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Behaviour of the quiet-day geomagnetic variation at Livingston Island and variability of the S_q focus position in the South American-Antarctic Peninsula region

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Characteristics of the regular daily variation, including seasonal and solar cycle variabilites, at the relatively new geomagnetic observatory of Livingston Island (Antarctica) have been studied. Such studies of solar cycle variability were possible due to the current availability of more than 11 years of definitive data. The seasonal behaviour of the quiet-time daily field variations are in agreement with those of earlier studies for a mid-latitude observatory placed at the south of the southern hemisphere current focus. We also found a clear dependence of the S_q amplitude on solar activity, although the S_q amplitude maximum occurs about 2 years later than the sunspot maximum. An analysis of contemporary data for solar cycle 23 was carried out for observatories located in the same longitudinal sector, with the aim of identifying the latitudinal displacements of the current focus that affect the observed S_q variations. This was also determined for solar cycle 20 using data from a different set of observatories. The uncertainties associated with the method employed for determining the focus positions are due to the scarcity of observatory data in the South American-Antarctic Peninsula region, but based on our analysis, we can state with a certain reliability that focus latitudes are higher during the summer and at equinoxes than during the winter. However, it is difficult to establish a correlation between focus latitudes and solar sunspot numbers.

Key words: S_q variation, quiet day, focus position, Livingston Island Observatory, South American-Antarctic Peninsula region, ionospheric current system, solar cycle 23.

1. Introduction

Although the ionospheric current system responsible for the regular daily variation has already been derived from observatory magnetograms (e.g., Chapman and Bartels, 1940; Mayaud, 1965; Matsushita and Maeda, 1965), it is interesting to determine the characteristic seasonal and solar activity dependences of the regular variation at a new observatory location. This regular variation is known as "solar quiet variation", or simply S_q. The difference between this and the variation termed S can be somewhat subjective on occasion. S usually refers to the variation resulting from an analysis carried out on all days except those classified as disturbed, while the term S_q tends to be assigned to the variation observed when only quiet (or those classified as quiet) days are used. When one deals with the regular variation over a single particular day, the term S_R is generally used.

The Livingston Island Observatory (62.67°S, 60.39°W, geomagnetic latitude 52.57°S) is operated by the Ebro Observatory Institute (Spain) and was deployed in December 1996 in the vicinity of the Spanish Antarctic Station, which is situated in the South Shetland Islands, north of the Antarctic Peninsula. The observatory has been operating reliably since its installation. The observatory installations consist of three huts. One hut houses the absolute instrument, the so-called D/I fluxgate theodolite, which enables the Declination and Inclination angles of the vector magnetic field to be manually measured in "absolute" terms (for a discussion of the uncertainties associated with this instrument, see Marsal and Torta, 2007). A second hut houses a variometer of the type $\delta D/\delta I$ vector magnetometer (Riddick *et al.*, 1995), which automatically measures the variations of the magnetic field vector once per minute. This instrument consists of two perpendicular pairs of Helmholtz coils, the polarization of which allows Declination and Inclination variations to be measured by means of a proton magnetometer located at their centre (see Marsal *et al.*, 2007 for an assessment of this instrument). The proton magnetometer, in turn, measures the total field intensity, F, when the coils are not polarized. The electronic system controlling this automatic instrument is found in the third hut. The International Association of Geomagnetism and Aeronomy (IAGA) has officially recognised the Livingston Island Observatory and given it the code name LIV. It has served as a base station for the reduction of marine magnetic surveys in the zone (Maldonado *et al.*, 2000; Livermore *et al.*, 2000; Catalán *et al.*, 2006), and its data have already been used in several studies and models (Torta *et al.*, 1999, 2001, 2002; Cain *et al.*, 2003; Gaya-Piqué *et al.*, 2006;

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Marsal and Torta, 2007; Marsal *et al.*, 2007). Apart from a few data gaps due to power supply interruptions, there are presently more than 11 years of definitive data (observatory data which have been corrected for baseline variations and which have had spikes removed) available, with the particular added value that they coincide with the complete solar cycle 23. Thus, it is now possible to obtain a complete picture of the seasonal and solar cycle evolutions of the amplitude ranges and other relevant characteristics of the S_q field at the location of LIV.

To understand S_q behaviour, it is necessary to examine the sources from which such variations originate: the current systems flowing in the so-called ionospheric dynamo region and the induced telluric currents in the Earth's upper mantle. These currents, in turn, generate additional magnetic field variations that are almost in phase with the primary variations. The morphology of the atmospheric tides gives the ionospheric currents a whorl configuration, with two vortices, one in each hemisphere, and foci at mid-geomagnetic latitudes that occur about 1 h before local noon. The variability of the current intensity and the complicated morphology of the corresponding whorl and its latitudinal or local time displacements with respect to a given observatory location give rise to different patterns of the daily variation of the geomagnetic elements at that specific observatory (Mayaud, 1965). Thus, it is also important to analyse contemporaneous patterns at neighbouring observatories, with the aim of identifying the shape and displacements of the current focus.

Geomagnetic observatories in the South American-Antarctic Peninsula region are rather scarce in comparison with those other regions of the world, such as Europe, North America or Eastern Asia. In those latter, more densely covered areas, it is possible to perform regional harmonic analyses that provide a motion picture representation of the current system, thereby allowing the study of continuous variations with either local or universal time (Haines and Torta, 1994; Torta *et al.*, 1997; Gaya-Piqué *et al.*, 2008; Stening, 2008). However, under regular conditions, the ionospheric current system is generally assumed to remain approximately constant in form over a given day, fixed with respect to the Sun, which is equivalent to assuming that the variations only depend on latitude and local time. For this reason, it is possible to carry out an estimation of the position of the current system focus using data available from only a certain group of observatories distributed in latitude over a narrow sector of the Earth (Stening *et al.*, 2005, 2007).

With all this in mind, the aim of the study reported here was to investigate the variations of S_q at LIV using the data corresponding to quiet days taken from the whole time span of data. We also examined the latitudes of the focus of the southern hemisphere ionospheric current system in the respective sector using the available observatory data. The results of our investigation are discussed relative to those from earlier studies.

2. Data

The data used were the mean hourly values of the horizontal intensity (H), declination (D) and vertical intensity

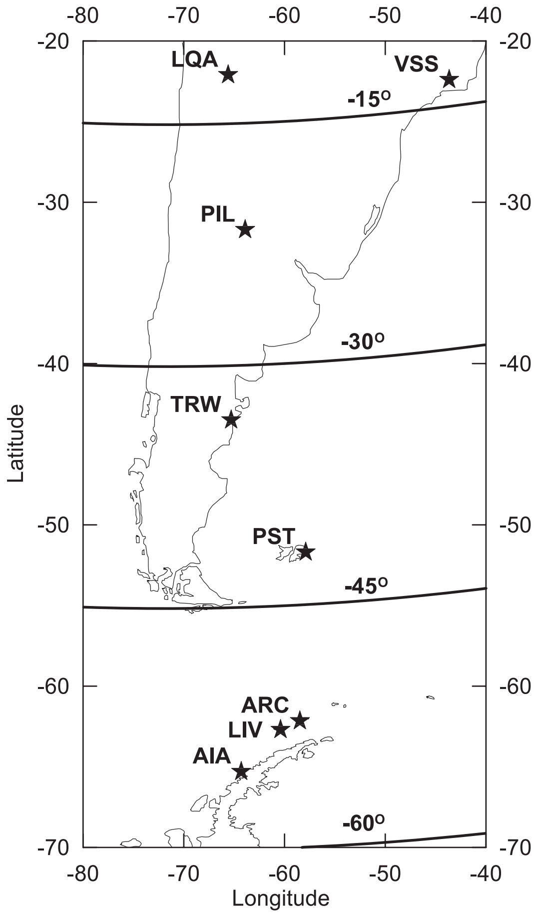

Fig. 1. Map showing the locations of the observatories in this study. Geomagnetic latitudes of −15°, −30°, −45° and −60° are shown. LIV, Livingston Island Observatory; VSS, Vassouras; LQA, La Quiaca; PIL, Pilar; TRW, Trelew; PST, Port Stanley; ARC, Arctowski; AIA, Argentine Islands.

(Z) recorded at LIV from January 1997 onwards. Values from Vassouras (VSS, 22.40°S, 43.65°W, geomagnetic latitude 13.29°S), La Quiaca (LQA, 22.10°S, 65.60°W, geomagnetic latitude 11.90°S), Pilar (PIL, 31.67°S, 63.88W, geomagnetic latitude 21.50°S), Trelew (TRW, 43.25°S, 65.31°W, geomagnetic latitude 33.05°S), Port Stanley (PST, 51.70°S, 57.88°W, geomagnetic latitude 41.69°S), Arctowski (ARC, 62.16°S, 58.48°W, geomagnetic latitude 52.11°S) and the Argentine Islands (65.25°S, 64.27°W, geomagnetic latitude 55.06°S) were obtained from the World Data Centre (WDC) for Geomagnetism in Edinburgh (http://wdc.bgs.ac.uk/catalog/master.html). The geographical location and availability of the different observatory data are given in Figs. 1 and 2, respectively. As stated in the Introduction, the data distribution in terms of both space and time is far from ideal. In addition to the gaps reported by the WDC catalogues, which are reflected in Fig. 2 and which represent a complete absence of three-element data in a particular month, a frequent finding is the appearance of months in which there are insufficient data to allow us to achieve an average quiet-day variation or of months lacking one or two elements. However, there are sufficient data to attempt an analysis of the focus position throughout solar cycle 23. For periods before solar cycle 23, PST and LIV

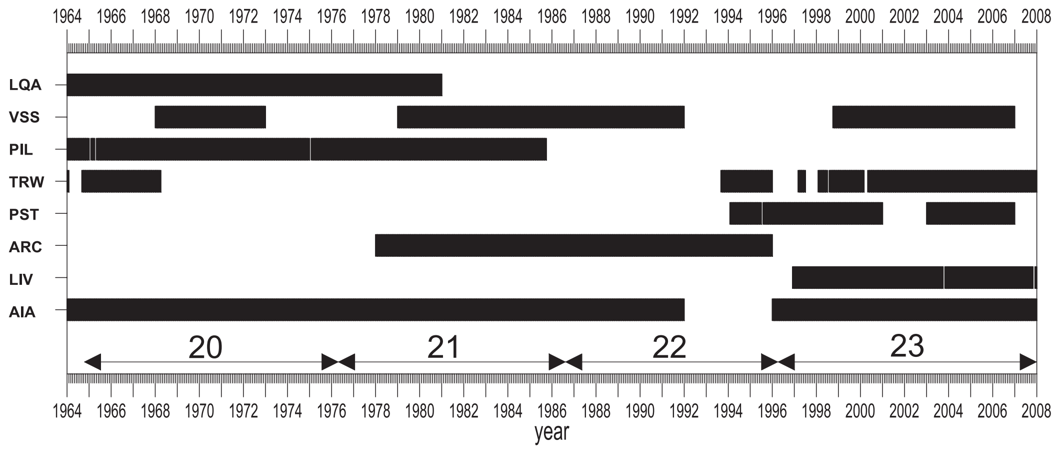

Fig. 2. Histogram showing the availability of data from the different stations with respect to the last four solar cycles.

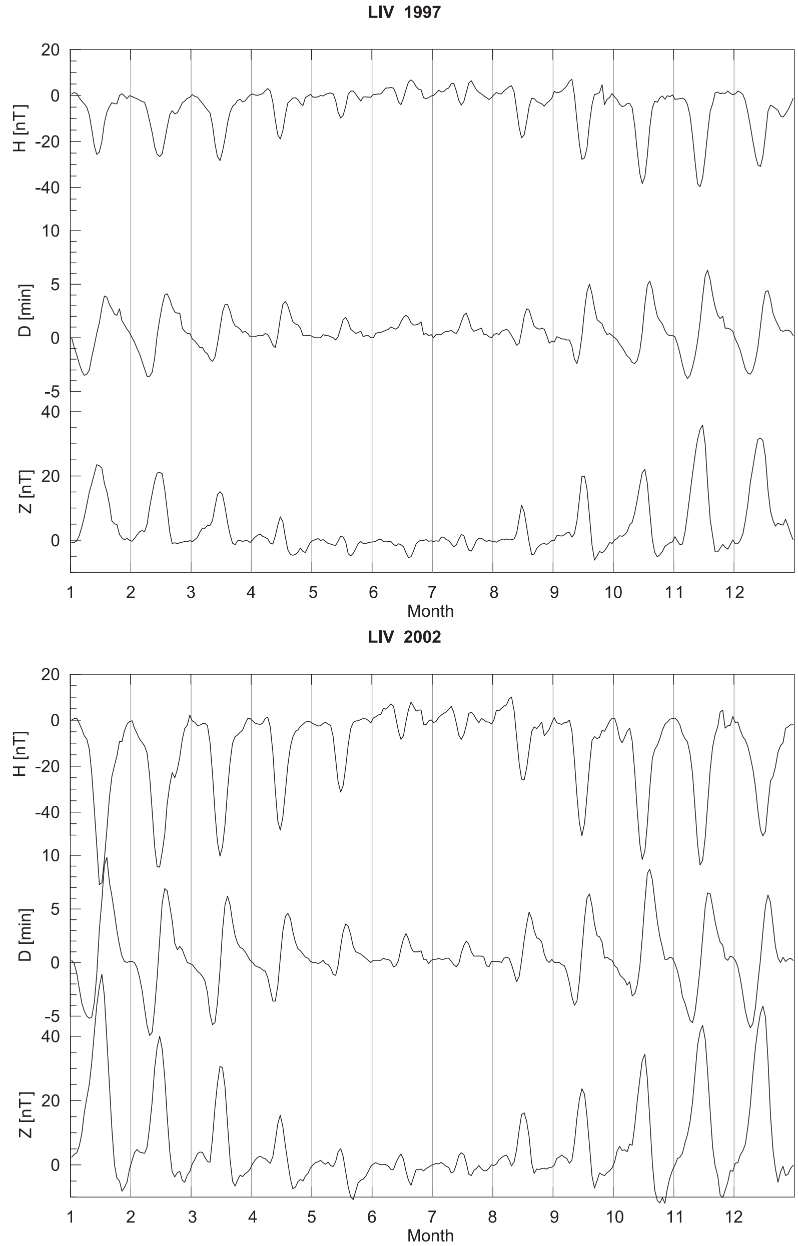

Fig. 3. Daily LT variations at LIV for a low- (top) and a high (bottom)-activity year. These variations were obtained from hourly mean values averaged over the five quietest days of each month.

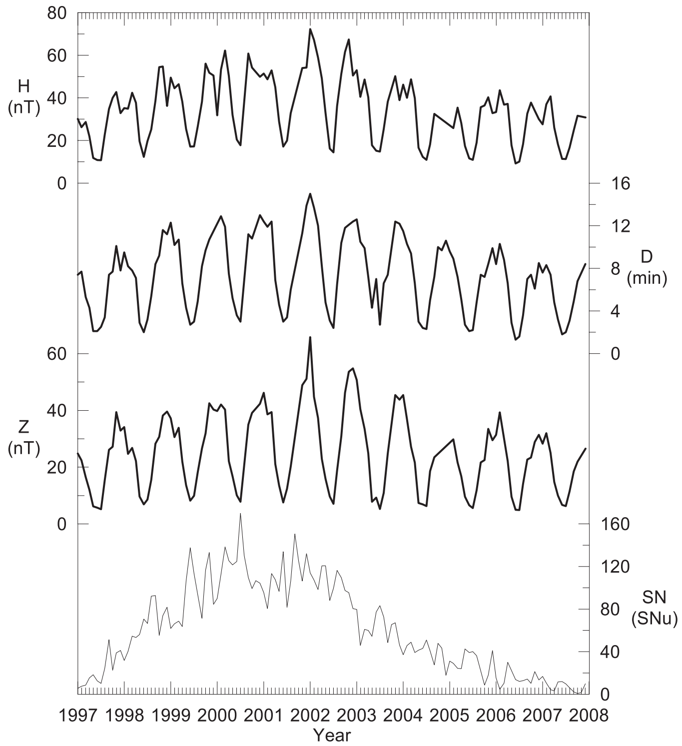

Fig. 4. Time evolution of the daily amplitude of the S_q variation at LIV and of the monthly averaged solar sunspot number (SN).

were not yet in operation, significantly limiting the southern control of such an analysis because, as will be discussed in Section 4, AIA is located too far south to provide suitable data for the focus determination during the winter. Data from ARC could be used to substitute LIV data for solar cycle 22 and part of solar cycle 21, and LQA and PIL provided useful data for solar cycle 20 and part of solar cycle 21 which served as the northern control of the analyses.

The values for the S_q variations were obtained by subtracting from the observatory hourly means, a trend determined by the two local midnight levels on each side of the quiet day. The local midnight level was computed as a four-hourly mean centred on local midnight. The study was carried out on a monthly basis, based on monthly averages using the five International Quiet Days of each month. This selection was chosen for simplicity and could certainly be improved, as it is well-known (Campbell, 1979; Torta *et al.*, 1997; Janzhura and Troshichev, 2008) that special attention has to be paid to the selection of the representative quiet days for the definition of the genuine S_q variation. Furthermore, the magnetic quiescence is defined for astronomical days (0–24 UT), which do not necessarily coincide with the LT days at the given observatories, which are located between 43° and 65° west of the Greenwich meridian. However, stricter selections frequently give rise to months with very few representative days left, or even none at all (Torta *et al.*, 1997). In addition to the scarcity of observatories, observatory data are not complete, and some important gaps are detected from time to time, so those better selections would have precluded obtaining representative results for the whole seasonal and solar cycle spans.

3. Variations at LIV

Monthly averaged quiet-day variations were obtained for H, D and Z at LIV following the procedure described in Section 2 for each year of the 1997–2007 period. Examples for typical high- and low-activity years are given in Fig. 3. The daily magnetic variation is at a maximum around the summer solstice (December and January) and progressively fades through the equinoxes to the winter solstice (June and July). This is coherent, since the variation of electron density in the ionospheric E-region is at its maximum in the summer and at its minimum in winter, as shown in the current density and the magnetic field that it generates. The S_q amplitudes are about twofold larger in active years than in quiet years.

The evolution of the monthly averaged daily ranges (maximum − minimum variation values) through the complete time span for the three elements is shown in Fig. 4. This figure also shows the seasonal and solar cycle variations (the monthly solar sunspot number (SSN) is also given for comparison), along with some sporadic deviations from the regular pattern due to sudden increases in magnetic activity. These deviations might have been worsened by the contemporaneous lack of available representative quiet-day data.

H amplitudes range from around 10 nT in winter to 30 nT in summer at the solar minimum, and from 15 nT to 70 nT at the solar maximum. D amplitudes range from around 2 arc-min in winter to 8 arc-min in summer at the solar minimum, and from 3 arc-min in winter to 15 arc-min in summer at the solar maximum. Z ranges from around 5 to 25 nT, and from 7 to 65 nT, respectively.

It is generally assumed that the amplitude of the ionospheric field variations, with its associated induced field

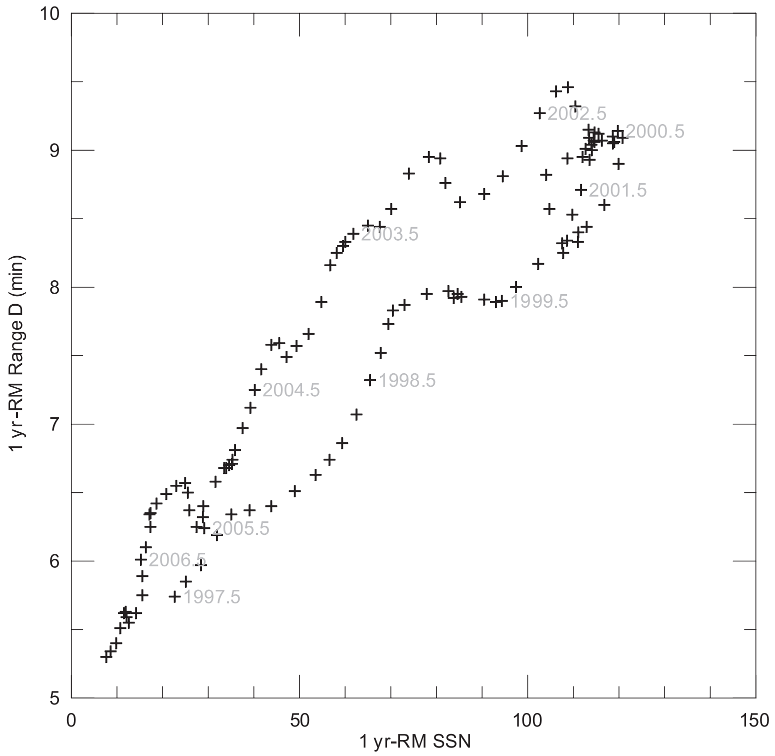

Fig. 5. One-year running mean of the monthly mean values of the daily range of D at LIV versus the corresponding values of the solar sunspot number (SSN). Labels every 12 months indicate the time evolution.

variations, varies linearly with the solar activity (Olsen, 1993). To verify if this is the case for LIV, we also studied the correlation between the 1-year running averaged D ranges and the corresponding smoothed (1-year running mean as well) monthly SSN (Fig. 5). As in Torta *et al.* (2009), this element (the Y component would be equivalent) was chosen because it is the most stable element when dealing with focus drifts; H and Z ranges can be more affected by latitudinal displacements of the S_q focus. Figure 5 shows that the points corresponding to the descending phase of the cycle do not lie around the same line as those corresponding to the ascending phase. The result is an overall elliptical shape pattern, indicating some hysteresis between both signals. There is, however, an apparent change to a lower slope between moderate and high activity in both phases of the cycle. With respect to the other observatories during solar cycle 23 (not shown here), AIA shows a very similar behaviour as does TRW, although with almost a null slope during moderate activity in both phases of the cycle. It is more difficult to follow the whole pattern at PST and VSS because the data from these two stations have a number of gaps (see Fig. 2), but the data are more erratic, especially during the descending phase of the cycle.

4. Variability of the S_q Focus Position

Using the available data from the chain of observatories described in Section 2, we estimated the variability of the S_q focus position with the method suggested by Stening *et al.* (2005, 2007). The first step was to determine the time t_0 when the variation of D passes through zero at each observatory. The variation ΔH evaluated at time t_0 is then plotted against latitude, and the focus position is obtained from a least squares fit; namely, that latitude at which this line crosses zero. The known strong day-to-day variability of the focus position along with some complexities that differ from the standard S_q current behaviour, which converts the monthly patterns into averages of heterogeneous behaviours on many occasions (Torta *et al.*, 1997), dissuaded us to study month-by-month changes. Thus, the analysis was developed on a seasonal basis (taking the variations of H and D from all the available international quiet days for each Lloyd's season of each year) and for the time span bounded by the availability of LIV data, i.e., 1997–2007, which roughly coincides with solar cycle 23. Lloyd's seasons (Lloyd, 1861) at the Southern hemisphere are divided into three categories: (1) winter (months of May, June, July and August); (2) equinoxes (March, April, September and October); (3) summer (January, February, November and December).

Figure 6 is an example (1999, equinoctial season) of the average daily variations for the three elements recorded at the different observatories, with typical amplitudes according to the latitudinal location of the observatory with respect to the focus position. At first glance, one realizes that the focus passes close to the location of TRW and that Z variation at PST is anomalous, since its amplitude should be higher (roughly a value between those of LIV and TRW). This different behaviour of Z at PST occurs for all seasons and years. Despite all of the difficulties that have been encountered at this site over the years (Macmillan *et al.*, 2009), it is doubtful that this deviant behaviour could be caused by any measurement effects (cultural noise or temperature-related). One possible cause may be the motional induction effect caused by ocean tides which, with the fairly deep water in

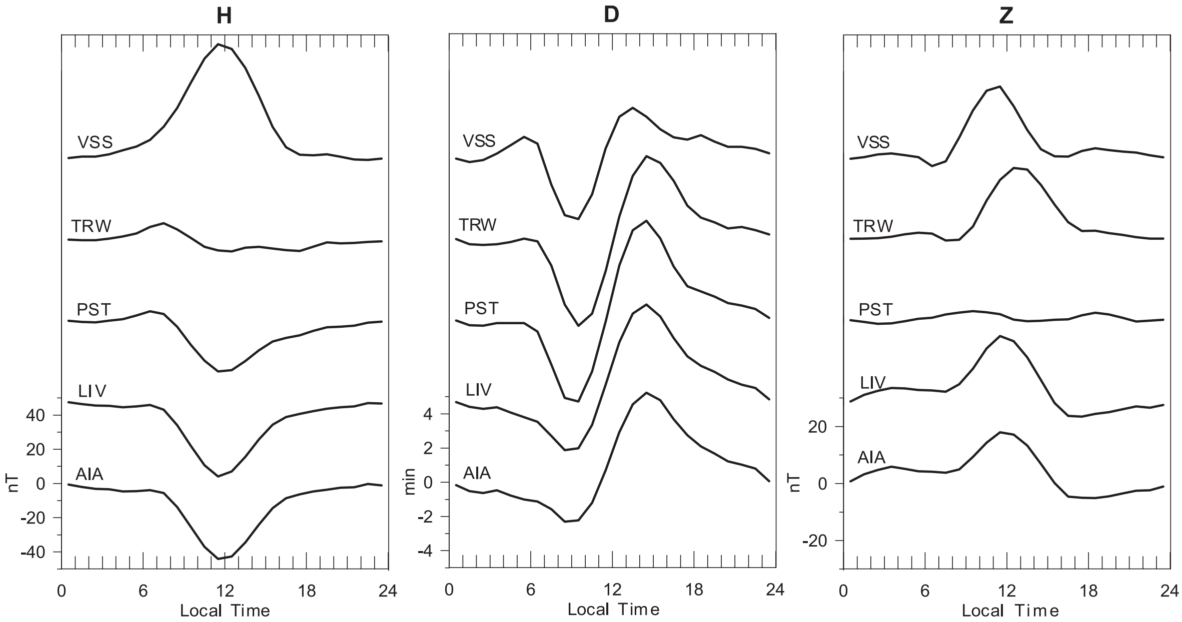

Fig. 6. Averages for the equinoctial season daily variations at the different observatories for 1999.

the region of the Falkland Islands, may be significant and counteract the vertical magnetic effect from the ionospheric current expected from the S_q dynamo (S. Macmillan, personal communication).

To evaluate our procedure and to determine whether some of the more peripheral observatories are actually suitable for focus latitude determination, we estimated the typical H variation when the variation of D passes through zero at different locations as a function of geomagnetic latitude from a comprehensive model of the quiet-time, near-Earth magnetic field (Sabaka *et al.*, 2004). This comprehensive model accounts for contributions from the Earth's core, lithosphere, ionosphere, magnetosphere and coupling currents and, additionally, accounts for influences of main field and solar activity variations on the ionosphere. The results for a specific year and for the three Lloyd seasons are given in Fig. 7. This figure shows that the linearity is acceptable for the range of geomagnetic latitudes considered in our investigation, with the exception of those of LQA and VSS for the summer and LIV and AIA for the winter. The latitudinal movement of the S_q current focus according to the solar zenith angle explains the exceptions; that is, the linearity only stands for locations relatively close to the focus.

The times at which the variation of D passes through zero at each observatory (t_0) are given in Fig. 8. The gaps in the figure for some observatories in particular seasons are either due to a lack of data or because the average daily variation of D in those seasons did not pass through zero, as it was always positive. This can occur on occasion during the winter at observatories located at the highest latitudes and did occur in 1997 and 2003 at LIV and in 1997, 1998, 2003, 2004, 2005 and 2006 at AIA. The explanation for this may be given by the fact that the variations appearing in the magnetograms mainly include the effect of the S_q currents but they also contain other contributions of magnetospheric origin, such as those from field-aligned currents (FAC) (e.g., Xu, 1992). Since the S_q variation of D is particularly weak in winter at those relatively high-latitude observatories, the superposition of the FAC magnetic effect masks the true S_q variation pattern. The solar zenith angle χ at AIA and LIV goes as high as 86° in winter compared to 39° in summer; as such it is the controlling influence on the amplitude in winter and may also explain the general erratic time of the appearance of the focus in winter. On the other hand, the delay usually observed at VSS in this season (always between 0.5–1.5 h after local noon) is suspected to be a consequence of another contamination current: the meridional current system at low latitudes connected to the equatorial electrojet (Richmond, 2002).

An example of the representation of the H amplitudes versus the observatory latitudes used to determine the focus of the current system by least squares fits is given in Fig. 9. The points of AIA and LIV for winter and VSS for summer do not lie close to the straight line given by the rest of the observatories due to the effect explained above and, consequently, they were not taken into account for the least squares fit. Similar behaviours were found for the remaining years considered in our study and, as already stated by Stening *et al.* (2005), the high correlation coefficient obtained for all the fits (between -0.96 and -1.00) gives a good indication of the reliability of the determination. An indication of the consistency between the data and the method is also provided by the standard uncertainty (see ISO, 1993) associated to the fits, represented in Fig. 9 as shaded areas.

The evolution of the focus latitude obtained using this approach for each year and season is given in Fig. 10. The error bars indicate the standard uncertainty of the determination associated solely with the method of fitting straight lines to the variation of H when $D = 0$ at each observatory, and for this reason it closely corresponds to the uncertainty of the zero-crossing associated with the shaded areas depicted in Fig. 9. We did not consider any additional uncer-

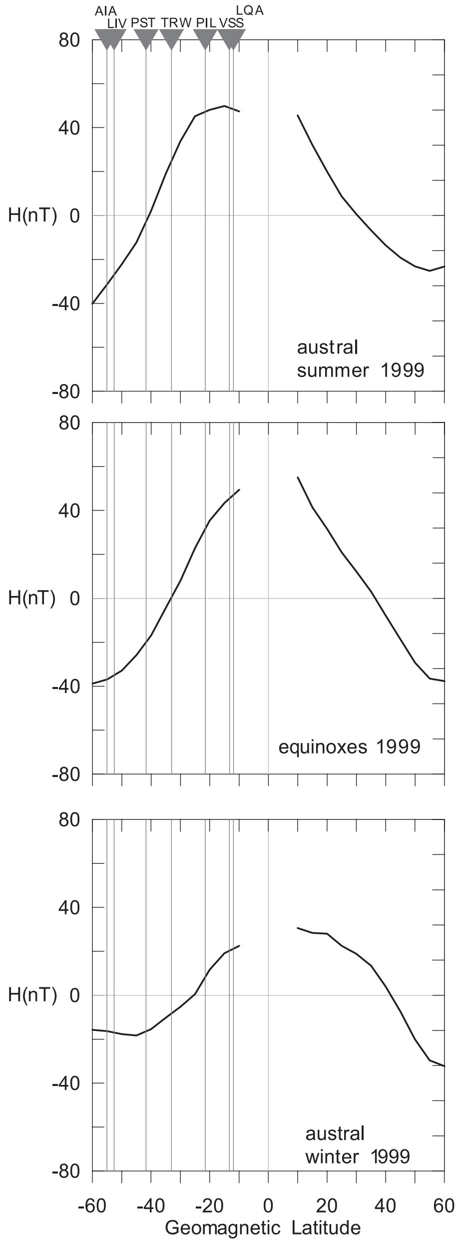

Fig. 7. Typical H variation for the average of five International Quiet Days of each month for 1999 when the variation of D passes through zero at different locations (every 5° and excluding the points closest to the geomagnetic equator) as a function of geomagnetic latitude from the CM4 model. Positions of the observatories used in the analyses are given according to their geomagnetic latitude.

tainty estimations associated with the degree of quietness of the selected five International Quiet Days of each month with the process of averaging per seasons or with the determination of the times at which the variation of D passes through zero at each observatory. The scarcity of the data, a situation worsened by our rejection of data obtained during the winter from the AIA and LIV stations, left some of the determinations with only two observatories. Although this did not impede the linear fitting, it did prevent an estimation of the uncertainty. We found that our method provided the most confidence for the summer season.

To further evaluate the consistency of the procedure, we determined from a different set of observatories the position of the focus for solar cycle 20, which has a maximum amplitude of SSN similar to solar cycle 23. As seen in Fig. 2, the observations used for our analysis of solar cycle 20 were from LQA, PIL, TRW and AIA. The results of this new determination are given in Fig. 11. The focus latitudes for each season can be seen to be similar to those obtained for solar cycle 23, with the exception of equinoxes in 1964 and from 1969 onwards, which tend to appear in higher latitudes. This could be due to the lack of data from TRW in those years, which reduced to three the number of observatories available for the determination. The resultant uncertainties in summer are now larger than those obtained for solar cycle 23.

5. Discussion

The major characteristics of the quiet-time daily field variations and their associated current functions found in this study for the Livingston Island Observatory are those expected based on the results from earlier studies. The largest amplitudes of S_q occur during the summer while the smallest occur in the winter. For locations south of the southern hemisphere current focus but still away from the auroral region, H decreases from dawn to about noon, when a minimum is achieved; it later increases up to dusk (the overhead vortex in the northern hemisphere circulates anticlockwise while the overhead vortex in the southern hemisphere moves clockwise). The variations of D were also found to consist of the normal type, the "South type" (Mayaud, 1965), i.e., a minimum in the west followed by a maximum in the east. Z variations show a maximum at about noon, given the clockwise sense of the southern hemisphere current circulation. In winter, however, negative Z variations can appear (see Fig. 3). A plausible explanation for the appearance of the latter can be found in a combination of factors affecting the induced Z signals, which at ground level have an opposite sign compared with the external signal. In general, the induced signals for S_q over the oceans are larger than those over the continents (simply due to their relative higher conductivity). In addition, as already mentioned for the case of the anomalous behaviour detected at PST, oceanic motional induction effects, such as those from ocean tides and global ocean circulation (e.g., Kuvshinov, 2008, and references therein) can also contribute to the variations. Irregularities are always more easily detected in the winter, when the S_q variation is particularly weak, so that the superposition of "contaminating" fields can mask the true S_q variation pattern.

The S_q amplitude is also clearly dependent on solar activity, which can be mainly explained by the effect of ionospheric conductivity. The time lag between both signals may be related to that observed globally between SSN and geomagnetic activity (through the *aa* index). Although the electrical conductivity is mainly controlled by the extreme ultraviolet (EUV) radiation, which is at its maximum in the toroidal part of the solar cycle (Simon and Legrand, 1989), the effects of the FAC are at a maximum in the poloidal part of the solar cycle via the solar wind (Legrand and Simon, 1989). The poloidal or dipolar field roughly coincides with the minimum of the solar cycle and transforms into a toroidal field producing the migration of the sunspot

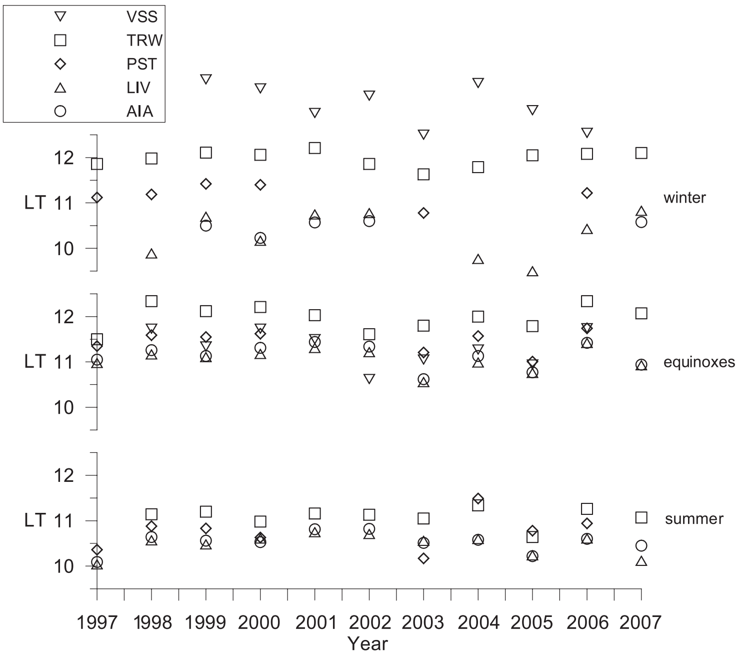

Fig. 8. Time at which the variation of D passes through zero for each season and year at each observatory.

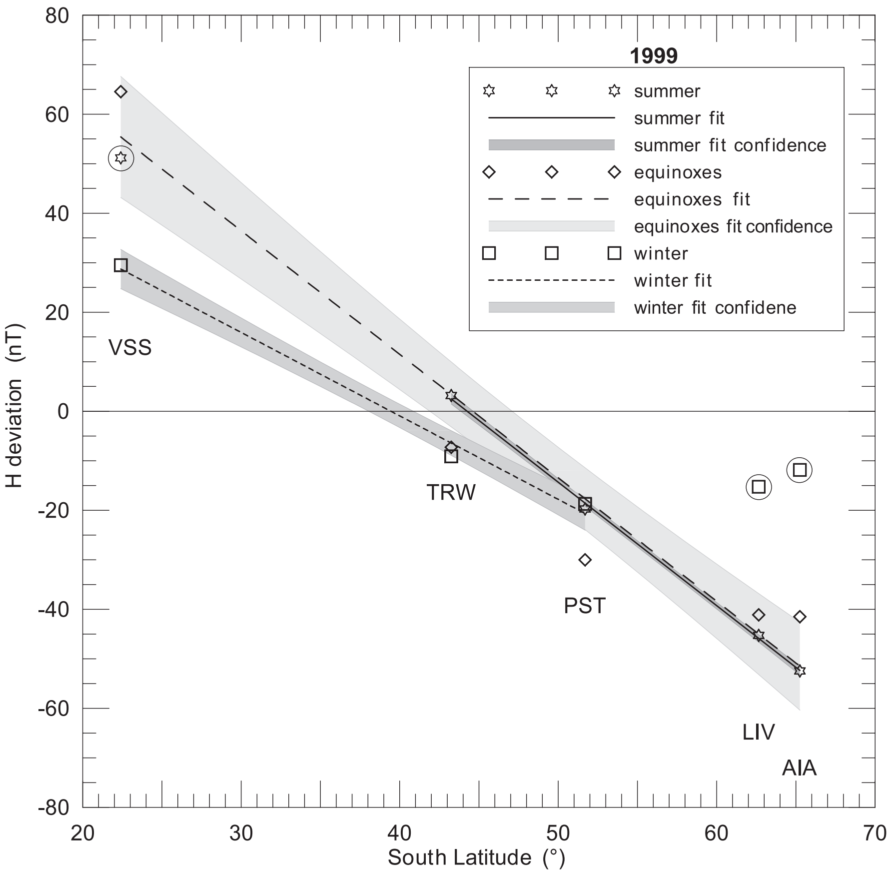

Fig. 9. Plot of variation of H versus observatory latitude used for the determination of the focus latitude of the ionospheric current system by least squares fits for each season of 1999. The standard uncertainties of the fits are also displayed as grey shadings. Symbols for AIA and LIV for winter and VSS for summer are encircled to indicate that they were not considered for the fit.

groups from the pole to the equator. Its maximum coincides with the maximum of the solar cycle. These effects would distort the apparent S_q signal by displacing the point of maximum variation and producing the observed delay (which could be estimated in 2 years), which shows up as an ellipse-like shape (Fig. 5). However, the ellipse of Fig. 5 is not perfect, and it changes towards a lower slope at around SSN = 70. This does not agree with the result of Olsen

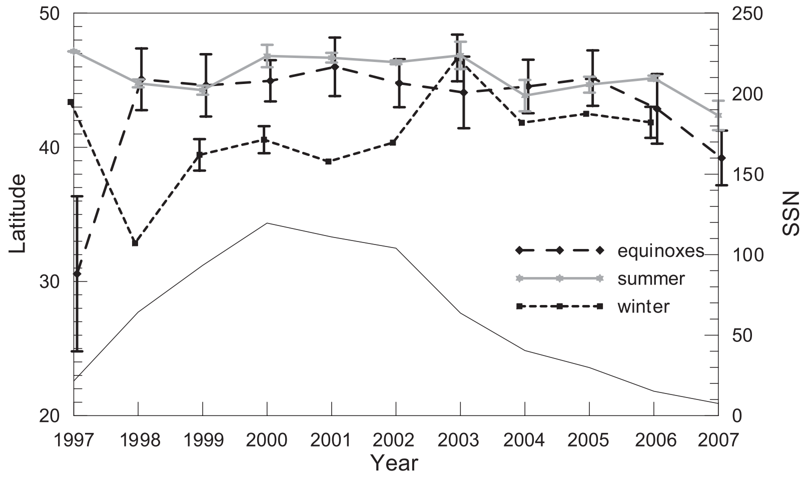

Fig. 10. Evolution of the determined focus latitude of the ionospheric current system for each year and season of solar cycle 23 (with their error bars), along with the yearly averaged SSN.

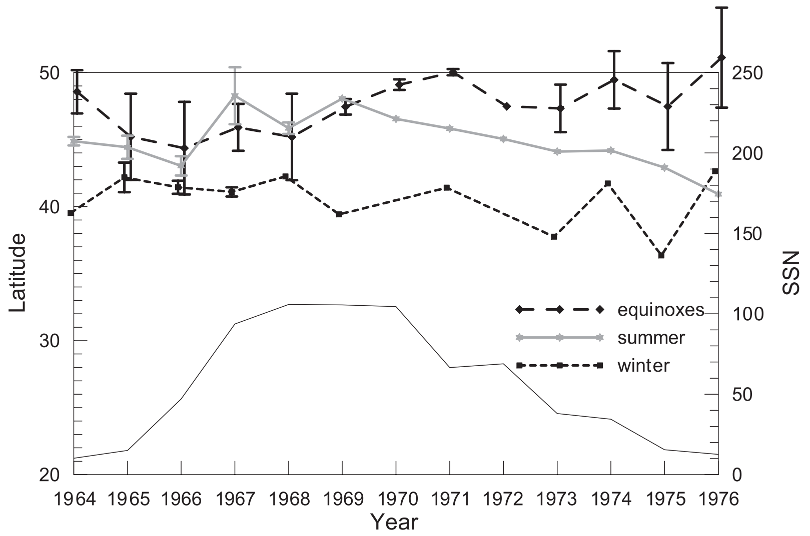

Fig. 11. Same as Fig. 10 but for solar cycle 20.

(1993), who found a completely linear dependence between the strength of the S_q and the SSN. In a long-term analysis of different observatories distributed worldwide, Torta *et al.* (2009) also found that the Y-component S_q range varies linearly with the SSN, regardless of the activity level. However, slightly different behaviours of low and moderate activity were found in that study when the authors plotted the S_q range versus the $F_{10.7}$ solar radio flux, although this was almost inappreciable between moderate and high activity. These earlier results are in contrast to what we found for LIV in Fig. 5.

Apart from the expected regular behaviour, we identified other properties that are characteristic of any continuous near-Earth geomagnetic recording. For example, even on exceptionally quiet days, one can find examples of residual disturbances still causing certain variations, thereby contaminating the average regular variation obtained from such days. This variation is usually negative and occurs in the late evening (Mayaud, 1980). When these short-term (1–2 h) disturbances of magnetospheric origin occur around—or close to—local midnight, they can shift the local midnight levels from which the baseline of the daily variation is computed.

Our analysis of the S_q focus position in the South American continent for a complete solar cycle has its origins in a study that had been pending since Kane (1990) proposed it in the conclusions of his analysis. Kane's analysis was limited to PIL and TRW and to the high sunspot year 1958. New data that have become available for high latitudes, such as data from PST and LIV, have finally allowed us to perform such a study. Our analysis confirms that TRW is, in general, very close to the southern S_q focus, although some movements do exist which depend on the season and the level of solar activity. Focus latitudes are higher during the summer and equinoxes than in the winter. Despite the different methods of analysis, this result does not seem to agree with those of Stening *et al.* (2007) and the other results discussed there, which showed an equatorward shift in the southern focus in November (they argued that if the northern focus moves poleward, the southern focus moves equatorward, but we only analysed the southern focus). Our results do agree with the CM4 model (see

Fig. 7) and with the results reported by Torta *et al.* (1997) for Europe and with the fact that, taking into account the change in electron density with latitude (it varies according to the solar zenith angle), the southern focus is expected to be located most poleward during the summer solstice. However, an explanation is still needed as to why the focus at the equinoxes presents such a poleward position, with latitudes that are as high as those observed in the summer—or even slightly higher in some years. We also attempted to find out whether a certain correlation exists between focus latitudes and SSN. Shiraki (1973) studied the latitudinal changes due to solar activity in the West Pacific and North America and concluded that the focus is at a higher latitude during solar quiet years than during solar active years. In our case, such a correlation is difficult to establish due to the lack of sufficient data for such a robust determination (such as in 1997 and 2007) or because in years of solar maximum (such as 2003), many of the five quiet days for each month contain a number of disturbed intervals that prevent a precise determination.

In terms of the time of appearance of the focus, in agreement with Torta *et al.* (1997), we found it to be closest to noon during the equinoxes. In winter, these times are erratic, probably due to the superposition of field-aligned currents resulting from inter-hemispherical asymmetries, as first suggested by van Sabben (1966). This superposition would give rise to the apparent invasions of one hemisphere's current pattern by that of the opposite hemisphere (Mayaud, 1965).

The results of this study confirm that S_q is a very changeable phenomenon, with a strong day-to-day variation, and that it is superimposed on magnetic disturbances of a magnetospheric origin that affect the determination of the true S_q variation. This can have repercussions for the derivation of the equivalent ionospheric currents in general and in the determination of their focus position in particular. Averaging over quiet days and seasons tends to smooth out the variability, and a seasonal and solar-cycle characteristic behaviour determination can be attempted, although sometimes the averages are of heterogeneous quantities.

Although we have been able to make a fairly consistent estimation of the focus position based on data from a few well-distributed stations, a dense network of geomagnetic observatories would facilitate the task. For this reason, we note the importance of a good coverage of ground-based observatories in the Southern hemisphere and encourage the corresponding agencies to continue with their recording task for the sake of modelling and understanding the global processes related to this branch of geophysics.

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