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Anomalous variations in ionospheric TEC prior to the 2011 Japan *Ms*9.0 earthquake

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Abstract: The ionospheric total-electron-content (TEC) data provided by the International GNSS Service (IGS) network and the VTEC data from the GPS reference stations of Crustal Movement Observational Network of China(CMONC) were processed and statistically analyzed to search for earthquake-related TEC anomalies prior to the 2011 magnitude 9.0 earthquake in Japan. Preliminary results showed that anomalous variations occurred 6 - 11 days and 0 - 4 days prior to the earthquake. After considering solar activity, geomagnetic conditions, and proximity in space and time to the earthquake, we tentatively concluded that the anomalous increase on March 5 may be related to the earthquake.

Key words: Japan earthquake; Total Electron Content(TEC); ionospheric anomalies; precursor

1 Introduction

Since a study on ionospheric variation at the time of the great 1964 Alaska earthquake [1-4], it has been recognized that anomalous ionosphere variations, including those of total electron content (TEC), may occur a few days or hours before strong earthquakes [5-17]. With the development of the Global Positioning System (GPS), we have a high-precision method to observe ionospheric TEC globally. Recent observation [18-26] of ionospheric TEC disturbance prior to the Wenchuan *Ms*8.0 earthquake has enhanced people's confidence in finding such precursors.

A huge earthquake of magnitude of 9.0 occurred near the east coast of Honshu, Japan at 05:46:23 UTC on March 11, 2011[27]; it triggered tsunamis, volcanic eruptions and nuclear leaks, and caused great life and property losses. In this paper, we report a statistical study of the ionospheric TEC data prior to the Japan *Ms*9.0 earthquake, based on the Global Ionospheric Maps (GIMs) of TEC provided by the International GNSS Service (IGS) network and on the VTEC derived from the GPS data recorded at the reference stations of Crustal Movement Observational Network of China(CMONC).

2 Data retrieval and analysis

The ionospheric TEC data provided by the IGS network has a resolution of 5° ×2.5° ×2 hour and is generated from hundreds of GPS stations worldwide. As a result of data interpolation and smoothing as well as the removal of small-scale spatial and temporal disturbances, the data can be used as an effective tool to study large-scale structures and changes of ionosphere TEC.

Assuming X_k^{ij} to be the value of the time series at a grid point in the two-dimensional ionospheric TEC, the mean $\overline{X}_k^{ij}$ and the standard deviation σ_k^{ij} are given by

$$\overline{X}_k^{ij} = \frac{1}{N} \sum_{L=K+1}^{K+N} X_L^{ij}, \quad K = 0,1,\cdots$$

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$$\sigma_k^{ij} = \sqrt{\frac{1}{N}\sum_{L=K+1}^{K+N}(X_L^{ij} - \overline{X}_k^{ij})^2} \quad K = 0,1,\cdots \quad (1)$$

where K is the serial number in time of the grid point $\overline{X}_k^{ij}$, N is taken as 10 and α is taken as 2. If the value was lower than the lower limit ($\overline{X} - 2\sigma$) or larger than the upper limit ($\overline{X} + 2\sigma$), we define it as an anomalous disturbance. When drawing the anomaly-distribution map, we used a map function [18].

3 Interpretation

By using this method, we processed and analyzed the global ionospheric TEC data for a period of 20 days prior to the earthquake's occurrence on March 11, 2011. As shown in figure 1, there was no obvious TEC disturbance most of the time, except 3 – 4 days and the 6 – 9 days before the earthquake. However, the first disturbance is quite different from previously observed earthquake-related anomalies; thus it may possibly be related to changes of the space environment. On the other hand, the second disturbance on March 5 occurred near the epicenter of this earthquake, as shown in figure 2, and thus may possibly be related.

Figure 2 shows the global distribution of ionospheric TEC observed on March 5 at two different points of time. The ionospheric TEC was normal at most grid points, except in some areas near the epicenter of the earthquake. The anomalies covered a large region of about 30° (110° – 140°E) in longitude and 10° (20° – 30°N) in latitude southwest of the epicenter, and in

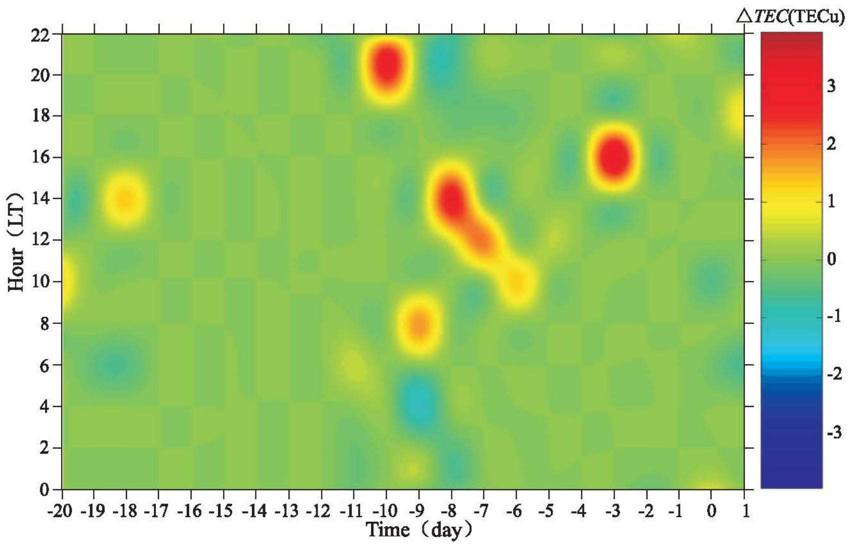

Figure 1 Distribution of the $\triangle TEC$ values in time of the day (y-axis) and day before the earthquake (x-axis) over the epicenter

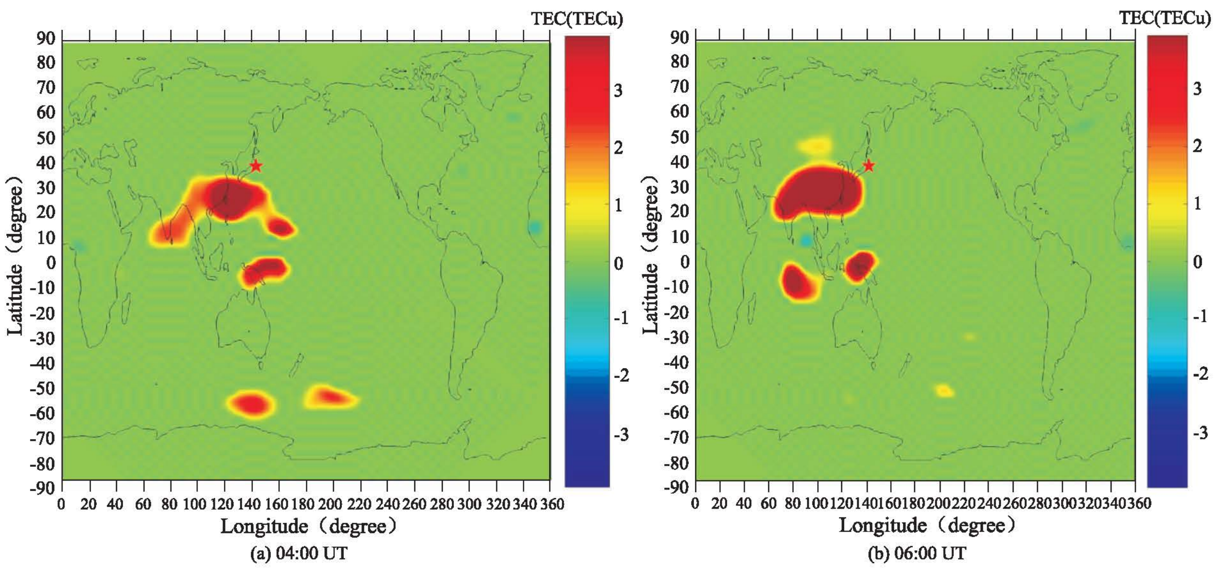

Figure 2 Global distribution of the ionospheric TEC anomalies on the 6th day prior to the earthquake (red star shows the epicenter of the earthquake)