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Ionospheric parameters estimation using GLONASS/GPS data

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Abstract

In recent time, GLONASS/GPS signals are widely used for continuous monitoring of the ionospheric plasma conditions. However the ground-based GLONASS/GPS station for sounding of the ionosphere cannot provide high spatial resolution. To solve this problem, ionospheric models are used. In this article the algorithm of ionospheric model adaptation according to GLONASS/GPS data is offered. The expediency of use as the adaptive parameter values of the solar 10.7 cm radio flux index, which characterizes the level of solar activity, is shown. The adaptation parameter is defined by the minimization of the difference between the correlation matrices of the experimental and modeled TEC values. Reducing errors in the determination of ionospheric parameters in comparison with the simulation results is confirmed by experimental works in Moscow.

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1. Introduction

The ionospheric parameters vary strongly depending on the time of day, season, location, the solar and geomagnetic activity. Therefore, there is a need to use the continuous monitoring of the propagation medium. The main sources of actual information about ionospheric conditions are sounding and tomography based on Global Navigation Satellite Systems (GNSS). These methods are based on different principles and each of them has advantages and disadvantages (Ivanov et al., 1998; Kunitsyn et al., 2007; Memarzadeh, 2009).

To provide the reliability of the high frequency (HF) communications, it is necessary to estimate such ionospheric parameter as the F2-layer critical frequency – the maximum frequency that can be reflected back to Earth by the ionosphere F2-layer for the vertical incidence. The vertical sounding (VS) is the most validated and reliable approach of measuring this parameter. However there are some disadvantages of sounding as well: the local measurements, large weight and size, high operational expenses and, in the case of using in the communication systems, electromagnetic compatibility problems. Nevertheless, this method remains the main source of getting information about the distribution of electron density (Bamford, 2000; Andreeva et al., 2010). To research the methods of ionospheric parameters estimation in this article, values of F2-layer critical frequency were obtained from the Digital Ionogram Data Base (DIDBase). DIDBase (http://ulcar.uml.edu/DIDBase/) is a web-based database of digisonde ionogram data for many locations and periods of time. All ionograms were manually processed to avoid additional errors.

Ionospheric empirical models can be used as an alternative to sounding. These models are the most widely used class, because they require a low computational cost and limited set of input data. The International Reference

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Ionosphere (IRI, last version is IRI-2012) model (Bilitza, 2001; Bilitza et al., 2014) and European ionospheric NeQuick model (Coisson, 2002; Radicella, 2008, 2009; Brunini et al., 2011) are well-known and most developed members of this class. Comparative analysis of the two models (see Coisson et al., 2002; Andreeva et al., 2010) has shown that they reproduce well the maximum electron density at different levels of geomagnetic disturbances but estimate worse the ionospheric electron density profile. The accuracy of calculation for vertical total electron content (TEC) is 10–15% higher while using NeQuick. It is necessary to note algorithmic simplicity of this model. Profile approximation is carried out by a single function (Epstein function) that avoids the problems with "stitching" of individual segments. Taking into account the advantages noted above the NeQuick model was preferred when implementing adaptive ionospheric model.

However, usage the most developed models may also cause large ionospheric parameter estimation errors, especially during the periods of high geomagnetic activity (Memarzadeh, 2009; Gulyaeva, 2012). Based on progress in GNSS systems, new opportunities of transionospheric sounding can solve this problem partially. The ionospheric total electron content can be estimated by using GNSS dual-frequency observations. Then TEC can be used to adjust the accuracy of the ionospheric model (Nava et al., 2005, 2006). This algorithm can be modified by using correlation technique to calculate the ionospheric model adaptation parameter.

Thus, the aim of this article is to estimate the advantage of the proposed algorithm to determine the ionospheric parameters, such as TEC and F2-layer critical frequency, and compare the obtained values with results calculated by the NeQuick model.

2. Method of critical frequency estimation

It is well known that dual frequency GNSS receivers have been widely used to estimate ionospheric total electron content. In this section, using GLONASS/GPS measurements with the ionospheric model NeQuick, we will consider the method for determining such parameters as TEC and F2-layer critical frequency.

2.1. Total electron content

The GNSS receiver can determine the pseudorange p and the carrier phase ϕ along the ray path from satellite to receiver at two different frequencies f_{L1}, f_{L2}. Using these dual-frequency measurements it is possible to estimate corresponding values of TEC (Zhang et al., 2003):

$$I_p = \gamma(p_{L1} - p_{L2}) + \Delta\mathrm{DCB}, \tag{1}$$

$$I_\phi = \gamma(\phi_{L2} - \phi_{L1} - b_{12} - N), \tag{2}$$

where $\gamma = f_{L1}^2 f_{L2}^2 / \left(40.3\left(f_{L2}^2 - f_{L1}^2\right)\right)$, b_{12} is the phase advance of the satellite and receiver instrument biases, N is the ambiguity of the carrier phase, $\Delta\mathrm{DCB} = \mathrm{DCB}_s + \mathrm{DCB}_r$ – sum of differential code biases of the satellites and differential code biases of the receivers, respectively.

To reduce the magnitude of noise level in TEC measurements, the weighted algorithm of smoothing code pseudorange with carrier phase (Lachapelle et al., 1986) may be used. A definition for smoothed pseudorange for the epoch of an entire satellite pass generally takes the following form:

$$I^i = w_m^i I_p^i + w_n^i\left(I^{i-1} + \left(I_\varphi^i - I_\varphi^{i-1}\right)\right), \tag{3}$$

where w_m and w_n are the weighting functions and the relationships between them are defined as:

$$w_m^i + w_n^i = 1. \tag{4}$$

After smoothing, the slant total electronic content $sTEC$ can be expressed as follows:

$$sTEC = I - \mathrm{DCB}_s - \mathrm{DCB}_r. \tag{5}$$

To separate reliable DCBs from $sTEC$ values the least squares method can be used.

2.2. Algorithm of DCB estimate

In the single layer model, all electrons in the ionosphere are concentrated in a thin shell enveloping the Earth as hollow sphere at altitude h. The intersection between line of sight ray path from the satellite to the receiver and this shell is called the Ionospheric Pierce Point (IPP). Based on the single layer model assumption the $sTEC$ can be converted into the vertical total electron content $vTEC$ as follows:

$$vTEC = sTEC\,\cos\left(\arcsin\left(\frac{R}{R+h}\right)\cos\beta\right), \tag{6}$$

where R is the earth's radius, β is the satellite elevation angle.

There are several methods of the differential code bias estimation (e.g. Schaer, 1997; Zhang et al., 2003; Sasibhushana Rao, 2007). In our research, we used the representation of the $vTEC$ as series of spherical harmonics function, which allows the separation of the DCBs from the $sTEC$ by the least squares method (Schaer, 1997; Jin et al., 2012). The $vTEC$ can be expressed as follows:

$$vTEC = \sum_{n=0}^{n_{\max}} \sum_{m=0}^{n} \tilde{P}_{nm}(\sin\theta)(a_{nm}\sin m\lambda_s + b_{nm}\sin m\lambda_s), \tag{7}$$

where a_{nm}, b_{nm} are the ionosphere model coefficients, θ is the geocentric latitude of the IPP, λ_s is the sun-fixed longitude of the IPP, defined as

$$\lambda_s = \lambda - \lambda_0, \tag{8}$$

where λ, λ_0 are the longitude of the IPP and the longitude of the Sun, respectively

$$\tilde{P}_{nm} = \Lambda_{nm} P_{nm}, \tag{9}$$

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