The UK broadband seismology network

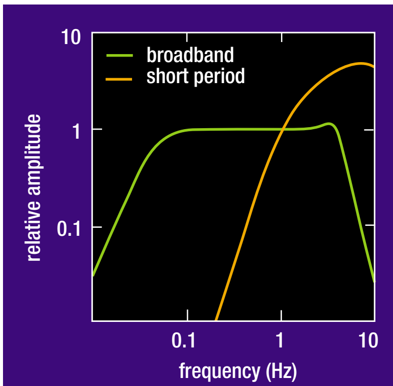
Alan Douglas considers the origins and the future of one of Britain's most successful seismic networks.

Broadband seismology is a powerful tool for geophysical research. Over the past decades, most seismometers have recorded only part of the spectrum of frequencies of vibration from earthquakes. Broadband seismology brings far greater research rewards. The UK has been a pioneer in its use and has had a broadband network for around 30 years. During this time, Britain has developed the technology and made significant research advances in the fields of earthquake source mechanisms, deep-Earth structure, detection and location of distant earthquakes and explosions, and nuclear explosion detection. The network has also played a part in the development of the Data Centre of the Observatories and Research Facilities for European Seismology. But changes in funding mean that the future of this pioneering network is now uncertain.

Some time during 1969, Peter Marshall, one of my colleagues in the Atomic Weapons Establishment Seismology Group at Blacknest (of which Hal Thirlaway was then the director), proposed that if it could be done, the Group should begin recording ground displacement in the broadband 0.01–10 Hz. Conventional short-period (SP ~ 1 Hz) and long-period (LP ~ 0.05 Hz) seismograms could then be derived from the broadband (BB). Discussions with Ron Burch, the instrumentation expert of the group, suggested that broadband recording could be achieved relatively easily and this was confirmed a few weeks later when our first broadband seismograms were written to magnetic tape. This marked the beginning of continuous tape recording of broadband seismograms in the UK. Eventually, a 12-element network (UKNET) of broadband seismometers was established, with all the signals being transmitted to Blacknest by telephone line to be recorded against a common time base; four of the elements being an array (aperture 11 km) around Blacknest, with the remainder spread across Great Britain.

End to funding

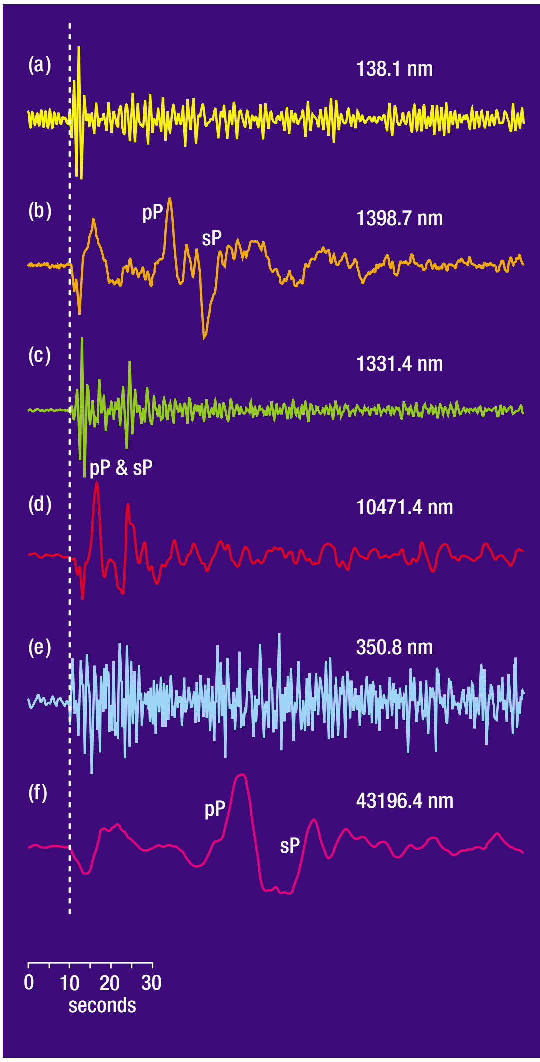
For the past 30 years the UKNET has been operated by the Blacknest group which I now head and has been funded by the UK Ministry of Defence (MOD), but due to changing priorities this funding is to stop. The MOD has agreed to provide some transitional funding to allow the Global Seismology and Geomagnetism group of the British Geological Survey (BGS) to take over the network, but the funds are insufficient to allow the whole network to be kept in operation and it is possible that without additional funds, parts of the network will close in the next two or three years. This would be disappointing, for the UK through UKNET has contributed much to BB seismology. This article describes some of the uses that have been made of the recordings from the UKNET and how the interest in broadband recording stimulated the development of broadband seismology and contributed to the Data Centre of the Observatories and Research Facilities for European Seismology (ORFEUS).



1: Response to ground displacement of the short-period and broadband recording systems. Magnification set to unity at 1 Hz.

Until the recent growth of interest in broadband recording it was customary for seismological observatories to operate SP and LP systems that only recorded that part of the seismic spectrum in which the signal-to-noise ratio is usually a maximum. These systems are ideal for detecting low-amplitude seismic signals such as those from disturbances with body-wave magnitude m_b 4 to 5. Such systems, however, have the disadvantage that the recorded signals give a limited view of the ground motion. To study seismic source functions and frequency-dependent attenuation in the Earth, particularly from body-waves, requires a broadband system. For example, to estimate S-wave attenuation it is essential to have broadband recordings; attenuation at around 1 Hz and higher frequencies is so strong that such waves are rarely seen on SP seismograms recorded at long range. The drawback of such BB systems is that the recording band includes the strong peak in the noise spectrum at around 0.17 Hz due to the oceanic microseisms and thus only relatively large signals, say above about $m_b = 5.5$, are seen above noise.

The original reason for the AWE group starting to record broadband was to try and reconcile disagreements in m_b between seismologists in the former eastern bloc countries (including the USSR) who measured such magnitudes on BB seismograms, and those in the west who measure m_b on SP seismograms. However, once recording started it became clear to us that we had discovered a new seismology – or more correctly that we had "reinvented the wheel" – for we saw seismograms like those of classical textbooks with all the standard phases, but whereas early seismologists had to make do with broadband visual recordings made on fixed (and highly compressed) time bases, magnifications and passbands, we had all the flexibility provided by magnetic tape recordings to get the most out of the broadband seismograms. One striking feature for us, who were used to trying to interpret the highly oscillatory seismograms of narrow-band systems, was how clear the source function of explosions and earthquakes often are when



2: Vertical-component P seismograms from a station in UKNET for three earthquakes. (a) and (b) Short-period and broadband respectively from the Burma–India border earthquake of 29 July 1970. (c) and (d) Short-period and broadband respectively from the Yunnan, China, earthquake of 3 February 1996. (e) and (f) Short-period and broadband respectively from the Volcano Islands earthquake of 28 March 2000. The first arrivals (onset marked by dashed line) are direct P, the arrivals pP and sP are reflections of P and S respectively from the free surface above the source. Note that the surface reflections are only clearly seen on the broadband seismograms. Further, comparison of the short-period and broadband for the Burma–India and Yunnan earthquakes shows that there is more short-period energy in direct P than in the surface reflections. One possible explanation of this is that the radiation is from a source that propagates downwards into the Earth. Then the direct P is from a source that is propagating towards the observer, whereas the pP and sP are from a source that is propagating away from the observer. That is, the direct P radiation is Doppler shifted towards higher frequencies and that of pP and sP towards lower frequencies, relative to the spectrum radiated at right angles to the direction of propagation of the source. The maximum range of the signals is shown in nanometres.

observed broadband (Marshall *et al.* 1972).

At about the same time that we were beginning to appreciate the value of broadband recording, others were also arguing that seismologists should move away from narrow-band recording and begin developing wide-band systems. Thus, for example, Baker (1978) in the USA suggested that arrays should be established specifically designed to suppress microseismic noise and so enhance the signal-to-noise ratio for wide-band recordings of body waves, and Berckhemer (1970) in Germany drew attention to the need for work on wide-band seismometers. It seems obvious now that when ground motion is being recorded on magnetic tape it should be recorded in such a way that seismic noise exceeds system noise over as wide a band as possible. Then, for signals that are below the wide-band noise-level, further filtering (ideally wave-number filtering using an array) can be applied after the recording to extract the signal with the best signal-to-noise ratio. Commenting on why so little effort had been given to the problem of wide-band seismometry, Berckhemer (1970) lists *inter alia* "psychological" reasons and certainly it was our experience that many seismologists claimed that they could see no value in broadband recording. However, during the 1970s much effort was put into the development of broadband seismometers. In the UK the University of Reading began the development of miniature broadband seismometers with the encouragement of AWE Blacknest and some support from the MOD (Usher *et al.* 1977, 1978, 1979, Burch 1984a and b, 1993). One outcome of this work on instrument development is that the UK through Guralp Systems is a world leader in the design and production of miniature broadband seismometers.

Initial drive

When the Blacknest group made its first recordings of broadband ground motion, we did not realize that we were at the start of a trend that would continue, so that now there are world networks of broadband stations. Much of the initial drive for broadband recording came from Europe. Germany began installing a broadband array in 1976 (Henger 1975, Harjes and Seidl 1978, Harjes 1975) and France its worldwide Geoscope network in 1981.

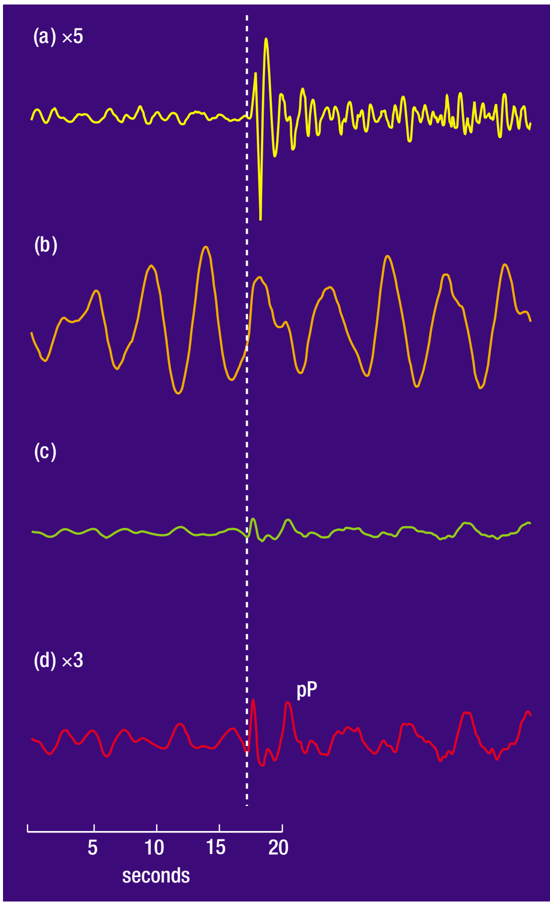
In the early 1980s, the Incorporated Research Institutions for Seismology (IRIS) in the USA began planning to set up world networks of seismographs. This stimulated discussion among European seismologists anxious to preserve their lead in broadband seismology and led to the ORFEUS Science Plan which was published in 1986. The aim of the plan was to provide facilities for the exchange of digital seismograms – the ORFEUS Data Centre – and encourage the establishment of broadband stations in Europe.

The Science Plan was accepted and money was provided by Holland to establish the Data Centre in Utrecht. The foresight of the Blacknest group under Hal Thirlaway in setting up UKNET meant that when the Data Centre asked for broadband data from the UK, we were able to offer the recordings from UKNET. The UK was one of the first countries to provide data to the ORFEUS Data Centre and has continued to supply data to the Centre to the present time. In return we receive, for a nominal fee, copies of all the data contributed to ORFEUS, and other UK groups can, by becoming institutional members (again for a nominal fee) also get copies of the data.

Recordings from UKNET have been used both in the UK and, through ORFEUS, in the rest of Europe for studies of European earthquakes (Braunmiller *et al.* 1994), and the structure of the UK and surrounding areas (Stuart 1978, 1981, El-Haddadeh 1986, Meredith 1989, Meredith and Pearce 1989). Recordings have been used by us to study array methods of suppressing oceanic microseisms (Burton 1974, Douglas and Young 1981), source functions of earthquakes (Douglas *et al.* 1983, Stewart and Douglas 1983, Douglas *et al.* 1990), detection and location of seismic disturbances at long range (Key and Warburton 1983), and discriminating between earthquakes, explosions (including multiple shots), and mining disturbances (Marshall and Hurley 1976, Marshall *et al.* 1989, Bowers and Walter 2001).

Broadband seismograms of earthquakes in the Fiji–Tonga region recorded in the UK are ideal for studying the structure of the Earth's deep interior. The UK is close to the optimum epicentral distance for such studies. Some preliminary work on the core–mantle boundary using UKNET seismograms from Fiji–Tonga earthquakes has recently been carried out by my group (Bowers *et al.* 2000). Now Mike Kendall (University of Leeds) and George Helffrich (University of Bristol) are making a detailed study (funded by the NERC) of the lowermost mantle and the inner and outer core by deploying portable broadband systems across the UK and France. The library of recordings from UKNET will obviously both complement and supplement the recordings made by the portable systems.

The ORFEUS Science Plan suggested that the two main long-term aims of European seismology should be the development of: improved broadband seismometers that are portable; and



3: Example of the extraction of a broadband signal from noise using wave-number filtering. Recordings are from the 20-seismometer array at Eskdalemuir, Scotland.
(a) Short-period recordings showing P signal from the Zaire earthquake of 25 September 1995 (×5).
(b) Broadband seismogram (derived from the SP) for one seismometer in the array – note large amplitude noise of about 5 s period obscures the signal.
(c) Result after wave-number filtering showing the broadband version of the signal from the Zaire earthquake.
(d) Seismogram (c) ×3. Note that as in figure 2 there appears to be a surface reflection (pP?) of longer period than direct P. The simplicity of the short-period with initial motion up (i.e. away from the source) is characteristic of an explosion. However, the presence of the low frequency pP, identifies the source as an earthquake.

a broadband network across Europe by 1996 with a station spacing of no more than 200 km. Through Guralp Systems, the UK produces some of the best portable BB seismometers in the world and has in UKNET a network in England and Wales that meets the requirements for stations at 200 km intervals. (To fully meet the requirements for 200 km spacing across the whole of the UK would require two or three extra stations in Scotland and at least one in Northern Ireland. Horizontal-component seismometers should also be installed. At present only one station is equipped with a three-component set; the other sites have only vertical-component seismometers.) Currently there are programmes in several European countries to extend their broadband networks. For example, Spain is planning a network of 50 broadband stations and Sweden and France are upgrading some of their existing stations to record broadband.

UK cuts

In contrast the UK, which has been such a pioneer in broadband seismometry and in recording and using broadband seismograms, now finds itself planning to cut down and possibly close one of the longest running broadband networks. It is its long history of recording that makes UKNET such a valuable network. Many new stations are being set up around the world as part of the International Monitoring System for the verification of the Comprehensive Test Ban (CTB). The limited value that the recordings from such stations have, until they build up a library of recordings, is shown up starkly when a seismic disturbance takes place (such as that of the 16 August 1997 in the Kara Sea) that might be a CTB Treaty violation (were the Treaty in force). For with such new stations it is impossible to make any comparisons with past recordings, something that is often crucial to distinguish between a possible explosion and other types of seismic disturbances. In a similar way the UKNET library has value for anyone wishing to compare recordings from new earthquakes with those that have occurred in the last 30 years.

If UKNET closes, not only do we lose continuity of recording broadband, but, because we would not be able to provide the recordings to ORFEUS, the UK would lose its membership at national and institutional level with the loss of associated privileges. More importantly this will leave a gap, geographically at the edge, but for the UK's scientific credibility at the heart, of the European BB enterprise.

With Blacknest unable to support the UKNET and BGS only able to take over part of the network and that on a best endeavour basis, some additional source of funding is required if the network is to continue in operation and be modernized. There was some discussion on possible sources of funding at the Seismology Workshop at Geoscience 2000, but this was inconclusive. Yet someone needs to take the initiative, so if there are any seismologists who have funds or feel they can obtain funds to support BB recording in the UK, I would be delighted to hear from them. ●

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Note: Any views expressed are those of the author and do not necessarily represent those of the Department, the Agency or HM Government.

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