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ON THE INFLUENCE OF THE MAIN IONOSPHERIC TROUGH LOCATION ON 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 means of model simulation. First, four distinct electron concentration distributions along the route considered are calculated using the mathematical model of the high-latitude ionosphere. One of the distributions does not contain any anomalies. Other three include the main ionospheric trough, which depth and width are identical but the distances from the beginning of the route are different. Then, the problem of how the main ionospheric trough affects the oblique HF propagation is examined by utilizing a two-dimensional ray-tracing computer program. The obtained distributions of the electron concentration are used to synthesize the ionograms of oblique sounding along the sub-auroral route using the above program. The results suggest that the location of the ionospheric trough essentially affects the form of the ionograms of oblique sounding.

Introduction

The mathematical models of the high-latitude ionosphere that we have developed earlier allow us to utilize them for simulating the large-scale inhomogeneous structure of the ionosphere. In particular, these models enable to simulate certain inhomogeneities that can affect HF radio wave propagation at the high latitudes. One of such structure of the sub-auroral ionosphere is the main ionospheric trough.

It is known that the trough is a fairly steady formation, which can exist for a long time, especially in winter and appears as a band of decreased electron concentration compared to the ionosphere both poleward and equatorward of it. The trough is found to be often observed at F-layer altitudes on the nightside of the Earth. At the same time, the location of the main ionospheric trough can vary in some latitudinal range depending on geophysical conditions, in particular, on geomagnetic activity. Therefore, the trough can intersect the sub-auroral route Murmansk–St. Petersburg being located at various distances from its edges.

The present paper is devoted to the investigation of the influence of the main ionospheric trough location on the oblique HF propagation along the route Murmansk–St. Petersburg by model simulation. It has to be noted that a similar study was performed earlier [*Orlova et al.*, 2001]. However, in the previous work the so-called "depth of the trough" was rather negligible to give an entire pattern of the trough influence on the HF radio waves propagation. Therefore, the investigation is continued in the present study, with new results being revealed.

Simulation of the main ionospheric trough formation

To obtain the electron concentration distributions along the sub-auroral route considered we have utilized the multi-component mathematical model of the high-latitude ionosphere developed earlier [*Lukicheva and Mingalev*, 2000]. The model enables to calculate the altitude profiles of ionospheric quantities, in particular, ion concentrations. Naturally, the ionosphere is assumed to be electrically neutral. We applied this model to calculate the electron density of the ionosphere over the height range from 90 to 420 km with the height step equal to 1 km.

It is known that various processes can affect the main ionospheric trough formation. One of the possible mechanisms of ionosperic trough formation is connected with the external electric field, which is enhanced at the trough latitudes. The meridional component of this field undergoes a latitudinal variation with enhanced values at the trough latitudes and produces a band of a fast zonal ion drift. Owing to this drift, a large velocity difference between neutral and ionized gases arises which, in turn, leads to the frictional heating of the ionospheric plasma due to elastic collisions between neutral particles and ions. The frictional plasma heating accelerates the reactions transforming the atomic ions O^+ into the molecular ions NO^+ and O_2^+, which vanish rapidly due to the dissociative recombination. 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]. It was this mechanism that we used in modeling trough formation in the previous work [*Orlova et al.*, 2001].

Similarly, in the present paper the formation of the main ionospheric trough is simulated within the framework of the above mechanism, however, some other geophysical conditions are considered. Namely, the simulations have been performed for equinox and evening time conditions (MLT=18.00) under medium solar activity ($F_{10.7}$=150), and maximum value of the external electric field meridional component, which is 100 mV/m at the trough latitudes. We apply the same mathematical model of the high-latitude ionosphere as in [*Orlova et al.*, 2001] and the same procedure of calculating two-dimensional electron concentration distributions along the route Murmansk to St. Petersburg.

We have obtained four distinct distributions of the electron concentration. The first one is calculated in the absence of the electric field and does not contain any anomalies (Fig.1a). Other three distributions contain the main ionospheric trough of the same depth and width but at different distances from the edge points of the route (Fig.1 b-d). It can be seen that the electron concentration in the absence of the trough is factor 3.7 larger than that with the trough located at the height of the F-region peak at the trough latitudes. Hence, the so-called "depth of the trough" is factor 3.7 at the level of the F-region peak.

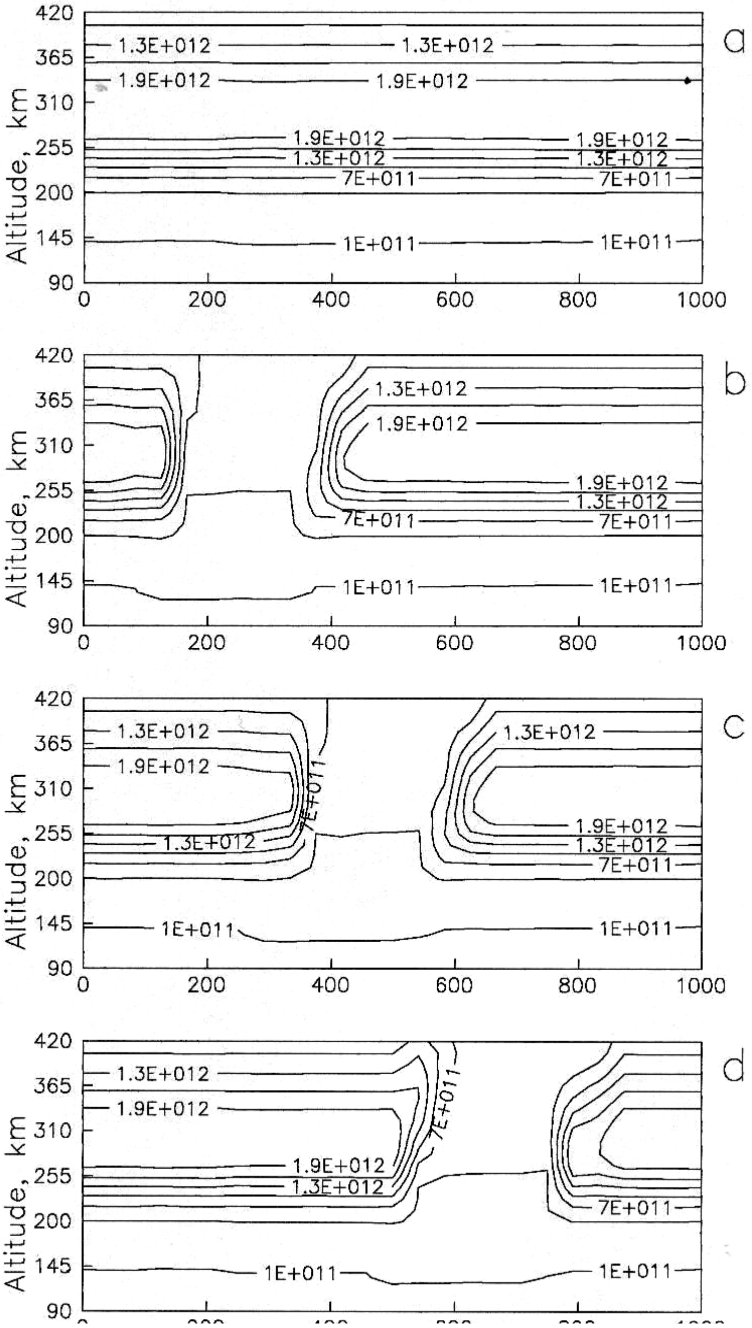

Fig.1. Four distinct distributions of the electron concentration (in m^3) between Murmansk and St. Petersburg. The distance from Murmansk (km) is shown on the horizontal axis.

Influence of the main ionospheric trough location on the HF radio wave propagation

For studying the influence of the main ionospheric trough location on the oblique HF propagation along the route Murmansk–St. Petersburg we apply the two-dimensional ray-tracing computer program developed earlier [*Orlova et al.*, 1988]. The program allows us to synthesize ionograms of oblique sounding by means of the so-called "shooting method". In accordance with this method we calculate ray-path trajectories of HF radio waves (both ordinary and extraordinary), originated from the transmitting point of the Earth's surface in the vertical plane for different values of the elevation angle and transmission frequency. After that, from the variety of calculated ray-path trajectories of HF radio signals, we choose those, which reach the receiver, and synthesize the ionogram of oblique sounding.

Using this method, we synthesized the ionograms of oblique sounding for each electron concentration distribution presented in Fig.1 and calculated the dependence of vertical elevation angles on the wave frequency. The results of modeling are shown in Figs.2 and 3, respectively. It is seen from the calculated ionograms that the results obtained in the absence of the trough are essentially different from those with the trough being present. The maximum possible values of the frequency for the tracks of 1F2, 2F2, and 3F2 propagation modes are seen to be the largest in the absence of the ionospheric trough. For the ionograms obtained with the ionisation trough being present, the track of 1F2 propagation mode has the least maximum possible value of the frequency when the trough is located around the medium point of the route considered (Fig.2c). It follows that the presence of the trough relaxes reflective properties of the F2 layer. Namely, the radio waves can pass through the ionosphere or achieve the Earth's surface at distances from the transmitter, which are much larger than the route length. Ray-path trajectories for the tracks of 2F2 and 3F2 propagation modes in the vicinity of maximum possible value of the frequency have a similar pattern in the region of the trough.

Minimum possible values of the frequency for the tracks of 1F2, 2F2, and 3F2 propagation modes differ significantly from each other. The frequency ranges of the tracks of 1F2 propagation mode obtained for the trough being present, are shorter than those obtained in the absence of the trough. This is connected with the trough influence on the length of the ray-path trajectory hop. However, it should be noted that the low frequency edges of the tracks of 2F2 and 3F2 propagation modes have the most significant variations in the presence of the trough. As seen from Fig.2, the ray-path trajectories corresponding to the tracks of 2F2 propagation mode at the low frequency edge are transformed into those of other types, namely, E-F or F-E. Similarly, the ray-path trajectories corresponding to the tracks of 3F2 propagation mode at the low frequency edge are transformed into E-F-F, F-E-F or F-E-E.

It can be seen that the tracks of 1E propagation mode differ from each other for the ionograms of oblique sounding obtained for different electron concentration distributions. Maximum possible value of the frequency is the largest for the track of 1E propagation mode in the case when the trough is located in the vicinity of the medium point of the route considered (Fig.2c). Put it in another way, the trajectory of 1E type can reach the receiver for the chosen values of the elevation angle and transmission frequency only under such location of the trough.

Another peculiarity from the ionogram obtained for the case of the ionisation trough being located between the initial and medium points of the route (Fig.2b) is worth mentioning. There are two tracks of 1E propagation mode, i.e. two trajectory rays of 1E type can achieve the receiver in the frequency range from ~6.5 to 8.5 MHz. It can be seen from Fig.3b that the values of the elevation angles of the 1E type trajectories being discussed have a noticeable difference. We can say that there exist upper and lower trajectory rays of 1E type.

Thus, the ionograms of oblique sounding obtained in the presence of the ionisation trough are essentially different from that obtained in its absence. The formers obtained for the cases when the trough is located at different distances from the beginning of the route considered, differ significantly from each other. It can be concluded that the location of the ionospheric trough affects appreciably the oblique HF propagation.

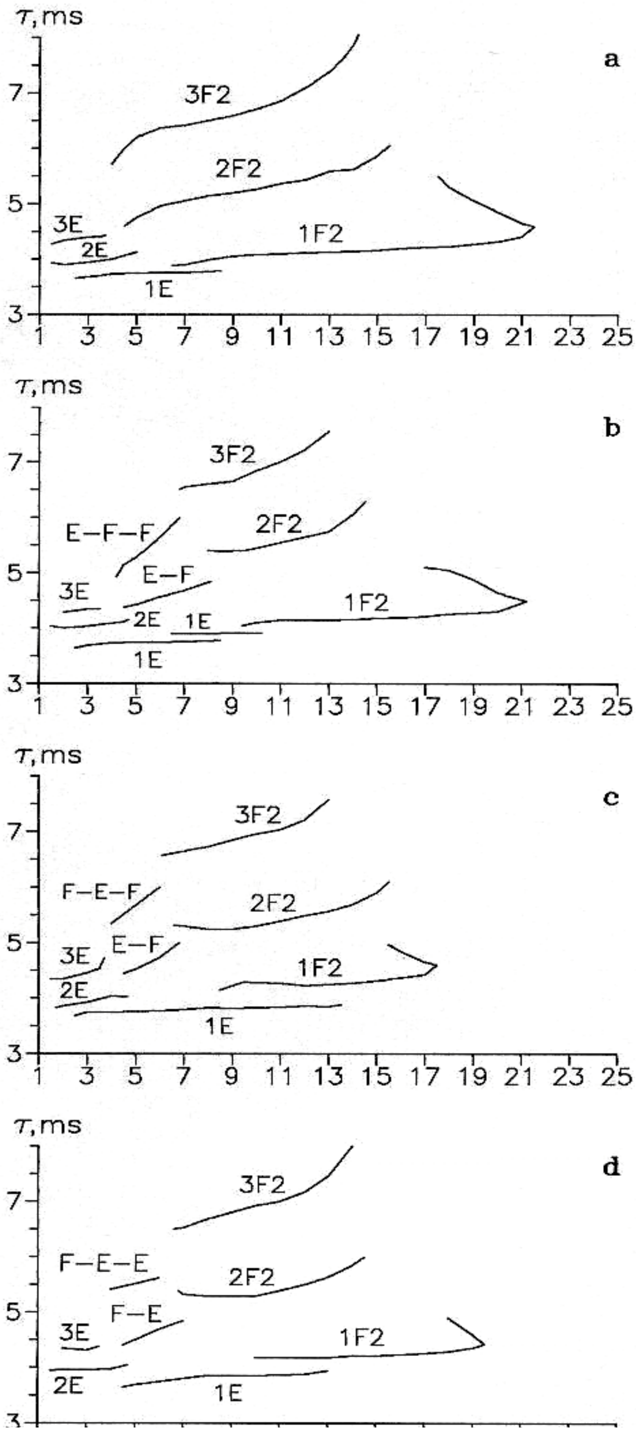

Fig.2. Four ionograms of oblique sounding for the route Murmansk–St. Petersburg calculated using four electron concentration distributions, presented in Fig.1, respectively.

Conclusions

Using the mathematical model of the high-latitude ionosphere, we have calculated four distinct electron concentration distributions along the route Murmansk–St. Petersburg. One distribution is taken to be smooth, without any anomalies. The other three contain the main ionospheric trough of the same depth and width but located at different distances from the initial point of the route. In simulating the ionisation trough we suggest that its formation is connected with the external electric field, having the enhanced value of 100 mV/m at the trough latitudes.

The respective four distributions of the electron concentration were utilized to synthesize the ionograms of oblique sounding between Murmansk and St. Petersburg by means of the two-dimensional ray-tracing computer program.

The above consideration indicates that the location of the main ionospheric trough affects significantly the form of the ionograms of oblique sounding. Consequently, the trough location ought to influence the oblique HF propagation along the route in question. According to the results obtained, the displacement of the trough along the route can lead to changes of the maximum possible values of the frequency for the tracks of 1E, 1F2, 2F2, and 3F2 propagation modes by more than 5, 3, 1, and 1 MHz, respectively. The minimum possible value of the frequency for the track of 1F2 propagation mode is changed by more than 3 MHz under the trough dislocation. The ray-path trajectories corresponding to the tracks of 2F2 and 3F2 propagation modes at the low frequency edges are transformed into other types, namely, E-F or F-E for the track of 2F2 propagation mode, and E-F-F, F-E-F or F-E-E for the track of 3F2 propagation mode, respectively.

The results of this paper are more representative than those previously obtained [*Orlova et al.*, 2001], because larger value of the "depth of the trough" is ascribed to the distributions of the electron concentration under consideration.

References

Aladjev, G.A., and V.S. Mingalev, On the role of electric fields in forming the main ionospheric trough, *Geomagnetism and Aeronomy*, 26, №1, 69-74, 1986 (Russian issue).

Aladjev, G.A., O.V. Evstafiev, V.S. Mingalev, G.I. Mingaleva, E.D. Tereshchenko, and B.Z. Khudukon, Interpretation of ionospheric F-region structures in the vicinity of ionisation troughs observed by satellite radio tomography, *Annal. Geophys.*, 19, 25-36, 2001.

Lukicheva, T.N., and V.S. Mingalev, Effects of thermospheric wind disturbances on the E and F1 regions of the nocturnal high-latitude ionosphere, *Geomagnetism and Aeronomy*, 40, №3, 86-93, 2000 (Russian issue).

Orlova, M.I., G.A. Aladjev, and V.S. Mingalev, The effect of sporadic auroral ionization on propagation of high-frequency radio waves, *Geomagnetism and Aeronomy*, 28, №3, 498-502, 1988 (Russian issue).

Orlova, M.I., T.N. Lukicheva, and V.S. Mingalev, A simulation study of how the main ionospheric trough affects the oblique HF propagation along the sub-auroral route, pp. 119-121, in *"Physics of Auroral Phenomena", Proc. XXIV Annual Seminar*, Apatity, Kola Science Center of the RAS, 2001.

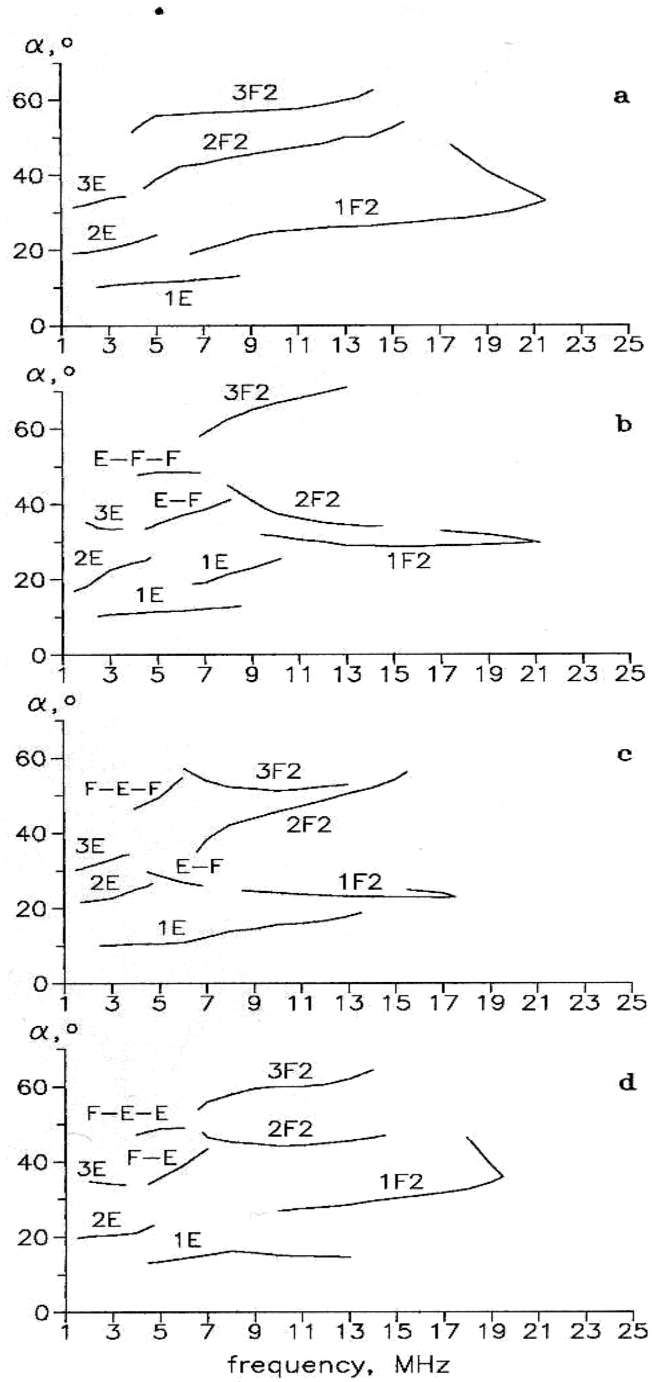

Fig.3. Variations of the vertical elevation angle of transmission as a function of radio wave frequency. The results are calculated using four electron concentration distributions, presented in Fig.1, respectively.