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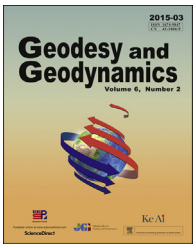

Ionospheric total electron content disturbance associated with May 12, 2008, Wenchuan earthquake☆

Li Jianyong[a,c,*], *Meng Guojie*[b], *You Xinzhao*[a], *Zhang Rui*[a], *Shi Hongbo*[a], *Han Yufei*[a]

[a] *National Earthquake Infrastructure Service, Beijing 100036, China*
[b] *Institute of Earthquake Science, China Earthquake Administration, Beijing 100036, China*
[c] *State Key Laboratory of Geodesy and Earth's Dynamics, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, China*

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ABSTRACT

Possible ionospheric disturbances relating to the May 12, 2008, Ms8.0 Wenchuan earthquake were identified by Global Positioning System (GPS)-derived total electron content (TEC), ionosonde observations, the global ionospheric map (GIM), and electron density profiles detected by the Constellation Observation System for Meteorology Ionosphere and Climate (COSMIC). We applied a statistical test to detect anomalous TEC signals and found that a unique enhancement in TEC, recorded at 16 GPS stations, appeared on May 9, 2008. The critical frequency at F2 peak (f_0F2), observed by the Chinese ionosondes, and maximal plasma frequency, derived from COSMIC data, revealed a characteristic similar to GPS TEC variations. The GIM showed that the anomalous variations of May 9 were located southeast of the epicenter. Using GPS data from 13 stations near the epicenter, we analyzed the TEC variations of satellite orbit traces during 04:00–11:00 UT. We found that TEC decreased to the east and increased to the southeast of the epicenter during this period. Results showed that the abnormal disturbance on May 9 was probably an ionospheric precursor of the Wenchuan earthquake of May 12, 2008.

1. Introduction

Ionospheric disturbances associated with earthquakes were first identified in the 1960s [1]. Kim [2] and Pulinets et al. [3] suggested that a strong vertical electric field at the Earth's surface prior to an earthquake could penetrate into the ionosphere to modify its dynamics and the distribution of electron density. Seismo-ionospheric coupling occurs when an anomalous electric field from the ground penetrates the

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* *Corresponding author*. National Earthquake Infrastructure Service, Beijing 100036, China
E-mail address: jyli@neis.cn (Li J.).

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ionosphere. Ionospheric variations before earthquakes have been widely reported, based on various ionosphere monitoring techniques such as ground-based and topside sounding [4–6], and Global Positioning System (GPS) total electron content (TEC) measurement [7–12]. Pulinets [13] advocated that satellites should be employed to capture ionospheric anomalies for short-term and imminent earthquake prediction. Recent research [4,7,14,15] has mostly analyzed ionospheric parameters such as the critical frequency of F2-layer (f_0F2), peak electron density of F2-layer (NmF2) and TEC, in an endeavor to infer the precursors of major earthquakes. So far, ionospheric variations associated with the process of strong earthquake preparation have been fairly well established [16,17]. Liu et al. [18] analyzed 35 $M \geq 6.0$ earthquakes in continental China during the decade 1998 to 2008 using the global ionospheric map (GIM), and suggested that GPS TEC above the epicenter decreased markedly three to five days before 17 earthquakes of $M \geq 6.3$.

At 14:28 LT, May 12, 2008, a Ms8.0 earthquake struck Wenchuan County (31.0°N, 103.4°E), Sichuan Province, China. This earthquake generated a 240 km and a 90 km long surface rupture along the Beichuan–Yingxiu and the Guanxian–Jiangyou faults, respectively, characterized by right-lateral oblique faulting [19]. After the main shock, 191 aftershocks occurred within a month, with five events greater than Ms6.0. The epicenter of Wenchuan earthquake is located within the network of permanent GPS stations in China (Crustal Movement Observation Network of China (CMONOC) and Sichuan Continuous GPS Network (SCGN)).

In this study, the data from 20 GPS receivers of CMONOC and SCGN are analyzed to examine the disturbance of ionospheric electron content. The critical frequency f_0F2, GIM and electron density profiles derived from the Constellation Observation System for Meteorology Ionosphere and Climate (COSMIC) are also employed to further understand the ionospheric anomalies associated with the Wenchuan earthquake.

2. TEC measurements

TEC, along the microwave ray path from a GPS satellite to a ground receiver, can be obtained by calculating the integral of electron density (also called slant total electron content, or STEC) along the line of sight from dual-frequency GPS pseudorange and phase data. The differential delay between the two frequencies is proportional to electron density along the ray path [20]. The phase and P-code delays between the two GPS frequencies allow for direct measurements of ionospheric TEC [15,21]:

$$STEC = \left(\varphi_2 - \frac{f_2}{f_1}\varphi_1 + f_2(t_{IFB} - t_{TGD}) + N\right) \times \frac{cf_1^2 f_2}{A\left(f_1^2 - f_2^2\right)} \quad (1)$$

where $A = 40.3\ m^3/s^2$ and f_1 and f_2 are GPS signal frequencies. φ_1 and φ_2 are phases of the two GPS frequencies. c is the speed of light, here $c = 0.2998 \times 109$ m/s. N is the integer cycle ambiguities. t_{TGD} is the group delay, which is given in the navigation message. t_{IFB} is the inter-frequency bias, which can be estimated from the GPS data using inversion techniques [20].

The Earth's ionosphere is assumed to be a thin-shell model with height in the range of 350–400 km, and STEC can be converted to vertical TEC (VTEC) by the following equations:

$$E_\theta = \sqrt{1 - \left(\frac{\sin\left(\frac{\pi}{2} - \theta\right)R_E}{R_E + h_{ion}}\right)^2} \quad (2)$$

$$VTEC = STEC \times E_\theta \quad (3)$$

where θ is the satellite elevation angle, R_E is the mean radius of the Earth. h_{ion} is the mean ionospheric height, usually at 350 km, which is close to the height of maximum electron density.

3. Data analysis

3.1. GPS receivers and geomagnetic conditions

The concept of an "earthquake preparation area" was introduced by Keylis-Borok and Malinovskaya [22]. Dobrovolsky et al. [23] pointed out that various magnitudes of earthquakes have correspondingly sized preparation areas and the statistical relationship $R = 10^{0.43M}$ km holds, where R and M denote the radius of preparation area and magnitude, respectively. Thus, the estimated radius of the Wenchuan Ms8.0 earthquake preparation zone is approximately 2700 km, with a total of 20 GPS stations of CMONOC and SCGN. We used data from these receivers to derive TEC and make comparisons with the critical frequency of F2-layer recorded by two neighboring ionosondes, Chongqing and KMIN. The locations of the Wenchuan epicenter, GPS receivers, and ionosondes are shown in Fig. 1.

Note: The red dot represents the epicenter of the Ms8.0 Wenchuan earthquake of May 12, 2008. Black dots denote the GPS receivers within the earthquake preparation zone. The two blue triangles indicate the ionosondes at KMIN and Chongqing.

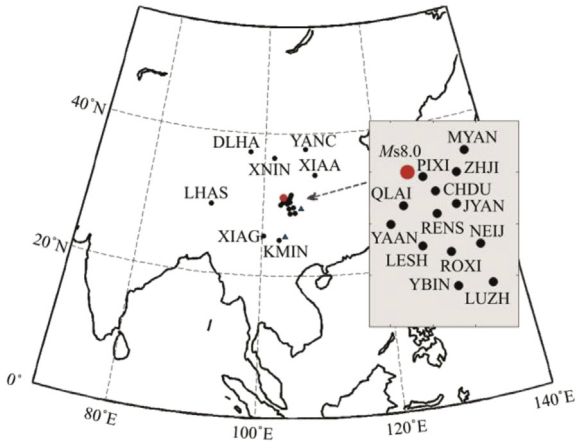

Fig. 1 – Location of the Wenchuan epicenter, GPS receivers, and ionosondes.