

Ascension and Port Stanley geomagnetic observatories and monitoring the South Atlantic Anomaly

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Abstract

Our 15-year experience of operating two remote observatories, Ascension and Port Stanley, in the south Atlantic is described. These observatories help monitor the South Atlantic Anomaly (SAA), a region of weak magnetic field which causes considerable problems for spacecraft operators. One-minute and one-second values from these observatories, and other observatories both inside and outside the SAA, are analysed. We investigate whether the SAA, and its growth over time, are having any tangible effect on the observed external field variations. Whilst only able to illustrate the long-term characteristics of the irregular external field related to the solar cycle and not due to any long-term changes in the internal field, we do isolate micropulsation signals at sites inside the SAA which contain more power than at sites outside.

Introduction

Since the early 1990s the British Geological Survey has operated two observatories, Ascension and Port Stanley, in the south Atlantic and as a result has produced near-homogeneous 1-minute mean absolute geomagnetic datasets which span about 15 years. Along with datasets from several other observatories, this provides an excellent resource for understanding the electromagnetic environment in this region of the world. One feature of particular interest is the South Atlantic Anomaly (SAA), an area where the radiation hazard from high proton fluxes and cosmic rays is high due to the relatively low shielding effect provided by the Earth's magnetic field. In this area, for example, a significantly higher number of so-called single event upsets (SEUs) occur in low earth-orbiting satellites (Heirtzler, 2002). This area is related to a region of reverse flux at the core mantle boundary beneath the south Atlantic where the magnetic field is directed into the core rather than out, as it is elsewhere in the southern hemisphere (Gubbins and Bloxham, 1985). The apparent growth of this reversed flux region over the last hundred years or so (Jackson *et al*, 2000) may be related to the Earth's magnetic field attempting to reverse (Gubbins, 2008).

In this paper we describe our experience of operating Ascension and Port Stanley observatories and the difficulties encountered in doing this remotely from the UK. Using data from these observatories and others in the area which have been running for several decades, and repeat station observations, we then look at how the SAA is evolving in space and in time.

We then investigate the hypothesis that the SAA, and any long-term changes in it, have an impact on the processes which generate external field variations. First, we investigate whether the growth of the reverse flux patch at the core-mantle boundary in the south Atlantic influences the irregular external magnetic fields observed in this part of the world (as opposed to the regular diurnal variation). We describe an analysis involving hourly standard deviations computed from one-minute data recorded at a number of observatories operating inside and outside the SAA area. We then look at the high frequency end of the spectrum, analysing pulsation signals from observatories inside and outside the SAA.

Ascension and Port Stanley operational experiences

The British Geological Survey (BGS) has operated magnetic observatories on Ascension Island (ASC) and the Falkland Islands (PST) since 1992 and 1994 respectively. These two remote South Atlantic locations were selected to increase the global distribution of continuous, quality vector magnetic data.

Unlike BGS observatories in the United Kingdom, it is not economically feasible to maintain the South Atlantic observatories as permanently manned stations. Operating an unmanned observatory demands that the instruments, recording facilities and data communications are reliable and cost-effective. In addition to instrumental complications, the remoteness and climatic conditions at the sites have given rise to a variety of operating problems, adversely affecting the recorded data.

Trained local staff oversee the routine operation of both of the BGS South Atlantic observatories and perform a fortnightly (PST) or monthly (ASC) set of absolute observations. Since neither observatory is permanently manned, the selection of a suitable site was heavily dependent on the available infrastructure. As well as cost considerations, sites have been selected based on the requirement for a reliable power source, available data communications and ease of access. In general, these criteria are in competition with the requirement to locate at a magnetically clean site, free from potential man-made magnetic interference and, therefore, sites have been selected as a compromise between the two. The huts housing the magnetometers at PST are shown in Figure 1.



Figure 1 The huts housing the magnetometers at Port Stanley

Since neither observatory is located on land owned or controlled by BGS, variometer data have frequently been contaminated by cultural noise. Often this noise is transient (temporary equipment or vehicles on site), but there have been instances of permanent interference, such as the installation of a steel mast at PST in June 1999. By operating both a fluxgate variometer and a proton precession magnetometer separated by a few metres, such interference can often be identified. At both observatories the absolute pillar is sited more remotely than the variometer (since electrical power is not required at the absolute pillar) and cultural noise can often be removed during post-processing of the variometer baselines. However, both observatories are located close to telecommunication installations and the instruments are intermittently subject to RF interference which can be less predictable in its effect and more difficult to remove. Some measures to reduce the effect of RF interference have had a degree of success, including shielding instruments and minimising cable lengths.

The logistics of operating a station remotely also have an effect on the continuity and quality of the data. Whilst absolute observations are made at least monthly, observatory visits by BGS staff for repairs, maintenance and observer training are normally restricted to once per year. The cost of transporting equipment to both sites is also restrictive - heavy items must be shipped by sea, a process which can take in excess of a month. As a consequence, instrument failures can lead to prolonged periods of missing data.

The upgrade of the communication link to both observatories in 2002 from a uni-directional satellite link to a bi-directional internet link provided a more robust, real-time means of monitoring the instrumentation, allowing faults to be diagnosed and often resolved remotely. This led to a significant improvement in the reliability of the data.

Prior to 2007, the fluxgate magnetometers, although insulated, were not maintained in a temperature stabilised environment. Although the insulation attenuated the diurnal temperature variations, the instruments were subject to seasonal temperature fluctuations, with a detrimental effect on the ability to maintain accurate baselines. The effect of external temperature variations on instrument baselines is more prominent in the temperate Falkland Island climate, rather than on the tropical Ascension Island. This problem is exacerbated at PST by the low frequency of absolute observations in the winter months due to the low temperature, strong winds and frequent precipitation. Therefore, temperature control (consisting of additional insulation, a 150 W non-magnetic heater and a proportional temperature controller) was added to the PST instrument enclosure in May 2007. The standard deviation in instrument temperature between May-December 2007 has been improved to 0.3°C compared to 4.0°C for the same period in 2006.

The frequency of absolute observations from PST has been improved since 2003 with the erection of a rudimentary fibre-glass enclosure, although the observatory often suffers from poor visibility affecting sighting the fixed mark.

The Falkland Islands also has a greater incidence of lightning strikes than Ascension Island and lightning has resulted in long periods of data loss on a number of occasions. In all cases, damage to electronic components has been caused by induced, transient currents in long data and power cables between the recording hut and the sensor hut, despite the inclusion of lightning protection barriers. It may be that the addition of large steel masts in close proximity to the instruments has increased the incidence of lightning strikes in recent years. Lightning induced failures have been eliminated since 2005 when all copper data lines were replaced with fibre-optic ones and the protection provided by the suppressors on the power lines was improved through better earthing.

Ascension Island, like many sites in the South Atlantic, is volcanic and magnetically anomalous - the observatory site has gradients in excess of 10 nT/m in parts. Although not evident in the ASC data, such localised magnetic signals can vary with time, temperature and perturbations such as lightning strikes. In high gradient fields, care must be taken to accurately locate absolute observing instruments, to avoid disturbing magnetised material (rocks) and to routinely survey the field intensity around the site. At very high gradient sites, it no longer becomes feasible to operate a vector observatory as the assumption that the field vectors at the variometer and absolute pillar are parallel is no longer valid. Consequently, it is not possible to apply baselines to correct the variometer data to the absolute pillar.

Analysis of geomagnetic data

The strength of the internal magnetic field is significantly lower in the south Atlantic compared to elsewhere in the world. This is shown in Figure 2 and it can be seen that the SAA is moving westwards and is deepening. From Figure 3 it can be seen that, as a percentage of the full field, the rate of change is also quite different in this part of the world. Both the magnitude of the

conductivity perpendicular to the magnetic field and the mean height of the ionospheric dynamo layer are affected by the field strength, but how this rapid change in an already weak field affects the numbers of SEUs is not yet known.

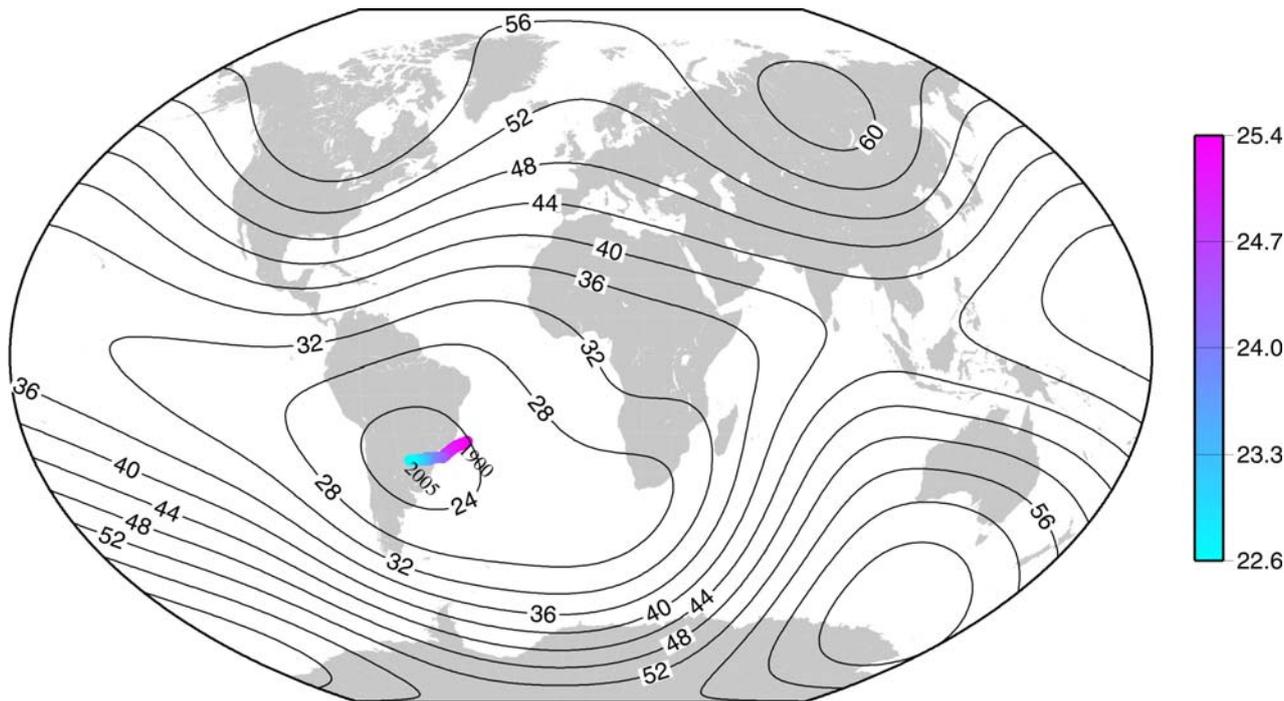


Figure 2 Magnetic field strength (μT) at 2005.0 and the loci of minima from 1900 from 10th Generation International Geomagnetic Reference Field (IGRF-10) (Maus *et al.*, 2005)

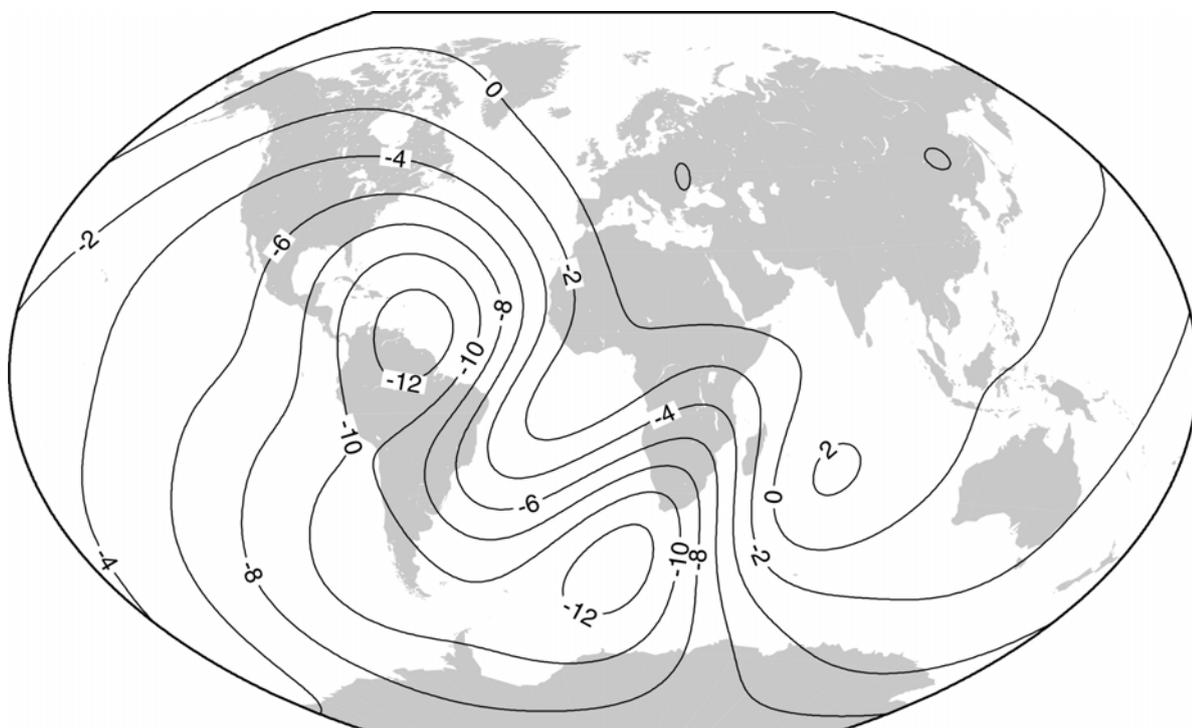


Figure 3 Change in magnetic field strength 1955.0-2005.0 as percentage of mean field for same period, from IGRF-10

Figure 4 shows the locations of the observatories and other sites where measurements of the full magnetic field vector have been made. These data are held at the World Data Centre (WDC) for Geomagnetism in Edinburgh. The locations selected are those where a magnetic field strength of

less than $30 \mu\text{T}$ has been observed at some time in the past. Along with the polar regions, this region sees many SEUs.

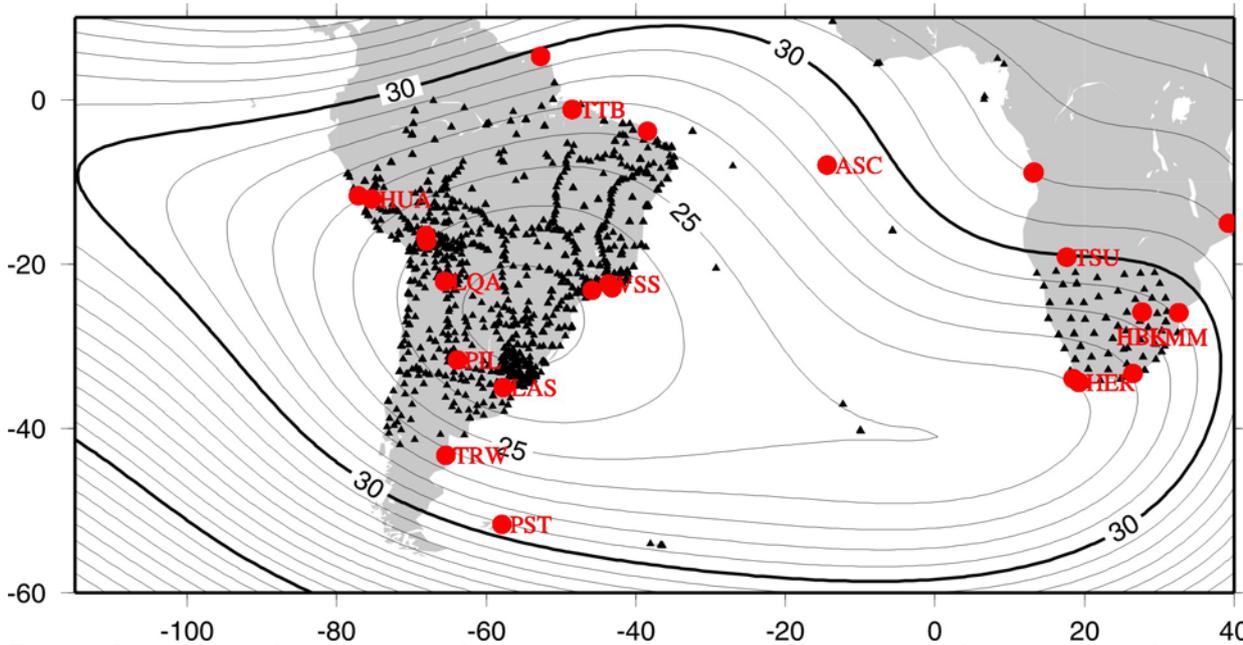


Figure 4 Locations of observatories (red circles), repeat stations and survey sites (black triangles) where a total intensity of less than $30 \mu\text{T}$ has been observed. Field intensity (μT) for 2005.0 from IGRF-10 also shown.

Annual means from observatories in this region with long records are plotted in Figure 5. By using annual means the most significant (i.e. largest amplitude) fields of external origin (storms, daily, seasonal and annual variation) are filtered out: the resulting values mainly represent the field arising from inside the Earth with a very small component attributable to solar cycle effects on fields of external origin. These data would have been used to derive the IGRF depicted in Figures 2-4 but as some of the series extend further back in time we can see that the decrease in the last 50 years is part of a longer-term decrease in the field strength in this part of the world. The sustained, rather high, rate of decrease over South Africa should be noted.

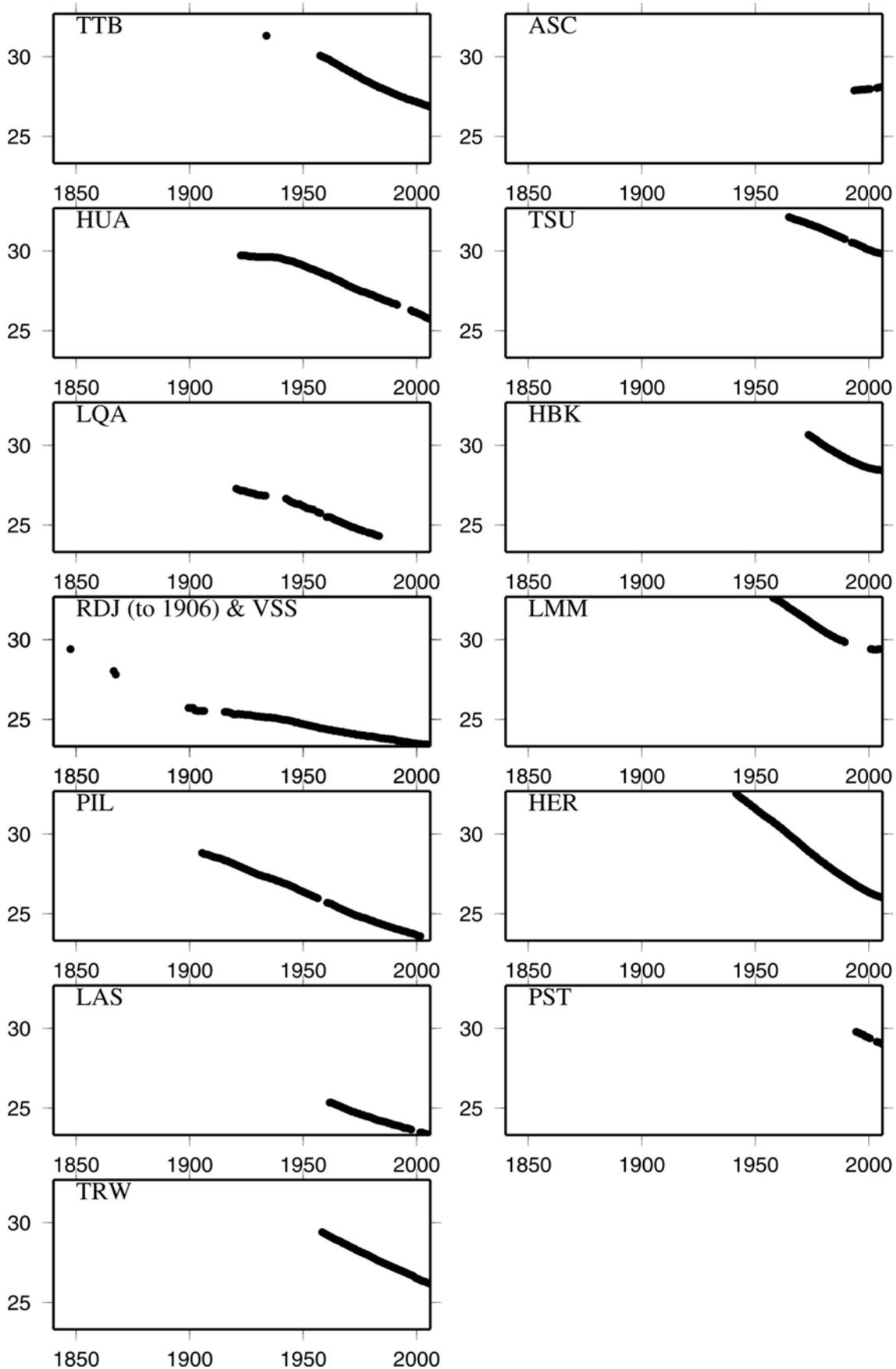


Figure 5 Annual means of total intensity (μT) at selected long-running observatories in region of SAA. Locations of observatories are shown in Figure 4.

To analyse the irregular external field one needs to use minute mean values or even 1-second samples. Minute mean values are available at the WDC for eight of the thirteen observatories shown in Figure 5. One robust, and fairly quick-to-compute, measure of the magnitude of the rapid

external field variations is hourly standard deviation. This measure is also widely used in the study of geomagnetically induced currents (GIC) as it is related to the power in the magnetic field variations that drive surface electric fields and GICs (Beamish *et al.*, 2002). However, in order to depict any long-term trends, we take 10-day means (thereby filtering out the diurnal variation) of these (Figure 6).

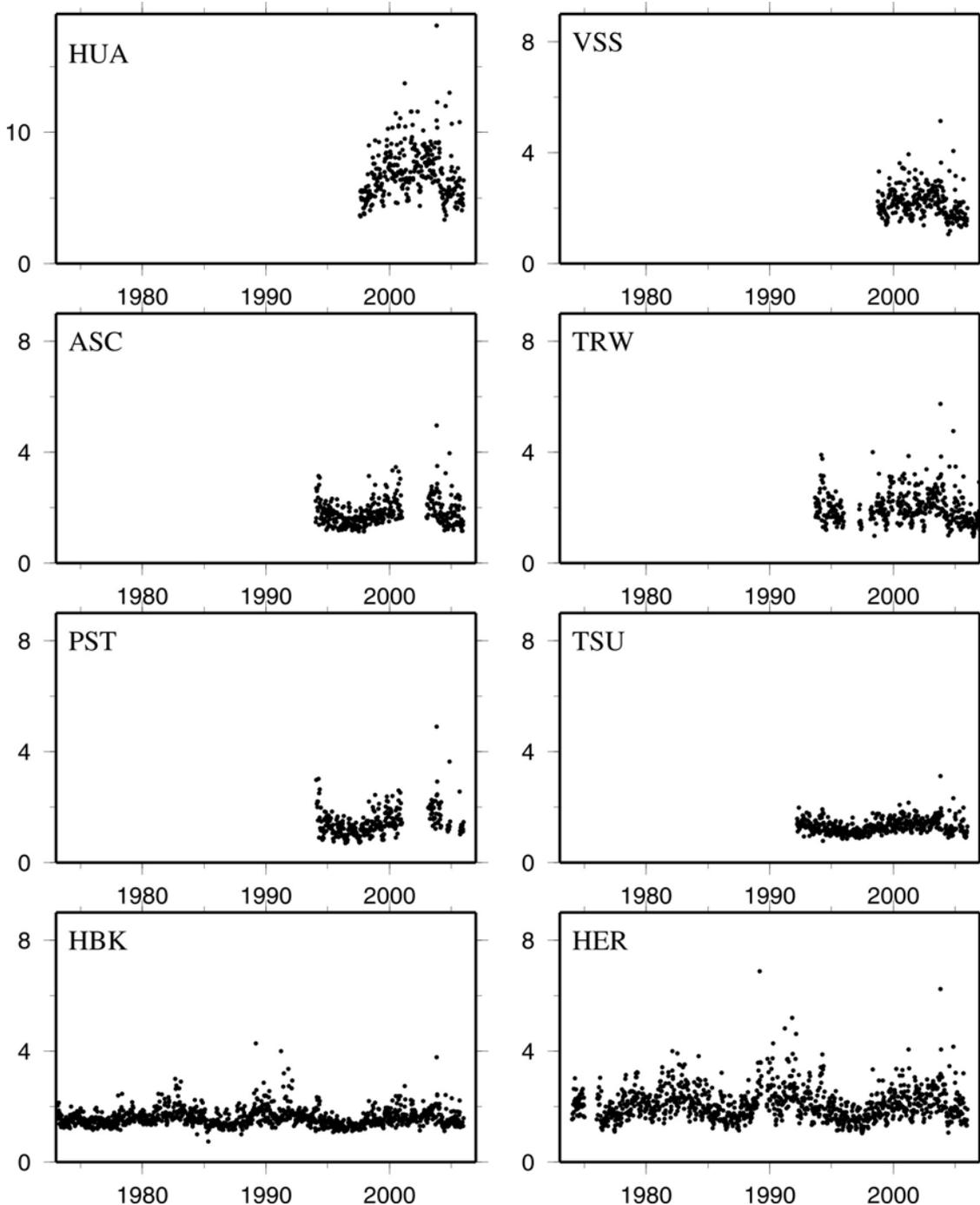


Figure 6 Ten-day means of hourly standard deviations of total intensity (nT). Note different scale used for HUA which is close to dip equator and therefore affected by the equatorial electrojet. Observatories organised by |inclination| from left to right, top to bottom.

From Figure 6, the solar cycle signal and the enhanced external field level for Huancayo (HUA) observatory near the dip equator are to be noted. No other obvious long-term trends are apparent.

The same exercise is undertaken for a selection of observatories outwith the SAA area but at similar (geomagnetic) latitudes to those inside. The selected observatories have magnetic field strength more than 30 μ T but are within the inclination range of those observatories inside the

SAA, and, additionally, have series of minute means which extend more than 10 years and have a good global coverage. To demonstrate this selection based on inclination and total intensity, and to illustrate the asymmetry of the Earth's magnetic field introduced by the SAA, Figure 7 shows the locus of modelled values (at 2005.0) of inclination and total intensity for the whole of the Earth's surface and for the observatories used in this study (JCO, LER, ESK and HAD not included in minute mean analysis but are shown on this plot because they are used later for comparing micropulsations).

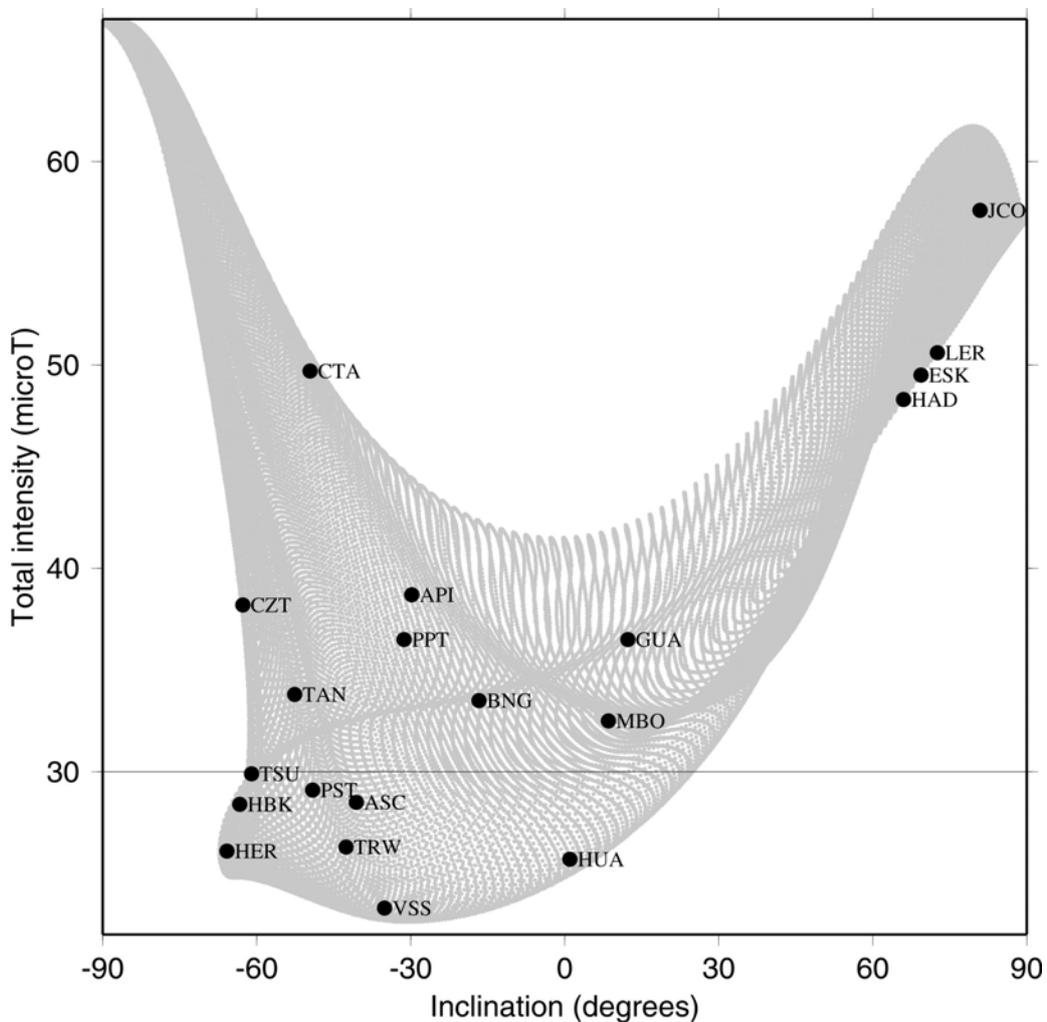


Figure 7 Locus of modelled values of inclination and total intensity from the 10th generation IGRF at 2005.0 for the whole of the Earth's surface and for the observatories whose minute means and 1-second values were used in this study. Below the 30 μ T line indicates region of the SAA. If the field was dipolar the locus would be a parabola

The effect of high latitude current systems in all selected observatories is assumed to be small. Ten-day means of hourly standard deviations are plotted in Figure 8.

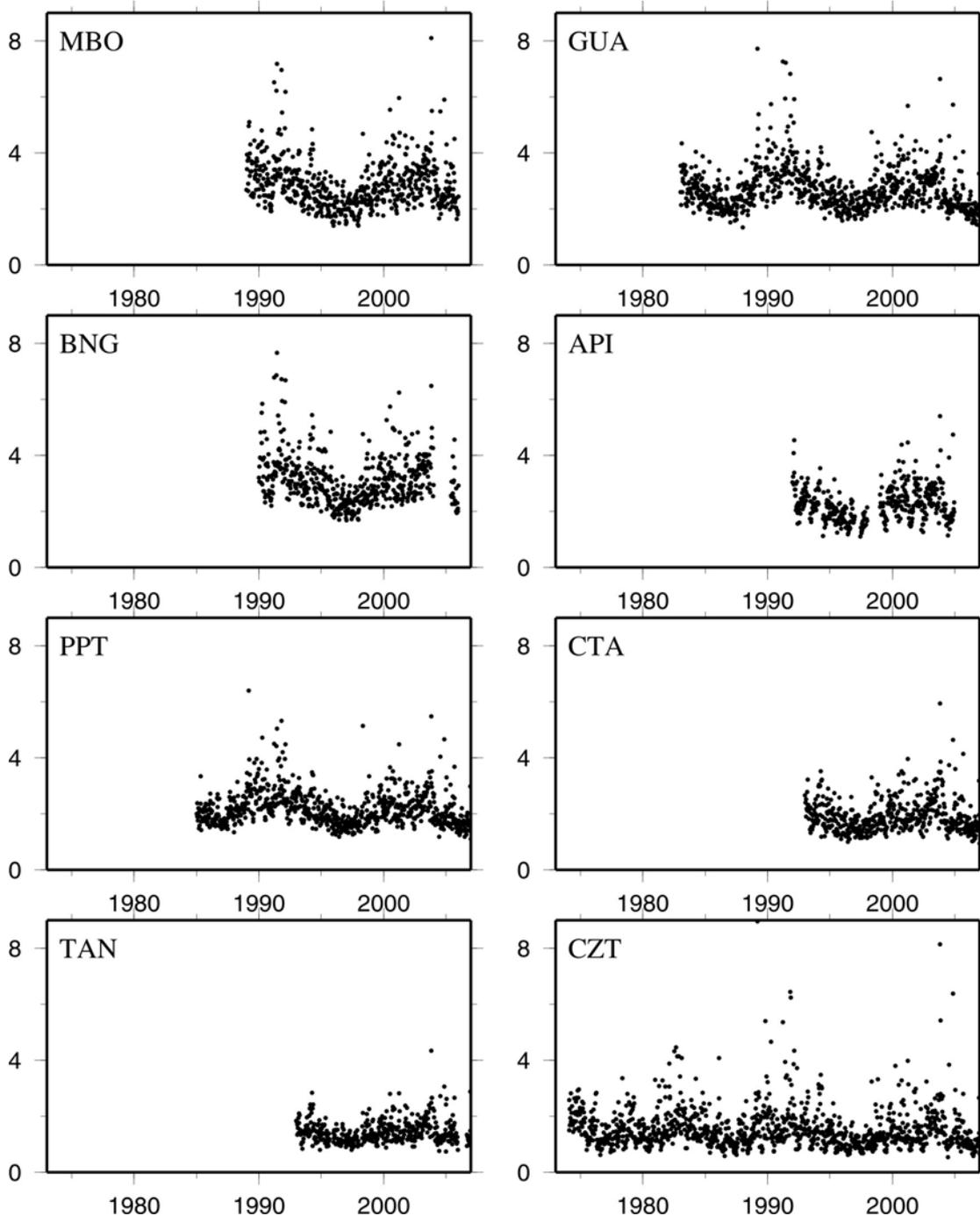


Figure 8 Ten-day means of hourly standard deviations of F (nT) for observatories outside SAA. Observatories organised by $|\text{inclination}|$ from left to right, top to bottom.

The variable solar cycle amplitude can be seen but without more detailed analysis it is not possible to say whether there is any “local” interaction, for example due to the SAA, between the system generating the external field signals and the internal magnetic field.

Both inclination and strength of the internal field at the observatories used in this study were expected to have an influence on the amplitudes of the external fields observed, but little discernible pattern is observed between the general amplitude of the external fields (as determined by 10-day means of hourly standard deviations) and long-term means of inclination or total intensity.

Finally we take a detailed look at a single magnetic storm and examine its characteristics using 1-second data at several observatories including Ascension and Port Stanley. This is possible because BGS observatories have been routinely collecting 1-second data since 2002. Figure 9

shows the filtered (2-1000 s) north and east components at BGS observatories during the 30th October 2003 “Halloween” magnetic storm. This represents the broadband pulsations. There is a relatively strong 10-20 minute period oscillation observed at PST between 20:30 and 22:30 that is not as clearly seen elsewhere.

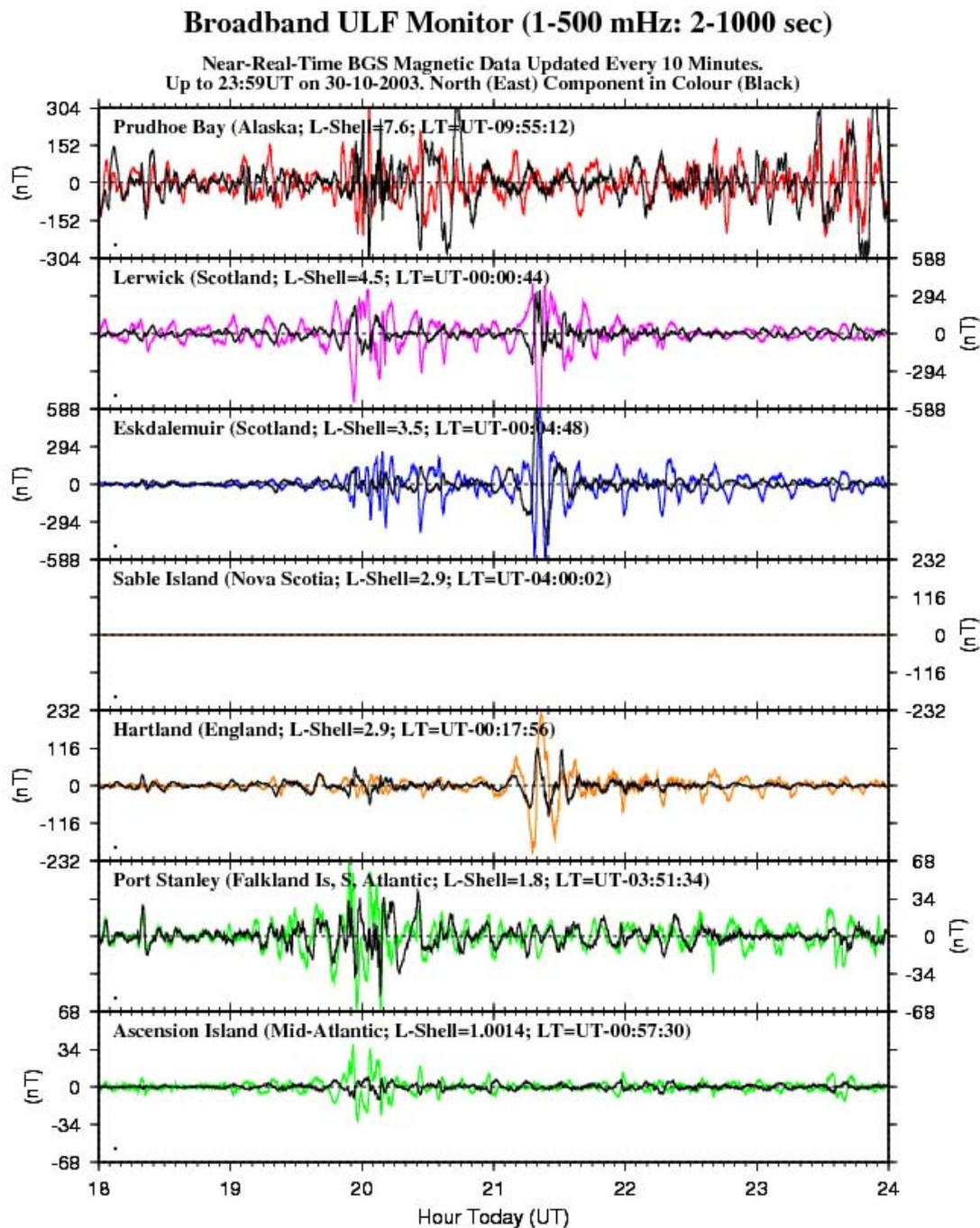


Figure 9 Stack plot of filtered (2-1000 s) north (X, coloured line) and east (Y, black line) BGS observatory measurements during the 30th October 2003 magnetic storm, for six hours when the 3-hour magnetic activity index ap was sustained at its maximum of 400. Magnetic L -shell (McIlwain, 1961) and local time (LT) are noted for each observatory. Note that 1-second data from the Sable Island observatory were unavailable at this time.

Figure 10 shows filtered (40 – 150 s) data, representing the Pi2 pulsation band. Activity in this band occurs in connection with magnetospheric substorms. Note the larger peak amplitude

observed at Port Stanley ($L = 1.8$) compared with Hartland around 20:00 UT, but absence of activity (or at least much reduced activity) from 21:00 – 23:00 at both PST and ASC, both inside the SAA.

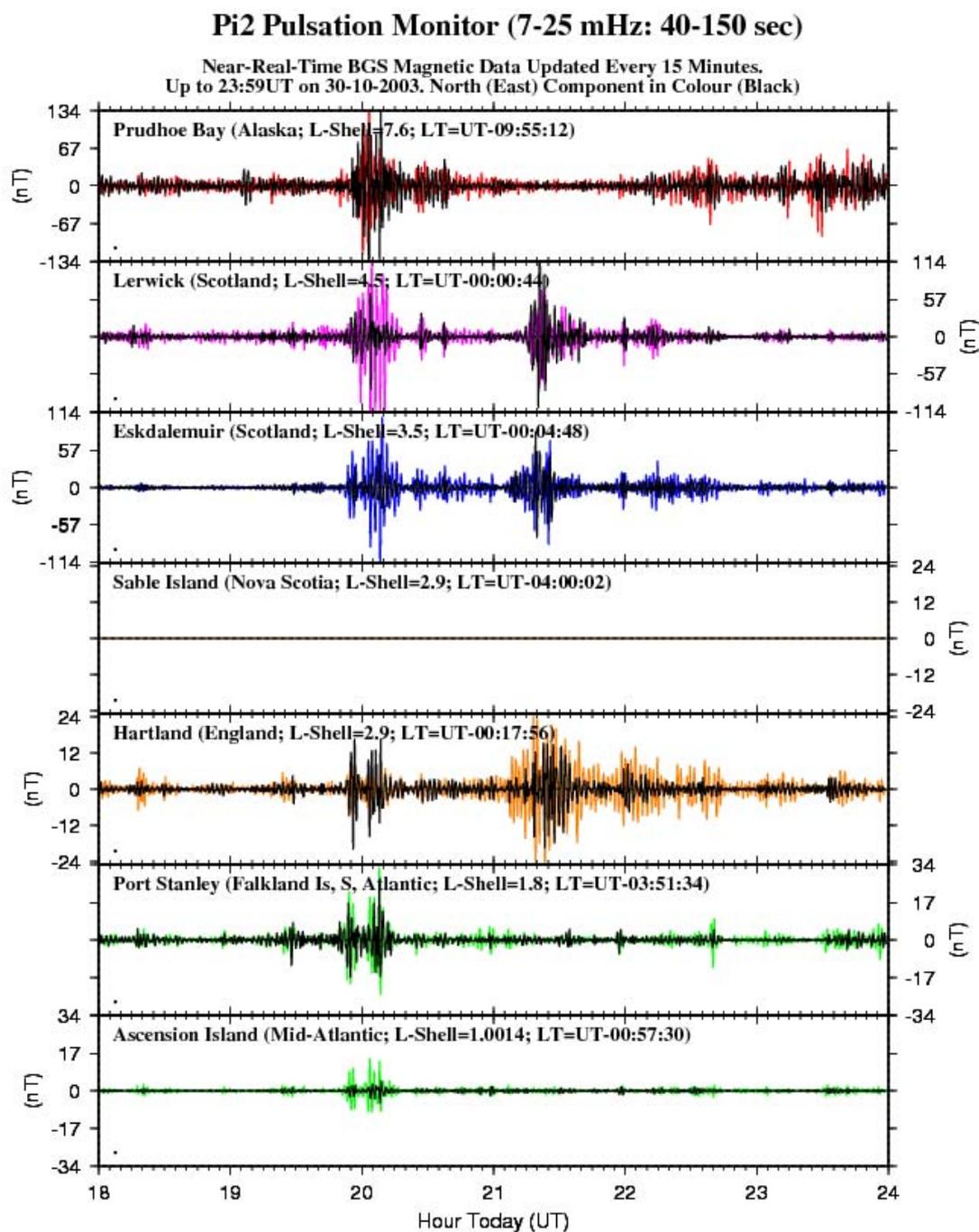


Figure 10 Similar to Figure 9 but output from the Pi2 waveband (40-150 s)

Tables 1 and 2 list the RMS and peak amplitudes associated with the pulsations during 30th October 2003 shown in Figures 9 and 10, and compares them with values from a quiet period at same time of day but a few days earlier.

Observatory	L-Shell (Earth Radii)	Activity Conditions	X rms (nT)	Y rms (nT)	X peak (nT)	Y peak (nT)
JCO Alaska	7.6	Storm	65.8	87.8	304.4	415.5
		Quiet	5.2	4.1	28.9	16.5
LER Scotland	4.5	Storm	112.0	45.8	949.6	339.3
		Quiet	0.4	0.4	2.2	2.9
ESK Scotland	3.5	Storm	96.6	70.6	614.2	706.5
		Quiet	0.4	0.3	2.1	1.8
HAD England	2.9	Storm	32.2	16.9	231.2	117.2
		Quiet	0.2	0.2	1.1	0.8
PST Falkland Islands	1.8	Storm	12.5	9.0	72.7	51.7
		Quiet	0.2	0.2	1.0	0.9
ASC Ascension	1.001	Storm	5.6	2.3	38.6	12.1
		Quiet	0.1	0.1	0.4	0.3

Table 1 RMS and peak amplitudes for the six observatory filtered series shown in Figure 9 (18:00 - 00:00 UT on 30th October 2003, when $ap = 400, 400$), compared to a quiet period from the same month (18:00 - 00:00 UT on 27th October 2003, when $ap = 5, 4$). North (X) and east (Y) geocentric amplitudes are given.

Observatory	L-Shell (Earth Radii)	Activity Conditions	X rms (nT)	Y rms (nT)	X peak (nT)	Y peak (nT)
JCO Alaska	7.6	Storm	16.3	16.2	133.7	173.2
		Quiet	0.6	0.4	3.4	1.8
LER Scotland	4.5	Storm	16.1	11.0	196.4	129.3
		Quiet	0.1	0.1	0.8	0.3
ESK Scotland	3.5	Storm	13.6	8.1	132.1	84.0
		Quiet	0.1	0.1	0.7	0.4
HAD England	2.9	Storm	4.2	2.8	27.6	20.1
		Quiet	0.1	0.1	0.6	0.2
PST Falkland Islands	1.8	Storm	3.0	2.2	33.2	25.4
		Quiet	0.1	0.1	0.2	0.1
ASC Ascension	1.001	Storm	1.3	0.5	14.0	5.3
		Quiet	0.1	0.1	0.2	0.1

Table 2 As Table 1, but showing the RMS and peak amplitudes for the six Pi2 observatory series shown in Figure 10

There is some evidence that SAA stations show more power (shaded in Table 2) in the Pi2 band (40 - 150 s) than might be expected due to their latitude (c.f. equivalent shaded boxes in Table 1 for 2 – 1000 s). This provides some support for the result of Trivedi *et al.* (2005), who claim extra electron precipitation due to SAA causes enhanced pulsation amplitudes. However what is demonstrated here is that this is the case only sporadically.

Conclusions

With 15 years experience in operating magnetic observatories on Ascension Island and the Falkland Islands, it is clear that operating a magnetic observatory at a remote location is challenging both in terms of engineering and logistics. It is also costly in time, money and resources, and hence it is not surprising that the distribution of observatories in the South Atlantic is sparse or that data from these observatories sometimes contain gaps. Despite this, the success of the BGS observatories has improved markedly over recent years as the points of failure have been removed and better communications and more reliable instrumentation have been put in place.

The principal factor, however, in successfully maintaining continuous recordings at the BGS observatories has been to have access to local staff with engineering experience. Although the

observatories are monitored from the United Kingdom, they have benefited greatly from the help of local engineers who are available to maintain instrumentation should the need arise, as well as to make absolute observations. Also, BGS sites have been selected with a preference for reliable power supply and bi-directional communications, even if this has been at the expense of some data quality. Although this means that the observatories are sited close to other facilities, making use of existing infrastructure to reduce costs, this simplifies installation and improves reliability.

With regards to the hypothesis that the remarkable changes in the internal magnetic field that have been seen in the last few decades in the south Atlantic should have an effect on the magnetic fields generated external to the Earth, we conclude that further analysis is required. At the moment none of the datasets are sufficiently long compared to the 11-year solar cycle to allow isolation of any significant trends. However, the existence of high frequency micropulsation signals at locations where the magnetic field lines close on the Earth far from the polar areas is unexpected. Clearly more study on this is needed using data during several storms. A polarisation study could also be revealing; it may be that there are different X/Y phase relationships observed at sites inside and outside the SAA.

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