Chinese Journal of Polar Science, Vol. 10, No. 2, 133 - 140, December 1999

Ionospheric absorption at Zhongshan Station, Antarctica during magnetic storms in early May, 1998

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Received September 15, 1999

Abstract In the paper the high latitude ionospheric absorption events, monitored by an imaging riometer at Zhongshan Station, Antarctica, are examined during magnetic storms in early May, 1998. The storm absorption at ~0639 UT on May 2 was mainly an equatorward progressing absorption event, which were associated with a strong negative bay of the magnetic H component and with a large Pc3 range pulsation. There was a time lag of about 1.5 hours between the onset of the ionospheric disturbance and the IMF southward turning in the solar wind. The event at 2222 UT on May 2 was a typical midnight absorption spike event. The absorption region took the form of an elongated strip with the length of 100 - 150 km and the width of 30 - 40 km. The absorption during 0830 - 1200 UT on May 6 was a polar cap absorption (PCA) event, caused by intense precipitation of high-energy protons erupted after a large solar flare explosion.

Key words ionospheric absorption, magnetic storms, riometer, Zhongshan Station, Antarctica.

1 Introduction

The riometer (Relative Ionospheric Opacity Meter) technique has been widely used to investigate the ionospheric radio wave absorption processes since the International Geographical Year (IGY) (Little and Leinbach 1958). The recent development of imaging riometer has enable observations of the complex dynamics of auroral and polar radio wave absorption events, and could provide detailed characteristics of the spatial and temporal structure of small-scale disturbance events, velocity vectors for drifting features and frequency spectra for modulated events (Detrick and Rosenberg 1990; Stauning 1996). In 1997, an 8×8 beam imaging riometer was installed at Zhongshan Station, Antarctica under the cooperation between the Polar Research Institute of China and the National Institute of Polar Research, Japan (Liu *et al.* 1999; Nishino *et al.* 1998).

The observation of imaging riometer has been used to study the ionospheric impacts to the space weather events (Stauning 1998). In the 23rd solar cycle the April/May, 1998 solar storms was a significant solar-terrestrial event, which caused the Galaxy 4 failure and other spacecraft problems (Baker *et al.* 1998). The derived early May geomagnetic storms consists of two storms. One of them had a sudden commencement at 2155 UT on May 1, and Dst reached to −100 nT at 1800 UT on May 2, and the other had a sudden commencement at 1742 UT on May 2, having the planetary magnetic index Kp of 9 on May 4. The Dst index reached to −206 nT and the auroral electrojet index A_E exceeded 2500 nT on that day, indicating a major magnetic storm.

In this paper the high latitude ionospheric absorption events, monitored by an imaging riometer at Zhongshan Station, are examined during May 1 - 7, 1998 to study the responses of the polar ionosphere to the major magnetic storm.

2 Observations

The imaging riometer at Zhongshan Station works at the frequency of 38. 2 MHz and adopted 8×8 receiving antennas. Description of the imaging riometer at Zhongshan Station is given in several papers (Nishino *et al.* 1998; Liu *et al.* 1999). This imaging riometer has been in operation since February, 1997. The ionospheric absorption is usually rather small during night time at quiet geomagnetic condition. The undisturbed level —— the quit day curve (QDC)—— can be derived from the recorded cosmic noise signal intensities. Knowing the quiet day curves, the ionospheric absorption during disturbed condition can be calculated for each beams. The 2-dimention picture of absorption can be combined by interpolation routines from all 64 beams.

Fig. 1 shows the ionospheric absorption events during May 1 - 7, 1998, which are derived values for a central beam (E4S4). The abscissa denotes the universal time. At Zhongshan Station the local time is 5 hours earlier than UT and the corrected magnetic local time is about 2 hours earlier than UT. It can be seen that there is no strong absorption events before or after the early May geomagnetic storm on May 1 and May 7 respectively, indicating that the ionosphere is in normal and quiet condition. During the storm period of May 2 - 6 the absorption events occurred quite frequently and complexly, sometimes were rather strong. In the following sector three selected events are analyzed and discussed.

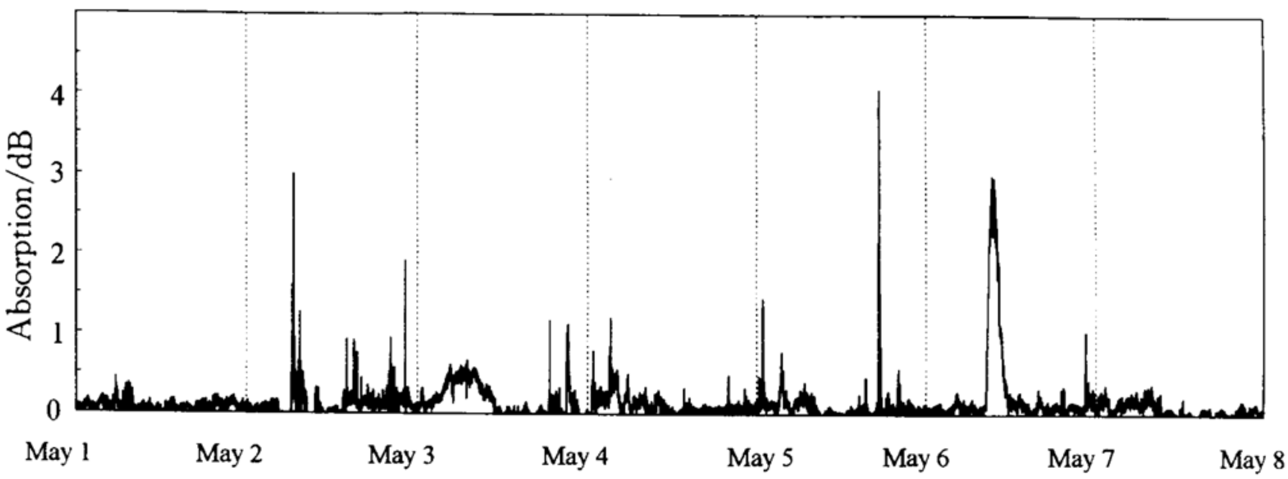

Fig. 1. Ionospheric absorption events observed at Zhongshan Station during May 1 - 7, 1998.

3 Analysis and discussion

3.1 The event at ~0630 UT on May 2

Fig. 2 illustrates the recordings of different imaging riometer channels during 0600 – 0700 UT on May 2. The upper panel displays the cosmic noise absorption received in each beam of the fourth southernmost row of beams. The absorption has been normalized with respect to the quiet day levels such that the undisturbed trace would be horizontal lines. The beams have been arranged in sequence from east (lower trace) to west (upper trace). The lower panel displays the corresponding set of absorption in the fourth-easternmost column of beams. The beams have been arranged in sequence from north (lower trace) to south (upper trace). In this representation the east-west and the north-

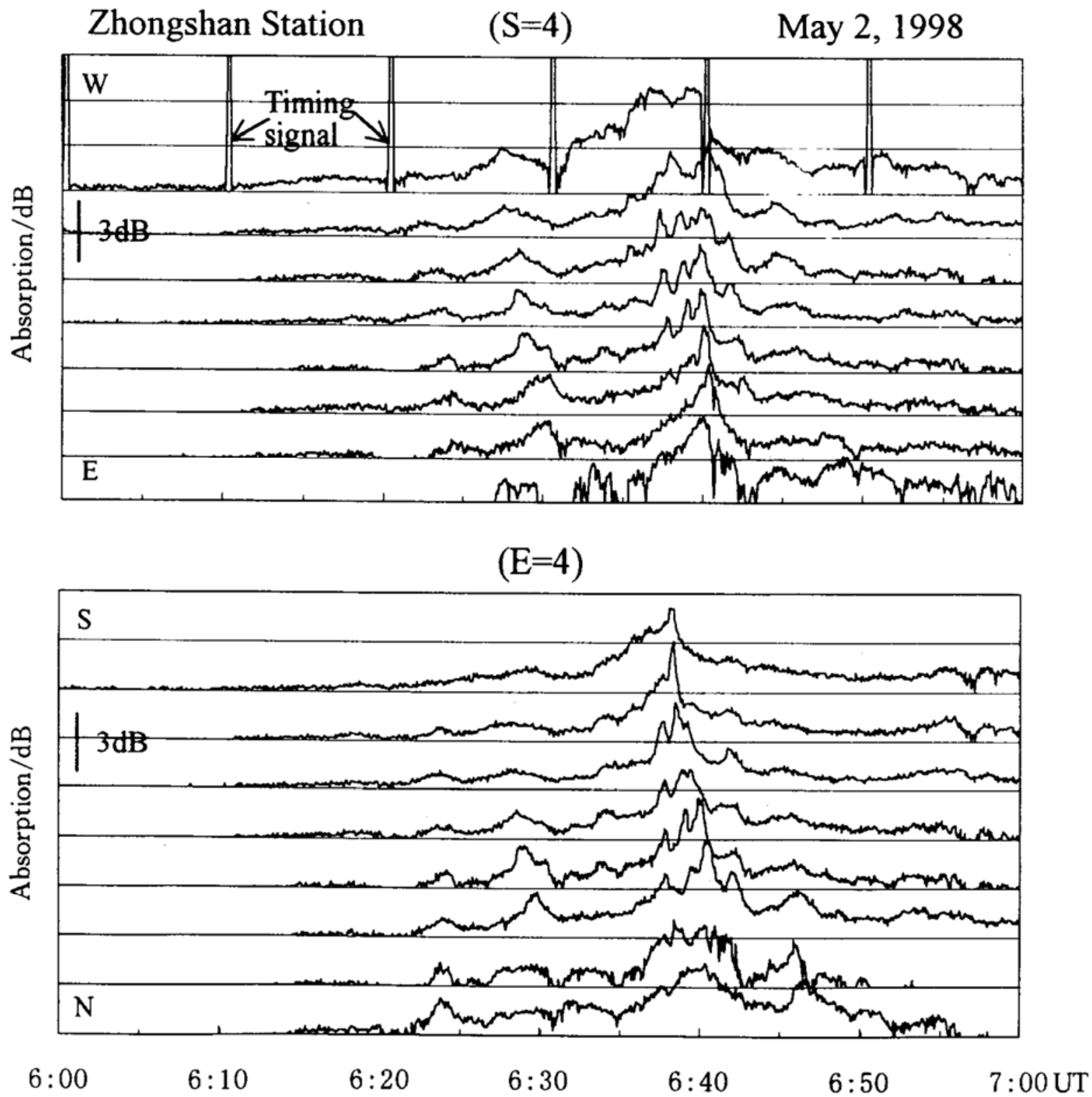

Fig. 2. Line plots of absorption intensities for different imaging riometer channels at Zhongshan Station during 0600 – 0700 UT on May 2, 1998.

south variations in the cosmic noise absorption are displayed.

Comparing the absorption peaks in each trace, it is seen that the movement of the absorption event is mainly north-south direction around 0639 UT. A northward (equatorward) velocity of ~600 m/s was calculated by the time lags between the sequent beams in the lower panel of Fig. 2 by assuming an effective altitude of 75 km for the absorption processes.

For each beam the average absorption intensities have been calculated at 16-second intervals. Based on the available 64 beams the 2-dimension absorption distribution over the antenna field of view has been derived from these 16-second values by interpolation routines. A time sequence of color-coded plots of the absorption intensity distribution during 0636:12 - 0642:04 UT on May 2, 1998 is displayed in Plate II. The small squares represent a region of sky of dimension 200×200 km centered above Zhongshan Station. The orientation of the square is indicated in the lower right field. The absorption intensity scale is placed at the bottom of the diagram. In the representation the temporal and spatial structures of the absorption event are much easier discernible than in the line plots of Fig. 2. There is a fine structure of absorption along northwest to southeast direction in the center of view field, with movements from southwest to northeast at first, and then from south to north (equatorwards).

Fig. 3 gives multiple observations on May 2. It is seen from Fig. 3 that there was an intense absorption event at ~0639 UT. In the mean time the magnetic H component had a large negative bay (−902 nT), the ULF spectral power (Pc3 range pulsation) had large values started at 0620 UT, the h_mF_2 rose very rapidly started at 0543 UT and then the reflected signal was disappeared. All these indicated that the polar ionosphere was suddenly disturbed. Comparing with solar wind data in Fig. 3(e) to 3(g), it is noticed that at ~0330 UT the IMF Bz turned southward from positive to large negative and then remained for a long period. During southward interplanetary magnetic field (IMF) conditions the polar cap ionosphere appears to be magnetically connected to the solar wind plasma. The IMF coupling power (described by the epsilon parameter ε of Akasofu (1981)), was put into the magnetosphere-ionosphere system and then caused substorms. During auroral substorms it seems that the intense 'cloud of energetic electrons' are injected on closed field lines. These clouds may drift eastward under the combined influence of the gradients in the geomagnetic field and the magnetospheric electric fields. At local time morning the precipitation of approximately 30 - 300 keV electrons to the D and lower E regions (60 - 100 km) produces the enhanced ionization responsible for this kind of absorption events. Comparing solar wind data, there was a time lag of about 1.5 hours (deduced the travelling time from WIND to the magnetospause) between the polar ionosphere disturbance and the IMF Bz southward turning point. It was suggested that this time delay can be ascribed to the processes which establish the electric field, particle convection and subsequent energization within the near-earth plasma sheet (Huang *et al.* 1998).

3.2 The event at 2222 UT on May 2

Fig. 4 displays a very intense and typical absorption spike event observed by the imaging riometer at Zhongshan Station in the time interval from 2210 UT to 2230 UT on

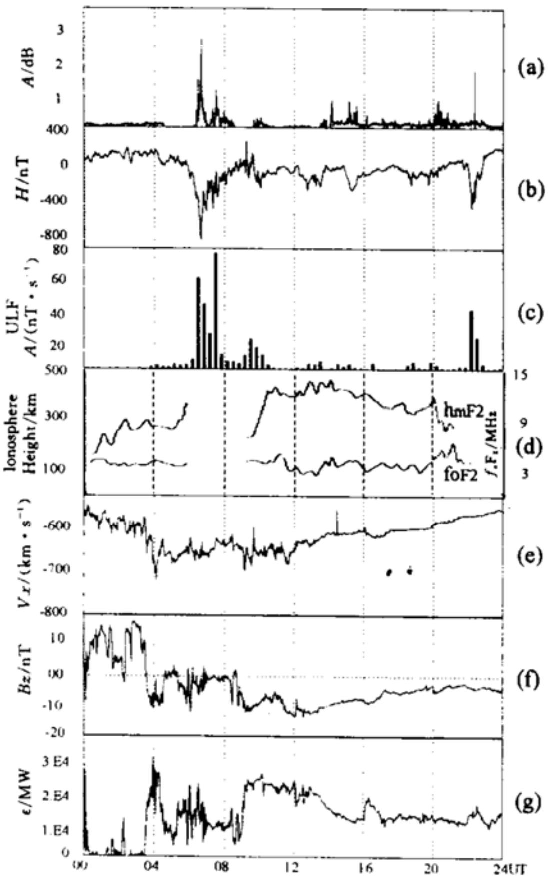

Fig. 3. Multiple observations on May 2, 1998. (a) Riometer absorption; (b) Geomagnetic field H component; (c) ULF spectral power; (d) Ionospheric parameters: upper curve shows h_mF_2; lower curve shows f_oF_2; (e) Solar wind speed Vx; (f) IMF Bz component; (g) Derived IMF coupling power.

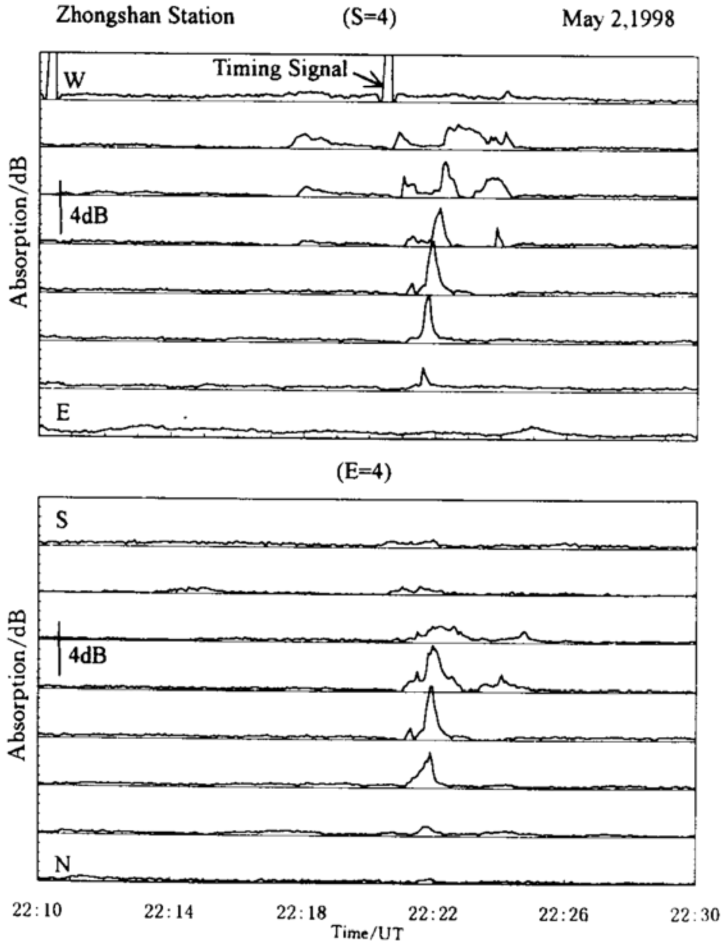

Fig. 4. Line plots of absorption intensities for different imaging riometer channels at Zhongshan Station during 2210 - 2230 UT on May 2, 1998.

May 2, 1998. The top panel presents the cosmic noise absorption received in each beam of the fourth-southmost row of beams. The bottom panel presents the corresponding set of absorption in the fourth-easternmost column of beams. It is seen from Fig. 4 that this is a typical midnight absorption spike event. The maximum of absorption intensity is about 4 dB. The duration of absorption peak is less than 2 min and the maximum extent of absorption region is about 100 km. Comparing the absorption peaks in each trace, it is seen that the movement of the absorption spike is mainly west-east direction at around 2222 UT. A large westward velocity of ~1900 m/s was calculated by the time lags between the sequent traces in the top panel of Fig. 4 by assuming an effective altitude of 75 km for the absorption processes. From Fig. 3(b) and (c) it is seen that before or during the spike event the local geomagnetic field had a larger negative deviation, and the ULF waves had large amptitude.

A time sequence of color-coded plots of absorption intensity distribution during

2221:21 – 2222:48 UT on May 2, 1998, is displayed in Plate III with a time interval of 4 s. Stauning and Rosenberg (1996) have studied high-latitude daytime absorption spike events. Nielson and Axford (1977), Hargreaves *et al.* (1979) have used observations with a narrow-beam riometer system to study nighttime spike events. Here we use the imaging riometer observation to give the direct evidence of the typical shape of the midnight spike event. It is shown from Plate III that the absorption region takes the form of an elongated strip. The length of the strip is between 100 km to 150 km with the width of 30 – 40 km assuming the absorption region is at 75 km altitude. The direction of the absorption strip was magnetic north-south at first, then changed to northwest-southeast (geographic north-south direction). This implies that the absorption region that produced a spike event is in rapid motion. There is a slight indication of a westward motion of the intense absorption clouds from an initial position east of the center of the display to a position a little west of the center as the event fades away.

3.3 The event during 0800 – 1200 UT on May 6

Fig. 5 shows a typical polar cap absorption event observed at Zhongshan Station during 0800 – 1200 UT on 6 May. The top panel presents the cosmic noise absorption received in central beam (S4E4). The middle panel presents the H component of geomagnetism measured by a fluxgate magnetometer at Zhongshan Station. It is seen from Fig. 5 that this absorption event had long period of about 4 hours started at 0830 UT. In the meantime the geomagnetic H component had no large fluctuation which was quite different from the former two events. It is noticed that there was a large solar flare explosion (X2.7/1N), which started at 0758 UT on May 6 and reached to the maximum at 0809 UT. Dense high-energy proton erupted after the large flare. The bottom panel of Fig. 5 shows the proton flux with energy greater than 10 MeV, which was measured by GOES-9 satellite. Comparing the shape and the start time between the curves of the riometer absorption and the proton flux, we concluded that the absorption event on May 6 was a kind of polar cap absorption (PCA) caused by precipitating high-energy solar flare protons.

During the large solar flare events the sun emit an intense radiation of high-energy protons. This radiation has immediate access to the atmosphere in the polar caps and auroral regions along the geomagnetic field lines. The hard radiation with protons energy above 10 MeV may cause substantial ionization at low altitude in the D region (50 – 80 km) where the electron-neutral collision frequency are very high, causing a large ionospheric absorption of cosmic noise.

4 Summary

The high latitude ionospheric absorption events are examined which was monitored by an imaging riometer at Zhongshan Station, Antarctica during magnetism storms in early May 1998. During the storm period of May 2 – 6 the absorption events were quite often and complex, sometimes even rather strong. There are no strong absorption events before or after the early May magnetic storms, indicating that the polar ionosphere is in quiet condition.

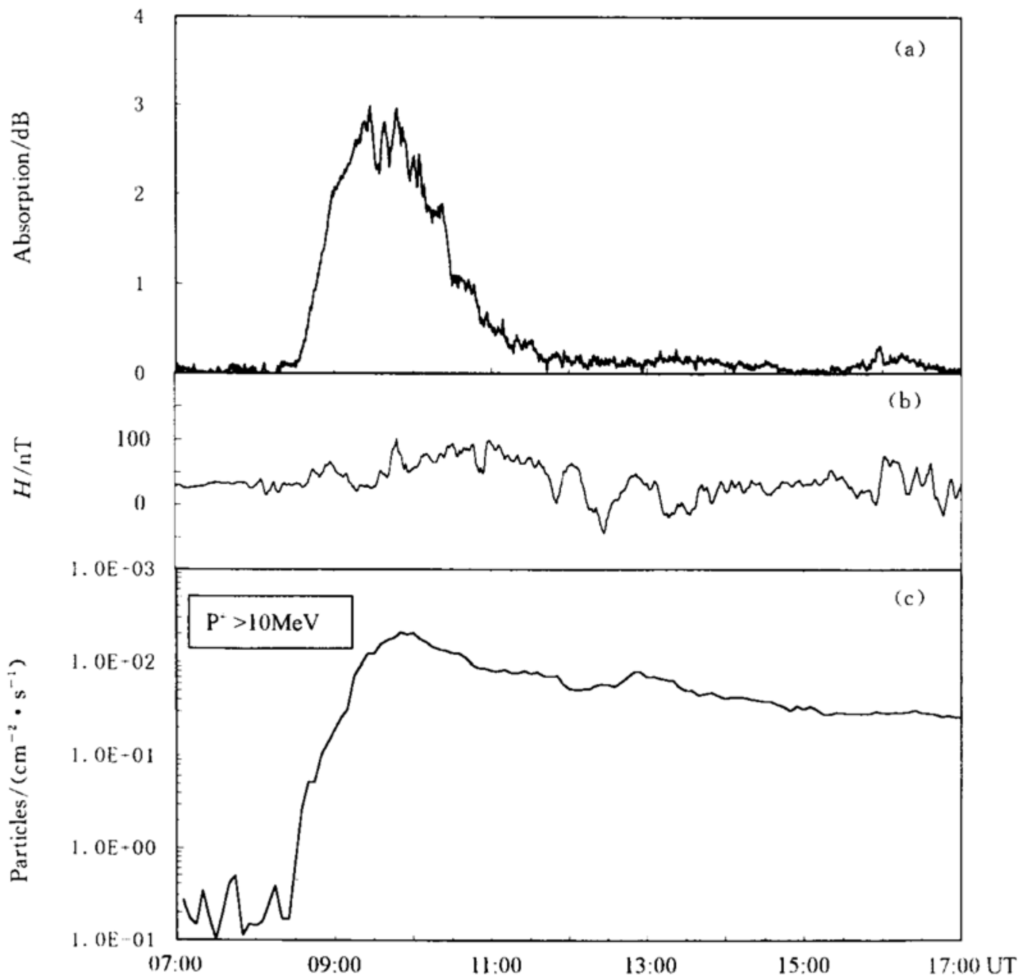

Fig. 5. Multiple observations on May 6, 1998. (a) Riometer absorption; (b) Geomagnetic field H component; (c) High-energy protons (GEOS-9).

There was an intense absorption event at ~0639 UT on May 2, which is mainly a equatorward progressing absorption with a speed of ~ 600 m/s. Simultaneous observations show that the geomagnetic H component had a strong negative bay, the ULF spectral power had large values and the h_mF_2 rose very rapidly. All these indicated that the polar ionosphere was suddenly disturbed. There was a time lag of about 1.5 hours between the onset of the ionospheric disturbance and the IMF southward turning point. This time delay could be ascribed to the processes, which establish the electric field, particle convection and subsequent energization within the near-earth plasma sheet.

Most of the absorption events in nighttime and in the morning were attributed to the precipitation of energetic electrons during auroral substorms. The event at 2222 UT on May 2 was a typical midnight absorption spike event with a maximum intense of 4 dB and duration of ~2 min. The imaging riometer observation gave direct evidence of the shape of the spike event. The absorption region that produces a spike event takes the form of an elongated strip with the length of 100 - 150 km and the width of 30 - 40 km. The direction of the absorption changed from geomagnetic north-south to geographic north-south.

The event during 0830 - 1200 UT on May 6 was a typical polar cap absorption event caused by intense radiation of high-energy proton erupted after a large solar flare explosion.

The imaging rioter technique is a valuable tool for study of a variety of ionospheric and magnetospheric disturbances.

Acknowledgements The Chinese Arctic and Antarctic Administration support the operation of instruments at Zhongshan Station. The imaging riometer and fluxgate magnetometer were supported by the Ministry of Education, Science, Sports and Culture of Japan(MONBUSHO). The observations at Zhongshan Station were carried out by the 14th CHINARE. Dr. K. Oglivie at NASA/GSFC provided the solar wind data observation by WIND through web service. The work is supported by the National Natural Science Foundation of China under grant (No. 49639160) and by the Chinese Academy of Sciences under grant (KJ951-1-305).

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