GPS-TEC variations, generated in midlatitude and highlatitude ionosphere by powerful HF-heating.

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Abstract

In this work we report on the results of the ionospheric heating experiments, which were carried out at the Sura (Russia) and EISCAT/Heating (Norway) facilities during several heating campaigns in 2009 and 2010. We present experimental evidences for the influence of the electron density perturbations, induced by HF-heating in the midlatitude and highlatitude ionosphere, on the GNSS radio signals. Variations in the total electron content (TEC), proportional to the reduced phases of navigational signals, were studied. Examples of the identification of the heating-induced variations in TEC, including determination of the amplitudes and temporal characteristics are presented.

1. Introduction

Numerous studies of the influence of powerful HF radio waves on the ionospheric plasma [1-3] showed the development of ponderomotive parametric, thermal (resonant) parametric and self-focusing instabilities near the reflection height of the powerful radio wave, which leads, in particular, to the strong electron heating of ionospheric plasma in this region and to the generation of artificial irregularities in the ionospheric electron density with the scale sizes from fractions of meter to dozens of kilometers [1]. These irregularities should have a considerable effect on the VHF/UHF/L-band radio waves propagating through the heated area of the ionosphere. Recently, methods for sounding of the heated ionosphere by radio signals from high-orbiting navigational GNSS satellites at frequencies 1.2–1.5 GHz started to develop [4-7]. In this paper, we present the experimental results of the influence of electron density perturbations produced by the high-frequency heating of the ionosphere on the GNSS signals at the Sura (Radiophysical Research Institute, N. Novgorod, Russia) and EISCAT/Heating (Tromsø, Norway) facilities .

2. Description of the experiments and processing scheme

The experiments were carried out at the Sura heating facility (56.15N, 46.1E) and at Tromsø heating facility (69.6N, 19.2E) during several heating campaings. The measurements were conducted when foF2>f (here f is the heater frequency and foF2 is a critical frequency of the F2 layer) and the ionospheric penetration points, calculated at the reflection height of the HF pump wave, of one or more GNSS satellites crossed the heated area. HF pump wave with O-mode polarization radiated with different heating schemes: 30 s heating with maximum effective radiated power followed by 30 s pause (or, in brief notation, ±30 s); ±3 min; ±5 min; ±10 min; +10 min -5 min. The half-power beamwidth for the Sura facility is ~12°, for the EISCAT/Heating ~14°, so ionospheric penetration points of slowly moving GNSS satellites could remain within the heated area for 35–50 min, which allows to obtain some information about the temporal characteristics of the heater-induced ionospheric disturbances. The experimental data for the experiments at Tromsø were taken from the IGS station tro1, located near Tromsø. For the experimets at the Sura facility we specially installed dual frequency GNSS receiver near the facility. GPS satellite radio transmissions were recorded with 10 Hz sampling at Sura and we obtained tro1 station data with the rate 1 measurement each 15 seconds from IGS. Both L1 and L2 GPS carrier phases were used in the analysis for calculating the relative slant total electron content (sTEC). The time series of sTEC were then detrended and TEC variations during the heating sessions were analyzed using the wavelet transform to estimate the local energy spectra of these variations.

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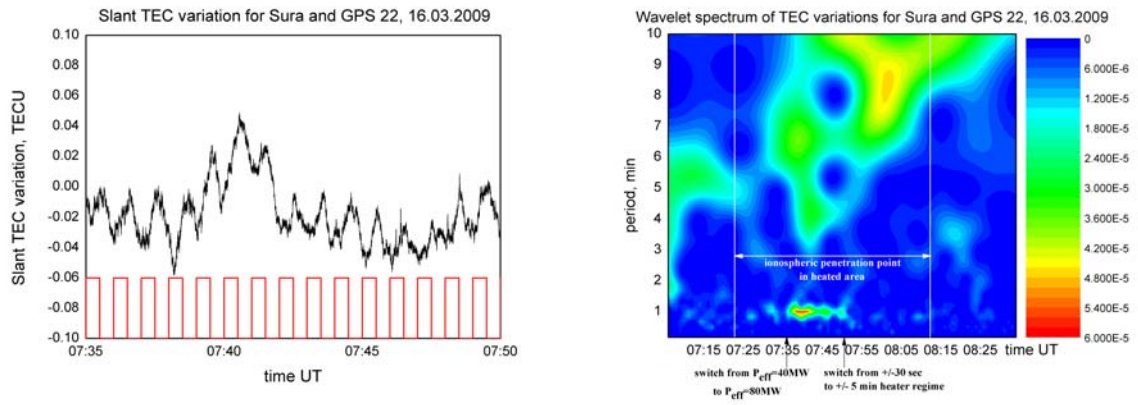
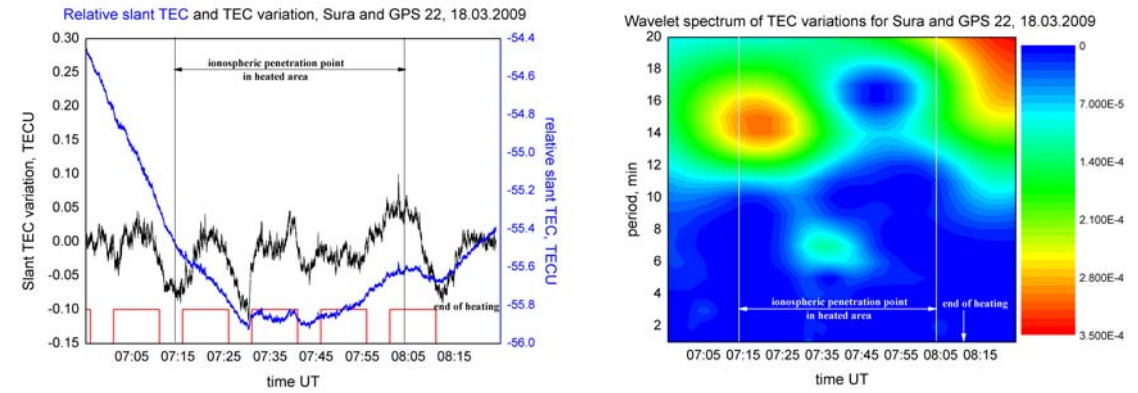
3. Obtained results

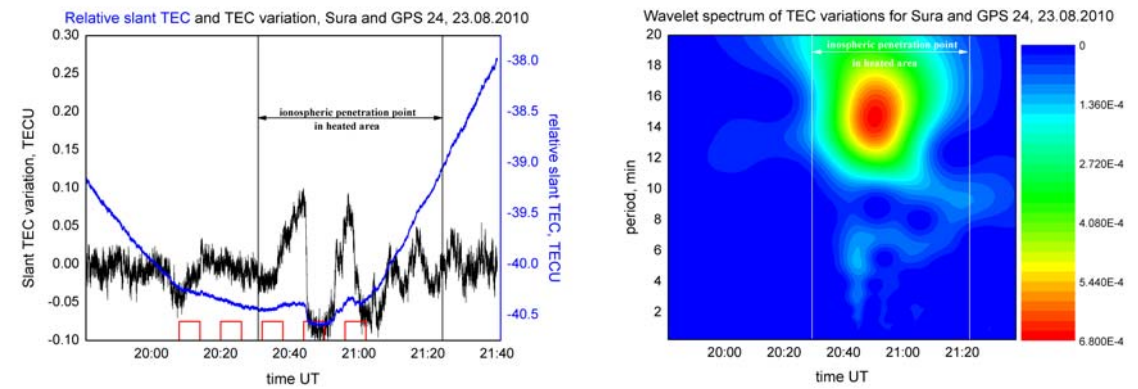
Results presented in Fig.1 are from experiments at Sura facility. Left panels are slant TECs and TEC variations, right panels are the corresponding wavelet spectra of TEC variations for the satellites which ionospheric penetration points crossed the heated area during heating experiments. The first two results (Fig.1.a,b) were obtained in daytime, the last one (Fig.1.c) in nighttime conditions. In the first part of the experiment shown in Fig.1.a the Sura



a) O-mode, f=4.3MHz, ERP~40MW until 7:36UT and 80MW after that, beam inclined by 12^0 from vertical to the south in the plane of the geomagnetic meridian to use magnetic zenith effect [1]; quiet geomagnetic conditions

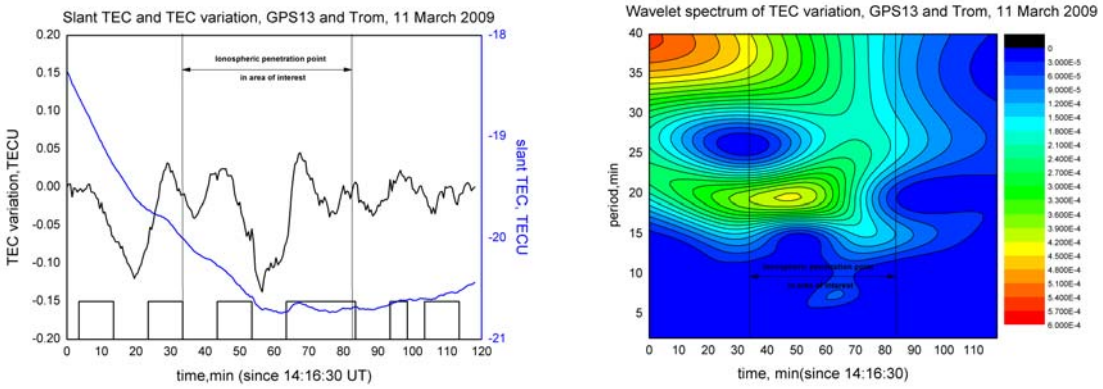


b) O-mode, f=4.3MHz, ERP~80MW, 12^0 from vertical to the south in the plane of the geomagnetic meridian; quiet geomagnetic conditions

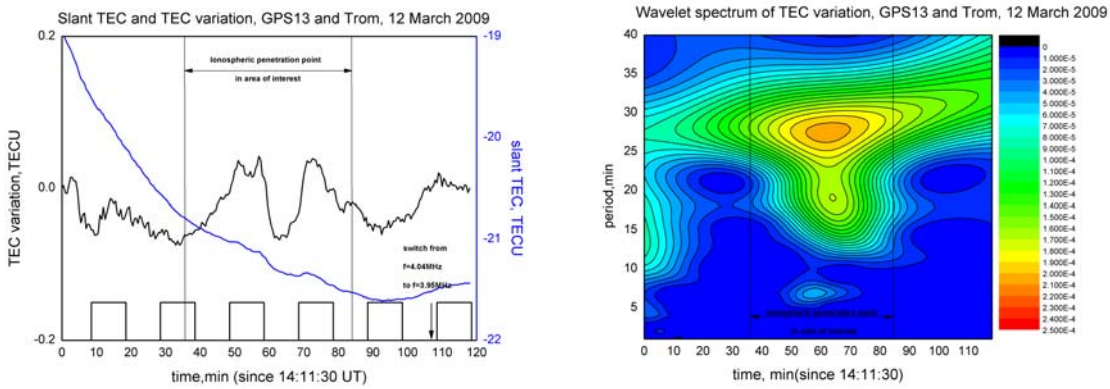


c) O-mode, f=4.3MHz, ERP~60MW, 12^0 from vertical to the south in the plane of the geomagnetic meridian; moderate geomagnetic conditions

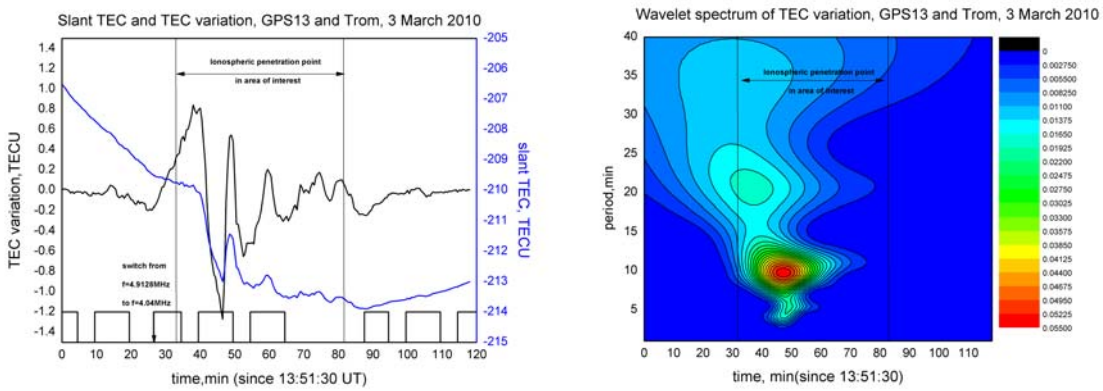
Figure 1. Heating results from the Sura facility. Variations of slant TEC (left panels) and local spectra of TEC variations (right panels) for GPS satellites, which ionospheric penetration points crossed the heated area. Borders of heated area are indicated by arrows, heating pulses are indicated with red rectangles.



a) O-mode, f=4.5443MHz till 15:01UT and f=4.0403MHz after that, ERP~200MW, 12^0 from vertical to the south in the plane of the geomagnetic meridian (towards the magnetic zenith); quiet geomagnetic conditions



b) O-mode, f=4.0403MHz till 16:00UT and f=3.9506MHz after that, ERP~200MW, 12^0 from vertical to the south in the plane of the geomagnetic meridian (towards the magnetic zenith); quiet geomagnetic conditions



c) O-mode, f=4.04MHz till, ERP~200MW, 12^0 from vertical to the south in the plane of the geomagnetic meridian (towards the magnetic zenith); disturbed geomagnetic conditions

Figure 2. Heating results from EISCAT/Heating facility. Variations of slant TEC (left panels) and local spectra of TEC variations (right panels) for GPS satellites, which ionospheric penetration points crossed the heated area. Borders of heated area are indicated by arrows, heating pulses are indicated with rectangles.

facility operated with ±30 s mode with the effective radiated power of 40 MW until 7:36 UT and 80 MW later. From 7:51 UT till 8:26 UT Sura heater started operating in ±5 min mode with the effective radiated power of 80 MW. The 1 min periodical component corresponding to the period of PW modulation is apparent in the plot of TEC variations and in the local spectrum of TEC variations, but only for the period, when the facility operated with the effective radiated power of 80 MW. The 1 min periodical component vanishes together with termination of ±30 s mode of

operation. This is an evident indication of the artificial nature of the observed variations as well as of the fact that under given ionospheric conditions, the effective radiated power of 40 MW with ±30 s mode of heating was insufficient to generate the disturbances in the electron density, detectable in GPS data. Harmonics of the main PW modulation frequency were also observed in the wavelet spectra of TEC variations in a number of our other experiments (Fig 1. b, c). Maximum TEC variations were observed in the area near the magnetic zenith. Note here also that amplitudes of TEC variations caused by heating were greater in nighttime conditions (up to ~0.3 TECU) than in daytime conditions even though the effective radiated power for the nighttime experiments was sometimes lower. It should be mentioned that under daytime conditions a typical TEC behavior is the increase in its value when PW switches-on (see Fig. 1a,b). As it was stated in [7], such TEC behavior is determined by plasma density growth at heights of about of 130 – 180 km when the ionosphere is pumped by powerful HF waves.

Similar results were obtained in heating experiments in dayside ionosphere at Tromsø. Examples presented in Fig 2. (a,b) show that for heating scheme ±10 min. the main periodic component 20 min and its 3rd harmonic are present in local spectra of TEC variations. TEC variations, observed during heating at Tromsø under daytime conditions were usually greater (up to 1TECU, see Fig 2c) compared to those obsereved at Sura. This can be explained both by the greater values of effective radiated power of EISCAT/Heating and higher efficiency of the artificial ionospheric turbulence generation in the auroral region. Note that TEC variations have complicated forms and some of them can be a result of auroral activity (for example obtained in disturbed geomagnetic conditions, Fig. 2.c). Relationship between contribution of artificial and natural disturbances has to be investigated separately.

4. Conclusion

Series of heating experimts at Sura and Tromsø showed that in GPS TEC variations appeared the spectral components that corresponded to the modulation of HF-heating, when the ionospheric penetration points of the tracked GPS satellites crossed the heated area. In these experiments, the harmonics of the main modulation frequency were often observed in the wavelet spectra of TEC variations. Our results showed the differences in TEC behaviour in heating experiments under day time and night time conditions as well as greater TEC variations for experimets at Tromsø and their complicated forms though the heating origin of these variations should be carefully investigated.

5. Acknowledgments

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