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Research article

Results of radio sounding of the south polar auroral oval performed with the GNSS signals of a sledge-track train around the Russian Antarctic station "Vostok"

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Abstract: Under the program of the 60th Russian Antarctic expedition of the 2014–2015s, during the sledge-tracked crossing of Antarctica to "Vostok" station 8.01.2015–19.01.2015, an experiment was conducted to receive signals from navigation services of satellite communication channels of GLONASS/GPS systems (GNSS). The technology of radio sounding and the criteria for diagnostics of the auroral oval in the total electron content of ionosphere (TEC) are discussed. Radio sounding of the ionosphere reveals traces of auroral oval in the latitudinal distribution of ionospheric delay of GLONASS/GPS signals. Examples of manifestation of the auroral oval are given. The transition route is calculated. The obtained results are compared to the results of SIMP2 modeling of the auroral oval and to data from the official internet page of the experiment. The necessity of creating of a TEC-model of the auroral oval is shown.

Keywords: ionosphere; GLONASS; GPS; positioning; ionospheric delay; electron content; receiver; auroral oval; technology; model

1. Introduction

Much attention has been paid to monitoring of the polar ionosphere in recent decades. The most important morphological element of the high-latitude ionosphere is the auroral oval. It is located near the border of the polar cap and represents the part of the ionosphere, which projects the plasma sheet and the cusp along the geomagnetic field lines. Here the northern lights are most often observed [1,2].

The source of electrons and ions in the auroral oval is plasma flow from the magnetotail. Daytime part of the oval usually coincides with the electron precipitation area (with energy of 100–300 eV) of boundary plasma sheet, which ionospheric projection is at higher latitude than associated with active auroral electrons (with energy up to 10 keV) of the central plasma sheet [2,3]. In the Arctic, the auroral oval is located above the Northern sea route. In its area, the frequency of failures of radio communications and navigation equipment increases.

Terrestrial and space-based sounding technologies are used to control high-latitude ionosphere and auroral oval zones. The well-known megaproject SuperDARN combines a network of terrestrial HF-radars with polar survey sectors and is designed to monitor the global convection system in the high-latitude ionosphere and in auroral ovals areas in calm and disturbed geomagnetic conditions [4]. The characteristics of the position of auroral ovals based on the model results are presented in [5,6]. As a tool for sensing the polar ionosphere, the technology of radio sounding with the signals of Global navigation satellite systems (GPS,GLONASS) is also used [7,8].

Figure 1 gives an idea of the network of stationary receivers of spacecraft signals (SC) of Global navigation satellite system (GNSS) used in foreign research of the Earth's polar caps.

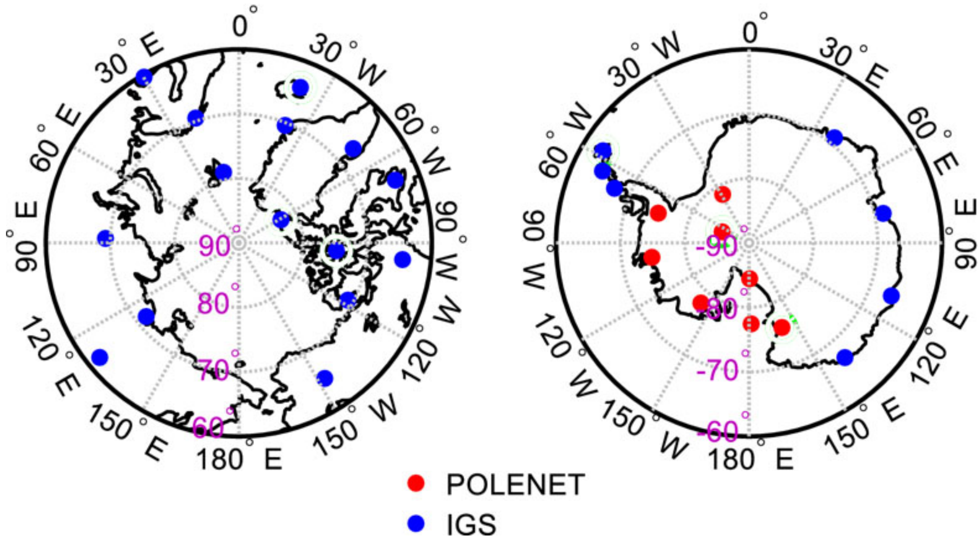

Figure 1. Position of navigation system receivers, used in [9] for the polar ionospheric research.

Stationary receivers in Antarctica are connected to the "POLENET" network [6]. Data from the arctic receivers, shown in Figure 1 with blue dots, are stored on the IGS website.

Severe climatic conditions make it advisable to use mobile sounding stations for sensing the high-latitude ionosphere [8]. One of these experiments was implemented using a GNSS signal receiver ("JAVAD"), which was included in the scientific equipment of the sledge-tracked crossing over Antarctica from the Russian Antarctic station "Progress" to the mainland station "Vostok" under the program of the 60th Russian Antarctic expedition 2014–2015 [9] on 8.01.2015–19.01. 2015. The receiver was used to sense ionospheric delay of GNSS signals.

The unique geographical position of the Vostok station, which is located almost in the center of the southern auroral oval, and the sledge-track transition route geography allowed us to obtain data on the state of the polar ionosphere and of the auroral oval zone traces in the TEC over Antarctica.

Sections of the ionosphere through the zone of the auroral oval are a promising area of research.

2. Features of the polar ionospheric sounding

The main focus of the ionospheric sounding experiment over Antarctica was on calculating the total electron content (TEC) at points under the GLONASS/GPS satellite receiver. Data from ionospheric sensing of GLONASS/GPS spacecraft signal delays was processed using the method of ionospheric and geodesic motion sensing presented in [3,10,11]. The morphology of the high-latitude ionosphere was taken into account [7], as well as the increase in small-scale inhomogeneities in the auroral oval zone, which was observed in experiments in the Arctic [8].

Due to inhomogeneities of the ionosphere, dimensions of which are comparable to the length of radio waves passing through them, it is possible to violate the canonical assumption used to formalize the laws of radio wave propagation, fading and flickering of radio signals, as well as positioning errors are possible [8]. For GNSS signals in regions of the high-latitude ionosphere with a high content of inhomogeneities, re-reflection occurs, and the trajectory of radio signals at shorter wavelengths may exceed the trajectory length of the first operating frequencies of the GNSS. This may lead to negative estimates of the relative TEC calculated by the traditional differential method [10,11] in order to assume a spherical-symmetric distribution of ionospheric parameters.

In this situation, to reduce interference in the received GNSS signals and diagnose morphostructural features of the high-latitude ionosphere, it makes sense to analyze the module of calculated estimates of the relative values of TEC along the meridians. It is assumed that the zone of the auroral oval can be characterized by an increased value of the relative TEC modulus in a narrow range of latitudes. The vagueness of this representation of the polar oval is associated with terminator zones both in the direction of the tail of the magnetosphere and in this of the Sun. In these zones, there is an increasing failure in received GNSS signals [3].

The information technology designed to process RINEX-files retrieved from navigation receiver has been verified and tested in a number of experiments in various climatic conditions. Instrumental correction for TEC observation for each GNSS spacecraft has been calculated and compared to the data of Ionospheric model IRI-2011.

Software processing of a daily observation file from a single receiver performed with a polling frequency of 1 Hz, on modern PCs takes up to 15–40 minutes. This creates up to one and a half million rows of data. Modern computers can simultaneously process up to 15 days of observations.

For the polar oval over the Antarctic there are certain climatic boundaries: central (equatorial), near-polar, middle latitude boundaries. They are associated with different energy of spilled electrons. For the South polar oval, the target boundaries can be the results of simulating the critical frequency of the E-layer of the ionosphere of the SIMP2 model [5] (Figure 2). We can clearly see the auroral oval position. It can be used as a reference point for searching for the auroral oval manifestation effects in GNSS signals.

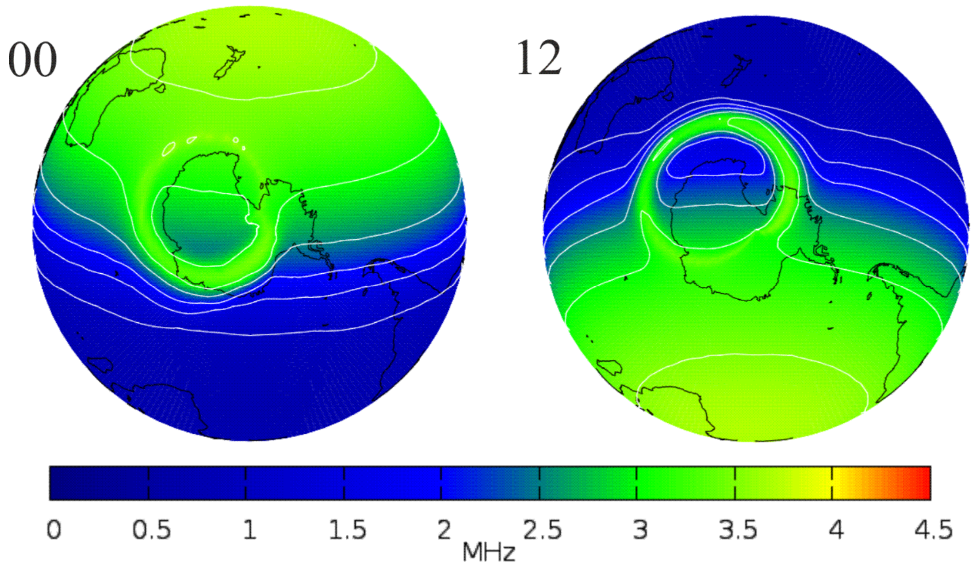

Figure 2. Results of modeling of critical frequency of ionospheric E-layer January 17, 2015 for 00:00 UT and 12:00 UT acc to model SIMP2 [5].

The shifting of zones of high concentration of the E-layer in the auroral oval is related to the position of the Sun. This is noted in the planetary dynamics of the Aurora Borealis over the Arctic [6]. However, in the TEC distributions according to the SIMP2 model [5], there is no manifestation of the auroral oval, which can be physically explained by the features of the vertical distribution of electron concentration over the E-layer of the high-latitude ionosphere. In marine experiments in the Arctic in 2011–2015, this was not confirmed for the North polar oval [3,8]. Its traces were diagnosed by signal characteristics of individual GNSS space crafts.

The peculiarities of sounding of the polar oval from the polar cap were explained by the fact that its position is associated with the Earth's magnetic field [8]. Therefore, when selecting tracks of subionospheric points of GNSS spacecraft for probing latitudinal gradients of TEC in the high-latitude ionosphere, it is necessary to take into account the divergence of the geographical and magnetic poles [12].

The choice of orbits of GNSS GLONASS/GPS spacecraft near the magnetic meridian of the navigation receiver's position and taking into account the daily evolution of the parameters of the ionosphere make it possible to increase the clarity detecting of the auroral oval.

3. The results of the auroral oval sounding over Antarctica

All the observed GNSS spacecraft was used to calculate the trajectory of the sledge-tracked crossing to the Russian Antarctic station Vostok. Pseudo-positioning estimates obtained with a discreteness of 10 seconds were averaged for each transition day. The estimated route is shown in Figure 3.

Deviations from the segment connecting the starting and ending points of the route correspond to the route of the sledge-crawler transition described in [13].

The position of the observed tracks of the GNSS space crafts was calculated using [10,11,14]. For example Figure 4 shows the calculated position of subionospheric points of GNSS satellites visible during 17. 01. 2015.

a) b)

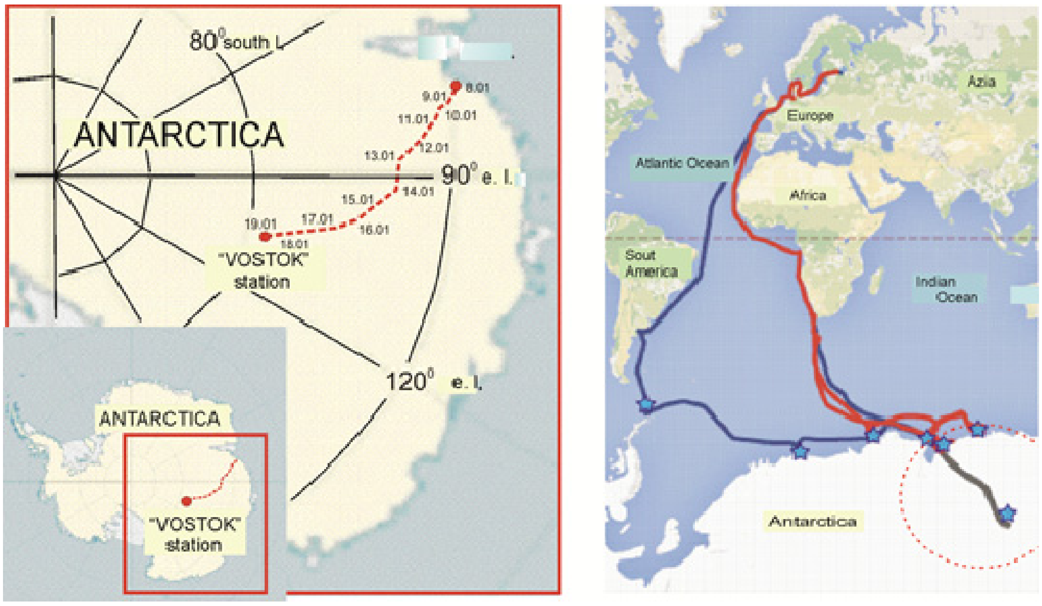

Figure 3. Average daily value position of the sledge-tracked vehicle crossing to "Vostok" 8.01.2015–19.01.2015: a: based on signals GNSS; b: route 60 RAE taken from the official internet page of the experiment [9] with enlarged fragment of the sledge-tracked crossing.

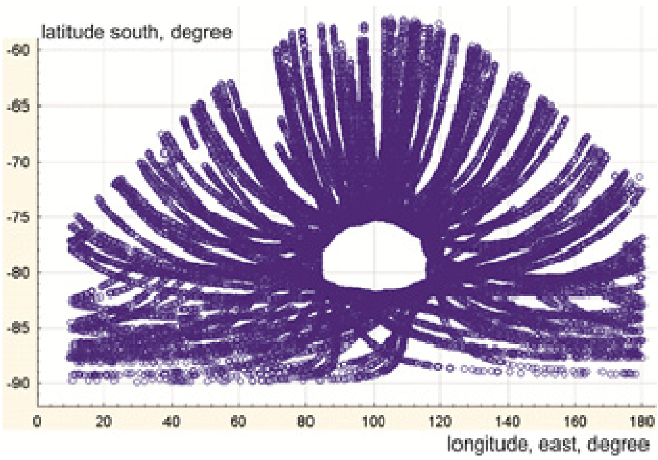

Figure 4. Position of tracks of GPS satellite points under the ionosphere 17.01.2015.

The location of the tracks shows that there was no significant shielding of the receiving antenna of the navigation receiver.

The change in the latitude of the TEC along the projection of the subionospheric points of the navigation spacecraft GPS G14, which crossed the auroral oval on 17.01.2015, is shown in Figure 5.

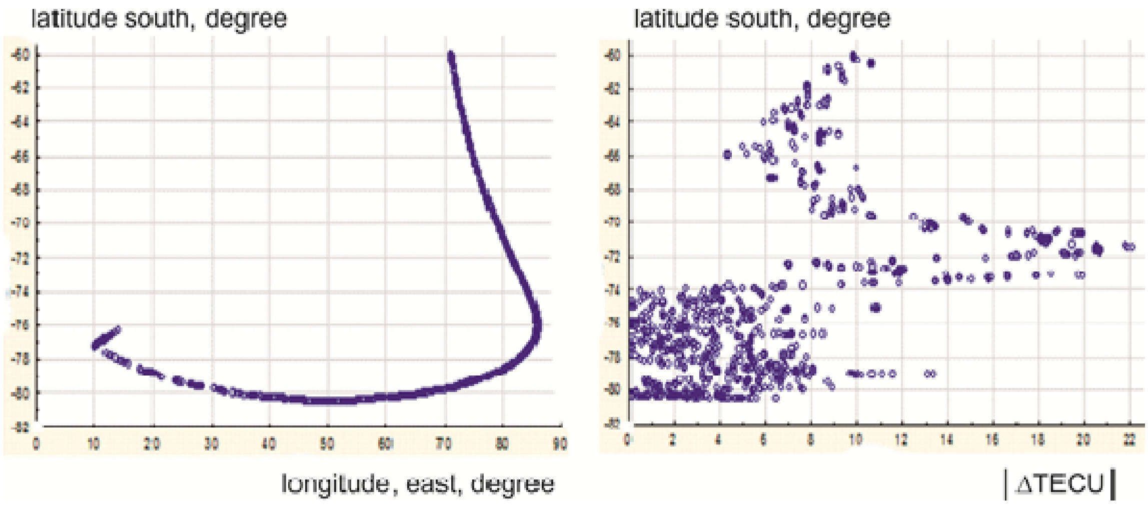

Figure 5. TEC variation by latitude along the subionospheric point of the G14 spacecraft (00: 55–05: 42 UT 17.01.2015).

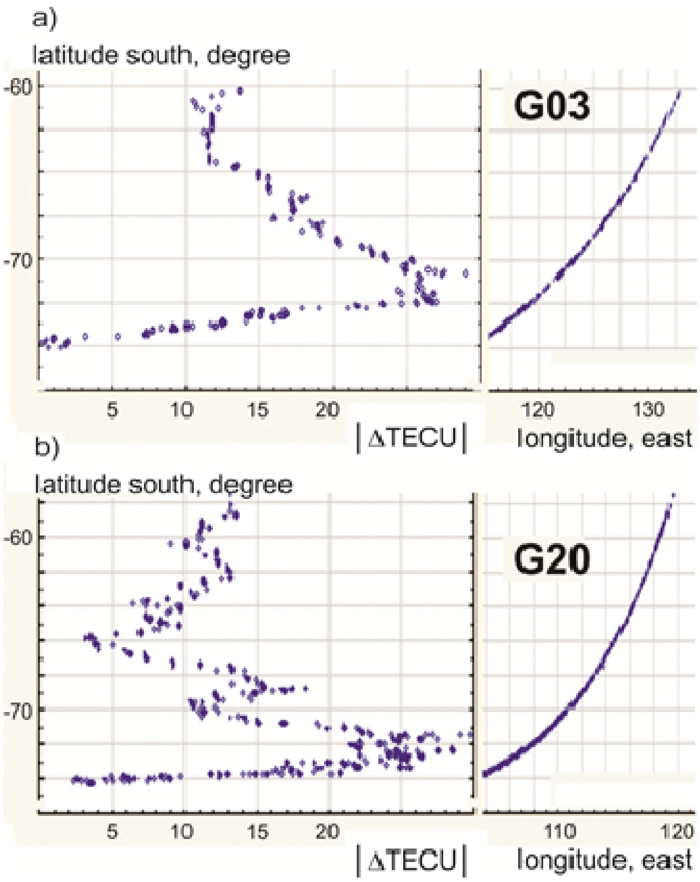

Figure 6. TEC variation by latitude along the ionospheric point tracks of the space crafts a: G04 (18: 00–19: 00 UT) and b: G20 (18: 00–20: 12 UT) 17.01.2015.

When GPS G14 crosses the latitude range of 72–73 degrees, there is a sharp change in the TEC module. Similar effects were recorded in the Arctic auroral oval zone [7,8]. There is a correspondence of zones of local increase of TEC values for G14 in Figure 5 with the results of simulating the e-layer of the ionosphere using the SIMP2 model (65–68 deg. S. on near 80 deg. E). Geomagnetic activity on January 17, 2015 was calm.

For other time periods, as well as for the 2nd half of the day, the results of auroral manifestation in the latitudinal distribution of ionospheric signal delays of GPS G03 and G20 are shown in Figure 6.

There is also a difference of about 5 degrees between the position latitude of the local extremum TEC values and the results of SIMP2 modeling of the E-layer of the ionosphere. For the G20 spacecraft, the second peak of about 69 degrees south should be marked in the TEC variation in latitude. Most likely, this is a manifestation of the complex structure of the night polar oval. The multi-mode latitude distribution of TEC in the zone of the auroral oval was registered by signals from other GNSS space crafts, including those of Arctic marine experiments [8].

Given the lack of adequate TEC modeling in the auroral oval, its position on 17.01.2015 over Antarctica in the meridian sector, 60-110 degrees east longitude may be associated with an increase TEC at 69–73 degrees south latitude. It is recalled that in the results of TEC calculations based on the SIMP2 model the auroral oval is not visible over the southern polar cap.

One of the options for averaging the observed values of the TEC module for all visible GPS spacecraft in the first quarter of the day 17.01.2015 is shown in Figure 7.

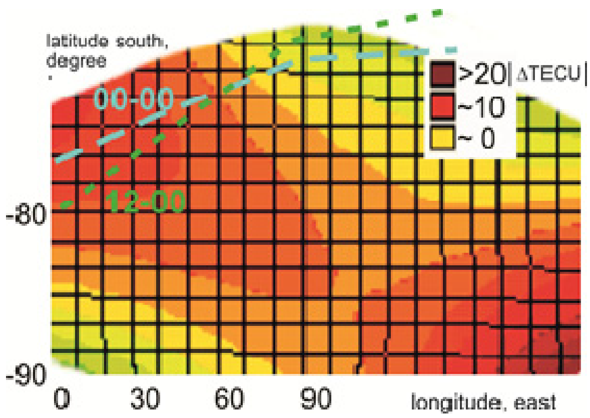

Figure 7. Restored relative TEC field for 00–06 UT 17.01.2015. Dashed lines are the position of the median of the ionospheric E-layer according to the SIMP2 models for two time points: 00 and 12 UT.

When averaging the probing results and calculating the TEC field, a five-point Hamming weight filter is used. The geographical South Pole is located in the lower left corner. Interpretation of zones of increased relative TEC values in Figure 7 involves consideration of the morphology of the polar ionosphere [1,3,4].

4. Conclusions

During the sledge-track transition of the 60th Russian Antarctic expedition to the Vostok station on 8–19.01.2015, the ionosphere of the southern polar cap was sounded using the GLONASS/GPS signals.

The route of a sledge-tracked crossing over Antarctica has been deciphered.

The Antarctic auroral oval zone appeared in the latitudinal gradient of the TEC, in accordance with the morphology of the auroral oval with an error of about 5 degrees, relative to the results of SIMP2 modeling of the E-layer median position of the ionosphere.

Sections of the ionosphere through the zone of the auroral oval are a promising area of research.

Conflict of interest

The authors declare no conflict of interest.

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