ON THE PROBLEM OF THE IONOSPHERE CONSTRUCTION WITH THE AID OF DORIS, GPS AND GLONASSSATELLITE SYSTEM

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ABSTRACT: *It is proposed the ionosphere state approximation technology on the DORIS, GPS and global IGS GPS network observations basis. The comparative estimates of the TEC extrapolation by means of the proposed technology based on the Nonparametric Methods Theory and traditional ones are carried out. The possibility of the regional ionosphere model construction for middle latitudes with the aid of one-frequency GLONASS/GPS receiver and the orbitography DORIS beacon transmitter are considered. The teaching models and algorithms of nonparametric type are used. The application areas of ionosphere one-frequency models for the dangerous structures monitoring in the Siberian region are shown. The monitoring possibility estimation with the use of present equipment of Krasnoyarsk Centre of geodynamics research in order to warn emergency situations is carried out. It is considered requirements for the DORIS and GLONASS/GPS receivers assigned for the dangerous structures monitoring. It is considered conditions of the DORIS and GLONASS/GPS systems equipment assigned for the dangerous structures monitoring.*

1. INTRODUCTION

The dangerous constructions monitoring problem on the Earth surface and into upper Earth crust layers in order to warn emergency situations is resolved at present as with traditional technologies as with the aid navigational GLONASS and/or GPS receivers. Moreover, it is necessary to achieve an accuracy of the mutual determination of Earth surface points position on the $10^{-7} \div 10^{-8}$ level of the base length. This is corresponding to errors not more millimetres of units over the 100 km bases. Today such accuracy achievement is possible with the aid of two frequency receivers. But indicated receivers have high price and their usage is under correspondent military authorities control. Therefore for the large satellite navigational systems use at the Earth surface movement monitoring the indicated accuracy achievement for one frequency civil receivers is desirable.

The compensation of the ephemerides systematic errors decorrelation and the time scale shift is the same as for one as for two frequency receivers. There is the same respect to troposphere delays. However, for the one-frequency receivers the indicated accuracy achievement become problematic because of ionosphere delays correction absence on the 30 and more kilometres bases. Then theirs decorrelation become noticeable. Therefore for the creation of the local monitoring system of the Earth surface movements on the one frequency receivers basis the ionosphere errors compensation is become more important.

South part of Krasnoyarsky krai is very interest with point of view of geodynamics monitoring since it is region with the concentration of dangerous constructions of different types such as: town building, underground metro tunnels, Krasnoyarsk and Sajano-Shushensky hydropower stations, storage places of dangerous plants waste products and so on… The Krasnoyarsk geodynamics

Centre creation at 1994 allowed to expand facilities of the geodynamics monitoring by modern satellite means. For these purposes in the Centre the GPS SNR-8000 receiver of International geodynamics Service and experimental specimens of GLONASS/GPS receivers worked out by NPO PM and KSTU are used. The use of two-frequency orbitography DORIS beacon measurements installed in 1995 and other beacons measurements of the Siberian region are planned.

The present paper is dedicated to methods of influence increasing of strong correlated ionosphere errors of one-frequency receivers that are used for the local geodynamics monitoring. This increasing is performed by means of the ionosphere global and regional models creation for the middle latitudes on the basis of measurements of two frequency GLONASS/GPS receivers and the DORIS beacons-transmitters. At the carrying out of the local geodynamics monitoring an information about the ionosphere state only in a given locality is necessary. Therefore one may confined only to a Local Ionosphere Model (LIM) creation that more fully takes into account the ionosphere behaviour peculiarity namely in this locality. The LIM is built with one-frequency receivers of the local monitoring system and allows to correct ionosphere errors on the bases up to 100 km.

The multitude of Global Ionosphere Models exist that allow to calculate the vertical profile of electron content and its maximum height in dependence on signals frequency [Bakitko 93]. All these models are very complex and present the combination of different functions type with coefficients fitted to observations. And nevertheless, because of all ionosphere parameters high variability all models accuracy does not precede 35 % for the value of electron content maximum and 11% for this maximum height. But the maximum error values achieve 70 % and 15 % accordingly. However the GLONASS and GPS spacecrafts are on the heights that on one order greater than the ionosphere upper border. Therefore at tacking into account the ionosphere delays influence to the spacecraft radio signals propagation the ionosphere can be considered as the lay with constant electron content and that is placed on the fix height (350 km) as it is accepted at the far Space radiolinks calculation [Bakitko 93].

As it is noticed in [Nisner 96], the ionosphere concentration vertical gradients more than one order precede its horizontal ones because of its stratified structure. We shall count the value of the zenith (vertical) delay is constant for all measurement station zone of visibility. We propose to resolve the state modelling problem of the ionosphere as the stochastic system at enough high level of a priori indeterminicity with the teaching models and algorithms of the nonparametric type. Moreover we shall take into account the already had a priori information that is verified by the many year practice. The initial data for the ionosphere parameters creation will serve measurements of the GPS (navigational receivers) and DORIS (orbitography beacons) equipment. As it is known, the Total Electron Content (TEC) value along the propagation line is determined with the aid of the equation [Flock 87]:

$$TEC = \frac{\delta t \cdot c}{A} \cdot \frac{f_1^2 \cdot f_2^2}{f_1^2 - f_2^2}, \qquad (1)$$

where

TEC	Total Electron Content along the signal propagation line,
f_1, f_2	Frequencies;
δt	Difference of delay time on two frequencies;
C	Light speed;
A	Empirical coefficient on frequencies up to 10 GGz its value is equal 40.3.

The Regional Ionosphere Model creation is based on TEC two frequency measurements with the aid of the equipment installed on this site (sites) in place of their location. For the Global Ionosphere Model creation accordingly are used the globally located sites.
The presented technique of ionosphere parameters approximation is based on nonparametric Rozenblatt-Parzen kernel density estimate. The basis for the choice of nonparametric approach is defined by following factors:

- by orientation on the work in conditions, when true density is unknown;
- by absence of necessity of parametrical assumptions;
- by the simplicity of technique in comparison to other one;
- and by positive experience in practice.

Elevation mapping function

The technique of the ionosphere state identification from a single site is limited to the region visibility by that site and the trajectories of the spacecrafts. This region is slightly less then 2000 km radius from the site; an area approaching 12.5 million square km. Line-of-sight measurements must be mapped to the vertical TEC (VTEC) through the use of an ionosphere model. If uniform ionosphere is assumed then we can use the mapping function in order to estimate VTEC using the equation [Bakitko]

$$TEC = \theta(\gamma) \cdot VTEC\,. \tag{2}$$

There are many mapping functions that map measured TEC to vertical TEC. As a result there is a problem of choosing the best function. The proposed method uses benefits of the nonparametric approach and is based on the nonparametric estimate of the regression curve. Nonparametric estimate of the regression curve obtains a fitted value by taking a weighted average of the observations, with the decreasing weights for points farther from the location of interest.

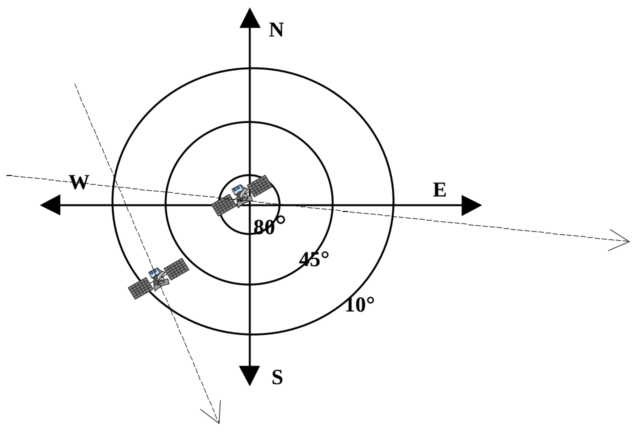

Fig. 1.

$$TEC = \hat{\theta}_n(\gamma) \cdot VTEC\,, \tag{3}$$

$$\hat{\theta}_n(\gamma) = \frac{\sum_{i=1}^{n} \theta_i K\left(\frac{\gamma - \gamma_i}{c_n}\right)}{\sum_{i=1}^{n} K\left(\frac{\gamma - \gamma_i}{c_n}\right)},\ \theta_i = \frac{TEC_i}{VTEC_i}\,, \tag{4}$$

where:

$VTEC$ is the measured vertical Total Electron Content (TECU),

TEC_i is the measured total electron content (TECU),

TEC_i and $VTEC_i$ are measured at the same time,

γ is the elevation angle of the spacecraft,

$K(\cdot)$ is the kernel function,

c_n is the bandwidth (smoothing) parameter, the bandwidth controls the smoothness degree.

Here θ is the mapping or slope function that allow to recount the VTEC values to TEC ones for any elevation angles γ.
In practice the algorithm of the best smoothing parameter finding are based on the cross-validation method [Lapko 96].
The presented technique uses orbits features of GLONASS spacecrafts. Their traces currently shift relatively on the Earth surface in the west direction. Hence we can see if only one spacecraft with elevation angle close 90 degrees in every point of Earth and the another spacecrafts with various elevation angles (Fig.1).

Nonparametric Global Ionosphere Mapping (NGIM) technique

The present paper proposes the method of the spatial ionosphere approximation based on the nonparametric estimate of the regression curve.

$$TEC_n(B,L)=\frac{\sum_{i=1}^{n} TEC_i K\left(\frac{B-B_i}{c_n}\right)K\left(\frac{L-L_i}{c_n}\right)}{\sum_{i=1}^{n} K\left(\frac{B-B_i}{c_n}\right)K\left(\frac{L-L_i}{c_n}\right)}. \quad (5)$$

where TEC_i is the measured vertical total electron content (TECU) at a point "i" with latitude B and longitude L.

Nonparametric Local Ionosphere Mapping (NLIM) technique

The recurrent analogue of the presented above estimate for any fixed point will save computer memory and improve the convergence speed.

$$TEC_n(B,L)=\frac{D_n}{N_n}, \quad (6)$$

$$D_n = D_{n-1} + TEC_n K\left(\frac{B-B_n}{c(n)}\right)K\left(\frac{L-L_n}{c(n)}\right), \quad (7)$$

$$N_n = N_{n-1} + K\left(\frac{B - B_n}{c(n)}\right)K\left(\frac{L - L_n}{c(n)}\right), \tag{8}$$
$$L = Const\ , B = Const\ .$$

Simulation results

We used the mapping function from the Klobuchar model as true. The Gaussian noise was added for the real condition simulation.

Simulation characteristics	
Measurements error	$\sigma = 5\ TEC$
Estimate error	$\sigma = 0.092$

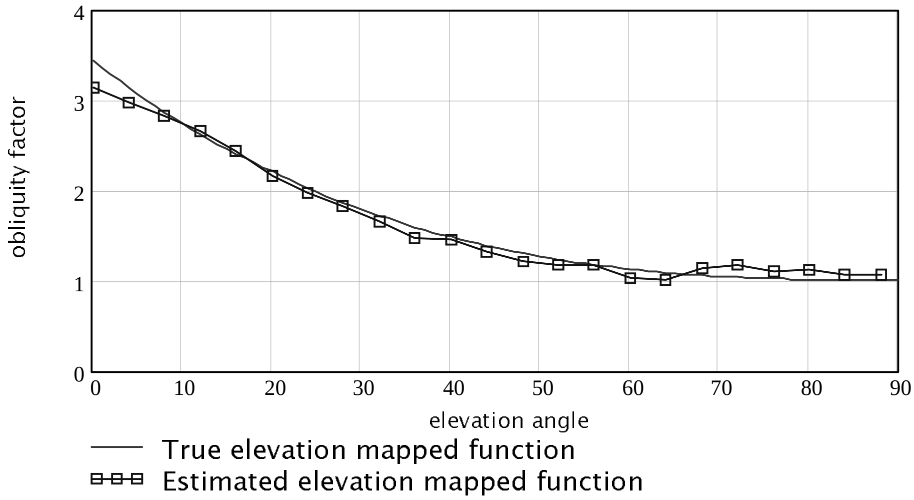

Fig.2. Nonparametric estimation of elevation mapping function

The ionosphere models presented in the given paper have the teaching possibilities. The ionosphere state estimate accuracy will continuously increase during the carrying out process of the measurement companies sequence.

The base peculiarities of the estimate algorithm of the signal ionosphere delay that is used in the models are:

- the cameral data processing,
- the operation at unknown noise distribution and estimated process model laws,
- the use possibility of one frequency at the local geodynamics monitoring.

So the Regional Ionosphere created on the NGIM base is the a priori one for the Local Model creation that is built on the one-frequency measurements carrying out.

The obtained models accuracy estimate allows hoping to their usage possibility for the practical application at the real information processing. Correspondent works at these models comprehensive approval is carried out at present in Krasnoyarsk Centre of Geodynamics Research. However there is the problem of sufficient operational information reception from GPS receivers and DORIS orbitography beacons of the Siberia region. An if the measurement accuracy of the DORIS and GPS equipment is sufficient for providing of the accuracy required for the local monitoring systems then the network cover that is necessary for the NRIM creation is obviously insufficient. For example, the nearest to Krasnoyarsk GPS receiver is installed in Novosibirsk (about 650 km), and DORIS orbitography beacon is installed in Kitab, Uzbekiston (about 3000 km).

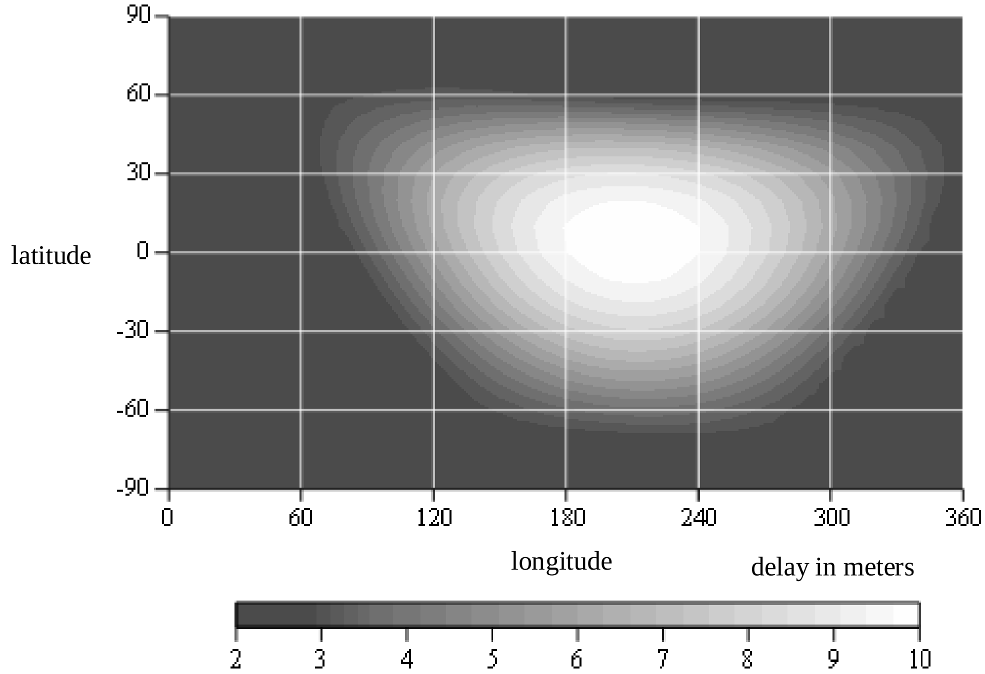

Fig. 3. Global Ionosphere Map according Klobuchar model at approximately 1:00, 01.01.98.

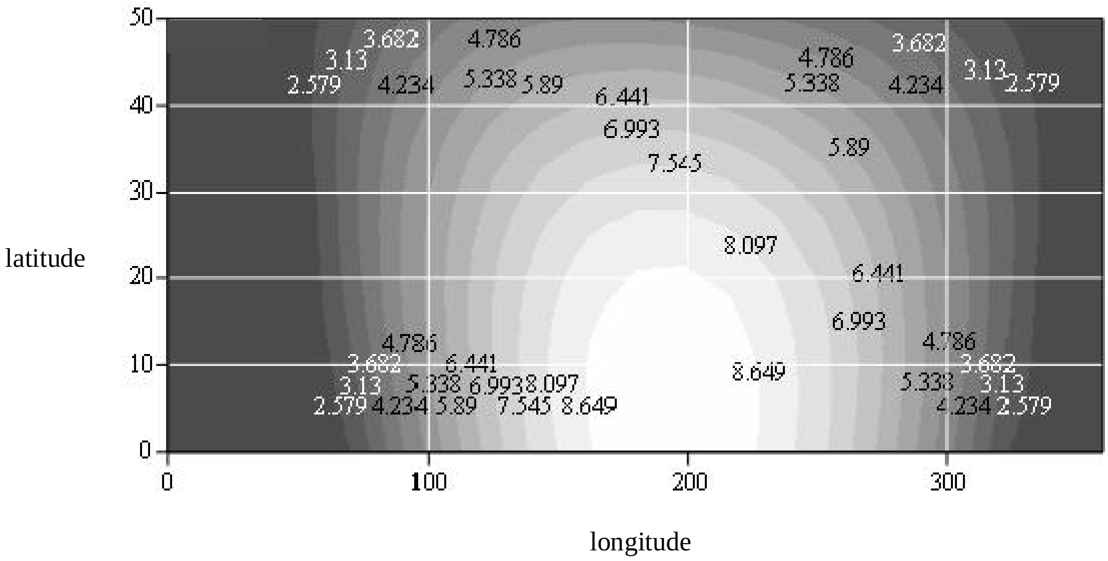

Fig. 4. Spatial ionosphere approximation by NGIM technique

In the ionosphere the propagation speed of the carrier frequency signal phase is greater than the light speed in the free space on some value. The modulated signal propagation speed is less than the light speed on the same value. Then the difference of the pseudo range measurements at the code delay and at the carrier phase delay is equal to the signal double ionosphere delay and may be used for it compensation.

$$\Delta R = \frac{r - \varphi\lambda}{2} + \varepsilon\,, \tag{9}$$

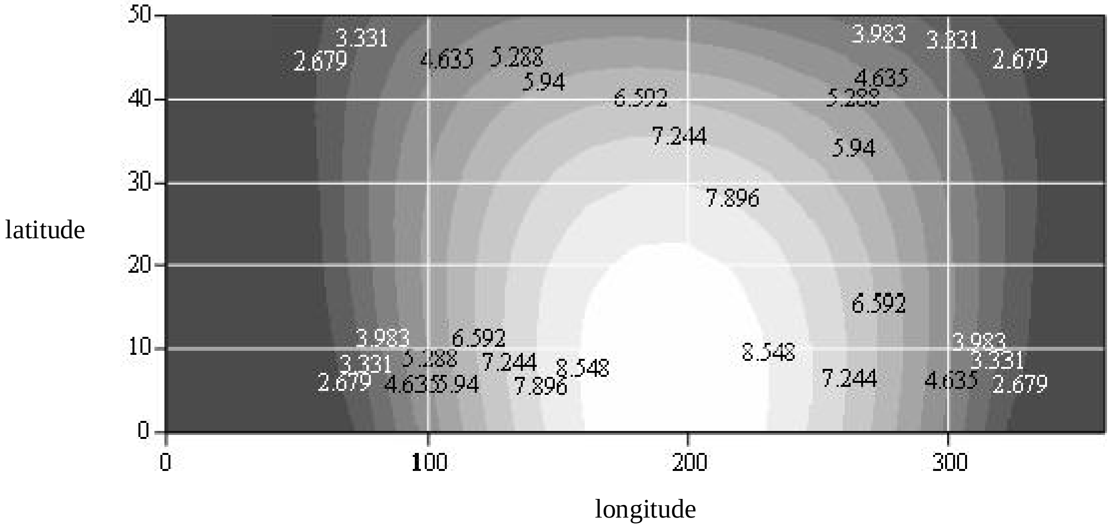

Fig. 5. Simulated ionosphere according Klobuchar model obtained as true

In the equation (9):

ΔR	-	The signal delay in the ionosphere,
r	-	The pseudo range at the code delay,
φ	-	The phase pseudo range,
λ	-	The signal wave length,
ε	-	The random noise.

The measurements processing for purposes of the local geodynamics monitoring is the static process and it is performed in the not real time regimen. Therefore the ionosphere delays calculation will carried out a posteriori during the determination process of mutual location of antennas phase centres of the navigational receivers pairs. For these purposes it is sufficient to determine only delays from spacecrafts and not to increase the state vector measure with the aid of including into it the space factor components. This circumstances allows refusing to the algorithm application based on the maximum of likelihood method. During the algorithms realisation used at present for the measurement information processing this information is gradually “forgotten“, that to say is not used during further estimating. This extremely makes difficult excluding irregular measurements. Moreover for such algorithms practical application it is necessary to give some probabilistic characteristics of measurements and model errors. The errors normal distribution hypotheses for such object as the ionosphere turn out to be incorrect and will lead to distinct decreasing of obtained results.

For processing of the obtained measurements the teaching nonparametric filter use is proposed [Kavtarashvily 97]. This filter is capable to operate in the nonparametric indeterminicity conditions as distinct from the above mentioned methods (when noise distribution laws and the process model structure with an accuracy till parameters are unknown). Besides this filter has the robust property to irregular measurements.

At present the working out of the Software of ionosphere errors compensation and the Nonparametric Regional and Local Models creation with the aid of the one-frequency receivers is completed. It is planned to perform the proposed algorithm approval with using the real measurements of experimental receiver specimen designed by KSTU and NPO PM. The development and manufacturing works of geodetic GLONASS/GPS one frequency receiver as standard one in the local monitoring system of dangerous objects are carried out by parallel manner.

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