INHOMOGENEOUS STRUCTURE OF THE HIGH-LATITUDE IONOSPHERE AS OBSERVED AT NORILSK

Yu. V. Lipko
Institute of Solar-Terrestrial Physics SD RAS,
p. o. box 4026, Irkutsk, 664033, Russia
fax: +7 3952 462557; e-mail: lipko@iszf.irk.ru

Abstract

In March and August/September 1995, February 1996, and in March-April 1998, observations of the inhomogeneous structure of the high-latitude ionosphere were carried out at Norilsk (geomagnetic latitude and longitude are 64.2°N and 160.4°E, and $L = 5.2$). Small-scale irregularities (with the lifetime of several seconds, and the spatial scale less than 5-7 km), and medium-size wave irregularities (with the period of 10-50 min, and the horizontal size of tens and hundreds of kilometres) of the ionospheric $F_2$ layer were investigated under different geophysical conditions. A total of 300 hours of observations was recorded, including 250 reflections from the $F_2$ layer, and the other reflections from the sporadic $E$ layer.

The diurnal variations of inhomogeneous structure parameters in March and April is obtained. Dependence of some ionospheric irregularity parameters on geomagnetic activity is presented.

1 Introduction

It is known, that there are simultaneously irregularities of an electron concentration of different spatial and time scales in the high-latitude ionosphere [1]. The structure, dynamics, generation mechanisms of such irregularities are different. This paper is devoted to examination of small-scale irregularities (SSI) and medium-scale travelling ionospheric disturbances (MS TID) at the high-latitude region of Siberia. SSI are irregularities of electron concentration with spatial scale of 0.1-10 km and time scale of several seconds [2]. The main mechanism of generation of small-scale structure are various sorts of instability in ionospheric plasma, associated with electric fields and currents, which are especially strong
in high-latitude region [3]. MS TIDs have period of 10-40 minutes, and the horizontal size of tens and hundreds kilometres. They are ionospheric manifestations of acoustic-gravity waves (AGW), generated in the lower thermosphere [4].

The observations of inhomogeneous structure of an ionosphere in high latitudes are carried out widely. For these purposes modern and expensive facilities are used [5, 6, 7, 8]. However structure and dynamic of ionospheric irregularities are investigated insufficiently. It is explained by complexity and variability high-latitude ionosphere. Besides there are huge areas, where the regular observations of inhomogeneous structure of the ionosphere aren’t carried out. Such area is practically all high-latitude region of Siberia. In the sixties-seventies at Norilsk the regular examinations of small-scale structure high-latitude ionosphere by method D1 [9, 10, 11, 12] were carried out. The average patterns of motions in and F-layers of the ionosphere for various seasons of year and for levels of geomagnetic activity were obtained. The studies of MS TIDs in Norilsk were not carried out earlier.

Norilsk integrated magnetio-ionospheric station (geomagnetic latitude and longitude 64.2°N and 160.4°E, $L = 5.2$) operated by the Institute of solar-terrestrial physics SD RAS is the Siberian region’s unique high-latitude station admirably equipped with an appropriate facility for investigating the fine structure of the ionosphere.

The objective of this study was to obtain average parameters both small-scale irregularities and medium-scale TIDs depending on season, local time and geomagnetic activity.

2 Experimental equipment and technique

The measuring facility includes a digital vertical-incidence sounding pulsed ionosonde [13]. The facility allows to receive of a radiosignal, reflex from an ionosphere, on three antennas. After analogue processing on each of three antennas amplitude, SIN- and COS- components of a radiosignal, reflex from an ionosphere, were obtained.

Amplitude time series were processed by both the Similar-Fading Method (SFM) and Correlation Method (CM) [9, 11]. SFM is based on calculation of time delays between similar changes of amplitude of the radiosignal. The SFM allows to determinate velocity and direction of the motion of irregularities in the ionosphere. The CM using characteristic ellipse (ellipse of anisotropy) allows to estimate the shape, size, orientation and motion of SSI. These methods are justified physically enough and supported by direct measuring using incoherent scatter method. For many years ones were applied on the network of stations (including Norilsk) to determinate parameters of small-scale irregularities. The following parameters of small-scale irregularities were calculated: velocity $v_s$ and
direction $\alpha_s$, size of major characteristic ellipse half-axes $a$, degree of anisotropy $\varepsilon$, lifetime of SSI $T_h$.

SIN- and COS- components of the radiosignal are handled by phase method [14, 15, 16]. The amplitude and phase spectrums of a signal, reflex from the ionosphere, are calculated. Then time and space derivatives are determined. They are used for estimation of direction $\alpha_m$ and velocity $v_m$ of the motion medium-scale TIDs. The method is applied since beginning of 70 years. Its adequacy is confirmed by model calculations and comparison with known results. At the high-latitude region of Siberia the phase method was used for the first time.

3 Experimental results

3.1 Dependence irregularity parameters on season and local time

The observations inhomogeneous structure of the polar ionosphere were carried out in Norilsk from March 18 to April 13, 1998. It was recorded about 160 hours of F2-layer radio-reflection. Obtained data was classed into two seasons. The division into seasons was made on base of results observations at Norilsk in the seventies.

The first period - equinox (March) - is characterise by high level of magnetic activity (average summary $K_p = 20$) and by the most strong gradient of pressure, which arises from the fact of space-nonuniform heating of an ionosphere by solar radiation. This month there is a reorganisation from winter system of ionospheric plasma circulation to summer one. The influence of solar radiation on processes of ionisation and dynamics in the high-latitude ionosphere amplifies. In the winter the ionosphere above Norilsk practically is not irradiated by the Sun, the basic contribution to ionisation produce auroral sources. In the summer the solar energy light on the large areas of the high-latitude thermosphere uniformly [11].

April, according to paper [11], belongs to the second period - summer. This month the magnetic activity considerably weakens, the role auroral processes is reduced, the role of solar radiation amplifies. The average summer $K_p$ coefficient per day equal 15.

The observations were carried out when geophysical conditions were satisfactory (presence of qualitative reflection from the ionosphere) and there were organisation opportunities. The time intervals of observation were from 15 minutes to 10 hours. The interval of processing both for phase method and for method D1 equal 40 s. The values and root-mean-square deviations (r.m.s.) of ionospheric irregularity (SSI and MS TID) parameters were averaged over hour. The values of direction $\alpha$ were calculated as the most probable values for a hour.
Our procedure differs from one used at Norilsk earlier [11]. In the seventies the averaging $\alpha_s$ and $v_s$ was carried thrice: over one minute (time of a stationarity of the high-latitude ionosphere); over interval of observation (5-6 min), and over every hour for every season. The high-latitude ionosphere is characterised by the high variability, thus three time averaging could give considerable error for obtained parameters.

For March it was processed 72 hour of data (6500 intervals of processing), received by reflection radiosignal from a F2-layer of the ionosphere, for April it was processed 86 hour of data (7700 intervals). The correlation of 50% data was above 0.5, so these data were handled by SFM. Approximately half of these data there was suitable for processing by method CM, since degree of anisotropy $ex$ was positive for these.

Fig. 1 presents the diurnal variations of medium-scale TID parameters for March and April. The dashed vertical line on the figures marks the moment of passage solar terminator at 100 km altitude, where the generation of acoustic-gravity waves takes place. Fig. 1 a, e display change of average value and r.m.s. of variations $f_d$ with time. For frequencies of sounding, which were used (from 3.2 MHz up to 4 MHz), 0.1 Hz variation $f_d$ is matched to 7-8 m/s vertical velocity of moving of the ionospheric layer as whole, the positive value variation $f_d$ associates with ionospheric layer going downwards, negative value - upwards. Both for March and for April it is evident, that the peak velocity of lowering (raising) of a layer in the sunrise and in the sundown reach 15-20 m/s, at noontime the layer as whole does not go almost, at night the velocity of raising is considerably reduced.

The width of the Doppler spectrum $\delta f_d$ is present in the Fig. 1 b, f. Generally it does not exceed value 0.5 Hz. Before sundown $\delta f_d$ is incremented that probably is explain by the generation of ionospheric different-scale irregularities during passage of solar terminator [17].

The most probable travelling direction MS TIDs in March and April was southward. It was maintained practically stationary values during all observation time (Fig. 1 c, g). It is well accorded with results obtained at the other stations. The various sources MS TIDs are given in different papers. The analysis our data has not allowed to allocate any source of generation MS TIDs. It is possible, as it is specified in paper [4], the generation occurs at centre of the auroral oval. The average velocity of travel MS TIDs $v_m$ was 50 m/s (see Fig. 1 d, h). After sundown the considerable deviation of velocity values was observed.

Both March and April variations of parameters MS TIDs have general features. March parameters are characterised major values r.m.s. and more abrupt changes. It is probably associated with greater auroral activity in this period and with major influence of solar terminator.

Fig. 2 presents the variations of parameters of small-scale irregularities in March and April. Fig. 2 a, e presents variations of degree of anisotropy $ex$, Fig. 2 b, f – variations of ”lifetime” $Th$. These parameters calculated using
ellipse of correlation with positive $\text{ex}$. Direction $\alpha_s$ and velocity $v_s$ of travel were obtained by SFM.

The degree of anisotropy $\text{ex}$, as it is visible from Fig. 2 a, e, is 50 $\%$, i.e. the irregularities extend in the ratio 2:1 between major and small half-axes of the ellipse. There is not the preferred direction of major half-axis, but as have shown our examinations, irregularities move across direction of major half-axis. Assumption, that irregularities extend along magnetic field and move across it, does not confirm in our experiments. The sizes of irregularities appreciated by the major axis $a$ of the correlation ellipse are 400 m in the morning and at noonday of April, being lowered up to 200 m at the night. In March the average value of $a$ is 400 m. Average "lifetime" $T_h$ of irregularities in March practically does not vary and equal 2 s (see Fig. 2 b), in April $T_h$ raises from 1 s in the morning up to 5 s in the evening and then $T_h$ again decreases up to 2 s (Fig. 2 f).

Fig. 2 c, g present the direction $v_s$ of travel of SSI in March and April accordingly. The light circles mark directions obtained in the seventies [10, 11, 12], black circles mark direction obtained in 1998. These directions coincide for March. Two-vortex system with western convective jet in evening and east jet in morning sectors obtained in the seventies, confirm that the essential role is played drift of ionisation due to electric fields created by a magnetosphere convection. The drift of irregularities in the morning and at the noonday occur in northward direction, it is associated with the gradient of pressure of solar terminator. In the evening the influence of east electrojet is increased and by reason of that the SSI move in westward direction. Then $\alpha_s$ changes to the eastward direction. Interpretation of the direction of ionospheric plasma drift in April it is more difficult. Practically during all measured period SSI move in eastward direction. This direction does not coincide with direction obtained in the seventies.

The average velocities of SSI travel $v_s$ are 100-150 m/s (in Fig. 2 d, h they are designated by black circles). It is much higher than velocities obtained in the seventies (are designated by light circles). The considerable differences of velocity values can be caused by the following moments. First, at the analysis in the seventies it was used thrice averaging, that gives reduction of average velocity. Secondly, the observations in 1998 were carried out during the phase of solar activity growth, that, apparently, has had an effect on magnification of velocity values.

Thus, as a result of the investigation the diurnal variations of inhomogeneous structure parameters in March and in April is obtained.
3.2 Dependence of parameters of ionospheric irregularities on geomagnetic activity

Fig. 3 presents dependence of ionospheric irregularity parameters on geomagnetic activity. Geomagnetic activity was estimated by using one-minute values of the coefficient of auroral electrojet intensity AE.

Average variation of $fd$, as shown on Fig. 3 a, is zero, but r.m.s. $fd$ is incremented from 0.1 Hz under 50 nT to 0.25 Hz under $E$ greater, than 350 nT. The influence of auroral activity on $f_d$ is well appreciable (see Fig. 3 b). There is a considerable broadening of $f_d$ spectrum from 0.4 Hz under $E$ is smaller, than 50 nT, up to 0.8 Hz under $E$ exceeding 350 nT. The velocity of MS TID travel $v_m$ (Fig. 3 c) under magnification AE up to 350 nT is incremented almost three times, from 25 m/s up to 70 m/s. Under exceeding 350 nT $v_m$ decreases.

"Lifetime" $T_h$ SSI under the increase of a level auroral activity changes insignificantly. As the coefficient increase up to 150 nT ex and a decrease, at the further magnification there is an inverse process – the $ex$ and $a$ are incremented. The velocity of travel of SSI $v_s$ grows from 110 m/s up to 190 m/s under magnification up to 350 nT (Fig. 3 d).

Thus, it is obvious, that auroral activity influences not only on structure and dynamics of small-scale irregularities, that was noted earlier, but also on behaviour medium-scale TIDs.

4 Conclusions

The following results were obtained:

1. The propagation directions and velocities of small-scale irregularities and medium-scale TIDs are different. Medium-scale TIDs travel predominantly in a southward direction with velocities of 40-100 m/s. The prevailing direction of small-scale irregularities is eastward and westward, and their velocities lie in the range of from 100 to 200 m/s.

2. For the Norilsk region, for each season we obtained a diurnal variation of averaged parameters of ionospheric irregularities of the frequency Doppler shift; of the width of the Doppler spectrum; propagation directions and velocities of medium-scale TIDs; and of the anisotropy and lifetime of small-scale irregularities.

3. A dependence of medium-scale TID parameters on geomagnetic activity was obtained. Auroral activity has a significant effect on the frequency Doppler shift, the width of the Doppler spectrum and on the propagation velocity of medium-scale TIDs.
4. The conclusions drawn on the basis of the observations from the 1970s that auroral activity influences the drift of small-scale ionospheric irregularities, specifically the 1.5-2-fold increase of the velocity during the substorm, were confirmed.

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Figure 1: Diurnal variations of characteristics of the ionosphere-reflected signal:

- **a, e** – frequency doppler shift \( f_d \); **b, f** – width of the Doppler spectrum \( \delta f_d \); and medium-scale TID parameters:
  - **c, g** – travelling direction \( \alpha_m \); **d, h** – travelling velocity \( v_m \) in March (**a, b, c, d**) and April (**e, f, g, h**), 1998.
Figure 2: Diurnal variations of small-scale irregularity parameters: a, e – degree of anisotropy $\alpha$; b, f – lifetime $T_h$; c, g – travelling direction $\alpha_s$; d, h – travelling velocity $v_s$ in March (a, b, c, d) and April (e, f, g, h), 1998. Light circles mark values of $\alpha_s$ and $v_s$ obtained in the seventies at Norilsk.
Figure 3: Dependence of parameters of ionospheric irregularities on geomagnetic activity:

- **a** – frequency doppler shift $f_d$;
- **b** – width of the Doppler spectrum $\delta f_d$;
- **c** – travelling velocity of medium-scale TIDs $v_m$;
- **d** – travelling velocity of small-scale irregularities $v_m$. 

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**Legend:**

- $f_{d}$: Doppler shift frequency
- $\delta f_{d}$: Doppler spectrum width
- $v_{m}$: Medium-scale TIDs velocity
- $v_{s}$: Small-scale irregularities velocity