Modelling of Atmosphere Time State Using Regular Observations of TEC Parameters

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Abstract – the use of a network of active reference stations to establish the numerical characteristics of the Earth's ionosphere allows to create an effective ionosphere monitoring technology on a regional scale, designed to address the scientific challenges of space weather and practical problems coordinate support geodetic accuracy class. In this work we decided the task of recovering the time state of the ionosphere using regular observations of the TEC parameters (VTEC – Vertical TEC) for permanent station SULP. The authors have described one possible way of solving this problem, which is based on mathematical modeling with using degree polynomials and trigonometric Fourier series. Degree polynomials describe the trend of function, whereas the trigonometric Fourier series in order to better simulate the fluctuation.

Key words – atmosphere, ionosphere parameters, degree polynomials, trigonometric Fourier series.

I. Introduction

Global Navigation Satellite Systems (GNSS) are currently the most effective and promising means of ionosphere on all radio physical methods. Using such measurements remote diagnostics has several advantages compared to classical radio physical means of probing the atmosphere, in particular - continuity of measurement, high spatial, temporal resolution and global monitoring ionospheric disturbances of different nature [3].

Generally, all errors carried by these sources can be described by next equation:

$$L = \rho + c \cdot (dT - dt) + \lambda \cdot N - d_{ion} + d_{trop} + d_{mp} + e, \qquad (1)$$

where L – distance to satellite, measured with phase method, ρ – geometric distance to satellite, *(dT-dt)* – unsynchronism of reciever's and sattelite's clocks, N – number of waves which insert in distance from satellite to reciever, d_{ion} – error by influence of atmosphere, d_{trop} – error by influence of troposphere, d_{mp} – error by multipath of signal spreading, e – user's error, c – spreading speed of radio signal.

The errors caused by the external environment influence have significant impact on their precisions among these sources of GNSS-measurements' errors. When radio signal (satellite-reciever) goes through the Earth's atmosphere - inhomogeneous covering of the Earth which contains of sum of gases, it changes speed. This change has the biggest when the radio signal goes through the ionosphere – the par of atmosphere, which is characterized by a high content of ions and free electrons.

The free electrons in the ionosphere strongly affect the propagation of radio waves, which leads to errors distances the signals GNSS [4]. For single-band GNSS receivers errors caused by the ionosph1gere, currently the most total error affecting the accuracy of the positioning. The value of residual ionospheric delay can cause a distance error of about 10 meters.

In view of the above, this paper has been given the task to recreate the time state of the ionosphere, according to regular observations indicator TEC, rather VTEC - (Vertical TEC) station SULP (NU "Lviv Polytechnic") and create your own ionospheric model that could locally carry the latest information on the status of ionospheric plasma at certain times.

II. Methodology

The permanent station SULP finds the meaning indicators of TEC every second by satellite radio navigation measurements - pseudorange to satellites [2]. These indicators TEC content of the total number of electrons make it possible to follow the change in ionospheric plasma state, increase or decrease in the number of electrons per unit volume and build a suitable model that would describe best the state of the ionosphere at a given time.

Therefore, in this study, we propose method for creating a model of the ionosphere parameters values TEC.

In order to obtain analytical dependence describing large amounts of data, including regular Indices TEC, use the method of approximating power polynomials, which describes trends in the data and provides the minimum sum of squared deviations of experimental data from this function [1].

The best criterion for approximation problems is the criterion of standard deviation. For the solution of this problem must be found polynomial power law of the form:

$$M(x) = \sum_{i=0}^{m} C_i \cdot x^i, \qquad (2)$$

such that the sum of squared deviations polynomial M (x) from a given experimental points system would be minimal. This problem is reduced to determining the polynomial coefficients $\{c_0, c_1, c_2, \ldots c_m\}$.

Considering the important elements of the vector-column C (x), we can build the time ionosphere model according to the definitions of regular rate TEC. This model is shown in figure 1.

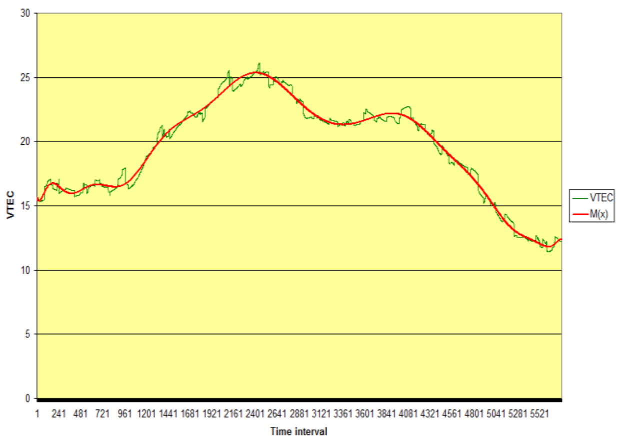

Fig. 1. The time ionosphere model M (x) built by approximating power polynomials

The criteria for evaluation of accuracy is the value of mean square error (MSE), which is given by:

$$\mu_{M_{(x)}} = \sqrt{\frac{V^T V}{n-1}}, \qquad (3)$$

where V is mentioned deviations i-th point of the experimental data of VTEC i-th point created a model with a power polynomial.

Then, following the appropriate matrix calculation, meaning MSE model M (x), built by power polynomials will be $\mu_{M_{(x)}} = 0{,}39$.

This value MSE generally acceptable. Therefore, our proposed method, which is to reduce deviations (fluctuateons) functional model of the ionosphere, built using approximating polynomials on values of experimental data VTEC (vector L). The essence of this technique is to create another model based on fitting deviations V_i using trigonometric Fourier series.

Let consequence of temporal ionosphere model M (x) there is an array of variations $V = (v_1, v_2, ..., v_n)$ the model of experimental points of the study. As a result, we get a model V (x), which is adding to the polynomial M (x), formed a new temporal model of the ionosphere ***I*** what will be the best place for experimental values VTEC and MSE indicator which is much smaller than power polynomials.

Summarizing, let note:

$$V(x) = \sum_{i=1}^{g} (a_i \cos ix + b_i \sin ix), \qquad (4)$$

where g is order of trigonometric Fourier series.

Task of modeling variation V is reduced to determine trigonometric Fourier series coefficients $\{a_1, a_2, ... a_n\}$ and $\{b_1, b_2, ... b_n\}$. It is well known, these factors can be determined by the close integration.

III. Results

General model ***I***, which restores the state of the ionosphere time according to regular indices TEC, is found as the sum of the previous two models:

$$I = M + V. \qquad (5)$$

If we analyze the resulting of model ***I*** it should be noted that it approximates values of VTEC with sufficient accuracy. The criteria for evaluation of the accuracy of the value will mean square error (MSE), which is given

$$\mu_I = \sqrt{\frac{W^T W}{n-1}}, \qquad (6)$$

where W is column vector containing important deviations w_i (fig. 2).

Then MSE values for the model is $\mu_I = 0{,}12$. This value MSE model ***I*** demonstrates the correctness of all actions in its creation, as implemented by the following inequality: $\mu_I < \mu_{M(x)}$.

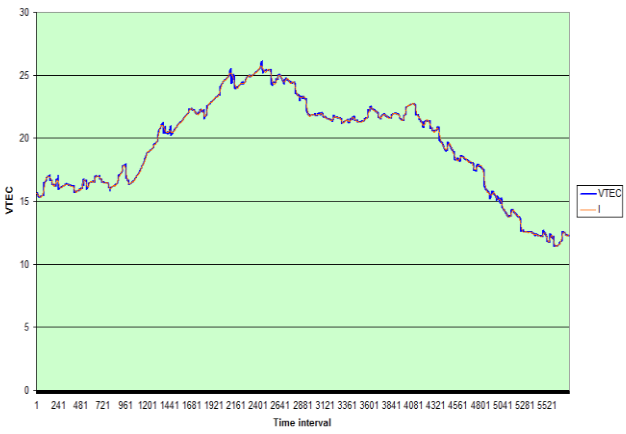

Fig. 2. The time ionosphere model and built using approximating power polynomials and trigonometric Fourier series

Conclusion

Software developed to restore VTEC field for permanent GNSS-stations SULP and its graphical display can be used in automated real-time, as well as data processing systems of other stations. Because the technique enables detailed analysis of the ionosphere in any area, will make short-term forecasting of ionosphere impact for high-precision coordinate determination using GNSS-technologies.

Rejection w_i of model ***I*** that was built using approximating power polynomials and trigonometric Fourier series of experimental parameters VTEC is acceptable.

Therefore, the application of this algorithm for data processing opens up opportunities to create temporal ionosphere models, analysis features ionosphere parameters, the study of external influences on their change over time, and to improve solving coordinate and time support.

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