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OCCURRENCE OF GPS SIGNALS PHASE FLUCTUATIONS DURING AURORAL ACTIVITY

I.I. Shagimuratov[1], S.A.Chernouss[2], I.I. Efishov[1], M.V.Filatov[2], N.Y.Tepenitsyna[1], G.A. Yakimova[1], E.M. Koltunenko[1], M.V. Shvec[2]

[1]*West Department of IZMIRAN, RAS, Kaliningrad, Russia*
[2]*Polar Geophysical Institute of KSC RAS, Apatity, Russia*

Abstract. We present the result of investigations of GNSS signal phase fluctuations occurrence during the geomagnetic storm on October 2, 2013. During this space weather event the intense phase fluctuations have been registrated at the permanent GNSS stations located not only in auroral and subauroral regions but even over midlatitude stations. In combination with optical and geomagnetic measurements this fact confirms the expansion of the auroral oval towards the equator.

Introduction

A trans-ionospheric radio wave propagating through electron density irregularities may experience phase and amplitude fluctuations. Such fluctuations are appeared due to irregularities with different scales that presents in the polar ionopsphere. Ionospheric irregularities can be structured with latitude and their intensity differ in the high-latitude ionosphere at subauroral, auroral, polar and cusp regions. In accordance with this, the fluctuation activity varies considerably with latitude and space weather's conditions.The small irregularities with scale lees than 1km cause 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 may be directly due to electron density changes along the radio ray path, or the total electron content (TEC) changes. Strong TEC fluctuations can complicate phase ambiguity resolution; increase the number of undetected and uncorrected cycle slips and loss of signal lock in GPS navigation[1-3]. and positioning errors [4]

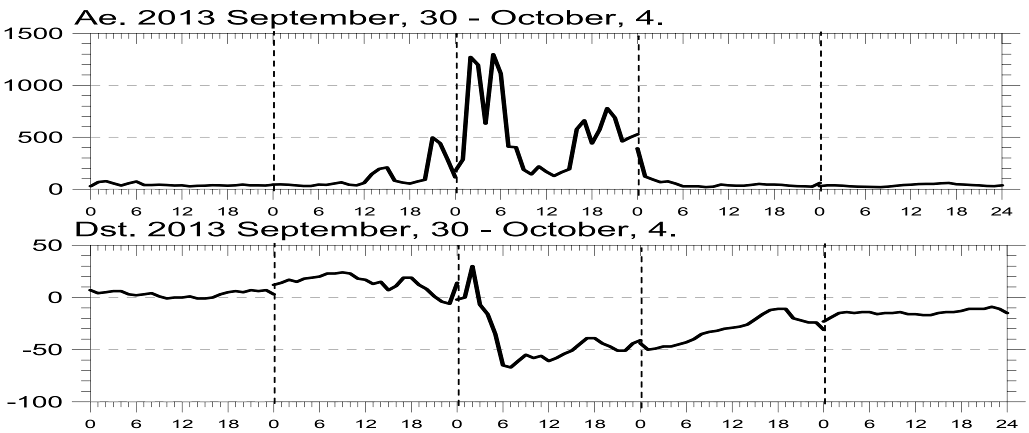

Figure 1. Ae and Dst variations for September 30 - October 4, 2013

Data and Geomagnetic conditions

The information about TEC fluctuations may be obtained using the regular GPS observations provided by the International GPS Service (IGS). The world wide and numerous network GPS stations are very opportunely to monitor the spatial distribution of ionospheric irregularities in planetary scale [5, 6].

RINEX-derived dual-frequency GPS observation with 30 sec sampling rate were processed to obtain the information about occurrence of the ionospheric irregularities. The TEC measurements for individual satellite passes served as raw data. During active phase of storm we used magnetometer data of chaim of the Scandinavian network. In this report 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 2 October 2013. The storm was rather moderate with active phase started 2 October 2013 after midnight. On the Fig. 1, the geomagnetic conditions for September 30 - October 4, 2013 are presented, including data of subauroral magnetometers.

GPS stations with geomagnetic coordinates higher than 55°N and different longitudes were involved in this investigation. Dual-frequency GPS measurements for individual satellite passes served as raw data. Standard GPS observations with 30 sec sampling interval provide information about occurrence of ionospheric irregularities with size more than10km.

As a measure of fluctuation activity the rate of TEC (ROT, in the unit of TECU/min, 1 TECU=10^{16} electron/m2) at 1 min. interval was used [7]. As measure intensity fluctuations index ROTI was used [8] .

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

Results

3.1 Comparison of TEC fluctuation data during weak and strong geomagnetic activity

The temporal occurrence of the TEC fluctuations is clearly observed in time variations of the dual frequency carrier phase along satellite passes. For example, the TEC variations, observed at midlatitude stations Kaliningrad for quiet and disturbed conditions, are presented at Fig. 2. The picture demonstrates the rates of TEC changes (ROT) along all satellite passes over 24 hour interval.

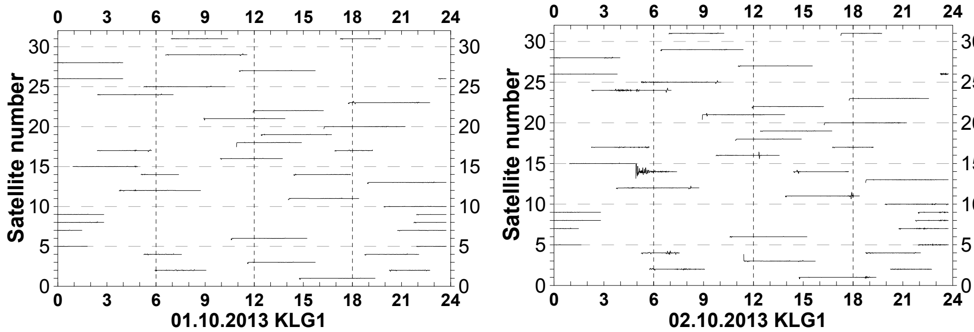

Figure 2. Development of TEC fluctuations at midlatitude Kaliningrad station for quiet (1 October) and disturbed (2 October) days

For quiet day the fluctuations were very low. During geomagnetic disturbed day the intensity of fluctuations was detected in satellite pass of PRN 14 around 05 UT.

Detaille picture fluctuations for PRN 14 for quiet and disturbed days is presented in Fig. 3. The satellite trajectory in the ionosphere (cross line) also shown on the picture.

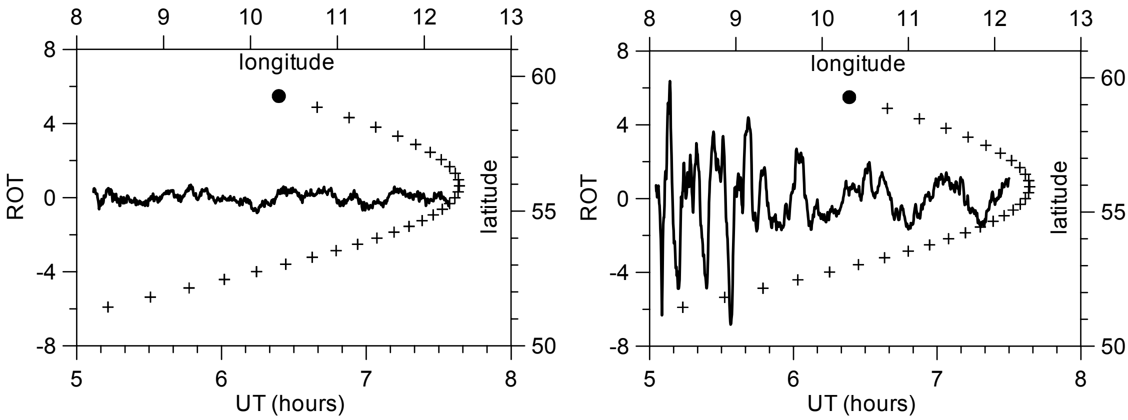

Figure 3. Development of TEC fluctuations at midlatitude Kaliningrad station for quiet and disturbed days

The intensive TEC fluctuations during storm day was localized at latitudes 57-58°N when magnetic bays were occurred on magnetogram of the Scandinavian network in time interval 05-06 UT (Fig. 4.).

Obviously, the time course of these effects coincide, moreover, the time course of events in both diagrams coincide with the temporal variations parameter ROT at Tromso and Kaliningrad stations together with records of spectral and temporal variations of the geomagnetic field at the stations Lovozero and Sodaynkyula shown in Fig. 5.

It appears that bear upon the maximum variations, as well as the pulsations of the geomagnetic field, we can determine the source which affect a destruction of the navigation signal in the ionosphere in the presence of auroral disturbances. This is particularly noticeable in the intervals substorm intensification of disturbances. For example, a small perturbation around 01.10.2013 21:00 UT, localized exclusively in the polar region, had little effect on variations of ROT in Kaliningrad. At the same time, strong disturbance about 02/10/2013 05:00 UT as reflected in magnetic observations at the latitude of Kaliningrad and in the values of ROT on this point. This correspondence suggests the possibility of diagnostics and prognosis of the state of the reception of navigation signals from measurements of geomagnetic field variations.

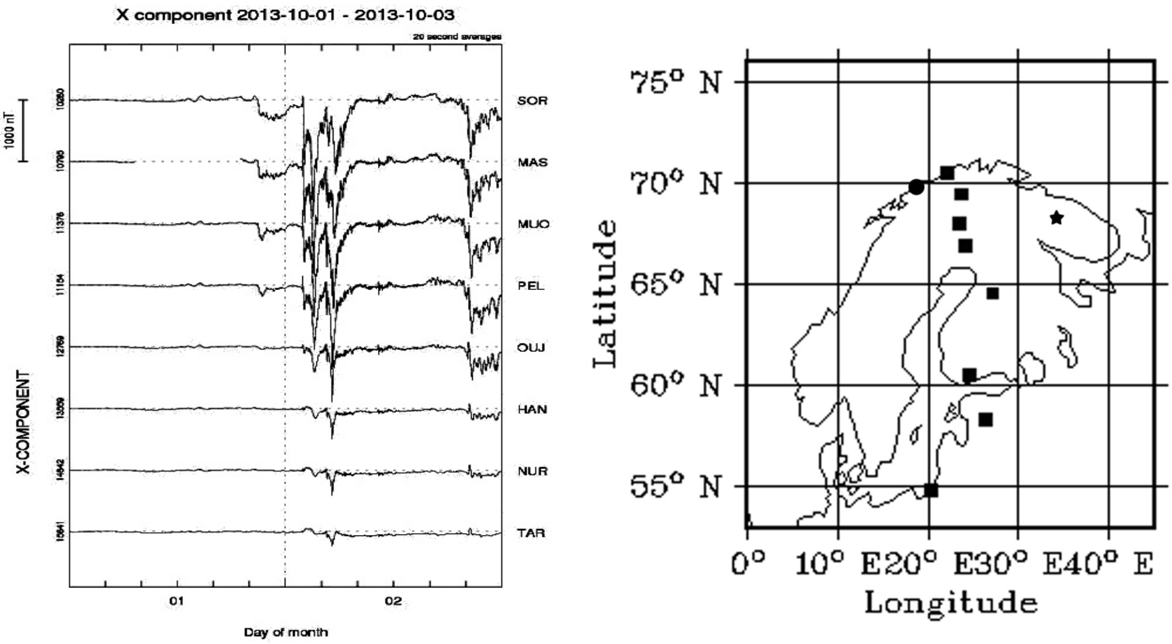

Figure 4. The variations of the geomagnetic field X-component at different stations and map of Scandinavian network

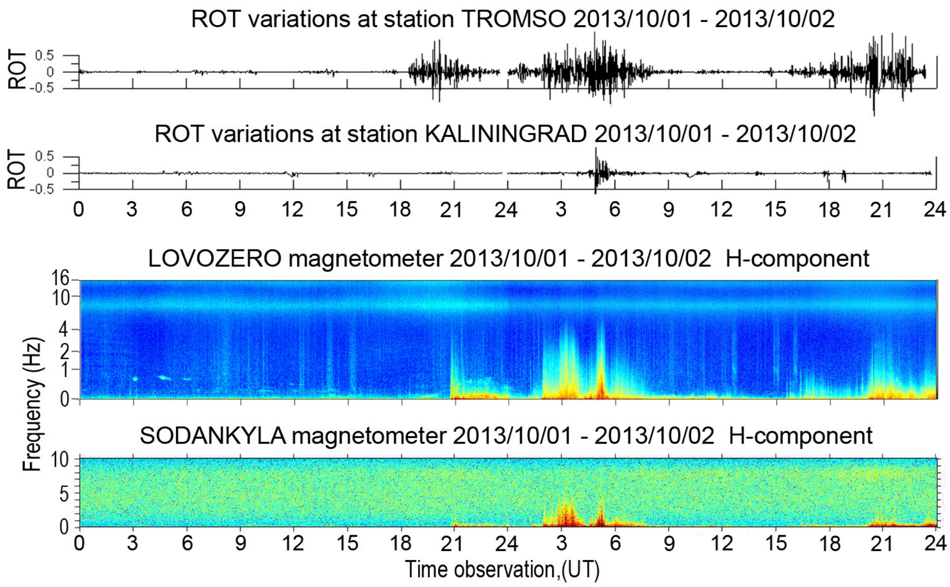

Figure 5. The variotions of ROT at Tromso and Kaliningrad and keogram at the stations Lovozero and Sodaynkyla

3.2 Comparison of optical and TEC irregularity planetary pictures

Based on the daily GPS measurements from 130-150 selected stations, the images of spatial distribution TEC fluctuations (index ROTI) in CGC and MLT coordinates was formed. These images demonstrate the irregularity oval, similarly to the auroral oval [9]. The occurrence of the irregularity oval relates with the auroral oval, cusp and polar cap. The irregularity oval expands mostly equatorward with an increase of the geomagnetic activity. In a case we study comparison of the auroral oval and oval of TEC irregularities at the TIXI station from 01.10.2013 to 03.10.2013. Position of the auroral oval was calculated by metods described in Starkov [10] and Sigernes [11] papers.

As an example, Fig. 6 presents the dynamics of the irregularity oval in dependance on a geomagnetic activity.

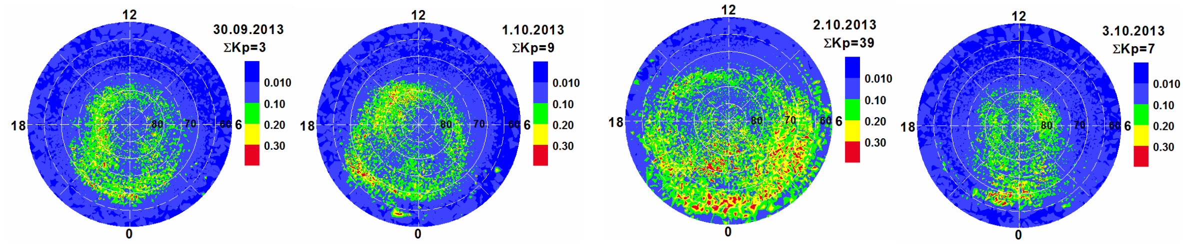

Figure 6. Daily dynamics of the irregularity oval in dependance on a geomagnetic activity from 30.09.2013 to 03.10.2013

Fig. 7 shows norths snd south borders of the auroral oval and TEC irregularities during from 01.10.2013 to 03.10.2013 at the TIXI station (71.38N, 128.52E). Width of the auroral oval rise during local night time and the oval of TEC irregularities mostly follow the auroral oval. It was a case sudy and next studies should be devoted to statistical ratio of position of both ovals.

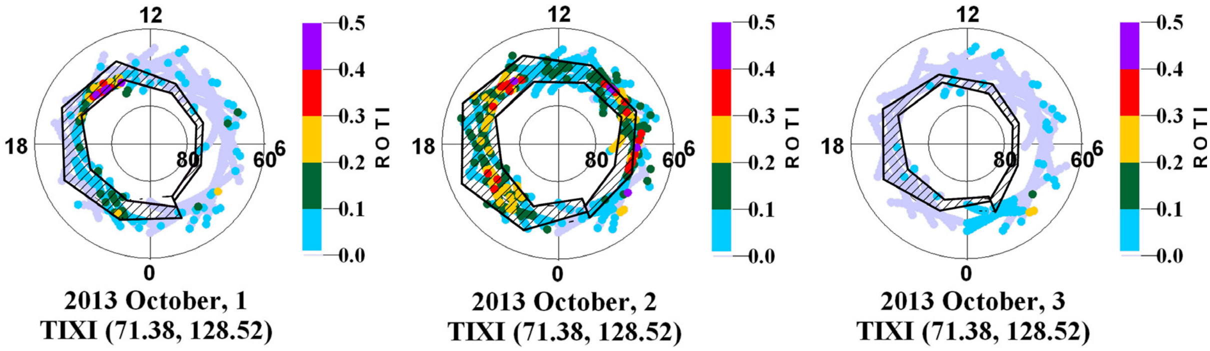

Figure 7. Boudaries of auroral oval and space time distribution of TEC irregularities by TIXI data. Auroral ovals showed by bold lines, TEC irregularities ovals showed by patches

Conclusions

During 2 October 2013 geomagnetic storm the intensive TEC fluctuations were observed at auroral and subauroral ionosphere. Joint analysis of observed phase fluctuations of GPS signals, and fluctuations of the geomagnetic field showed good agreement of both events during auroral activity. In time the maximal activity aurora the intensive phase fluctuations were registered even at midlatitude station Kaliningrad. In combination with optical and geomagnetical measurements this fact is explained by an expansion of the auroral oval towards the equator during high geomagnetic activity.

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