

POSITIONING OF SMALL-SCALE IRREGULARITIES OF THE AURORAL OVAL WITH HELP OF MID-LATITUDE LFM HF RADAR BISTATIC CONFIGURATION*

V.P. Uryadov⁽¹⁾, G.G. Vertogradov⁽²⁾, V.G. Vertogradov⁽²⁾, A.A. Ponyatov⁽¹⁾

⁽¹⁾*Radiophysical Research Institute, 603950, B.Pecherskaya str.25, Nizhny Novgorod, Russia, email: ur@nirfi.sci-nnov.ru*

⁽²⁾*Rostov State University, 334090, Zorge str.5, Rostov-Don, Russia, email: vgg@rost.ru*

ABSTRACT

The experimental results of HF propagation features on a mid-latitude Inskip (England) - Rostov - Don (Russia) chirp sounding path at distance of 3050 km during magnetic storm October 29-31, 2003 are presented. During magnetic storm on oblique sounding ionogram was observed an additional spread side signal. The spread side signal had time delay 2-3 ms relatively of direct mode. On the basis of calculations and comparison to the experimental data at the oblique sounding mid-latitude path, the spread side signals are identified as signals scattered at small-scale field-aligned irregularities their location positioning to the southern boundary of the auroral oval.

INTRODUCTION

Effects of space weather exert a different and considerable influence on various sides of human activity and work of radio-electronic systems. First of all these effects are manifested at high latitudes as a result of magnetosphere-ionosphere interaction of electric and magnetic fields at conditions of intensification of solar wind and changes in the configuration of interplanetary magnetic field. Geomagnetic disturbances being a determining factor for HF propagation at polar latitudes [1,2] exert considerably influence at signals characteristics at mid-latitude and sub-auroral paths [3-6].

The main ionospheric trough and auroral oval are the important features of the high-latitude ionosphere. The interest to them is due to the fact that trough borders on the mid-latitude ionosphere where the main channels of the HF communication pass and shift of trough to lower latitudes during magnetic storms can lead to undesirable effects of decreasing the maximum observed frequency (MOF) and variation of the signal mode structure.

The ionosphere irregularities of various scales generated in the vicinity of the southern boundary of the auroral oval lead to an increase of the signal spread of standard modes of propagation and to appearance of anomalous signals with delays increasing considerably the delays of the main modes propagating along the great circle. The level of such signals is sufficiently high and they influence on the work of radio-electronic systems of various application. On the other hand the presence of additional signals on oblique sounding ionograms in the period of disturbances may be used for determination of boundaries of the main ionospheric trough and diagnostic of small-scale ionosphere irregularities located in the vicinity of the southern boundary of the auroral oval.

For study of irregularities in the high-latitude ionosphere the SuperDARN HF radars are successfully used [7]. However it is known that during geomagnetic storms a motion the region with irregularities responsible for the scatter from high to middle latitudes is observed. In this situation due to the conditions of propagation and geometry of the scatter the irregularities are found outside the "visibility" zone of the high-latitude HF radars. The latter fact makes difficult a detailed study by these radars of the dynamics of small-scale irregularities localized at the southern boundary of the auroral oval at all stages of a magnetic storm. So to obtain a complete picture of the ionospheric irregularity dynamics during magnetic storm a considerable interest represents use together with high-latitude radars also radars located at middle latitudes. For this task the Russian and global network of the LFM ionosondes [8] located at middle latitudes may be used as HF radars in a bistatic configuration. The experiments carried out during the recent years on the basis of the LFM ionosondes network demonstrated a perspective of such approach for studying of ionospheric irregularities dynamics and wave processes in the ionosphere and magnetosphere during magnetic storms [9].

RESULTS OF OBSERVATIONS

The experimental data during magnetic storm 29-31 October 2003 obtained at the Inskip (England, 53.8°N, 2.8°W)—Rostov on Don (Russia, 47.3°N, 39.7°E) path at distance of 3050 km are analyzed. The chirp sounder

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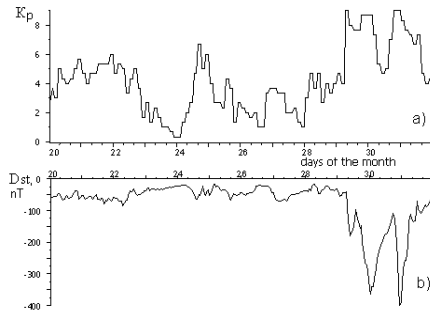


Fig. 1. Behavior of the geomagnetic indices during 20 – 31 October 2003.

in Inskip radiated every 5 minutes in the frequency range 4.2—30 MHz. The rate of the frequency variations was 100 kHz s^{-1} . The strong disturbance of the magnetic field took place on 29—31 October and was caused by a series of powerful solar flares. From them it is necessary to pick out a solar flare of class X17.2/4B which began on 28 October at 09:51 UT. During flare dense and fast emission of solar substance with a speed exceeding 2100 km/s was observed. In the evening on 29 October there was one more powerful proton flare X10.0/2B S15W02. In result a series of extremely strong magnetic storms began. According to the ACE satellite data [10] at 06:12 UT on 29 October 2003 there was a sharp increase in the IMF magnitude from 10 nT to 35 nT and a sharp change of the B_z component orientation to southward with the value of -25 nT . Fig. 1 shows the geomagnetic activity

level expressed in the Kp (a) and Dst (b) indices.

The ionogram during geomagnetic disturbances presented in Fig. 2a illustrates appearance at the Inskip—Rostov on Don path the additional signal. The time of propagation of an additional signal exceeds time of propagation of the basic mode and on the ionogram this signal is marked by SS (side-signal). The direct signal propagating along the great circle is marked by DS. One can see that side-signal is spread signal, its intensity being comparable to the intensity of the DS.

MODELING AND DISCUSSION

During magnetic storms the mid-latitude ionosphere gets features of the high-latitude ionosphere. This is manifested in appearance of a sufficiently strong anomalous signals associated either to side reflection of radio waves from the northern wall of the ionospheric trough or from large-scale structures of the globules types with enhanced electron concentration or to the scatter at intense small-scale irregularities located at the southern boundary of the auroral oval, as well as to a combination of all this factors. The side signals were registered

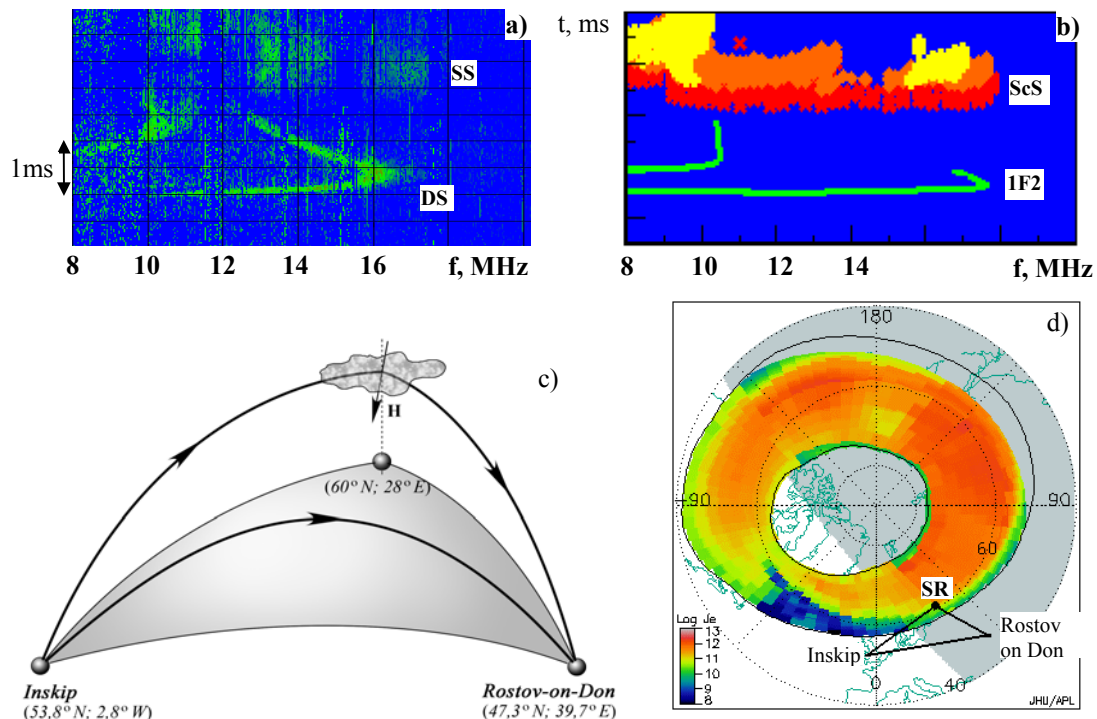


Fig. 2. Experimental (a) and calculated (b) ionograms at the Inskip—Rostov on Don path during the magnetic storm 14:42 UT 29 October 2003 (DS, SS, and ScS are direct, side, and scattered signals, respectively), \times , \diamond , and $+$ are markers for scattering regions (SR) which centers have sub-ionospheric coordinates $(60^\circ\text{N}, 28^\circ\text{E})$, $(61^\circ\text{N}, 28^\circ\text{E})$, and $(60^\circ\text{N}, 32^\circ\text{E})$ respectively; (c) ray tracing for frequency 16 MHz; (d) is the position of the auroral oval (15:08 UT) with the position of the SR.

during geomagnetic disturbances at frequencies both below and above MOF of the hop propagation modes. The frequency range of SS and its position relative to the main mode depends on some factors and is determined by the geometry of the ionosondes location, ionospheric conditions at the propagation path, and geophysical situation.

In the report the basic attention we shall give interpretation a strongly spread signals observed on the Inskip - Rostov - on-Don path during extremely strong magnetic storm on October 29-31, 2003. We believe that spread side signals are caused by scattering of radio waves on small-scale field-aligned irregularities. Such irregularities exist at the southern boundary of the auroral oval [11]. They may serve as an indicator for determination of the position of the auroral oval during magnetic disturbances by registration of the side (scattered) signals at oblique sounding ionograms.

For Inskip—Rostov on Don path where spread side signals were observed during a magnetic storm we performed calculations in order to localize the region with the irregularities responsible for the scatter. In calculations the background model IRI and put on it the empirical model of the main ionospheric trough [12,13] were used. The concentration in maximum F-layer on walls of a trough coincides with values on model IRI. Inside of trough interpolation is made proceeding from width, depth and position of a concentration minimum. Besides for ensuring of conformity experimental and simulated ionograms for direct signal the correction of values of electron concentration on the VS data of station Chilton (51.6°N, 1.3°E) [14] was carried out.

Evidently the region with the irregularities should be located within the ellipse with the focal points in the reception and transmission stations. The position of the scattering region within the ellipse itself was fitted by calculations, comparing the model and experimental ionograms and using the aspect scatter condition at strongly stretched field-aligned irregularities. The location of such scattering regions was taken in the form of a latitude—longitude net in the vicinity of the southern boundary of the auroral oval. In calculations position of area with irregularities as a disk in radius of 50 km is varied in significant limits as on latitude (from 58°N up to 62°N), and on a longitude (from 25°E up to 40°E) in an interval of heights from 230 km up to height of the F-layer maximum. As have shown calculations, basically, the side signals caused by scattering of radio waves on small-scale field-aligned irregularities can come from various areas. Criterion of selection was the best concurrence experimental and simulated ionograms.

Fig. 2b shows the ionogram at the Inskip—Rostov on Don path calculated for the conditions of the experiment (14:42 UT, 29 October 2003) taking into account radio wave scatter at field-aligned irregularities. The spread signal delayed concerning a direct signal is marked by marker ScS (scatter signal). This signal is caused by scattering from irregularities located in the upper ionosphere. Sub-ionospheric coordinates of the centers of areas with irregularities scattered on which gives the best concordance of the experimental and simulated data lay in an interval of latitudes 60-61°N and longitudes 28-32°E.

Comparing Fig. 2a and 2b one can see a quite satisfactory agreement between the calculated and experimental ionograms. Fig. 2c shows trajectories of rays on frequency of 16 MHz realized on a direct path along of great circle Inskip - Rostov - on-Don and on a path with a deviation from the great circle at aspect scattering on field-aligned irregularities located in the upper ionosphere at heights of 270-300 km. Calculations are executed for area with irregularities which center has sub-ionospheric coordinates 60°N, 28°E.

Fig. 2d shows the geographical position in the map of the auroral oval the scattering region which according to the propagation conditions and scattering geometry provides the main input to the spread (scattered) side signal in the oblique sounding ionogram for the given position of the transmitting and reception points. One can see the calculated area with irregularities responsible for scattering and occurrence on ionograms OS the side spread signal is well positioned with location of southern boundary of the auroral oval (on measurements of DMSP [15]), that testifies for the benefit of the suggested interpretation of the nature of the side signal.

It should be noted that during the registration of side spread signals in the OS ionograms in the period 13:40—15:30 UT on 29 October 2003 the B_z component of the interplanetary magnetic field (IMF) was northward ($B_z > 0$), however the value of the IMF magnitude was high. It is known that magnetic storms well correlate to the southward component of IMF ($B_z < 0$). The data on the dynamics of the auroral oval obtained on the basis of the oblique sounding of the disturbed ionosphere confirm a possibility of a substorm development and southward motion of the auroral oval also in the periods when $B_z > 0$. These data show also that with an increase of the magnitude of the interplanetary magnetic field the energy injected into the magnetosphere increases and this causes intensification of the magnetospheric and ionospheric current systems determining the dynamics of the high-latitude ionosphere and formation of irregularities. The equatorward motion of the auroral oval directly or indirectly manifests changes in the magnetospheric configuration as a result of the reconnection of field lines of the interplanetary and geomagnetic fields and intensification of the ring current. According to [16] the intensity of the ring current measured by Dst provides the main input into variation in the equatorial boundary of the auroral oval. Moreover it is considered, that the equatorial boundary of the oval is displaced to the south in connection with increase of the auroral electrojet activity [16]. It is interesting to notice that during period of extremely strong magnetic storm 29-31.10.2003 the aurora was observed at middle-latitude station IZMIRAN (Troitsk, Russia, 55°N 37°E) [17].

SUMMARY

1. It is demonstrated that the system of the oblique sounding paths covering a vast Eurasian longitudinal sector may serve as an effective tool for monitoring of ionospheric effects of geomagnetic disturbances. The network of LFM ionosondes may be used as bistatic HF radars sensitive to both large-scale structures (the main ionospheric trough, auroral oval, traveling ionospheric disturbances, patches with increased electron concentration) and small-scale irregularities accompanying such large-scale formations.
2. On the basis of numerical simulations and comparison to the experimental data of oblique sounding the identification is performed of the additional strongly spread signals registered during magnetic storm at the mid-latitude Inskip (England)—Rostov on Don path as signals scattered at small-scale field-aligned irregularities located at the southern boundary of the auroral oval. Note that ionospheric effects observed on a middle-latitude Inskip - Rostov - on-Don path during extremely strong magnetic storm 29-31.10.2003 are more characteristic for conditions auroral zones of Arctic region.

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