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MODEL CALCULATIONS OF ERRORS IN DETERMINATION OF THE TOTAL ELECTRON CONTENT FOR GPS SATELLITE SYSTEM

YURIJ N. KORENKOV, VLADIMIR A. SUROTKIN[†], VLADIMIR V. KLIMENKO AND MAXIM V. KLIMENKO[*†]

[*]West Department of N.V. Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Kaliningrad, Russia

[†] Kaliningrad State Technical University, Kaliningrad, Russia

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Abstract. The Global Self-consistent Model of the Thermosphere, Ionosphere, and Protonosphere of the Earth (GSM TIP), making it possible to calculate all the main parameters of the near-Earth plasma, is used to calculate the total electron content (TEC). The values of TEC calculated according to model satellite data are compared with the "true model" value of TEC. Relative errors in determination of the satellite TEC for two European and two American stations are calculated. It is demonstrated that an increase of the number of the observed satellites does not always lead to an increase of the accuracy of the TEC measured with the help of the satellites.

1 INTRODUCTION

With the development of the satellite navigation, a new era in the near-Earth space began. The development of the positioning system of satellites (Global Positioning System, GPS) made it possible to obtain information on the ionospheric state regularly and on the global scale. Currently GPS is used for studying such ionospheric characteristics as total electron content (TEC)[1], electron concentration profiles[2], ionospheric irregularities[3], and sporadic E layer[4], and for forecasting of the ionospheric state[5]. Thus, currently, the entire GPS system is a powerful tool for studying of the ionosphere structure[6]. The method of using the radio signal delays for calculation of the total electron content (TEC) became widely distributed. Because of this many studies have been carried out concerning the impact of various factors on the accuracy of calculation of this parameter[7]. In this paper we present the model simulations of TEC along the radio ray between the receiver and satellite with the following determination of the vertical TEC and "true model" TEC calculated using the GSM TIP model. The errors of the quasi-experimental method of TEC determination are studied for various view angles of the receiving device for stations of the European and American regions.

2 STATEMENT OF THE PROBLEM

The Global Positioning System presents a group of satellites located at six orbits at a height of about 20200 km above the Earth surface. The orbits are inclined by 55° toward the equator. At each orbit there are four satellites separated from each other by 90°. The satellite orbital period is 12 hours. The satellites are equipped by standards of time and frequency and transmit signals with a digital modulation at frequencies of 1227.60 MHz (L1) and 1575.42 MHz (L2). The time delay in the L1 and L2 channels may be used for calculation of TEC along the oblique radio ray ($OTEC$) between the satellite and receiver[1]1, at this OTEC is recalculated into the equivalent vertical $TEC(VTEC)$, using

$$VTEC = OTEC \cos \chi' + C \tag{1}$$

$$\chi' = \arcsin(R_E \sin \chi / (R_E + h)) \tag{2}$$

where C is some value depending on the equipment parameters, χ is the angle between the vertical and direction to the satellite, R_E is the radius of the Earth, and h is the mean ionospheric height equal to 350 km. The base value C contains terms depending on the transmitter and receiver systems (including cables and antennas), etc. In our model study we suppose C to be equal to zero. The error in TEC determination in this case would be of the order of a few units of TEC (1 TECU = $10^{16} elm^{-2}$).

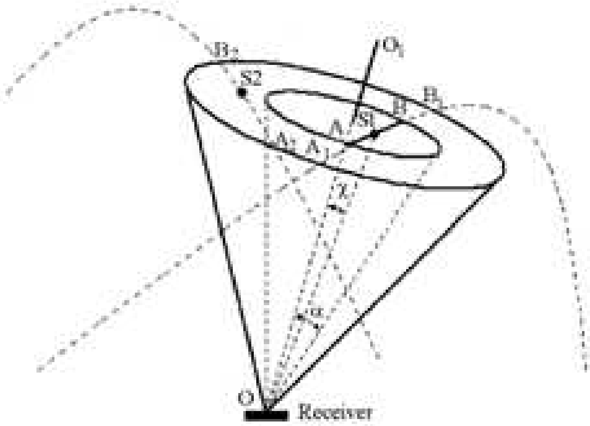

Figure 1: Schematic picture of the geometry of observations and TEC calculations for GPS satellites

Figure 1 shows a schematic picture of the geometry of satellite observations. One can see that at small view angles (α) only one satellite S_1 would be observed, and its signals would be received only during its motion along the fragment AB. With an increase of the α angle other satellites are falling down into the field of view of the receiver (for example, S_1 (A_2B_2)) and the observation time of the S_1 satellite increases (the trajectory fragment (A_1B_1)). The GSM TIP model is described in detail1[2]. The model makes it possible to calculate spatial-time distributions of the electron concentration Ne in the near-Earth space at altitudes from 80 km up to 15 Earth radii. Knowing the N_e distribution we are able to calculate the "model" value of TEC along the vertical (OO_1) from the receiver to the height of 20200 km. Simultaneously TEC along the radio ray between the receiver and visible satellite (for example OS_1) is calculated. These values $OTEC$ at each moment of time are recalculated into the equivalent vertical $VTEC$ and are averaged over the number of the observed satellites. The obtained value is compared to the "accurate" vertical value of TEC and the relative error of these values is calculated.

3 DESCRIPTION OF CALCULATION RESULTS

The calculations of TEC were performed for magnetically quiet conditions of the spring equinox (21 March 1993) for moderate solar activity ($F_{10.7} \sim 130$) for two European stations EISCAT (69.6°N, 19.2°E) and Kaliningrad (55°N, 20E) and two American stations Millstone Hill (42.6°N, 71.5°W) and Arecibo (18.3°N, 66.8°W). Diurnal variations in the TECU "model" TEC, satellite TEC, and the modulus of the relative error in percents and the number of observed satellites in every moment of time for various angles of the view cone of the receiver are shown in Figures 2 and 3.

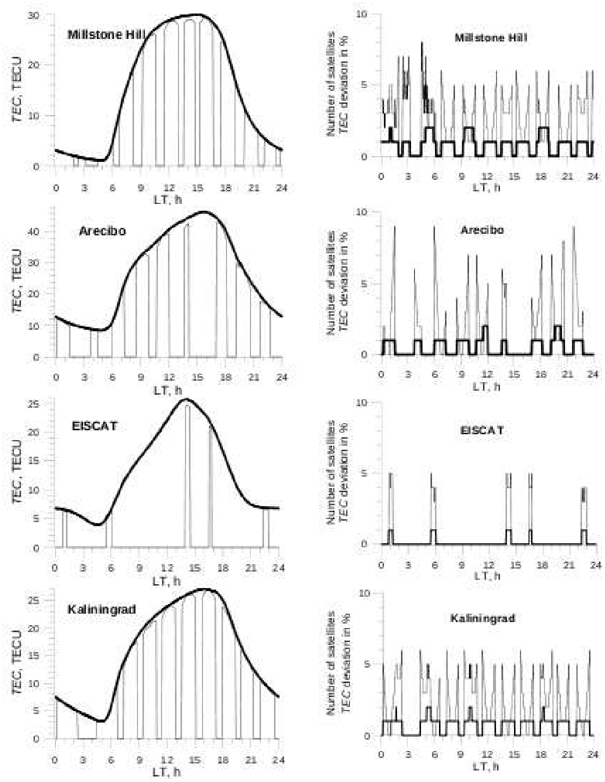

Figure 2: Diurnal variations for different stations of the "model" (thick lines) and satellite (thin lines) values of TEC (left panels); diurnal variations in the number of observed satellites (thick lines) and in the relative error of TEC calculations (thin lines) for the view angle α of 20° (right panels).

Figure 2 shows the calculation results for all four stations under study at small angles

$\alpha = 20°$. One can see that there are troughs in the diurnal behavior of the satellite TEC, that is, there are moments of time when no satellites fall into the view cone. The longest interval of satellite absence is for EISCAT station. The maximum error does not exceed 9% for Millstone Hill and Arecibo and are observed in the morning and evening hours. In the periods when two satellites are observed the error is reduced to 4though there are time intervals when at observation of only one satellite the error also does not exceed 4%. With an in-crease of the view angle up to 40° (Figure 3) the troughs in the diurnal variations in the satellite TEC disappear. The number of observed satellites increases and varies with time from one to three. However, the latter fact does not lead to a decrease of the error, but vice versa raises it. The maximum value of the error is observed is ∼20%.

4 DISCUSSION

One should note that the method of recalculation of OTEC into VTEC used in these calculations is not an exact copy of the method used at processing of real experimental data. In our calculations there are no terms thin "ionosphere" and "subionospheric point for which the χ angle is recalculated. Strictly speaking, the recalculation formula is true for homogeneous stationary ionosphere and works well only at small values of the zenith angle χ. However, the presented results illustrate well the influence of the number of observed satellites on the diurnal variations of the relative errors in determination of the vertical TEC from satellite data. The presented figures make it possible to state that for obtaining of a continuous diurnal variation of TEC one needs either larger number of satellites at the view angle of $\sim 20°$, or an increase of the view angle up to 40°. The first version is principally possible because usually there are extra satellites at orbits and if they are activated their observation becomes possible. At an increase of the view angle (as we have noted above) there is some loss in the accuracy (up to 10%) and there are moments (see Figure 3) when the error is $\sim 20°$

In the experimental data, this may be interpreted as a wave perturbation in TEC, though the "true" diurnal variations show a complete absence of the latter.

5 CONCLUSIONS

1. At small view angles of the receiving station $\sim 20°$, time periods may exist when no satellites are observed. At these moments determination of TEC is impossible. However, in other moments the accuracy of TEC determination from the satellite data is very high ($\sim 5\%$).

2. - At an increase of the view angle up to 40° the troughs in TEC determination from the satellite signal delays disappear, but the relative error of the experimental TEC increases on the average up to 10%. There are periods of time when considerable depletions in TEC are observed as compared to the "model" value (especially in the daytime). In the processing of the experimental result only, these TEC variations may be interpreted as variations in time, though actually the latter are absent.

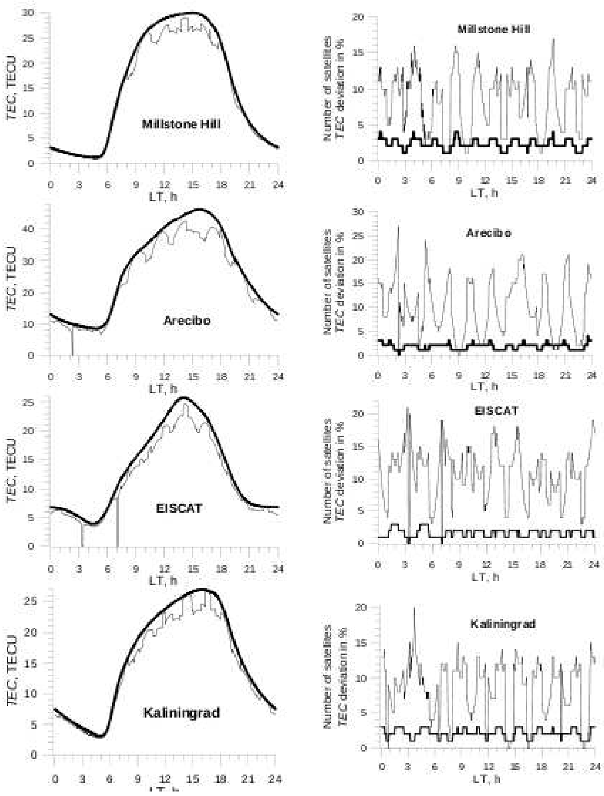

Figure 3: The same as in Fig. 2 for the view angle of 40.

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