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Ionospheric density and velocity anomalies before M ≥ 6.5 earthquakes observed by DEMETER satellite

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ABSTRACT

The seismo-ionospheric density anomalies have been widely studied for last decades based on ground GPS and satellite in situ observations. In this paper, we analyze both ion density and ion velocity observed by the French satellite DEMETER before 49 earthquakes with M ≥ 6.5 in 2010. The results show that both ion density and ion velocity increase anomalously before the earthquakes. The differences before and after earthquakes are more significant with larger magnitude and shallower depth. The density variations have a positive correlation with the perpendicular velocity, which is related to the perpendicular electric field by $E_{\perp} = V_{\perp}B_0$ (B_0 is the background geomagnetic field). The slopes of $\Delta N_i/N_i$ (in units of %) vs. $V_{\perp}$ (in units of m/s) ranges from 0.13 to 0.7. This suggests that the ion density variation is associated with the presence of ion velocity or electric field in the ionosphere. The observed peak perpendicular velocity can reach 300–1300 m/s before the earthquakes, corresponding to a perpendicular electric field $E_{\perp} \approx 7.5$–32.5 mV/m.

1. Introduction

Seismo-ionospheric anomalies have been intensively investigated based on ground ionosonde or GPS observations (Liu et al., 2001, 2009; Chen et al., 2004) or based on satellite observations (Kakinami et al., 2010; Sarkar et al., 2011). Liu et al. (2001, 2009) reported the electron density of the ionospheric F2-peak *N*mF2 and the total electron content (TEC) frequently and significantly decrease or increase before large earthquakes by using a median-base analysis. Liperovskaya et al. (2006) provided the statistics of *f*oF2 for more than 60 M > 6.0 Japan earthquakes during the years 1957–1990. They found that on the average, *f*oF2 decreases before the earthquakes.

Oyama et al. (2011) observed a minimum of the O^+ ion density near the epicenter from the DE-2 satellite 5 days before the 1981 M7.5 Chile earthquake. By contrast, Píša et al. (2011) and Ho et al. (2013a) reported increases of ion and electron density from the DEMETER data over the epicenter before the 2010 M8.8 Chile earthquake. Ho et al. (2013b) further cross-compared the electron density of DEMETER and the ground-based GIM TEC during the Chile earthquake. They confirmed that both the electron density by DEMETER and GIM TEC reveal temporal anomalies specifically appearing in 2010 and the spatial anomalies tend to appear around the epicenter. Ryu et al. (2014a; 2014b) analyzed the ionospheric density observed by DEMETER and CHAMP during 2005 Sumatra earthquake, 2007 Pisco earthquake, and 2008 Wenchuan earthquake. They found that the electron and O^+ density enhancements occur 1 month before and reach their maximum values a week before the main shock.

The French micro-satellite DEMETER with an altitude 670 km is designed to detect the ionospheric parameter variations before and after earthquakes from June 2004 to December 2010. Due to its 98° inclination and sun-synchronous orbit, DEMETER provides data within 65° invariant latitude at 1030 and 2230LT (Parrot, 2006). There are 6 payloads onboard the satellite detecting and recording continuous plasma and wave parameters. One of the scientific payloads, Instrument d'Analyse du Plasma (IAP) ion analyzer experiment, detected the main parameters of the thermal ion population, such as the density of H^+, He^+ and O^+, their temperature and the ion flow velocity (Berthelier et al., 2006).

In the first part of this paper, we analyze both ion density (O^+) and velocity variations before and after the 2010 Chile earthquake by using DEMETER/IAP. In the second part, a statistical study of density and velocity variations for 49 earthquakes with M ≥ 6.5 in 2010 is performed. In the third part, we examine the correlation between density and velocity variations. Possible mechanisms of the plasma motion related to earthquake are also discussed.

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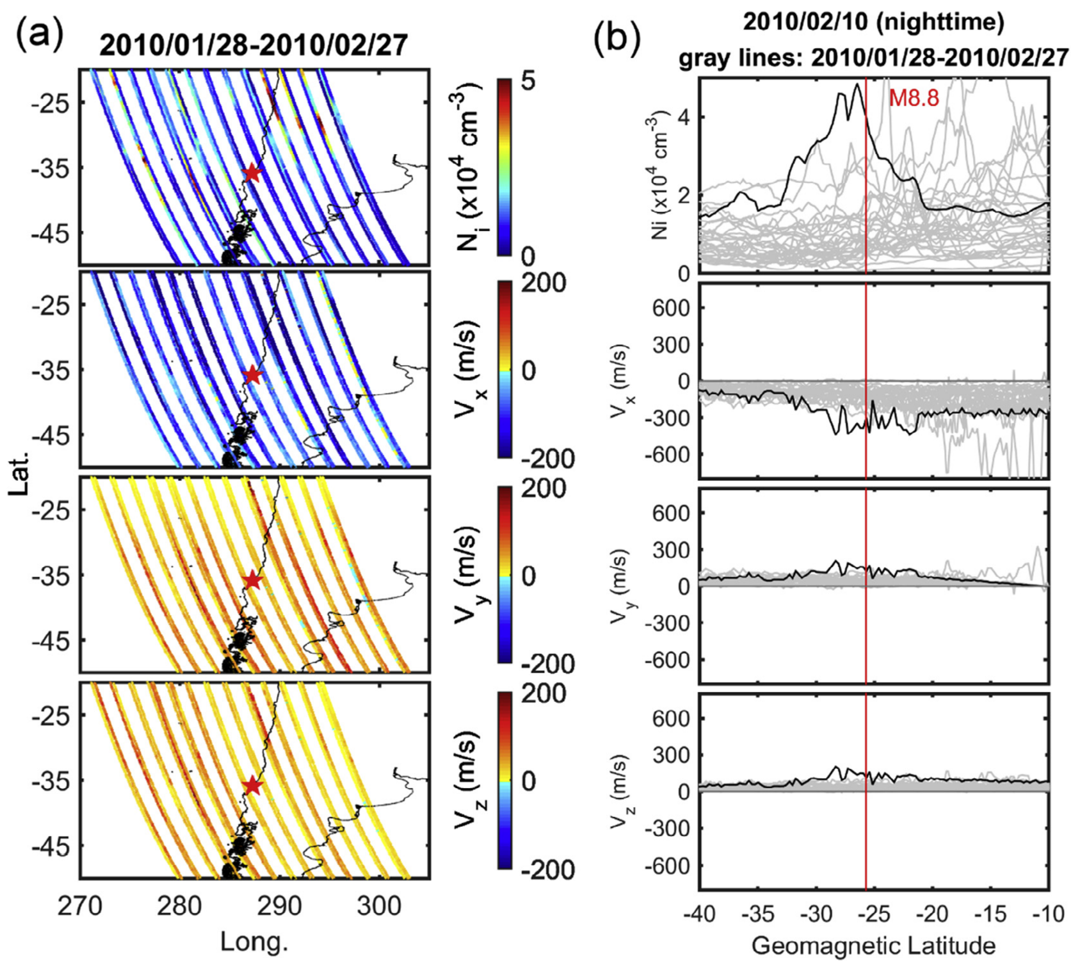

Fig. 1. (a) The ion density and velocities along the DEMETER satellite path 30 days before and on the Chile earthquake (28 January to 27 February). From upper to lower panels are ion density, velocity parallel to the geomagnetic field (V_x), radial velocity (V_y), and eastward velocity (V_z), respectively. The red star denotes the epicenter. For velocity components, yellow to red is for positive velocity and green to blue is for negative velocity. (b) The parameters in (a) are plotted as a function of geomagnetic latitude. The black line shows the observation on 10 February and the gray lines are for other days from 28 January to 27 February. The red line denotes the latitude of the epicenter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Observations: Chile earthquake

First, we start with a case study on the 2010 Chile earthquake (27 February, M8.8). The epicenter was located at 35.91°S, 72.73°W (25.74°S, 0.46°W in geomagnetic coordinates) with a depth of 35 km in the circum-Pacific seismic zone, one of the most active seismic areas in the world. Ho et al. (2013a,b) reported that the plasma density was enhanced mainly during the nighttime before the earthquake. We will focus on the nighttime variations in this paper.

2.1. Temporal variations of density and velocity before and after earthquake

Fig. 1a shows the ionospheric density and velocity observations along the orbits of DEMETER from 28 January to 27 February (30 days before to the day of the earthquake). The density (N_i) and velocities (V_x, V_y, V_z) along most orbits increase near the latitude of epicenter, especially on 10 February. We draw the parameter variations of each orbit as a function of geomagnetic latitude in Fig. 1b. Observations on 10 February and other days are shown. It is obvious that the density and velocities become higher near the latitude of epicenter.

To identify the anomalous strength of a given parameter, we adopt a median base method (Liu et al, 2011) in the following analysis. To simply explain the anomalous strength, we select one observation point of each orbit which is the nearest location to the epicenter (Fig. 2b) in each analysis day from 30 days before to 30 days after. The previous 30-day data of a certain observation day are utilized to set up the reference of anomalies. We define the upper bound UB and lower bound LB as

$$UB = M + 1.5(UQ - M) \quad \text{(upper bound)} \tag{1a}$$

$$LB = M - 1.5(M - LQ) \quad \text{(lower bound)} \tag{1b}$$

where the notation M, UQ, LQ are the 30-day running median, upper quartile, and lower quartile, respectively. The observed ion density which is denoted by red line increases anomalously 9–19 and 25 days before the earthquake (Fig. 2c). The bars in Fig. 2 denote the anomalous strength of density which is defined as

$$\Delta N_i = \begin{cases} N_i - UB(N_i), & (N_i > UB) \\ LB(N_i) - N_i, & (N_i < LB) \end{cases} \tag{2a}$$

The anomalous strength will be positive under the criterion $N_i >$ UB (upper anomaly) and $N_i <$ LB (lower anomaly). Then we check the ion velocities in 3 directions (Fig. 2d). The velocity parallel to the magnetic field line V_x is negative, indicating a southward velocity. A positive value for V_y (V_z) indicates that V_y (V_z) is in the radial (eastward) direction. Note that the velocity component during the