GLONASS/GPS SINGLE FREQUENCY RECEIVER TEST VALIDATION USING IGS AND DORIS DATA

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The numerous investigations testify that on the eve of an earthquake there are various perturbations of electromagnetic waves propagated in near-the-Earth space. These perturbations are fixed by various devices and can serve as earthquake forecasting signs.

In [1] the method consisting in the web use of controlling and correcting stations (CCS) of a differential subsystem of space navigational systems (SNS) is offered for seismic monitoring of the Earth. The essence of the given method lies in the idea that above the site of the coming earthquake a site of ionosphere perturbations arises, in comparison with the adjacent sites causing a higher carrier charge concentration. As each navigational SNS satellite moves along an orbit known in advance and the CCS coordinates are known with a high precision, the true values of ranges CCS-satellites are also known with a high precision. The predicted and known distance difference is an error in measurement, the magnitude of that substantially depends on ionosphere conditions, so it can be used for earthquake forecasting. Being aware of a satellite position with irregular measurement values, it is possible to find the area of a higher electronic concentration in ionosphere, and thus to locate coming earthquake.

A disadvantage of the offered method lies in expensive two-frequency navigation receivers used for ionosphere parameters defining.

To define ionosphere parameters, the orbitographic satellite system DORIS can be used. The system is based on the satellite onboard measuring the Doppler shift frequency of signals received from on-ground beacons. The measurements are fulfilled at two frequencies 2036.25 and 401.25 MHz, that allows taking into account an ionospheric condition [2]. The international DORIS service (IDS) publishes data on an ionospheric and troposheric condition, and meteorological data for the locationing transmitters of the DORIS system [3]. The ionosphere data acquired also can be used for earthquake forecasting for on-ground DORIS-system stations locations.

The disadvantages of the DORIS system for earthquake forecasting are: an impossibility of operative ionosphere parameters defining in the beacon location, a high cost of the equipment, difficulty of its installation, the necessity of the installation permission given in France and the permission on the frequency utilization in the country of its allocation. The above disadvantages restrict the possibilities of the DORIS system use for a seismic activities monitoring in the Globe various areas.

The report submitted is dedicated to the solution of a problem to evaluate ionosphere conditions through a navigational GLONASS/GPS single-frequency phase receiver.

The method of ionosphere influence account through GLONASS/GPS single-frequency receivers seems to be the most efficient. It is based on the account of contrasting phase signs and group delays of signal distribution. This approach enables to detect an ionosphere signal delay through single-frequency receivers, on differences between the code and phase pseudo-ranges [6]. Measurement differences in pseudo-ranges on a code and a phase delay is equal to double ionosphere signal delay, and may be used for its definition.

$$\mathrm{I_i(k)}=\frac{\mathrm{r_i(k)}-\varphi_\mathrm{i}(\mathrm{k})+\mathrm{N_i(k)}\lambda_\mathrm{i}}{2}, \tag{1}$$

where: $I_i(k)$ - an ionosphere delay of a signal in k step ($k=1,2,\dots$); $r_i(k)$- a measured pseudo-range code; $\varphi_i(k)$- a measured pseudo-range carrier frequency phase; $N_i(k)$- a starting phase measurement ambiguity; λ_i- a satellite signal wavelength; i- a satellite number, $i=\overline{1,n(k)}$; $n(k)$ - the total satellite number observed.

Methods described in abstracts [5, 6, 7] have a series of drawbacks in practical realization, to be eliminated by research carried out in KSTU. The principal problem when realizing a phase-group approach is phase measurements $N_i(k)$ starting ambiguity determination. Alongside with that, far-distant code pseudo-range measurement casual error per order exceeds the far-distant carrier frequency phase pseudo-range measurement error of the satellite signal.

With the purpose of elimination the above disadvantage, the method of finding out the ionosphere signal delay according to code and phase measurements increment difference. The pseudo-range code is determined by expression [6]:

$$r_i(k)=\rho_i(k)+I_i(k)+T_i(k)+\Delta\tau(k)\cdot c+\delta_i(k)+\xi_i(k), \qquad (2)$$

where: $\rho_i(k)$- range up to the satellite; $T_i(k)$- a troposphere satellite signal delay; $\Delta\tau(k)$ - clock divergence between the satellite and the receiver; c - speed of light; $\delta_i(k)$- systematic error; $\xi_i(k)$- casual error. The carrier frequency phase pseudo-range is determined by expression [6]:

$$\varphi_i(k)=\rho_i(k)-N_i(k)\lambda_i-I_i(k)+T_i(k)+\Delta\tau(k)\cdot c+\delta_i(k)+\zeta_i(k), \qquad (3)$$

where: $N_i(k)$ - the starting ambiguity of the carrier frequency phase measurements; λ_i- a signal wavelength; $\zeta_i(k)$- a casual error.

The value of the error caused by ionosphere influence will depend on an satellite signal path length in ionosphere. For satellites with low elevation angles the signal path length will be longer, than for satellites with high elevations. Therefore, the ionosphere error will be reciprocal to a satellite elevation. The vertical delay (satellite elevation angle $\gamma=90^0$) and the sloping delay (satellite elevation angle $\gamma<90^0$) are distinguished. Their correlation is found out by the following expression [6, 7]

$$I_i(k)=Ob(\gamma_i(k))I_v(k), \qquad (4)$$

where: $Ob(\gamma_i(k))$ - a mapping function [7]; $I_v(k)$ - a vertical delay of an ionosphere signal; $\gamma_i(k)$- the satellite elevation angle. The mapping function intended for recalculation of a vertical delay in a sloping delay, is defined by the following expression [7]:

$$Ob(\gamma_i(k))=\frac{1}{\sqrt{1-\left(\frac{R_\oplus}{R_\oplus+h}\cos\gamma_i(k)\right)^2}}, \qquad (5)$$

where: $R_\oplus$ - the Earth radius; h - the ionosphere stratum height.

Proceeding from the equations (2) and (3), the increment code differences and the carrier frequency phase pseudo-ranges in time $\Delta t = k - l$ (Δt - an interval of measurements) is equal to the double increment of an ionosphere signal delay for the same period of time

$$(r_i(k) - r_i(k-1)) - (\varphi_i(k) - \varphi_i(k-1)) = 2 \cdot (I_i(k) - I_i(k-1)).$$

For theoretical investigation check up, there was developed the algorithm and GPS/GLONSASS phase receiver software for the satellite signal ionosphere delay definition. This receiver is created at KSTU and operates due to L1-band frequencies GPS/GLONASS signal. During experimental investigation, the registration of radio navigational measurement parameters and navigational GPS/GLONASS satellite message was fulfilled. The data and developed method were used for the determination of the satellite signal ionosphere delay. In 2001 several measuring campaigns under various geomagnetic conditions (perturbed and quiet ionosphere) were carried out. In Tab.1 the Ap-index for the geomagnetic activity description is presented.

Tab.1. Research Experimental Outcomes

Experiment date	Duration, h	Ap-index, nT	RMS of single frequency method σ_1, m	RMS of Klobuchar model σ_2, m	$\frac{\sigma_2}{\sigma_1}$
April, 25	26	6	0.45930220	2.16281361	4.7089119
April, 26		6			
April, 28	29	40	0.86405742	2.02093429	2.3388889
April, 29		13			
May, 16	46	7	0.3878384	1.23400857	3.1817600
May, 17		6			
May, 18		8			
October, 8	24	16	1.08973087	2.24708779	2.0620576
October, 9		18			
Averaged value on all the experiments			0.69675343	1.76357926	2.7712769

For checking up of the developed method accuracy, we use the information about the ionosphere state that were obtained from a Crustal Dynamics Data Information System (CDDIS) center. These data were obtained from the International GPS Service for Geodinamics (IGS). The justification of the ionosphere state information for Krasnoyarsk is defined by the fact that there operates a two-frequency navigational TurboRugue SNR-8000 GPS receiver at KSTU, incorporated into the IGS stations net. For an experimental data precision estimation, there was used the DORIS system information, a beacon of which is also located in KSTU area. During the experiment, the tested GPS/GLONASS receiver was placed directly close to TR SNR-8000 and the DORIS beacon, that enabled to accept DORIS and IGS measurements as the reference ones.

Fig.1-2 represents ionosphere vertical signal delay estimation, they were obtained through the method developed, a Klobuchar model and data processing centers of IGS: CODE (Center for Orbit Determination in Europe), Bern, Switzerland; JPL (Jet Propulsion Laboratory) and Pasadena USA.

The graphs show on the abscissa ax a number of hours, passed since the first experimental day. The day beginning is determined by the local wintertime ZT = GLONASS system time + 4 hours.

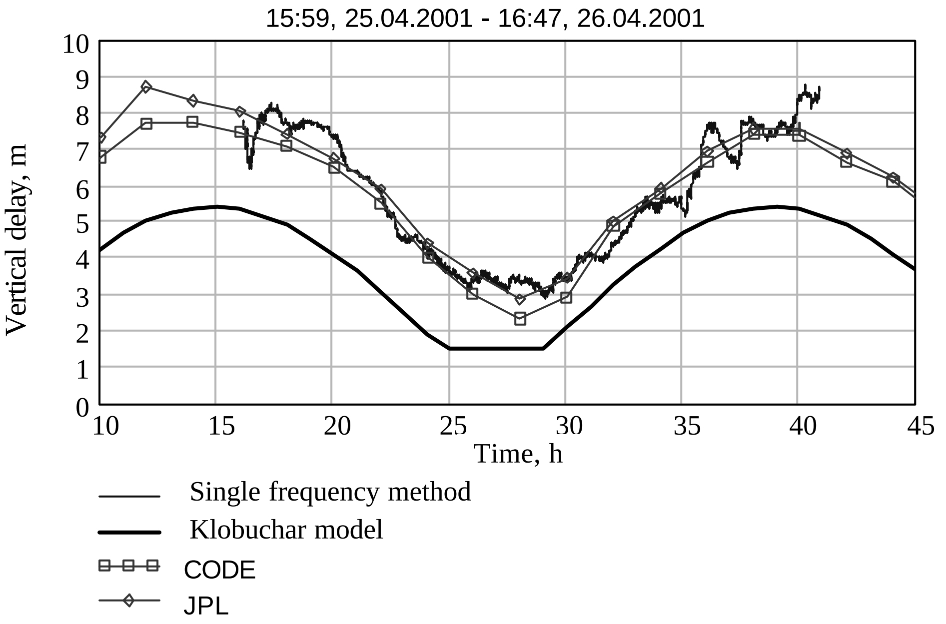

Fig.1. Experimental results, April 25-26, 2001

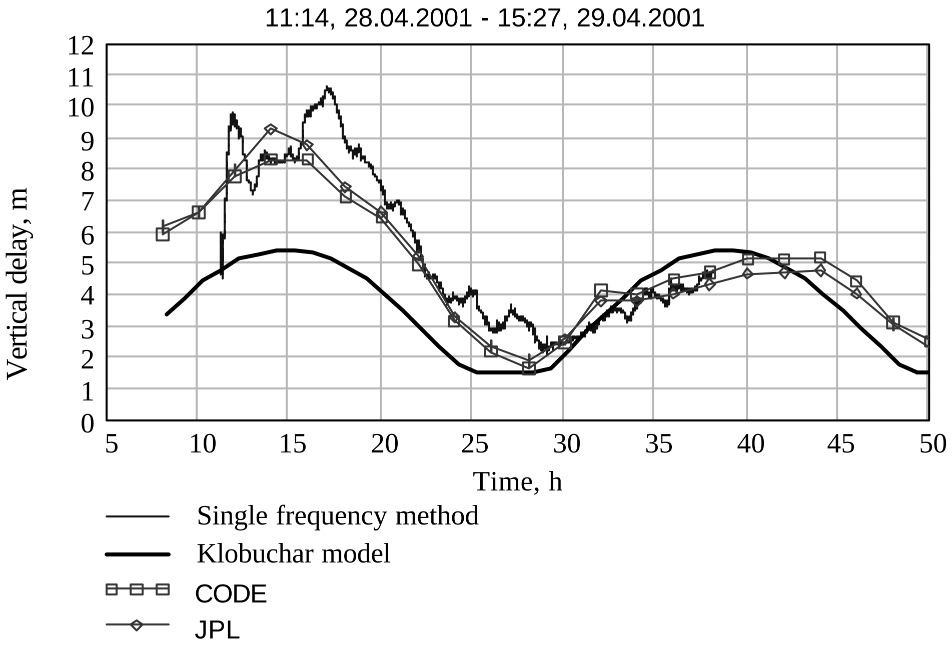

Fig.2. Experimental results, April 28-29, 2001

The comparison of experimental results with the DORIS and IGS data demonstrates a high precision of the method developed and its stability to a wide range of ionosphere conditions alterations. This method enables to increase the ionosphere delay detection accuracy in comparison with the Klobuchar model and it may be used for seismic activity monitoring in hazardous areas.

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