British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

UK Earthquake Monitoring 2011/2012

BGS Seismic Monitoring and Information Service

Twenty-third Annual Report

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT OR/12/092

UK Earthquake Monitoring 2011/2012

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Key words

Monitoring, Earthquakes, Seismology.

Front cover

Winter fieldwork at Ladybower

Bibliographical reference

BAPTIE, B., 2012. UK Earthquake Monitoring 2011/2012. *British Geological Survey Commissioned Report*, OR/12/092

39pp.

Edinburgh British Geological Survey 2012

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Summary

The British Geological Survey (BGS) operates a network of seismometers throughout the UK in order to acquire seismic data on a long-term basis. The aims of the Seismic Monitoring and Information Service are to develop and maintain a national database of seismic activity in the UK for use in seismic hazard assessment, and to provide near-immediate responses to the occurrence, or reported occurrence, of significant events. The project is supported by a group of organisations under the chairmanship of the Office for Nuclear Regulation (ONR) with major financial input from the Natural Environment Research Council (NERC).

In the 23rd year of the project, five new broadband seismograph stations were established, giving a total of 38 broadband stations. Real-time data from all broadband stations and nearly all other short period stations are being transferred directly to Edinburgh for near real-time detection and location of seismic events as well as archival and storage of continuous data. We have also upgraded data acquisition hardware at most broadband stations to improve local storage and data communications.

All significant events were reported rapidly to the Customer Group through seismic alerts sent by e-mail. The alerts were also published on the Internet (http://www.earthquakes.bgs.ac.uk). Monthly seismic bulletins were issued six weeks in arrears and compiled in a finalised annual bulletin (Galloway, 2012). In all reporting areas, scheduled targets have been met.

Seven papers have been published in peer-reviewed journals. A chapter was also published in a book. Two presentations were made at international conferences. Three BGS internal reports were prepared along with six confidential reports. We have continued to collaborate widely with academic partners across the UK and overseas on a number of research initiatives.

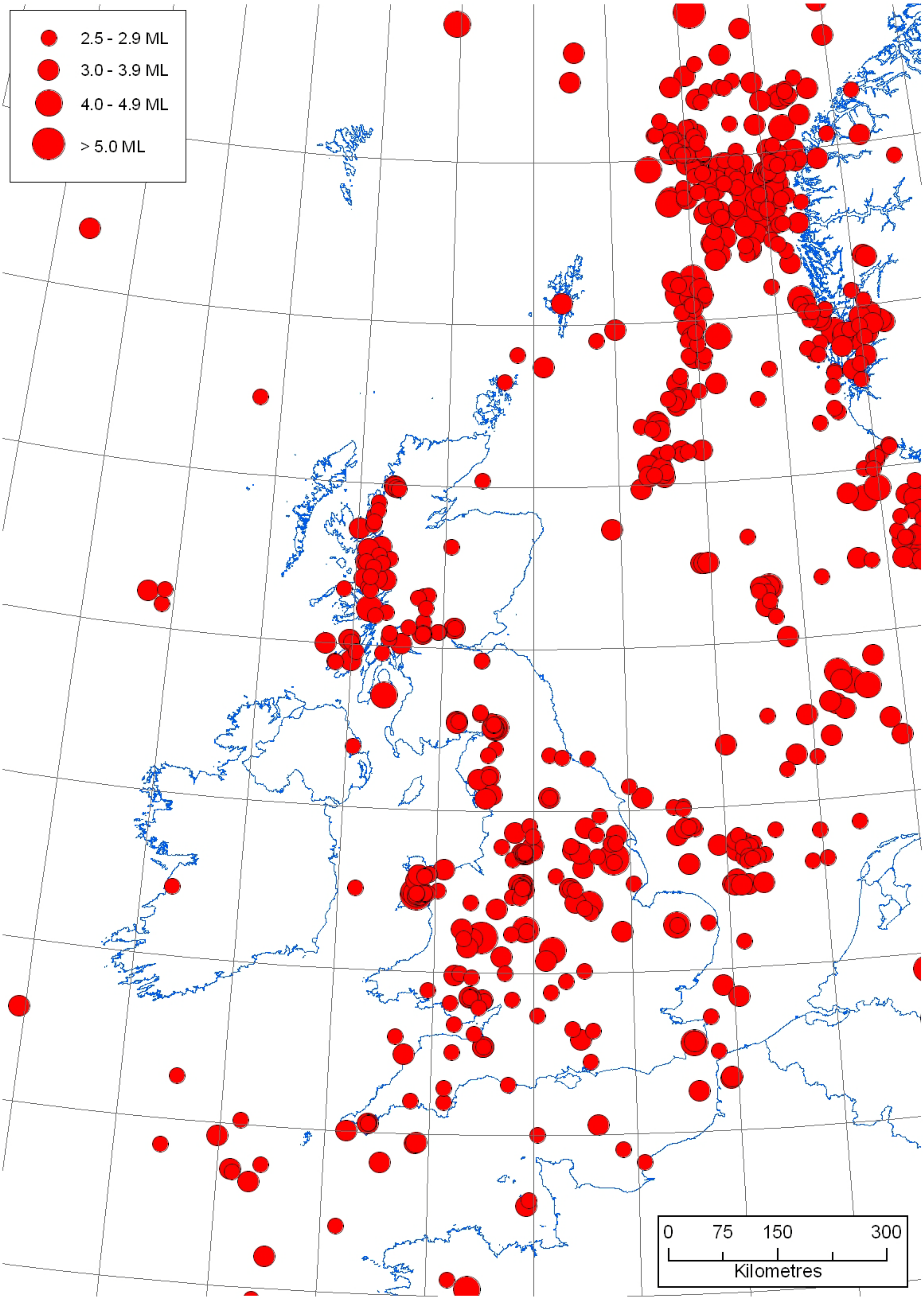
Introduction

The BGS Seismic Monitoring and Information Service has developed as a result of the commitment of a group of organisations with an interest in the seismic hazard of the UK and the immediate effects of felt or damaging vibrations on people and structures. The supporters of the project, drawn from industry and central and local government are referred to as the Customer Group.

Almost every week, seismic events are reported to be felt somewhere in the UK. A small number of these prove to be sonic booms or are spurious, but a large proportion are natural or mining-induced earthquakes often felt at intensities which cause concern and, occasionally, some damage. The Information Service aims to rapidly identify these various sources and causes of seismic events, which are felt or heard.

In an average year, about 150 earthquakes are detected and located by BGS with around 15% being felt by people. Historically, the largest known British earthquake occurred on the Dogger Bank in 1931, with a magnitude of 6.1 M_L. Fortunately, it was 60 miles offshore but it was still powerful enough to cause minor damage to buildings on the east coast of England. The most damaging UK earthquake known in the last 400 years was in the Colchester area (1884) with the modest magnitude of 4.6 M_L. Some 1200 buildings needed repairs and, in the worst cases, walls, chimneys and roofs collapsed.

Long term earthquake monitoring is required to refine our understanding of the level of seismic hazard in the UK. Although seismic hazard and risk are low by world standards they are by no means negligible, particularly with respect to potentially hazardous installations and sensitive structures. The monitoring results help in assessment of the level of precautionary measures which should be taken to prevent damage and disruption to new buildings, constructions and installations which otherwise could prove hazardous to the population. For nuclear sites, seismic monitoring provides objective information to verify the nature of seismic events or to confirm false alarms, which might result from locally generated instrument triggers.



Epicentres of earthquakes with magnitudes 2.5 ML or greater, for the period 1979 to March 2012.

Introduction

Monitoring Network

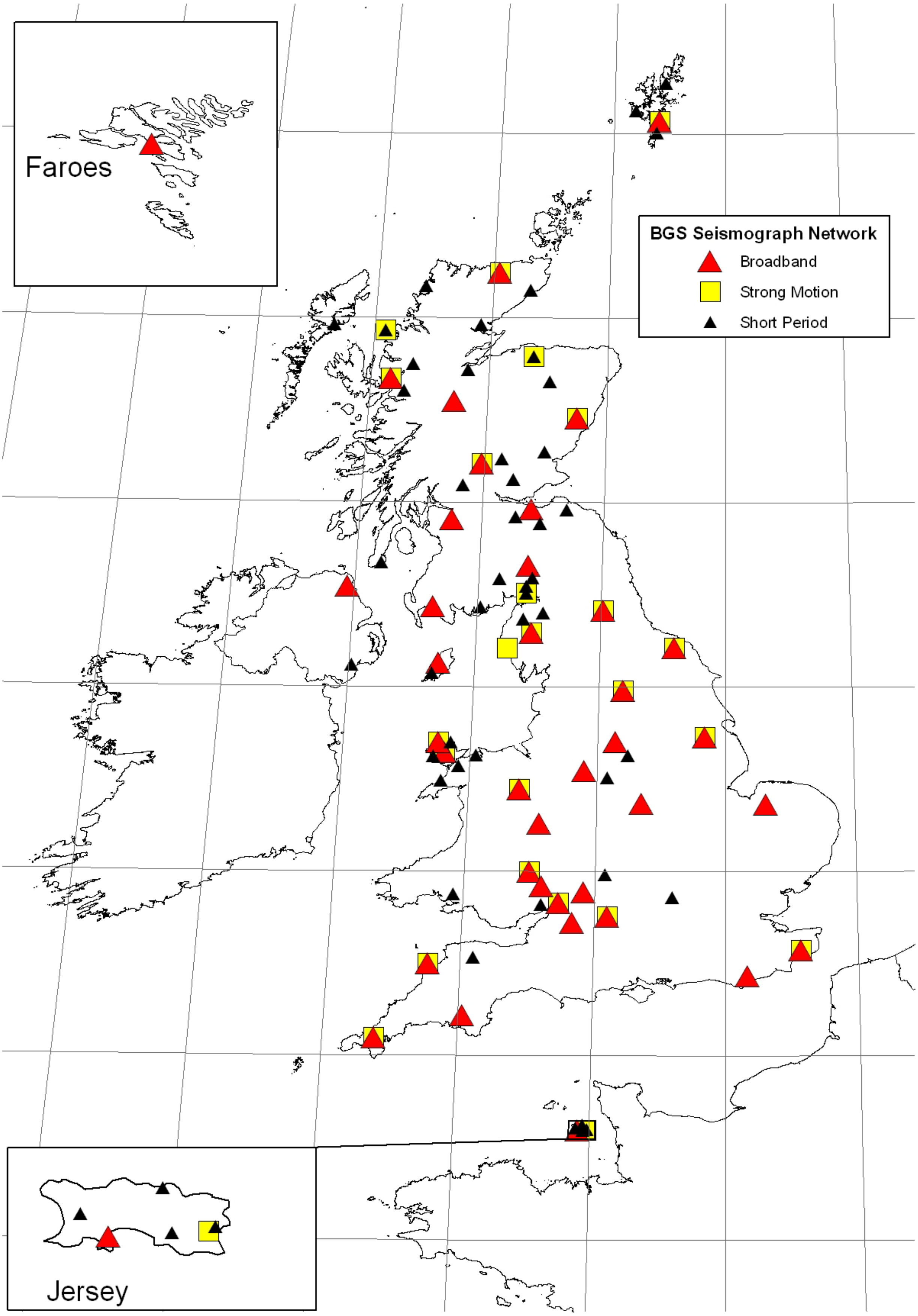
The BGS National Earthquake Monitoring project started in April 1989, building on local networks of seismograph stations, which had been installed previously for various purposes. By the late 1990s, the number of stations reached its peak of 146, with an average spacing of 70 km. We are now in the process of a major upgrade, with the installation of broadband seismometers that will provide high quality data for both monitoring and scientific research.

In the late 1960s BGS installed a network of eight seismograph stations centred on Edinburgh, with data transmitted to the recording site in Edinburgh by radio, over distances of up to 100 km. Data were recorded on a slow running FM magnetic tape system. Over the next thirty years the network grew in size, both in response to specific events, such as the Lleyn Peninsula earthquake in 1984, and as a result of specific initiatives, such as monitoring North Sea seismicity, reaching a peak of 146 stations by the late nineties.

The network was divided into a number of sub-networks, each consisting of up to ten 'outstation' seismometers radio-linked to a central site, where the continuous data were recorded digitally. Each sub-network was accessed several times each day using Internet or dial-up modems to transfer any automatically detected event to the BGS offices in Edinburgh. Once transferred, the events were analysed to provide a rapid response for location and magnitude.

However, scientific objectives, such as measuring the attenuation of seismic waves, or accurate determination of source parameters, were restricted by both the limited bandwidth and dynamic range of the seismic data acquisition. The extremely wide dynamic range of natural seismic signals means that instrumentation capable of recording small local micro-earthquakes will not remain on scale for larger signals.

This year we have continued with our plans to upgrade the BGS seismograph network. Over the next few years we intend to develop a network of 40-50 broadband seismograph stations across the UK with near real-time data transfer to Edinburgh. These stations will provide high quality data with a larger dynamic range and over a wider frequency band for many years to come. So far, we have installed 38 broadband sensors at stations across the UK along with 26 strong motion accelerometers with high dynamic range recording for recording very large signals.



BGS seismograph stations, March 2012

Achievements

Network Development

Broadband sensors with 24-bit acquisition are being deployed to improve the scientific value of the data and improve the services provided to customers. We continue to improve our near real-time data processing capability including the detection and location of significant seismic events in the UK and offshore area.

In the last year five new broadband stations were installed at: West Acre, (Norfolk), Glaisdale (North Yorkshire Moors), Ladybower Reservoir (Peak District), Kirk Michael (Isle of Man) and Cushendall (Northern Ireland). This takes the total number of broadband stations operated by BGS to 38. Continuous data from all broadband stations are transmitted in real-time to Edinburgh, where they are used for analysis and archived. In addition, we receive continuous real-time data from all short period stations, except for stations in the Borders and Minch networks. Event data from these networks is downloaded using a dial-up connection.

In addition, we have carried out site surveys for new broadband stations in Pembrokeshire, Argyll and Suffolk. We intend to install permanent stations in these areas in 2012.

During May 2011, the seismology team installed four temporary seismometers at Viriksjokull, an outlet glacier of the Vatnajokull icecap in southeast Iceland. These were installed as part of a multi-disciplinary monitoring project run by BGS scientists. The aim is to relate icequake activity to local climate change and meltwater flux from the outlet glacier. We also receive real-time data from one of these stations which is combined with other real-time data from Iceland to help improve early warning and forecasting of any future eruptions of these volcanoes.

We maintain a pool of seismometers that can be rapidly deployed for studying aftershock sequences, earthquake swarms and specific studies. Four of these instruments were deployed to capture seismicity induced by fluid injection during exploration for shale gas in the Bowland Basin, Lancashire. Two

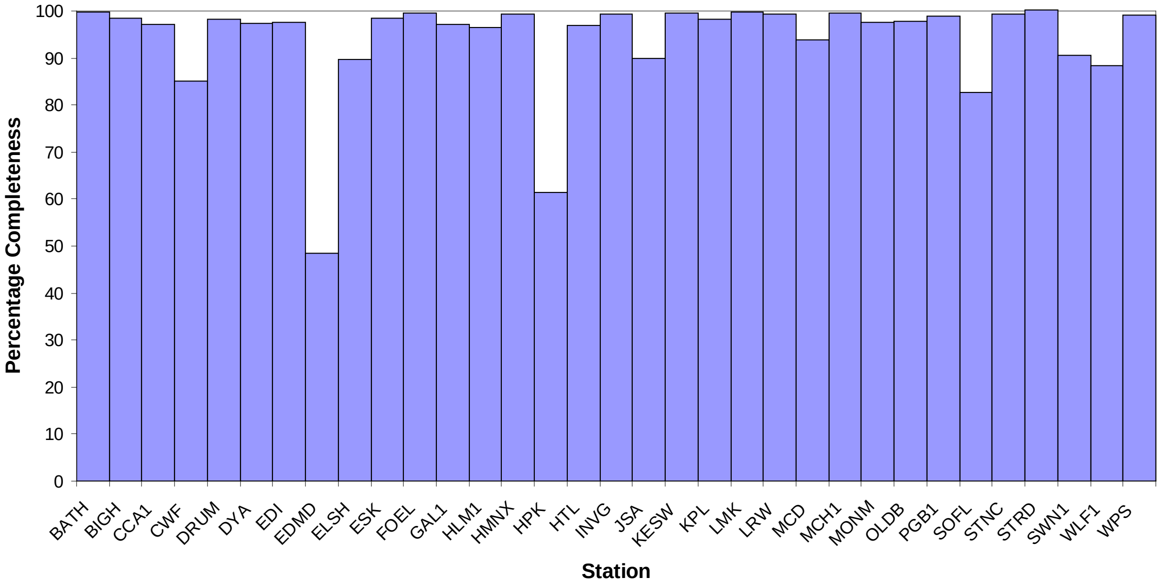
instruments were installed near Blackpool in late April 2011, with a further two installed in June. These instruments recorded 33 or the 51 earthquakes detected near the Preese Hall well and provided important data for linking the earthquake activity to fluid injection.

We have continued to incorporate data from seismic stations operated by European partner agencies into our near real-time processing to improve our detection capability in offshore areas. In particular, stations, recently installed and operated by the Dublin Institute of Advanced Studies, in Ireland, are vital for detection and location of a number of felt earthquakes in the border region of Northern Ireland.

We are continuing to refine our use of the EarthWorm software (developed by the US Geological Survey and contributed to by BGS) for the automatic detection, location and notification of earthquake activity in the UK and immediate offshore area. Work is ongoing on optimisation of the picking and association modules for the current network configuration, so that our analysts receive reliable alerts for earthquakes above a given magnitude threshold.

Additionally, our EarlyBird alert system continues to provide rapid notification of potentially damaging earthquakes anywhere in the world using data from over 200 stations throughout the world. Reliable locations and magnitudes are typically produced within a few minutes of the origin time.

Continuous data from all our broadband and most of our short period stations are now online within the BGS storage area network. The completeness of these data can be easily checked to gain an accurate picture of network performance. In general, we find that the data from most broadband stations are over 95% complete. Data losses result from failure of outstation hardware, communications problems, or failure of central data processing. The data acquisition is able to recover from short breaks in communications links to outstations by re-requesting missing packets of data from local data buffers, but failure of outstation hardware requires intervention by local operators or maintenance visits.



Data completeness for all broadband stations that operated throughout 2011-2012.

Achievements

Information Dissemination

It is a requirement of the Information Service that objective data and information be distributed rapidly and effectively after an event. Customer Group members have received notification by e-mail whenever an event was felt or heard by more than two individuals.

Notifications were issued for 43 UK events within the reporting period, five of which were of a sonic origin. Notifications for all local earthquakes were issued to Customer Group members within two hours of a member of the 24-hour on-call team being notified. The alerts include earthquake parameters, reports from members of the public, damage and background information. In addition, eight enquiries were received from Nuclear Power Stations after alarms triggered: Hartlepool, 7 April and 19 April (twice) 2011; Wylfa, 25 July and 24 October, 2011; Heysham, 29 December and 8 March, 2012; and Chapelcross, 18 March 2012. In each case a response was given within 15 minutes.

A major revamp of the Seismology web pages was completed in July 2011. The new pages incorporate a direct link to our earthquake database to provide near real-time lists of significant earthquake activity, together with automatically generated pages for each event. This greatly simplifies the task of providing earthquake information and the details are updated whenever the event parameters change. The new pages also incorporate our automatic macroseismic processing system, which remains a key part of our response to felt events and is used to produce macroseismic maps for the seismology web pages that are updated in near real-time as data is contributed. This was used to collate and process macroseismic data for a number of events in the course of the year. We received over 300 replies following the Newton Abbot earthquake on 23 June 2011 (2.7 ML) and over 260 replies after the English Channel earthquake on 14 July 2011 (3.9 ML).

Data from the questionnaires are grouped by location into 5x5 km squares using postcodes and an intensity value is assigned to each square, given at least five responses are received from any square. Where fewer responses are received (especially the case in sparsely populated areas) the intensity is either given as “felt” or “not felt” (which is also defined as intensity 1). These data are processed automatically to produce the macroseismic maps for the seismology web pages.

Preliminary monthly bulletins of seismic information were produced and distributed to the Customer Group within six weeks of the end of each month. The project aim is to publish the revised annual Bulletin of British Earthquakes within six months of the end of a calendar year. For 2011, it was issued in June 2012.

Collaboration and Data Exchange

Data from the seismograph network are freely available for academic use and we have continued to collaborate with researchers at academic institutes within the UK throughout the past year, as well as exchanging data with European and world agencies.

A student at Edinburgh University, funded partially by BGS, has completed her PhD thesis. Nicholson (2011) used ambient seismic noise recorded across the UK to derive the first surface wave group velocity maps of the UK using only ambient seismic noise. Another PhD student at Edinburgh University is studying new methods to construct seismic signals from noise.

A BGS CASE student at the University of Cambridge has also completed his PhD thesis on investigating causes of regional uplift in the British Isles (Davis, 2012). Analysis of teleseismic receiver functions shows significant variations in crustal thickness across the British Isles. Thinner crust beneath northwest Scotland may suggest that present-day topography is maintained by regional dynamic support, originating beneath the lithosphere.

BGS are co-investigators in the 'Earthquakes Without Frontiers' consortium led by the University of Cambridge, that recently won funding in the NERC ‘Improving Resilience to Natural Hazards’ call. This will provide approximately three years of funding for a post-doctoral researcher.

The European Mediterranean Seismological Centre (EMSC), BGS and others have continued to collaborate on development of online macroseismic surveys, now within the framework of an European Seismological Commission (ESC) working group in Internet Seismology.

BGS staff visited Concern Worldwide in Bangladesh in June 2012 to learn more about their use of scientific information. As a result, we are designing a training course that will cover various aspects of earthquake risk and risk management. A key part of this is for staff to know what to do in an earthquake and how to work in and around damaged buildings. An important objective of the training is to encourage staff to think about the risk from earthquakes and how they might manage it.

BGS data are exchanged with other agencies to help improve source parameters for regional and global earthquakes. Phase data are distributed to the (EMSC) to assist with relocation of regional earthquakes and rapid determination of source parameters. Phase data for global earthquakes are sent to both the National Earthquake Information Centre (NEIC) at the USGS and the International Seismological Centre (ISC). This year, data from 447 teleseismic events were sent. Data from the BGS broadband stations are transmitted to both ORFEUS, the regional data centre for broadband data, and IRIS (Incorporated Research in Seismology), the leading global data centre for waveform data, in near real-time.

Achievements

Communicating Our Science

An important part of the BGS mission is to provide accurate, impartial information in a timely fashion to our stakeholders, the public and the media. We promote understanding of Earth Sciences by engaging with schools through our "School Seismology" project and by creating dynamic web pages with background information and topical content.

A major overhaul of the Seismology web pages was completed in July 2011. The new pages have been designed to provide earthquake information as quickly as possible following an event. Earthquake lists, maps and specific pages are generated and updated automatically whenever a new event is entered in our database or when the parameters for an existing event are modified. We have also continued to provide displays of real-time data from most of our seismic stations that allow users to check activity or look for specific events. In addition, we continue to add event-specific content for significant earthquakes in the UK and around the world. These document the parameters of these events and provide information on the tectonic setting and background seismic activity in the region.

We actively use Twitter, Facebook, Audioboo and YouTube to post earthquake alerts, to provide news of new web pages, and showcase podcasts and videos of our seismologists. Facebook also offers a way for the public to engage with us by asking questions related to various postings.

The UK School Seismology Project (UKSSP) continues to grow and create new partnerships. The aim of the project is to develop specific resources for teaching and learning seismology in UK schools, including an inexpensive seismometer that is robust enough to be used in schools, but still sensitive enough to record earthquakes from the other side of the world. These provide teachers and students with the excitement of being able to record their own scientific data and help students conduct investigations using their own data.

Northern Ireland has now joined the UK School Seismology Project, in addition to exhibits set up at the W5 science centre in Belfast and the visitor centre at Marble Arch Caves, a total of six schools have been trained and provided with sensors making the project a truly national enterprise.

BGS assisted the National Science Learning Centre develop a Continuing Professional Development (CPD) course for teachers on "Earthquakes and other Natural Hazards" which has now run (with assistance from UKSSP staff) at three separate Science Learning Centres, receiving excellent feedback from teachers attending.

A second tranche of funding for the UKSSP has been won from the Petroleum Exploration Society of Great Britain, which will enable partnerships with eight university earth science departments across the UK to continue the roll out of resources to new schools.

BGS are taking the lead in an EU-funded initiative that will run from 2010-14 and will enable school seismology projects in the UK, France, Switzerland and Italy to set up a data exchange system and to share best practice in teaching activities and resources.

The 2012 BGS Open Day attracted 923 visitors with many of them visiting the interactive earthquake display. A further 132 school pupils from 7 different schools visited during the following Schools Week.

The seismology web site continues to be widely accessed, with over 890,000 visitors logged in the year (over 13 million hits). Significant peaks (over twice the daily average) were observed following the Newton Abbot earthquake (June 2011) and the English Channel earthquake (July 2011). Smaller peaks were also observed following the Lochailort and Islay earthquakes (August, 2011 and February, 2012)

BGS remains a principal point of contact for the public and the media for information on earthquakes and seismicity, both in the UK and overseas. During 2011-2012, 915 enquiries were answered. These were logged using a new enquiries tracking database. Many of these were from the media, which often led to TV and radio interviews, particularly after significant earthquakes.

Seismic Activity

The details of all earthquakes, felt explosions and sonic booms detected by the BGS seismic network have been published in monthly bulletins and compiled in the BGS Annual Bulletin for 2011, published and distributed in June 2012 (Galloway, 2012).

There were 131 local earthquakes located by the monitoring network during 2011-2012, with 29 having magnitudes of 2.0 ML or greater, and four having magnitudes of 3.0 ML or greater. Eighteen events with a magnitude of 2.0 ML or greater were reported felt, together with a further 26 smaller ones, bringing the total to 44 felt earthquakes in 2011-2012.

A magnitude 2.7 ML earthquake occurred on 23 June 2011 at 13:43 UTC near Newton Abbot, Devon. The earthquake was felt across much of south Devon and we received over 300 responses to our online macroseismic survey. The maximum intensity was 5 EMS (European Macroseismic Scale). The earthquake was felt at up to 25-30 km from the epicentre.

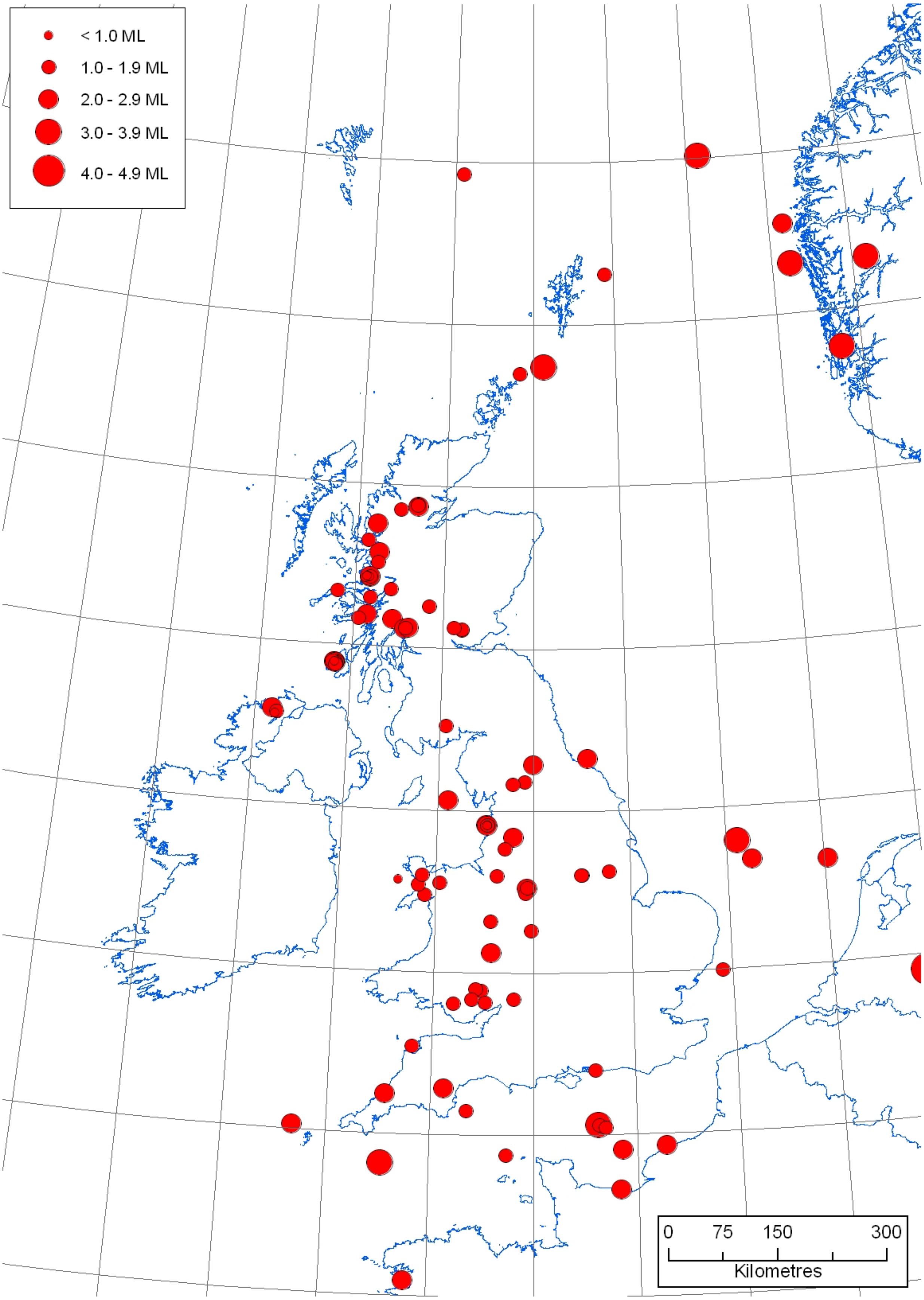
A magnitude 2.9 ML earthquake occurred on 21 August 2011 at 08:37 UTC at Lochailort, Highland. This event was followed by a series of seven aftershocks over the next 19 hours, ranging in magnitude from 0.5 to 2.0 ML. We received 45 reports from people who felt the mainshock. The maximum intensity was 3 EMS. The earthquake was felt as far away as Spean Bridge (45 km to the east).

A magnitude of 2.8 ML earthquake occurred on 29 February 2012 at 09:14 UTC, on the Isle of Islay, Argyll and Bute. This was the largest of 9 earthquakes that occurred on the island in early 2012. All nine of the earthquakes were felt by residents on the island. The largest was felt at a distance of 15 km from the epicentre.

A magnitude 2.8 ML earthquake occurred on 4 March at 23:23 UTC, near Arrochar, Argyll and Bute. This was preceded by a magnitude of 1.8 ML event at 08:34 UTC. The larger event was felt as far away as Crieff, 60 km to the east.

The largest offshore earthquake occurred in the English Channel on 14 July, 81 km south of Chichester. It had a magnitude of 3.9 ML and was widely felt in coastal towns stretching from Portsmouth to Eastbourne. We received over 260 responses to the online macroseismic survey. The maximum intensity was 3 EMS in Worthing, 80 km NNE of the epicentre.

The UK monitoring network also detects large earthquakes from around the world, depending on the event size and epicentral distance. Recordings of such earthquakes can be used to provide valuable information on the properties of the crust and upper mantle under the UK, which, in turn, helps to improve location capabilities for local earthquakes. During the period April 2011 to March 2012, a total of 447 teleseismic earthquakes were detected and analysed.



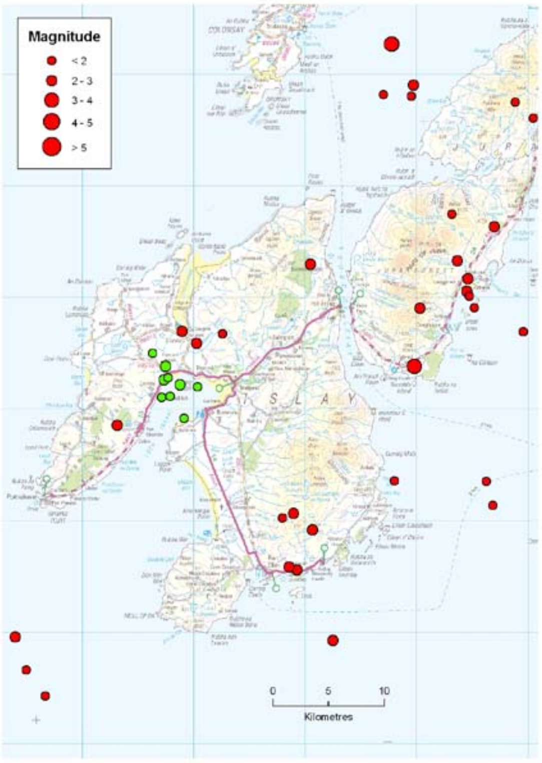
Epicentres of all earthquakes in and around the UK detected in the reporting period (1 April 2011 – 31 March 2012).

Seismic Activity

Islay Earthquakes, February 2012

The island of Islay, on the west coast of Scotland, was struck by a sequence of nine small earthquakes in February/March 2012. The largest of the earthquakes had a magnitude of 2.8 ML, while two others had magnitudes in excess of 2.0 ML. All of the earthquakes were felt by local residents

Such earthquake sequences can occur in two ways. Firstly, moderate to large size earthquakes are usually followed by aftershocks, which occur due to readjustment to a new state of stress. The pattern of the aftershock sequence depends on the size of the event and the local tectonic setting. Normally, the largest aftershock is about one magnitude unit smaller than the main shock. For example, the magnitude 5.4 ML Lleyn Peninsula earthquake that occurred in North Wales in 1984 was followed by some hundreds of aftershocks in the subsequent months, the largest of which was a magnitude 4.3 ML earthquake that occurred one month later.



Islay earthquakes (green) and other seismicity (red).

Secondly, earthquake swarms are sequences of earthquakes clustered in time and space without a clear distinction of main shock and aftershocks. Such earthquake sequences or swarms are relatively common in Great Britain, examples include Comrie (1788-1801, 1839-46), Glenalmond (1970-72), Kintail (1974), Doune (1997), Blackford (1997-98, 2000-01), Constantine (1981, 1986, 1992-4), Johnstonebridge (mid 1980s), Dumfries (1991, 1999), Manchester (2002) and Aberfoyle (2003). The largest event in the Comrie sequence was a magnitude 4.8 ML event in 1839. The magnitudes of these historic events are determined from macroseismic observations and are calibrated against the instrumental local magnitude scale (Musson, 1996). The largest event in the Kintail earthquake swarm in 1974/1975 had a magnitude of 4.4 ML.

By comparison, the Islay earthquakes of February 2012 were relatively small, and no damage would be expected from events of this size. Seismic activity in and around Islay is relatively low, although a number of magnitude 3+ events have occurred in recent times including a magnitude 3.4 earthquake off Jura in 1998. However, larger events have occurred elsewhere in Argyll in recent times including a magnitude 4.1 ML earthquake near Oban in 1986. The largest known Scottish earthquake occurred near Loch Awe in 1880, with a magnitude of 5.2 ML.

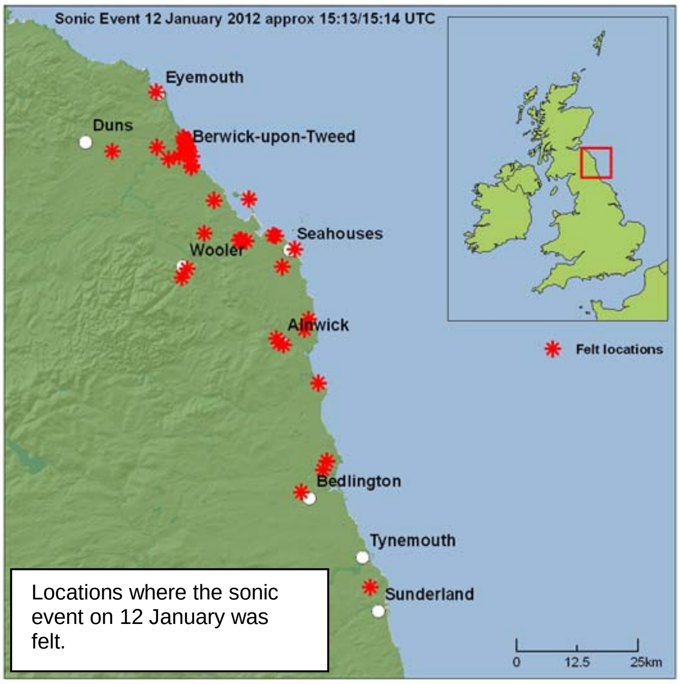
Seismic Activity

Sonic Booms, January 2012

Sonic booms generated by supersonic aircraft can cause shaking that is often mistaken for an earthquake. Two such events occurred in January 2012 caused by military aircraft on exercise. Ground coupled air-waves were well-recorded by instruments across northern England in both cases.

On the afternoon of 12 January 2012, from around 15:20 UTC, we received numerous reports from the media, the police and residents of coastal towns and villages in the southern Scottish Borders, Northumberland and Tyne & Wear, that there had been an earthquake.

Data recorded by seismometers in the region suggested a possible sonic event at around 15:13/15:14 UTC. The felt effects were also similar to previous sonic booms and several members of the public reported seeing military aircraft in the area. The RAF were contacted and confirmed that a single Tornado GR4 fighter aircraft had completed a pre-planned supersonic sortie to RAF Marham in Norfolk.



Locations where the sonic event on 12 January was felt.

The effects of the sonic boom were felt over a distance of approximately 115 km, stretching from Eyemouth, Scottish Borders, to just north of Sunderland, Tyne and Wear. The locations furthest inland from where reports were received were Duns, Wooler and Bedlington. Reports described roofs rattling and houses shaking violently for a few seconds.

A sonic boom is the sound associated with the shock waves created when an object, such as an aircraft, breaks the sound barrier (e.g. McDonald and Goforth, 1969). An aircraft travelling slower than the speed of sound (~760 mph) creates a series of audible pressure waves that spread out in front and behind it. These waves travel at the speed of sound. As the speed of the aircraft increases these waves get closer together and at the speed of sound they merge into a single shock wave that starts at the nose and ends at the tail of the aircraft.

The boom is created by the sudden increase in pressure at the nose and also as the pressure returns to normal at the tail as the aircraft passes. This can lead to a distinctive "double boom". The shock wave or boom continues to be generated for as long as the aircraft is supersonic, which is why they are typically observed along a long strip along the flight path of the aircraft.

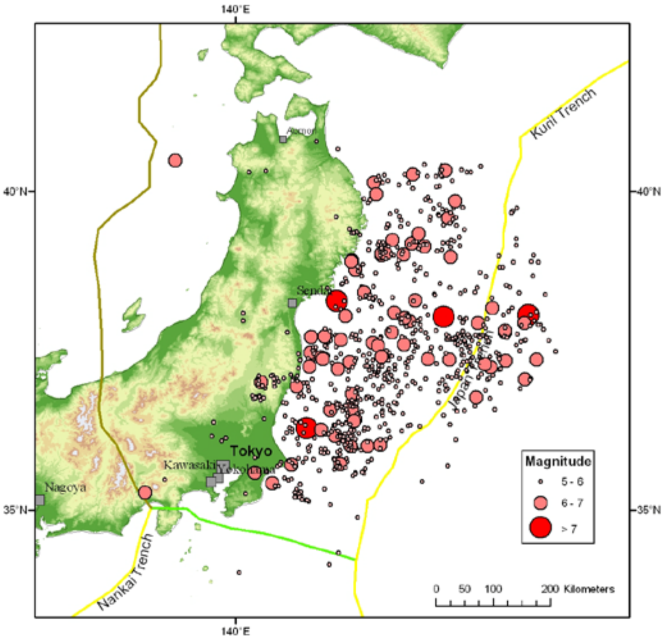
Seismic Activity

Overview of global earthquake activity

Worldwide, there were fifteen earthquakes with magnitudes of 7.0 or greater and 135 with magnitudes of 6.0 or greater. These numbers are in keeping with longer term annual averages based on data since 1900, which suggest that on average there are 16 earthquakes with magnitude 7.0 or greater and 150 with magnitudes of 6.0 or greater each year.

The island of Honshu continued to be hit by large aftershocks following the magnitude 9.0 earthquake on 11 March 2011. There have been four aftershocks with magnitudes of 7.0 or greater and 74 with magnitudes of 6.0 or greater. Most of these earthquakes occurred in the offshore area west of Honshu.

Similarly, the city of Christchurch on the south island of New Zealand was hit by three further significant earthquakes following the magnitude 6.1 event on 2 February 2011. A magnitude 6.0 event occurred on 13 June 2011 and two events with magnitudes of 5.8 and 5.9 occurred on 23 December 2011. These earthquakes caused further damage and considerable disruption to reconstruction efforts in the city. Aftershock locations appear to suggest that the seismicity is migrating from west to east through the city, with the events in December occurring a few kilometres offshore.



Aftershock activity following the magnitude 9.0 earthquake west of Honshu.

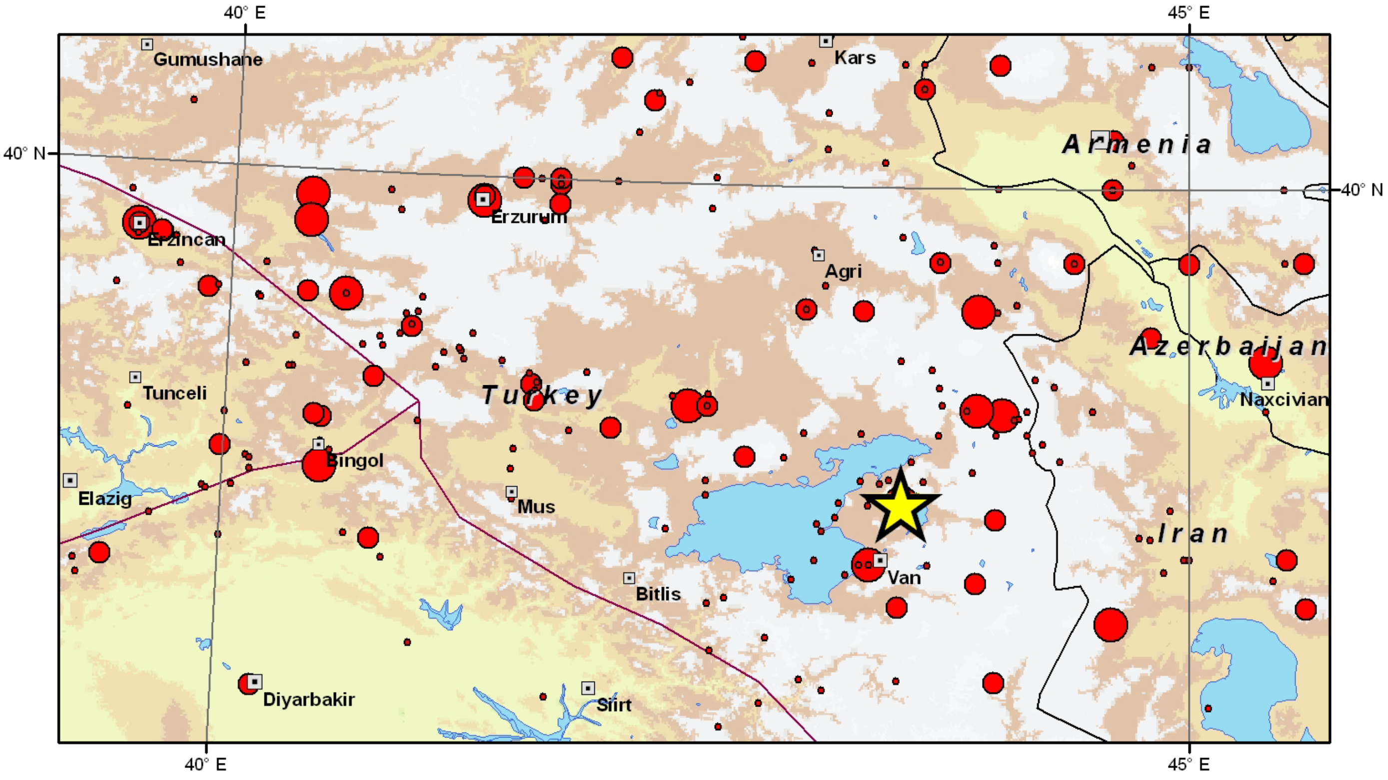
On 11 May 2012, an earthquake with a magnitude of 5.1 occurred near the town of Lorca in the south of Spain. This event caused a significant amount of damage given its size, with at least ten people killed and dozens more injured. The earthquake was preceded by a magnitude 4.5 foreshock just under two hours before. The aftershock sequence included events with magnitudes up to 4.1

A magnitude 5.8 earthquake struck Viriginia, U.S.A. on 23 August 2011. The earthquake was felt over a large part of the east coast North America and caused significant disruption and interruption to business and transport.

At least 108 people were killed by a magnitude 6.9 earthquake in the Sikkim region of northern India on 18 September 2011. The earthquake occurred in the mountainous region of northeast India near the Nepalese boarder at the boundary between the India and Eurasia plates. Mud and landslides triggered by the earthquake destroyed houses and many roads and bridges, cutting of villages and greatly hampering the relief effort. Over 100,000 buildings have suffered extensive damage and many thousands of people were displaced.

An earthquake with a magnitude of 7.1 struck the Ercis-Tabanli-Van area of eastern Turkey on 23 October 2011. At least 601 people were killed and over 2,600 others injured. Over 10,500 buildings were either destroyed or badly damaged. Telecommunications, electricity and water services were also badly disrupted. The earthquake occurred directly as a result of convergence between the Arabian and Eurasian plates, rather than strike-slip motion on the north and east Anatolian fault systems. In the area of Lake Van, the Arabian plate is moving north at a rate of around 24 mm/yr. The focal mechanism earthquake is consistent with oblique-thrust faulting.

Four of the magnitude 7.0 or greater earthquakes in the reporting period occurred in Vanuatu. Two earthquakes with magnitudes of 7.1 and 7.0 occurred a few hours apart on 20 August 2011. These were followed by a magnitude 7.0 event on 3 September. A further magnitude 7.1 earthquake occurred on 2 February 2012.



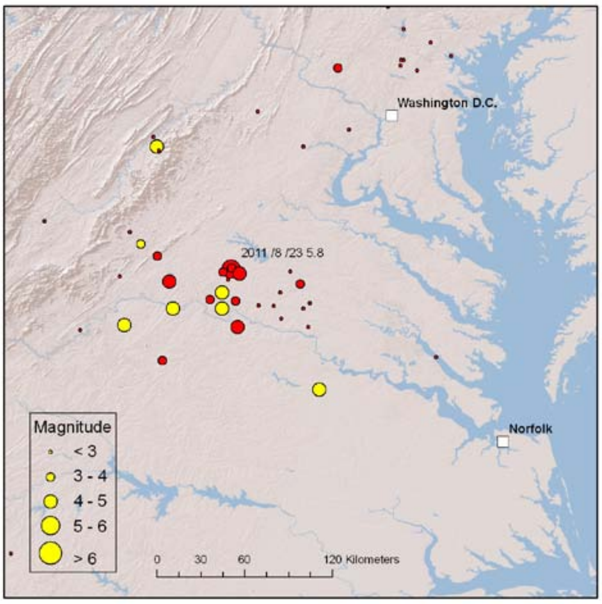
Seismicity in eastern Turkey. The epicentre of the magnitude 7.1 earthquake on 23 October 2011 is shown by the yellow star.

Seismic Activity

The Viriginia Earthquake, 23 August 2011

This earthquake highlights the disruption that such moderate earthquakes can cause to infrastructure, buildings and communications, even if the physical damage is comparatively minor. It also reinforces the need for adequate emergency planning and preparedness even in areas of low earthquake activity. There is particular relevance for sensitive structures, such as nuclear power plants, in ensuring that appropriate measures are in place, e.g. automatic shutdown procedures.

A magnitude 5.8 Mw earthquake struck Virginia at 12:51 local time on 23 August 2011, 135 km (84 miles) southwest of Washington D.C. The earthquake was felt over a large part of the east coast North America. Although there were no deaths or serious injuries and only minor damage, the earthquake did cause significant disruption and interruption to business. The Pentagon and US Capitol were evacuated along with schools and other office buildings.



Instrumentally recorded (red) and historical (yellow) earthquake activity in the Cenrtral Virginai Seismic Zone.

Reported damage included collapse of unreinforced masonry walls, gable walls, and chimneys. Falling ceilings and furniture added to the damage and disruption. There was also damage to historic buildings, including the National Cathedral in Washington. The Washington Monument was also closed.

Two nuclear reactors at the North Anna Power Station (7 miles from epicenter) were automatically shutdown. Backup generators were used to keep spent nuclear fuel cooled. No damage was reported at the site.

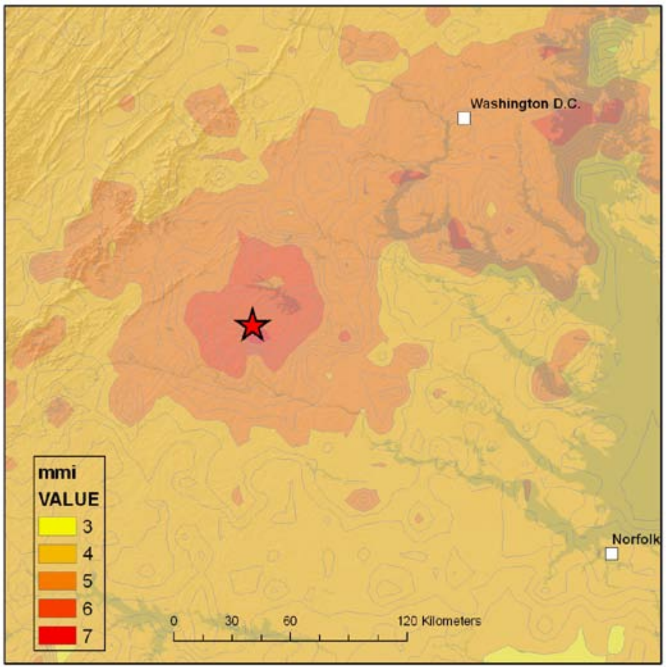
Flights from New York's John F. Kennedy and Newark airports were delayed while authorities checked for damage from the quake, but later resumed. Flights out of Reagan National Airport in Washington were also put on hold, but also resumed normal service shortly after the quake.

The Amtrak passenger train network slowed its trains on north-eastern routes, and advised passengers to expect delays. In Washington, the Metro public transportation system was running trains at 15mph (24km/h) while workers inspected the tracks, and said customers should expect delays. There were also extensive traffic delays.

The earthquake disrupted both telephone and internet connections. Mobile phone service remained intermittent for some time afterwards.

The earthquake occurred within, the "Central Virginia Seismic Zone", a previously recognized seismic zone. The zone is characterized by diffuse seismic activity, with earthquakes distributed over an area of approximately 120 km by 120 km. Earthquake activity has not been attributed to any single causative fault. Instrumentally recorded earthquakes have had diverse focal mechanisms. Focal depths are typically shallow with an average depth about 8 km. The focal mechanism for the magnitude 5.8 event shows reverse faulting on a north or northeast-striking plane, however, a causative fault has not been identified and fault dimensions are not yet known.

The Central Virginia Seismic Zone has produced small and moderate earthquakes since at least the 18th century. The previous largest historical shock from the Central Virginia Seismic Zone occurred in 1875. The felt area suggests that it had a magnitude of about 4.8. The 1875 earthquake shook bricks from chimneys, broke plaster and windows, and overturned furniture at several locations. A magnitude 4.5 earthquake on 9 December, 2003, also produced minor damage.



Expected intensity of ground shaking from the magnitude 5.8 Virigina earthquake on 23 August, 2011.

Scientific Objectives

Automatic Detection and Location

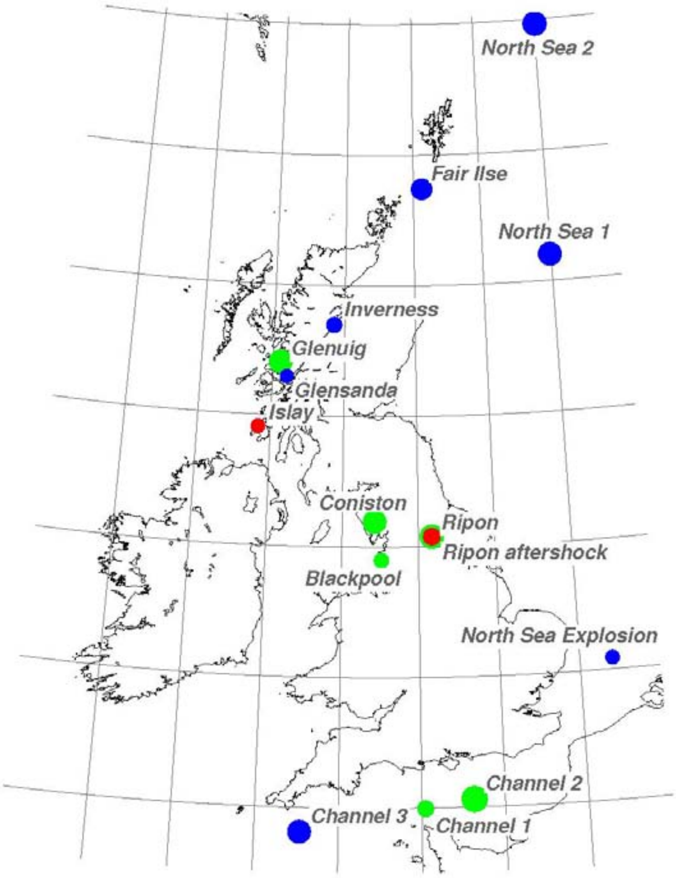
Reliable automatic location of local seismic events is a long term goal of the project. This year we have made significant progress towards this, with the implementation and testing of software incorporated in our real-time data acquisition. The system will provide rapid notification of significant earthquakes within the British Isles and immediate offshore areas, which will allow analysts to quickly confirm that an event has happened and to manually analyse all available data.

The real-time seismic data processing system, EarthWorm (Bittenbinder et al. 1995), is used at BGS for seismic event detection. This uses a standard STA/LTA detector on incoming data channels. The STA/LTA method compares the average energy in a shorter window to that in a longer window. If the average value in shorter window exceeds the long term average by a given ratio then the station is “triggered”. If more than a given number of stations “trigger” within a short time window an event is registered. This method has worked well for many years and reliably finds most events that are reported as felt. However, it requires an analyst to examine all detections to reject false triggers, and manually locate any real events. In addition, if there are many noisy stations the number of false detections may be unreasonably high.

Earthworm also contains a more powerful event detector known as the “mega-module” or “sausage”. This comprises of a number of modules to pick and associate phase arrivals, determine event locations and magnitudes and provide email notification of any events that meet the specified criteria. However, the phase picking and association modules need careful tuning, with many parameters which need to be set depending on network conditions, and, until now, it was considered that the BGS network was changing too rapidly to get optimal performance.

This year we have carried out systematic testing of these modules to find the best parameters for the UK, so that the majority of events over a certain magnitude will be automatically located and that an email alert will be sent with a location and magnitude within a few minutes of the occurrence of an event. This should allow a more pro-active response to significant felt earthquakes.

The first part of event detection and location is recognising phase arrivals on individual stations. In Earthworm this is done using a picking algorithm developed by Allen (1978) to scan streams of incoming data. For each current station in the network all past events with a pick for that station were used to find the optimum parameters that, on average, reduce the offset between the manual picks in the database and the automatic picks. We find that after tuning, the picker is able to find at least 85% of manually picked events. Before tuning, this was less than 50% in many cases.



The events used to tune and test the association algorithm. The green events were detected by the association algorithm before tuning, the blue events after tuning, and the red events not at all.

The second part of event detection is associating picks to find a common source. The EarthWorm association module outputs a preliminary location for any event and initiates subsequent processing. We used fifteen events from the last 18 months to tune the associator, which has over 20 adjustable parameters. These test events were chosen to cover as large a geographical area as possible and to have a range of magnitudes.

At this stage the parameters have been tuned so that twelve of the fifteen events are routinely detected in tests. Those not detected are a 2.6 ML aftershock of the magnitude 3.6 Ripon earthquake in 2011 and a 2.1 ML earthquake near Islay. The former is probably too soon after the main shock for an associator of this type to ever work. The Islay event was in an area of sparse network coverage that will hopefully be improved with the installation of an Argyll station in 2012/2013.

The final stage of testing is gauging and reducing the number of false detections by associator, especially those that result in email alerts. This process is ongoing. Each time a false detection is made adjustments are made to the associator configuration. The new configuration is then tested with the 15 real events to ensure that none of those would be missed.

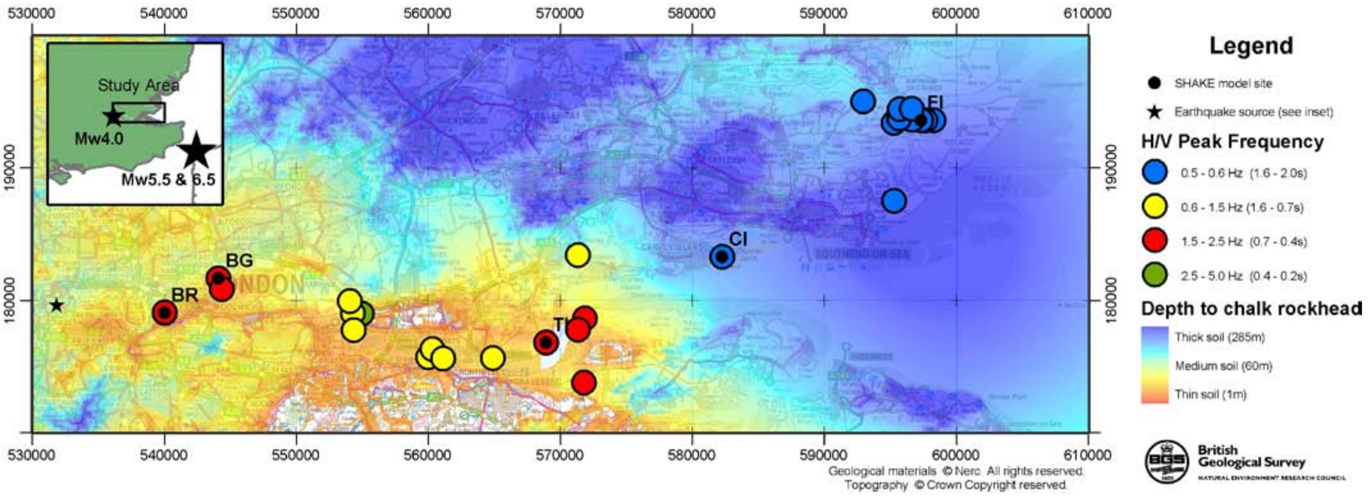
Scientific Objectives

Ground motion amplification in London

The potential for amplification of ground motion due to characteristics of the near-surface geology is well known. After the 2007 Folkestone earthquake, some correlation between the distribution of colluvial sediments and damage was observed. Intensity observations from other British earthquakes also indicate that felt effects are likely to be stronger where soft sediments are present, such as river flood plains. A collaborative project with BGS engineering geologists, investigated the potential for ground motion amplification beneath London.

London has been affected by earthquakes throughout the historical and instrumental period and some of these are known to have caused damage (e.g. 1580 Dover Straits, 5.5 Mw; February and March 1750, London, <3.0 Mw). The deep geology of London is dictated by its position within the London Basin, characterised by a broad synclinal structure which extends beneath a large part of south-eastern England. Engineering ground conditions in London are largely influenced by the geotechnical characteristics of the widespread Quaternary deposits that comprise often soft unconsolidated sediments including made ground, river and estuarine alluvium, river terraces, peats and wind-blown silt. The Quaternary sediments directly overlie stiffer material, either Palaeogene sediments (very stiff clays and dense sands) and/or Cretaceous chalk (soft rock). Within the vicinity of the capital, these softer unconsolidated sediments can be up to 30 m thick and the soil column to rock (chalk) can be up to 60 m thick.

In order to investigate the potential for ground motion amplification in London for future earthquakes, we characterised



Results of the study showing depth to bedrock (chalk) and H/V peak frequencies geotechnical properties of the near-surface at five sites along the Thames Estuary using the BGS physical properties database and published data. The shear-wave velocity profile of the soil column was estimated using two complementary approaches: a microtremor H/V spectral ratio method and empirically-based effective stress-dependent physical property inter-relationships. The horizontal to vertical (H/V) spectral ratio technique (Noghoshi and Igarashi, 1970, 1971; Nakamura, 1989) is used to estimate the site response from three-component recordings of background seismic noise and to map the fundamental periods of the soil column. The peaks in the spectral ratio of the two components are related to sharp impedance contrasts below the recording site. This technique is expected to reveal the fundamental frequencies at which amplification occurs

The velocity/stress inter-relationships provide more realistic depth profiles of the stress-dependent physical properties input into SHAKE91 (Idriss *et al*, 1993), which in turn approximates the non-linear response of the soil column. Possible earthquake scenarios for London that consider various epicentres, magnitudes and stress drops have been used to compute ground motion at bedrock for each of the sites. The properties of the soil columns and ground motions estimated at bedrock were input into SHAKE91 and used to compute how seismic waves are modified as they propagate upwards through the soil column. Our results indicate significant amplification occurs at the ground surface where Quaternary sediments are present above a chalk rockhead and this effect seems to be particularly pronounced for local earthquake sources.

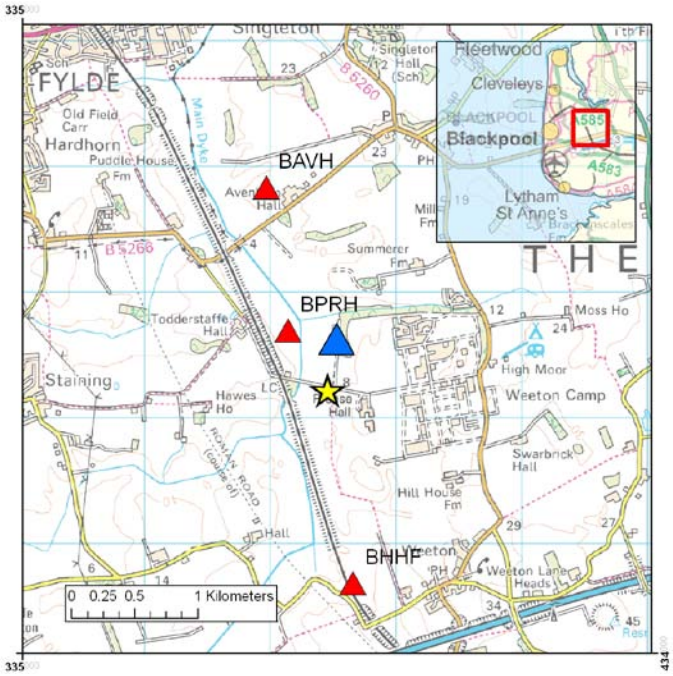
Making H/V measurements in the London Basin.

Scientific Objectives

Hazard from earthquakes induced by fluid injection

The earthquake activity near Blackpool in April/May 2011 and its relation to hydraulic fracturing operations during exploration of a nearby shale-gas reservoir suggest a need to re-examine the hazard posed by such events.

On 1 April and 27 May 2011, two earthquakes with magnitudes of 2.3 ML and 1.5 ML were detected in the Blackpool area. These earthquakes were immediately suspected to be linked to hydraulic fracture injections at the Preese Hall well (PH1), operated by Cuadrilla Resources Ltd. This well was hydraulically fractured during exploration of a shale gas reservoir in the Bowland basin. As a result of the earthquakes, operations were suspended at PH1 and Cuadrilla Resources commissioned a number of studies into the relationship between the earthquakes and their operations (e.g. de Pater and Baisch, 2011).



Epicentre of the Blackpool earthquakes (yellow star) in relation to the Preese Hall well. Depth is approximately 2250 m, which places the events close to the point of injection.

A recent report commissioned by DECC (Green et al, 2012) that included a BGS co-author concluded that the earthquakes near Blackpool in April and May 2011 were induced by hydraulic fracture treatments at the Preese Hall well, operated by Cuadrilla Resources Ltd. The report also concluded that further small earthquakes cannot be ruled out, however the risk from these earthquakes is low, and structural damage is unlikely.

The report also recommended a number of measures to reduce the likelihood of earthquakes associated with hydraulic fracturing in future. These include using smaller injected volumes and allowing the fluid to 'flow back' out of the formation after the hydraulic fracture forms.

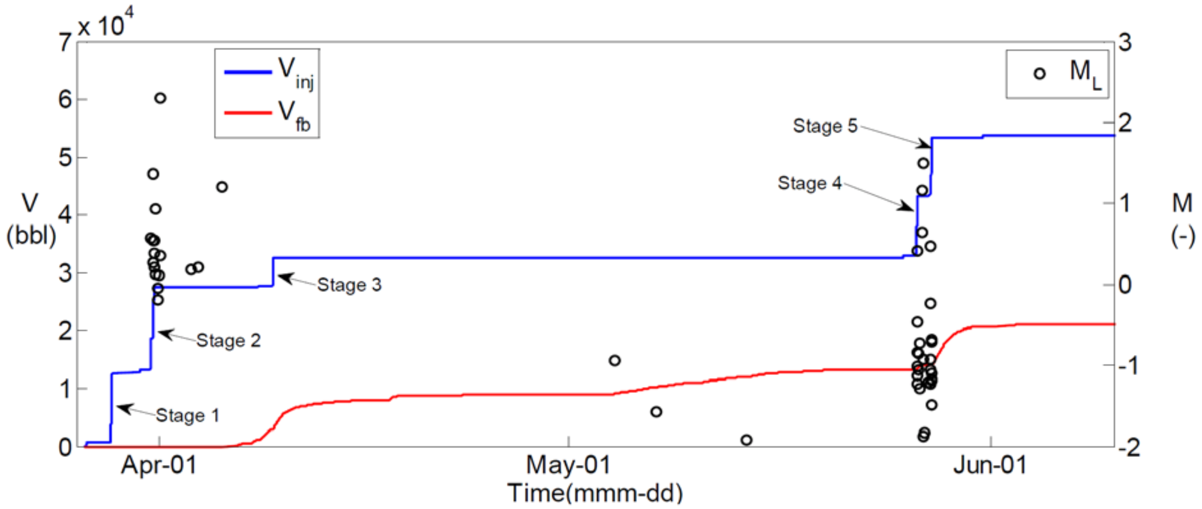
In addition, earthquake activity should be carefully monitored before, during and after fracture treatments. If any earthquakes above a certain magnitude threshold occur, the operations should be temporarily suspended. Such a traffic light system is based on extensive experience in Enhanced Geothermal Systems (EGS)

Detailed microseismic monitoring should be carried out for the next hydraulic fracture treatment in the Bowland shale.

Hydraulic-fracture induced micro-seismicity has been widely used in the oil and gas industry over the past decade to image fracture networks and estimate the orientation and size of a stimulated volume (Rutledge and Phillips, 2003). This should improve understanding of fracture growth and the hazards associated with this.

There are numerous examples of induced earthquakes in hydrocarbon fields (e.g. Suckale, 2010). For example, in 2001 a magnitude 4.1 Mw earthquake occurred in the Ekofisk field in the central North Sea (Ottemoller et al., 2005). The earthquake was thought to be related to the pressure maintenance injection of around 1.9×10^6 m^3 of water. Induced earthquakes with magnitudes as large as 3.5 ML are well documented in Enhanced Geothermal Systems (EGS) (Majer et al., 2007), where the injected volumes may be much larger than in hydrocarbon fields and the reservoir rocks are much stronger. In general, the number of fluid injection induced earthquakes above a given magnitude will increase approximately proportionally to the injected fluid volume (Shapiro, 2010).Magnitudes of the earthquakes during hydraulic fracture stimulation in reservoirs such as the Barnett Shale, Texas, are typically less than 1 ML. This suggests that the earthquake activity observed at Preese Hall is rather unusual.

However, both the tectonic history and the present-day stress regime in the British Isles is rather different to many of these areas of exploration and production. Also, it should be noted that many US shale gas plays are in relatively remote locations, with no monitoring networks in place. A recent study by Holland (2011) suggests that hydraulic fracturing induced seismicity may be a potential issue for other reservoirs. There are also examples of seismicity induced by fluid disposal in deeper wells (e.g. Frohlich et al, 2011).



Overview of injection volume and seismicity during the five treatment stages at PH1. Earthquake activity closely correlates with stages 2 and 4. The blue line shows the injected fluid volume (V_{inj}) while the blue line shows the flow-back volume (V_{fb}). The largest event with a magnitude of 2.3 ML at 02:34 on 1/4/2011 occurred shortly after stage 2 (from de Pater and Baisch, 2011).

PSHA Validated by Quasi Observational Means

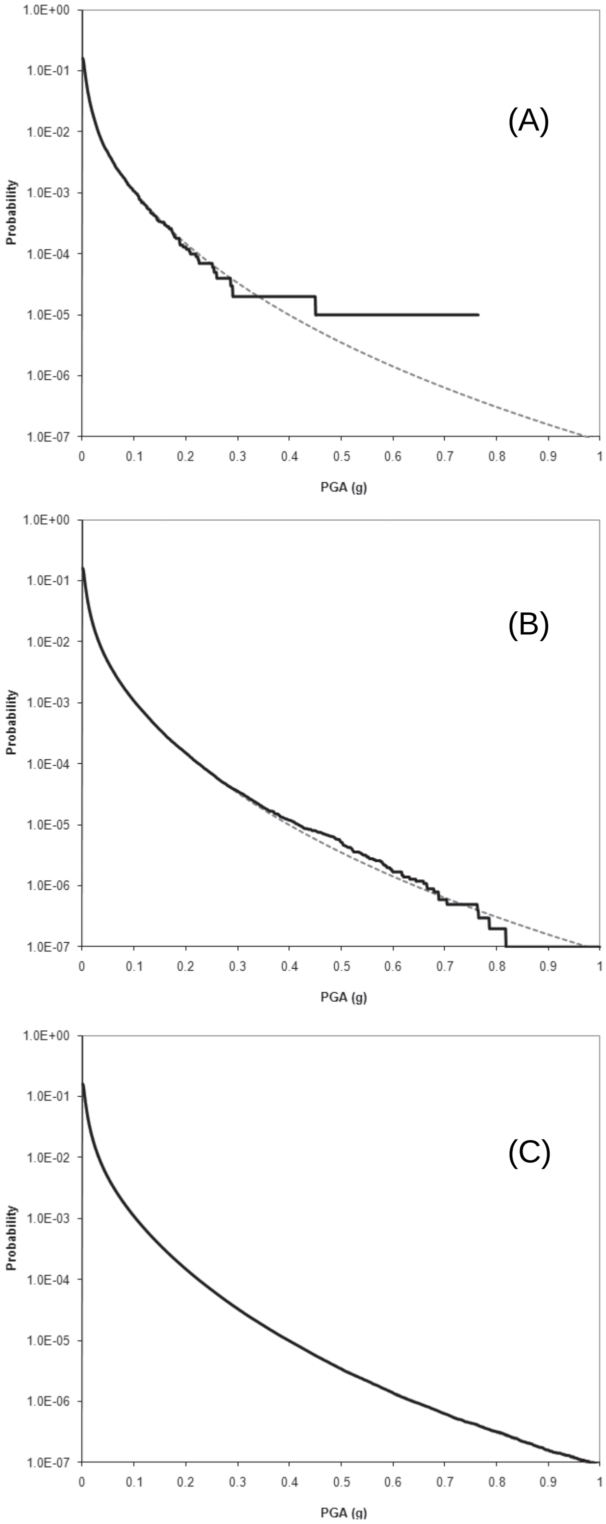
The primary objective of probabilistic seismic hazard assessment (PSHA) is to estimate the probability of a given ground motion at a site. In a recent paper, Musson (2012) shows how the results of a PSHA study using the Cornell-McGuire method can be duplicated using Monte-Carlo simulations. The fact that two completely different approaches yield the same answer indicates the validity of both methods.

Despite the fact that probabilistic seismic hazard assessment has been widely used throughout the world over the last 40 years, occasionally claims are made by contrarians that the entire method is invalid because of basic mathematical errors in the formulation of the classic method, which relies on evaluation of a hazard integral. It turns out to be unnecessary to refute these arguments mathematically, because the same result as that obtained by the classic “Cornell” method can be obtained independently using a Monte Carlo simulation approach to seismic hazard (Musson 1998, 2000).

Probabilistic seismic hazard assessment (PSHA) can be described as consisting of two parts: a model (represented by a PSHA input file) and a process (represented by a seismic hazard program). The model is a conceptualization of the seismic process expressed in numerical form, describing: (1) where earthquakes occur; (2) how often they occur, both in terms of inter-event time and magnitude-frequency; and (3) what effects they have. These three elements describe everything that determines the statistical properties of the seismic effects that will occur at a given site in the future. This allows one to simulate that future ground shaking using the aggregate properties of the seismicity and the ground motion propagation.

In the Monte Carlo approach simulated earthquake catalogues are generated in which the probability density functions for earthquake occurrence in the model are randomly sampled to produce one possible outcome. This process is repeated a large number of time, so a 50-year catalogue repeated 200,000 times gives 10,000,000 years of pseudo-observational data, from which computing the probability of any result is as simple as counting.

Epistemic uncertainty is introduced by using a suitable probability density function, say for maximum magnitude, and randomly sampling this in each simulated catalogue. In practice, it is usually simpler to discretize this as a logic tree, with a value drawn from the tree according to the weights of the branches in each simulation, but the process is conceptually the same. However, the way a logic tree is treated is totally different in conventional PSHA and the Monte Carlo simulation approach. In conventional PSHA (Coppersmith and Youngs, 1986), hazard is computed for each branch, giving a number of hazard values equal to the number of branches. The final expected value is the weighted mean. In the Monte Carlo simulation approach, the individual branches are not evaluated in their entirety; all branches are sampled randomly, and a single hazard calculation made at the end. The total mass of simulated observations reflects all the possible outcomes that are implicit in the complete structure of the logic tree.



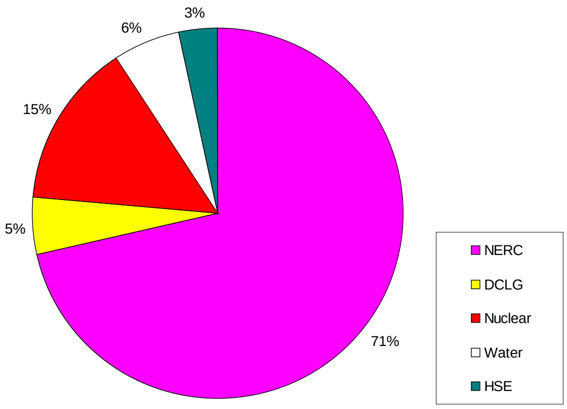
Reproducing a Cornell-McGuire study (dashed lines) with a Monte Carlo simulation study: (A) 100,000 years of “data,” (B) 10,000,000 years of “data,” (C) 1,000,000,000 years of “data.”

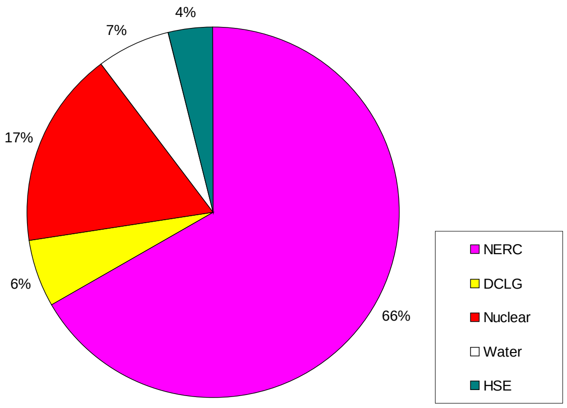
The two approaches, however, despite being entirely different and sharing no common procedures, give exactly the same results for the same input models. It is impossible for both methods to include the same error when they operate in entirely different ways, and therefore they can only give the same results if 1) they include different errors that somehow consistently have exactly the same effect, or 2) they are both right. The first of these is not credible, which leaves the second.

A specific example is shown in the figure. This relates to a model originally constructed for assessing hazard to a nuclear site in southern England (Seismic Hazard Working Party 1987). The original study employed a logic tree, seven source zones, and one fault source, and used a program called PRISK (originally based on EQRISK) to perform the calculations. The source model was reconstructed in the format used by the BGS in-house software M3C, which uses the Monte Carlo simulation approach. As one increases the number of years of “observation,” the hazard curve gradually converges with that calculated in the original study until the agreement is perfect. This agreement is achieved despite the fact that the calculation methods have nothing in common. Therefore, they validate one another

Funding and Expenditure

In 2011-2012 the project received a total of £663k from NERC. Some of this was won from specific funding calls and £80k of additional capital funding for equipment was also received. This was used to purchase spare hardware for the monitoring network. This was matched by a total contribution of £266k from the customer group drawn from industry, regulatory bodies and central and local government.


Funding Received 2011-2012


Funding Expected 2012-2013

The projected income for 2012-2013 is similar to that received in 2011-2012, albeit with a slight reduction. The NERC contribution for 2012-2013 currently stands at £603k, but we hope to increase this through applications for additional funding through the year. The total expected customer group contribution currently stands at £258k. Currently, other potential sponsors are being explored.

Acknowledgements

This work would not be possible without the continued support of the Customer Group. Station operators and landowners throughout the UK have made an important contribution and the BGS technical and analysis staff have been at the sharp end of the operation. The work is supported by the Natural Environment Research Council and this report is published with the approval of the Director of the British Geological Survey (NERC).

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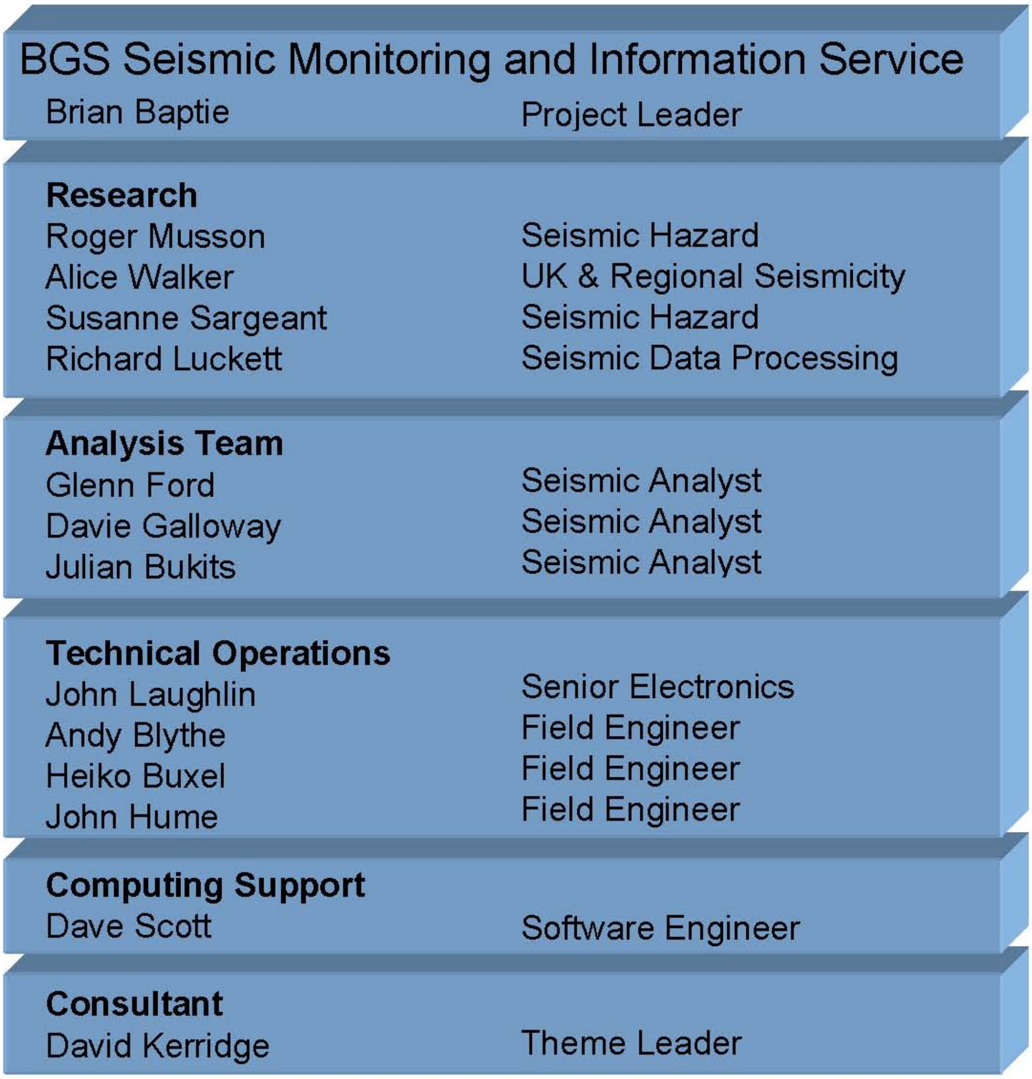
Appendix 1 The Project Team



BGS Seismic Monitoring and Information Service

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Alice Walker	UK & Regional Seismicity
Susanne Sargeant	Seismic Hazard
Richard Luckett	Seismic Data Processing

Analysis Team

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Davie Galloway	Seismic Analyst
Julian Bukits	Seismic Analyst

Technical Operations

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Andy Blythe	Field Engineer
Heiko Buxel	Field Engineer
John Hume	Field Engineer

Computing Support

Dave Scott	Software Engineer

Consultant

David Kerridge	Theme Leader

Appendix 2 Publications

BGS Internal Reports

Baptie, B. 2011. Earthquake Monitoring 2010/2011, BGS Seismic Monitoring and Information Service, Twenty second Annual Report, BGS Internal Report OR/11/031.

Galloway, D. D., 2011. Bulletin of British earthquakes 2011, BGS Report OR/12/028.

In addition, six confidential reports were prepared and bulletins of seismic activity were produced monthly, up to six weeks in arrears for the Customer Group.

External Publications

M.W. Davis, M.W., White, N.J., Priestley, K.F., Baptie, B.J. and Tilmann, F.J.,2012. Crustal Structure of the British Isles and its Epeirogenic Consequences, Geophysical Journal International, 190, 705-725.

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Appendix 3 Publication Summaries

Crustal Structure of the British Isles and its Epeirogenic Consequences

M.W. Davis, N.J. White, K.F. Priestley, B.J. Baptie and F.J. Tilmann

Crustal receiver functions have been calculated for a network of 51 three-component broadband seismometers distributed across the British Isles and NW Europe. Over 3200 receiver functions were assembled for 1055 events. For each station, preliminary estimates of crustal thickness and Vp/Vs ratio were obtained from H-_ plots. Stacked receiver functions were then inverted to determine shear wave velocity as a function of depth. Each result was checked by guided forward modelling and by Monte Carlo error analysis. In this way, the robustness of our final calculated velocity profiles was carefully tested. A set of depth migrated profiles was also constructed using an average of 50 events for each station over a range of back azimuths. These profiles agree well with legacy wide-angle crustal models. Our results show that crustal thickness varies between 24 and 36 km across the British Isles. Thicker crust is found beneath North Wales and beneath central Scotland. Thinner crust occurs beneath northwest Scotland and northwest Ireland. By combining our database with the results of controlled source, wide-angle experiments and with depth-converted reflection profiles, we have produced a detailed crustal thickness map for a region encompassing the British Isles. Our synthesis of crustal thickness and structure has important implications for the tectonic and magmatic histories of this region. Complex Moho structure with lower crustal P-wave velocities of >7 km s−1 occurs beneath regions of Cenozoic magmatism, which may be consistent with magmatic underplating. Thin crust beneath northern Britain suggests that present-day long wavelength topography is maintained by regional dynamic support, originating beneath the lithospheric plate.

General levels of seismic hazard in the UK

R.M.W. Musson

The 2007 release of seismic hazard maps for the UK showed levels of ground motion hazard that were considered surprisingly low by some. This is in a large part due to a previously unrecognised issue with magnitude scales. Some work on seismic hazard in the 1980s and 1990s in the UK employed the surface-wave magnitude scale without understanding that there are two versions of the scale, which are not compatible at low magnitudes. Converting from surface magnitude using an inappropriate formula can inflate ground motion hazard by as much as a factor of four.

Great earthquakes

R.M.W. Musson

This book chapter discusses some of the most important large earthquakes in the history of seismology, particularly 1755 Lisbon, 1906 San Francisco and 2004 Sumatra.

Objective assessment of source models for seismic hazard studies: with a worked example from UK data

R.M.W. Musson and P.W Winter

Up to now, the search for increased reliability in probabilistic seismic hazard analysis (PSHA) has concentrated on ways of assessing expert opinion and subjective judgement. Although in some areas of PSHA subjective opinion is unavoidable, there is an all too present danger that assessment procedures and review methods simply pile up further subjective judgements on top of those already elicited. Such reviews are in danger of assessing only the form and neglecting the content. The time has come to find ways to demonstrate objectively, where possible, if interpretations are valid or not. This can be done by studying what these interpretations physically mean in terms of seismicity. Experience shows that well-meaning but flawed design decisions can lead to source models that are actually incompatible with seismic history. One such method is as follows: from a seismic source model one can generate large numbers of synthetic earthquake catalogues that match the completeness thresholds of the historical catalogue. The question is then posed, is the historical earthquake catalogue a credible member of the set of all possible catalogues derived from the model? If the answer to this is no, and this can be determined statistically, then one can reject, with a specified confidence level, the hypothesis that the model is a valid depiction of the long-term seismicity rates that will govern the future hazard.

UK seismic hazard assessments for strategic facilities

R.M.W. Musson

There is a widespread misapprehension that Britain is a country without earthquakes; and before the 1970s, this notion extended to the UK engineering community. This was despite the fact that the first commercial nuclear power plant (NPP) in the UK commenced operation in 1956. Around the mid 1970s, awareness dawned that even in a low seismicity country like the UK, earthquakes still occur, and can be sufficiently large (albeit rarely) to be significant for high-consequence structures. The history of seismic hazard research for the nuclear industry is traced, in the context of the UK regulatory environment.

PSHA validated by quasi observational means

R.M.W. Musson

It might seem odd to be writing about confirmation of the validity of probabilistic seismic hazard assessment (PSHA) in 2011, given that the method has been successfully applied in countless studies worldwide over the last 40 years. However, the fact that papers still occasionally find their way into print attacking the method as mathematically invalid seems to indicate that there is still some requirement, if small, to demonstrate the soundness of the method. The intention of this paper is to point out that the results of a PSHA study using the Cornell-McGuire method can be duplicated by a completely different route, and without any but the simplest mathematics, using a quasi-observational approach.

Interpreting intraplate tectonics for seismic hazard: a UK historical perspective

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It is notoriously difficult to construct seismic source models for probabilistic seismic hazard assessment in intraplate areas on the basis of geological information, and many practitioners have given up the task in favour of purely seismicity-based models. This risks losing potentially valuable information in regions where the earthquake catalogue is short compared to the seismic cycle. It is interesting to survey how attitudes to this issue have evolved over the past 30 years. This paper takes the UK as an example, and traces the evolution of seismic source models through generations of hazard studies. It is found that in the UK, while the earliest studies did not consider regional tectonics in any way, there has been a gradual evolution towards more tectonically-based models. Experience in other countries, of course, may differ.

Seismic interferometry and ambient noise tomography in the British Isles

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Traditional methods of imaging the Earth's subsurface using seismic waves require an identifiable, impulsive source of seismic energy, for example an earthquake or explosive source. Naturally occurring, ambient seismic waves form an ever-present source of energy that is conventionally regarded as unusable since it is not impulsive. As such it is generally removed from seismic data and subsequent analysis. A new method known as seismic interferometry can be used to extract useful information about the Earth's subsurface from the ambient noise wavefield. Consequently, seismic interferometry is an important new tool for exploring areas which are otherwise seismically quiescent, such as the British Isles in which there are relatively few strong earthquakes. One of the possible applications of seismic interferometry is ambient noise tomography (ANT). ANT is a way of using interferometry to image subsurface seismic velocity variations using seismic (surface) waves extracted from the background ambient vibrations of the Earth. To date, ANT has been used successfully to image the Earth's crust and upper-mantle on regional and continental scales in many locations and has the power to resolve major geological features such as sedimentary basins and igneous and metamorphic cores. Here we provide a review of seismic interferometry and ANT, and show that the seismic interferometry method works well within the British Isles. We illustrate the usefulness of the method in seismically quiescent areas by presenting the first surface wave group velocity maps of the Scottish Highlands using only ambient seismic noise. These maps show low velocity anomalies in sedimentary basins such as the Moray Firth, and high velocity anomalies in igneous and metamorphic centres such as the Lewisian complex. They also suggest that the Moho shallows from south to north across Scotland which agrees with previous geophysical studies in the region.

Field observations from the Aquila, Italy earthquake of April 6, 2009.

T. Rossetto et al.

On April 6, 2009 an earthquake of magnitude 6.2 (Mw) struck the Abbruzzo region of Italy causing widespread damage to buildings in the city of L'Aquila and surrounding areas. This paper summarizes field observations made by the Earthquake Engineering Field Investigation Team (EEFIT) after the event. The paper presents an overview of seismological and geotechnical aspects of the earthquake as well as a summary of the observed damage to buildings and infrastructure. A brief overview of the earthquake casualties is also reported.

Predicting uncertainty and risk in the natural sciences: bridging the gap between academics and industry.

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The increase in large-scale disasters in recent years, such as the 2007 floods in the UK, has caused disruptions of livelihood, enormous economic losses and increase in fatalities. Losses from natural hazards are only partially derived from the physical event itself but are also caused by society's vulnerability to it. In the first three months of 2010, an unprecedented US$16 billion in losses occurred from natural hazards caused by events such as the Haiti and Chilean earthquakes, and the European storm Xynthia. This made it the worst ever first quarter for natural hazard losses and left the insurance industry exposed financially to the more loss-prone third and forth quarters. NERC science has a central role to play in the forecasting and mitigation of natural hazards. Research in this area forms the basis for technological solutions to early warning systems, designing mitigation strategies and providing critical information for decision makers to help save lives and avoid economic losses. Understanding uncertainty is essential if reliable forecasting and risk assessments are to be made. However, the quantification and assessment of uncertainty in natural hazards has in general been limited particularly in terms of model limitations and multiplicity. There are several reasons for this; most notably the fragmented nature of natural hazard research which is split both across science areas and between research, risk management and policy. Because of this, each sector has developed its own concepts and language which has acted as a barrier for effective communication and prevented the production of generic methods that have the potential to be used across sectors. It is clear therefore that by bringing the natural hazard community together significant breakthroughs in the visualisation and understanding of risk and uncertainty could be achieved. To accomplish this, this research programme has 4 prime objectives: 1.To improve communication and networking between researchers and risk managers within the financial services sector 2.To provide a platform for the dissemination of information on uncertainty and risk analysis between a range of researchers and practitioners 3.To generate a portfolio of best practice in uncertainty and risk analysis 4.To act as a focal point between the financial sector and natural hazard research in NERC This paper will discuss how the Natural Environmental Research Council, in partnership with other organisations such as TSB, EA and EPSRC etc, is working with academics and industry to bring about a step change in the way that uncertainty and risk assessments are achieved throughout the natural hazard community.