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HIGHLATITUDE MEASUREMENTS OF IONOSPHERIC TEC FROM GPS SIGNALS

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Abstract. Preliminary results of using navigational GPS system signals for studying structures and their movements in the high-latitude ionosphere are presented. The first observations of the GPS satellite signals were conducted in July-August 1998 in Murmansk (68.80^{0}N, 33.10^{0}E). Measurements of the group and phase delays of GPS signals for all passes of the satellites during a 24 hour interval were used for recovering a diurnal variation of the total electron content (TEC) above Murmansk. TEC variations were obtained both for quiet and disturbed geomagnetic conditions. During disturbances, large-scale ionospheric structures with significant different levels of TEC are observed in high latitudes. In the records of signal frequency phase and Doppler shift of the frequency intensifications of quasi-wave types of irregularities of different scales are observed.

Introduction

The satellite navigational system GPS (Global Positioning System) allows us to conduct permanent total electron content (TEC) measurements all over the Earth. For the last years GPS has been actively used in studying irregularities and phase fluctuations of signals in the polar ionosphere /1,2/. Earlier, such data were obtained from the Doppler measurements of 150/400 MHz signals from navigational satellites of Transit-type systems /3/, which usage was notorious. The possibilities of the GPS system are much broader. The system consists of 24 satellites, moreover, simultaneously in the area of radiovisibility at least 4 satellites are presented, which ensures diagnostics of the ionosphere simultaneously from several directions.

Irregularities' studying is based on the relative phase observations. In the present work recovering absolute values of TEC diurnal variation above Murmansk is under consideration. The first observations have shown that GPS can ensure a regular reception of TEC data in high latitudes. Herewith it is important that in the situations, when diagnostics of the polar ionosphere with using vertical sounding is impossible because of geophysical conditions, efficiency of the GPS method keeps sufficiently high.

GPS DATA

Observations of two types have been realized: those of code one correspond to group delay measurements and phase ones. Code observations potentially allow to get absolute values of signal delays, but they are strongly influenced by multipaths. Phase observations are relative, but they are an order more exact, than the code ones.

GPS satellites move on the orbits at the heights of about 20000 km with a period of approximately 12 hours and with orbit plane bending ~55^0. Each satellite radiates two signals which are modulated by ranging codes: L1 (f1 = 1.574 GHz) and L2 (f2 = 1.227 GHz). The differential delay is proportional to the total electron content along the ray of vision to the satellite from a receiver. The GPS system consists of 24 satellites and simultaneously up to 8 satellites can be observed above Murmansk. In the observations the two-frequency GPS receiver Trimble 4000 S was used, which can trace 12 satellites simultaneously. The minimum interval of the two frequency sampling was 0.5 s.

Processing of GPS observations

As it is well known /4/, measured group delays of GPS observations are biased by delays of signal in the equipment of a satellite and a receiver. In this respect the code measurements are equivalent to those of relative phase measurements. So, to get an absolute value of an ionospheric delay, it is necessary to determine an instrumental delay for the code observations or an unknown initial phase for the phase ones. Another problem of the GPS observations is how to separate spatial and temporary variations of ionospheric delays. This problem arises, firstly, because of GPS satellites small velocities. Duration of a pass of a single satellite in the area of radiovisibility is 4-6 hours, which is comparable to the temporary changes in the ionosphere. Fig. 1 shows a chart of passes of satellites above Murmansk, where utter lines are chosen passes, which measurements of delays were used in the calculation of TEC.

Secondly, measurements cover sufficiently greater area of the ionosphere in the vicinity of a station. For the Murmansk station this area is shown in Fig. 2. For the determination of an absolute TEC value and recovering a diurnal variation an algorithm was used, which was approbated for mid-latitude observations /5/. The algorithm was completed with geometry evaluation for the measurements on high latitudes. At the calculations of the diurnal variation of TEC were used measurements of all passes of satellites above the station during a 24-hour interval.

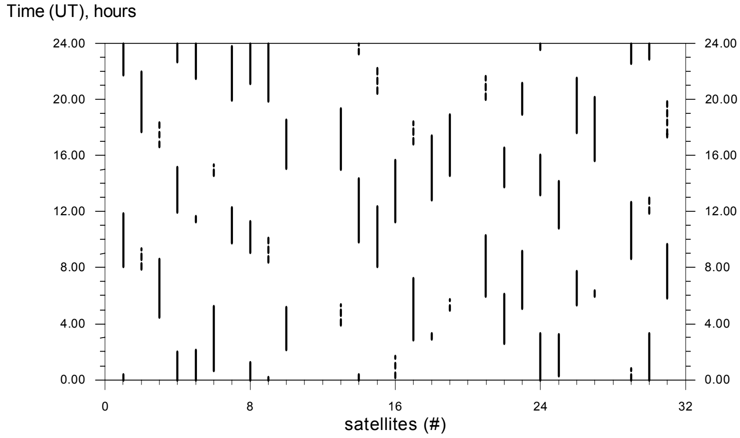

Fig.1. Satellites passes in a radiovisibility zone
of a station Murmansk (68.8^{0}N, 33.17^{0}E) 22.08.1998 г.

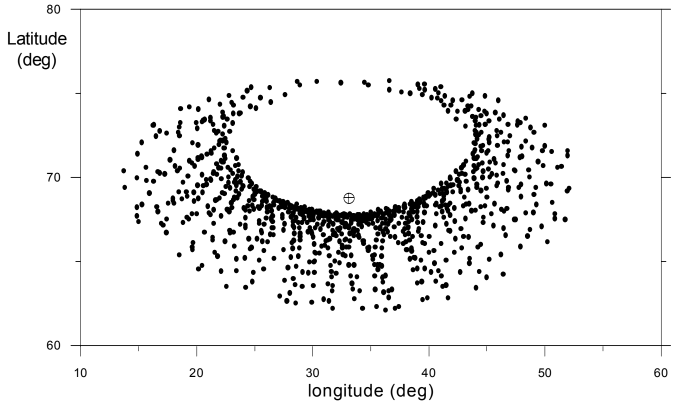

Fig.2. Subionospheric points coordinates
for a station Murmansk (68.8 N, 33.17 E).22.08.1998 г.

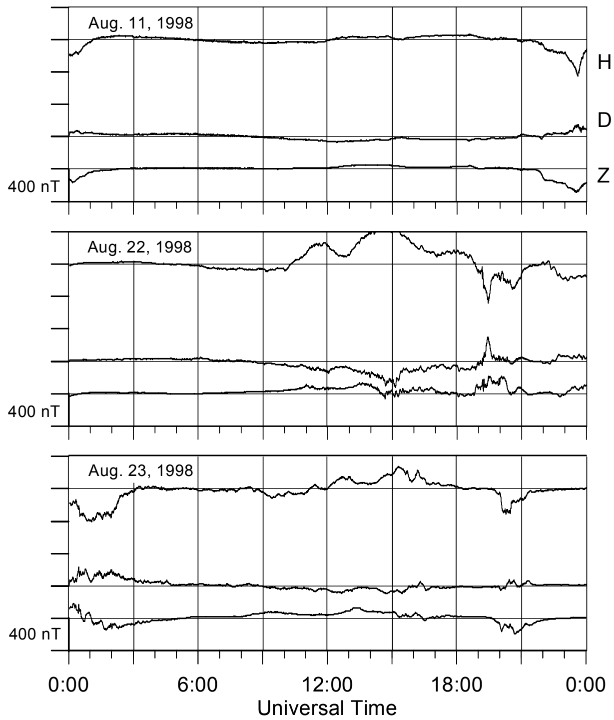

Fig.3. Geomagnetic field variations for 11 August 1998
and 22-23 August 1998

Results of measurements and discussion

The data of TEC variations have been obtained for quiet and disturbed periods. For quiet geomagnetic conditions we had data for 11 August 1998 (Fig. 3), when K index on the Loparskaya station (68.25N, 33.08E) was 2 /6/. Disturbed conditions are referred to the observations on 22 and 23 August 1998. In Fig. 3 variations of the geomagnetic field for 22-23 August are presented. The maximum value of the index reached 6. Diurnal variations of TEC obtained from GPS observations in Murmansk for the considered periods are illustrated in Fig. 4. During the first day of the disturbance, i.e. 22 August, a sharp growth of TEC (positive disturbance) is distinctly seen, when TEC (spots) has a level 1,5-1,6 times that of a quiet day (utter line). The excess of the disturbed level above the quiet one is fixed about 6 UT, the maximum phase is about 10 UT. On the second day of the TEC is observed a well-pronounced depression of the ionosphere (negative disturbance). It should be noted that for the observations on the middle latitudes such a TEC depression of the ionosphere (a negative phase of the disturbance) is usually weakly pronounced. The degree of the disturbance for the considered period can be evaluated as moderate. In GPS measurements on the mid-latitude station LAMA (53.9N, 20.7E) on 22 August TEC exceeded only in 1.1-1.2 times the level for 11 August. This value is comparable with the variations of TEC from day to day. For the period under consideration the negative phase for this station is not shown.

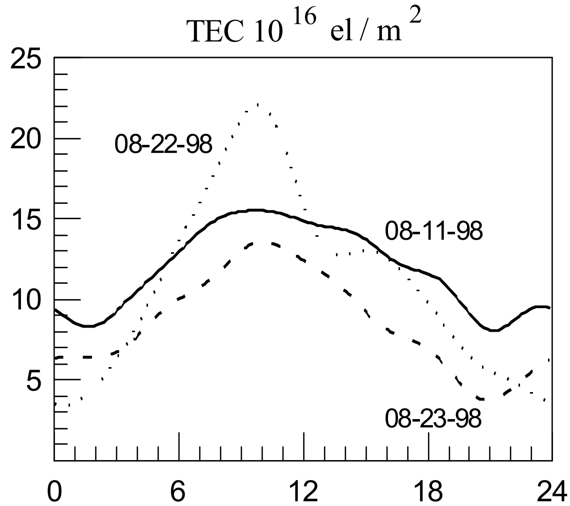

Fig.4. Diurnal variations of TEC at Murmansk for a quiet day (11 August 1998) and disturbed days (22 and 23 August 1998)

The data of the diurnal TEC variation have been obtained by averaging the measurements of all satellite passes from different azimuths. In Fig. 5 variations of vertical TEC for particular satellite passes for the considered period are presented. Here for comparison is also given frequency Doppler shift variations received during phase measurements. On the time scale azimuths for rays of vision to the satellite (alpha), latitudes and longitudes of underionospheric points are shown. As these parameters changed slowly from day to day, they are given for one date only. The disturbance of 22 August is clearly shown both in TEC variations and in the behavior of the Doppler shift of the frequency. From the Figure one can see that in contrast to the quiet daytime data different scales of irregularities are observed in the ionosphere. Large-scale ionospheric structures are displayed in significant, of order $(5\div7)\times10^{16}$ el/m^2, deviations of the TEC level. At the same time it is seen that behavior of TEC and Doppler for 23 August is characterized as quiet. The passes of satellites 14 and 16 are close, with a time shift of about 30 minutes. From these passes it is seen that a disturbed ionospheric structure is quasi-steady for a time period of 30 minutes.

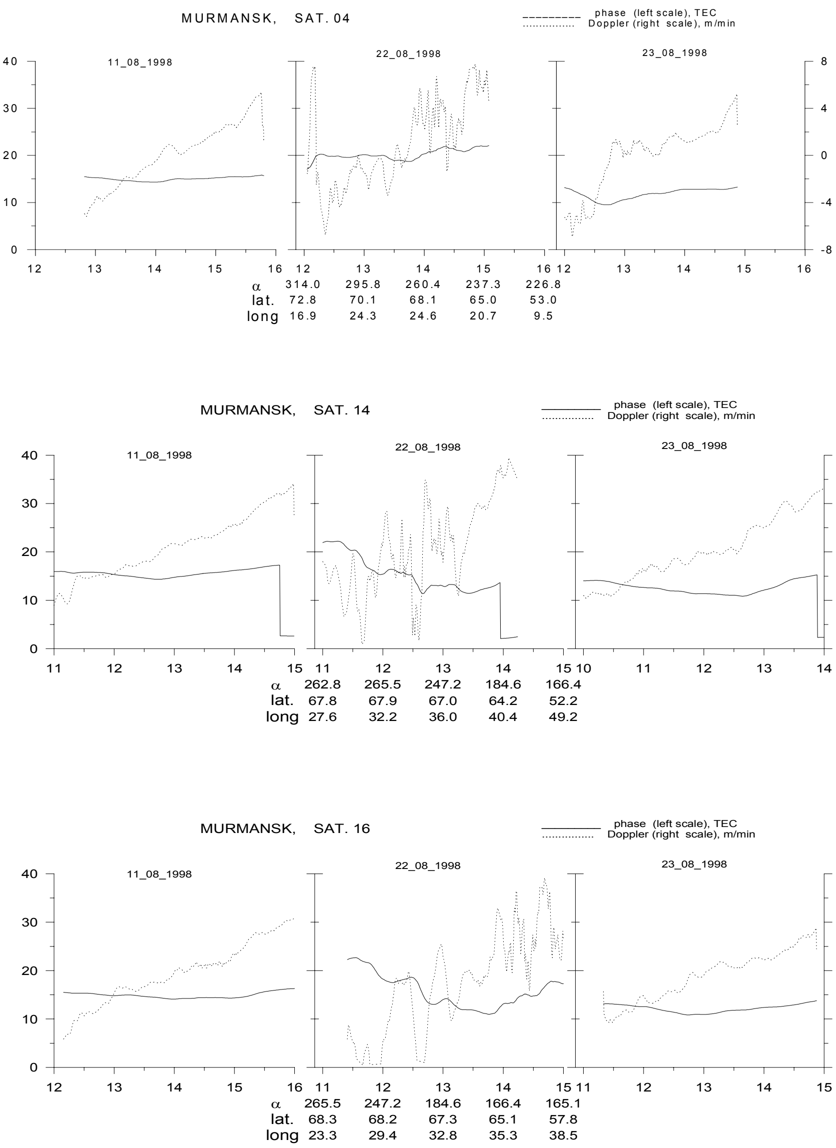

Fig. 5. Variations of vertical ionospheric TEC (solid line) and ionospheric Doppler shifts (dotted line) during quiet and disturbed days.

As can be seen from the data presented, disturbance in the ionosphere is manifested earlier than disturbances in the geomagnetic field. TEC increase on the first day of disturbance is observed for all passes, shown in Fig. 5.

From the comparison of TEC and Doppler behavior for different satellites and for different azimuths it is seen that the amplitude of fluctuations and characteristic times differ significantly. We can say that irregularities are displayed as heels of different sizes.

Conclusion

In spite of strongly irregular structure of the high-latitude ionosphere, GPS observations give a possibility to restore, on the regular base, diurnal variation of TEC above the station of observations. Unlike vertical sounding, the GPS method guarantees a reception of the total electron content values and their variations for different geomagnetic conditions. Phase measurements and ionospheric Doppler shifts of frequencies serve as a good indicator of a condition in the ionosphere. Phase measurements can be effectively used for the irregularities study and phase fluctuations of signals in the polar ionosphere.

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