Chinese Journal of Polar Science, Vol. 12, No. 2, 145 - 152, December 2001

Study and observation of the great solar event in July 2000 at cusp latitude

Liu Yonghua (刘勇华), Liu Ruiyuan(刘瑞源), Hu Hongqiao (胡红桥) and
Xu Zhonghua (徐中华)
Polar Research Institute of China, Shanghai 200129, China

Received August 22, 2001

Abstract A series of solar flare and coronal mass ejection (CME) event occurred in July 2000, particularly the largest flare (X5.7/3B) with CME on 14th of July since 1989, which stimulated a great geomagnetic storm with D_{st} index reaching - 300 nT. A number of data have been obtained from the Chinese Antarctic Zhongshan Station (ZHS, INT Lat. 74.5°, L≈14), which is located at cusp latitude, and from the ACE satellite. After analyzing these data we have got the results as follows: a lot of solar high energy particles penetrated into the polar ionosphere and ionized it, which significantly increased the cosmic noise absorption (CNA) and blanked the DPS-4 data for more than two days. The magnetic pulsation in Pc 3/5 frequency band on the ground has a high relation with the fluctuation of interplanetary magnetic field (IMF) B_z, which shows the contribution of interplanetary magnetohydrodynamical (MHD) waves to the Pc 3/5 pulsation on the ground. The Pc 3/5 pulsation was intensified much during the great magnetic storm. The H component of the magnetic field at ZHS varied with the southern value of IMF B_z but lagged behind for about 8 - 10 h. While D_{st} index responded to the variation of the IMF B_z very quickly, which suggested that the magnetic storm occurred at low latitude firstly and then effected the ionospheric current at high latitude.
Key words flare, CME event, geomagnetic storm, cusp, Zhongshan Station.

1 Introduction

Along with the development of science and technology, the influences of solar activities on the Earth have attracted us increasing attentions. Human activities, such as satellite, radio communication system, air navigation and even long-distance electricity transmit system, etc., could be disturbed or damaged by intense solar activities. Actually, such events occurred several times before (Tu *et al*. 1988).

Flare and CME are the two main types of intense solar activities. By them, the Sun could disturb the Earth's magnetosphere and ionosphere and then influence human activities (Tu *et al*. 1988; Baker 2000). They often happen and make disturbance on the Earth together. Great flare and CME event could induce extreme geophysical effect in geospace. Comprehensive analysis of the effect is one of the efficient ways to get a deep insight into space physical phenomena (Zolotukhina *et al*. 2000; Taylor *et al*. 1997).

Great magnetic storms on the Earth often have relation with interplanetary shock including those caused by CME events, as thought by Gosling *et al*., while small storms occur without interplanetary shock. CME with slow speed can not induce interplanetary shock and then can not induce particular effect on the Earth (Gosling *et al*. 1990, 1991).

The strongest solar flare and CME events since 1989 occurred on July 14 2000, which disturbed the ionosphere dramatically and induced a great magnetic storm on the Earth during July 15 – 16. During the period of this storm, the minimum value of the D_{st} index reached − 300 nT. This event has attracted the interest of the global scientists of space physics.

ZHS is located at cusp latitude and under the cusp region at noon and polar cap in nighttime, crossing auroral zone twice in each day. So it is an ideal site to observe upper atmospheric phenomena at high latitude (Liu and Liu 1994; Liu *et al*. 2000). In this paper we will analyze the geophysical effect of the great solar event at polar region based on the observations at ZHS ground and ACE satellite.

2 Observed results

At ZHS has been built up a composite system on upper atmospheric physics, which includes eight different instruments that work continuously and record observed results into disk automatically. In this paper we take use of four types of these data, which are observed by the digisonde (DPS-4), the induction magnetometer, the fluxgate magnetometer and the imaging riometer, to investigate the response of polar upper atmosphere to the great solar event. Meanwhile, the ACE satellite data is also used to investigate the variation of solar wind parameters in space near the Earth during the period of the solar event and then to compare them with the simultaneously observed results at ZHS.

2.1 The solar events

A series of solar flare and CME event occurred in July 2000. From July 12 to July 20, at the Sun occurred two flares in X grade, twenty-two flares in M grade (two of them beyond M5.0) and nineteen flares in C grade. The strongest one with X5.7/3B grade occurred at 1003 UT on July 14 2000, accompanying with a intense CME (the monthly report of solar observations at Yunnan Observatory, Chinese Academy of Sciences). This is also the strongest flare and CME event since 1989, which has aroused scientists´ attention to the geophysical effect on interplanetary and geospace. Therefore, it provides a good opportunity for us to study the effect of great solar event in geospace and has actually been widely focused by the global community of space physics.

2.2 Interplanetary response

Interplanetary data are observed by ACE satellite that is located at L1 point of Sun-Earth line, at a distance of 215 Earth´s radius to the Earth. In Fig. 1 (a) – (e) are displayed the variations of the hydrogen ion density, hydrogen ion temperature, bulk speed of solar wind, high energy proton (> 10 MeV) flux and high energy proton (> 30 MeV) flux, respectively. From these panels, it can be seen that high energy proton flux began to enhance dramatically at 1100 UT on July 14 and approximated to peak value at 1200 UT. The peak value of the flux surpassed its normal level by four orders and lasted for more than one day. This event was extremely strong in the past but happened the least and it was calculated that the flare occurred at 1003 UT on July 14 according the appearing time. At 2100 UT on July 18, the flux of high energy proton enhanced again by one order. During July 14 – 15, solar wind data were blanked when the high energy proton flux enhanced dramatically, which might be caused by high energy proton damaging the instruments in the satellite or making the observed value beyond the threshold of the instruments. On July 16, solar wind data are recovered, and we can still see that the bulk speed reached a very high level, beyond 900 km/s. Fig. 1 (f) shows the variation of IMF B_z during the period of this event. It can be seen that IMF B_z began to fluctuate intensely at 1400 UT on July 15 and then downed dramatically, with its bottom value of − 57.69 nT at 1930 UT, and then bounced up with peak value beyond 30 nT. The IMF B_z recovered at 0400 UT on July 16. Around 1200 UT on July 13 and 1400 UT on July 14, the IMF B_z also fluctuated apparently.

2.3 *Planetary magnetic D_{st}, K_p and A_p index*

This solar event induce a great geomagnetic storm as shown in Fig. 1 (g). The D_{st} index began to down rapidly at 2000 UT on July 15 and reached its bottom value of − 300 nT at 2100 UT, and then restored to a value of − 281 nT at 0000 UT on July 16 and downed again to a value of − 295 nT at 0100 UT on July 16. The D_{st} index recovered gradually after 0200 UT on July 16. During the period of the great storm, the K_p index reached the maximum value of 9, while the A_p index reached its maximum value of 400. On July 15, ΣK_p reached 50 and the averaged A_p index reached 164. Apparently, this is a great geomagnetic storm.

2.4 *Observation at Zhongshan Station*

2.4.1 *Geomagnetic observation*

ZHS is located at cusp latitude. The geomagnetic data observed at ZHS reflect current activities at high latitude, especially those in regions 1 and 2. In this point it is different from the D_{st} index, as it mainly reflects variation of equatorial current ring. In Fig. 1 (k) – (l) is shown the variation of H and Z components of geomagnetic field observed at ZHS. Based on these panels, we can see apparently that there are three geomagnetic disturbances at ZHS that occurred at 2000 UT on July 13, 0300 UT on July 15 and 0000 UT on July 16, respectively. Of them the last one is the strongest one, lasting for more than 14 h, with a bottom value of − 1000 nT.

2.4.2 *Variation of f_oF_2*

In Fig. 1 (m) is shown the variation of f_oF_2 observed by the DPS-4 at ZHS. We can see that the data of DPS-4 are blanked out for several times. The first blank began at 1000 UT on 13 July and lasted for about 8 h. The second one began at 1200 UT on July 14 and lasted for more than two days. The third one began at 1300 UT on July 16 and almost continued to 0900 UT on July 17. Then the data of DPS-4 recovered gradually. During the period of this solar event, what we find is data blank with long time rather than decline of f_oF_2 value.

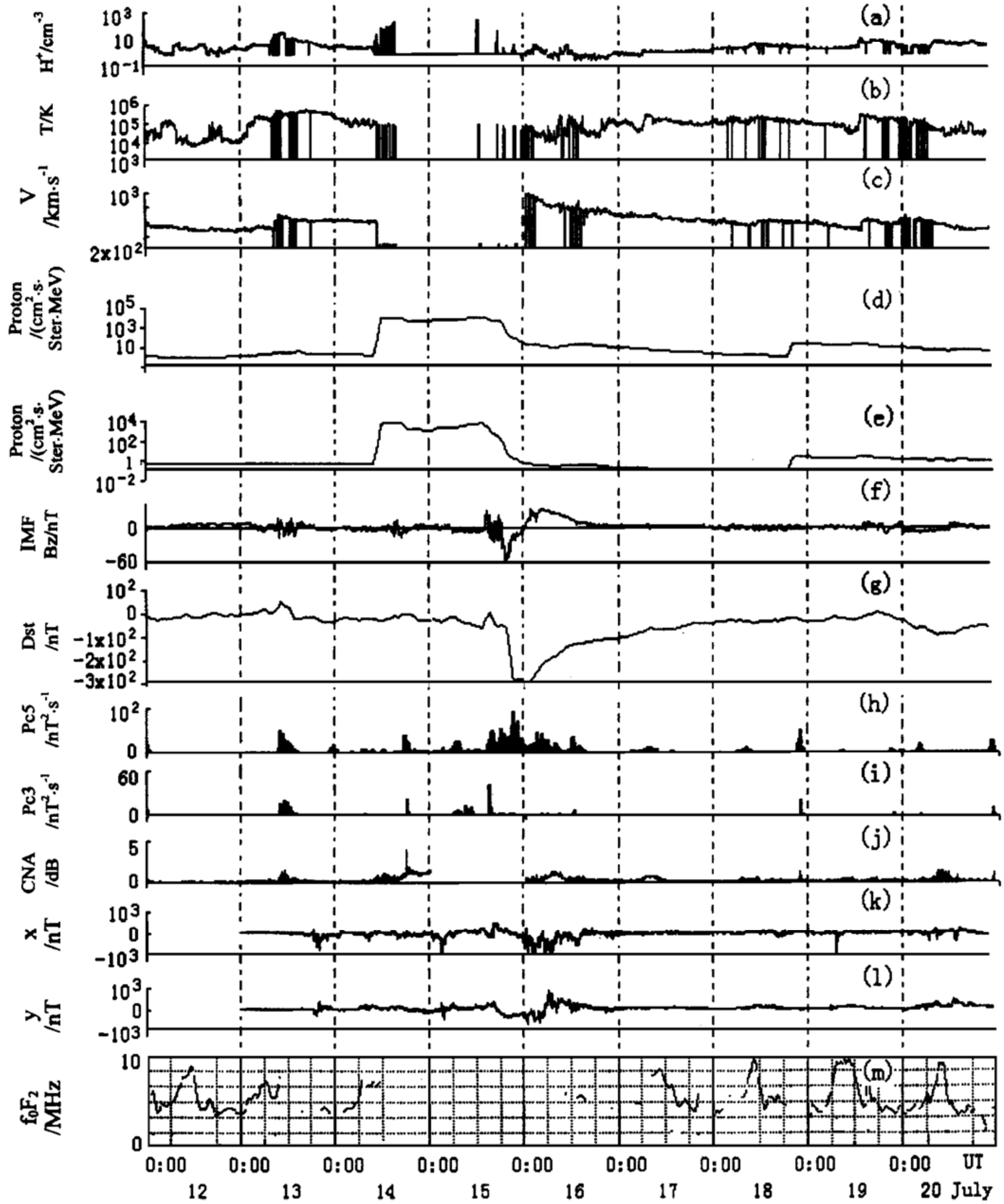

Fig. 1. Geophysical effects of the great solar event on July 14, 2000: observation at ACE satellite and Antarctic Zhongshan Station (ZHS) from July 12 – 20. (a) Solar wind H^+ density; (b) Solar wind H^+ temperature; (c) Solar wind bulk speed; (d) Interplanetary proton (> 10 MeV) flux; (e) Interplanetary proton (> 30 MeV) flux; (f) B_z component of interplanetary magnetic field; (g) Earth's D_{st} index; (h) Spectrum of Pc5 magnetic pulsation observed at ZHS; (i) Spectrum of Pc3 magnetic pulsation observed at ZHS; (j) Cosmic noise absorption observed at ZHS; (k) X component of magnetic field observed at ZHS; (l) Z component of magnetic field observed at ZHS; (m) Critical frequency of ionospheric F_2 layer above ZHS.

2.4.3 *Geomagnetic pulsation*

Geomagnetic pulsation data were observed by the induction magnetometer. Fourier transforming and visual waveform checked methods are used to select Pc3/5 pulsation events. It is regarded as a Pc3/5 pulsation event when the peak value of the spectrum in Pc3/5 band is six times larger than that of background (Nose *et al*. 1998; Liu *et al*. 2000). In Fig. 1(h) – (i) are shown geomagnetic Pc3/5 activities during the period of the solar event. We can see apparently there are three times intensification of Pc3/5 activities which occurred around 1200 UT on July 13, 1500 UT on July 14 and 1500 UT on July 15 respectively.

2.4.4 *Cosmic noise absorption (CNA)*

CNA data are observed by the imaging riometer at ZHS, which has an antenna array composed of sixty-four (8×8) dipole antennas and can obtain a two-dimension image of the CNA in the ionosphere above ZHS (Liu *et al*. 1999). The data from the center beam is chosen and shown in Fig. 1(j). From this panel, it can be seen that the CNA were intensified several times around 1100 UT on July 13, 1800 UT on July 14 and 0600 UT on July 16 respectively. The CNA value reached to 4 dB at 1753 UT on July 14, and particularly to 21.5 dB at 0704 UT on July 15. Unfortunately, after 0739 UT, the data were broke up resulting from an error in signal of GPS. On July 16, the data was restored normally.

3 Analysis and discussion

In July 2000, a series of solar flare and CME events occurred at the Sun, especially the largest flare with CME event on July 14 since 1989 and the flare is graded with X5.7/3B. The ACE satellite is located at the L1 point of Sun-Earth line, at a distance of 215 Earth's radius with the Earth. Normally, it will take about 1 h for solar wind to arrive at the geo-magnetopause after passing ACE satellite. ZHS is located under ionospheric project of magnetospheric cusp region and so there occur a lot of upper atmospheric phenomena. Responding to the solar event in July 2000, intense geophysical effects were induced in the interplanetary and the magnetosphere according to the data from ACE and ZHS.

3.1 *IMF southern and geomagnetic storm*

In Fig. 1 are shown the interplanetary data and ground data that are observed by ACE satellite and ZHS ground respectively. It can be seen from Fig. 1(f) – (g) that the variation of D_{st} index may be correlated with that of IMF B_z very well. The great geomagnetic storm was induced from the southern value of IMF B_z with large magnitude and long time. The IMF B_z value shifted to the bottom value of −57.69 nT at 1930 UT on July 15 and correspondingly D_{st} index value downed to the bottom value of −300 nT at 2100 UT that day. The latter occurred about 1.5 h later than did the former. This is exactly a time segment taken by a magnetic cloud travelling from the ACE satellite to the magnetopause and interior magnetosphere responding to it. We can also see that there were fluctuations of IMF around 1200 UT on July 13 and 1400 UT on July 14 respectively. Correspondingly, fluctuations of D_{st} index occurred. From 0600 UT to 1400 UT on July 15 and 0000 UT to 1300 UT on July 20, the IMF B_z were negative continuously, which resulted in apparent decline of D_{st}

index value respectively. At 1400 UT on July 15, the D_{st} index downed to − 60 nT, while at 1000 UT on July 20, the D_{st} index downed to − 95 nT.

3.2 High energy particle event and CNA

It can be seen from Fig. 1 (d) ~ (e) and (j) that the interplanetary high energy particle event produced an extremely strong CNA event. Graded in X5.7/3B the flare blasted at 1003 UT on July 14, while at 1100 UT the high energy particle flux observed by the ACE enhanced dramatically and it reached to its peak value at 1200 UT. The flux enhanced totally beyond four orders. Ground CNA at ZHS increased obviously at 1010 UT on July 14 and got a value of 0.74 dB at 1014 UT, which was caused directly by solar X-ray ionizing the atmosphere. At 1200 UT the CNA value was larger than 1 dB and at 1507 UT the CNA value reached to 4 dB. Particularly, at 0704 UT on July 15 the CNA value attained 21.5 dB! These CAN events were caused by high energy particles ionizing the atmosphere.

The ground CNA increased obviously at 1100 UT on July 13 and 1000 UT on July 20, but the interplanetary high energy particle flux didn't enhance apparently and the ground geomagnetic field didn't decline apparently, which suggested that in these cases the CNA might not result from the particle radiation or precipitation. Since in this time segment ZHS is located under the cusp region and the IMF has a southern disturbance, the interplanetary electric field ($\boldsymbol{E} = -\boldsymbol{V} \times \boldsymbol{B}$) might directly map to the ionosphere of cusp region and heat the electrons. That could result in enhancement of the collision frequency between the electrons and neutral particles and lastly enhanced the CNA (Detrick and Rosenberg 1990; Stauning *et al*. 1995).

3.3 IMF fluctuation and magnetic pulsation

Fig. 1 (f) and (h) ~ (i) show that ground magnetic pulsation may be correlated with IMF fluctuation. The intensification of the magnetic pulsation for several times at ZHS obviously corresponded to the IMF southern disturbance. For example, around 1200 UT on July 13, 1400 UT on July 14, 1000 UT and 1400 UT on July 15, the intensification of the magnetic pulsation at ZHS corresponded respectively to the IMF southern disturbance very well. Around 2000 UT on July 18 the ground pulsation increased obviously in line with the IMF B_z. Further, on July 12, the ground pulsation activity was very quietly and almost disappeared, which was in line with a state that the IMF B_z sustained a northern value. Here, we can also see that ground pulsation was controlled by the obvious fluctuation of IMF B_z component. When the IMF B_z was southern, the IMF could easily connect with the geomagnetic field, and then interplanetary MHD waves could easily be transmitted into the magnetosphere to induce resonance of the geomagnetic field line or to modulate the particle fluency. These would increase activities of the ground pulsation. After 1400 UT on July 14, the magnitude of Pc3/5 enhanced greatly, which responded to that the IMF fluctuated dramatically. Along with the gradual recovery of the IMF B_z activities, the magnetic storm came into its recovery phase. While, the ground pulsation sustained a certain activity since the storm recovery phase, the resonance of magnetosphere still existed but weakened gradually.

3.4 *IMF disturbance and ground magnetic variation*

Comparing Fig. 1 (k) ~ (l) with Fig. 1 (f), we can see that the magnetic disturbance at ZHS apparently corresponded to the IMF B_z disturbance but lagged behind about 8 h. There were three times of magnetic disturbances at ZHS around 2000 UT on July 13, 0300 UT on July 15 and 0000 UT on July 16 respectively. Correspondingly, there were three times of IMF B_z disturbances around 1200 UT on July 13, 1400 UT on July 14 and 1400 UT on July 15 respectively. The magnetic disturbance at ZHS apparently lagged behind the IMF B_z disturbance correspondingly. However, the D_{st} index responded to the variation of IMF very quickly, which suggested that the magnetic storm happened firstly at low latitude. Therefore, the equatorial current ring enhanced firstly, and then the high latitude current enhanced.

3.5 *Cause of the DPS-4 data blank*

DPS-4 data would be blanked when the instrument didn′t receive strong enough signals which were absorbed or reflected obliquely by the ionosphere. Comparing Fig. 1 (m) with Fig. 1 (d) ~ (e), we can see that the DPS-4 data blanked for more than two days after 1200 UT on July 14, which wholly in line with the flux of interplanetary high energy particle enhancing dramatically. The interplanetary high energy particles penetrated into the ionosphere and ionized the neutral component, which would enhance the electronic density of the ionosphere. Those particles with enough energy could penetrate into D region and even lower altitude. These would enhance the absorption in the ionosphere and blank out the DPS-4 data. After 1000 UT on July 13, the DPS-4 data were also blanked for about 8 h. But, in this time segment there was not any apparent enhancement of the flux of interplanetary high energy particle. Meanwhile, the ground magnetic field was also quiet and a certain magnitude of CNA occurred. Therefore, the DPS-4 data which were blanked on July 13 might result from that the IEF disturbance mapped directly to the ionosphere and heated the electrons in the ionosphere.

4 Summary

A series of solar flare and CME events occurred in July 2000, particularly the strongest flare (X5.7/3B) with CME on 14 July since 1989, which induced intense interplanetary disturbance with IMF B_z reaching to -57.96 nT and a great geomagnetic storm with D_{st} index reaching to -300 nT. After analyzing the data observed from the ACE satellite and ZHS ground during the period of the great solar events we get the results as follows:

(1) A lot of solar high energy particles penetrated into the polar ionosphere and ionized it, which significantly increased the CNA and blanked out the DPS-4 data for more than two days.

(2) The magnetic pulsation in Pc 3/5 frequency band on the ground had a high relation with the fluctuation of interplanetary magnetic field (IMF) B_z, which showed the contribution of interplanetary MHD waves to the Pc 3/5 pulsation on the ground. The Pc 3/5 pulsation was intensified greatly during the period of the great

magnetic storm.

(3) The H component of the magnetic field at ZHS varied with the IMF B_z but lagged behind about 8 h, while D_{st} index responded to the IMF B_z very rapidly, which suggested that the magnetic storm occurred at low latitude firstly and then affected the ionospheric current at high latitude.

(4) The D_{st} index may be highly correlated with the variation of IMF. The magnetic storm should be subjected to IMF B_z component with large southern value and long lasting time. There was not any magnetic storm under condition of small negative value of IMF B_z.

Acknowledgements This project was supported by the key program (No. 49634160) and the youth program (No. 40004007) of National Natural Science Foundation of China.

References

Baker DN(2000): Effects of the Sun on the Earth's environment. J. Atmos. Terr. Phys., 62: 1669 - 1680.

Detrick DL, Rosenberg TJ (1990): A phase-array radio wave imager for studies of cosmic noise absorption. Radio Sci., 25: 325 - 338.

Gosling JT, Bame SJ, McComas DJ, Phillips JL(1990): Coronal mass ejections and large geomagnetic storms. Geophys. Res. Lett., 17: 901 - 904.

Gosling JT, McComas DJ, Phillips JL, Bame SJ(1991): Geomagnetic activity associated with the Earth passage of interplanetary shock disturbances and coronal mass ejections. J. Geophys. Res., 96: 7831 - 7839.

Liu RY, Liu SL (1994): Solar terrestrial physics observation and study at Antarctica. Chinese Journal of Polar Research (name used before: Antarctic Research), 6(4): 43 - 58.

Liu YH, Liu RY, He LS, Hu HQ, Nishino M, Sano Y, Yamagishi H, Sato N (1999): Preliminary result of imaging riometer at Zhongshan Station, Antarctica. Chinese Journal of Polar Science, 10 (1): 33 - 40.

Liu YH, Liu RY, Yang SF, He LS, Fraser BJ(2000): Propagation and source of Pc3 frequency range pulsation at cusp latitude. Chinese Journal of Polar Science, 12 (2): 121 - 128.

Nose M, Lyemori, Nakabe S, Nagai T, Matsumoto H, Goka T (1998): ULF pulsations observed by the ETS-VI satellite: Substorm associated azimuthal Pc4 pulsation on the nightside. Earth Planets Space, 50: 63 - 80.

Stauning P, Yamagishi H, Nishino M, and Rosenberg TJ(1995): Dynamics of cusp-latitude absorption events observed by imaging riometers. J. Geomag. Geoelectr., 47: 823 - 845.

Taylor JR, Lester M, Yeoman TK (1997): The response of the magnetosphere to the passage of a coronal mass ejection on March 20 - 21, 1990. Annales Geophysicae, 15: 671.

Tu CY *et al*. (1988): Solar Terrestrial Space Physics (interplanetary and magnetosphere), Ⅰ. Beijing: Science Press.

Zolotukhina NA, Polekh NM, Rakhmatulin RA, Kharchenko IP(2000): Geophysical effects of the interplanetary magnetic cloud on October 18 - 19, 1995, as deduced from observations at Irkutsk. J. Atmos. Terr. Phys., 62: 737 - 749.