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Unique Variations of the Total Electron Content in the Preparation Period of Haitian Earthquake (M7.9) on January 12, 2010

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Abstract—Variations of the total electron content according to the index IONEX IGS in the period of preparation of the earthquake in Haiti (M7.9) on January 12, 2010, are considered. The situation is exceptional owing to the unique position of the island of Haiti relative to the structure of the ionosphere over the Caribbean Sea: the ionospheric region over Haiti is in the trough formed by the northern slope of the equatorial anomaly and additional maximum formed at latitudes of approximately 30° N within this longitudinal interval. Distortion of the shape of the equatorial anomaly, total decrease in the electron content in the equatorial anomaly a few days prior to the earthquake, increase in the electron concentration directly over the earthquake epicenter a few days prior to the earthquake, increase in the additional maximum at latitudes of ~30° N, and formation of an additional maximum in the Southern Hemisphere in the region conjugated to the additional maximum in the Northern Hemisphere in the periods of its intensification are observed. The configuration of the equatorial anomaly is restored after the earthquake.

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1. INTRODUCTION

The first decade of the 21st century was, unfortunately, rich with large seismic events taking place in densely populated regions of the world at low latitudes. These events became the basis for intensification of studies of ionospheric anomalies related to preparation of strong earthquakes because the first data on short-term ionospheric precursors of earthquakes gave fairly promising results (see the history of the problem in [Pulinets and Boyarchuk, 2004]). One of the most often used sources of data is the global maps of total electron content (TEC) published by the ionospheric group of the international service of the global positioning system IGS (see examples of use of these data in [Zakharenkova et al., 2006, 2008; Pulinets et al., 2010]).

A substantial number of intense earthquakes occur at low latitudes, where for study of inospheric events one should take into account the influence of the equatorial anomaly. The electrodynamics of the equatorial anomaly is rather complicated, especially in afternoon hours, in the periods of its maximal development. This leads to the fact that ionospheric anomalies are formed not only over the epicenter of the future earthquake (if it is located in the equatorial anomaly region), but also in the magnetically conjugated region and also in regions located eastward or westward from the vertical projection of the epicenter onto the ionosphere [Namgaladze et al., 2009; Pulinets, 2009]. In the case of Haiti, the situation is aggravated by the fact that the geomagnetic equator in this longitudinal sector is located at a latitude of 14° S, and because of this almost the entire equatorial anomaly is located in the Southern Hemisphere.

This paper is dedicated to consideration of the anomalous variations in TEC in the equatorial anomaly region in the period of preparation of the Haitian earthquake on January 12, 2010.

2. EXPERIMENTAL DATA, METHOD OF PROCESSING, AND GEOPHYSICAL SITUATION

The international network of GPS receivers IGS (International GNSS Service) was the source of data on TEC. After the initial processing, global maps of TEC in the IONEX format having a resolution of 5° and 2.5° in longitude and latitude, respectively, with a step of 2 h in UT were formed. The data are available at the ISDC server (ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ionex).

For drawing of meridional cross-sections, a longitude of 75° W was used (the longitude of the epicenter is 72.5° W). The equatorial anomaly reaches a substantially developed degree by 1500 LT, so the global

TEC maps for 2000 UT were taken from the IONEX files.

One should note that the considered period of time was characterized by a quiet geomagnetic situation. The *Dst* geomagnetic activity index was within the interval of –4 to +2 nT1 in the period from December 16, 2009, to January 16, 2010.

3. CONFIGURATION OF THE EQUATORIAL ANOMALY AT LONGITUDES OF HAITI AND POSSIBLE MECHANISM OF FORMATION OF THE ADDITIONAL MAXIMUM AT LATITUDES NEAR 30° N

The morphological studies of the global dynamics of the equatorial anomaly revealed an asymmetry of its development in the solstice periods [Mendillo et al., 2005]. It lies in the fact that the electron concentration in the equatorial anomaly crest located in the winter hemisphere is higher than in the summer hemisphere crest. This difference is expressed by the asymmetry index *AI*:

$$AI = \frac{\mathrm{TEC}_{\mathrm{Dec}} - \mathrm{TEC}_{\mathrm{Jun}}}{\mathrm{TEC}_{\mathrm{Dec}} + \mathrm{TEC}_{\mathrm{Jun}}},$$

where $\mathrm{TEC}_{\mathrm{Dec}}$ and $\mathrm{TEC}_{\mathrm{Jun}}$ are the average TEC values for December and June, respectively. According to Mendillo et al. [2005], this value for 2002 was 0.15, which exceeded substantially the changes in solar illumination due to the seasonal change in the distance between the Sun and the Earth (0.035).

Although the mechanism of formation of the seasonal asymmetry of the equatorial anomaly is not conclusively established, the meridional wind from the summer hemisphere to the winter one involving in its motion the charged component and leading to an increase in the concentration in the winter crest of the equatorial anomaly [Rishbeth, 1977] is one of the most commonly accepted ideas. However, in the case of Haiti, both crests of the equatorial anomaly are located in the Southern Hemisphere (see Fig. 1) and the meridional wind meets on its way no obstacle in the form of a convection system of the northern crest of the equatorial anomaly. It continues to move northward until complete dissipation, bringing with it the charged component. This leads to formation of an additional electron concentration maximum at a latitude of approximately 30° N, which is also distinctly seen in Fig. 1. Formation of the additional maximum at longitudes of the Caribbean Sea was detected yet in the data of vertical sounding from the *Intercosmos-19* satellite [Pulinets et al., 2003].

Thus we can note that the configuration of the equatorial anomaly in the longitudinal sector of the Caribbean Sea is quite unusual: the equatorial anomaly is located almost completely in the Southern Hemisphere (to the left-hand side of the solid vertical line showing the position of the geographic equator),

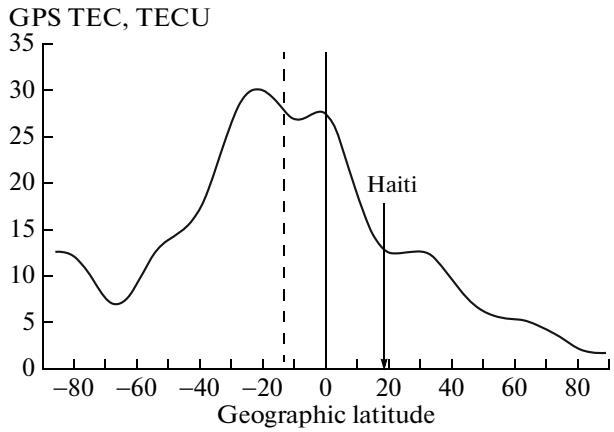

Fig. 1. Typical latitudinal profile of the equatorial anomaly (TEC) at the Haitian meridian (January 2, 2010, 1500 LT).

the additional ionization maximum is formed at a latitude of ~30°N, and Haiti is located in the trough formed by the northern slope of the equatorial anomaly and the additional maximum at a latitude of 30° N.

4. DYNAMICS OF THE EQUATORIAL ANOMALY IN THE PERIOD OF PREPARATION OF THE HAITIAN EARTHQUAKE

According to the method described in Section 2, we studied changes in the intensity of development and shape of the equatorial anomaly at a longitude of 75° W in the period from January 1, 2010, to January 15, 2010. The results are presented in Fig. 2. One can see in Fig. 2 that, as the earthquake comes nearer, the integral TEC of the equatorial anomaly (that is, the area under the TEC curve between the inflections characterizing the latitudinal limits of the anomaly) decreases. The absolute minimum of the integral TEC is observed on the day of the earthquake (January 12, 2010); the two-hump structure of the anomaly disappears already beginning from January 8, 2010; the amplitude of the additional maximum at a latitude of ~30° N increases; and on January 9 and 10, 2010, a distinct additional maximum in the Southern Hemisphere at latitudes of 55°–60° S in the region conjugated magnetically to the additional northern crest at a latitude of ~30° N is formed. The additional maxima are marked in Fig. 2 by symbols *a* and *b*. Immediately after the earthquake, the electron content in the equatorial anomaly begins to recover and its shape is completely recovered up to the undisturbed value shown in Fig. 1 by January 15, 2010 (thick black solid curve).

5. VARIATIONS IN THE ELECTRON CONTENT AT THE EPICENTER LATITUDE

Unlike the general tendency in the period of the earthquake preparation (the decrease in the integral

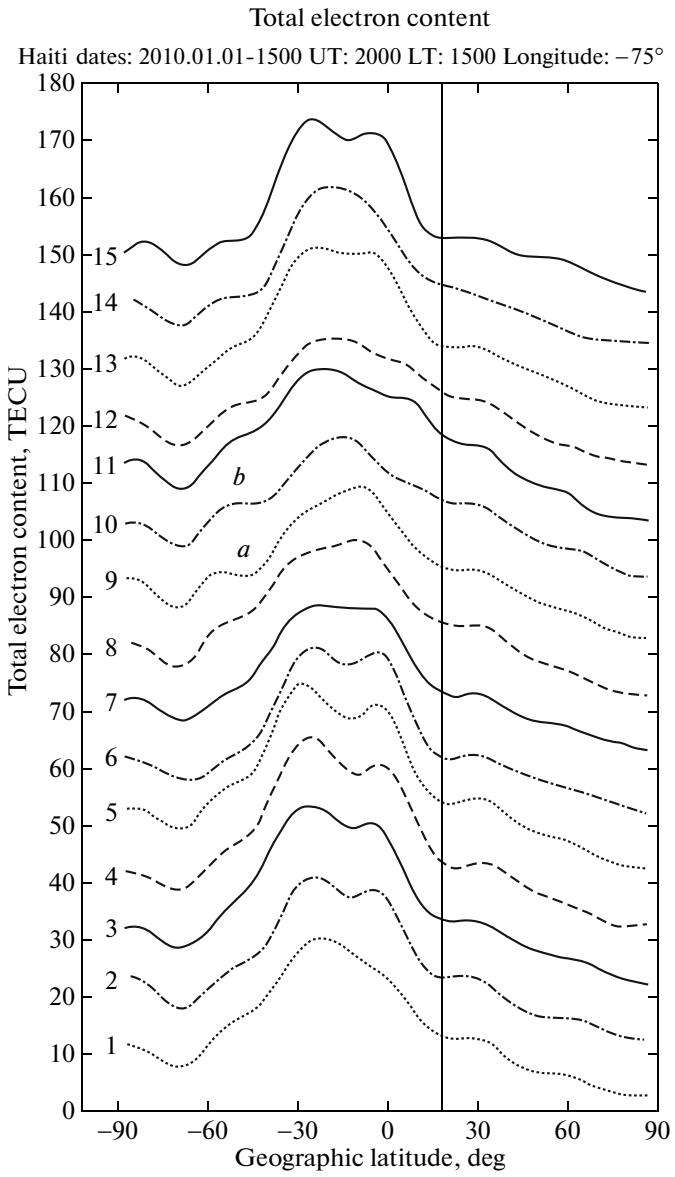

Fig. 2. Latitudinal profiles of TEC along the 75° W meridian for 1500 LT. Each graph is marked on the left-hand side by a numeral indicating the date from January 1, 2010, to January 15, 2010. For the sake of clarity, the graphs are shifted in sequence by 10 TEC units relative to each other.

electron content in the equatorial anomaly), the electron concentration value at the epicenter latitude increases as the moment of the earthquake comes nearer and reaches its maximum one day prior to the earthquake on January 11, 2010 (Fig. 3). Such behavior is typical of the ionospheric region located between the equatorial anomaly crests in the period of its degradation with the only difference that in this case the studied region is located between the northern crest of the equatorial anomaly and the additional maximum at a latitude of ~30° N.

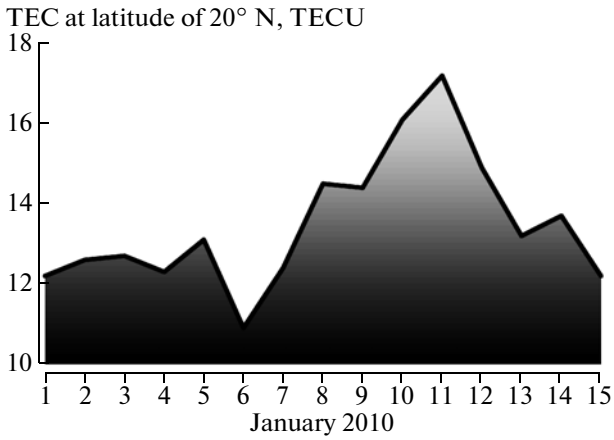

Fig. 3. Variations in TEC from January 1, 2010, to January 15, 2010, near the Haitian earthquake epicenter (75° W, 20° N).

6. TWO-DIMENSIONAL REPRESENTATION OF THE ANOMALOUS VARIATIONS OF THE ELECTRON CONTENT IN THE PERIOD OF EARTHQUAKE PREPARATION

The TEC variations over a month (from December 21, 2009, to January 21, 2010) were studied using the following method. To estimate the TEC deviations from the average value for the given date, maps of TEC for the same universal time for the previous 15 days were selected from the IONEX database. After that, the maps were averaged; that is, the arithmetical mean value of TEC for each point of the map was calculated according to the resolution in latitude and longitude of IONEX maps. Then the 15-day moving averages were subtracted from the TEC values for the given data. The variations obtained in such a way were shown in the form of maps.

Figure 4 presents the deviation of TEC from the moving average obtained by this method for January 11, 2010, when the main maximum in the concentration increase at the epicenter latitude was observed. One can see in Fig. 4 that the additional maximum was formed not only at the epicenter longitude marked by a cross in Fig. 4 but was stretched westward from the epicenter. The latter fact makes it possible to postulate a substantial decrease in the atmospheric potential relative to the ground over the epicenter region in agreement with the mechanism presented by Pulinets [2009].

7. CONCLUSIONS

Variations of TEC in the region of the equatorial anomaly in the period preceding the Haitian earthquake on January 12, 2010, were studied. The following events were observed:

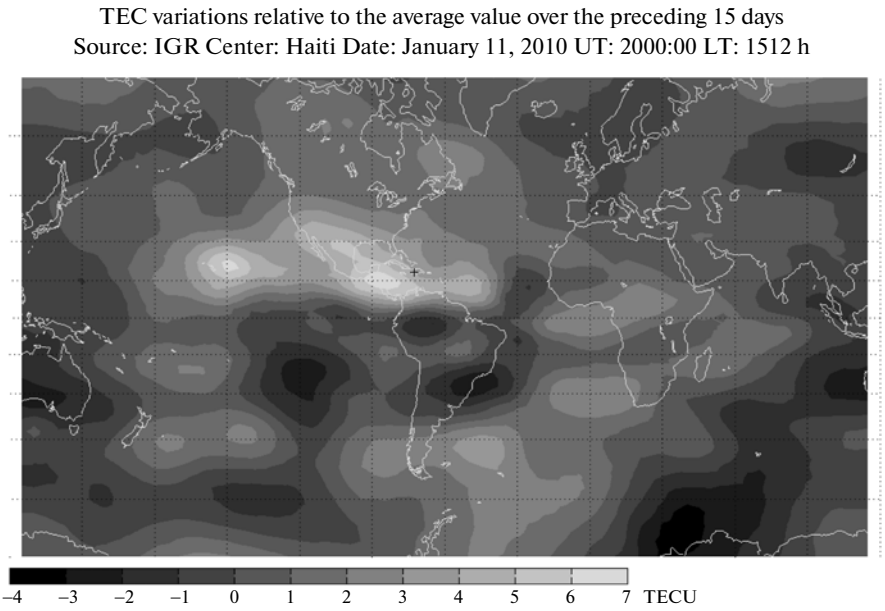

Fig. 4. Map of TEC deviations from the running average over the preceding 15 days for 2000 UT on January 11, 2010.

Distortion of the shape of the latitudinal profile of the equatorial anomaly.

Total depletion of the electron content in the equatorial anomaly on days preceding the earthquake.

Local increase in the electron concentration in the ionospheric region at the epicenter latitude.

Amplification of the additional maximum at a latitude of 30° N and formation of an additional maximum at the magnetically conjugated point.

Since the geomagnetic situation was quiet and the magnetic anomaly shape returned to the shape typical of the period before the earthquake, the observed effects are, evidently, related to the process of the earthquake preparation. As sources having led to the distortion of the shape of the equatorial anomaly in the period of the earthquake preparation, one can indicate the appearance of an additional zonal electric field [Namgaladze et al., 2009] and plasma convection along magnetic field lines leading to formation of the additional maximum in the Southern Hemisphere.

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