"Physics of Auroral Phenomena", Proc. XXVIII Annual Seminar, Apatity, pp. 178-181 , 2005

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ANALYSIS OF THE PHASE FLUCTUATIONS OF GPS SIGNALS IN THE POLAR IONOSPHERE DURING STORMS

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Abstract. Dual frequency measurements of differential carrier phase of GPS: L_1 (f1=1.6 GHz) and L_2 (f_2=1.2 GHz) signals have been used to study storm-time development of the phase of TEC fluctuations in the Antarctic region. We used GPS measurements of the International GPS service (IGS) network stations. The phase fluctuations are caused by the presence of irregularities of different scale in the high-latitude ionosphere. The standard GPS measurement provided by the global network are sampled with 30 s. The interval enables to detect the ionosphere irregularities with a scale larger than tens of kilometers. For analysis of the data the temporal variations of TEC along individual satellite passes were used. A strong TEC fluctuation as an enhancement of TEC relative phone was found out at the polar station. The enhancement of TEC exceeded 2-10 times the relative background, while the TEC increased to 10-40 TECU in the interval of about 5-10 min. The duration of such structures was up to 10-20 min. It was observed during the storm as well as during moderate geomagnetic activity. We attribute the structures to the occurrence of polar patches. The intensity of TEC fluctuations increased during the geomagnetic activity. As a measure of patch activity we used the rate of TEC with 1 min interval (ROT). In this study, the diurnal, seasonal, latitudinal and storm-time features of occurrence of polar patches are presented.

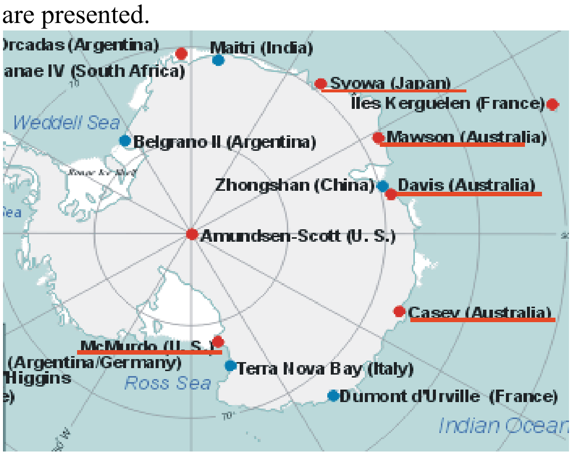

Fig.1. Map of high latitude GPS stations used in this study

Introduction

The structure of the high-latitude ionosphere is very complicated and variable. Strong changes of the ionosphere occur during geomagnetic disturbances. Several studies have used GPS observations from a single site or local network to monitor TEC fluctuations and related irregularities at high latitude ionosphere (Coker et al, 1995; Aarons et al., 1997, 2000) and equatorial regions (Mendillo et al., 2000). The correlation between amplitude scintillations and TEC fluctuations was analyzed (Bhattachryya et al., 2000). The possibility of using the International GPS Service (IGS) to monitor global effects in the ionosphere has been presented by Pi et al. (1997). The above studies concerned the irregularities with a dimension smaller than 100 km.

In this paper we present an analysis of the occurrence of large-scale TEC fluctuations in the Antarctic for 2001. In Fig.1 shows a map of the stations and their coordinates (Table 1) used in this study.

Table 1. Antarctic IGS stations.

Station	Geographic		Corrected Geomagnetic		MLT mid-night
	Lati tude	Longi tude	Lati Tude	Longi tude	
CAS1	-66.28	110.52	-80.66	159.10	18:19
MCM4	-77.84	166.67	-79.95	325.00	07:07
SYOG	-69.01	39.58	-66.65	72.51	23:55
MAW1	-67.60	62.87	-70.68	91.49	22:39
DAV1	-68.58	77.97	-74.91	101.92	21:56

Polar cap patches in TEC fluctuations

The spatial and temporal development of the TEC or phase fluctuations is clearly exhibited in time variations of the dual frequency carrier phase along satellite passes.

In Fig.2, as an example, TEC variations at single passes at various Antarctic stations for quiet and disturbed days are presented. Here it is also shown, in geographic coordinates, satellites ionospheric tracks at 450 km altitude. Since the GPS satellites are in 12 sidereal hour orbits, the tracks are the same day after day (only the satellites arrive 4 min earlier each day). The plot approximately indicates the satellite ionospheric traces for two days under consideration.

A series of large-scale fluctuations as an enhancement of TEC are clearly seen in the temporal patterns (Fig.2). At the polar stations (CAS1, MCM4, DAW1) the TEC patterns exhibit a great variability on disturbed days as well as on quiet ones. During a storm, the intensity of the fluctuations dramatically increases. The TEC increase by a factor of 2-8, the enhancement of TEC can exceed 10-20 TECU relative to the background. We attribute the TEC enhancement to the occurrence of polar cap ionospheric patches, first observed in GPS data by Weber (Weber et all 1984).

Sometimes, the patterns of TEC fluctuations display the structures similar to those at space stations. This is well seen in Fig.2 for DAV1 and MAW1. A very similar picture of the patch structures shows the TEC variations for PRN 15 and PRN 17 at CAS1 stations (top panel in Fig.2) for March 2001. The time delays between the similar discrete structures correspond to the propagation velocity of the patch, which is about 700 ms^{-1}.

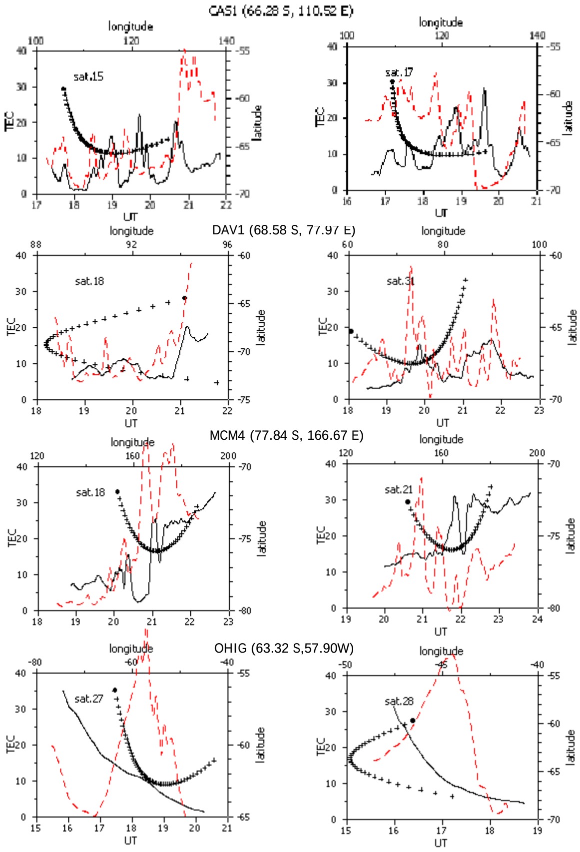

Fig.2. TEC variations for the satellites observed at different stations during the storm (dashed line) and quiet (solid line) periods.

The deep variations of TEC are observed very frequently at polar stations. The analysis of data of MCM4 stations shows that patch-like structures (about 90% cases) were registered during March-April 2001 interval. To compare the patch occurrence, in Fig.2 are also presented TEC variations at subauroral station OHIG(Φ=49º). On a quiet day, the TEC demonstrates a smooth run; during a storm, TEC irregularities can develop here. The amplitudes of TEC fluctuations in this region are smaller than at the polar station. At the station OHIG during a storm we can see a large-scale structure (Fig2), which we suggest to be connected with the main ionospheric trough.

We have determined the absolute level of TEC in the patch relative to the background. Fig.3 presents a TEC variation in long satellite passes during 23 September 2001 and the rate of TEC changes (left panel) and absolute level of TEC to the background. The TEC enhancement in patches can reach 30-40 TECU.

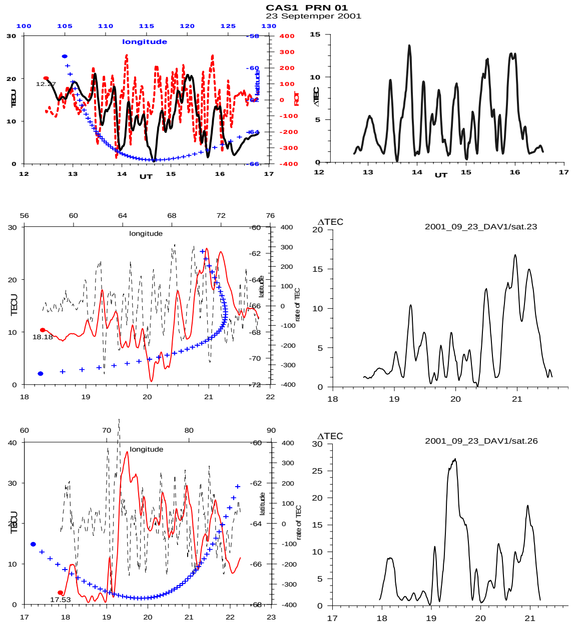

Fig. 3. Left panel: TEC variations (solid) for a single satellite observed at different stations on September 23 and the rate of TEC changes – ROT (dashed). Right panel: the level of TEC enhancement in the patches relative to the background. Along single satellite passes up to 6-8 patches of different intensity can be observed.

Storm-time development of phase fluctuations

To analyse the occurrence of phase fluctuations we used the rate of TEC change data (ROT) (Pi et al., 1997). Fig.4 presents the development of phase fluctuations, obtained with using ROT, for geomagnetic storms in June and September.

The pictures illustrate the occurrence of phase fluctuations for all passes of the satellites observed at CAS1, MCM4, DAV1 and MAW1 over 24 hour interval during quiet and disturbed days. The top panel demonstrates the variation of geomagnetic field at Mawson and Bz component of the Interplanetary Magnetic Field. During storm, the intensity of fluctuations strongly increases as compared to the quiet conditions. The occurence of TEC fluctuations correlates with the variations of magnetic field at Mawson. In Fig. 4 we can see that during storms the occurrence of TEC fluctuation is controlled by UT. The intensity of the patch structure increases when Bz IMF is negative. The occurrence of patches depends to a low extent on the sum of Kp index. The maximum occurrence of phase fluctuations usually takes place around the local midnight (Aarons et al., 2000), which is clearly seen at the auroral station. To analyse the distribution of patches in time, we used the TEC index (ROTI), calculated for 30 min interval.(Pi et al.,1997) Fig.5. presents the distribution of the number of patches of moderate and strong intensity at CAS1 station over 2001.

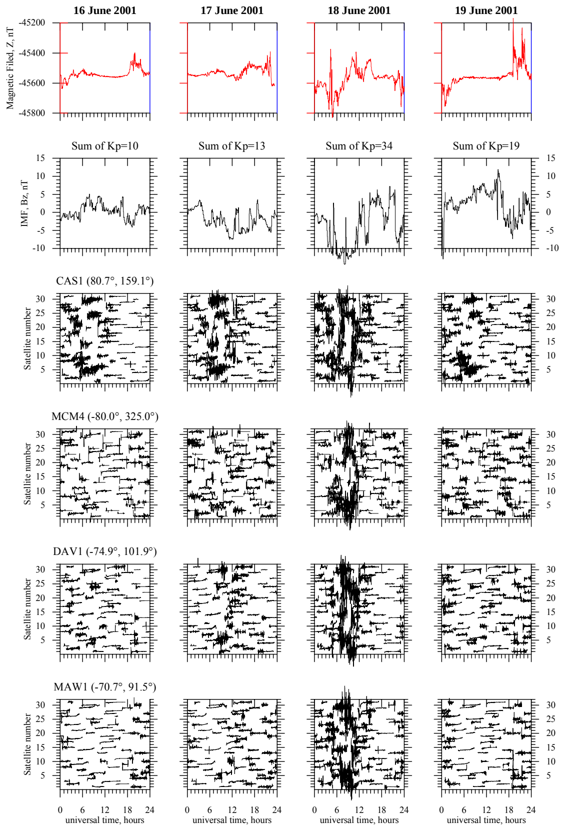

Fig.4a. The magnetic activity at Mawson and phase fluctuations occurrence at different stations on June 16-19 2001. The plots show the phase fluctuations for individual satellites.

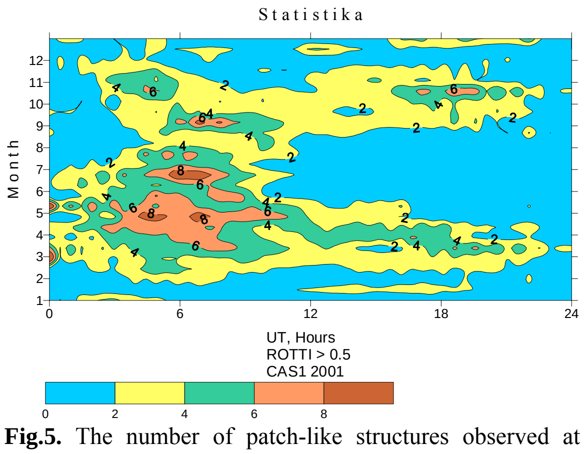

Fig.5. The number of patch-like structures observed at CAS1 station for 2001

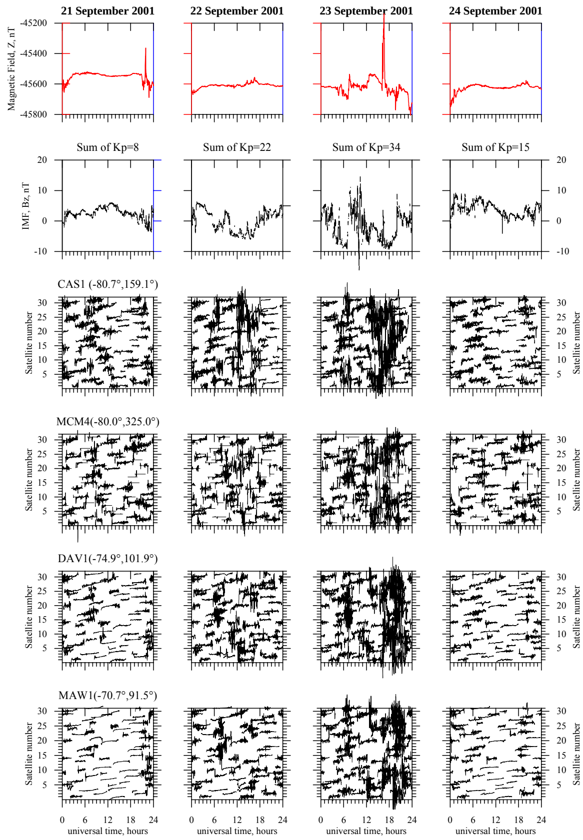

Fig.4b. The magnetic activity at Mawson and phase fluctuations occurrence at different stations on September 21-24 2001. The plots show the phase fluctuations for individual satellites.

Conclusion

The strong TEC fluctuations are regularly detected at polar stations. We associate these fluctuations with polar patches. The fluctuations of TEC during a storm reach 10-40 TEC. The enhancement of TEC exceeds 2-8 times the relative background.

The maximum rate of TEC changes registered at MCM4 station reaches 5-6 TECU/min, which exceeds 2-3 times that at the equatorial stations.

At single satellite pass (the time interval of about 4-6 hours) there can be detected 5-8 patch-like structures of different intensity. The occurrence of patches depends to a low extent on the sum of Kp index but the intensity of TEC fluctuation increases during substorm activity.

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