Pre-seismic TEC Anomalies: comparative analysis of regional and global TEC variations

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Abstract

A number of papers have reported about deviations of daily values of the maximum electron concentration of the ionospheric F2 layer and/or total electron content (TEC) in the vicinity of an earthquake's epicenter some time prior to the quake. Owing to the importance of this problem, a question of a "locality" of those effects is arising. To study this issue we have developed a method based on calculation of global electron content and of local electron content in "check-region" with low seismic activity. The effect of TEC day to day changes before strong earthquakes is analyzed in this work. It is shown that in some cases this effect might be a reflection of global changes of the ionization caused by the 27-day variations as well as other fast alterations due solar activity changes. We discuss the problem of the certain data corrections that let us to distinguish local changes from global ones.

1. Introduction

The ionospheric effects produced by seismic activity have attracted geophysicists' attention for few dozens of years. This was caused by the acute need of the timely prediction of large earthquakes that cause numerous destructions and many hundreds of human deaths for a year. In this respect, the study of the ionosphere state before large earthquakes is one of the most important tasks of modern geophysics and radio physics. Many papers have been devoted to the validation of different ionospheric methods of earthquakes' forecasts. A number of papers have reported about deviations of daily values of the total electron content (TEC) in the vicinity of an earthquake's epicenter within some days prior to the main shock (e.g., review by Pulinets et al., [1] Pulinets and Boyarchuk, [2]; Liu et al., [3]; Zakharenkova et al., [4]). However, it is necessary to obtain stronger evidences for the statistical significance of the observed precursors, taking into account the real accuracy of the vertical TEC estimations (no more than 20-30%); besides, an analysis of such anomalies not related to the earthquakes' preparation processes is important. On the other hand, any methods used for such purposes, must be based on reliable physical mechanisms. In this work propose a method that allows us to test whether TEC daily variations before earthquakes are of local character; the method takes into account possible influence of 27-days variations of the ionosphere parameters, caused by the rotation of the Sun as well as other global TEC variations.

In this paper we show that in some cases local TEC changes represent global TEC changes and, therefore, might not be caused by earthquake preparation processes.

2. Estimation of global and regional TEC

First of all, it is important to distinguish local anomalies in the regular daily TEC changes, probably, initiated by earthquakes preparation processes, from those caused by the global influence of geomagnetic or solar activity changes. It is known that geomagnetic activity variations raise not only global changes, but also well pronounced local perturbations of the ionosphere parameters that can mask processes of earthquake preparation [5, 6]. Therefore, our chances to reveal ionosphere precursors of earthquakes are very few, under moderate and, especially, high geomagnetic activity. Thus, it is very important to take into account variations of solar activity that are of pure global character. For this purpose, we calculate global electron content (GEC) that is equal to the total number of electrons in the near-Earth space environment within the GPS orbital altitude of about 20200 km [6, 7]. Therefore, such approach allows us to track the dynamics of global ionosphere.

In this study we use the GEC conception in order to check the "locality" of observed TEC anomalies. We estimated the mean TEC value over an examined area, i.e. the mean total electron content $<I(t)>$. The value of $<I(t)>$ for the whole globe is proportional to the value of GEC. GEC can be calculated from global ionosphere maps (GIM) that are available from ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ionex/; GIM contain data of the vertical TEC with spatial step 5° of longitude and 2.5° of latitude - the elementary GIM cell, and temporal step of 2 hours. Total number of cells equals 5184 (72 cells of longitude multiplied by 72 cells of latitude). Then, mean total electron content <I(t)> was calculated by summation of the absolute vertical TEC values $I_{i,j}$ for every GIM cell [6, 7]:

$$< \mathrm{I} > = \sum \mathrm{I}_{i,j} / N \tag{1}$$

where i, j are the numbers of GIM cell; i=1,2,…N. It should be noted that the accuracy of the estimation of the global mean TEC <I(t)> is higher than 0.5 TECU [7], whereas that of the local mean TEC is less than 5 TECU.

The main idea of the proposed study is following. Monotonous increase (or decrease) of the maximum TEC within some days might not be concerned with local TEC changes, but with increase (or decrease) of the global electron content caused by the certain alterations in the Solar UV radiation flux. Afraimovich et al. [7] have found the strong resemblance of the GEC and UV radiation and solar radio emission at 10.7-cm wavelength changes during the 23rd cycle of solar activity. Spectrum of the GEC variations is very wide and includes the components with various time periods. GEC is characterized by strong seasonal (semi-annual) variations with maximum relative amplitude about 10% during the rising and falling parts of the solar activity and up to 30% during the period of maximum. However, the period of such variations is much longer than the duration of observed “anomalies”, so they can be not taken into account. This is even more important concerning GEC variations due to solar cycle activity changes.

At the same time, the maximal deviations of relative amplitude of 27-day GEC variations can exceed 20-30% (see Figure 1a and 2a; [7]). For the absolute TEC values of 20 TECU this amounts to TEC changes within 10 TECU (or more) that is of comparable amplitude with TEC “anomalies” reported before [1-5]. At that, the duration of the phase of 27-day GEC variations with maximum derivative value is of the same order (about 7 days) as the duration of TEC anomalies, recorded in the mentioned above papers. Apart from that, GEC changes can be caused not only by 27-day variations but also by the dynamics of the UV radiation from different active regions in the Sun. The contribution of such regions to the total UV flux may be comparable with changes due to solar rotation. Especially it became apparent during the period of high solar activity in autumn-winter of 2003 and in autumn of 2004 [7].

For the additional test of the “locality” of TEC anomalies we compare local TEC changes with simultaneous TEC changes within a “check-area” with low seismic activity. In the case if a TEC “anomaly” is caused by global variations of ionization, analogous anomalies are supposed to be observed also in seismically-quiet regions. In this work we estimated mean TEC value for the territories 62-65 N; 125-130 E (Yakutsk area) and 50-60 N; 90-105 W (North Canada). We have chosen several seismically-quiet (in the certain time intervals) “check-regions” with geophysical conditions similar to the ones of the examined areas (geomagnetic latitude, longitudinal range etc.).

3. Observations

Let us firstly analyze local dependence of the mean TEC <I(t)> level before the earthquake on 25 September 2003 (the Tokachi-oki earthquake) in the vicinity of Hokkaido Island, Japan, with a magnitude M=8.3 (indicated as by an black triangle in Figure 1c). Local TEC values <I(t)> were estimated by averaging over the territory 32-38°N; 130-140°E and within the time interval of 10 days before and 10 days after the earthquake (Figure 1b and 1c, brown curves). The arrow on the panel **c**) shows “anomalous” (against previous days) increasing of TEC maximum level 2-3 days prior to the earthquake [4].

Figure 1a shows global <I(t)> variations for the whole 2003 year, Figure 1b – global and local variations for the examined period of 20 days (thick blue and brown curves, respectively). As one can see, increase of the local TEC value 2 days prior to the main shock coincides with global TEC increase related to 27-day variations. Comparison with TEC changes in the “check-region” Yakutsk (Figure 1c, green curve) showed that analogous variations appeared there 2 hours later. Thus, comparison of local and global dependencies <I(t)> showed that the observed TEC variations seem to have been controlled by the solar activity instead of being associated with any expected processes that usually accompany the earthquake preparation.

As the other example, we would like to present our calculations for the earthquake on 29 September 2004 with a magnitude M=6.0 (the Parkfield earthquake, Figure 2). Following the paper by Dautermann et al. [5], we estimated local TEC within the territory (32-37 °N; 114-123 °W), for the time period from 262 to 283 day of the year 2004. The arrow in Fig.2c indicates “anomalous” (as compared to other days) decrease of the maximum TEC level 3-4 days before the earthquake. However, comparing Fig. 2b and 2c one can conclude that such decrease is well pronounced also in global data series as well as in data of the “check-region” in North Canada (but 1.5 hours before, according to the difference in local time). Therefore, also in these cases, the observed local anomaly follows changes of global TEC.

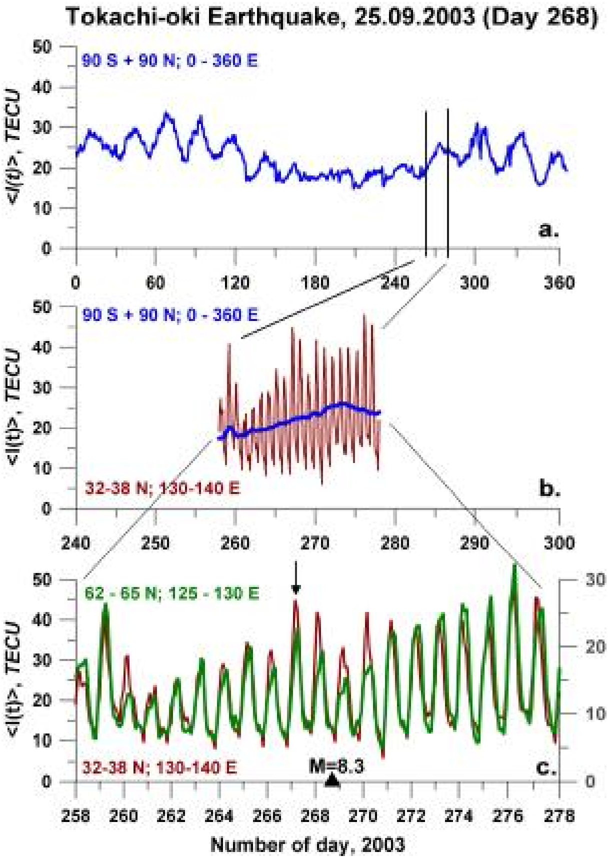

FIGURE 1. Global and local TEC variations before and after the Tokachi-oki earthquake on 25.09.2003.

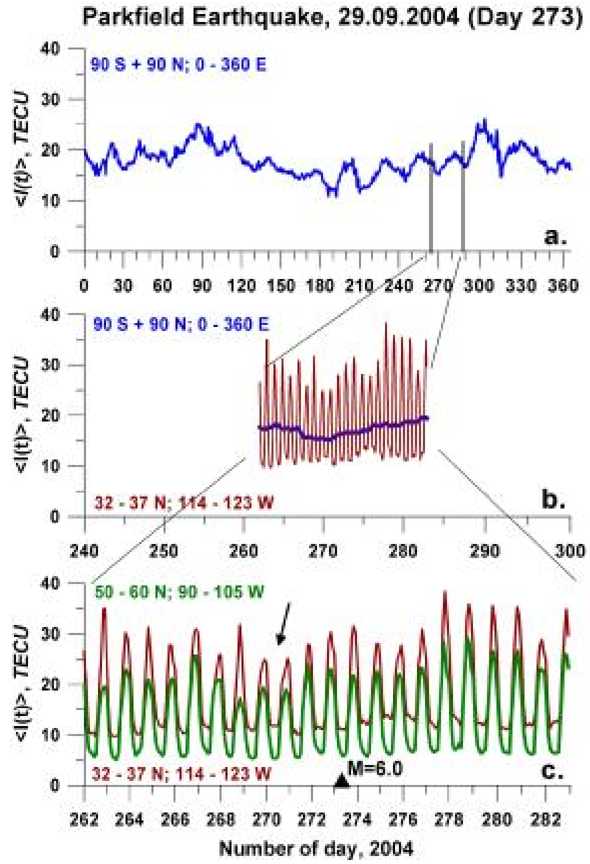

FIGURE 2. Global and local TEC variations before and after the Parkfield earthquake on 29.09.2004.

4. Discussion and Conclusion

Thus, comparison of local and global TEC values for the events, examined here, showed that TEC anomalies recorded in a series of publications [1-4], could be caused not as much by the enhanced seismic activity before earthquakes as by changes of the global ionization due to dynamics of the UV solar radiation. The delay of analogous changes in the “check-region” is caused by the difference in local time and by latitudinal distinctions.

The results of our comparative analysis of global and regional TEC changes before earthquakes conform to the known fact that “the affected area of the ionosphere at the height of the F-layer maximum reaches ~ 40° both in latitude and longitude” [1]. This fact appears to be an additional evidence that the observed anomalies can be consequences of the global changes of the ionization but not processes in the area of earthquakes’ preparation.

Thus, to establish fact of earthquake preparation for certain, it is not sufficient to carry out only statistical analysis of TEC changes within a seismo-active region as it has been performed in a majority of papers [1-4]. It is necessary to accomplish a fundamental analysis of the main global factors responsible for the formation and changes of local TEC – solar UV radiation and redistribution of ionization during geomagnetic disturbances. Dautermann et al. [5] analyzed variations of F10.7 solar flux in order to show that local TEC changes can be caused by large fluctuations in the solar flux. However, the proposed here approach allows use of global TEC and local TEC changes in “check-region” with low seismic activity as a more appropriate indicator of global changes of ionization, that takes into account not only changes of solar radiation but also dynamics of geomagnetic activity.

In order to separate the relative contribution of these processes to TEC changes, supplementary investigations are necessary, as well as development of special methods for realizing such distinction, based on a model of seismo-ionosphere coupling. This problem is a complex one and is out of the frame of this study. As a result of such correction, the seismo-ionosphere effect of earthquakes preparation may become either more pronounced, or impaired. In any case, the reliability of conclusions concerning the connection of observed TEC changes with earthquake preparation processes will become higher.

The proposed here method and quantitative estimations are correct for variations of critical frequencies measured at ionosondes as well. Therefore, further analysis of the obtained before data series of critical frequency data or TEC with dynamics of global electron content would be of interest. The stated above approach can be performed in a majority of situations, when “anomalies” of ionosphere parameters are considered to be related not only with earthquakes, but with other local events such as hurricanes, typhoons, weather cyclones and anthropogenic effects.

5. Acknowledgments

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6. References

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