

Ionospheric manifestations of geomagnetic pulsations at high latitudes

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ABSTRACT

In this paper the interrelation between geomagnetic pulsations and variations in frequency Doppler shift f_d of the ionosphere-reflected radio signal is under investigation. The experiment on simultaneous recording of f_d variations and geomagnetic pulsations was organised at high latitude station in Norilsk (geomagnetic latitude and longitude 64.2° N, 160.4° E, $L = 5.3$) during February-April of 1995-98. Thirty cases of simultaneous recording of duration from 10 min to two hour were analysed: 6 cases of simultaneous recording of variations f_d and regular geomagnetic pulsations Pc5; and 25 cases of recording of f_d variations and irregular pulsations Pi2.

On the basis of experimental results, the following conclusions have been drawn: a) Hydromagnetic waves in the range of regular Pc5 pulsations, when interacting with the ionospheric F2 layer, make the main contribution to short-period f_d variations. The possible mechanism of f_d variations are oscillations of electron density, associated with distribution of a hydromagnetic wave in an ionosphere. b) There exists an unquestionable interrelation between f_d variations of the sporadic E layer-reflected radio signal and irregular Pi2 pulsations, but for some reasons it is traced poorly.

Keywords: geomagnetic pulsations, high-latitude ionosphere

1. INTRODUCTION

The correlation between variations of ionospheric parameters and variations of the Earth's geomagnetic field has attracted the attention of researchers over decades [1, 2, 3]. Comparison of fragments of simultaneously recorded geomagnetic pulsations and short-period variations in frequency Doppler shift f_d of the ionosphere-reflected radio signal point to an unquestionable correlation between ionospheric parameter variations and the excitation regime of geomagnetic pulsations. The possibility of investigating Pi2 geomagnetic pulsations by recording f_d variations is discussed in [4, 5]. In [5], it is confirmed that geomagnetic pulsations are hydromagnetic waves generated in the magnetosphere. The authors of [5, 6] have established that hydromagnetic waves in the ionosphere can be studied by using the Doppler method.

In [7], it is suggested that hydromagnetic waves give rise to a displacement of the ionospheric layer, and hence to the appearance in the ionosphere of small-scale wave disturbances with frequencies ranging from 1.5 mHz to 100-200 mHz. It is also argued that there is a close relationship between short-period disturbances in the ionosphere and Pi2, Pip and PiC geomagnetic pulsations [7]. The authors of [8] have revealed that wave disturbances in the high-latitude ionosphere are accompanied by the generation of Pi2 pulsations.

In spite of many years of theoretical and experimental research, it has not yet been possible to conclusively elucidate the mechanisms [6, 9, 10] accounting for the relationship between short-period variations in frequency Doppler shift of the ionosphere-reflected radio signal and geomagnetic pulsations. One of the reasons for this, as suggested by the authors of [10], has to do with the difficulty in obtaining statistically significant sets of experimental data.

Thus the relationship between f_d variations and geomagnetic pulsations is of profound importance for the investigation of the influence of hydromagnetic waves on the structure and dynamics of the high-latitude ionosphere, on the one hand, and for the study of the geomagnetic pulsations themselves, on the other. Unfortunately, currently there is no clear understanding both of the morphology and of the physical origin of the relationships between ionospheric parameter variations and geomagnetic pulsations. The objective of this experimental paper is to establish the behavior patterns of the high-latitude ionosphere during periods of observation of different kinds of geomagnetic pulsations.

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During 1995-1998, at the high-latitude station in Norilsk (geomagnetic latitude and longitude 64.2°N , 160.4°E , $L=5.3$), an experiment was organized on a simultaneous recording of f_d variations and geomagnetic pulsations.

2. EXPERIMENTAL EQUIPMENT AND TECHNIQUE

The measurements of ionospheric parameters were made with the hardware-software facility for vertical-incidence ionospheric sounding that was developed on the basis of ionosonde R-017 and a personal computer [11]. Some characteristics of the facility are: 2 kW transmitter pulse power, 135 ± 15 ms pulse duration, and 50 Hz sounding pulse repetition rate.

The impulse signal in the vertical-incidence sounding mode was transmitted using the broadband delta-type antenna, with the main lobe width of the beam of 60° . Half-wave dipole antennas operating at the mean frequency of the working range, 6 MHz, were used as receive antennas.

When operated at fixed frequency, the facility provided a Doppler spectrum of the ionosphere-reflected radio signal, as well as making it possible to calculate the weighted mean frequency Doppler shift f_d . The interval for spectral analysis was taken to be 20 s., which ensured a frequency resolution of 0.05 Hz. A spectral analysis was carried out in the frequency band ± 6 Hz. Observations as long as 15 min. to several hours were carried out with the signal/noise ratio of at least 10. The experiment used working frequencies in the range 2-4 MHz; the signal reflected from the ionospheric Es and F2 layers was received. Geomagnetic pulsations were recorded on a 24-hour basis with the induction magnetometer in the frequency band 0.5-0.005 Hz, in the dynamic range 0.01-100 nT.

3. EXPERIMENTAL RESULTS

The observations were carried out in March, 1995, February, 1996, in March - April 1998. The f_d variations were recorded during passage of the high latitude geomagnetic pulsations (GP): regular pulsations Pc5 and irregular pulsations Pi2. In total was analysed about 30 cases of simultaneous recording of f_d variations and GP. From them six cases were of recording f_d variations during passage of pulsations Pc5 and 25 cases were of recording of f_d variations during passage Pi2.

Let's consider in more detail two cases of simultaneous recording of f_d variations and regular pulsations Pc5 which were observed in April 1, 1998 at 12.38-13.00 UT (18.38-19.00 LT) and in April 5, 1998 at 11.20-11.40 UT (17.20-17.40 LT). The geomagnetic conditions of April 1, 1998 were quiet, the coefficient of geomagnetic activity K_p was equal 1. The amplitude north-south component Pc5 was 33 nT, period of oscillations - 350 s (Fig. 1 a). Amplitude by east-west component Pc5 - 30 nT, principal periods of oscillations - 210 s and 480 s (Fig. 1 b). The sounding was conducted on frequency 4.5 MHz at a relation signal/noise not less than 10. The signal reflected from a F2-layer of ionosphere was accepted. The critical frequency f_0F_2 was 6-7 MHz, effective height $h' - 270$ -300 km. Amplitude f_d was 0.49 Hz, the periods - 210 s and 480 s. Fig. 1 d, e, f submit the diagrams of the spectrum time analysis (STAN) at coordinates time - period - spectral density (d) - north-south (N-S) component of GP; (e) - east-west (E-W) component of GP; (f) - variations f_d . The variations of f_d respond to occurrence of geomagnetic pulsations and they are in an antiphase with oscillations of east-west component GP. Thus the variations f_d react not only to pulsation of major amplitude (30 nT at 12.38 UT), but also ones respond to on feeble oscillations 7 nT at 12.10 UT. The diagrams STAN submitted on fig. 1 г, д, е clearly show this fact. The response of f_d variations on feeble oscillations GP is imposed on f_d variation with period approximately 30 min. The f_d variations with such periods is explain by passage of acoustic-gravity waves (AGW), which periods for heights of a F2-layer lies in the range between 10 and 40 min.

The regular pulsations Pc5 in April 5, 1998 also were observed under quiet geomagnetic requirements ($K_p=1$) (Fig. 2). The amplitude of north-south Pc5 component was 16.5 nT, period of oscillations - 360 s (Fig. 2 a). Amplitude of east-west Pc5 component - 9.5 nT, period of oscillations - 360 s (Fig. 2 b). Variations of f_d are submitted on Fig. 2 c. The sounding operation was performed at 5 MHz frequency at a relation signal/noise not less than 15-20. The radiosignal reflected from a F2 layer of an ionosphere was accepted. The critical frequency f_0F_2 was 7-8 MHz, effective height $h' - 270$ km. The amplitude of f_d variations was 0.56 Hz, a period of oscillations - 360 s. As well as in case of April 5 the long-period variations with a period of medium-scale TIDs (1.7 MHz) are superimposed on f_d variations. It clearly that f_d variations correlate with oscillations of GP. The variations f_d are in a phase with oscillations of east - west GP component and are displaced in phase by 2-3 minutes for the north-south components of GP oscillations. The principal frequency of f_d variations coincides with frequency of both north-south and east-west components of GP oscillations.

During observation of regular pulsations Pc5 in 5 of six cases the good correlation of a time series both spectrums of pulsations and f_d variations is observed; for one or for both components of the field of pulsations. In each individual case the

responses of an ionosphere on GP oscillations have some different. Specifically the f_d variations can be react on both components of GP or on one of them.

Irregularity pulsations Pi2 are observed in the explosive phase of geomagnetic substorm. Norilsk at this time was in auroral zone. The regular layer F2 was screened by a sporadic layer E. . The severity of the recording problem implied that a total absorption of radio waves is generally observed in the ionosphere, when the strongest, longest-lasting geomagnetic pulsations are excited. Nevertheless the most part of observational data (25 cases) were received for pulsations Pi2.

In six cases from these 25 the conformity between Pi2 and f_d is marked. Fig. 3 present the case in February 15, 1996 at 19.25-19.44 UT. At generation Pi2 there is a abrupt amplification of f_d variations. The maximum amplitude of north-south Pi2 component reach 21 nT, principal periods of oscillations - 50 s and 160 s (Fig. 3 a). Amplitude of east-west Pi2 component was 15 nT, the principal periods of oscillations - 65 s and 120 s (Fig. 3 b). Fig. 3 c presents f_d variations. The sounding was conducted on frequency 3 MHz at a relation signal / noise about 5. The radiosignal reflected from E_{sr} -layer was accepted. The amplitude of f_d variations at the moment of oscillation Pi2 sharply has increased to 0.34 Hz. The principal periods of f_d variations were 45 s, 65 s, 120 s, 180 s. Results for other five cases are simultaneous. At occurrence irregularity pulsations Pi2 the amplitude of f_d variations was incremented and in the spectrum of variations f_d there are spectral components with GP periods. The spectrum of f_d variations is the complex, it include more spectral components, than spectrum GP. It is explained by that variation of parameters of the ionosphere cause not only geomagnetic pulsations, but also series of other factors.

In the majority of cases was revealed not any of conformity between f_d variations and irregularity pulsations neither in a time series, nor in spectrums. One of such cases (March 27, 1998) is given on Fig. 4. In these cases on f_d variations influence mechanisms more strong, than mechanisms associated with GP.

4. DISCUSSION

It is universally accepted that geomagnetic pulsations, observed on the ground, represent the manifestations of magnetospheric hydrodynamic waves propagating downward through the ionosphere [11]. It is common knowledge that the ionosphere modifies the characteristics of hydromagnetic waves. On the other hand, ionospheric parameters can also undergo changes under the effect of hydrodynamic waves. This is confirmed by simultaneous recordings of variations in frequency Doppler shift f_d of the ionosphere-reflected radio signal and geomagnetic pulsations [1-3, 6, 9, 10]. The time coincidence of f_d variations and geomagnetic pulsations suggests that hydromagnetic waves in the range of pulsations have a pronounced effect on the ionosphere.

It should be noted that the mechanisms accounting for the correlation between geomagnetic pulsations and FDS variations still remain unclear [9, 10].

As has been pointed out above, the time series of Pc5 pulsations and f_d variations have a high degree of correlation (Fig.). The ratio of amplitudes of f_d variations and geomagnetic pulsations was 0.02-0.07 Hz/nT. This value is consistent with results (from 0.01 Hz/nT to 0.4 Hz/nT) obtained in [2, 10]. It is clearly seen from Fig. 2b and 2c that at the time of observation of Pc5 pulsations the spectral component of the f_d variations, corresponding to the frequency of Pc5, increases abruptly. The agreement between the time series and spectra of the simultaneously recorded geomagnetic pulsations and f_d variations suggests that hydromagnetic waves of the Pc5 range, when interacting with the ionospheric F2 layer, make the main contribution to short-period f_d variations.

As in [2, 3, 6], in most cases we detected only a slight correlation between f_d variations and geomagnetic pulsations. The simultaneous recording of Pi2 geomagnetic pulsations and f_d variations shows: a) at all events an almost total absence of correlation between the time series; and b) in series of cases coincidence of the principal maxima on the plots of spectral density of these phenomena at the time of Pi2 observation. A similar situation was observed in the case of a simultaneous recording of the luminosity of polar auroras and Pi2 pulsations. The absence of correlation between time series of irregular Pi2 pulsations and f_d variations of the E_s layer-reflected radio signal may be attributed to a variety of factors. In the first place, in high latitudes there may exist several sources of Pi2 spaced by several degrees in latitude. Secondly, at the sporadic E layer heights the density of the neutral component is significantly higher, and its influence on ionospheric plasma drifts is stronger when compared with the F2 layer. And thirdly, magnetic variations may be the response of ionospheric currents within the field of view of magnetometers (within the range of several hundred kilometres), whereas the ionosonde measures less distant disturbances in the ionosphere over the observation site, within the range of 50-100 km [4]. Furthermore, there may be interference of the reflected radio waves from ionospheric irregularities, as pointed out in [3, 4].

Nevertheless, it's suggest that there is unquestionable correlation between f_d variations of the sporadic E layer-reflected radio signal and irregular Pi2 pulsations.

5. CONCLUSION

An experiment has been conducted on a simultaneous recording of the variations in frequency Doppler shift f_d of the ionosphere-reflected radio signal and geomagnetic pulsations measured on the ground.

Experimental results have revealed the following basic features:

- a) the presence of a good correlation between regular Pc5 geomagnetic pulsations and variations in frequency Doppler shift f_d of the ionospheric F2 layer-reflected radio signal;
- b) the abrupt enhancement of the spectral component of variations f_d at the frequency coinciding with that pulsations, at the time of Pc5 observation;
- c) absence of a correlation between irregular Pi2 geomagnetic pulsations and variations in frequency Doppler shift of the radio signal reflected from the sporadic E layer of the auroral ionosphere;
- d) in the series of cases at the time of Pi2 observation - an enhancement of the short-period components of the spectrum of FDS variations, and the coincidence of the principal maxima on the plots of spectral density of f_d variations and Pi2.

On the basis of these main results, the following conclusions have been drawn:

- Hydromagnetic waves in the range of regular Pc5 pulsations, when interacting with the ionospheric F2 layer, make the main contribution to short-period f_d variations. The possible mechanism of f_d variations are oscillations of electron density, associated with distribution of a hydromagnetic wave in an ionosphere
- There exists an unquestionable interrelation between f_d variations of the sporadic E layer-reflected radio signal and irregular Pi2 pulsations, but for some reasons it is noted poorly.

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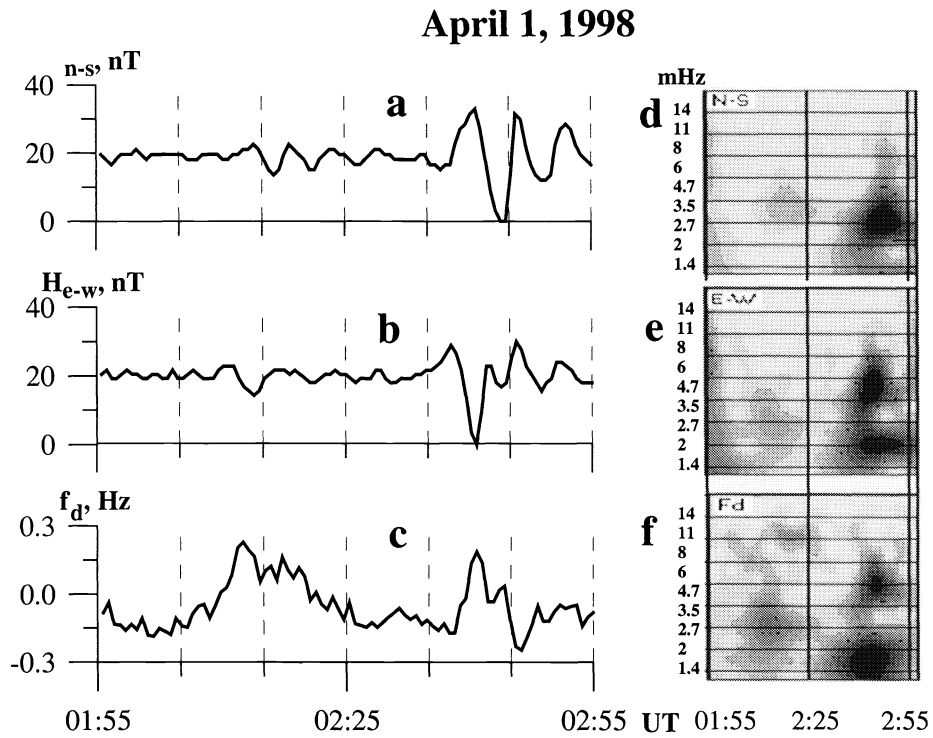


Figure 1. The regular Pc5 geomagnetic pulsations and variations of frequency Doppler shift (f_d), April 1, 1998.

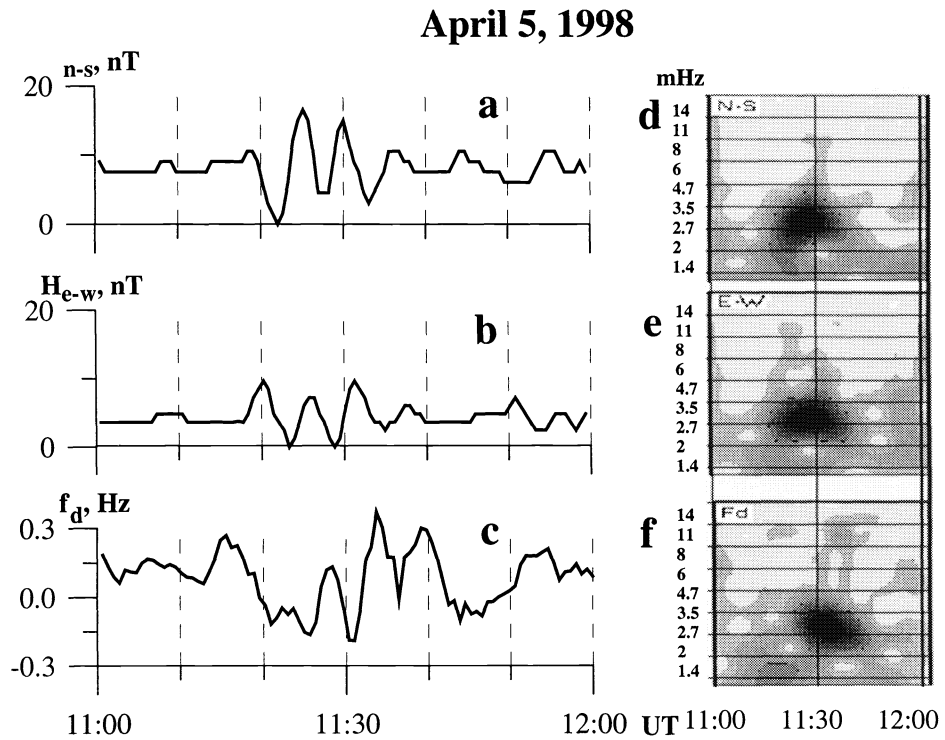


Figure 2. The regular Pc5 geomagnetic pulsations and variations of frequency Doppler shift (f_d), April 5, 1998.

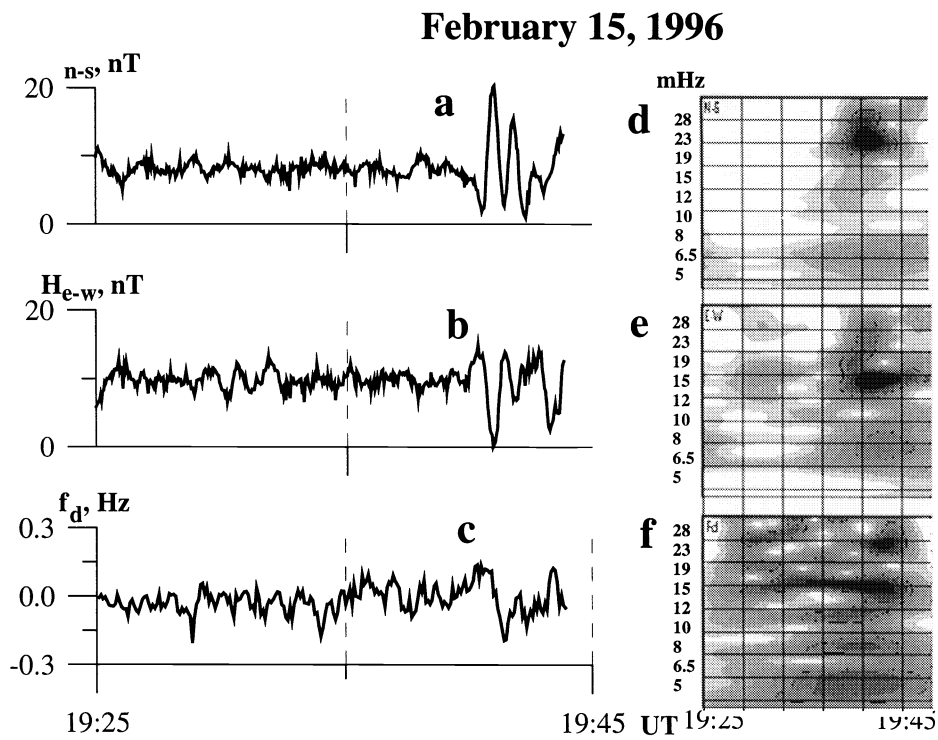


Figure 3. The irregular Pi2 geomagnetic pulsations and variations of frequency Doppler shift (f_d), February 15, 1996.

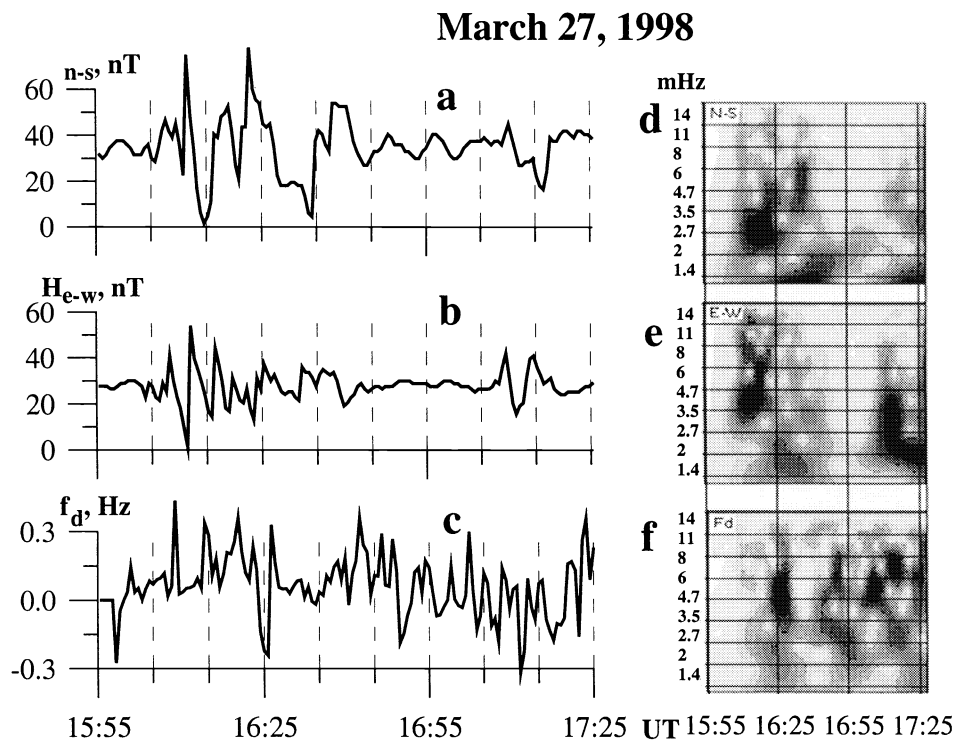


Figure 4. The irregular Pi2 geomagnetic pulsations and variations of frequency Doppler shift (f_d), March 27, 1998.