Local time behaviour of low frequency geomagnetic field fluctuation power at low latitude

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Abstract
In this paper we present a statistical study of the local time behaviour of low frequency (0.7-4.0 mHz) geomagnetic field fluctuation power at a low latitude station (corrected geomagnetic latitude 36.2°N). The analysis was conducted for two contiguous years during the ascending phase of the solar cycle. We found that the power of the horizontal east-west geomagnetic field component shows a diurnal and seasonal variation which can be related to variations of the ionospheric current system (*Sq*) mainly produced by dynamo-action in the ionospheric *E* region. The power of the horizontal north-south geomagnetic field component is higher in the local afternoon with respect to the morning; this asymmetry is more evident during time intervals characterized by high solar wind dynamic pressure.

Key words *geomagnetic pulsations – MHD waves and instabilities*

1. Introduction

The availability at L'Aquila (AQ, IGRF95 corrected geomagnetic coordinates: 36.2°N, 87.5°E; MLT = UT + 01:40) of continuous geomagnetic field measurements over many years enables us to perform studies to characterize geomagnetic ULF fluctuations and their relation with the external Solar Wind (SW) parameters.

The most typical fluctuations detected at AQ occur during daytime hours in the *Pc*3 (20-100 mHz) frequency band (Vellante *et al.*, 1989). In particular, two dominant oscillation modes have been preferentially detected at the minimum of the solar cycle; the lower frequency mode (about 40 mHz), which tends to perturb both horizontal components of the geomagnetic field (*H*, geomagnetic north-south and *D*, geomagnetic east-west), has been interpreted in terms of upstream waves penetrating into the magnetosphere, while the higher frequency mode (about 80 mHz), which mostly occurs along the *H* component, has been interpreted in terms of resonant oscillations of the local field line at the fundamental frequency. Through the solar cycle, due to variations in the interplanetary parameters (Lanzerotti, 1991) as well as in the magnetospheric conditions, the two dominant frequencies change and at solar maximum they become very close (Vellante *et al.*, 1996).

In the lower frequency range, a statistical study of the geomagnetic field variations during minimum and maximum of the solar cycle (Francia *et al.*, 1995) has shown that, for fluctuations with periods between 0.1 and 1.7 mHz, the *H* component power level is minimum in the local

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morning and then progressively increases in the local afternoon, reaching maximum values at local midnight, when there is the typical occurrence of bays. Regarding the *D* component, at solar maximum the power level shows a sharp peak in the postnoon sector, more explicit in winter and equinoctial months; the authors argued that this feature could be related to the daily geomagnetic variation *Sq* (mainly due to ionospheric currents produced by dynamo-action in the ionospheric *E* region; Campbell, 1989) and superimposed features.

A more detailed analysis in the frequency range 0.3-5 mHz of the power spectra of the horizontal components at AQ (Francia and Villante, 1997) has shown evidence, during daytime intervals, of power enhancements at discrete frequencies (approximately 1.3, 1.9, 2.6 and 3.4 mHz) which are close to those predicted for global cavity/waveguide modes of the magnetosphere (Harrold and Samson, 1992) and previously observed mainly at auroral latitudes (Walker *et al.*, 1992; Ziesolleck and Chamalaun, 1993; Ziesolleck and McDiarmid, 1995). In this sense, the study of individual events related to the Earth's passage of interplanetary structures (Villante *et al.*, 1998; Lepidi *et al.*, 1999a) has shown that coherent wave modes, triggered by SW pressure pulses, can be simultaneously observed at AQ and at the Antarctic station Terra Nova Bay, at a wide latitudinal and longitudinal separation, with a high coherence between the two stations. These results are consistent with an interpretation in terms of global modes of the magnetospheric cavity, set up by SW pressure pulses (Walker *et al.*, 1992).

Another aspect of the low frequency fluctuations at AQ is related to their polarization pattern; Lepidi *et al.* (1999b) have shown that in the frequency band (0.8-3.6 mHz) the polarization sense in the local afternoon reverses with respect to the morning, as expected for signals propagating in the antisunward direction (Samson, 1972). However, the polarization reversal is delayed by a few hours with respect to the local noon, suggesting that the observed pulsations could be generated by SW discontinuities impacting the magnetopause in the postnoon sector (Rostoker and Sullivan, 1987).

Recently, Francia *et al.* (1999) studied the geomagnetic field response at AQ to continuous variations of the SW dynamic pressure (Psw) during northward Interplanetary Magnetic Field (IMF) conditions and found that the *H* component responds well to the SW pressure changes on a timescale of a few minutes. Moreover, the amplitude of the ground response has been found to depend on the local time, showing minimum values during the morning and maximum values around local noon and midnight; this result suggests that at our latitudes the effects of auroral ionospheric Hall currents, as well as magnetopause currents, can be detected (Russell and Ginskey, 1995).

In this paper we statistically analyze the local time behaviour of low frequency (0.7-4 mHz) fluctuations at AQ during two contiguous years. Besides a peak around local noon, the *D* component power shows evident enhancements in the local morning and afternoon; the time at which these enhancements occur depends on the season. These features have been interpreted in terms of fluctuations related to the *Sq* ionospheric current system. Conversely, the *H* component power level shows minimum values in the local morning, then increases and is enhanced from the local noon through the whole afternoon till midnight; this behaviour is more evident during periods characterized by high SW dynamic pressure.

2. Data analysis and experimental results

We analyzed the power of the low frequency fluctuations of the geomagnetic field measured at AQ; as original data we adopted the 1 min averages of the horizontal geomagnetic field components *H* and *D* computed from 1 s measurements from a three-components fluxgate magnetometer during the years 1997 and 1998.

In particular, we computed the hourly values of the *H* and *D* power integrated over the frequency band 0.7-4.0 mHz (T = 4-24 min); due to small data gaps, the total number of available hourly intervals is 17365. To investigate the local time dependence of the low frequency power, we logarithmically averaged the power values corresponding to the same hour.

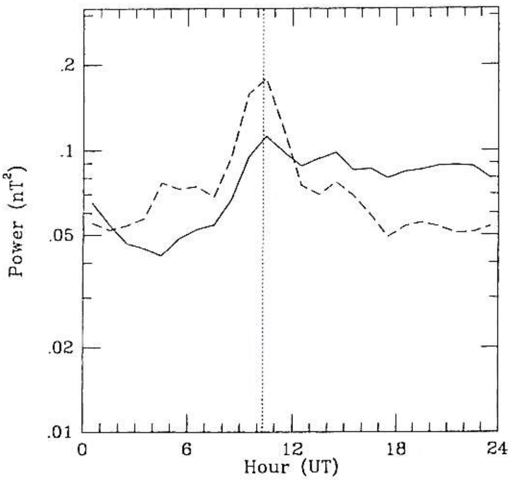


Fig. 1. The local time dependence of the average *H* (solid line) and *D* (dashed line) power; the dotted vertical line indicates local geomagnetic noon.

Figure 1 shows the daily distribution of the average *H* and *D* power. As can be seen, the power of the *D* component (dashed line) has a principal maximum at local magnetic noon (indicated by the vertical dotted line); moreover, in the afternoon (about 16 MLT) and morning (06-08 MLT) two minor power enhancements seem to appear. Conversely, the local time behaviour of the *H* component power (solid line) shows minimum values in the local morning and higher values from the local magnetic noon till midnight. Comparing the two horizontal components, it is evident that the power of the *D* component dominates in the local morning and around local noon while the *H* component dominates during the local afternoon.

In order to investigate the possible seasonal dependence, we considered separately the three Lloyd seasons: winter (November-February), equinoxes (March-April and September-October) and summer (May-August). As shown in fig. 2a-c, the power level, as well as the diurnal

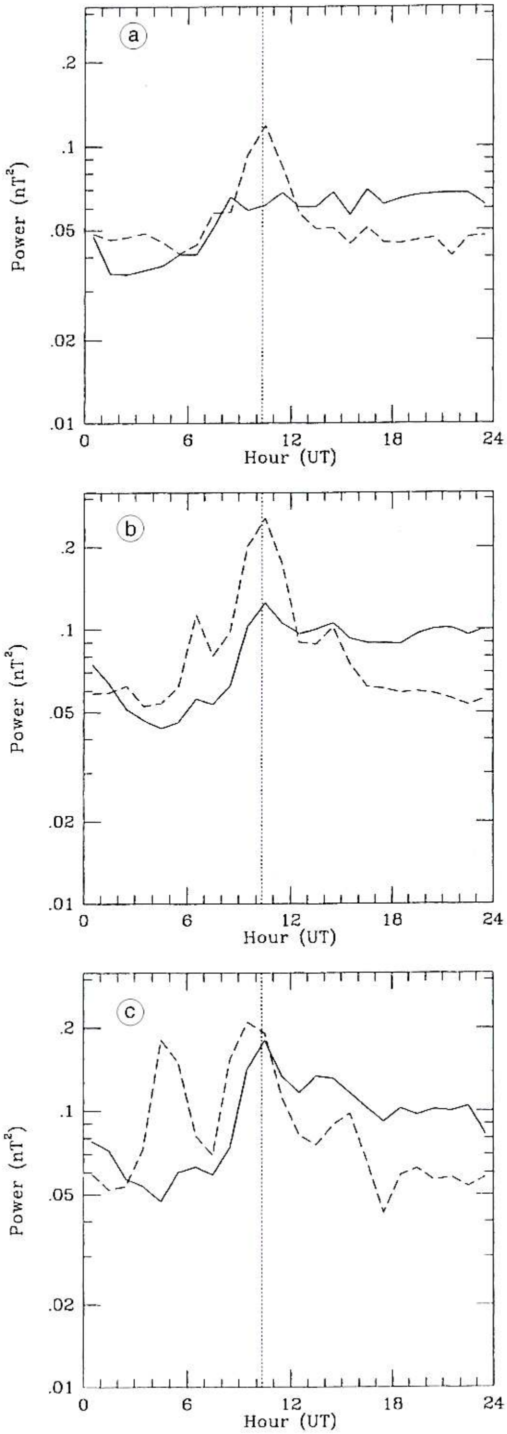


Fig. 2a-c. The same as fig. 1, separately for: a) winter; b) equinoxes; c) summer months.

excursion between minimum and maximum values, tends to increase from winter to equinoxes and summer for both components. The local time distribution of the *H* component power does not show any evident seasonal dependence except, perhaps, for some tendency during summer to a decrease in the local magnetic afternoon with respect to noon. The *D* component shows a very prominent peak at local geomagnetic noon independently of the season, while the peaks in the local morning and local afternoon seem to disappear during winter and more clearly emerge during summer. In addition, the position of the morning peak shifts to earlier hours (06-07 MLT) in the summer with respect to equinoxes (08 MLT), while the position of the afternoon peak shifts to later hours (about 17 MLT) in the summer with respect to equinoxes (16 MLT).

It is also interesting to consider the results obtained when only the quietest five days of each month are considered (fig. 3a-c); in this case of course the power level is definitely lower and, as can be seen from the figure, there is a greater diurnal excursion between minimum and maximum (around local noon) values. The main differences which emerge from a comparison with fig. 2a-c regard the *H* component which, during the quietest days, shows a significant power decrease in the local magnetic afternoon with respect to noon and also some tendency for a minor power increase around midnight. It can be also seen that the morning and afternoon power peaks of the *D* component tend to emerge also during winter, at a local magnetic time (09 MLT and 15 MLT, respectively) which confirms a shift, from winter to summer, toward earlier hours in the morning and later hours in the afternoon. This feature seems to suggest that the power peak detected in the local morning and afternoon on the *D* component could be related to the ionospheric *Sq* current system and to the strong east-west conductivity gradients which are present in the ionosphere at dawn and dusk due to the sunrise and sunset effect.

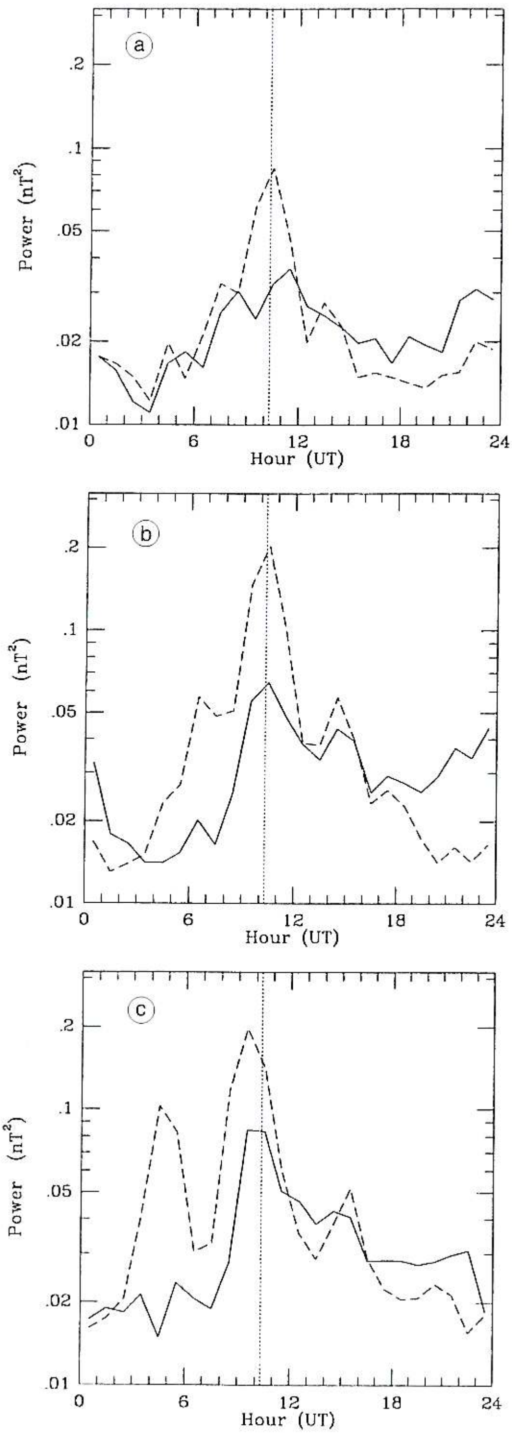


Fig. 3a-c. The same as fig. 1, considering only the five quietest days of each month for: a) winter; b) equinoxes; c) summer months.

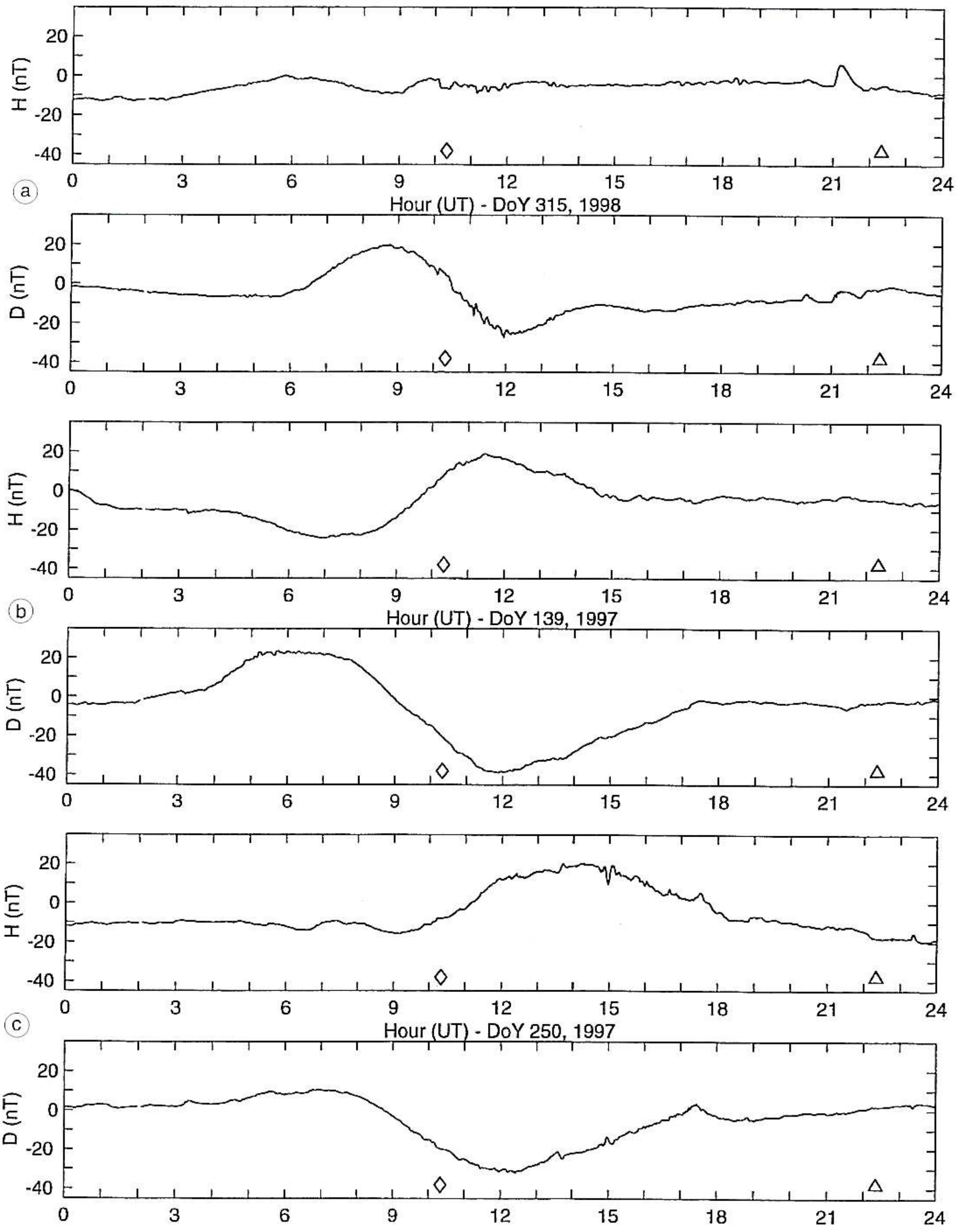
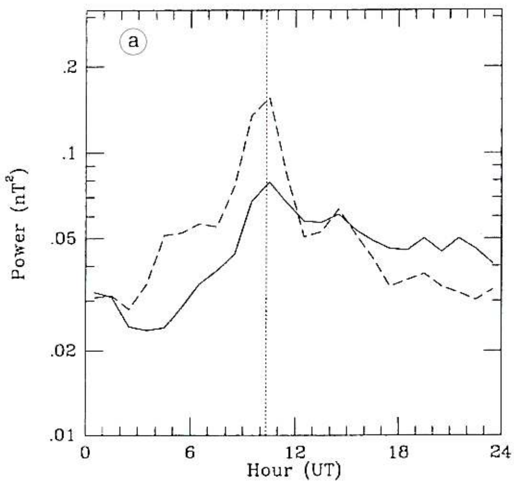


Fig. 4a-c. The *H* and *D* component variations on days: a) 315, 1998; b) 139, 1997; c) 250, 1997. Diamonds and triangles indicate the local geomagnetic noon and midnight, respectively.

In order to ascertain which kind of geomagnetic signals are typically detected in the hours characterized by higher power level, we visually inspected the magnetograms of the quietest days. Typically, the daily *Sq* variation at AQ emerges more clearly on the *D* component (Meloni and Molina, 1989); around noon there is usually an enhanced level of fluctuations on both components while, around or just before local midnight, on the *H* component the typical signatures of bays (which at our latitude are mostly positive; Nishida, 1978) sometimes appear. In fig. 4a we show, as an example, the *H* and *D* components recorded on day 315, 1998, when both the fluctuations around local noon and a signature of a bay before midnight are evident. Figure 4b and 4c show respectively an example of wave activity detected in the local morning (mainly on the *D* component) and in the local afternoon (on both components).

In order to investigate the possible influence of the SW parameters on the local time dependence of the power, we considered separately time intervals characterized by different SW conditions; in particular we found interesting results on the possible influence of the SW dynamic pressure. Indeed, if we consider separately the time intervals characterized by Psw < 1.5 nPa and Psw > 2 nPa (6252 and 5899 hourly time intervals, respectively), we find that for low Psw conditions (fig. 5a) the power of the *H* component maximizes at local geomagnetic noon and then during the afternoon it progressively decreases, while for high Psw conditions (fig. 5b) it remains at a maximum level throughout the afternoon. This feature seems to suggest that the *H* component fluctuations in the local afternoon could be related to SW structures characterized by high Psw values. As an example, the fluctuations detected on day 250, 1997 (fig. 4c) occur during a period which is geomagnetically quiet but is characterized by several variations of Psw.



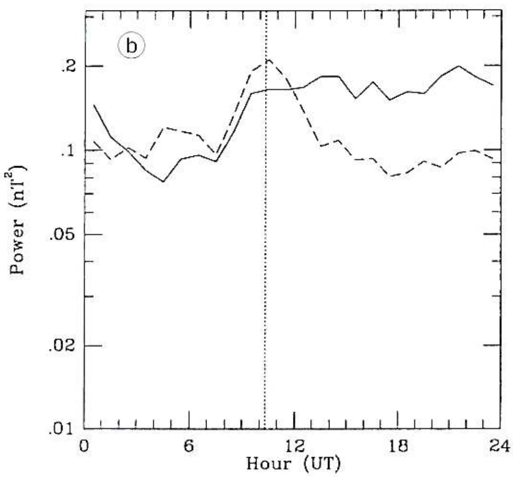


Fig. 5a,b. The same as fig. 1, separately for time intervals with: a) Psw < 1.5 nPa; b) Psw > 2.0 nPa.

3. Summary and discussion

In this paper we statistically analyzed the local time dependence of the low frequency (0.7-4.0 mHz) horizontal geomagnetic field fluctuation power at a low latitude station (AQ).

As regards to the *D* component, we found that the average power exhibits a clear peak at local geomagnetic noon and two minor enhancements in the morning and afternoon; these features emerge more clearly during the quietest days. The morning and afternoon enhancements also show a seasonal dependence in that they become progressively more evident from winter to equinoxes and summer and their position also shows a time shift: indeed the morning peak shifts toward earlier hours from winter (when it appears at about 09 MLT) to equinoxes (about 08 MLT) and summer (06-07 MLT), while the afternoon peak shows the opposite behaviour (in the order, it appears at about 15 MLT, 16 MLT and 17 MLT). This finding suggests that the fluctuations detected in the local morning and afternoon on the *D* component could be related to the ionospheric *Sq* current system and to the strong east-west gradients of the ionosphere at dawn and dusk. In this sense, it is interesting that at our latitude (AQ lies in the *Sq* focus latitude belt) the daily variation related to the *Sq* current system more clearly emerges on the *D* component (Meloni and Molina, 1989) and that from winter to summer the intensity of the *Sq* current system progressively increases and its spatial distribution, approximately centered around noon, progressively extends toward the dawn and dusk sector (Campbell, 1989). An analysis of the diurnal variation of the geomagnetic fluctuation power was previously conducted also by Lanzerotti and Robbins (1973) in a higher frequency range (2-33 mHz) and at higher latitude (geomagnetic latitude ~ 60°) during three very quiet days (January 7-9, 1971). They found that the power has higher intensities during local day between 06-07 LT and 15-16 LT; since these times are approximately the times when the stations might be expected to be passing into and out of the *Sq* current system, they suggested that the geomagnetic power variations might be related to variation in the *Sq* current system.

As regards the *H* component, we found that its average power level is lower in the local morning and is enhanced from the local magnetic noon throughout the afternoon till midnight. Conversely, when only the quietest days are considered, the *H* power level shows a maximum around local magnetic noon, then decreases during the afternoon and shows some tendency to increase again around local midnight; the latter feature can be explained in terms of bays which appear on the *H* component in relation to substorm occurrence (Francia *et al.*, 1995). We also found that the enhanced power level throughout the afternoon is more typical of periods characterized by high SW dynamic pressure conditions; this result suggested that in the local afternoon compressional fluctuations could be triggered by pressure pulses of the SW, which typically impact the magnetopause in the postnoon sector (Rostoker and Sullivan, 1987). In this sense it is interesting to recall the results of Lepidi *et al.* (1999b), who analyzed the polarization pattern of low frequency fluctuations detected at AQ and found that the reversal from westward to eastward propagation does not occur at local noon but a few hours later, in the local afternoon; these results have been interpreted in terms of compressional waves in the magnetosphere generated by SW discontinuities impacting the magnetopause mostly in the postnoon sector. Chisham and Orr (1997), who studied *Pc*5 events detected at mid latitudes, also interpreted the afternoon events as ground signatures of compressional magnetospheric waves, mainly cavity/waveguide modes driven by SW pressure pulses (Walker *et al.*, 1992). Another very recent experimental result which could be important to understand the higher *H* component power level in the postnoon sector was found by Francia *et al.* (1999), who studied the geomagnetic response at AQ to continuous SW pressure variations lasting several hours during northward IMF conditions. The results of this analysis have shown that this response is minimum in the local morning and maximum around local noon and midnight, with higher values in the local afternoon with respect to the local morning. This behaviour has been interpreted in terms of auroral ionospheric Hall currents whose effects can also be detected at our latitude, as they are at subauroral latitudes (Russell and Ginskey, 1995).

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(received September 5, 2000;
accepted February 19, 2001)