Phase fluctuations of GPS signals and irregularities in the high latitude ionosphere during geomagnetic storm

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Accepted: 30 January 2015

Abstract: In this report we analysed latitudinal occurrence of TEC fluctuations over Europe during October 2, 2013 geomagnetic storm. The data of GPS stations spaced in latitudinal range 68°-54°N over longitude of 20°E were involved in this investigation. The magnetograms of the IMAGE network and geomagnetic pulsations at Lovozero (68°02`N 35°00`W) and Sodankyla (67°22`N 26°38`W) observatories were used as indicator of auroral activity. During October 2, 2013 the strong geomagnetic field variations took place near 05 UT at auroral IMAGE network. We found good similarities between time development of substorm and fluctuations of GPS signals. The bay-like geomagnetic variations were followed by intensive phase fluctuations at auroral and subauroral stations. The strong short-term phase fluctuations were also found at mid-latitude Kaliningrad station near 05 UT that correspond to the maximal intense geomagnetic bay variations. This date confirms the equatorward expansion of the auroral oval. It brings in evidence also the storm time behavior of the irregularities oval obtained from multi-site GPS observations.

Keywords: ionosphere, auroral oval, GNSS, phase fluctuations, geomagnetic storm.

Introduction

A trans-ionospheric radio wave propagating through the electron density irregularities may experience phase and amplitude fluctuations. Such fluctuations occur due to irregularities with different scales that are present in the polar ionosphere. The ionospheric irregularities can be structured with latitude and are related to the auroral oval, cusp, and polar-cap patches (Prikryl et al. 2013; Skone et al. 2009; Spogli et al. 2009). In accordance with this the fluctuation activity varies considerably with latitude and space weather conditions. Strong fluctuations are associated with polar-cap patches (Krankowski et al. 2006; Jin et al. 2014). The high GPS phase fluctuation /scintillation activity occur around magnetic noon and around magnetic midnight. The scintillation occurrence rate is higher around noon, while the scintillation level is stronger around magnetic midnight. The occurrence rate of the GPS dayside phase scintillation is highest inside the auroral cusp (Jin et al.2015). The intensity of fluctuations increase usually during geomagnetic disturbances (Shagimuratov et al. 2013, 2014; Prikryl et al. 2011; Spogli et al.2009). Strong fluctuations can complicate phase ambiguity resolution and increase the number of the undetected and uncorrected cycle slips (Forte and Radicella, 2004; Chernouss and Kalitenkov, 2011). A strong positive correlation between Precise Point Positioning (PPP) error and index ROTI was revealed by Jacobsen and Dahnn (2014) at latitudes of 64^0–79^0N.

The loss of signal lock in GPS navigation can be associated with aurora (Smith et al. 2008). The experimental evidence of positioning errors related with spatial and temporal variations in the intensity of auroral arcs was demonstrated by Chernouss (2014,2015).

Standard GPS observations with 30 sec sampling interval provide information about low frequency phase fluctuations. The phase fluctuations occur due to electron density changes along the radio wave path, or the total electron content (TEC) changes. The information about TEC fluctuations may be obtained using the regular GPS observations provided by the International GPS Service (IGS). The worldwide dense network of the GPS stations is very useful for permanent monitoring of the spatial distribution of the ionospheric irregularities on a global scale (Pi et al. 1997; Shagimuratov et al. 2012).

In this report GPS measurements of global IGS network were used to study the storm time occurrence of the phase fluctuations (TEC changes) in the high latitude ionosphere during October 2, 2013 storm.

Data and geomagnetic conditions

TEC measurements for individual satellite passes were 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 (Aarons, 1997). As measure of the phase fluctuation intensity the ROTI index was used (Pi, 1997).

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

During the main phase of the storm we used the magnetometer measurements provided by the chain of the Scandinavian network. Figure 1 presents the geomagnetic conditions for September 30 ÷ October 2013.

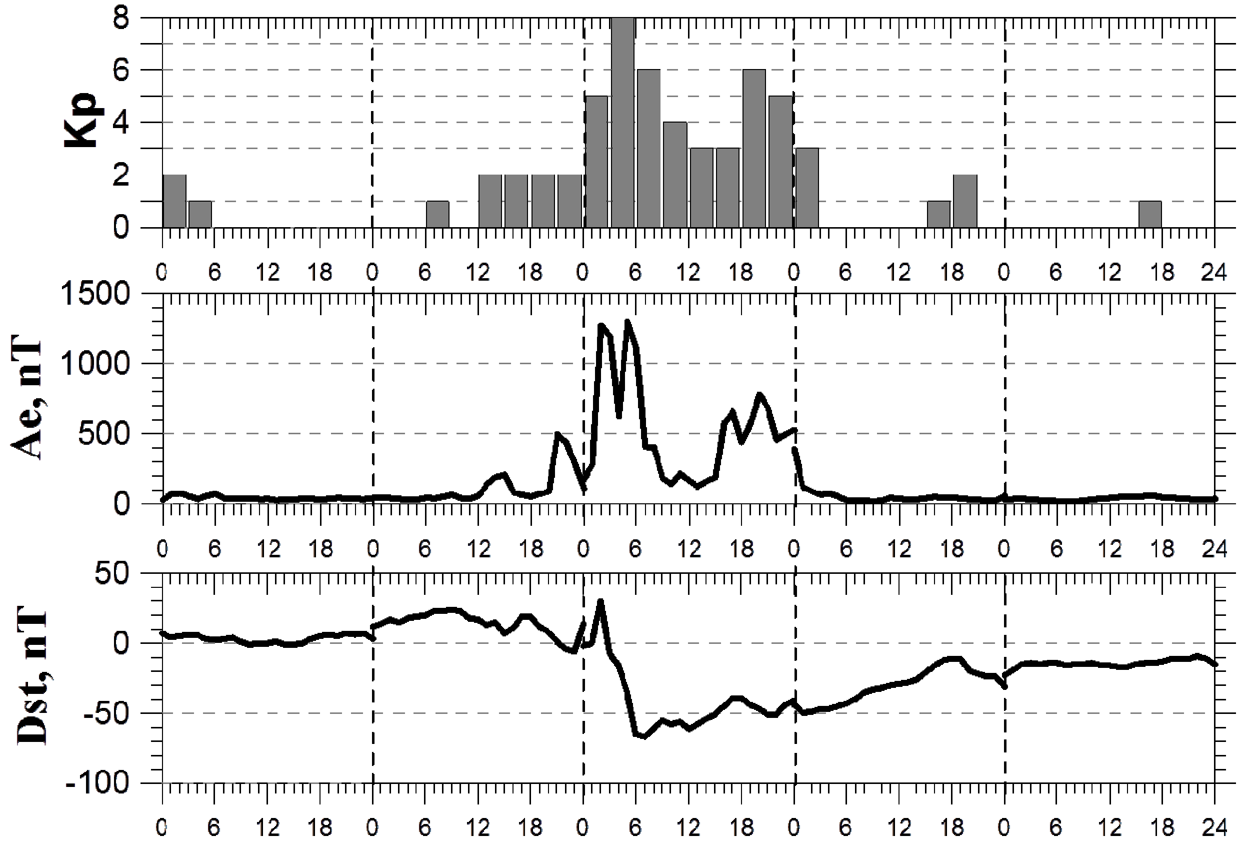

Fig. 1. Kp, Dst and Ae variations for September 30 - October 4, 2013.

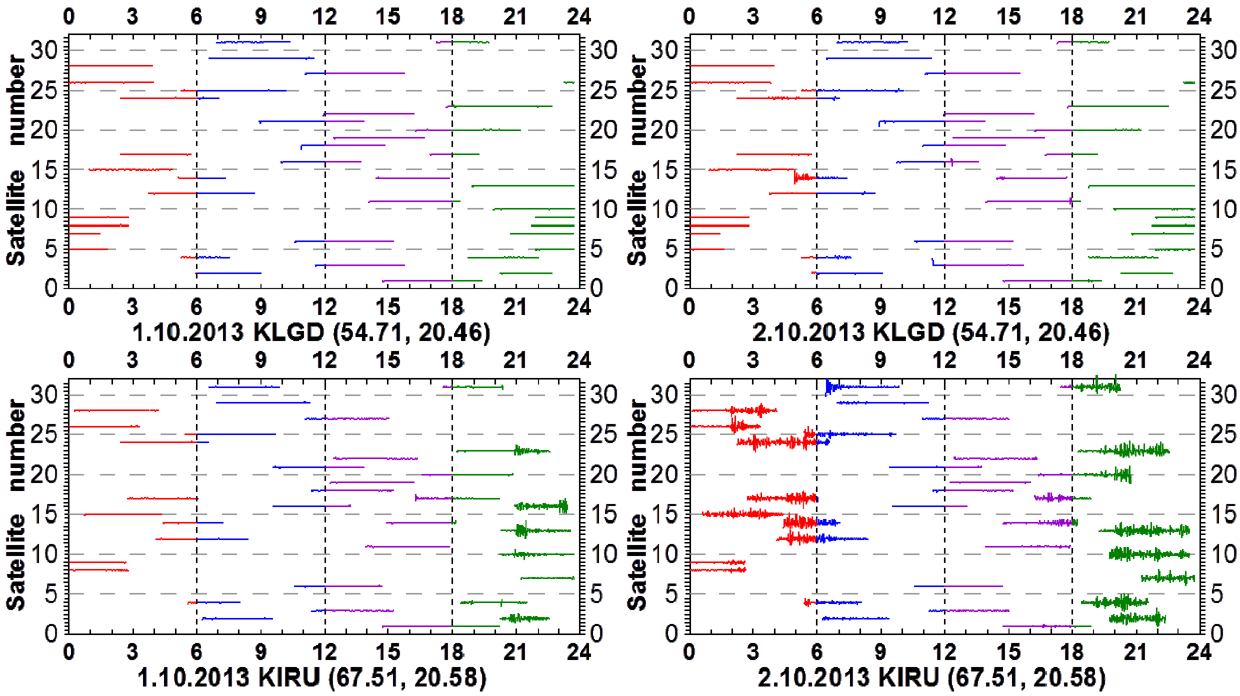

Fig. 2.Development of TEC fluctuations (ROT) at midlatitude Kaliningrad (54.71, 20.46) and Kiruna (67.51, 20.58) stations for quiet (October 1) and disturbed (October 2) days.

The storm was rather moderate with active phase started on October 2, 2013 after midnight. Maximal value of Kp reached 8 during the time interval 03-06 UT when the active phase of storm developed, maximal value of Dst was about -70 nT. Auroral activity was registered in morning and evening time. Index Ae reached 1300 nT during the main phase.

Results and discussion

Occurrence of the TEC fluctuations can be clearly observed in the temporal variations of the dual frequency carrier phase along satellite passes. For example, the TEC variations, observed at the auroral KIRO and mid-latitude Kaliningrad stations for quiet and disturbed conditions are presented at Figure 2. The figure demonstrates the rate of TEC changes (ROT) along all satellite passes over 24 hour interval. At the Kaliningrad station for quiet day the fluctuations activity was very low. At the high latitudes the moderate fluctuations were observed in evening time, near the magnetic midnight time period on single satellite passes which appears to enter into the auroral oval (Aarons, Lin and Mendillo, 2000). At the Kiruna station during geomagnetic disturbed day the intensive fluctuations were detected in the morning and evening time period. At the Kaliningrad station moderate fluctuations were registered at only satellite pass of PRN 14 around 05 UT.

Detailed picture of the fluctuations for PRN 14 at Kaliningrad stations for quiet and disturbed days is presented in Figure 3. It can be seen the TEC fluctuations during storm day were localized at the latitudes 57°-58°N. Figure 4 shows the magnetic bays on magnetogram of the IMIAGE Scandinavian network. The network includes the stations located in auroral, subauroral and mid-latitude area. Two series of magnetic activity took place, in morning and evening time. The intensity of the magnetic bay is decreased from north to south. The strongest magnetic variations were registered at 5-6 UT, when a weak bay was observed even at a latitude of 55°N.

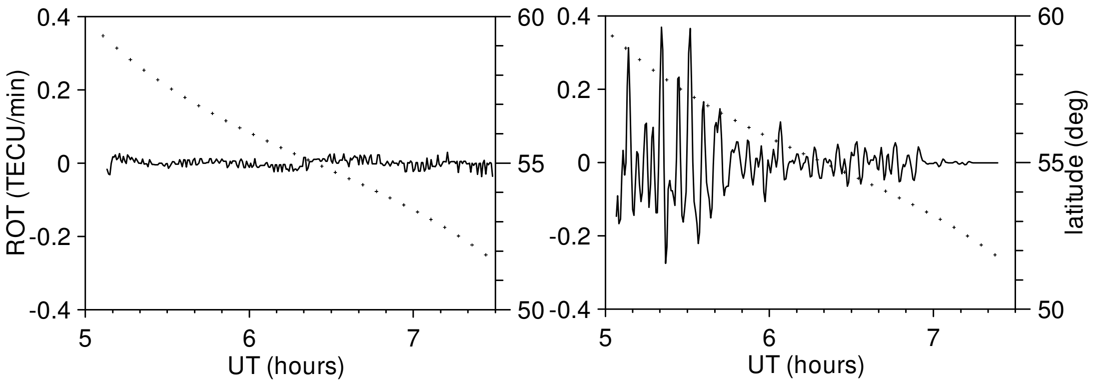

Fig. 3. TEC fluctuations along satellite pass of PRN14 at Kaliningrad station for quiet and disturbed days. Cross-latitudinal location of the “Ionospheric Pierce Point (IPP)”.

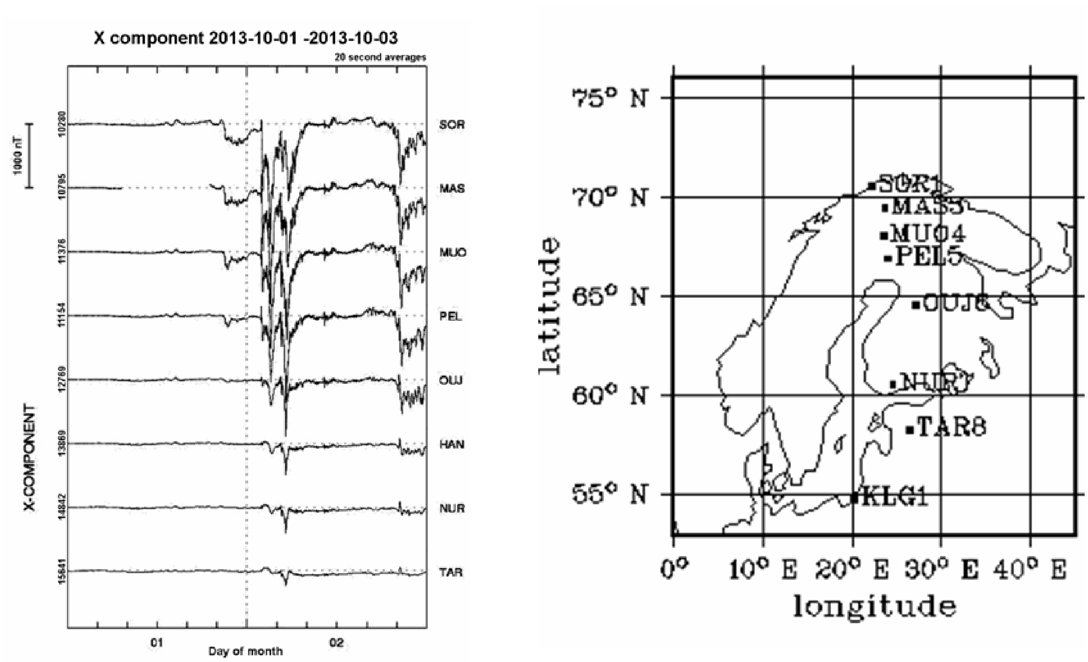

Fig. 4. The variations of the geomagnetic field X-component at different stations (left panel) and map of Scandinavian network (right panel).

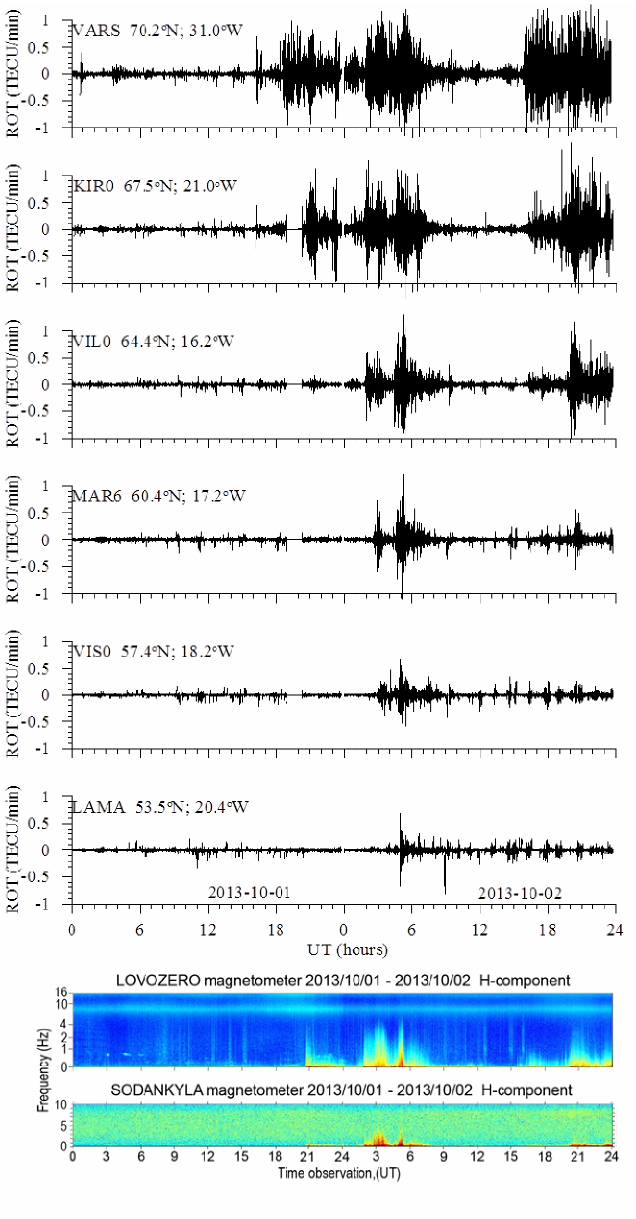

Fig. 5. Latitudinal occurrence of TEC fluctuations and keograms at the stations Lovozero (68.0°N, 35.0°E) and Sodaynkyla (67.4°N, 26.6°E) for October 1-2, 2013.

Figure 5 shows the ROT variations at the stations arranged from north to south and keogram at the stations Lovozero and Sodaynkyla. The fluctuations intensity decreased towards lower latitudes. At auroral stations the strong TEC fluctuations were registered at the morning and evening time. At lower stations the fluctuations were observed around 5-6 UT when the magnetic field variation had the strongest intensity. Obviously, the occurrence of large ROT values coincides with the geomagnetic field variations at the Lovozero and Sodankyla stations, as well as with the variations of the geomagnetic field X-component at different stations of the Scandinavian network.

According to evidence of the maximum TEC variations as well as the pulsations of the geomagnetic field we can determine the source which cause a disruptions of the navigation signal in the ionosphere in the presence of the auroral disturbances. This is particularly noticeable in the intervals of the substorm intensification.

For example, a small perturbation around 2100 UT of October 1, 2013, localized in the polar region, had a little effect on the ROT variations over Kaliningrad. On the other hand, the strong disturbance about 05:00 UT of October 2, 2013, was reflected in magnetic observations at the latitude of Kaliningrad and in the ROT values at this point.

Irregularities Oval

Based on the daily GPS measurements from 130-150 selected stations, the images of spatial distribution of TEC fluctuations (index ROTI) in CGL (Corrected Geomagnetic Latitude) and Magnetic Local Time (MLT) coordinates were constructed. Similarly to the auroral oval, these images demonstrate the irregularities oval (Shagimuratov et al.2012). The occurrence of the irregularities oval relates with the auroral oval, cusp and polar cap. As an example, Figure 6 presents the dynamics of the irregularities oval in dependance on a geomagnetic activity. It can be see on the pictures that the irregularity oval expands equatorward during the storm day.

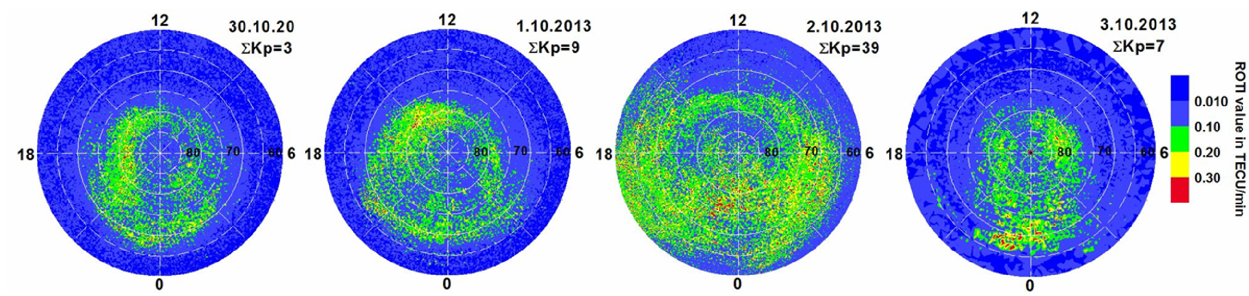

Fig. 6. Dynamics of the irregularity oval during September 30 - October 3, 2013 in CGL and MLT coordinates.

Conclusions

During October 2, 2013 geomagnetic storm, intense TEC fluctuations (ROT) were observed in the auroral and subauroral ionosphere. Joint analysis of the observed phase fluctuations of GPS signals and fluctuations of the geomagnetic field demonstrated rather good agreement during intensification of the auroral activity. During the peaks of the auroral activity the intense GPS phase fluctuations were registered even at the mid-latitude station Kaliningrad. This date evidence the equatorward expansion of the auroral oval. The analysis shows that position and intensity of the irregularities oval are very sensitive to the variations of the auroral activity and thus the magnetic fluctuation measurements can be used as an indicator of the space weather conditions.

Acknowledgment

We thank the Institutes who maintain the IMAGE Magnetometer Array, Grant RFBR 14-05-98820 r-sever-a and grant RFBR 14-07-00512. The authors are very grateful to world data centers for the free availability of the data WDC-C, Kyoto University, Japan.

References

Aarons J.: 1997, J. of Geophys. Res. 102, 17219.

Aarons J., Lin B. and Mendillo M.: 2000, J. of Geophys. Res. 105, 5201.

Chernouss S.A. and Kalitenkov N.V.: 2011, International J. of Remote Sensing. 32, 3005.

Chernous S.A., Shvets M.V., Filatov M. V., Shagimuratov I.I., and Kalitenkov N.V.: 2015, Russian Journal of Physical Chemistry B. 9(5). 778.

Chernouss S., Shvets M., Filatov M., Shagimuratov I., Kalitenkov N.:2014. Atmosphere, Ionosphere, Safety Proceedings of IV International conference Kaliningrad 2014. 243.

Forte B., Radicella S.: 2004, Radio Science. 39. RS5014.

Jin Y., Moen J. I. and Miloch W. J.:2015. J. Geophys. Res.: Space Physics. 10. DOI: 10.1002/2015JA021449.

Jin Y., Moen Y.J. and Miloch W.J.: 2014, J. Space Weather Space Clim. 4, DOI: 10.1051/swsc/2014019.

Krankowski A., Shagimuratov I.I., Baran L., Efishov I.I. and Tepenitzyna N.Yu.: 2006. Adv. Space Res. 38. 2601.

Pi X., Manucci A.J., Lindqwister U.J. and Ho C.M.: 1997. Geophys. Res. Letters. 24. 2283.

Prikryl P., Ghoddousi-Fard R., Kunduri B.S.R., Thomas E.G., Coster A.J., Jayachandran P.T., Spanswick E. and Danskin D.W. :2013. Ann. Geophys. 31(5). 805.

Prikryl P, Spogli L., Jayachandran P.T., Kinrade J., Mitchell C.N., Ning B., Li G., Cilliers P.J., Terkildsen M., Danskin D.W., Spanswick E., Donovan E., Weatherwax A.T., Bristow W.A., Alfonsi A., De Franceschi G., Romano V., Ngwira C.M. and Opperman B.D.L: 2011. Ann. Geophys. 29. 2287

Shagimuratov I., Chernouss S., Efishov I., Cherniak Yu., Koltunenko L.:2014. Atmosphere, Ionosphere, Safety Proceedings of IV International conference Kaliningrad 2014.. 251.

Shagimuratov I.I., Efishov I.I., Cherniak Iu.V., Tepentsyna N.Yu. and Koltunenko L.: 2013. Proceedings Beacon Satellite Symposium.

Shagimuratov I.I., Efishov I.I., and Tepenitsyna N.Yu.: 2009. Proceeding EuCAP 2009.

Shagimuratov I.I., Krankowski A., Efishov I.I., Cherniak Yu.V., Wielgosz P. and Zaharenkova I.E.: 2012. Earth Planets Space. 64. 521.

Skone, S., M. Feng, R. Tiwari, and A. Coster: 2009. Proceedings of the 22nd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2009). 2551.

Smith A.M., Mitchell C.N., Watson R.J., Meggs R.W., Kintner P.M., Kauristie K.and Honary F.: 2008. Space Weather. 6. S03D01.

Spogli, L., Alfonsi L, De Franceschi., Romano V., Aquino M.H.O. and Dodson A.: 2009. Ann.Geophys. 27. 3429.