URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Plasmasphere Contribution to Total Electron Content at High and Middle Latitudes

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Abstract

We analyze the level of the plasmasphere contribution to total electron content (TEC) in middle and high latitude regions. The study is based on the data of TEC measurements from Global Navigation Satellite System (GNSS) and ionosondes. The plasmasphere contribution to TEC is shown to vary with local time and season. On daytime, plasmasphere electron content (PEC) is 25-30% of TEC and has its minimum value around noon. At nighttime, the plasmasphere contribution increases substantially: it averages about half of TEC, and, reaches, in some periods, 70%. At high-latitude station the nighttime plasmasphere contribution is higher than at mid-latitude one. The PEC/TEC ratio begins to increase after sunset and reaches a maximum before sunrise. The ratio does not change with increase in solar activity. The IRI-Plas model is found to significantly underestimate the level of the plasmasphere contribution to TEC, especially at night.

1 Introduction

Currently, the research of the ionosphere based on Global Navigation Satellite Systems (GNSS) measurements have been actively developed. The GNSS data have several advantages (time resolution, spatial coverage, availability). However, as the measured total electron content (TEC) is the sum of the ionosphere (IEC) and plasmasphere (PEC) electron contents along the satellite-receiver line-of-sight (LoS), these data, in a certain sense, "mix" the ionospheric and plasmasphere contents. Herewith, it is the plasmasphere contribution that may be crucial in a number of applications (satellite positioning, for example). That's why, it is essential to adequately describe typical cycles in the plasmasphere and their intensity, as well as the effects of the near-Earth space on the plasmasphere.

It is impossible to separate the ionosphere and plasmasphere contribution to TEC from GNSS measurements only. There are different approaches to evaluate the plasmasphere electron content, including radio occultation measurements [1-3], satellite altimeters [4], radio plasma imagers [5-6]. Belehaki et al. [7] proposed the method for estimating the plasmasphere contribution to TEC using the combination of GNSS data and ionosonde measurements [7]. Some advances have been achieved in empirical modeling of the plasmasphere [8-9].

2 Data and methods

GNSS measurements enable to obtain TEC values along the entire "receiver-satellite" LoS (up to ~ 20000 km altitude). To calculate TEC data, we use the measurements from dual-frequency GNSS receivers of international IGS network [10]. The receivers are located at middle (IRKJ, 52°N, 104°E) and high (NRIL, 69N, 88E) latitudes. We analyze the data for the 2010-2013 period which is characterized by a sharp increase in solar activity. From the initial data, we calculate series of absolute vertical TEC values by the method described in [11].

To estimate ionospheric electron content, we use the measurements from ionosondes located in Irkutsk and Norilsk, close to the GNSS stations. Ionosphere electron content is calculated from experimental electron density profiles by the procedure described in [12]. The authors [12] showed that the calculated IEC values for ionosondes in Millstone Hill, Wallops Island and Jicamarca were in good agreement with the measurements from the incoherent scatter radar and the TOPEX satellite.

To separate the ionosphere and plasmasphere contributions we applied a method proposed in [7]. We define plasmasphere electron content as the difference between TEC and IEC values: PEC = TEC - IEC. The temporal resolution of the calculated TEC and PEC values corresponds to the ionosondes resolution and is 15 minutes.

3 Results

Figure 1 presents the dynamics in daytime (black) and nighttime (blue) PEC (a, c) values and PEC/TEC ratio (b, d) at mid-latitude point Irkutsk (a, b) and high-latitude point Norilsk (c, d) along with the changes in the solar UV central flux (0.1-50 nm, red lines) for the 2010-2013 period. PEC/TEC ratio represents the plasmasphere contribution to TEC.

The figure shows that daytime PEC values follow the changes in the level of solar activity. Semiannual variations with maxima during equinox periods are clearly pronounced in dynamics of daytime PEC. The maxima of semiannual variations depend on the solar activity level. Nighttime PEC values have the different seasonal variations with maximum values in summer months and minimum values in winter.

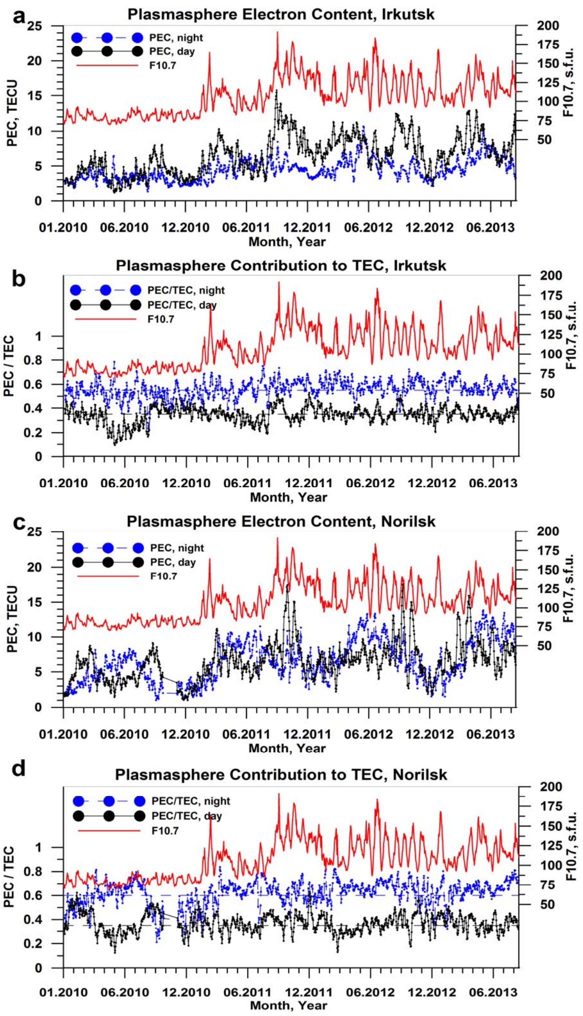

Figure 1. Changes in daytime (black) and nighttime (blue) PEC values (a, c) and PEC/TEC ratio (b, d) in Irkutsk (a, b) and Norilsk (c, d) for the 2010-2013 period. Red lines show dynamics in the solar UV central flux.

On daytime, PEC is 25-30% of the total electron content. At nighttime, the plasmasphere contribution increases substantially. It averages about half of TEC value and can reach 70% in some periods. At quiet daytime conditions the plasmasphere is filled from the ionosphere by the charge-exchange reactions at the plasmasphere lower boundary. While at night, in the absence of ionizing Sun radiation, the plasmasphere turns the main source of IEC due to the reverse exchange reactions. At high-latitude station the nighttime plasmasphere contribution is higher than at mid-latitude one. It is interesting to note that PEC/TEC ratio practically does not change with increase in solar activity. It fluctuates around 0.35 at midday and ~0.55-0.6 at night.

Figure 2 shows diurnal variations in PEC/TEC ratio for different seasons in Irkutsk (a-d) and Norilsk (e-h). To obtain these diurnal variations we averaged TEC and PEC values for periods, corresponding to winter/summer solstices and equinoxes ± 30 days.

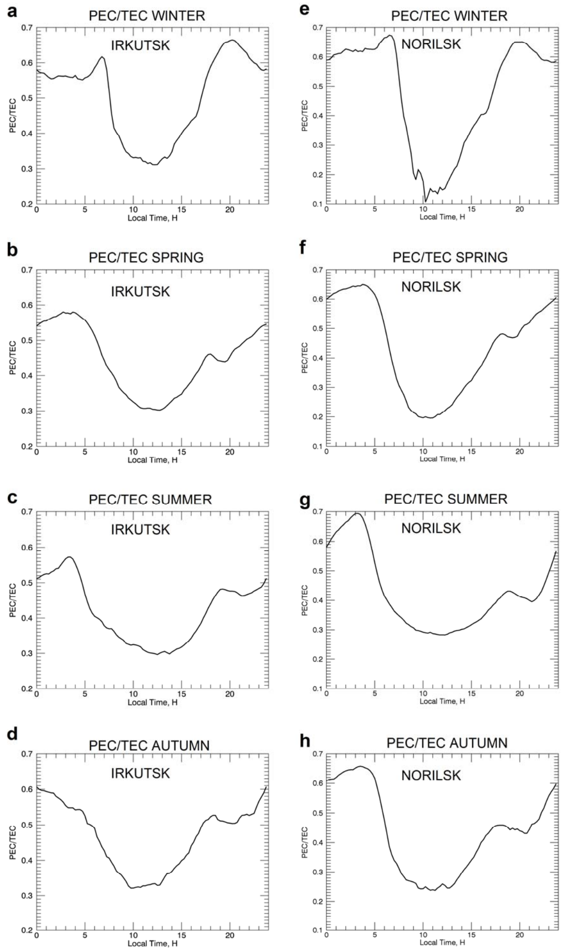

Figure 2. Diurnal variations in PEC/TEC ratio in Irkutsk (a-d) and Norilsk (e-h) in different seasons.

We can see that PEC/TEC ratio varies significantly within local time. The PEC/TEC ratio reaches up to 0.6-0.7 at the nighttime. The maximum contribution of the plasmasphere to TEC is registered in most cases before sunrice. During the daytime the ratio drops substantially and has it minimum value (0.2-0.3) around midday. This minimum is the narrowest in winter and the widest in summer. The smallest plasmasheric contribution to TEC is observed during daytime in winter in Norilsk and is about 10 %.

Figure 3 presents the local time versus day-of-year distributions of PEC (a, c) and PEC/TEC ratio (b, d) in Irkutsk (a, b) and Norilsk (c, d) averaged for the period considered. Panels (e-h) show the same distributions but obtained from the IRI-Plas model [9] simulations.

PEC and PEC/TEC ratio distributions feature significant diurnal variations. PEC diurnal maxima in Irkutsk are recorded in the evening, near the time of sunset solar terminator. At nighttime, PEC values reduce. In Norilsk maximum PEC values are observed at 00-05 LT. We can also observe seasonal variations in daytime PEC values with maxima at the equinoxes and minima at the solstices.

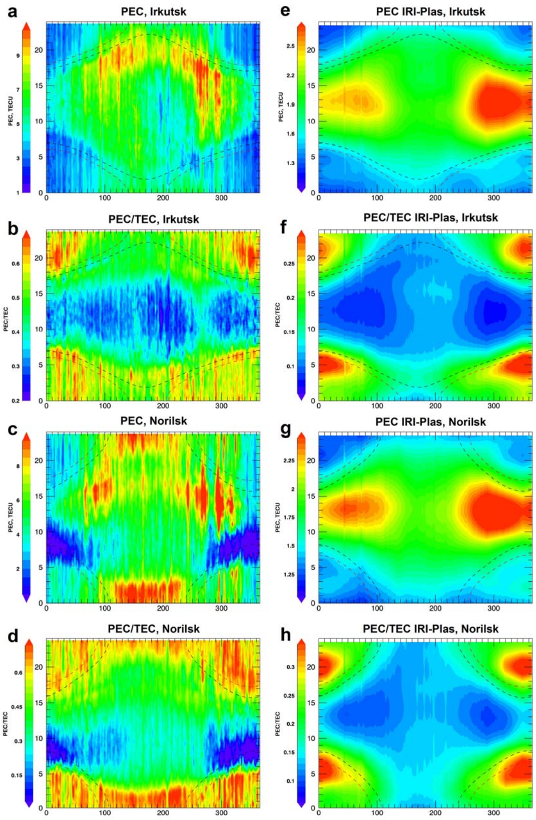

Fig. 3. Local time versus day-of-year distributions of PEC (a, c, e, g) and PEC/TEC ratio (b, d, f, h) from experimental data (a-d), and IRI-Plas model simulation (e-h). Dashed lines show the time of solar terminator at 100 and 200 km.

The dynamics in PEC and plasmasphere contribution to TEC from experimental data and IRI-Plas model are close in general. However, the model significantly underestimates the level of the plasmasphere contribution, especially at night. The model also does not reproduce an increase in PEC before sunset.

4 Acknowledgements

The authors are grateful to the IGS service for the GNSS data and to NCEI NOAA and WDC, Kyoto services for solar and geomagnetic data. The ionosondes data were recorded by the Angara Multiaccess Center facilities at ISTP SB RAS (http://ckp-angara.iszf.irk.ru/). The study is supported by the Russian Foundation for Basic Research Grant No. 18-35-20038. We used data processing techniques developed within the base financing of FR program II.16.

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