Ann. Geophys., 35, 139–146, 2017
www.ann-geophys.net/35/139/2017/
doi:10.5194/angeo-35-139-2017

Annales Geophysicae
Open Access

A study of geomagnetic field variations along the 80° S geomagnetic parallel

Stefania Lepidi[1], Lili Cafarella[1], Patrizia Francia[2], Andrea Piancatelli[2], Manuela Pietrolungo[1], Lucia Santarelli[1], and Stefano Urbini[1]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Rome, 00143, Italy
[2]Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila, L'Aquila, 67100, Italy

Correspondence to: Stefania Lepidi (stefania.lepidi@ingv.it)

Received: 7 June 2016 – Revised: 1 December 2016 – Accepted: 14 December 2016 – Published: 24 January 2017

Abstract. The availability of measurements of the geomagnetic field variations in Antarctica at three sites along the 80° S geomagnetic parallel, separated by approximately 1 h in magnetic local time, allows us to study the longitudinal dependence of the observed variations. In particular, using 1 min data from Mario Zucchelli Station, Scott Base and Talos Dome, a temporary installation during 2007–2008 Antarctic campaign, we investigated the diurnal variation and the low-frequency fluctuations (approximately in the Pc5 range, ∼ 1–7 mHz). We found that the daily variation is clearly ordered by local time, suggesting a predominant effect of the polar extension of midlatitude ionospheric currents. On the other hand, the pulsation power is dependent on magnetic local time maximizing around magnetic local noon, when the stations are closer to the polar cusp, while the highest coherence between pairs of stations is observed in the magnetic local nighttime sector. The wave propagation direction observed during selected events, one around local magnetic noon and the other around local magnetic midnight, is consistent with a solar-wind-driven source in the daytime and with substorm-associated processes in the nighttime.

Keywords. Magnetospheric physics (polar cap phenomena)

1 Introduction

Geomagnetic field measurements in Antarctica are particularly valuable for the study of magnetospheric dynamics and dynamic processes controlling the energy transfer from the solar wind (SW) to the Earth's magnetosphere in that local field lines reach extreme magnetospheric regions where this interaction occurs. In previous studies we used measurements from the Italian Geomagnetic Observatory Mario Zucchelli Station (TNB, formerly Terra Nova Bay), at 80° S corrected geomagnetic latitude, and from the French–Italian Observatory Concordia at Dome C (DMC) close to the geomagnetic pole, in order to characterize the ultra low-frequency (ULF; 1 mHz–1 Hz) pulsation activity and its relation with SW parameters in the Antarctic region (Lepidi et al., 1996, 2003; Villante et al., 2000; Francia et al., 2005, 2009).

The global distribution of geomagnetic observatories is still quite unbalanced in favor of the Northern Hemisphere; in this sense, the installation of a magnetometer in a new observation site in the Antarctic continent is useful in the study of the magnetospheric dynamics at high latitudes. For this reason, during the 2007–2008 Antarctic campaign, we installed a low-power magnetometer (LPM) at Talos Dome (TLD), within the framework of the AIMNet (Antarctic International Magnetometer Network) project, proposed and coordinated by the British Antarctic Survey and joined by the Italian Programma Nazionale Ricerche in Antartide (PNRA). TLD is located at ∼ 300 km from TNB, approximately at the same corrected geomagnetic latitude.

The availability of simultaneous measurements from TNB and Scott Base (SBA; data provided by INTERMAGNET database) allows us to make an interesting comparison in that the three stations are located approximately at the same geomagnetic latitude (∼ 80° S); stations at such latitudes are located generally in the polar cap but approach the dayside cusp around local magnetic noon. Moreover, SBA, TNB and TLD are at approximately 2 h total displacement in magnetic local time (MLT; see Table 1 and Fig. 1). This location is particularly useful for investigating the azimuthal signal distribution and propagation. A previous analysis has shown that

Table 1. Geographic coordinates, IGRF08 corrected geomagnetic coordinates and time in UT of the geomagnetic local noon (NN) for the three stations.

Station	Geographic coord.	Corr. geom. coord.	MLT NN (UT)
SBA	77.8S 166.8° E	79.9S 326.1° E	19:03
TNB	74.7S 164.1° E	80.0S 306.7° E	20:13
TLD	72.8S 159.0° E	80.4S 292.4° E	21:06

Pc5 pulsations at SBA and TNB (separated by 1 h in MLT) are highly coherent in the magnetic noon and midnight sectors and that they propagate preferably from midnight for the southward interplanetary magnetic field (IMF) and from noon for the northward IMF (Santarelli et al., 2007). More recently, Lepidi et al. (2011a) made a comparative analysis of Pc5 pulsations at TNB and Dumont d'Urville, both located at 80° S and separated by 5 h in MLT; they observed coherent fluctuations when the stations are on the same side with respect to the cusp; also, in this case, the propagation direction was found to be away from midnight, as expected for substorm-related phenomena, and from noon, as expected for the Kelvin–Helmholtz instability mechanism or SW pressure fluctuation transmission into the magnetosphere.

Polar areas are important also to study the daily variation, which, at high latitudes, is due to two different contributions: the polar extension of the midlatitude ionospheric current systems and an additional electric current system, related to field-aligned currents, characteristic of the polar cap (Matsushita and Xu, 1982; Akasofu et al., 1983). In previous papers we also investigated the 24 h periodicity at TNB and DMC, as well as in other polar observatories, to ascertain its dependence on solar cycle season, IMF conditions and geomagnetic activity level (Cafarella et al., 2007, 2009; Pietrolungo et al., 2008; Lepidi et al., 2011b). One result, evident for different latitudes within the polar cap and in both hemispheres, is that the geographic reference system, with X and Y geomagnetic field components against local time (LT) as a sorting parameter, is more suitable than the geomagnetic one (with H, D and MLT) to describe and compare the diurnal variation at such high latitudes.

In this study we show a comparative analysis of geomagnetic field horizontal components recorded at TLD, TNB and SBA from 18 January to 14 March 2008, focusing attention on the daily variation and low-frequency pulsations at the three sites.

2 Data analysis

Variations in the Earth's magnetic field were measured at the three sites by means of three-axis fluxgate magnetometers. The field variations are measured along three directions oriented with reference to the local magnetic meridian: the horizontal magnetic field intensity H component (south–north), the orthogonal component D in the horizontal plane (west–east) and the vertical intensity Z component (consequently increasing inward). For this analysis we used 1 min values of the H and D horizontal geomagnetic field components recorded in the period 18 January–14 March 2008.

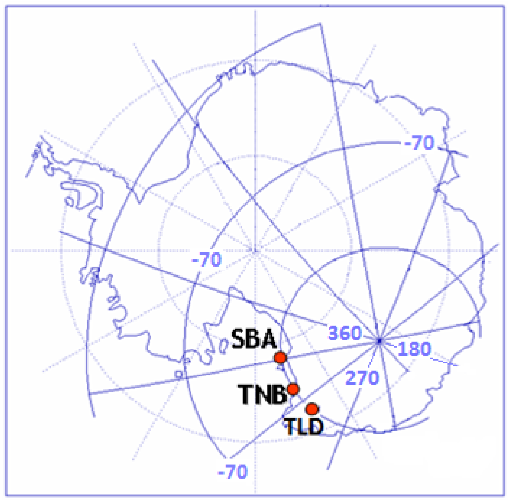

Figure 1. Location of the three Antarctic sites TNB, SBA and TLD. The geographic and the corrected geomagnetic coordinate systems are indicated as dashed and solid lines, respectively.

Spectral and coherence analysis was performed with MATLAB processing tools, based on the fast Fourier transform (FFT) method. The use of the Fourier transform in comparison to other spectral analysis methods has been extensively discussed in Balasis et al. (2012, 2015).

We first focused on the analysis of the daily variation; in Fig. 2 the hourly average values of the horizontal component H and D variations are shown, together with the Kp index. The presence of a quite regular daily variation is evident; its amplitude strongly varies from day to day and closely follows the level of magnetospheric activity, as can be seen from the Kp index.

We also performed a dynamical spectral analysis of these hourly data, computing the spectra for each 3-day interval with a 1-day step size. The dynamic spectra (Fig. 3; H and D components) show a sharp, persistent power peak corresponding to the 24 h period; sometimes, also the 12 h harmonic emerges.

A comparison of the daily variation at SBA, TNB and TLD is shown in Fig. 4 (thick lines), which reports the daily distribution of the average 10 min values of the two horizontal geomagnetic field components at the three stations; in addition to the H–D horizontal components ordered according to MLT, for this analysis we also show data rotated into the geographically oriented reference system, i.e., the X and Y geomagnetic field components (along the geographic meridian and parallel, respectively) ordered according to LT (Pietrol-

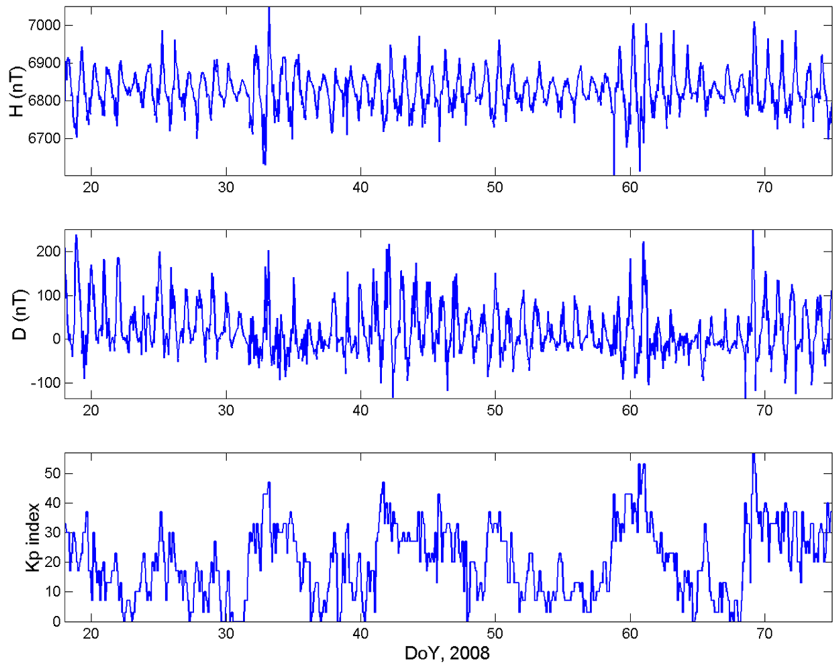

Figure 2. Upper panels: hourly average values of the horizontal component H and D variations at TLD for the whole analyzed time period (from 18 January to 14 March, 2008); lower panel: Kp index.

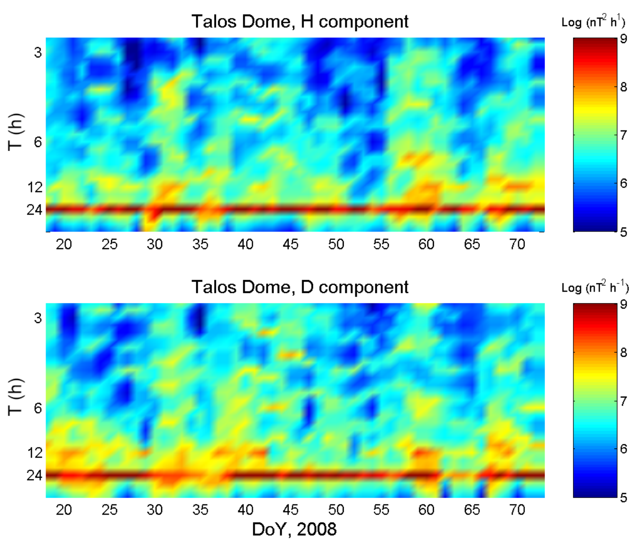

Figure 3. Dynamic spectra from hourly data at TLD.

ungo et al., 2008). The results of Fig. 4 show that the daily variation at the three stations is very similar, both regarding the shape and the amplitude. It is interesting to note that when ordered according to LT, the daily variations are perfectly in phase, while, according to MLT, there is a slight time shift, especially between TLD and the other two stations. This feature is more evident from the comparison of the fits of the experimental curves (Fig. 4, thin lines), where the short period fluctuations due to the quite short data series are eliminated.

Besides the daily variation, we also investigated the ULF activity at the three stations. In Fig. 5 two examples of daily magnetograms of the horizontal components H and D at SBA, TNB and TLD are shown; it is evident that the observations at the three stations are very similar. The 23 February (top panels) is a quiet day, with the sum of the eight 3 h Kp values sum(Kp) = 10; the plots show that the geomagnetic fluctuations increase in the last hours of the day, when the stations are closer to their magnetic local noon (indicated by the arrows). The magnetograms for 11 March (lower panels) show a more intense activity; indeed, it is a more disturbed day, with sum(Kp) = 23; also, in this case, there is evident geomagnetic activity in the dayside MLT sector, around local magnetic noon with simultaneous signals of comparable amplitude at the three stations. We may note that the signal observed at all stations around 07:00 UT has a different amplitude, maximizing at SBA, which is at MLT midnight; it can be related to substorm activity, as confirmed by the high AE (auroral electrojet index) values (∼ 500 nT) observed in the same time interval (http://wdc.kugi.kyoto-u.ac.jp/).

We analyzed the low-frequency geomagnetic field fluctuations in the H component at the three stations, computing the power spectra and coherence between pairs of stations, with TNB as reference station. The spectral and coherence analysis was performed computing the spectra for each 2 h interval (averaging four 30 min subintervals) with a 1 h step size.

The average power spectra of the H component as a function of UT at the three stations are shown in Fig. 6 (upper

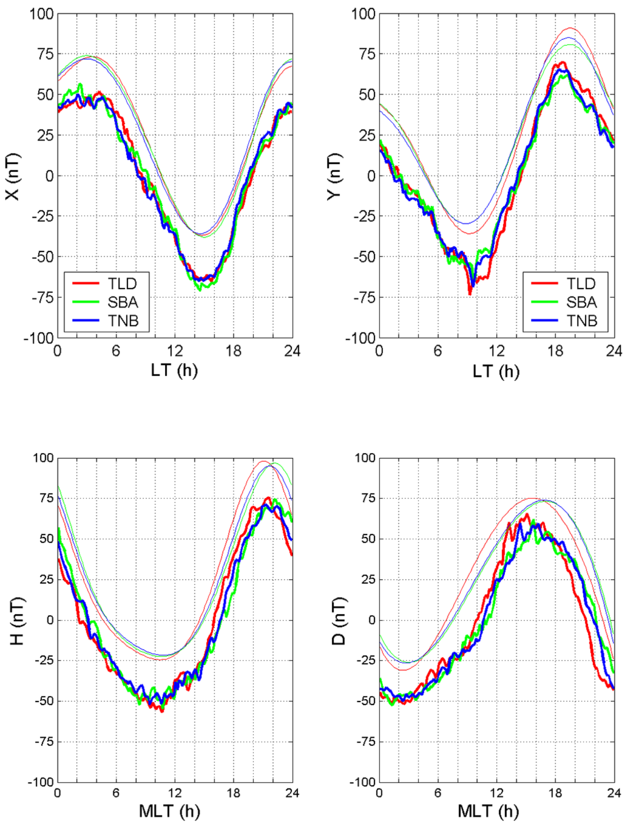

Figure 4. Daily distribution of the average 10 min values of the two horizontal geomagnetic field component variation in the geographic reference system vs. LT (upper panels, thick lines) and in the geomagnetic reference system vs. MLT (lower panels, thick lines). Each point represents the variation at a fixed 10 min interval, averaged over the whole analyzed time period. In all panels thin lines represent the fits of the experimental curves, upward shifted of 25 nT.

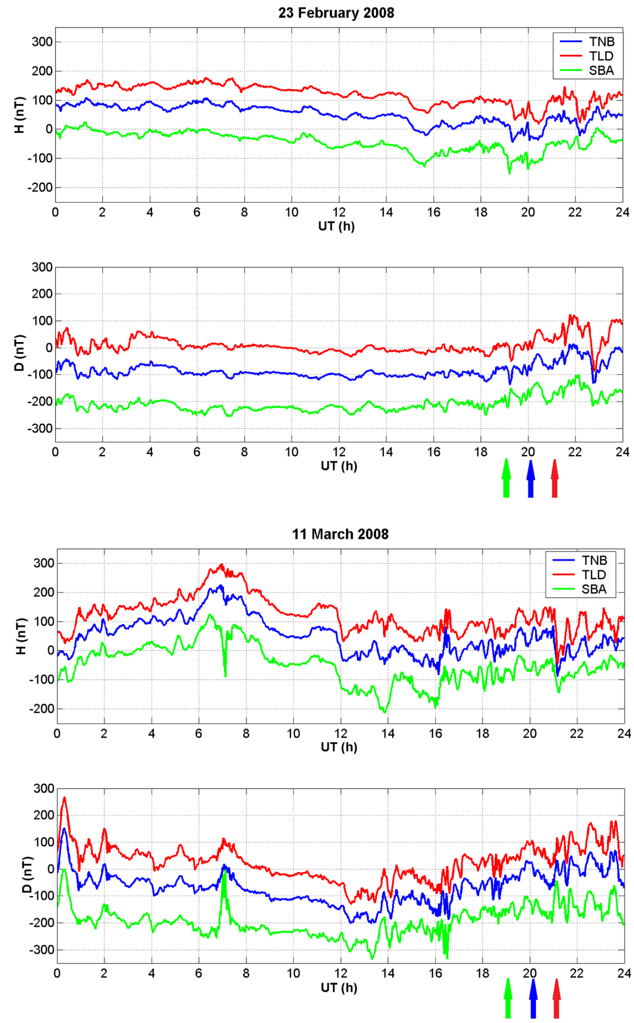

Figure 5. Daily magnetograms of the horizontal components H and D at SBA, TNB and TLD. The arrows indicate MLT noon at the three stations. An arbitrary value has been added to each time series to show the variations in the same plot.

panels). It is evident that the power at each station maximizes at all frequencies around MLT noon (indicated by the arrows), while the minimum power occurs in the postmidnight/early morning sector (around 03:00 MLT). The shift in the maximum, due to the different MLT noon at the stations, is made more evident by computing the average ratio between the power spectra at the pairs of stations SBA–TNB and TNB–TLD (Fig. 6, lower panels). The ratios show a bipolar variation, varying sharply from maximum to minimum values around the MLT noon at each pair of stations.

Figure 7 shows the daily distribution of the average coherence between H component fluctuations at the pairs of stations TNB–SBA and TNB–TLD. In the nighttime (02:00–12:00 UT), when the stations are well within the polar cap, far from the cusp, the coherence maximizes at all frequencies; conversely, in the daytime, when the stations are close to the cusp, the coherence is high only for the lowest frequencies (up to 1.5–2 mHz). Moreover, the signal correspondence is more evident between TNB and TLD than between TNB and SBA, probably due to the smaller separation both in MLT and in geographic latitude (Table 1).

We lastly analyzed the fluctuations during the 2 days shown in Fig. 5 for a comparison between the geomagnetic signals at the three stations. Figures 8 and 9 show, from the top, the variations in the geomagnetic field H component, filtered in the 1–5 mHz frequency range, and the dynamical power spectra (computed for 1 h overlapping intervals with a 30 min step size). For the event occurring on 23 February 2008, the wave activity starts from $\sim$ 17:30 UT, when the stations approach the cusp. Satellite measurements at the Lagrangian point show, corresponding to this, SW speed higher than 430 km s^{-1} and dynamic pressure fluctuations (OMNI data from http://omniweb.gsfc.nasa.gov; not shown here). As can be seen both from the filtered data and the power spectra, the time interval of higher activity shifts from 17:00–

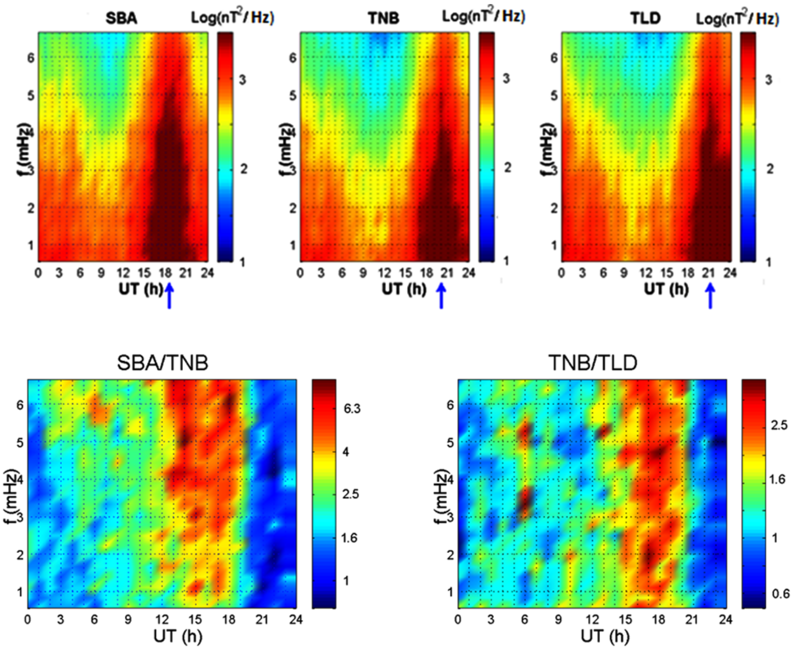

Figure 6. Upper panels: average power spectra of the H component at the three stations. Lower panels: average ratio between power spectra at pairs of stations.

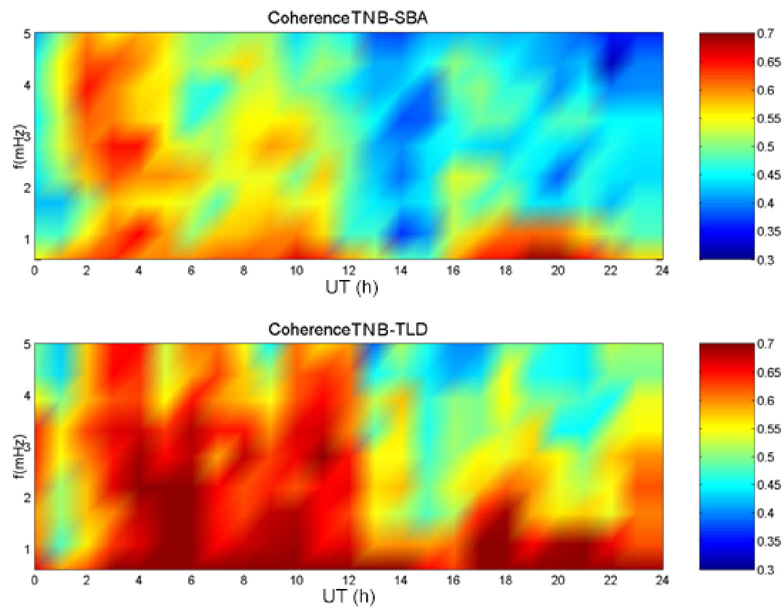

Figure 7. Average coherence between H component fluctuations at pairs of stations.

21:00 UT at SBA to 18:00–22:00 UT at TNB until 19:00–23:00 UT at TLD, corresponding to the different magnetic noon sectors (in Fig. 8 the magnetic noon at each station is indicated by an arrow). In order to make more evident the effect of cusp activation, we show in Fig. 9 the MLT dependence of the hourly pulsation power-integrated in the 1–5 mHz frequency band; as expected, the power is strongly enhanced around magnetic local noon at each station. From Fig. 8 it can also be seen that when the activity is high at all stations, approximately between 19:30 and 20:00 UT, it is characterized by simultaneous power enhancements at discrete frequencies, in particular at ~ 1.1, 1.7 and 2.5 mHz, corresponding to clear, regular fluctuations at the three stations; we may note that SBA observes them in advance; then they occur at TNB and lastly at TLD. From a visual inspection of the filtered data, we also estimated the time delay (note that using

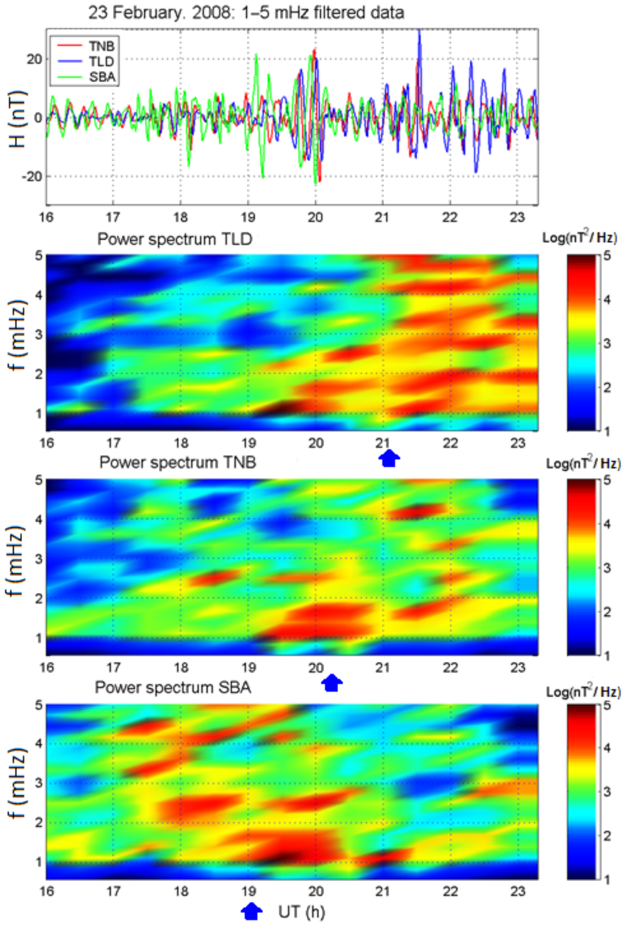

Figure 8. From top: variations in the geomagnetic field H component filtered in the 1–5 mHz frequency range and dynamical power spectra for the event on 28 February 2008. The arrows indicate MLT noon at the three stations.

1 min data, it can be determined with an accuracy not better than 1 min), which is ~ 3 min between SBA and TNB and ~ 2 min between TNB and TLD and indicates waves propagating from SBA (the station closest to the noon) to TNB to TLD in the antisunward direction, with an azimuthal number $m \sim 4$ (computed by the formula $m = f \cdot \Delta t \cdot 360° / \Delta\lambda$, where f is the wave frequency, Δt is the time shift and $\Delta\lambda$ is the longitudinal distance in degrees between stations).

For the event occurring on 11 March 2008, a more disturbed day, we focused on the nighttime sector (Fig. 10). We found a burst of activity around 07:00 UT, with a definitely greater amplitude at SBA, i.e., the station that at 07:03 UT is at magnetic midnight. The power spectra at TNB and TLD show several similar enhancements in the whole frequency range; at SBA a broad power enhancement between 1 and 2.5 mHz dominates the spectrum. Also, in this case SBA observes the signal in advance; it indicates a sunward propagation from a source located around midnight. In this case, the time delay is definitely shorter, of the order of 1 min, from which an azimuthal number $m \sim 1$–2 can

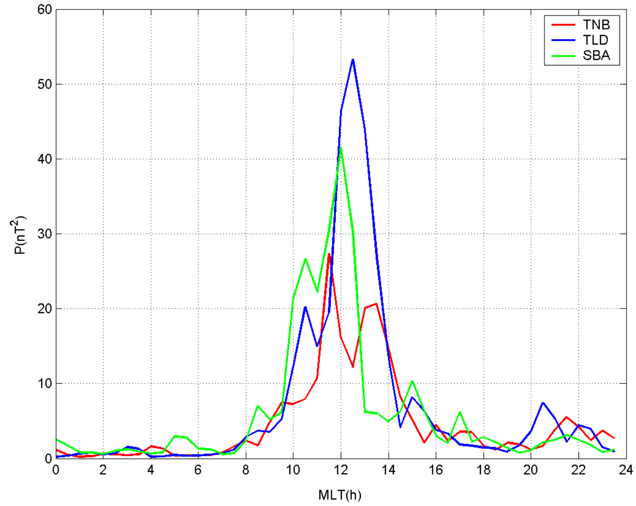

Figure 9. The MLT dependence of the pulsation power for the event on 28 February 2008, integrated in the 1–5 mHz frequency band at the three stations.

be estimated. An inspection of IMF data at the Lagrangian point shows, corresponding to this, a high SW speed and a definitely southward IMF, suggesting a substorm-related generation mechanism as confirmed also by high AE values (http://wdc.kugi.kyoto-u.ac.jp/).

3 Summary and discussion

During the 2007–2008 Antarctic campaign, we installed a magnetometer at Talos Dome (TLD), a new observation site in Antarctica to extend the observation facilities in the southern polar cap. The availability of simultaneous measurements from TNB and SBA allows us to investigate the azimuthal signal distribution and propagation in that the three stations are located approximately at the same geomagnetic latitude ($\sim 80°$ S), with approximately 2 h total displacement in magnetic local time. In this work we present a comparative analysis of geomagnetic field variations observed at the temporary station TLD and at the two observatories TNB and SBA; the three Antarctic sites are situated along the 80° S parallel, with ~ 1 h separation in MLT (actually 70 min for the pair SBA–TNB and 53 min for the pair TNB–TLD). The analysis is based on measurements recorded during a 2-month campaign at TLD in the local summer (January–March 2008).

The diurnal variation in the geomagnetic field at TLD shows an amplitude dependence on the geomagnetic activity level, as previously found at TNB (Pietrolungo et al., 2008). Its shape is the same at the three stations, perfectly in phase when considering the X and Y components ordered in LT: the X component shows a minimum around 13:00 LT and a maximum in the postmidnight hours; the Y component shows a negative–positive bipolar behavior around 13:00 LT. When considering the H and D components ordered in MLT,

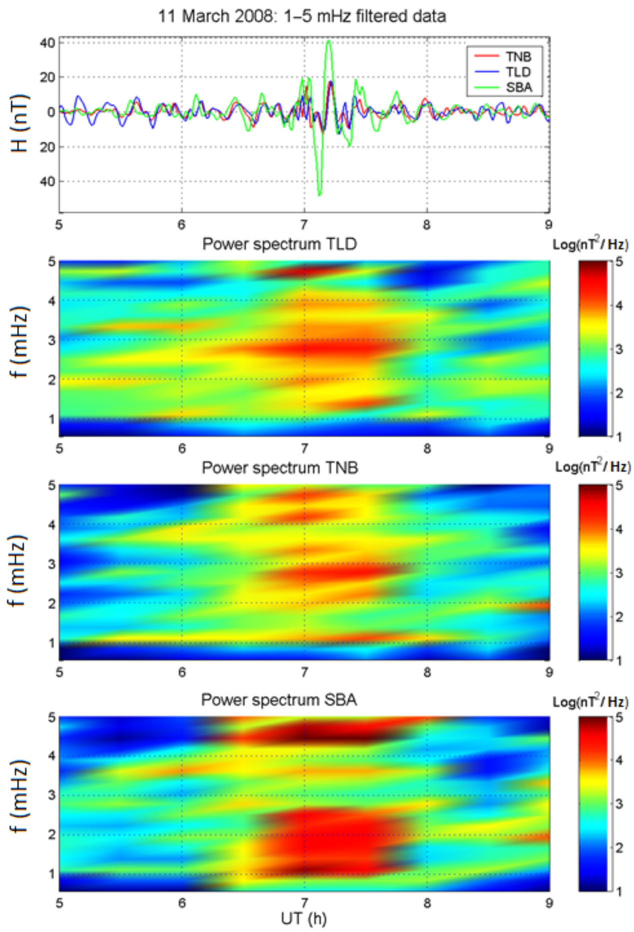

Figure 10. From top: variations in the geomagnetic field H component filtered in the 1–5 mHz frequency range and dynamical power spectra for the event on 11 March 2008.

a slight time shift between the stations emerges; this shift is much smaller than the one found by Pietrolungo et al. (2008), who considered stations with a much wider spatial separation. The observed LT dependence demonstrates that the effects of midlatitude ionospheric currents extend to such high latitudes, being dominant with respect to the field-aligned currents in determining the diurnal variation in the geomagnetic field.

The Pc5 fluctuation power at all stations presents the well-known maximum around local magnetic noon, when the stations approach the polar cusp and the local field lines are closer to the magnetopause (Lepidi et al., 1996; Villante et al., 2000; Francia et al., 2005), and a minimum in the magnetic postmidnight sector. It is worth noting that the daytime Pc5 power maximum at high-latitude stations could be considered as a marker of the auroral oval position (Lepidi and Francia, 2003). The maximum around noon extends to the whole analyzed frequency range (0.6–5 mHz), but the coherence between pairs of stations is high only at the lowest frequencies, up to 1–1.5 mHz; this result can be interpreted taking into account that these frequencies are related to the Kelvin–Helmholtz instability on the magnetopause, which is a large-scale process. On the other hand, fluctuations at higher frequencies are, more likely, signatures of field line resonances (FLRs) occurring on lower-latitude closed field lines which each station approaches at its own local noon (Lepidi et al., 1999; De Lauretis et al., 2009). Conversely, during the nighttime, when the power is lower, the fluctuations are coherent independently of frequency; this result can be explained in terms of substorm-related phenomena (Menk, 2011), which extend to a large portion of the nightside magnetosphere, as observed in the 11 March 2008 event (Fig. 10), as well as in terms of specific cap activity which is characterized by low-amplitude, coherent fluctuations (Yagova et al., 2004).

The analysis of a daytime event shows that for simultaneous long-duration fluctuations, the amplitude maximizes at each station around local magnetic noon (i.e., not simultaneously), the propagation direction is antisunward, as for SW-driven waves (Kepko et al., 2002; Kim et al., 2002), and the estimated azimuthal wave number m is ~ 4, in agreement with values found in previous studies for daytime fluctuations (Lepidi et al., 2011a) and consistently with the classification of dayside Pc5 resonances with small m as waves excited by an external mechanism (Glassmeier, 1995; Baker et al., 2003; Samson, 1991). We note that the 80° S stations used in the present analysis are usually located at the footprint of open field lines, so they cannot directly observe FLRs; however, the FLR effects occurring at somewhat lower latitudes can be detected also at such high latitudes around local noon, when the stations approach the cusp (Lepidi et al., 1999; De Lauretis et al., 2009). The observational evidence of FLR effects at open field lines is also discussed by Yagova et al. (2010); of course, the contribution of the Alfvén FLRs to broadband ULF disturbances in the dayside polar cap does not imply that all the spectral content is due to lower-latitude FLRs.

The analysis of a nightside event shows just a few oscillation cycles, with maximum amplitude at the station which, at the moment, is located at local magnetic midnight; in this case, the propagation direction is sunward (with an m value ~ 1–2), consistently with waves originating in the tail and associated with substorm instabilities (Yagova et al., 2002).

4 Data availability

TNB data can be downloaded from the INGV web site: http://geomag.rm.ingv.it/index.php. SBA data can be downloaded from the INTERMAGNET web site: http://www.intermagnet.org. TLD data can be requested from Stefania Lepidi: stefania.lepidi@ingv.it.

Acknowledgements. The research activity at Mario Zucchelli station and Talos Dome has been supported by the Italian PNRA

(Programma Nazionale Ricerche in Antartide). The results presented in this paper rely on the data collected at Scott Base; we thank the Institute of Geological & Nuclear Sciences Limited (New Zealand), for supporting its operation and INTERMAGNET for promoting high standards of magnetic observatory practice (http://www.intermagnet.org).

The topical editor, G. Balasis, thanks N. Yagova and one anonymous referee for help in evaluating this paper.

References

Akasofu, S. I., Ahn, B. H., and Romick, G. J.: A study of the polar current system using the IMS meridian chains of magnetometers, Space Sci. Rev., 36, 337–413, 1983.

Balasis, G., Daglis, I. A., Zesta, E., Papadimitriou, C., Georgiou, M., Haagmans, R., and Tsinganos, K.: ULF wave activity during the 2003 Halloween superstorm: multipoint observations from CHAMP, Cluster and Geotail missions, Ann. Geophys., 30, 1751–1768, doi:10.5194/angeo-30-1751-2012, 2012.

Balasis, G., Daglis, I. A., Mann, I. R., Papadimitriou, C., Zesta, E., Georgiou, M., Haagmans, R., and Tsinganos, K.: Multi-satellite study of the excitation of Pc3 and Pc4-5 ULF waves and their penetration across the plasmapause during the 2003 Halloween superstorm, Ann. Geophys., 33, 1237–1252, doi:10.5194/angeo-33-1237-2015, 2015.

Baker, G. J., Donovan, E. F., and Jackel, B. J.: A comprehensive survey of auroral latitude Pc5 pulsation characteristics, J. Geophys. Res., 108, 1384, doi:10.1029/2002JA009801, 2003.

Cafarella, L., Di Mauro, D., Lepidi, S., Meloni, A., Pietrolungo, M., Santarelli, L., and Schott, J. J.: Daily variation at Concordia station (Antarctica) and its dependence on IMF conditions, Ann. Geophys., 25, 2045–2051, doi:10.5194/angeo-25-2045-2007, 2007.

Cafarella, L., Lepidi, S., Meloni, A., and Santarelli, L.: Twenty years of geomagnetic observations at Mario Zucchelli Station (Antarctica), Ann. Geophys., 52, 1-14, doi:10.4401/ag-4567, 2009.

De Lauretis, M., Francia, P., Piancatelli, A., Vellante, M., and Villante, U.: Low and mid-frequency pulsations in the polar cap: polarization pattern and MLT dependence of the spectral power during the descending phase of the solar cycle, Ann. Geophys., 52, 27–34, doi:10.4401/ag-4570, 2009.

Francia, P., Lanzerotti, L. J., Villante, U., Lepidi, S., and Di Memmo, D.: A statistical analysis of low-frequency magnetic pulsations at cusp and cap latitudes in Antarctica, J. Geophys. Res., 110, A02205, doi:10.1029/2004JA010680, 2005.

Francia, P., De Lauretis, M., Vellante, M., Villante, U., and Piancatelli, A.: ULF geomagnetic pulsations at different latitudes in Antarctica, Ann. Geophys., 27, 3621–3629, doi:10.5194/angeo-27-3621-2009, 2009.

Glassmeier, K. H.: ULF pulsations, Handbook of Atmospheric Electrodynamics, Vol. II, edited by: Volland, H., 463–502, CRC Press, Boca Raton, FL, 1995.

Kepko, L., Spence, H. E., and Singer, H. J.: ULF waves in the solar wind as direct drivers of magnetospheric pulsations, Geophys. Res. Lett., 29, 1197, doi:10.1029/2001GL014405, 2002.

Kim, K.-H., Cattell, C. A., Lee, D.-H. , Takahashi, K., Yumoto, K., Shiokawa, K., Mozer, F. S., and Andre, M.: Magnetospheric responses to sudden and quasiperiodical solar wind variations, J. Geophys. Res., 107, 1406, doi:10.1029/2002JA009342, 2002.

Lepidi, S. and Francia, P.: Low-frequency (1–4 mHz) geomagnetic field fluctuation power at different latitudes for a diagnosis of the auroral oval position, Memorie Soc. Astron. Italiana, 74, 762–765, 2003.

Lepidi, S., Villante, U., Vellante, M., Palangio, P., and Meloni, A.: High resolution geomagnetic field observations at Terra Nova Bay, Antarctica, Ann. Geofis., 34, 519–528, 1996.

Lepidi, S., Francia, P., Villante, U., Lanzerotti, L. J., and Meloni, A.: Polarization pattern of low frequency geomagnetic field variations (0.8–3.6 mHz) at high and low latitude, J. Geophys. Res., 104, 305–310, 1999.

Lepidi, S., Cafarella, L., Francia, P., Meloni, A., Palangio, P., and Schott, J. J.: Low frequency geomagnetic field variations at Dome C (Antarctica), Ann. Geophys., 21, 923–932, doi:10.5194/angeo-21-923-2003, 2003.

Lepidi, S., Cafarella, L., Pietrolungo, M., and Santarelli, L.: Azimuthal propagation of Pc5 geomagnetic field pulsations in the southern polar cap, Adv. Space Res., 47, 966–977, doi:10.1016/j.asr.2010.10.027, 2011a.

Lepidi, S., Cafarella, L., Pietrolungo, M., and Di Mauro, D.: Daily variation characteristics at polar geomagnetic observatories, Adv. Space Res., 48, 521–528, doi:10.1016/j.asr.2011.03.039, 2011b.

Matsushita, S. and Xu, W.: Equivalent ionospheric current system representing solar daily variations of the polar geomagnetic field, J. Geophys. Res., 87, 8241–8254, 1982.

Menk, F.: Magnetospheric ULF waves: a review, in: The Dynamic Magnetosphere, edited by: Liu, W. and Fujimoto, M., IAGA Special Sopron Book Series 3, 223, doi:10.1007/978-94-007-0501-2_13, 2011.

Pietrolungo, M., Lepidi, S., Cafarella, L., Santarelli, L., and Di Mauro, D.: Daily variation at three Antarctic geomagnetic observatories within the polar cap, Ann. Geophys., 26, 2179–2190, doi:10.5194/angeo-26-2179-2008, 2008.

Samson, J. C.: Geomagnetic pulsations and plasma waves in the Earth's magnetosphere, in: Geomagnetism, edited by: Jacobs, J. A., Vol. 4, Academic Press, 481–592, 1991.

Santarelli, L., Lepidi, S., and Cafarella, L.: Propagation of low frequency geomagnetic field fluctuations in Antarctica: comparison between two polar cap stations, Ann. Geophys., 25, 2405–2412, doi:10.5194/angeo-25-2405-2007, 2007.

Villante, U., Lepidi, S., Francia, P., Vellante, M., Meloni, A., and Palangio, P.: ULF fluctuations at Terra Nova Bay (Antarctica), Ann. Geofis., 43, 217–227, 2000.

Yagova, N. V., Lanzerotti, L., Villante, U., Pilipenko, V., Lepidi, S., Francia, P., Papitashvili, V., and Rodger, A.: Magnetic activity in the ULF Pc5-6 band at very high latitudes in Antarctica, J. Geophys. Res., 107, 1195, doi:10.1029/2001JA900143, 2002.

Yagova, N. V., Pilipenko, V. A., Lanzerotti, L. J., Engebretson, M. J., Rodger, A. S., Lepidi, S., and Papitashvili, V. O.: Two-dimensional structure of long-period pulsations at polar latitudes in Antarctica, J. Geophys. Res., 109, A03222, doi:10.1029/2003JA010166, 2004.

Yagova, N. V., Pilipenko, V. A., Baransky, L. N., and Engebretson, M. J.: Spatial distribution of spectral parameters of high latitude geomagnetic disturbances in the Pc5/Pi3 frequency range, Ann. Geophys., 28, 1761–1775, doi:10.5194/angeo-28-1761-2010, 2010.