British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Predicting the South Atlantic Anomaly

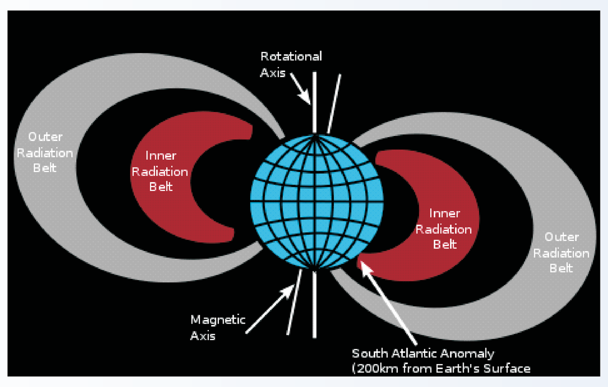
Hamilton, B., Macmillan, S., Beggan, C., Thomson, A. and Turbitt C., British Geological Survey, West Mains Road, Edinburgh, UK

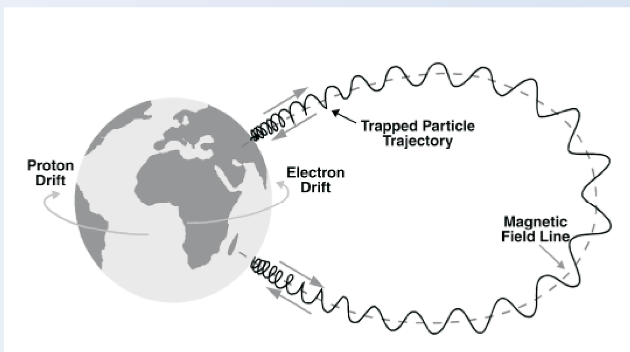
The shielding that the Earth's magnetic field provides from solar emissions and cosmic rays is significantly less in the area of the southern Atlantic and South America known as the South Atlantic Anomaly (SAA). The resulting increase in low altitude radiation is known to damage satellites. Observations indicate that the SAA has been growing in extent and moving westwards. The ability to accurately predict the SAA for the next 1-100 years is therefore very important. In this presentation we describe efforts to reduce uncertainties in forecasts of the geomagnetic field using surface observations of the magnetic field, data from the Ørsted-CHAMP-Swarm suite of magnetic survey satellites and magnetic field predictions from realistic core flow estimations.

What is the SAA and how has it changed over the past 50 years?

The South Atlantic Anomaly (SAA) is a region spanning the southern Atlantic and South America where the Earth's magnetic field is at its weakest. In the SAA the field is about 1/3 the strength of the field near the magnetic poles and this affects how close to the Earth energetic charged particles can reach. What's more, the SAA is deepening - the minimum strength now is 6% lower than it was 50 years ago. Low Earth orbiting (LEO) satellites (defined as having altitude < 2000 km) are particularly vulnerable to the resulting radiation hazard.

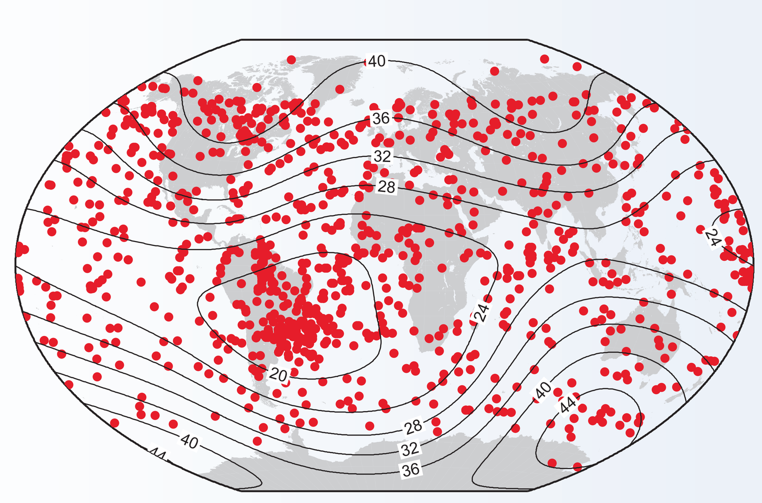
The radiation has 2 main sources: (1) trapped radiation (figures below) which originates from the Sun with the protons being the most dangerous and (2) galactic cosmic rays (GCRs) which are extremely energetic. For LEO satellites this radiation affects electronic, optical and computer systems and can also cause surface charging. These problems are worse over the SAA.

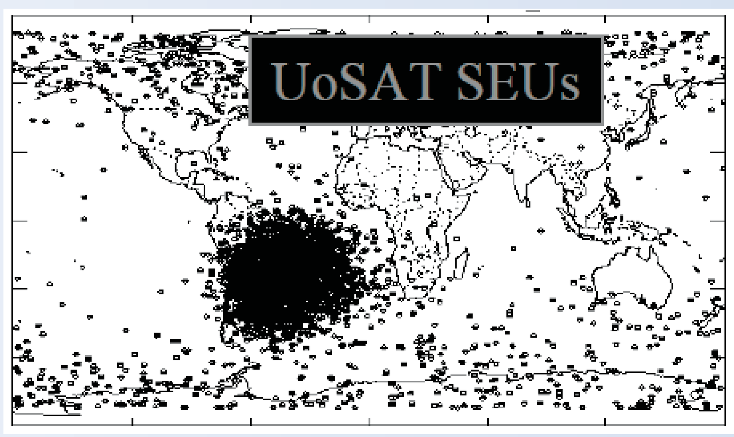




Below we show examples of satellite anomalies clustering in SAA. Left: satellite anomaly dataset anom5j.xls from www.ngdc.noaa.gov/stp/satellite/anomaly/doc/ and total intensity from model (Finlay *et al*, 2011). Right: locations of University of Surrey satellite single event upsets.

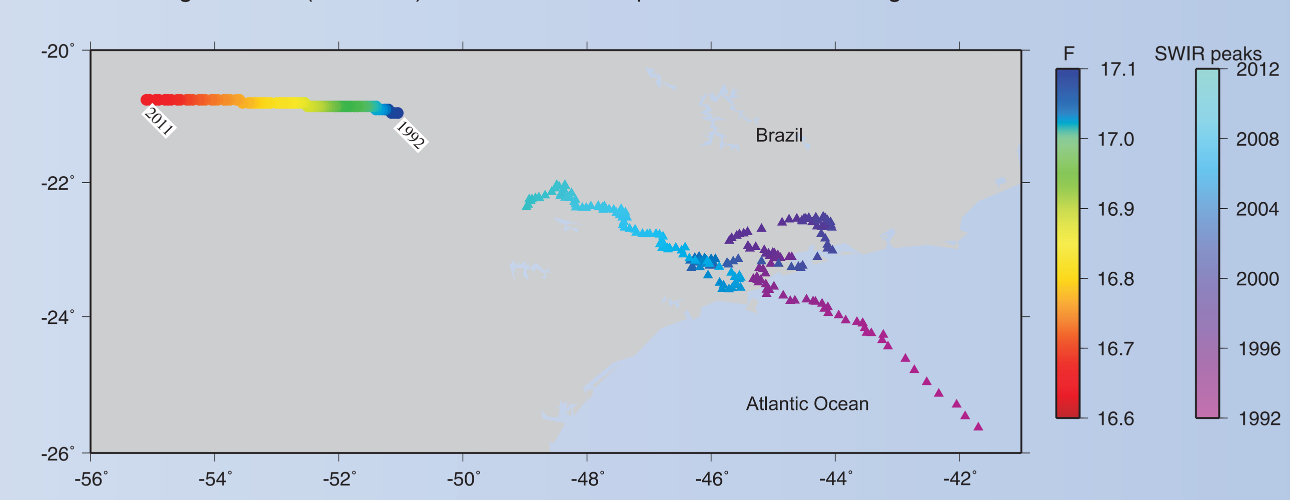
IGRF total intensity at 1990 at 800 km and NGDC satellite anomalies 1986-1992





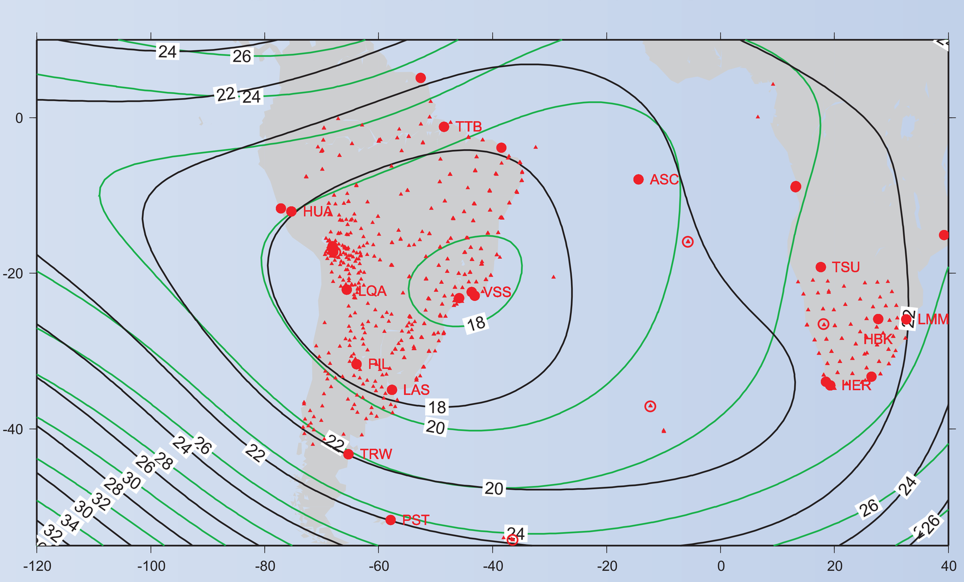
The plot below shows the westward movement of the SAA from magnetic field model (updated from Thomson *et al*, 2010) and from analysis of noise in nightside short-wavelength infrared (SWIR) radiometer data from ERS-1, ERS-2 and ENVISAT satellites (Casadio & Arino, 2011, Casadio, 2011). The deepening of the SAA can also be seen from the magnetic data. The cause of the offset between loci of magnetic field minima and SAA peaks as derived from SWIR data is not understood.

1992-2011 magnetic min (F microT) at 800 km & SAA peaks from satellite nightside SWIR data



The majority of the magnetic field is generated in the fluid region deep inside the Earth. Heat convection, buoyancy forces and planetary rotation cause the iron-rich fluid in the outer core to flow in a complex way and the movement of this electrical conductor through existing magnetic field generates electrical current. This current produces more magnetic field in an advective process. Some of it diffuses away resulting in a reasonably stable magnetic field which is broadly dipolar outside the planet and which occasionally reverses its polarity. The SAA may be a sign that the field is attempting to reverse.

F at 800 km at 1960 (green) and 2010 (black) & sites (red) of magnetic observations 1960+

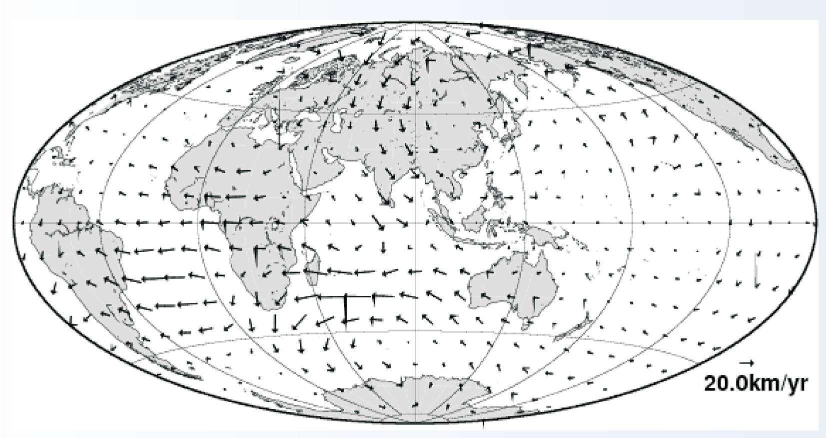


We know from observations and models of the magnetic field that the SAA during the satellite era (1960+) is growing in extent, is deepening and is moving westwards. The gufm1 model (Jackson *et al*, 2000) shows that this has been happening since 1590. Observatories are sparse in the area but recently several have been installed (red circles). The IAGA code is included for observatories with > 15 years record. Triangles show repeat stations.

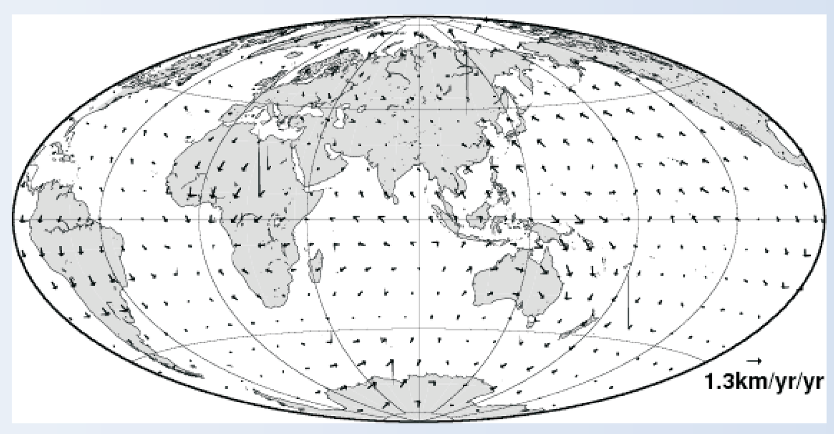
Making predictions requires magnetic field observations and models

But what about the future? Inverting magnetic data directly for core flow and acceleration (assuming flux is frozen which is deemed valid over the relatively short time spans of the data) and then advecting the resultant field forward in time improves forecast accuracy (Beggan & Whaler, 2010). The relatively strong westward flow in the area of the south Atlantic explains the westward movement of the SAA.

Estimated core flow at 2005 at core mantle boundary



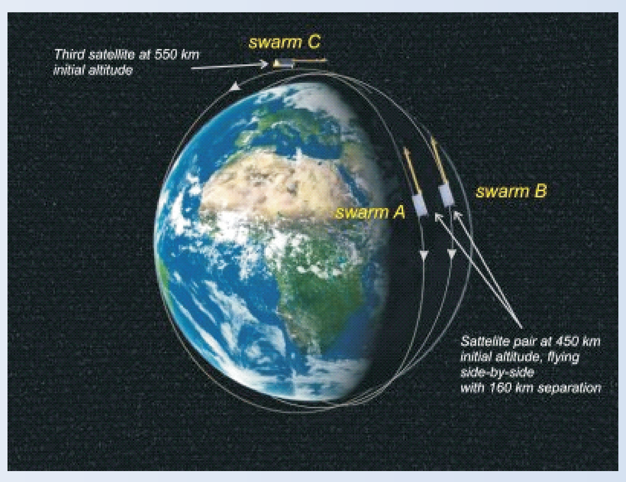
Estimated core flow acceleration at 2005



Accurate predictions of the SAA's behaviour depends upon good models and data:

ESA Swarm Mission

In mid-2012 ESA will launch its 3 satellite Swarm constellation to study the Earth's magnetic field in unprecedented detail. Two satellites will fly in formation whilst a third flies at a higher orbit (see graphic opposite) that together will provide better global coverage over the 5 year mission than previously possible.



BGS is one of 6 institutions in ESA's SCARF consortium, that is working to provide magnetic models and derived products from the SWARM mission to the scientific community. These include comprehensive and dedicated modelling of the Earth's magnetic field from core to magnetosphere. Products will be released at varying frequencies from near real-time models of the large-scale magnetospheric field (a Dst proxy), to annually updated comprehensive models of the Earth's magnetic field and 3D mantle conductivity. Swarm data and products should start to become available from late 2012.

Observatory and repeat station measurements

The BGS operates ASC and PST observatories (Macmillan *et al*, 2009) and trains Navy surveyors to make repeat station observations in the South Atlantic. In Feb 2011 BGS completed the installation of a new observatory at King Edward Point on South Georgia, occupying the same site as an observatory run by the British Antarctic Survey between 1975 and 1982. The ability to collect long time-series of magnetic data in the vicinity of the SAA is of great benefit to modelling its behaviour.

Major unknowns remain

- To what extent do changes in solar activity and the upper atmosphere affect radiation hazard in the SAA?
- Predictions of the Sun for next 100 years?
- What is causing the growth of the SAA?
- Predictions of the magnetic field for next 100 years?
- What is the interaction between the changing magnetic field and the charged and neutral atmosphere in the thermosphere?

Continued observation of the Earth's magnetic field from observatories and satellites, and maintenance of long-term datasets are crucial to answering these unknowns.

References

Beggan and Whaler, 2010. Forecasting secular variation using core flows, *Earth Planets Space*, 62, 821-828.
Casadio and Arino, 2011. Monitoring the South Atlantic Anomaly using ATR instrument series, *Advances in Space Research*, 48, 1056-1066.
Casadio, 2011. New scheme for SAA monitoring using ATSR SWIR radiance. ESA unclassified TN.
Finlay *et al*, 2010. International Geomagnetic Reference Field: the eleventh generation. *Geophys. J. Int.*, 183, 1216–1230.
Jackson, Jonkers and Walker, 2000. Four centuries of geomagnetic secular variation from historical records. *Phil. Trans. R. Soc. Lond. A*, 358, 957-990.
Macmillan, Turbitt and Thomson, 2009. Ascension and Port Stanley geomagnetic observatories and monitoring the South Atlantic Anomaly. *Annals of Geophysics*, 52, 83-96.
Thomson, Hamilton, Macmillan and Reay, 2010. A Novel Weighting Method for Satellite Magnetic Data and a New Global Magnetic Field Model. *Geophys. J. Int.*, 181, 250-260.

Magnetic Relaxation 2012
University of Liverpool
4-5th January 2012