OBSERVATION OF PC 3/5 MAGNETIC PULSATIONS AROUND THE CUSP AT MID ALTITUDE

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ABSTRACT

Since launched in year 2000 the Cluster mission has passed the region around the cusp at mid-altitude (~6Re) for many times, where ULF wave activities are rich in. From 0800 to 1300UT on October 30 2002 the Cluster spacecrafts ran along an orbit of southern cusp-plasmasphere-northern cusp that provides an excellent observation of ULF waves in dayside magnetosphere. Flux gate magnetometer (FGM) data in the GSE system from the spacecrafts were transformed in a field aligned coordinated system, and the results showed that in the equatorial side of the cusp existed plenty of narrow band ULF waves in Pc3~5 range. The frequency band of the ULF waves is confined in narrow Pc5 band near the cusp and evolved into Pc3 band when the spacecrafts went to about L~5 where the plasmasphere is situated. This is consistent with the geomagnetic field line resonance (FLR) theory. However, in the cusp region only broadband waves were observed, which seem to be a magnetosheath-like turbulence due to that the cusp is located in the open field line area where the condition to excite FLR does not be satisfied but plasma disturbance from upstream solar wind is allowed to come into. By this way, a clear wave boundary of the cusp is identified, that is, the transferring position from the broadband waves to the narrow band waves is the right boundary of open field lines to the closed ones.

1. INTRODUCTION

ULF wave is a common physical phenomenon in near-earth space, and actually it exists everywhere and every time and relates with kinds of space physical courses such as boundary course, plasma instability and particle precipitation. Magnetic pulsations in Pc 3~5 band are one of the most typical ULF waves activities in the magnetosphere (Allan and Poulter, 1992).

An enhancement in the spectral power of Pc3 magnetic pulsations near the magnetospheric cusp suggests that the cusp may act as a passage allowing the ULF waves to be transmitted straightforwardly from solar wind to the ionosphere (Bolshakova & Troitskaia, 1984). So far most research work on such topic are on basis of observation at ground or/and data from satellite located in the upstream of solar wind or in the magnetosheath. To my knowledge, few authors take a study based on the measurement at the mid-altitude of the cusp. It seems reasonable to assume that such a measurement be a direct evidence of the cusp guiding Pc3 pulsations (Pilipenko and Engebretson, 2002).

Studied the relationship among the interplanetary magnetic field (IMF), Pc 3-4 pulsations detected at the GOES 2 geostationary satellite (L=6.67), and those observed at the ground sation at College (5.6,) and the other three stations at low latitude, Yumoto et al (1985) inferred that there are two different external sources for the daytime Pc 3-4 pulsations. One is surface waves excited near the magnetopause, and the other source is the upstream wave in the earth's foreshock. The surface waves are the major source of the pulsations in the outer magnetosphere (L>10), whereas the upstream wave is the major source of the compressional Pc 3-4 waves at synchronous orbit and the ground.

Engebretson et al (1995) used magnetometer data from 10 locations in Arctic Canada and Greenland to characterize the dayside patterns of enhanced long-period ULF (10- to 600-s period) wave power at cusp/cleft latitudes. They found no evidence for a distinctive ``cusp" signature in broadband ULF waves in this frequency range. They used satellite data on the level of trapped energetic electron fluxes at geosynchronous orbit and showed that broadband power levels appeared to correlate with enhanced flux levels on the time scale of days.

Howard and Menk (2005) studied Pc3-4 waves recorded on the ground with the IMAGE magnetometer array. Their results suggested the waves are generated by the upstream ion-cyclotron resonance mechanism, with no evidence of generation by the Kelvin-Helmholtz

Proceedings Cluster and Double Star Symposium – 5th Anniversary of Cluster in Space, Noordwijk, The Netherlands, 19 - 23 September 2005 (ESA SP-598, January 2006)

instability. They found that these daytime Pc3-4 pulsations usually have maximum amplitude near the magnetopause projection, and didn't find evidence that the remaining events arise from cavity modes or localized modulated electron precipitation.

Pc5 pulsations occur frequently near the cusp latitude and may relate with the boundary of the open/closed geomagnetic field lines (Liu, et al, 2003; Ables and Fraser, 2005). But it is not so simple to derive the location of such border(Henize, et. al, 2001). Here we will show the straightforward evidence of Pc3~5 in and out the cusp region, and as a comparison, o pulsations ur analysis will cover the waves activities occurred in the plasmasphere.

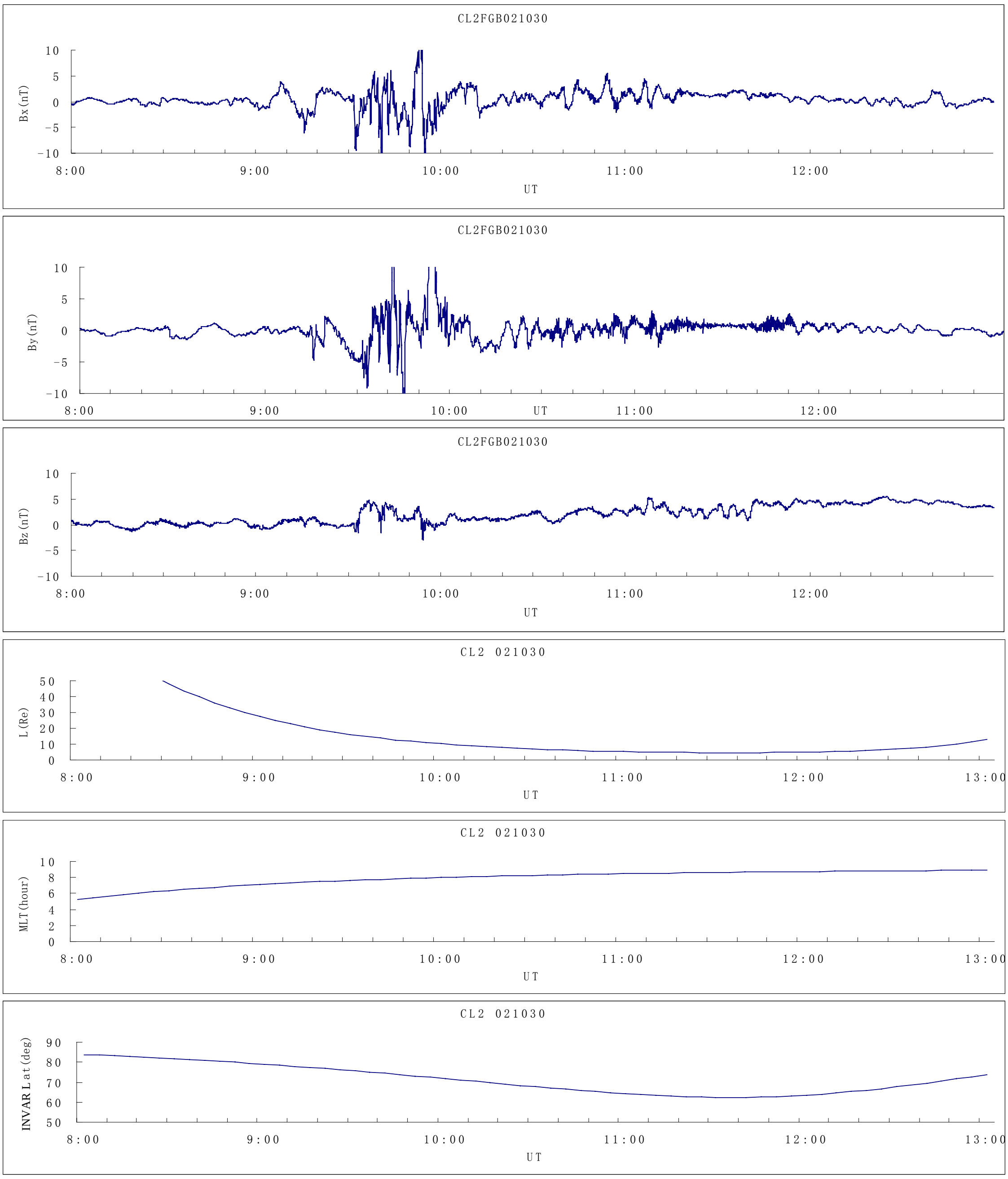

Figure 1. The FGM data are observed by the second spacecraft of the Cluster-II satellites from 0800 to 1300UT on October 2002, and have already been transformed in the field aligned coordinate system (FAS). From the top to the bottom panels are the wave components of poloidal (Bx), toroidal (By) and compressional (Bz) respectively. L, MLT and INVARLat are the magnetospheric L valus, magnetic local time and invariant magnetic latitude. The figures show that there is a high relationship between the Pc3~5 patterns and the structure of the magnetosphere. In the cusp region there are only broadband waves recorded while out of the cusp regular Pc 3~5 pulsations are observed.

2. DATA

The FGM data were observed from the four Cluster-II satellites that were launched in year 2000 and run along a polar orbit with a perigee of 3Re (earth radius, 6371km) and an apogee of 19.8Re. The FGM data was originally sampled at 64Hz (Balogh, et al, 1997). In this paper the data has a time resolution of 4s. This should be OK to be used to deal with the ULF wave with a typical period at about 30s (Pc3) and 300s (Pc5) on which we focus in this paper.

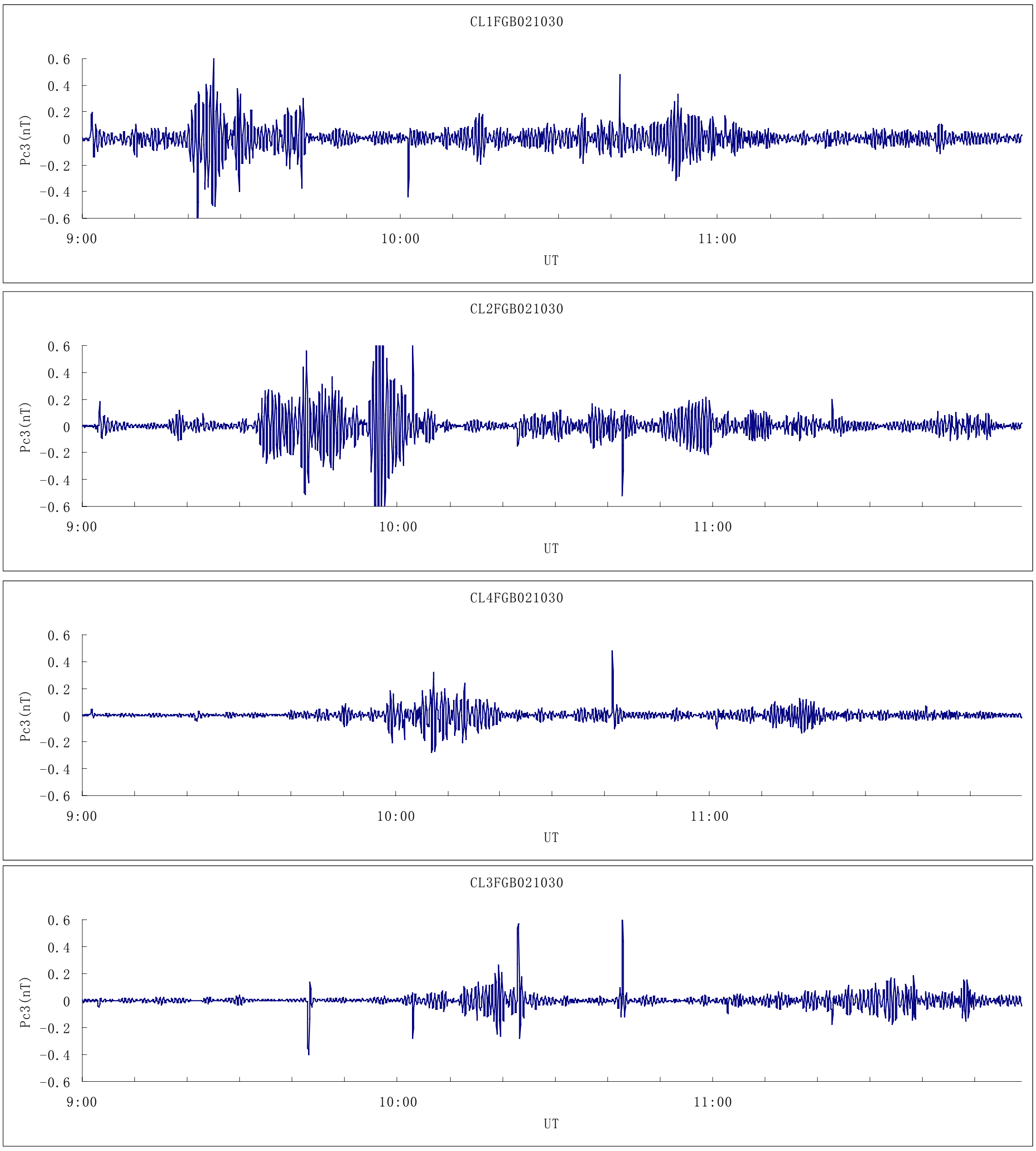

Figure 2. The magnetic data on the toroidal (y) component are filtered in the Pc3 band from the four Cluster-II satellites during 0900~1200UT on October 30 2002. “CL1FGB021030” indicate the data are from the first Cluster-II satellite (CL1), in the field aligned coordinate system (FGB) and on October 30 2002 (021030). It can be seen that two major temporal segments are intensified on the Pc3 pulsations, one is around the cusp and the other is in the plasmasphere. The vertical axis denotes the amplitude (nT) and the horizontal axis denotes time (UT).

On October 30 2002, the Cluster-II is expected to across the southern cusp around 1000UT. The observational particle data and the FGM data from the second satellite of the Cluster-II show the spacecraft was right located in the cusp from 0930-1000UT that day when the plasma density was enhanced significantly and the magnetic field looked like more turbulence (Zong, et. al, 2004).

In order to see clearly the wavelike feature, the FGM data has been transformed in a geomagnetic field aligned coordinate system. In the system, the $\mathbf{B_z}$ is along the background magnetic field direction that is obtained by averaging the data with a time windows of 20min that centered at the data point being processed. $\mathbf{B_y}$ is determined by $\mathbf{B_z} \times \mathbf{r_e}$ and $\mathbf{B_x}$ by $\mathbf{B_y} \times \mathbf{B_z}$. Where, $\mathbf{r}_e$ is unit vector along the earth center-satellite line. **W**aves in $\mathbf{B_x}$, $\mathbf{B_y}$, $\mathbf{B_z}$ direction are called poloidal, toroidal and compressional ones respectively. A detrend procedure with a windows of 20min was carried out to remove the long periodic variation with period larger than the window time 20min. The value of L (distance from the field line to the earth center in the equatorial plane), MLT (magnetic local time) and INVARLat (invariant magnetic latitude) is derived by calculation based on the model (HTTP://WWW.CLUSTER.RL.AC.UK/). Figure 1 show the FGM data from the second satellite (CL2) of the Cluster-II and the satellite position from 0800 to 1300UT on October 2002.

3. ANALYSIS

3.1 DIFFERENT PULSATION PATTERNS

From 0900 to 1300UT on October 30 2002 the Cluster spacecraft ran along an orbit of southern cusp-plasmasphere-northern cusp that provides an excellent observation of ULF waves in dayside magnetosphere. We can see from Figure 1 that all the three components Bx, By and Bz of the magnetic field keeps quite stable before 0900UT. After 0900UT, the magnetic field becomes to be fluctuated. Especially in the duration from 0930 to 1010UT, the amplitude of the three magnetic components varies much but irregularly. Obviously, it belongs to broadband pulsations. The spectra calculation also shows that in this time interval a wide range of frequency of pulsation has been observed covering a frequency range from Pc3 to Pc5 (see Figure 3). Spectra at higher frequency band could not be accessed here due to the limitation of the 4s sample resolution. After 1010UT, the magnetic field varies much more regularly. Particularly on By component, a typical wave form of Pc5 and Pc3 were recorded.

Combining with the position of the spacecraft and pulsation pattern, it can be easily concluded that before 0900UT that day, the satellite was located in the polar cap region where no significant wave activities existed. After 0900UT, the satellite ran approaching the cusp region. The magnetic field becomes disturbed. Broadband pulsations have been observed in the cusp. At about 1010UT, the spacecraft ran over the equatorial boundary of the cusp region and thereafter moved in the dayside magnetosphere with closed field line. More exactly, the pulsation pattern on the By component indicates that the spacecraft should ran into the entry layer on the low latitude boundary of the cusp around 1005UT. The pulsation pattern was changed from the broadband into the narrowband ones at 1005UT. Here should be the location of the last closed field line neighboring the cusp in the dayside magnetosphere, and the L~10Re showed in the L value panel the fourth from the top in Figure 1.

3.2 FIELD LINE RESONANCES

As described above, in the cusp region only broadband pulsations have been observed in the cusp crossing on October 30 2002. But in the equatorial side of the cusp, a lot of narrowband pulsations have been observed. This should be result from the open/closed nature of the field line. In the cusp the field line is generally open and extend to the magnetosheath and even the solar wind, which is favorable in solar wind and/or magnetosheath turbulence come into directly but not favorable in field line resonance which is a main source of the pulsation in the magnetosphere. In the polar side of the cusp the field line is usually open and extends to magnetotail. While in the low latitude side of the cusp is the right closed field line region where the field line resonance could be excited under certain circumstance.

Interplanetary magnetic field (IMF) data from the ACE satellite at upstream solar wind L1 site shows the south-north component (Bz) of the IMF was consecutively negative until near 1200UT and lasted for more than 10hr. particularly around 0700UT the IMF Bz reached its minimum ~-7nT. Such solar wind condition favors the magnetic reconnection between the solar wind and the magnetosphere, allowing the energy and mass entry from the interplanetary to the magnetosphere. No significant magnetic storm occurred in that time and the Dst~-40. This may due to the IMF Bz kept at a relatively small negative value in that duration. All these should favor the field line resonance excitation.

From Figure 1 we can see that the narrowband Pc5 pulsations occurred at high latitude near the cusp latitude, and began to signify at 1016UT where the L is ~8.3 and the invariant magnetic latitude is ~70º. Its magnetic footprint should be projected to the aurora zone. From 1030 to 1110UT the Pc 3 pulsations were superimposed on the Pc 5 waveform. In the time interval of 1110~1125UT pure Pc 3 pulsations have been observed where the L is ~4.9 and the invariant latitude is ~63º. This implies the spacecraft ran into the plasmasphere. The frequency of the pulsation varying with magnetosphere shell L values that indicates that the observational narrowband Pc3/5 pulsations are right the consequence of the geomagnetic field line resonance.

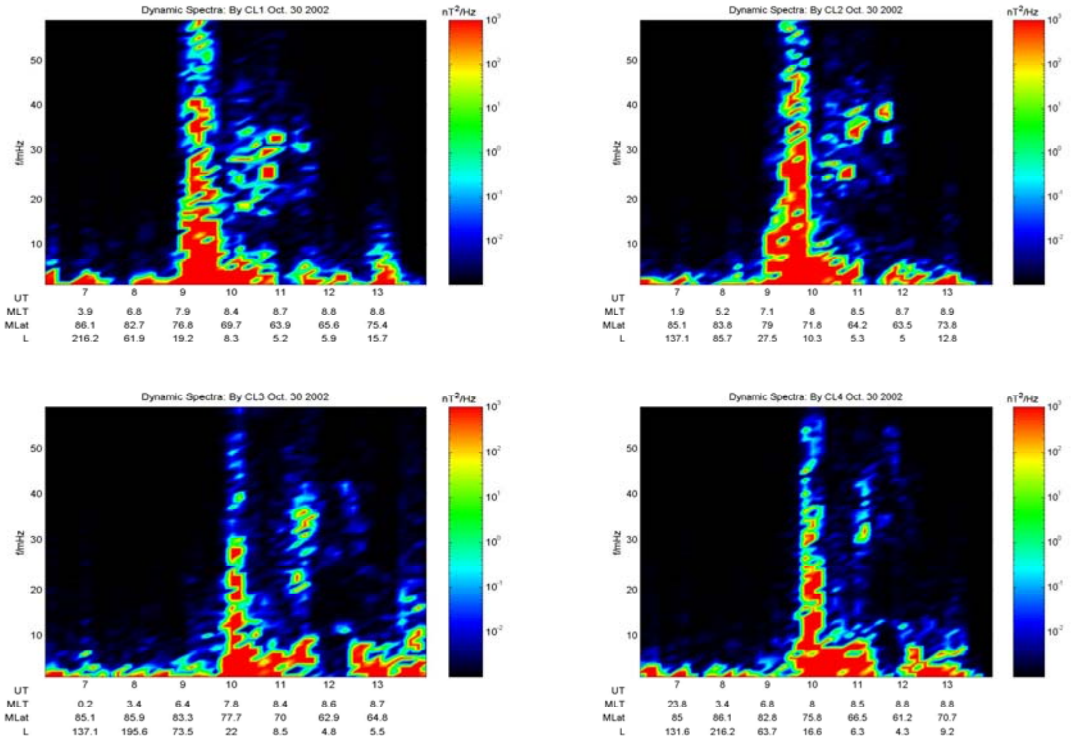

Figure 3. Dynamic Spectra of the ULF waves. A wide broadband pulsation occurred in the cusp region centered on 1000UT with L~15, and a narrowband pulsation in Pc 3 band were observed when it went to 1130UT and L~5 where the plasmasphere is located.

3.3 LOCAL EXCITATION

The filtered data in the Pc3 frequency range from the four satellites are showed in the figure 2. Referring to the Figure 1 and the Figure 3 we confirm that the Pc3 pulsations in the cusp region are broadband pattern while that are narrowband ones in the closed field line of dayside magnetopshere.

The intensification of the Pc3 pulsations shows the timing order of the four satellites with respect to their crossing through these magnetospheric regions. According to the Figure 2, the CL1 (the first Cluster-II satellite) ran into the cusp region at 0920UT and out the cusp at 1041UT. While the CL2 moved in the cusp at 0934UT and out at 1005UT. The CL4 and the CL3 went into the cusp region later. This suggests only in the cusp region could observe the broadband pulsations in the interested period.

Shown in the Figure 2, a significant wave packet was observed by the CL1 around the 1052UT while the CL2 monitored a wave train whose magnitude increased gradually and maximized at 1059UT. However, the CL4 and the CL3 did not record the wave activities at any sense. These imply that the Pc3 pulsations were excited very locally.

4. SUMMARY

A case study has been done on the FGM data from the Cluster-II on September 30 2002 when the Cluster spacecrafts ran across the cusp region and the dayside magnetosphere, and the results show

(1) In the equatorial side of the cusp existed plenty of narrow band ULF waves in Pc3~5 range.
(2) The frequency band of the ULF waves is confined in narrow Pc5 band near the cusp and evolved into Pc3 band when the SCs went to the plasmasphere. This is consistent with the geomagnetic field line resonance (FLR) theory.
(3) In the cusp region only broadband waves were observed, which seem to be a magnetosheath-like turbulence due to that the cusp is located in the open field line area where the condition to excite FLR does not be satisfied but plasma disturbance from upstream solar wind is allowed to come into.
(4) A clear wave boundary of the cusp is identified, that is, the transferring position from the broadband waves to the narrow band waves is the right boundary of open field lines to the closed ones.

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Acknowledgment. We acknowledge the use of CDAweb data base at NASA, USA and the Dst index data from WDC-2 at Kyoto University, Japan. This work is supported by the Chinese National Scientific Foundation (40574076).