"Physics of Auroral Phenomena", Proc. XXII Annual Seminar, Apatity, pp.61-64, 1999

Polar Geophysical Institute

NUMERICAL SIMULATION OF THE HIGH-LATITUDE F-LAYER MODIFICATION BY HF WAVES WITH DIFFERENT POWERS

V.S.Mingalev and G.I.Mingaleva *(Polar Geophysical Institute, Apatity,Russia)*

Abstract. The mathematical model of the high-latitude F region, developed earlier in the Polar Geophysical Institute, is applied to simulate the F-layer response at auroral latitudes to high-power, high-frequency waves. The model produces the time variations of the electron density, positive ion velocity, and ion and electron temperature profiles within a magnetic field tube carried over an ionospheric heater by the convection electric field. Simulations are performed for the point with geographic coordinates of the ionospheric heater near Tromso, Norway, when it is located near the midnight magnetic meridian. The calculations are made for distinct cases in which the effective absorbed power varies from 5 to 120 MW. The results indicate that appreciable variations of the electron temperature, positive ion velocity, and electron density profiles can be produced by HF heating in the high-latitude F region, with the maximal amplitudes of variations depending significantly on the value of the effective absorbed power.

Introduction

Within the past three decades, experiments with high-power, high-frequency radio waves were successfully used for the investigation of the ionospheric plasma's properties. Many different effects were observed as a result of the ionospheric heating by HF waves. The majority of these experimental investigations were directed to study the mid-latitude ionosphere. This is essentially because of the location of the earlier high-power radio wave heaters in the mid-latitudes, for example, Platteville, Arecibo, Gorky. Nevertheless, the high-latitude ionosphere was investigated by experiments with HF heating too. In particular, the HF heating facilities near Monchegorsk, Russia and near Tromso, Norway were utilized for these investigations. Many interesting results concerning the auroral lower-ionosphere modification by a powerful HF wave were obtained [*Kapustin et al.*, 1977; *Stubbe et al.*, 1981; *Stubbe et al.*, 1985; *Rietveld et al.*, 1989]. The ionospheric heater near Tromso, Norway is successfully utilized for the experimental investigations up to now. It should be emphasized that the experimental studies of the high-latitude ionosphere just mentioned dealt with the lower ionosphere (D and E regions) only. The modification of the high-latitude F region by high-power, high-frequency radio waves has yet to be achieved. In contrast to the absence of experimental works on the high-latitude F-region modification, many experimental studies were applied to the mid-latitude F-region modification by powerful HF waves and many interesting results were obtained [*Utlaut and Violette*, 1974; *Gordon and Carlson*, 1974; *Mantas et al.*, 1981; *Djuth et al.*, 1987; *Duncan et al.*,1988; *Hansen et al.*, 1992; *Mantas et al.*,1994; *Leyser et al.*,1994]. It is doubtful that the high-latitude F region does not respond to high power radio waves. It is hopeful, that some specific features, characteristic of the high-latitude F-region ionosphere obstruct the observation of the F-layer modification.

To predict a possible response of the high-latitude F-region ionosphere in artificial modification experiments by HF radio waves it is instructive to examine this question by using the numerical simulation. By the way, simulation studies of the ways high-power, high-frequency radio waves affect the mid-latitude F region were successfully carried out. Up to now, there have been very few simulation studies of the high-latitude F-region modification by HF radio waves, primarily because of the complexity of the numerical models of the polar ionosphere. Recently, we have developed the numerical model of the high-latitude F region which can be affected by a powerful HF wave [*Mingaleva and Mingalev*, 1996]. This model was used for the prediction of the expected F-layer response at auroral latitudes to high-power, high-frequency waves [*Mingaleva and Mingalev*, 1997]. The results of numerical simulations indicated that significant variations in the electron temperature profiles can be produced by HF heating in the high-latitude F layer. These variations can ultimately lead to detectable decrease in the electrons concentration at the level of the F-region peak. However, in contrast to the mid-latitude ionosphere, minimal values of the electron concentration in the high-latitude ionosphere are not found straight over a ground-based ionospheric heater but are displaced for rather a long distance from it. This displacement is the specific feature of the high-latitude F-layer ionosphere, as for the modification by a powerful HF wave, which is due to the convection of the ionospheric plasma.

It can be noted that the results by *Mingaleva and Mingalev* [1997] were obtained for the fixed value of the effective absorbed power (EAP) only. It is of interest to study how the EAP influences the expected high-latitude F-region response to a powerful HF wave. The purpose of this paper is to predict time variations of ionospheric quantities in the high-latitude F region produced by the HF heating facility near Tromso, Norway for distinct cases in which the EAP varies from 5 to 120 MW.

Ionospheric model

The numerical model of the high-latitude F-region ionosphere, which can be affected by a powerful HF wave, developed earlier by *Mingaleva and Mingalev* [1996; 1997], is used in the present study. The model takes into account the geomagnetic field declination, the strong magnetization of the plasma at F-layer altitudes, and the convection of the ionospheric plasma. In the model calculations the temporal history is traced of the ionospheric plasma in the part of the magnetic field tube, moving along the convection trajectory through a neutral atmosphere 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. As a consequence of the strong magnetization of plasma at F-layer altitudes, its motion may be separated into two flows: The first, plasma flow, parallel to the magnetic field; the second, plasma drift perpendicular in the direction to the magnetic field. The parallel plasma flow in the considered part of the magnetic field tube is described by the system of transport equations, which consists of the continuity equation, the equation of motion for ion gas, and the heat conduction equations for ion and electron gases. The model produces time variations of the electron density, positive ion velocity, and ion and electron temperature profiles within the magnetic field tube carried over the ionospheric heater by the convection electric field. The velocity of the magnetic field tube along the convection trajectory coincides with the perpendicular (to the magnetic field) plasma drift speed which may be easily obtained by using the convection electric field. In the present study we use the pattern B of the empirical convection models of *Heppner* [1977]. From the plasma convection pattern, we choose the convection trajectory, which intersects the F-layer volume illuminated by the ionospheric heater near Tromso, Norway, when it is located near the midnight magnetic meridian. By analogy with the study by *Blaunshtein et al*. [1992], we assume that the main fraction of the energy of the powerful HF wave is absorbed when the wave frequency is equal to the frequency of the electron hybrid resonance.

Presentation and discussion of results

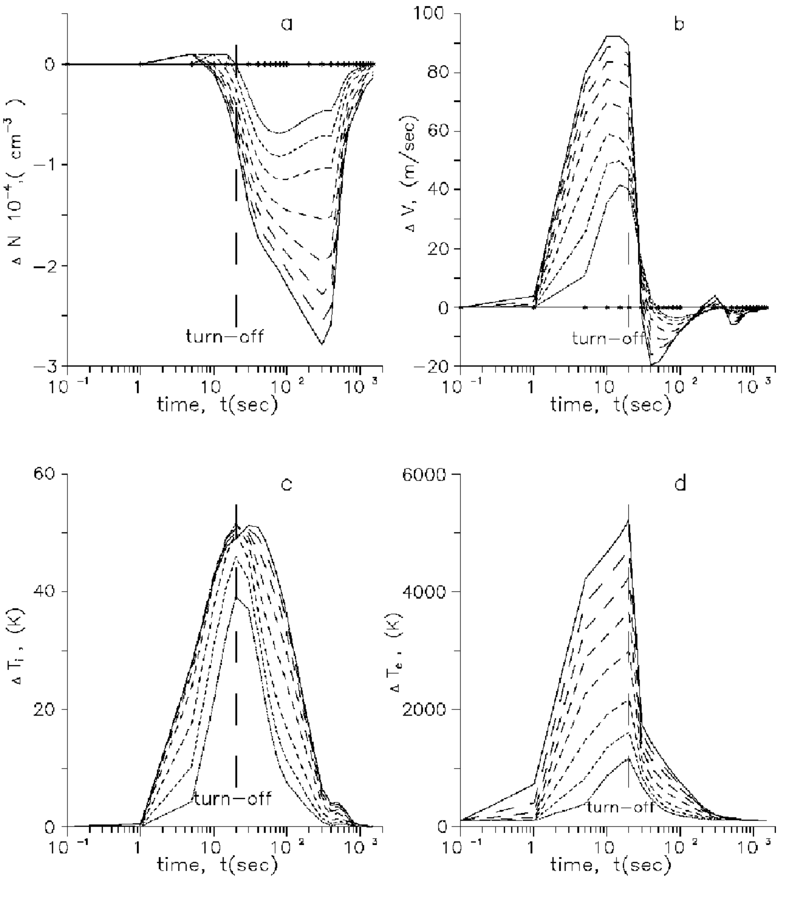

Fig.1. The time variations of the differences between heated and unheated electron concenrations (**a**), parallel components of the positive ion velocities (**b**), ion temperatures (**c**), and electron temperatures (**d**) at the level of the F-layer peak after the turn-on of the HF heater for distinct values of the EAP: 5, 10, 20, 40, 60, 80, 100, and 120 MW.

Our model can describe different combinations of the solar cycle, geomagnetic activity level, and season. For the present study, the calculations were performed for equinox and high solar activity conditions under low geomagnetic activity. It is known that the high-latitude ionosphere possesses a natural spatial inhomogeneity which leads to horizontal variations of ionospheric quantities even without any HF heating. Therefore, we started from solving the model transport equations and obtaining the variations of calculated profiles along the chosen convection trajectory under natural conditions without a powerful HF wave effect. When this was done, we obtained the variations of the electron density, positive ion velocity and ion and electron temperature profiles with time (along the chosen trajectory) following the turning on of a powerful square HF pulse. We supposed that the ionospheric HF heater was turned on, when the considered magnetic field tube was situated straight over it, and operated for 20 seconds. The ionospheric heater was assumed to operate at the frequency of 5 MHz. The calculations were made for eight distinct values of the EAP: 5,10,20,40,60,80,100, and 120 MW.

The moment of the turning-on of the ionospheric heater was the initial moment of our examination .We considered the temporal history of the ionospheric plasma in the magnetic field tube during the period of 1500 s. This period is sufficient for the magnetic field tube to be displaced for a distance of 630 km from the HF heater. Results of simulation indicated that the time variations of the electron density, positive ion velocity, and ion and electron temperature profiles in the high-latitude F layer following the turning on of the powerful 20-s square HF pulse, obtained for distinct values of the EAP, are qualitatively very similar. The maximum energy input from the powerful HF wave is to occur at the level of about 316 km. At this level, a pronounced peak arises in the electron temperature profile due to the great energy input from the powerful HF wave. 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. The energy input from the powerful HF wave can result in visible changes of the electron concentration profile. The variation of electron concentration can be produced not only near the level of maximum energy absorption from the powerful HF wave, but also near the F-region peak. The concrete calculated profiles of the electron concentration, parallel component of the positive ion velocity, and ion and electron temperatures at distinct moments after the turning on of the HF heater were presented in the studies by *Mingaleva and Mingalev* [1996; 1997] for two distinct values of the EAP: 60 and 120 MW.

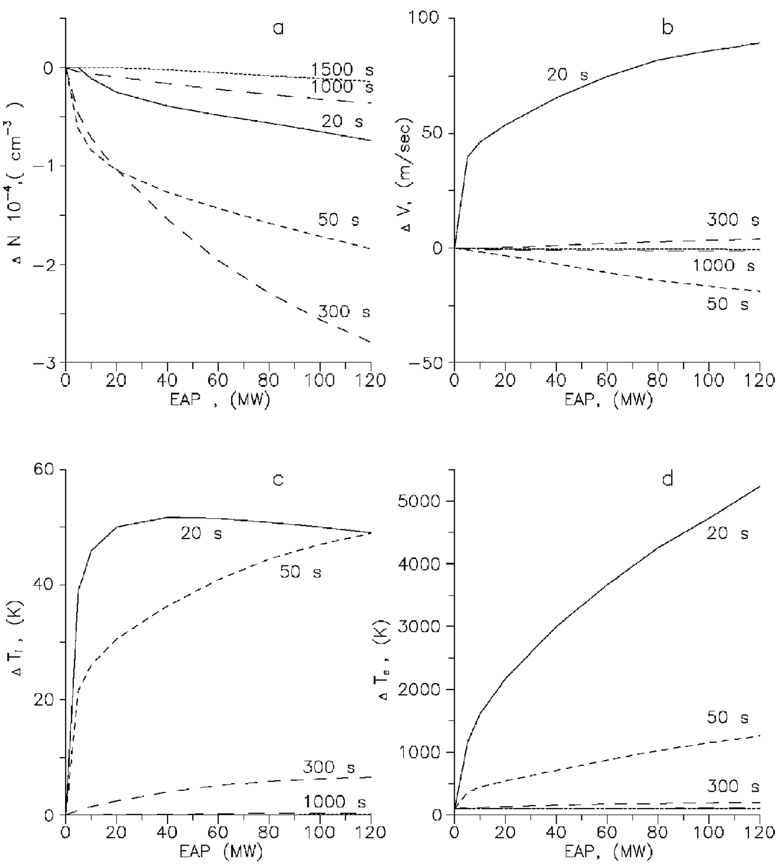

Fig.2. The dependence of differences between heated and unheated electron concentrations (**a**), parallel components of the positive ion velocities (**b**), ion temperatures (**c**), and electron temperatures (**d**) at the level of the F-layer peak on the value of the EAP at distinct moments after the turn-on: 20, 50, 300, 1000, and 1500 s.

As pointed out previously, the variations of ionospheric quantities do exist under natural conditions without a powerful HF wave effect. Therefore, to obtain the pure HF heating effect we must evaluate the differences between heated and unheated ionospheric quantities. Figure 1 presents the time variations of the differences between heated and unheated ionospheric quantities at the level of the F-layer peak, occurred at the distance of about 380 km from the earth, after the turning-on of the HF heater for various values of the EAP. It is seen from results presented, that the amplitudes of variations of electron and ion temperatures, and the parallel component of the positive ion velocity produced by a powerful HF wave achieve the maxima at moments close to 20 s, when the HF heater is turned off. After the turning off of the ionospheric heater, the period of the recovery of the ionospheric quantities enumerated above begins. The electron concentration variation amplitude can be maximal at a later time, which depends on the EAP and can achieve up to 5 min. The maximal amplitudes of variations of ionospheric quantities depend on the value of the EAP. The considered HF pulse should lead to a decrease of more than 7% in electron concentration at the level of the F-region peak when the EAP is 120 MW.

It turns out that the differences between heated and unheated quantities have essentially distinct values at various moments (Fig. 2). It can be seen from Figure 2 that the electron concentration at the level of the F-layer peak may be dropped by means of elevating of the energy of the radiated HF wave.

Conclusions

Using the mathematical model of the high-latitude F layer, we have predicted the time variations of ionospheric quantities in the high-latitude F region produced by the HF heating facility near Tromso, Norway for distinct cases in which the EAP varies from 5 to 120 MW. The simulation results indicate that the more the EAP is, the higher values of maximal amplitudes of variations of ionospheric quantities, produced by the HF heating, ought to be. The maximal amplitude of the variation of difference between the heated and unheated electron concentrations at the level of the F-layer peak is displaced along the convection trajectory for a distance of more than 120 km from the ground-based HF heater when the EAP is more than 40 MW. On the contrary, the maximal amplitude of the variation of difference between the heated and unheated electron temperatures must be situated almost straight over the HF heater. These specifications must be taken into consideration for the preparation and organization of artificial modification experiments by HF radio waves in the high-latitude F-region ionosphere and for planning the operation of the diagnostic facility.

References

Blaunshtein, N.Sh., V.V.Vas'kov, and Ya.S.Dimant, Resonance heating of the F region by a powerful radio wave, *Geomagnetism and Aeronomia,* 32(2), 95-99,1992.

Djuth, F.T., B.Thide, H.M.Ierkic, and M.P.Sulzer, Large F-region electron-temperature enhancements generated by high-power HF radio waves, *Geoph.Res.Lett.,*14, 953-956, 1987.

Duncan, L.M., J.P.Sheerin, and R.A.Behnke, Observations of ionospheric cavities generated by high-power radio waves, *Phys.Rev.Lett.,* 61, 239-242, 1988.

Gordon, W.E.,and H.C.Carlson, Arecibo heating experiments, *Radio Sci.,* 9, 1041-1047, 1974.

Hansen, J.D., G.J.Morales, L.M.Duncan, and G.Dimonte, Large-scale HF-induced ionospheric modification: experiments. *J.Geophys.Res.,* 97, 113-122, 1992.

Heppner, J.P., Empirical models of high-latitude electric fields, *J.Geophys.Res.,* 82,1115-1125, 1977.

Kapustin, I.N., R.A.Pertsovskii, A.N.Vasil'ev, V.S.Smirnov, O.M.Raspopov, L.E.Solov'eva, A.A.Ul'yanchenko, A.A.Arykov, and N.V.Galachova, Generation of radiation at combination frequencies in the region of the auroral electric jet, *JETP Lett.,* 25, 228-231,1977.

Leyser, T.B., B.Thide, M.Waldenvik, E.Veszelei, V.L.Frolov, S.M.Grach, and G.P.Komrakov, Downshifted maximum features in stimulated electromagnetic emission spectra, *J.Geophys.Res.,* 99, 19555-19568, 1994.

Mantas, G.P., H.C.Carlson, and C.H.La Hoz, Thermal response of F-region ionosphere in artificial modification experiments by HF radio waves, *J.Geophys.Res.,* 86,561-574, 1981.

Mantas, G.P.,Large 6300-A airglow intensity enhancements observed in ionosphere heating experiments are excited by thermal electrons, *J.Geophys.Res.,* 99, 8993-9002, 1994.

Mingaleva, G.I., and V.S.Mingalev, Computational study of the response of the high-latitude F layer to a powerful HF wave, In: *"Physics of Auroral Phenomena".Proc. XIX Annual Seminar,* Apatity, pp.87-88, 1996.

Mingaleva, G.I., and V.S.Mingalev, Response of the convecting high-latitude F layer to a powerful HF wave, *Ann.Geophys.,* 15, 1291-1300, 1997.

Rietveld, M.T., P.Stubbe, and H.Kopka, On the frequency dependence of ELF/VLF waves produced by modulated ionospheric heating, *Radio Sci.,* 24, 270-278, 1989.

Stubbe, P., H.Kopka, and R.L.Dowden, Generation of ELF and VLF waves by polar electrojet modulation: Experimental results, *J.Geophys.Res.,* 86, 9073-9078, 1981.

Stubbe, P., H.Kopka, M.T.Rietveld, Ionospheric modification experiments with the Tromso heating facility, *J.Atmos.Terr.Phys.,* 47, 1151-1163, 1985.

Utlaut, W.F., and E.J.Violette, A summary of vertical incidence radio observations of ionospheric modification, *Radio Sci.,* 9, 895-903, 1974.