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The extremely intense CNA events observed at Zhongshan Station in July, 2000

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Abstract Using the ground observation data at Zhongshan Station of Antarctica during July 13 to 17, 2000, the intense absorption events associated with the activities of the solar active region R9077 are analyzed. It was shown that an intense polar cap absorption event lasted more than 3 days, which was caused by the solar proton event associated with the X5/3B major flare at 1024 UT on July 13. The polar cap event started at about 1040 UT on July 14, and lasted to about 1940 UT on July 17, with a typical day-night variation. At the same time, the intense solar activities extremely disturbed the magnetosphere, therefore aurora substorms occurred frequently. The energetic particle precipitation from the magnetosphere caused several absorption spikes superposing on the background of polar cap absorption. One distinct event is the absorption enhancement that started at about 0300 UT on July 15, reached its peak of 26 dB at about 0645 UT and recovered at about 1110 UT on the same day, which was the strongest absorption event observed at Zhongshan Station since the imaging riometer installed in February, 1997. Another outstanding absorption spike with pulsation occurred at about 1753 UT on 14th, its peak reached to 6 dB.

Key words polar ionosphere, cosmic noise absorption, polar cap absorption, solar activity, Zhongshan Station, Antarctica.

1 Introduction

Along with the arrival of 23rd solar active peak and the development of the space science, the scientists are more and more interested in topics of geospace effects caused by the intense solar activities. The geospace effects of several extreme solar active events, such as the 1993 November event, the 1997 January event and the 1998 May event have been discussed extensively (Knipp *et al*. 1998; Fox *et al*. 1998; Obara *et al*. 2000). The geospace effects caused by frequent solar activities in July 2000 also attract attentions of many space scientists. Since the special geomagnetic field configuration in the polar region, the energetic particles from the extremely disturbed magnetosphere and directly from the Sun will precipitate into the polar ionosphere along the geomagnetic field lines. It will cause intense additional ionization in polar ionosphere, and result in the enhancements of the ionospheric electron density and the collision frequencies between electron and other particles, and cause polar ionospheric cosmic noise absorption (CNA) enhancement in turn. Therefore, CNA observations are commonly used for polar ionosphere monitor (Stauning 1996a). Antarctic Zhongshan Station (69.4°S, 76.4°E) is located at cusp/cleft latitude, its invariant latitude is 74.5°S. Its local time LT = UT + 5h, magnetic local time MLT = UT + 2h. Usually, Zhongshan Station is under the ionospheric projection of the magnetospheric cusp in the magnetic local noon, lies on the low latitude boundary of the polar cap at the magnetic midnight, and passes through the auroral oval twice every day. Therefore, Zhongshan Station is very suitable to monitor high latitude ionospheric cosmic noise absorption. Using the multiple observational data at Zhongshan Station, polar geospace effects caused by 2000 July solar active events, specially the intense absorption events during July 13 – 17th resulted from R9077 are preliminarily analyzed.

2 Solar activities related to R9077 and their geospace effects

In July of 2000 the solar activities were extremely frequent, there were more than 20 active areas successively, which caused a series of geospace effects. R9077 was one of the most active regions, which produced the strongest geospace effect. Among several intense solar active events caused by R9077, an X5/3B flare occurring at 1024 UT on July 14 was most prominent, which was simultaneously accompanied with an 2600SFU 10 cm burst, an II/IV radio burst, a fast corona mass eject (CME) and a solar proton event. Among all of their geospace effects, the most prominent was the major magnetic storm occurring on 15 – 17th of July. Another distinct geospace effect was a proton event that caused an intense polar cap absorption (PCA) event. As the X5/3B flare burst on 14th of July, the strongest proton event with energy more than 100 MeV occurring since 1989 in the Earth synchronous orbit. Following the proton event, intensive polar cap absorption events occurred in the vicinities of the two polar caps and auroral ovals, and lasted for 3 days.

Fig. 1 shows interplanetary environment variations observed by ACE satellite on the upstream of the magnetopause and the global geomagnetic index variations during July 13th to 17th. It presents the solar wind velocity, the solar wind plasma density, interplanetary magnetic field (IMF) total intensity and its B_z component, as well as global three hours geomagnetic index K_p, auroral electrojet index AE and equatorial current index D_{st}. It is shown that three obvious interplanetary shock structures appeared during July 13th to 17th, which are denoted by three dotted vertical lines respectively. These interplanetary shocks are all related to the CME events caused by R9077. As the shocks arrived at ACE, the IMF intensity enhanced by leaps. When the first shock arrived at ACE satellite, ACE observed the enhancements by leaps of the solar wind velocity and of the solar wind plasma density at the same time. For the sake of the energetic proton event (see Fig. 2 (d)), the solar wind velocity and plasma density data of the last two shocks observed by ACE satellite are not complete, but it still demonstrates that the solar wind speed and the solar wind plasma density increased greatly. Among the three shocks, the strongest one occurred at 1410 UT on 15th, which was related to the CME event associated with the X5/3B major flare occurring at R9077 on 14th of July.

The interplanetary space effects caused by R9077 passed to the geospace, and resulted in very tremendous influence there. When every shock passed the ACE satellite, the D_{st} index had an enhancement after one hour or so (Fig. 1 (g)). The delay reflects the transiting time of the

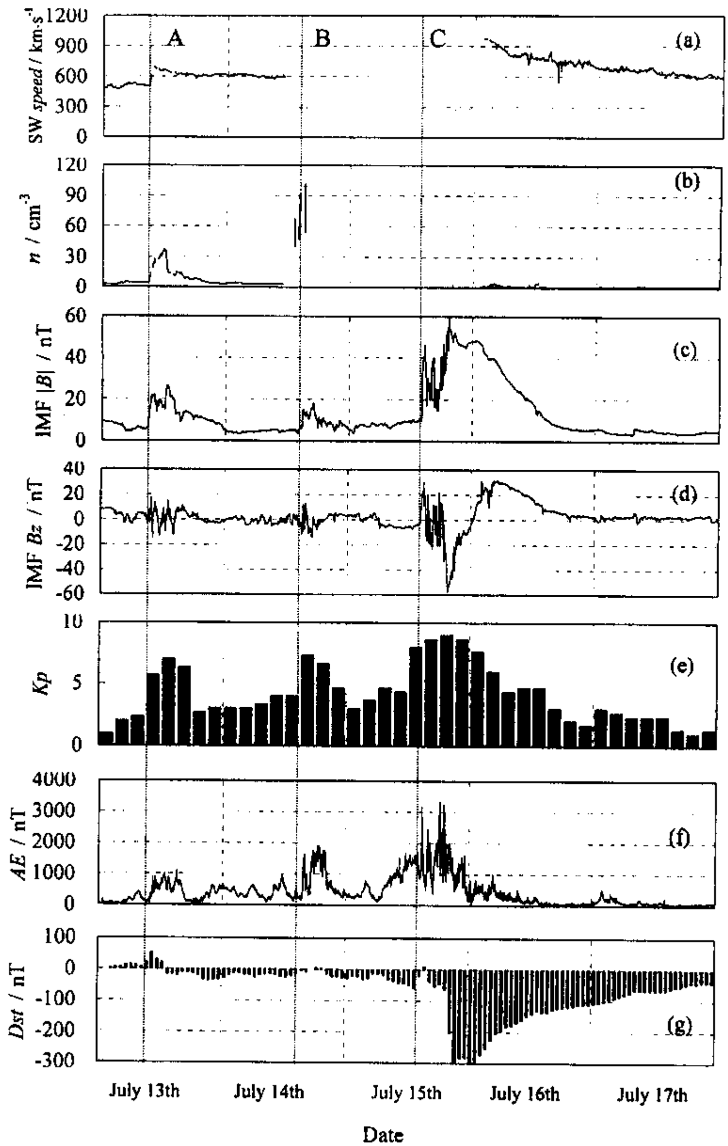

Fig. 1. Solar wind parameters obseved by ACE satellite and global geomagnetic indices during July 13 – 17, 2000.

interplanetary shock from the ACE satellite to the magnetopause. Fig. 1 (e) and 1 (f) show that, as the interplanetary shocks made an impact on the magnetopause, the global geomagnetic disturbance was obviously enhanced, the auroral substorms occurred frequently. Especially, the third shock made an impact on the magnetopause and caused a major magnetic storm during July 15th to 17th, which was the strongest magnetic storm since 1989. During this period, the D_{st} peak reached to -300 nT, the K_p rapidly increased to 9, the AE exceeded 3000 nT.

3 The polar ionospheric absorption

The polar ionosphere as well as the energetic particle precipitation that causes polar ionospheric electron density to increase greatly, can be monitored by the cosmic noise absorption (CNA). So far, the imaging riometer is the most advanced equipment to monitor the cosmic noise absorption, which is able to monitor the 2D distribution of the energetic particle precipitation in the polar region. In February 1997, Polar Research Institute of China and National Institute of Polar Research, Japan jointly installed an imaging riometer in the Antarctic Zhongshan Station (Liu *et al*. 1999). This equipment with an 8 × 8 dipole antenna array, is able to form 8 × 8 beams. On July 15, 2000 this equipment observed a strong absorption event with a peak of 26 dB, which is the strongest event since the instrument was installed.

Fig. 2 shows the ground-based observations at Zhongshan Station and the solar energetic proton flux observed by Soho during July 13th to 17th. Geomagnetic H component variation observed at Zhongshan Station is shown in Fig. 2 (a), with the FM-105B fluxgate magnetometer produced by the Canadian EDA Equipment Company. Its time resolution is 1 Hz, its dynamic range is ± 1000 nT. In Fig. 2 (b), the lower curve shows the variation of the critical frequency of the F_2 layer, f_oF_2, which corresponds to the right y-coordinate; while the higher curve shows the high of the peak of F_2 layer electron density, h_mF_2, which corresponds to the left y-coordinate. These ionospheric parameters were deduced from the ionogram observed by the DPS-4 digisonde produced by the University of Massachusetts at Lowell, USA. Fig. 2(c) shows the absorption variation observed by the central beam (N4E4) of the imaging riometer at Zhongshan Station, the lower curve corresponds to 10 dB scale (left y-coordinate), and the higher curve corresponds to 2 dB (the right y-coordinate). Fig. 2(d) shows the solar energetic proton flux observed by Soho during July 13th to 17th.

As shown in Fig. 2, the intense energetic particle precipitation caused by the solar proton event, and the auroral substorms led to a series of very intense absorption events over Zhongshan Station. Among these absorption events, besides the polar cap absorption that was caused by the solar proton event and acted as a background for a long time, absorption peaks occurring on July 14th 1753 UT and on 15th 0645 UT are distinct. These absorption events are discussed in detail as follows.

3.1 The polar cap absorption event

It is shown in Fig. 2 (c) that, during July 13th to 17th, except for some absorption spikes with short duration, the most outstanding feature was the intense absorption background beginning at about 1040 UT on 14th of July and ending at about 1940 UT on 17th of July, which was so called polar cap absorption (PCA) event caused by the solar proton event (Stauning 1996b). In Fig. 2, the vertical line of dashes (D) denotes arrival of the proton event observed by Soho, which indicates the PCA and the proton event occurring in consistently. The intense solar proton event is related with an X5/3B flare on July 14th 1024 UT, the time delay between the flare and the PCA event is only 16 minutes.

Following the PCA occurring, the DPS-4 's echo blanked out soon (Fig. 2 (b)), the Japanese Syowa Station HF radar toward Zhongshan Station had no echo during 14th 1500 UT to 16th 1200 UT either, which indicates the HF signal emitted by those instruments was absorbed by the ionosphere at that time. DMSP F13/14 satellites that passed through overhead of the Antarctic Zhongshan Station many times during that period, caught sights of enhanced particle precipitation background over the polar cap and the auroral oval. It was that enhanced the pre-

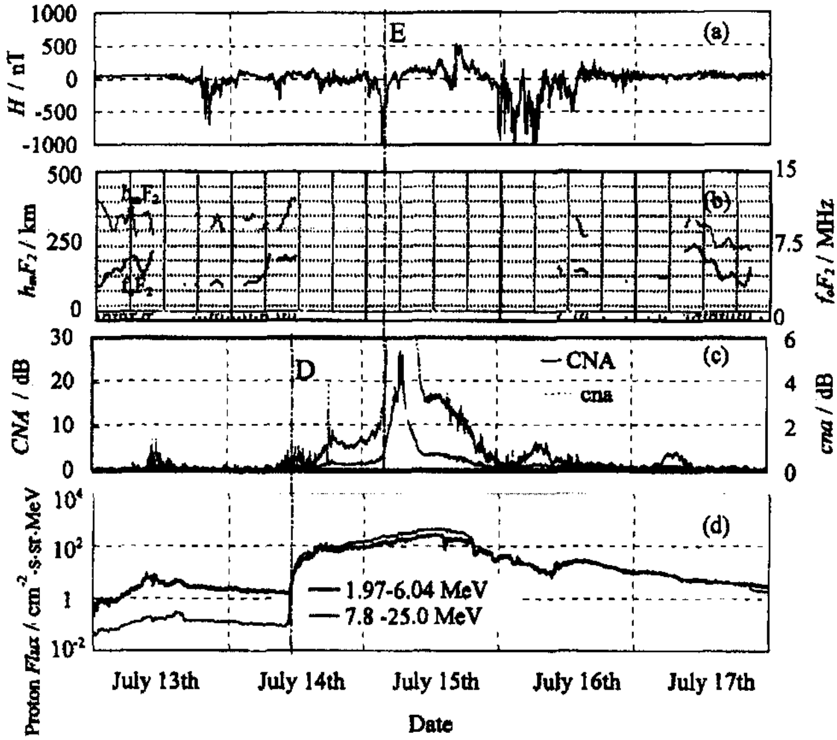

Fig.2. Ground-based observations at Zhongshan Station of Antarctica and energetic proton flux observation at Soho Satellite during July 13 – 17, 2000.

cipitation caused the PCA.

The PCA observed at Zhongshan Station with a smooth diurnal variation, the absorption in daytime was 2 – 10 times larger than those in nighttime. This is due to that electrons are easy to compound with neutral particles in the night. From about 0930 UT of July 13th, an absorption event also corresponds with the proton flux enhancement (Fig. 2 (d)), this event is possibly another PCA event caused by the solar energetic particle precipitation.

3.2 *Absorption peak at 1753 UT on 14th of July*

Superposing on the background of the PCA, the energetic particle precipitation from the magnetosphere caused an absorption peak with the minute average value of 3.9 dB at 1753 UT on 14th of July. The absorption peak occurred after the 2nd shock impacting upon the magnetopause. At that time, the auroral substorm occurred very frequently (Fig.1), and the geomagnetic H had a small negative deviation at Zhongshan Station (Fig.2(a)). Therefore, this absorption peak is possibly related with the auroral particle precipitation caused by the auroral substorms.

Fig.3 shows the absorption variation observed by the central beam of Zhongshan Station imaging riometer during 1745 – 1815 UT on 14th. It is shown that there is a pulsation structure superposed on an 1.0 dB absorption background, with peak value exceeding 6 dB. At Arctic Sdr. Str. Mfjord Station, Stauning (1998) using an imaging riometer observed a similar absorption event at about 2200 UT on November 4th, 1993 during a substorm. This kind of absorption is possibly caused by the magnetospheric precipitation of the particles accelerated by the transient field aligned potential difference (10 – 30 keV) repeatedly. The field aligned potential difference is related with the field aligned currents.

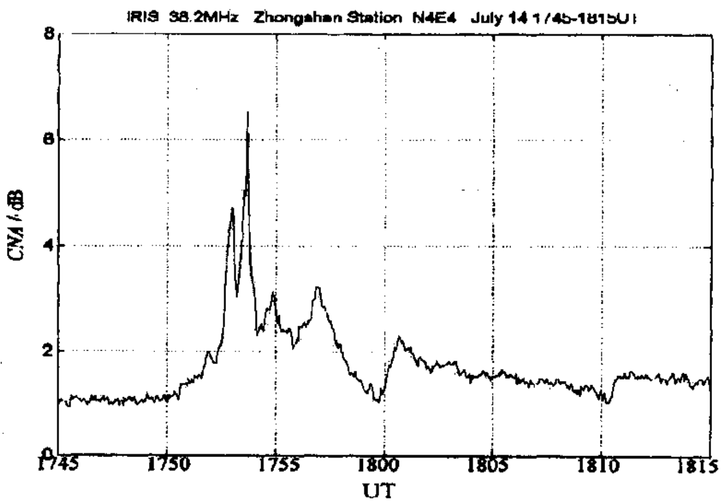

Fig. 3. Absorption at Zhongshan Station, Antarctica observed by central beam of the imaging riometer during 1745 – 1815 UT on July 14, 2000.

3.3 Absorption enhancement on 15th of July

The absorption peak of 26 dB occurring at 0645 UT on 15th is the most distinct phenomena in Fig. 2 (c). The absorption enhancement superimposed on the PCA background, beginning at about 0300 UT, and recovering to the absorption background level at about 1110 UT. Although the enhancement occurred at the daytime of Zhongshan Station (ionospheric height), it couldn't be simply interpreted by the PCA diurnal variation that is smoothly changed usually, while the enhancement here is abrupt. On the other hand, when the absorption enhancement occurred, the solar energetic proton flux didn't increase obviously.

There are some other sakes to cause absorption enhancement, such as solar X flare, auroral particle precipitation. Because Zhongshan Station was in the shadow of the Earth during Antarctic midwinter, the solar X ray couldn't reach the ionosphere over there. Therefore, the absorption peak is not caused by the solar X flare. The usual auroral particle precipitation is difficult to cause such intense absorption.

During the solar energetic proton reaching the Earth, 3 interplanetary shocks ahead to Earth successively caused the magnetosphere to be extremely disturbed as the PCA occurred. Therefore, the absorption peak was possible caused by the magnetospheric dynamics. Although the 3rd interplanetary shock was strongest, which caused a major storm in the magnetosphere, it had no relation with the absorption peak here because it arrived at the Earth after the occurrence of absorption peak. But on the intense PCA background caused by the solar proton event, the magnetospheric dynamics caused by the first two shocks is possible to result in such an absorption peak.

At the beginning of the absorption enhancement, the Geomagnetic *H* component had a − 1000 nT deviation at about 0300 UT on 15th (Fig.2(a)). In fact, this negative deviation had got to the saturation of the magnetometer. The *AE* index indicates that the *H* component deviation was related with an isolated auroral substorm, and occurred during the main phase of the substorm. According to *AE*, the substorm was not strong. But its center was very close to Zhongshan Station, because the geomagnetic disturbance at Zhongshan Station was very intense. Therefore, we suggest that the absorption enhancement was related with the auroral substorm, however, it was not caused by the normal auroral particle precipitation.

During main phase of the auroral substorm" energetic electron clouds "would be poured into the closed magnetic field lines, and drift eastward under the actions of the geomagnetic gradient and of the magnetospheric electric field, and be accelerated during drifting. At the morning sector, the electrons got energy as high as 30 – 300 keV. When they precipitated into the ionosphere, they enhanced the ionization at D and E layer (60 – 100 km), and resulted in the intense ionosphere absorption in turn (Stauning 1996a). The 2D ionospheric absorption variation indicates, when absorption enhancement occurred on July 15th, the absorption at the lower latitude region was stronger than the higher latitude. At that time, Zhongshan Station was located at the boundary of open/close regions, which suggests that the absorption enhancement is possibly caused by the" energetic electron clouds". When Cummer *et al*. (2000) analyzed auroral substorm multi-spectra image, they found that there were localized X ray auroral enhancements at the post- midnight and dawn sector, they also suggested that the enhancement was caused by the precipitation of the eastward drift and accelerated energetic particles resulting from substorm.

The" energetic electron clouds" drifted eastward, which was in the same direction as Zhongshan Station slipping related to the auroral oval, therefore the absorption enhancement lasted for a long time.

4 Conclusion

The energetic particles caused by R9077 activities, precipitating into the polar cap and the auroral oval, led to an intense PCA event. This was observed by the imaging riometer at Zhongshan Station during about 1040 UT 14th to 1940 UT 17th.

The activities of R9077 resulted in magnetospheric intensive disturbance. Auroral substorms occurred frequently, which caused a lot of absorption spikes superposed on the intense PCA background. There were two distinct absorption peaks. One appeared at about 1753 UT on July 14, with some pulsation characteristics, and with a peak exceeding 6 dB. This event was possibly related with the auroral particles repeatedly accelerated by the field aligned potential difference during auroral substorm. Another event with a peak of 26 dB occurred in the early morning of 15th, which was the strongest absorption event since the imaging riometer installed at Zhongshan Station in February 1997. Besides the diurnal variation of the PCA, it was related to the precipitation of the" energetic electron clouds "in close field line region poured by auroral substorm during its main phase. As drifting eastward, electrons in the" clouds "were accelerated, and precipitated into ionosphere in the morning sector.

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