Mapping technique for the USTEC-derived field of velocity of TEC redistribution

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Abstract

We proposed a method for calculation of regional maps of velocities of total electron content isolines movement (TECIM) using USTEC maps (http://www.ngdc.noaa.gov/stp/IONO/USTEC/home.html) with a high temporal and spatial resolution. Applying of our method allows us to obtain additional information about the ionosphere plasma redistribution. Thus, at the main phase of geomagnetic storm on 8 November 2004 (maximum level Kp = 9), during local nighttime a large-scale ionization redistribution the velocity of TECIM reached 1000 m/s. On the contrary, during similar time interval on geomagnetically quiet day 15 November 2004 (maximum level Kp = 1), the velocity of TECIM did not exceed 100 m/s.

1. Introduction

Study of ionosphere dynamics is one of the most important problems of geophysics. A quantity of papers has been devoted to study of the ionospheric response to strong geomagnetic storms [1, 2]. At equatorial and midlatitude regions one of the most outstanding modifications are alterations in ionospheric total electron content (TEC). Drastic changes in ionosphere vertical TEC can be produced by intense disturbance electric fields originating from the magnetosphere–ionosphere interaction [3]. These electric fields, depending on their polarity and duration, could cause large uplifts or downdrafts of the ionosphere plasma leading to large-scale local time enhancements or decreases of the vertical TEC.

TEC measurements from GPS networks provide information about perturbations in an ionization distribution. Using techniques mentioned extensively in the literature [4] Global Ionosphere Maps (GIM) of vertical TEC can be calculated. However, the ionosphere maps can only describe spatial distribution of TEC but they cannot provide quantitative characteristics of TEC dynamics. Astafyeva et al. [5] proposed a method for calculation of global or regional maps of velocity of TEC isoline movement (TECIM) using GIM. But low spatio-temporal resolution of GIM (2.5º of latitude and 5º of longitude spatial grid and 2-hours resolution) do not make it possible to investigate in detail dynamics of ionization redistribution. Here we present first results of analysis of TEC quantitative dynamics during geomagnetic storm November 8, 2004, performed by using the method [5] and USTEC data.

2. Direction and velocity of TEC isoline movement

The method is based on calculations of TEC time derivatives $I'_t(t)$ and spatial derivatives $I'_y(t)$ and $I'_x(t)$. Spatio-temporal changes of TEC $I(t,x,y)$ at each time moment t in range of GIM or USTEC cell can be presented as plane wave phase front, propagating without changes of its shape [5]

$$I(t,x,y) = F(t - \frac{x}{u_x} - \frac{y}{u_y}) \quad (1)$$

here $u_x(t)$ and $u_y(t)$ are velocities of TEC isoline movement along X (directed eastward) and Y (directed northward) axes, respectively. Then we determine orientation $\alpha(t)$ of a wave vector U in the range of 0°÷360°

(calculated clockwise from the northward direction) as well as the absolute value of horizontal velocity *u(t)* at each time moment using the formulas:

$$u_x(t) = \frac{I'_t(t)}{I'_x(t)} = \frac{u(t)}{\cos\alpha(t)}; \; u_y(t) = \frac{I'_t(t)}{I'_y(t)} = \frac{u(t)}{\sin\alpha(t)}; \; u(t) = \frac{\left|u_x(t)\cdot u_y(t)\right|}{\sqrt{u_x^2(t)+u_y^2(t)}}; \; \alpha(t) = arctg\left(\frac{u_x(t)}{u_y(t)}\right) \qquad (2)$$

Using equations (1, 2) we can determine azimuth of the wave vector and phase velocity of TECIM. Values of derivatives for each cell can be derived using TEC increment for all four nodes of the cell and for two consequent moments of time t_1 and $t_2=t_1+dt$ [5]

$$\begin{aligned} I'_x &= (I_{c1} - I_{b1} + I_{d1} - I_{a1} + I_{c2} - I_{b2} + I_{d2} - I_{a2})/4d_e, \\ I'_y &= (I_{a1} - I_{b1} + I_{d1} - I_{c1} + I_{a2} - I_{b2} + I_{d2} - I_{c2})/4d_n, \\ I'_t &= (I_{a2} - I_{a1} + I_{b2} - I_{b1} + I_{c2} - I_{c1} + I_{d2} - I_{d1})/4d_t \end{aligned} \qquad (3)$$

here d_e and d_n are linear size of the USTEC rectangular cell in longitude and latitude, respectively. Procedures (2) and (3) are realized for all the cells of chosen spatial range and interval of time. We calculated TEC spatial and time derivatives using USTEC data (http://www.ngdc.noaa.gov/stp/IONO/USTEC/home.html). USTEC contain data of the vertical TEC from 130ºW to 60ºW of longitude and from 20º to 50º of latitude with 15-min time resolution. When our method is applied to the USTEC with its 1º of latitude and 1º of longitude spatial grid, we obtain a map of TECIM velocity where each velocity vector starts from a cell of USTEC and shows direction of the TECIM. The magnitude of the velocity is indicated by the length of vector (Figures 1c, 2c, 3c).

We tested our method by calculation of TECIM velocity at local sunrise (06:00 LT for 105°W) in geomagnetically quiet conditions, on January 9, 2005 (value of planetary index Kp = 1). It is seen from Figure 1 that velocity vectors of TECIM are directed mainly to the northwest. The velocity was about 290±140 m/s that close to the velocity of solar terminator movement at the ionospheric heights [6].

3. Observations

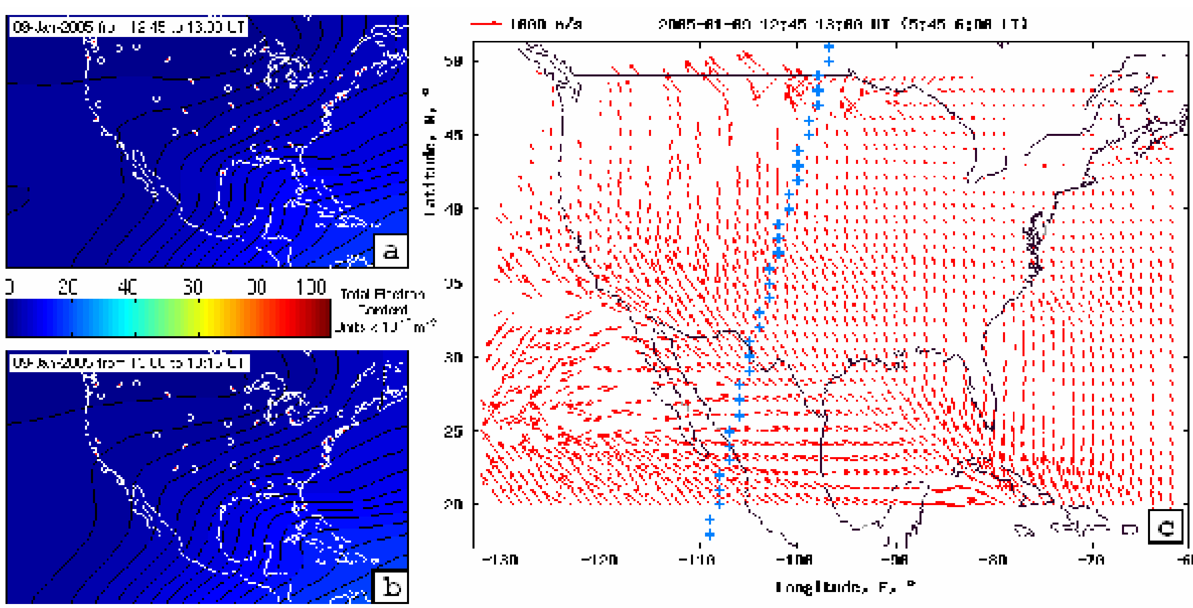

FIGURE 1. Dynamics of TEC redistribution at the time of traveling of the morning terminator on geomagnetically quiet day of 9 January 2005. (a), (b) - two consecutive TEC maps used for the velocity estimation by formula (3); the isolines correspond to the scale of TEC depicted on the panel; the white circles mark USTEC reference GPS sites. (c) – map of TECIM velocity movement; the line of the terminator at the height of 200 km from the ground is shown by crosses. Local Time 6:00 LT corresponds to the longitude 105°W.

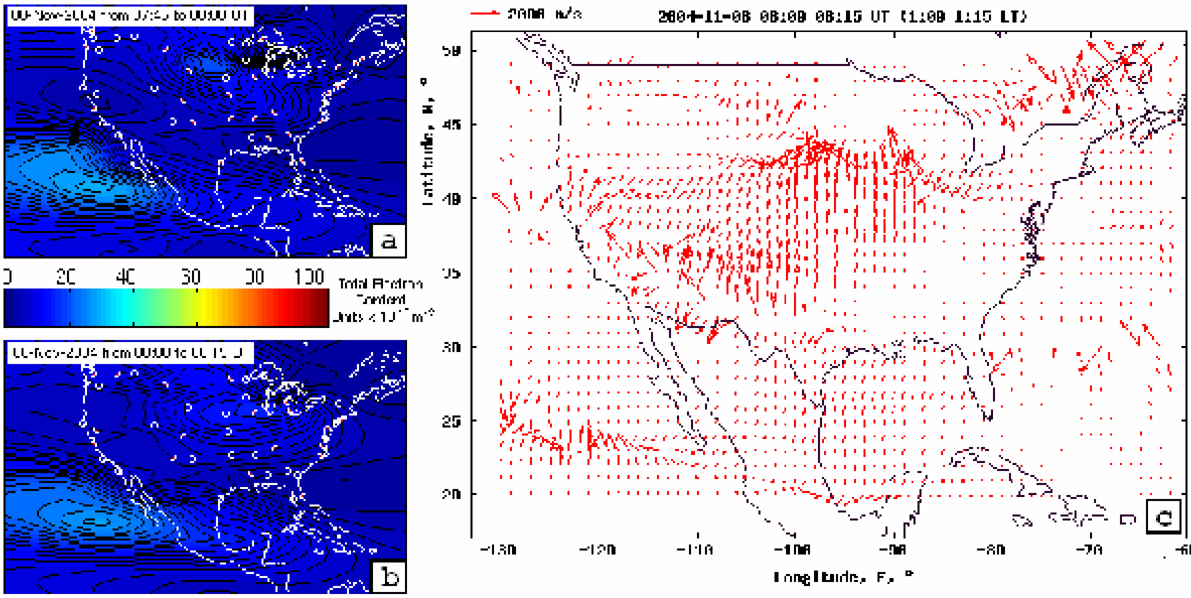

FIGURE 2. The same as in Fig. 1, but for the time of the main phase of geomagnetic storm on 8 November 2004 (daily summary Kp level is 50). In the USA region the velocity of TECIM reached 1000 m/s.

Let us now consider in more detail TEC redistribution in the USA region during the main phase of geomagnetic storm on 8 November 2004. The perturbation started to form in the examined area at 08:00 UT (00:00-05:00 LT; Figure 2a, 2b). At the same time, the velocities of TECIM increased significantly in the whole USA region (Figure 2c). The velocity of TEC isolines movement exceeded 1000 m/s and the vectors of TEC isolines were oriented poleward. The velocity of TECIM within the whole USA region (34-48° N; 120-85° W) was about 484±409 m/s.

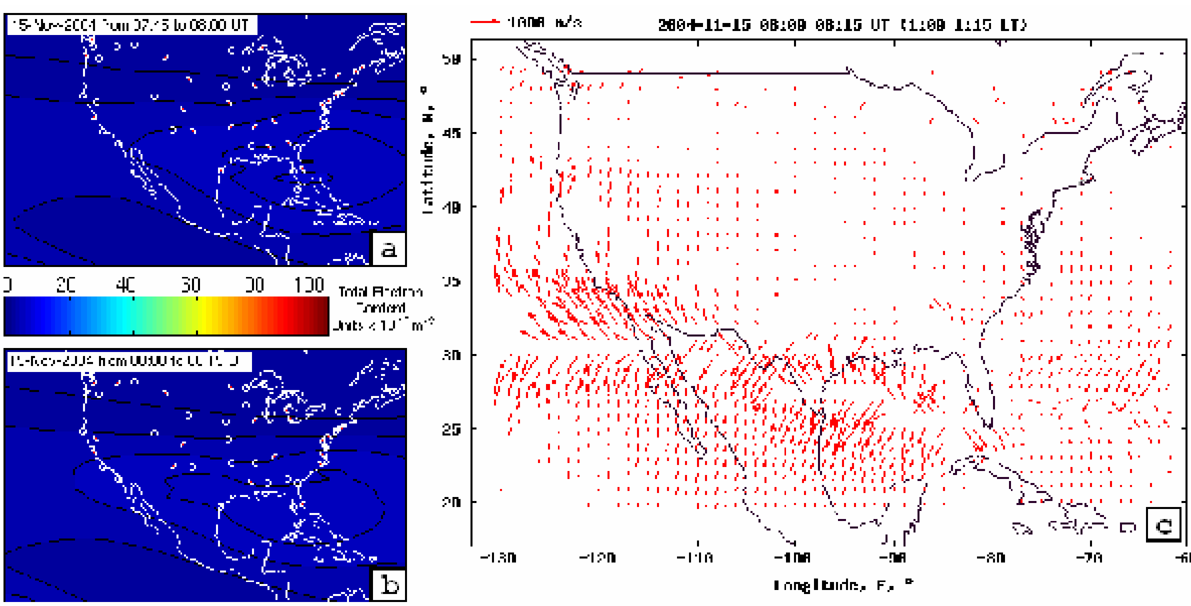

FIGURE 3. The same as in Fig. 1, but for geomagnetically quiet day 15 November 2004 (maximum Kp = 1).

On the contrary, within a similar time interval 00:00-05:00 LT during geomagnetically quiet day of 15 November 2004 (maximum level Kp = 1), the velocity of TECIM did not exceed 100 m/s (Figure 3a, 3b, 3c). The velocity of TECIM in whole USA region was about 71±66 m/s.

4. Discussion and Conclusions

The presented here examples illustrate significant distinctions of the dynamics of the ionization redistribution under geomagnetically quiet and disturbed conditions. During quiet time periods the velocity of the night ionization changes far off the terminator is much smaller than the velocity of the terminator. On the contrary, during geomagnetic storms fast changes of the spatial TEC distribution essentially exceed the terminator velocity value. Such changes are determined by the spatial configuration and the intensity of the electric field originating from the magnetosphere–ionosphere interaction [3]. The field of TECIM velocity calculated by the proposed here method can be useful when analyzing the ionosphere dynamics during geomagnetic storms.

Thus, our method appears to be a good tool for investigation of TEC dynamics, it allows making of quantitative mapping of global field of velocity of TEC redistribution during geomagnetically quiet and disturbed conditions.

The proposed here method can be used for other TEC maps of vertical TEC, which have high temporal and spatial resolutions: European maps, temporal resolution is 10 min, spatial resolution is 1° (http://ionosphere.rcru.rl.ac.uk/cgi-bin/SWWpagedis.pl?page=TEC/TEC_index&sel=2); South-American maps LPIM (http://cplat.fcaglp.unlp.edu.ar/products/iono/grids/), temporal resolution is 1 hour, spatial resolution is 1°; Japanese maps (http://wdc.nict.go.jp/IONO/contents/E011_TECmap.html), temporal resolution is 5 and 15 min, spatial resolution is 0.5°.

The stated above approach can be performed in a majority of situations, when the dynamics of ionosphere parameters are considered to be related not only with ionosphere plasma redistribution during magnetic storms, but with local events such as hurricanes, typhoons, weather cyclones and anthropogenic effects.

5. Acknowledgments

The authors are grateful to Space Weather Prediction Center for USTEC data. The work was supported by the RFBR grants N 06-05-39026 and 07-05-00127, the SB RAS collaboration project N 3.24.

6. References

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