Co-seismic ionospheric disturbances following the 2008 Mw8.0 Wenchuan Earthquake from GPS observations

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Abstract

The Mw 8.0 Wenchuan earthquake occurred at the Longmen Shan fault in southwestern China on May 12, 2008, killing ten thousands of people in several cities and large economic losses. Near-field Global Positioning System (GPS) observations could provide the kinematic rupture and the size of the earthquake as well as other insights on the details of continental events. In this paper, coseismic ionospheric disturbances on this event are investigated from national GPS network observations. It has found an intensive N-shape shock-acoustic wave propagating south-eastward at about 600 m/s. The wave front of the N-shape is parallel with the earthquake rupture direction (from NE to SW). It is almost consistent with seismometer, indicating the co-seismic ionospheric TEC disturbances were mainly derived from the main shock due to coupling of solid-Earth and atmosphere.

1. Introduction

The Wenchuan earthquake with 8.0 Mw occurred on May 12, 2008 in Sichuan province, West China, along the Longmen Shan fault, which is a thrust structure along the border of the Tibetan Plateau and the western Sichuan Basin [1]. This event was a deadly earthquake to hit China since the 1976 Tangshan earthquake, which killed ten thousands of lives in several cities along the western Sichuan basin in China (Fig 1). The earthquake reflects tectonic stresses evaluation from the convergence of crustal material slowly moving from the high Tibetan Plateau, to the west, against strong crust underlying the Sichuan Basin and southeastern China (http://earthquake.usgs.gov). The rupture started from the Wenchuan County and propagated at an average speed of 3.1 kilometers per second, 49° toward northeast, rupturing a total of about 300 km (http://www.csi.ac.cn). Although robust seismic signals around the globe could estimate the gross nature of this event, but the details of rupture are obscure due to the lack of near-field observations. Local geodetic measurements can provide more details on the kinematic rupture and processes and the size of this continental event. For example, GPS observation results showed that co-seismic deformations move towards the earthquake epicenter and the largest magnitude is up to 2.3 meters in the horizontal and 0.7 meter in the vertical in Beichuan rather than in the epicenter [2].

Additionally, when GPS signals propagate the atmosphere, the GPS signals are delayed by the atmospheric (tropospheric and ionospheric) refraction, which results in lengthening of the geometric path of the ray, usually referred to as the tropospheric and ionospheric delays. Since the first time Calais and Minster [3] after the earthquake in California on 17 January 1994 observed in the time series of total electron content (TEC) anomalous signal in the period range 3-10 min, numerous studies have been trying to look for co-seismic or pre-seismic ionospheric anomalies. In this paper, dense GPS network observation data are collected from China national continuous and campaign GPS network, and the coseismic ionospheric disturbances are investigated during this event.

2. GPS Observations and TEC

The "Crustal Movement Observation Network of China (CMONC) was initiated in August 1998, including a nationwide fiducial network of 28 permanent GPS sites observed from August 1998 to now, and 56 survey mode sites

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with yearly operations for the period 1998-2008 as well as ~1000 regional campaign GPS stations operated by the State Bureau of Surveying and Mapping (SBSM) and the China Earthquake Administration (CEA) in 1999, 2001, 2004, 2007 and 2008 with at least 4-day observations in each session. Unfortunately, only 28 continuous GPS sites observations data are available around this event on May 12, 2008. Figure 1 shows the continuous GPS site distribution, where the triangle stands for the continuous GPS observing sites and the large gray solid circle shows the epicenter of the mainshock.

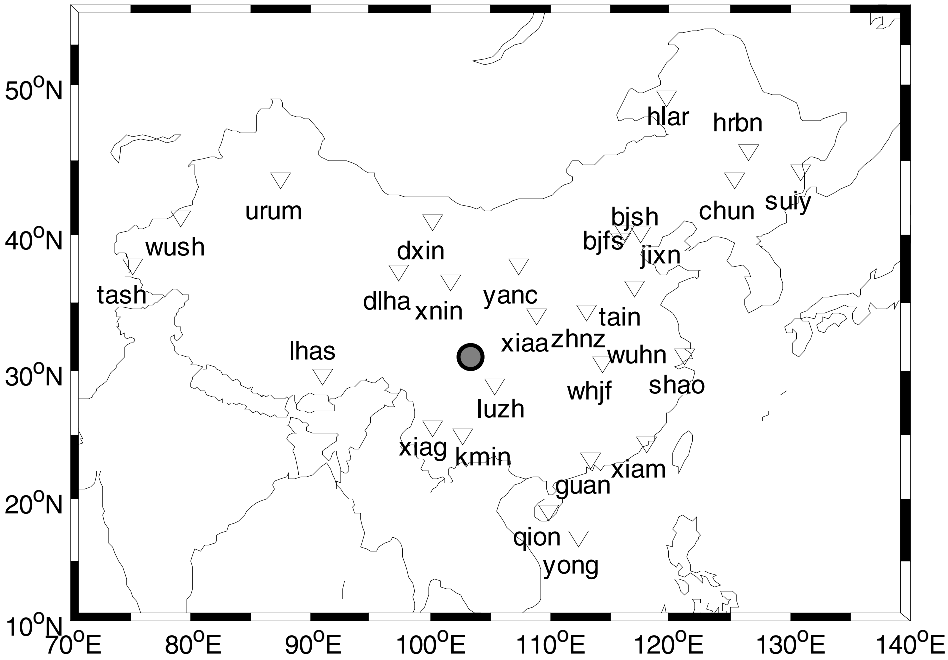

Fig. 1 Map of the GPS observation network and the epicenter of the May 12, 2008 Wenchuan Earthquake mainshock with about Mw=7.9. The triangle is the continuous GPS observing sites and the large solid circle is the epicenter of this event mainshock.

Since the ionosphere is a dispersive medium, dual frequency GPS receivers are able to estimate the total ionospheric delay or eliminate the ionospheric delay effect with measurement of the modulations on the pseudoranges and the carrier phases. The equations of carrier phase (L) and code observations (pseudorange P) of double frequency GPS can be expressed as follows:

$$L^i_{k,j} = \lambda_k \phi^i_{k,j} = \left|\vec{r}^{\,i} - \vec{r}_j\right| - d^i_{ion,k,j} + d^i_{trop,j} + c(\tau^i - \tau_j) - \lambda_k (b^i_{k,j} + N^i_{k,j}) \qquad (1)$$

$$P^i_{k,j} = \left|\vec{r}^{\,i} - \vec{r}_j\right| + d^i_{ion,k,j} + d^i_{trop,j} + c(\tau^i - \tau_j) + d^i_{q,k} + d_{q,k,j} + \varepsilon^i_j \qquad (2)$$

where k is the frequency (k=1,2), superscript i and subscript j represent the satellite and ground-based GPS receiver, respectively, $\vec{r}^{\,i}$ is the position of satellite i; $\vec{r}_j$ is the coordinate of GPS receiver j; d_{ion} and d_{trop} are the ionospheric and tropospheric delays, respectively; c is the speed of light in vacuum space; τ is the satellite or receiver clock offset; b is the phase delay of satellite and receiver instrument bias; d_q is the code delay of satellite and receiver instrumental bias; λ is the carrier wavelength; ϕ is the total carrier phase between the satellite and receiver; N is the ambiguity of carrier phase; and ε is the other residuals. After combining the dual frequency pseudorange and carrier phase observations, the slant total electron content (TEC) can be obtained and then transferred into the vertical TEC [4].

3. Results and Discussion

At the time t, each i-th element of the vertical TEC is denoted by the measured TEC value $I_i(t)$. Duration of TEC time series depends on the time span when the GPS-satellite is in the zone of a corresponding receiver's radio visibility. TEC time series reflect regular changes of the ionosphere and abnormal variations caused by irregularities of electron concentration of various scales, such as geological events due to the coupling of the solid-Earth and the ionosphere. We here filtered TEC series $dI(t)$ by removing the trend with a time window of 5-20 min in order to show characteristic ionospheric disturbances. The filteredTEC variations during the mainshock are investigated and significant ionospheric disturbances are found at continuous GPS sites within 500 km from the epicenter. We check the solar activity indices (e.g. Auroral Electrojet (AE) and $F_{10.7}$ cm solar radio flux) and geomagnetic indices (e.g. Kp and Dst) and found that the day of May 12 2008 is a quiet day without geomagnetic storms. Therefore, these coseismic ionospheric characteristics mainly reflect the coupling of the ionosphere and Wenchuan earthquake.

For example, Figure 2 shows the significant TEC variations at KUNM station during the mainshock, indicating a significant coseismic ionospheric disturbance. Here the used ionospheric pierced points are the satellite PRN14, PRN22, PRN05 and PRN18 at time tmax of maximum TEC response on main earthquake shock for line-of-site KUNM. Figure 3 shows a comparison of TEC variations at LUZH station around the mainshock from days 11-13 May, showing a significant coseismic ionospheric disturbance on May 12, 2008. Here the used ionospheric pierced points are the satellite PRN14 and PRN22 at time t_{max} of maximum TEC response on main earthquake shock for line-of-site LUZH. In order to determine propagation dynamics of the ionospheric disturbance, a simple interferometric method D1 and the quasi-optimum algorithm (QOA) method [5] are used to determine the angular characteristics of the wave vector and phase velocity of ionospheric disturbances due to the Wenchuan earthquake. We found that an intensive N-shape shock-acoustic waves with a plane waveform and with half-period of about 200 sec propagated toward northeast with a mean velocity 600 m/s for a distance of about 1000 km from the epicenter, in parallel with the rupture direction. More detailed description of methods and results are referred to [6].

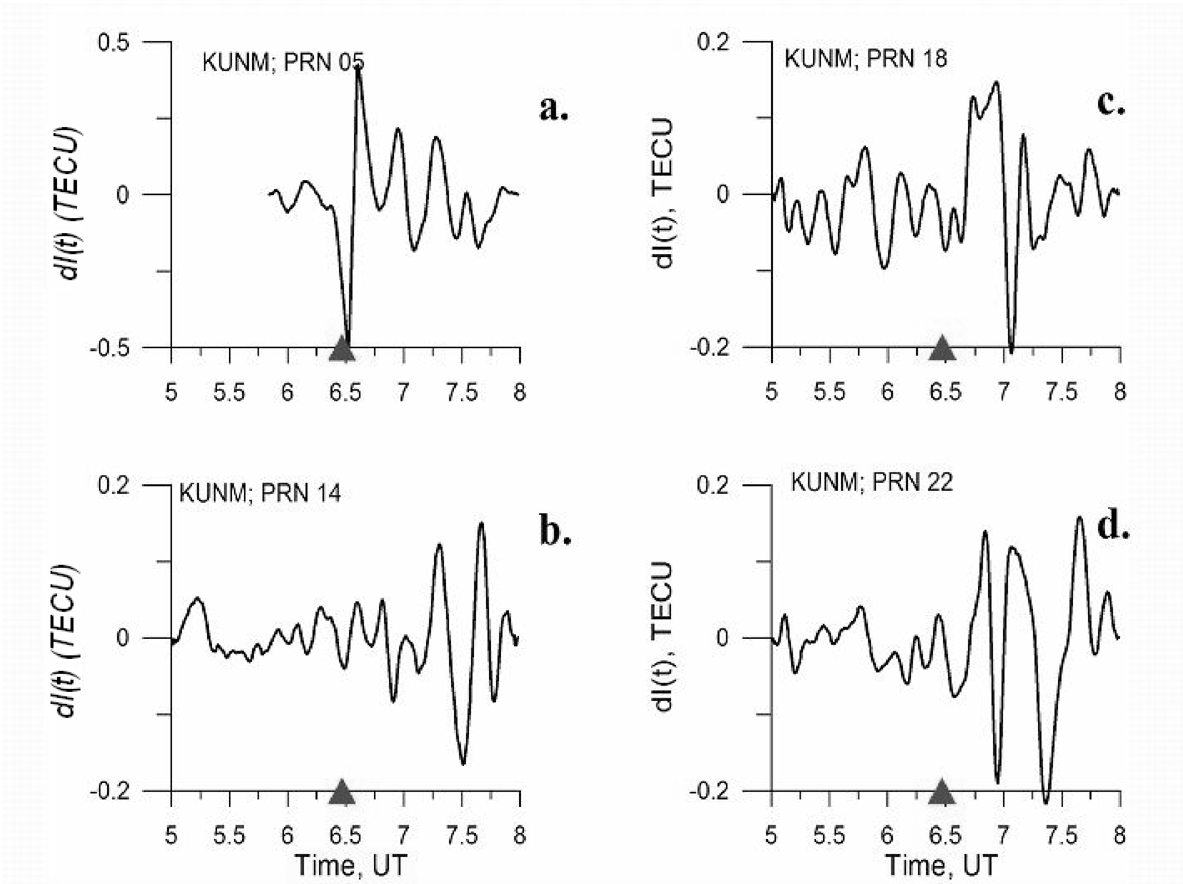

Fig.2 The filtered TEC series $dI(t)$ for KUNM-PRN05 (a), PRN14 (b), PRN18 (c) and PRN22 (d). The time of the Wenchuan earthquake main shock is marked by red solid triangles.

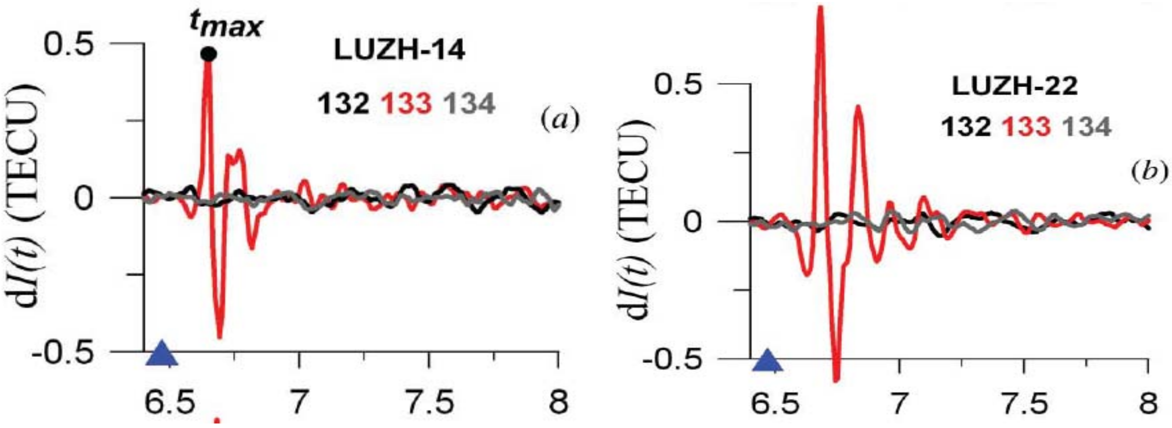

Fig. 3 The filtered TEC series $dI(t)$ for LUZH-PRN14 (a) and PRN22 (b) on days of 132(May 11), 133 (May 12) and 134 (May 13), 2008. The time of the Wenchuan earthquake main shock is marked by red solid triangles.

We also compare TEC response to the Wenchuan Earthquake with the Great Sumatra Earthquake occurred on 26 December 2004. The coseismic ionospheric disturbance during the Sumatra earthquake was very powerful [7] and was commensurable with the response to the Wenchuan Earthquake. The significant coseismic ionospheric disturbances are possibly driven by the ground-coupled air waves from ground vertical motion of seismic waves propagating with acoustic coupling effect of the atmosphere and solid-Earth. In the future, more information or details are needed to be further investigated, such as the coupling processes and mechanism of the seismo-ionospheric TEC variations.

4. Conclusion

The near-field TEC responses to the Wenchuan Earthquake on 12 May 2008 are investigated using GPS observations. It has found an intensive N-shape shock-acoustic wave propagating south-eastward at about 600 m/s and the wave front of the N-shape is parallel with the earthquake rupture direction (from NE to SW). The far-field TEC effects are very small, e.g., South Korea and Japan. The properties of coseismic ionospheric response are determined by the geodynamics of the Wenchuan Earthquake. While the driving mechanism may be due to the acoustic coupling effect of the atmosphere and solid-Earth with air wave propagation from the ground to the ionosphere. In the future, more works are needed to do, including their detailed processes and mechanism of coseismic ionospheric disturbances.

5. Acknowledgments

We are grateful to those who made GPS observations available. This work was supported by the key program of Chinese Academy of Sciences (Grant No. KJCX2-YW-T26)

6. References

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