Ground based observations of *Pc*3-*Pc*5 geomagnetic pulsation power at Antarctic McMurdo station

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Abstract
The two horizontal geomagnetic components *H* and *D*, measured by a fluxgate magnetometer at Antarctic McMurdo station (corrected geomagnetic coordinates 80.0 S, 327.5 E), are analyzed for the period May-June 1994; the spectral powers are calculated and integrated over three frequency intervals corresponding to the nominal *Pc*3, *Pc*4, *Pc*5 ranges. The time dependence of those integrated powers and their correlations with northern auroral indices and solar wind speed are considered. The observations are compared with previous results reported from Terra Nova Bay station (located near McMurdo at the same corrected geomagnetic latitude) during Antarctic summer intervals. The differences found between the two stations are discussed in terms of the seasonal dependence of geomagnetic field line configurations in the near cusp region.

Key words *magnetospheric physics – geomagnetic pulsations – hydromagnetic waves – Antarctica*

1. Introduction

In previous studies related to auroral and polar latitudes one diurnal peak (*e.g.*, Gupta, 1975; Morris and Cole, 1987) or two peaks (*e.g.*, Gupta, 1975; Olson, 1986) were found for the time distribution of low frequency (*Pc*3, *Pc*4, *Pc*5 ranges) geomagnetic pulsation power. At these latitudes, when enhancements of pulsation power occur close to Magnetic Local Noon (MLN) they are interpreted in terms of proximity to the cusp, as the cusp (characterized by its dayside magnetospheric opened field lines) is a region where several generation mechanisms for hydromagnetic waves are active. When enhancements of pulsation power are detected far away from the MLN they have been explained in terms of the occasional location of the station under closed field lines for a polar cap location (Gupta, 1975) or, when the enhancement is close to Magnetic Local Midnight (MLM), in terms of impulsive substorm related features at average auroral/polar cap latitudes (*e.g.*, Olson, 1986). The power level of the nightside peak, when it is present, can be higher than the local noon amplitude (*e.g.*, Olson, 1986). In addition, from simultaneous observations at different longitudes, it has been found that often ULF pulsations occur within a few minutes at all stations independently of their local time (Engebretson *et al.*, 1995).

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At Antarctic latitudes a good correlation has been found between ULF pulsations (both power and occurrence) and solar wind speed, indicating that the Kelvin-Helmoltz instability at the magnetopause is one of the driving mechanisms for the observed phenomena (*e.g.*, Odera, 1986; Arnoldy *et al.*, 1988; and references therein). However, at different times and different locations, several different mechanisms can contribute. In particular, several results (correlations with *Dst*, single event observations, etc.) show the possible substorm related origin of the ULF power. Good correlations of the amplitude of the auroral electrojet index *AE* (considered a good indicator of substorm activity at a planetary level) have been found with low frequency ground-based geomagnetic pulsation power level (Wolfe and Meloni, 1981) and with satellite broadband ULF observations (Anderson, 1994), during both daytime and nighttime.

In the present paper we analyze the time dependence of the ULF geomagnetic pulsation power at the United States Antarctic McMurdo (MCM) station. We also investigate the correlations of ULF power with auroral indices and solar wind speed. The results are compared to those previously obtained at the Italian Terra Nova Bay (TNB) station (*e.g.*, Ballatore *et al.*, 1996, 1997; Lepidi *et al.*, 1996), which is located at the same corrected geomagnetic latitude, with a geomagnetic longitude difference of only 20 degrees from MCM.

2. Observations

The horizontal geomagnetic field components (*H* refers to the geomagnetic N-S and *D* to the geomagnetic E-W direction), measured by a fluxgate magnetometer located at McMurdo (geographic coordinates: 77.85 S and 166.67 E; corrected geomagnetic coordinates: 79.94 S, 327.53 E; MLT = UT − 6.91 h) have been analysed for the time period May-June (61 days) 1994. Spectra have been calculated over one hour intervals using ten-second resolution data (360 data points for each spectrum). The maximum entropy method was used with an order m = 90 of the prediction error filter (Press *et al.*, 1990). The spectral powers have been separately integrated over the frequency ranges: 1.7-6.7 mHz (nominal *Pc*5), 6.7-22.2 mHz (nominal *Pc*4), and 22.2-50.0 mHz (included within the nominal *Pc*3), 50 mHz being the Nyquist frequency.

For each frequency range, the one-hour integrated spectral powers have been averaged separately for each UT hour and results are illustrated in fig. 1. Higher activity is shown between 04 and 11 UT at all frequencies, the increase being sharper at the lower frequencies (in fact, for *Pc*5 this feature is most clear and for *Pc*3 it is not clearly visible). In fig. 1, considering the two geomagnetic horizontal components separately, one can see that for Pc3 the intensity of the *H* and *D* power is almost equal; on the contrary, at the lower frequencies, a clear increase in the *D* power with respect to *H* is present in the interval of maximum power (04-11 UT). The peak for the time distribution of power can be identified around 06 UT, *i.e.* at about 23 MLT so that the association with substorm-related effects is clearly suggested.

The power distributions were calculated considering separately periods with $K_p \leq 2$ and with $K_p \geq 3$. The results are respectively illustrated in figs. 2 and 3, where the number of data points averaged for each one-hour interval is indicated at the top of the graphics. We note that there are no significant peaks in fig. 2. The enhancements of the *D* component power in the intervals 9-10 UT and 22-23 UT are not significant. In fact the ranges from the minimum to the maximum value considered for each power range are not plotted because they are off-scale, large with respect to the power enhancements themselves. In particular, no peak of activity exists near 23 MLT (6-7 UT). No significant difference is evident among the frequency ranges considered. In particular the *H* power is about the same as the *D* power except that a slightly higher average *D* power is observed around 21 UT (14 MLT) and around 09 UT (about 2 MLT) at all frequency ranges. A similar result is obtained if the hourly medians are considered.

The results obtained for the most disturbed periods, as illustrated in fig. 3, are very similar

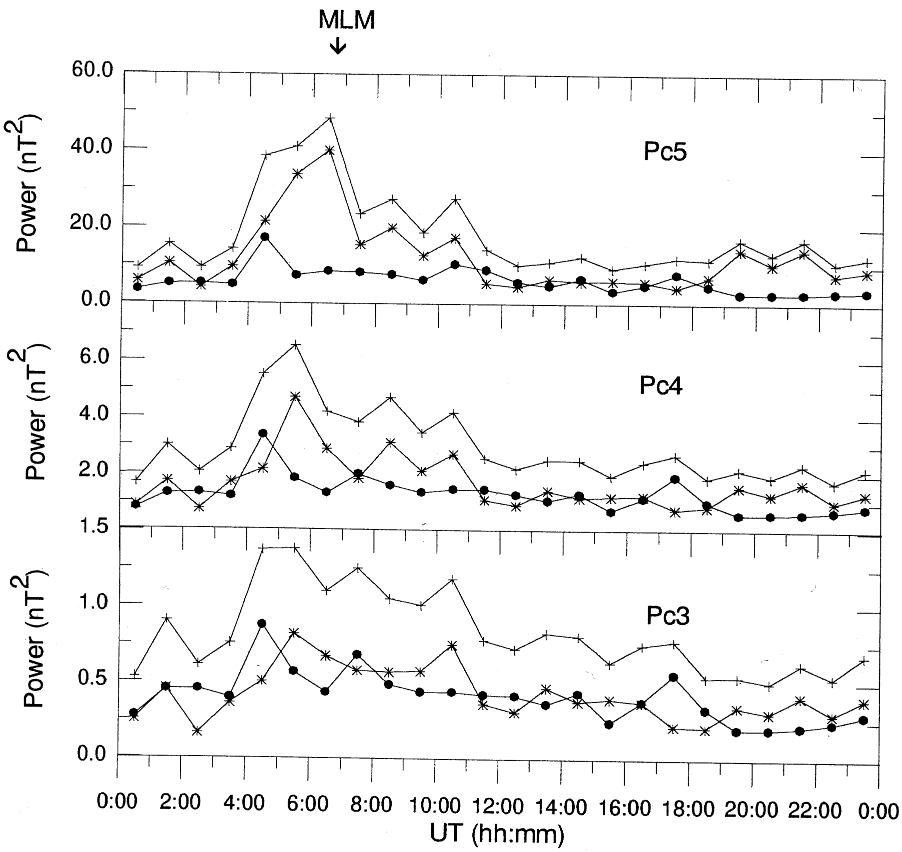

Fig. 1. Average values for integrated spectral powers (of H [•] and D [*] components separately and for their sum H+D [+]) *versus* UT; each panel refers to the specific frequency range indicated ($Pc3$, $Pc4$, $Pc5$). The arrow indicates the Magnetic Local Midnight (MLM).

to those shown in fig. 1, which is therefore dominated by the most geomagnetically active intervals. In particular a power increase is present just before MLM for $Pc5$ and is still present for $Pc4$, but is only marginally visible for $Pc3$. For the $Pc5$ frequency range, the D power intensity is much higher than H. On the contrary, for $Pc4$ the difference between the two components is not significant; similar results are seen in fig. 3 for the $Pc3$ frequency range. The local night enhancement in average $Pc5$ power is also seen if hourly median values are used.

The correlations of the logarithmic powers in the $Pc3$, $Pc4$, $Pc5$ bands with the solar wind speed and with the logarithm of the auroral indices (absolute values have been considered for possibly negative AL and AU) have been calculated. The correlation coefficients are reported in table I. We have not differentiated between dayside and nightside data points, but have considered all the data. All of the correlation coefficients are significant at a confidence level above 99.9%. In addition, the correlations slightly increase from the $Pc3$ towards the $Pc5$ frequency range. Considering separately the

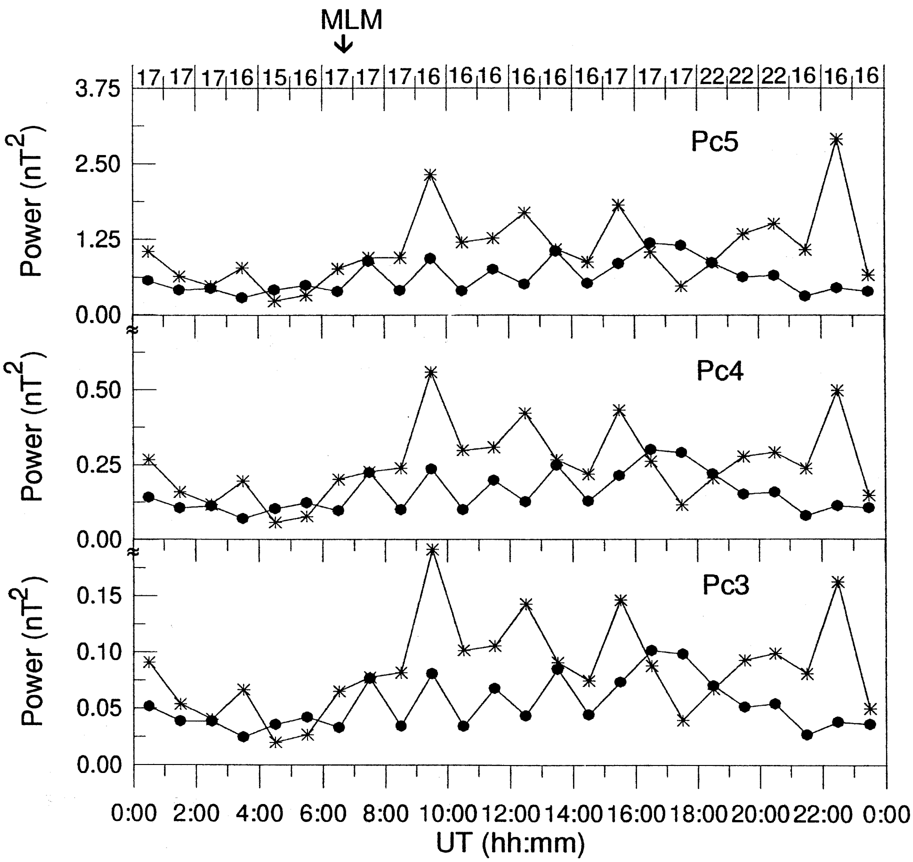

Fig. 2. Average values for integrated spectral powers (of H [•] and D [*] components) *versus* UT obtained considering only data points with $K_p \leq 2$; as in fig. 1, each panel refers to the specific frequency range indicated ($Pc3$, $Pc4$, $Pc5$). The Magnetic Local Midnight (MLM) is indicated by the arrow. The numbers at the top of the graph indicate the number of data points averaged for each one-hour interval.

H and D components, slightly less significant (than for the total H+D) correlations are always found. In particular, the correlation coefficients obtained with H are higher than the ones obtained with D, but this difference decreases towards the lower frequencies.

The results of a similar correlation, calculated separately for each two-hour interval in UT, are shown in fig. 4. In this case we have considered one-hour averaged values for the solar wind speed (from IMP-8 satellite data), provisional one-hour AE, AL, AU data, and the one-hour pulsation power values. We have considered the data grouped two-hours by two-hours in order to have a greater number of data points (than for correlations calculated separately for each hour) and to increase the statistical significance for each interval. This is important in particular when considering the solar wind data, which has several missing values due to the orbit of the IMP-8 satellite with respect to the Earth. In fig. 4 it can be seen that no correlation peak is found at any specific time, either in the correlations with the auroral

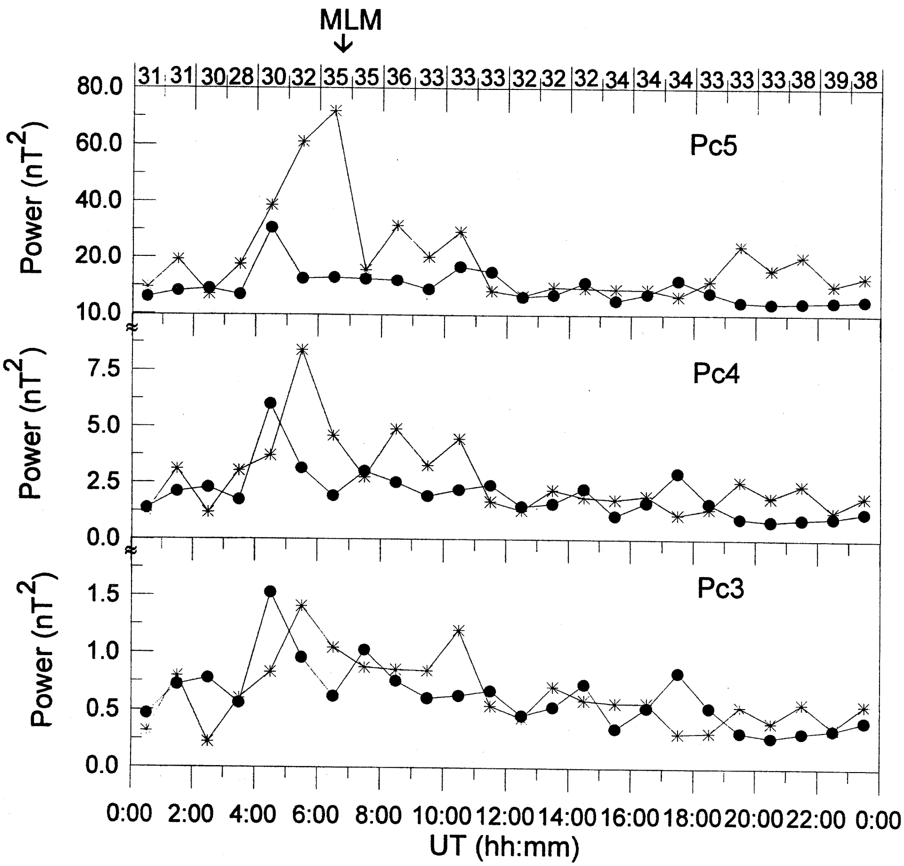

Fig. 3. Similar to fig. 2, but considering data points with $K_p \geq 3$.

Table I. Correlation coefficients in the *Pc*3, *Pc*4 and *Pc*5 bands.

		V_{sw} (km/s)	*AE* (nT)	*AL* (nT)	*AU* (nT)
		N = 750	N = 1426	N = 1423	N = 1426
*Pc*3	*H*	0.57	0.65	0.61	0.60
(nT^2)	*D*	0.53	0.56	0.54	0.52
	H+D	0.61	0.68	0.65	0.62
*Pc*4	*H*	0.59	0.65	0.62	0.60
(nT^2)	*D*	0.58	0.62	0.59	0.57
	H+D	0.63	0.70	0.67	0.64
*Pc*5	*H*	0.60	0.65	0.62	0.60
(nT^2)	*D*	0.60	0.63	0.61	0.59
	H+D	0.64	0.70	0.67	0.65

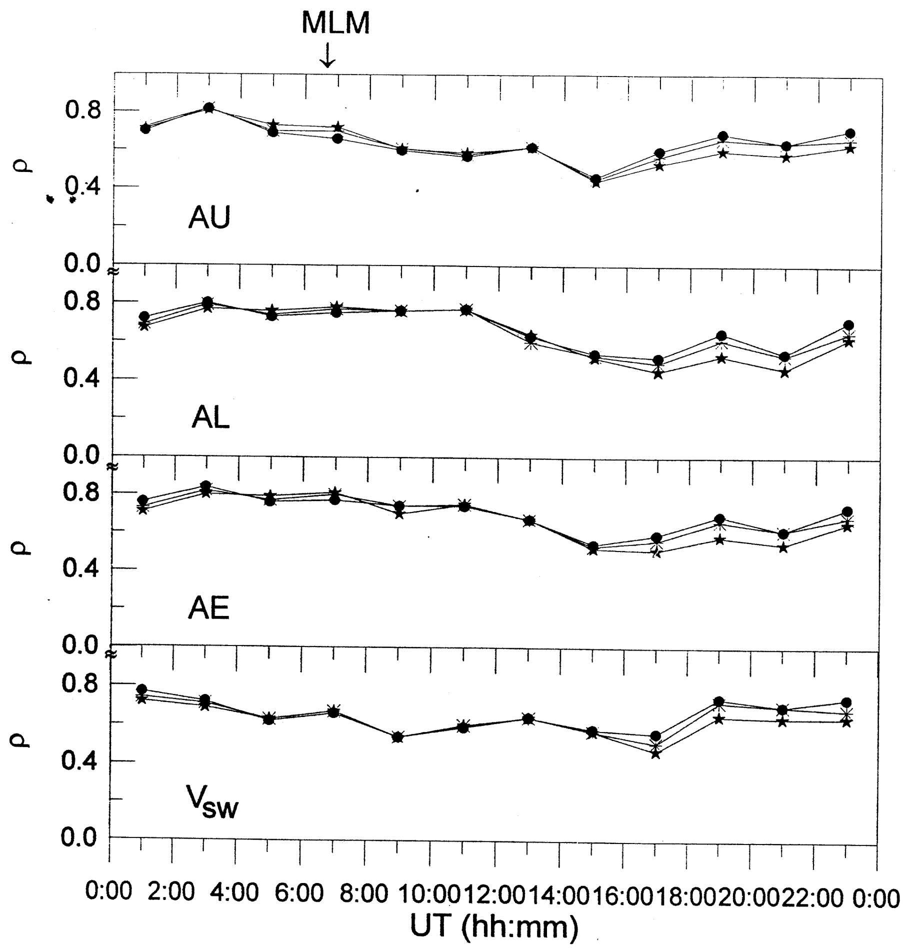

Fig. 4. Coefficients (ρ) *versus* UT of the correlations between logarithm of integrated *Pc*3 (★), *Pc*4 (*), *Pc*5 (•) powers with V_{sw} (bottom panel), logarithm of *AE* (second panel from the bottom), logarithm of *AL* (second panel from the top), logarithm of *AU* (top panel); each data point is illustrated at the center of the time interval to which it refers.

indices or with the solar wind speed. The results do not significantly depend on the range of variability of the parameters in the specific time intervals considered. The number of data points in each two-hour UT range is between 114 and 120 in the correlations with auroral indices; it is between 57 and 74 when considering the solar wind speed. The correlations are all significant at a confidence level above 99.9% at all time intervals.

3. Discussion

In a previous analysis of TNB (corrected geomagnetic coordinates: 80.03 S, 307.68 E) geomagnetic data for the Antarctic summers 1987/1988 and 1989/1990, the time distribution of *Pc*5 pulsation power was found to have a single peak just before MLN; this peak was explained in terms of the location of the station near the cusp region (Ballatore *et al.*, 1996). In addition, the same noon time single peak was observed in all frequency ranges from $Pc1$ to $Pc5$ using high-resolution TNB data for ten days of February 1994 (Lepidi *et al.*, 1996).

On the contrary, in the present study we have found that MCM magnetic noon is a quiet time for geomagnetic pulsations in the frequency ranges $Pc3$-$Pc5$, independent of the geomagnetic activity level. We explain this result by noting that observations at TNB were performed during the local summers (due to low sampling rate resolution measurements during Antarctic winters) whereas, in the present MCM study, we have considered data for the

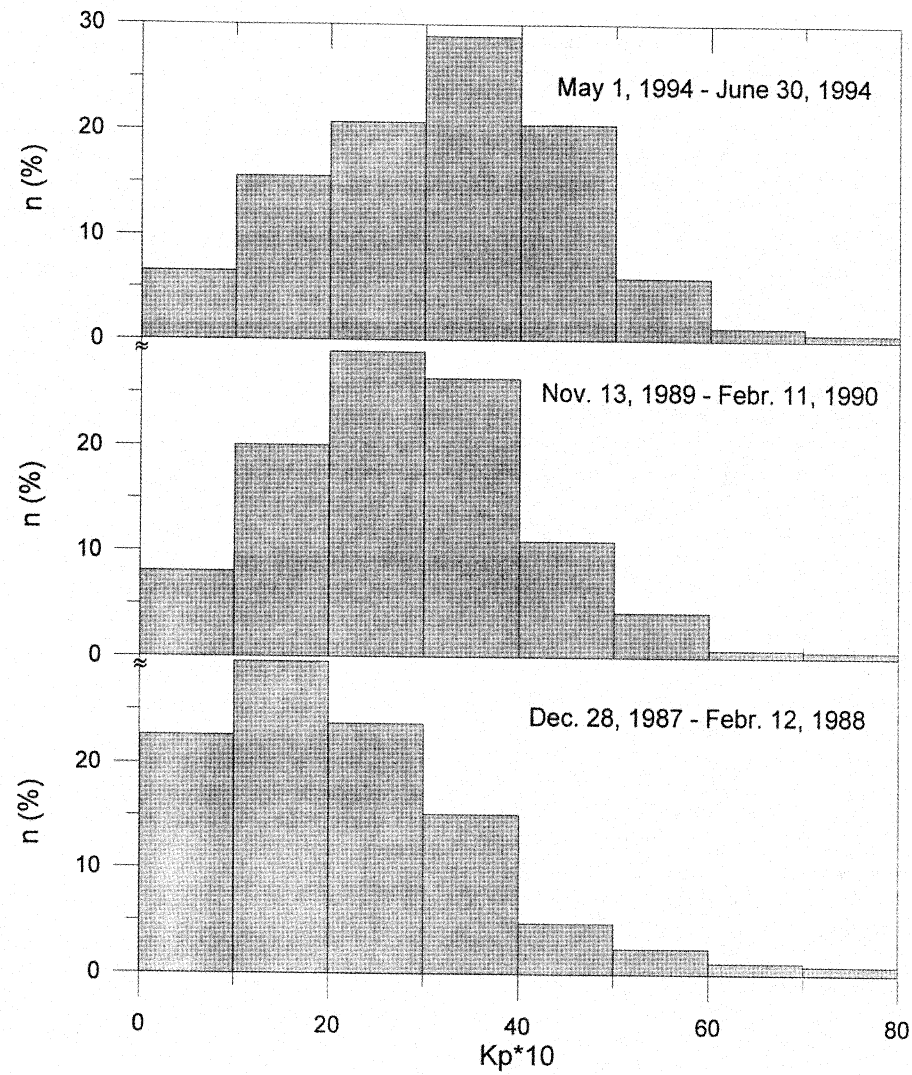

Fig. 5. Histograms of K_p values during the periods: May 1st - June 30th, 1994; November 13th, 1989 - February 11th, 1990; December 28th, 1987 - February 12th, 1988.

months May and June. In particular Newell and Meng (1989) found that the proper cusp latitude shifts when the dipole tilt angle increases and the difference between the winter and summer average cusp position is close to 4 degrees in MLAT, being lower in the winter than in the summer. This is in agreement with our present observation that identifies no effect of the cusp on MCM ULF pulsation power during austral winter.

In contrast to previous TNB results, we have found a peak of ULF geomagnetic pulsation power close to MLM. This peak emerges better for *Pc5* and it is not as clear for the higher *Pc*3 frequencies. Since this enhancement is near MLM it is most likely related to the substorm activity (as in previous references, *e.g.*, Gupta, 1975 or Olson, 1986). It is worth noting that the enhancement at magnetic midnight could exist also at frequencies lower than *Pc*5, which would imply that the results are not a specific characteristics of only the *Pc*3, *Pc*4, *Pc*5 pulsation regimes.

In order to investigate the effect of the geomagnetic activity level on the results during the interval under investigation we have plotted in fig. 5 the histogram of the K_p values at this time (upper panel). In the lower two panels, the distribution of K_p for the intervals December 28th, 1987 - February 12th, 1988 and November 13th, 1989 - February 11th, 1990 considered in the TNB study by Ballatore *et al.* (1996) are also illustrated. Figure 5 shows that the difference in the K_p distributions between the 1987-1988 and the 1989-1990 data intervals is at least as significant as the difference between the 1989-1990 and the 1994 data interval. In addition, during both the 1987/1988 and the 1989/1990 intervals the pulsation power enhancement was located near the MLN. Therefore, the absence of the MLN power enhancement and the MLM peak at MCM cannot be explained in terms of a difference in the geomagnetic activity level among the considered time intervals.

At TNB station, significant correlations between low frequency pulsation power and auroral indices were obtained only during magnetic local night, with the highest coefficients obtained near MLM; in particular no significant correlations were found considering all data together without dayside/nightside separation (Ballatore *et al.*, 1997). This result was interpreted in the sense that a good agreement between planetary (and in particular northern auroral oval) and high southern geomagnetic activity was present only during the night hours due to the dayside cusp effects during local day.

In the present paper we find that the *Pc*3-*Pc*5 power has a significant correlation with auroral indices at all local time intervals and this observation is in agreement with the fact that no cusp effects are evidenced in low frequency geomagnetic pulsation power at MCM during the interval considered. Moreover this result is in agreement with previous findings by Wolfe and Meloni (1981) at $L = 4$ and with satellite observations of low frequency pulsation power by Anderson (1994).

In agreement with previous results (Arnoldy *et al.*, 1988; and references therein), as well as at TNB the solar wind speed is found to be a key parameter in controlling low frequency pulsation power. However, a peculiar characteristic at TNB station was that the correlation coefficient became significantly lower around magnetic local noon, in agreement with a higher internal magnetospheric contribution due to the cusp location (Ballatore *et al.*, 1996). In this sense, our present MCM observation is rather different. In fact, the correlation of *Pc*3-*Pc*5 power *versus* solar wind speed is good at all time intervals considered. In terms of the cusp location, this result represents a further confirmation of the absence of cusp effects at the examined geomagnetic locations during the Antarctic winter interval considered.

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