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Simultaneous quasi-periodic optical and HF radar signatures observed in the postnoon sector

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Abstract: Zhongshan Station in Antarctica is located close to the polar cusp/cleft latitude. The field of view of the Syowa East HF radar also covers Zhongshan Station. Simultaneous quasi-periodic phenomena of optical aurora, HF radar backscatter power and Doppler velocity, and ground based magnetograms were observed in the magnetic postnoon sector (~330 MLT to 1510 MLT) on 3 August 1997. The characteristics of the quasi-periodic event are summarized in the following; 1) East-west aligned band/arc type discrete aurora showed quasi-periodic luminosity variations with period of ~6–10 min, 2) Quasi-periodic variations of the optical aurora had one to one correspondence with the variations of HF radar backscatter powers and magnetic pulsations, 3) The HF backscatter region was located at the lower latitude of the quasi-periodic optical aurora, 4) Quasi-periodic variations of line-of-site Doppler velocity detected by HF radar showed very close relation to the magnetic pulsations observed at Zhongshan in Antarctica and the IMAGE magnetometer array in the northern hemisphere, 5) The IMAGE data revealed that the region of quasi-periodic HF radar backscatter (irregularities) corresponds to the region of intensity maximum of magnetic pulsations.

1. Introduction

Ultralow frequency (ULF) magnetohydrodynamic (MHD) waves are important energy carriers in the process leading to the coupling between the solar wind and the Earth's magnetosphere and ionosphere. In addition to solar wind-magnetosphere-ionosphere coupling and the transmission of energy to the auroral ionosphere, a number of authors have suggested that MHD waves might also contribute directly to the energization of electrons which produce optical aurora (Hasegawa, 1976; Samson *et al.*, 1991a). Most studies of luminosity variations in optical aurora have focused on pulsating aurora with much higher frequencies than the MHD waves we consider here, typically greater than 50 mHz (*e.g.*, Campbell, 1970). However, there have been a few published observations of auroral pulsations in the ULF frequency range (typically 1–4 mHz) of the MHD waves we are studying here. Morse and Romick (1982) have reported that luminosity fluctuation with period of about 10-min are common in quiet intervals just prior to substorm intensification. Samson *et al.* (1992) also observed luminosity fluctuations in auroral structures in the 1–4 mHz band prior to and after substorm intensification. Samson *et al* (1991a) noted 1.9 mHz luminosity fluctuations in a detached arc in the evening sector and near local midnight. Xu *et al.* (1993) demonstrated that the modulation luminosity phenomena in the frequency range of 1–4 mHz were common features occurring in the auroral oval. They also found one event that the modulation process accompanied by an inverted *V* structure of electron precipitation in the evening sector near 72°. The above studies have given concrete evidence that the field line resonances were the direct cause of the ULF luminosity modulation. All published observation evidences, mentioned above, were limited in the nightside sector from evening to early morning associated with substorm phenomena. Note that there have been no published observations of optical auroral pulsations with period of about 10-min in the postnoon sector we are studying here.

In the following we briefly review the generation mechanism of ULF waves in the Pc 5 range of period (150–600 s) we are studying in this paper. Pc 5 waves are often referred to as geomagnetic field line resonance. The waves are thought to excited by the solar wind through Kelvin-Helmholtz (KH) instabilities, impulsive stimulation of the magnetopause by perturbations in the interplanetary magnetic field (IMF) or solar wind dynamic pressure variations (*e.g.*, Walker *et al.*, 1992; Samson *et al.*, 1992; Lysak *et al.*, 1994). A number of studies of ULF waves using ground-based magnetometers and radars at high latitudes in the local midnight and early morning sectors have revealed discrete frequency components (Ruohoniemi *et al.*, 1991; Samson *et al.*, 1991b). Even in the dayside and dusk sectors, the magnetic Pc 5 pulsations reveal typical field line resonance characteristics, namely the latitudinal dependence of the spectral and polarization parameters (Ziesolleck and McDiarmid, 1994; Fenrich *et al.*, 1995). Magnetospheric cavity (Samson *et al.*, 1991b) and waveguide modes (Samson *et al.*, 1992; Walker *et al.*, 1992) were suggested to explain some of the observed discrete frequencies.

Using ground-based magnetometer data during a pulsation event, Shimazu *et al.* (1995) detected waveforms that were similar and coherent over a wide range of locations. They concluded that these magnetic pulsations were global compressions of the magnetosphere due to the variations of solar wind pressure. Potemra *et al.* (1992) invoked field line resonance and solar wind pressure variations in their interpretation of a pulsation event associated with a flux transfer event (FTE) signature. They emphasized that both magnetospheric resonant processes and processes driven by the solar wind determine many phenomena observed in the dayside magnetosphere and ionosphere. Recently, Prikryl *et al.* (1998) examined a series of observations by satellites of the solar wind and magnetosphere, by HF radars of *F* region, and by ground-based magnetometer of *E* region currents. They found that the compressional MHD waves in the solar wind applied oscillating magnetic/electric fields and the dynamic pressure on the dayside magnetopause, and also applied driving compressional oscillations in the magnetosphere. Ables *et al.* (1998) examined the ionospheric signatures of the cusp/cleft region using phase techniques for Pc 5 waves.

The region located a few hours past noon MLT (approximately 14 to 16 MLT) in high latitude has a special significance for a variety of magnetospheric phenomena. The UV images obtained with the Viking satellite often show bright features with resemble "beads" or "pearls" aligned in the east-west direction (Lui *et al.*, 1989), and most intense upward field-aligned current are located in this region (Iijima and Potemra, 1978). Zhongshan Station in Antarctica is located at ~74.5° magnetic latitude. This location is an ideal site to study a special feature in this postnoon region.

In this paper we present a case study showing the ~10-min quasi-periodic phenomena observed simultaneously by ground-based optical aurora and magnetometers and by HF radar in the postnoon sector near the polar cusp/cleft regions. An optical auroral data obtained by all-sky TV camera at Zhongshan is very useful to investigate the spatial and temporal variation of electron precipitation. These unique data sets may offer important information to examine the generation mechanism of luminosity pulsations and magnetic pulsations.

2. Instruments and data sources

The field of view of the Syowa East HF radar covers over Zhongshan Station. Syowa Station in Antarctica is located under the auroral zone at the geographic coordinates of 69.00°S, 39.58°E and at 66.54°S, 71.79°E in geomagnetic coordinates. Zhongshan Station is located close to the polar cusp/cleft latitude at 69.37°S, 76.38°E in geographic coordinates, and 74.49°S and 96.32°E in geomagnetic coordinates. The Syowa East HF radar is a Japan-operated component of the extended network of HF radars called SuperDARN (Super Dual Auroral Radar Network, Greenwald *et al.*, 1995). The field of view of this radar extends from ~65°S to ~85°S and covers ~4.5 hours in magnetic local time. The radar employs linear phased arrays of 16 log-periodic antennas and the operational frequency is between 8 and 20 MHz. A complete radar scan over a 52° angular segment is made each 60 or 120 s by sweeping the single beam through 16 successive positions differing by 3.25°. In near-real time, the backscatter power, line-of-sight Doppler velocity, and Doppler spectral width are found at each beam position by fitting the autocorrelation functions for 70 range bins of width 45 km, starting at aslant range of 180 km. The field of view of the Syowa East and other SuperDARN radars in the southern hemisphere in 1997 are shown in Fig. 1. Also shown are the locations of ground-based observatories including Zhongshan and Syowa.

The quasi-periodic event, we will examine here, occurred during ~12–14 UT on 3 August 1997, where 12 UT is ~1330 MLT at Zhongshan Station. The high time resolution camping beam of the Syowa HF radar with the sampling period of 17 s over Zhongshan Station operated under the clear sky and geomagnetically disturbed conditions. We analyzed this event using the data from a panchromatic all-sky TV camera at Zhongshan, and magnetometers at Zhongshan and Syowa in the southern hemisphere, and the IMAGE magnetometer array in the Scandinavia region in the northern hemisphere, located at almost the same geomagnetic conjugate meridian as Zhongshan Station. A detailed description of IMAGE stations has been given by Lühr *et al.* (1984)

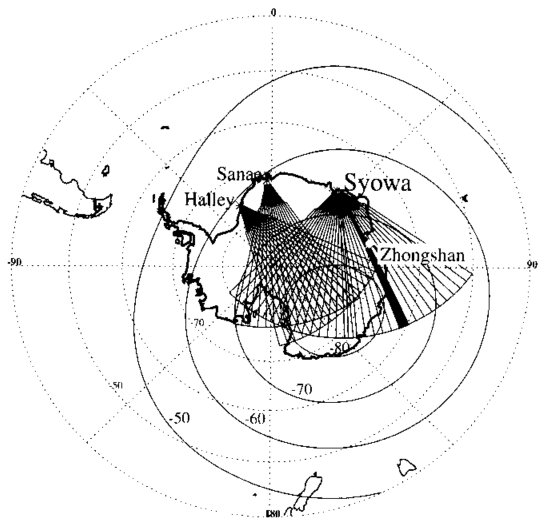

Fig. 1. Field of view of southern hemisphere SuperDARN radars in 1997.

3. Results

The high time resolution camping beam over the field of view of Zhongshan Station was operating on 3 August 1997 during the SuperDARN discretionary time allocation period. The quasi-periodic variations of optical aurora and HF radar backscatter echoes were observed simultaneously during the interval ~12 UT–14 UT. During this quasi-periodic event, IMF B_z was between ~0 and +5 and By was ~+2 on board the WIND satellite.

Figure 2 shows the optical auroral images observed by all-sky TV camera at Zhongshan from 1214:00 UT to 1236:30 UT. The directions of up, down, right and left in the all-sky image data indicate the magnetic southward, northward, eastward and westward, respectively. Three snapshot auroral images in the left panel of this figure correspond to the maximum phase of auroral luminosity, and the right side three images correspond to the luminosity minimum phase. Therefore it can say that the period of the luminosity pulsation on this event was ~9 min. It is clearly found from these all-sky images that the fine structure of the optical aurora showed east-west aligned band/arc type discrete aurora. The scanning photometer data (not shown in figure) showed that 557.7 nm intensity was much higher than the intensity of 630.0 nm. Therefore it is suggesting that high-energy electrons accelerated in the magnetosphere should enhance this optical auroral emission.

The upper panel of Fig. 3 shows a Keogram reproduced from all-sky TV images. The vertical axis of this Keogram shows the elevation angle directed along the beam 6 of the Syowa East HF radar. The middle two panels show the backscatter power and line-of-sight Doppler velocity of beam 6, respectively. The lower panel shows the H-component of magnetic variations observed at Zhongshan and Syowa. It is found that both of optical auroral luminosity and backscatter power showed quasi-periodic variations

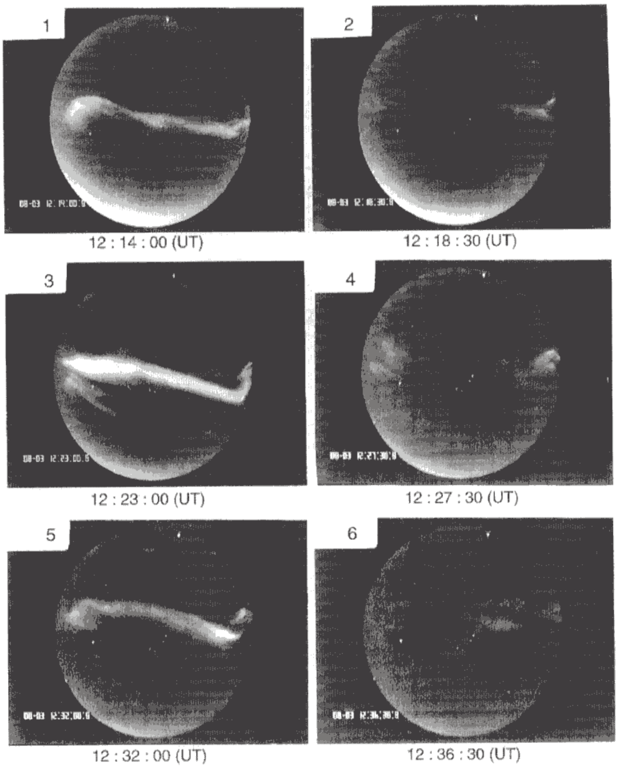

Fig. 2. All-sky TV images of optical aurora observed at Zhongshan.

with period of ~6–10 min during 1210–1310 UT, and the variations of line-of-sight Doppler velocity showed close relation to the magnetic variations on the ground.

Figure 4 shows the field of view of the all-sky TV images at Zhongshan, where the auroral altitude is assumed as 120 km, and the spatial distribution of line-of-sight Doppler velocity observed by the Syowa East radar during the quasi-periodic phenomena at 1308–1310 UT. It is found that the HF backscatter region is located at lower latitude than the region of optical aurora.

Figure 5 shows the relation between the zenithward-direction luminosity variations of optical aurora reproduced from all-sky TV images and the H-component of magnetic variations observed at Zhongshan. It is clearly found that the variations of the both phenomena show good correlation. It is notable that the enhancement of optical auroral luminosity started from the minimum phase of the *H*-component of magnetic variation. Figure 6 shows the magnetic variations observed at Zhongshan and the line-of-sight HF Doppler velocity at the 11-th range bin. A good correlation was found between the two phenomena, especially at the time intervals as shown by dotted lines, though there are some phase difference between the Doppler velocity variations and the magnetic variations.

Figure 7 shows the magnetogram observed by the IMAGE magnetometer network in the northern hemisphere which is located near the same geomagnetic meridian plane as

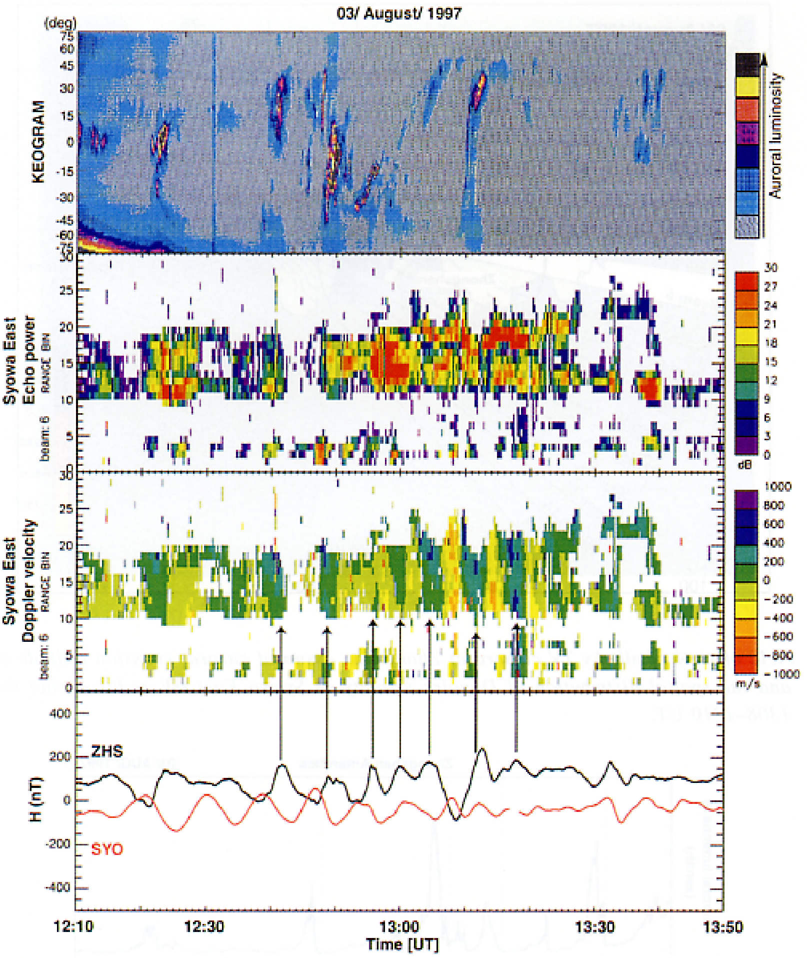

Fig. 3. Keogram of optical aurora, HF radar echo power, Doppler velocity and magnetic variations on 3 August 1997 during the interval 1210–1350 UT.

Zhongshan in the southern hemisphere, where the conjugate point of Zhongshan is located at a point between HOR (Hornsund: 74.02°, 110.48° in magnetic coordinates) and LYR (Longyearbyen: 75.12°, 113.00°). The IMAGE network data showed very similar waveform at different magnetic latitudes. It is important that the intensity maximum of the ULF waves occurred at BJN (Bear Island: 71.33°, 108.73°), HOP (Hopen Island: 72.93°, 115.91°), and HOR. The pulsation intensity is larger at these observatories. For example, the peak-to-peak amplitude of the pulsations reached more than 170 nT during ~1246–1250 UT at HOP. It is also clearly found that the phase relation drastically changed between BJN and SOR (Sørøya: 67.24°, 106.71°). Furthermore, a phase lag occurred with the function of geomagnetic latitude at higher latitude stations between BJN and NAL (Ny-Ålesund: 76.07°, 112.25°), though there is small phase lag in the lower latitude region between SOR and NUR (Nurmijärvi: 56.81°, 104.99°). It is very

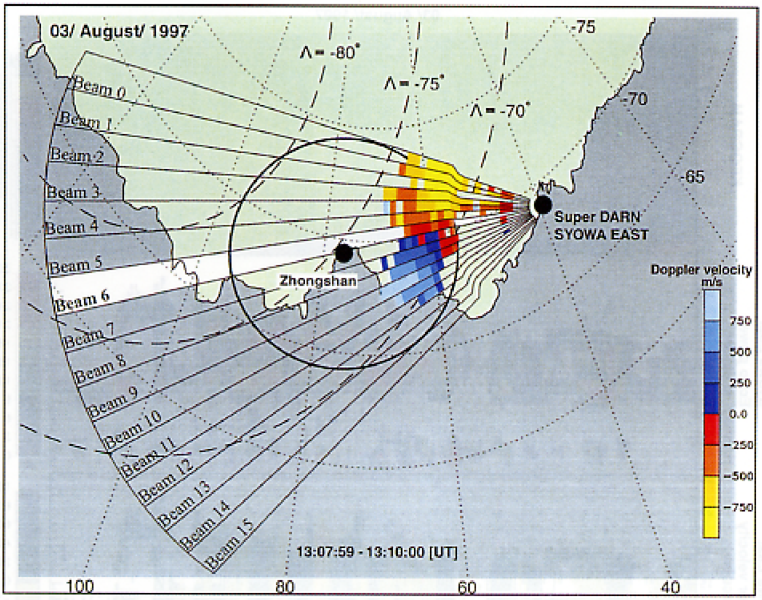

Fig. 4. Field of view of all-sky TV camera at Zhongshan assumed auroral emission altitude at 120 km, and the spatial distribution of Doppler velocity of Syowa East HF radar during the interval 1308–1310 UT.

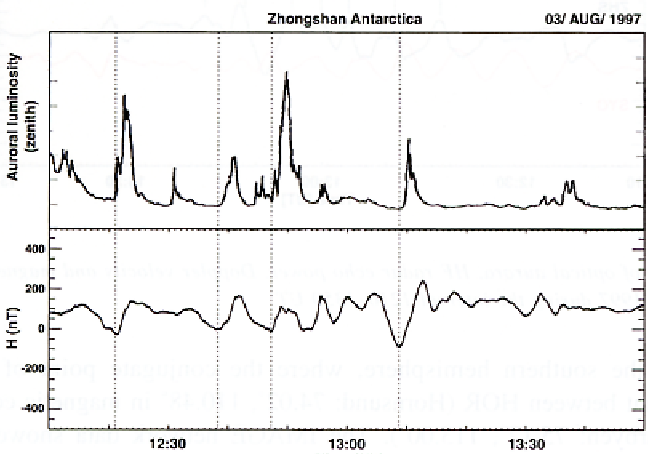

Fig. 5. The zenithward luminosity variations of optical aurora and the H-component of magnetic variations at Zhongshan.

interesting and important that such intensity maximum region is located at the region where quasi-periodic variations of HF backscatter power occurred in the conjugate southern hemisphere. It is suggested that all transmitted HF radar emissions were reflected at the region of the intense magnetic pulsations. However, we can not say that there were not rich irregularities to allow HF backscatter directly from the region of

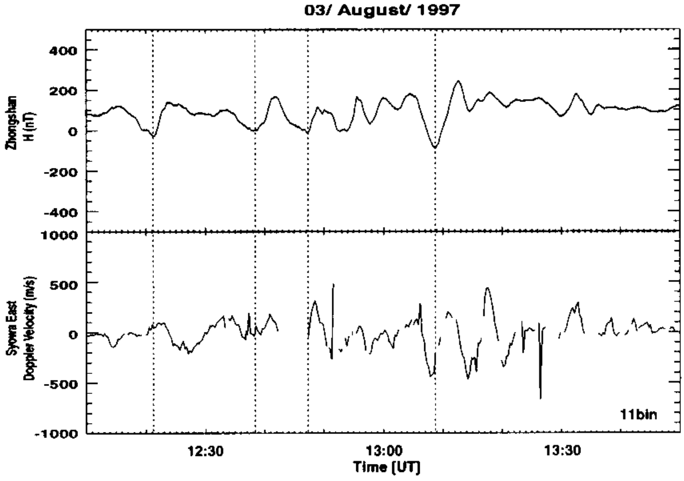

Fig. 6. H-component of magnetic variations at Zhongshan and the line-of-sight Syowa East HF Doppler velocity at the 11-th range bin.

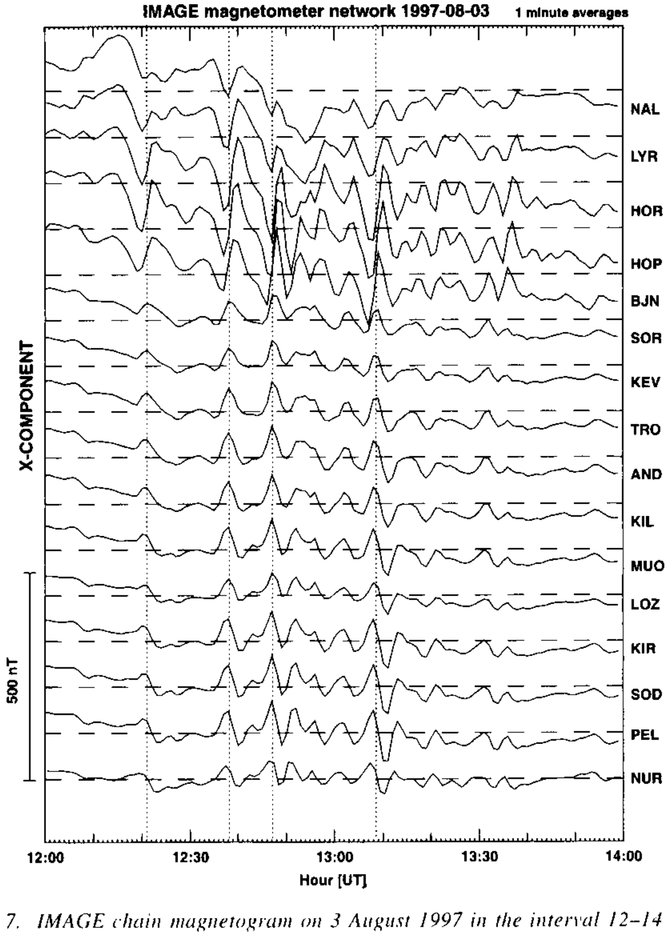

Fig. 7. IMAGE chain magnetogram on 3 August 1997 in the interval 12–14 UT.

quasi-periodic optical aurora over Zhongshan. Because the places satisfying the reflection condition of HF radar signals are dependent on the radar transmission frequency and ionospheric electron density distribution together with the geometry of geomagnetic field. Ogawa *et al.* (1990) calculated a ray path at different frequency ranges of 10, 15 and 20 MHz emitted from Syowa. They demonstrated that the detection of radar echoes at distant ranges from Syowa required a higher HF frequency and an antenna beam with lower elevation angle. The Syowa East radar operated at the frequency of 11.1 MHz during the time interval of this quasi-periodic event. So there is a possibility that the emitting HF frequency was lower in order to satisfy the reflection condition from the region of quasi-periodic optical aurora over Zhongshan even if there are rich irregularities in the region. We have to confirm this expectation by using the CUTLASS HF radars operating in the conjugate hemisphere.

4. Summary

We examined quasi-periodic phenomena of optical aurora, HF radar backscatter power and Doppler velocity, and ground based magnetogram observed in the geomagnetic postnoon sector (~1330 MLT to 1510 MLT) on 3 August 1997. The observational characteristics are summarized in the following;

1) East-west aligned band/arc type discrete aurora showed quasi-periodic luminosity variations with period of ~6–10 min.
2) Quasi-periodic variations of optical aurora had one to one correspondence with the variations of HF radar backscatter powers and magnetic pulsations.
3) The location of quasi-periodic HF backscatter occurred at lower latitude than that of quasi-periodic optical aurora.
4) Quasi-periodic structures of line-of-site Doppler velocity detected by HF radar showed very close relation to the magnetic pulsations, which are observed at Zhongshan.
5) The magnetometer array data (IMAGE) in the conjugate northern hemisphere showed that the intensity maximum of the magnetic pulsations occurred between BJN and HOR.
6) When we assume good conjugacy between southern and northern hemisphere it is expecting that the region of quasi-periodic HF radar backscatter (irregularities) corresponds to that of intensity maximum of Pc 5 magnetic pulsations.

We consider that the observational results summarized above include important evidence to examine the generation and modulation mechanism of ~10-min quasi-periodic optical aurora in the postnoon sector with the relation to Pc 5 magnetic pulsations.

In order to examine the explicit mechanism we must analyze the correlation among the optical aurora and other related phenomena, such as, solar wind density and magnetic field, particle data on board satellite, field-aligned current, SuperDARN radar data in the conjugate hemisphere, global magnetic field variation (*e.g.*, Greenland chain, CANOPUS), etc.

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