Conference materials
UDC 551.510.535
DOI: https://doi.org/10.18721/JPM.161.277

Structure and variations of the south-polar ionosphere by GNSS-tomography

D.A. Trofimov[1]✉, S.D. Petrov[2], A.S. Kalishin[2],
V.V. Lukin[2], Yu.A. Serov[2], I.V. Chekunov[3]

[1] St. Petersburg State University, St. Petersburg, Russia;
[2] Arctic and Antarctic Research Institute, St. Petersburg, Russia;
[3] Bauman Moscow State Technical University, Moscow, Russia
✉ d.trofimov@spbu.ru

Abstract. The paper is devoted to determination of the total electron content in the vicinity of the South geomagnetic pole using observations by global navigation satellite systems. Observations were carried out at the Russian Antarctic station Vostok in the periods February 2016 – January 2017, February 2018 – February 2019 and February 2020 – January 2021. Observations were made with satellites of GPS and GLONASS systems. Processing of observations was carried out by use of the TEC-suite software. Total electron content series were obtained for the specified time periods. Our results were compared with those of Center for Orbit Determination in Europe, there is a good agreement, based on which we conclude that our data are reliable. For all periods of observation, average daily profiles of changes in the total electron content in winter and summer were plotted. An excess of the winter total electron content measured from global navigation satellite systems observations over the model data provided by Center for Orbit Determination in Europe by about 5 total electron content unit was noted.

Keywords: GNSS, ionosphere, total electron content

Citation: Trofimov D.A., Petrov S.D., Kalishin A.S., Lukin V.V., Serov Yu.A., Chekunov I.V., Structure and variations of the south-polar ionosphere by GNSS-tomography, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (1.2) (2023) 505–510. DOI: https://doi.org/10.18721/JPM.161.277

Материалы конференции
УДК 551.510.535
DOI: https://doi.org/10.18721/JPM.161.277

Структура и вариации южнополярной ионосферы по данным ГНСС-томографии

Д.А. Трофимов[1]✉, С.Д. Петров[1], А.С. Калишин[2],
В.В. Лукин[2], Ю.А. Серов[2], И.В. Чекунов[3]

[1] Санкт-Петербургский государственный университет, Санкт-Петербург, Россия;
[2] Арктический и антарктический научно-исследовательский институт, Санкт-Петербург, Россия;
[3] Московский государственный технический университет им. Н.Э. Баумана, Москва, Россия
✉ d.trofimov@spbu.ru

Аннотация. Статья посвящена определению полного электронного содержания в окрестности южного геомагнитного полюса из ГНСС-наблюдений. Наблюдения выполнялись на антарктической станции Восток с февраля 2016 по январь 2017, с февраля 2018 по февраль 2019, с февраля 2020 по январь 2021. Наблюдались спутники систем GPS и ГЛОНАСС. Обработка наблюдений проводилась с использованием программного обеспечения TEC-suite. Были получены ряды полного электронного содержания за указанные периоды времени. Наши результаты сравнивались с данными CODE. Для всех периодов наблюдений строились среднесуточные профили изменения полного электронного содержания зимой и летом. Отмечено превышение зимнего полного электронного содержания, измеренного по нашим ГНСС-наблюдениям, над данными, предоставленными CODE, примерно на 5 TECU.

Ключевые слова: ГНСС, ионосфера, полное электронное содержание

Ссылка при цитировании: Трофимов Д.А., Петров С.Д., Калишин А.С., Лукин В.В., Серов Ю.А., Чекунов И.В. Структура и вариации южнополярной ионосферы по данным ГНСС-томографии // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 16. № 1.2. С. 505–510. DOI: https://doi.org/10.18721/JPM.161.277

Introduction

The presented paper is a continuation of the earlier work [1] devoted to estimation of ionospheric parameters from global navigation satellite systems (GNSS) observations at the Antarctic station Vostok. The ionosphere is a layer of the Earth's atmosphere, ionized primarily by solar radiation. It consists of neutral gases and quasi-neutral plasma. Such important branches of human activity as radio communication and radar, radio navigation depend on the state of the ionosphere. There are connections between the processes in the troposphere, tectonic processes and phenomena in the ionosphere. Thus, the study of the ionosphere, the physical processes occurring in it, and their relationship with other geophysical processes is an important scientific task. One of the main characteristics of the ionosphere is the total electron content (TEC), which is the number of free electrons and ions in a cylinder with a cross-sectional area of 1 square meter, oriented along the line of sight. It is measured in total electron content (TECU), 1 TECU = 10^{16} electron/m^2. One of the most accessible methods for studying the ionosphere under present conditions are GNSS. All modern GNSS are built on similar principles; they transmit the navigation signal over two frequencies, specifically to take into account the signal delay in the ionosphere. Thus, having observations of GNSS satellites at two frequencies, determining the total electron content can be performed according to the method described in the paper [2]. The spread of GNSS, the wide coverage of various networks of scientific and economic importance of large areas provide a huge array of information for determining the total electronic content. However, there are areas where the coverage of GNSS stations is clearly insufficient. One of such areas is Antarctica. The number of stations included in the network of the International GNSS Service (IGS) is only 8. All these stations are located on the coast of Antarctica. In 2016, together with the Department of Astronomy of St. Petersburg State University and the Arctic and Antarctic Research Institute, a GNSS site was organized at the Vostok station. Station coordinates are 78°28′ south latitude and 106°50′ east longitude. The height of the station is 3488 m. This was done to solve several scientific problems, the main ones being the study of the dynamics of the ice shield [3] and the determination of the parameters of the atmosphere and ionosphere near Vostok station. Vostok station is located in the vicinity of the South geomagnetic pole; therefore, the determination of ionospheric parameters in the vicinity of the station is of a special interest.

Materials and Methods

In this paper, we used GNSS observations made during three expeditions to the Vostok station. The first observation period is from 7 February 2016 to 31 January 2017, the second observation period is from 4 February 2018 to 10 February 2019 and the third observation period is from 7 February 2020 to 01 February 2021. All observations were performed continuously with the Javad Triumph-1 receiver provided by the Department of Astronomy of St. Petersburg State University.

The organization of the observation post is described in a previous paper [1]. The receiver used in all observations is the same. Code and phase measurements were performed at two frequencies. GPS and GLONASS satellites were observed, the time resolution of observations was 30 seconds. We also used global ionospheric maps provided by the Center for Orbit Determination in Europe (CODE). This data is provided with a time resolution of 1 hour, on a grid of 2.5° in latitude and 5° in longitude. We also used data on differential code biases (DCB-files) provided by CODE.

Data processing and results

Data processing was performed using the TEC-suite [4][5] program. With its help, the oblique TEC series were obtained for each observed satellite, both in phase and in code measurements. Subsequently, the slant TEC calculated from the code measurements was corrected for each satellite by DCB, and based on the corrected TEC, the uncertainty for the slant TEC calculated from the phase measurements was eliminated. Based on the slope TEC from the phase measurements, the vertical TEC was calculated using the mapping function. When calculating the mapping function, according to the method described in the paper [2], the height of the thin layer ionosphere was assumed to be H = 450 km. The same height is assumed in the model used to calculate ionospheric map CODE. The vertical TEC for all available satellites was averaged over an hourly interval. Using the method described above, we obtained complete annual series of the total electron content of the ionosphere over Vostok station for all three expedition periods. We compare our TEC series with the TEC provided by CODE to verify our results (see Figs. 1–4).

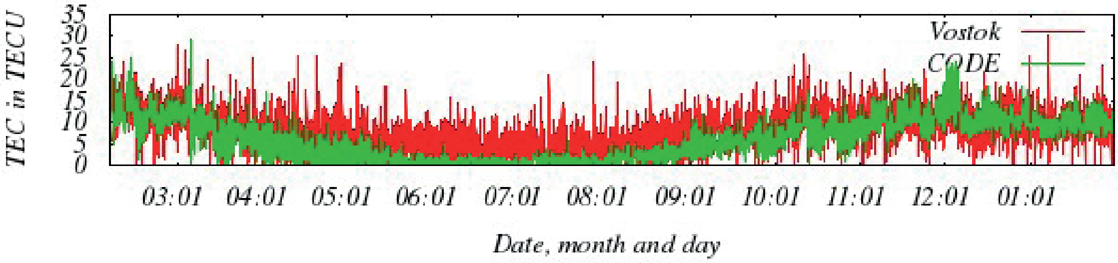

Fig. 1. Total ionospheric electron content over Vostok station according to GNSS observations (red line) of the 2016–2017 expedition in comparison with CODE data (green line). 1.0 (*a*)

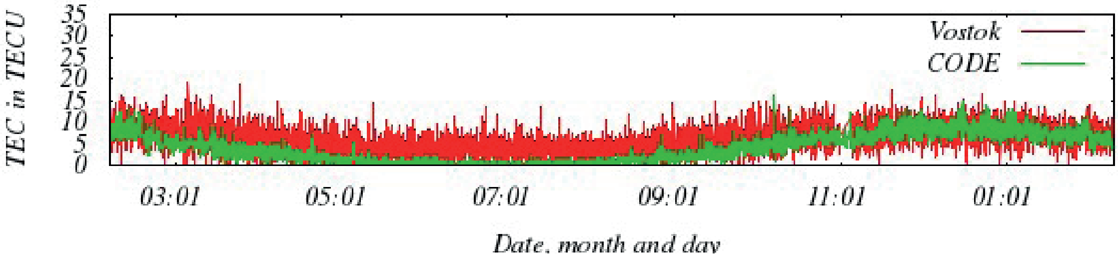

Fig. 2. Total ionospheric electron content over Vostok station according to GNSS observations (red line) of the 2018–2019 expedition in comparison with CODE data (green line) (*a*)

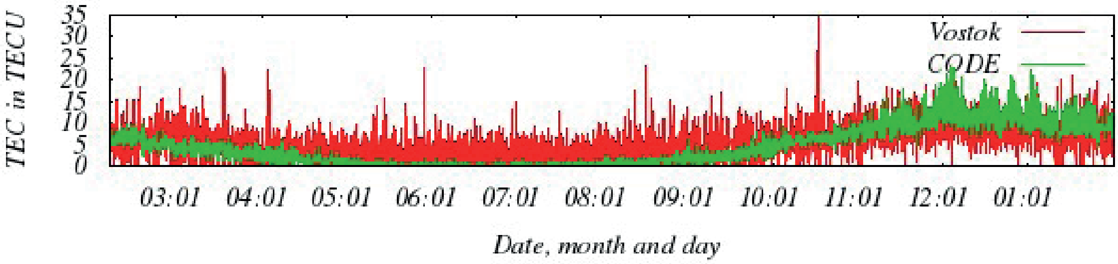

Fig. 3. Total ionospheric electron content over Vostok station according to GNSS observations (red line) of the 2020–2021 expedition in comparison with CODE data (green line) (*a*)

The results obtained by us, as can be seen from the graphs, in general, are in good agreement with the CODE data, which, in our opinion, indicates that the technique we use is correct and we did not make any gross errors in data processing. The results obtained by us are, in general, in good agreement with the CODE data, the seasonal component is clearly visible, which is present both in our series and in the CODE series.

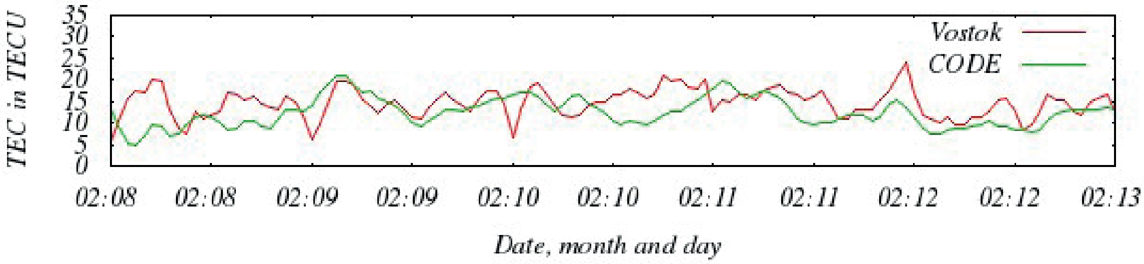

Fig. 4. Total ionospheric electron content over Vostok station according to GNSS observations (red line) 8 – 12 February 2016 in comparison with CODE data (green line)

The accumulated data make it possible to construct daily profiles of the variability of the total electron content of the ionosphere. Graphs of the average daily change in the total electron content for the winter period (in the southern hemisphere this is June-July) and summer periods are given (see Fig. 5–7). The graphs are built separately for each expedition period, 2016-2017, 2018-2019 and 2020-2021. The complete electronic content was built both for all observed satellites and separately for GPS and GLONASS systems. Also for comparison there are graphs constructed according to ionospheric maps from CODE.

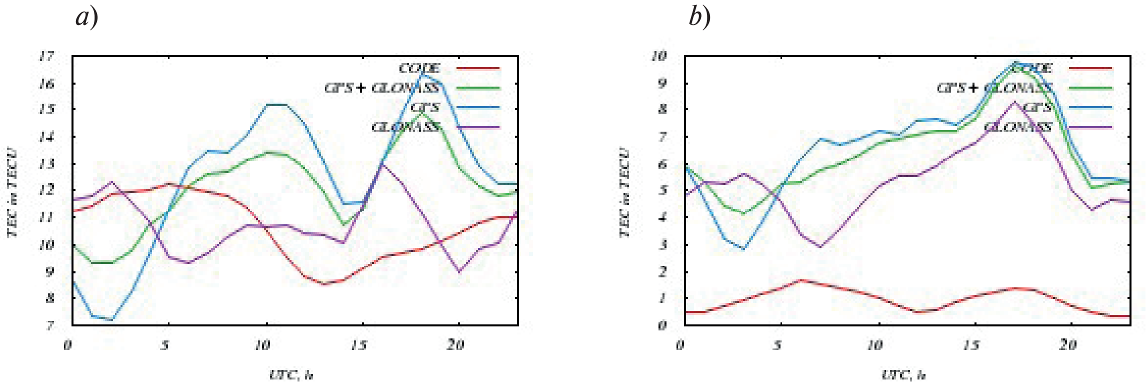

Fig. 5. Average daily TEC profile for June – July 2016 (*a*) and December 2016 – January 2017 (*b*)

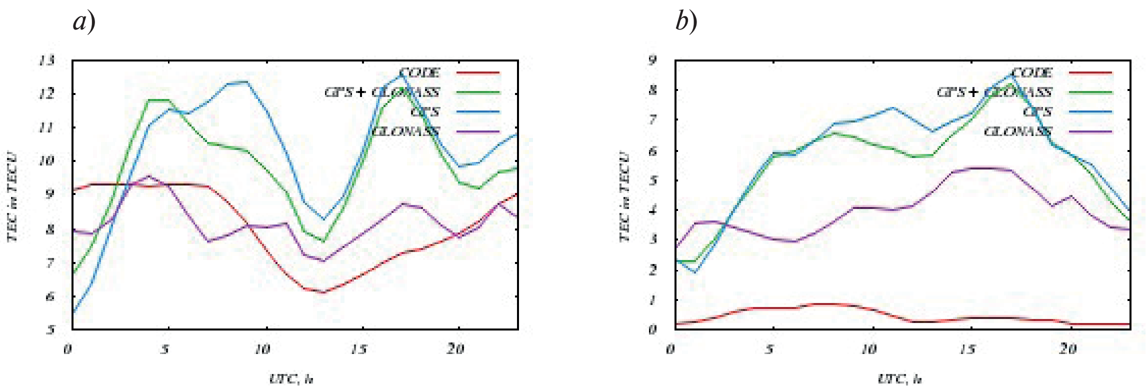

Fig. 6. Average daily TEC profile for June – July 2018 (*a*) and December 2018 – January 2019 (*b*)

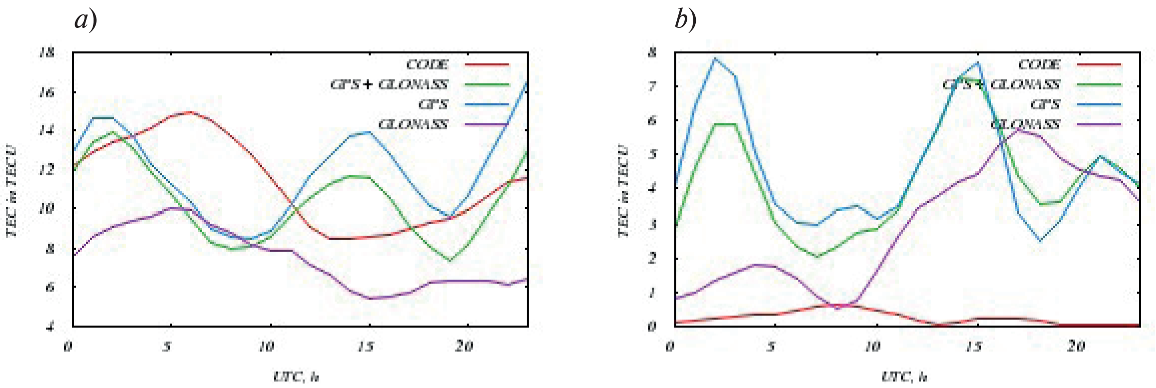

Fig. 7. Average daily TEC profile for June – July 2018 (*a*) and December 2018 – January 2019 (*b*)

As one of the interesting features of the TEC series obtained by us, it should be noted that the TEC values estimated by us in winter are significantly higher than the TEC estimates provided by CODE. The difference is about 5 TECU. This value is significant and needs to be explained. The standard deviation of the vertical TEC value, obtained from one observation epoch is about 3.4 TECU. To obtain one hourly value TEC, we average 120 TEC values, obtained from one epoch each. The difference between our data and CODE data exceeds the standard deviation of the TEC estimation error from one measurment. Consider the possible reasons for such a difference. On the one hand, we can assume that this value is an artifact of observations. As follows from the technique described by us, obtaining the final series of vertical TEC, we average all available observations, but due to the geographical location of our observation point, not a single satellite passes through the zenith, the points of intersection of the satellite-receiver line and the ionosphere are very far from the receiver. Hense, the averaged value The TEC may not display the situation above the receiver. On the other hand, it should be noted that the data, provided by CODE, are built based on available GNSS observations, which are carried out at the coastal stations of the IGS. These stations are located at a great distance from Vostok station and the same statements are true for them that we can make for our observation post. However, it should be noted that in summer the TEC series obtained by us is in good agreement with the CODE data, both at short intervals and at longer intervals, which, in our opinion, indicates that the winter TEC value obtained by us reflects the real physical picture. Perhaps the reason for this phenomenon is the proximity of the south geomagnetic pole of the Earth, near which the Vostok station is located. The ionization of gas in the ionosphere occurs due to the influence of ultraviolet and X-ray radiation from the Sun and due to the influence of charged cosmic particles. Taking into account the proximity of our observation point to the geomagnetic pole, we can assume that there is an additional TEC caused due to gas ionization by the solar wind. However, the question arises as to why this effect is observed only in winter.

Conclusion

The observations of three expeditions to Vostok station were processed. Annual series of the total electron content of the ionosphere were constructed from phase measurements using the TEC-suite program. The resulting total electron content was compared with data from global ionospheric maps provided by CODE. In general, the series are similar, the same daily and seasonal variations are traced, based on which we can judge the reliability of our data. Typical summer and winter diurnal profiles of the vertical TEC change were estimated with the obtained array of observations. An interesting point was noted that the typical winter TEC value exceeds the TEC value from global ionospheric maps by about 5 TECU. It is concluded that this is a real effect, which cannot be fully explained by the unknown value of the receiver calibration correction. Perhaps there are effects caused by the proximity of the South geomagnetic pole. We are going to continue the study of the causes of this effect in the following publications.

REFERENCES

1. **Zheltova K.V., Trofimov D. A., Petrov S. D., Smirnov S.S., Chekunov I.V., Serov Yu. A., Troshichev O.A.,** Probing ionospheric TEC near South Geomagnetic Pole by use of GNSS observations, Journal of Physics: Conference Series. 1697. (2020) 012035. 10.1088/1742-6596/1697/1/012035.

2. **Alizadeh M., Wijaya, D., Hobiger, T., Weber R., Schuh H**., Atmospheric Effects in Space Geodesy, Springer Berlin, 2013. 10.1007/978-3-642-36932-2_2.

3. **Trofimov D. A, Serov Y. A., Petrov S. D., Chekunov I. V., Shombina L. A**. 2017. GNSS-observations at the Vostok station, In: Proceedings of Geodesy, cartography, geoinformatics and cadastre. From idea to application, St. Petersburg, Russia, 8 – 10 November 2017, p 74–80.

4. http://www.gnss-lab.org/tec-suite.html

5. https://tec-suite.readthedocs.io/_/downloads/en/latest/pdf/

THE AUTHORS

TROFIMOV Dmitrii A.
d.trofimov@spbu.ru
ORCID: 0000-0001-5119-8510

PETROV Sergey D.
s.d.petrov@spbu.ru
ORCID: 0000-0002-9742-2909

KALISHIN Alexey S.
askalishin@aari.ru
ORCID: 0000-0001-7299-6546

LUKIN Valeriy V.
lukin@aari.ru
ORCID: 0000-0003-1726-7361

SEROV Yuri A.
yuras1981@yandex.ru
ORCID: 0000-0000-0000-0000

CHEKUNOV Ilya V.
onip4@mail.ru
ORCID: 0000-0000-0000-0000

Received 30.10.2022. Approved after reviewing 08.11.2022. Accepted 23.11.2022.