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Ionospheric VTEC anomalies before *Ms*7.1 Yushu earthquake

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Abstract: Vertical total electron content is examined to check whether the *Ms*7.1 Yushu earthquake on April 14, 2010, may have caused any anomalous ionospheric changes. The result shows two TEC increases over the epicenter vicinity on April 1 and 5; these anomalies drifted from east to west, the latter across the whole China. The increase on April 5 was probably related to geomagnetic activity, whereas the one on April 1 may possibly be related to the Yushu earthquake.

Key words: vertical total electron content; ionospheric anomaly; earthquake; precursor; Global Navigation Satellite System (GNSS)

1 Introduction

The earth's ionosphere has been increasingly studied recently in association with earthquake occurrences in search for possible premonitory anomalies[1-6]. Liu, et al [3-4] examined the ionospheric Total Electron Content (TEC) observed by a network of Global Navigation Satellite System (GNSS) receivers in Taiwan area; they found that 5 days prior to the 1999 Chi-Chi earthquake, the TEC value above the epicenter area decreased significantly and the crest of the equatorial anomaly moved toward the geomagnetic equator. They conducted a statistical analysis of TEC disturbances for $M \geqslant 6.0$ earthquakes in Taiwan from September 1999 to December 2002, and found similar TEC decreases. Wu, et al [5] examined the TEC data for three strong earthquakes in Asia. They found that significant TEC disturbances (increase followed by decrease) occurred over the earthquake-preparation zones within 10 days before the respective earthquakes. Liu, et al [6] used the global ionospheric map to search for TEC variations associated with 35 $M \geqslant 6.0$ earthquakes that occurred in China during 1998 and 2008. They found that the TEC above the epicenters decreased significantly 3 -5 days before 17 of these earthquakes. For the Wenchuan earthquake on May 12, 2008 that was included in their study, the TEC decreased significantly in the afternoons of day 4 -6 and the evening of day 3 before the earthquake, but increased significantly in the afternoon of the day of the earthquake. Zhou, et al [7], Lin, et al [8], Zhu, et al [9], and Zhao, et al [10] used the TEC data from ground-based GNSS observations over China to calculate single-station ionospheric VTEC (Vertical Total Electron Content) variations near the Wenchuan earthquake and two-dimensional TEC distribution over China. They all found that the ionospheric TEC near the epicenter increased by as much as 70% on May 9 during a period of decrease of many days before the earthquake over epicenter (and over the magnetically conjugate area). The anomaly area was closer to the equator than the epicenter. In this study, we used the data from the Crustal Movement Observation Network of China (CMONOC) to investigate TEC varia-

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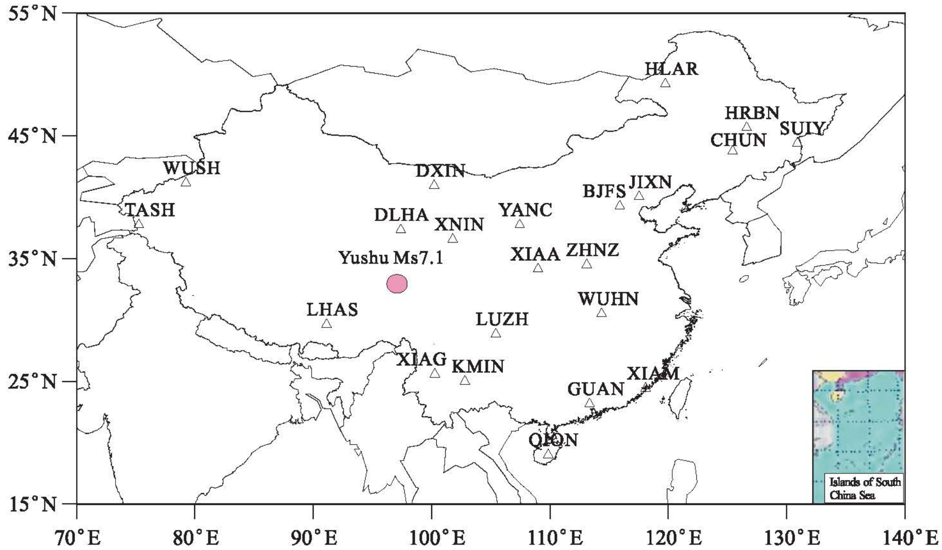

Figure 1 Locations of GNSS station network in China and the epicenter of Yushu *M*s7. 1 earthquake

tion before the *M*s7. 1 Yushu earthquake, which occurred on April 14, 2010 in China.

2 Data and calculation

We used the Vertical Total Electron Content (VTEC) inversion method[11] to calculate time series of VTEC over four GNSS stations (LHAS, LUZH, DLHA, WUSH) near the epicenter, and used data from 25 stations to calculate time series of two-dimensional TEC distribution over whole China. The results were expressed in Universal Time (UT) and TECu (10^{16} el/m^2) as unit for TEC.

3 Anomaly-detection methods

3.1 Single-station VTEC time series

We used a 10-day moving window (with periods of earthquake occurrence, solar flare, and magnetic storm excluded) for the VTEC time series at a station near the epicenter to establish a normal-variation background. In order to identify an anomalous ionospheric disturbance, we computed the mean value μ_2 and standard deviation σ_2 and used $[\mu_2 + 2\sigma_2]$ as the upper bound and $[\mu_2 - 2\sigma_2]$ as the lower bound. Any observed TEC outside these bounds more than 2 hours were considered as anomalous with a confidence level of about 95%. This method may be used to obtain such information as amplitude and beginning time of a pre-earthquake anomalous disturbance.

3.2 Time series of two-dimensional TEC distribution

Time series of two-dimensional TEC distribution were computed on the basis of data (at two-hour sampling intervals) from 25 GNSS stations to determine the time, location, range and amplitude of possible pre-earthquake ionospheric anomalies. The anomaly-recognition method is similar to that of the single-station method mentioned above.

Previous studies showed that the diurnal variation of TEC over a region was usually regular, when there was no intense disturbance, such as by solar and geomagnetic activities[12]. Ionospheric disturbance may also be caused by earthquakes, and a variety of other kinds of events. Pulinets[13] suggested that the disturbance by the magnetic storm was characterized by its wide range (all over the global), long duration (more than 12 hours), large amplitude, and consistency, while the disturbance by an earthquake was characterized by small range, short duration (4 to 6 hours), weak amplitude, and either positive or negative, except for unusually large earthquakes. A latter example is the 12-hour anomalous disturbance before the 1964 Alaska earthquake. Thus by synthesizing the analytical results of the spatial and temporal characteristics of an anomalous disturbance and the space-physical environment at that time, we may identify the disturbance source without too much difficulty.

4 Results of data processing

4.1 Single-station TEC time series

The calculated TEC time series for the 4 GNSS base stations near the epicenter of Yushu earthquake are shown in figures 2 – 5. It may be seen that the TEC values at LHAS, LUZH, WUSH exceeded the upper bound in the afternoon of April 1, and those at LHAS, LUZH, DLHA exceeded the upper bound at midnight on April 5.

4.2 Time series of two-dimensional TEC distribution

In order to obtain a fuller view of the ionospheric anomalies on April 1 and 5, we computed differential two-dimensional distributions ΔTEC ($\Delta TEC = TEC_{obs} - TEC_{up}$) (Fig. 6 and Fig. 7), using spherical-harmonics method to fit the data from 25 GNSS stations around the epicenter in China.

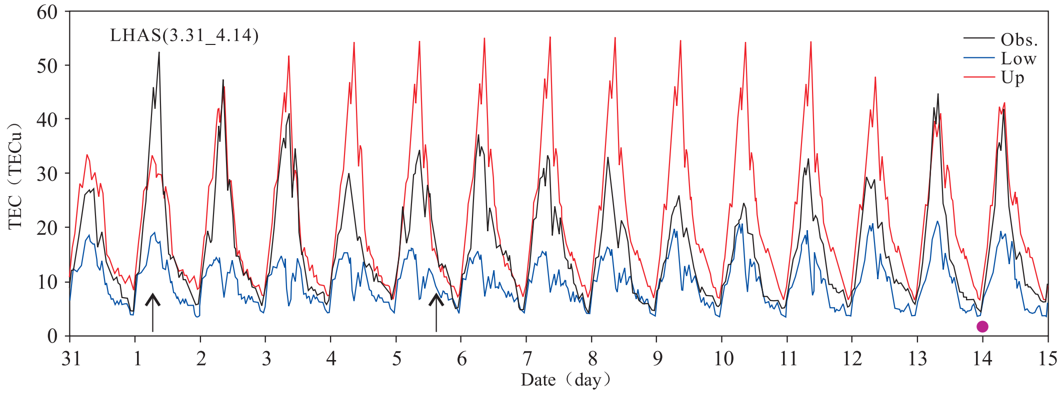

Figure 2 TEC time series at LHAS station (March 31 to April 14)

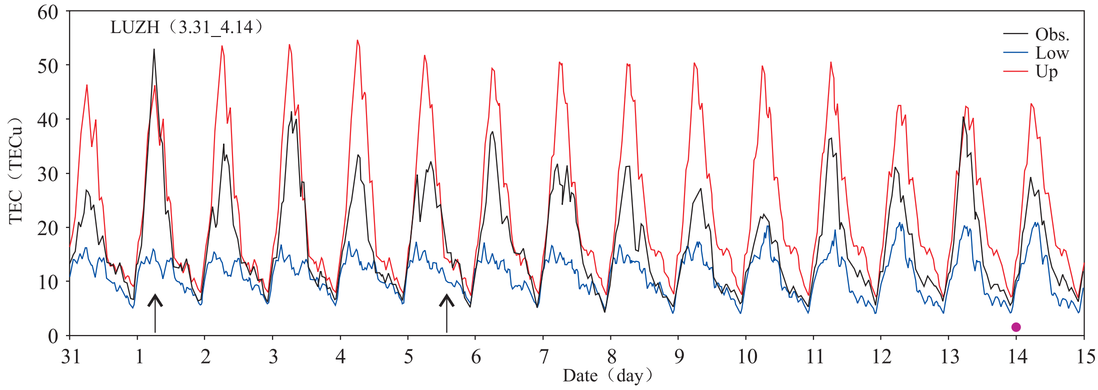

Figure 3 TEC time series at LUZH station (March 31 to April 14)

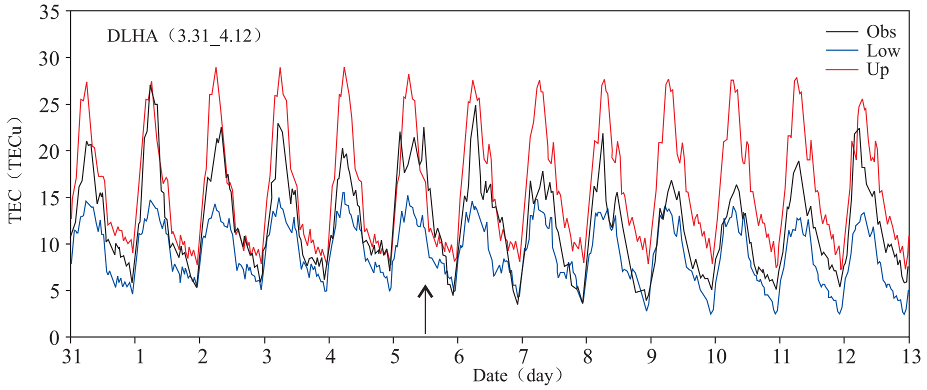

Figure 4 TEC time series at DLHA station (March 31 to April 12)

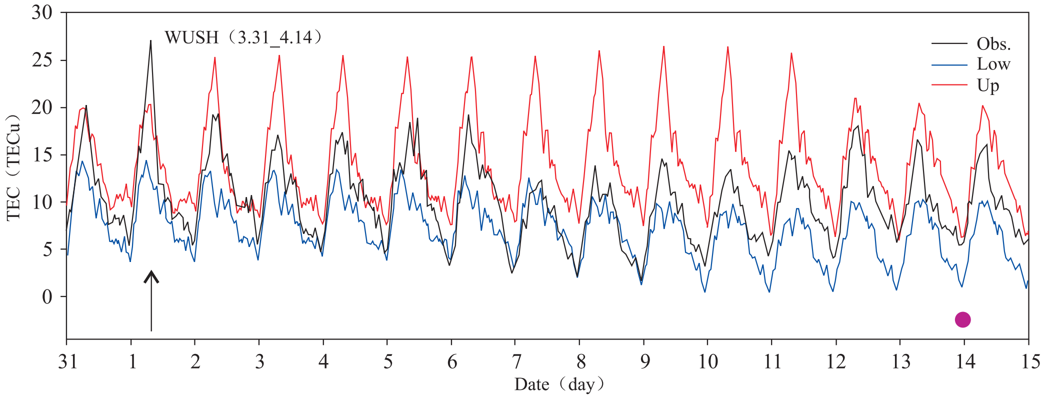

Figure 5 TEC time series at WUSH station (March 31 to April 14)

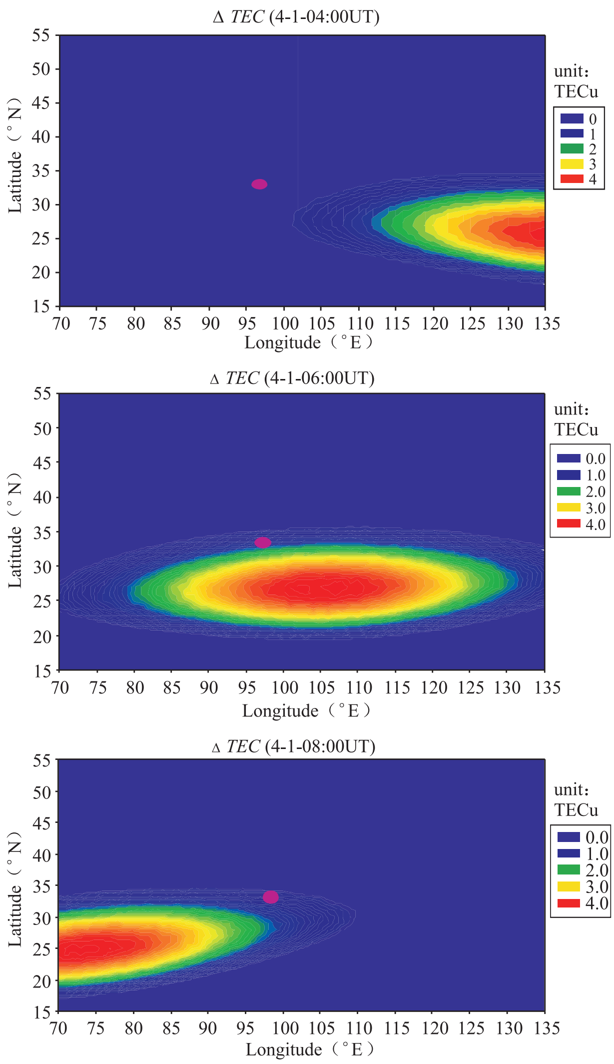

Figure 6 ΔTEC distribution on April 1 (04:00UT, 06:00UT, 08:00UT)

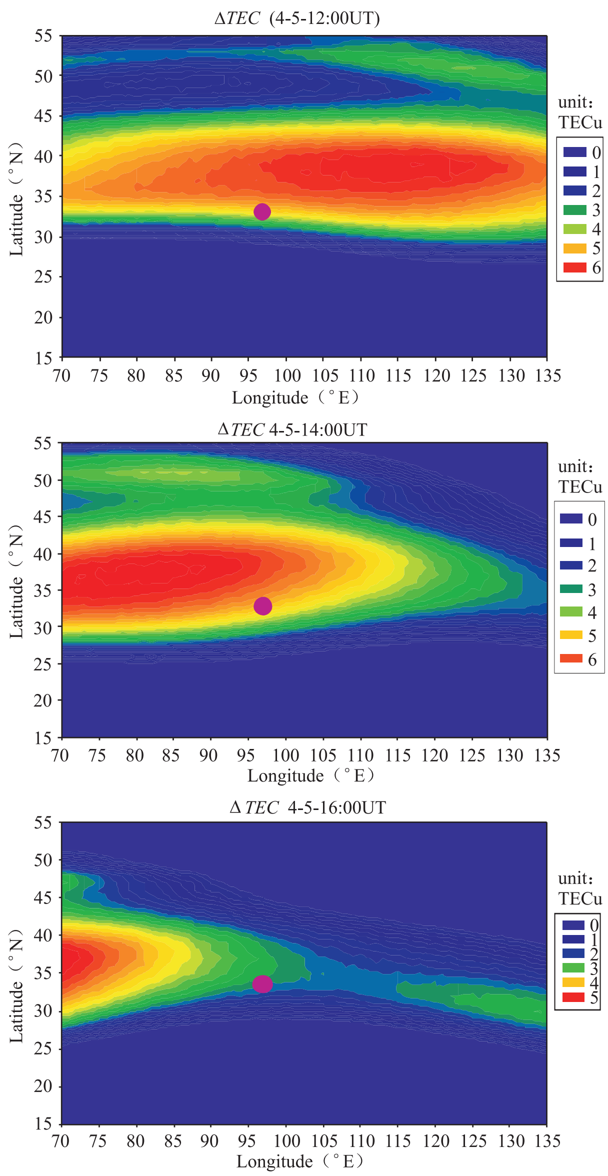

Figure 7 ΔTEC distribution on April 5 (12:00UT, 14:00UT, 16:00UT)

From these maps we may clearly see snapshots of the range, location, amplitude and duration of these ionospheric anomalies. These maps show a west-to-east drift of the anomalies; the relatively large anomaly on April 5 drifted even across the whole China.

4.3 Analysis of result

Our results show that ionospheric TEC increased 9 and

13 days before the Yushu earthquake, and the anomalies drifted from east to west, passing through the epicenter vicinity. In order to check whether the anomalies were related to the earthquake, we examined the data from National Satellite Meteorological Centre (http://www.spaceweather.gov.cn) about the level of solar and geomagnetic activities. We found that the solar activity was relatively quiet in the study period, but the geomagnetic activity was quite active on April 1, lasting for 3 hours; also moderate magnetic storm appeared during April 4 to 7. Thus the ionospheric anomalies on April 5 might be related to the magnetic storm. We are not sure whether the anomalies on April 1 were earthquake related for the following reasons: 1) Geomagnetic activity appeared on April 1 for 3 hours. 2) The anomalies appeared 12 days before the earthquake, not 0 to 6 days as reported previously by Punilets and Liu[14-15]. However, as shown in figure 2, the TEC value at LHAS increased nearly to the upper bound the day before and the day after the earthquake.

5 Conclusion

Our results show that TEC obviously increased over the epicenter vicinity on April 1 and 5. However, geomagnetic activity was not quiet on these two days neither. The anomalies on April 5 might be magnetic-storm related. In view of the increases recorded at LHSA, we think the anomalies on April 1 may possibly be related to the earthquake, even though the occurrence time was somewhat earlier than those reported in previously cases.

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