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High resolution geomagnetic field observations at Terra Nova Bay, Antarctica

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Abstract
The preliminary results obtained from the analysis in the micropulsation frequency range of high time resolution magnetic field data recorded at the Antarctic Italian geomagnetic observatory at Terra Nova Bay for 11 consecutive days in February 1994 are reported. The spectral index over the whole Pc1-Pc5 frequency range is of the order of 3.5 and its value significantly increases beyond about 50 mHz. Spectral peaks in the Pc3 frequency range are common, especially during the daytime hours, and are probably due to the direct penetration of upstream waves in the cusp region. From the local time distribution of the micropulsation power, a significant activity enhancement around the local magnetic noon emerges, in agreement with previous observations. The analysis of the signal polarization characteristics in the horizontal plane shows a predominant CW polarization in the Pc1-Pc3 frequency ranges with the major axis of the polarization ellipse in the first quadrant.

Key words *geomagnetic pulsations – spectral index – wave polarization – Antarctica*

1. Introduction

As underlined by several authors (Rostoker *et al.*, 1972; Lanzerotti, 1978; Lanzerotti *et al.*, 1986; Morris and Cole, 1987; Yumoto *et al.*, 1987; Arnoldy *et al.*, 1988; Lee *et al.*, 1988; Meloni *et al.*, 1992) Antarctic geomagnetic measurements are very important for the study of the Earth's magnetic field and for a better understanding of the dynamic processes of the Earth's magnetosphere. In particular, they provide unique conditions for the study of geomagnetic micropulsations (0.2 s < T < 600 s) in that local field lines penetrate extreme magnetospheric regions (close to the magnetopause) and the polar cusp, where several generation mechanisms for the ULF waves are active (Arnoldy *et al.*, 1988 and references therein).

The Antarctic Italian geomagnetic observatory was installed in Terra Nova Bay (geographic coordinates: 74.7S, 164.1E; geomagnetic coordinates, IGRF85: 77.3S, 279.4E; L.T. = U.T. + 13; M.L.T. = U.T. – 8; altitude = 28 m a.s.l.) during the 1986-1987 austral summer. In the first Antarctic surveys the instrumentation included only proton precession and fluxgate magnetometers with sampling rate of the magnetic field components between 2 min and 30 s (Meloni *et al.*, 1992). During the 1993-1994 campaign, a search-coil magnetometer was added to the instrumentation, and was operating for 11 consecutive days in February 1994. In this paper we report the results obtained from the analysis of this preliminary set of high resolution data; such a detailed case study is important to establish the main characteristics of the micropulsation activity at Terra Nova Bay. In a forthcoming paper the analysis will be extended to longer time intervals, using observations performed for several months during the 1994-1995 austral summer.

2. Instrumentation and data analysis

In the present investigation we analyzed the variations of the geomagnetic field horizontal components measured at Terra Nova Bay from February 7 to February 17, 1994, a period characterized by a K_p index ranging between 3 and 6+. The analysis covers the standard con-

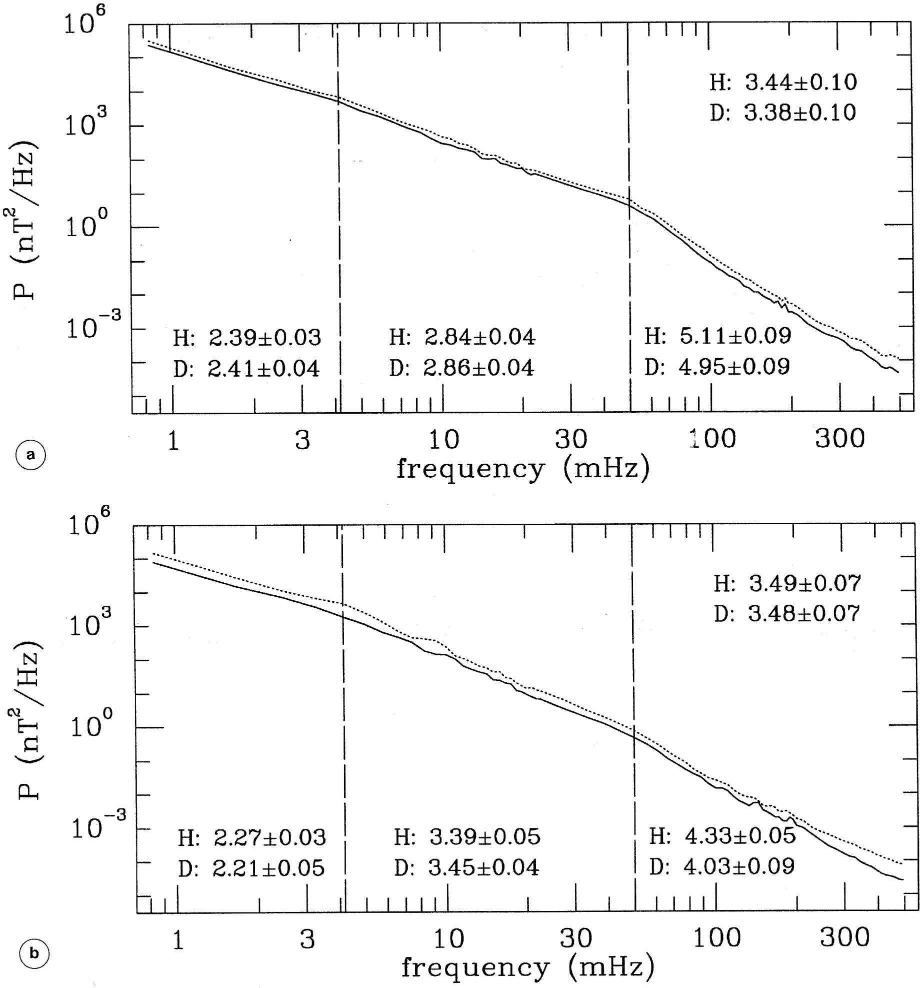

Fig. 1a,b. Average power spectral densities for the *H* (solid line) and *D* (dotted line) components computed over the 11 days; the results obtained for the day and the nighttime hours are shown in (a) and (b) respectively. The numbers at the top right are the spectral indices calculated for the whole frequency range, the ones at the bottom are the spectral indices calculated for the three frequency subranges delimited by the vertical dashed lines.

tinuous pulsations frequency ranges: Pc5 (1.7 mHz $< f <$ 6.7 mHz), Pc4 (6.7 mHz $< f <$ 22.2 mHz), Pc3 (22.2 mHz $< f <$ 100 mHz), Pc2 (100 mHz $< f <$ 200 mHz) and part of the Pc1 (200 mHz $< f <$ 500 mHz). The instrumentation, which consists of three perpendicular search-coil magnetometers, measures the variations in the geomagnetic North-South (*H* component), East-West (*D* component) and vertical (*Z* component) directions; the declination in the period of interest is about 137°. The data, originally sampled at 10 Hz, are averaged and stored at 1 Hz. For frequencies between about 0.7 mHz and 500 mHz, the instrument transfer function is linear with the frequency, with a slope of 10.72 Volt $\mathrm{nT}^{-1}\,\mathrm{Hz}^{-1}$.

We conducted a spectral analysis of the *H* and *D* geomagnetic data by means of the DFT (Discrete Fourier Transform) technique. Hourly spectra were computed by averaging 3 consecutive 20 min spectra (with a resolution of 0.83 mHz) for the Pc4 and Pc5 frequency ranges and by averaging 20 consecutive 3 min spectra (with a resolution of 5.56 mHz) for the Pc1, Pc2 and Pc3 frequency ranges. Pc1 spectra were further averaged over intervals corresponding to three adjacent frequency bands (16.7 mHz). In this way, the number of frequency bands in the Pc1-Pc5 ranges is 18, 18, 15, 18 and 7 respectively.

A cross-spectral analysis between horizontal components was also conducted by means of the DFT technique; in the Pc1, Pc2 and Pc3 frequency ranges, 15 min transfer functions were calculated by averaging five 180 s spectra, while in the Pc4 and Pc5 frequency ranges hourly transfer functions were calculated by averaging three 1200 s spectra; the spectra were also averaged in frequency over each of the five Pc frequency bands: the transfer functions obtained in this way for the Pc1-Pc5 ranges have 540, 180, 150, 108 and 42 degrees of freedom respectively.

3. Experimental results

The average spectra obtained for the two horizontal components, for the daytime and the nighttime intervals respectively, are shown in fig. 1a,b (after a visual inspection of the hourly spectra, we decided to consider as daytime

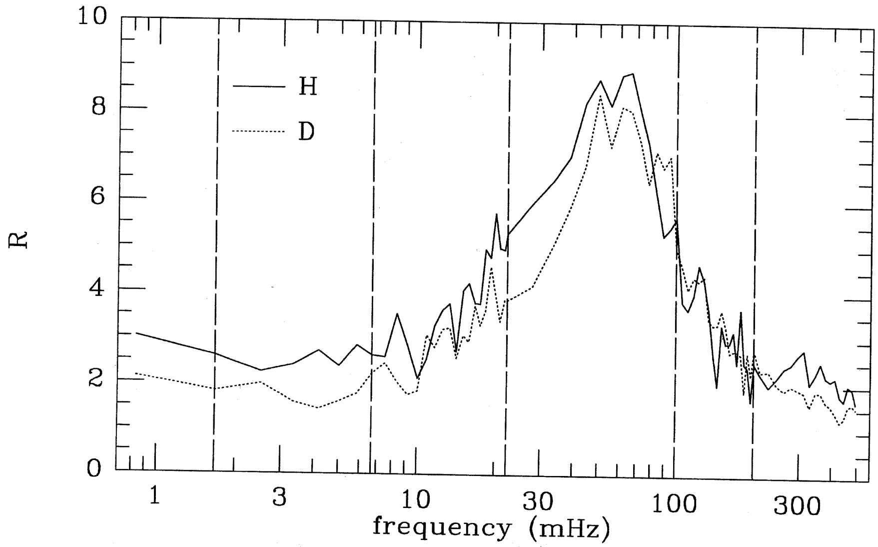

Fig. 2. Ratio *R* between the daytime and the nighttime average spectra, separately for the two components. The vertical dashed lines separate the five Pc frequency ranges.

hours the period 05:00-17:00 L.T. and as nighttime hours the period 17:00-05:00 L.T.); they were calculated by averaging 123 and 128 hourly spectra respectively. It can be seen that the *D* component power is somewhat higher than the *H* component power, and the power level is higher during daytime hours. From the spectral density levels shown in fig. 1a we estimated that the average signal amplitudes in the Pc1-5 ranges are respectively 0.005, 0.05, 0.5, 1 and 5 nT.

Figure 1a,b also indicates the spectral indices, estimated by a least-square approximation on log frequency equispaced points. At the top right we show the spectral indices obtained for the whole frequency range, while at the bottom we show the ones obtained for the three separate frequency subranges identified by the vertical dashed lines; these frequency subranges were chosen from a visual inspection of the average spectra, which reveal significant changes of the spectral slopes approximately at 4 and 50 mHz, the frequencies that typically correspond to enhanced power levels in the cusp region (Olson, 1986). The spectral slopes calculated over the whole frequency

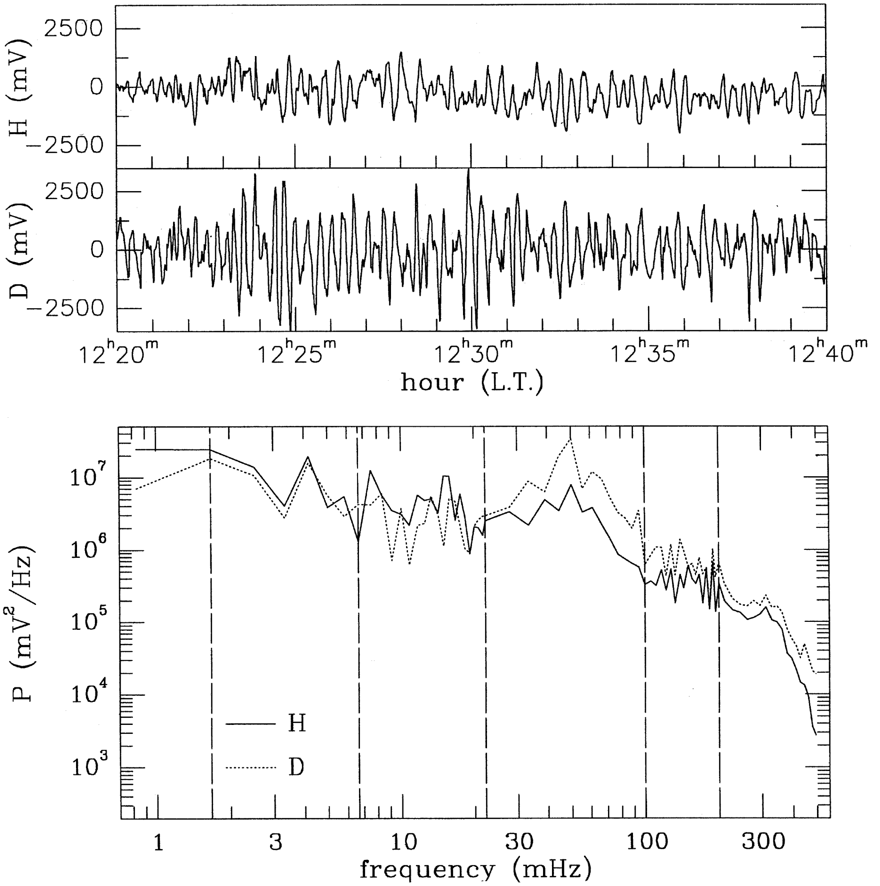

Fig. 3. Example of daytime micropulsation activity detected on February 12, 1994; the power spectral densities calculated for the whole corresponding hour are also shown. The vertical dashed lines separate the five Pc frequency ranges.

range for the *H* and *D* components and both for the day and the nighttime intervals are all consistent within the errors. A comparison between results obtained for different frequency subranges shows for both components a marked tendency for the spectral indices to increase with increasing frequency.

Figure 2 shows the ratio *R* between the daytime and the nighttime average spectra, separately for the two components. Figure 2 confirms that the power level is higher during the daytime hours and shows that this feature may be less evident for the *D* component, especially at low frequencies. Moreover, a pronounced peak at about 50-60 mHz emerges in both curves, indicating that the daytime hours are characterized by a higher activity level in the Pc3 frequency range.

Figures 3 and 4 show two typical examples of wave trains, detected during day and nighttime hours respectively, together with the power spectra calculated for the whole corresponding hour. For the daytime event (fig. 3) the spectra of the two horizontal components are very similar, with a major peak, somewhat higher for the *D* component, in the Pc3 range. A similar peak at much

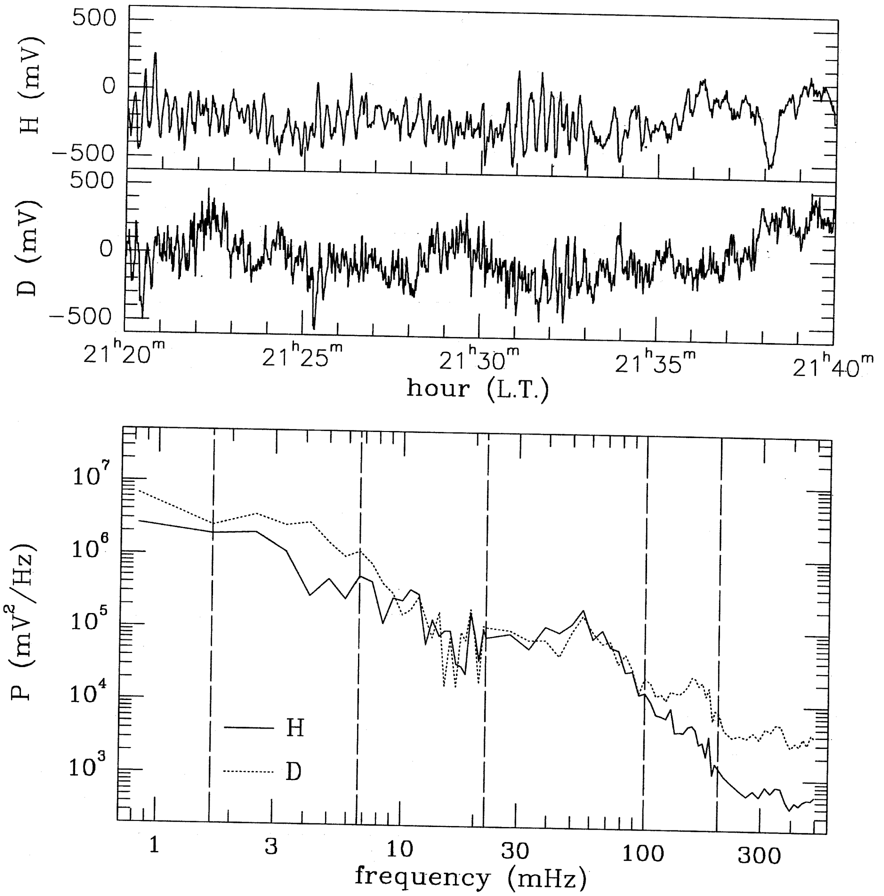

Fig. 4. Example of nighttime micropulsation activity detected on February 7, 1994; the power spectral densities calculated for the whole corresponding hour are also shown. The vertical dashed lines separate the five Pc frequency ranges.

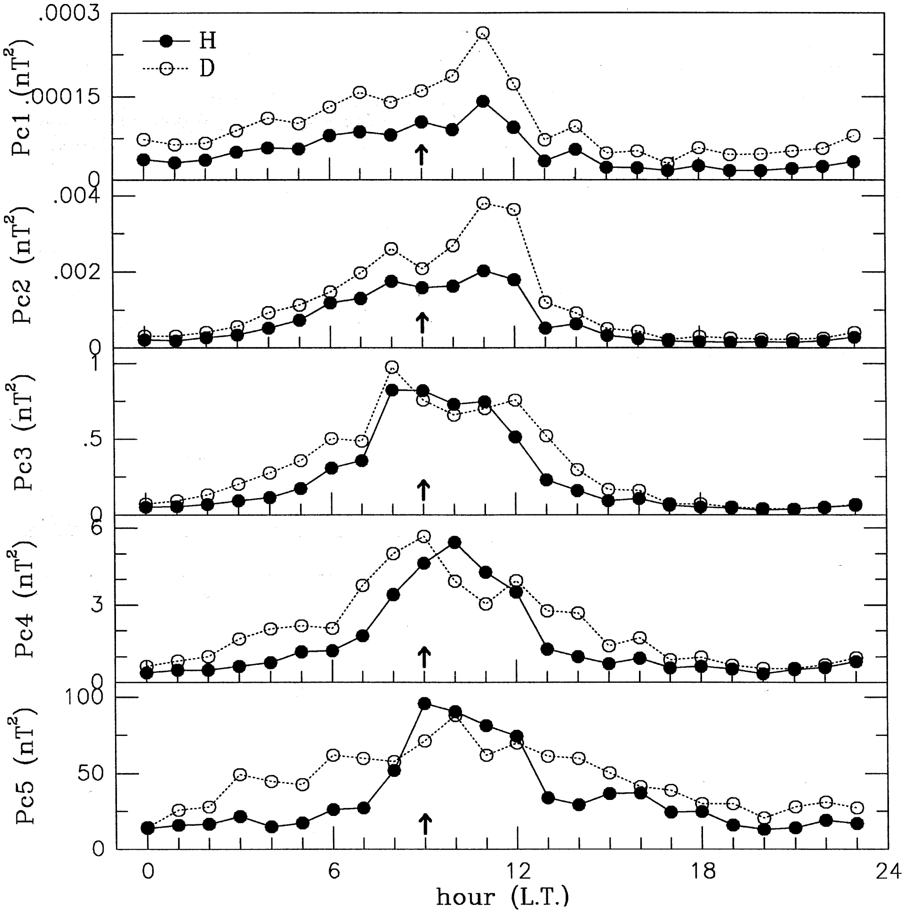

Fig. 5. Daily distribution *vs.* L.T. of the average power integrated over the five Pc ranges; the solid arrows indicate the magnetic local noon.

lower power level also emerges for the nighttime event (fig. 4); however in this case the major *D* enhancement over *H* emerges in the Pc1 and Pc2 bands, as observed also in several other cases in the period of interest.

To investigate the local time dependence of the micropulsations power, the hourly power spectra were integrated over each of the five Pc ranges, and the values corresponding to the same hour were logarithmically averaged. Figure 5 shows the daily distribution of the average integrated power of the *H* and *D* components *vs.* L.T. It can be seen that in each frequency range there is a significant power enhancement around the magnetic local noon (solid arrows in fig. 5), corresponding to the late local morning hours; note moreover that the *D* component power level is usually higher than the *H* one, except in the Pc3, Pc4 and Pc5 ranges in a few hours just before local noon. It has been verified that for the Pc3, Pc4 and Pc5 ranges the daily distributions shown in fig. 5 are very close to the ones obtained for the individual days; conversely, significant day to day differ-

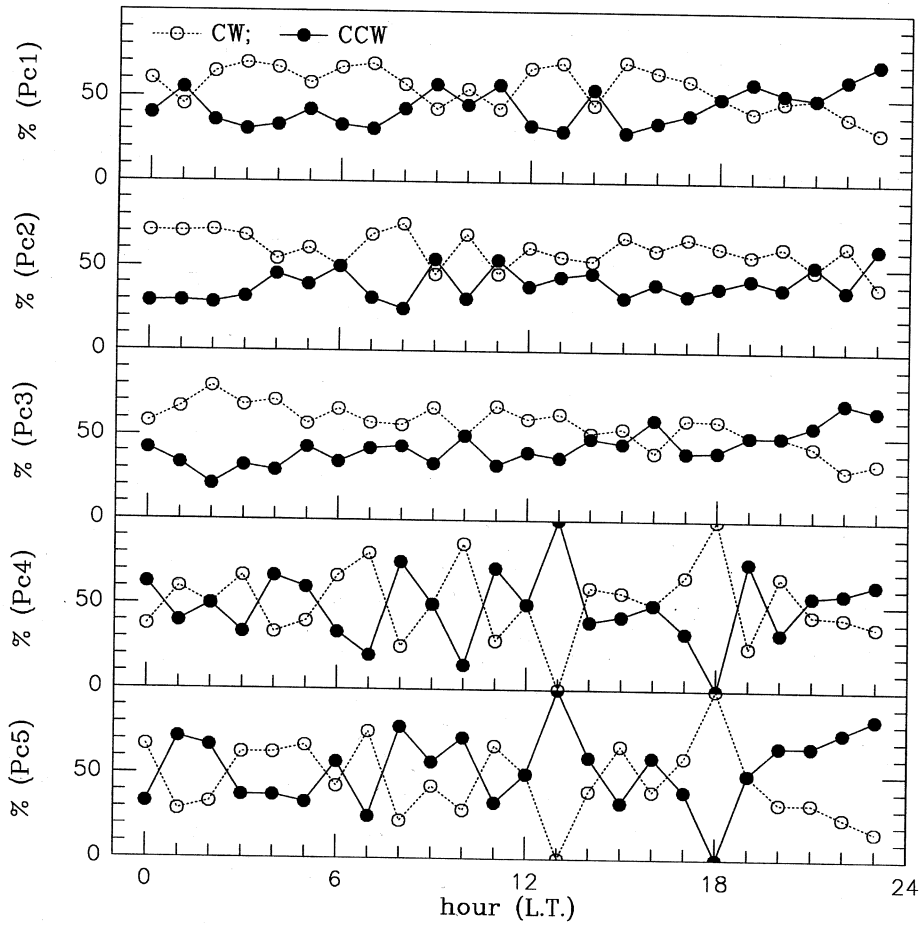

Fig. 6. Daily distribution *vs.* L.T. of the percentage of events with CW and CCW polarization, separately for the five Pc ranges.

ences can be found for the Pc1 and Pc2 ranges (showing a more irregular behaviour of the high frequency ranges, Olson, 1986), implying that the average values in fig. 5 mostly reflect the behaviour of the field during single active days.

An analysis of the polarization characteristics for micropulsation events with coherency between components greater than 0.5 was conducted by means of a cross-spectral technique between the two horizontal components. Positive and negative values of the phase difference between the *H* and *D* component indicate respectively clockwise (CW, corresponding to left-hand polarized waves) and counterclockwise (CCW, corresponding to right-hand polarized waves) polarization; moreover, phase differences between −90° and 0° or between 90° and 180° indicate that the major axis of the polarization ellipse is in the first quadrant, while values between −180° and −90° or between 0° and 90° indicate that it is in the second quadrant.

Figure 6 shows the daily distributions of the percentage of events with CW (dashed line) and CCW (solid line) polarization, separately for the five Pc frequency ranges. It can be seen that in the Pc1, Pc2 and Pc3 ranges the CW polarization is generally dominant, especially in the postmidnight to early morning sector, while in the Pc4 and Pc5 ranges there is no evidence for any dominant polarization. Note moreover that just before local midnight the occurrence of the CCW polarization seems to become more probable in all frequency ranges.

Table I reports, both for the CW and the CCW polarization, the total number of events (indicated respectively with CW and CCW), the number of events for which the major axis of the polarization ellipse is in the first quadrant (respectively CW-1st and CCW-1st) and the number of events for which it is in the second quadrant (respectively CW-2nd and CCW-2nd). It can be seen that the CW polarization is generally associated with a major axis of the polarization ellipse situated in the first quadrant, while the contrary holds for the CCW polarization, CCW polarization being associated with second quadrant major axis; this result does not show any dependence on the local time.

Within the limits of the present statistics, we lastly considered the possible influence of the SW parameters on the Pc micropulsations power on hourly time scale; in this regard, we found that, both for the *H* and *D* component, the logarithmic power integrated over each of the five Pc ranges does not show any significant dependence on the SW speed nor on the cone-angle. The highest correlation coefficient was found in the Pc3 range for the daytime hours, when the correlation coefficient between the power of the *D* component and the SW speed (and cone-angle) is 0.35 (and −0.34) with 37 data points. The lack of a higher correlation could be explained in terms of the low variability of the SW speed which in the period of interest was always greater than 550 km/s. In this sense it might be interesting to recall the results obtained by Yedidia *et al.* (1991) who found at low latitudes a good correlation between the micropulsation power and the SW speed below 600 km/s, while above this threshold any further increase in the SW speed did not provide a corresponding increase in micropulsation power.

4. Discussion and summary

In this paper we analyzed the high resolution magnetic field variations of the *H* and *D* components recorded at Terra Nova Bay for 11 days during February 1994, in a period characterized by high geomagnetic activity at planetary level.

To characterize the hydromagnetic activity in the whole Pc1-Pc5 frequency range, we calculated the average power spectra separately for the day and nighttime hours. We found that the power level of the *D* component is generally higher than the *H* component power level, and that the daytime power is higher than the nighttime one; these results are consistent with those found by De Lauretis *et al.* (1991) at different geomagnetic latitudes (42N, 51N, 74N); conversely, during very quiet days, at geomagnetic latitudes of ≈60N, Lanzerotti and Robbins (1973) found that the *H* power far exceeds the *D* one.

As to the spectral indices, we obtained for both components, values of the order of 3.5,

Table I. Polarization characteristics in the five Pc frequency ranges.

	CW	CCW	CW-1st	CW-2nd	CCW-1st	CCW-2nd
Pc1	294	232	234	60	60	172
Pc2	391	259	347	44	22	237
Pc3	359	283	328	31	25	258
Pc4	82	84	55	27	28	56
Pc5	71	86	44	27	33	53

which are similar to the ones found by De Lauretis *et al.* (1991) at Iqaluit (geomagnetic latitude: 74.0°N) in the Pc3-Pc5 frequency range; conversely, Olson (1986) found that the spectral index at Cape Parry (geomagnetic latitude: 73.8°N) in the Pc1-Pc5 frequency range was about 2.6. We also obtained that the spectral slopes significantly increase with increasing frequency: beyond 50 mHz they reach values of about 5 during the daytime hours and 4 at night.

Spectral peaks at about 50 mHz have often been found to occur in the daytime hourly spectra, and just occasionally in the nighttime ones. This feature can find correspondence in one of the typical frequencies of enhanced power (40-50 mHz) which have been found by Tonegawa *et al.* (1984) and by Olson (1986) at auroral oval latitudes and interpreted in terms of direct penetration of upstream waves into the cusp region. As a matter of fact, the average value of the interplanetary field strength during the daytime hours in the period of interest (about 7.6 nT) leads to a prediction of frequency in the order of 45 mHz for the upstream waves, which is well consistent with the present results. Conversely, we found no evidence for the power enhancement at about 5 mHz reported by Tonegawa *et al.* (1984) and Olson (1986), which has been interpreted in terms of fluctuations in ionospheric currents associated with the cusp.

The daily distribution of the average power level integrated over each of the five Pc frequency ranges shows a significant enhancement around the magnetic local noon. This result is similar to that obtained by Morris and Cole (1987; 1991), who found that the occurrence distribution *vs.* L.T. of Pc1-2 and Pc3 events at Davis, Antarctica (geomagnetic latitude 74.3S) maximizes approximately around the magnetic local noon; in contrast, Olson (1986) found that at Cape Parry (geomagnetic latitude 73.8N) the power in the Pc3, Pc4 and Pc5 ranges, as well as in two frequency bands in the Pc1 range, has two diurnal peaks: a principal one near local midnight and a secondary one near local noon. The power increase near the magnetic local noon has been explained in terms of a smaller distance from the polar cusp (*i.e.* from the magnetopause field lines), where several mechanisms of excitation of ULF waves are active (Rostoker *et al.*, 1972; Olson, 1986).

In order to investigate the polarization characteristics of the signals, a cross-spectral analysis between the two horizontal components was performed. We found that in the Pc1, Pc2 and Pc3 ranges the CW polarization (corresponding to left-hand polarized waves) tends to be dominant, especially during the local morning, while in the Pc4 and Pc5 ranges no dominant sense of polarization emerges. Moreover, in the space of a very few hours just before local midnight, in all frequency ranges the CCW polarization (corresponding to right-hand polarized waves) seems to become more frequent. We also found that the CW and CCW polarizations tend to be associated with a major axis of the polarization ellipse situated in the first and in the second quadrant respectively. These results are only in part consistent with the theory by Chen and Hasegawa (1974) of local field line resonances excited by surface waves on the magnetopause due to the *K-H* instability; this theory indeed predicts a CW polarization with a major axis of the polarization ellipse in the first quadrant during local morning and a CCW polarization with a major axis of the polarization ellipse in the second quadrant during local afternoon. Previous investigations of the Pc3, Pc4 and Pc5 polarization characteristics from low to high latitudes have usually led to results which are consistent with the theory by Chen and Hasegawa (Samson *et al.*, 1971; Samson, 1972; Fukunishi and Lanzerotti, 1974; Fukunishi *et al.*, 1975; Lanzerotti *et al.*, 1981; Morris and Cole, 1987). In our case, however, it has to be taken into account that, even near local noon, the Terra Nova Bay station is situated northward of the average position of the auroral oval (Akasofu, 1978), so that local field lines might not be closed in the day-side magnetosphere, where field line resonances take place. As to the higher frequency pulsations (Pc1-3), the dominant CW polarization is consistent with the results by Morris and Cole (1991), who found that at Davis, Antarctica, the Pc1-2 continuous pulsations are generally left-hand polarized, and interpreted the experimental observations in terms of Alfven wave manifestations.

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