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A SIMULATION STUDY OF HOW THE MAIN IONOSPHERIC TROUGH AFFECTS THE OBLIQUE HF PROPAGATION ALONG THE SUB-AURORAL ROUTE

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Abstract. The influence of the main ionospheric trough location on the oblique HF propagation along the route Murmansk to St. Petersburg is investigated by a model simulation. Initially, the electron concentration distributions along the considered sub-auroral route are calculated using the mathematical model of the high-latitude ionosphere. Four distinct distributions of the electron concentration were obtained. The first distribution is smooth and does not contain any anomalies. Other three distributions contain the main ionospheric trough the width of which is identical but the distances from the beginning of the route are different. Next, the main ionospheric trough effects on the oblique HF propagation were studied utilizing a two-dimensional ray-tracing computer program. The ionograms of oblique sounding between Murmansk and St. Petersburg were calculated by using this program, with the obtained four distributions of the electron concentration having been applied. It turns out that the location of the ionospheric trough ought to influence conspicuously on the form of the ionogram of oblique sounding.

Introduction

One of the morphological feature of the sub-auroral ionosphere is the main ionospheric trough. The trough is often observed at F-layer altitudes on the nightside of the Earth and appears as a band of decreased electron concentration relative to the ionosphere both poleward and equatorward of it. Over the last three decades, the main ionospheric trough has been extensively studied both experimentally and theoretically. The main characteristics of the trough have been summarised by *Moffett and Quegan* [1983] on the basis of both observations and theoretical studies. They have summarised the observed morphology of the main ionospheric trough and have listed the physical processes that may be important in the trough region. The further progress in describing the morphology and modelling of the main ionospheric trough has been reviewed by *Rodger et al*. [1992].

It is known that the location of the main ionospheric trough depends on geophysical conditions, in particular, on geomagnetic activity. Therefore, the trough can intersect the sub-auroral route Murmansk-St. Petersburg being situated at various distances from the edges of the route. This paper is intended to study how the location of the main ionospheric trough affects the oblique HF propagation along the route Murmansk-St. Petersburg using a model simulation.

Calculation of the electron concentration distributions

To obtain the electron concentration distributions along the considered sub-auroral route we have applied the multi-component mathematical model of the high-latitude ionosphere developed earlier [*Lukicheva and Mingalev,* 2000]. The model is based on the numerical solution of the appropriate system of transport equations for the ions O^+, O_2^+, NO^+, N^+, and N_2^+. This system consists of the continuity equations, simplified equations of motion, and simplified internal energy equations for the ions. The model enables to calculate the altitude profiles of ionospheric quantities, in particular, ion concentrations. An altitude profile of the electron concentration is obtained from the condition that the ionosphere is electrically neutral. We have applied this model to calculate the electron density of the ionosphere over the height range from 90 to 420 km, with the height step having been equal to 1 km. Since the applied model is one-dimensional in altitude, therefore, to obtain a two-dimensional distribution of the electron concentration along the considered route we have calculated the altitude profiles of the electron concentration at numerous points situated along the route with a small distance step and then have constructed the desirable distribution.

One of the acknowledged mechanisms capable of the formation of the ionospheric trough is connected with an action of an external electric field having enhanced values at the trough latitudes. The meridional component of the external electric field, which has a latitudinal variation with enhanced values at the trough latitudes, is known to cause a band of a fast zonal ion drift. Due to this drift, a large velocity difference between neutral and ionized gases arises which leads to the frictional heating of the ionospheric plasma due to elastic collisions between neutral particles and ions. As a consequence of the frictional plasma heating, an acceleration takes place of the reactions transforming the atomic ions O^+ into the molecular ions NO^+ and O_2^+ which vanish rapidly due to the dissociative recombination. It follows from numerical simulations that, as a result of these processes, the F2-layer electron concentration decreases and the ionisation trough is formed [*Aladjev and Mingalev*, 1986; *Aladjev et al*., 2001].

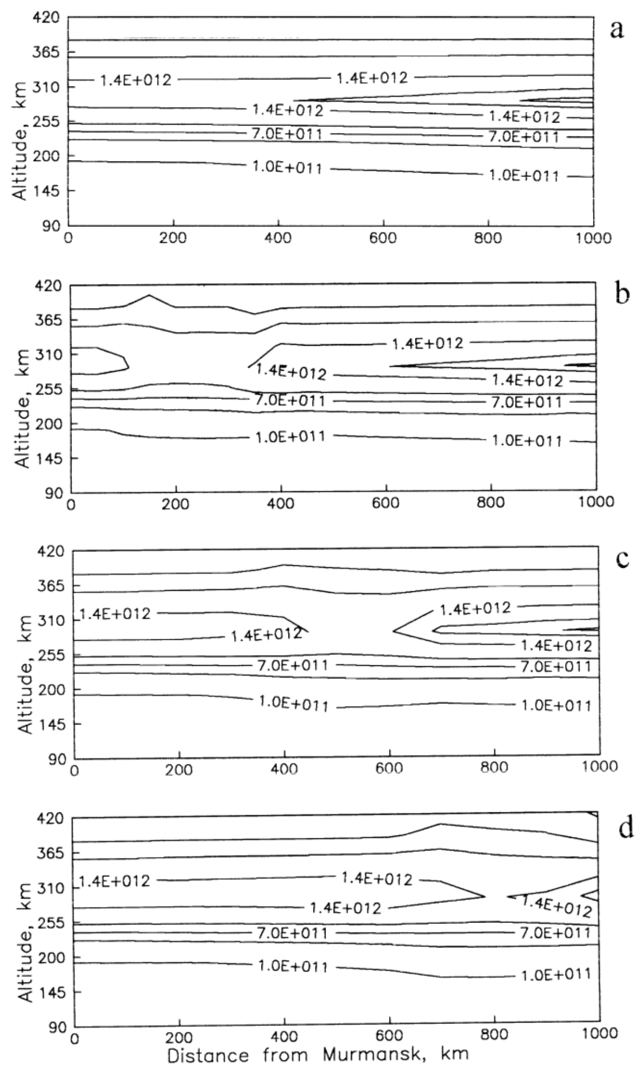

Fig.1. Four distinct distributions of the electron concentration (in m^{-3}) between Murmansk and St. Petersburg. The distance from Murmansk (km) is shown on the horizontal axis.

The formation mechanism described above has been applied by us in the present paper to simulate the two-dimensional electron concentration distributions containing the ionisation trough, with a latitudinally inhomogeneous meridional component of the external electric field having been employed as an input parameter of the model. The simulations have been made assuming that the maximum value of the external electric field meridional component is 50 mV/m at the trough latitudes.

We have obtained four distinct distributions of the electron concentration. The first distribution is smooth and does not contain whatever anomalies (Fig.1a), with a large-scale inhomogeneity being conditioned by non-uniform solar illumination. Another three distributions contain the ionospheric trough the width of which is identical but the distances from the beginning of the route are different (Fig.1 b-d). It can be seen that the electron concentration in the absence of the trough is a factor of 1.2 larger than that in the presence of the trough at the level of the F-region peak at the trough latitudes. Consequently, the so-called ‘depth of the trough” has a value of 1.2 at the level of the F-region peak. It can be noticed that the electron concentration distributions, presented in Fig.1, were calculated for equinox and medium solar activity ($F_{10.7}$=150) conditions.

Simulation of the HF radio wave propagation

The effect of the location of the main ionospheric trough on the oblique HF propagation were studied utilizing the two-dimensional ray-tracing computer program [*Orlova et al.*, 1988]. The utilized program is based on the numerical solution of the Haselgrove ray-tracing differential equations, with the Appleton-Hartree equation for the refraction index being used. This program enables us to evaluate the ionospheric propagation of HF radio signals in terms of the ray-tracing based on the geometric-optics treatment. Using this program, we can calculate ray-path trajectories of HF radio waves (both ordinary and extraordinary), originated from a point of the earth surface in the vertical plane for different values of the elevation angle and transmission frequency, with the dipole model of the magnetic field being taken into account by the program. From the variety of calculated ray-path trajectories of HF radio signals, originated from Murmansk in the direction of St. Petersburg and having different values of the elevation angle and transmission frequency, we choose those which reach St. Petersburg and synthesize the ionogram of oblique sounding. This is the essence of the so-called “shooting method”.

Using this method, we synthesized the ionograms of oblique sounding for each electron concentration distribution presented in Fig.1. The obtained results are shown in Fig.2. It is seen from the presented results that all calculated ionograms of oblique sounding contain the tracks of four propagation modes: 1E, 1F2, 2F2, and 3F2. However, the maximum possible values of the frequency of these tracks differ conspicuously from each other. For the first ionogram corresponding to the first electron concentration distribution containing no ionisation trough, the maximum possible values of the frequency are largest for the tracks of 1F2, 2F2, and 3F2 propagation modes. For the second ionogram, obtained for the case when the ionisation trough is located most northward, the maximum possible values of the frequency are least for the tracks of 1F2 and 2F2 propagation modes. On the contrary, the maximum possible value of the frequency for the track of 1E propagation mode is largest. It can be seen that the minimum possible values of the frequency for the tracks of 1E, 1F2, 2F2, and 3F2 propagation modes are largest for the second ionogram. Moreover, the second ionogram contains the track of 2E propagation mode which is absent in all other ionograms.

Thus, the ionograms of oblique sounding, obtained in the presence of the ionisation trough, differ appreciably from the ionogram, obtained in the absence of the ionisation trough. The ionograms of oblique sounding, obtained in the presence of the ionisation trough for the cases when it is located at different distances from the beginning of the route, differ conspicuously from each other. It is found that the location of the ionospheric trough ought to influence perceptibly on the form of the ionogram of oblique sounding.

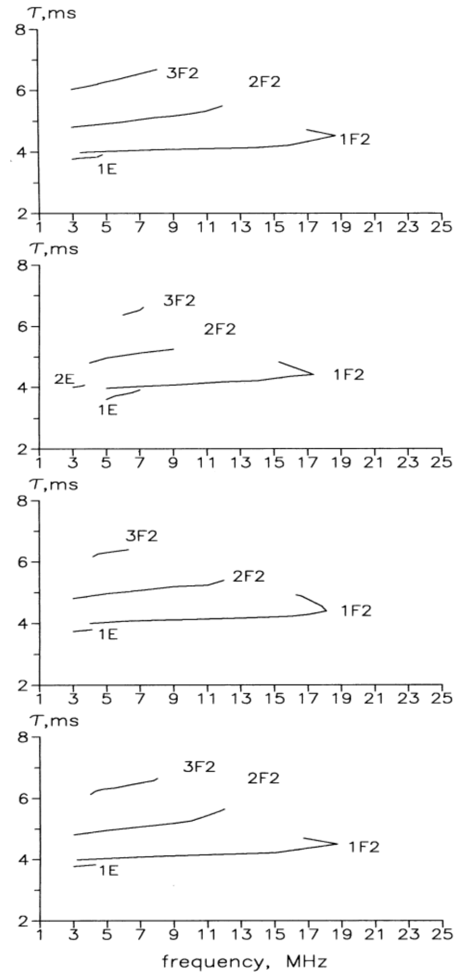

Fig.2. Four ionograms of oblique sounding for the route Murmansk – St. Petersburg calculated using four electron concentration distributions, presented in Fig.1, respectively.

Conclusions

Utilizing the multi-component mathematical model of the high-latitude ionosphere, four distinct distributions of the electron concentration were obtained along the sub-auroral route Murmansk- St. Petersburg. The first distribution does not contain whatever anomalies, there can be and other three distributions include the main ionospheric trough the width of which is identical but the distances from the beginning of the route are different, witch the value of the "depth of the trough" being 1.2 at the level of the F-region peak. The ionospheric trough was simulated by application of the formation mechanism connected with the action of the external electric field having enhanced the values of 50 mV/m at the trough latitudes.

The two-dimensional ray-tracing computer program was used to synthesize the ionograms of oblique sounding for the route Murmansk – St. Petersburg applying the "shooting method", with the obtained four distributions of the electron concentration having been utilized.

The simulation results indicated that the location of the main ionospheric trough ought to influence conspicuously the oblique HF propagation along the sub-auroral route, in particular, the form of the ionogram of oblique sounding. The displacement of the trough along the route can result in changes of the maximum possible values of the frequency for the traks of 1E, 1F2, 2F2, and 3F2 propagation modes for more than 3, 1, 3, and 1 MHz, respectively. The minimum possible values of the frequency can differ for more than 2, 2, 1, and 2 MHz for the traks of 1E, 1F2, 2F2, and 3F2 propagation modes, respectively.

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