data analysis and model development/use of OpenAir, and the student will need to use R. It is recommended that the Atmospheric Physics course is also taken to gain some basic knowledge of aerosols.
Modern jerks: Mapping rapid geomagnetic variations

Supervisors: Will Brown [wb@bgs.ac.uk] (British Geological Survey) and Kathy Whaler (School of GeoSciences)

Suitable for: one/two semester (bear in mind BGS moves to Heriot-Watt campus during Semester 2)

Geomagnetic jerks are rapid variations of the internal magnetic field generated in the Earth’s outer core, whose origins and dynamics remain elusive. Jerks appear as ‘v’ or ‘^’ shapes in the secular variation, the first time derivative of the magnetic field (Figure 1). Understanding the rapid behaviour that jerks represent may lead to an improved ability to predict the future variations of the geomagnetic field.

Geomagnetic observatories, run by institutions such as the British Geological Survey (BGS), monitor the Earth’s magnetic field and provide a constantly updated database of geomagnetic variations that can be used to investigate jerks.

Brown et al. [2013] developed a probabilistic technique to identify jerks in observatory time series, studying monthly mean data from the period 1957 to 2008. They suggested that jerks are far more common than previously thought. Recently developed geomagnetic field models, such as CHAOS-4 by Olsen et al. [2014], have noted several jerk-like variations since 2008 which have yet to be studied in detail. This project involves applying the technique of Brown et al. [2013] to recent observatory data to better understand and map these variations.

The student will adapt and run code (in Matlab) to identify and map jerks in a set of up to date observatory data, provided by BGS. The investigation of recent observatory data could be extended by comparison with time series from satellite and observatory measurement based models.

References


Separating signals: Directional analysis of geomagnetic observatory data

Supervisors: Will Brown [wb@bgs.ac.uk] (British Geological Survey) and Kathy Whaler (School of GeoSciences)

Suitable for: one/two semester (bear in mind BGS moves to Heriot-Watt campus during Semester 2)

Geomagnetic observatories, run by institutions such as the British Geological Survey (BGS), monitor the Earth’s magnetic field. The various signals from internal (e.g. core, crust) and external (e.g. ionosphere, magnetosphere) geomagnetic sources are recorded simultaneously and must be separated in order to be analysed further.

Wardinski and Holme [2011] document a method to remove secular variation, the time variations of the magnetic field, associated with the magnetospheric equatorial ring current from observatory time series. They use eigenvector analysis to separate North-South aligned external signals (Figure 1), indicative of the ring current, from the data leaving a cleaner representation of the internal geomagnetic field (Figure 2). Brown et al. [2013] applied this technique to a greater expanse of observatory data from 1957 to 2008.

This technique could be developed to search for other common signal alignments in the data. Such signals can be correlated with geomagnetic indices, measures of external magnetic field activity through time, to identify the responsible phenomenon. It may, for example, be possible to identify and remove auroral variations more completely using this method. If successful, this technique could lead to improved internal field models of the secular variation, less contaminated by unwanted external signals.

The student will adapt code (in Matlab) to perform the eigenanalysis and subsequent correlation with observatory data provided by BGS and geomagnetic indices available from the World Data Centre. The applicability to the modern era and/or to the historic data catalogue could be investigated.

References


**Joint interpretation of PP and PS fracture maps**

*Mark Chapman - Semester 1 project.*

Understanding the spatial variations of fracture systems is a key step in characterizing subsurface reservoirs, both for hydrocarbon production and Carbon Capture and Storage projects. Methods exist to map orientation and density of fractures using seismic data. Such methods are often based on measuring the directional variation of seismic properties—known as seismic anisotropy (Li, 1997). The methods can be applied either to standard P-wave data or to converted-wave (P-wave down, S-wave back up) data. When both PP and PS data are collected over the same area, we would hope that the fracture maps from the two methods would agree.

Recent industrial experience indicates that the PP and PS results often do not agree, and one recent project in fact showed strong anti-correlation between the results—what was shown as a high fracture zone on the PP map was a low fracture zone on the PS, and vice-versa.

At the same time, laboratory measurements on fractured and fluid-saturated rocks (Tillotson et al., 2014) have shown that seismic anisotropy depends systematically not only on the fracture system but also on rock type, porosity and fluid saturation. In particular, P- and S-wave anisotropy respond very differently to these parameters.

This project aims to understand the potential impact of the relations observed by Tillotson on PP and PS fracture maps. The student will create models with spatial variations of fractures, fluids, rock types and porosity, and calculate PP and PS anisotropy parameters. A key component of the project will be to understand what combination of circumstances can give rise to anti-correlation between the PP and PS responses. The student will also test some simple rock physics model based inversion schemes for the PP and PS data. Possible extensions of the project into a second semester would involve analysis of field data on the basis of the developed numerical results.

References


Seismic waves from a subsurface source — without using a subsurface source! [1 semester]

Prof. Andrew Curtis & PhD student Carlos da Costa Filho

Introduction

In applied geophysics, seismic data is frequently used to obtain structural and material information about the Earth. In exploration seismology, for example, active seismic sources (vibroseis trucks, air-gun arrays, etc.) are placed on the Earth’s surface (or sea) that generate seismic waves which travel through the Earth’s subsurface. When these waves return to the Earth’s surface after being reflected underground, they are recorded using seismometers (geophones or hydrophones). The seismic reflection method spans a series of techniques that address the problem of how to obtain indirect subsurface information from these reflected waves.

Recently, a new tool has been developed under the name of Marchenko redatuming. This method uses the reflection data and a smooth estimate of the subsurface velocities to construct responses from virtual subsurface sources. That is, using only information obtained at the Earth’s surface, we may estimate responses (including scattering!) as if we had placed sources underground. These newly obtained virtual responses may be used for a variety of purposes, including seismic imaging, redatuming and internal multiple prediction in acoustic and elastic media.

In theory, Marchenko redatuming constructs the exact responses; in practice, certain physical assumptions may not hold and estimates may be degraded. If the subsurface region contains only mildly curving interfaces, it performs excellently as can be seen Figures 1 and 2, but if it contains point scatterers or complex features (salt bodies) the method may not yield exact responses. Therefore, there are still pertinent theoretical and practical issues that underlie the Marchenko method.

Figure 1: Comparison between common-shot gathers from true subsurface source (left) and the Marchenko estimate (right).

Figure 2: Traces from true subsurface source (black) and the Marchenko estimate (red).
Project

The Edinburgh Interferometry Project led by Professor Andrew Curtis has been engaged in developing theory, applications and numerical algorithms related to the Marchenko methods in relation to exploration seismology. Nevertheless, not many works have yet been developed about these methods specifically in the presence of scatterers. The goal of this Project is to investigate how the physical assumptions in the Marchenko methods affect the response estimates in the presence of scatterers, and if better assumptions may be found to improve them.

The student will be guided in generating the synthetic data from a scattering Earth model to be used in this Project, and in applying the standard Marchenko method to it. The student will then be expected to investigate how modifications of the method may affect the estimates of the responses.

The student must be comfortable in a UNIX environment and must have some experience with the MATLAB environment or the Python programming language. While no extensive coding will be needed, the student will need to be comfortable in adapting the already written codes.

Introductory reading


PDFs of all references are available at the webpage of Kees Wapenaar from Delft University.
A method developed 10 years ago known as seismic wavefield interferometry is revolutionising the fields of earthquake and exploration seismology. Traditionally, seismologists must wait for an earthquake to occur, or initiate an artificial source, before they can record wave energy propagating in the Earth. However, naturally occurring waves (for example those caused by wind and waves) are travelling in the Earth all the time, propagating through the same subsurface as earthquakes and explosions, and so contain similar information about the internal structure. These naturally occurring waves are usually regarded as ‘noise’ and much time and energy is put into trying to remove them from seismic data. The new techniques, however, allow us to extract a signal containing useful information from such ‘passive’ seismic data.

The interferometry technique involves cross-correlating seismic noise data recorded at two stations. The result is the “virtual” surface wave seismogram that would be obtained at one of the stations if there had been a real earthquake at the other. The virtual seismogram can then be treated like a real seismogram when using traditional methods to image the Earth’s interior e.g. surface wave tomography. The top trace 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 by applying interferometry to every station pair in the entire Californian seismic network. The features of the tomographic map correspond very well with the known regional geology.

Figure 1: (a) seismograms for Californian stations PHL and MLAC at 5-10s period, (b) high resolution group speed map for 7.5s period. From Shapiro et al. (2005).
In a previous project an undergraduate (now Dr. Erica Galetti) applied these methods to stations across the Scottish Highlands (Nicolson et al., 2011). Erica Galetti then did a PhD here in Edinburgh on similar methods but applied to Love waves across the UK. Dr. Heather Nicolson herself did a project on this topic when she was an undergraduate here, and then a PhD using the methods to perform Rayleigh wave tomography across the whole of the UK. Dr. Elizabeth Entwistle progressed through the same route, but devised and tested a method to measure seismograms of old earthquakes on newly-installed seismometers. All of the papers from these previous Geophysics-undergraduates are on the web link below.

This Project – The Edinburgh TerraCorrelator: The above students all performed interferometry using old data, months or years after the data had been recorded and stored. This project aims to carry out similar types of studies but using nearly real-time data streams: to perform passive seismic interferometry between seismometers across the UK and elsewhere, then apply various analysis methods such as surface wave tomography (to create maps as in Figure 1), or coda wave interferometry (to look for time-dependent changes in the Earth), in order to investigate the structure of the subsurface in near-real time as the data are being recorded. This will make it possible to have live tomography maps – updated automatically continuously or periodically as new data arrives at seismometers across the UK. The project will make use of a new super-computer system installed in Edinburgh, the TerraCorrelator – a machine designed to perform the required cross-correlations hundreds of thousands of times per hour, and with real-time data feeds from world-wide seismometers. This project should contribute towards a scientific publication.

You should be comfortable working in a UNIX environment, should already be familiar with the Python programming language, and will be required to learn Python in detail during the project and to work with it extensively. This project is for 2-semesters only.

Introductory Reading:


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Figure 1: (a) seismograms for Californian stations PHL and MLAC at 5-10s period, (b) high resolution group speed map for 7.5s period. From Shapiro et al. (2005).
As an undergraduate, Erica Galetti applied these methods to stations across the Scottish Highlands in a 4th year project (published in Nicolson et al., 2012), and then did a PhD here in Edinburgh on similar methods but applied to Love waves across the UK. Dr. Heather Nicolson herself did a 4th year project on this topic when she was an undergraduate here, and then a PhD using the methods for Rayleigh wave tomography across the UK.

**This Project:** The North Sea is a relatively shallow (<700 m) epicontinental sea which originated from crustal extension and thinning in the Triassic and Jurassic caused by the break-up of Pangaea, and opening of the Atlantic Ocean until the Cretaceous. It is regarded as a failed rift system and its subsurface is dominated by extensional structures such as horst and grabens. Following rifting in the Cenozoic, the cooling of the lithosphere caused substantial thermal subsidence and the formation of the North Sea sedimentary basin. Seismically the North Sea is characterised by a strongly attenuating zone which has been the focus of a number of studies in the last few decades. It mainly affects low-frequency surface waves propagating in the central and northern part of the basin.

This project will study the subsurface structure of the North Sea using interferometric Green’s functions obtained from the cross-correlation of 5 years of ambient-noise data. Using an existing set of vertical- and horizontal-component, inter-station Green’s functions, you will analyse surface-wave attenuation and create subsurface models of the North Sea from seismic traveltome tomography and depth inversion. A selection of the following will be included depending on the duration of the project: resolution analysis and interpretation of velocity structure and attenuation from Rayleigh- and Love-wave passive seismic tomography, and inversion of the tomography results for shear velocity structure with depth.

You should be comfortable working in a UNIX environment and with the Matlab programming language. The project will also include the use of the Seismic Analysis Code (SAC) and interaction with Fortran90 codes (no previous experience required as tutoring can be arranged throughout). This project can be for either 1 or 2 semesters.

**Introductory Reading:**


Assessing Geostatistical Simulation Algorithms in Different Geological Environments

Supervisors: Prof. Andrew Curtis and M. Atif Nawaz (The University of Edinburgh)

Petroleum reservoirs are heterogeneous. As more and more data is acquired, the geological complexity and degree of heterogeneity becomes more and more evident. The degree of heterogeneity of a reservoir is almost always underestimated because the amount of available data is always limited and is usually sparse compared to the scale of variation of subsurface geological properties. For instance, seismic data provides an exhaustive coverage of a reservoir but is limited in resolution, while data from drilled wells provides high resolution sampling of the subsurface but is sparse in terms of its 3D coverage.

In order to obtain geological models with reasonable resolution and exhaustive coverage across a reservoir, interpolation algorithms such as Kriging have been introduced to interpolate the high-resolution well data into the inter-well space using the 3D seismic images as a guide. However, they lack geological realism, and when tested they often fail to provide accurate reservoir volume estimates.

Alternative stochastic (statistical) simulation methods can be used to obtain detailed subsurface models while capturing geological realism. These algorithms should honour both the seismic and well-based data, and also the (subjective) geological expectations of expert geologists. The experts’ expectations are captured in the form of training images – images that represent the type of structures/properties that we expect to see in the Earth.

Unlike interpolation methods which only preserve the mean of the data and aim to provide locally best estimates of whatever property is of interest (e.g., rock type, or pore-fluid type), stochastic simulations also preserve the variance of the data and aim to provide a globally realistic model of the subsurface. They can also generate multiple equi-probable alternative models of the subsurface, which allows us to perform statistical inference using the models and to assess uncertainty in order to provide more accurate volume estimates.

Since stochastic simulations capture a fair degree of heterogeneity while honouring various types of available data, they may also allow model resolution to be improved beyond the resolution limits of the constraining seismic and well-based data (see Figure overleaf). For example, if our geological prior information dictates that gas must overlie oil which must overlie water, then models might predict this order of appearance of fluids in the subsurface all within half a seismic wavelength (which is roughly the limit of seismic resolution).

A number of stochastic simulation algorithms are being used in the petroleum industry. Different algorithms are used in different scenarios depending on factors such as type of geological property to be simulated, and the amount and type of conditioning data available. Different algorithms may be more suitable in some geological environments than others.

This 1- or 2-semester project aims to assess the ability of various geostatistical simulation algorithms to capture geological heterogeneity and realism, and improve model resolution under the constraints of available data and subjective geological knowledge on different types of geological environments. As a 2-semester project, it may be extended to evaluate different simulation algorithms in terms of computational efficiency, scalability and modifiability for

For more information contact: Prof. Andrew Curtis (Andrew.Curtis@ed.ac.uk)
the parallel computer architectures that are so pervasive and necessary in today’s professional Geophysical work environments.

Example Figure: An example of a stochastic simulation method.

Top-left: target structure (synthetic, but treated here as though it was the real Earth subsurface). Shale is black, sand filled with brine is orange, and sand filled with gas is blue. Top-right: Noisy synthetic P-wave impedance data constructed for the target structure (treated here as the measured P-wave impedance data). The sand and gas-sand targets are barely visible above the noise. Even with such noisy seismic data, by combining experts’ Geological information, the stochastic method is able to predict (lower-left) the probability of sand and (lower-right) the probability of gas sand at each point in the subsurface. These estimates are better than could be achieved using the noisy seismic data on its own.

Further Reading:


For more information contact: Prof. Andrew Curtis (Andrew.Curtis@ed.ac.uk)
Petroleum reservoirs are heterogeneous. As more and more data is acquired, the geological complexity and degree of heterogeneity becomes more and more evident. The degree of heterogeneity of a reservoir is almost always underestimated because the amount of available data is always limited and is usually sparse compared to the scale of variation of subsurface geological properties. For instance, seismic data provides an exhaustive coverage of a reservoir but is limited in resolution, while data from drilled wells provides high resolution sampling of the subsurface but is sparse in terms of its 3D coverage.

In order to obtain geological models with reasonable resolution and exhaustive coverage across a reservoir, interpolation algorithms such as Kriging have been introduced to interpolate the high-resolution well data into the inter-well space using the 3D seismic images as a guide. However, they lack geological realism, and when tested they often fail to provide accurate reservoir volume estimates.

Alternative stochastic (statistical) simulation methods can be used to obtain detailed subsurface models while capturing geological realism. These algorithms should honour both the seismic and well-based data, and also the (subjective) geological expectations of expert geologists. The experts’ expectations are captured in the form of training images – images that represent the type of structures/properties that we expect to see in the Earth.

Training image selection (the geological prior information) may have a substantial influence over the final statistics presented. These statistics are subsequently used to estimate probability of a successful reservoir development, and thus influence future investment decisions. An optimum (best-performance) training image would accurately reflect the subsurface properties of the region of interest. However, these are predominantly unknown at the time of training image creation, thus a circular problem arises – geological prior information is required that best reflects the subsurface structures of a region that it is being used to estimate. With no objective alternative, this has resulted in the subjective selection of geological priors, with geologists asked for their best-guess of the subsurface based on their previous experience and any available geological information. How well these subjective priors represent the subsurface however is unknown and thus there may be large unknown uncertainties attached to the output of these geo-statistical models.

Sensitivity analyses can greatly contribute to the quantification of uncertainties arising in cases where subjective decisions are unavoidable. These are undertaken by varying the subjective parameters and monitoring any consequent variation in output.

This 1- or 2-semester project aims to assess the sensitivity of an existing geo-statistical algorithm (Walker & Curtis, 2014, shown below) to variations in the training image employed. These may include (but are not limited to) the number of rock types, the structure dimensions (size and shape), boundary variations (smooth transitions between rock types vs distinct changes vs fractured edges), and the relative size of the training and target images. The results
will aid quantification of subjective uncertainty and shed further light on the significant issue of non-uniqueness within seismic inversion. As a 2-semester project, it may be extended to evaluate different geological environments in order to assess common well-performing traits and thus potentially improving current training image guidelines, or within situations where distinctly different geological interpretations are possible.

Further Reading:


Example Figure (Walker & Curtis, 2014): An example of a stochastic simulation method: Top-left: target structure (synthetic, but treated here as though it was the real Earth subsurface). Top-right: Noisy synthetic P-wave impedance data constructed for the target structure (treated here as the measured P-wave impedance data). The sand and gas-sand targets are barely visible above the noise. Even with such noisy seismic data, by combining experts’ Geological information captured in a training image (centre), the stochastic method is able to predict (lower-left) the probability of sand and (lower-right) the probability of gas sand at each point in the subsurface. These estimates are better than could be achieved using the noisy seismic data on its own, but the resulting probabilities do not adequately reflect the uncertainty inherent in the results by incorporation of the subjective geological prior.

For more information contact: Prof. Andrew Curtis (Andrew.Curtis@ed.ac.uk)
Measurement and prediction of diffuse solar radiation

Richard Essery (richard.essery@ed.ac.uk), Chris MacLellan (NERC FSF)
20 credits, semester 1 or 2

Total shortwave radiation arriving at the Earth surface (“global radiation”) consists of direct radiation from the Sun and diffuse radiation scattered by molecules, droplets and particles in the atmosphere. Global radiation can be measured with pyranometers, which are fairly expensive for good quality instruments. Diffuse radiation can be measured by simply shading a pyranometer, which can be done at little additional cost using a shading ring, but careful alignment of the ring is required. Direct radiation can be measured by a sun photometer – a radiometer with a narrow field of view that automatically tracks the Sun as it moves in the sky. Sun photometers are very expensive instruments but can make measurements of radiances in multiple wavelengths, which can be inverted to estimate amounts of aerosols and water vapour in the atmosphere.

We have recently installed a diffuse radiometer in the GeoSciences weather station on the roof of JCMB, and there is a sun photometer on the roof of the BGS building. The aims of this project will be to use statistical analysis of data from these instruments and simple models to determine how well diffuse radiation can be estimated by comparing measured global radiation with modelled fluxes for clear skies and how well aerosol optical depth can be estimated from broad-band diffuse radiation measurements.

The data for this project could be handled in Excel, but more sophisticated analyses and a more professional presentation of the results will be possible using Python (preferred), IDL, Matlab or R.

Background reading:

http://solarenergyengineering.asmedigitalcollection.asme.org/article.aspx?articleID=1457653


The structure of Chinook winds in Western Canada

Richard Essery (richard.essery@ed.ac.uk)
20 credits, semester 1 or 2

Warm, dry downslope winds occur on the lee sides of many mountain ranges around the world and often have local names, such as Föhn in the Alps, Zonda in the Andes and Chinook in the Rockies. These can be extreme weather events; in Calgary, Alberta, temperatures rose by 30°C in just 4 hours during a Chinook on 11 January 1983, and Chinooks caused more than $200 million of wind damage in November 2011. The classical explanation for the formation of such winds is that air ascending windward slopes becomes saturated and cools at the wet adiabatic lapse rate but then warms at the greater dry adiabatic lapse rate as it descends the lee slope. Alternatively, low level flow can be blocked by the mountains and upper-level air descends the lee slope without cooling and precipitation on the windward side.

In this project, data from Canadian weather stations will first be used to identify a set of major Chinook events. Ground-based near-surface and upper-air observations are too sparse to track the development of air masses as they cross the Rockies, but assimilation of these observations in numerical weather prediction systems provides complete 3D analyses of the atmosphere; analyses from the European Centre for Medium Range Weather Forecasts will be used to investigate the synoptic situations leading up to the selected events. A trajectory model will be used to track air parcels backwards and test hypotheses for the development of the winds.

This project will require the use of a programming language with utilities for reading and mapping large datasets in binary formats commonly used for meteorological data. Basic programs will be supplied in Python but will have to be modified as the project progresses, providing an excellent opportunity to apply skills learnt in Computational Modelling for Geosciences to meteorological problems.

Background reading:


http://dx.doi.org/10.1080/02723646.1997.10642610

East windy and west endy: Extent and persistence of haar

Richard Essery (richard.essery@ed.ac.uk), Christine Duffy (Met Office)
20 credits, semester 1 or 2

Haar – fog formed by cooling of a warm air mass as it passes over cooler sea water and is then carried onshore by wind – is a common feature of the east coast of Scotland in spring and summer, sometimes giving cold and damp conditions in Edinburgh while Glasgow is enjoying warm sunshine. The aim of this project is to use data from Met Office weather stations across Scotland to identify occurrences of low visibility confined to the eastern side of the country. Having identified a number of such events, synoptic charts can be examined to determine the conditions in which they occur and satellite images can be examined to determine their extent. The persistence of haar events could be compared with simple methods for forecasting fog clearance; if there is a haar during the course of the project (most likely early in semester 1 or late in semester 2), you could compare your forecast with the official forecast from the Met Office.

Apart from giving insight into atmospheric processes and measurements, this project will provide experience with the common geophysical requirement of handling large datasets. The data analysis would be possible in Excel, but IDL, Matlab, Python or R would provide more sophisticated utilities for reading, analysing and plotting the data. The Edinburgh branch of the Met Office will collaborate in the supervision of this project.

Background reading:

Chapter 5 in Ahrens, Meteorology Today.


Using observations of glacial stick-slip to characterise effects of subglacial lake drainage events on ice sheet flow

40-credit project

Supervisors: Dan Goldberg and Giorgos Papageorgiou
(contact: dan.goldberg@ed.ac.uk)

The aim of this project is to understand how subglacial lake-draining events in Antarctica influence the subglacial environment and the flow of the ice sheet, through the use of a model of ice movement together with high-frequency satellite and ground observations of a fast-flowing ice outlet.

While most glaciers and ice sheets are thought to flow steadily, it is known from GPS deployment that Whillans Ice Stream (a 100-km wide region of the Antarctic Ice Sheet which flows into the Ross Ice Shelf) flows in punctuated episodes of rapid movement, sometimes referred to as “Stick-Slip” motion. Long periods (10-20 hours) of stagnancy are broken by rapid surges of movement, lasting less than half an hour but with equivalent rates of 15-20 kilometers per year. Thought to be caused by failure at the ice-bed interface, the episodes are not unlike small earthquakes that happen with some degree of regularity. Meanwhile, fast movement of ice sheets is facilitated by sub-ice transport of water which pressurizes and lubricates the ice-bed interface. It is known from satellite altimetry that subglacial lakes periodically form and drain, flooding the underside of ice streams and potentially affecting their flow.

This project will bring together an inertial model of stick-slip motion with a long time series of stick-slip event observations and subglacial lake height, as well as Ross Sea tidal height (which modulates stick-slip cycling). The model will draw from previous studies (Winberry et al, 2009, J Geopys Res; Sergienko, 2009, Ann. Glaciol) and make use of rate-and-state friction, commonly used to describe rock friction in earthquake faults (e.g. Rubin and Ampuero, 2009, J Geopys Res). The methodology is as follows: use stick-slip and tidal data in the absence of lake-draining events to tune/calibrate the friction parameters of the model in terms of frequency and amplitude. Then, use the stick-slip data during lake-draining events to infer the effect that the lake-draining has on effective pressure at the ice-bed interface and/or stress loading. The results will yield a better understanding of how lake-draining affects subglacial water pressures, which may in turn reveal information regarding the subglacial hydrological environment.
Changes in European climate: How cold are wet winters, and how dry are hot summers?

Gabriele Hegerl (gabi.hegerl@ed.ac.uk) and Debbie Polson

One semester project, potentially extendible to two semesters.

While wet summers in the UK tend to be cold, globally, rainfall increases as temperatures increase due to increasing humidity. In this project, you will analyse European mean and subregion (British Isles, Mediterranean, Northern Europe, Central Europe) temperatures and precipitation and see to what extent anomalous conditions in temperature are linked to anomalous conditions in precipitation. You will also check if one variable predicts the other, such as do dry springs lead to hotter summers, as observed during the 2003 heat wave?

European data will be supplied, both from a climate model and from observations, but the student will do the analysis, and connect it to available literature. In the course of the project you will also analyse if long-term changes (e.g. trends or differences between two periods of decades) connect between precipitation and temperature, and to what extent recent trends or changes in both variables show a move towards a different climate. If the project is extended to two semesters, the role of circulation features such as the North Atlantic Oscillation in these combined temperature and precipitation data will be further explored. The project is ideally done in matlab, NCL or IDL.

References:


Temperature anomalies during the 2003 heat wave, from Reading University via Wikipedia
Do islands get drier after volcanic eruptions, and for how long?

Gabriele Hegerl (gabi.hegerl@ed.ac.uk), Debbie Polson, and Carley Iles

This project examines a database of precipitation from islands with longterm rainfall records. Islands are interesting to investigate because they reflect precipitation changes over ocean, which tends to show particularly clear changes that are not complicated by water availability constraints over land (Hegerl et al., 2015). Most islands are situated over wet regions, which tend to get drier following volcanic eruptions due to reduced evaporation and a more stable atmosphere. Interestingly, this drying response in climate models is far longer-lived over ocean than land. Over land, the model response is strongest in the first year and disappears quickly while the ocean response lingers for a few years (Iles et al., 2014). However, such a long response is not observed in satellite retrievals of precipitation. Is this because satellites don’t capture the full response, or are climate models wrong? You can help answer this question by analysing island precipitation following volcanic eruptions.

The project is ideally done with matlab, IDL or python, but excel might work as well. Island data will be provided to the student.

References:


Monitoring of CO2 and other pollutants on Edinburgh City streets

Jim Jack (jim.jack@ed.ac.uk) 1 or 2 semester project

There is a great deal of concern about rising levels of CO2 and the effect this may have on long term climate change. While there are many space based instruments probing the atmosphere and collecting data on a global scale, there are few experiments attempting to measure and map CO2 concentrations at street level.

We have a number of portable CO2 sensor and are about to integrate these with GPS receivers. The CO2 sensor is based on a commercial sensor made by Gas Sensing Solution GSS, located in Cumbernauld near Glasgow. With the current battery, approximately 3 hours of data may be recorded. This is then subsequently downloaded and after some processing is plotted on a map using Google Maps. During March 2014, the instrument was carried on a route within Edinburgh City and data plotted. The concentrations measured were then correlated with the local environment, traffic volume and weather.

The first step in the Project is to collect the instrument and understand what is available and how calibration may be addressed. A trial data collection and analysis could be carried out on the Kings Buildings campus by collecting data on a defined path [to be defined by the student] at different times of the day and perhaps different weather conditions. The student would have to decide this and the spatial separation of your observation points. The data, in the form of PPM CO2, can then be plotted on a map of the KB Campus. Features may emerge which are worth exploring in more detail. The data recordings give CO2 concentration, time and location. The student will then decide on how to present the data in the most useful manner and if correlations are to be investigated.

Of more interest would be to carry out a survey along certain Edinburgh streets including Princes Street at different times of the day and in different weather conditions and plot a concentration profile superimposed on a map. If there is time after this an additional set of measurements at right angles to Princes Street, say along Frederick Street from Queens Street to the Gardens would be very interesting. Alternate routes across the city would also have value. The student will be expected to plan and execute the data gathering campaign.

The project is somewhat open-ended as one could collect data for the next ten years, so the student will have to limit the project by the amount of time to be invested. It is also difficult to predict the value of the results or their potential civic interest, but Edinburgh City Council are interested to know if they are complying with any relevant legislation covering both CO2 levels and pollution. The student may also have to interact with the general public if you are making measurements in the city and you are engaged in conversation.
Monitoring of CO2 Using Integrated Path Absorption

Jim Jack (jim.jack@ed.ac.uk) 1 or 2 semester project.

There is a great deal of concern about rising levels of CO2 and the effect this may have on long term climate change. While there are many space based instruments probing the atmosphere and collecting data on a global scale, there are few experiments attempting to measure and map CO2 concentrations at low level within the atmosphere.

Within the School of GeoSciences, we are building a large laser based instrument to measure trace gases in the lower troposphere. The concept uses the absorption of a specific laser wavelength by an absorption line of the trace gas of interest. We are currently developing a Mark 2 instrument which will measure CO2 along a sightline of several kilometres length. As part of the development and test it is intended to measure CO2 concentration using the simpler technique of Integrated Path Absorption.

With the instrument installed in a room on Level 6 in the JCMB, and a receiver mounted a short distance from the instrument, likely on the roof of the Murray library, the absorption of the laser beam over the separation will be measured. Using standard absorption theory, the average concentration of CO2 within the path will be calculated. An opportunity is offered to take part in the operation of the instrument, the collection of data and the calculation of trace gas concentration.

This is an opportunity for a student to become involved in an on-going research project and would be attractive to a student with interests in the engineering of instruments to measure our environment by working with an existing team. While the long term project objective is to measure CO2 concentration along a path of several kilometres using Differential Absorption Lidar, involvement in the initial development and testing of functions such as Integrated Path Absorption, offers an introduction to the problems of accurately monitoring our environment remotely.

The student project activity would need to match the availability of the instrument and its successful operation and could include simple modelling, data gathering, analysis and understanding of the basic operation of Lidar.
Water in the Earth’s lower mantle

Area: Solid Earth geophysics and high-pressure petrology
Supervisor: Tetsuya Komabayashi (tetsuya.komabayashi@ed.ac.uk)
Semester 1 or 2, or across 2 semesters

Project summary
The subduction of oceanic lithosphere transports water into the mantle (Fig. 1). The concentration of water has significant effects on mantle properties such as melting temperature, rheology, and electrical conductivities. Understanding of the mechanisms of water circulation in the mantle will therefore provide vital information about how water is related to the dynamics and evolution of the solid Earth. For water subduction, stability relations of hydrous phases in subducting slabs are essential because they carry water into the deep mantle. Such phase relations to the mantle transition zone (410-660 km depth) were extensively studied while those in the lower mantle have been poorly understood.

This project is aimed at elucidating the stability relations of the hydrous minerals and fluids under lower mantle conditions. You will employ analyses of published experimental papers and construct a phase diagram which is applicable to the lower mantle conditions. Results of this project will contribute to our understanding of behaviour of water transported in the deep Earth. Basic knowledge of petrology and chemical thermodynamics is beneficial.

References
Evolution of induced seismicity

Supervisors: Ian Main (ian.main@ed.ac.uk), Mark Naylor (mark.naylor@ed.ac.uk), Andrew Jupe (EGS Energy Ltd); Single semester project, potentially extendible to two semesters

Earthquakes can be induced by a number of engineering activities, including coal mining, hydrocarbon extraction, dam impoundment and extraction of geothermal energy. Conventional ‘traffic light’ systems introduced by regulators often concentrate not on a given level of risk, but on avoiding exceeding a specific magnitude threshold, for example $M=0.5$ in the case of hydraulic fracturing in the onshore UK. Such limits are often determined relative to an induced event that is felt by the general public and reported. In this project you will have access to data on induced seismicity recorded as part of the UK ‘Hot Dry Rock’ geothermal experiment in Rosemanows, Cornwall. You will compare the overall level of seismicity and the evolution of the extreme magnitude events with the total injected volume of water, and develop an operational forecasting model for both the overall risk and the occurrence of extreme magnitude events, including estimates of the uncertainty and variability. You will then compare this to published data based on water injection in a variety of other cases of induced seismicity, to acoustic emissions generated in laboratory experiments, and also to the results of a numerical model for the evolution of such extreme events in a complex medium.

References

Seismotectonics of Nepal

Supervisors: Ian Main (ian.main@ed.ac.uk), Mark Naylor (mark.naylor@ed.ac.uk); Single semester project, potentially extendible to two semesters

The April 2015 Nepal earthquake (also known as the Gorkha earthquake) killed over 9,000 people and injured more than 23,000. Aftershocks are continuing, and the risk from future events remains high. In this project you will study the forces responsible for the present-day tectonics of Nepal and the surrounding regions, using the global centroid moment tensor catalogue to plot event locations and density, and to infer the regional strain tensor field. You will then compare this with independent observations of the deformation field from satellite-based geodesy and from a literature based survey of the geological record. You will also quantify the degree of seismic coupling, thereby allowing an estimate of the potential for even greater events in future.


The mesosphere, lying at altitudes between 50 and 80 km, is one of the least-understood regions of the atmosphere. One way to study its composition is to use a millimetre-wave receiver (essentially a radio telescope) sited on the ground (preferably on a high mountain). The spectra from such an instrument can provide information on the mixing ratio of a variety of chemical species of interest. Recent improvements in technology are permitting easier access to higher frequencies.

This, then, poses these questions: which species might one usefully measure with this technique? What characteristics (bandwidth, resolution, noise level) would a spectrometer require in order to make the measurement? How badly affected would the measurement be by a wet troposphere (and hence, how high a mountain would you need)? The basic technique of the project is to simulate a measurement using a readily-available radiative-transfer model (ARTS: see http://www.sat.ltu.se/arts) and apply the standard techniques of inverse theory[1] to the simulation to determine what information the measurements would contain. Several projects along these lines would be possible, to answer such questions as:

- Which of the various absorption lines of HCN is most suitable for sounding the mesosphere?
- Is it possible to use ground-based sensing of HCl to track the chlorine loading of the middle atmosphere?

Two years of measurements of the 230GHz carbon monoxide spectral line taken from the Norwegian Antarctic base using the British Antarctic Survey’s microwave radiometer. The project was run in 2011-12 to study CO. If run again, it would target different species.

These projects would probably be 20-point projects available in either semester. It would be suitable for students on any physics or geophysics-based degree programme. The ARTS output would be analysed using a data analysis language such as R, MATLAB, Octave or python/matplotlib.

Title: Using a trajectory model to track SO\textsubscript{2} from volcanoes
Area: Atmospheric physics
Contact: Hugh Pumphrey (Room 313, Crew Building, extn. 50 6026, email: hugh.pumphrey@ed.ac.uk)

Trajectory modelling is an established technique for studying pollution from isolated point sources such as volcanos, chemical plants, disasters at nuclear power stations, and so forth. The widely-used trajectory model FLEXTRA is freely available (http://transport.nilu.no/flexpart) and relatively easy to use. The wind fields needed to drive the model are also freely available. The model can either trace air parcels forwards in time in order to see where polluted air might have gone, or backwards in time in order to see where an airmass observed to be polluted might have come from.

The MLS instrument on NASA’s Aura satellite has been observing sulphur dioxide (SO\textsubscript{2}) in the stratosphere since 2004. Although there have been no large volcanic eruptions in that period there have been a number of moderate-sized ones which have injected measurable amounts of SO\textsubscript{2} into the stratosphere. The basic idea of the project would be to identify these events and then to run back trajectories from the observations of high SO\textsubscript{2} to locate the volcano from which the SO\textsubscript{2} came.

Map on left shows an example of trajectories. These are run backwards from locations where MLS observed unusual amounts of CO. The trajectories go past the site of the Black Saturday bush fires of February 2009 [1]. Map on right shows MLS observations of SO\textsubscript{2} a few days after the eruption of the volcano Sarychev in Japan, in 2009. This eruption was analysed by a student in 2011-12. The 2008 eruption of Kasatochi has also been done, but there are a number of other eruptions in the record available for study[2].

An extension of the project would be to use the Flexpart particle dispersion model to attempt to make more detailed simulations of the plume. The basic project could be a 20-point honours project for either the Physics or Geophysics degree programme groupings. If suitably extended it would be suitable for a 40-point geophysics project or an M.Phys/M.EarthPhys project.

It should be added that because trajectory modelling has wide applicability it could provide a basis for students to design their own projects. The project would require competence in a data-analysis language such as MATLAB, R, Octave, IDL, python/matplotlib etc. and also good general computing competence.


Title: Gravity surveying projects
Area: Solid-Earth Geophysics: Gravity
Contact: Hugh Pumphrey (Room 313, Crew Building, extn. 50 6026, email: hugh.pumphrey@ed.ac.uk)

Three of the School of GeoSciences' classic Lacoste & Romberg gravimeters have recently been serviced and are available for use in final year projects. The UK has all been surveyed at a resolution of about 1 km, but there are many possible targets which are smaller than this. A typical project would consist of a number of days fieldwork to collect gravity data, followed by mapping of the data and modelling of the possible underground density contrasts which might give rise to it. A GIS package (such as the freely available Quantum GIS from http://qgis.org/) is useful for the mapping the data. Possible targets include (but are not restricted to) the following:

(1) Density of volcanic intrusions by Nettleton's method

Edinburgh and East Lothian contain a number of isolated volcanic hills of which Arthur's Seat, North Berwick Law and Traprain Law are the most obvious. The density of the basalt which makes them up could be estimated by making a profile of gravity measurements across the hill and then finding the density value which provides the best correction for the effect of altitude on gravity. Using a surveyor's level for the altitude surveying is difficult in these cases; an alternative method (such as a total station, of which we have one available) would need to be used.

(2) The gravity signal of a railway tunnel

A tunnel causes a mathematically simple gravity anomaly. Edinburgh has several examples, including the innocent tunnel under Pollock Halls / Holyrood park. (Students did this in 2012-13 and 2013-14, but I think that better results could be obtained using more closely-spaced points. It may also be possible to obtain a better value for the density of the surrounding rock by taking a measurement inside the tunnel.)

(3) The ancient volcanoes of Dunbar

The geology under the town of Dunbar is a mixture of sandstones (grey, beige) and volcanic rocks, which are in turn a mixture of (presumably) dense basalts (green) and (presumably) less dense tufts (orange). The town is not too hilly and has several long straight east-west streets, which would expedite a gravity survey. (This project has the potential to be expanded to a 40-credit project or an M.EarthPhys project.)

As a gravity survey requires a levelling survey, which is a 2-person job, a single student would require assistance in the field from the supervisor. It would also be possible for two students to work together in the field to carry out two different surveys, and then for each student to write up one of the surveys.
Title: **Time series analysis of gravity data**
Area: Solid-Earth Geophysics: Gravity
Contact: Hugh Pumphrey (Room 313, Crew Building, extn. 50 6026, email: hugh.pumphrey@ed.ac.uk)

One of the School of GeoSciences’ gravity meters has been left running and recording gravity for the last year or two (with some large gaps); the data have been archived at a rate of one point every 5 seconds. The data for the last week can (usually) be seen at [http://www.geos.ed.ac.uk/~hcp/gravity/](http://www.geos.ed.ac.uk/~hcp/gravity/).

This record contains a number of features including the daily gravity tide, signals from earthquakes, and longer noisy periods which might be associated with storms and ocean waves.

![Graph showing gravity data](image)

The figure shows an example of the data, taken from July 2014. Note the earthquake on 7 July and the period of non-earthquake noise during 3-4 July.

The project would consist of a detailed analysis of this time series with the intention of answering some of these questions:

1. How strong (and how close) does an earthquake have to be in order to prevent gravity surveying from being carried out?
2. Are the bursts of non-earthquake noise correlated with periods of high wind? If not, what does cause them?
3. Are there any other features in the data beyond those I have identified?

This project would require competence in a programming language designed for data analysis, such as MATLAB, R, python/matplotlib, IDL etc.
The gravity of the mainland of the United Kingdom has been surveyed at a resolution of about one point per kilometre. The data are freely available from the British Geological Survey at http://www.bgs.ac.uk/products/geophysics/landGravity.html Euler deconvolution [1] is a technique for analysing large quantities of potential field data (usually gravity or magnetic field data) in order to identify geological structures.

The figure shows an example of the technique applied to magnetic field data. The project would consist of applying the same technique to the BGS gravity data and attempting to interpret the results in terms of the known geology. The technique requires horizontal and vertical gradients of the field; the measurements do not contain these so they would have to be calculated using Fourier methods. The project would require competence in a programming language designed for data analysis, such as MATLAB, R, python/matplotlib, IDL etc. and would provide experience in the use of a GIS. A basic study of a sensibly chosen area would form a 20-credit project --- this could be extended to a 40-credit project by analysing a larger area and doing a more detailed geological interpretation. A slight extension of the scope would make the project suitable as an M.EarthSci project.

What has driven the evolution of atmospheric methane concentrations since 1850?

David Stevenson (dstevens@staffmail.ed.ac.uk)

Single semester project, potentially extendible to 40 credits.

Methane (CH\textsubscript{4}) is the second most important anthropogenically emitted greenhouse gas. Its atmospheric concentration has grown from a pre-industrial value of about 700 ppb to over 1800 ppb (see figure). Recent decades have seen large variations in its growth rate, that currently have been interpreted in a variety of different ways. These boil down to changes in either the sources or sinks of CH\textsubscript{4}. The main sink for methane is reaction with the hydroxyl radical (OH). Concentrations of OH are influenced by many factors, including temperature, absolute humidity, and concentrations of atmospheric nitrogen oxides.

This project will use CH\textsubscript{4} measurements and simple models of the global CH\textsubscript{4} budget to explore different influences on its evolution. Recent modelling with full atmospheric chemistry/climate models has produced estimates of the impact of various anthropogenic emissions on the methane lifetime, and also how water vapour and temperature have affected the methane lifetime (i.e. its sink).

The project will involve manipulating data and simple models using a programming language of your choice.

Reference