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Polarization characteristics of Pc3 pulsations at Zhongshan Station of Antarctica

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Abstract In this paper the data of geomagnetic pulsations at Zhongshan Station from February 3 to November 30 in 1996 are analyzed in order to study polarization characteristics of Zhongshan Station Pc3 pulsations which comprises the cusp Pc3 pulsation and the nightside Pc3 pulsation. For the cusp Pc3 pulsation, the right-handed polarization is always dominant. But their orientation of major axes of polarizations changes with season, NW-SE is dominant in summer and NE-SW in winter. For the nightside Pc3 pulsation, the right-handed with NE-SW is always dominant before midnight. But the left-handed with the mixing orientation of major axes is dominant in summer and the NE-SW with the mixing polarization sense is dominant in winter after midnight. It means that the two types of Zongshan Station Pc3 pulsations have different sources.

Key words Zhongshan Station, Pc3 pulsation, Polarization.

1 Introduction

Zhongshan Station of Antarctica is the highest latitude station of China, which locates near the cusp where strong Pc3 pulsations can be observed. The space-time variation of polarization characteristics for these high latitude Pc3 pulsations could provide source feature and give modes of hydromagnetic waves propagating in the solar wind and the magnetosphere. It is of interest to the interaction between the solar wind and the magnetosphere (Yang *et al.* 1997).

Troitskaya (1985) set up a chain of magnetic pulsations at Greenland of the Arctic region and demonstrated that amplitudes of Pc3 pulsations are great at the cusp region, and even they gave a method of tracking the cusp by means of Pc3 pulsations. Some scientists conformed that frequency bands of cusp ULF waves including broadband Pc3 pulsations and short life Pc5 pulsations change very much and correlation of Pc3 pulsations at the cusp conjugate points is not clear (Olson and Fraser 1994). Olson and Szubrela (1997) studied Pc3 coherence at cusp latitude in Canada. However the generation mechanism of cusp latitude Pc3 pulsations is not clear so far and more observations of the cusp Pc3 pulsations are needed in order to investigate them.

The data of geomagnetic pulsations at Zhongshan Station from February 3 to November 30, 1996 are analyzed in order to study polarization characteristics of high-

latitude Pc3 pulsations in Antarctica. Observation instrument is induction magnetometer made in Australia which records horizontal magnetic components of H(N-S) and D(E-W) with sampling rate of 2 s and GPS timer. Digital signal processing is completed in experiment house. Fig. 1 gives an example of Pc3 pulsations recorded at Zhongshan Station on Feb. 24, 1996.

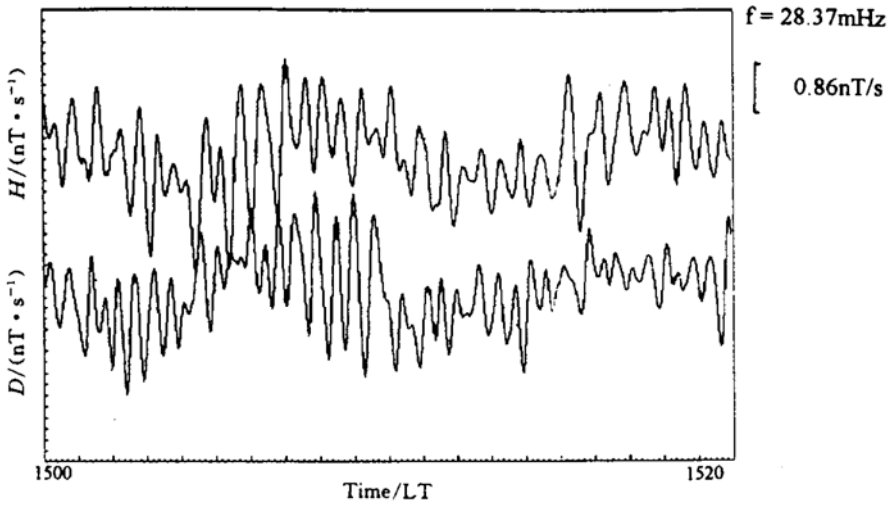

Fig. 1. An example of Pc3 pulsations at Zhongshan Station.

2 Analysis method of polarization characteristics

Polarization analyses of Zhongshan Station Pc3 pulsations are fulfilled by studying orientations of major axes and ellipticities for polarization ellipses of horizontal magnetic components. First of all, Fourier analyses of 20 min data segment have to be done in order to find out maximum peak value in frequency range of Pc3 pulsations and to qualify it as the main frequency at this segment. Fig. 2 gives the Fourier analysis of H

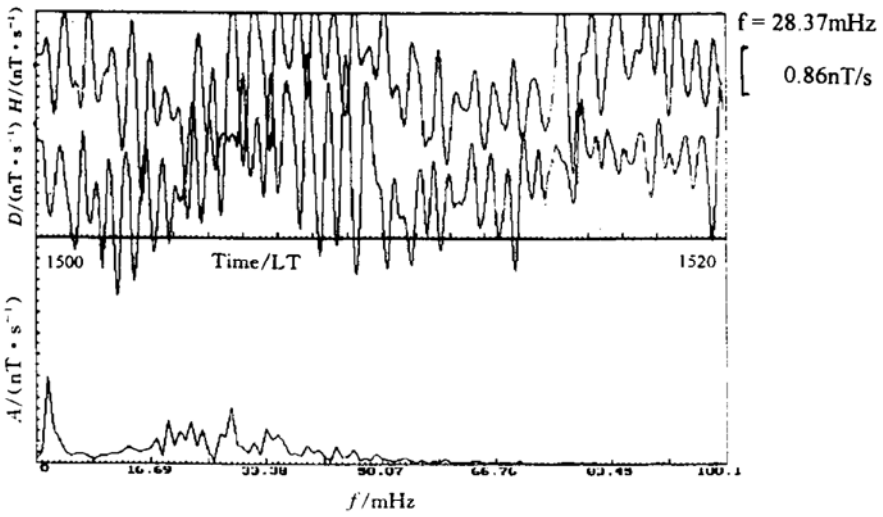

Fig. 2. Fourier spectrum analysis of magnetic pulsations at 1500 - 1520 LT on February 24, 1996.

component from 1500 LT to 1520 LT on Feb. 24, 1996. It can be seen from Fig. 2 that H component at this time interval has two types of pulsations: narrowband Pc5 pulsations with peak of 1. 67 mHz and broadband Pc3 pulsations with peak of 28. 37 mHz.

The main frequency of Pc3 pulsations at the 20 min data segment appears as a centric frequency and the bands are ± 1.7 mHz. Then, band-pass filters are set up for H and D components to get polarization ellipses. The direction of the magnetic field lines is upward in Antarctica. Seeing along the magnetic field lines, counterclockwise polarization is called as left-handed polarization (LH) and clockwise polarization as right-handed polarization (RH). Azimuth of major axes is defined as the angle between the major axis and magnetic east. Negative ellipticity indicates right-handed polarization and means that H component follows D component. Ellipse is one for the circle polarization and zero for the linear polarization.

Fig. 3 gives the result of polarization analyses for Zhongshan Station Pc3 pulsations from 1500 LT to 1520 LT on Feb. 24, 1996. The upper panel indicates the filtered waveforms of H and D components at Zhongshan Station and the lower panel expresses the variation of ellipticities and azimuths with local time, the Fourier spectrum of the filtered H component, and polarization ellipses. Comparing occurrences of positive and negative ellipses, if positive (negative) values are dominant, polarization in the data segment is defined as left-handed (right-handed). In a similar way, comparing occurrence of positive and negative azimuths of major axes, if positive (negative) values are dominant, azimuth in the data segment is NE-SW (NW-SE). It is known from Fig. 3 that left-handed is dominant and average ellipticity is -0.32, NW-SE is prominent and the average azimuth for negative values is $-40.94°$ for Zhongshan Station Pc3 pulsations in this segment.

Fig. 4 gives diurnal variation of azimuth and ellipticity of Zhongshan Station Pc3 pulsations with local time on Feb. 24, 1996. The ordinate in Fig. 4(a) and Fig. 4(b) indicates ellipticity and azimuth of major axes, respectively, while the abscissa indicates

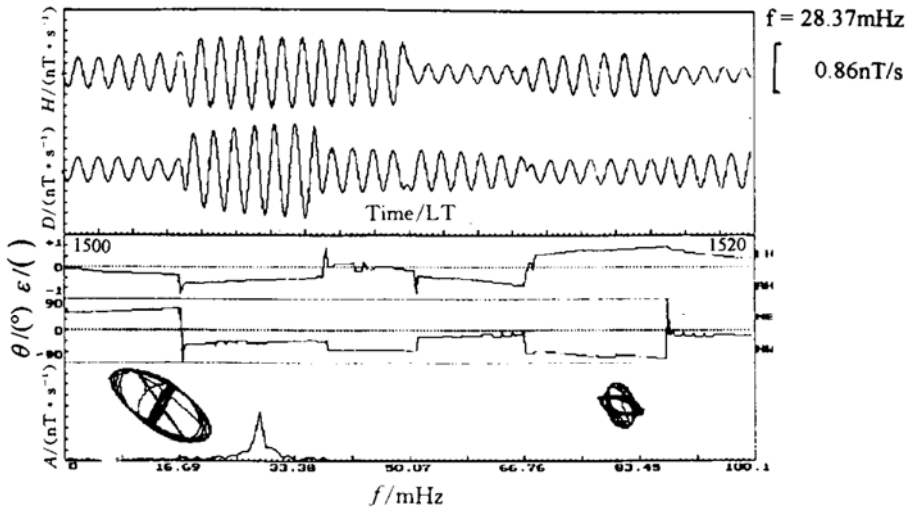

Fig. 3. Polarization analysis of Zhongshan Station Pc3 pulsation at 1500 - 1520 LT on February 24, 1996.

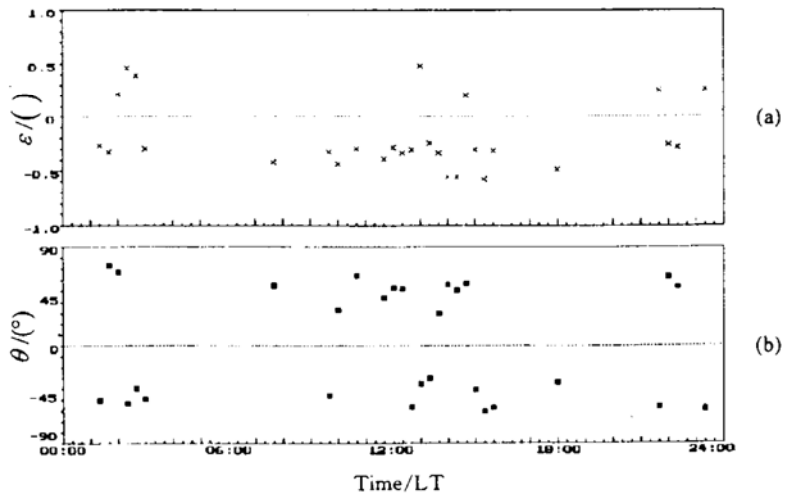

Fig. 4. Distribution of polarization characteristics for Zhongshan Station Pc3 pulsations with local time on February 24, 1996.

the local time. The ellipticity and azimuth of major axes which have been got by the above method for 20 min data segments of a day are plotted by " × " and " ■ ", respectively. In this paper we choose Pc3 pulsation events with amplitudes big enough which are more than 2.5 nT/s and less than 50 nT/s. It is seen in Fig. 4(a) that Pc3 pulsations occur mainly in the daytime and right-handed polarizations are dominant in the morning (0600 - 1200 LT), rate is 100%(6/6), and average ellipticity is −0.37; right-handed are dominant too in the afternoon (1200 - 1800 LT), rate is 83.33% (10/12) and average ellipticity is −0.41. Azimuth of major axes changes obviously in daytime. NE-SW is dominant in the morning, rate is 83.33%(5/6) and average value is 49.40°; NW-SE is dominant in the afternoon, rate is 58.33%(7/12) and average value is −45.30°. Observations show that a little Pc3 pulsations occur at night and total number is 10 in Fig. 4. Positive and negative occurrences of ellipticity and azimuth of major axes are the same number of 2 from 1800 LT to 2400 LT. And positive and negative occurrences of ellipticity are the same as 3, but occurrences of negative azimuth are dominant, rate is 66.67%(4/6) and average value is −48.17° from 0000 LT to 0600 LT.

Although diurnal variation of polarizations for Zhongshan Station Pc3 pulsations can be seen from Fig. 4, the samples are so poor that do not reflect the statistical characteristics. We have analyzed data of magnetic pulsations observed at Zhongshan Station all the year in 1996 to get statistical polarization characteristics of Pc3 pulsations. There are seasonal variations at Zhongshan Station. We study polarization characteristics of Zhongshan Station Pc3 pulsation in summer and winter, respectively.

3 Polarization characteristics of Zhongshan Station Pc3 pulsations in summer

Summer at Zhongshan Station of Antarctica is from October to March. Fig. 5 gives the distribution of polarization characteristics of Zhongshan Station Pc3 pulsations in local time in February 1996. The ordinate and abscissa in Fig. 5 are the same as those in Fig. 4. The ellipticity and azimuth of major axes which have been got by the above

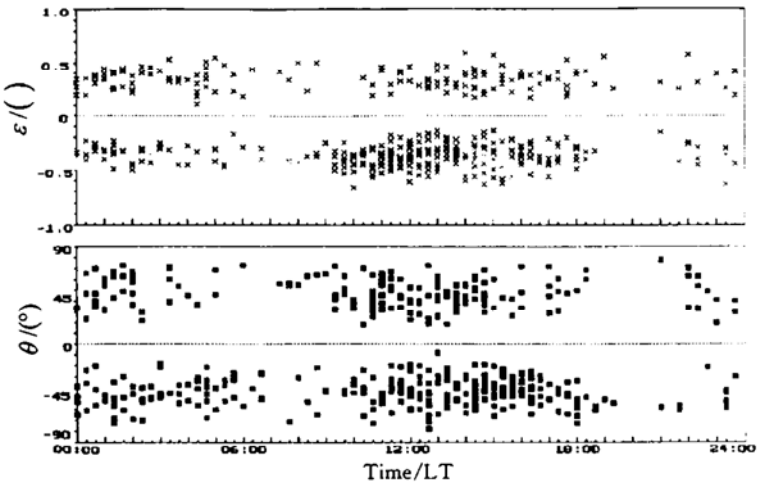

Fig. 5. Distribution of polarization characteristics for Zhongshan Station Pc3 pulsations with local time in February of 1996.

method for 20 min data segments of a month are plotted by "×" and "■", respectively. The method of choosing Pc3 pulsation events is the same as that in Fig. 4. In daytime, right-handed polarizations are dominant in the morning (0600 - 1200 LT), the rate is 82.73% (91/110), and the average ellipticity is −0.40, negative azimuths (NW-SE) of major axes are little dominant in the morning, the rate is 51.82% (57/110) and the average azimuth is −43.67°. The right-handed are dominant too in the afternoon (1200 - 1800 LT), the rate is 68.91% (133/193) and the average ellipticity is −0.36. NW-SE is still dominant in the afternoon, the rate is 66.32% (128/193) and the average value is −43.71°. At night, the right-handed polarizations are dominant from 1800 LT to 0000 LT, the rate is 58.06% (18/31) and the average ellipticity is −0.36, NE-SW is little dominant before midnight, the rate is 51.61% (16/31) and the average value is 49.37°. The left-handed polarizations are dominant from 0000 LT to 0600 LT, the rate is 56.12% (55/98) and the average ellipticity is 0.34. NW-SE is dominant after midnight, the rate is 64.29% (63/98) and the average value is −45.94°.

Table 1 is statistical table of polarization characteristics for Zhongshan Station Pc3 pulsations in summer (no data in January and December). It gives statistical average values of ellipticity and azimuth of major axes after midnight, in the morning, in the afternoon and before midnight, respectively. The fraction in bracket indicates the rate of the dominant data segment number and total data segment number.

Table 1. Statistical table of polarization characteristics for Zhongshan Station Pc3 pulsation in summer

Month	0000 - 0600 LT		0600 - 1200 LT		1200 - 1800 LT		1800 - 2400 LT	
	Ellipticity	Azimuth	Ellipticity	Azimuth	Ellipticity	Azimuth	Ellipticity	Azimuth
Feb.	0.40 (55/98)	−45.94° (63/98)	−0.40 (91/110)	−47.67° (57/110)	−0.36 (133/193)	−43.71° (128/193)	−0.36 (18/31)	49.37° (16/31)
Mar.	0.34 (53/105)	48.03° (60/105)	−0.38 (98/120)	−50.02° (60/120)	−0.38 (136/189)	−48.03° (95/189)	−0.35 (27/44)	49.02° (28/44)
Oct.	0.32 (51/98)	−47.95° (49/98)	−0.41 (104/128)	−44.40° (69/128)	−0.39 (141/198)	−45.33° (101/198)	−0.34 (20/30)	60.48° (18/30)
Nov.	0.33 (26/45)	51.47° (25/45)	−0.39 (41/51)	−37.72° (33/51)	−0.35 (47/68)	−42.19° (41/68)	0.37 (9/15)	46.31° (8/15)

It can be seen from Table 1 that polarization characteristics of Zhongshan Station Pc3 pulsations in the summer are as follows. (1) Absolute values of ellipticity are small and generally less than 0.5. (2) Pc3 pulsation events occur mainly in daytime, right-handed polarizations with NW-SE azimuths of major axes are dominant. (3) Occurrence of Pc3 pulsation events is a little at night and the polarization characteristics before midnight is contrary to that after midnight. The right-handed polarizations with NE-SW azimuths are dominant before midnight and the left-handed polarizations with NW-SE or NE-SW azimuths are dominant after midnight.

4 Polarization characteristics of Zhongshan Station Pc3 pulsations in winter

Winter at Zhongshan Station of Antarctica is from April to September. Fig. 6 gives the distribution of polarization characteristics of Zhongshan Station Pc3 pulsations in local time in August 1996. The ordinate and abscissa in Fig. 6 are the same as those in Fig. 5. The ellipticity and azimuth of major axes which have been got by above method for 20 min data segments of a month are plotted by "×" and "■", respectively. The choice method of Pc3 pulsation events is the same as that in Fig. 4. In daytime, right-handed polarizations are dominant in the morning (0600 - 1200 LT), the rate is 67.78% (61/90), and the average ellipticity is −0.37, positive azimuths (NE-SW) of major axes are dominant in the morning, the rate is 61.11% (55/90) and the average azimuth is 42.28°. Right-handed are dominant in the afternoon (1200 - 1800 LT), the rate is 68.62% (140/204) and the average ellipticity is −0.37. NE-SW is still dominant in the afternoon, the rate is 60.78% (124/204) and the average value is 49.53°. At night, right-handed polarizations are dominant from 1800 LT to 0000 LT, the rate is 62.06% (18/29) and the average ellipticity is −0.31, NE-SW is little dominant before midnight, the rate is 55.17% (16/29) and the average value is 52.96°. Left-handed polarizations are dominant from 0000 LT to 0600 LT, the rate is 55.75% (63/113) and the average ellipticity is 0.34. NE-SW is still dominant after midnight, the rate is 53.10% (60/113) and the average value is 49.20°.

Table 2 is a statistical table of polarization characteristics for Zhongshan Station Pc3 pulsations in winter. It gives average values of ellipticity and azimuth of major axes after midnight, in the morning, in the afternoon and before midnight, respectively. The fraction

Table 2. Statistical table of polarization characteristics for Zhongshan Station Pc3 pulsation in winter

Month	0000 - 0600 LT		0600 - 1200 LT		1200 - 1800 LT		1800 - 2400 LT	
	Ellipticity	Azimuth	Ellipticity	Azimuth	Ellipticity	Azimuth	Ellipticity	Azimuth
Apr.	−0.35 (64/115)	−45.47° (66/115)	−0.38 (65/88)	46.30° (55/88)	−0.38 (130/197)	49.08° (112/197)	−0.30 (16/29)	39.64° (19/29)
May	0.34 (51/90)	52.71° (56/90)	−0.37 (28/39)	−52.66° (28/39)	−0.37 (83/125)	−50.21° (70/125)	−0.37 (8/11)	44.12° (6/11)
Jun.	−0.35 (54/84)	49.20° (51/84)	−0.34 (23/28)	44.71° (17/28)	−0.35 (57/70)	51.12° (37/70)	−0.34 (2/4)	44.48° (3/4)
Jul.	0.30 (42/83)	45.95° (51/83)	−0.42 (50/59)	45.45° (35/59)	−0.37 (106/145)	51.10° (106/145)	−0.32 (5/9)	50.83° (6/9)
Aug.	−0.34 (63/119)	49.20° (60/119)	−0.37 (61/90)	42.28° (55/90)	−0.37 (140/204)	49.53° (124/204)	−0.31 (18/29)	52.96° (16/29)
Sep.	0.33 (61/116)	47.94° (74/116)	−0.39 (111/134)	46.44° (71/134)	−0.38 (197/280)	44.15° (147/280)	−0.30 (33/51)	50.99° (26/51)

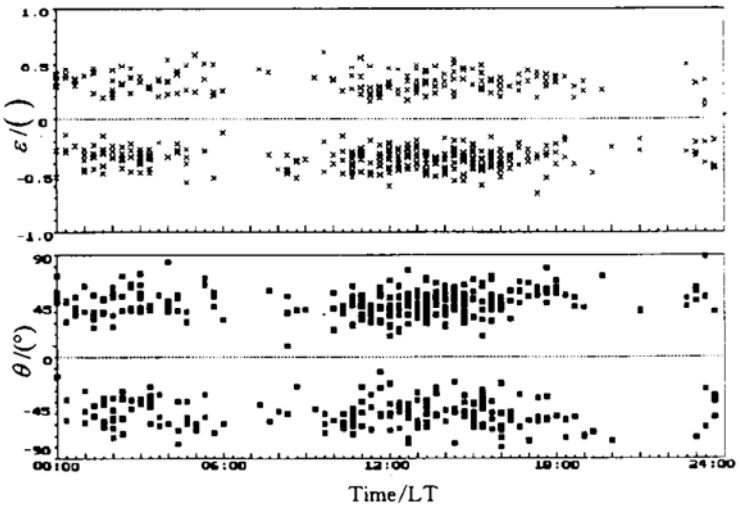

Fig. 6. Distribution of polarization characteristics for Zhongshan Station Pc3 pulsation with local time in August of 1996.

in bracket indicates the rate of the dominant data segment number and total data segment number.

It can be seen from Table 2 that polarization characteristics of Zhongshan Station Pc3 pulsations in winter are as follows. (1) Absolute values of ellipticity are small and generally less than 0.5. (2) Pc3 pulsation events occur mainly in daytime, right-handed polarizations with NE-SW azimuths of major axes are dominant. (3) Occurrence of Pc3 pulsation events is a little at night and the polarization characteristics before midnight are not completely contrary to that after midnight. Right-handed polarizations with NE-SW azimuths of major axes are dominant before midnight and NW-SE azimuths are dominant after midnight, but polarization senses are mixing, the left-handed is dominant in some months and the right handed is dominant in other months.

5 Discussion

According to above analyses of polarization characteristics, Pc3 pulsations at Zhongshan Station comprise two types: one is Pc3 pulsations recorded at the cusp, another is Pc3 pulsations recorded at nightside. Polarization senses of the cusp Pc3 pulsations are always the right-handed either in summer and winter or in the morning and the afternoon. But their orientation of major axes of polarizations changes with season, NW-SE is dominant in summer and NE-SW in winter. The right-handed polarization of nightside Pc3 pulsations with NE-SW orientation of major axis does not change with season before midnight. However, after midnight, the left-handed polarization of nightside Pc3 pulsations with the mixing orientation of major axis is dominant in summer, while NE-SW orientation with the mixing polarization sense is dominant in winter. It is possible that there are transform status in which season variations are mixing near March and September. The orientations of major axes for nightside Pc3 pulsations are almost dominant in NE-SW at all night except that NE-SW is dominant before midnight and NW-SE is dominant after midnight in February, April,

and October.

Cusp Pc3 pulsations are dayside events which have great amplitude and occurrence. Polarization characteristics of the cusp Pc3 pulsations are stable in all year, it means they have relative stable excitation resource. Observations demonstrate that one of the most possible excitation resource of the cusp Pc3 pulsations in Antarctica are low frequency hydromagnetic waves in front of the Earth's bow shock (Yang *et al.* 1997). The cusp region is directly connected with the solar wind and these low frequency hydromagnetic waves with the solar wind propagate to the cusp. It is proved theoretically that the interaction between the solar wind and its reflected ions in the bow shock generates electromagnetic ion beam instability with low frequency and excites ion gyrate waves propagating into the magnetosphere (Yang and Sun 1990). These ion gyrate waves are right-handed polarization. Therefore, cusp Pc3 pulsations in Antarctica have obvious characteristics of dominant right-handed polarizations.

Polarization characteristics of nightside Pc3 pulsations are more complicated because of special space environment in Antarctica. Zhongshan Station locates at high latitude where aurora, magnetospheric substorm, and ionospheric disturbance could excite Pc3 pulsations. Engebretson *et al.* (1990) demonstrated by his observations that the precipitation of high energy particles generating ionospheric disturbance could be excitation source of Pc3 pulsations. An observational fact that Pc3 pulsation events increase after midnight is related to pulsating aurora in the dawn side. Disturbances from the magnetotail could excite Alfven waves which propagate to the polar region and generate Pc3 pulsations together with Pi types of pulsations.

In addition, Zhongshan Station Pc3 pulsations occurring in a day could be excited by various sources individually or commonly. We may distinguish the source of each Pc3 pulsation event by means of polarization analyses and recognize the reaction between the solar wind and the magnetosphere as well as the characteristics of upper atmosphere in Antarctica in real time. These works will be done with studies in detail of high latitude magnetic pulsations.

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