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GENERATION OF ANNULAR LARGE-SCALE TRAVELING IONOSPHERIC DISTURBANCES IN AURORAL ZONE

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Abstract. We proposed methods for visualization of the wave front of auroral traveling ionospheric disturbances (TIDs) on the basis of phase measurements of the total electron content (TEC) using the international GPS network. To define the wave front shape and phase velocity of the TID during large magnetic storm on October 29, 2003 we used data obtained from GPS receivers located in five sectors of northern hemisphere: West-American, East-American, European, Asian and Far-Eastern. Proposed methods make it possible to determine in experiment that the solitary type large-scale wave with the annular front is generated in the northern ionosphere as a result of auroral perturbation. The ring center is located inside of auroral oval near the geomagnetic pole. The wave has a period of about 40-60 min and travels equatorward at distance up to 4500 km. The relative TID amplitude ΔI/I is of order 10-20%. The comparison with the ionosonde data has shown that this value corresponds to relative amplitude of electron density disturbance in the F-layer maximum of about 45-50%.

1. Introduction

Geomagnetic storms on October 29, 2003 and October 30, 2003 belong to the number of the most powerful storms, registered in the last years. Many publications have been devoted to the study of effects of these storms [Afraimovich et al., 2004; 2005; 2006a; 2006b; Mannucci et al., 2005; Foster and Rideout, 2005; Zhao et al., 2005]. A number of original procedures for determination of parameters of large-scale traveling ionospheric disturbances (LS TIDs) are developed and the unique experimental data are obtained by GPS Monitoring Work Group in ISTP SB RAS. In particular it was shown, that LS TIDs occur during the sharp changes of the Earth magnetic field [Afraimovich et al., 2005]. It was demonstrated, that small-scale disturbances are generated at the front of LS TIDs [Afraimovich et al., 2006a] and this process was accompanied by the degradation of GPS signals and subsequent positioning error increase [Afraimovich et al., 2004]. This paper presents the results of investigation of the wave front shape of LS TID registered during the magnetic storm on October 29, 2003 using GPS data.

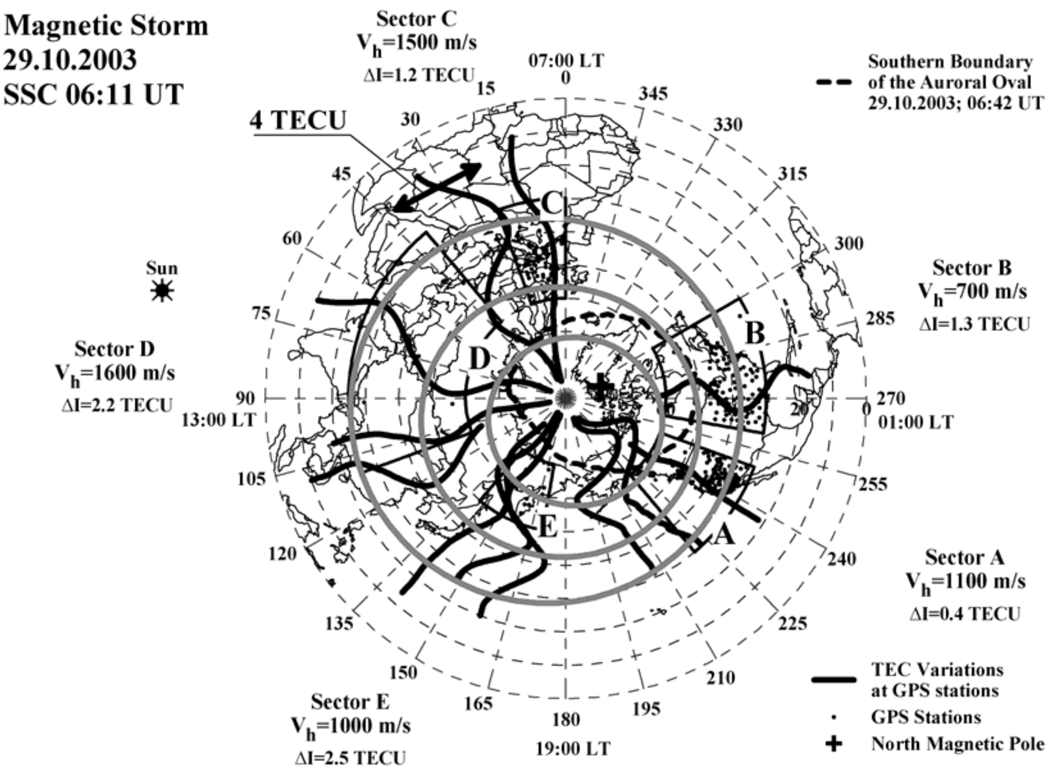

Fig. 1. The wave front shape of LS TID registered during strong magnetic storm on 29.10.2003 using GPS data.

2. Data and Methods of Analysis

Fig. 1 presents the geometry of TEC measurements during the strong magnetic storm on October 29, 2003. The data of Space Environmental Monitor (SEM, http://www.sec.noaa.gov/pmap) were used to mark the displacement and dynamics of the Auroral Oval.

To define the wave front shape and TID phase velocity we used data obtained from GPS receivers located in five sectors of northern hemisphere: West-American, East-American, European, Asian and Far-Eastern (regions **A**, **B**, **C**, **D**, **E** on Fig. 1). Input data were represented by series of "oblique" TEC, calculated from the data of GPS phase measurements [Afraimovich et al., 2000]. We converted initial TEC series to an equivalent "vertical" value [Klobuchar, 1986] and filtered them over the period range of 30-60 min for detection of the LS TID [Afraimovich et al., 2000]. The LS TID horizontal phase velocity V_h was calculated using the algorithm SADM-GPS [Afraimovich et al., 2000].

3. The parameters of LS TID as deduced from GPS data on October 29, 2003

After the sudden storm commencement (SSC, 06:11UT) the TEC wave disturbances with time period of about 40-60 min were detected in all sectors. Calculated mean LS TID velocity V_h in different sectors varied from 700 to 1600 m/s (Fig. 1). The mean values of LS TID amplitude ΔI for each sector are given in Fig. 1 ($1\ \text{TECU} = 10^{16}\ \text{m}^{-2}$). The relative LS TID amplitude ΔI/I calculated using the data of Global Ionospheric Maps (GIM, ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ionex) is 10-20%. The comparison with the results of ionosonde measurements in Irkutsk during October 29, 2003 has shown that this value corresponds to relative amplitude of electron density disturbance in the F-layer maximum of about 45-50% [Afraimovich et al., 2006b].

For LS TID form visualization we have introduced special references frame in each sector. Axis Ox of this frame is directed along LS TID wave vector **K**, but in the opposite direction [Afraimovich et al., 2005]. Fig. 2 shows the filtered TEC variations in each sector mapped in one graph with a vertical shift proportional to distance D between the start point O and GPS receiver location. Thus Fig. 2 represents dynamics of LS TID along its traveling directions at distance from 800 to 4500 km. The detected disturbance is a large-scale wave of a solitary type with the duration of about 40 min.

We developed a special method for visualization TEC disturbances to define LS TID wave front shape. To reconstruct the spatial picture of TEC variations TEC series were represented as curves of longitude deviation from receiver longitude (spatial TEC images). For construction of spatial TEC images there was used filtered TEC series dI(t) for time interval 06:00-08:00 UT. In every sector we chose a few filtered TEC series (from 1 to 3, depending on the longitudinal size of the sector). The latitudinal extension of the spatial TEC image was calculated as a product of average value of LS TID meridional velocity in the sector on series duration. The central latitude of the image was detected as a latitude of corresponding GPS receiver. Derived spatial TEC images for 07:00 UT are shown in Fig. 1 (black curves).

Gray circles in Fig. 1 mark approximate positions of maximums and minimums in spatial TEC variations. TEC disturbance generated during magnetic storm had the annular front shape. The ring center was situated inside of auroral oval near the geomagnetic pole. LS TID traveled toward lower

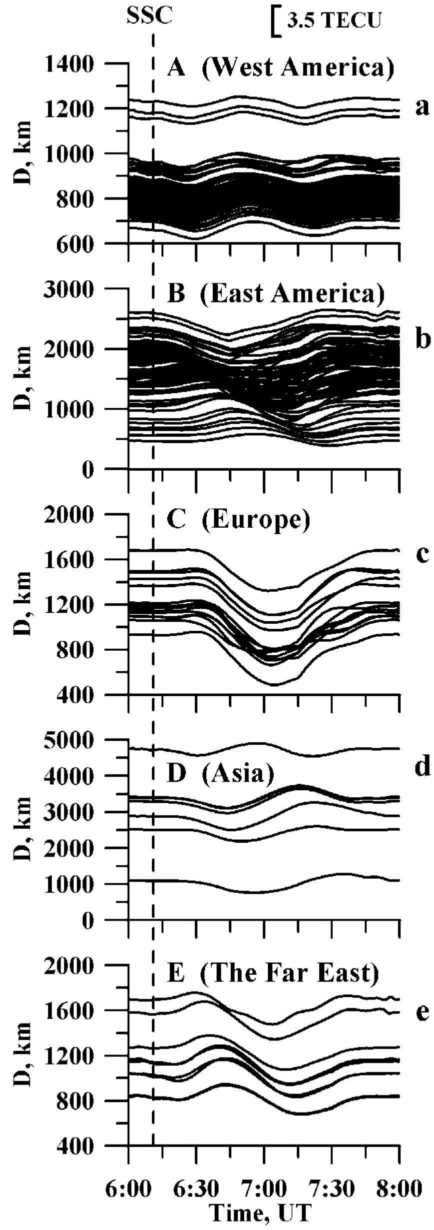

Fig. 2. Filtered TEC variations at different distances D from the chosen start points O in five sectors.

latitudes. The least velocity values were observed on the night side. The LS TID traveled almost without change its annular front shape. According to Fig. 1, difference in velocities of movement in night and day sectors appear more in removal of the ring center from the geomagnetic pole to the day side.

4. Ionospheric response to storm on October 29, 2003 deduced from Global Ionospheric Maps

For the last years the Global Ionospheric Maps are widely used. GIM technology provides an opportunity to create global maps of absolute "vertical" TEC value I_A by interpolation international GPS network data [Mannucci et al., 1998; ftp://cddisa.gsfc.nasa.gov]. The spatial resolution of this maps is 5° of longitude and 2.5° of latitude; time resolution is 2 hours.

We have tried to reveal ionospheric response to the magnetic storm on October 29, 2003 using GIM. Fig. 3 (at the left) presents GIM mapped in polar coordinates for three sequential moments on October 29, 2003. GIM for the same moments on October 23, 2003 (magnetically quiet day) are given in Fig. 3 (at the right). Both in quiet and in disturbed conditions the daily motion of ionization with a maximum about 14:00 LT and minimum about 04:00 LT are well traced on the maps. The equatorial anomaly is brightly expressed. In quiet conditions the northern crest of the anomaly is observed at latitudes 10-17° in morning, day time and evening sectors. The TEC value in the crest does not exceed 80 TECU. During magnetic storm the northern crest of the equatorial anomaly was displaced northward up to latitudes 20-22°. This effect is in good agreement with the results obtained in [Astafyeva et al., 2007]. The TEC value in a crest increase up to 130 TECU. At the same time, we can't reveal LS TID detected by GPS receivers. During magnetic storm monotonic increase of ionization from the pole to equator (similar to quiet conditions) is observed, but this is more sharply expressed.

For details we have constructed Global Maps of TEC Relative Deviation dI (Fig. 4):

$$dI = 100\% \cdot (I_{29} - I_{23}) / I_{23},$$

where I_{29}, I_{23} are GIM TEC values for 29.10.2003 and 23.10.2003, respectively. Up to the SSC TEC values on October 29, 2003 exceeded one in quite day (Fig. 4a) due to higher level of magnetic activity. After the storm beginning it is possible to select two large areas with increased TEC values (Fig. 4b-c): along the crest of the equatorial anomaly (TEC increase in comparison with a quiet level is 150-200%) and at high latitudes in the night hemisphere (TEC increases up to 400 %). The area of the high-latitude TEC increasing follows the shape of the southern boundary of the auroral oval (Fig. 4b). The essential decrease of TEC values (up to 50-100%) is observed in night ionosphere at mid and low latitudes. The described distribution of TEC deviation is stationary enough and does not vary within several hours. It was not possible to select LS TID on maps of deviation of TEC.

Probably, the spatial-time resolution of GIM appears insufficient for detections of such ionospheric structures. The authors [Ho et al., 1996] reported, that they observed TIDs using maps of TEC deviation during the geomagnetic storm on

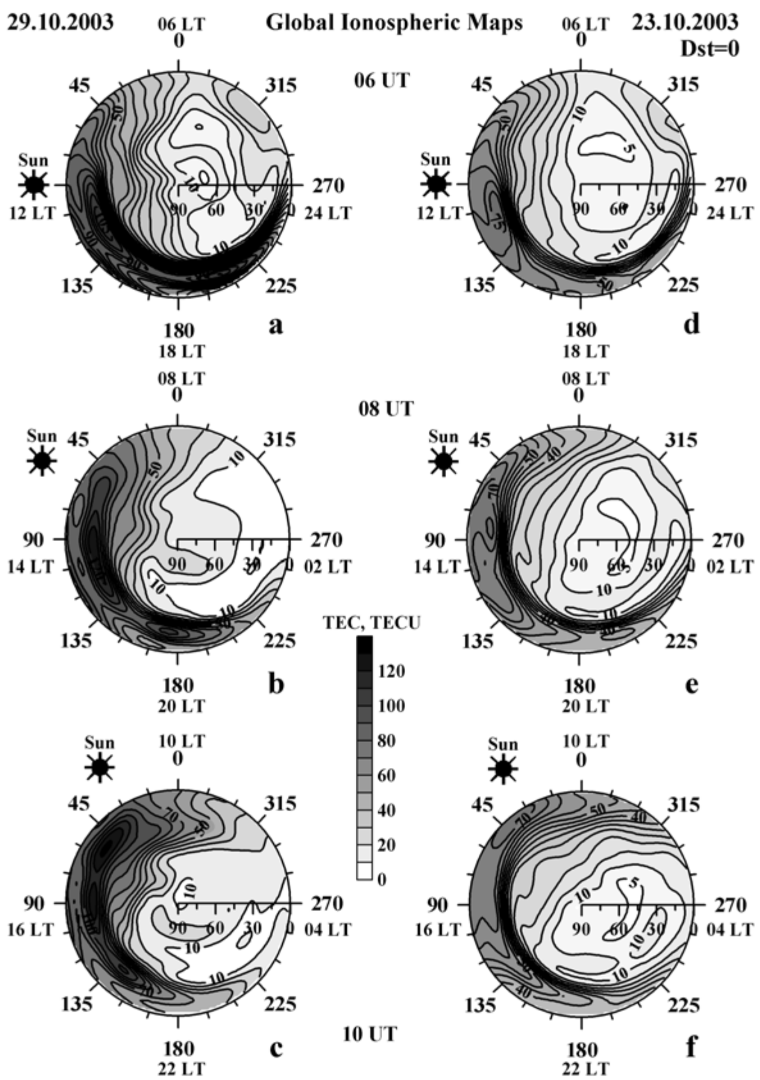

Fig. 3. Global Ionospheric Maps in magnetically quite day (23.10.2003) and during geomagnetic storm (29.10.2003).

November 26, 1994. However they used GIM with higher time resolutions (15 min).

5. Conclusion

Using the GPS-derived TEC data we found that the large-scale wave of a solitary type with the annular front shape was generated in the northern ionosphere as a result of auroral perturbation on October 29, 2003. The ring center was located near the geomagnetic pole. The wave had a period of about 40-60 min and traveled equatorward at distance up to 4500 km. The LS TID velocity varied from 700 to 1600 m/s. The detected LS TID was characterized as an ionospheric response to SSC. The relative amplitude of TID ΔI/I was of order 10-12%. The comparison with the ionosonde data has shown that this value corresponds to the relative amplitude of electron density disturbance in the F-layer maximum of about 45-50%.

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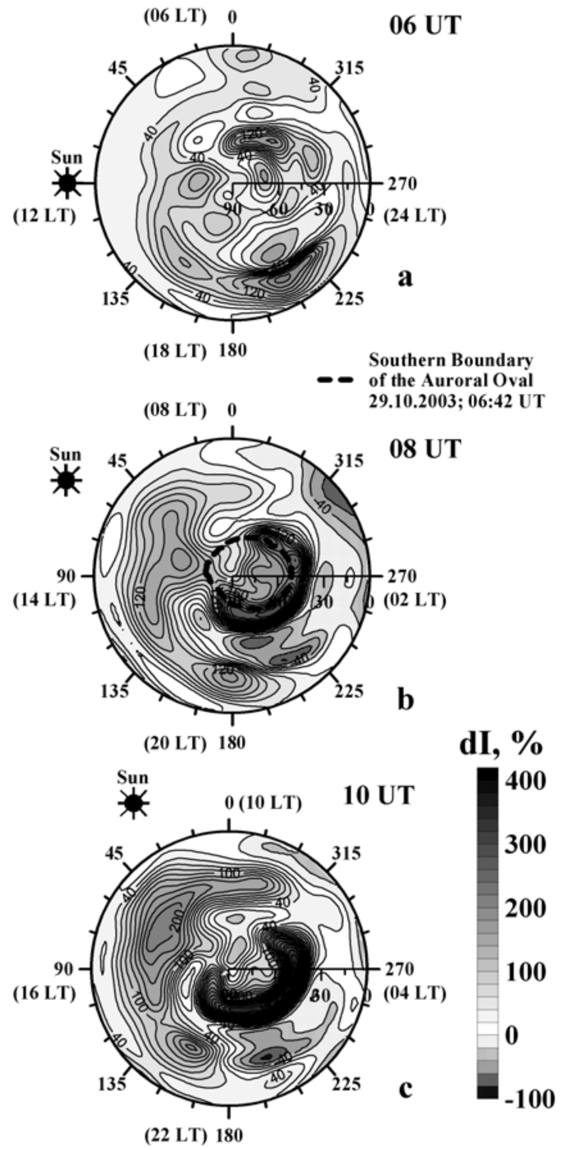

Fig. 4. Global Maps of TEC Relative Deviation.