

OBSERVATIONS OF GPS TEC FLUCTUATIONS IN ANTARCTIC AND ARCTIC IONOSPHERE DURING 28 OCTOBER 2003 STORM

I.I. Shagimuratov, I.I. Efishov, N.Yu. Tepenitsyna, I.E. Zakharenkova (*West Department of IZMIRAN: 41, Av. Pobeda, Kaliningrad, 236010, Russia e-mail: shagimuratov@mail.ru*)

Abstract

The paper presents the analysis on the storm-time occurrence of phase fluctuations of GPS signals observed at high latitude ionosphere using both north and south hemisphere GPS stations. GPS phase measurements provide information about TEC variations. The fluctuations are caused by different scales ionospheric irregularities which were associated with auroral oval and polar cap. During storm intensity phase fluctuations essentially increased. The strongest fluctuations associated with polar patches which were usually observed in the polar ionosphere. During storm strong TEC fluctuations were detected at geomagnetic latitudes lower than 60N.

1. Introduction

GPS radio signals propagating through ionosphere suffer amplitude and phase scintillations. The scintillation occurrence and its effects are caused the different scale ionospheric irregularities. The maximal radio waves scintillation activity took place in equatorial and high latitude ionosphere. High latitude scintillation occurrence relates with auroral oval, cusp and polar cap [1,2].

The scintillation effects can influence on the performance of space radio communication, navigation systems. Both phase and amplitude scintillations can have different impact on GPS measurements and data processing for high precision GPS positioning. They affect phase ambiguity resolution, increase the number of undetected and uncorrected cycle slips and loss of signal lock [3].

The standard GPS measurements provided by global IGS network are sampled with 30 sec. The interval enables to detect the ionospheric irregularities with scale more than tenth kilometers. The RINEX-file data provide adequate information on phase fluctuations associated with middle and large-scale ionospheric irregularities. The dual-frequency GPS phase measurements enable to retrieve information about variations of the ionospheric total electron content (TEC). In this paper we describe the development of TEC fluctuations during October 29, 2003 geomagnetic storm on the base of Antarctic and Arctic GPS measurements. For analysis of the temporal variations of different carrier phase the GPS signals along individual satellite passes were used. As the measure of phase fluctuation activity we used the rate of TEC on 1 min interval (ROT) and index ROTI [4].

We used more than 20 GPS stations of both northern and southern hemispheres located in auroral and polar regions.

2. Temporal variations of TEC

The temporal occurrence of TEC fluctuations is clearly observed in time variations in the dual frequency carrier phase along satellite passes. The strongest TEC fluctuations took place on polar stations. For example TEC variations observed at polar Antarctic stations CAS1 and MAW1 for quiet and disturbed conditions presented in Fig.1. The picture demonstrates temporal TEC variations (left column) along individual satellite passes during disturbed (red line) and quiet days (blue) observed at different stations.

This figure also shows the satellite ionospheric tracks at the altitude of 400 km in geographic coordinates. The increase in TEC can exceed the factor of 2-4, and the enhancement of TEC can exceed 10 TECU ($1 \text{ TECU} = 10^{16} \text{ el/m}^2$) relative to the background.

The rates of TEC changes are presented on the left panel of Fig.1. During disturbance the fluctuations of TEC have been essentially increased relative to the quiet condition, maximal values of ROT (3 TEC/min) were reached.

The strong and deep fluctuations of TEC presented in Fig.1 were caused by the presence of large-scale ionospheric structures of enhanced electron density in the polar ionosphere. These structures were associated with the occurrence of polar patches. Polar cap patches are large regions of enhanced F region plasma density. They were observed to travel through the ionospheric polar caps, under the influence of the high-latitude convection [5]. Discrete F region electron density is enhanced by a factor 2 or more. Patches are typically considered to be of the order of 100-1000 km in horizontal extent. The traveling speed of the patch is between 300-900 $\text{m}\cdot\text{s}^{-1}$ [6]. Thus, in the temporary pattern showing the variations of TEC along satellite passes, the duration of the patches occurrence can be 10 min or more.

The numbers of patches were evaluated by counting peaks of TEC enhancement along single satellites trajectories. A number of 4 to 8 patches of different intensity can be observed along individual satellite passes.

The picture of the patch structures occurrence can essentially changed at neighbor stations. In Fig.2 it is presented the behavior of TEC fluctuations on neighboring polar stations for the same satellite passes. There is good correlation of TEC fluctuations between Antarctic stations BFTO and CRZO stations,

at short distance of about 80 km. The correlation between BFTO-BRMO (distance is about 340km) and BFTO-DEVO (distance is about 460 km) is deteriorated respectively.

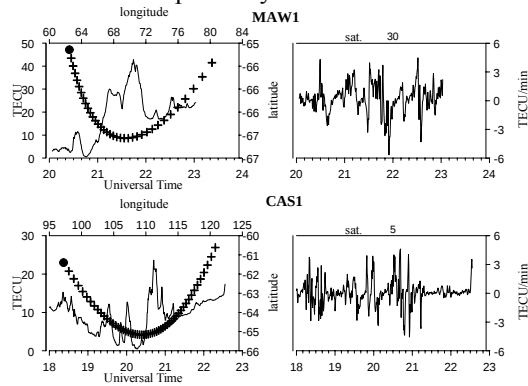


Fig.1. Temporal TEC variations (left column) and rate of TEC along individual satellite passes.

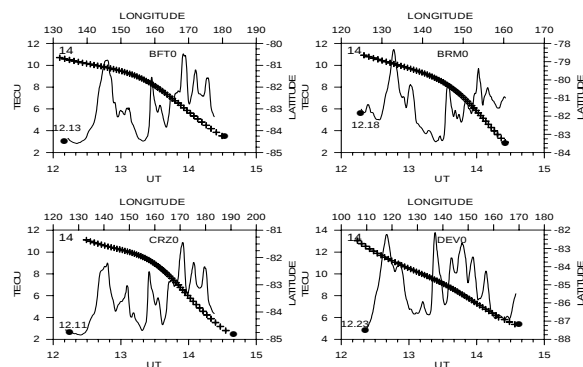


Fig.2. Temporal TEC variations at the nearest GPS stations.

3. Storm-time development of phase fluctuations

The occurrence of TEC fluctuations was analyzed by using the rate of TEC changes: $ROT = 9.53((\Phi_1 - \Phi_2)_{ij} - (\Phi_1 - \Phi_2)_{i-1}) / (t_j - t_{j-1})$, where $(t_j - t_{j-1}) = 1$ min, Φ_1 and Φ_2 [m] denote measured differential carrier phase observable of L_1 and L_2 . A scaling factor converts the differential ionospheric delay to units of electrons/m². The ROT can be successfully applied to process large data files, because it eliminates phase ambiguities. Figure 3 presents the development of TEC fluctuations, using ROT, for geomagnetic active period: 28-31 October 2003 over both hemispheres. The pictures illustrate the occurrence of TEC fluctuations for all passes of satellites observed at different stations over 24 hour interval on moderate (28 October) and disturbed days (29 and 30 October).

At the polar stations CAS1 and RESO weak and moderate TEC fluctuations are detected all time during day of 28 October, during severe storm days of 29 and 30 October the intensity of TEC fluctuations essentially increased. Maximal activity of fluctuations took place at 16-24 UT 29 and 30 October. The analysis shows that the occurrence of TEC fluctuations depends on substorm activity which

was maximal observed after noon of 29 and 30 October 2003. Strong TEC fluctuations at high latitude ionosphere associated with polar patches. Dandekar and Bullett [7] showed that patches activity weakly depended on the magnetic activity. At the same time they found out that for other periods polar patches were more often observed during disturbed magnetic condition when Kp index exceeded 4. Our analysis of TEC fluctuations during the severe geomagnetic storm of November 2004 has also shown that strong TEC fluctuations were observed when Kp reached 7-8 [8].

At lower latitudes stations located in auroral oval during moderate geomagnetic conditions TEC fluctuations were less pronounced relative to polar stations. Intensity of TEC fluctuations at auroral stations essentially increased. The severe geomagnetic storm was demonstrated that strong TEC fluctuations can be detected even on midlatitude ionosphere as it can be seen at METS station.

The pictures clearly demonstrate that the patch activity in the disturbed days controlled by UT. At different stations, spaced by longitude and latitude, the occurrence of TEC fluctuations took place at the same time of UT. During the storm, the activity and intensity of TEC fluctuations strongly increased relative to quiet conditions.

4. TEC fluctuations and oval of irregularities

The TEC fluctuations are caused by the presence of medium and large-scale irregularities in the ionosphere. As a measure of fluctuation activity we used the Rate of TEC Index (ROTI) based on standard deviation of ROT [4]. ROTI has been estimated in 10-min interval.

Figures 4 shows the location of TEC fluctuations for northern southern hemisphere in Geomagnetic local time and Corrected geomagnetic latitude during 28.10-31.10.2003 using data all discussed high-latitude GPS stations. Intensity of the fluctuations is indicated with different symbols. At northern hemisphere number GPS stations is limited and equator region of the ionosphere which can be seen by GPS restricted near 60CGL.

The figure demonstrates location of irregularities oval probing by GPS measurements in depend on geomagnetic activity. The picture clearly shows that during weaker geomagnetic disturbances the oval situated at higher latitudes.

During the severe storm the irregularities oval is expanded and displaced equatorward until 50CGL. The intensity of TEC fluctuations essentially increase during disturbance. The intensity of TEC fluctuations was more strong in winter hemisphere than in summer one, it can be determined seasonal effects.

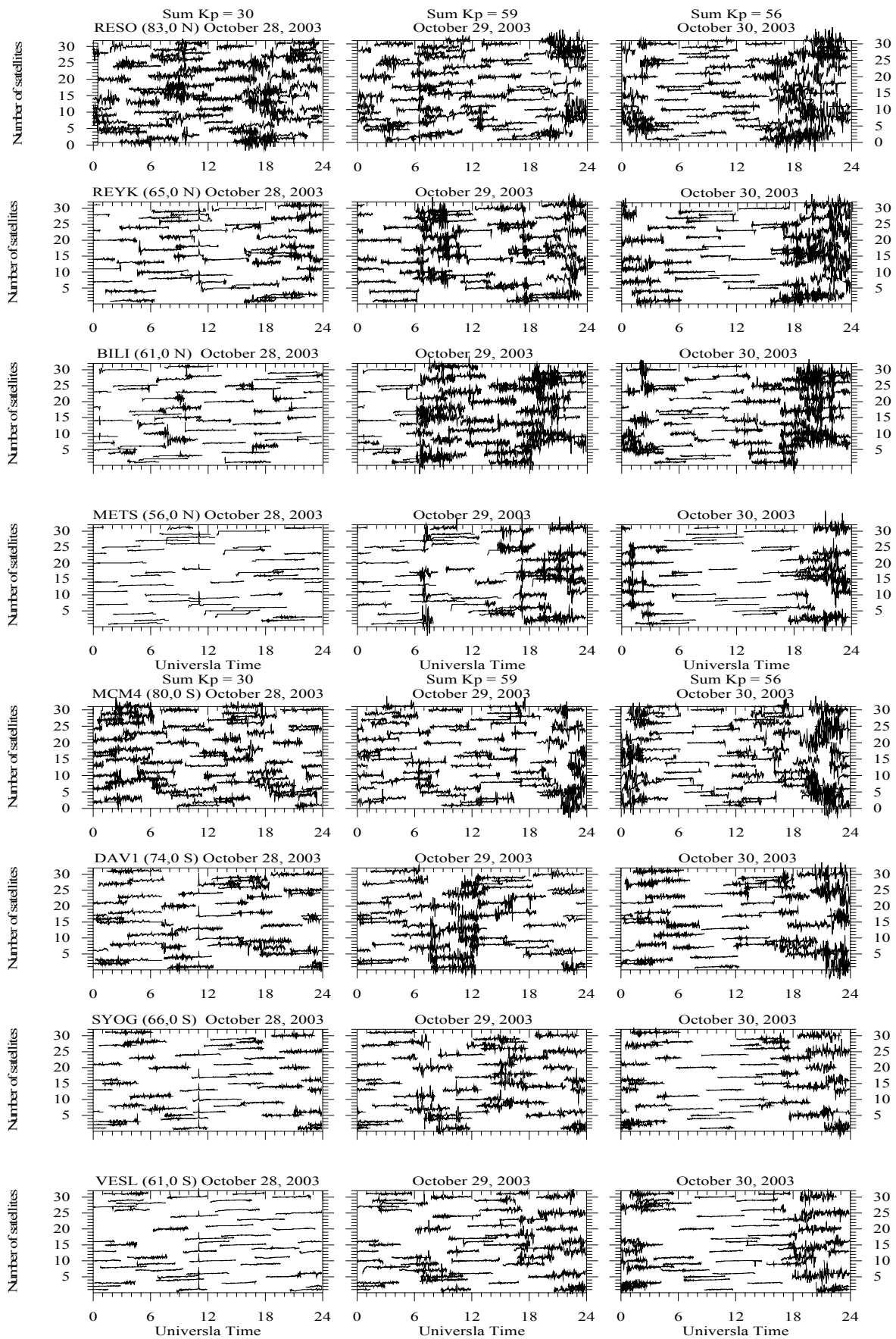


Fig.3. Rate of TEC along individual satellite passes observed at the different GPS stations in northern and southern hemispheres during 28-30 October 2003. Location of stations are given in Corrected Geomagnetic Coordinates

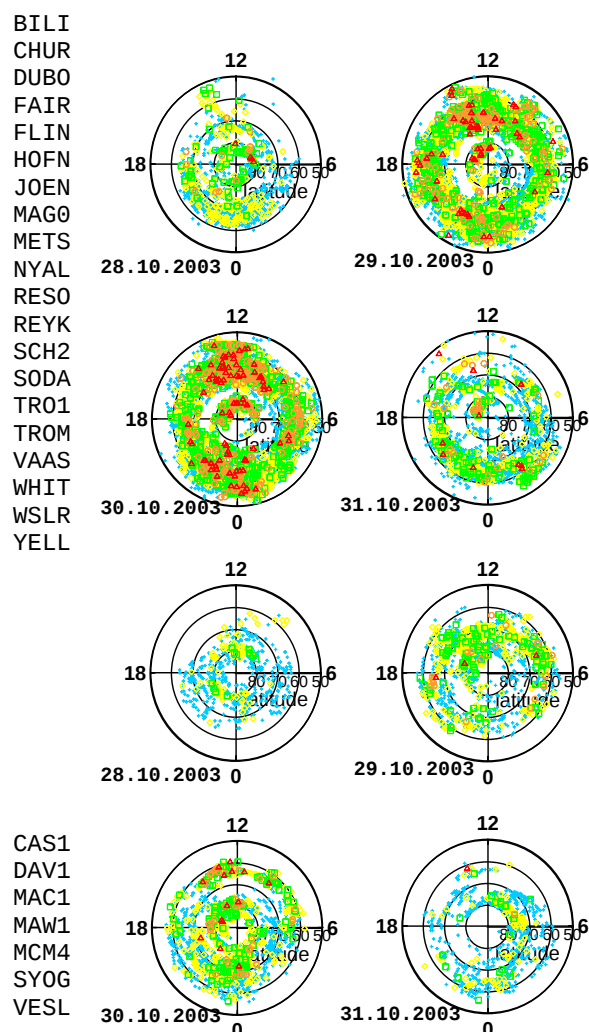


Fig.4. Location of TEC fluctuations derived from GPS measurements in geomagnetic local time for 28-31 October 2003. The intensity of fluctuations is indicated with following symbols: blue – 0.5-1.0 TECU/min, green – 1.0-1.5 TECU/min, yellow – 1.5-2.0 TECU/min, pink – 2.0-2.5 TECU/min, red – more than 2.5 TECU/min.

5. Summary

The occurrence of TEC fluctuations depends on the geomagnetic latitude of a site. Maximal TEC fluctuations took place at polar stations. The variations of TEC during storm can reach the value of 10 TECU. The enhancement of TEC exceeded 2-8 times a relative phone. Deep variations of TEC observed along individual satellite passes related to polar patches. At lower latitudes the fluctuations of GPS signals are attributed to auroral oval. The oval irregularities are effectively diagnosed by use of GPS measurements. The intensity of phase fluctuations depends on geomagnetic activity. Storm-time occurrences of phase fluctuations were controlled by UT. The intensity of TEC fluctuations was pronounced in winter hemisphere This result is now under consideration. The IGS network of GPS stations can effectively use to monitor condition

high-latitude ionosphere as well as space weather near real time.

References

- [1].J. Aarons. "Global positioning system phase fluctuations at auroral latitudes", *JGR*, **102**, NA8, pp.17.219-17.231, (1997).
- [2].A. Krankowski, I. I. Shagimuratov, L. W. Baran, I. I. Efishov, N. J. Tepenitzyna. "The occurrence of polar cap patches in TEC fluctuations detected using GPS measurements in southern hemisphere", *Advances in Space Research*, **38**, 11, pp.2061-2069, (2006).
- [3].L. Wanninger. "Monitoring ionospheric disturbances using IGS Network", in *IGS Workshop Proceedings*, Special Topics and New Direction, Potsdam, (1995).
- [4].X. Pi, A. J. Manucci, U. J. Lindqwister, C. M. Ho. "Monitoring of global ionospheric irregularities using the worldwide GPS network", *Geophysical Research Letters*, **24**, pp. 2283-2286, (1997).
- [5].T. R. Pedersen, B. G. Fejer, R. A. Doe, E. J. Weber. "An incoherent scatter radar technique for determining two dimensional horizontal ionization structure in polar cap F region patches", *Journal of Geophysical Research*, **105**, A5, pp.10637-10655, (2000).
- [6].A. S. Rodger, M. Pinnock, J. R. Dudeney, K. B. Baker, R. A. Greenwald. "A new mechanism for polar patch formation", *Journal of Geophysical Research*, **99**, pp.6425, (1994)
- [7].B. S. Dandekar, T. W. Bullett. "Morphology of polar cap patch activity", *Radio Science*, **34**, 5, pp.1187-1205, (1999).
- [8].I. Shagimuratov, I. Ephishov, A. Krankowski, I. Zakharenkova, G. Yakimova. "Monitoring of phase fluctuations of GPS signals in polar ionosphere", *Proc. EuCAP 2006*, Nice, France, 6-10 November, 2006.