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THE COLLISION ABSORPTION OF HF RADIO WAVES ALONG A HIGH - LATITUDE ROUTE

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Abstract. The electron concentration distribution along the route Murmansk - St.Petersburg has been calculated using a mathematical model of the high-latitude ionosphere developed recently. The mathematical model enables to calculate the composition of the ionosphere at the F-, E-, and D-region altitudes. The calculations have been performed for winter and day time conditions. The obtained election concentration distribution has been used for calculation of the ray- path trajectories of HF radio waves, absorption coefficient, and integral absorption along ray - path trajectories. Peculiarities of the collision absorption of HF radio waves along the high latitude route have been analysed.

Introduction

Over the last years we have been developing ray - tracing computer programs which enable to calculate the ray- path trajectories of HF radio waves not only in two dimensional regions, but also in three dimensional ones [*Orlova et al.*, 1988; *Mingalev et al.*, 1988; *Mingalev et al.*, 1994]. These computer programs treat the electron concentration distributions obtained by using the mathematical models of the high - latitude ionosphere developed earlier in the Polar Geophysical Institute. However, in the previous works these mathematical models had covered only the F and E regions of the ionosphere. Recently, we have developed a new mathematical model of the high - latitude ionosphere which enables to calculate the electron concentration not only in the F and E regions, but also at D - region altitudes [*Mingalev et al.*, 1996], which yields an opportunity to calculate the collision absorption of HF radio waves. So recently, we have improved the two-dimensional ray - tracing computer program by including the calculation of the collision absorption of HF radio signals in it [*Mingalev et al.*, 1996]. The purpose of this paper is to present some results of simulations of HF radio wave propagation along the sub-auroral route Murmansk - St.Petersburg obtained by using the improved version of the two - dimensional ray - tracing computer program.

Calculations of the electron density distribution

To obtain the electron concentration distribution along the considered high - latitude route we have used the mathematical model of the high - latitude ionosphere developed recently [*Mingalev et al.*, 1996]. The model is based on the numerical solution of the coupled continuity equations for 39 species including positive and negative ions, electrons as well as major, minor, and excited neutral components, with the effects of the vertical transport being taken into account. It is the non-stationary one-dimensional mathematical model which includes 139 chemical reactions and enables to calculate the composition of the ionosphere over the height range from 50 to 500 km. Altitude profile of the electron concentration is obtained under the assumption that the ionosphere is electrically neutral, i.e.

$$n_e = \sum n_i ,$$

where summation runs over all the charged components, with the number densities being denoted by n_i. By calculating the altitude profiles of the electron concentration at numerous points located along the route Murmansk - St.Petersburg with a small distance step, we have constructed a two - dimensional distribution of the electron concentration. The calculations have been performed for winter (26 December) and day time (14 MLT) conditions under medium solar activity ($F_{10.7}$=153) and low geomagnetic activity (Kp=1). The calculated electron concentration distribution is presented in Fig.1.

Simulations of the HF radio wave propagation

To simulate the HF radio wave propagation along the sub-auroral route Murmansk - St.Petersburg we have applied the improved version of the two-dimensional ray-tracing computer program [*Mingalev et* al., 1996]. The applied program is based on the numerical solution of the Haselgrove ray-tracing differential equations [*Haselgrove,* 1955], with the Appleton - Hartree equation for the refraction index being used. This program enables to evaluate the ionospheric propagation of HF radio signals in terms of ray-tracing based on the geometric -optics treatment. By using this program, we can calculate not only ray-path trajectories of HF radio waves, originated from different points of the earth surface in the vertical plane for different values of the elevation angle and transmission frequency, but also the absorption coefficient and integral absorption along the ray-path trajectories.

We suggest that the effects of collisions between the ionospheric plasma particles on the ray paths of HF radio signals can be neglected [*Davis*, 1969]. In fact, in the lower ionosphere where the collisions considerably affect the propagation, the deviation of the ray from a straight line path is negligible. In the upper ionosphere where significant ray bending takes place, the collision frequency is usually small enough to be neglected except possibly near the reflection point. So, we have initially calculated a ray-path trajectory without taking the collisions into account. Then we have estimated the collision absorption of the HF radio wave along the calculated ray-path trajectory. To evaluate the absorption coefficient, κ, we have used the formula,

$$\kappa = 8.68 \frac{2\pi f}{c} \chi , \qquad (1)$$

where f is the frequency of transmission, c is the velocity of light in vacuum, and χ is the imaginary part of the complex refraction index including the magnetic field and the collisions between ionospheric plasma particles. An integral absorption, L, along a ray-path trajectory is estimated by the formula

$$L = 8.68 \frac{2\pi f}{c} \int_l \chi \;\; Cos\alpha \;\; dl , \qquad (2)$$

where α is the angle between the direction of the ray and the unit vector normal to the wavefront, the integration being performed over the whole ray-path trajectory, l.

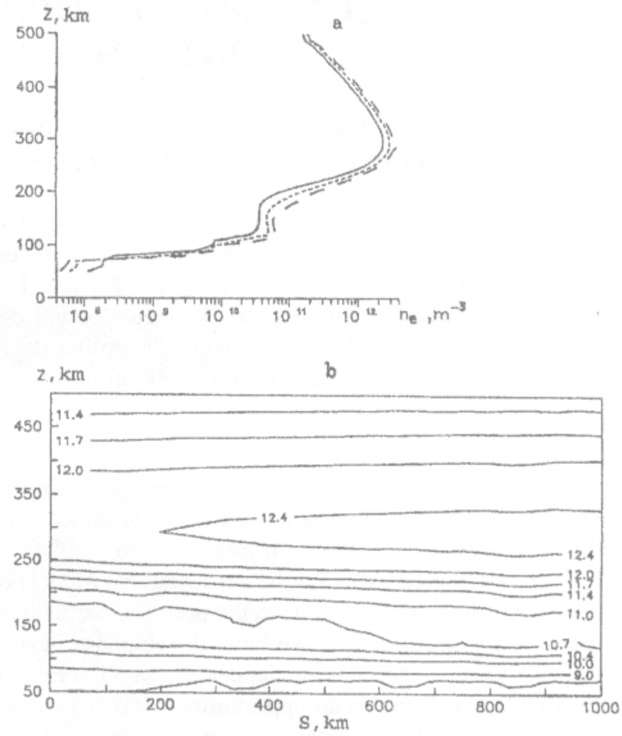

Fig.1. **a** The computed altitude profiles of the electron concentration in Murmansk (solid line), St.Petersburg (dashed line), and the middle point of the route (dotted line). **b** The computed isolines of the common logarithm of the electron concentration (in m^{-3}) between Murmansk and St.Petersburg. The distance from Murmansk S (in km) is shown on the horizontal axis.

Using the improved version of the ray-tracing computer program briefly described above and the electron concentration distribution presented in Fig.1, we have calculated trajectories of ordinary rays (o-rays) and extraordinary rays (x-rays), originated from Murmansk in the direction of St.Petersburg in the vertical plane for different values of the elevation angle and frequency of transmission. Some results of the calculations are presented in Fig.2a. It can be seen that a visible separation between the o-and x- ray trajectories may take place. For the frequencies and elevation angles of the transmission being equal, the ray apogee heights are greater for the o-ray than for the x-ray. As a consequence, the distance of the first hop is larger for the o-ray than for the x-ray when the rays have the same frequencies and elevation angles of transmission.

Also, for the trajectories of o- and x-rays, we have calculated the absorption coefficient, κ, defined in (1). The results of the calculation for one-hopped trajectories, presented in Fig.2a, are shown in Fig.2b-d. It can be seen that the calculated absorption coefficients are irregular along ray-path trajectories. They have pronounced peaks in the distance ranges where the ray-path trajectory crosses the D-region. A smaller peak can take place in the distance range where the ray-path trajectory crosses the F2-region maximum (Fig.2d). Moreover, we have calculated the integral absorption, L, defined in (2), along a family of rays originated from Murmansk in the direction of St.Petersburg in the vertical plane for different values of the elevation angle, denoted by Δ , and frequency of transmission. It turns out that the value of the elevation angle, Δ , affects appreciably the distance of the first hop of the ray. The dependence of the distance of the first hop of the ray, denoted by D, on the elevation angle for the transmission frequency of 9 MHz is presented in Fig.3a. The calculated integral absorption, L, as a function of the elevation angle, Δ , is shown in Fig.3b for the transmission frequency of 9 MHz. It can be seen that the integral collision absorption depends on the elevation angle significantly. The lower the elevation angle is, the higher the values of the integral collision absorption ought to be. The established dependence is a natural consequence of the connection between the elevation angle and the length of the part of the ray-path trajectory crossing the D-region. It turns out that the integral absorption depends on the frequency of transmission significantly. The lower the transmission frequency is, the higher the values of the integral collision absorption ought to be.

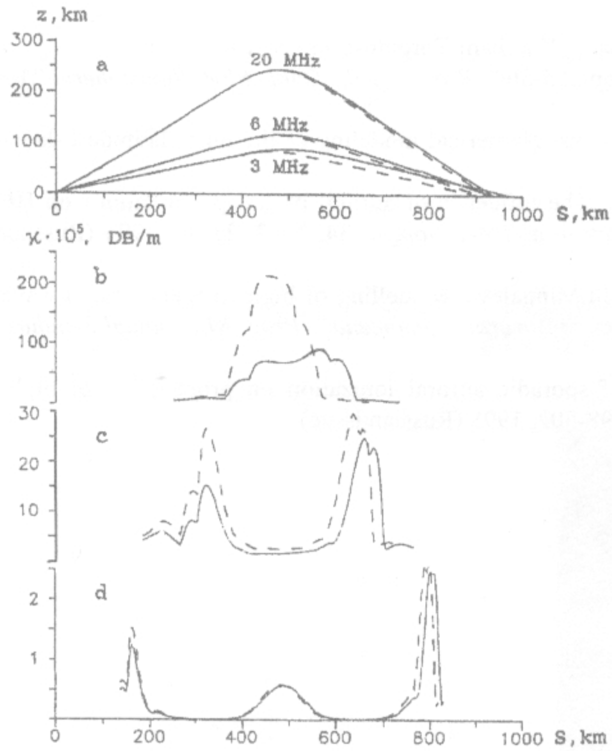

Fig.2 **a-d**. Some of the one-hopped trajectories of o-rays (solid line) and x-rays (dashed line) originated from Murmansk in the direction of St.Petersburg for different frequencies and elevation angles of transmission. The frequencies of transmission, indicated by the numbers near the curves, are 3,6, and 20 MHz (**a**). Dependence of the absorption coefficient κ (in units of 10^{-5} decibel/m) on the distance from Murmansk S(in km) for the trajectories presented in (**a**) and obtained for three different values of transmission frequency: 3 MHz (**b**), 6 MHz(**c**), and 20 MHz(**d**). Results are shown for the *o*-ray by the solid line and for the *x*-ray by the dashed line.

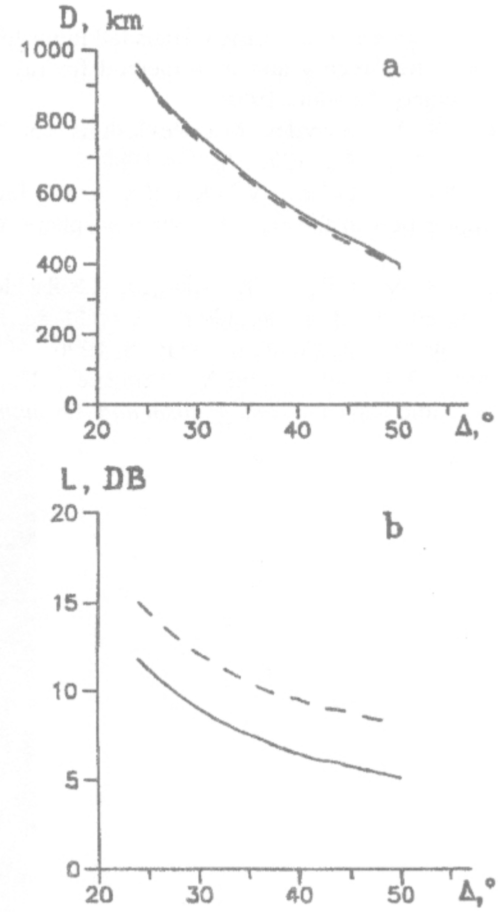

Fig.3. Dependences of the first hop distance of the ray D (in km) (**a**) and the integral absorption L (in decibel) (**b**) on the elevation angle Δ (in deg) for a family of one-hopped rays originated from Murmansk in the direction of St.Petersburg in the vertical plane for the transmission frequency of 9 MHz. The results are shown for the *o*-ray by the solid line and for the *x*-ray by the dashed line.

Conclusions

Using the mathematical model of the high-latitude ionosphere, including the D-region, and the improved version of the two-dimensional ray-tracing computer program, we have simulated HF radio wave propagation along the sub-auroral route Murmansk - St.Petersburg. We have calculated not only the trajectories of ordinary and extraordinary rays, originated from Murmansk in the direction of St.Petersburg in the vertical plane for different values of the elevation angle and frequency of transmission, but also the absorption coefficient and the integral absorption along the ray-path trajectories.

It turns out that for the frequencies and elevation angles of transmission being equal, the ray apogee heights and the distances of the first hops are larger for the o-ray than for the x-ray. As HF radio wave propagates through the ionosphere, it is partly absorbed due to collisions between ionospheric electrons and other particles of the ionospheric plasma. It is found that the absorption coefficient has pronounced peaks on those parts of the ray-path trajectory, which cross the D-region. For all the other parameters being equal, the absorption coefficient and the integral absorption are greater for the x-ray than for the 0-ray. With all other conditions being the same, the lower the transmission frequency is, the higher the values of the absorption coefficient and the integral absorption ought to be.

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