Structural features in the disturbed ionosphere as revealed by radio tomography

***V.E.Kunitsyn*[1], *E.D.Tereshchenko*[2], *E.S.Andreeva*[1], *M.O.Nazarenko*[1], *I.A.Nesterov*[1], *A.M.Padokhin*[1]**

[1]M.Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia; kunitsyn@phys.msu.ru
[2] Polar Geophysical Institute of the Russian Academy of Sciences, Murmansk, Russia; evgteres@pgi.ru

Abstract

Results of radio tomographic (RT) imaging of the ionosphere during periods of severe geomagnetic storms (1991-2007) are reported. Both methods of low-orbital (LO) and high-orbital (HO) radio tomography are used. During disturbed periods RT reveals splitting of the trough and its equatorial shift, emergence of spots of enhanced ionization within the trough, diverse wavelike structures, various AGW manifestations, steep gradients in electron density, etc. Abnormally high electron density values are often detected. Ionospheric effects related to particle precipitation are analyzed. Numerous examples are shown and structural peculiarities revealed in the ionosphere by LORT and HORT are discussed.

1. Introduction

Ionospheric conditions during periods of geomagnetic storms remain a subject of poignant interest of the researchers (e.g., [3-5] and many other). It is well known that the behavior of ionospheric parameters is defined by a set of extremely complicated and diverse processes involved in the solar-terrestrial coupling. The spatio-temporal structure and intensity of these processes observed during different storms are unique in many respects. In this connection a detailed study of specific "individual" manifestations of storms in the near-Earth environment including the ionosphere becomes an issue of great importance. Ionospheric manifestations of geomagnetic disturbances strongly vary both in scales (days to seconds and dozen thousand kilometers to a few meters) and amplitudes. This requires non-local methods to be used capable of obtaining nearly instantaneous ionospheric snapshots not at a single site but within a large enough spatial interval with sufficiently high resolution. One of the best suitable tools here is the ionospheric satellite radio tomography. In the presentation results are described of studying the ionospheric structure during periods of a series of severe geomagnetic storms revealed by high-orbital and low-orbital radio tomographic techniques.

2. Radio Tomography methods

In this work two modifications of radio tomographic method are used, low-orbital radio tomography (LO RT) and high-orbital radio tomography (HO RT) [1, 4]. LORT is based on the analysis of 150- and 400-MHz radio transmissions from low-orbiting navigational satellites measured at a chain of ground receivers. This method yields 2D cross-sections (a few thousand kilometers as long) of ionospheric electron density distribution in a vertical plane containing the satellite path and the receiving chain for a 10-15 minutes interval. Horizontal resolution of LORT is 20-30 km and vertical resolution is 30-40 km. In HORT the use is made of dual frequency (L1 and L2) radio transmissions from high-orbiting satellites like GPS/GLONASS measured at two-dimensional ground receiving networks. This enables 4D imaging of the ionosphere (three spatial coordinates and time). Due to low angular velocity of high-orbiting satellites and uneven coverage of different regions by GPS receivers the spatial resolution of HORT is lower than that of LORT (not exceeding 100 km). However, HORT makes it possible to obtain 3D patterns of electron density distribution in the ionosphere over extended regions up to a few dozen thousand kilometers as large at 20-30 minutes time resolution. Combined application of LORT and HORT in the studies of the disturbed ionospherice structure allows one to trace regional and global variations in electron density distribution (owing to HORT) and, at the same time, to identify local details of these large-scale patterns (owing to LORT). Besides, LORT and HORT combination enables reciprocal verification of LORT and HORT results and thus considerably increases the quality of imaging.

3. Storms of 1990-ies

RT studies of substorms of 18-20 and 24-28 March, 1991 showed that the ionospheric structures usually typical of auroral ionosphere (troughs, anomalous F-region ionization) reached middle latitudes. In particular, on 18.03.1991 and 19.03.1991 quasi-regular ionospheric cross-sections with smooth northward decrease in electron density were observed. Extremely high untypical values of electron concentration in middle, subauroral and auroral latitudes are noteworthy. For example, on 18.03.91 at 11:07LT (Fig.1) maximum electron density was as high as $2.36 \cdot 10^{12} m^{-3}$ and the range of corresponding phase variations exceeded 6000 radians. Comparison of RT results with the vertical ionospheric sounding data proves such a high level of electron concentration.

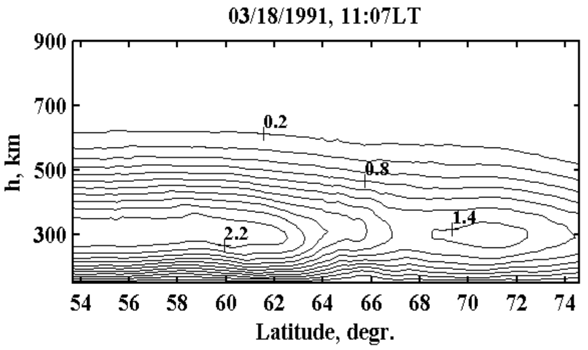

Fig.1. RT image of the ionosphere (Moscow-Murmansk) at 11:07UT on 18.03.1991

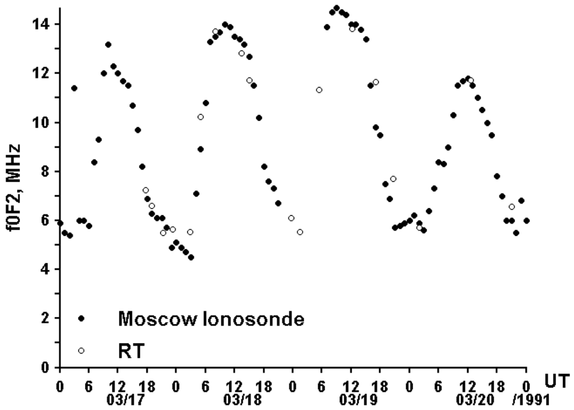

Fig.2 Comparison between *f0F2* values calculated fromRT and from ionosonde data in Moscow

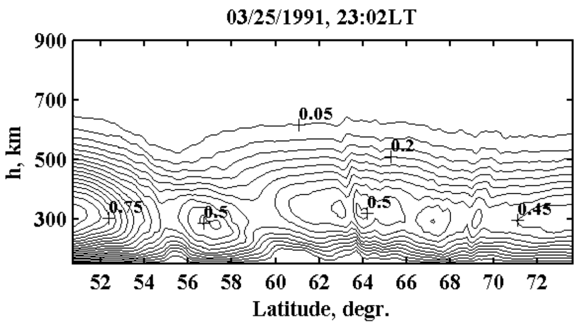

Fig.3. RT image of the ionosphere (Moscow-Murmansk) during geomagnetic storm at 23:02LT on 25.03.1991

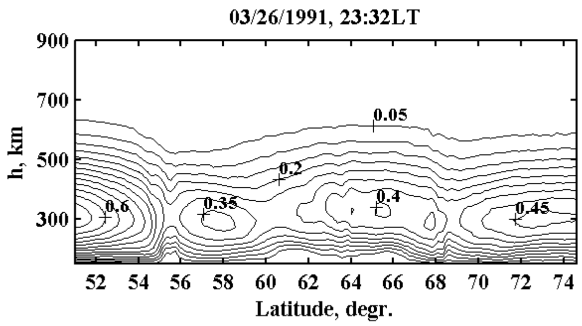

Fig.4. RT image of the ionosphere (Moscow-Murmansk) during geomagnetic storm at 23:32LT on 26.03.1991

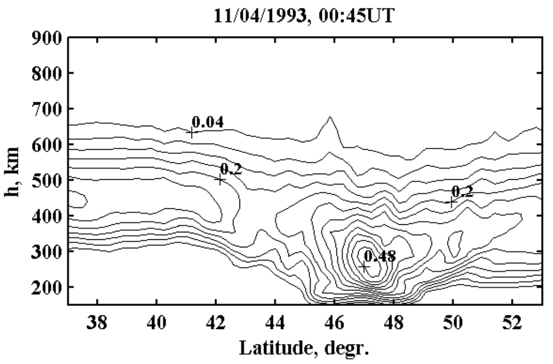

Fig.5. RT image of the ionosphere (northeast USA) during geomagnetic storm at 00:45UT on 11/04/1993

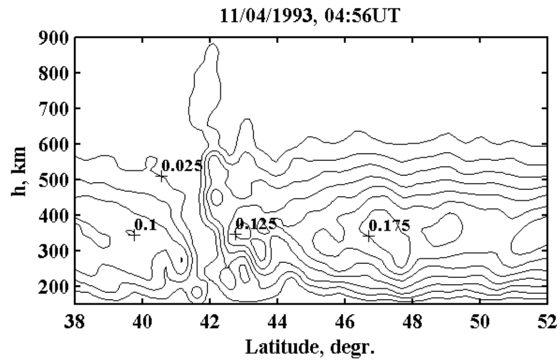

Fig.6. RT image of the ionosphere (northeast USA) during geomagnetic storm at 04:56UT on 11/04/1993

Shown in Fig.2 is time dependency of *f0F2* calculated from RT and ionosonde data in Moscow for 17-21 March, 1991. Examples of RT imaging of wavelike disturbances, trough splitting and its shift towards the latitude of Moscow (55.7ºN) are shown in Figs.3 and 4 in contours of 10^{12} m^{-3} units.

A complicated unusual pattern of ionospheric structure over the North America (Fig.5) was detected during the storm of 3-4 November 1993 in the Russian-American Tomography Experiment (RATE'93): intense uplift of the F-region ionosphere to the south of 45° latitude, the trough at about 44° and a spot of enhanced ionization at the F-layer bottom heights within latitudinal sector from 46°N to 51°N caused by low-energy particle precipitation [8, 9]. In this experiment a narrow (<2°) tilted trough has been detected at 41° - 42° by both the Millstone Hill IS radar and LORT (Fig.6).

4. Storms of 2003-2007

The presented RT images of the ionosphere along the path Moscow-Barentsburg (Svalbard) and in the Alaska region during periods of geomagnetic storms in 2003-2007 reveal rather complicated patterns of ionospheric plasma distribution. The Halloween storm of 29-31 October 2003 relates to extremely severe events (Kp index for the first time reached its maximum Kp=9). In the night of 30/31 October a spot of enhanced ionization with electron density as high as $1.5\cdot10^{12}m^{-3}$ has been observed over Europe. Example in Figure 7 shows the RT image of the ionosphere between Moscow and Barentsburg on 10/30/2003 at 21:25 UT. A complex multi-extremal pattern of electron density distribution with the spot of enhanced electron concentration centered at 70º is apparent. The presence of this spot of enhanced ionization over Europe in the pre-night hours of 30 October is proved by HORT results [6, 7]. At that time a series of European ionosondes evidenced an increase in *foF2* corresponding to the spot passage [5]. The motion of the spot cannot be monitored by ionosondes but it is easily captured by HORT, which is convincingly illustrated by the movie shown in the presentation. Figure 8 displays an example of ionospheric RT image (along Moscow-Barentsburg path) showing sharp wall-like contrasts in ionization observed during the geomagnetic storm in July 2004 (Kp reached 8.7). During the November 2004 storm multiextremal wavelike structures as well as ionization troughs were detected repeatedly in the region of Alaska (Figure 9). RT cross-section in Fig.10 (Moscow-Barentsburg) relates to the onset of geomagnetic storm in the late April 2007. Here we see rather complicated pattern with wavelike structures in the region of 68°-70°. In the presentation examples are given of comparison of the upper atmosphere ionization detected by RT with the ionizing particle fluxes measured by DMSP satellites.

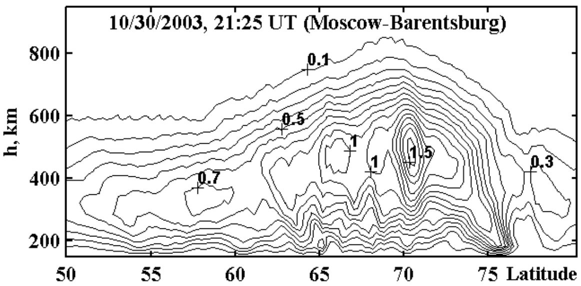

Fig.7. RT image of the ionosphere during geomagnetic storm at 21:25UT on 10/30/2003

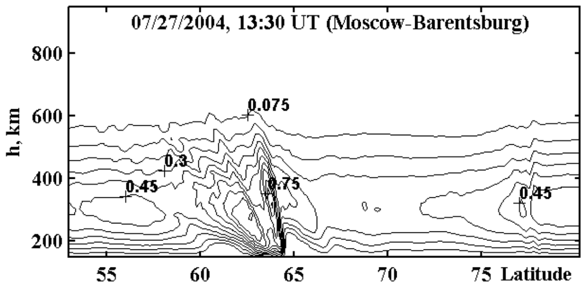

Fig.8. RT image of the ionosphere during geomagnetic storm at 13:30UT on 07/27/2004

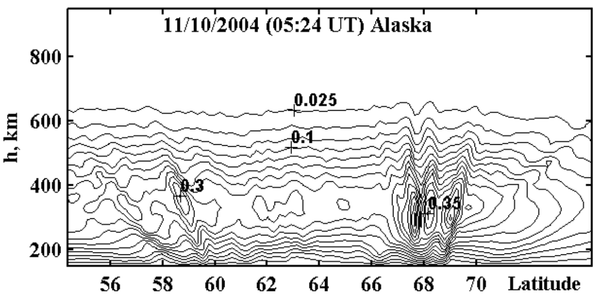

Fig.9 RT image of the ionosphere during geomagnetic storm at 05:24UT on 11/10/2004

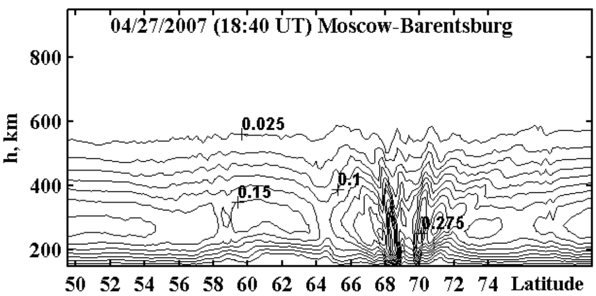

Fig.10. RT image of the ionosphere during geomagnetic storm at 18:40UT on 04/27/2007

5. Conclusion

The analysis carried out showed that during periods of geomagnetic storms highly complicated patterns of ionospheric electron density distribution (uplifting, bending, fingerlike structures, local extrema, wavelike disturbances, splitting of the trough and its southward shift and other) are often observed. These features are generated by different factors. Under quiet solar-geophysical conditions the ionospheric structure is quasi-regular and smooth. To reproduce such regular ionosphere it is quite sufficient to have a set of standard profiles and ionosonde measurements at a few sites. But in disturbed and stormy periods the situation becomes quite different: the ionosphere has a highly complicated structure and its reconstruction requires application of RT methods. For example, ionosonde measurements cannot help a detection of a narrow trough or revelation of its internal structure; in addition, the performance of ionosondes is very unstable in geomagnetically disturbed periods. Unlike the ionosondes, the RT imaging is not prone to the effects of increased geomagnetic activity and it does allow discerning fine details and the internal structure of the trough as well as many other ionospheric irregularities.

6. Acknowledgments

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7. References

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