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GPS/TEC FLUCTUATIONS AT HIGH LATITUDE DURING GEOMAGNETIC STORM OF 11 OCTOBER 2010

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1. Introduction

A trans-ionospheric radio wave propagating through electron density irregularities can caused phase and amplitude ionospheric fluctuations. The small irregularities with scale lees than 1 km lead to fast fluctuations it is usually called scintillations. The medium and large scale ionospheric irregularities are responsible for slow fluctuations. The low frequency GPS phase fluctuations occurred directly to electron density changes along the radio ray path or rapid total electron content (TEC) changes. Strong high latitude TEC fluctuations can complicate phase ambiguity resolution; increase the number of undetected and uncorrected cycle slips and loss of signal lock in GPS navigation [*Forte et al.*, 2004]. The aurora-induced ionosphere disturbances are supposed to be one of the main sources of GPS faults in the Arctic and the Antarctic [*Chernouss and Kalitenkov*, 2011].

The information about TEC fluctuations can be obtained using of the regular GPS observations provided by the International GPS Service (IGS). The world wide and numerous networks of permanent GPS stations are very promising to monitor the spatial distribution of ionospheric irregularities in planetary scale [*Shagimuratov et al.*, 2009]. In this report the GPS measurements of global IGS network were used to study the storm time occurrence of phase fluctuations (TEC changes) in the high latitude ionosphere during 11 October 2010 storm.

2. Solar and geomagnetic condition

The considered in this study isolated geomagnetic storm October 11, 2010 was rather moderate. Active phase of the storm started on 11 October after 11 UT, maximal value of Kp was 4, Dst reached -80 nT. The satellite WIND registered sharp change of the solar wind parameters and the interplanetary geomagnetic field.

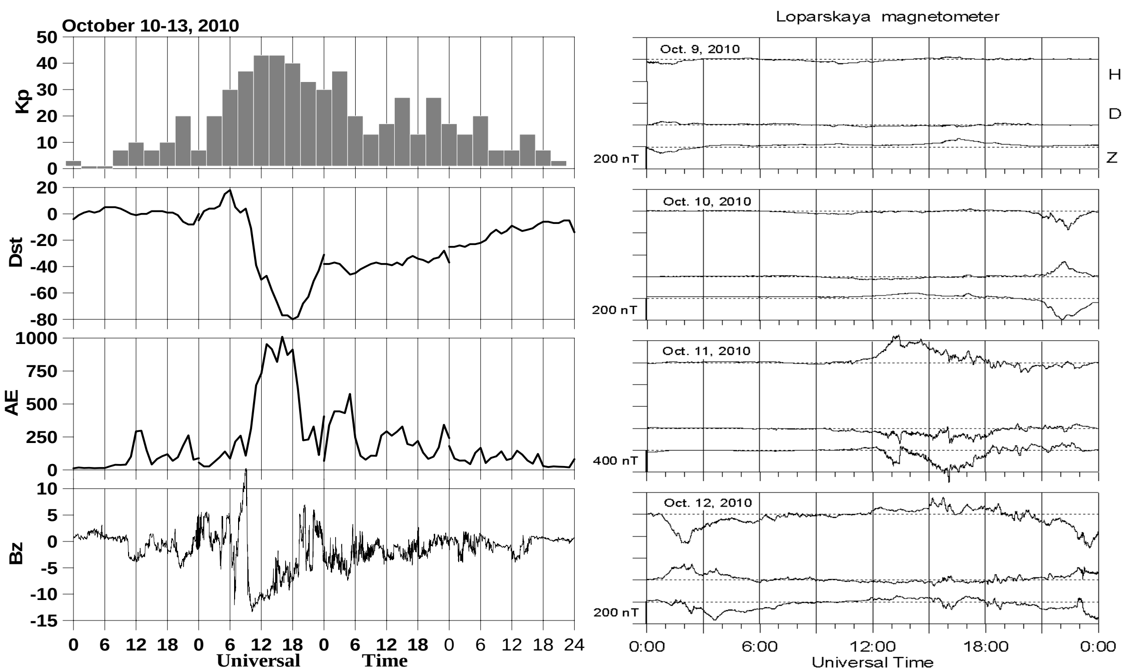

Fig. 1 Geomagnetic characteristics

The variations Kp, Dst, Ae and IMF Bz component during 10-12 October are presented on the Fig.1 (left panel). The storm-time variations of the geomagnetic field at Loparskaya station (*http://pgia.ru*) are demonstrated the right panel. At storm day the Bz component was positive before 09:30 UT and turned negative after with maximal values -13 nT, the Z component geomagnetic field at Laparskaya decrease after 12 UT and reached minimal value near 16 UT.

3. Data source

The GPS stations with geomagnetic coordinates higher than 55° N and different longitudes were involved to this investigation. The dual-frequency GPS measurements for individual satellite passes used as raw data. Standard GPS observations with 30 sec sampling interval provide information about occurrence of the ionospheric irregularities with size more than 10 km. The GPS measurements of Greenland network were used to study the detail occurrence of TEC fluctuations at the northern high latitude ionosphere. This network provides unique opportunity to monitor TEC variability in polar ionosphere on a regular base. GPS stations are arranged along the latitude over the range 60-83° N (65-87° Corrected Geomagnetic Latitude) near of 30-40° longitudes. It covers subauroral, auroral and polar ionosphere.

As a measure of fluctuation 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 [*Aarons*, 1997]).

4. Temporal occurrence of TEC fluctuations

The temporal occurrence of the TEC fluctuations is clearly seen on time variations with the dual frequency carrier phase along satellite passes. As example the TEC variations observed at auroral KELY station for quiet and disturbed conditions presented in Fig. 2. The picture demonstrates the rates of TEC changes along individual satellite pass (PRN15) during quiet (left) and disturbed (right) days. During disturbed conditions the fluctuations of TEC have been essentially increased relative to the quiet condition, the peak values of ROT (0.8 TEC/min) were reached.

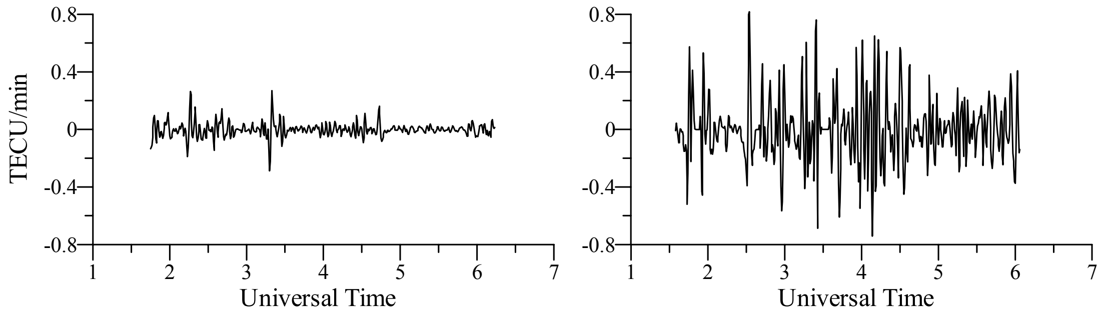

Fig. 2 The behavior of TEC fluctuations along individual satellite passes of PRN 15 during quiet and disturbed day.

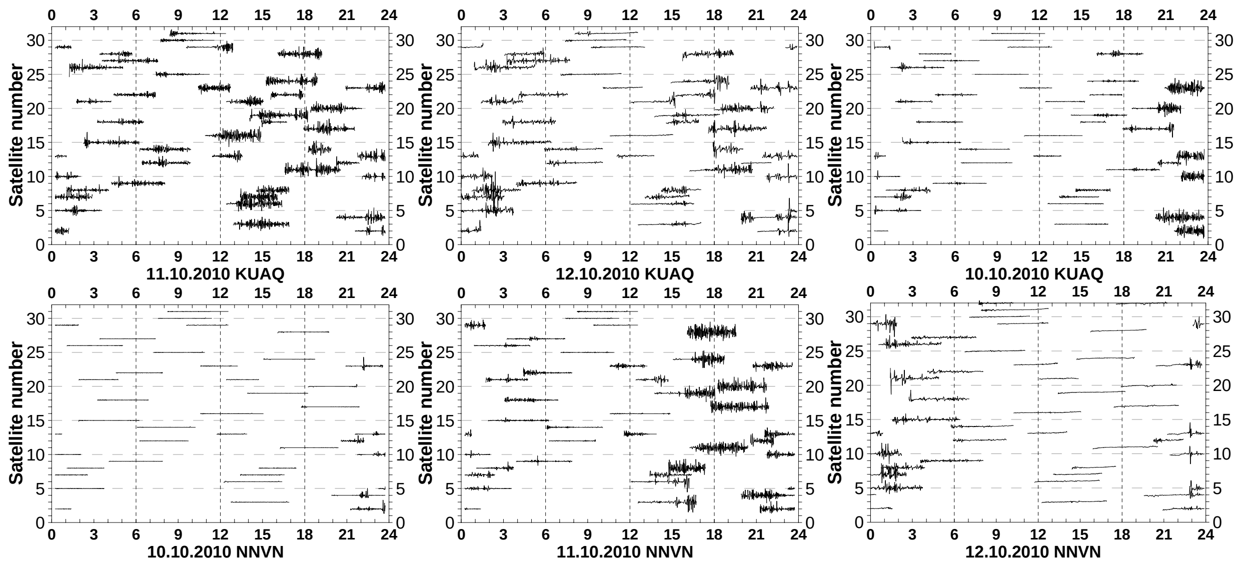

Fig. 3 Development of TEC fluctuations at subauroral and auroral stations for quiet and disturbed days.

Fig. 3 presents the development of TEC fluctuations for all passes of the satellites observed on subauroral NNVN and auroral KUAQ stations over a 24-hour interval on quiet and disturbed days. For quiet day on subauroral station fluctuations were very low, during geomagnetic disturbed day of 11 October the intensity fluctuations essentially increase after 14 UT. On auroral station during quiet conditions the moderate fluctuations were observed after 20 UT (evening time), at storm day the fluctuations were observed during all day with maximal intensity after

12 UT. It is necessary to note that the strong TEC fluctuations were observed on different azimuth directions over stations. For both stations maximal intensity took place simultaneously, but in some cases fluctuations intensity peaks was observed over subauroral station later than over auroral station.

5. Latitudinal and temporal occurrence of TEC fluctuations

As a measure of the fluctuation activity the Rate of TEC Index (ROTI) based on standard deviation of ROT was used [Pi et al., 2009]. The ROTI was estimated on 10-minute interval.

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

The occurrence of TEC fluctuations essentially depend on geomagnetic latitude. Latitudinal behavior of TEC it was analyzed using ROTI measurements over stations located at different latitudes. To obtain spatial and temporal distribution of the TEC fluctuations it was formed images ROTI in Corrected Geomagnetic Latitude (CGL) and Magnetic Local Time (MLT) coordinates (Fig. 4). Stations were chosen due to their location relative to auroral oval. Over subauroral NNVN station during quiet day the low fluctuations were observed at evening time that indicates that the station locates out side auroral oval. During driven phase of storm strong the fluctuations were observed after 12 MLT when Bz is persistently kept negative. The TEC fluctuations development next days were occurred according to development substorm activity on recovery phase storm and strong fluctuations were observed near local midnight.

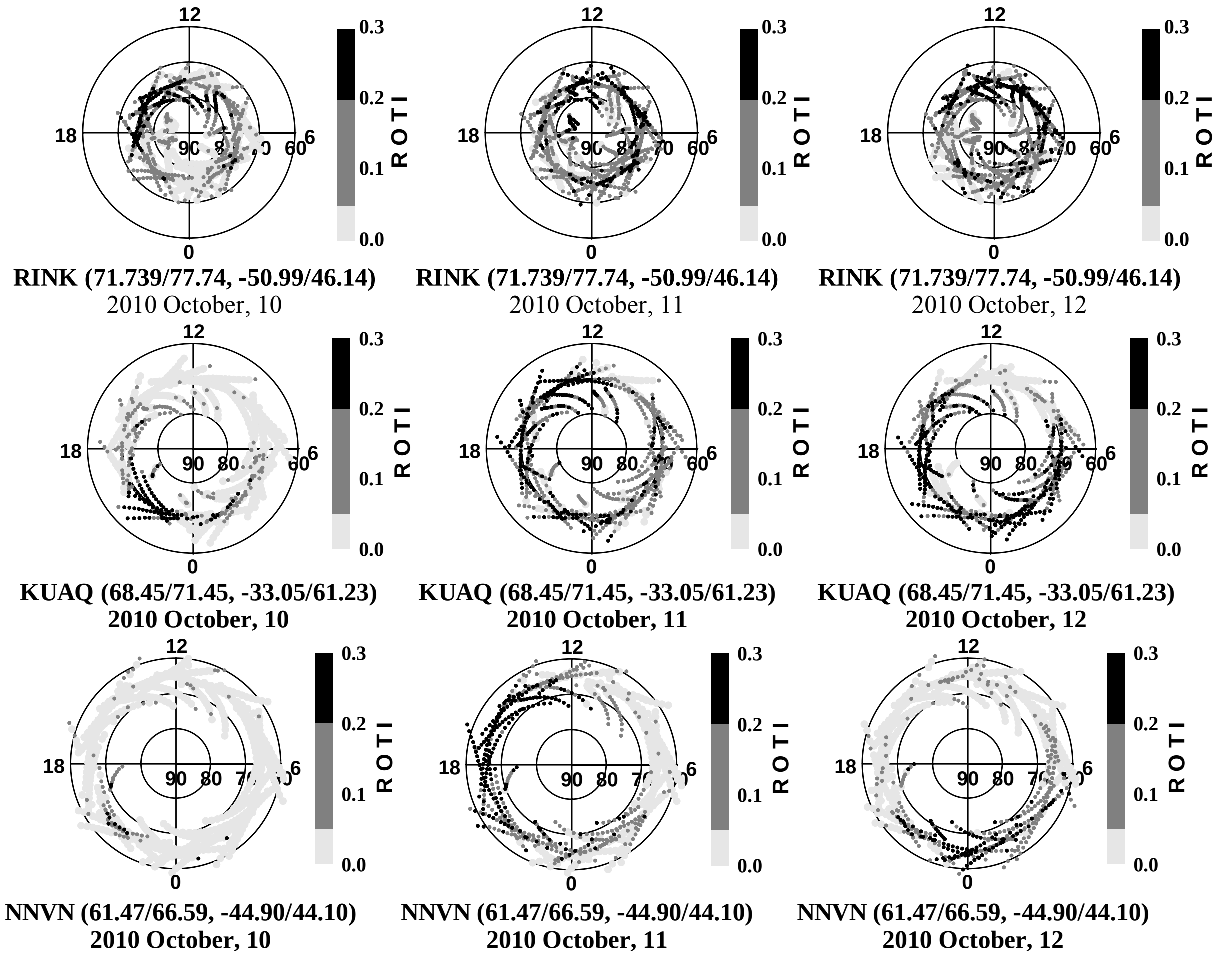

Fig. 4 The occurrence of TEC fluctuations at different latitudes.

At station KUAQ the low TEC fluctuations were observed during all day. The fluctuations intensity increased during storms. Generally the development of fluctuations was similar to subauroral NNVN station but intensive fluctuations were detected during more continuous time. Increase of TEC fluctuations were detected at the same UT time, similar NNVN stations. On the Fig. 4 the occurrence TEC fluctuations at RINK station also are presented. This station on dayside corresponds to the cusp region. Over this station the behavior of TEC fluctuations rather differ against them in the auroral ionosphere. As seen on the picture during quit day strong fluctuations were predominated at day time. At storm day the moderate fluctuations were occurred during whole day, maximal intensity took place day time. During next day the TEC fluctuations development is followed with dynamic of the solar- magnetic activity and strong fluctuations were at day time.

6. Oval irregularities

Based on the daily GPS measurements from 130-150 high latitude it was created images of the spatial distribution TEC fluctuations (index ROTI) in CGC and MLT coordinates for selected periods. Similarly to the auroral oval, these images demonstrate the irregularity oval [*Shagimuratov et al*., 2012, 2013]. The occurrence of the irregularity oval relates with auroral oval, cusp and polar cap. On the Fig. 5 the picture of the irregularity oval development during storm is presented. For quiet day the maximal TEC fluctuation activity took place in evening sector at 68-72° CGL. The developing of fluctuations is begun after 12 MLT. Maximal activity was observed in interval 13-16 MLT on latitudes of 68-70° CGL. During storm the equator edge of irregularities oval was occurred near 60° CGL. Strong TEC fluctuations were registered in cusp region near 12 MLT. On recovery phase of 12 October 2010 storm the occurrence of TEC fluctuations show distinctly image of irregularity oval. The equator edge of the oval was located near 62-63° at local midnight. In day-side irregularity oval was located higher than 70-75° CGL.

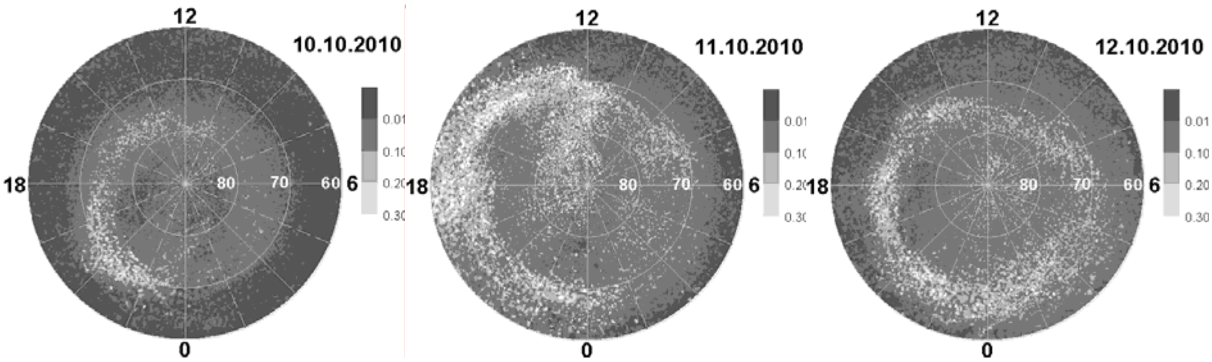

Fig. 5 Images of irregularities oval for quiet and storm-time days.

7. Summary

The investigations results showed that TEC fluctuation activity in the high latitude ionosphere is depended on geomagnetic conditions. Intensity of fluctuations essentially increases during geomagnetic storm; maximal effect took place when Bz IMF component for a long time is maintained negative. During geomagnetic disturbed conditions the strong TEC fluctuations were registered at latitudes low than 60-62 º. The occurrence of GPS- TEC fluctuation is very sensitive to solar–geomagnetic changes and can be use to evaluate space weather conditions. Similarly to the auroral oval the spatial distribution of the fluctuations demonstrate the irregularity of oval images. The irregularity oval expands equatorward with increase of the magnetic activity.

The study showed that the operating high-latitudes GPS stations provides opportunity to monitoring of the irregularity oval in near real-time.

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