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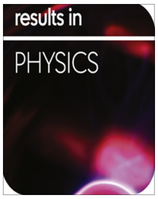

Microarticle

Estimating the total electron content absolute value from the GPS/GLONASS data

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ABSTRACT

When determining the absolute oblique total electron content (TEC) of the ionosphere using both GLONASS/GPS code and phase measurements, there occurs a systematic error associated with the differential code biases (DCBs). A 1-ns DCB leads to the ~2.9 TECU error when determining L1-L2 dual-frequency oblique TEC. We have developed an algorithm for DCB estimation from the data of a single GPS/GLONASS station. Presented are the results of the algorithm operation compared with the oblique TEC correction by using CODE laboratory DCB data.

Global navigation satellite systems (GNSS) have enabled to study the ionosphere in different regions of the world [1]. One may say today that such studies have become global and have involved both more-or-less investigated mid- and equatorial latitudes and poorly investigated Arctic and Antarctic ones. The total electron content (TEC) of the Earth ionosphere can be determined from code and phase dual-frequency pseudorange measurements performed by receivers of GNSS signals. This technique is widely described in the literature [4].

Phase measurements are weakly noised, but they are relative due to the ambiguity of the initial phase definition. Code measurements are absolute, however, they feature very high noise, up to hundred percent at low elevation angles. For this reason, to obtain the absolute TEC values, phase measurements are usually used, and the ambiguity is eliminated with code ones. Thus, there occurs a systematic error termed differential code biases (DCBs). DCBs depend on both satellite and receiver, and are related to that the signal transit times in radio frequency paths of the receiver and the satellite differ for the L1 and L2 ranges, and depend on the signal frequency. This error may significantly exceed the real TEC value and lead to obtaining unphysical negative TEC values [6].

To determine the absolute TEC accounting for DCBs from the data of a single GPS/GLONASS station, we have developed the following algorithm:

(1) To calculate the TEC from code I_p and phase I_φ measurements.
(2) To separate data sequences into continuous-time intervals.
(3) To detect and eliminate the impact of outliers and signal tracking losses in the TEC data [2].
(4) To remove the ambiguity of phase measurements: $const = \frac{1}{N}\sum_{i=1}^{N}(I_p - I_\varphi)_i$, where N is the number of measurements at a continuous interval.
(5) To estimate DCBs by using a simple model of measurements. The model parameters are determined based on the minimization of the standard deviation between the experimental and model data (see below).
(6) To correct TEC sequences obtained in item 4 by the DCB value.

We use the following model of TEC measurements:

$$I_M = S_j^i\Big[I_V(\phi_0, l_0, t_o) + G_\phi \Delta\phi_j^i + G_{q\_\phi}\left(\Delta\phi_j^i\right)^2 + G_l \Delta l_j^i + G_{q\_l}\left(\Delta l_j^i\right)^2$$
$$+ G_t \Delta t_j^i + G_{q\_t}\left(\Delta t_j^i\right)^2\Big] + I_{DCB,j}.$$

where I_V is the absolute vertical TEC value; $\Delta\phi$ is the latitude difference between the ionospheric point coordinate ϕ and that of the ϕ_0 station; Δl is the longitude difference between the ionospheric point coordinate l and that of the l_0 station; Δt is the difference between the measurement time t and the time t_0, for which the calculation is performed; $G_\phi = \partial I_V/\partial\phi$, $G_l = \partial I_V/\partial l$, $G_{q\_\phi} = \partial^2 I_V/\partial\phi^2$, and $G_{q\_l} = \partial^2 I_V/\partial l^2$ are linear and quadratic spatial TEC gradients;

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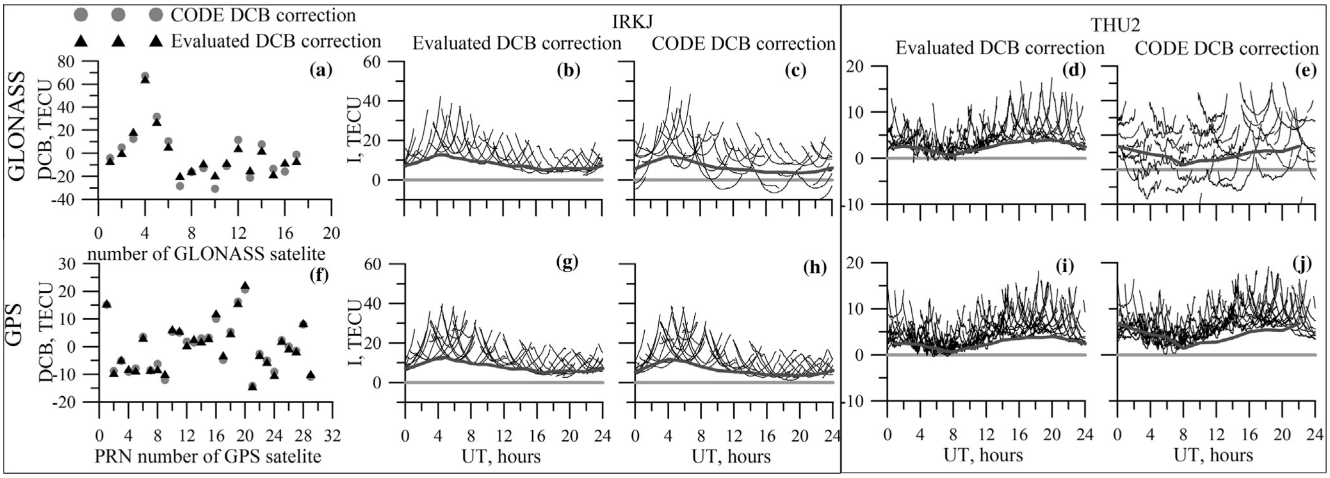

Fig. 1. (a, f) DCB results obtained by the above algorithm and by the CODE data for all GLONASS (a) and GPS (f) satellites observed at the IRKJ mid-latitude station. (b, c, d, e, g, h, i, j) Variations in TEC from all the satellites for IRKJ (b, g, c, h) and for THU2 (d, e, i, j), using correction based on the described algorithm (b, g, d, i) and on the CODE data (c, h, e, j). The thick grey line is the absolute vertical TEC data obtained by the above algorithm (b, g, d, i) and by the CODE data (c, h, e, j).

$G_t = \partial I_V/\partial t$ and $G_{q\_t} = \partial^2 I_V/\partial t^2$ are the first and second time derivatives respectively. Here, mixed spatial and time derivatives are neglected. This assumes that TEC changes more slowly in space during the time interval for which the calculation is performed, than the vertical TEC value at the same time does.

$S_i^j = \left[\cos\left\{\arcsin\left(\frac{R_E}{R_E+h_{\max}}\sin[\alpha\cdot(90-\theta_i^j)]\right)\right\}\right]^{-1}$ is the oblique factor, R_E is the Earth radius, h_{max} is the height of the thin spherical layer (450 km), and $\alpha = 0.97$ [7]. We note that there are other algorithms and models to determine DCBs, for example [3,5,7].

The model is a classical second-order Taylor series expansion of vertical TEC $I_V(\phi,l,t)$ at station coordinates (ϕ_0,l_0) in space and time. The difference from, for example, spherical harmonic expansion [7] is in simple evaluating spatial gradients and time derivative.

Fig. 1 presents the comparison between the DCB results (a, f) obtained by the above algorithm and by the CODE data for all the satellites. Also, we present the results of correcting the initial oblique TEC for all the satellites accounting for DCBs obtained by the above algorithm (b, g, d, i), and by the CODE [ftp://cddis.gsfc.nasa.gov/gps/products/ionex] data (c, h, e, j). The thick grey line shows the absolute vertical TEC data obtained by the above algorithm (b, g, d, i) and by the CODE data (c, h, e, j). These results were obtained with GPS and GLONASS measurements from the IRKJ station ($\phi = 52.2°$ N, $l = 104.3°$ E) (b, c, g, h) and for THU2 arctic station ($\phi = 76°$ N, $l = -111°$ W) (d, e, i, j), within the International GNSS Service [http://igscb.jpl.nasa.gov/]. The data correspond low solar activity level: 2009 March 12 (61.4 sfu). The initial uncorrected TEC can possess very high and unphysical values. It is due to a high DCB value. After the CODE DCB correction, there appear unphysical negative TEC values in the GLONASS data. This indicates the revaluation of the DCB values. The TEC values obtained by the described algorithm are more physically plausible. In the THU2 arctic station data associated with low solar activity (Fig. 1d, e, i, j), unphysical negative TEC values appear in the GLONASS data after the CODE DCB correction. There are also very small untypical values (~0 TECU) in the GPS and GLONASS data after correction based on the above algorithm.

For the data associated with high solar activity we found that very small untypical values (much lower than the absolute vertical TEC data) appear for this period in the GPS data after the CODE DCB correction. This also may be related to the revaluation of the DCB values.

We also found a TEC peak during dusktime at IRKJ summer data. This behaviour for summer diurnal TEC and foF2 variations usually is observed at mid-latitude stations [8].

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