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Influence of the Ionosphere to GLONASS/GPS Positioning During Geomagnetic Storms

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Introduction. Total electron content fluctuations at high latitudes are caused presence in the ionosphere of different scale irregularities. The TEC fluctuations are occurred as phase fluctuations GPS/GLONASS signals. The GPS measurements are importance as for investigation of physical processes in the high latitude ionosphere as well as for study of influence on GLONASS/GPS navigation. Strong TEC fluctuations can complicate phase ambiguity resolution and to increase the number of undetected and uncorrected cycle slips and loss of signal lock in GPS navigation what ultimately increase positioning errors.

In auroral ionosphere the increase of TEC fluctuations intensity are followed by auroral activity [1, 2]. The relation between the intensity of TEC fluctuations and GPS positioning errors over Europe was presented by Jacobsen and Dähnn, 2014; Jacobsen and Andalsvik, 2016 [3, 4].

In this paper the occurrence TEC fluctuations and positioning errors over Europe June 22—23, 2015 geomagnetic storm.

Data and Method. In this analyze standard GPS observations carried out within the IGS network provided TEC were used. The TEC measurements at 30 sec interval of individual satellite passes served as raw data. As a measure of fluctuations activity the rate of TEC (ROT, in the unit of TECU/min, 1 TECU = 10^{16} electron/m^2) at 1 min interval was used. As a measure intensity fluctuations index ROTI was used.

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

The Precise Point Positioning (PPP) errors were determined using the GIPSY-OASIS software (http://apps.gdgps.net).

Geomagnetic conditions. Geomagnetic data were downloaded from the website: http://wdc.kugi.kyoto-u.ac.jp. The storm of June 2015 was rather strong. In Fig. 1 geomagnetic conditions for storms on June 2015 are presented. Figure 1 demonstrated development of the storm by time series of Dst and AE indices. The Dst index reached near –120 nT around 21 UT on 22 June. Maximal value of Dst reached about –200 nT at 05 UT on 23 June. The maximal auroral index AE was~ 1600 nT and occurred at near 19 UT.

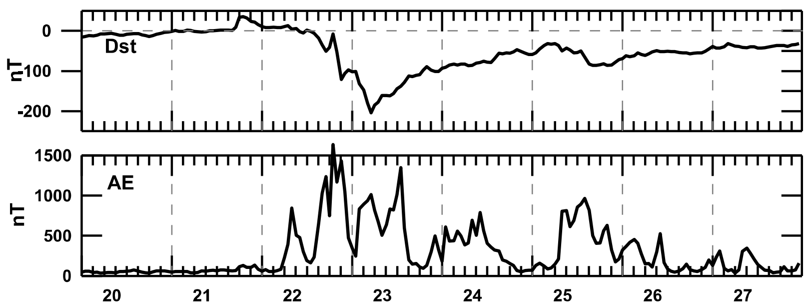

FIGURE 1. Geomagnetic conditions for storms of June 2015.

Previous analysis of the storm pointed that maximal intensity of TEC fluctuations is occurred during substorm activity [2]. As indicator substorm activity was used magnetometer dataof the Scandinavian chain. (http://space.fmi.fi/image). The network includes the stations located in auroral, subauroral and mid-latitude area. The intensity of the magnetic bay is decreased from north to south. The strongest magnetic variations were registered on time interval 19—20 UT when auroral activity was maximal (Fig. 1) Weak bay was observed even at midlatitude of 54°N.

Observation and discussion. The temporal occurrence of the TEC fluctuations we analyzed standard 30 seconds GPS phase measurements using observation files of RINEX format. Fluctuation activity was evaluated by TEC (ROT) rate at 1 min interval. On their base we formed a picture (Fig. 3) which demonstrates the behavior of ROT over station for all satellite passes on 24-hour interval. We analyzed latitudinal behavior of TEC fluctuations. The occurrence of fluctuations were registered at all discussed stations. Figure 3 shows time developed TEC fluctuations over individual station. During strong auroral activity of 22 June TEC fluctuations were detected over Europe from auroral to midlatitude stations. Strong fluctuations were observed in auroral zone. At the same time weak fluctuations were detected even at midlatitude station of Kaliningrad (KLG1). A rather good consistency is in the time evolution of the substorm activity (Fig. 1) and TEC fluctuations (Fig. 3). Maximal effect both of them takes place on 19—20 UT.

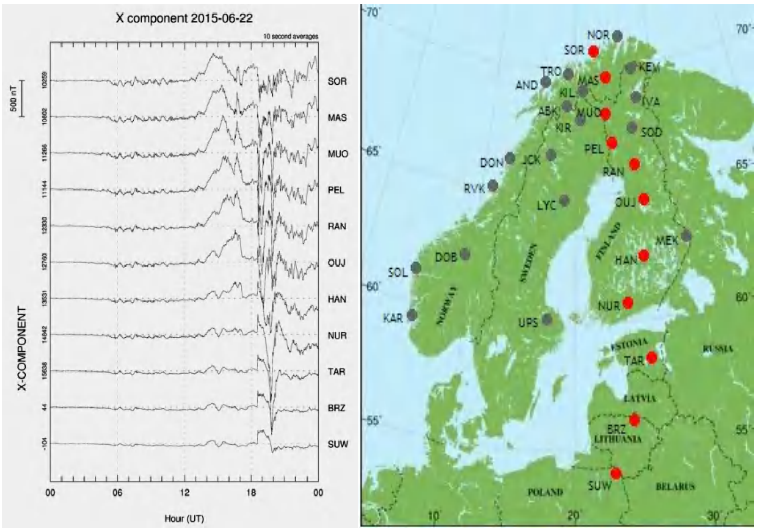

FIGURE 2. IMAGE magnetometers data on 22 June 2015 and the map of IMAGE network.

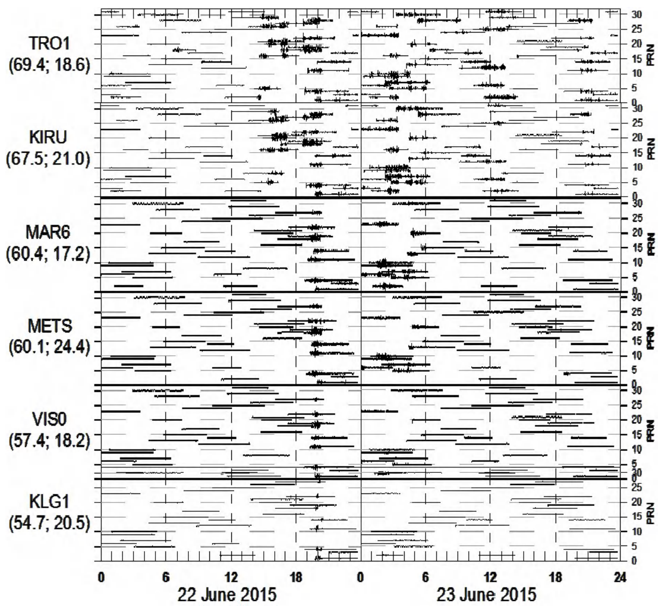

FIGURE 3. Development of TEC fluctuations (ROT) over Europe at different latitudes during June 22—23, 2015.

TEC fluctuations and GPS positioning errors. The accuracy of GPS positioning is strongly influenced ionospheric fluctuations (scintillations) which increase during geomagnetic disturbances. The intensive fluctuations leading to phase cycle slips and signal loss lock which are much more on the L2 signal. Losses of signal can cause problems when applying the ionosphere free combination (ion-free) that is generally used in PPP. Kinematic positioning is in general degraded when a small number of satellites is available, which frequently occurs under fluctuation activity GPS signals. As it shown by Marques et al., (2018) [3] under the intensive fluctuations number cycle slips and loss lock signals can sharp increase causing jumps in the positioning errors which reached about 8 m for height component.

We analyzed the link between intensity of TEC fluctuations (index ROTI) and Precise Point Positioning (PPP) errors using the GIPSY software of NASA Jet Propulsion Laboratory (http://apps.gdgps.net). Precise Point Positioning is a single receiver processing strategy for GNSS observations that enables the efficient computation of high-quality coordinates, utilizing undifferenced dual-frequency code and phase observations (RINEX files) by using precise satellite orbit and clock data products. We analyzed influence TEC fluctuations on positioning errors for station located different latitudes at longitude of 20 during active phase of storm (22 June).

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

The 3D position errors were computed with 5-min interval. The high correlation between positioning errors and ROTI was found by Jacobsen and Dähnn (2014) [4], as well as by Jacobsen and Andalsvik for 17 March 2015 geomagnetic storm at European sector [5]. Positioning errors increase exponentially with ROTI increasing [6]. We analyzed link between ROTI and the 3D position errors for stations located in latitude range 69—54°N. In calculating of index ROTI the satellites observations with elevations above 20° have been included. In calculating of the 3D position errors we used also the same procedure.

Figure 4 shows during storm temporal variations ROTI and the 3D positioning errors at stations spaced by latitude. On picture variability of ROTI values calculated for all visible GPS satellite passes over selected stations for every epoch shown by dots. We can see very good similarity in ROTI and positioning errors behavior, the increase of ROTI values followed by increase of positioning error at all discussed stations. The positioning errors reached 4—6 m at auroral latitudes where intensity fluctuations were maximal. On lower latitudes errors decrease as well as intensity of fluctuations. At subauroral latitudes the errors decrease to background, although the fluctuations remain noticeable.

Summary. We have analyzed an occurrence of the GPS TEC fluctuations associated with auroral disturbances. We studied the impact of the disturbance on GPS precise positioning errors over Eropean from auroral (TROM1) to mdllatitude (KLG1) stations during June 22, 2015 storm. Maximal auroral activity was observed during 19—20 UT. Index ROTI was used as measured intensity of TEC fluctuations. Maximal value of ROTI was registered also at the same time interval.

We calculated 3D positioning errors with 5 min interval using the GIPSY-OASIS software. It found that the high correlation of the GPS positioning errors with ROTI index exists. The positioning error increases exponentially with increasing of ROTI values. During maximal auroral activity, on 19—20 UT, the positioning errors reached 4—6 m over auroral stations. In quiet period the positioning errors were less than 50 cm. Maximal positioning error took place on auroal latitudes where intensity TECof fluctuationswas maximal. On midlatitude and subauroral latitudes the errors do not exided background.

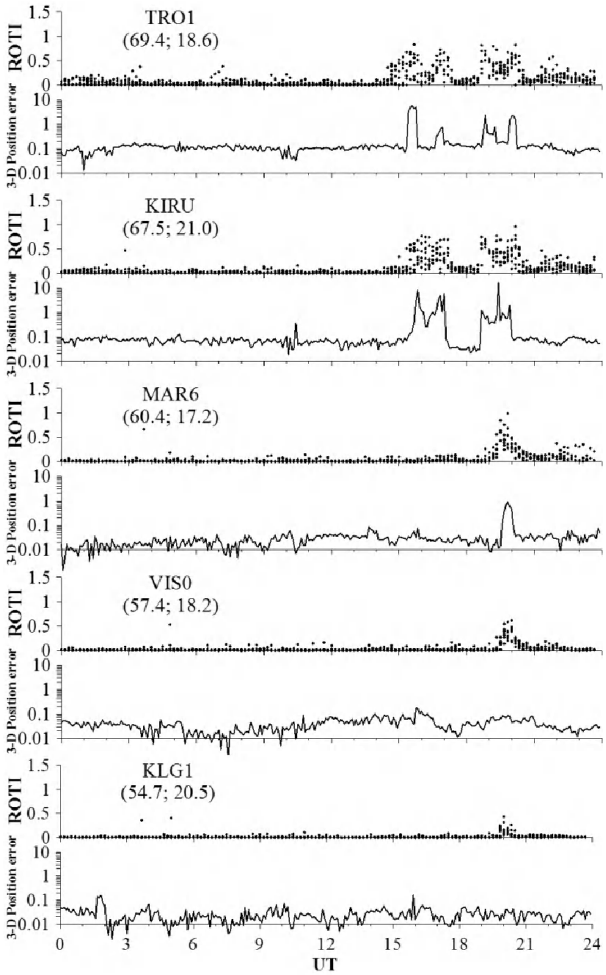

FIGURE 4. Time variations of TEC fluctuations (index ROTI) and 3D positioning errors during storm day of 22 June 2015 at different latitudes.

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Oblique Sounding Ionogram Simulation for HF Ray Traces over Siberian and Far Eastern regions

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Introduction. There are still issues in simulation and, as a consequence, predicting the ionospheric propagation of HF radio waves. Mainly, these issues are involved two aspects: the correctness simulation of the medium by ionospheric models and an effective and robust method for calculating the characteristics of radio paths.

The current paper is devoted to demonstrate the possibilities of the direct variational method for ionospheric point-to-point ray tracing and the synthesis of oblique ionograms as well. The direct variational method had been proposed [1—3] as an effective tool for solving the boundary problem of ionospheric ray tracing, when the positions of the transmitter and the receiver are fixed. The recent modification of the direct approach [4], based on the optimization procedure, has a possibility of the global identification of the ionosphere rays for the chosen frequency.