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Propagation and source of Pc5 frequency range pulsation at cusp latitude

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Abstract Two induction magnetometers have been installed at Chinese Zhongshan Station and Australia Davis Station, Antarctica respectively. We adopt the cross-spectral analysis technique to analyze the data of the two induction magnetometers, in June, September, December 1996 and March 1997, and to investigate Pc5 frequency range pulsation (150 - 600 s) occurrence and propagation in cusp latitude. The results are summarized as follows: At Zhongshan-Davis Station, the magnetic pulsations in Pc5 frequency band can occurs over a wide time, but more frequently at pre local magnetic noon and pre local magnetic midnight. The Pc5 pulsations have no significant seasonal variation in the amplitude, occurrence and propagation. The amplitude has a small peak at pre local magnetic noon and large value sometimes at pre local magnetic midnight. In daytime, the Pc5 pulsations propagate westward in morning and eastward in afternoon, and reversal at local magnetic noon. In nighttime, the Pc5 pulsations propagate westward before 20:00 MLT and eastward after 20:00 MLT. Near dusk time, the Pc5 pulsations propagate irregularly. These characteristics indicate that the Pc5 pulsations have different source at different local magnetic time.

Key words cusp latitude, Pc5 pulsations, local magnetic noon, propagation.

1 Introduction

The polar region is an important area for energetic coupling between solar wind and earth's magnetosphere. The cusp is the direct path for solar wind penetrating into the magnetosphere or even into the ionosphere and it also is a convergent region for a lot of magnetospheric boundary layers (Liu and Liu 1994). Among these regions, there are a number of complicated dynamic processes of energetic transportation or material interaction, typically associated with excitation of magnetic hydrodynamic waves at ultra low frequency band (ULF). Investigating and studying the source and propagation of these ULF will be helpful to realize and understand these processes.

Magnetic pulsations in Pc5 band (150 - 600 s) are often considered as a result of interaction between solar wind and magnetosphere at magnetopause via K-H instability (Lanzerotti and Southwood 1979). Comparing data between dawn and dusk, asymmetry of occurrence of Pc5 pulsations was found (Nose *et al*. 1995). Rostoker *et al*. investigated the polarization characteristics and found that the polarization of the Pc5 pulsation in the afternoon is inconsistent with the prediction of K-H instability theory and thus they suggested another origin for Pc5 pulsation in the afternoon (Rostoker and Sullivan 1987).

During winter time of southern hemispheric, 1992, Australian deployed a temporary array of induction magnetometers at Law Base and a plateau site respectively for two weeks, which constituted a equal-side triangle with the induction magnetometer at Davis Station. Where, the Law Base is very close to Zhongshan Station at a distance of 4 kilometers. Based on the collected data, the Pc1-2 pulsations at southern cusp/cleft latitude were studied (Neudgg *et al*. 1995).

Both Chinese Zhongshan Station (G. Lat. 69.37°S, G. Long. 76.38°E; M. Lat. 77.2°S; INT. Lat. 74.5°S, L = 13.9) and Australia Davis Station (G. Lat. 68.58°S, G. Long. 77.97°E; M. Lat. 76.8°S; INT. Lat. 74.5°S, L = 13.8) are located at cusp latitude that is favorable to observe solar-terrestrial physical phenomena at high latitude. An induction magnetometers has been installed successfully in Jan. 1996 at Zhongshan Station, Antarctica under the collaboration between Polar Research Institute of China, University of Newcastle of Australia and Australia Antarctic Division. An identical induction magnetometer had been installed at Davis Station earlier. Then the two induction magnetometers constitute a short-baseline to investigate ULF plasma waves in the ionosphere/magnetosphere. The magnetometer is controlled by personal computer and the data are recorded automatically. The time accuracy between the two magnetometers can reach 1 ms through the advance embedded time board and the GPS receiving system (Fraser *et al*. 1991).

Here we adopt the cross-spectral analysis technique (Liu *et al*. 2000), analyze the data obtained by the two induction magnetometers in Pc5 frequency band and present the results in the following.

2 The data and the analytical method

Four months' data were selected. They are Mar. 1996 and Jun., Sept., Dec. 1997, representing austral autumn, winter, spring, summer respectively. Adopted the cross-spectral analysis technique, the data were analyzed to investigate Pc5 occurrence and propagation characteristics.

We use two methods to process the data and find that the results are consistent fundamentally. One is to use Digital Fourier Transform method to calculate spectral and then select pulsation events with power peak at least 10 times greater than background level (Nose *et al*. 1998). The other is to use filter technique to derive Pc5 frequency range pulsation and then calculate their cross-spectral, select the pulsation events with power peak greater than 0.45 nT (Liu *et al*. 2000). The latter method is described in detail below.

Firstly, we filter the data and derive the Pc5 pulsation. Hanning window is chosen. Window time is chosen as twenty minutes, covering 600 digital points. Sample period of the data is 6 second, corresponding sample frequency is 0.1667 Hz. As an example, Fig. 1 shows original recorded data and the derived Pc5 data during 8:00 – 9:00 on 11 Sept. 1996 from the induction magnetometers at both Zhongshan Station and Davis Station.

Secondly, calculation is made of cross spectra of the derived from the Pc5 frequency range pulsation between the two stations to select those events with power peak greater than 0.45 nT. According to principle of the cross spectra, the frequency having the maximum amplitude among the spectra can be regarded as the most correlated frequency, and the corresponding cross phase can be regarded as the phase difference of the frequency propagating between the two stations.

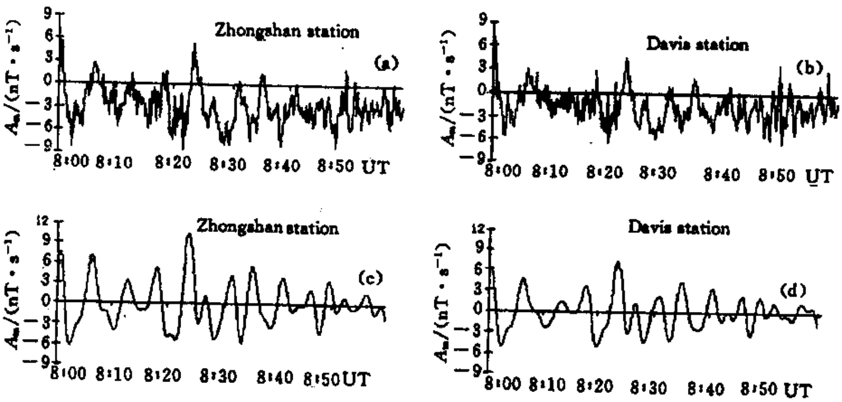

Fig.1. The original data (a, b) and Pc5 frequency range pulsation (c, d) of *D* component during 8:00 - 9:00 UT on 11 Sept. 1996 from the induction magnetometers at Zhongshan (a, c) and Davis Stations(b, d).

The wave numbers are got when the phase difference is divided by the geographic longitude difference between the two stations. The signs of the wave number mark the propagating direction of the Pc5. In our analysis, the positive value indicates the Pc5 waves to propagate westward, from Davis to Zhongshan Station, and the negative value indicates the Pc5 waves to propagate eastward, from Zhongshan Station to Davis Station.

Fig.2 shows the diurnal variation of amplitude (a) and phase difference (b) of Pc5 frequency range pulsation on 11 Sept., 1996 between Zhongshan Station and Davis Station. In the panel (a), it can be seen that the Pc5 occur around pre local magnetic noon and local magnetic midnight. In the panel (b), in daytime, the wave number is pure positive which implies that the Pc5 waves propagate westward before about local magnetic noon but the wave number turns to be negative partly which implies that part of the wave propagate eastward after about local magnetic noon. The duration of the former is longer than the latter. In nighttime, the wave is negative which implies that the wave propagate eastward.

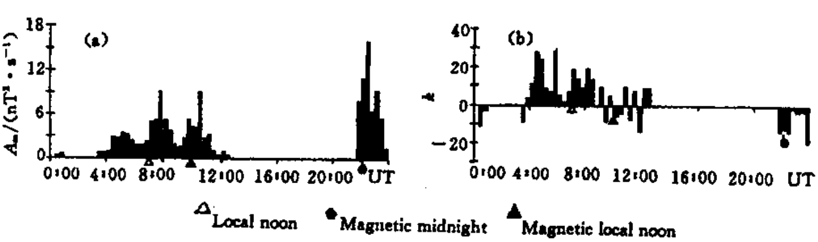

Fig.2. Diurnal variation of the amplitude (a) and phase (b) of Pc5 frequency range pulsation on 11 Sept., 1997 between Zhongshan and Davis.

The diurnal variation of amplitude (or phase difference) of Pc5 pulsation in a specific month is obtained by calculating the monthly median values of the amplitude (or phase difference) in each window time in that month. In this calculation, it is demanded that the number of the selected amplitude is greater than 2. Since small number of the selected amplitude suggests the pulsation occurring just occasionally and it should be omitted. The occurrence of the Pc5 pulsation is expressed by the number of the days.

3 Results

Utilizing the method described above we obtain the diurnal variations of occurrence, amplitude and phase difference of Pc5 pulsation for four months, March 1997 and June, September, December 1996. These results are shown in Figs.3, 4 and Fig. 5, respectively.

Fig.3 shows diurnal variation of the occurrence of the pulsation in these months between Zhongshan Station and Davis Station. It can be seen that the Pc5 occurs more frequently near pre local magnetic noon and pre local magnetic midnight. In daytime, the Pc5 occurs more frequently in morning than in afternoon. Especially, near dusk time, the Pc5 is rare. There is a little variation in the Pc5 occurrence between different seasons.

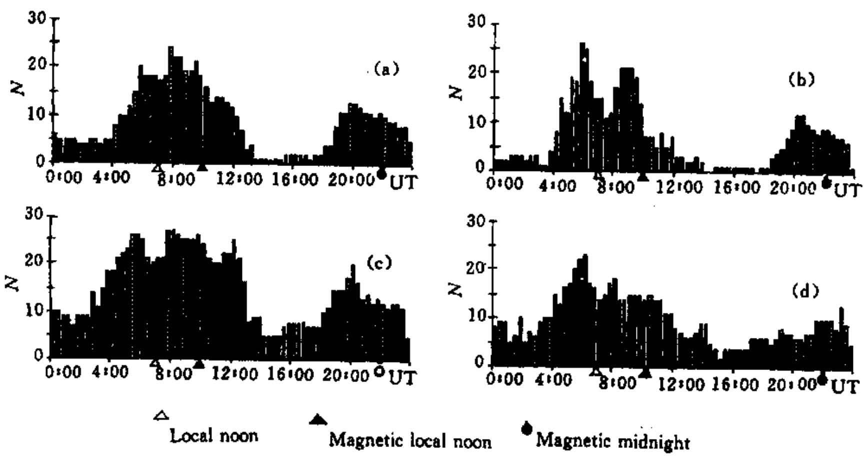

Fig.3. Diurnal variation of the occurrence of Pc5 frequency range pulsation in Mar. 1997(a) and Jun.(b), Sept. (c), Dec.(d) 1996 between Zhongshan Station and Davis Station.

Fig. 4 shows the pulsation amplitude diurnal variation for the months. From these results, it can be seen that in daytime the Pc5 amplitude has a little peak around pre local magnetic noon and large value sometimes in nighttime. Near dusk time, the Pc5 amplitude is small, or even disappear. Comparing with the panel (a), (b), (c) and (d), it can be seen that the Pc5 amplitude has no significant seasonal variation.

Fig. 5 shows diurnal variation of the phase difference of the Pc5 pulsation in these months. The positive value implies that the Pc5 waves propagate westward while the negative value implies that they propagate eastward. From here it can be seen that the Pc5 pulsation has different propagating characteristics at different local time. In daytime, the Propagating direction is reversal at the local magnetic noon, westward in morning and eastward in afternoon. In morning, the Pc5 wave propagates westward stably and fundamentally consistent in different seasons. In nighttime, the Pc5 propagates eastward predominately from about 20:00 MLT to about 5:00 MLT, continue for more than 9h and not variant with season. Before 20:00 MLT, the Pc5 tends to propagate westward but for a short time. Near dusk time, the propagating direction becomes irregularly. Watching Fig. 5 carefully, it can be seen that in daytime the propagation direction is

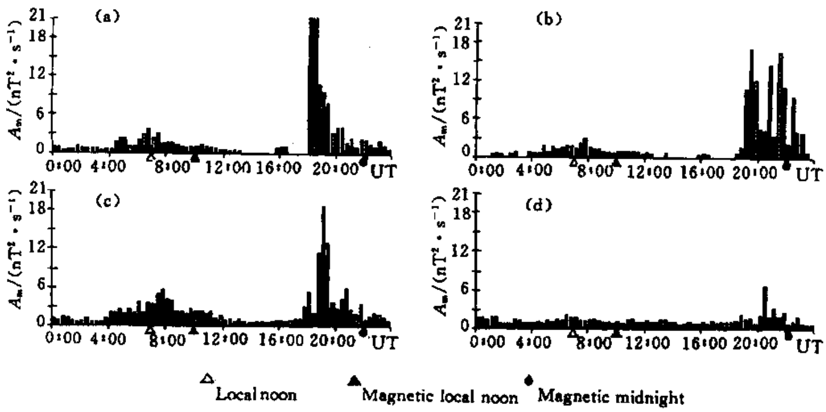

Fig.4. Diurnal variation of the amplitude of the Pc5 frequency range pulsation in Mar. 1997 (a) and Jun. (b), Sept. (c), Dec. (d) 1996 between Zhongshan Station and Davis Station.

reversal at 10:40 UT in June and at 9:40 in December. The reversal o'clock is one hour earlier in austral summer (December) than in austral winter (June). In September and March, the reversal o'clock is at the average location of the local magnetic noon marked by a black triangle. We think, the results here imply that the location of the local magnetic noon varies with season to some extent (we will discuss this topic in detail in another paper).

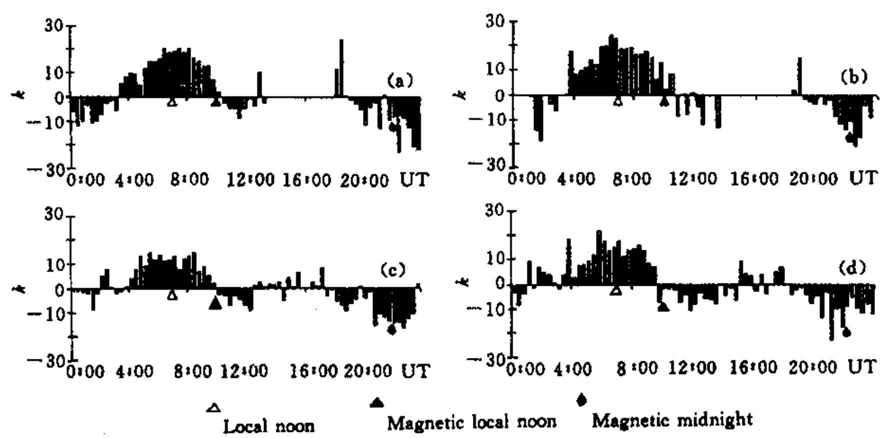

Fig.5. Diurnal variation of the phase difference of the Pc5 frequency range pulsation in Mar. 1997 (a) and Jun. (b), Sept. (c), Dec. (d) 1996 between Zhongshan Station and Davis Station.

4 Analysis and discussion

Both Antarctic Zhongshan Station and Davis Station are year-round investigating stations, and they neigheach other at a distance of 113 km. The two stations are located under the ionospheric projection of the magnetospheric cusp in local magnetic noon and the polar cap region and the polarward of the aurora oval in the nighttime. Both stations have been installed with the identical induction magnetometers, which constitute a baseline between the two stations used to investigate the ULF MHD waves propagating over the stations area in order to deduce the source and originating mechanism of ULF wave (Neudgg *et al*. 1995).

The Pc5 occurs more frequently near pre local magnetic noon and pre local magnetic midnight (Fig.3). This indicates that the solar wind plays a crucial role on origination of the Pc5 in daytime, likewise, the earth-toward magneto-tail plasma/particle stream on that of Pc5 in nighttime. In daytime, the Pc5 occurs more frequently in morning than in afternoon. Especially, near dusk time, the Pc5 is rare. This may be related with the complicated dynamics of upper atmosphere in dusk. In nighttime, the Pc5 pulsation sometimes has a large of amplitude (Fig. 4), which indicates they are associated with magnetospheric substorm activities (Ballatore *et al*. 1998).

From Fig. 5 we can see that the Pc5 has different propagating characteristics at different local time. In daytime, the Propagating direction is reversal on the two sides of local magnetic noon, westward in morning and eastward in afternoon. In morning, the Pc5 wave propagates westward stably and fundamentally consistent in different seasons. This feature is similar to the case at low/mid latitude, and can be ascribed to the solar wind-magnetopause interaction through K-H instability (Lanzerotti and Southwood 1979). In afternoon, the Pc5 propagates eastward for 3 h, from local magnetic noon to about 15:00 MLT, which is shorter than the duration which about 6 h of westward propagation in morning. After 15:00 MLT, near dusk time, the propagation direction is not so regular and variable with season. We call it Pc5 propagating asymmetry between morning and afternoon. From local magnetic noon to about 15:00 MLT, the Pc5 propagates eastward, just similar to low latitude, which implies that in this time the solar wind-magnetopause interaction still dominate the origination of the Pc5. After 15:00 MLT, near dusk, the Pc5 propagating direction is irregular and variable with season. It implies that in this time the K-H instability does not dominate the origination of the Pc5. The Pc5 may has other originating mechanism. Alternatively, it may be induced via westward electrojet (Posch *et al*. 1999). It is also possible that the two mechanisms exist at the same time, but they are hard to distinguish between them at ground. Investigating polarization of Pc5 shows that asymmetry exists between in morning and in afternoon (Rostoker and Sullivan 1987). In morning, the Pc5 has left-hand polarization which is consistent with the K-H instability mechanism. But in afternoon, the Pc5 polarization is not pure right-hand, and left-hand also exists. This is not fully consistent with the K-H instability mechanism and suggested that other mechanism may exist at that time.

In nighttime, the Pc5 propagates eastward predominately from about 20:00 MLT to about 5:00 MLT, continuing for more than 9h and not variant with season. Before 20:00 MLT, the Pc5 tends to propagate westward but for a short time. Near dusk time, the propagating direction becomes irregular. From here we can see that asymmetry on Pc5 propagation exists in nighttime. The direction is reversal at 20:00 MLT. Comparing with the case in daytime, it is suggested that there are a plasma or particle stream coming from magneto-tail blow toward to earth' inner magnetosphere in nighttime. The entrance is at about 20:00 MLT. This is similar to solar wind blowing against magnetopause in daytime. It is the case during magnetic storm/ substorm. The plasma or particle stream from magneto-tail flow to earth and would evolve into westward electrojet or eastward electrojet in earth's ionosphere through complicated interactions. Actually, magnetic pulsation observed at ground is mainly produced by ionospheric current fluctuation that can be induced by ULF wave or energetic particle precipitation (Saka *et al*. 1982). Furthermore, the ionospheric conductivity fluctuation produced by precipitation could even induce the magnetic pulsation at ground (Yamamoto *et al*. 1988) Therefore, we think, in nighttime, the Pc5 propagating westward may be associated with ionospheric westward electrojet while the Pc5 propagating eastward may be associated with ionospheric eastward electrojet. The ULF waves coming from magneto-tail may contribute to the pulsation at ground. The interaction between the plasma/particle stream coming from magneto-tail and the inner magnetosphere may also contribute to the origination of the Pc5 in nighttime (Woch *et al*. 1988; Lopez *et al*. 1986). An eastward propagating compressional Pc5 wave was observed by AMPTE/CCE in the post-midnight sector (Takahashi *et al*. 1987). This is consistent qualitatively with the result here.

5 Summary

Two induction magnetometers have been installed at Zhongshan and Davis Stations, Antarctica respectively. We adopt with cross-spectral analysis technique to analyze the two induction magnetometer data for four months: June, September, December 1996 and March 1997, to investigate the Pc5 frequency range pulsation occurrence and propagation in cusp region. The results are summarized in the following:

(1) At Zhongshan and Davis Stations, the Pc5 frequency range pulsation occurs over a wide time, more frequently at pre local magnetic noon and pre local midnight. In winter (June), the Pc5 pulsation occurrence decreases a little, especially in magnetic dusk time.

(2) The Pc5 pulsation amplitude has a small peak at pre local magnetic noon and a large value sometimes in nighttime.

(3) In daytime, the Pc5 propagates westward in the morning and eastward in the afternoon, but it is a reversal at local magnetic noon. In nighttime, the Pc5 propagates westward before 20:00 MLT and eastward after it. The Pc5 propagating direction is irregular near magnetic dusk time.

(4) There is no significant seasonal variation in the Pc5 occurrence, amplitude and propagating direction.

(5) It can be thought that the Pc5 is dominated by solar wind-magnetopause interaction via K-H instability in daytime and by earth-toward magneto-tail plasma/particle stream in nighttime.

It is necessary to point out that we just have two stations to observe the pulsations now. So we can only investigate the projection of the Pc5 propagation to the baseline between Zhongshan and Davis Stations, which extends along west-east direction. In order to study the pulsation propagation characteristics along north-south direction, we need more observing sites.

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