ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2015) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

The measurement of the ionospheric total content variations caused by a powerful radio emission of "Sura" facility on a network of GNSS-receivers

I.A. Nasyrov [a,*], D.A. Kogogin [a], A.V. Shindin [b], S.M. Grach [b], R.V. Zagretdinov [a]

[a] *Kazan Volga Region Federal University, Kremlyovskaya 18, Kazan 420008, Russian Federation*
[b] *Lobachevsky State University of Nizhni Novgorod, Gagarina 23, N. Novgorod 603950, Russian Federation*

Received 12 October 2015; received in revised form 1 December 2015; accepted 10 December 2015

Abstract

Observations of the perturbations of total electron content (TEC) caused by a powerful radio emission of "Sura" facility (Radio Physical Research Institute, N. Novgorod) were carried out during several experimental campaigns from March of 2010 to March 2013. In this paper the data of experimental measurements of TEC-variations conducted on March, 15, 2010 and on March, 12, 2013, are presented. Parameters of TEC-variations were obtained by dual-frequency global navigation satellite systems (GNSS) diagnostics. Registration of signal parameters from GNSS-transmitters was performed at spatially separated sites along the geomagnetic latitude: Vasilsursk (56°08′N, 46°05′ E), Zelenodolsk (55°52′N, 48°33′E) and Kazan (55°48′N, 49°08′E). In the experiments radio path from GNSS satellite to Vasilsursk passed over the disturbed region of ionosphere, but radio paths to Zelenodolsk and to Kazan did not. However, TEC-variations correlated with pumping of ionosphere by "Sura" facility were detected for all up to three ground measurements sites. Magnitudes of TEC-variations reached up to $\sim$ 0.6–0.7 TECU. The speculation that a sharp gradient of the electron density formed at the border of the main lobe of "Sura" facility may cause the generation of IGW is presented.

Keywords: Total electron content; Large-scale irregularities of the ionospheric plasma; Global navigation satellite systems; Sura ionospheric heating facility; Internal gravity waves; Travelling ionospheric disturbances

1. Introduction

A basic problem of upper atmosphere physics (altitudes from 80 to 1000 km) is the identification of physical mechanisms of plasma instabilities evolvement responsible for the development of electronic density fluctuations. A powerful O-mode electromagnetic pump wave transmitted vertically into the bottomside ionospheric *F* region plasma excites a wide range of plasma processes leading to the appearance of the artificial ionospheric turbulence, i.e., generation of the different *HF* and *LF* plasma modes, plasma density inhomogeneities on the scales from tens of centimeters to kilometers, enhancement of the electron temperature, electron acceleration and ionization, etc. (Gurevich, 2007). Large-scale irregularities with the scales of 5–50 km can be effectively studied using dual-frequency signals of the Navstar (GPS) or GLONASS microwave satellite systems. Propagated through the heated region, such signals acquire an additional phase increment stipulated by the dispersion of the radio waves in the ionospheric plasma and linearly related to the total electron content (TEC) on the propagation trajectory (Ginzburg, 1970; Afraimovich and Perevalova, 2006).

* Corresponding author. Tel.: +7 843 2337119, mobile: +7 9063216108.
E-mail addresses: inasyrov@kpfu.ru (I.A. Nasyrov), dkogogin@kpfu.ru (D.A. Kogogin), freaz@bk.ru (A.V. Shindin), sgrach@rf.unn.ru (S.M. Grach), Renat.Zagretdinov@kpfu.ru (R.V. Zagretdinov).

http://dx.doi.org/10.1016/j.asr.2015.12.008
0273-1177/

Please cite this article in press as: Nasyrov, I.A., et al. The measurement of the ionospheric total content variations caused by a powerful radio emission of "Sura" facility on a network of GNSS-receivers. Adv. Space Res. (2015), http://dx.doi.org/10.1016/j.asr.2015.12.008

Since the early eighties, this method has been used to determine the TEC in the ionosphere under natural conditions, and since 2007 the Navstar satellites were intensely used to determine the total electron content in the ionosphere during the experiments on ionosphere modification by high-power HF radio emission. Such studies were based on the HAARP (Milikh et al., 2008) and Sura facilities (see for example Tereshchenko et al., 2008; Frolov et al., 2010; Ryabov et al., 2011; Kunitsyn et al., 2011). A TEC increase correlated with the ionospheric heating was observed in the daytime experiments (Frolov et al., 2010; Kunitsyn et al., 2011). In Tereshchenko et al. (2008), where the observations were performed mainly after sunset with the beam of the Sura facility inclined to 12° south in the geomagnetic meridian plane, both a notable TEC increase in the heated region determined by the angular size of the antenna pattern and long-period (10–15 min) TEC variations relative to the average value were recorded. On the basis of obtained results, the authors of Tereshchenko et al. (2008) made a statement about the manifestation of the magnetic-zenith effect as the most effective impact on the ionosphere in the direction along the geomagnetic field.

Some experimental results of ionospheric TEC-variation observations caused by a powerful radio emission of "Sura" facility carried out during several experimental companies from March of 2010 to May 2013 are presented in this paper. Parameters of TEC-variations were obtained by dual-frequency global navigation satellite systems (GNSS) diagnostics. Registration of signal parameters from GNSS-transmitters were performed at spatially separated sites along the geomagnetic latitude.

The artificial TEC variations observed in our experiments did not depend on the time of the day. Since the successful sessions in the morning and afternoon time were not sufficient to detect any features associated with observations at a certain time, the main attention was paid to the evening and night observations. The experimental conditions are described in Section 2. The procedure and the results of obtained data analysis are given in Section 3. In Section 4 the results are discussed.

2. Experimental conditions

Data collection was carried out on a network of spatially separated sites situated along the geomagnetic latitude of "Sura" ionospheric heating facility, as is shown in Fig. 1. All of the experimental sites were equipped with GNSS-receivers of a geodetic accuracy class. The GNSS-receivers allow to collect a number of parameters of navigating messages used further for post processing, in particular, for definition of TEC: (1) measurements of pseudorange for P and C/A code, IS, GPS (2013); (2) phase measurements of subband $L1$ and $L2$ ($L1$ GPS — 1574.42 MHz; $L2$ GPS — 1227.60 MHz; $L1$ GLONASS — $1602\,\text{MHz} + K \times 562.5\,\text{kHz}$; $L2$ GLONASS — $1246\,\text{MHz} + K \times 437.5\,\text{kHz}$, where K is the number of the carrier frequencies of the navigation signals radiated by satellites in frequency sub-bands $L1$ and $L2$, respectively $K = -7 \ldots + 6$, ICD Glonass, 2008); (3) measurements of Doppler frequency shift, etc. Collected data from all of the experimental sites were rewritten into RINEX format (Gutner and Estey, 2007) for further processing and storage.

In all experimental sessions, the ionosphere was affected by an O-mode wave at the frequencies $f_0 = 4.3$ MHz and $f_0 = 4.74$ MHz, the frequency of heating was chosen according to the condition $f_0 < f_oF2$, the critical frequency f_oF2 and reflection height of the ionosphere during the measurements were monitored by the ionosonde located close to the "Sura" facility and was varied in the experiments from 4.4 to 6.0 MHz. The effective radiated power (P_{eff}) at the chosen frequencies amounted to 65–150 MW depending on the number of transmitters and antenna sections involved in the experiments and the operating frequency. A scheme of experiments are shown in Fig. 1.

As is seen in Fig. 1, a radio path GNSS-satellite — Vasilsursk passes through a disturbed region of an ionosphere while radio paths from GNSS-satellite to Zelenodolsk and to Kazan did not. Note that the GNSS satellites move rather slowly so that their ionospheric penetration point (IPP) remains within the disturbed region for approximately 26 min, that allows to obtain the information about the spatial and temporal characteristics of the ionospheric disturbances in the heated area.

During several experimental campaigns, namely, in 11–15 March 2010, 11–29 May 2010, 1–11 September 2010, 26 August — 3 September 2011, 11–18 September 2012, 11–14 March 2013, 13–17 May 2013 and 21–30 August 2014 over 100 sessions were made. In the morning and daytime hours (untill 14:00 LT), the TEC variations were recorded in less than 10% of the sessions, while in the later hours the TEC variations took place in more than one-half of the sessions.

3. Data processing technique and analysis of the results

The RINEX files are used for a further processing of experimental data (Gutner and Estey, 2007). The calculation of the orbital motion of satellites is done with the aid of navigation messages included into the RINEX data file in accordance with IS, GPS (2013) or ICD Glonass (2008). Example of IPP trajectory for GPS G08 in March 15, 2010 are presented in Fig. 2.

The initial data containing measurements of the phase L and pseudorange P for the operating frequencies $f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz are RINEX files. This format preserves the data from each satellite in the form of blocks of a certain length, and each block consists of the exact world time, the phase increment relative to the reference signal of the receiver, and the pseudorange for each operating frequency. Data processing was performed by a technique described in Ryabov et al. (2011).

For a detailed study of small TEC variations based on the initial dependence $I(t)$, the trend was removed by