Study of large-scale traveling ionospheric disturbances using the data of SuperDARN Hokkaido radar and Russian chirp sounding network

***Oinats A.V.*[1], *Kurkin V.I.*[1], *Kutelev K.A.*[1], *Nishitani N.*[2] *and Tolstikov M.V.*[1]**

[1]Institute of Solar-Terrestrial Physics, Russia, 664033, Irkutsk, P.O. Box 291, E-mail: oinats@iszf.irk.ru

[2]Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan,
E-mail: nisitani@stelab.nagoya-u.ac.jp

Abstract

In the paper a study of the large-scale traveling ionospheric disturbances observed on March 17, 2007 is presented. The TIDs main parameters were estimated using the data of SuperDARN Hokkaido radar and Russian chirp sounding network separately. The comparison of the estimations shows some discrepancies in propagation direction that can be explained by convex shape of the TID`s front.

1. Introduction

Large-scale traveling ionospheric disturbances (LSTIDs) are localized wavelike heterogeneities of the electron density with period of 0.5–3 h and horizontal wavelength of more than 1000 km [1]. In the paper the study of LSTIDs is carried out using two instruments which allow independently estimating main LSTIDs parameters (azimuth of the propagation direction, horizontal velocity and period). The scheme of the instruments disposition is shown on the figure 1. SuperDARN Hokkaido HF radar is shown by a star [2]. The field of radar view consists of 16 beams. Hokkaido HF radar operating with a temporal resolution of 1 min and a range resolution of 45 km. SuperDARN Hokkaido HF radar measures backscatter echoes from decameter-scale ionospheric irregularities, as well as echoes backscattered from the ground. The second instrument is Russian chirp sounding network (RCSN) [3]. Here we used the data obtained from two oblique-incident sounding paths: Magadan-Irkutsk (Mag-Irk, 2950 km) and Norilsk-Irkutsk (Nor-Irk, 2034 km). The Irkutsk vertical sounder DPS-4 [4] was used to provide independent measurements in the third point. The main goal of this paper is to compare the LSTIDs parameters estimated using the data of two mentioned instruments separately.

2. Observational data description

Figure 2 shows the observational data on March 17, 2007. There are ground scatter echo power dependence measured by SuperDARN Hokkaido HF radar (beam 0), maximal observable frequency (MOF) time-dependences obtained by chirp sounders, critical frequency (foF2) and peak height (hmF2) time-dependences obtained by DPS-4. The approximations of the observational data by second-order polynomials are shown by thin lines. The approximation is used to compensate undisturbed diurnal trends of the mentioned parameters. As we can see from the figure 2, there is a good agreement between variations of the radar minimal group path and hmF2 in Irkutsk. There is also a good agreement between MOF dependencies and foF2 in Irkutsk. The noted agreement allows us to assume that observed variations of the measured parameters are caused by the same large-scale ionospheric disturbances.

3. Determination of the TID parameters using Russian chirp sounding network

The reflection points (or middle points) of the oblique-incidence chirp sounding paths and the point of DPS-4 location constitute a triangle that can be considered as a long baseline interferometer. Thus in the assumption of the planar TIDs front the TIDs parameters can be estimated from time lags between the apexes of the triangle. The time lags are determined based on correlation function calculation. It needed to be noted that TIDs spatial 3D-reconstruction can be made by reconstruction of electron density profile in the reflection points from oblique-incidence ionogramm as shown in [5]. But here we used more simple method determining only horizontal components of velocity and propagation direction of TIDs.

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The calculation showed that there were two prominent disturbances characterized by different azimuths and velocities. The first LSTID (TID1) propagated in the south-westward direction (azimuth ~240°) with horizontal velocity of ~190 m/s between 19 UT (16.03.2007) and 02 UT (17.03.2007). The second LSTID (TID2) propagated in the north-eastward direction (azimuth ~55°) with horizontal velocity of ~145 m/s between 02-10 UT (17.03.2007). Azimuth is measured from geographic north.

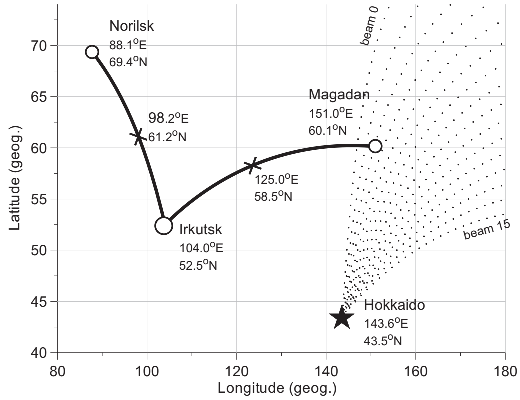

Figure 1. Scheme of the instruments disposition

4. Determination of the TID parameters using the SuperDARN ground scatter

In this paper we used a technique for TID`s parameters estimation based on the analysis of the minimal group path variations of the ground scattering signal. The variations of the minimal group path (corresponding to skip distance) are mainly caused by variations of the ionospheric reflection point height due to the TID`s propagation through the SuperDARN radar coverage area. Similar approach was also used earlier by other researches [6].

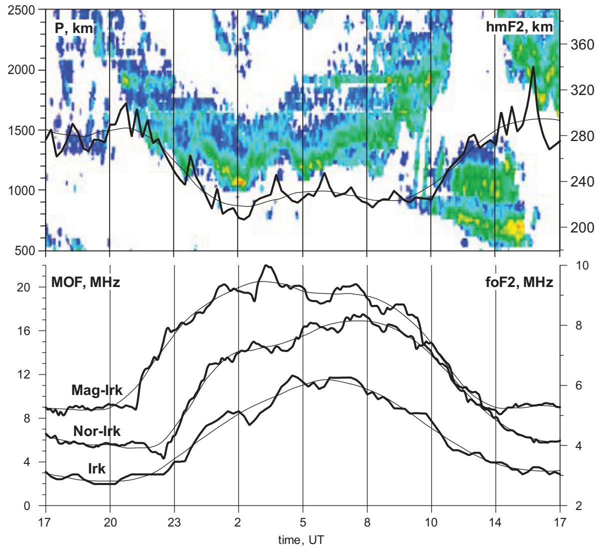

Figure 2. Observational data on March 17, 2007

The minimal group path variations are derived from echo power data (see figure 2) by finding the leading edge at fixed time moments. Derived variations are approximated by second-order polynomials that best fit the data values in the least-squares sense. The absolute deviations of the minimal group path with regard to undisturbed diurnal variations are shown on the figure 3 for all 16 beams of the SuperDARN Hokkaido radar. For convenience the curves for each beam are plotted with shift 100 km. As we can see from the figure there are similar variations for all beams but they have some distortion from each other and different phase shifts at a fixed time moment. Thus TID`s front propagates from one reflection point to another one with some temporal lag. If we fixed the disturbance phase and calculated coordinates of the reflection points for all beams and corresponding time lags, we could estimate the TID`s front position in assumption of the TID`s front shape. The coordinates of the reflection points can be approximately calculated as a half of the skip distance. One way to fix the disturbance phase is to consider the local minimums (or maximums) of the obtained curves (see figure 3).

Let assume that TID`s front is planar, and neglect the sphericity of the Earth surface within the field of radar view. In that case the horizontal projection of the disturbance will be considered as $A = \exp(i\vec{k}\vec{r} - \upsilon t)$, where $\vec{k} = \{k_x, k_y\}$ is a wave vector specifying the direction of disturbance propagation, $\vec{r} = \{x, y\}$ is a radius-vector in the plane, υ is a horizontal velocity of the disturbance. Let assume $|\vec{k}| = 1$ and $k_y / k_x = \alpha$. Then the wave phase of the disturbance at the point (x, y) and time moment t will be expressed by formula (φ_0 is an initial phase)

$$\varphi(x, y, t) = \frac{1}{\sqrt{1+\alpha^2}}(x + \alpha y) - \upsilon t + \varphi_0 . \tag{1}$$

Let imagine that we have phase detectors at the reflection points of each beam. Each detector characterizes by its coordinates (x_i, y_i) and snaps into action at t_i time moment ($i = 0 \ldots 15$). We can easily derive from (1) the phase taper for j-th detector with regard to i-th detector

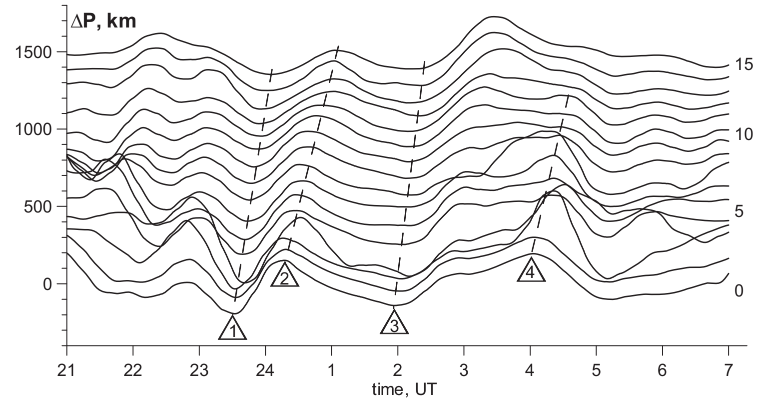

Figure 3. The absolute deviations of the minimal group path with regard to undisturbed diurnal variations are shown on the figure 3 for all 16 beams of the SuperDARN Hokkaido radar on March, 2007

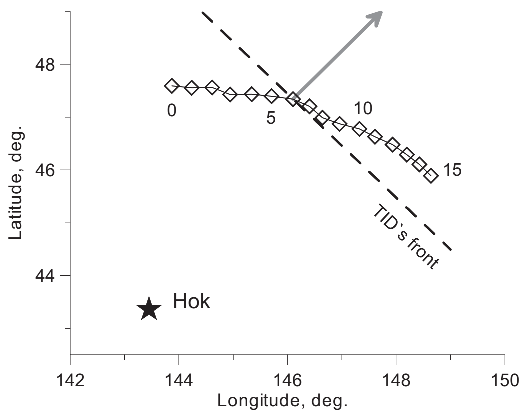

Figure 4. Mutual disposition of the reflection points (diamonds), the TID`s front (dotted line) and direction of the propagation (arrow)

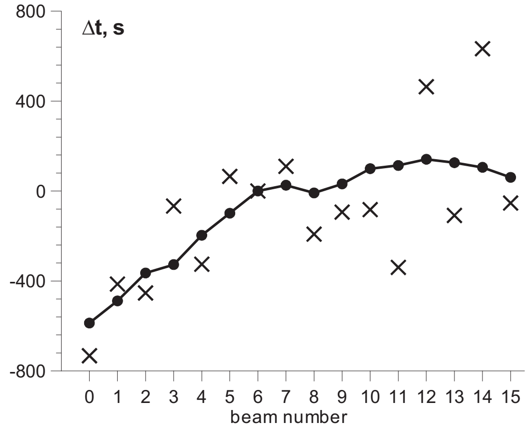

Figure 5. The measured (crosses) and theoretical (circles) time lags for different beams

$$\Delta\varphi_{ij} = \frac{1}{\sqrt{1+\alpha^2}}(x_j - x_i + \alpha(y_j - y_i)) - \upsilon(t_j - t_i)\,. \tag{2}$$

If each detector snaps into action when the disturbance phase is equal to φ' (the phase φ' could correspond to maximum or minimum of the deviation from the undisturbed case), then comparing (2) to zero we will obtain

$$t_j = t_i + \frac{1}{\upsilon\sqrt{1+\alpha^2}}(x_j - x_i + \alpha(y_j - y_i)) = t_{ji}(\alpha,\upsilon)\,. \tag{3}$$

Let the measured time moment t'_j when j-th detector snaps. Then we can minimize the discrepancy between theoretical (3) and measured time moments by least-squares method according to all beams

$$\delta_i(\alpha,\upsilon) = \sum_{j=0,\,j\neq i}^{15}(t'_j - t_{ji}(\alpha,\upsilon))^2\,. \tag{4}$$

Thus we can calculate the TID`s parameters (α and υ) that reduce to the best fit between theoretical and measured time moments by selecting the least discrepancy $\delta_i(\alpha,\upsilon)$. For example, for the minimum N3 (see figure 3) there were found the azimuth 32^{o} and horizontal velocity 182 m/s. Figure 4 illustrates mutual disposition of the reflection points for the different beams (diamonds), the calculated position of the TID`s front (dotted line) and direction of the propagation (arrow). The measured (crosses) and theoretical (circles) time lags for all beams are shown on the figure 5. It is necessary to emphasize that the accuracy of the described technique is sufficiently dependent on the mutual disposition of the reflection points for different beams.

Table 1. TIDs parameters estimated using SuperDARN Hokkaido and Russian chirp sounding network (RCSN)

Instrument	**RCSN**	**SuperDARN**		**RCSN**	**SuperDARN**	
Time, UT	19-2 UT	23UT (N1)	0.7UT (N2)	2-10 UT	2.1UT (N3)	4UT (N4)
Azimuth, deg.	240	160	153	55	32	52
Velocity, m/s	190	190	189	145	182	203

Table 1 summarizes the results of estimation of the TIDs parameters using the SuperDARN ground scatter data. As we can see from table 1 there is a discrepancy for TID1 propagation azimuth calculated by two instruments but the velocities coincide. The SuperDARN radar data show that TID1 propagates in south-westward direction where as chirp sounders network shows the south-eastward direction. The discrepancy can be explained under assumption of distorted TID`s front. It should be convex in the southward direction. The assumption is very likely but it needs to be tested by additional independent observational data. The southward propagation of TIDs is usual for northern hemisphere since the source is more often located in the polar cap. The parameters of TID2 determined by two instruments are in good agreement. The observation of the northward TID`s in the northern hemisphere is very rarely. The authors of [2] found the LSTID propagating from the southern into the northern hemisphere.

5. Conclusion

The comparison between the two different instruments shows a good agreement in estimated TID`s parameters. The joint use of the SuperDARN Hokkaido HF radar and Russian chirp sounding network data allows to take more information about large-scale TID`s propagating in the Asia north-east.

6. Acknowledgments

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7. References

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