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NATURAL ENVIRONMENT RESEARCH COUNCIL

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Geomagnetism

Review 2010

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Key words

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Front cover

A view of the new South Georgia magnetic observatory, established at King Edward Point, next to an existing BAS station, in 2010-2011.

Bibliographical reference

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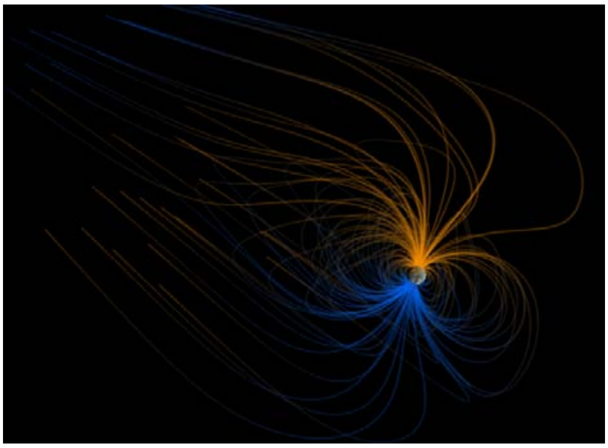


An artist's depiction of the magnetic field of the Earth (Image courtesy of NASA, Goddard Space Flight Center)

Who we are and what we do

The Geomagnetism team measures, records, models and interprets variations in the Earth's natural magnetic fields, across the world and over time. Our data and expertise help to develop scientific understanding of the evolution of the solid Earth and it's atmospheric, oceanic and space environments. We also provide geomagnetic products and services to industry and academics and we use our knowledge to inform and educate the public, government and the private sector.

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

Geomagnetism science is represented in BGS as a team within the Earth Hazards and Systems (EHS) science theme, alongside Earthquake Seismology and Volcanology.

EHS is one of ten BGS science themes that deliver the BGS science strategy. Science strategy in BGS is supported by the Information and Knowledge Exchange (IKE), Science Facilities, and Resources and Operations programmes.

The Geomagnetism team is based in the BGS Edinburgh office and in 2010 numbered twenty-three full and part-time staff. In addition in 2010 we had three PhD students and two MSc students. We also received additional support locally from BGS Edinburgh Business Support, Business Administration and System and Network Services.

For the purposes of continuous geomagnetic monitoring in the UK BGS operates three magnetic observatories and a network of repeat stations. 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, Port Stanley (Falkland Islands) and, from 2011, at King Edward Point on South Georgia. We oversee and maintain magnetic observatory operations on Sable Island (Canada) and in Prudhoe Bay, Alaska (USA).

Our observatory work and the data we collect is one part of our core function:

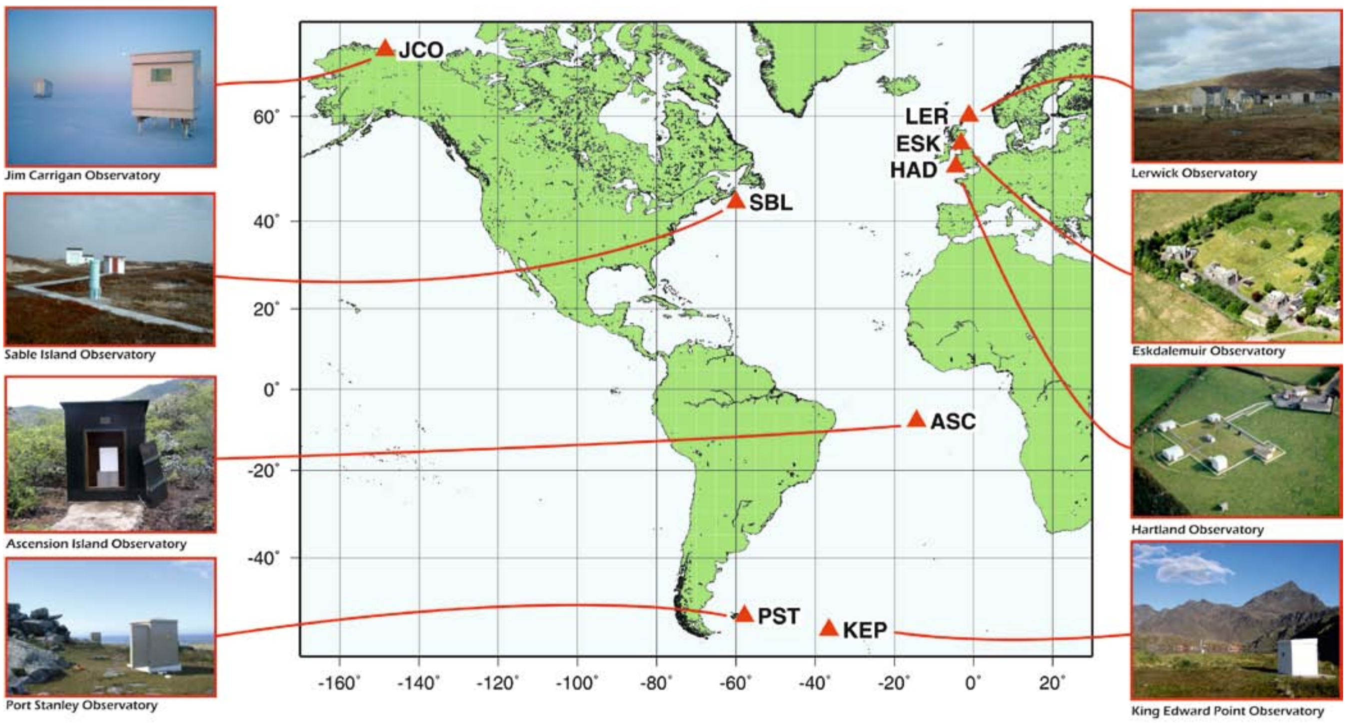
Long-term geomagnetic monitoring and allied research to improve our understanding of the Earth and its natural environment.

Other activities of the team are mathematical modelling of the geomagnetic field and its changes, and the provision of information, data and products for the benefit of society.

In support of our core function, the team has three primary aims.

We aim to be a world leader in

- measuring, recording, modelling and interpreting the Earth's natural magnetic fields and their sources;
- delivering tailored geomagnetic data, products and services to academics, business and the public;
- providing geomagnetism knowledge and information to all sectors of society: what it tells us about the Earth and how it can be used in practical ways.



The seven observatories operated by BGS Geomagnetism in 2010 (King Edward Point observatory on South Georgia was installed during 2010-2011 and became fully operational in 2011)

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Introduction:

2010 in Perspective

Tony Swan making a site check near the Port Stanley observatory on Sapper Hill, Falklands

Objectives and Achievements

Geomagnetism team objectives for 2010 were set in response to NERC and BGS science and knowledge exchange strategies and to new and existing customer requirements. What we achieved in the year was supported by the NERC-funded National Geomagnetic Service (NGS) and our externally funded projects. In this section we provide an overview of the range of our activities in 2010. In the rest of this report we describe in detail particular activities and achievements.

Key Objectives

In late 2009 we set major objectives for 2010.

- To operate the BGS magnetic observatories and the UK magnetic survey to the highest standards.

Installing an induction coil magnetometer test system at Eskdalemuir, October 2010

- To further develop the World Data Centre for Geomagnetism and to continue the archiving and scanning of paper records of observatory data.
- To produce and publish mathematical models of core, lithospheric and other natural magnetic fields.
- To provide valued services and data products to academic and business customers and to assure the continuation of external income from our long-established customer group.
- To collaborate as a member of the 'Swarm' international magnetic science consortium (a European Space Agency mission), and in an EU Framework funded space weather hazard project.

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- To actively pursue new collaborations with UK universities and institutes on geomagnetism hazards and on magnetic field science.
- To coordinate our IKE activities with relevant BGS IKE teams and externally.
- To hold influential positions in UK and international scientific bodies such as INTERMAGNET and IAGA.

Key Deliverables and Achievements

These key objectives were achieved through the following deliverables and activities.

- Completion of the maintenance programme for the observatory network.
- The first phase of installation for the South Georgia observatory, leading to operational status in early 2011, following a second phase of installation.
- The occupation of ten sites in the UK magnetic repeat station network.
- Development of the INDIGO geomagnetic network (a developing country project) to include Pilar observatory, Argentina.
- Completion of the second year of a programme of electronic scanning of the 256,000+ UK observatory magnetograms and numerous observatory yearbooks held by BGS.
- Maintenance of the World Data Centre for Geomagnetism (Edinburgh), in accordance with the rules of the World Data Centre system.
- The production of geomagnetic models:
  - A 2010 revision of the UK magnetic model.
  - A 2010 revision of the BGS global geomagnetic field model (BGGM),
- The 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.
- The delivery of real-time UK observatory data and data products via the upgraded Geomagnetism website www.geomag.bgs.ac.uk.
- The initial set-up for In-Field Referencing (IFR) at 37 new oil fields around the world and completion of 24 commissioned reports.
- Magnetic north data supplied for 98 OS map products.
- The delivery of definitive data from the UK magnetic observatories (to the timetable set by INTERMAGNET) for publication on the INTERMAGNET 2010 DVD.
- The publication of UK observatory data and data products in the BGS monthly bulletin series.

Monthly bulletins from BGS observatories

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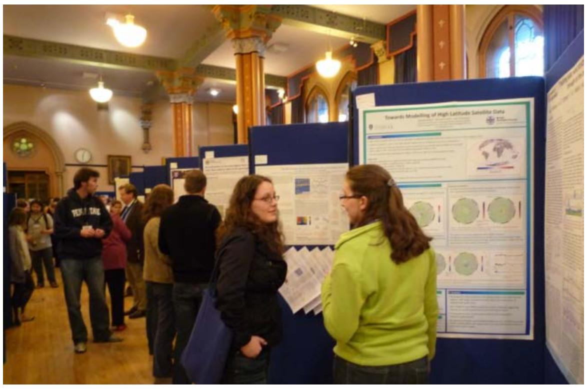
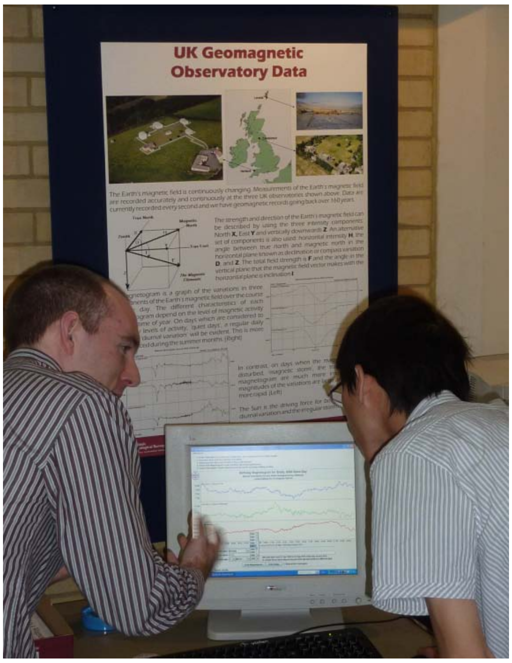
- 100%/99.7% data coverage was achieved for the UK/Overseas observatories and near real-time UK data was available to customers a few minutes after collection.
- Commencement of a (NERC) National Centre for Earth Observation project, with a new post-doctorate research associate, to support science activities during the ESA Swarm mission, in association with University of Liverpool.
- Kick-off of the six-institute consortium developing a 'level 2' science data product facility for ESA over two and a half years.
- The supervision of BUFI-supported PhD students at the University of Lancaster (on geomagnetic hazard), University of Liverpool (polar magnetism) and University of Edinburgh (satellite magnetometry and the ESA Swarm mission).



Student posters (Gemma Kelly in foreground, right) at the National Astronomy Meeting in Glasgow

- Supervision of two MSc students on web service development, in association with Robert Gordon University, Aberdeen.
- The publication of 13 papers in scientific journals, various articles in other journals and educational and information material for the BGS web site: www.bgs.ac.uk.
- The preparation of the 2009 Geomagnetism team Annual Review.
- The delivery of 15 presentations and posters on BGS geomagnetic science at various scientific conferences.
- Committee activities including chair and co-chair duties at INTERMAGNET meetings and IAGA and MagNetE workshops.



Brian Hamilton (left) explaining magnetic data to the public at the Edinburgh office 'Open Day' in September 2010

Other Notable Achievements

However we achieved more in terms of science, applications and outreach than we set through our key objectives.

We briefly summarise some of these activities here, in no particular order, as they are not discussed elsewhere in this report. These activities are worth noting, both for current and future operations, and in terms of strategy development.

- An independent off-site data processing and delivery system was installed at the Hartland observatory, to maintain data supply during outages in Edinburgh.
- Ciaran Beggan shared teaching of the 4th year Honours class at Edinburgh University with Prof. Kathy Whaler. Student final year projects were also supervised.
- Chris Turbitt represented BGS on the five-year review panel for the USGS Geomagnetism Programme in Golden, Colorado.
- Alan Thomson represented BGS at an RAS discussion meeting to promote space weather research through NERC. He also took part in discussions at National Grid control centre on planning for space weather hazard to UK power system over next decade (involving NG, BGS, RAL, Cabinet Office, DECC).
- Alan Thomson and David Kerridge contributed to a briefing note for the Prime Minister on space weather and geomagnetic hazard. Alan Thomson also contributed to a briefing note for Lloyds Insurance on space weather.
- In November 2010, BGS Geomagnetism capabilities were highlighted at a House of Commons Select Committee investigation into space weather hazard.
- David Kerridge represented BGS on the new UK Space Environment Impact Expert Group (SEIEG), advising government.
- David Kerridge and Alan Thomson had discussions with the UK Met Office on a proposed 'natural hazards centre', during a visit of the Met Office chief executive and chief scientist to Edinburgh.
- Land purchases to create 'buffer zones' (to ensure data quality) at Hartland and Lerwick were discussed.

Some Key Figures for 2010 at a Glance

Figures in parentheses are last year's equivalent numbers, where appropriate.

- 100% (100%) UK observatory 1-minute data collection.
- 99.7% (99.9%) Overseas observatory 1-minute data collection.
- 2 (4) new or updated geomagnetic models & software: BGGM and OS model.
- 13 (6) journal papers; 9 (12) scientific meetings.
- 35 (31) presentations and posters (all).
- 3 (3) PhD students.
- 2 (1) MSc students.
- Compass data supplied for 98 (95) OS maps.
- 37 (27) field set-ups for IIFR/IFR oil industry services and 24 (20) customer reports.
- 115,434 (97,000) digitally scanned magnetograms. 126,170 magnetograms are now fully archived.
- 84 (84) magnetic bulletins published.
- 6 (6) articles on space weather for RIN 'Navigation News'.
- 2 (2) new NERC grant-funded bids.
- 2 RAS Prizes at National Astronomy Meeting, Glasgow.
- Positions on 3 (3) scientific and technical geomagnetism bodies (IAGA, MagnetE, INTERMAGNET).
- Updated Geomagnetism web pages (www.geomag.bgs.ac.uk).
- A new, online, UK magnetogram archive (http://www.bgs.ac.uk/data/Magnetograms/home.html).
- 2 (-) articles for NERC magazine 'Planet Earth' and BGS 'Earthwise'.
- Numerous contributions under 'news', 'press releases' and 'research highlights' on the BGS website (www.bgs.ac.uk).

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Introduction:

2011 in Perspective

South Georgia observatory, at King Edward Point, is now operational. The host BAS base can be seen in the background

Looking Ahead to 2011

The Geomagnetism team's new activities in 2011 will centre on the ESA Swarm magnetic survey mission, the space weather hazard to British and European power grids, and operation of the South Georgia magnetic observatory. Operating with reduced BGS/NERC funding, as NERC's National Capability funding continues to decrease, the team will endeavour to operate the BGS magnetic observatories and the UK magnetic survey to international standards. We will also continue to produce industry standard and academic quality geomagnetic models and publish scientific results.

Key Objectives

Our major objectives all support the goals of the BGS strategy 2009-2014, through the National Geomagnetic Service (NGS) and our external income projects. We will provide

- Uninterrupted magnetic observatory operations and continuation of the rolling 10 sites per year UK magnetic survey.
- Quality-assured geomagnetic data products.
- Mathematical models of spatial and temporal variations in Earth's magnetic fields.
- Geomagnetic information and knowledge exchange, scientific collaboration, publications and outreach, and leadership within scientific bodies concerned with geomagnetism.

Main Deliverables

Specific deliverables for 2011 will include

- Maintenance of the BGS INTERMAGNET-standard UK observatory network.
- Maintenance of our overseas observatories and the final year of a

programme to establish a new magnetic observatory on South Georgia, delivering data to INTERMAGNET standards.

2nd phase of the installation of South Georgia observatory in early 2011

- Re-survey of 11 sites in the UK magnetic repeat station network, a survey season report and a revised UK magnetic model for 2011.
- Publication of observatory data and data products in the 2011 Monthly Bulletins and in the Observatory Yearbook series.
- Supply of 2011 observatory data to INTERMAGNET, according to INTERMAGNET's timetable.
- Supply of magnetic index products to the International Service for Geomagnetic Indices (ISGI), according to ISGI's timetable.
- On-line provision of real-time UK observatory data products through the BGS Geomagnetism website.
- Continuation of the scanning programme of UK observatory paper magnetograms, yearbooks and other records and further development of the on-line database for academic and public research (http://www.bgs.ac.uk/data/Magnetograms/home.html).
- Production of the 2011 revision of the BGS global geomagnetic field model (BGGM), using the latest observatory and magnetic survey satellite data.
- Operation of the World Data Centre for Geomagnetism (Edinburgh), supplementing our data holdings through an annual 'call for data' and associated quality control activities.
- Participation in the 6-institute European Swarm Level 2 products facility for ESA, to deliver scientific data products from the forthcoming Swarm magnetic satellite mission.
- Participation in the 6-institute EU Framework project 'EURISGIC' to model and predict space weather impacts on the European high voltage power network.
- Co-supervision of BUFI PhD students with the Universities of Edinburgh (satellite magnetometry and ESA Swarm mission) and Liverpool (polar magnetism). Co-supervision of a PDRA at Liverpool (Swarm mission).
- Pursuing of new scientific collaborations that address BGS challenges and NERC themes, e.g. through grant opportunities in the UK and Europe on solar-terrestrial physics, space weather and the deep Earth.
- Collaboration in existing international geomagnetic observatory (INDIGO) and survey (MagNetE) programmes.
- Collaboration with UK Met Office on space weather issues.
- Active participation in at least one major scientific conference in addition to the IUGG Congress in Melbourne.
- Publication of at least two first-author papers in scientific and professional journals, the writing of articles, the provision of information and educational material for the BGS web site and publication of a team Annual Review for 2011.

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Site difference measurement at Ascension Island observatory

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 2010. BGS also runs 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. This year the first phase of a work program to re-establish a magnetic observatory on South Georgia was completed.

UK Observatories

In December a new wireless network was installed at Lerwick observatory to replace the damaged fibre optic cables that connect the recording equipment huts on the site. Since the Met Office confirmed that their new office construction was going ahead in 2011, extensive contingency and project planning has been carried out to mitigate the impact of site disruption and building works on the supply and quality of our magnetic data. The wireless links will provide a more flexible infrastructure during this period of change.

In October work was completed at Hartland to provide completely independent data processing and web server systems in order to maintain the availability of our data products in the event of a service interruption at the Edinburgh site.

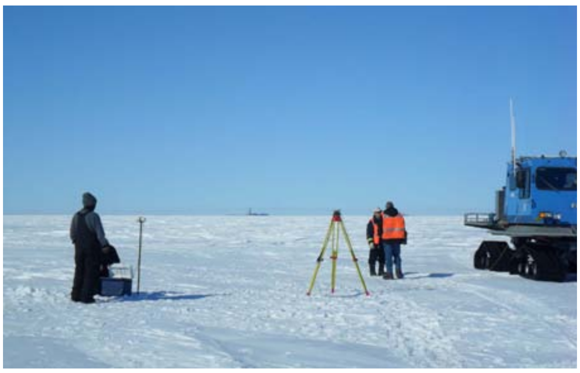
Eskdalemuir, Lerwick and Hartland observatories have all run for the last year again without interruption whilst also delivering continuous, quasi real-time data to our commercial customers. All three observatories have been able to submit 100% data coverage to the international magnetometer network (INTERMAGNET) for the fifth consecutive year.

Overseas Observatories

By the end of February 2010, civil engineering works carried out as part of a programme to re-establish a magnetic observatory at King Edward Point, South Georgia were completed. Foundations for the three instrument enclosures were laid with trenches and ducting installed to allow cabling between the instruments. The observatory commissioning phase of the work is due to be completed in early 2011. The King Edward Point observatory will provide data of high scientific interest (in the 'South Atlantic Anomaly', or SAA) in an area of low spatial density of magnetic observatories.

Cable trench digging at King Edward Point, South Georgia

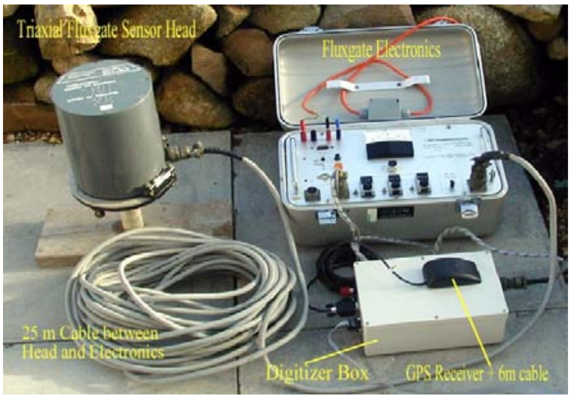
In April a series of absolute, vector and scalar measurements, were carried out on the frozen sea ice in the vicinity of the Liberty oil field near Jim Carrigan Observatory, Alaska. This study provided a comparison of the IIFR derived field values for a specific position and time with empirical observations made at the same location, to better quantify the uncertainties associated with the supply of IIFR data at high latitudes.



Absolute observations on sea ice near the Liberty field

Supplementary to regular manual absolute measurements by local staff, BGS engineers visited three of the four overseas observatories during 2010 to make manual absolute observations, calibrate instrumentation, and upgrade equipment. Ascension and Port Stanley observatories were serviced in February 2010. Port Stanley and Ascension have reported uninterrupted, INTERMAGNET-standard data for 2010, save for a short servicing downtime.

The 2010 service visit to Sable Island observatory was postponed until 2011 due to uncertainty about future commercial funding for running costs. Despite this extended period between services, the observatory has operated with high reliability and provided an uninterrupted supply of quality data for the year with regular absolute observations being supplied by local staff.



INDIGO observatory instrumentation

As part of BGS's commitment to support expansion of the global network of magnetic observatories, an INDIGO system was supplied to Pilar observatory in Argentina in June. Pilar observatory became operational in November, 2010 and since then has been supplying continuous data to the Edinburgh World Data Centre. The successful installation of the instrumentation at Pilar brings the number of INDIGO assisted observatories to ten (*see also the section on INDIGO*).

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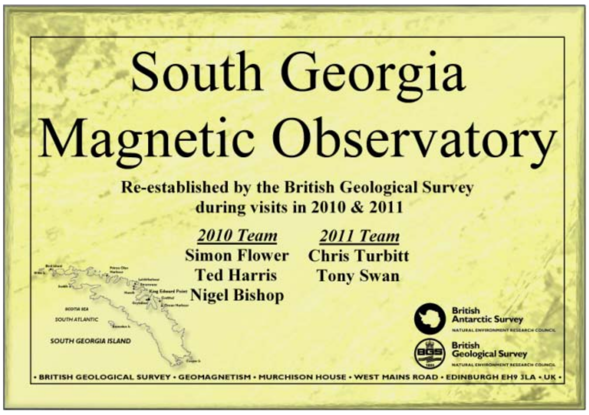
Technical, Observatory and Field Operations



King Edward Point Geomagnetic Observatory

From 1975 to 1982 a Magnetic Observatory operated and magnetic observations were made at King Edward point, South Georgia, by British Antarctic Survey. During the Falklands conflict of 1982 and subsequent invasion of South Georgia, the observatory installation became a casualty of war and did not survive. In 2008 the decision was taken by BGS to re-establish a magnetic observatory on the same site.

Mid-ocean islands are important locations for geomagnetic observatories, since an even spatial distribution of observing locations improves the quality of derived geomagnetic models. South Georgia is particularly interesting because it sits over an anomaly in the field generated in the Earth's core, known as the South Atlantic anomaly.

View of the observatory, towards the old whaling station, during the installation

The BGS observatory was planned for King Edward Point (KEP), immediately to the north of the British Antarctic Survey BAS/South Georgia government scientific base, at the foot of Mount Duse. Instrumentation to be installed would be a standard BGS Geomagnetic Data Acquisition System (GDAS).

Absolute observations at KEP during the installation

The GDAS logger makes one-second samples of a tri-axial fluxgate magnetometer and ten-second samples from an Overhauser Proton Precession Magnetometer (PPM). Although the fluxgate data are vector measurements, the limited range of the instrument requires that a set of baselines values must be applied to generate the full-field vector. These baselines are derived from frequent manual (i.e. absolute) measurements at the observatory site, along with the automatically recorded, full-field, scalar measurements from the PPM.

The success of the observatory will depend on the cooperation of BAS and the training of suitable personnel, who will be required to perform regular absolute observations and maintain the observatory installation in between BGS site visits.

The observatory is being established in two phases. The goals of the initial phase were to select suitable sites for the observatory components and the building of the necessary infrastructure. The second phase is concerned with installing geomagnetic instruments and fully commissioning the observatory.

In February 2010, the foundations for the Absolute House and Fluxgate housing were excavated and laid. The Proton Precession Magnetometer installation and intermediate cable housing were completed and all underground ducting and junction boxes, to take signal and power cables, were completed. The work was done by two BGS staff from Edinburgh, together with a colleague from the Falkland Islands, who all made the trip to South Georgia.

In February 2011, another two BGS staff journeyed to South Georgia to complete the installation, erecting the prefabricated Absolute House, installing the instrumentation, cabling and communications and interfacing the observatory to the resident satellite transmission system.

On the 25th February 2011, the first data from the new King Edward Point Magnetic Observatory was successfully received in Edinburgh.

Photographs taken during the installation of the observatory in 2010 and 2011

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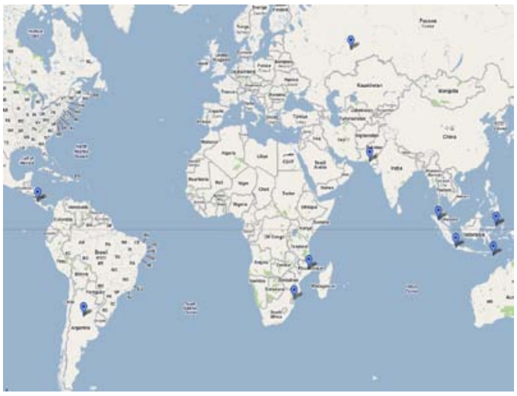
Technical, Observatory and Field Operations



The ten INDIGO sites as of 2010

Project INDIGO: 'INTERMAGNET- Compatible Digital Geomagnetic Observatory'

The INDIGO project was set up to assist magnetic observatories in developing countries change from classical analogue paper recording of the Earth's magnetic field and its changes, to producing digital recordings, which are now widely expected by the global scientific community.

The INDIGO project began in 2004, following the donation to BGS of fifteen EDA triaxial fluxgate magnetometers.

A partnership between BGS and the Institut Royal Meteorologique de Belgique was set up, the magnetometers were renovated and instrumentation and digitising hardware was developed. This hardware, along with a software package to control recording and provide basic data analysis facilities, formed the basis of a simple instrumentation package.

This instrumentation package could be deployed at any magnetic observatory allowing it to produce digital data which would conform to the rigorous standards set out by INTERMAGNET.

By 2010 this digital observatory package had been installed in ten observatories in six different countries. Today eight of these observatories continue to generate INTERMAGNET compatible digital data and carry out regular absolute observing programs.

Maputo variometer hut (Mozambique)

Annual mean values, from at least six of these institutes are now submitted to the World Data Centres.

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Applications from two of the observatories for full membership to INTERMAGNET are currently being considered, with applications from a further four observatories being prepared for presentation at the next committee meeting of INTERMAGNET.

INDIGO system installed at the Arti observatory (Russia)

It is planned that in 2011 INDIGO hardware will be installed in Base Orcadas observatory in the South Orkney Islands. This observatory was originally installed by the Scottish National Antarctic Expedition led by William Speirs Bruce in 1902.

The observatory has been operated by Argentinian scientists since 1904 but this continued Scottish involvement in the operation of the site is of great significance, not only historically, but also scientifically, as it continues an unbroken association of over 100 years.

As noted in the observatories report in this Annual Review, Geomagnetism team staff also supplied INDIGO instrumentation to Pilar observatory in Argentina, in 2010.

Base Orcadas observatory (South Orkney Islands)

Tunungan observatory (Indonesia)

PC processing system at Pilar observatory (Argentina)

Kupang observatory (Indonesia)

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Technical, Observatory and Field Operations

Changchun Magnetic Observatory, China

IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing

The XIVth IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing took place in Changchun, China in September 2010. This biennial workshop provides a forum for observatory operators to discuss and compare the instruments and techniques used to measure geomagnetic data. The XIVth workshop was hosted by the Earthquake Administration of Jilin Province, a division of the Institute of Geophysics, China Earthquake Administration. As with other geomagnetic observatory workshops, the timetable was split into a measurement session and a scientific session.

Measurement Session

The workshop opened at Changchun Magnetic Observatory, some 40 km outside the city of Changchun, Jilin Province. During the initial measurement sessions, observers were invited to use the observing pillars, instrument houses and data processing facilities provided by Changchun Observatory to compare absolute and variometer instruments. Making these comparisons allows observers to maintain an internationally traceable quality control standard for observatory data.

The measurement sessions also provided an opportunity for practical demonstrations of new instruments or of instruments under development, the most significant of which is an automated fluxgate-theodolite for absolute measurements.

During the measurement session, BGS co-hosted an INTERMAGNET question and answer session to encourage overseas observatories, particularly the numerous Chinese observatories, to strive to meet INTERMAGNET measurement standards and to co-operate in the INTERMAGNET network.

Following the workshop, Changchun (CNH) and Urumqi (UMQ) observatories submitted successful applications to join INTERMAGNET.

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Photographs of the workshop, including measurements (second top) and science presentations (third top)

Scientific Session

The scientific session, held in Changchun city, comprised three days of oral and poster presentations covering many aspects of observatory practice - from measurement technique, instrument development, surveys, data processing and data application.

There is noticeably more research on possible links between geomagnetic variations and seismic activity in East Asia than in any other region. Accordingly, a number of papers reported efforts to identify geomagnetic activity coincident with, or preceding, a seismic event. One long-term aim of this type of research is identifying geomagnetic precursors for earthquake prediction.

It is significant that these studies rely on high quality observatory networks, publishing data in near real-time. The need for such data for the wider scientific community was also stressed at the workshop. For example, papers were presented on the upcoming quasi-definitive data (QD) standard in anticipation of the Swarm satellite mission, and the important inter-dependence of ground-based and satellite data for modelling internal and external field sources.

As a principle data user for main field modelling and space-weather hazard, BGS, through INTERMAGNET, is active in establishing the QD standard and in encouraging observatories to participate in the global network. The BGS-backed INDIGO project is one initiative to expand the observatories network and the latest developments of this project were presented to the workshop.

Opportunity was also taken by other institutes at the workshop to announce new observatories in Pakistan, Italy, Alaska, Easter Island and Tristan da Cunha.

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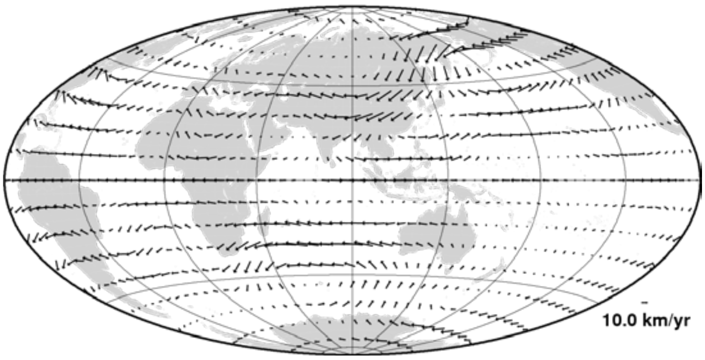

A model of the average 'steady' flow of the liquid outer core along the core-mantle boundary. Continent outlines are illustrative. Average velocity is 11 km/year

Science

Forecasting Magnetic Field Change using Core Flows

Scientific capability in accurately forecasting the change in the strength and direction of the magnetic field, even a few years ahead, is still relatively poor. However a new method that uses predictions from a model of the flow of liquid iron in the outer core can improve forecasts of field changes.

The recently released International Geomagnetic Reference Field (IGRF-11) model includes, (a) a representation of the main field at 2010.0 and (b) a prediction of the average secular variation (SV) i.e. field change, for five years, valid until 2015.0.

Over the past ten years, satellite measurements in combination with data from ground-based observatories have allowed very detailed models of the secular variation of the Earth's magnetic field to be constructed. However, forecasting the future change of the main field still remains a challenge, primarily because the processes in the outer core controlling secular variation are not sufficiently well understood. Hence, most forecasts do not appeal to any physics-based forecasting but use, for example, polynomial extrapolation from previous measurements.

To investigate whether a physics-based approach would produce any improvements, we use a model of the flow along the core-mantle boundary of the outer core to forecast the average SV during 2010–2015. First, a 'steady' or average flow model is computed by examining how the field changed during 2004.5 to 2009.5.

By analogy with weather forecasting, by looking at how the direction of the magnetic field has changed in the previous few years, it is possible to infer a picture of the average flow in the outer core that caused that change. A major assumption is that the magnetic field is effectively 'frozen' into the core flow, though research shows this is valid only on short time-scales, and so is appropriate for our use.

The resulting large-scale flow model is shown in the figure above. Note that the velocity of the flow is about 11 km/year, on average. Large scale features include the persistent gyre under the Indian Ocean region and the westward drift in the Atlantic hemisphere.

We now assume that the average steady

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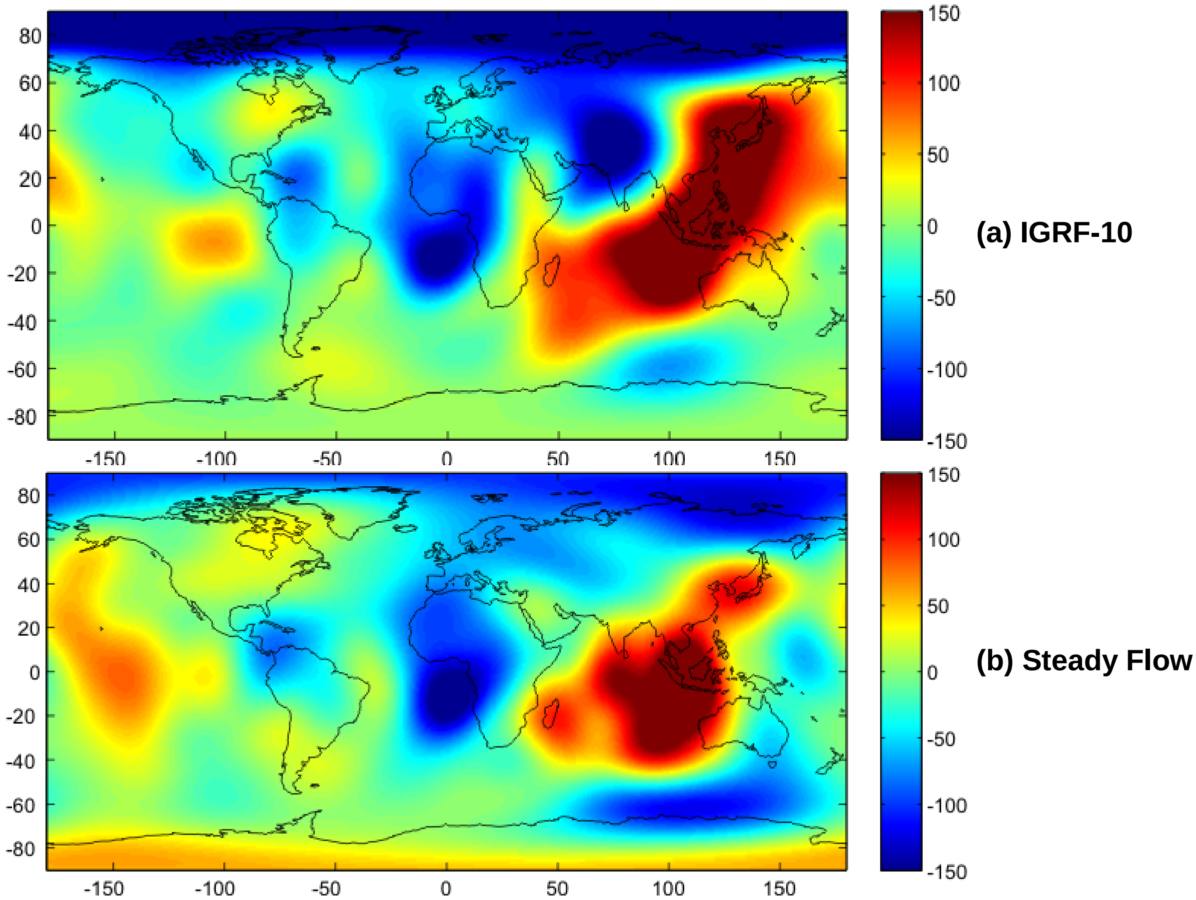
flow that has been computed for 2004.5-2009.5 will continue for the next five and a half years. The flow is converted to SV and the change of the magnetic field over five years is computed.

To check that this method has merit, we compared the prediction made using IGRF-10 for 2005.0-2009.5 with a forecast from a flow model. We prepared a steady flow model using magnetic field data from 2001.0-2004.5. We then produced a forecast of the field change from 2005.0-2009.5 (the end of the study period). Using a global metric, the root-mean-square (RMS) of the differences between the models, we compared the forecasts from the IGRF-10 and the flow model with the 'true' magnetic field, as estimated from a recent model of the field.

After 4.5 years of forecasting, the IGRF-10 model had an RMS difference of 103.5 nT, while the flow model forecast was 82.5 nT. The flow model therefore represents a useful improvement on previous methods.

As well as the global RMS difference we examine the spatial differences between the forecasts and the true field. The figures below show how each forecast differs from the true magnetic field after 4.5 years. It can be seen (e.g. south-east Asia and the Arctic) that the flow model produces a much lower overall difference.

This forecasting technique will be integrated into future BGS field models. Further research will concentrate on more sophisticated flow models to reduce the misfit between the actual and the forecast magnetic field changes.



*Spatial difference in the vertical intensity (Z component) of the magnetic field (in nT) at epoch 2009.5, for **(a)** the IGRF10 field model and the actual field after 4.5 years and **(b)** the steady flow forecast field model and the actual field after 4.5 years. Note, the strongest spatial differences in both models are located at the northern polar region and over the eastern Indian Ocean. These are areas where magnetic flux expulsion is believed to have taken place between 2005 and 2010*

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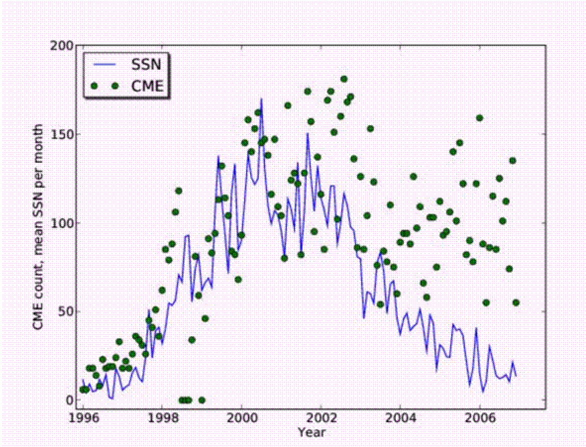


The monthly sunspot number (line) and monthly coronal mass ejection count (spots) during solar cycle 23. (Data courtesy of NGDC/NOAA and NASA/ESA, SOHO/LASCO). (from Thomson et al, 2010)

Current Challenges in Understanding the Geomagnetic Hazard to Power Systems

At a Royal Society funded workshop in South Africa, BGS and other scientists and engineers discussed the current understanding of the geomagnetic hazard, as it affects major power systems in Europe and Africa. They also summarised, to better inform the public and industry, what can be said with some certainty about the hazard, and what research is yet required to develop useful tools for geomagnetic hazard mitigation.

Geomagnetically induced currents (GIC) are a natural hazard that can affect conducting infrastructures, such as power grids and pipelines GIC are a direct result of solar activity, which gives rise to space weather and consequently to geomagnetic storms. Besides power grids and pipelines, space weather can disrupt communications, use of the global positioning system (GPS), and pose risks to aircraft, satellite and spacecraft operations.

One aim of the South African GIC workshop was the free exchange of ideas, insights and knowledge on the natural geomagnetic hazard and on GIC risk. This was for mutual education and to help promote future research between the two countries in a cross-disciplinary manner. A second aim of the workshop was to summarise the scientific and engineering ‘state of play’ for the power engineering industry, for the public and for policy makers. The workshop participants therefore compiled a short list of major points that they believed with some confidence that scientists and engineers do know about the GIC risk to electric power systems, as well as major things we still don’t understand.

In the following sections we summarise, in relatively simple terms, five major ‘do knows’ and five major ‘don’t knows’ about GIC hazard. The five items on each of the two lists are arguably the most significant known and unknown pieces of scientific knowledge on this subject at the current time.

A more extensive list and further discussion is given in a recently published paper (Thomson *et al*, 2010).

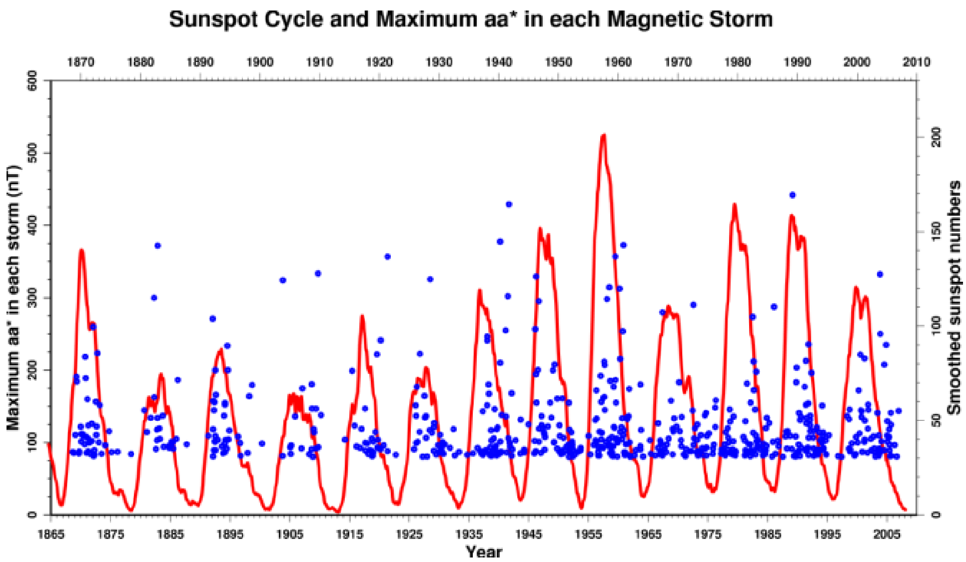
Compared with the ‘do knows’, the ‘don’t knows’ may be more contentious within the scientific community. It may be debated which items are most important at the present time, understanding that other issues might yet become more relevant. However by making scientific progress on our current 'don't knows' it is believed that scientists will improve their ability to monitor, model and predict the impacts of space weather and GICs on power grids.

Five major things we do know about the GIC risk to power grids

- Solar storms causing high GIC are more likely during solar maximum and in the descending phase of the solar cycle, but they do also occur at other times in the solar cycle.
- The magnetospheric and ionospheric currents that drive GIC are different at different latitudes, but the dominant cause of GIC in power grids is the time rate of change of the magnetic field.
- Interpolating the magnetic field from spatially distributed geomagnetic observations improves the prediction of GIC. Also, a multi-layered and laterally varying ground conductivity model gives better prediction of GIC than the assumption of an homogeneous Earth.
- GIC are known to affect power systems at all latitudes and GIC can affect power transformers simultaneously at multiple points across power networks.
- Series capacitors in transmission lines may interrupt GIC in power networks, but are expensive. Strategies involving capacitors may increase GIC and reactive power demands. It is also possible from transformer dissolved gas analysis to identify GIC-initiated damage before complete transformer failure occurs.

Five major things we *don't* know about the GIC risk to power grids

- What are the characteristics of extreme geomagnetic storms that pose the highest risk to power systems?
- What are the definitive spatial and temporal scales of the magnetospheric and ionospheric currents that drive significant GIC in grids?
- In modelling GIC in a power grid, what is an appropriate level of detail required of Earth conductivity models?
- What are the characteristics of power transformers that determine their susceptibility to GIC and therefore determine the extent of damage sustained under different levels of GIC?
- What are the transformer failure mechanisms subsequent to damage initiated by GIC?



Large storms identified by the peak (spots) in the 24-hour running average (aa) of the 3-hour geomagnetic aa index against time, since 1868, overlain with monthly smoothed solar sunspot number (line). A threshold of 80 nT has been used to identify the largest storms. (Thomson et al, 2010)*

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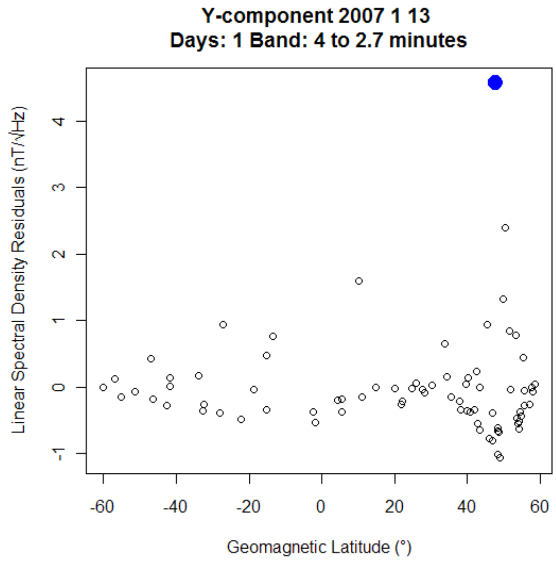
IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing



A representation of signal amplitude for 92 INTERMAGNET observatories against geomagnetic latitude for a quiet day. The signal level of the observatory highlighted in blue is clearly irregular, possibly due to artificial noise.

The XIVth IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing took place in Changchun, China in September 2010. The goal of this workshop was to bring together observers from the global community to calibrate instruments and discuss developments in instrumentation, measurement techniques and data processing. BGS Geomagnetism team members were in attendance and presented the results of recent studies on characteristics of observatory data noise and the development of *K* indices for the Port Stanley magnetic observatory.

An Investigation into Techniques for Isolating Noise in Observatory Data

Man-made electromagnetic noise is an increasing problem for the international observatory network as existing sites are threatened by urbanisation. Often noise is not readily distinguishable from natural signal, leading to a need for tools to identify & remove non-natural signals. As new observatory sites are sought to improve global data coverage and next generation instruments capture smaller amplitude signals, this need can only increase.

Existing techniques, such as instrument or observatory comparisons in the time-domain, can isolate particular types of noise, but are otherwise very limited. A BGS study presented at the workshop built upon earlier work using the global observatory network to identify observatories of high noise.

In this study we make the assumption that the natural signal amplitude is comparable among observatories of a similar latitude at a particular time, even though the time series are not necessarily similar (due to phase differences, etc.). Plotting signal amplitude against geomagnetic latitude yields a regular curve, supporting that assumption and allowing observatories

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with higher than expected signal amplitude, which may result from artificial noise, to be identified. Since observatories are being compared in the frequency domain, it is also possible to investigate the periodic nature of any noise by limiting the band.

We aim to further develop this tool to incorporate it into our regular data quality control. This work will be published later this year (Turbitt *et al.*, 2011)

First Steps towards *K* indices from BGS South Atlantic Observatories: Port Stanley Observatory

To enhance the quality and near real time production of *K*-based planetary magnetic activity indices such as *am* and longitude-sector indices, *a•*, there is a requirement from ISGI for local *K* index values from the South Atlantic observatory at Port Stanley (PST).

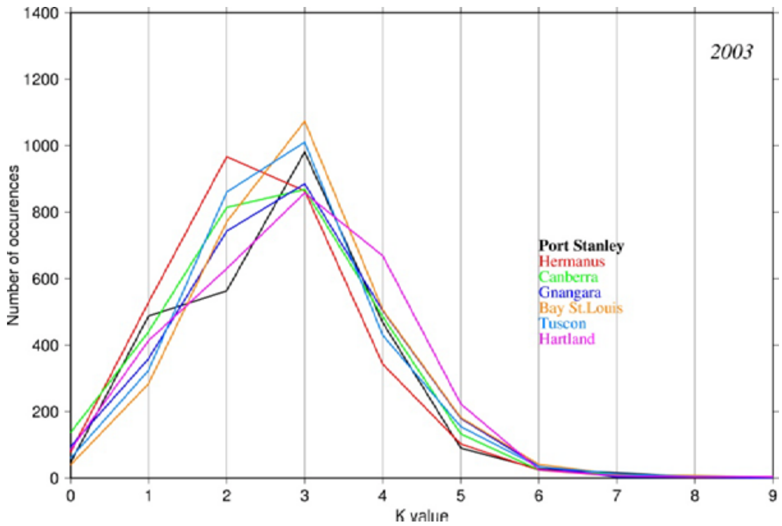
The *K* index is a three-hourly resolution range index, derived from the larger of the two ranges in the horizontal components *D* (declination) and *H* (horizontal intensity) after the subtraction of the regular daily variation S_R. This range, measured in nT, is denoted by a single digit code from 0 to 9 according to a quasi-logarithmic scale.

Traditionally, *K* indices were determined by hand. However since the early 90s automated computer *K* scaling has been used, eliminating the variability between hand-scalers and allowing faster access to data products.

To calculate *K* the solar regular variation, S_R, must first be estimated. Parameters, such as seasonal and UT weightings, required to derive the *K* indices computationally, must also be determined.

Once optimum parameters for PST were selected we analysed the results by comparing the distributions of PST *K* values with observatories at similar geomagnetic latitude and thus with likely similar levels of geomagnetic activity.

We also looked for biases by comparing the indices directly to those from nearby observatories. Both sets of results show a good overall agreement. However further adjustment of input parameters might yet be necessary if improved agreement with indices from other observatories is required. Otherwise this work will be published later this year (Reay *et al.*, 2011)



Distribution of K values during 2003, a geomagnetically active year, for seven selected observatories. PST is in black

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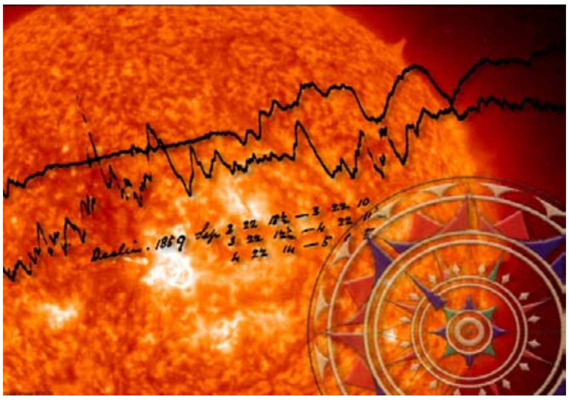
Science

Digital Magnetogram Archive



Past solar and geomagnetic storms will be extracted from the archive data

In December 2010 the Geomagnetism team launched its on-line UK digital magnetogram archive (www.bgs.ac.uk/data/Magnetograms/home.html). Intended as an open resource for public and academics alike, the launch represented the completion of stage one of our ambitious digital scanning programme, now in its third year.

BGS holds over 280,000 daily magnetograms, as recordings on photographic paper, and spanning the years from the 1840s to the 1980s. These magnetograms are unique as a continuous record of magnetic variations across the UK. (From the early 1980s onwards all UK magnetic data has been recorded in digital form.)

The collection is a valuable, partly untapped, data resource for studying geomagnetic storms, space weather and the evolution of the Earth's magnetic field.

The magnetogram archive facility at the BGS Edinburgh office

The magnetograms provide insight into:

- The Earth's outer core — long-term change (years to centuries) in the dynamo that sustains our magnetic field
- Space weather — short-term changes (seconds to days) in near-Earth space and on the ground
- Space climate — long-term change (decades to centuries) in solar activity and consequences for Earth's environment

These all have an impact on human activities: for example, disturbed space weather affects technologies that we increasingly rely on, such as electrical power and GPS networks.

In the last decade it was increasingly realised that many of the paper records were in poor physical condition. Many were loosely bound or boxed and were stored in unsuitable environmental conditions at Hartland observatory.

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Curled and fragile magnetograms will require specialist treatment before being handled and photographed

In 2008 the decision was made to re-house the records at the BGS office in Edinburgh, in environmentally controlled conditions. The transfer of the records was completed in 2010.

The campaign to capture digital photographs of every magnetogram continued throughout 2010. Both the front and back sides of the magnetograms are captured, as often the observers would make pencil marks regarding scaling data and other observations on the reverse.

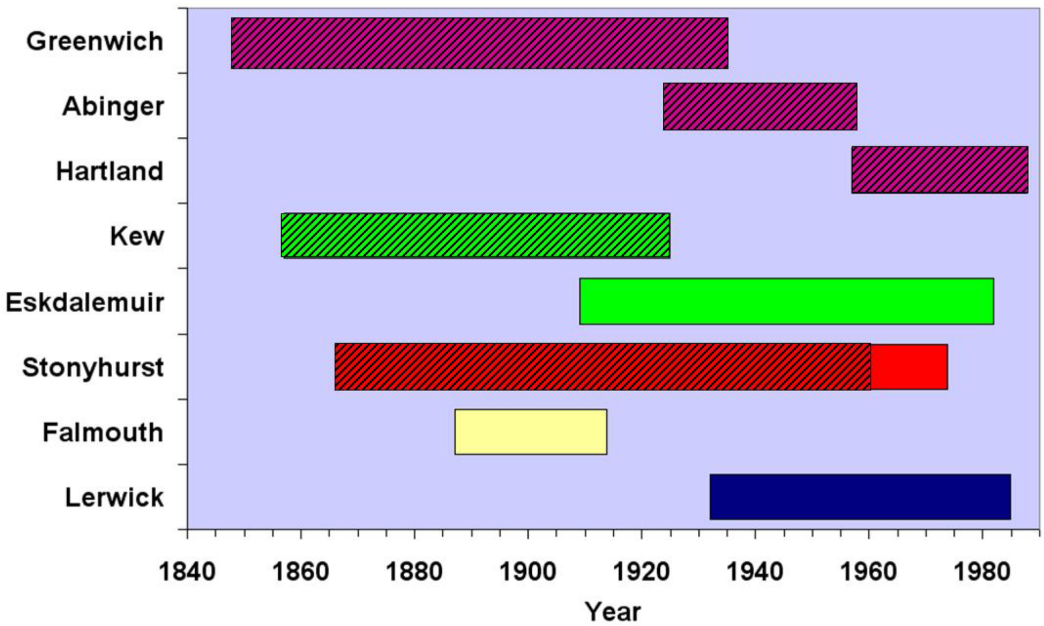
A programme of work to design the high resolution image database and web based search tool was also completed in 2010 enabling the launch of the online magnetogram archive (www.bgs.ac.uk/data/Magnetograms) in December.

Scientists and the general public around the world can now gain easy access to this historical dataset.

Kew, Greenwich and Abinger magnetograms are currently available and the remainder will be added in time.

Work also began in 2010 to digitise the complete set of UK yearbooks that are held in the archive. These contain the published results from each observatory, including data manually transcribed from magnetograms, series of single or spot manual observations of the magnetic components and other derived results.

Significantly, the yearbooks provide information on the observatory operations, observing equipment and observation methods, which are essential for meaningful use of the magnetograms and other data. They will be available online in 2011.



Continuous geomagnetic measurements at eight UK observatories showing the years for which magnetograms are held (solid colour), and the proportion of records that have now been digitally photographed (hatched areas)

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Science

Pragna Reddy and Ewan Dawson discuss developments to BGS web services

Student Activities

Katie Turnbull, Gemma Kelly, Rob Shore, Sadiq Sani and Pragna Reddy made significant contributions to the scientific and IT outputs of the Geomagnetism Team in 2010. Here we summarise what they studied and produced as part of their studentships in this past year.

Katie Turnbull is in the final year of her joint PhD studentship at Lancaster University, part funded through the BGS BUFI initiative and partly by the EPSRC. Katie is investigating the geomagnetic induced current (GIC) hazard throughout the UK high voltage power network.

Having examined the relationship between sub-storm onsets and the peak in the field rate-of-change (the governing factor in determining the size of GIC), Katie developed a MATLAB model of the high voltage UK grid and its response to space weather.

By also using the technique of Spherical Elementary Current Systems (SECS) to interpolate the magnetic field variations across the UK during major storms, Katie produced detailed maps of GIC flow during the October 2003 ‘Halloween storm’. She also found that the topology of the grid strongly determines where the largest GIC flows, regardless of whether hypothetical or actual magnetic variations are tested with the model.

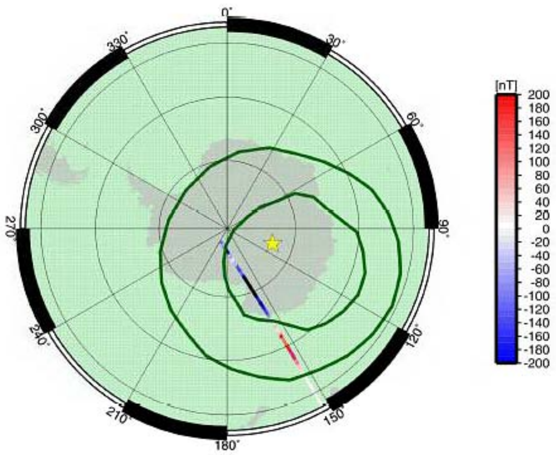
This work is currently being written up as her second paper. Katie has also completed her PhD thesis. Katie’s work won a ‘best student presentation’ prize at the April 2010 National Astronomy Meeting in Glasgow.

Gemma Kelly is in the second year of her PhD studentship, based at the University of Liverpool and part funded by BUFI and by NERC.

Gemma is studying the complexity of the polar ionospheric magnetic field and the implications of this complexity for improving models of the internal field of the Earth at high latitudes. Gemma has identified combinations of magnetic index and auroral oval data to better isolate ‘quiet’ geomagnetic activity regions in polar latitudes. She is currently exploring how SECS estimates of components of the ionospheric field, from ground observatories, can also help ‘clean up’ satellite data.

The Figure below shows the auroral oval

(the ‘doughnut’ shaped region) as estimated from independent data from the DMSP satellite. CHAMP satellite magnetic residuals (blue/red dots) can be seen to change sign (colour) as the satellite passes through this region. By using such an independent data set we hope to identify *a priori* regions of active ionospheric field and hence automate a process for removing their contribution from data sets used to model the internal field.



The sign of magnetic residuals changes through the auroral oval, where the oval boundaries are determined by independent data

Rob Shore is based at the University of Edinburgh. Rob is in the second year of his PhD research into global magnetic modelling with Swarm satellite data. Rob is also part funded by BUFI and by NERC.

Rob’s project focuses on improving our capabilities in quantifying the sources of the Earth’s magnetic field.

In the first few months of this study the “virtual observatory” (VO) technique was applied to simulated measurements from the satellite constellation Swarm.

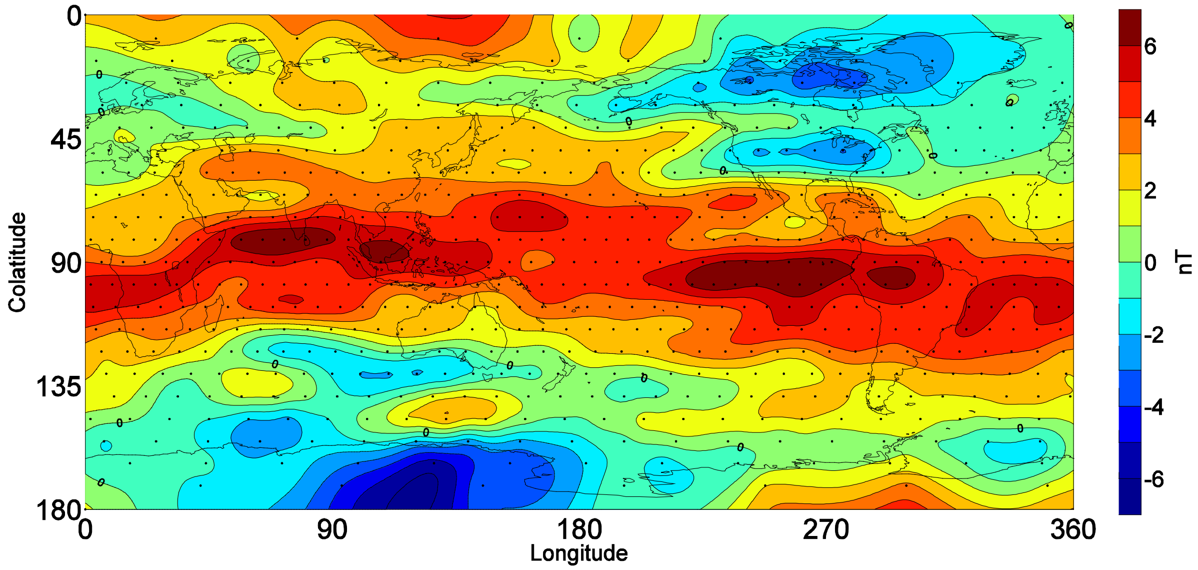
Early results produced models that, in spite of using the unique constellation geometry of Swarm, were still apparently contaminated with time-varying external fields. An earlier result of Beggan *et al* (2009) suggested that although a large proportion of the contamination is linked to the symmetric ring current, correcting for this introduces a time-varying residual signal in the model solutions.

This was therefore evidence for a significant local time dependency in the contamination, yet the results from Swarm data appear to refute this. Modifications of the VO method were tested for their ability to mitigate the contamination – the VOs were expanded spatially to smooth out the spatial aliasing from the time-varying signals, and expanded temporally so that the data in each VO encompassed the full 24-hour range of local times.

However, neither of these worked any more effectively than simply using the Swarm constellation geometry. Separating the external field signal in the input synthetic data confirmed that the majority of it arises from the symmetric ring current.

It was concluded that the deviation of the Swarm results from the real data results of Beggan *et al* is likely to be due to the low contribution of local time-dependent terms in the simplified synthetic data.

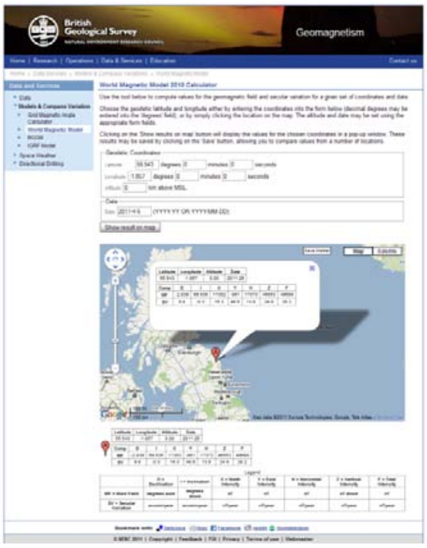
Further study in the near future will use data from real satellites and permanent observatories to resolve this ambiguity and improve the models – particularly prudent given the delay of Swarm launch to mid-2012 at the earliest.



Contribution from magnetospheric fields in a single month to a prediction from a global model derived using the VO technique (VO locations shown by dots)

Sadiq Sani is a post-graduate student at Robert Gordon University, who completed the industrial placement portion of his MSc course at BGS.

Sadiq worked with the Geomagnetism Team on web-services technologies for four months at the beginning of 2010, producing a proof-of-concept web-service. Sadiq's work was eventually developed into a web-service providing World Magnetic Model data via an interactive interface on the BGS Geomagnetism web-site (*as in Figure below*).



Sadiq presenting on web services at a Geomagnetism team seminar in 2010

Pragna Reddy is an MSc student at Robert Gordon University in Aberdeen, studying Computing & Information Engineering. She is undertaking her nine-month industrial placement at BGS.

Pragna is helping to advance BGS capabilities in data delivery by developing a suite of web-services providing access to geomagnetic observatory data, metadata, and derived data products.

The web-services provide a way for

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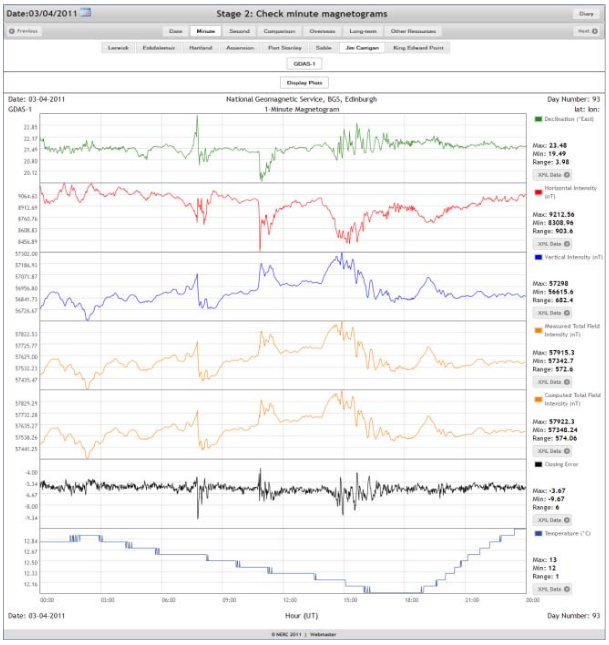
client software to access a range of geomagnetism data products, simply by retrieving a URL. The data are made available in a number of standard data exchange formats, from which the client can choose. Compare this with data access in existing software, which must locate, parse and convert the files of the data repository directly.

Some of the benefits of using web-services for data access are:

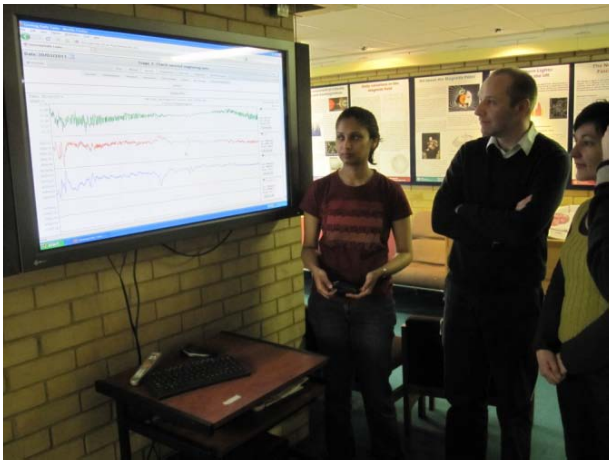
- Ease of access: clients need only know how to access a URL and parse the returned content; they need know nothing of how the data is formatted and stored in the repository.
- Reduction of code duplication: low-level data access code is isolated in the web-service software – client software need not duplicate this code. This leads to faster and more reliable client development.
- Increased resilience to change: since the low-level data access details are abstracted away by the web-service, changes to the data repository (location, storage format, structure) need only be reflected in a single place – the web-service – while clients using the data are unaffected.
- Increased security: client authentication and authorisation can be managed at a single point, simplifying the protection of commercially sensitive data.
- Interoperability: the web-service can provide data in a number of standard formats (e.g. XML, JSON), so it becomes much easier to integrate BGS geomagnetism data into existing software and systems.

We are already taking advantage of the benefits offered by these web-services by developing software to aid observatory operations staff in data analysis and quality control. This software provides a web browser-based graphical interface with which to visualise the various geomagnetic observatory data products in real-time.

Many of these web-services will also be made available publicly, which will give academics, industry and the public unprecedented and easy access to BGS geomagnetic data products.



New web service access to BGS observatory data



Pragna (left) discussing a development version of the web service with Geomagnetism colleagues

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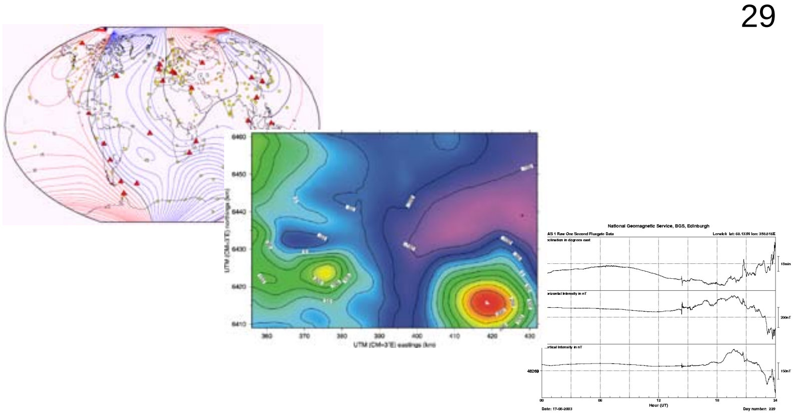


The sources of the Earth's magnetic field separated into models of the field dominated by the core (top), the lithosphere (middle) and the ionosphere/magnetosphere (bottom)

Applications

Directional Drilling

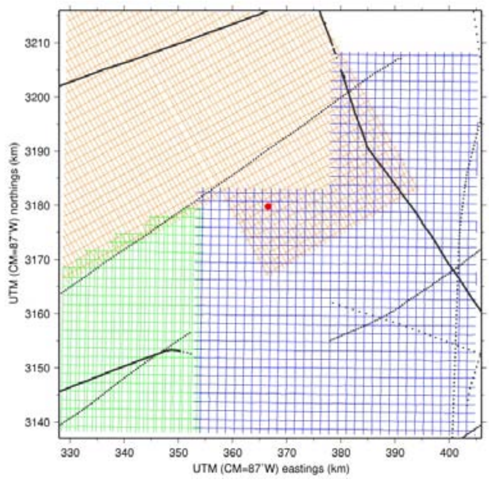
High quality data and improved models have enabled better separation of the sources of the geomagnetic field. These science advances have led to the development of an important application of geomagnetism, in directional drilling with magnetic survey tools. In 2010 BGS continued to supply geomagnetic referencing services to the oil industry, providing accurate estimates of the geomagnetic field to aid directional drilling activities around the world.

A total of 37 new areas around the world were set up in 2010 for BGS geomagnetic referencing services.

In particular, in April BGS responded rapidly to a request from BP to provide In-Field Referencing (IFR) services for the drilling of relief wells in the stricken Macondo field in the Gulf of Mexico.

IFR includes the main and crustal fields, but not the rapidly varying external field (spherical harmonic degree and order 1). IFR is required for well survey management that uses magnetic measurement while drilling (MWD) techniques. For these relief wells BP were using every directional drilling technique available, including magnetic MWD with IFR.

The BGS IFR work involved obtaining local aeromagnetic data, performing various checks on the processing that



Locations of magnetic data in vicinity of the Macondo field in the Gulf of Mexico. Orange, blue and green represent different aeromagnetic surveys and black lines indicate marine surveys

had previously been done to the data, adjusting the data according to the version of BGS Global Geomagnetic Model employed, transforming the scalar anomaly data at the aeromagnetic observation surface to vector anomaly data at various depths and, finally,

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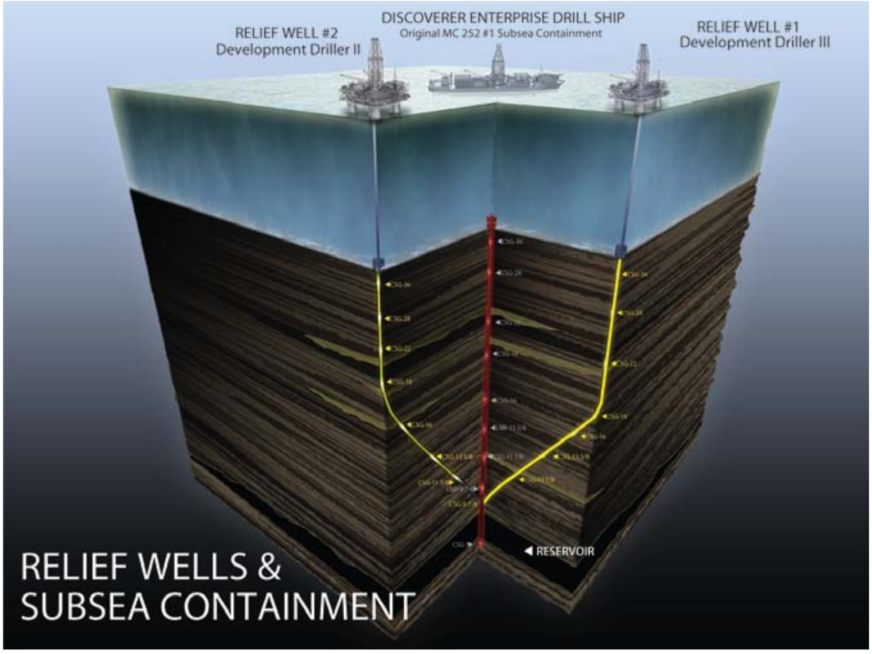


The main Macondo well and the two relief wells.

(Diagram courtesy of BP)

assessing the site-specific uncertainties.

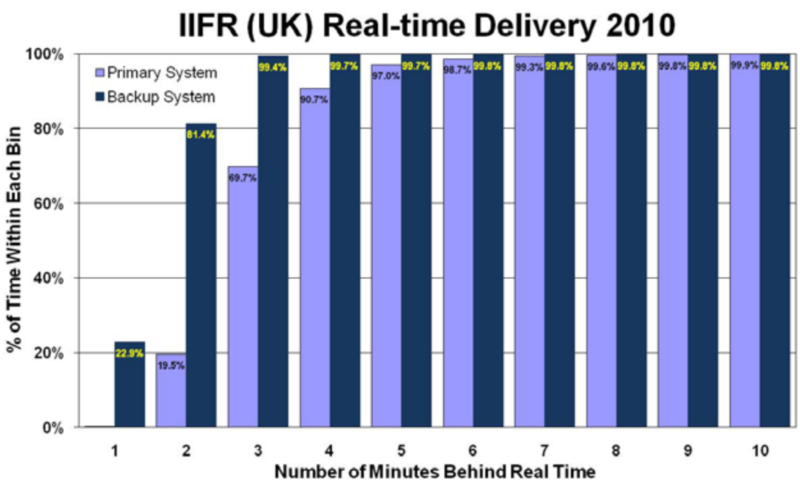
Within six days of BGS receiving notification of the work, IFR results started to be delivered. BP have since reported back to BGS that the magnetic MWD in conjunction with gyro surveys achieved well placement accuracies of around 10 feet

In other work, a large number of the new fields set up in 2010 for geomagnetic referencing services were in support of directional drilling operations in Alberta, Western Canada. Drilling operations there have increased in recent years.

Outside the UK sector these geomagnetic referencing services are provided in collaboration with other institutes operating geomagnetic observatories and suppliers of aeromagnetic data, to the benefit of those institutes.

In particular we have long-standing collaborations with the University of Tromsø who operate observatories and stations in Norway, and the Geological Survey of Canada, who operate Meanook observatory in Alberta. These institutes support real-time Interpolation In-Field Referencing (IIFR) services which includes all sources of the magnetic field.

The timeliness of IIFR data (see below – data is available through both data servers) is very important as the drilling engineers are making quick decisions concerning downhole tool adjustments based on the real-time magnetic MWD data.



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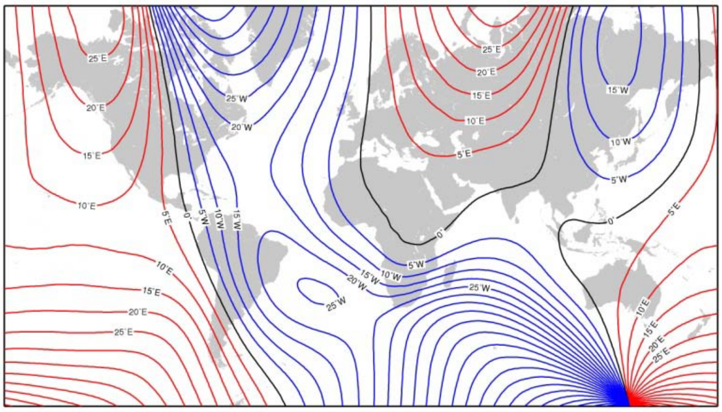
Applications

Magnetic Data for Navigation



Compass variation at start of 2011 from BGGM2010

One of the main uses of the Earth's magnetic field is to convert magnetic headings obtained from magnetised needles and fluxgate sensors, to geographic headings relative to true or grid north, and vice versa. Accurate models of the Earth's magnetic field are essential in doing this.

Using the latest observations of the Earth's magnetic field from satellites and observatories around the world, the Geomagnetism team has updated its global model for use in directional drilling, the BGS Global Geomagnetic Model (BGGM). In this past year we have also updated the UK annual model, mainly for the benefit of the UK Ordnance Survey.

To create accurate models it is important to have magnetic data with good global and temporal coverage and as low a noise level as possible.

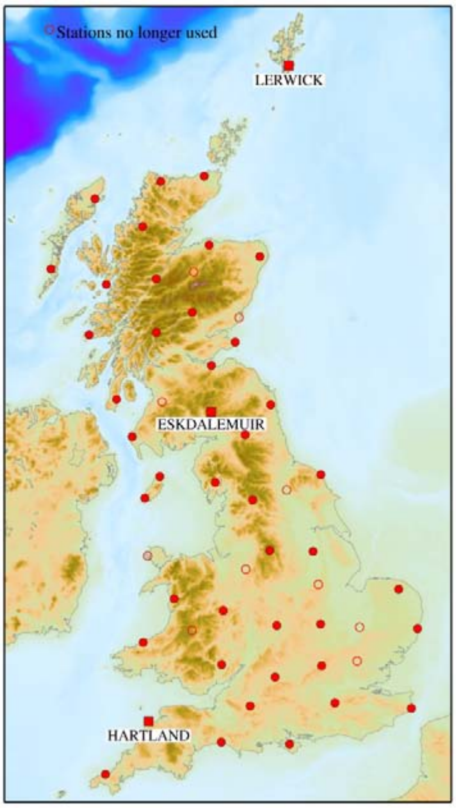
The Ørsted and CHAMP near-polar orbiting satellites provide high quality vector and scalar data at almost all latitudes and longitudes. The temporal coverage is less even because of difficulties associated with using data collected in the sunlit hemisphere. (This is due to ionospheric magnetic fields being energised by sunlight.) As Ørsted takes over 2 years to sample all local times and CHAMP 4-5 months, a 'night-time only' data selection process results in some gaps in time. The satellite data are therefore augmented with observatory data, which provide a complete coverage in time and valuable constraints on the time variations of the field contained in the model.

In order to minimise contamination of the models by rapidly varying ionospheric and external fields, careful selections of the data are made. Night-side data collected during magnetically quiet periods, determined by magnetic activity indices and solar wind data, are selected. Parameters for any remaining large-scale external field are included in the model solution and data which include magnetic fields from sources that are not parameterised are weighted appropriately. All satellite data are also weighted according to along-track noise.

Contamination of the models by local crustal magnetic fields is minimised by including observatory crustal biases in the model solution. Much of the crustal field signal in the satellite data is attenuated because of the distance of the satellites from the sources (over 600 km for Ørsted and 300 km for CHAMP), but any remaining signal that can be robustly modelled is included.

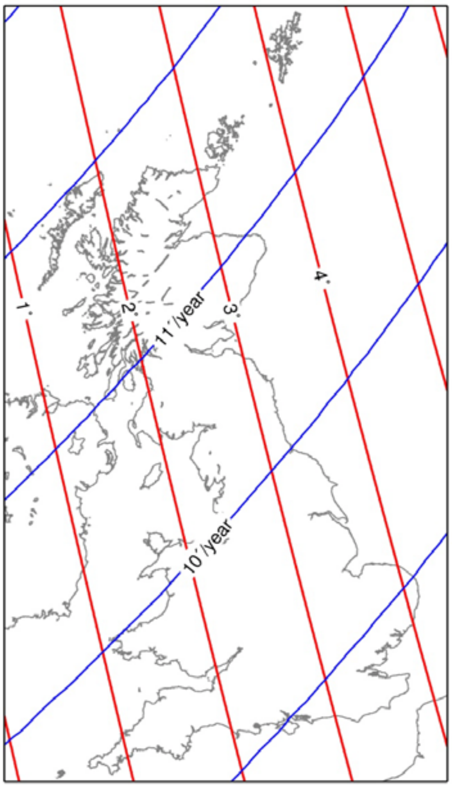
About 2.5 million data are used to determine over 6000 parameters in a 'parent model'. There are many more parameters in the parent model than are necessary for the final BGGM; for example more than 5% of the parameters are due to the varying external field, and the values of many of the high degree internal field terms are not considered robustly estimated.

The parent model was produced by first fitting a model to the data assuming that the data uncertainties followed a Gaussian, or Normal, probability distribution. This was then used as the 'initial-guess model' in an iterative procedure, where the data uncertainties were assumed to follow the more realistic Laplacian probability distribution. This inversion for the model parameters was an iterative reweighted least-squares process; the iterations being necessary on account of the non-linearity of the data in terms of the model parameters and the assumed uncertainty distribution.



UK repeat station locations

BGS is responsible for monitoring the Earth's magnetic field over the UK and to complement the data from the three UK observatories we operate a network of repeat stations (*see above*).



The red contours show the angle between grid north and magnetic north for mid-2010. Magnetic north is to the west of grid north by the amount shown. The blue contours show the current annual decrease in the angle.

In order to improve the temporal sampling provided by the repeat station network and to discard stations with access problems or encroaching cultural noise, the number of stations has recently been reduced from 51 to 41. These permanently marked stations are spread throughout the country and each year at least 10 of them are visited for a day at a time in order to make accurate measurements of the direction and strength of the magnetic field.

The observations are then processed to remove any transient magnetic storm or daily variation contributions and a UK regional model is calculated. This model is used to provide magnetic north data to the Ordnance Survey.

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Examining the 'singing fluxgate' display at the BGS Open Day in September 2010

Outreach and Knowledge Exchange

Geomagnetism remains an active research area within the Earth and space sciences. Not least, a decade of continuous sampling of the magnetic field by satellites has just been completed. These data, together with measurements from the global network of magnetic observatories, have enabled us to study the Earth's magnetic field at a finer resolution than before and to increase our basic knowledge of the Earth. The Geomagnetism team has been active in such basic research and in communicating the exciting new developments and why they matter.

Our outreach and IKE activities take the form of talks, presentations, demonstrations, observatory 'tours', university teaching, web-articles and, of course, paper and poster presentations at national and international scientific meetings.

One particularly regular activity for the team is participation in the BGS 'Open Day' held in Edinburgh every September, intended for the general public, and the 'Schools Week', for school children.

Another regular activity is our bi-monthly column on 'Space Weather and Navigation' published in the Royal Institute of Navigation's 'Navigation News'.

Ewan Dawson (left) at a poster session at the RAS NAM 2010 held at Glasgow University, where BGS science posters were displayed

Scientific Journal Publications

Published 2010

Beggan, C., Hamilton, C.W., 2010. New image processing software for analyzing object size-frequency distributions, geometry, orientation, and spatial distribution, *Computers and Geosciences*, 36, 539-549. 10.1016/j.cageo.2009.09.003

Beggan, C., Whaler, K., 2010. Forecasting secular variation using core flows, *Earth Planets Space*, 62, 821–828, 10.5047/eps.2010.07.004

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Finlay C.C., Maus S., **Beggan C.D.**, Hamoudi M., Lowes F. J., Olsen N., and Thébault E., 2010. Evaluation of candidate geomagnetic field models for IGRF-11, *Earth Planets Space*, 62, 787–804, 10.5047/eps.2010.11.005

Finlay, C.C., Maus, S., **Beggan, C.D.**, Bondar, T. N., Chambodut, A., Chernova, T.A. , Chulliat, A. , Golovkov, V.P. , **Hamilton, B.**, Hamoudi, M. , Holme, R., Hulot, G., Kuang, W., Langlais, B., Lesur, V., Lowes, F.J., Lühr, H., **Macmillan, S.**, Mandea, M., McLean, S., Manoj, C., Menvielle, M., Michaelis, I., Olsen, N., Rauberg, J., Rother, M. , Sabaka, T.J., Tangborn, A., Tøffner-Clausen, L., Thébault, E., **Thomson, A.W.P.**, Wardinski, I., Wei, Z. and Zvereva, T. I., 2010. International Geomagnetic Reference Field: the eleventh generation, *Geophys. J. Int.* 10.1111/j.1365-246X.2010.04804.x

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Macmillan, S. and Rycroft, M. J., 2010. The Earth's Magnetic Field, Encyclopedia of Aerospace Engineering, R. Blockley and W. Shyy (eds), Vol. 6, Part 27, Chap. 276, 3371-3382, Wiley.

McLay S.A. and **Beggan C.D.**, 2010. Interpolation of externally-caused magnetic fields over large sparse arrays using Spherical Elementary Current Systems, *Ann. Geophys.*, 28, 1795–1805, 10.5194/angeo-28-1795-2010

Thomson, A.W.P., Gaunt, C.T., Cilliers, P., Wild, J.A., Opperman, B., McKinnell, L.-A., Kotze, P., Ngwira, C.M., Lotz, S.I., 2010. Present day challenges in understanding the geomagnetic hazard to national power grids. *Advances in Space Research*, 45 (9). 1182-1190. 10.1016/j.asr.2009.11.023

Thomson, A.W.P., Hamilton, B., Macmillan, S. and Reay, S.J., 2010. A Novel Weighting Method for Satellite Magnetic Data and a New Global Magnetic Field Model, *Geophys. J. Int*., 181, 250-260, 10.1111/j.1365-246X.2010.04510.x

Thomson, A., and Wild, J. 2010. When the lights go out... *Astronomy and Geophysics*, 51 (5). 23-24. 10.1111/j.1468-4004.2010.51523.x

Turnbull, K. 2010. Modelling GIC in the UK *Astronomy and Geophysics*, 51 (5). 25-26. 10.1111/j.1468-4004.2010.51525.x

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Lesur, V. B. F., Olsen, N. and **Thomson, A.W.P.**, 2011. Geomagnetic core field models in the satellite era, In: Mandea M, Korte M (eds) Geomagnetic Observations and Models, IAGA Special Sopron Book Series 5, DOI 10.1007/978-90-481-9858-0_11

Macmillan, S. and Clarke E., 2011. Resolving issues concerning Eskdalemuir geomagnetic hourly values, *Ann. Geophys.*, 29, 283–288, 10.5194/angeo-29-283-2011

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Macmillan, S., and Finlay, C., 2011. The International Geomagnetic Reference Field, In: Mandea M, Korte M (eds) Geomagnetic Observations and Models, IAGA Special Sopron Book Series 5, DOI 10.1007/978-90-481-9858-0_10

Reay, S.J., Clarke, E., and **Hamilton, B.** 2011. First Steps towards *K* Indices from South Atlantic Observatories: Port Stanley Observatory, *Data Science Journal* (submitted)

Reay S.J., Herzog D.C., Alex S., Kharin E., McLean S., Nosé M. and Sergeyeva N., 2011. Magnetic Observatory Data and Metadata: Types and Availability. In: Mandea M, Korte M (eds) Geomagnetic Observations and Models, IAGA Special Sopron Book Series 5, DOI 10.1007/978-90-481-9858-0_7 pp149-181

Reda, J., Fouassier, D., Isac, A., Linthe, H-J., Matzka, J., and **Turbitt C.W.**, 2011. Improvements in Geomagnetic Observatory Data Quality, In: Mandea M, Korte M (eds) Geomagnetic Observations and Models, IAGA Special Sopron Book Series 5, DOI 10.1007/978-90-481-9858-0_6

Turbitt C.W., Baillie, O., Kerridge, D.K., Clarke, E. 2011. An Investigation into Techniques for Isolating Noise in Observatory Data, *Data Science Journal* (submitted)

Other Publications

26 customer Reports (including UK survey & OS and oil industry services)

84 Observatory Monthly Bulletins: www.geomag.bgs.ac.uk/data_service/data/bulletins/bulletins.html

New-look BGS Geomagnetism website: www.geomag.bgs.ac.uk

NERC ‘Planet Earth’ feature article – “Where is North?” (Winter 2010)

BGS ‘Earthwise’ article for BGS 175th Science Symposium

Bi-monthly column on Space Weather for Royal Institute of Navigation’s ‘Navigation News’

Geomagnetism activities on BGS website (enter “geomagnetism” in search parameter)

www.bgs.ac.uk/news/

New layout of BGS Geomagnetism website.

Ciaran Beggan presenting at the iMAGINE conference, Tromsø, June

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Conference Presentations, Posters and Related Activities

RAS National Astronomy Meeting, inc. UKSP/MIST, Glasgow, April,

1 Presentation (Turnbull – PhD student), 4 Posters, Organising Committee Member

European Geophysical Union, Vienna, Austria, April

1 Presentation (Thomson)

iMAGINE conference, Tromsø, Norway, June

1 Presentation (Beggan), 1 Poster

AGU Meeting of the Americas, Foz do Iguassu, Brazil, August,

1 Presentation (Beggan)

GEOSPACE consortium science meeting, Edinburgh, September

1 Presentation (Beggan), 1 Poster

IAGA Observatories Workshop, Changchun, China, September

1 Presentation (Turbitt), 1 Poster

BGS 175th Anniversary Science Symposium, London, September

1 Presentation (Kerridge), 1 Poster

ISCWSA (SPE wellbore positioning) meeting, Florence, Italy, September

2 Presentations (Thomson & Clarke)

European Space Weather Week 7, Bruges, Belgium, November

Ground Effects Topical Group and COST ES0803 Action management meetings (Thomson & Clarke)

Geomagnetism Team seminars, Edinburgh

20 Presentations throughout the year

Some Other Notable Outputs

MIST Rishbeth Prize – Best Talk (April)

Katie Turnbull (BUFI student, BGS supervisor was Alan Thomson)

MIST Rishbeth Prize – Best Poster (April)

Alan Thomson and Jim Wild (University of Lancaster)

Edinburgh University Undergraduate Lecture Series (September-December)

4th Year Honours Course on ‘Geomagnetism’, by Ciaran Beggan

Public Lectures, Presentations and Demonstrations

Educational and training activities. including class activities at Roslin Primary School, Midlothian; visit of the Lockerbie ‘PROBUS’ group to Eskdalemuir; and the Edinburgh ‘Grad School’ weekend workshop.

On-line archive of digitised historical UK analogue magnetograms

http://www.bgs.ac.uk/data/Magnetograms/home.html

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Acknowledgements

The Geomagnetism team would like to acknowledge the support of team stakeholders, such as the Geomagnetism Advisory Group, BGS management and the Natural Environment Research Council.

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

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

Selected Glossary, Acronyms and Links

AGU American Geophysical Union. *(www.agu.org/)*

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

BGGM BGS Global Geomagnetic Model *(www.geomag.bgs.ac.uk/bggm.html)*

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

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

Cabinet Office The *department* of the UK *Government* responsible for supporting the *Prime Minister and Cabinet* (http://www.cabinetoffice.gov.uk/)

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

CME Coronal Mass Ejection

COST/ COST Action ES0803 European Cooperation in Science and Technology *(www.cost.esf.org/)* / "Developing Space Weather Products and Services in Europe *(www.costes0803.noa.gr/)*

DECC Department of Energy and Climate Change *(www.decc.gov.uk/)*

DMSP Defense Meteorological Satellites Program

(http://heasarc.nasa.gov/docs/heasarc/missions/dmsp.html)

EDA EDA Electronics Ltd.

EHS Earth Hazards and Systems *(www.bgs.ac.uk/research/earth_hazards.html)*

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

EPSRC Engineering and Physical Sciences Research Council *(www.epsrc.ac.uk/Pages/default.aspx).*

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

GDAS BGS Geomagnetic Data Acquisition System *(www.geomag.bgs.ac.uk/documents/gdas2002complete.pdf)*

EURISGIC European Risk from Geomagnetically Induced Currents

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

GIC Geomagnetically induced currents (a natural hazard to power systems and pipeline networks).

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

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

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

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IIFR/IFR Interpolated In-Field Referencing/In-Field Referencing. (*www.geomag.bgs.ac.uk/documents/estec_iifr.pdf*)

IKE Information and knowledge exchange.

INDIGO Intermagnet Compatible Digital Geomagnetic Observatory (*http://pubs.usgs.gov/of/2009/1226/*)

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. (*http://iscwsa.org/*)

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

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

JSON JavaScript Object Notation (*www.json.org/*)

MagNetE European magnetic repeat station network (e.g. *http://space.fmi.fi/MagNetE2009/?page=welcome*).

MATLAB (matrix laboratory) a numerical computing environment (*www.mathworks.com/products/matlab/*)

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

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

MWD Measurement While Drilling

NAM National Astronomy Meeting (*www.ras.org.uk/*)

NASA National Aeronautics and Space Administration (*www.nasa.gov/*)

NCEO National Centre for Earth Observation (*www.nerc.ac.uk/research/sites/collaborative/nceo.asp*)

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

NG National Grid plc (*www.nationalgrid.com/*)

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

NOAA/NGDC National Oceanic and Atmospheric Administration/National Geophysical Data Center (*www.ngdc.noaa.gov/*)

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

OS Ordnance Survey (*www.ordnancesurvey.co.uk/oswebsite/*)

PDRA Post-Doctoratal Research Associate.

PPM Proton Precession Magnetometer.

QD Quasi-definitive data.

RAL Rutherford Appleton Laboratory (*www.stfc.ac.uk/home.aspx*)

RAS Royal Astronomical Society (*www.ras.org.uk/*)

RIN Royal Institute of Navigation (*www.rin.org.uk/*)

Royal Society UK National Academy of Science (*www.royalsociety.org/*)

SAA South Atlantic Anomaly (*www.bgs.ac.uk/research/highlights/southAtlantic2010.html*)

SECS Spherical Elementary Current Systems

SEIEG Space Environment Impact Expert Group

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SOHO/LASCO Solar and Heliospheric Observatory / Large Angle and Spectrometric COronagraph experiment (*http://soho.esac.esa.int/*)

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

SV Secular Variation

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

VO Virtual Observatory

WDC World Data Centre (*www.wdc.bgs.ac.uk/*)

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

XML Extensible Markup Language (*www.w3.org/XML/*)

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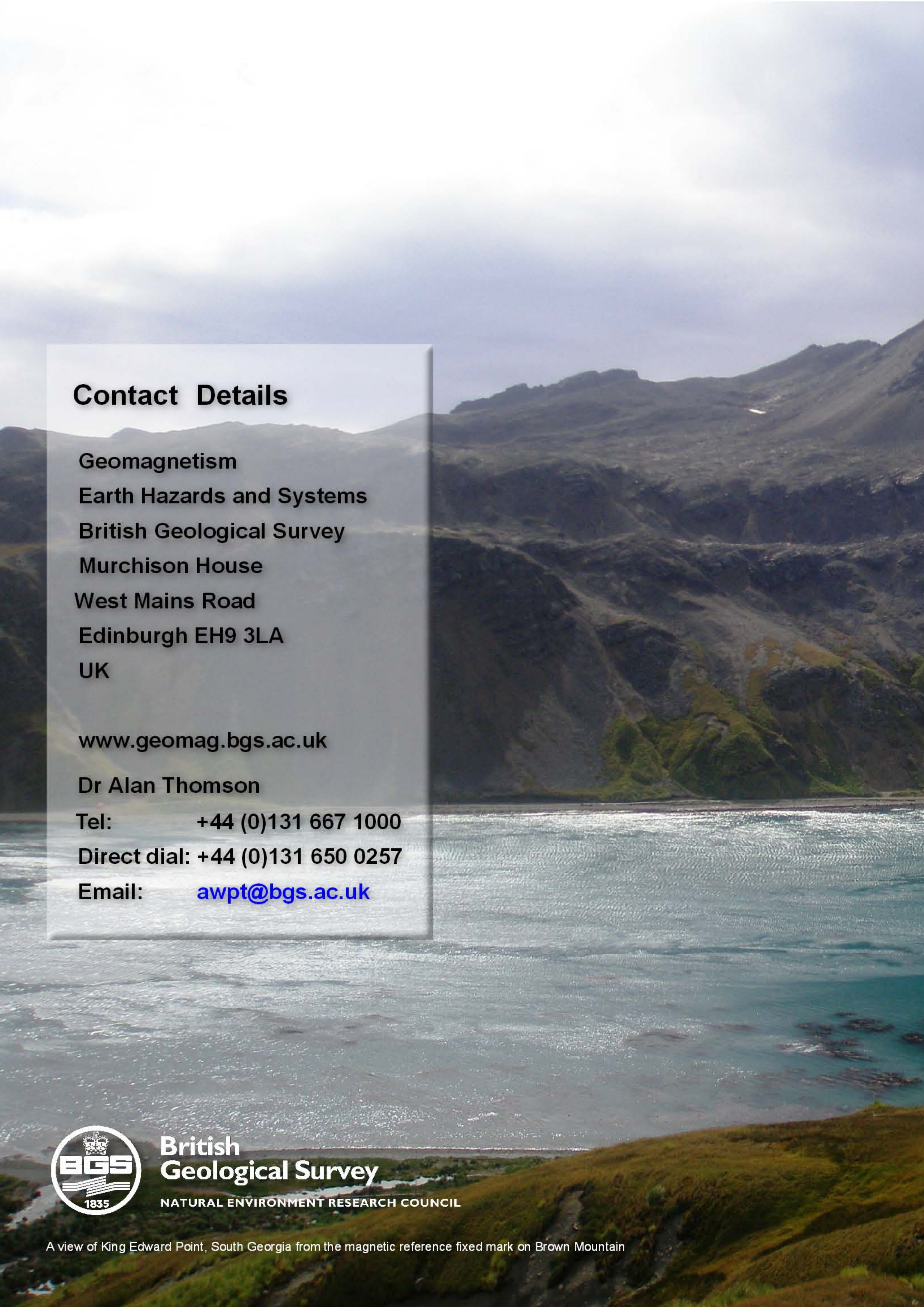
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL



A view of King Edward Point, South Georgia from the magnetic reference fixed mark on Brown Mountain