Low-frequency (0.7-7.4 mHz) geomagnetic field fluctuations at high latitude: frequency dependence of the polarization pattern

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Abstract
A statistical analysis of the polarization pattern of low-frequency geomagnetic field fluctuations (0.7-7.4 mHz) covering the entire 24-h interval was performed at the Antarctic station Terra Nova Bay (80.0°S geomagnetic latitude) throughout 1997 and 1998. The results show that the polarization pattern exhibits a frequency dependence, as can be expected from the frequency dependence of the latitude where the coupling between the magnetospheric compressional mode and the field line resonance takes place. The polarization analysis of single pulsation events shows that wave packets with different polarization sense, depending on frequency, can be simultaneously observed.

Key words *geomagnetic pulsations – MHD waves and instabilities – wave polarization – Antarctica*

1. Introduction

An interesting aspect of the interaction between the Solar Wind (SW) and the Earth's magnetosphere is the generation of low frequency hydromagnetic magnetospheric waves driven by the Kelvin-Helmholtz instability at the magnetopause as well as by impulsive variations in the SW pressure. These magnetospheric compressional waves propagate in the antisunward direction, *i.e.* westward in the morning and eastward in the afternoon, so the resulting polarization sense of the ground pulsations in the horizontal plane should be counterclockwise (CCW) in the morning and clockwise (CW) in the afternoon (note that in the southern hemisphere the polarization sense is reversed; Southwood, 1974). However the polarization pattern is modified by the coupling between the magnetospheric compressional waves and the field line resonant mechanism (Southwood, 1974; Chen and Hasegawa, 1974). In particular, for any given frequency, the theory predicts a first polarization reversal at the latitude of the amplitude minimum between the resonant field line and the magnetopause, and a second reversal across the latitude of the resonant field line (which has a local time dependence, due to the different length of the geomagnetic field lines through the day). The emerging overview for the polarization of low frequency *Pc*5 pulsa-

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tions would then suggest a complex pattern (Samson, 1972, fig. 13) in which, depending on frequency, at any given latitude two or more polarization reversals at different magnetic local times might be expected.

In a previous paper (Lepidi *et al.*, 1999), we conducted a statistical analysis of the polarization pattern of low frequency geomagnetic field variations (0.8-3.6 mHz) recorded at the Antarctic station Terra Nova Bay (IGRF95 corrected geomagnetic latitude 80.0°S) and at the low latitude station L'Aquila (36.2°N) during 1995. We found that, consistently with predictions drawn from previous theoretical and experimental works, four polarization reversals over the local day occur at Terra Nova Bay. These results indicate that approximately in the geomagnetic noon sector the effects of low frequency field line resonances can be observed also at Terra Nova Bay. In this sense, it is interesting to recall that Terra Nova Bay, which during the major part of the day is located in the polar cap, approaching local geomagnetic noon progressively moves toward closed field lines.

In this paper we extend the statistical analysis of the polarization pattern at Terra Nova Bay to 1997-1998 and for frequencies up to 7.4 mHz (covering the entire frequency range of standing Alfven waves on the last closed magnetosphere field lines; Lanzerotti *et al.*, 1999) and show that the polarization pattern exhibits a frequency dependence. We also analyze the polarization characteristics of two pulsation events for which it clearly emerges that simultaneous wave packets with different frequency can have opposite polarization sense.

2. Data analysis and experimental observations

We analyzed the 1 min values of the geomagnetic field measured at Terra Nova Bay (TNB, IGRF95 corrected geomagnetic coordinates: 80.0°S, 307.7°E; MLT = UT-08:06) by a three-component fluxgate magnetometer with a flat frequency response in the range 0-1 Hz (Meloni *et al.*, 1992) throughout the years 1997 and 1998 (data gaps occurred from March 10, 1998 to March 13, 1998 and from December 7, 1998 to the end of the year). The availability of 1-min measurements allowed us to extend the statistical analysis of the polarization pattern of low frequency fluctuation beyond the frequency range analyzed in the previous paper by Lepidi *et al.* (1999).

We conducted a cross-spectral analysis between the two horizontal components using the technique for partially polarized waves as proposed by Fowler *et al.* (1967). In order to well follow the local time dependence of the polarization pattern (with severals during the day, Lepidi *et al.*, 1999), we performed our analysis over 1-h intervals; in particular, for each 1-h interval the polarization ratio R (*i.e.* the ratio between the polarized and total intensity of the horizontal signal) and the ellipticity (*i.e.* the ratio between the minor and the major axis of the polarization ellipse in the horizontal plane) were computed with 12 degrees of freedom over four equally-spaced frequency bands between 0.7 and 7.4 mHz (T = 2-24 min). The total number of analyzed hourly intervals is 16791. In order to exclude intervals for which the sense of polarization is not clearly defined, we considered only cases with R greater than 0.7 and an ellipticity greater than 0.2 (Lepidi *et al.*, 1999). In this way, the number of selected intervals reduces to ~ 22.6% of the total number.

Figure 1a,b shows the daily distribution of the percentage of selected intervals with CW polarization for the two frequency ranges 0.7-4.0 mHz and 4.0-7.4 mHz (the cross-spectral estimates corresponding to the first two and last two original frequency bands were grouped together since they give very similar results). As can be seen, in the lower frequency range (fig. 1a) the percentage of CW intervals clearly dominates (with values of ~ 85%) in the local postmidnight sector while during local morning the sense of polarization sharply reverses, becoming definitely CCW between ~ 0700 MLT and ~ 1100 MLT. After ~ 1200 MLT, the percentage of CW polarization dominates again, then it decreases from almost 90% to ~ 45% (at ~ 1900 MLT) and then increases again. These results are consistent with the polarization pattern proposed by Samson (1972) for low frequency $Pc5$ pulsations (f < 4 mHz) at latitudes

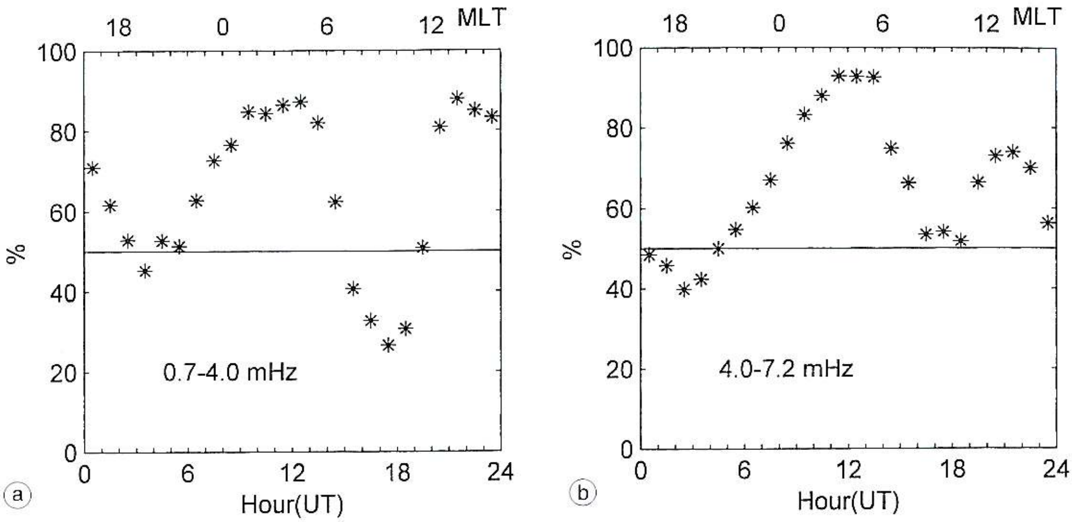

Fig. 1a,b. The daily distribution of the percentage of hourly intervals with CW polarization in the frequency ranges: a) 0.7-4.0 mHz; b) 4.0-7.2 mHz. Times are shown in UT (lower margin) and MLT (upper margin).

of the order of 80° as well as with the findings previously obtained for TNB in a different year and in almost the same frequency range (Lepidi *et al.*, 1999).

In the higher frequency range (fig. 1b), the results are somewhat different in that during the local morning the reversal from CW to CCW polarization does not clearly emerge (the percentage of CW intervals decreases just to ~ 50% between ~ 0800 MLT and ~ 1100 MLT), while the reversal in the late afternoon is more evident (with dominant CCW polarization between ~ 1600 MLT and ~ 2000 MLT). These results could be still explained in terms of the polarization pattern proposed by Samson (1972) taking into account that for higher frequencies the resonant region shifts toward lower latitudes.

We found it interesting to show, as an example, a pulsation event lasting several hours for which the frequency dependence of the polarization sense clearly emerges. In fig. 2a,b we show the geomagnetic field fluctuations filtered in the two frequency bands 2.4-4.0 mHz (fig. 2a) and 4.0-5.7 mHz (fig. 2b) measured at TNB from January 8, 1997, 1400 UT until January 9, 1997, 0300 UT (corresponding to approximately 0600-1900 MLT); the solid horizontal bars indicate the hourly intervals for which a CW polarization sense emerges from the cross-spectral analysis. It can be seen that, in agreement with previous statistical results, in the local morning a longer time interval with CCW polarization is observed at lower frequency and in the local afternoon a short time interval with CCW polarization emerges only at higher frequency. This result indicates that simultaneous wave packets in the two analyzed frequency bands have opposite polarization sense. In fig. 3a,b we show the hodograms corresponding to the time periods 1552-1603 UT (0752-0803 MLT, fig. 3a) and 0000-0013 UT (1600-1613 MLT, fig. 3b); it is evident that in the first time interval the polarization sense of the 2.4-4.0 mHz (left panel) and 4.0-5.7 mHz (right panel) signals is CCW and CW, respectively, while the contrary holds for the second time interval.

We also selected another pulsation event, driven by a sharp SW pressure increase, for which simultaneous wave packets at different frequency show a different polarization sense. In fig. 4 we show the *H* and *D* components at

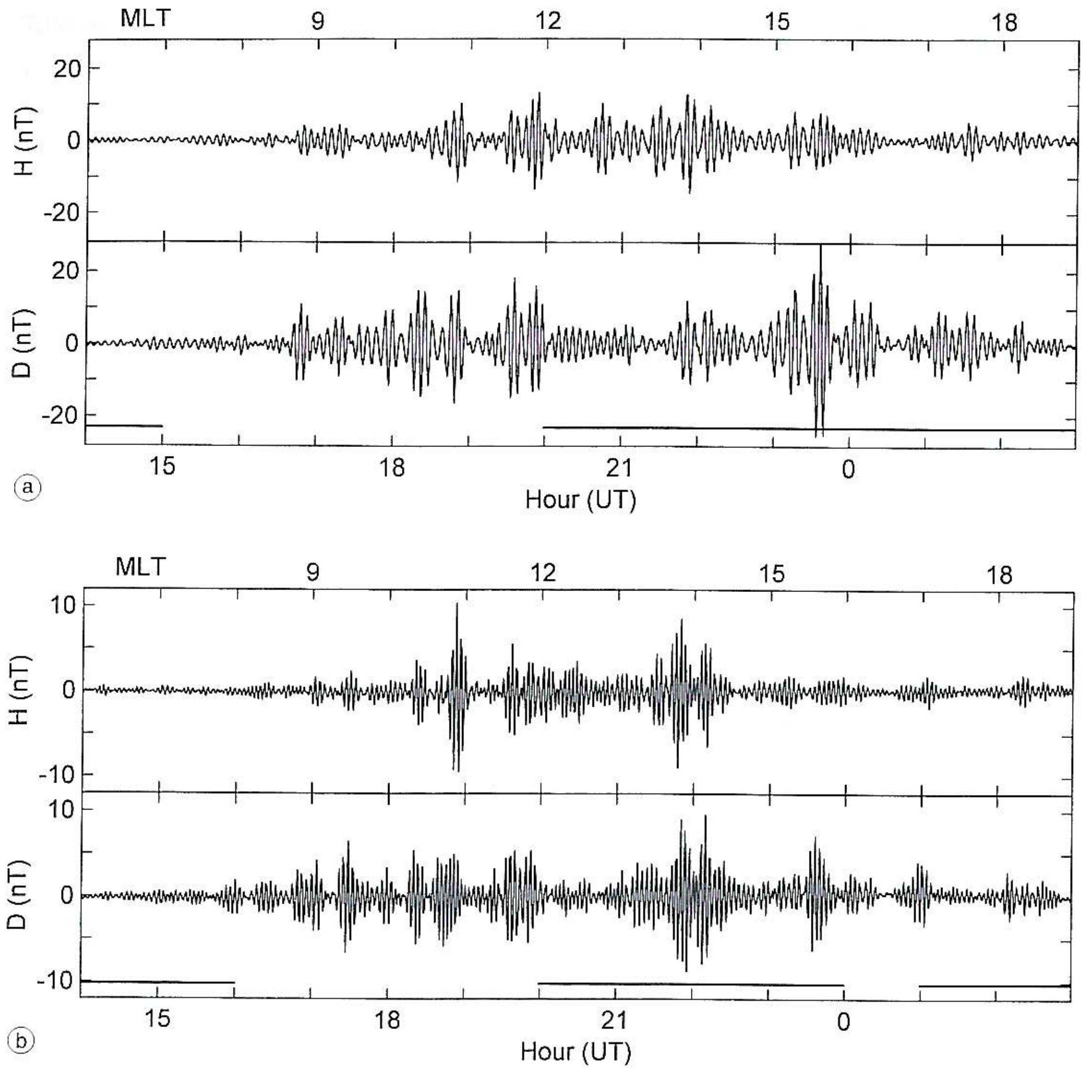

Fig. 2a,b. The filtered signals in the frequency bands: a) 2.4-4.0 mHz; b) 4.0-5.7 mHz for the time period January 8, 1997, 1400 UT until January 9, 1997, 0300 UT. The solid bars indicate the hourly intervals with CW polarization. Times are shown in UT (lower margin) and MLT (upper margin).

TNB and the simultaneous interplanetary data from Wind spacecraft on October 10, 1997, 1530-1830 UT. As can be seen, Wind observed just before 1600 UT a discontinuity characterized by an increase in the interplanetary magnetic field strength and of the SW speed and number density. The Earth's arrival of the discontinuity can be identified at TNB by an SI at ~ 1610 UT (~ 0810 MLT). The polarization sense of the SI (fig. 5) is CCW; interpreting the SIs in terms of hydromagnetic waves driven by external sources impinging the dayside magnetosphere (Araki and Allen, 1982), this polarization sense is consistent with the statistical results obtained at this

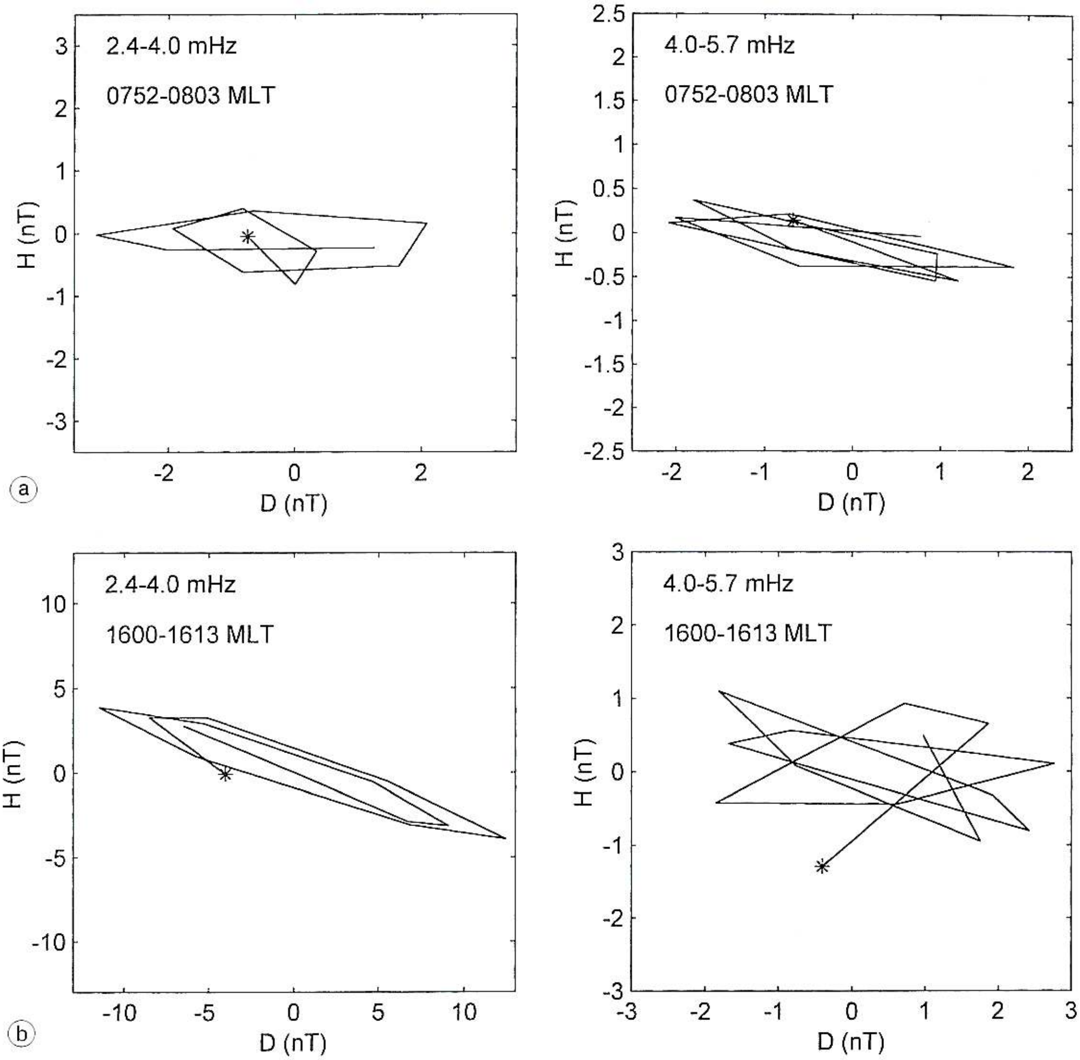

Fig. 3a,b. Hodograms of the 2.4-4.0 mHz (left panels) and 4.0-5.7 mHz (right panels) filtered signals for the time intervals: a) 1552-1603 UT (0752-0803 MLT); b) 0000-0013 UT (1600-1613 MLT) on January 8-9, 1997. Stars indicate the initial points.

MLT for fluctuations in the lower frequency range. The spectral analysis conducted over the following 2-h interval (1620-1820 UT, corresponding to approximately 0820-1020 MLT) reveals that power peaks emerge for both horizontal components at frequencies of 2.0-3.0 mHz and 4.2-5.2 mHz; the dominant polarization sense of the corresponding filtered signals is CCW and CW, respectively. In fig. 6 we show, as an example, the hodograms corresponding to the time interval 1740-1755 UT (0940-0955 MLT); it is evident that simultaneous fluctuations at lower and higher frequency have the opposite polarization sense.

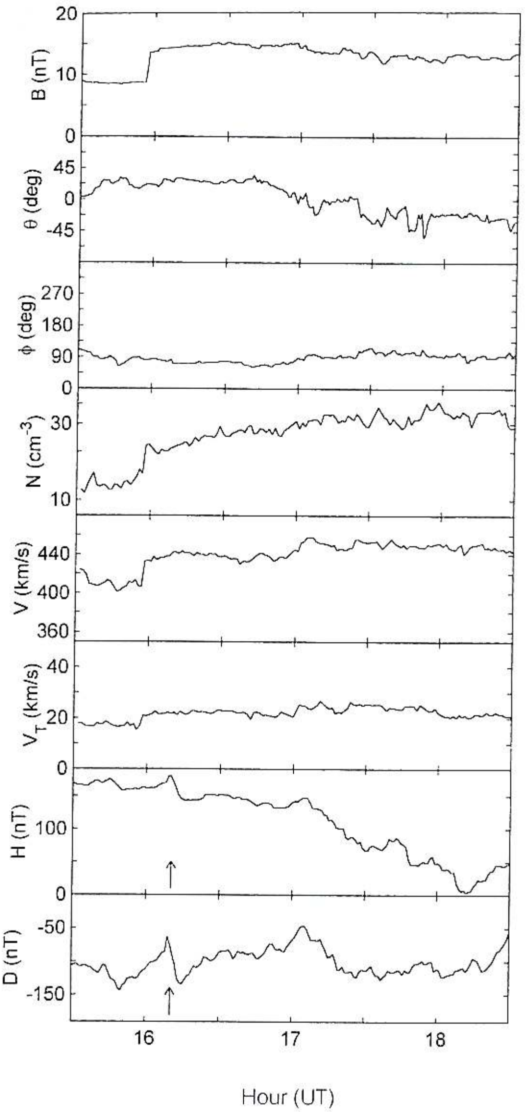

Fig. 4. Interplanetary and geomagnetic field data for the time interval 1530-1830 UT on October 10, 1997. From the top are shown: the interplanetary magnetic field strength, latitude and longitude, the solar wind number density, speed and thermal speed and the horizontal components H and D at TNB. The arrows indicate the SI onset discussed in the text.

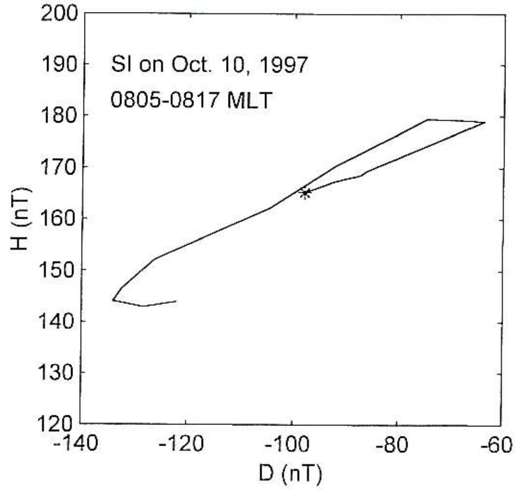

Fig. 5. Hodogram of the SI detected on October 10, 1997 in the time interval 1605-1617 UT (0805-0817 MLT). Star indicates the initial point.

3. Summary and discussion

In this paper we performed a statistical analysis of the polarization pattern of low-frequency geomagnetic field fluctuations (0.7-7.4 mHz) recorded at the high-latitude station TNB during 1997 and 1998. We found that the polarization pattern shows a frequency dependence, in that different results are obtained in the two frequency ranges 0.7-4.0 mHz and 4.0-7.4 mHz (as shown in fig. 1a,b).

At lower frequencies the results are consistent with the complex polarization pattern, with four reversals at different local times, inferred by Samson (1972) for low frequency *Pc*5 pulsations ($f < 4$ mHz) at latitudes of ~ 80°: the CW polarization generally dominates during the day (with percentages up to 80-90% in the local postmidnight and postnoon sectors), while the CCW polarization emerges in the local morning (~ 0600-1000 MLT) and, less clearly, in the late afternoon (~ 1900 MLT). Similar results have been previously found from the analysis of the polarization pattern of 0.8-3.6 mHz fluctuations at TNB during a different year (Lepidi *et al.*, 1999).

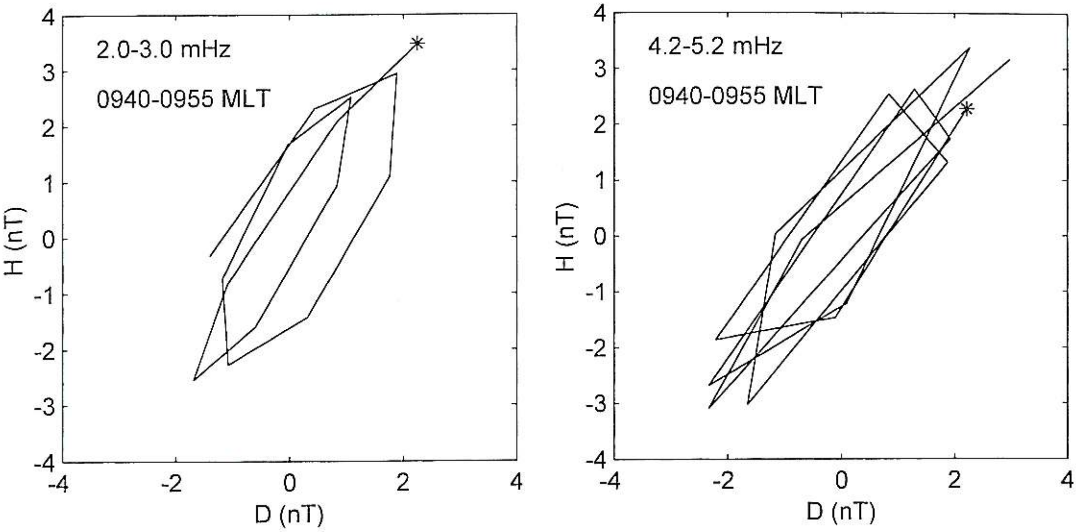

Fig. 6. Hodograms of the 2.0-3.0 mHz (left panel) and 4.2-5.2 mHz (right panel) filtered signals for the time interval 1740-1755 UT (0940-0955 MLT) on October 10, 1997. Stars indicate the initial points.

At higher frequencies, the reversal in the local morning is less evident (with similar percentages of the two polarization senses between 0800 MLT and 1100 MLT), while the reversal in the late afternoon more clearly emerges. These results can be still considered consistent with the pattern proposed by Samson (1972), taking into account that for higher frequency the whole resonant region shifts toward lower latitudes, so the effects of field line resonances cannot be detected at TNB any more.

We found it interesting also to conduct a study of individual pulsation events in order to find a correspondence with the general, statistical behavior previously shown, and in particular to focus on events for which it clearly emerges that fluctuations with opposite polarization sense, depending on frequency, can be detected simultaneously. As an example, we show a long pulsation event detected during a 13-h interval for which simultaneous fluctuations at lower and higher frequency are characterized by CCW and CW polarization, respectively, in the local morning (~ 0700 MLT) and by CW and CCW polarization, respectively, in the local afternoon (~ 1600 MLT). Similarly, we show a shorter duration (~ 2-h) pulsation event, triggered by a SW discontinuity, occurring in the local morning; we found that the polarization sense is CCW for the lower frequency fluctuations, as well as for the preceding SI (detected in correspondence to the arrival of the SW pressure increase), while it is CW for the higher frequency fluctuations. This result clearly indicates that, around local magnetic noon, the resonant region for the lower frequency (0.7-4.0 mHz) waves usually extends to the latitude of TNB.

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