TOTAL ELECTRON CONTENT OVER VOSTOK ANTARCTIC STATION

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ABSTRACT. Total Electron Content (TEC) is one of the most important parameters of the ionosphere for propagation of radio waves. TEC is now being routinely monitored by global GNSS networks almost everywhere on Earth except geomagnetic poles. In order to study TEC evolution near the southern magnetic pole, two series of GNSS observations were carried out at the Vostok Antarctic station. Every of the two series lasted about one year each, 2016 and 2018. The collected GNSS observations were processed with RTKLIB and GeNeSiS software packages. TEC was estimated both from code and phase observables. The resulting TEC time series were analysed and compared to the global TEC map. These results may potentially augment our knowledge about ionosphere structure and evolution near the geomagnetic poles. As a continuation of this study a permanent GNSS receiver is considered to be installed at the Vostok Antarctic station.

1. INTRODUCTION

The ionosphere is a layer of the Earth's atmosphere that is highly ionized due to exposure to the Sun. The Earth's ionosphere consists of a mixture of neutral gases and a quasi-neutral plasma. The ionosphere starts at about 60 km. One of the main characteristics of the state of the ionosphere is the total electron content - the number of free electrons located in a cylinder with a cross section of 1 square meter and oriented along the line of sight. This value is measured in TECU (Total Electron Content Unit), 1 TECU $= 1 \times 10^{16} m^{-2}$. TEC is determined by the delay of the radio signal passing through the ionosphere. Signal transmission at two frequencies allows you to fully take into account this effect, which is used in VLBI and GNSS. At present, GNSS is the most convenient technology for determining the TEC, since the receiving equipment is the cheapest among analogues, and the constellations of the existing GNSS systems (GPS, GLONASS, Galileo and Baidou) provide a fairly dense coverage of the celestial sphere for the observer. For GNSS, TEC can be obtained based on the technique described in Alizadeh et al., 2013. In the case of code measurements, the TEC is determined from the ratio:

$$P_2 - P_1 = \frac{40.4 \cdot (f_1^2 - f_2^2)}{f_1^2 \cdot f_2^2} TEC + B^s + B_r + \epsilon,$$

where P_2, P_1 are pseudo-range at frequencies f_2 and f_1, B^s and B_r are delays in the satellite and receiver equipment. Thus, GNSS is a good and inexpensive method for determining the state of the ionosphere. Radio communication depends on the state of the ionosphere, thus determining the parameters of the ionosphere is an important task. Of interest is the determination of ionosphere parameters at high latitudes of the northern and southern hemispheres.

Now, quite a lot of work (Correia et al., 2013, Purohit et al., 2011, Sulaiman et al., 2007) has been completed on the definition of TEC over Antarctica. As a rule, all work was performed on the basis of GNSS observations, or based on measurements of the signal from satellite altimetry missions. At the same time, it is necessary to note the following disadvantages of these works, organically arising from the conditions of their implementation. Almost all observation points where GNSS receivers are installed are located on the coast of Antarctica, that is, in the zone of latitudes from 63° to 78° south latitude. Given the fact that the orbital inclination of GPS satellites is 55°, and GLONASS satellites 64.8°, it becomes clear that it is difficult to determine the total electron content directly above the observation points. Only GLONASS satellites can pass directly above the receiver, for GPS satellites the minimum zenith distance z is about 15°. Thus, from GNSS observations performed on the coast, it is impossible to construct a map of the ionosphere covering the Antarctic coast itself and a strip of southern territory about 400 km deep. In order to determine the total electron content over these territories, the observations should be performed substantially farther south. One of the most convenient places for installing the receiver for this purpose is the Russian Antarctic station Vostok. Vostok station is located at $78^\circ27'51''$ south latitude and $106^\circ50'14''$ east longitude near the south geomagnetic pole. Regular geomagnetic observations are made at the station, the corresponding series of geomagnetic indices are displayed, which will make it possible, if necessary, to compare our TEC series with the series of geomagnetic indices. The climate at the station is extremely severe, which leads to the need to protect equipment from external conditions.

Figure 1: Receiver installation at Vostok station

2. OBSERVATIONS

The observations were carried out jointly by Saint-Petersburg State University and Arctic and Antarctic Research Institute. To carry out observations, the Department of Astronomy of St.Petersburg State University provided the JAVAD TRIUMPH-1 geodetic GNSS receiver. During the first expedition of 2016-2017, a GNSS observation point was laid at Vostok station. A beam was frozen in the firn, and a platform with a heating cable and a screw mark was installed on top of the beam, where the receiver was fixed. Before the receiver was delivered to the Vostok station, a 24-day series of observations was made at Progress station on the coast of Antarctica. The observations at Vostok station were carried out from February 7, 2016 and ended on January

31, 2017. In 2017, the receiver returned to the department. Based on these observations were obtained coordinates and velocity of point Trofimov et al., 2017. The obtained velocity are in good agreement with the results of measurements of the radar satellite missions. A year later, a new expedition was organized, where observations were made at the same receiver and observation post from February 4, 2018 to February 10, 2019. In all series, observations were carried out at two frequencies with the possibility of phase and code measurements. The interval between measurements is 30 seconds.

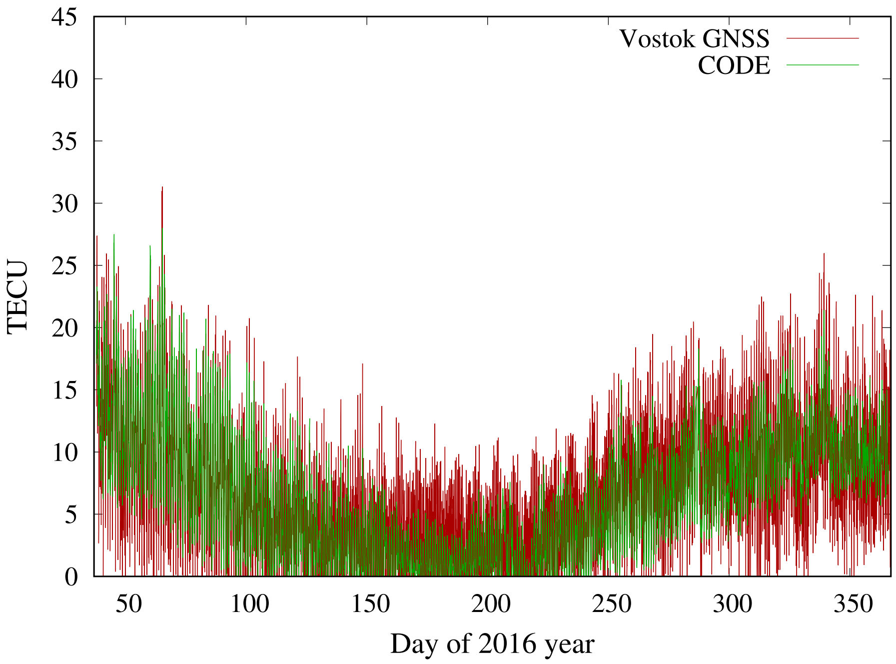

Figure 2: TEC from GNSS observations and from CODE

3. DATA PROCESSING AND RESULTS

The TEC shown in the figures below was calculated on the basis of code measurements, from a linear combination of the pseudo-range obtained at two frequencies (used frequencies L1 and L2) for each satellite, the slant electron content in the ionosphere (along the line of sight) was calculated, after which the vertical electron content was determined based on the mapping function described in Alizadeh et al., 2013 for each satellite.

$$VTEC = \frac{1}{F(z)} STEC,$$

$$F(z) = \frac{1}{\sqrt{1 - \sin^2 z'}},$$

$$\sin z' = \frac{R}{R+H} \sin z,$$

where R is the mean Earth radius and H is the height of the single layer, z - zenith angle on the ground station and z' -zenith angle on the point, where signal transmitted from satellite to receiver crosses ionospheric shell, $STEC$ - slant TEC and $VTEC$ - vertical TEC. The height of the conductive layer was taken equal to 350 km. The final result was obtained by simple averaging over the hourly interval. Thus, the share of obtaining one value was averaged by the results of 120 measurements. The program that calculates TEC values includes the filtering of knowingly false TEC values (too large and too small), vertical TEC from satellites that do not meet these conditions do not participate in the derivation of the final TEC value. The software calculated TEC based on all GNSS measurements, and only on the basis of GPS and GLONASS observations.

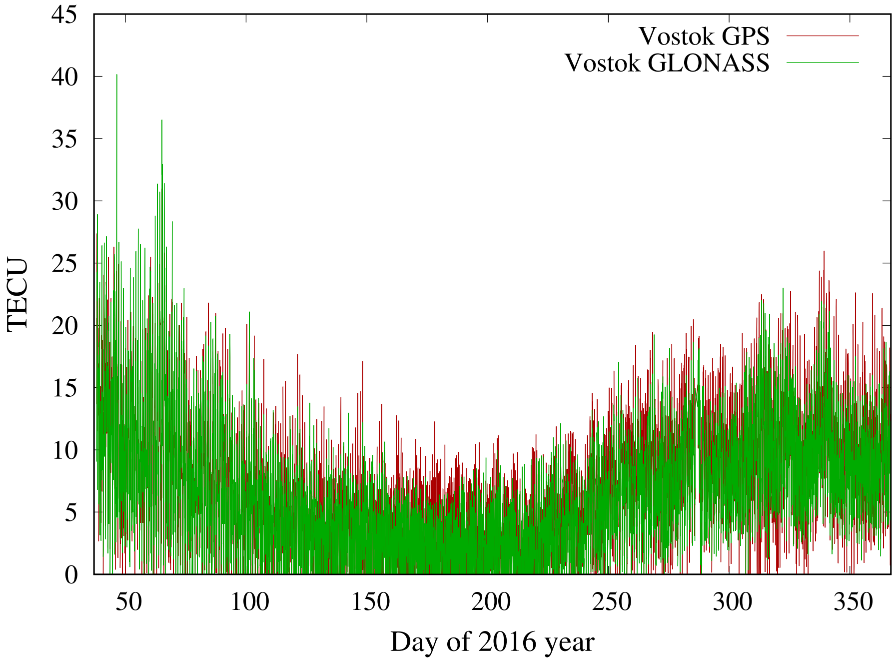

Figure 3: TEC from GPS and GLONASS observations on the Vostok station

The result of the first observation series of 2016 was compared with the global ionospheric maps of CODE. Due to the fact that the observations were carried out at very high latitudes, it was interesting to compare the results of GPS and GLONASS observations. GLONASS satellites have a higher inclination of the orbit, which was done in order to improve positioning accuracy at high latitudes. As can be seen from the graphs, the TEC received from the GLONASS satellites is in good agreement with the data obtained by GPS and the data provided by CODE. As an advantage of GLONASS, it can be noted that during processing the number of filtered false values was less, in comparison with GPS.

It seems interesting to compare the series of the total electron content of the ionosphere of different years, since ionization of the ionosphere is caused by solar radiation. It can be seen that the characteristic seasonal features are repeated: a decrease in the TEC during the polar night. However, there is some difference. The figures shows the series for 2016 and 2018.

4. CONCLUSION

As a result of the work done a seasonal GNSS station was established at the Vostok Antarctic base. Observations in 2016 and 2018 were performed and processed. A comparison of the data shows that the characteristic seasonal features of the TEC change are repeated. In 2018, the changes were less drastic than in 2016. Comparison of data with independent sources shows the high reliability of our TEC values. The observations will be continued.

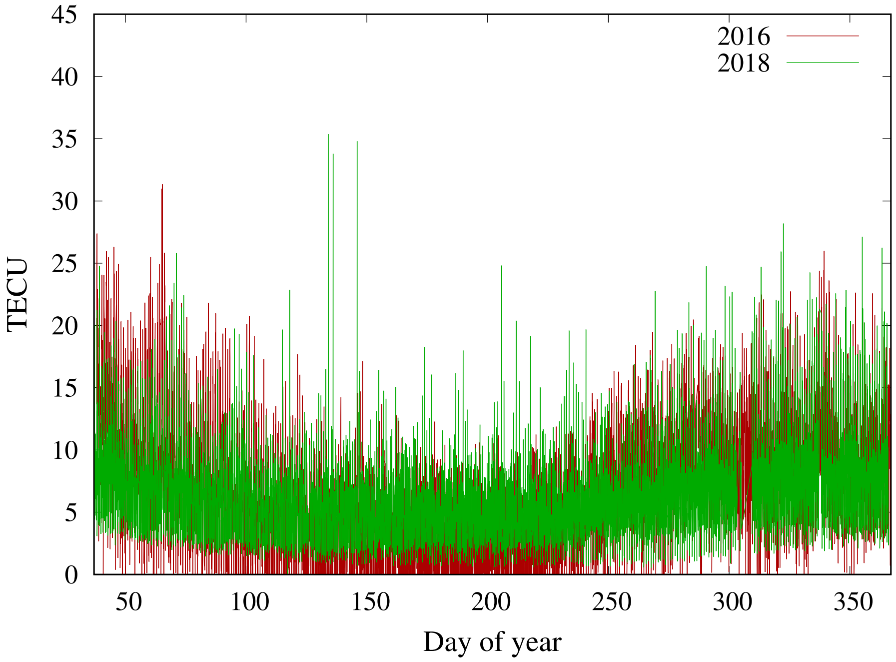

Figure 4: TEC depending on the time of year for 2016 and 2018

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