Seismo-ionospheric precursors and disturbances of total electron content induced by the 12 May 2008 M8.0 Wenchuan Earthquake

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Abstract

The GPS total electron content (TEC) of the global ionospheric map (GIM) is employed to simultaneously observe seismo-ionospheric anomalies during an M8.0 earthquake near Wenchuan, China on 12 May 2008. It is found that TEC above the forthcoming epicenter anomalously decreases in the afternoon period of day 6 to 4 and in the late evening period of day 3 before the earthquake, but enhances in the afternoon of day 3 before the earthquake. The spatial distributions of the anomalous and extreme reductions and enhancements indicate that the earthquake preparation area is about 1650km and 2850km from the epicenter in the latitudinal and longitudinal directions, respectively. On the other hand, a network of 6 ground-based GPS receivers in China is employed to study traveling ionospheric disturbances triggered by the Wenchuan earthquake (TIDEs). The network detects 5 TIDEs in the Southside of the epicenter area. A study on the distances of the detected TIDEs to the epicenter vs. their associated traveling times shows that the horizontal speed is 600 m/s. Applying the circle method, we find that the 5 circles intercept a point right above the epicenter when the horizontal speed of 600 m/s is given. Global searches of the ray tracing and the beam forming techniques are employed to confirm the 5 TIDEs being induced by the Wenchuan Earthquake. Results show that TEC variations before the earthquake resulted from seismo-ionospheric signals (electromagnetic mechanisms) are much greater than those after caused by vertical motions of the Earth's surface (mechanical mechanisms).

1. Introduction

The global ionosphere map (GIM) of the total electron content (TEC) constructed with about 200 of worldwide ground-based receivers of the GPS is routinely published in a 2-hour time interval. Similar to a Geostationary Meteorological Satellite hourly observing clouds for the metrological weather, the GIM can be used to observe signatures of the lithospheric, atmospheric, and ionospheric weather (such as thunderstorm, ionospheric storm, and earthquake). We statistically examine variations of the GPS TEC extracted from the GIM over 35 M≥6.0 earthquakes occurring in China during the 10-year period of 1 May 1998-30 April 2008 and find earthquake precursors in China are the ionospheric TEC significantly decreases in the afternoon period of day 1-6 before the earthquakes. Based on the statistical results, we investigate temporal and spatial signatures of seismo-ionospheric electron density anomalies induced by a devastating earthquake with magnitude Mw7.9 occurring in eastern Sichuan (Wenchuan), China (30.986°N, 103.364°E, Depth 19km) at 06:28:01UT on 12 May 2008 [1].

During earthquake occurrences, vertical motions of the Earth's surface create mechanical disturbances (waves) in the neutral atmosphere which propagate into the ionosphere and interact with the ionized gas (hereafter, traveling ionospheric disturbance by earthquake; TIDE). Recently, the TEC derived from data recorded by dense ground-based receivers of the GPS have been employed to examine TIDEs of excited by earthquakes, such as Rayleigh, gravity, shock, tsunami waves (see papers listed in [2-4]) employ the beam-forming and/or ray-tracing methods analyzing GPS TEC observations to locate the origin and compute average propagation speeds of TIDEs triggered by large earthquakes. We employ the time-distance relationship estimating the propagation speed, the circle method locating the source, and the ray-tracing method simultaneously finding the speed, source, and onset time of TIDEs triggered by the 12 May 2008 Mw8.0 Wenchuan Earthquake.

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2. Result and Interpretation

Figure 1 displays the GPS TEC above the Wenchuan epicenter isolated from the GIM database, and the upper (enhancement) and lower (reduction) anomalies appearing before and after the earthquake. The Dst index shows that the geomagnetic activity is relatively quiet. It can be seen that the GPS TEC anomalously reduces during 06:00-10:00UT (the afternoon period of 13:00-17:00LT; LT=UT+7hours) on 6, 7, and 8 May as well as 14:00-17:00UT (the late evening period of 21:00-24:00LT) on 9 May 2008. Meanwhile, there is a GPS TEC anomalous enhancement occurring in the afternoon period of 9 May 2008. In fact, the epicentral GPS TEC at 08:00UT (15:00LT) on 6 May and at 06:00UT (13:00LT) on 8 May reach their time-point extreme minima (reductions) of 1-30 days before the Wenchuan earthquake. This indicates that the GPS TECs around the epicenter not only statistical significantly reduce (exceeding the LB) but also extremely (with a chance of 3.3%=1/30) decrease during the four time periods. In general, the reduction anomaly day occurs more frequently before than after the Wenchuan earthquake.

To see if the GPS TECs in the earthquake region extremely decrease during the four periods, a spatial analysis is conducted. The GIM covers ±87.5°N latitude and ±180°E longitude ranges with spatial resolutions of 2.5° and 5°, respectively. Therefore, each map consists of 5040 (=70×72) grid points. For each grid point, to have a more stringent criterion, we now compute the median of the GPS TEC at a certain time point during 1-30 days before the earthquake (12 April to 11 May 2008). We then find for each time point the difference between the observed GPS TEC and the associated median at grid point. Here, the median represents the undisturbed background GPS TEC, while the negative (positive) difference indicates the reduction (enhancement) of the GPS TEC. Among the available 30 differences at each time and grid point, the extreme reduction is of primary interest. Figure 2 displays, in particular, the GIMs at 08:00 UT, day 6 before the earthquake (6 May 2008), the associated median, and the grid points with the extremely reduced difference occurring on 6 May 2008. The magnified plot in Figure 2 shows the difference of 6 May from its associated median and the 30-day extreme minimum (or reduction) on the day in detail. Figure 2 reveals that the GPS TEC at 08:00UT on 6 May 2008 and the associated median yield remarkable enhancements of the equatorial ionization anomaly (EIA) [*Ratcliffe*, 1974] centering at about 20°N and 0°N, and ranging from 90 to 120°E in the northern and southern hemisphere, respectively. It is interesting to observe that the 30-40% drastic reduction of the GPS TEC with respect to the associated median and the extreme minimum generally appear near and south of the forthcoming Wenchuan epicenter, nearby the northern EIA crest. Taking into account the EIA and/or local time effects, a sequence of GIMs for global fixed local time at 15:00LT is also examined. It is found that the severe reductions and extreme minima in the GPS TEC are once again mainly located around the forthcoming epicenter and EIA region (Figure 2). Note that the extreme minima appear in the northern hemisphere and its geomagnetic conjugate points of the southern hemisphere at both 08:00 UT and global fixed 15:00 LT. Similar signatures can be found in the afternoon or evening period of day 3-6 before the earthquake.

Figure 3 reveals that 5 pronounced fluctuations of TIDEs observed at kunm at 06:35-07:15UT which is about 10s minutes after the earthquake occurrence. A study of temporal variations of the filtered TEC and the associated distance to the epicenter versus time has been conducted. Two parallel slopes, one being the least square fitted of the 5 TIDE arrival times with the intersect of 06:36UT and the other going through the reported earthquake onset time (06:28UT), and the time difference 480 seconds between the two lines show that the average horizontal and vertical speeds are about 557.2 ± 30 m/s and 729 (=350km/480sec) m/s, respectively. Since the TIDEs are assumed to be detected at 350 km altitude, we can simplify consider their horizontal distances and speeds. Thus, for the circular method, therefore we let the onset time be 06:36UT instead of 06:28UT. Various horizontal speeds 400-800 m/s have been tested. Results show that when the horizontal speed of 600 m/s is given, the 5 circles intersect at one location, where is right above the Wenchuan epicenter. In both the ray tracing and beam forming calculations, we have tested the trial center within 20°-33°N and 95°-111°E shifting by 1°. For the ray tracing search, we try with the horizontal speed VH ranging from 200 to 1000 m/s. The optimal results can be obtained by finding the minimum values of the standard deviation of the calculated onset times, the time difference between the calculated average and reported onset times, as well as the distance between the calculated center (disturbance origin) and the Wenchuan epicenter. It is found that when the horizontal speed 600 m/s, the contour converges at 31.0°N, 103.1°E where is about 30 km west of the Wenchuan epicenter. Note that the Wenchuan is within the standard deviation of 60 seconds. The associated onset time is 06:36UT (=06:28UT+8 minutes of the vertical traveling time). For the beam forming technique, we try with the onset time varying from 06:00 to 08:00UT and compute the mean speed and standard deviation from each trial center to the 5 TIDEs. Figure 5 displays that the onset time at 06:38UT yields the best result of the TIDEs origin being located about 30 km west of the Wenchuan epicenter. The optimal result of the mean horizontal speed and standard deviation is VH=614±15 m/s traveling away from the TIDE origin.

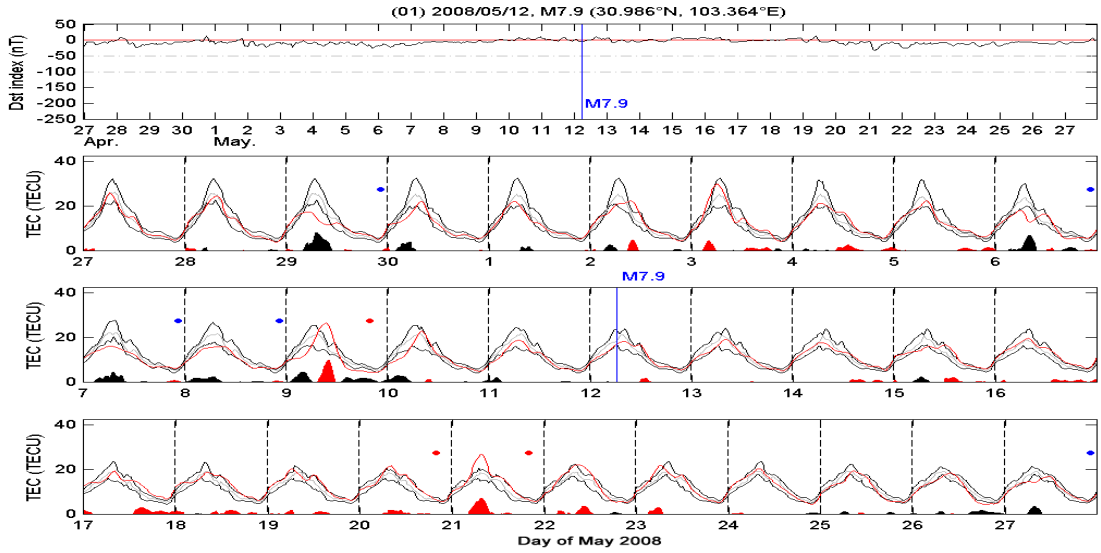

Figure 1. A time series of GPS TEC right above the Wenchuan epicenter extracted from GIMs in May 2008. The Mw7.9 Wenchuan earthquake occurred at 06:28:01 UT on Monday 12 May 2008. The top panel displays variations of the Dst index, which shows the geomagnetic activity being generally quiet. The red, gray and two black curves denote the observed GPS TEC, associated median and upper/lower bound (*UB*/*LB*), respectively. Red and blue dots represent the upper and lower anomalous days identified by the computer routine, respectively. The *LB* and *UB* are constructed by the 1-15 previous days moving median ($\widetilde{M}$), lower quartile (*LQ*), and upper quartile (*UQ*). Here, $LB=\widetilde{M}-1.5(\widetilde{M}-LQ)$ and $UB=\widetilde{M}+1.5(UQ-\widetilde{M})$. Red and black shaded areas respectively denote differences of *O*-*UB* and *LB*-*O*, where *O* is observed GPS TEC.

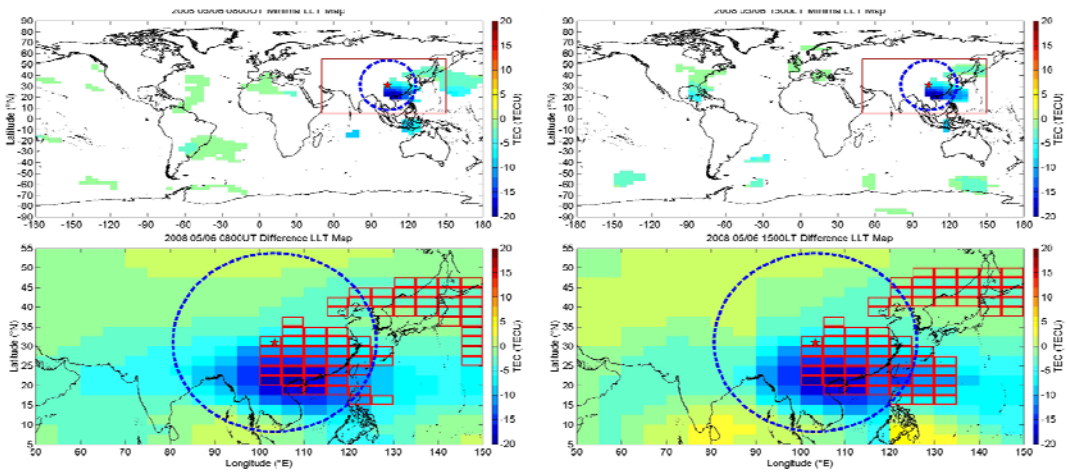

Figure 2. The GIMs observed at 08:00UT and global fixed 15:00 LT on day 6 before the 2008 Mw7.9 Wenchuan Earthquake. The left and right columns are GIMs at 08:00UT and global fixed local time of 15:00LT, respectively. The top panels denote the extreme decreases of the 30-day period that appeared on 6 May 2008. The color denotes the difference of the TEC observed on 6 May 2008 from the associated median. The circle with the radius *R*=2495km stands for the earthquake preparation area of the lithosphere. The bottom panels are the magnified of the difference between 6 May 2008 and the associated median. The red grids denote the 30-day extreme decreases. The red grids of the two magnified appeared around 30-50°N, 115-150°E might be related to the 7 May 2008 M7.0 (36.23°N, 141.61°E; D51km) earthquake.

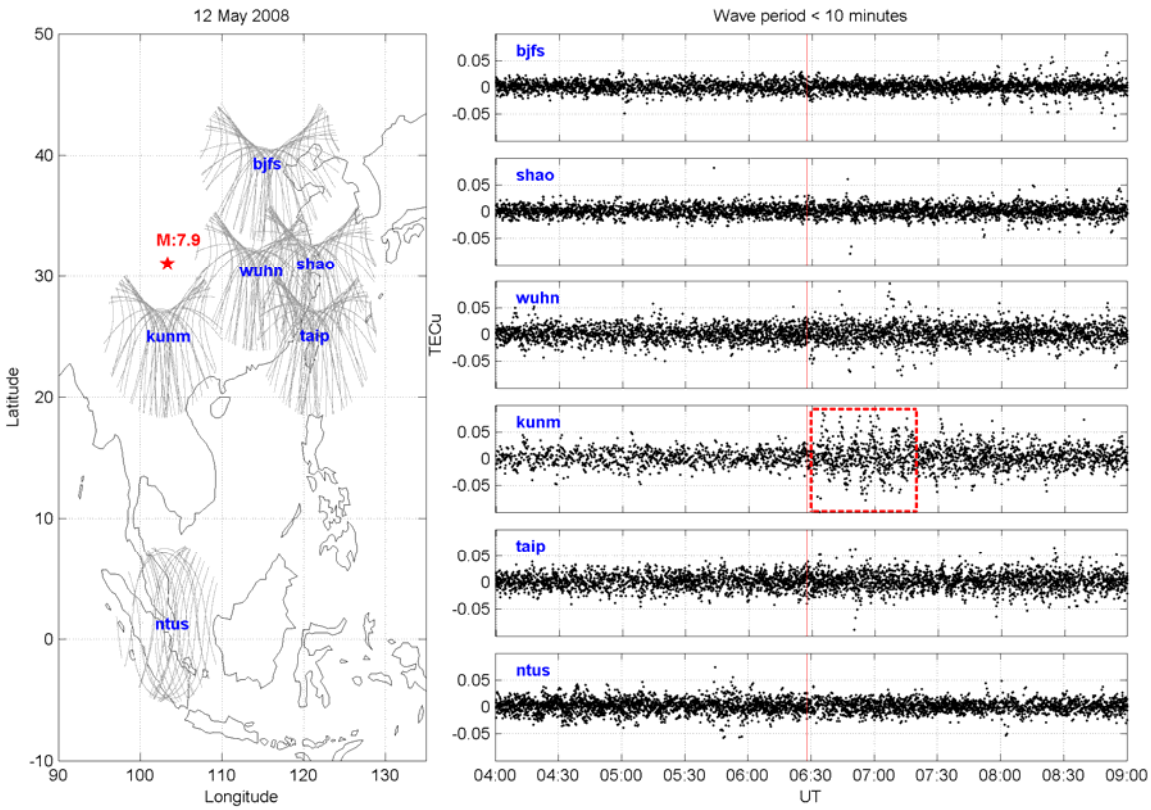

Figure 3. Locations of the Wenchuan epicenter as well as 6 GPS receivers and their associated coverage/observation. A 10-minute high pass filter is applied to analyze the TECs observed at the 6 stations.

3. References

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