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Case studies of height structure of TID propagation characteristics using cross-correlation analysis of incoherent scatter radar and DPS-4 ionosonde data

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Abstract

The height structure of TID characteristics is studied on the base of the electron density profiles measured by two beams of the incoherent scatter radar and DPS-4 ionosonde. The height profiles of the TID propagation characteristics are obtained by means of cross-correlation and spectrum analysis of the radar and ionosonde data. The noticeable height variability of the TID parameters is observed. The variability is explained by interference of several TIDs. The obtained TID propagation characteristics are compared with known results of the TID studies.

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Keywords: Traveling ionospheric disturbances; Incoherent scatter radar; DPS-4 ionosonde; Propagation characteristics; Height variability; Interference

1. Introduction

The phenomenon of atmospheric gravity waves (AGW) and their ionospheric manifestation, travelling ionospheric disturbances (TID), have been studied both experimentally and theoretically since the 1960s. Recent theoretical studies are developed in the directions of numerical simulation of AGW generation and propagation (Ahmadov and Kunitsyn, 2004) and interrelations between AGW and TID characteristics (Kirchengast, 1996). Experimental progress is associated with measurements of most complete set of TID parameters.

For studying the both vertical and horizontal structure of TIDs we have to measure height profiles of ionospheric parameters at horizontally separated points. Such measurements were made using multiple beams of EISCAT (Ma et al., 1998) and MU radar (Oliver et al., 1988). Herewith only Ma et al. (1998) have investigated the complete wave propagation vector of TIDs as function of height. In this paper the case studies of TID propagation characteristics using cross-correlation analysis of the incoherent scatter radar (ISR) (Zherebtsov et al., 2002) and DPS-4 ionosonde (Reinisch et al., 1997) data are presented. The both tools are located near Irkutsk (52.5N, 104.3E, LT = UT + 7). The ISR antenna system allows beam steering in the plane passing through the major axis of the antenna. As a beam lying out of this plane we used the ionosonde measurements. The ISR and DPS-4 positions and the ground projections of two ISR beams are shown in Fig. 1.

The experimental data are the electron density profiles measured by two ISR beams depicted in Fig. 1 and by DPS-4 ionosonde. The distinctive property of the Irkutsk ISR implies that the electron density profile is measured by the Faraday rotation method (Shpynev, 2004) and hence ISR has no need of calibration by ionosonde. All DPS-4 ionograms have been manually scaled with the interactive ionogram scaling technology described by Reinisch et al. (2004). The electron density profiles were constructed from the ionogram traces using the Reinisch and Huang (1983) method with the extrapolation above a peak height (Reinisch and Huang, 2001).

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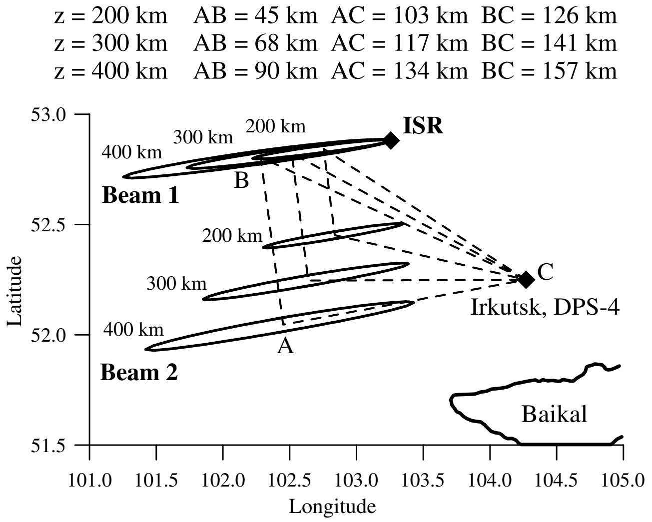

Fig. 1. Positions of ISR and DPS-4. Ground projection of two ISR beams at heights of 200, 300 and 400 km.

For the analysis we selected magnetically disturbed day of September 11, 2005. The $\sum K_p$ was 50^+, K_p index was not less than 6^+ for 0–15 UT interval and reached its peak of 8^- on 6–9 UT interval.

2. Analysis method

As mentioned above, the data are the electron density (Ne) profiles measured by two beams of ISR and by DPS-4 ionosonde. The Ne-TIDs were selected from Ne diurnal variations by band-pass filtering with period band of 1–4 hour. The selected Ne-TIDs are shown in Fig. 2.

We assume that Ne-TIDs have the form of planar wave:

$$\Delta \mathrm{Ne}(\vec{R},t) = \Delta N_0(z) A(t-\tau(\vec{R})), \tag{1}$$

where $\Delta N_0(z)$ is height profile of TID, $A(t)$ is its temporal form,

$$\tau(\vec{R}) = (\vec{e}\cdot\vec{R})/V, \tag{2}$$

$\vec{R} = \{R_x, R_y, R_z\}$ is radius-vector of observation point, $\vec{e} = \{e_x, e_y, e_z\}$ is unit vector specifying the wave propagation direction, V is wave velocity. As a coordinate system we chose Cartesian system with the origin in ISR location, where the z-axis is upward, the x-axis is northward, y-axis is eastward. In this system the $\vec{e}$ vector has the coordinates $\{\cos\theta\cos\psi,\ \cos\theta\sin\psi,\ \sin\theta\}$, where θ is elevation angle over the horizon with upward wave propagation direction as a positive, ψ is azimuth angle with respect to north, taking clockwise as a positive.

The delay (or time difference) between the Ne-TIDs observed at the points with radius-vectors $\vec{R}_1$ and $\vec{R}_2$ is

$$\Delta\tau(\vec{R}_1,\vec{R}_2) = (\vec{q}\cdot(\vec{R}_1-\vec{R}_2)), \qquad \text{where } \vec{q} = \vec{e}/V. \tag{3}$$

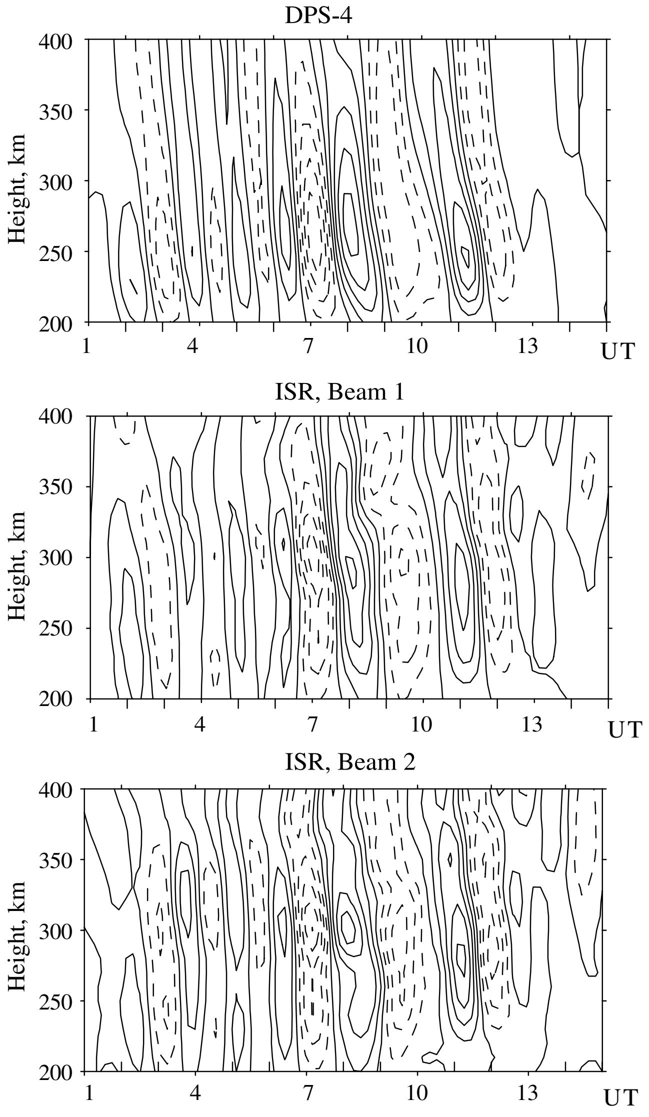

Fig. 2. Ne-TIDs within a period band of 1–4 h. September 11, 2005. LT = UT + 7. Positive contours are solid lines and negative contours are dashed. The contour step is $0.4\times10^{11}\ \mathrm{m}^{-3}$.

Using the mutual delays between the Ne-TIDs observed by two beams of ISR and DPS-4 at the same heights we obtain the linear system of equations for determination of q_x and q_y:

$$\begin{cases} q_x(x_1-x_2)+q_y(y_1-y_2)=\Delta\tau_{12} \\ q_x(x_2-x_3)+q_y(y_2-y_3)=\Delta\tau_{23} \\ q_x(x_3-x_1)+q_y(y_3-y_1)=\Delta\tau_{31} \end{cases} \tag{4}$$

where (x_1,y_1), $(x_2,\ y_2)$ and (x_3,y_3) are observing points coordinates in xy-plain for two beams of ISR and DPS-4, respectively. By solving this system we obtain the expressions for q_x and q_y

$$\begin{cases} q_x = (\Delta\tau_{12}(\Delta y_{23}-\Delta y_{31})+\Delta\tau_{23}(\Delta y_{31}-\Delta y_{12}) \\ \qquad +\Delta\tau_{31}(\Delta y_{12}-\Delta y_{23}))/3S \\ q_y = -(\Delta\tau_{12}(\Delta x_{23}-\Delta x_{31})+\Delta\tau_{23}(\Delta x_{31}-\Delta x_{12}) \\ \qquad +\Delta\tau_{31}(\Delta x_{12}-\Delta x_{23}))/3S \end{cases} \tag{5}$$

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