

The Dynamic Earth and Geohazards

1. Summary

Earthquakes and volcanic eruptions, together with the tsunamis and landslides that they trigger, represent a significant proportion of the natural hazards faced by human societies. The public perception that risks from these phenomena are growing is well founded; vulnerable populations are increasing within, and sometimes migrating towards, areas of hazard. During this century, several million deaths, and severe economic damage, will be caused directly by earthquakes and volcanic eruptions. Moreover, volcanic gases contribute significantly to the long-term average atmospheric composition, while major eruptions can modulate regional or global atmospheric composition and climate in detrimental ways.

NERC's strategy on natural hazards recognizes that fundamental scientific advances are needed if policy makers, and those responsible for disaster management, are to make informed decisions about preparing for such events, and mitigating their consequences. This theme approaches the issues by drawing together groups with strong track records in tectonics and geodesy (Cambridge, Oxford, UCL) and volcanology (Cambridge, ESSC, Leeds, Oxford) in a programme of observations of (i) the earthquake cycle, (ii) regional-scale continental deformation, (iii) targeted measurements of plate-boundary deformation, (iv) global budgets of volcanic emissions, particularly of SO₂, and (v) regional- to local-scale coupled measurements of volcanic emissions, ground deformation, and seismicity. This programme will be underpinned by advances in measurement techniques, by field observation, and by mathematical modelling of the physical processes.

We request the resources to enable us to use the full range of observations and modeling; in particular, we are requesting support for nine postdoctoral researchers over two to three years each (23.5 person-years in total) and three studentships.

2. Background and Motivation

Earth Observation (EO) is essential to investigation of earthquakes and volcanic processes because the ultimate controls on these phenomena lie deep within the Earth; even the immediate triggers of earthquakes or eruptions are hidden from direct observation beneath kilometres of rock. EO techniques give synoptic-scale and/or high-resolution measurements of ground deformation and volcanic emissions which open up the processes up to analysis in a way that is otherwise simply not possible. The basis of this proposal is to use EO techniques, combined with complementary terrestrial observations and with physical models, to measure and analyze the earthquake and volcanic cycles on a global scale.

Global observations are necessary because of the time scales of the processes. The earthquake cycle on any one fault may take hundreds to thousands of years, and individual volcanoes yield major explosive eruptions on time scales of centuries to tens of thousands of years. But on a global basis these events occur frequently, and understanding gained in one location can then be applied generally. An important aspect of space-based platforms is that we can investigate areas in which land-based observations are not possible because of physical or political constraints. Earth observation also facilitates the combination of multiple observations, such as topography, surface imagery, radar observations of deformation, and thermal emissions.

There are strong reasons for combining the study of earthquakes and volcanoes. The EO measurements used to determine deformation around volcanoes and earthquake faults – InSAR, GPS, digital topography, multispectral imagery – overlap to a large extent, and the same is true for the mathematical tools required to interpret the deformation and to construct physical models of the underlying processes. It is relatively rare to find groups of scientists who study both earthquakes and volcanoes with the full suite of tools proposed here; this theme will exploit the synergies between the groups to maximize the use of the observation and modelling resources available.

Independently of their societal impact, earthquakes and volcanoes are central to our basic understanding of the earth system; they are messengers of the fundamental processes that shape the surface of the Earth and, ultimately, the environment in which we live. Volcanoes are the surface expression of partial melting of the Earth's mantle, which is the major engine of chemical

differentiation of the earth. The main loci of volcanic activity are the oceanic ridges, where two-thirds of the earth's crust is created, and the volcanic arcs, where most of the Earth's explosive eruptions occur and where continental crust begins its life. Earthquakes play a key role in demonstrating that plate tectonics does not apply to the continents. Because the continents are where most of the human race resides, where many of our natural resources lie, and where most of geological history is recorded, investigation of the tectonics of continents is also a central problem in Earth Sciences.

3. Earth Observation of Tectonics and Volcanic Activity

The research strands described later depend on measurements of several different aspects of the seismic cycle and volcanoes. The techniques we shall employ are intertwined with more than one scientific theme, so we summarize them (and their interdependencies on field observations) here.

Earthquakes cause surface displacements that can be measured with InSAR (ERS, ENVISAT, RADARSAT, ALOS) and satellite positioning systems (GPS, GALILEO) using well-established techniques. The horizontal components of those displacements, particularly the offsets occurring where earthquakes break the surface may be determined with both optical (SPOT, ASTER) and radar image matching. These techniques are complemented by seismological and field measurements (as in the Bam earthquake, Box 1 below, and many others).

The seismic cycle takes place over centuries to millennia; measuring the accumulation of strain at the present day pushes space geodetic techniques to their limits, and improvements to techniques form an important part of this theme. We shall use, and improve, InSAR and GPS techniques to make measurements of the slow accumulation of crustal strain occurring between earthquakes, of the transient motions following large earthquakes as the earth adjusts to the stresses imposed by the earthquake, and of transient, or silent slip, events which are recently discovered and still enigmatic part of the earthquake cycle. To increase the range of InSAR signals that may be detected in such measurements, as well as for measurements of volcanic deformation, we will assimilate observations of tropospheric water vapour (GPS, MODIS, MERIS, AIRS/AMSU-A/HSB) into high-resolution nested meteorological models to correct for the effects of water vapour.

Tectonic geomorphology holds much of the information needed to build from observations of present-day deformation towards long-term seismic hazard, because the landforms and drainage patterns in tectonically active regions develop in response to topography produced in past earthquakes. Geomorphology has been transformed, in the scale and resolution of what it can achieve, by optical imagery (LANDSAT, SPOT, ASTER, QUICKBIRD) and digital elevation models (DEMs) from stereo image matching (SPOT, ASTER, ALOS), InSAR (ERS, ENVISAT, TERRASAR-X) and lidar. We shall use these data, together with surface dating, and other field observations, to provide estimates of long-term deformation rates. Better knowledge of the deeper structure of the lithosphere is essential for understanding the mechanics of continental deformation, and we shall combine with colleagues outside this proposal to measure this structure using satellite gravity measurements (GRACE, GOCE) and measurements of variations in seismic wave speed.

Volcanoes produce ground deformation of comparable magnitude to that of earthquakes, and which can be observed by the same means. These motions arise from a combination of magma movement in the crust, and the exsolution of gas from the magma as it rises and crystallizes. Measurements of gas flux are therefore important indicators of the internal processes of volcanoes on the local and regional scales, but they are also essential for quantifying the contribution of volcanoes to the composition of the atmosphere. A new generation of spaceborne instruments (e.g. OMI, AIRS, IASI) is now capable of providing estimates of the mass of sulphur dioxide and other volcanic gas species with sufficient resolution for these purposes. We shall complement those data by ground-based measurements of gas flux, both for purposes of comparison and because some aspects of volcanic processes are revealed by details of gas composition not accessible to remote observation. Continuous monitoring by field portable gas spectrometers gives yields gas fluxes and composition; the fluxes depend on magma budgets, the composition on magma composition and the depths (pressures) at which exsolution occurs.

Eruption processes, magma evolution and gas fluxes are intimately linked, hence the construction of a unified budget of magma, ash, and gas emissions is essential for understanding the mechanics of volcanoes. We shall measure volcanic growth using new satellite data from the high-resolution radar spotlight mode of TERRASAR-X and proxy estimates via satellite-detected thermal radiation from hot surfaces. Tephra mass will be estimated from surface measurements of proximal deposits and by satellite absorption techniques (e.g. GOES IR) for the distal component. Imaging radiometers (MODIS, AVHRR, AATSR) enable thermal emissions and ash cloud morphology to be monitored globally at reasonable resolution, with a higher resolution possible for targeted events (ASTER, CALIPSO). These measurements will be augmented by surface observations of emplaced lava mass using ground survey techniques such as photogrammetry, lidar, mm-radar techniques, and we will track sub-surface deformation by locating the small volcanic earthquakes generated during movement of magma and fluids.