DEMETER Satellite Observations of Particle Burst Prior to Chile Earthquake

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The lithosphere activity during seismogenic or occurrence of one earthquake may emit electromagnetic wave which propagate to ionosphere and radiation belt, then induce disturbance of electric and magnetic field and the precipitation of high energy charged particles. This paper, based on the data detected by DEMETER satellite, present the high energy charged particle burst (PB) with 4 to 6 times enhancement over the average value observed about ten days days before Chile earthquake. The obvious particle burst was also observed in the northern hemisphere mirror points conjugate of epicenter and no PB events in different years over the same epicenter region was found. The energy spectra of the PBs are different from the one averaged within the first three months in 2010. At the same time, the disturbance of the VLF electric spectrum in ionosphere over the epicenter detected by the DEMETER satellite are also observed in the same two orbits. Those observations from energetic PB and VLF electric spectrum disturbance demonstrates the coupling relation among the electromagnetic wave emitted by seismic activity, energetic particle and electric field in ionosphere. We eliminate the possible origination of PB including magnetic burst and Solar activities. Finally we think the PB is likely to be related to Chile earthquake and can be taken as the precursor of this earthquake.

1. Introduction

The correlation between the phenomena of ionospheric disturbance and seismic activity have been studying for about twenty years, involving electric and magnetic field variation in horizontal and vertical components, fluctuations in ion density, thermal change and energetic particle burst detected on board the ionospheric satellite. The electromagnetic pulsation at low frequency was observed on the Intericosmos-Bulgaria-1300 satellite in the near-equatorial ionosphere over the epicenter of an earthquake zone on 21st January 1982 (Chmyrev [1989]). By ample statistical data analysis of GEOS-2 satellite, Parrot et.al worked out that the correlation coefficient between electromagnetic signal intensification of extreme low frequency and earthquake with magnitude larger than 4.8 reaches to 5.4 (Parrot [1985]). The Intercosmos 19 data was researched and an anomalous increase in the intensity of low-frequency(0.1-16kHz) radiowave emissions was observed, with the correlation coefficient of that more than 0.8 (Larkina [1989]). Other important electromagnetic phenomena (see the papers by Parrot [1989], Parrot [2006], Parrot [2009], Nemec [2007], Nemec [2008], Xuemin [2009]) ever observed by satellites also confirmed the coupling of ionosphere disturbance and seismic activity.

Noorhondzadeh M. et al. [2010] observed that the disturbances of the electron and ion densities in the vicinity of four large earthquakes and obtained the agreement of anomalies between DEMETER and GPS (Global Positioning System). The earlier event on local plasma density fluctuations prior to earthquake was reported by Gokhberg MB, et al. [1983], which was based on the detection on board AE-C and ISIS-2 satellites. There are many others papers which reported the disturbances of ion density in ionosphere associated with seismic activity several hours to days before the shock by satellites detections. Shivalika Sarkar, et al. [2010] presented and discussed an anomalous effects of plasma density disturbances and electric field perturbations associated with Wenchuan earthquake with the magnitude 7.9 occurred on May 12th, 2008.

As for the high energy particle, Voronov S. A. et al. [1987] and Voronov S. A. et al. [1989] analyzed the data obtained from the MARIA experiment and reported the correlation between short-term bursts of energetic charged particle in near-Earth space and seismic activity for the first time. Later the further study of high energy charged particle flux was performed by MARIA-2 magnetic spectrometer on board the MIR station, ELECTRON instruments on board INTERCOSMOS-BULGARIA-1300 and METEOR-3 satellites.

Using the new experimental results of MARIA-2, GAMMA-1, ELECTRON and PET instruments, S. Yu, Aleksandrim, et al. [2003] observed high energy charged particle bursts in ionosphere and confirmed the evidence for the temporal and spatial correlation between particle bursts and seismic activity in agreement with the previous work working out from the same experiment instruments. Li X Qi, et al. [2010] found that both the electron flux and energy spectrum have significant change in the NWC VLF electron precipitation belt in the vicinity of epicenter of Wenchuan earthquake. They also reported that the 400Hz magnetic field appeared the similar evolution trend with the energetic particle in the same longitude range.

A review of recent developments of the correlation study between ionospheric disturbances and seismic activity illuminates that the events of high energy charged particle bursts associated with seismic activity are not so many as that of electromagnetic and ion density variation.

DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) is devoted to the investigation of the Earth ionosphere disturbances due to seismic and volcanic activities. The detailed description of its
science payloads can be found in papers (Cussac [2006], Lasoutte [2006], Sauvaud [2006]). One of the objectives of payload IDP (Instrument for Particle Detection) on board DEMETER Satellite is to understand the chain of physical processes leading to the observations before and after earthquakes. The main objective of another payload ICE experiment on board DEMETER Satellite is to detect and characterize the electromagnetic perturbations in the ionosphere that are associated with seismic activity. Chile earthquake, one of the ten largest earthquakes in recorded history, had magnitude 8.8 on the Richter Scale and occurred in the morning 3:34 o’clock on February 27th, 2010 with latitude of 36.1°S and longitude of 72.9°W. The corresponding Mc Ilwain parameter value of epicenter is 1.32 in southern hemisphere. In this paper, we present the results in search of PB and VLF electric spectrum disturbance which occurred more than ten days before Chile earthquake and study the relation between them and seismic activity and compare the situation of the different years.

2. Observations

The orbit of DEMETER is quasi sun-synchronous orbit. The half orbit from northern to southern is downward orbit, and the corresponding local time is day time. While the corresponding local time of the half orbit from southern to northern (upward orbit) is night time. Here we select the satellite detected data of upward orbit to perform analysis because the VLF electric and magnetic wave can transmit into the ionosphere in night easier. We analyzed the high energy particle flux data detected by IDP in the first three months of 2010. The charged particle counting rates were considered in three energy regions 90.7∼600keV, 600∼1000keV and 1000∼2351keV, respectively. In order to obtain the distribution of averaged particle counting rates for every day, we selected the satellites orbits which fly across the epicenter region (longitude 72.9°W and latitude 36.1°S or Mc Ilwain parameter 1.32) within the range of longitude 10 degree and 0.1 Mc Ilwain parameter value. So the total orbits number of satellite across epicenter of Chile earthquake during seismic activity in the first three months of 2010 is 42 which are plotted in Figure. 1. Every orbits

Figure 1. Orbits over epicenter region of Chile earthquake in the first three months of 2010. The black pentagram denotes the epicenter position of the quake.

Figure 2. The distribution of high energy charged particle counting rates in 2010 for three different energy regions. The blue line denotes the mean value of counting rates. The peak in the top plot occurred on 16th February from orbit 30109 and the peaks in below two plots are occurred on 15th February from orbit 30094.

Figure 3. The distribution of high energy charged particle counting rates of the northern hemisphere mirror points conjugate of Chile earthquake in 2010 for three different energy regions. The blue line denotes the mean value of counting rates. The peak in the top plot occurred on 14th February from orbit 30079.
can fly across over the epicenter region of Chile earthquake for about several minutes. From Figure. 2 which is the distribution of high energy charged particle counting rates in 2010, three PBs are very clearly shown on 16th, February for lower energy region 90.7∼600keV and on 15th, February for two higher energy regions 600∼1000keV and 1000∼2351keV. The orbit numbers of three PBs on 15th and 16th February are 30094 and 30109, respectively. We can found all the three PBs for different energy region exceed about 4 to 6 times enhancement over the average value.

3. The relation of the particle burst and Chile earthquake

It was known that the charged particles can be trapped by magnetic fields in a quasi-dipole magnetic field of Earth which conduct three distinctive motions: gyration, bounce and drift (Li Xinlin [2001]). Electron drift eastward around the Earth but proton westward. The trapped particles gy-
rate around the local magnetic field when they bounce between the stronger magnetic fields of Earth in the northern and southern hemispheres. In northern hemisphere with the same longitude and Mc Ilwain parameter value to epicenter region, the obvious enhancement of counting rates of low energy charged particle in 90.7~600KeV was discovered 13 days before occurrence of earthquake, shown in Figure 3, with the significance of more than 5 times of average value. The corresponding orbit number for this PB is 30079. There are also obvious energetic particle burst for the higher energy range of 1000~2351KeV. It is the bounce motions that induce the appearance of PB in the mirror region of epicenter of Chile earthquake.

We also analyzed the IDP data of DEMETER detected in previous years for the same region and the result were shown in Figure 4 which describes the distribution of energetic particle counting rates in the first three months of the year 2007, 2008 and 2009, respectively. There are not obvious enhancement observed except for some irregular statistic fluctuations.

The magnetic index Kp is officially adopted by the IAGA (the International Association for Geomagnetism and Astronomy), which is an usual way to determine if there has been a disturbance in the Earth’s magnetic field and how severe the disturbance is. Generally the Kp values below 4 indicates little disturbance. We investigated Kp values and found there no days with Kp larger than 4 during the occurrence of the energetic charged particle burst on 15th and 16th February, 2010. So we can get the conclusion that the particle burst 11 and 12 days before Chile earthquake is not caused by disturbance in the Earth’s magnetic field.

We also investigated Solar activities which mainly include the energetic electron flux, proton flux and Solar flare during the particle burst prior to Chile earthquake according to the record of GOES satellite (http://www.swpc.noaa.gov/). There are also not enough effect from Solar activity to induce the particle burst reported here.

4. The energy spectrum characteristic of the particle burst

The average energy spectrum of high energy charged particle is shown in Figure 5. It is detected over epicenter region of Chile earthquake for the first three months in 2010 except the date from orbit of 30109 and 30094 is shown in Figure 5. Taking this distribution as background, the energy spectrum change of particle burst on 15th and 16th February can be easily compared. From Figure 5, we find that from 15th to 16th February, the energy spectrum in this region has the evolvement process from soft to hard. The enhancement of energy spectrum on 15th February is uniform for the energy larger than 150keV. The enhancement of energy spectrum on 16th February mainly concentrate below the energy of 250keV. This phenomenon is linked with the coupling relation of wave frequency and particle energy, which will be discussed later. This indicates that the electromagnetic wave emitted by seismic activity couples firstly with higher energy particle and then with lower energy particle.

5. Related observation of VLF electric spectrum disturbance

According to the theoretical study of X. D. Gu, et al. [2008], there is easier coupling between the electromagnetic wave of lower frequency and higher energetic particles, while the electromagnetic wave of higher frequency has a stronger interaction with lower energetic particle. If electromagnetic wave is induced by the seismic activity of Chile earthquake, we can deduce that lithosphere in Earth is likely to emit lower frequency electromagnetic wave at first, then higher frequency of that. The electromagnetic wave emitted by seismic activity may also induce the disturbance of electric spectrum. As expected, we surely found the evidence of enhancement of VLF electric spectrum E12 corresponding to the energetic PB observed in this paper. The observation of the disturbance of the electric field in ionosphere over the epicenter detected by the DEMETER satellite in the same two orbit numbers 30109 and 30094 are shown in figure 6. In the top plot related to orbit number 30109 on 15th February, the frequency range with disturbance of the electric field located at around 14 to 20 kHz and in the below plot related to orbit number 30094 on 16th February, the frequency range with disturbance is less than 100Hz. This phenomenon is consistent with our deduction of the interaction of wave and particle. What the most important is that there are no similar disturbance of VLF electric field observed on other orbits flying across the epicenter position before the earthquake.

The particle burst which has the value of signal over local average background equal or larger than 2 for three energy ranges respectively are shown in Figure 7. The average background includes the particle counting rates for all local orbits of the first three months, except the two orbits of 30109 and 30094. The UT time of the appearance of energetic particle

Figure 7. The distribution of position and the duration UT of the energetic particle burst in which the value of signal over average background equal or larger than 2 for three energy ranges respectively. The black star denotes the position of the epicenter of Chile earthquake. The pixel size is $2^\circ \times 2^\circ$ for latitude and longitude.
burst in the 90.7–600keV frequency range is from 03:04:30 to 03:15:30 on 16th February, that in the 600–1000keV frequency range from 02:40:22 to 02:49:42 on 15th February, and that in the 1000–2351keV frequency range from 02:40:46 to 02:48:02 on 15th February. The particle burst for three energy ranges spread almost in the same longitude region in the center of the epicenter.

As for the evolution of the disturbance of VLF electric spectrum near the epicenter, corresponding to Figure 6, the duration UT time of disturbance of the 30094 orbit is from 02:43:42 to 02:50:00 on 15th February, respectively. There are two parts of VLF electric spectrum enhancement for the 30109 orbit shown in Figure 6 and the duration UT time of the disturbance is from 03:12:00 to 03:13:00 and from 03:13:00 to 03:14:00, respectively. We can find that the occurrence of energetic particle burst and the disturbance in the VLF electric spectrum is almost simultaneous, but on 16th February the energetic particle burst in 30109 orbit appearing a little earlier than the VLF electric spectrum disturbance. Because the satellite fly from south to north for the upward orbit mode, the later appearance of VLF electric spectrum disturbance indicate its lower latitude distribution. This tells us the phenomenon that the longitude position of electric field change is lower than that of the precipitation of energetic particle when the electromagnetic wave is transmitted into ionosphere and induce the coupling with electric field and energetic particle simultaneously. Sauvaud J.-A. et al. [2008] also reported the same phenomenon coming from DEMETER satellite data which observed the VLF signal of NWC (US Navy transmitter). The VLF signal detected by ICE located in the vicinity of south latitude 17.5 degree and the precipitation of electron in around south latitude 30 degree. So for the upward orbit at nighttime, the electron burst signal is detected earlier than VLF electric signal. This is agreement with the phenomenon reported by this paper here.

This indicates that the energetic particle burst and the disturbance in the VLF electric spectrum above epicenter of Chile earthquake be caused by the same electromagnetic wave which was mostly likely to be caused by Chile earthquake, transmitted into ionosphere and act with electric field and high energy particle in ionosphere.

6. Summary

In this paper, we discovered the energetic charged particle burst over the epicenter of Chile seismic activity about 11 days before the quake and the enhancement of them in three energy ranges all exceed about 4 to 6 times of average value, respectively. In the mirror points conjugate of epicenter, the particle burst are also observed obviously with the enhancement in low energy range 90.7–600keV exceeding 5 times of average value and in high energy range 1000–2351keV reaching to around 3 times of average value. The enhancement of counting rates of the energetic particle over average background almost occurs in the same longitude region in the center of the epicenter of Chile earthquake. After considering every probable production reason including magnetic burst (magnetic index Kp), Solar activity and so on, it’s likely that this particle burst is caused by Chile seismic activity and can be looked as the precursor of it.

At the same time, the disturbance of the VLF electric spectrum in ionosphere over the epicenter detected by the DEMETER satellite are also observed from the same two orbits. We still studied the characteristic of energy spectrum of the related orbit with particle burst on 15th and 16th February and discussed the coupling relation among the electromagnetic wave emitted by seismic activity, energetic charged particle and electric field in ionosphere. We find the phenomenon that the latitude position of electric field change is lower than that of the precipitation of energetic particle when the electromagnetic wave is transmitted into ionosphere and induce the coupling with electric field and energetic particle simultaneously. This phenomenon is consistent with the study associated with NWC signal transmitter by DEMETER satellite detection.

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