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EFFECTS OF THE DISTURBED THERMOSPHERIC WIND IN THE HIGH-LATITUDE E AND F1 REGIONS IN THE DAYTIME

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Abstract. The time variations of the ion composition of the high-latitude ionosphere at the E- and F1-region altitudes are investigated which arise due to the horizontal neutral wind disturbance caused by a Rossby wave. The multi-component, non-stationary, one-dimensional mathematical model of the high-latitude ionosphere is applied which enables to calculate the composition of the ionosphere over the heigt range from 90 to 164 km. The behaviour of the ionosphere is considered for the daytime. From our study it follows that the horizontal neutral wind disturbance caused by a Rossby wave can produce a few-peaked sporadic layer at the E- and F1-region altitudes. The mechanism of the vertical separation of ions in sporadic E and F1 layers, operated in the daytime, is identical with the mechanism, operated at night. However, the efficiency of this mechanism in the daytime is by far less than at night. Therefore, the changes of the ion concentration altitude profiles, caused by a Rossby wave, ought to be negligible in the daytime E- and F1-region ionosphere whereas, as it is known, these changes must be significant in the nocturnal E and F1 regions.

Introduction

Recently, we have developed the mathematical model of the high-latitude ionosphere, which enables to calculate the ion composition at the E- and F1-region altitudes [*Lukicheva and Mingalev*, 1998]. This model have been applied to investigate how the horizontal neutral wind disturbance, which is assumed to have a vertical extent of about 30 km, affects the height structure of the nocturnal E and F1 regions. It was supposed that the neutral wind velocity reverses its direction inside the disturbance height range so as zonal and meridional components of the neutral wind velocity depend on altitude similary to sinusoidal curve.

It is generally understood now that the neutral wind with alternating directions at the close altitudes can arise in the lower thermosphere owing to various effects, for example, atmospheric tides, planetary waves, atmospheric gravity waves, and so forth. In particular, a Rossby wave can produce the horizontal neutral wind disturbance in which zonal and meridional components of the thermospheric wind velocity depend on altitude similary to sinusoidal curve. In fact, a Rossby wave is a spatially localized, large-scale traveling structure in the neutral atmosphere which has a horizontal extent of a few thousand kilometres and a vertical extent of only several kilometres. In a horizontal plane, a Rossby wave structure consists roughly of two parts and represents twin vortices, rotating slowly in opposite directions. In the vertical direction, each part of a Rossby wave structure is a pair of vortices, rotating slowly in opposite directions too. Once formed the Rossby wave structures propagate in the westward direction at speeds of several tens m/s [*Ivanov-Kholodny et al*., 1987; *Ivanov-Kholodny et. al*., 1988]. It is evident that, along the vertical axis, crossing a pair vortices located one above the other and rotating in opposite directions, the horizontal components of the neutral wind velocity ought to depend on altitude similarly to sinusoidal curve, if the considered vertical axis does not coincide with the central line of the vortices. It is exactly such neutral wind disturbance whose effects on the nocturnal E and F1 regions have been investigated by *Lukicheva and Mingalev* [1988]. It have been established by *Lukicheva and Mingalev* [1998] that a Rossby wave can produce considerable ion and electron concentration profiles changes in the nocturnal E- and F1-region ionosphere owing to dynamical coupling between the neutral and ionized atmosphere. The purpose of this paper is to present some simulation results of effects of the horizontal neutral wind disturbance caused by a Rossby wave on the high-latitude E and F1 regions in the daytime.

The ionospheric model

We applied the mathematical model of the high-latitude ionosphere the same as in the study by *Lukicheva and Mingalev* [1998]. It is the multi-component, non-stationary, one-dimensional mathematical model of the high-latitude E- and F1-region ionosphere. The model is based on the numerical solution of the 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 considered ions. The model produces the time variations of the altitude profiles of the concentrations, velocities, and temperatures of the considered ions over the height range from 90 to 164 km. The altitude profile of the electron concentration N_e is obtained from the condition that the ionosphere is electrically neutral, i.e.

$$N_e=\Sigma N_i ,$$

where summation runs over five ion components considered, with the ion concentrations being denoted by N_i. Altitude distributions of zonal and meridional components of the neutral wind are the input parameters of the model. The vertical component of the neutral wind is assumed to be zero in the present study. It is supposed that the velocites of neutral particles of different types are the same. The neutral atmosphere composition, ionization processes, chemistry of positive ions, numerical method of solving of the system of coupled nonlinear partial differential equations, boundary conditions, and other details were taken the same as in our previous models [*Lukicheva and Mingalev*, 1990, and references therein].

Ionospheric simulation

The mathematical model used in the present paper can describe different combinations of geomagnetic activity level, solar cycle, and season. We performed calculations for medium solar activity ($F_{10.7}$=150) and low geomagnetic activity (K_p=0) conditions, and for equinox (21 March). The calculations were made for the point with magnetic latitude of Murmansk (66^0) when it is located near the magnetic meridian of 12 MLT at 10.36 UT. By analogy with the study by *Lukicheva and Mingalev* [1998], we held to the following procedure. Initially, we obtained steady-state profiles of calculated quantities by solving the stationary system of transport equations on condition that zonal and meridional thermospheric winds are absent. Next, the obtained steady-state profiles were taken as initial conditions and non-stationary profiles of calculated quatities were obtained by solving the system of transport equations on condition that the zonal and meridional thermospheric winds are turned on as a step function, with the horizontal components of the thermospheric wind velocity depending on altitude similary to sinusoidal curve inside the disturbance height range.

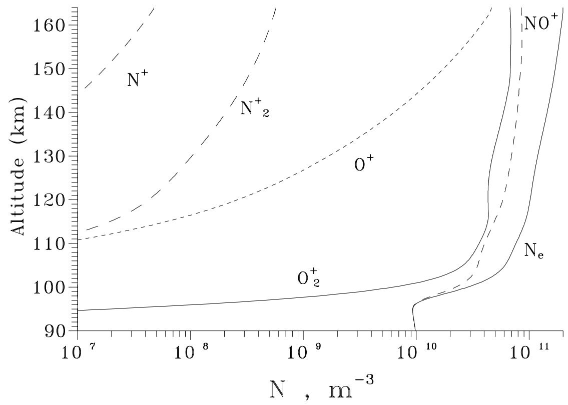

Fig.1. Steady-state profiles of the number densities of ions of different types and electron concentration N_e at the initial moment in absence of the thermospheric wind.

The moment of the turn-on of the disturbed thermospheric wind was the initial moment of our examination. Steady-state profiles of the calculated ion and electron concentrations corresponding to the initial moment are presented in Fig.1. It may be noted that the values of number densities of the individual ions at fixed altitudes, obtained for the daytime and presented in Fig.1, are much greater than those, obtained for the night and presented in the study by *Lukicheva and Mingalev* [1998]. In particular, the number densities of the O^+ , O_2^+ , and NO^+ ions at 130 km, presented in Fig.1, are greater than those, calculated by *Lukicheva and Mingalev* [1998], approximately by factors of 10^4, 7×10^3 , and 8×10, respectively. As a consequence, the electron concentration at 130 km, presented in Fig.1, is approximately a factor of 10^2 greater than that, calculated by *Lukicheva and Mingalev* [1998]. The distinction between the concentrations of the charged particles, calculated for day and night conditions, is no doubt interpreted as being caused by the change in extreme ultraviolet (EUV) solar radiation.

The simulation of non-stationary processes, connected with effects of the disturbed thermospheric wind, was started from the case in which the amplitude of the horizontal thermospheric wind velocity, depending on altitude similary to sinusoidal curve, was the same as in the study by *Lukicheva and Mingalev* [1998], namely, 50 m/s, with the disturbance height range having a vertical extent of 30 km. It turned out that the changes of altitude profiles of the charged particles concentrations, caused by the thermospheric wind disturbance with such amplitude, are so negligible that they are indistinguishable in the scale of Fig.1.

To obtain more conspicuous changes of the charged particles concentrations we increased the amplitude of the neutral wind velocity to 200 m/s. The results of the simulation indicated that after the turn-on of the disturbed neutral wind with such amplitude, the horizontal components of the drift velocities of the individual ions grew during a shot period of time from the initial values, been equal to zero, to those which stayed nearly invariable in following. The shot period of time mentioned above was about 1 sec. On the contrary, the vertical components of the ions drift velocities and concentrations of the individual ions changed during the more prolonged period until they became invariable. The period of the ionospheric establishment after the turn-on of the disturbed thermospheric wind continued about two minutes in the daytime E and F1 regions.

To investigate how the altitude of height range in which the thermospheric wind is disturbed affects the ionospheric response to a Rossby wave we made calculations for three cases in which the horizontal neutral wind velocity was assumed to be disturbed over the height ranges from 95 to 125 km, from 105 to 135 km, and from 125 to 155 km. The total ion density, which is supposed to be equal to the electron concentration N_e, calculated at successive moments after the turn-on of disturbed thermospheric wind, is shown in Fig.2 for three cases mentioned above. It can be seen from Fig 2 that the thermospheric wind disturbance with the amplitude of 200 m/s produces perceptible changes of altitude profiles of the total ion density. We can see that single-peaked and double-peaked ionization layers tend to arise at the E- and F1-region altitudes. The analysis of the simulation results indicated that the mechanism of the vertical separation of ions in sporadic E and F1 layers, operated in the daytime, is identical with the mechanism, operated at night and established by *Lukicheva and Mingalev* [1998]. This mechanism is conditioned by dynamical coupling between the neutral and ionized atmosphere which leads to arising of some peaks on the altitude profile of the vertical component of the ion drift velocity. The origin of the ion drift non-homogeneous in the vertical direction results ultimately in arising of a few-peaked sporadic layer at the E- and F1-region altitudes.

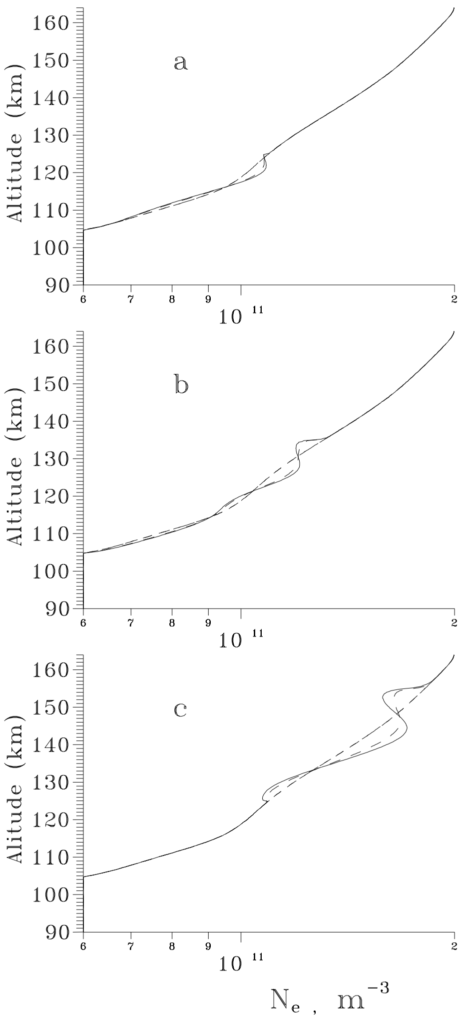

Fig.2. Altitudinal profiles of the electron concentration at different moments after the turn-on of the disturbed neutral wind: 0,0.1,30, and 120 s. The results are presented for three cases in which the horizontal neutral wind velocity is disturbed over the height ranges from 95 to 125 km (**a**), from 105 to 135 (**b**), and from 125 to 155 km (**c**).

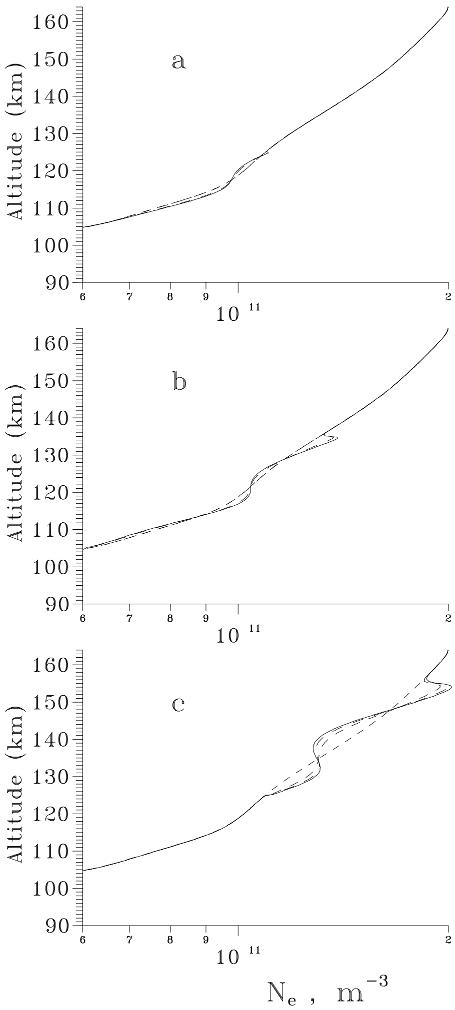

Fig.3. The same as in Fig.2 but for the opposite direction of the disturbed neutral wind velocity.

To investigate how the direction of the neutral wind affects the ionospheric response to a Rossby wave we made calculations analogous to those described above but obtained on the assumption that the disturbed thermospheric wind velocity has the opposite direction. The results of calculations are shown in Fig.3. It can be seen from Fig.3 that the neutral wind disturbance with the opposite direction of the velocity tends to produce double-peaked ionization layers at the E- and F1-region altitudes. The mechanism responsible for the formation of the double-peaked sporadic structures is the same as in the previous consideration. We can see from results presented in Figs.2 and 3 that the efficiency of this mechanism in the daytime is by far less than at night. In fact, the relative changes of the total ion density at fixed altitudes, calculated for the daytime and presented in Figs. 2 and 3, are by far less than those, calculated for the night and presented in the study by *Lukicheva and Mingalev* [1998], with the amplitude of the disturbed neutral wind velocity, taken by *Lukicheva and Mingalev* [1998], being a factor of 4 less than that, used in the present study. Thus, we obtained the confirmation of the fact that, in contrast to the nocturnal ionosphere, in the daytime E and lower F regions, ion formation and loss processes predominate over transport processes. As it is seen from Figs.2 and 3, the role of transport processes on the formation of the electron concentration altitude profile increases with rising of the height in the daytime E and F1 regions.

Conclusions

The multi-component, non-stationary, one-dimensional mathematical model of the high-latitude ionosphere which enables to calculate the composition of the ionosphere throughout the 90-164 km height range has been applied to investigate how the horizontal neutral wind disturbance caused by a Rossby wave influences the high-latitude E and F1 regions in the daytime. The role of the altitude of height range in which the thermospheric wind is disturbed and direction of the neutral wind on the height structure of the daytime E and F1 regions have been investigated too. The simulation results indicated that the horizontal neutral wind disturbance caused by a Rossby wave can produce single-peaked and double-peaked ionization layers at the E- and F1-region altitudes. The formation mechanism of these sporadic ionization layers, operated in the daytime, is identical with the mechanism, operated at night and established by *Lukicheva and Mingalev* [1998]. Nevertheless, the efficiency of this mechanism in the daytime is by far less than at night. As a consequence, the relative changes of the ion concentrations at fixed altitudes are negligible in the daytime in comparison with those at night. The characteristic time of the ionosperic establishment after the turn-on of the disturbed thermospheric wind is about two minutes in the daytime which is a factor of 30 less than that at night. The more the altitude of the disturbance height range is, the higher effects of the disturbed neutral wind ought to be in the daytime E and F1 regions.

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