Dynamic Earth, Surface Processes & Natural Hazards

Projects 2014-2015

(1) **Climate Scenarios for Water Security Assessment in major African river basins**
Simon Dadson (Geography) and Fredericke Otto (Geography)

This project will use regional climate models coupled with river flow routing models, in conjunction with the on-going Oxford projects weather@home and ACE-AFRICA, to investigate future scenarios of hydrological change and water security in major river basins in Africa.

(2) **Geomicrobiology of desert surfaces: How do microbial processes influence erosion and the mobilisation of dust?**
Prof. Heather Vilees (Geography)

The geomicrobiology of arid and semi-arid areas is poorly understood, but it is hypothesized that microbial biofilm communities play key roles in many surface processes including facilitating geochemical transformations, and retarding physical erosion and dust mobilisation. Dust mobilisation from desert regions is known to be an important contributor to Earth system behaviour, and microbial biofilms are commonly found on dusty desert surfaces. In order to answer the question 'How do microbial processes influence erosion and the mobilisation of dust?' the project has two main aims: a) To characterise the ecological structure and function of microbial biofilms across a climatic gradient in Namibia, b) To quantify their influence on surface processes. In order to achieve these aims, the project will combine cutting edge molecular phylogenetic techniques to provide culture-independent assessments of the microorganisms present, novel field monitoring techniques including miniaturised sensors, and controlled laboratory experimentation.

(3) **Bayesian calibration for flood risk analysis**
Prof Jim Hall (Geography) & co-supervisor in Statistics

Even in advanced computer simulations, predictions of the extent and depth of floods are inherently uncertain, due to observation errors, uncertainties in model calibration and structural uncertainties: the miss-match between models and reality. There are many methodologies that address these sources of error, in order to provide scientists and decision makers with better information about the uncertainties in flood predictions, but few that deal with all sources of uncertainty. Bayesian theory for the calibration of computer models is, arguably the most complete and coherent approach to dealing with these multiple sources of uncertainty, and in particular the very difficult problem of the discrepancy between models and reality. The aim of the proposed doctoral project is to extend the use of Bayesian statistical methodology to quantify the uncertainties in the coupled set of processes that lead from rainfall, to runoff and river flooding.

(4) The role of water quality in regional water resources assessment
Prof Jim Hall (Geography) & Prof Paul Whitehead (Geography)

Water quantity and quality are often dealt with as separate issues. Water resources management plans aim to ensure a secure supply of water over some future planning horizon, whilst setting aside sufficient water to allow a healthy aquatic environment in rivers and wetlands. However, the health of the aquatic environment is also profoundly influenced by water quality and, in a changed climate, water temperature. Moreover, the usability of water in reservoirs depends on its quality, which may deteriorate as reservoir levels go down and temperatures increase. Thus there is a strong interaction between management of water supplies and water quality. This DPhil project aims to take an integrated approach to the assessment and management of water quantity and quality. It will develop and demonstrate a probabilistic approach to managing the risks of water shortage and harmful water quality.

(5) **Testing models of dune system sensitivity to climate change: empirical protocols and numerical analysis**
Prof. David Thomas (Geography), Dr. Richard Bailey (Geography)

This project will use OSL dating applications and modelling to greatly improve the utility of desert dune accumulation records as proxies of desert climate change in the Quaternary. Two approaches will be taken: a) global dune age datasets will be applied to a new numerical model of dune accumulation (Bailey and Thomas 2013) to establish record sensitivity in relation to other palaeoproxies; b) new empirical sampling and OSL dating frameworks will be developed from cores to be collected from a desert dunefield to establish appropriate analytical frameworks for achieving meaningful records of climate change.

(6) **Determining arid landscape sensitivity to natural and human disturbance using OSL dating (cases in China, Mongolia or the Kalahari)**
Prof. David Thomas (Geography), Dr. Richard Bailey (Geography)

This project will use novel applications of OSL dating and climate datasets to establish the frequencies and sensitivities of arid landscapes to both natural and human induced disturbances (desertification). This approach will allow for the first time quantification of the magnitude of frequency of human disturbances compared to those resulting from natural climate variability, allowing human impacts and natural hazards to be distinguished. Through application to data collected from the Kalahari, China or Mongolia, a new methodology for assessing desertification risk will be developed.

(7) **Aeolian dust emissions from dryland landscapes in a warming world**
Prof. David Thomas (Geography), Dr. Giles Wiggs (Geography)

This project will test the assertion that atmospheric dust sources will change markedly under global warming impacts, particularly the hypothesis that desert interdunes will become major sources of atmospheric dust during this century. Focussing on the SW Kalahari, predicted to experience major landscape changes in a warming world, the project will: use state of the art monitoring equipment to capture atmospheric and land surface data pertinent to dust emission over a range of dryland land surfaces, (pans, dry valleys, dunes interdunes); measure and monitor current natural dust emissions and use experimental plots to replicate future surface changes; model future dust emission under GCM-driven climate scenarios for the next 100 years.

(8) "Reconstructing past climates and physiology using new old molecules"
Prof Ros Rickaby and Dr Renee Lee (Earth Sciences)

We have pioneered novel approaches for extracting organic molecules associated with biominerals within ocean sediments. This provides an exciting new avenue for reconstructing the biochemistry of biomienralisation over millions of years as well as allowing insight into evolving physiological adaptation to the environment captured within isotopes of these molecules. This project aims to calibrate and apply our new techniques to develop records of evolving mineralisation in response to altered saturation state of the ocean in the past. The student will be trained in molecular biological techniques, culture of algae and state of the art isotopic analysis.

(9) "Phytoplankton optimisation to evolving carbon: Implications for the past and future"
Prof. Ros Rickaby and Dr Ben Rae (Earth Sciences)

This project aims to elucidate the architecture and function of the Carbon Concentrating Mechanism in eukaryotic algae. It is well acknowledged that ambient carbon dioxide concentrations in seawater and suboptimal for the inefficient Rubisco enzyme, which underpins all marine photosynthesis. Algae therefore have had toe volve ways of concentrating carbon within the cell to elevate the carbon dioxide concentration at the active site of Rubisco. Very little is known in detail about the eukaryotic CCM although carbonic anhydrase, bicarbonate transporters and the pyrenoid are all implicated. This project aims to furnish detail about these eukaryotic CCMs largely through detailed visualization of cells using state of the art TEM, confocal microscopy and NanoSIMS, to assess whether all species are optimally adapted to their environment or whether there are winners and losers in the carbon race.

(10) Understanding the volcanism of the Tasmantid seamount chain
Tamsin Mather (Earth Sciences), David Pyle (Earth Sciences), Lara Kalnins (Durham), Ben Cohen (Glasgow)

The Tasmantid seamount chain deep under the surface in the Tasman Sea is one of three sub-parallel lines of volcanoes (along with the East Australian Volcanic Chain and the Lord Howe Seamount chain) in the eastern Australia and Tasman Sea region. These chains are separated by an average of only 500 km and formed contemporaneously over a period spanning at least 35 to 5 Ma. The East Australian Volcanic Chain, the best studied of the three, shows a strong age progression from north to south, as do the limited data available from 1980s expeditions to the Tasmantids. Many fundamental questions remain about how this unusual pattern of volcanism formed and remained stable for at least 30 Myr and how it interacted with the changing regional tectonics during that period.

This project will focus on tying together the petrology and geochemistry of recent dredge samples with the physical volcanology (from recent bathymetry surveys) of three of the seamounts along the Tasmantid chain: Stradbroke, Recorder, Cato and Wreck. A particular focus will be on discerning any systematic volcanological, petrological or geochemical differences that might arise due to seamounts like Cato in the north of the chain being on a drowned fragment of continental crust while those like Stradbroke in the south are on oceanic crust.

(11) Volcanic CO_2 emissions in the Main Ethiopian Rift

Tamsin Mather (Earth Sciences), David Pyle (Earth Sciences)

The Main Ethiopian Rift (MER) is in many ways the type example of a continental rift where continental Africa is splitting apart and will likely one day form a new ocean. Models of continental break-up show that rifting is achieved through a combination of mechanical weakening of the lithosphere by stretching and intrusive heating, and dynamic processes within the asthenosphere (White & McKenzie 1989), but their relative importance in general remains uncertain. While broad progress has been made (e.g. Keranen et al., 2004), lack of focus on volcanoes and volcanic plumbing systems means fundamental questions remain regarding the locus and timescales of magma migration and storage through the lithosphere, and the interaction between magmatic and hydrothermal systems in the upper crust. The MER includes volcanism that ranges from focussed silicic centres, to large basaltic fields (Abebe et al, 2007; Corti, 2008). Recent satellite studies have identified four volcanoes that experienced periods of unrest characterised by deformation in the last decade, raising important questions regarding the processes occurring at volcanoes that were previously believed to be quiescent (Biggs et al, 2011).

This project will aim to contribute to key questions about magmatism in this region by mapping CO_2 gas fluxes (using accumulation chamber methods, e.g., Parks et al., 2013) on individual volcanoes and more coarsely as transects across the rift. Initial work at Alutu volcano shows that the spatial pattern of degassing is strongly influenced by both volcanic features and rift-related faulting with shallow sub-surface characteristics thought to impart significant controls on degassing. Testing these hypotheses and comparison with other datastreams such as deformation data and magnetotelluric data will allow us to distinguish the information contained in gas fluxes concerning magma movement, fault structures and hydrothermal interactions.

(12) Magma/mantle dynamics: production and extraction of melt from the convecting mantle

Dr Richard Katz (Earth Sciences)

Mantle melting and melt segregation are the primary means of chemical differentiation of the Earth, yet our understanding of melt transport processes remains limited. A leading theory states that melt segregates from its source by percolation through the pores of the crystalline mantle under the force of buoyancy. This theory is expressed in terms of partial differential equations; solutions of these equations can be obtained using numerical algorithms on supercomputers, and can be interpreted in terms of the dynamics of coupled magma and mantle dynamics. There are many extensions of this theory that remain completely unexplored, but which may provide significant new insight into the inner workings of the mantle.

This project area therefore includes a broad range of possible subjects, ranging from the fluid dynamics of two-phase flows at the laboratory scale to the geodynamics of melting and melt segregation at plate tectonic boundaries. Laboratory experiments on partially molten rock analogues could be developed, and numerical modelling of flows is a core expertise of the research group in Oxford. Model extensions to capture geochemical transport would provide a means for comparison with measurements of erupted lavas. There is hence scope for collaboration with seismologists, rock mechanicians, and geochemists to better understand the link between partial melting and observable features of the mantle system.

The successful applicant, whose first degree might be in Earth sciences, engineering, physics or mathematics, will have an excellent training in maths and physics and an interest in modeling of geophysical phenomena.

(13) Melting and water drainage from ice-stream margins: theory and computation

Dr. Richard Katz (Earth Sciences) & Dr. Ian Hewitt (Mathematics)

Antarctica is blanketed with ice sheets that represent an enormous reservoir of water. The mass of this reservoirs is set by a balance between the accumulation of snow, on the one hand, and the flow of the ice into the sea, on the other. A change in this flow has the potential to cause a rapid rise in sea level, with catastrophic consequences for humans. How ice sheets will respond to the perturbations of a changing climate is a question of critical importance. Answers will require a deep understanding of the mechanics of ice sheets, and in particular of ice streams. These are the large 'rivers' of fast flowing ice, which are responsible for discharging much of Antartica's ice, but who's origin remains enigmatic.

Recent work indicates that viscous dissipation at the margins of ice streams can locally raise the temperature of an ice sheet to the melting point, and subsequently generate melt water. The detailed physics of this two-phase system remain largely unexplored: What is the rate and volumetric extent of melting? How rapidly does melt drain from the source region and what is the ambient porosity and permeability of that region? How does the presence of melt-water feed back on ice dynamics via the ice rheology? These are just a few of the open questions. The purpose of this project is to develop and extend theory based on fundamental conservation principals (mass, momentum, and energy) for an ice/water system in terms of partial differential equations. Furthermore, it is to obtain solutions to these equations at various levels of complexity, using analytical and numerical methods. Finally, it is to generate physical predictions based on simple model assumptions and compare those predictions with data and with eachother.

There has been relatively little work on two-phase models of ice sheets, but the present is an opportune time to develop them. Recent advances in two-phase modelling of coupled magma/mantle dynamics have introduced methods from metallurgy into geodynamic calculations to impose conservation of energy in a multi-phase system. These methods can be applied in glaciology, and indeed an early effort to this end has been published. The project supervisors can draw on expertise in both magma/mantle and ice-sheet dynamics to guide development of theory appropriate for this project.

The student will extend the typical treatment of an ice sheet (incompressible Stokes equation for viscous flow) to incorporate the mechanics of a low-viscosity phase (water) in the pores between ice crystals. The thermodynamics of this system will be constrained via the Enthalpy Method, or a similar technique. The resulting PDEs will be treated with a range of tools, from scaling analysis to full numerical solutions, in geometries and domains from highly simplified to moderately detailed.

The successful applicant, whose first degree might be in earth sciences, engineering, physics or mathematics, will have a good background in maths and physics and an interest in computer modeling of physical phenomena.

(14) The crust and upper mantle structure of the UAE/Oman mountains: Implications for foreland basin formation and ophiolite emplacement

A. B. Watts and M. Y. Ali (Earth Sciences)

Seismic reflection and refraction profile data provide constraints on the structure, composition and rheological properties of mountain belts, but little is known about the mechanism by which the crust thickens in orogenic belts and the relative role of isostatic processes such as thrust/fold loading compared to non-isostatic processes such as mantle convection. One problem is the limited number of seismic transects of mountain belts. Arguably, the best seismic reflection profile data has been acquired offshore of orogenic belts (e.g. BIRPS). One orogenic belt, which is bounded on both its sides by water, but has not yet been explored, is located in the Middle East, in UAE/Oman. This mountain belt comprises one of the world's best known ophiolites which were emplaced on the Arabian rifted continental margin during the Late Cretaceous by obduction of oceanic crust and upper mantle that formed in a supra-subduction zone setting. This studentship forms part of a joint project between the Petroleum Institute and the University of Oxford to use land recording stations and a research vessel equipped with a large-volume air-gun array, a long multichannel seismic streamer and ocean bottom seismometers to constrain the deep structure of the UAE/Oman mountain belt.

(15) Origin of seaward dipping reflectors in volcanic rifted margins: Insights from "process-oriented" gravity and flexure modelling

Joe Cartwright and Tony Watts (Earth Sciences)

This project aims to explain the origin of seaward dipping reflectors (SDRs) in a geodynamic context of early plate break up and separation. SDRs represent a key component of transitional crust in this setting, but their systematic seaward dip has not been adequately explained. SDRs will be mapped on a length scale of over 1000km for the first time using regional 2D reflection seismic data, and this will allow their geometry and thickness to be placed in a lithospheric context. Modelling of potential field data will be undertaken to constrain crustal structure, and subsidence analysis will further constrain the geological context.

(16) Measuring the viscosity of Earth's upper mantle with electron microscopy: Calibration and application of a new paleopiezometer

Lars Hansen (Earth Sciences)

This project aims to test laboratory-derived models for the viscosity of the upper mantle using a new method for estimating the viscous behaviour of materials with high-resolution microscopy. Under guidance, the D.Phil. student will deform olivine single crystals in laboratory experiments, then map lattice dislocations using a new method (recently developed in the materials science community) that will allow us to define a relationship between applied stress and the resulting dislocation density (i.e., a dislocation-density piezometer). We will then use the calibration to map dislocation densities in both synthetic and natural olivine-rich rocks, finally comparing those results to numerical simulations to ensure that extrapolations from the lab to the Earth capture the physics of deformation.

(17) The effect of nanoscale structures on the strength of the lithosphere: Quantification through micromechanical testing

Lars Hansen (Earth Sciences)

Estimates from the laboratory and field disagree regarding the strength of the lithosphere. This discrepancy in measured strength may be due to the differences in grain size between laboratory samples and natural rocks, an effect that has not been systematically tested at conditions relevant to the high-strength portion of the lithosphere. This project aims to quantify the relationship between grain size and strength for lower-crustal and upper-mantle rocks and assess the effect of those results on predictions of lithospheric strength in a variety of geodynamic settings.

(18) **Assessing seismic source properties by waveform modeling**

Dr. Tarje Nissen-Meyer, Dr. Karin Sigloch (Earth Sciences)

Investigating seismic source properties is important not only for understanding their nature, but also to avoid mapping large source uncertainties into structural heterogeneities. Seismic sources are all those that generate seismic waves, including ambient noise sources in the oceans, calving glaciers, landslides, nuclear explosions. Through full waveform modelling, we propose to extend conventional source imaging and estimation methodologies such as:

1) Source back-projection imaging is commonly used for quick determination of rupture patterns for large earthquakes, but so far relies on ray-theoretical traveltimes.
2) Probabilistic inversion for source properties has been proposed and applied in a few studies, but never with full waveforms. The frequency-dependence of source properties shall be better illuminated if full waveform modelling is incorporated.

We will use results from full dynamic rupture modelling of earthquakes as a basis for testing the newly developed methodologies listed above, and this may eventually lead towards incorporating dynamic rupture properties into the inversion problem.

(19) **Seismological investigations of the Earth's core-mantle boundary region**

Dr. Tarje Nissen-Meyer, Dr. Karin Sigloch (Earth Sciences)

The deepest part of the earth’s interior is essential to understanding global earth dynamics and evolution, as well as the magnetic field. Imaging of the earth’s deep interior relies primarily on seismic waves. Various modelling approaches, datasets, and target regions have produced a diverse picture of processes at scales ranging from 10 km to thousands of kilometres. The challenge is to tie together findings across these scales, and to connect seismological observations to geodynamics and mineral physics. This ambitious project is aimed at combining various seismic methods and data to illuminate the lowermost mantle. This will involve lower-frequency tomography and high-frequency waveform modelling, and target structures such as ultra-low-velocity zones, large-low shear velocity provinces ("superplumes"), as well as core-mantle boundary topography. These tasks will be carried out by utilising and further developing modern numerical methods for seismic modelling and inversion, Big Data analysis, and state-of-the-art waveform processing.

(20) **Scattering approaches to global wave propagation and Earth model validation**
Dr. Tarje Nissen-Meyer, Dr. Karin Sigloch (Earth Sciences)

Seismic wave propagation is well understood, but remains computationally challenging. Considering the amount of simulations necessary for solving tomographic waveform inversion problems (tens of thousands), it is desirable to harness efficient approximations in modelling the wavefield or some of its attributes. First-order scattering approaches based on Born or Rytov theory represent a solid basis at least for body waves. We propose to conduct a comprehensive study to fully implement such scattering into our newly released global wave propagation code for spherically symmetric models ("AxiSEM"), and to apply it to investigating the validity bounds of these approaches. We will run a large number of simulations through existent and likely tomographic models, and compare their data fit, which will yield uncertainty estimates of the high-dimensional model parameter space. Time permitting, this may be extended in the context of probabilistic modelling and inversion of waveforms for source properties or bulk earth structure.

(21) **Imaging a mantle plume under the hotspot of La Réunion**
Dr. Karin Sigloch, Dr. Tarje Nissen-Meyer (Earth Sciences)

Forty years after the existence of mantle plumes was first hypothesised, it remains controversial whether such upwellings from the deepest part of the earth's mantle exist, and whether they contribute substantially to the heat budget of the solid earth. From 2011 to 2013, we acquired a very large seismological data set around the volcanic hotspot island of La Réunion, western Indian Ocean, in an international collaborative project named RHUM-RUM. The overarching objective is to study whether this intraplate hotspot is underlain by a deep, "classical" plume, or what else might have been driving its intense volcanic activity over the past 65 million years. At Oxford, we will apply the most cutting-edge methods of seismic body-wave tomography to this mixed terrestrial / ocean-bottom data set, with the goal of seismically illuminating the entire column of mantle beneath La Réunion and to obtain 3-D images of its structure from crust to core. You will interact with other project participants, mostly in France and Germany, who will be applying complementary methods of analysis to these novel data. For more information, visit the project website www.rhum-rum.net

(22) **Seismic waveform tomography on a global scale**
Dr. Karin Sigloch, Dr. Tarje Nissen-Meyer (Earth Sciences)

Global tomography pulls together large and rapidly growing volumes of seismological data from international data centres in order to compute 3-D maps of heterogeneities in the earth's interior, from crust to core. Technically, this amounts to numerically solving a very large geophysical inverse problem on high-performance computers. The scientific objectives are to better understand the geodynamics of the convecting mantle, and to help reconstruct the past distributions of continents and oceans, up to a few hundred million years back in time. We use novel physical approximations to seismic wave propagation to efficiently extract a maximum of information from modern broadband seismograms, up to the highest relevant frequencies, which yield the highest possible spatial resolution for tomographic imaging. Our primary goal is thus summed up as "Sharper images deeper down, and thus further back into the geological past".

(23) **Uncertainty analysis in seismic tomography**

Dr. Karin Sigloch, Dr. Tarje Nissen-Meyer (Earth Sciences), Michael Osborne (Machine Learning), Chris Farmer (Applied Mathematics)

Seismic tomography, a geophysical imaging method that works large amounts of seismogram data into three-dimensional maps of the earth's interior, is a compute-intensive application of geophysical inverse modelling. Estimating the spatial uncertainties for the 3-D images thus obtained is REALLY compute-intensive. The second big challenge is to condense the resulting, vast quantities of spatial covariance and resolution metrics into representations of uncertainty that can be intuitively grasped and evaluated by the human brain. We are looking for a numerically and statistically minded doctoral student to work in this relatively underdeveloped, but rapidly growing field. This study will be conducted in collaboration with groups in Engineering and Applied Mathematics, both world-leaders in probabilistic optimisation.