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DAY BY DAY BEHAVIOR OF GNNS POSITIONING ERRORS AND TEC FLUCTUATIONS ASSOCIATED AURORAL DISTURBANCES OVER MARCH 2015

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Abstract. We analyzed the occurrence of TEC fluctuations and an impact of auroral disturbances on the Precise Point Positioning (PPP) errors in European sector using GPS measurements of EPN network. Index AE was used as indicator of auroral activity. The fluctuation activity was evaluated by indexes ROT and ROTI. The positioning errors were determined using the GIPSY-OASIS software (http://apps.gdgps.net). The Precise Point Positioning is the processing strategy of the single receiver for GNSS observations that enables the efficient computation of the high-quality coordinates. For quiet conditions the algorithm provided for TRO1 stations daily average PPP errors less than 4-5 sm. The analysis indicated regular increasing positioning errors around MLT (22 UT) during March 2015. While raising the auroral activity it was observed increasing TEC fluctuation as well as positioning errors. In the report we discus also behavior PPP errors during super storm 17 March 2015. During storm at TRO1 the PPP errors reached more than 20 m. The increasing errors were observed on latitudes low than 52-54°N.

Introduction

The electron density irregularities occurred in the high latitude ionosphere may be experience the rapid of phase and amplitude fluctuations (scintillations) of the GPS signals The intensity of the fluctuations increases during geomagnetic storms and substorms. Many publications are devoted to the study of the occurrences of GPS signals fluctuations in the different regions of high latitude ionosphere [*Cherniak et al.*, 2015; *Prikryl et al.*, 2015; *Jin et al.*, 2018]. The strong ionospheric fluctuations of the GPS signals registered in the auroral oval and associated with the auroral disturbances [*Chernouss et al.*, 2015]. The fluctuations are frequently observed near the magnetic midnight.

Low frequency fluctuations of the GPS phase may be directly due to the electron density changes along the radio ray path or to the fluctuations of the total electron content (TEC). Strong TEC fluctuations can complicate the phase ambiguity resolution, can increase the number of the undetected and uncorrected cycle slips. Therewith, scintillations of the GPS signals can lead to the loss of the lock on the receiver tracking, and thereby to the disrupting of the performance of the satellite navigation system [*Juan et al.*, 2018]. Much attention has been paid on the impact of the geomagnetic disturbances on the PPP in the recent years [*Jacobsen and Andalsvik*, 2016; *Marques et al.*, 2018; *Shagimuratov et al.*, 2018]. The direct comparison the fluctuations intensity and the positioning errors at the auroral stations make it clear that the accuracy of the point positioning at the high latitudes is worse during geomagnetic storms.

In this work the analysis of TEC fluctuations and positioning errors over auroral region during March 2015 were presented. We particular attention give to the super storm of March 17, 2015. It was evaluated maximal PPP errors which we can be expected during geomagnetic storms.

Data

In this paper we used data from following GPS stations:

station	latitude	longitude	CGL	MLT, midnight
NYAL	78.9°	11.9°	76.6°	21.12 UT
TRO1	69.7°	18.9°	66.9°	21.54 UT
MAR6	59.0°	17.3°	57.4°	21.96 UT
KLG1	54.7°	54.7°	50.9°	21.88 UT

Geomagnetic conditions

Figure 1 shows the variability of Dst during March 2015. Most days of March were quiet, super strong storm took place on March 17. During storm AE index exceeded 2000 nT.

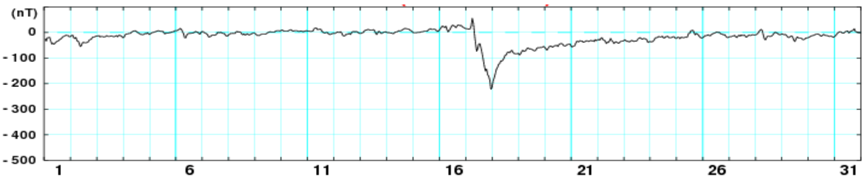

Figure 1. Dst over a period of March 2015.

Auroral activity and TEC fluctuations

The fluctuation activity was evaluated by the ROT (Rate of TEC) at 1-minutes interval. On their base was formed the pictures which demonstrates the behavior of the ROT over the single station for all satellite passes on 24-hour interval. In figure 2 the response of the ionosphere to auroral activity, as example, for single events is presented. The picture demonstrates occurrence TEC fluctuations (ROT) depend on intensity and time developed of auroral activity at different latitudes. The intensity of fluctuations decrease towards low latitudes. The analysis shown that remarkable fluctuations occurred at auroral stations when auroral intensity exceeded 500 nT. During storm day of March 17 the fluctuations were observed even at midllatitudes stations of Kaliningrad. We associate it with behavior of the irregularity oval which represent dynamic auroral oval [*Chernouss et al.*, 2018] During the storm the irregularity oval expanded equatorward and poleward in response to disturbed geomagnetic activity [*Shagimuratov et al.*, 2012].

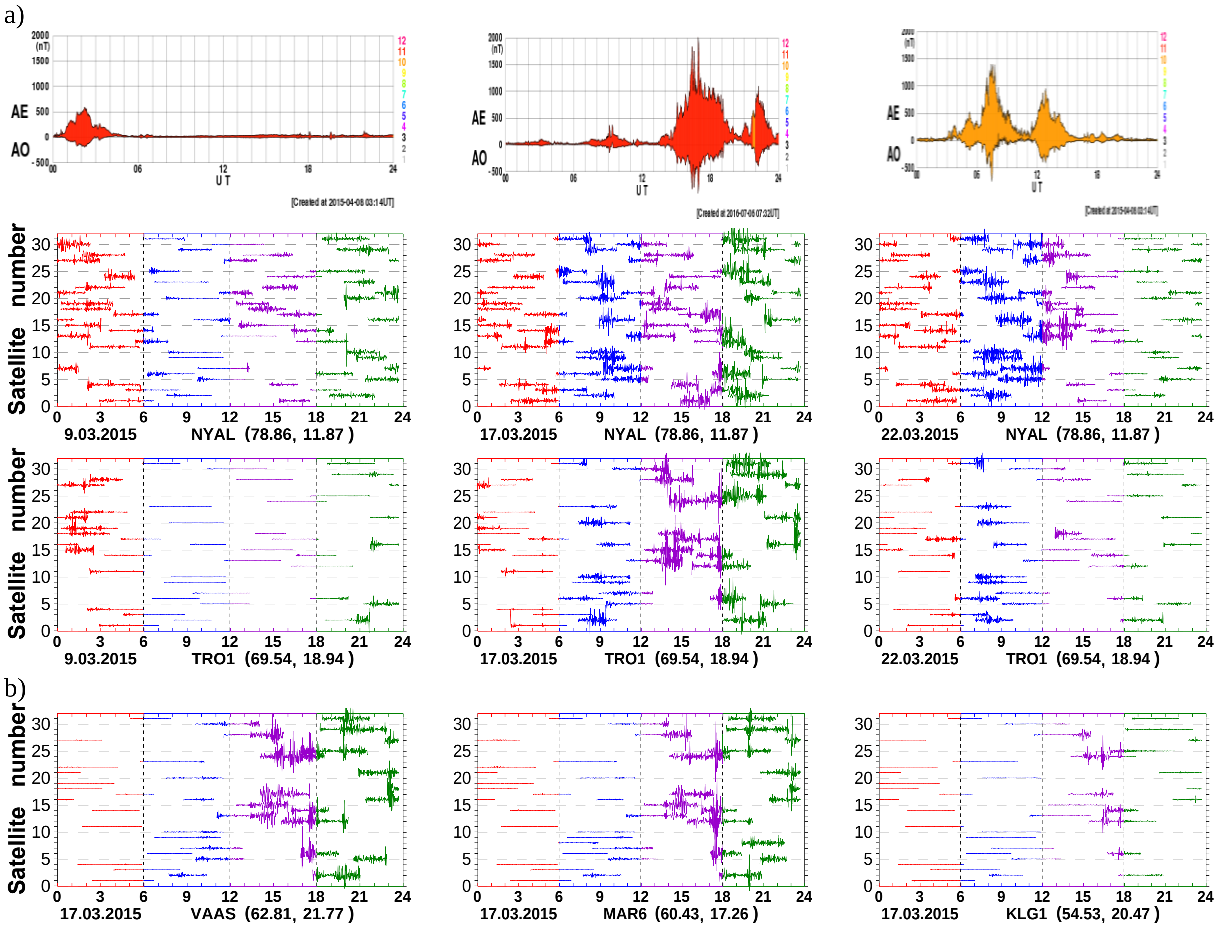

Figure 2. Development of the TEC fluctuations (ROT) at NYAL and TRO1 stations on 9, 17 and 22 March 2015 (a) and VAAS, MAR6 and KLG1 stations for storm day of March17 (b).

In figure 2 the some events are presented when auroral disturbances developed during morning (March 9), post noon (March 17) and near noon (March 22). For all cases TEC fluctuations at TRO1 are followed by AE indexes. It is interesting that fluctuation were registered even in day time of March 22, though this day was not too disturbed one. Diurnal occurrence of TEC fluctuations at NYAL station differ essential from lower latitude TRO1 stations. The reason such behavior associated with station location. The NYAL located near cusp, but TRO1 over auroral zone. At the same development fluctuations corresponds well with the variations of the AE index at both stations.

During low auroral activity at lower than subauroral latitudes fluctuations were very weak (data not shown). During storm fluctuations were registered even at midlatitude station of Kaliningrad.

Analysis GPS positioning errors

The PPP errors were calculated using the GIPSY software of the NASA Jet Propulsion Laboratory in the kinematic mode (http://apps.gdgps.net). On the base the 3D position errors were computed with 5-min interval. The 3D position error (P_{3D}) was defined as the offset of the detrended coordinate from its median value (x_0, y_0, z_0) and it was calculated for each epoch [*Jacobsen and Dähnn*, 2014]:

$$P_{3D}(i)=\sqrt{(x(i)-x_0)^2+(y(i)-y_0)^2+(z(i)-z_0)^2}$$

The high correlation between the positioning errors and the ROTI for year 2012 at the latitudes 59°-79°N was found by *Jacobsen and Dähnn* [2014], it was found also for European sector in the study of geomagnetic storm on 17 March 2015. Positioning errors increase exponentially with the increasing of the ROTI. Figure 3 illustrate the diurnal distribution PPP errors over March 2015 dependence of severe errors. The low values errors which are registered all day characterize accuracy used PPP algorithm for quiet geomagnetic conditions for TRO1 station. Position errors >1 m occurred corresponding to the development of ionospheric irregularities within the auroral oval. Their maximum occurrence is mostly at the equatorward edge of the nightside irregularities oval around magnetic midnight.

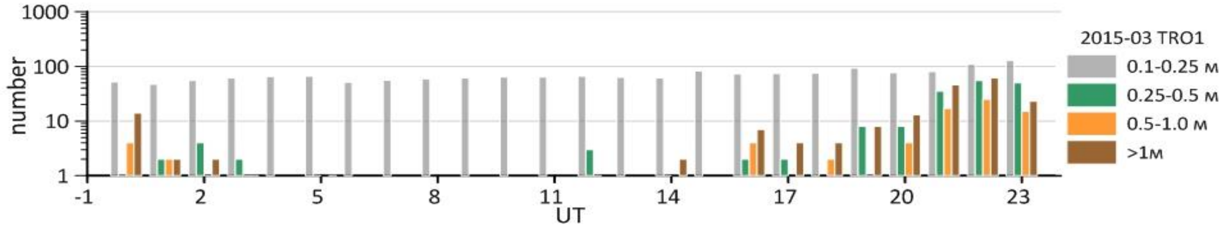

Figure 3. Diurnal distribution the PPP errors over March 2015 for TRO1 station.

It is well known that positioning errors essentially increase during geomagnetic disturbances. Maximal PPP errors over March 2015 are registered during severe storm of March 17. The storm time errors can are considered as indicator of extreme PPP errors at the high latitude ionosphere.

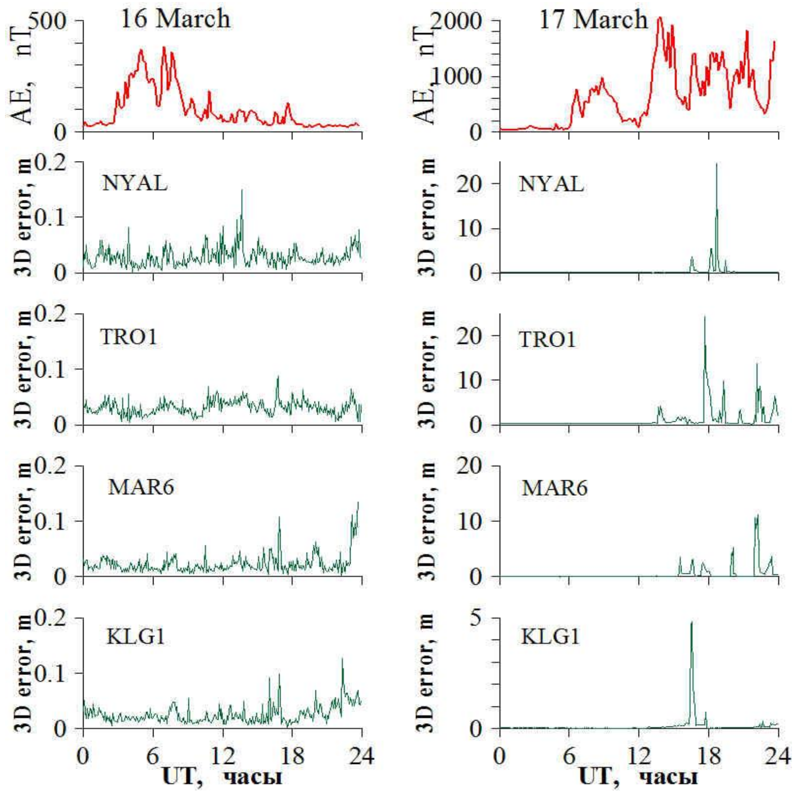

Figure 4. The 3D positioning errors at different stations for 16 (quiet day) and 17 (storm day) March 2015.

Figure 4 illustrate that storm time error errors are more than an order of magnitude higher than quiet time. At auroral latitude maximal errors exceed 20 m. At subaural latitudes errors reached 8-10 m, middle station of Kaliningrad errors exceed 4 m.

Summary

We analyzed the occurrence of the TEC fluctuations and the positioning errors associated with the auroral disturbances over Europe during March 2015. These disturbances occurred at the evening time. The maximal intensity of the TEC fluctuations took place at the auroral ionosphere. Weak fluctuations were observed over subauroral stations. The effects were related with the dynamics of the auroral oval. We analyzed also an impact of the geomagnetic disturbances on the Precise Point Positioning errors. The positioning errors were determined using the GIPSY-OASIS software (APS-NASA). Statistics shown under normal conditions, a centimeter - to decimeter - level PPP accuracy were registered. During the geomagnetic storm on March 17, 2015 positioning errors dramatic increased. At auroral stations errors are exceed more than 20 m. Even at middle station of Kaliningrad PPP errors are reached 5 m.

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