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The Examples of the Large-Scale Electron-Density Features Revealed by the Radio Tomographic Methods in the Distributions of the Ionospheric Plasma During the Space Weather Disturbances

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Introduction

The geomagnetic storms pertain to the most important elements of the space weather. During the geomagnetic storms, the dynamical regime of the ionosphere strikingly changes; the ionospheric parameters experience strong variations. The complexity and global scale of the processes that take place in the disturbed ionosphere require applying the nonlocal methods for identifying the spatiotemporal structure of the ionospheric disturbances. The ionospheric satellite radio tomography (RT) based on the low-orbiting (Transit, Parus) and high-orbiting (GPS, GLONASS) Global Navigation Satellite Systems (GNSS) is one of the most suitable instruments for this research. Probing the ionosphere along different directions by the radio signals transmitted from the GNSS satellites and recorded by the network of the ground receivers yields the data that can be processed by the RT methods (either LO or HO RT depending on the particular GNSS scheme used). In the present work, we demonstrate the RT images of the ionosphere during the periods of the disturbed space weather in the 23rd and 24th solar cycles.

Methods and approaches

The theory, approaches, algorithms, methods, and the main results of application of LORT are described in detail in [1-4]. Here, we only recall that this method provides two-dimensional (2D) distributions of electron density in the ionosphere in the height interval from 100 to 1000 km above the chain of the ground receivers. The horizontal and vertical resolution of LORT is 20--30 km and 30--40 km, respectively. The method is efficient for diagnosing a broad range of the ionospheric structures including the ionospheric responses to particle precipitation. The HORT method is capable of reconstructing the four-dimensional (4D) structure of the ionosphere (three spatial coordinates an time) [5].

Typically, HORT has the vertical and horizontal resolution of about 100 km and the time spacing between the successive images of 60-20 min. At the dense receiving networks, the resolution can be improved to 30-50 km and the time step, to 30-10. In the regions with very dense coverage by the receivers (e.g., California and Japan), the resolution can be even higher: 10-30 km in space and up to 2 min in time. In contrast to the ionosondes which use the HF radio waves, the RT methods are immune to the ionospheric disturbances and are applicable even during the periods of the strongest geomagnetic storms since due to the high sounding frequency, the absorption in the RT problems can be as a rule disregarded. The main results of the RT studies of the ionosphere are presented in [2-4, 6, 7].

Experimental observations

The RT reconstructions in the different regions of the world revealed a broad variety of the ionospheric structures including the wavelike disturbances, ionization troughs, the distributions with multiple extrema (plasma enhancements and depletions with different sizes and configurations), travelling ionospheric disturbances (TIDs), blobs, patches, etc. The examples are presented in Fig. 1 which shows the LORT reconstructions above the Russian RT chain (Moscow-Svalbard). The LORT image in the left-hand panel of Fig, 1 demonstrates a wide ionization trough in the latitude interval 60-66N, the quasi-wave disturbances in the region of Svalbard (78-79N), and a localized structure in the form of a wall in the distribution of electron density in the area 68-69N. These features were observed in the weakly disturbed ionosphere (Kp = 2.3). The RT cross section in the right-hand side of the figure (at Kp = 3.3) shows a distinct deep and narrow trough in the ionization in the interval 60-62N. The wavelike structures are observed north of the trough at 62--69N. In our presentation we demonstrate the examples of LORT reconstructions in the different regions (Northwest Russia, Alaska, U.S. West Coast) under different geomagnetic activity.

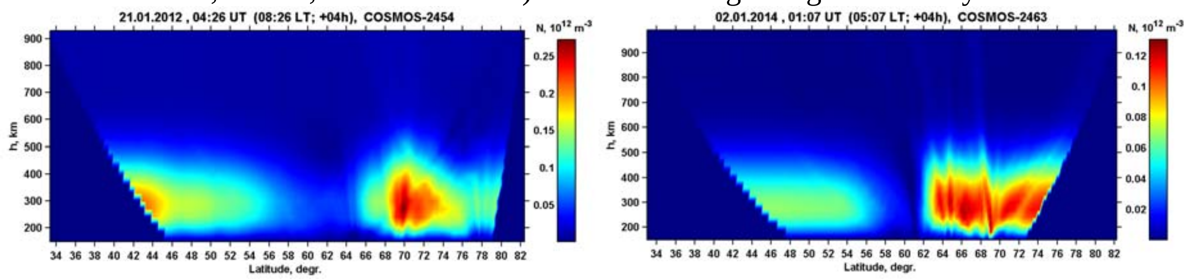

Figure 1. Example of LORT image above Northwest Russia, January 21, 2012 (left) and January 2, 2014 (right)

The examples of the ionization troughs above the North America and Europe reconstructed by HORT during the geomagnetic storm of September 12, 2014 (maximum Kp reached 7) are presented in Fig. 2.

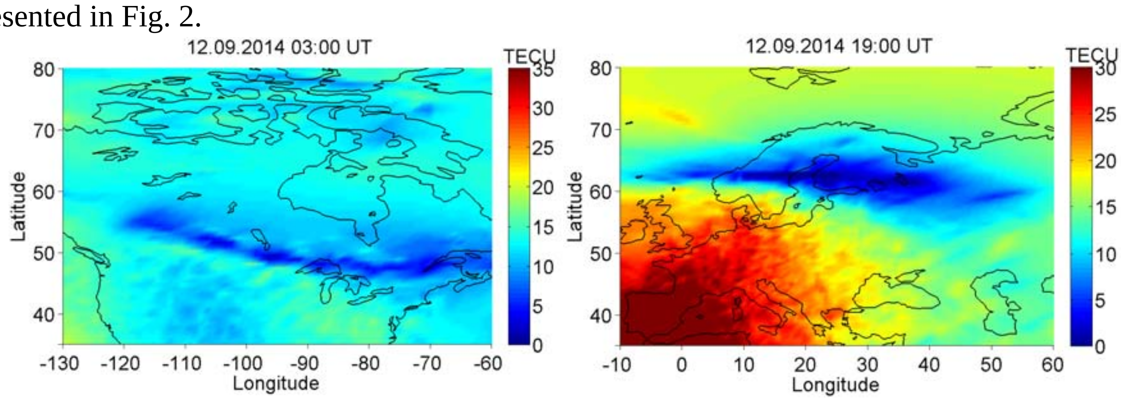

Figure 2. TEC maps with ionization trough above North America (left) and Europe (right), September 12, 2014

The maps of the vertical TEC calculated from the 4D HORT reconstructions demonstrate the ionization trough above the North America in the latitudinal region of 55-48N at 03:00UT (Fig. 2, left panel). A deep trough above Europe in the latitudinal interval from 65 to 55N is reconstructed at 19:00 UT (Fig. 2, right panel). We show the different examples of the evolution of the ionization trough above the North America and Europe under different geomagnetic perturbations according to the HORT reconstructions. As the geomagnetic activity increases, the position of the minimum ionization within the trough shifts equatorwards. The depth and width of the trough widely vary from a few dozen to few hundred km. We analyze the spatiotemporal features and dynamics of the ionosphere depending on the solar-geophysical conditions. Based on the comparison of the RT images and the observations onboard the DMSP satellites, we explore the effects of the corpuscular ionization of the ionosphere. The comparisons show that the spatial structure of the additional corpuscular ionization in the RT images is qualitatively close to the latitudinal distributions of the fluxes of the ionizing particles according to the DMSP data. We discuss the comparison of the ionospheric RT images with the measurements by the ionosondes.

Conclusions

The obtained RT reconstructions generally demonstrate a broad range and variability of the distributions of the ionospheric plasma during the space weather variations. The RT methods are capable of retrieving a broad range of the ionospheric features such as the troughs in the ionization, wavelike disturbances, local irregularities, tongues of ionization, patches of ionization, specific circumpolar ring-shaped structures, etc. The RT approach based on the combined application of the HORT and LORT methods is a highly efficient instrument for studying the structure and evolution of the ionospheric features on the different spatial and time scales.

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