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A MODEL STUDY OF THE LARGE-SCALE MODIFICATION OF THE NOCTURNAL MIDDLE-LATITUDE F LAYER BY POWERFUL HF WAVES WITH DIFFERENT POWERS

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Abstract. A mathematical model of the ionosphere, which can be affected by powerful HF waves, is applied for simulations of the large-scale middle-latitude F-layer modification by HF waves. The applied model has been developed earlier in the Polar Geophysical Institute. Simulations are performed for the point with geographic coordinates of the "Sura" heating facility (Nizhny Novgorod, Russia) for autumn conditions. The calculations are made for different cases in which the effective absorbed power has distinct values belonging to the 5-100 MW range. The results indicate that the effective absorbed power can influence considerably on the F-layer response to high power radio waves in the nocturnal middle-latitude ionosphere.

Introduction

The ionospheric plasma's properties were successfully investigated by using experiments with high-power, high-frequency radio waves in recent years. Many interesting results concerning the ionosphere modification by a powerful HF wave were obtained [*Gustavsson et al.,* 2001 and references therein]. It turns out that significant variations in the electron temperatures and densities can be produced by powerful HF waves in the F layer. Moreover, the experimental investigations were accompanied by simulation studies of the ionosphere's response to HF heating. In particular, the mathematical model of the F layer, which can be affected by a powerful HF wave, has been developed by *Mingaleva and Mingalev* [1997]. This model has been used to simulate the influence of the HF wave power and frequency on the expected response of the high-latitude F layer to HF heating [*Mingaleva and Mingalev,* 2002; *Mingaleva et al.,* 2003; *Mingaleva and Mingalev,* 2003]. This model has been recently utilized to study the expected F-layer response to powerful HF waves with different frequencies for the "Sura" heating facility (Nizhny Novgorod, Russia) for nocturnal conditions [*Mingaleva and Mingalev*, 2006]. It has been found that the strong dependence exists of heater induced electron temperature and concentration changes at the level of the F2-layer peak on the incident wave frequency for nocturnal conditions. The purpose of this paper is to examine how the value of the effective absorbed power affects the changes in the large-scale structure of the middle-latitude F2 layer near to the "Sura" heating facility for nocturnal conditions.

Numerical model

The mathematical model of the F-region ionosphere, which can be affected by a powerful HF wave, developed earlier by *Mingaleva and Mingalev* [1997], is utilized in the present study. The model takes into account the geomagnetic field declination, magnetization of the plasma at F-layer altitudes, and convection of the ionospheric plasma. The model uses the electric field distribution which is the combination of the pattern B of the empirical models of high-latitude electric fields of *Heppner* [1977] and the empirical model of ionospheric electric fields at middle latitudes, developed by *Richmond* [1976] and *Richmond et al*. [1980]. In the model calculations the temporal history is traced of the ionospheric plasma in the part of the magnetic field tube situated in the illuminated region over an ionospheric heater. A part of the magnetic field tube of the ionospheric plasma is considered at distances between 100-700 km from the Earth along the magnetic field line. In the present study, we assume that the part of the magnetic field tube can be in the illuminated region over an ionospheric heater during the period longer than five minutes. The parallel (to the magnetic field) plasma flow in the magnetic field tube is described by the system of transport equations, which consists of the continuity equation, equation of motion for ion gas, and heat conduction equations for ion and electron gases. The profiles of ionospheric quantities versus distance from the Earth along the geomagnetic field line are obtained by solving this system of transport equations. The natural time variations of the ionospheric parameters, which can take place in the mid-latitude F layer, are taken into account by the utilized numerical model. In the model calculations, the effect of HF heating is taken into account by analogy with the study by *Blaunshtein et al.* [1992]. It is assumed that the main fraction of the energy of the powerful HF wave is absorbed when the wave frequency is close to the frequency of the electron hybrid resonance. More complete details of the utilized model have been presented by *Mingaleva and Mingalev* [1997; 2003].

Presentation and discussion of results

In the present study, we apply the numerical model described above for simulations of the mid-latitude F-layer modification by HF waves radiated by the "Sura" heating facility, when it is located on the night side of the Earth. We suppose that the heating facility operates continuously during the period of five minutes. In the initial moment, the "Sura" heating facility and corresponding magnetic field tube are assumed to be on the magnetic meridian of 01.45 MLT. The calculations are performed for autumn (1 September) and high solar activity ($F_{10.7}$ =230) conditions under moderate geomagnetic activity (K_p=3).

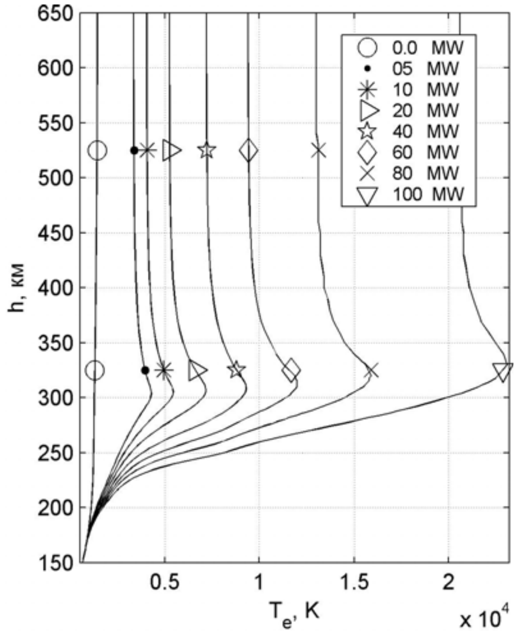

Fig.1. Profiles of the electron temperature versus distance from the Earth along the geomagnetic field line situated in the illuminated region at the moment of 300 sec after turn on. The results are given for different values of the EAP: 5, 10, 20, 40, 60, 80, and 100 MW, with symbol 0 MW indicating the results obtained under natural conditions without heating.

To investigate how the value of the effective absorbed power (EAP) influences the expected ionosphere's response to HF heating we calculate the time variations of ionospheric quantities following the turn on of the heater for different cases in which the EAP has distinct values belonging to the 5-100 MW range. The important input parameter of the numerical model is the incident wave frequency. In the present study, the value of the incident wave frequency is assumed to be 3.0 MHz that is quite attainable for the "Sura" heating facility. This value of the incident wave frequency is slightly less than the F-layer critical frequency at the initial moment. Some results of the calculations for nocturnal conditions are presented in Figs. 1-3.

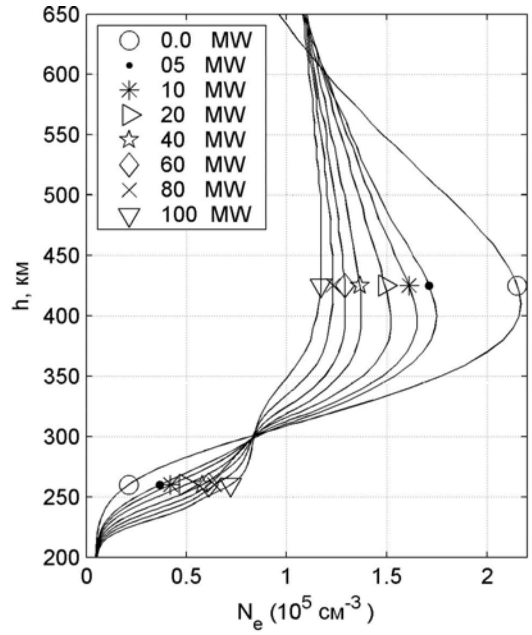

Fig.2. Profiles of the electron concentration versus distance from the Earth along the geomagnetic field line situated in the illuminated region at the moment of 300 sec after turn on. The results are given for the same cases as in Fig.1.

It turned out that essential time variations of the electron temperature, positive ion velocity, and electron concentration profiles can be produced by powerful HF waves in the mid-latitude F region in the night time. These variations, obtained for such HF wave frequencies that are with confidence less than the F-layer critical frequency, are qualitatively very similar. A pronounced peak arises in the electron temperature profile at the level where the wave frequency is equal to the frequency of the electron hybrid resonance. As a consequence of the great increase in the electron temperature, the upward and downward ionospheric plasma fluxes arise from the level where the electron temperature peak is located. Visible changes of the electron concentration profile are ultimately produced by the energy input from the powerful HF wave. These changes arise not only near the level of maximum energy absorption from the powerful HF wave, but also above this level including the height of the F-region peak.

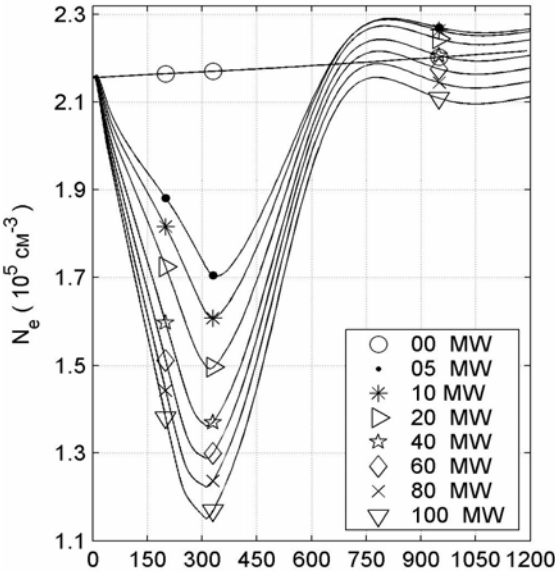

Fig.3. The time variations of the electron concentration (in units of 10^5 cm^{-3}) at the level h=410 km. The results are given for different values of the EAP: 5, 10, 20, 40, 60, 80, and 100 MW, with symbol 0 MW indicating the results obtained under natural conditions without heating.

Simulation results indicate that appreciable variations of the electron temperature, positive ion velocity, and electron density profiles can be produced by HF heating during the period of 5 min in the nocturnal middle-latitude F region, with the maximal amplitudes of variations depending significantly on the values of the EAP. It appears that the more the EAP is, the higher values of maximal amplitudes of variations of ionospheric quantities, produced by HF heating, ought to be. Powerful HF waves should lead to a decrease of more than 47% in electron concentration at the level of the F-region peak when the EAP is 100 MW.

Conclusions

Using the mathematical model of the ionosphere, we have predicted the time variations of ionospheric parameters in the middle-latitude F layer, produced by the “Sura” heating facility (Nizhny Novgorod, Russia), for different cases in which the effective absorbed power has distinct values belonging to the 5-100 MW range. It appears that conspicuous variations of the electron temperature, positive ion velocity, and electron concentration profiles can be produced by HF heating during the period of 5 min in the mid-latitude F region under nocturnal conditions, with the maximal amplitudes of the variations depending appreciably on the value of the EAP. It appears that the more the EAP is, the higher values of maximal amplitudes of variations of ionospheric quantities, produced by HF heating, ought to be. Powerful HF waves should lead to a decrease of more than 47% in electron concentration at the level of the F-region peak when the EAP is 100 MW.

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