British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

Geomagnetism *Review* 2007 - 2008

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT OR/09/016

Geomagnetism

Review 2007-2008

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Front cover

The aurora borealis observed on 30th October 2003 in Scotland. The visual aurora accompanies a magnetic storm. Magnetic storms can have serious consequences for technological systems, such as power grids, pipelines and communications. The Geomagnetism team monitors, analyses and predicts storms and advises on the risk to technology. (Photo courtesy of Jim Henderson Photography.)

Bibliographical reference

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Introduction

Navigation by compass and Earth's magnetic field
OS topography © Crown Copyright

Geomagnetism

The Geomagnetism team of the British Geological Survey measures, records, models and interprets the Earth's natural magnetic field and its variations over time and across the world. Our data, as well as our knowledge and expertise, help to develop scientific understanding of the Earth, seen as a system of coupled magnetic processes operating from within the inner core out to space. We also provide geomagnetic services to industry and we use our understanding to inform the public and stakeholders in government and private sectors.

The British Geological Survey (BGS) is the main Earth Science centre for the UK and is funded primarily through the Natural Environment Research Council (NERC).

Geomagnetic science is represented in BGS as a team within the Earth Hazards and Systems (EHS) science programme of the Research Centre, along with Earthquake Seismology and Volcanology. EHS is one of fourteen BGS science programmes that help deliver the BGS and NERC science strategies.

For the purposes of continuous geomagnetic monitoring BGS operates three magnetic observatories in the UK. These are located (*see main figure opposite*) in Lerwick (Shetland), at Eskdalemuir (Scottish Borders) and in Hartland (North Devon).

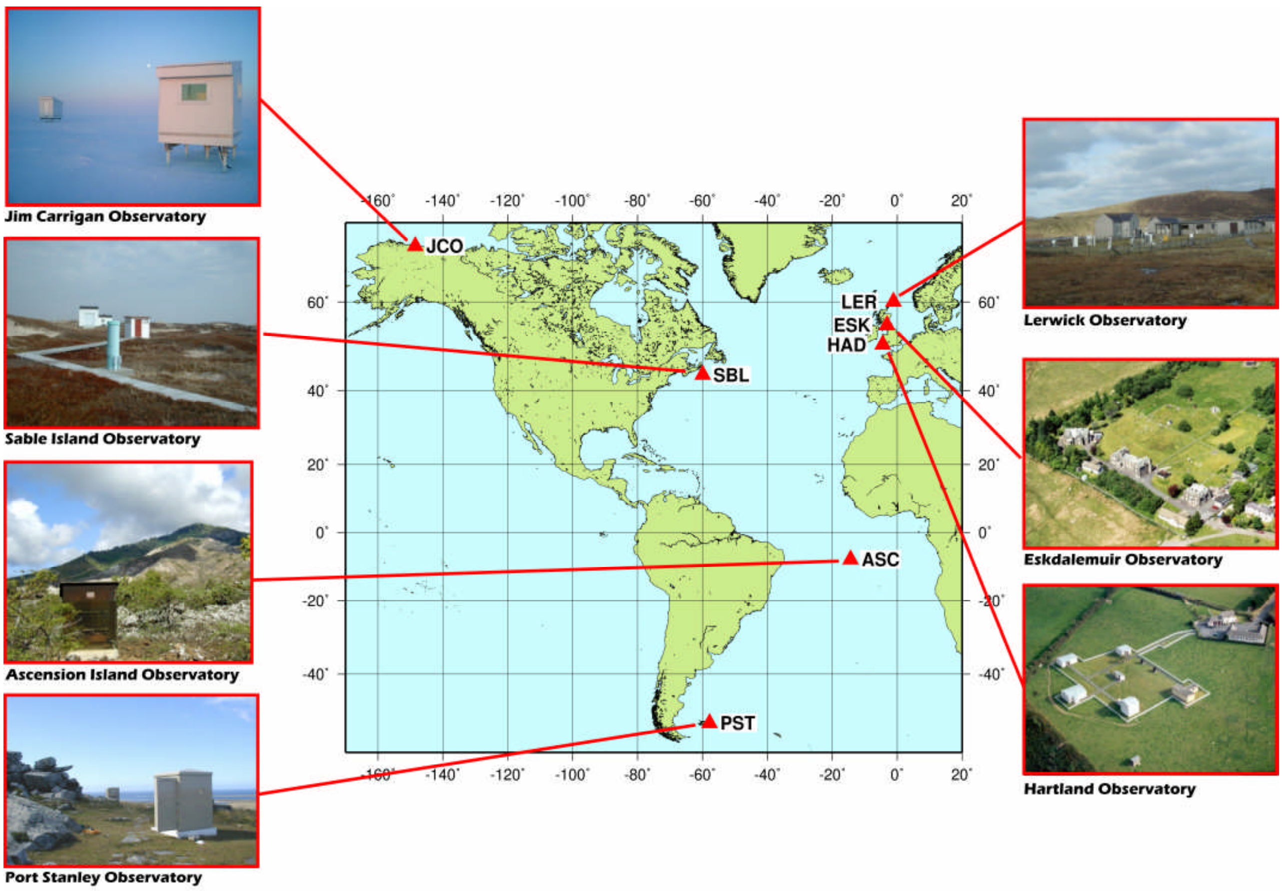
We also operate magnetic observatories overseas on Ascension Island, in Port Stanley (Falkland Islands), and oversee observatory operations on Sable Island (Canada) and on the north slope of Alaska (USA).

Our observatories and the data they produce are the 'bedrock' of our activities and science. For example we develop global models of the geomagnetic field from our data, from satellite and other survey data, and from data obtained from the global network of magnetic observatories. These models take into account detailed variations of the field in time and space.

Our geomagnetic models can be used to infer physical properties of the Earth and to understand, for example, the magnetic interaction between the Earth and the Sun.

The Geomagnetism team has three goals. We aim to be a world leader in

- Research into all aspects of measuring, recording, modelling and interpreting the Earth's natural magnetic field and its sources;
- Delivering geomagnetic data, products and services to the academic, business and public sectors;
- Communications on geomagnetism science and applications to all sectors of society.



The locations of the three UK and four overseas magnetic observatories operated by BGS.

Making detailed measurements of the magnetic field direction on Ascension Island

Objectives and Achievements in 2007 and 2008

The Geomagnetism Team fully met its science, application and technical objectives for 2007-2008. These objectives were formulated and developed from the project plan of the NERC-funded National Geomagnetic Service (NGS) and from the plans of our major commercially funded projects.

Our objectives and achievements were that

- We provided 'national capability' for NERC in geomagnetic field monitoring by operating the BGS magnetic observatories to the highest international standards.
- We generated scientific products from observatory time series in near real time and made them available via the BGS web site.
- We fulfilled all our commitments to
  - The International Service for Geomagnetic Indices (ISGI), the body responsible for the production of global geomagnetic activity indices;
  - INTERMAGNET, the organisation responsible for co-ordinating the operations of magnetic observatories worldwide;
  - SWENET, the European Space Agency (ESA) Space Weather European Network of data.
- We successfully operated a World Data Centre (WDC) for Geomagnetism.
- We ran the UK magnetic survey to provide data on the variation of the geomagnetic field across the UK.
- We constructed mathematical models of the geomagnetic field on national and global scales.

- We undertook outreach activities and information and knowledge exchange with academic (e.g. two GEOSPACE scientific meetings – *see figure above*) and professional sectors and with the general public.

- We developed our commercial data services for the team's customer base (a consortium of interests that include the MoD, the Ordnance Survey, numerous operating and service companies in the hydrocarbons industry, ESA, and the electricity generation and transmission industries).
- We delivered basic science and data during a time of changing BGS and NERC goals, for example on geo-science knowledge, on resources, on 'whole-Earth' processes and on Earth hazards.

Other Notable Achievements

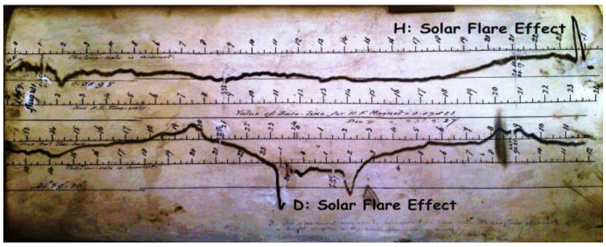
We achieved more, in terms of science and outreach, than was defined in our original list of objectives.

Most notably

- Geomagnetism team members published four papers in peer-reviewed journals.

- Many oral and poster presentations were made at international conferences, including the European Geophysical Union (EGU), ESA Space Weather Week (ESWW – *see figure above*), and International Association of Geomagnetism and Aeronomy (IAGA) meetings.
- Team members served in senior positions on committees for IAGA and ESWW.
- Two PhD studentships, partly funded by the BGS Universities Funding Initiative (BUFI) were started at the Universities of Lancaster (on geomagnetic hazard) and Liverpool (on polar geomagnetism).
- A third PhD student at the University of Edinburgh, part funded by our participation in the UK geomagnetism GEOSPACE project, is completing a thesis on Earth core fluid flow and predictive secular variation.
- The Geomagnetism team took an active part in BGS 'Open Days' to the public.
- We also celebrated the 50th anniversary of the opening of the Hartland magnetic observatory with an 'Open Weekend' at the observatory for residents and visitors to Hartland (*see figure below*).

- A workshop on space weather hazard to power grids in the UK and South Africa was led by the team, hosted in South Africa, and was funded by the Royal Society and National Science Foundation of South Africa.



160 years of BGS archive magnetograms will be scanned and made available as a research resource.

A Look Ahead to 2009 and 2010

The Geomagnetism team operates its magnetic observatories and conducts the UK magnetic survey to the highest standards in instrumentation, data processing and data exchange. We have much experience of developing and publishing mathematical models of Earth's magnetic field. We operate a World Data Centre for Geomagnetism. We hold senior positions in international scientific bodies. We continue to provide successful services and data products to academic and business customers. Our activities contribute to BGS goals on geo-science knowledge, resources, whole-Earth processes, Earth hazards and provide national capability for NERC in environmental monitoring.

Science and Applications

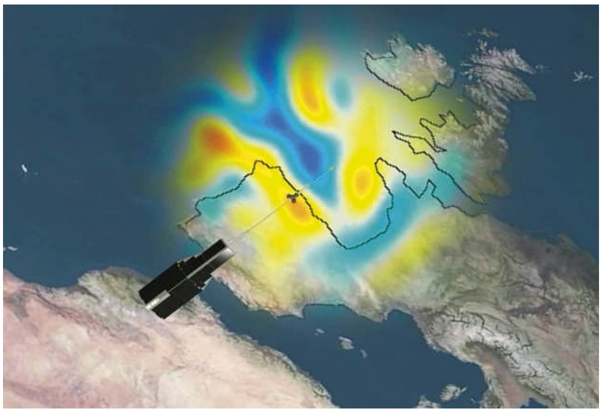
In 2009-2010 we will maintain our high standards of operation in all current science and application areas. The 'main deliverables' within the National Geomagnetic Service (NGS) project and the other activities within our external income projects fully encapsulate our aims. Our NGS science and application deliverables for 2009-2010 include

- Upgrading the environmental conditions and installations for backup sensors at UK observatories and the installation of a high resolution geomagnetic sensor at one observatory.
- Occupation of a minimum of 10 sites in the UK magnetic repeat station network.
- Maintenance of the World Data Centre (WDC) for Geomagnetism (Edinburgh) in accordance with the rules of the World Data Centre system.
- Commencing the scanning of around 256,000 UK observatory magnetograms (*see figure at top*), subject to a successful trial period in financial year 08/09. We plan to store the scanned copies on a database, to become an IKE facility and for scientific exploitation.
- Production of the 2010 revision of the UK magnetic model.
- Production of a global geomagnetic field model for 2009-2010, using the latest observatory and satellite magnetic survey data.

- Production of a candidate model for the International Geomagnetic Reference Field (IGRF), to the timetable established by IAGA in 2009.
- Collaboration with US counterparts over the production of the next revision of the World Magnetic Model, WMM2010.
- Supervision of BUFI-supported PhD students at the University of Lancaster (on geomagnetic hazards) and University of Liverpool (on polar geomagnetism).
- Pursuing scientific collaboration activities to address BGS challenges and NERC themes.
- Incorporation of science and IT advances in products and services to customers.
- Delivery of definitive data from the UK magnetic observatories to the timetable set by INTERMAGNET for publication on the INTERMAGNET 2008 DVD.
- Supply of data products to the International Service for Geomagnetic Indices (ISGI), to the timetable set by ISGI for the production of global geomagnetic activity indices.
- Delivery of real-time UK observatory data and data products suitable for integration with the real-time updated Geomagnetism team website.
- Publication of UK observatory data and data products in monthly bulletins and the 2008 UK Observatory yearbook.

The science of Geomagnetism has been developing rapidly during a decade of high quality satellite surveys of the Earth's magnetism.

The Geomagnetism team will be a key member of the future European Space Agency 'Swarm' science consortium (*below shows a satellite sampling the lithospheric magnetic field – illustration courtesy of ESA*). We will therefore be well-placed to exploit the high resolution data that will follow from the satellite constellation launch in 2011.



Another active geomagnetism theme is the dynamic interaction of solar and terrestrial magnetic fields and the consequent geomagnetic hazard (*e.g. figure below: the aurora over Edinburgh in October 2003*). In the UK there are likely to be new opportunities in the funding of solar-terrestrial geophysics.

In 2009-2010 we therefore intend to continue to develop capability in modelling magnetic sources internal and external to the Earth; in particular within the core, the ionosphere and the magnetosphere.

We will also seek to develop our geomagnetic hazard science. These activities will be based on current capabilities and through increased interaction with other BGS teams, collaboration with NERC and other institutes, with the universities sector and through the development of the team's scientific skills.

Communications

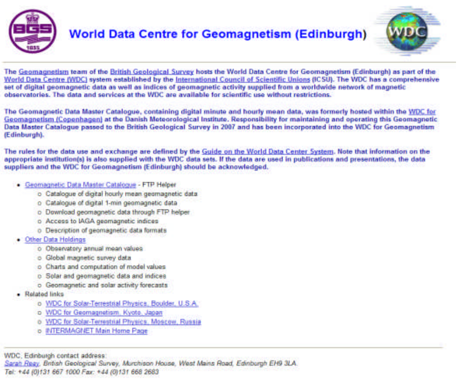
The Geomagnetism team has a track record of positive and successful communication of data, services and consultancy with our customer group and with other external stakeholders. In 2009-2010 our minimum aim will be to continue this high standard of interaction.

The Geomagnetism team will also take advantage of structural changes in BGS and the re-shaping of BGS and NERC science goals. We will talk to more people: we will open up communications with other BGS teams, the senior leadership of BGS, colleagues within NERC and with the university sector.

Our goal in this strategy will be to maximise future scientific opportunities and to maximise our visibility in terms of our existing science and outreach activities.

Communication deliverables for 2009-2010 include

- Preparation of the Geomagnetism team annual review for 2009-2010.
- Presentation of geomagnetic science outputs (orally and/or posters) to major international scientific conferences, such as EGU, IAGA, the UK space physics 'MIST' meetings, and oil industry meetings, such as SPE and ISCWSA.
- Publishing of two or more first-author papers in scientific and professional journals, based on scientific and other activities.
- Prompt communication of science data and products to new and existing customers (e.g. the World Data Centre – *figure below*).



World Data Centre for Geomagnetism (Edinburgh)

The Geomagnetism team of the British Geological Survey hosts the World Data Centre for Geomagnetism (Edinburgh) as part of the World Data Centre (WDC) system established by the International Council of Scientific Unions (ICSU). The WDC has a comprehensive set of digital geomagnetic data as well as indices of geomagnetic activity supplied from a worldwide network of magnetic observatories. The data and services at the WDC are available for scientific use without restrictions.

The Geomagnetic Data Master Catalogue, containing digital minute and hourly mean data, was formerly hosted within the WDC for Geomagnetism (Copenhagen) at the Danish Meteorological Institute. Responsibility for maintaining and operating this Geomagnetic Data Master Catalogue passed to the British Geological Survey in 2007 and has been incorporated into the WDC for Geomagnetism (Edinburgh).

The rules for the data use and exchange are defined by the Guide on the World Data Center System. Note that information on the appropriate institution(s) is also supplied with the WDC data sets. If the data are used in publications and presentations, the data suppliers and the WDC for Geomagnetism (Edinburgh) should be acknowledged.

- Geomagnetic Data Master Catalogue - FTP Helper
  - Catalogue of digital hourly mean geomagnetic data
  - Catalogue of digital 1-min geomagnetic data
  - Download geomagnetic data through FTP helper
  - Access to IAGA geomagnetic indices
  - Description of geomagnetic data formats
- Other Data Holdings
  - Observatory annual mean values
  - Global magnetic survey data
  - Charts and computation of model values
  - Solar and geomagnetic data and indices
  - Geomagnetic and solar activity forecasts
- Related links
  - WDC for Solar-Terrestrial Physics, Boulder, U.S.A.
  - WDC for Geomagnetism, Kyoto, Japan
  - WDC for Solar-Terrestrial Physics, Moscow, Russia
  - INTERMAGNET Main Home Page

WDC, Edinburgh contact address:
Sarah Reay, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA.
Tel: +44 (0)131 667 1000 Fax: +44 (0)131 668 2683

- The writing of articles, dissemination of data products and provision of information and educational material (*e.g. see main figures to right*), as requested, for the BGS web site (www.bgs.ac.uk) and Geomagnetism Team site (www.geomag.bgs.ac.uk) (*see figure below*).

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Monitoring | Data Products | Home

Geomagnetism

Geomagnetism is a science area within Earth Hazards and Systems, a programme of the British Geological Survey (BGS). BGS is a component body of the Natural Environment Research Council.

The main function of the geomagnetism team is to monitor the earth's magnetic field in the United Kingdom. This work involves the continuous operation of three observatories and regular occupation of repeat stations in the UK.

Additionally, contributions are made to the international effort of global monitoring of the magnetic field by the operation of four observatories overseas.

Geomagnetism staff have expertise in the production of local and global models of the field and analyses and interpretations of geomagnetic data in real-time to serve both the academic and commercial communities.

- Magnetic Observatories
- Magnetic Surveys
- Models, Charts and Magnetic Data for Navigation
- GIFS - Geomagnetic Information and Forecast Service
- Geomagnetic Hazard and Space Weather
- Services and Applications
- Academic Partnerships
- Education and General Interest
- World Data Centre for Geomagnetism, Edinburgh

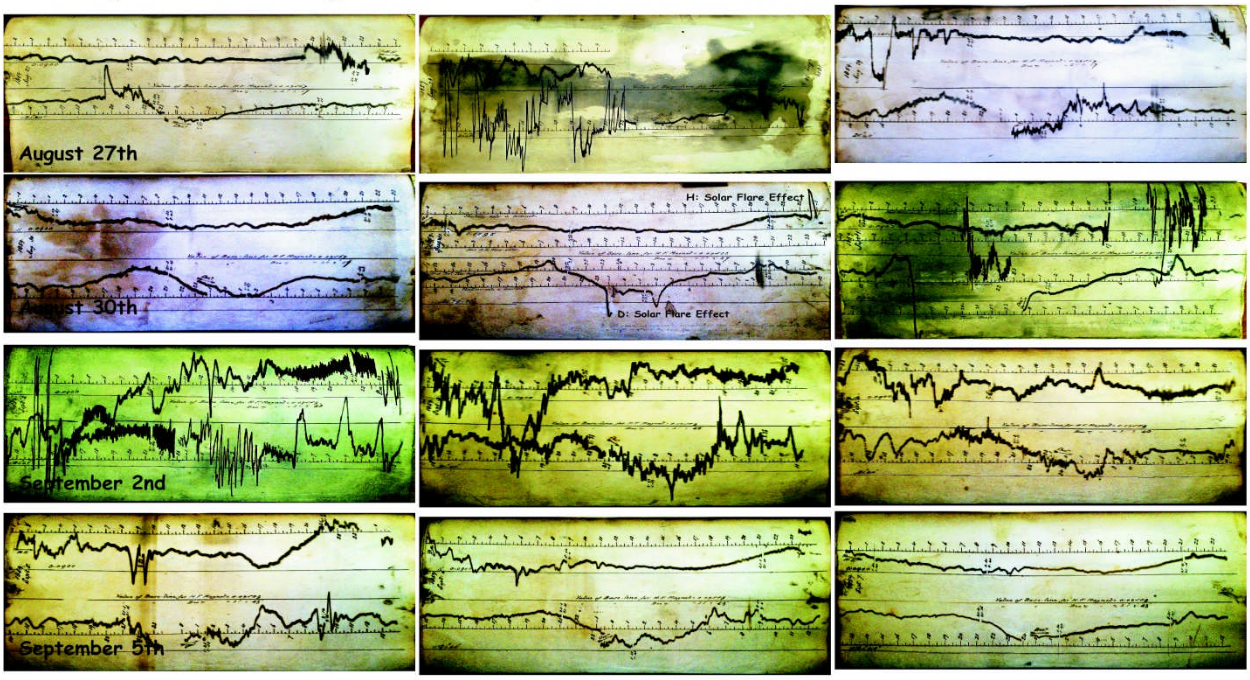
Latest News

- RAS 2009 Awards - Services to Geophysics to Dr David Kerridge

Celebrate the International Heliophysical Year and learn more about the Sun-Earth connection at sunearthplan.net

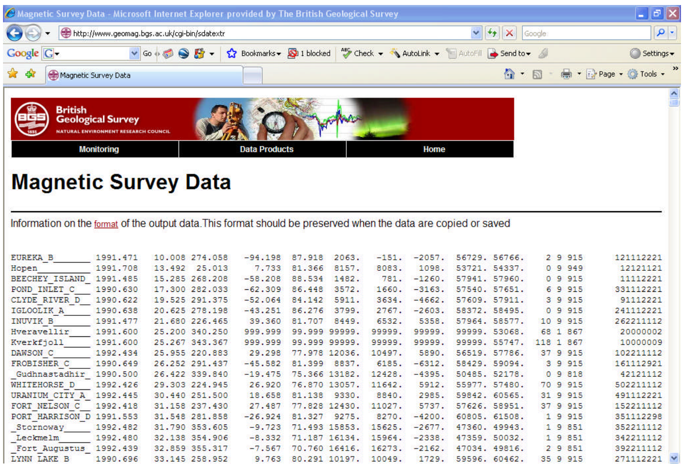
The Largest Magnetic Storm on Record

The 'Carrington Event' of August 27th to September 7th, 1859, Recorded at Kew Observatory, London



Declination, or compass direction, (*D*) is the lower trace on each image and the horizontal force (*H*) is the upper trace.
Universal Time is the time recorded here (astronomical) plus 12 hours and measured *D* precedes *H* by approximately 12 hours.
For reference the marked 'solar flare effect', beginning at 23:15 recorded time on August 31st, is at 11:15 Universal Time on September 1st.
It has been measured as 110 nT in *H* and 0.283 degrees in *D*.

The size and scale of each image is only approximately similar, day-to-day. Some data have also been lost, either due to ink and paper degradation, or because the variations were so large they were off-scale.



Magnetic Survey Data

Information on the format of the output data.This format should be preserved when the data are copied or saved

EUREKA_B_______	1991.471	10.008	274.058	-94.198	87.918	2063.	-151.	-2057.	56729.	56766.	2	9	915	121112221
Hopen__________	1991.708	13.492	25.013	7.733	81.366	8157.	8083.	1098.	53721.	54337.	0	9	949	12121121
BEECHEY_ISLAND_	1991.485	15.285	268.208	-58.208	88.534	1482.	781.	-1260.	57941.	57960.	0	9	915	11112221
POND_INLET_C___	1990.630	17.300	282.033	-62.309	86.448	3572.	1660.	-3163.	57540.	57651.	6	9	915	331112221
CLYDE_RIVER_D__	1990.622	19.525	291.375	-52.064	84.142	5911.	3634.	-4662.	57609.	57911.	3	9	915	91112221
IGLOOLIK_A_____	1990.638	20.625	278.198	-43.251	86.276	3799.	2767.	-2603.	58372.	58495.	0	9	915	241112221
INUVIK_B_______	1991.477	21.680	226.465	39.360	81.707	8449.	6532.	5358.	57964.	58577.	10	9	915	262211112
Hveravellir____	1991.600	25.200	340.250	999.999	99.999	99999.	99999.	99999.	99999.	53068.	68	1	867	20000002
Kverkfjoll_____	1991.600	25.267	343.367	999.999	99.999	99999.	99999.	99999.	99999.	55747.	118	1	867	10000009
DAWSON_C_______	1992.434	25.955	220.883	29.298	77.978	12036.	10497.	5890.	56519.	57786.	37	9	915	102211112
FROBISHER_C____	1990.649	26.252	291.437	-45.582	81.399	8837.	6185.	-6312.	58429.	59094.	3	9	915	161112921
Gudhnastadhir	1990.500	26.422	339.840	-19.475	75.366	13182.	12428.	-4395.	50485.	52178.	0	9	818	42121112
WHITEHORSE_D___	1992.426	29.303	224.945	26.920	76.870	13057.	11642.	5912.	55977.	57480.	70	9	915	502211112
URANIUM_CITY_A_	1992.445	30.440	251.500	18.658	81.138	9330.	8840.	2985.	59842.	60565.	31	9	915	491112221
FORT_NELSON_C__	1992.418	31.158	237.430	27.487	77.828	12430.	11027.	5737.	57626.	58951.	37	9	915	152211112
PORT_HARRISON_D	1991.553	31.548	281.858	-26.924	81.327	9275.	8270.	-4200.	60805.	61508.	1	9	915	351112298
_Stornoway_____	1992.482	31.790	353.605	-9.723	71.493	15853.	15625.	-2677.	47360.	49943.	1	9	851	352211112
_Leckmelm______	1992.480	32.138	354.906	-8.332	71.187	16134.	15964.	-2338.	47359.	50032.	1	9	851	342211112
_Fort_Augustus_	1992.439	32.859	355.317	-7.567	70.760	16416.	16273.	-2162.	47034.	49816.	2	9	851	392211112
LYNN LAKE B	1990.696	33.145	258.952	9.763	80.291	10197.	10049.	1729.	59596.	60462.	35	9	915	271112221

A few examples of educational and other materials used in web and print publications, e.g. NERC's 'Planet Earth' (bottom right).

Lerwick observatory in winter

Technical, Observatory and Field Operations

UK and Overseas Observatories

BGS operates three magnetic observatories in the UK. These provide the high quality, near-real-time data that underpins products we provide to the directional drilling industry, as well as to other commercial and academic users. The Geomagnetism team attained one hundred percent data coverage from the UK observatories in 2008. BGS also runs four overseas magnetic observatories and takes a leading role in the expansion of the global network of digital magnetic observatories, both for improved global field modelling and for local commercial application of the data.

The UK Observatories

Data products, derived from measurements at Lerwick (*see figure at top*), Eskdalemuir and Hartland Magnetic Observatories, are made available on-line to commercial and academic customers within minutes of recording.

These recordings are made to a standard defined by INTERMAGNET, a global network of magnetic observatories. Finalised data from the UK are submitted for publication via INTERMAGNET and the World Data Centre for Geomagnetism, amongst other international databases.

Instruments at the three BGS observatories are maintained in a controlled environment and are calibrated every four months to a NAMAS-traceable standard. In addition, weekly manual observations are used to provide a level of quality control, such that continuous, quasi-absolute vector data can be produced in real-time throughout the year.

Small instrument enclosure at Hartland observatory

In 2008 BGS-designed temperature-regulated small instrument enclosures were deployed at Eskdalemuir and Hartland Observatories (*see* previous *figure*). These are intended to improve the resilience of the observatory data to man-made disturbances by dispersing the recordings across each site. Such disturbances have included tree felling & replanting at Eskdalemuir and the 50th Anniversary Open Day at Hartland.

Contingency measures have been put in place at Lerwick Observatory following concern over potential mains failure and the likelihood of redevelopment at this Met Office owned site. These measures, and those at Eskdalemuir and Hartland, should ensure that the BGS record of zero data loss since June 2005 is extended throughout 2009.

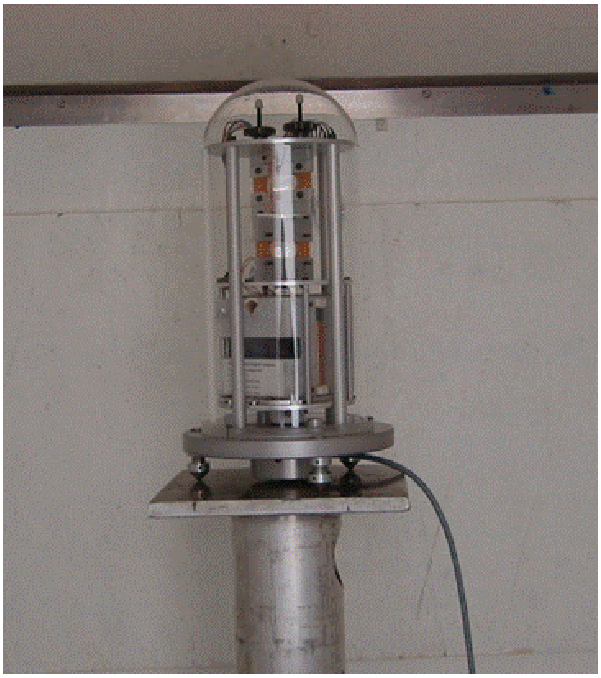
The Geomagnetism Team promotes diversification in the scientific observations made at the BGS observatories. We encourage and assist other institutes in taking advantage of the low-noise environment of our observatories, their good communications and their infrastructure and facilities.

As well as magnetic, seismic and meteorological instruments, Eskdalemuir is currently host to an atmospheric electricity monitor (University of Reading) and two global positioning system (GPS) ground stations for the Ordnance Survey and the University of Nottingham.

Induction coil magnetometers under test at Eskdalemuir, with a colleague from University of Bath

Other recent visitors have included Proudman Oceanographic Laboratory (gravity meter), British Antarctic Survey (VLF radio receiver) and the University of Bath (induction coil magnetometers – *see figure below left*).

Hartland Observatory provides a calibration facility for down-hole tools used by the directional drilling industry. Hartland was also used in 2008 by a commercial magnetometer manufacturer and an avionics company.



Conventionally, observatories publish one minute data records to 0.1nT resolution (*recorded by instruments such as in the figure above*). However a recent survey of scientific data users has highlighted a need for broader band, high resolution data.

INTERMAGNET is in the process of defining data standards for one-second data. In anticipation of these forthcoming standards, the Geomagnetism team has performed some initial assessments of existing instrumentation (with results presented at the *XIII*th IAGA Observatories Workshop in Boulder, Colorado) and devised a new instrument design strategy.

This will help maintain BGS' position at the leading edge of geomagnetic observatory development, as well as addressing the needs of all its users.

The Overseas Observatories

Since 1992, BGS has operated observatories in the South Atlantic, an area of particular scientific interest. Near-Earth space in this region of the globe is susceptible to higher particle radiation caused, in part, by the lower magnetic field intensity and this is of concern to satellite operators, amongst others.

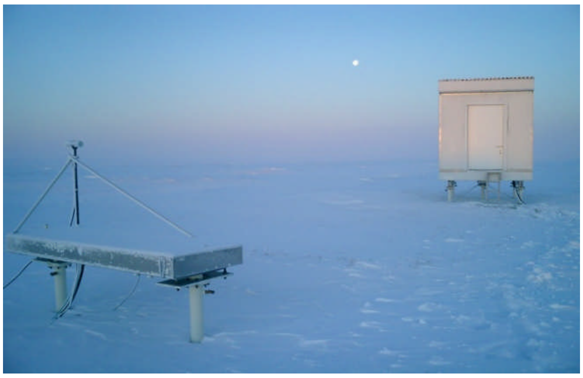
The nature of this 'South Atlantic Anomaly' is slowly changing with the decrease in the earth's magnetic field intensity. Hence there is a need for reliable, long-term observatory-standard magnetic observations in this region, a region that is otherwise sparsely populated with observatories.

The Port Stanley and Ascension Island observatories successfully operated throughout 2007 & 2008 to INTERMAGNET specifications, broadcasting data in real-time and submitting final data sets for publication.

As recently as two years ago, Port Stanley Observatory (*above*) suffered from discontinuous data and large daily and annual variations in instrument baselines. This situation was exacerbated by the remoteness of the site and the harsh operating conditions.

Following the installation of lightning protection measures, temperature regulation and an improvement in the manual observation programme, the data quality and reliability have significantly improved.

BGS also oversees the operation of two magnetic observatories on behalf of Halliburton Energy Services (HES).



Sable Island and Jim Carrigan Observatories (*above*) are located close to the Sable gas field (Nova Scotia) and the Prudhoe Bay oil field (Alaska), in order to monitor, in real-time, magnetic field variations for the local directional drilling industry.

BGS' role is to monitor data quality and to provide expertise in the application of the data, as well as to make an annual audit visit to each station. As the observatories are operated with BGS instrumentation, these visits are an opportunity to make calibrations and upgrades, and to verify the data through manual observations. Both of these observatories have provided reliable data with accurate baseline estimates throughout 2008.

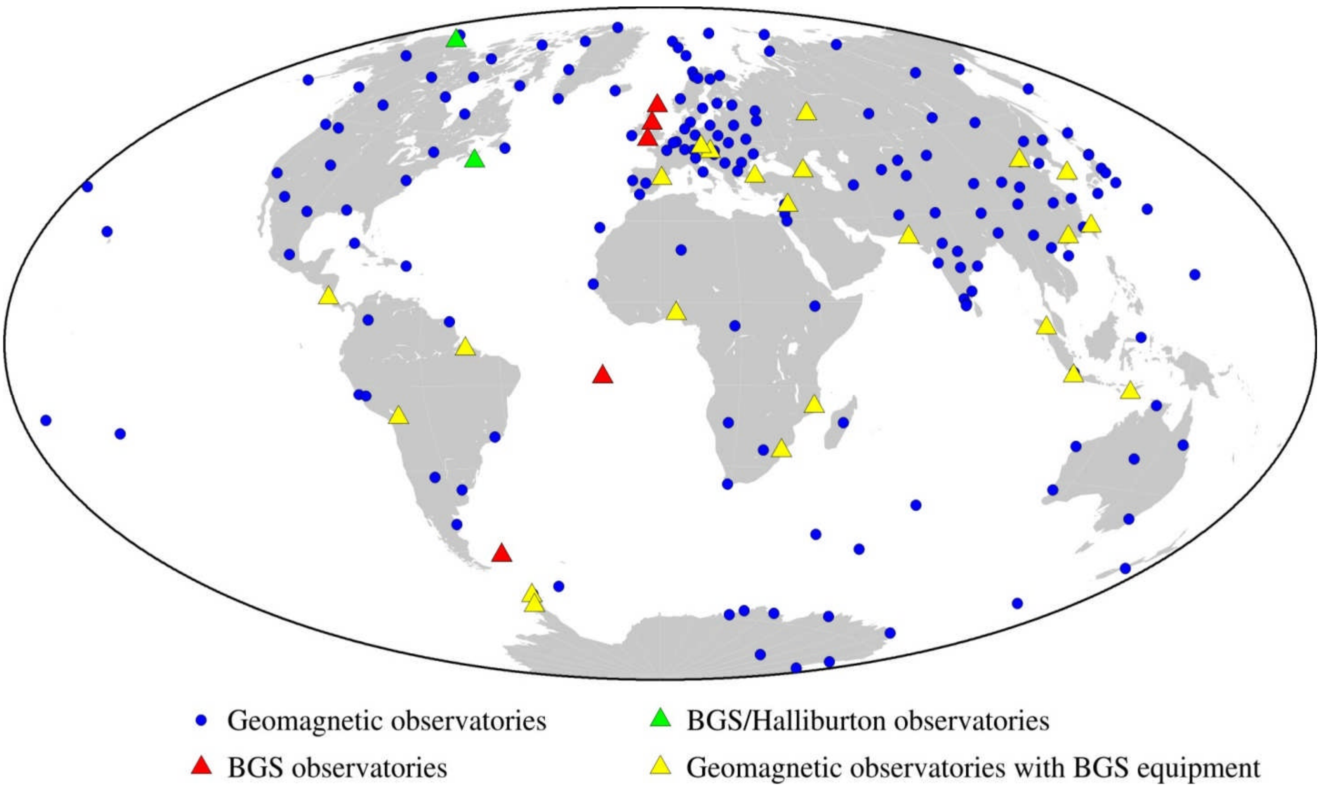
INDIGO project magnetic observatories (red triangles) and other observatories (blue)

BGS is also committed to the expansion of the global digital magnetic observatory network, leading the INDIGO project in partnership with the Institut Royal Météorologique de Belgique. The INDIGO project has provided renovated ex-NERC instrumentation, coupled with digitisers, software and training, to other institutes around the world for the purpose of establishing or supplementing digital magnetic recordings.

INDIGO instrumentation was installed in Karachi Observatory in November 2007 (*see figure below left*), bringing the number of INDIGO-assisted observatories to seven. Further instrumentation was sent to Tuntungan Observatory, Indonesia and this is anticipated to be operational in 2009. These observatories are encouraged to make regular manual observations and transmit the data to Edinburgh, part of the prerequisite for INTERMAGNET membership.

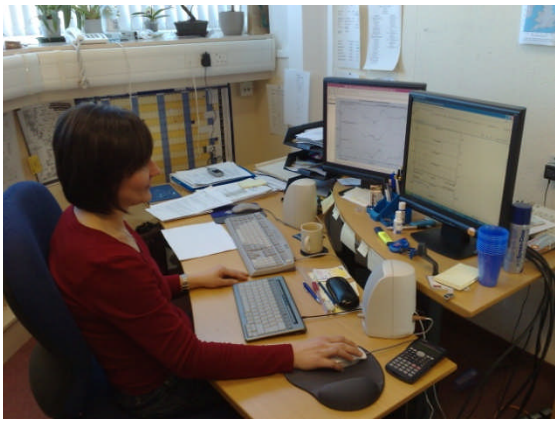
BGS has a significant role in the administration of INTERMAGNET, holding the Secretarial post, two chairs on the Operations Committee and one position on the Executive Council.

BGS also provides a data audit service for the Western European region, prior to publication of data on the INTERMAGNET DVD.



The locations of BGS and other BGS-supported magnetic observatories worldwide

Technical, Observatory and Field Operations



Quality controlled data is provided from the Edinburgh office of BGS

Communications, Data Processing and Delivery

Observatory operations include a programme to deliver the magnetic results to both scientific and commercial users. From both there is a requirement for high accuracy, as well as rapid access to the data products. Developing these attributes in tandem is a primary objective of the operations and data processing team.

Data are retrieved automatically to Edinburgh (*see figure below*) from all seven observatories in near real-time using two dedicated PCs. The data are then transferred to a Sun Workstation where they are stored in 'day files'.

Subsequent data processing and quality control is carried out automatically to produce one-minute values and other data products, using a combination of FORTRAN programs and UNIX C-Shell scripts. The final check on the quality of the data is the responsibility of staff in Edinburgh who examine all magneto-grams and data comparison plots each day.

Any errors, undetected by the automatic quality control procedures, will be identified at this stage. If required, data from one of the two other back-up systems can be used to replace values or fill any gaps in the data from the primary system.

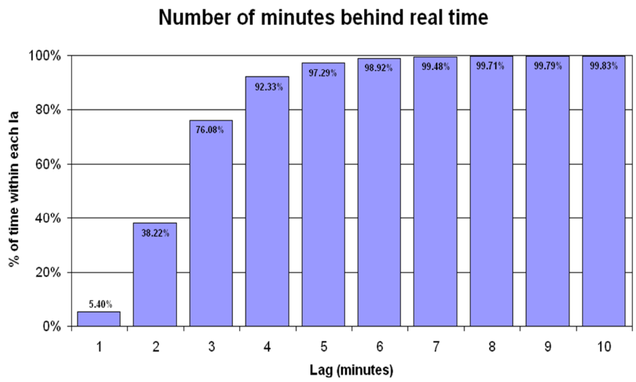
Absolute observation measurements are processed to determine spot baseline values, to which continuous baselines are fitted. Preliminary observatory results are published in monthly magnetic bulletins (*see figure below*).

The scientific and commercial demand for rapid access to BGS observatory data and data products has increased dramatically over the last decade.

To help meet these requirements, improvements to the data communications, computer systems, automatic data processing software and quality control procedures have been made during 2007 and 2008. Additionally, development work has continued to progress towards establishing backup systems that cover every possible point of failure (*see below*).

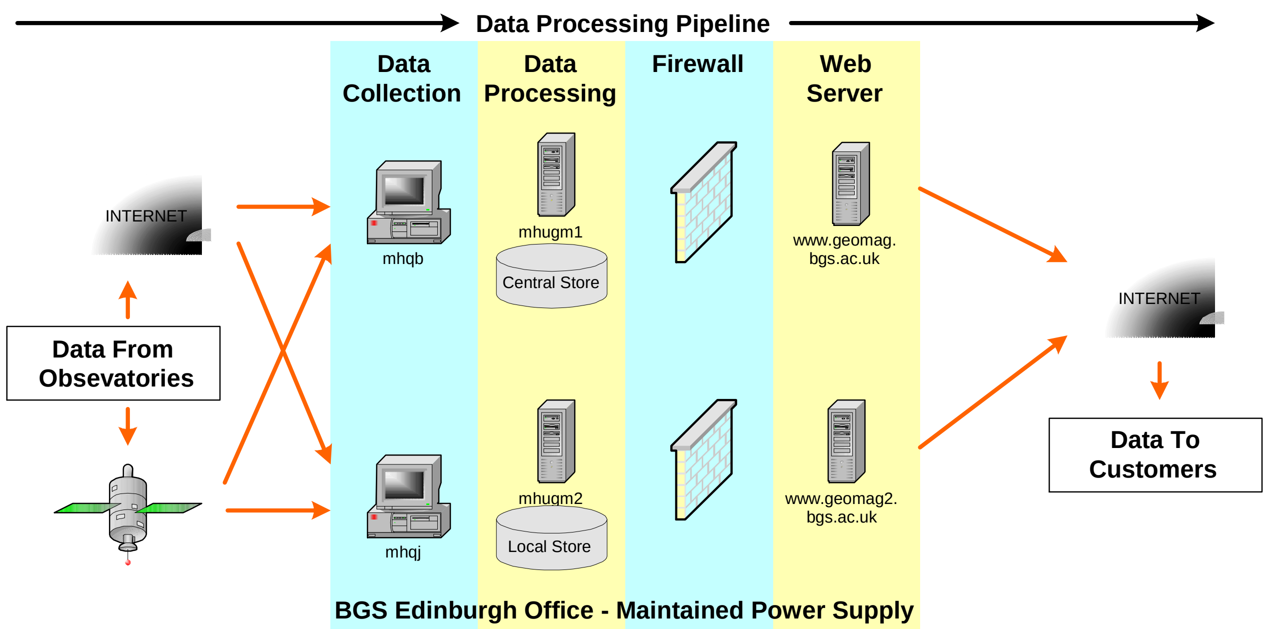
Results and data products are made available on the internet, for academic and commercial users worldwide, via two dedicated web servers. As a measure of the delivery capabilities, the delay or lag time is monitored by logging the number of minutes behind real-time the data are made available on the web servers.

For one commercial application, during 2008, 99.5% of data were delivered to the customers within 7 minutes (*see below*).



The time-series of one-minute values from the UK observatories are 100% complete throughout 2007 and 2008.

Final results for 2007 from the UK, Ascension Island and Port Stanley observatories were submitted for publication via INTERMAGNET and the World Data Centre for Geomagnetism.



The current infrastructure for the observatory data communications, processing and delivery pipeline.

Technical, Observatory and Field Operations

Using a proton precession magnetometer in field operations

The UK Magnetic Survey

The repeat station survey delivers a programme of annual magnetic measurements across the UK for the purpose of producing a high accuracy, regional model of the magnetic field. The UK model is also used to supply the Ordnance Survey with current and projected magnetic north data for publication on their maps.

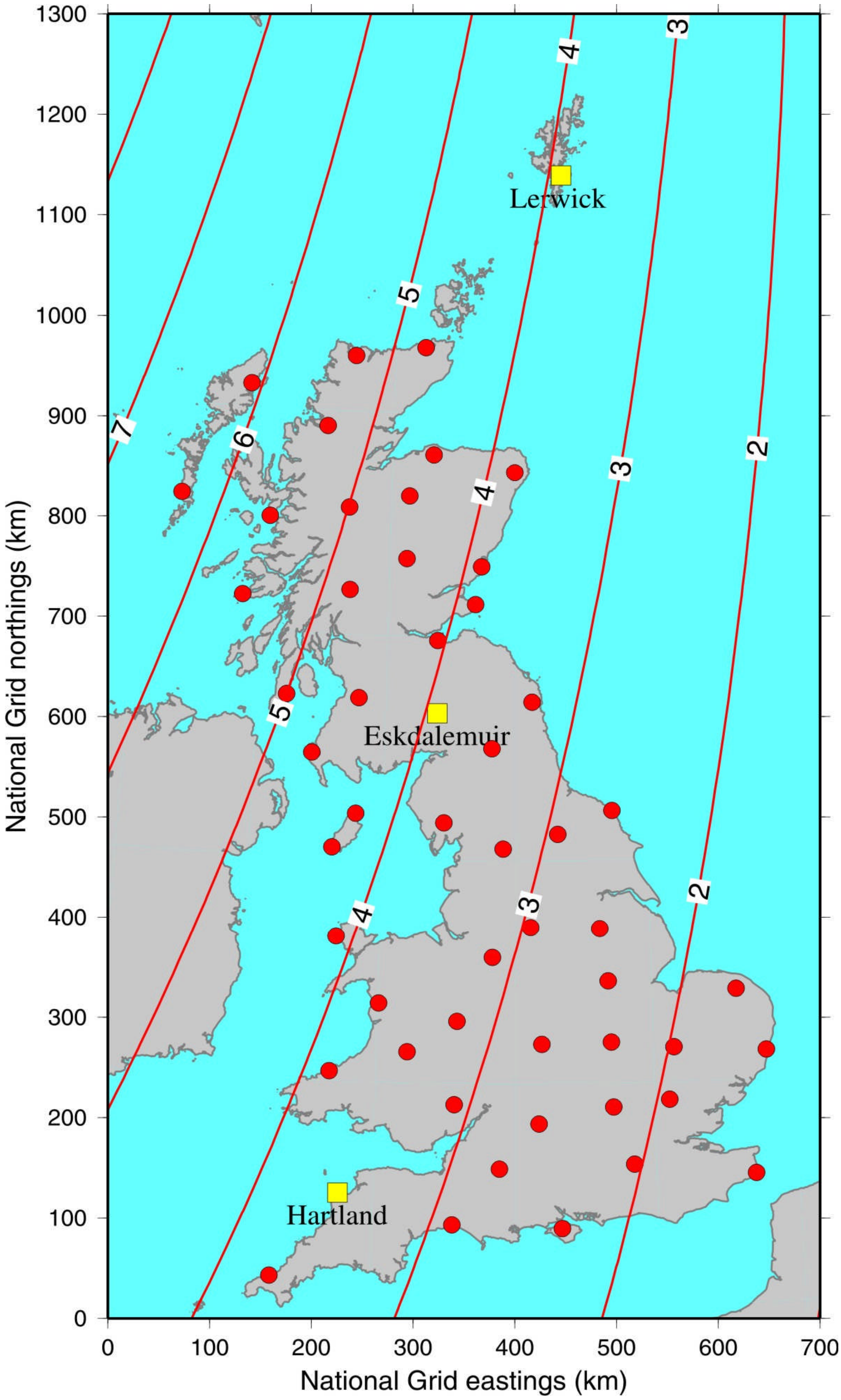
The annual repeat station survey provides data used to produce a high accuracy regional model of the slowly changing core magnetic field throughout the UK. The survey results are high accuracy, timely data collected from a national network of measurement stations. The resulting UK model can be used to predict grid magnetic angle for up to three years into the future.

Typical repeat station site arrangement

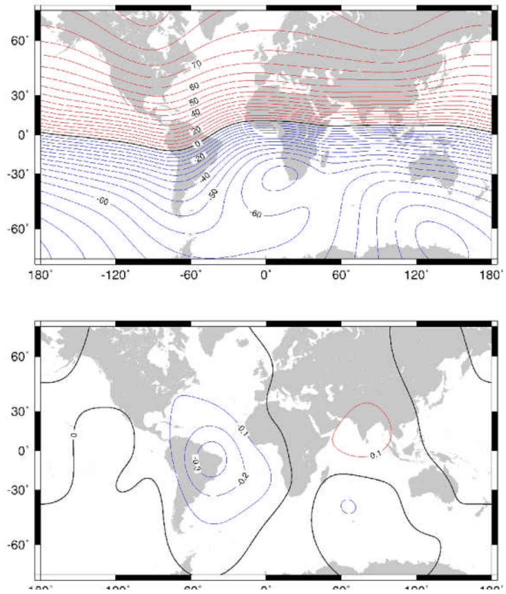
In summer 2007 and 2008, repeat station measurements were performed at seventeen observation sites across the UK These sites were selected to give good spatial and temporal sampling of the magnetic field over the UK, as compared with previous measurements made in 2006.

The raw data collected from the sites were post-processed to extract the core field source and to remove any external source variations, in a process called reduction. Reduction relies on the continuous time series data provided by the BGS magnetic observatories at Lerwick, Eskdalemuir and Hartland. These data act as a reference for correcting survey measurements for the effects of daily and more rapid magnetic variations. High quality data from the observatories therefore underpins the accuracy of the final core-field values used in the production of the UK magnetic model.

The distribution of repeat stations is currently being reviewed with a view to reducing the number of stations. This would then allow a decrease in the interval between site re-occupations. We are also considering using only those survey stations that have lower levels of man-made magnetic noise.



The magnetic declination (in degrees west of true north) for the UK at mid-2008. Red spots indicate the positions of geomagnetic repeat survey sites. The three UK permanent observatories are also noted, by the yellow squares.



Inclination (degrees) from a BGS model (top) and its annual rate of change (bottom)

Science

GEOSPACE and Internal Geomagnetism

The Geomagnetism team is a partner in a NERC-funded consortium project on geomagnetism, called GEOSPACE. Scientific advances from this project, particularly in improving core and lithospheric magnetic field models, are being incorporated into BGS scientific products. GEOSPACE has also allowed us to better understand the different internal sources of the geomagnetic field and hence potentially better predict changes in the field.

The internal field of the Earth comprises the field generated within the liquid outer core of the Earth, the field induced in the mantle by external (e.g. magnetospheric) field sources, the static field of the lithosphere (where temperature is low enough to allow permanent magnetisation) and sources due to tides and currents in the oceans.

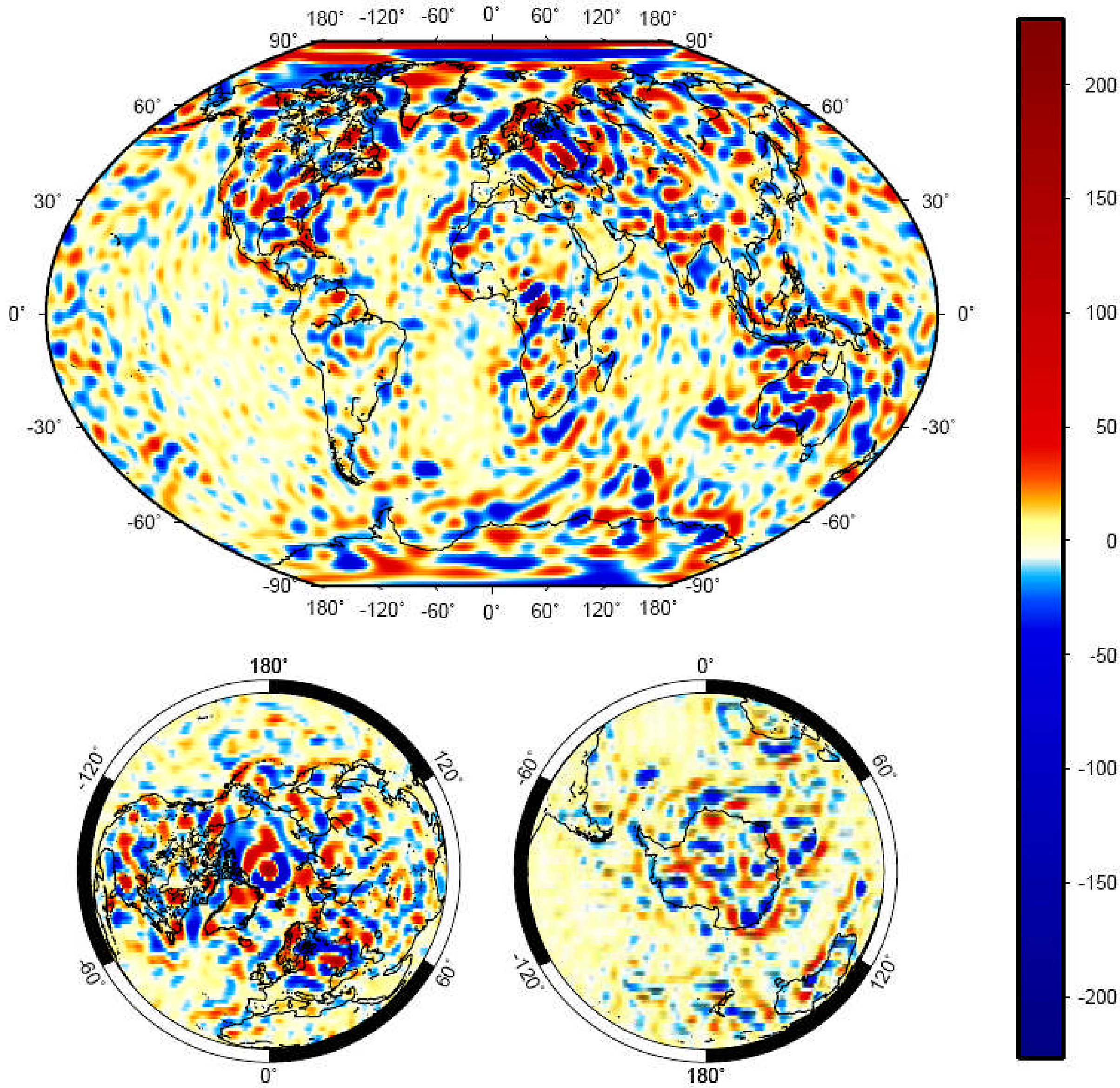
Magnetic survey data from the Danish Ørsted and German Champ satellites are now routinely combined with ground-based magnetic observatory data in BGS global models of the core and lithospheric fields. (Modelling of other internal sources is part of our scientific development plan for future years.) These models are updated annually and involve substantial investment in data collection and data processing to assure the highest accuracy.

Within the GEOSPACE project BGS has also improved the time varying component of its global models, decreased the minimum wavelength of the lithospheric features modelled and improved the separation of internal from external field sources at polar latitudes.

BGS has jointly funded a PhD studentship through GEOSPACE, to improve models and forecasts of the secular - linear in time - variation of the field, directly from the estimated flow of the iron-rich fluid in the outer core. The PhD project has also introduced novel forecasting techniques into the field, involving Kalman filtering and data assimilation techniques. These ideas have attracted interest from the wider geomagnetic science community.

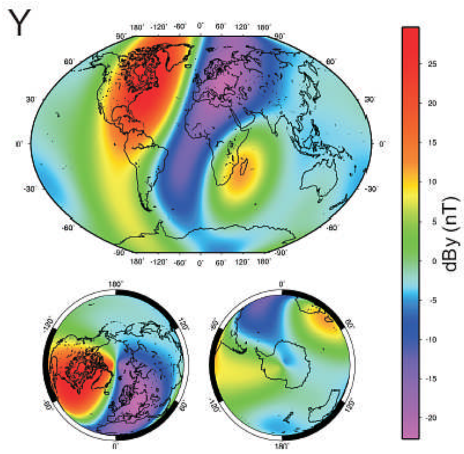
More accurate knowledge of future secular variation will significantly improve the usefulness and lifetime of our magnetic models. Otherwise these have to be updated regularly to be of most use for scientific and other purposes.

Participation in GEOSPACE has also proved beneficial to BGS' involvement in the future European Space Agency 'Swarm' satellite mission. Swarm survey data should lead to even finer detail in models of the Earth's magnetic fields of internal origin, for example by bridging some of the gap in scale between satellite-based magnetic surveys and regional aero- and marine- magnetic surveys.



The figure shows the vertical lithospheric field between wavelengths of 667 km and 2500 km at the surface of the Earth. Longer wavelengths are dominated by the time-varying core magnetic field. Shorter wavelengths are (currently) dominated by noise. The scale is in nano-Tesla (nT) and the colour scheme highlights the higher amplitude 'anomalies', for example those observed over many continental regions. Major linear sea-floor spreading anomalies can also be seen, for example in the North Atlantic.

Science



BGS model of the 'quiet' daily magnetic variation in the east (Y)

GEOSPACE and Quiet-Time Daily Geomagnetic Variations

The magnetic field measured near the Earth's surface has many sources. These are both internal, in the core and lithosphere, and external, extending from the ionosphere to the magnetosphere. Most of the short time-scale variations are too irregular to be accurately modelled. However, there are sources of magnetic field in the ionosphere and magnetosphere that do have a regular daily signal due to the Earth's rotation relative to the Sun-direction. Models of these variations are of scientific and also commercial interest, for example in improving directional-drilling accuracy in the oil and gas industry.

At BGS we have been working, within the GEOSPACE consortium, towards a global model of the observed regular daily variation in the Earth's magnetic field, based on hourly mean data from a network of observatories across all continents.

Our model produces an estimate of the regular daily signal's contribution to the magnetic field for any date and time, and geographic location. It also includes a simple model of the of how the daily variation changes throughout the year and the solar-cycle.

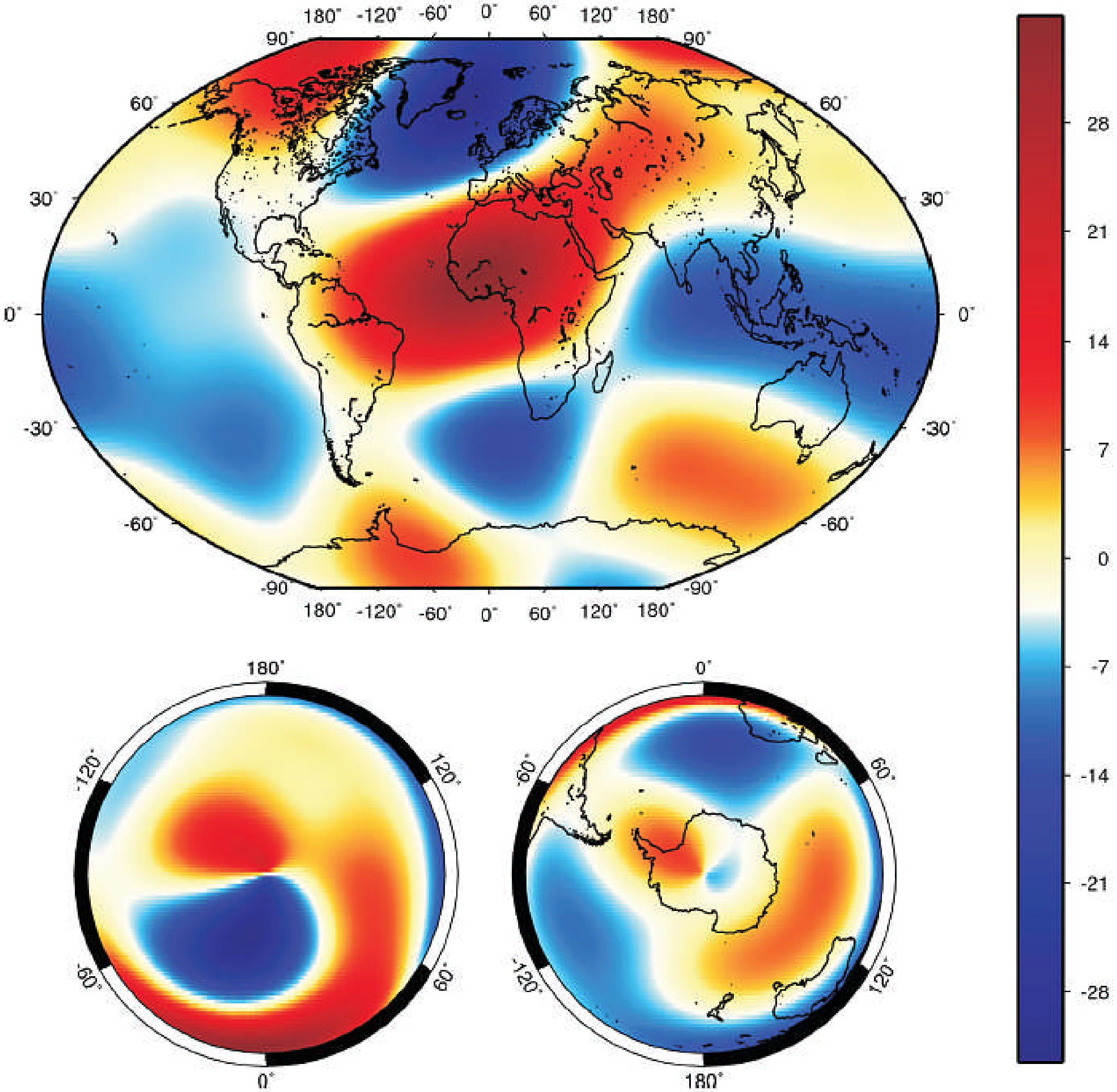
The latest version of the model compares well with published models such as WDCA/SQ1 and CM4 at mid-latitudes, especially in the north and east field-components and where the spatial density of observatory data is high.

However, there are several respects in which we plan to improve the model in the near future:

- The model's estimate of the vertical field-component, which is relatively poor compared with other published models.
- The model's maximum spatial resolution, which is currently too low to reproduce the small-scale daily-variation in the polar regions and around the magnetic dip equator.
- The inclusion of satellite data in our model, since satellite data generally have a better global coverage and resolution than observatory data. Currently we only use observatory data, which results in a poorer fit to the observed variation compared with other published models that include satellite data.

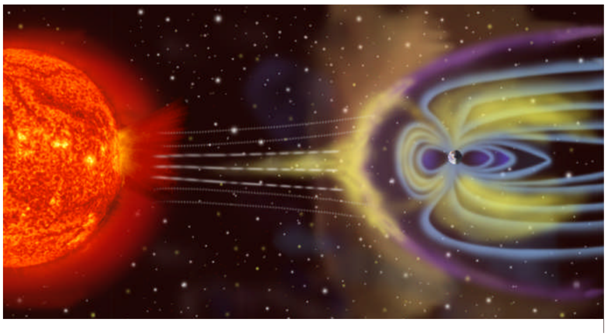
In this past year we have presented the model to various interested groups. These include the Geomagnetism Advisory Group, the BGGM users group, IAGA, and the GEOSPACE consortium.

In 2009 it is our intention to use more sophisticated modelling techniques and to increase the model's resolution. We also plan to publish the 'next generation' of results in a peer reviewed journal.



The BGS model of daily variation in the north component of the field, in this example for 12:00UT in June 1986. The model is consistent with observed daytime anti-clockwise and clockwise current systems in the northern and southern hemispheres respectively. Small scale ionospheric features such as the equatorial electrojet are too localised to be reproduced by the current BGS model. Units are nT.

Science



The Sun's magnetic activity drives geomagnetic storms (illustration courtesy NASA)

Geomagnetic Hazard, GEOSPACE and External Geomagnetism

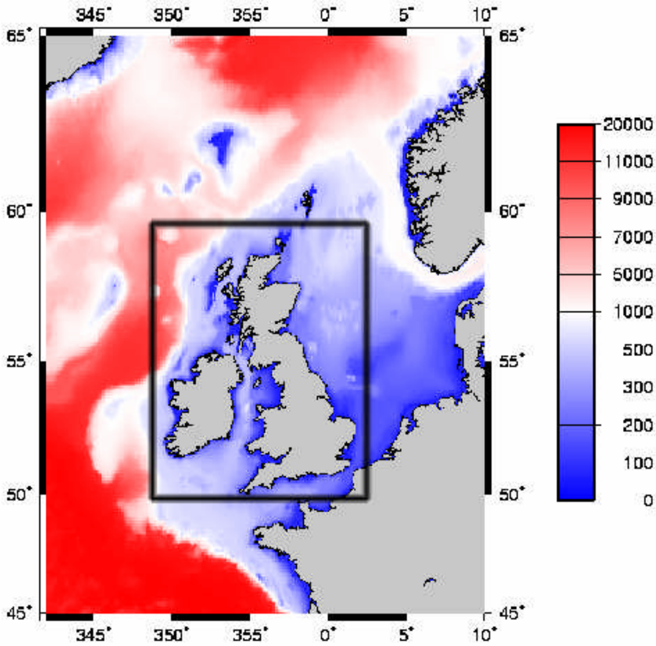
Rapid, high amplitude geomagnetic variations during magnetic storms create the geomagnetic hazard. This hazard primarily affects technologies such as power grids and pipeline networks. Longer period variations in the magnetic fields of near-Earth space are also modelled in order to better separate sources internal and external to the solid Earth.

Geomagnetic Hazard

BGS provided a service to Scottish Power plc, between 1999 and 2005, in monitoring and evaluating the geomagnetic hazard to the Scottish high voltage power grid. This hazard is from geomagnetically induced currents (GIC) that can damage high voltage power transformers.

The service had a number of components. Real-time monitoring data gave confirmation of a magnetic storm in progress. Post-event analysis of major storms, together with Scottish Power's own GIC monitoring data, provided data on grid 'hot-spots' and aided decision making by engineers.

A detailed geophysical conductivity model of the UK was developed (*see figure at right; units are Siemens*), including the off-shore sea bed. This model was coupled with a DC network model to allow simulation of GIC flow in the full power grid.



With European Space Agency support, BGS developed a demonstrator web-page based system in 2005-2006, for displaying the 'state of the art' in GIC monitoring, modelling and prediction.

Since 2006 BGS activities have been largely focussed through a joint PhD studentship (part financed by the BGS-Universities Funding Initiative) with the University of Lancaster. In this studentship, the model of the power grid BGS previously used for Scotland is being upgraded and extended both north and south. It is planned to analyse power grid performance, in respect of predicted GIC, under realistic magnetic storm conditions.

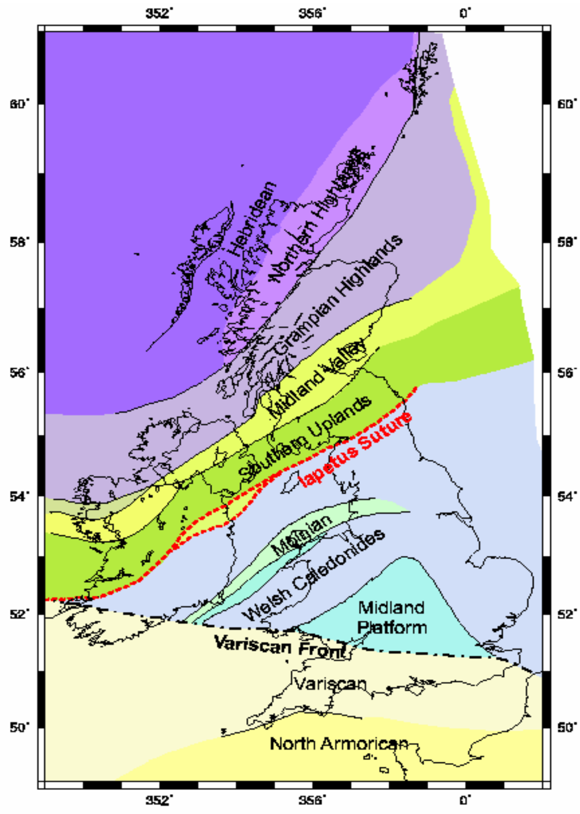
In 2007-2008 modelling results demonstrated that earth current interactions between closely located high voltage transformers could modify the GIC levels expected within the grid. This is pertinent to the dense network of transformers found in the UK.

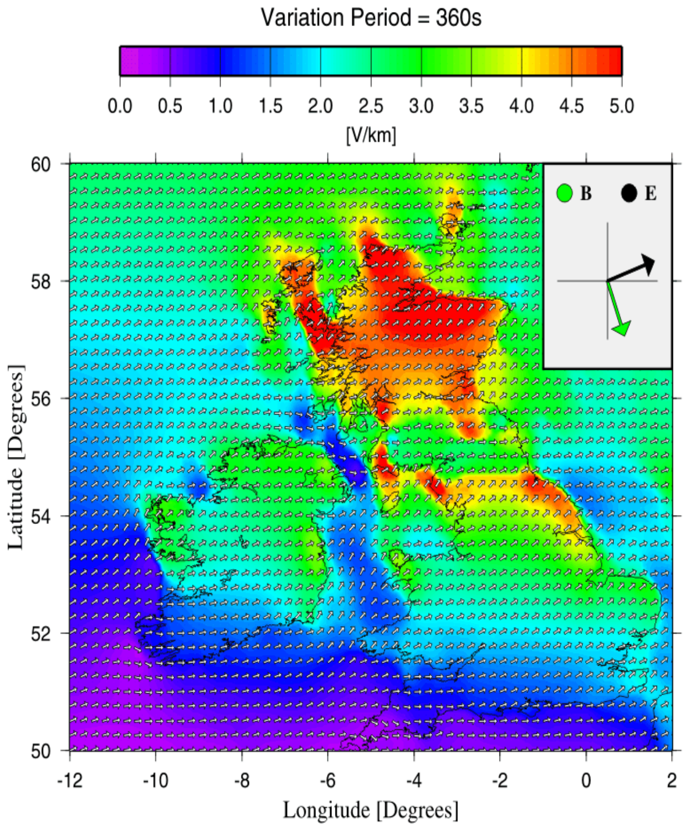
Proposals have been made to Scottish Power in late 2008 to extend our activities to a full study of planned developments in the Scottish part of the UK grid.

External Geomagnetic Field Models

Modelling of longer period, less active, external fields is also a part of our global modelling programme within the GEOSPACE project. External variations are characterised by annual and semi-annual variations and by dependence on time-varying magnetic indices.

In 2008 we upgraded our global model of the magnetic fields of the Earth. Our most recent external field model remains comparable with many published models and is satisfactory for all commercial applications.





Left*: A BGS geological terrain model for the UK.* Right*: modelled surface electric field (V/km) at the peak of the October 2003 magnetic storm. Model amplitudes are an order of magnitude larger than during typical 'quiet-time' magnetic variations.*

Science

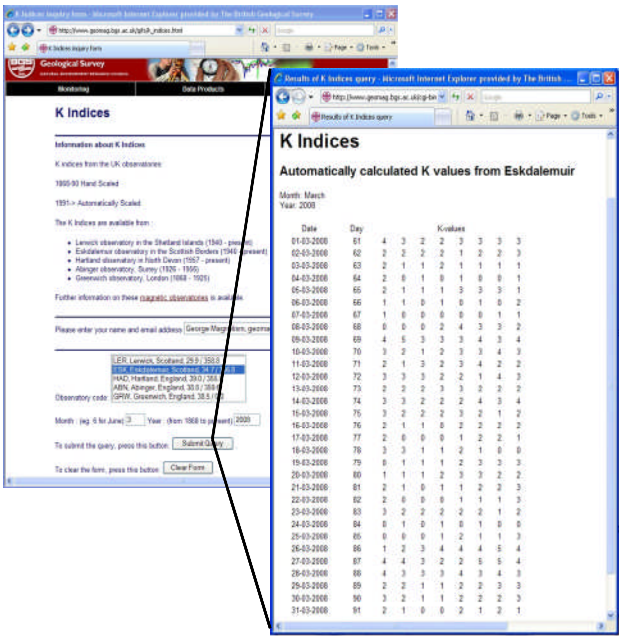
Magnetic Products and Data Services

Navigation products are derived from detailed BGS geomagnetic data

Observatory data and products are important for the advancement of scientific research, for example in predictions of the rates of change of the magnetic field, studies into the long-term changes in magnetic activity levels and other research in solar terrestrial physics.

We deliver our observatory results to the World Data Centre for Geomagnetism and INTERMAGNET, where they are distributed to a wide variety of users, along with data from worldwide observatories.

Near real-time data and other magnetic products derived by BGS are also made available to the scientific community on the geomagnetism web site (*see figure below*) at www.geomag.bgs.ac.uk/on_line_gifs.html.



First established in 1987, the Geomagnetism Information and Forecast Service (*GIFS*), has provided easy on-line access to magnetic data sets and products for nearly 22 years (two solar cycles). Regular updates are made, providing provisional magnetic field values and indices on a next day basis.

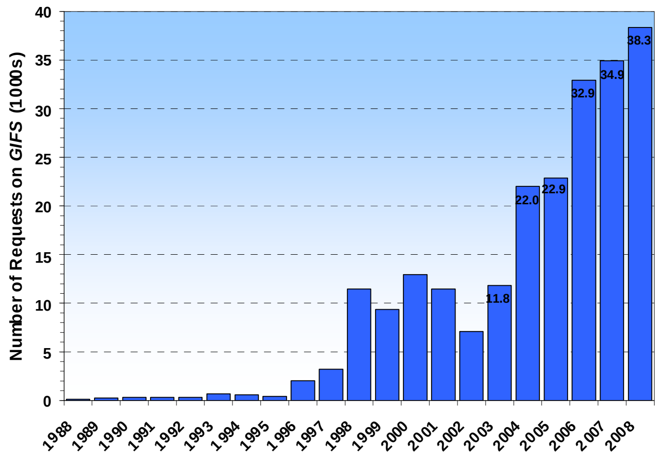
Real-time 'now-casts' and forecasts of local and global magnetic activity and solar activity are also provided using algorithms developed in BGS over many years. These are particularly useful for many space weather applications and space weather research.

On-line BGS products and services include:

- A grid magnetic angle calculator
- A world magnetic model calculator and maps
- The International Geomagnetic Reference Field (IGRF)
- Observatory hourly mean values
- *K* Indices (*as shown on the left*)
- Monthly magnetic bulletins

- Geomagnetic activity indices - *Aa* and *Ap* (*e.g. as shown in main figure below*)
- Geomagnetic and solar activity forecasts (*also shown below*)

The use of the services provided on *GIFS* is monitored and, as can be seen in this plot (*below*), has continued to grow over the years.



The UK observatory *K*-indices and rapid variations, which are described in the on-line monthly bulletins at

www.geomag.bgs.ac.uk/bulletins/bulletins.html

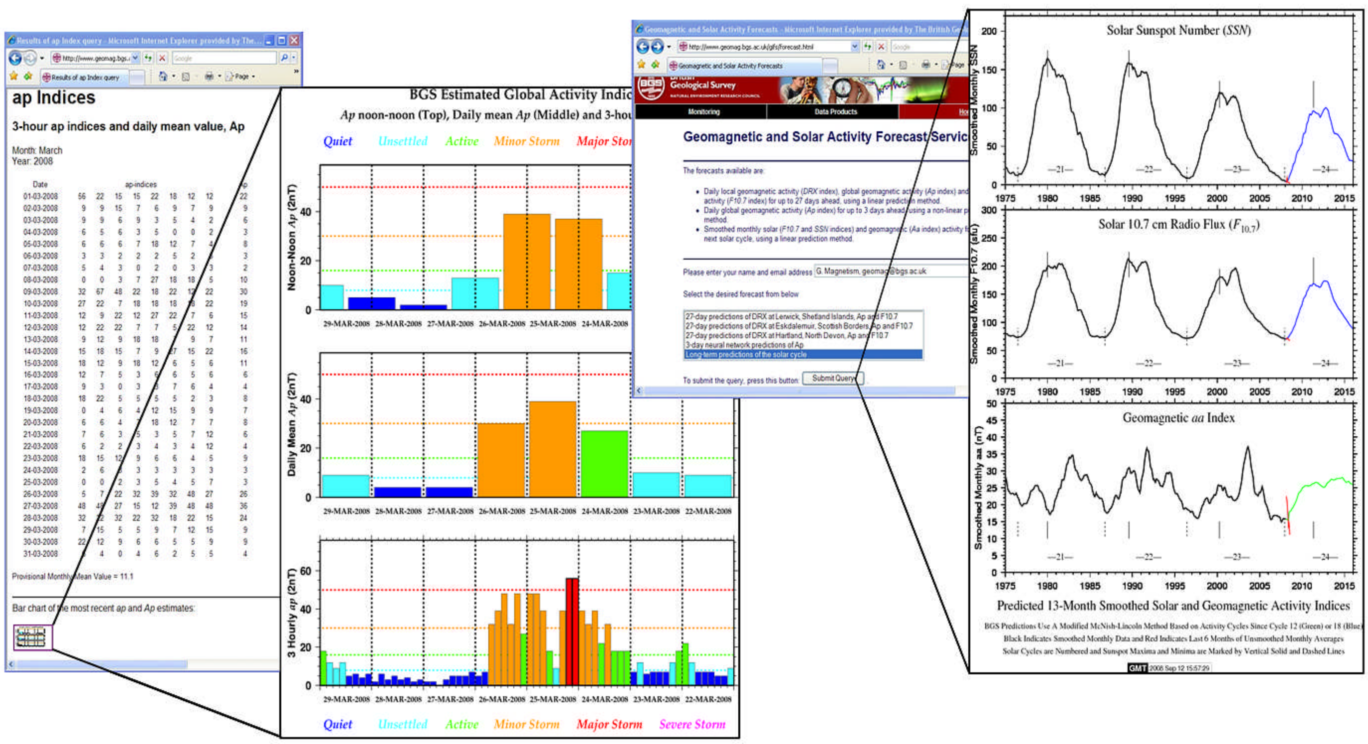
are also delivered to the International Service of Geomagnetic Indices (ISGI) in Paris.

BGS Geomagnetism nowcasts and forecasts also form part of a service provided to the European Space Agency's Space Weather European Network (*SWENET*), where they are distributed to the growing numbers of space weather users.

SWENET

www.esaspaceweather.net/swenet/index.html

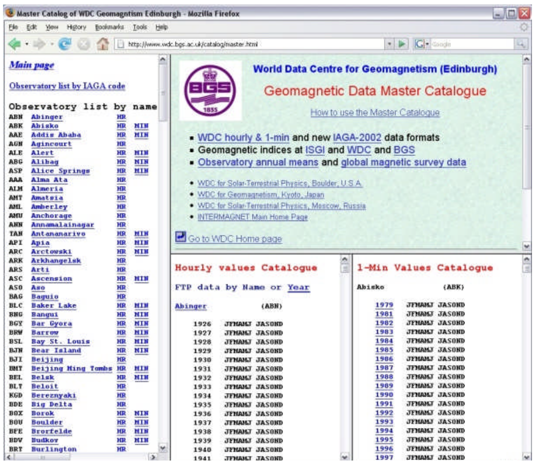
is a response to the need in Europe for near real-time data services in support of space weather monitoring and protection of space- and ground-based technologies.



Examples of products and services provided through GIFS.

Science

World Data Centre



Edinburgh World Data Centre on the web

The Geomagnetism Team operates a World Data Centre for Geomagnetism. We hold records from around 280 observatories worldwide, on a number of time-scales, along with various survey, model and activity index data. The operation of this dynamic data centre contributes towards our own global modelling efforts and provides a valuable service to the worldwide research community.

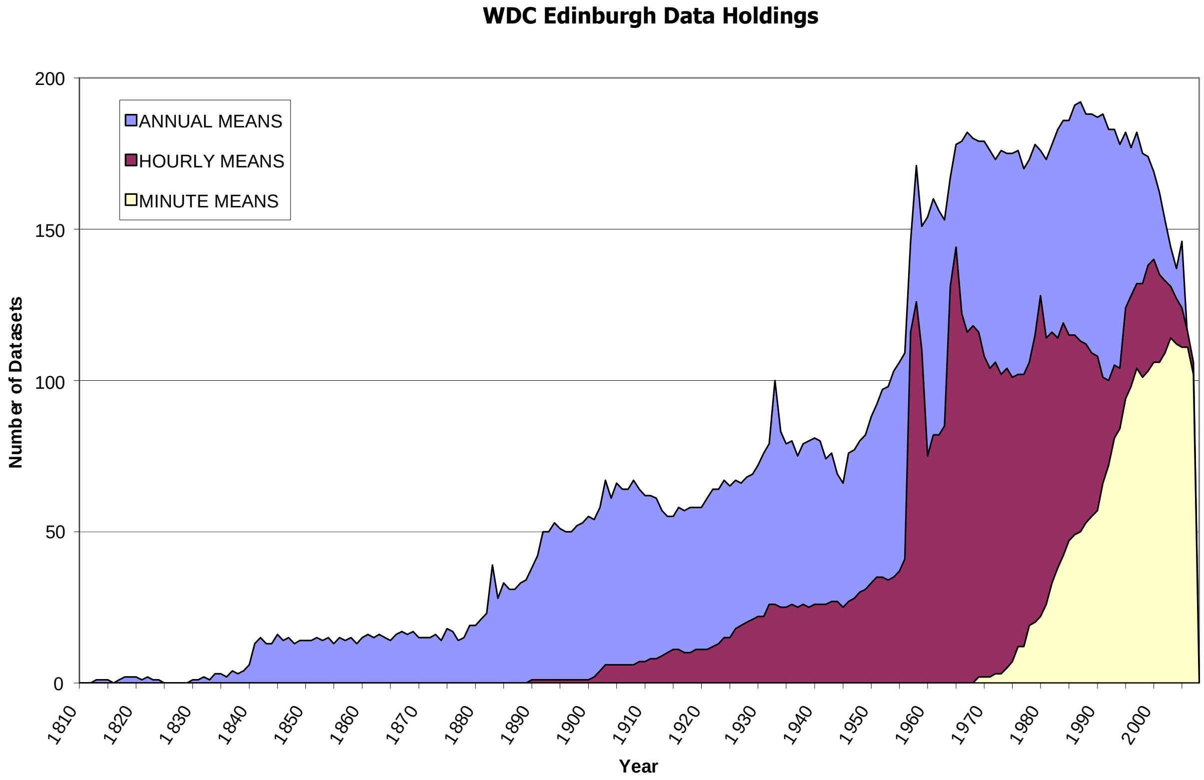
Our World Data Centre (WDC) for Geomagnetism was established in 1966 at Herstmonceux in Sussex and moved to Edinburgh in 1977. Since then BGS has concentrated on gathering data primarily for global magnetic field modelling. During this time the WDC in Copenhagen gathered minute-mean and hourly-mean records from worldwide magnetic observatories and provided access to these data sets via a 'Data Catalogue' website. Following the retirement of a key member of staff at WDC Copenhagen, BGS agreed to take over responsibility for these data sets and the operation of the 'Data Catalogue' website.

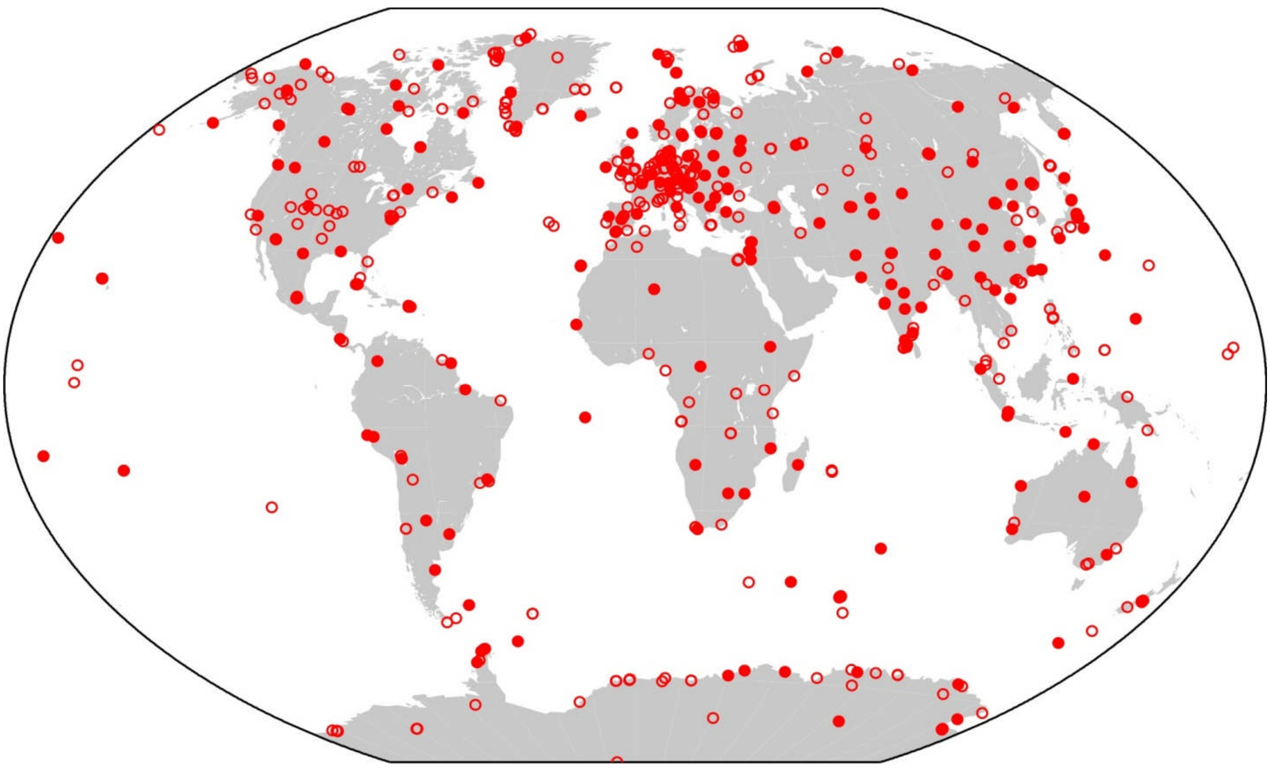
We assumed this responsibility in January 2007 and by April 2007 the new 'Data Catalogue' website and data sets were live on our servers. This was achieved ahead of schedule and in good time for the promotion of this new WDC service at several key scientific conferences including the WDC directors meeting (May 2007), IUGG, and the eGY launch (July 2007).

Since 2007 much effort has been made to maintain and expand the volume of data held at our WDC (*see figure opposite*). We now hold observatory annual mean data from 1813. We have approximately 60 million hourly observations and means from 1890 and approximately 1.2 billion one-minute means from 1969 onwards.

We have conducted two successful *'calls for data'* within the global observatory community requesting additions to our data centre. This not only increased our data holdings but renewed and updated observatory contact information and fostered new relationships with data providers.

BGS does not operate the only WDC for Geomagnetism. Other providers include institutes in Kyoto (Japan), Boulder (USA), Moscow (Russia) and Mumbai (India). In the past 18 months we have established a working relationship with the WDCs in Boulder and Kyoto, collaborating on common goals such as metadata standards and data sharing protocols. We have developed a *wiki* site to facilitate these discussions and we also organised the inaugural WDC Geomagnetism meeting in Boulder in July 2008.





Top*: The number of data holdings at the World Data Centre at various time resolutions.*
Bottom*: Locations of geomagnetic observatories worldwide, with data held in our World Data Centre. Currently operating observatories are indicated by a solid dot, open dots are sites that are currently closed.*

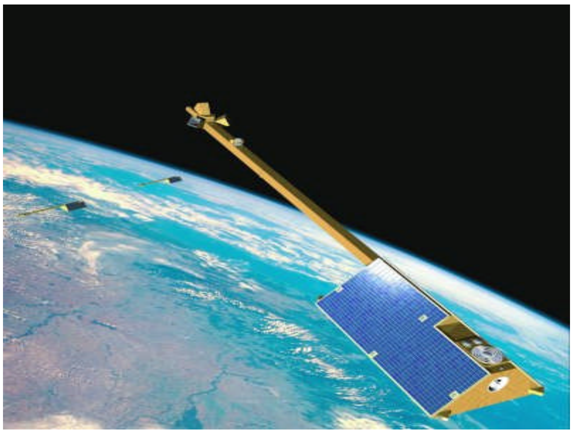


Illustration of the Swarm satellites in orbit (courtesy of ESA)

The ESA Swarm Satellite Mission

The forthcoming European Space Agency (ESA) Swarm mission will provide vector magnetic data from three low-Earth orbit satellites for scientific and other uses. Swarm has been designed to reveal Earth's magnetic sources and processes with an unparalleled resolution and precision. In 2008 BGS took part as a key member of a science consortium formed by ESA to plan a 'data processing centre' to receive, process and disseminate data and science products after the mission launch, expected in 2010 or 2011. BGS is therefore well-placed to contribute new scientific insights and to deliver products to academic and other customers well into the next decade.

ESA plans to launch a 'mini-constellation' of three Earth observation satellites, collectively known as Swarm, with a launch date likely to be 2010. Two of the Swarm satellites (*see illustration at top*) will fly at a relatively low altitude (c. 450km) in a 'side-by-side' formation, separated by as little as 160 km, in orbits that will drift in order to sample all local times. This configuration will help determine East-West crustal magnetic anomalies as never before.

A third satellite will operate at a higher altitude (c. 550 km) and in a different - also drifting - local time orbit from the lower pair. This will aid separation and resolution of, for example, core and magnetospheric magnetic field sources.

The Geomagnetism team were funded by ESA, as part of a year-long scoping study to help design what is known as the 'Level 2' science data processing architecture for Swarm. ESA intends to establish a data centre to not only handle and disseminate the data returned from the satellites, but also add value by turning these data into scientific products for use by the academic community, to extract maximum value from the mission.

Three other institutes from around Europe were also involved in the study: GFZ Potsdam (Germany), DTU Space (Denmark) and DEOS, TU Delft (Netherlands). Additional scientific and technical details were provided by the Swarm Mission Advisory Group (MAG), which includes leading geomagnetic scientists from both Europe and the rest of the world.

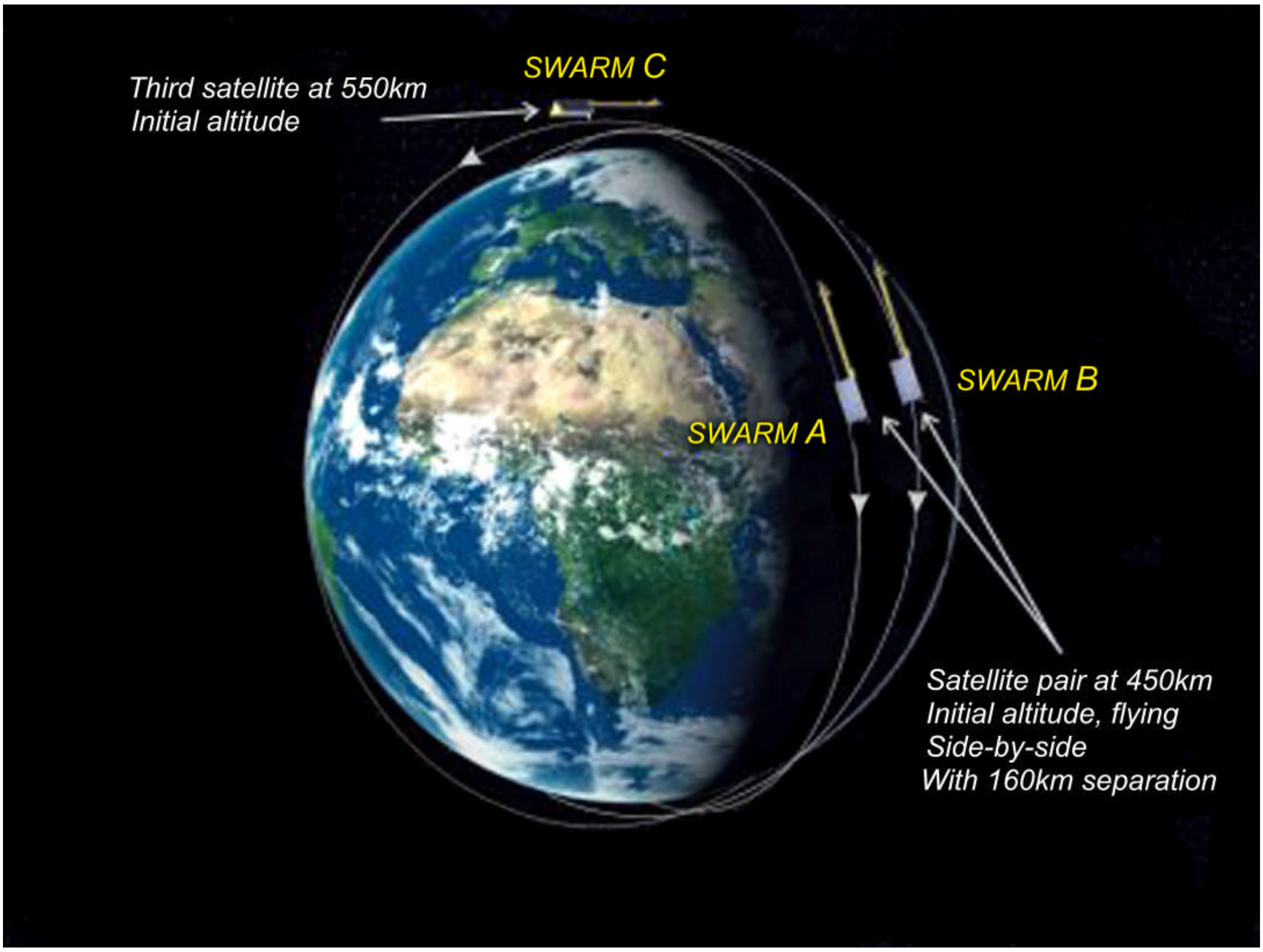
The Geomagnetism team led the outline design of the 'quick-look' and 'validation' products that will be provided by the science data centre. These products include, for example, quality-controlled maps and time series of the various sources of the Earth's magnetic field, including the core, crust, and magnetosphere.

Swarm will also return data on Earth's atmosphere and ionosphere and BGS collated the planned quick-look and validation products in these areas.

In contrast to previous ESA supported magnetometry missions, Swarm data and science products will be effectively provided at a higher level of quality control. Swarm data and data products have also been influenced by the views of the world's geomagnetic science community.

In the coming months ESA will decide on the final make-up of the Level 2 processing centre. The current plan is to retain the current consortium with a lead provided by DTU (Space) in Copenhagen, who were responsible for the still-operating Ørsted magnetic survey satellite. If fully funded, the BGS commitment would be for around ten man-years of activity, spread over two years of development and five years of operation.

ESA and its partners will also explore other funding for parts of the mission. The BGS Geomagnetism team will discuss options with NERC and with the British National Space Agency (BNSC), the appropriate bodies in the UK, and in association with colleagues in the GEOSPACE NERC-funded geomagnetism consortium.



The planned Swarm mission profile (illustration courtesy of ESA).

BGGM executable software distribution

Applications

BGS Global Magnetic Field Model

The BGS Global Geomagnetic Model (BGGM) is produced to support directional drilling in the oil industry, where there is a requirement to provide a directional reference when magnetometers are used in the bottom-hole assembly.

Much of our magnetic modelling effort this year concentrated on upgrading the BGGM. A 'normal' annual update of the BGGM benefits from any data assimilation that has been carried out for all of our global models. Such an upgrade usually also incorporates incremental improvements to the modelling methodology that may result from our research throughout the year. It does not normally include software changes.

However the upgrade this year was more than 'normal', in that it was driven by a desire to provide a more accurate and higher resolution model (in terms of spherical harmonic degree). This was made possible because of the plentiful high-quality magnetic data being returned by two satellites, the Danish-led Ørsted mission and the German-led CHAMP mission.

This year's upgrade also required the BGGM software to be updated. As the drilling industry has this software embedded in a variety of systems, agreement that we should go ahead with this upgrade was obtained at a BGGM consortium meeting we organised in Aberdeen. Subsequently BGGM2008, with much improved parameterisation, executable software completely rewritten in JAVA and the *C* source software revised, was released in May 2008.

Vector satellite data at all latitudes rather than at only low and mid-latitudes are now being incorporated into our global models and this has been made possible by a new data weighting scheme based on along-track variations and simultaneous variations measured at nearby observatories.

A perennial question about magnetic field models concerns their accuracy and efforts have been made this year to address this, with particular emphasis on the BGGM. Differences between BGGM estimates of the magnetic field and the true magnetic field experienced by the down-hole magnetometers arise from the local crustal magnetic field, the time-varying external field and inaccurate model predictions.

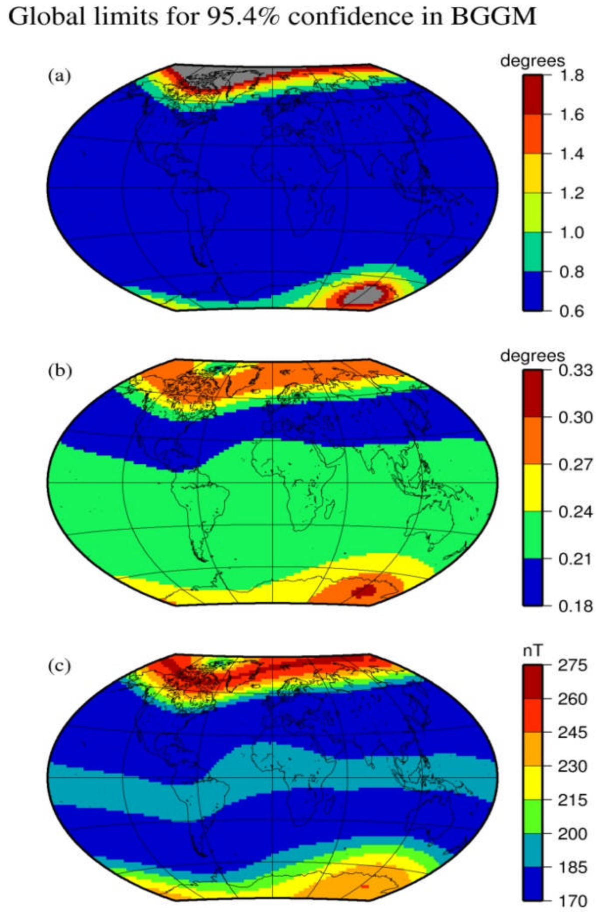
To assess model accuracy, orientated magnetic down-hole data, uncontaminated by drill-string interference, were simulated using geomagnetic observatory data. Spot absolute measurements of the magnetic field made at observatories around the world were then adjusted for the crustal magnetic field to make them applicable to hydrocarbon geology. The adjusted observatory data were compared with the predicted values from the BGGM to assess the uncertainty.

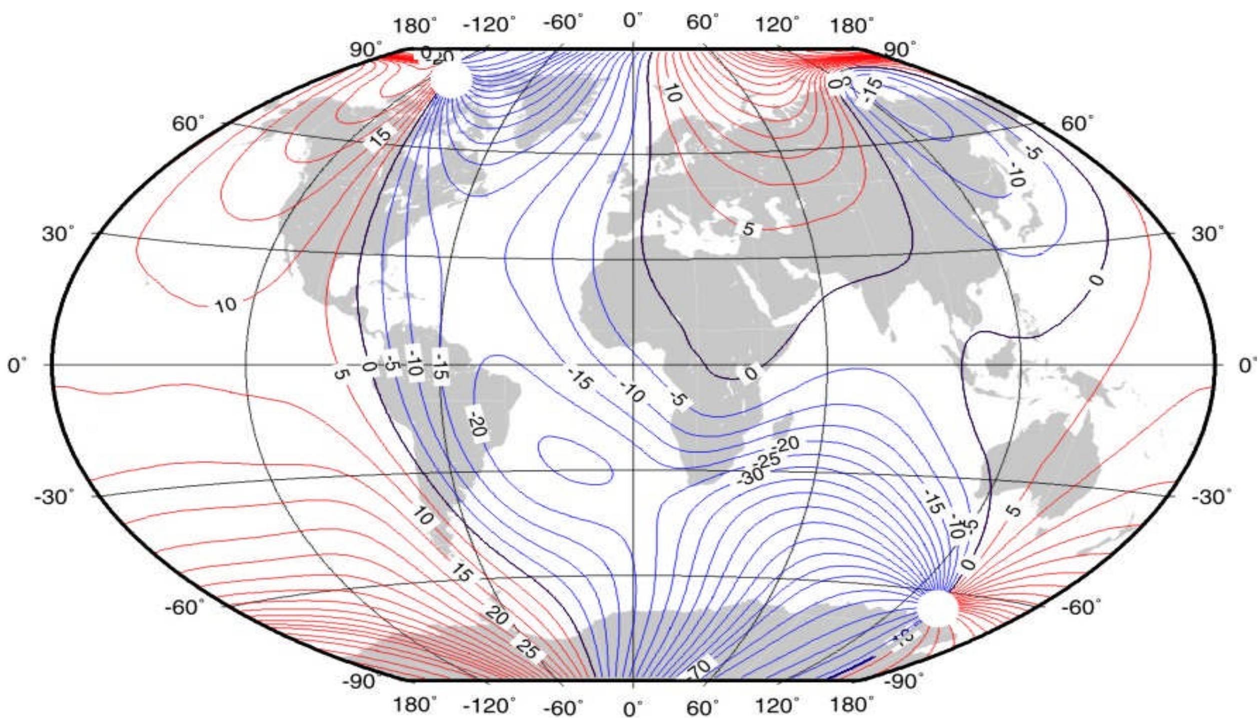
The uncertainties do not fit a Gaussian error distribution so they are expressed as limits for various confidence levels. They vary with time and with location and, in their derivation, do not assume any underlying empirical error distribution.

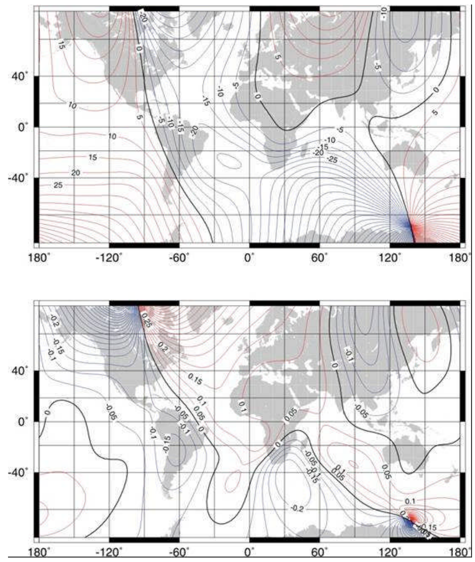
This work has now been submitted to the Society of Petroleum Engineers (SPE) for publication.

figure (below): Global confidence limits for the BGGM (declination, inclination and total field strength).

figure (bottom): Compass variation (declination) at 2009.0 from BGGM2008.







Charts from the World Magnetic Model: declination (degrees) and its rate of change (deg/year).

World Magnetic Model

The current World Magnetic Model, WMM2005, is valid until 2010.0 and is widely used in air and sea navigation systems. The WMM is a model of the Earth's magnetic field that is generated in the Earth's core and is revised once every five years.

WMM2005 was produced by the British Geological Survey (BGS) and the US National Geophysical Data Center (NGDC), with funding provided by the Defence Geographic Imagery and Intelligence Agency (DGIA) in the UK and by the US National Geospatial-Intelligence Agency (NGA) in the USA.

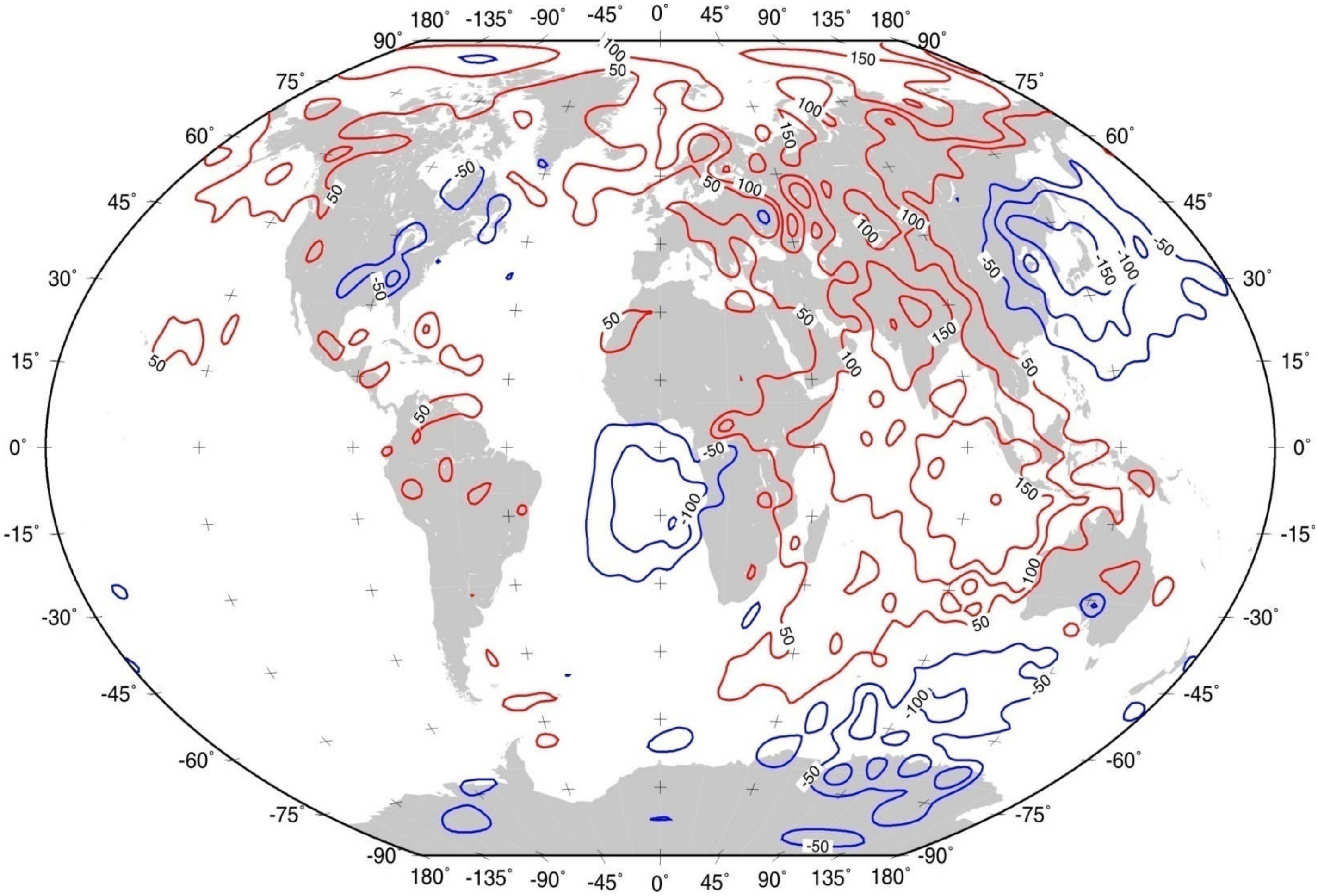
The WMM is the standard magnetic field model in navigation and attitude and heading referencing systems, including charts, used by the UK Ministry of Defence and the US Department of Defense, the North Atlantic Treaty Organization (NATO), and the World Hydrographic Office (WHO). It is also used extensively in civilian navigation systems. In 2009 a new model, WMM2010, will be produced.

The accuracy of WMM2005 can be tracked during its lifetime, and in late 2008 the differences between it and an annually updated model (BGGM2008) were computed. The military specification MIL-W-89500 (Defense Mapping Agency, 1993), whilst currently declared as "inactive", is the only accuracy specification for the WMM available. It specifies that the model should output values that are within 140 nT of the true values (in a root-mean-square sense) for the north and east components, 200 nT for the vertical and horizontal components, 280 nT for the total intensity, and 1° for declination and inclination.

Comparisons of the WMM with another model assume that the latter represents the true values, including the crustal field and external field contributions. Clearly this is not the case and more detailed work, along the lines of that done for the BGGM, is required to answer the question "does the WMM meet its accuracy requirements for the duration of its lifetime".

The BGGM is known to have 68% confidence limits (equivalent to 1 standard deviation or root-mean-square difference) for declination and inclination that are well within 1° for all locations around the world outside the immediate vicinity of the poles. The limits for total intensity are also well within the stated 280 nT WMM limit, with a maximum BGGM uncertainty of about 110 nT. When these BGGM errors are combined with the differences between WMM2005 and BGGM2008 in late 2008, the overall errors in the WMM are within those of the military specification.

A complete assessment of WMM2005 accuracy will be made at the end of its lifetime, as part of the process of production of WMM2010.

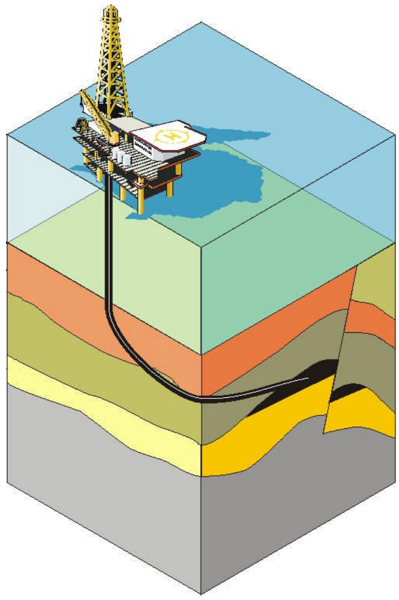


The difference between WMM2005 and BGGM2008 in their synthesis of total intensity of the field at 31st December 2008 at the Earth's surface. Units are nT.

Applications

Oil Industry Services

The geomagnetic field is the vector sum of magnetic fields from several sources. High quality data and improved models have enabled better separation of these sources. A spin off from this science is in the application of directional drilling. Working with oil industry customers, BGS has developed geomagnetic services to meet the industry needs.

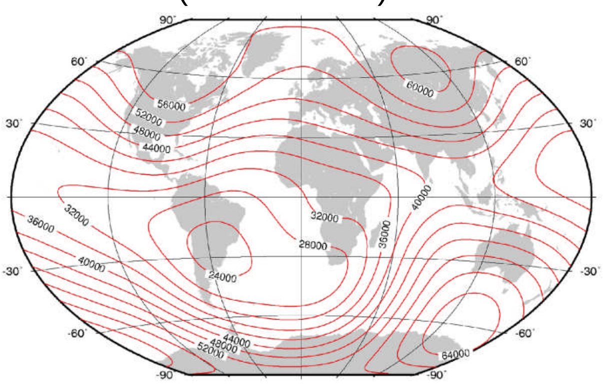


Navigating a well-bore from a drilling platform to a small oil target

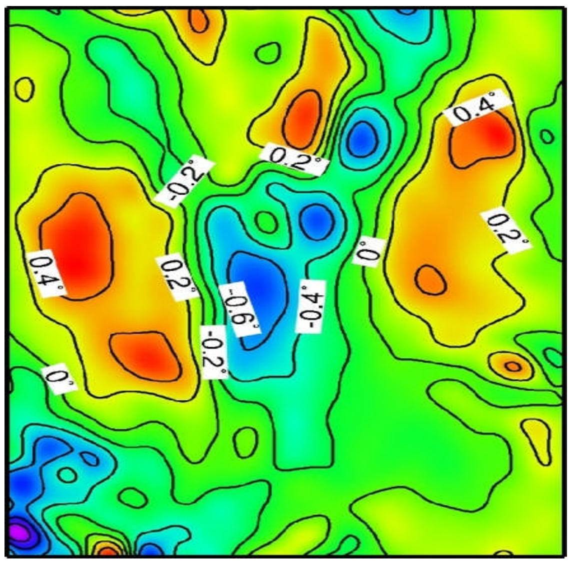
Modern technology enables wells to be drilled along paths reaching over 10 km horizontally and 5 km vertically below ground. Magnetic sensor survey tools rely on reference values of the geomagnetic field vector at the time and location of each survey measurement to accurately monitor the well bore position.

To ensure that the well conforms to the planned path, within certain tolerances, the reference field needs to include the effects of each source, which, if ignored, would create an error of significance for drilling. The desired accuracies in the direction and strength are around 0.1° and 50nT, respectively.

The main source of the magnetic field, represented by a global model such as the BGGM, is generated in the Earth's outer core (*below – in nT*).

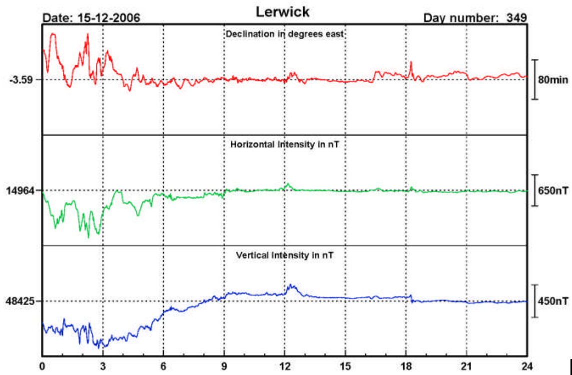


Locally, the main field is perturbed by magnetic fields created by rocks containing magnetic minerals. The magnitude of the crustal field is generally less than 1% of the main field, but it can cause changes in field direction much larger than 0.1° and the effect is a systematic bias (*below – in degrees*).



Aeromagnetic and marine magnetic survey data are used to quantify perturbations in the strength of the crustal field. From these scalar data we obtain directional information at the surface and down hole using mathematical transformations.

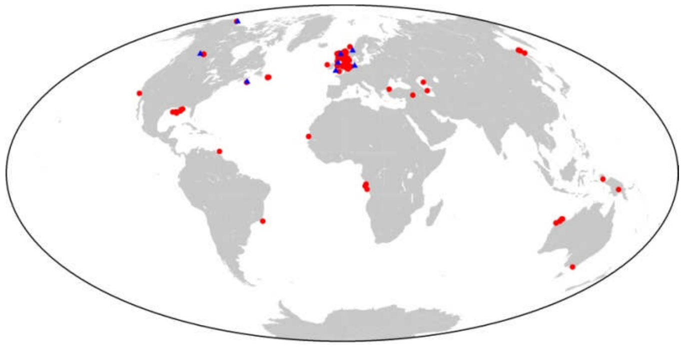
Global and local variations occur due to a combined external field from electrical currents flowing in the upper atmosphere and magnetosphere, which in turn can induce electrical currents in the sea and the ground. There are regular daily changes due to ionospheric currents, and more sporadic disturbances due to increased solar activity, that can cause short-term changes of a few degrees (*figure below*).



Magnetic observatories monitor these external field effects and the measurements are used to estimate the disturbance field at nearby drilling locations.

In 2007-2008 magnetic reference values were supplied for nearly 500 wells in oil fields in the North Sea and worldwide.

Over several years the number of oil fields using these services has increased. *The figure below* shows the locations of fields using these services (red dots) and the collaborating magnetic observatories (blue triangles).

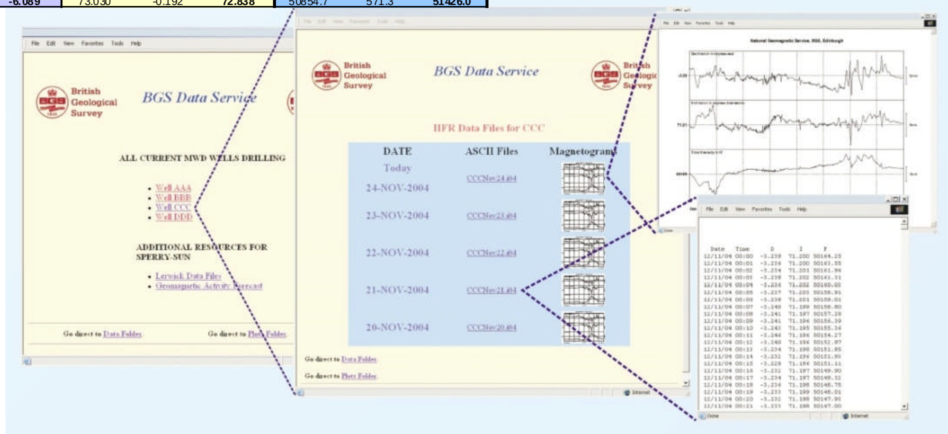


The services provided include In-Field Referencing (IFR) where only the main and crustal field sources are included. These are delivered in tables (*below left*) via email.

Improved accuracy at mid to high latitudes is gained with the service of Interpolation In-Field Referencing (IIFR), where all sources are accounted for in one-minute values of *D*, *I* and *F,* for a selected position along the well path. Using observatory data these are provided in real-time via password protected user accounts on the geomagnetism web servers (*below right*).

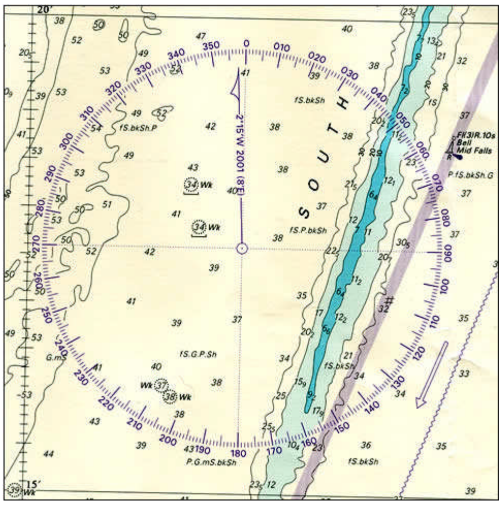
IFR values at xxxx, well xxx/xx-xxxx (slot x) for XX

	Latitude ° North	Longitude ° West	TVD (km)	Declination (degrees) BGGM	Declination Crustal	Declination Baseline	Inclination (degrees) BGGM	Inclination Crustal	Inclination Baseline	Total Field Intensity (nT) BGGM	Total Field Crustal	Total Field Baseline
1	60.69246	2.54249	0.000	-5.035	-0.474	**-5.509**	73.025	-0.080	**72.945**	50809.4	216.3	**51025.7**
2	60.69305	2.54006	0.874	-5.033	-0.674	**-5.707**	73.026	-0.133	**72.893**	50828.5	270.5	**51099.0**
3	60.69398	2.53590	1.307	-5.031	-0.826	**-5.857**	73.027	-0.186	**72.841**	50838.1	287.1	**51125.2**
4	60.69501	2.53477	1.519	-5.030	-0.910	**-5.940**	73.027	-0.214	**72.813**	50842.9	305.3	**51148.2**
5	60.69632	2.53557	1.714	-5.031	-0.983	**-6.014**	73.028	-0.235	**72.793**	50847.5	342.2	**51189.7**
6	60.69844	2.54213	1.942	-5.035	-1.048	**-6.083**	73.030	-0.227	**72.803**	50852.9	449.6	**51302.5**
7	60.69867	2.54708	1.983	-5.038	-1.017	**-6.055**	73.030	-0.204	**72.826**	50853.9	499.8	**51353.7**
8	60.69886	2.55160	2.017	-5.040	-1.049	**-6.089**	73.030	-0.192	**72.838**	50854.7	571.3	**51426.0**



Applications

Navigation and Mapping Services



Magnetic products are supplied to the UK Hydrographic Office

Knowing the local geomagnetic field direction is essential when using a magnetic compass. Compass users invariably use a map or chart at the same time, so it is convenient to have the magnetic north direction provided on the map. These north directions are ideally valid for the period from the publication of the map to the time when the next map revision is available. Since this period is normally a number of years, a published estimate of the annual rate of change is also necessary.

The UK Hydrographic Office (UKHO) publishes sea charts for areas all around the world and the magnetic north information on these charts is derived from the World Magnetic Model (WMM). This model is updated once every 5 years.

The UK national mapping agency, the Ordnance Survey (OS), publishes maps on a variety of scales covering the whole of Great Britain and the magnetic north information is obtained directly from BGS. The magnetic model used is a UK model of declination, which is updated every year with data assimilated from the previous year's repeat station and observatory observations. As the north lines on OS maps are grid north lines the difference between grid north and true north must be applied to the declination values.

The BGS has supplied the Ordnance Survey with magnetic north data for 70 Landranger and 167 Leisure series maps from the 2007 UK magnetic field model. The accuracy of the UK model, based on differences between recent measurements and model values, is estimated to be 0.5° with a 95% confidence level.

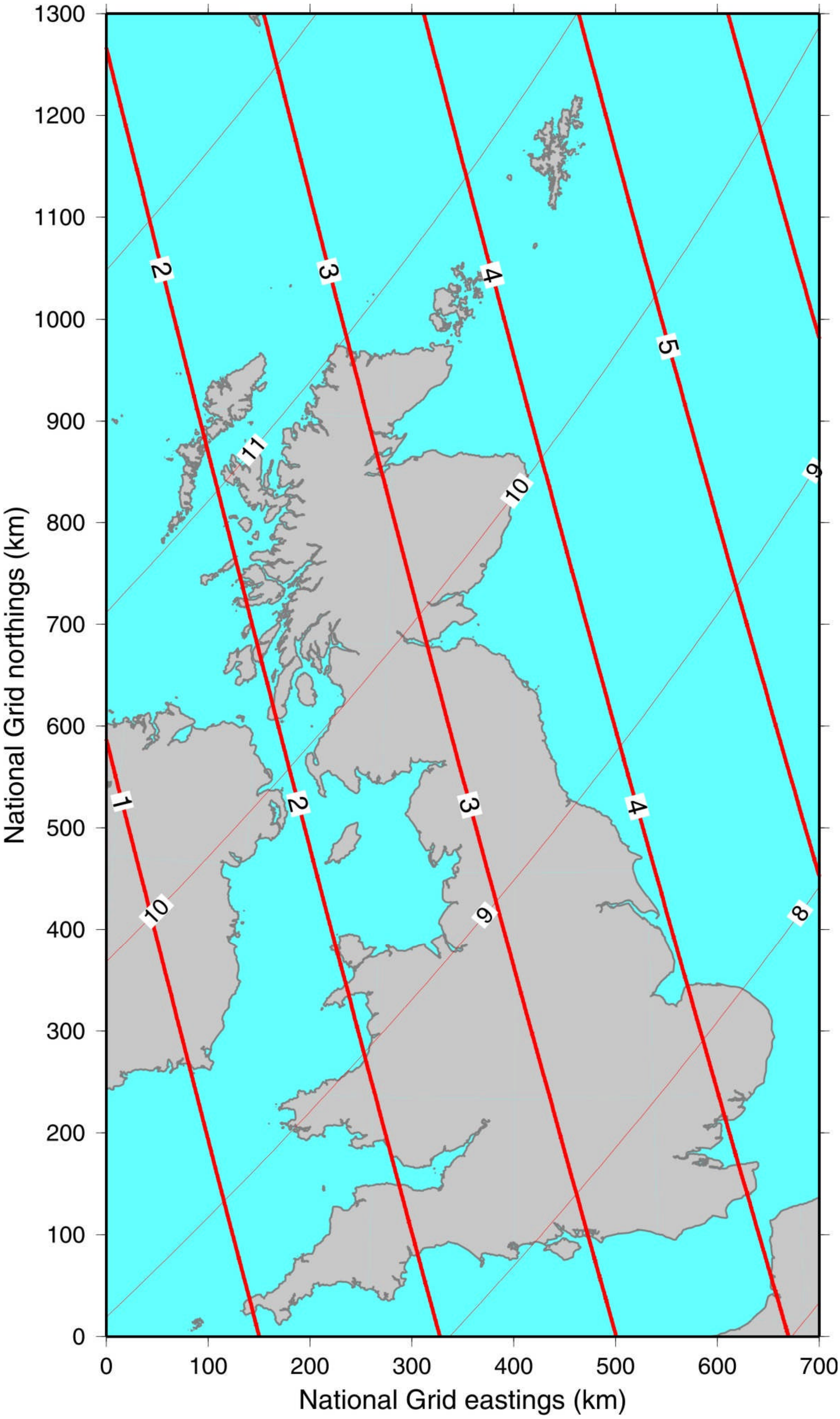
Up-to-date magnetic north information can be computed for any location using an on-line BGS calculator at

www.geomag.bgs.ac.uk/gifs/wmm_calc.html

This link provides declination values from the World Magnetic Model, while the calculator at

www.geomag.bgs.ac.uk/gifs/gma_calc.html

provides grid magnetic angle for the UK.



Thick lines show grid magnetic angle (degrees west of grid north) and thin lines show annual rate change (arc-minutes per year to the east) for mid-2008.

Hartland observatory 'Open Weekend' June 2007

Outreach Activities

Communicating what we do in Geomagnetism; why it is exciting science and why it matters, is an integral part of our work. We aim to communicate with all stakeholders in the subject, including academic colleagues, the public, industry and government. The Geomagnetism Team have always been active at conferences, presenting papers and posters and serving on scientific bodies. However 2007 and 2008 were particularly busy years for us.

Our outreach activities are summarised in the main figure (*on page opposite*). Of particular note, perhaps, are the team's activities at BGS 'Open Days' in Edinburgh and the 'Open Weekend' to celebrate the 50th anniversary of Hartland magnetic observatory (*below and top*).

A regular bi-monthly column was contributed on 'space weather and navigation' for the Royal Institute of Navigation's 'Navigation News'.

The Geomagnetism team hosted two GEOSPACE meetings during 2007 and 2008 (*see below*).

The team published four papers in scientific journals on internal and external Geomagnetism. These papers covered our scientific advances in understanding the Earth's deep interior and the effect of solar activity on the Earth system and on technology.

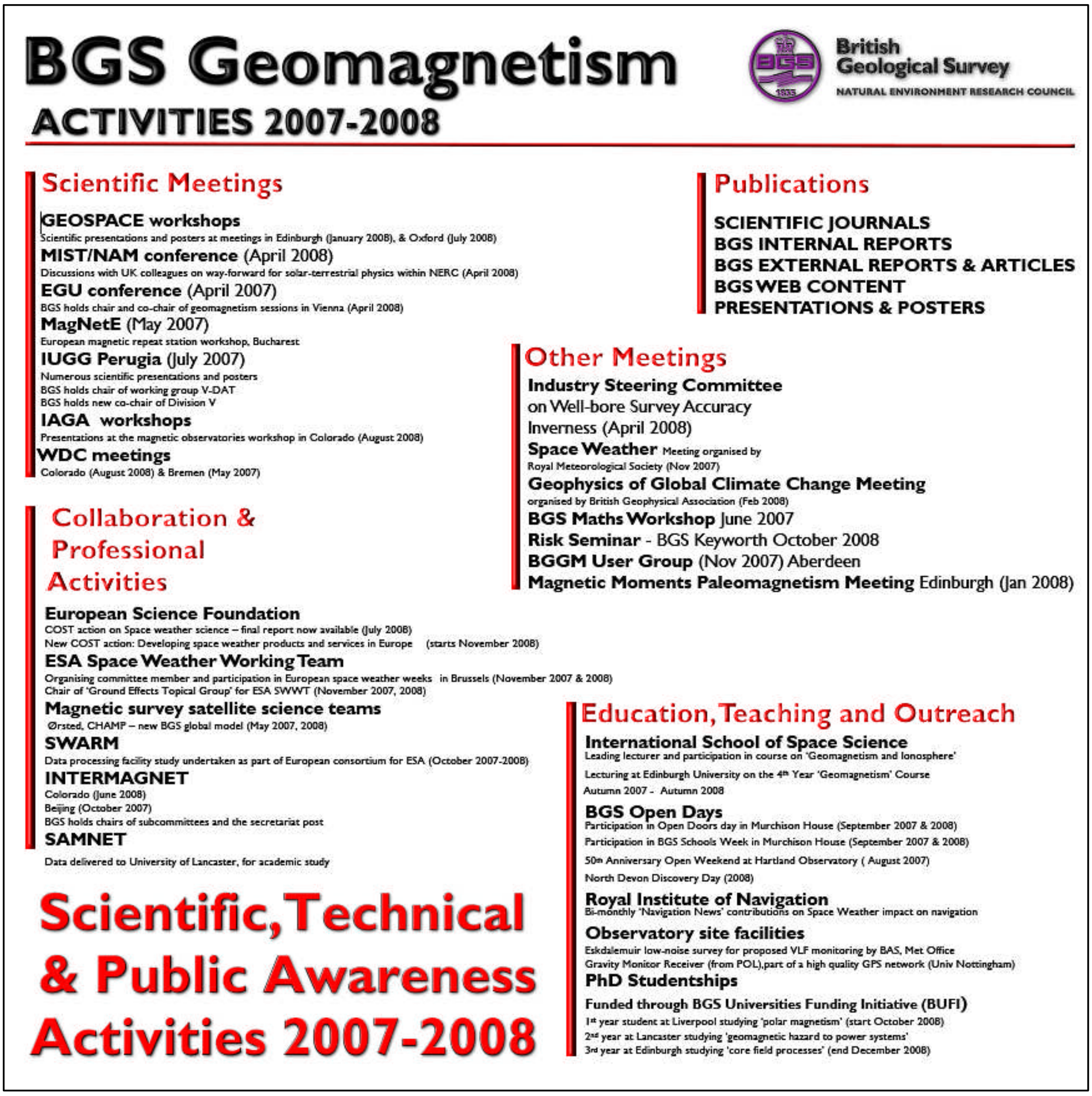
Scientific Journal Publications

Thomson, Alan W. P., **McKay, Allan J.** and Viljanen, A. (2008). A review of progress in modelling of induced geoelectric and geomagnetic fields with special regard to induced currents. *Acta Geophysica*, doi:10.2478/s11600-008-0061-7.

Thomson, A. W. P. and Lesur, V. (2007). An improved geomagnetic data selection algorithm for global geomagnetic field modelling. *Geophys. J. Int.*, doi: 10.1111/j.1365-246X.2007.03354.x.

Macmillan, S. and Droujinina, A**.** (2007). Long-term trends in geomagnetic daily variation, *Earth Planets, Space*, **59**, 391-395.

Trichtchenko, L., A. Zhukov, R. van der Linden, S. M. Stankov, N. Jakowski, I. Stanislawska, G. Juchnikowski, P. Wilkinson, G. Patterson, **A.W.P. Thomson** (2007). November 2004 Space Weather Events Real-Time Observations and Forecasts. *AGU Space Weather*, doi:10.1029/2006SW000281.



A summary of scientific and other outreach activities in 2007-2008.

Acknowledgements

The work described in this document would not have been possible without the continued support of Geomagnetism team customers, the Geomagnetism Advisory Group, and of the Natural Environment Research Council.

Geomagnetic and other data provided by scientific institutes and scientific bodies around the world are also gratefully acknowledged.

The editor would like to thank Ellen, Brian, Sue, Sarah, Tom and Chris for their contributions to this review and the Geomagnetism team as a whole for their activities and effort in 2007-2008.

This report is published with the approval of the Executive Director of the British Geological Survey (NERC).

A few of the Geomagnetism team (and friends) at the end of the Hartland Observatory 50th anniversary 'Open Weekend' in June 2007.

Selected Glossary, Acronyms and Links

BAS *British Antarctic Survey*
(www.antarctica.ac.uk/)

BGGM *BGS Global Magnetic Model*
(www.geomag.bgs.ac.uk/navigation.html)

BGA *British Geophysical Association*
(www.ras.org.uk)

BGS *British Geological Survey*
(www.bgs.ac.uk/)

BNSC *British National Space Centre*
(www.bnsc.gov.uk/)

BUFI *BGS-Universities Funding Initiative*
(www.bgs.ac.uk/research/who.html)

CHAMP *German magnetic survey satellite*
(www-app2.gfz-potsdam.de/pb1/op/champ/)

CM4 *Comprehensive magnetic field model (version 4)*
(denali.gsfc.nasa.gov/cm/)

DEOS *Department of Earth Observation and Space Systems, Technical University, Delft*
(www.lr.tudelft.nl/)

DTU *Danish Technical University*
(www.space.dtu.dk/English.aspx)

EGU *European Geophysical Union*
(www.egu.eu/)

eGY *Electronic Geophysical Year*
(www.egy.org/index.php)

ESA *European Space Agency*
(www.esa.int/esaCP/index.html)

ESWW *European Space Weather Week*
(sidc.oma.be/esww5/)

IAGA *International Association of Geomagnetism and Aeronomy*
(www.iugg.org/IAGA/)

IGRF *International Geomagnetic Reference Field*
(www.ngdc.noaa.gov/IAGA/vmod/igrf.html)

INTERMAGNET

International Magnetometer Network: a global network of magnetic observatories operating to common standards
(www.intermagnet.org/)

ISCWSA ***The Industry Steering Committee on Wellbore Survey Accuracy***
(iscwsa.org/)

ISGI ***International Service for Geomagnetic Indices***
(www.icsu-fags.org/ps06isgi.htm)

IUGG. ***International Union of Geodesy and Geophysics***
(www.iugg.org/)

GEOSPACE ***NERC consortium of UK universities and institutes studying geomagnetism***
(www.geos.ed.ac.uk/research/geospace/)

GFZ ***Helmholtz centre, Potsdam, Germany***
(www.gfz-potsdam.de)

GPS ***Global Positioning System***
(www.gps.gov/)

Met Office ***UK Meteorological Office***
(www.metoffice.gov.uk/)

MIST ***Magnetosphere, Ionosphere, Solar-Terrestrial (Physics)***
(www.mist.ac.uk/)

NAMAS ***National Measurement and Accreditation Service***
(www.ukas.com/)

NGS ***National Geomagnetic Service***
(www.geomag.bgs.ac.uk)

NERC ***Natural Environment Research Council***
(www.nerc.ac.uk/)

Ørsted ***Danish magnetic survey satellite***
(web.dmi.dk/projects/oersted/)

POL **Proudman** ***Oceanographic Laboratory, NERC institute for marine and ocean science***
(www.pol.ac.uk/)

RIN ***Royal Institute of Navigation***
(www.rin.org.uk/resources/navigation-news)

RS ***Royal Society, National Academy of Science***
(royalsociety.org/)

SPE ***Society of Petroleum Engineers***
(www.spe.org/spe-app/spe/index.jsp)

Swarm ***Proposed three-satellite min-constellation for magnetic field surveying***
(www.esa.int/esaLP/LPswarm.html)

SWENET ***Space weather network (ESA)***
(www.esa-spaceweather.net/swenet/index.html)

WDC ***World Data Centre***
(www.wdc.rl.ac.uk/wdcmain/) & (www.wdc.rl.ac.uk/wdcmain/europe/edinburgh.html)

WDCA/SQ1 ***Model of 'quiet-time' ionospheric magnetic field***
(www.agu.org/pubs/crossref/1989/89EO00039.shtml)

WMM ***World Magnetic Model***
(www.ngdc.noaa.gov/geomag/WMM/)

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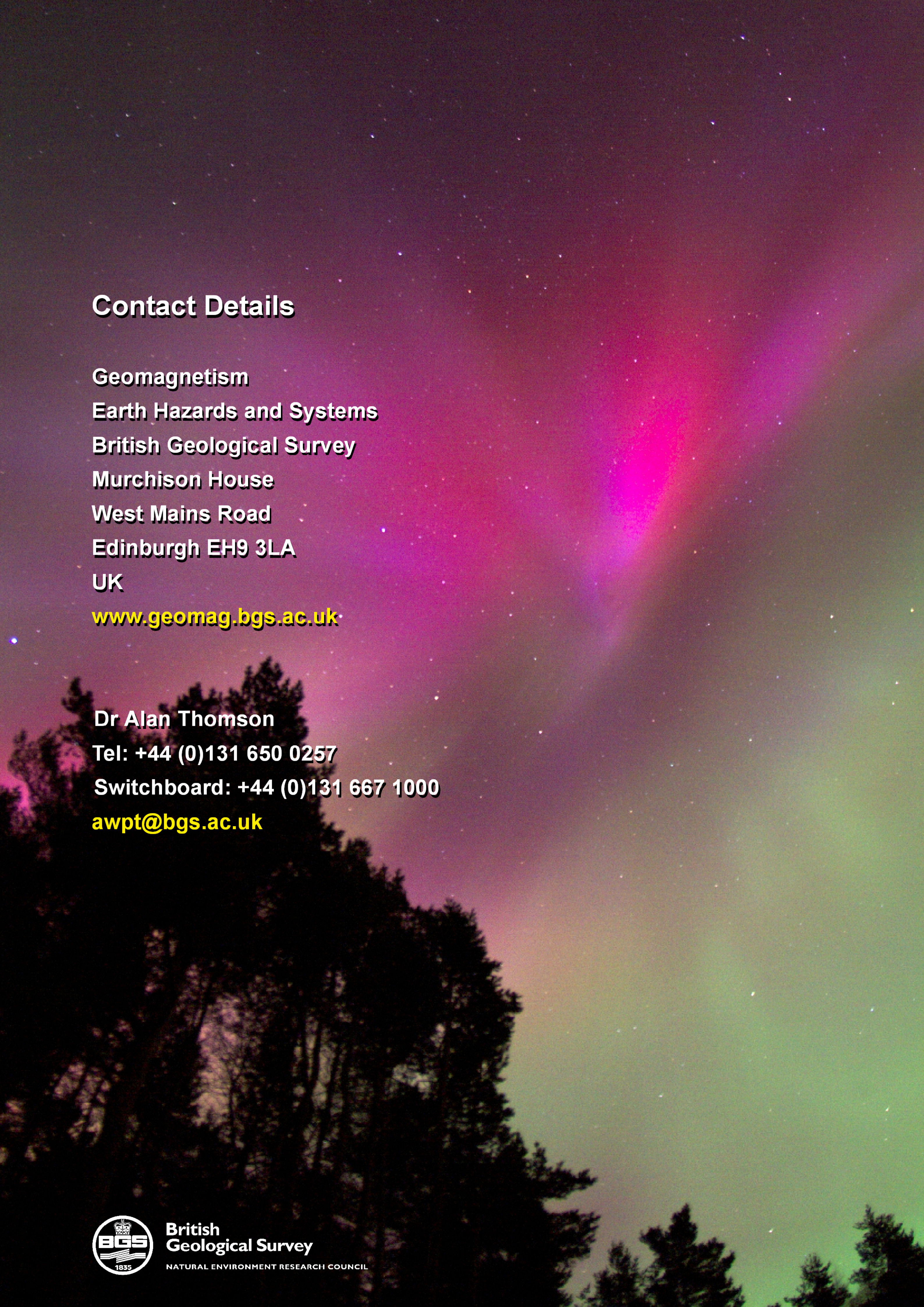

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