

EFFECTS OF THE DISTURBED THERMOSPHERIC WIND IN THE NOCTURNAL E AND F1 REGIONS

T.N. Lukicheva and V.S. Mingalev (*Polar Geophysical Institute, Apatity, Russia*)

Abstract. The mathematical model of the high-latitude ionosphere is applied to investigate how the horizontal thermospheric wind affects the height structure of the nocturnal E and F1 regions. By means of numerical simulations of dynamical coupling between the neutral and ionized atmosphere, we have identified the mechanism responsible for the vertical separation of ions in sporadic E and F1 layers. From our study it follows that this mechanism can generate single-peaked, double-peaked, and even triple-peaked ionization layers at the E- and F1- region altitudes. A few-peaked sporadic layer can arise owing to the horizontal thermospheric wind when the latter reverses its direction at the close altitudes.

1. Introduction

It is generally accepted now that the horizontal neutral wind in the lower thermosphere is non-homogeneous in the vertical direction. The observed altitude profiles of zonal and meridional winds can have complex properties, in particular, various directions of the neutral wind may take place at different altitudes [Murphy *et al.*, 1966; Fraser, 1968; Wright, 1968; Kent and Wright, 68]. The formation of altitude profiles of zonal and meridional winds may be influenced by various effects, for example, by atmospheric gravity waves, traveling ionospheric disturbances, planetary waves, atmospheric tides, and so forth. In particular, the altitude profile of neutral wind with alternating directions can arise owing to Rossby waves in the lower thermosphere. A Rossby soliton corresponds to a spatially localized, large-scale traveling structure in the neutral atmosphere. A Rossby soliton structure has a horizontal extent of a few thousand kilometres and a vertical extent of only several kilometres. In a horizontal plane a Rossby soliton structure consists roughly of two parts and represents twin vortices, rotating slowly in opposite directions. In the vertical direction, each part of a Rossby soliton structure is a pair of vortices, rotating slowly in opposite directions too. Once formed the Rossby soliton structures propagate in the westward direction at speeds of several m/s [Ivanov-Kholodny *et al.*, 1987; Ivanov-Kholodny *et al.*, 1988]. It can be seen that along the vertical axis the horizontal neutral wind velocity ought to depend on altitude similarly to sinusoidal curve crossing a pair of vortices located one above the other and rotating in opposite directions, if the vertical axis considered does not coincide with the central line of the vortices. It may be expected that a disturbance of the thermospheric wind caused by a Rossby soliton can affect the height structure of the ionosphere. Our interest is not in modelling the Rossby soliton structures, but in calculating the ionospheric response to such a structure. To investigate how the horizontal neutral wind disturbance affects the altitude profile of the electron concentration in the E and F1 regions we apply the mathematical model of the high-latitude ionosphere.

2. The mathematical model

We have developed a multi-component, non-stationary, one-dimensional mathematical model of the high-latitude ionosphere which enables to calculate the composition of the ionosphere over the height range from 90 to 164 km. Altitude profiles of ionospheric quantities are obtained by solving the appropriate 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 ions. In Cartesian coordinates with the x -axis pointing towards the South, the y -axis towards the East, and the z -axis towards the zenith, the system of transport equations for ions of type i may be written in the following form:

$$\frac{\partial N_i}{\partial t} + \frac{\partial}{\partial z} (N_i V_i^z) = Q_i - L_i \quad (1)$$

$$g - 2(\Omega \times \nabla_i) - \frac{1}{m_i N_i} \text{grad}(N_i k T_i) + \frac{q_i}{m_i} (\mathbf{E} + \nabla_i \times \mathbf{B}) = \sum_n \frac{1}{t} (\nabla_i - \mathbf{U}_n) \quad (2)$$

$$\sum_n \frac{m_i N_i}{m_i + m_n} \frac{1}{\tau_{in}} [3k(T_n - T_i) + m_n (\bar{U}_n - \bar{V}_i)^2] = 0 \quad (3)$$

where N_i , \bar{V}_i , and T_i are the number density, drift velocity, and temperature of ions of type i , respectively; Q_i and L_i are the production and loss rates of ions of type i , respectively; m_i and q_i are the mass and charge of ions of type i , respectively; g is the gravity acceleration; Ω is the Earth's angular velocity, k is the Boltzmann constant, \mathbf{E} is the

electric field, \vec{B} is the magnetic field, \vec{U}_p , T_n , and m_n are the velocity, temperature, and mass of neutral particles of type n , respectively and $1/\tau_{in}$ is the collision frequency between ions of type i and neutral particles of type n . In equations (2) and (3), the summation with respect to n runs over all types of neutral particles presented in the thermosphere and included into the mathematical model. The electron concentration N_e is obtained from the condition that the ionosphere is electrically neutral, i.e.

$$N_e = \sum_{i=1}^5 N_i.$$

The thermospheric composition, ionization processes, chemistry of positive ions, expressions for the values in system (1)-(3), input parameters of the model, and other details have been taken from our previous models [Lukicheva and Mingalev, 1990, and references therein].

3. Ionospheric simulation

The mathematical model described above has been used to calculate the ionospheric response to the disturbance of the thermospheric wind caused by a Rossby soliton. We have performed calculations for the point with magnetic latitude of Murmansk (66°) when it is located near the magnetic meridian of 03 MLT at 10.36 UT. The calculations have been made for equinox (21 March) and medium solar activity ($F_{10.7}=150$) conditions under low geomagnetic activity ($K_p=0$). Initially, we obtained steady-state profiles of ionospheric quantities by solving the stationary system of transport equations under condition that zonal and meridional winds are absent. Next, the calculated steady-state profiles were taken as initial conditions and non-stationary profiles of ionospheric quantities were obtained by solving system (1)-(3) under condition that the zonal and meridional winds are turned on as a step function. Thus, zonal and meridional components of the neutral wind are the input parameters of the model with the altitude profiles shown in Fig.1 a and c. The vertical component of the neutral wind is supposed to be zero in the present study. We suggest that the velocities of neutral particles of different types are the same.

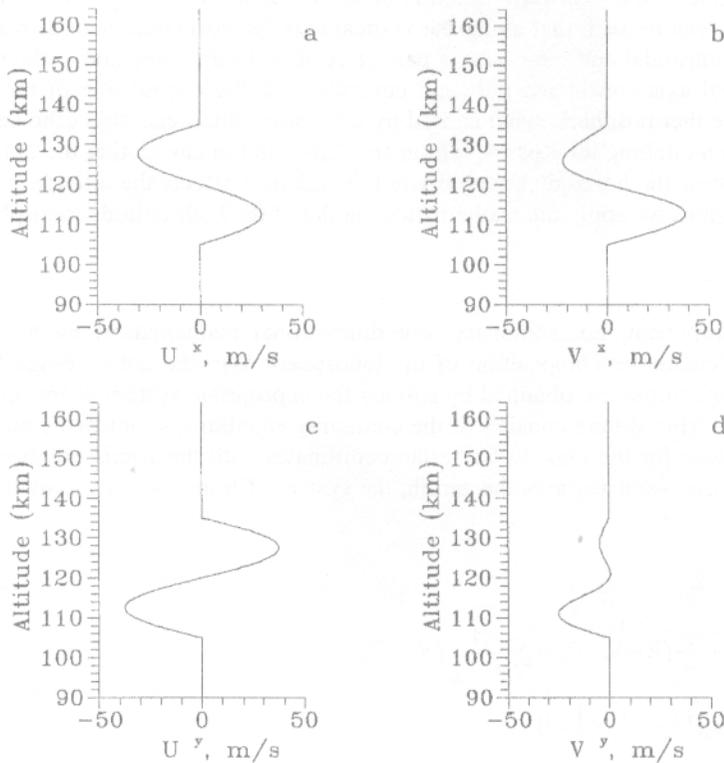


Fig.1. Altitudinal profiles of the North-South neutral wind velocity component (a) and correspondent component of the ion drift velocity (b), the West-East neutral wind velocity component (c) and correspondent component of the ion drift velocity (d).

From the results of the simulation, it has been found that after the turn-on of the disturbed thermospheric wind, the horizontal components of the ion drift velocity increase from the initial values equal to zero to those corresponding to nearly stationary profiles presented in Fig.1 b and d during a short period of time. After this period, changes in the calculated profiles of the horizontal components of the ion drift velocity are negligible. On the contrary, the vertical component of the ion drift velocity changes during the period of about one hour (Fig.2 d), with the calculated non-stationary profiles of the vertical component of the ion drift velocity differing significantly from the initial profile obtained under the condition that the thermospheric wind is absent. As it can be seen from the results of the simulation presented in Fig. 2, the disturbed thermospheric wind can considerably affect the altitude profile of the electron concentration. We can see that the double-peaked sporadic E layer arises at the level of the lower thermosphere. The mechanism responsible for the vertical separation of ions in the simulated sporadic E layer is connected with the origin of two peaks on the altitude profile of the vertical component of the ion drift velocity (Fig.2 d). These peaks arise due to specific dynamical coupling between the neutral and ionized atmosphere which is essentially different above and under the boundary between a strongly magnetized plasma for which only transport along magnetic field lines is important and non-magnetized, collision dominated plasma. Thus, the disturbance of the thermospheric wind caused by a Rossby soliton can result in noticeable electron concentration profile changes, in particular, in origin of the double-peaked sporadic E layer. In all of the model simulations described above, we have assumed that the horizontal neutral wind velocity is disturbed by a Rossby wave only over the height range from 105 to 135 km.

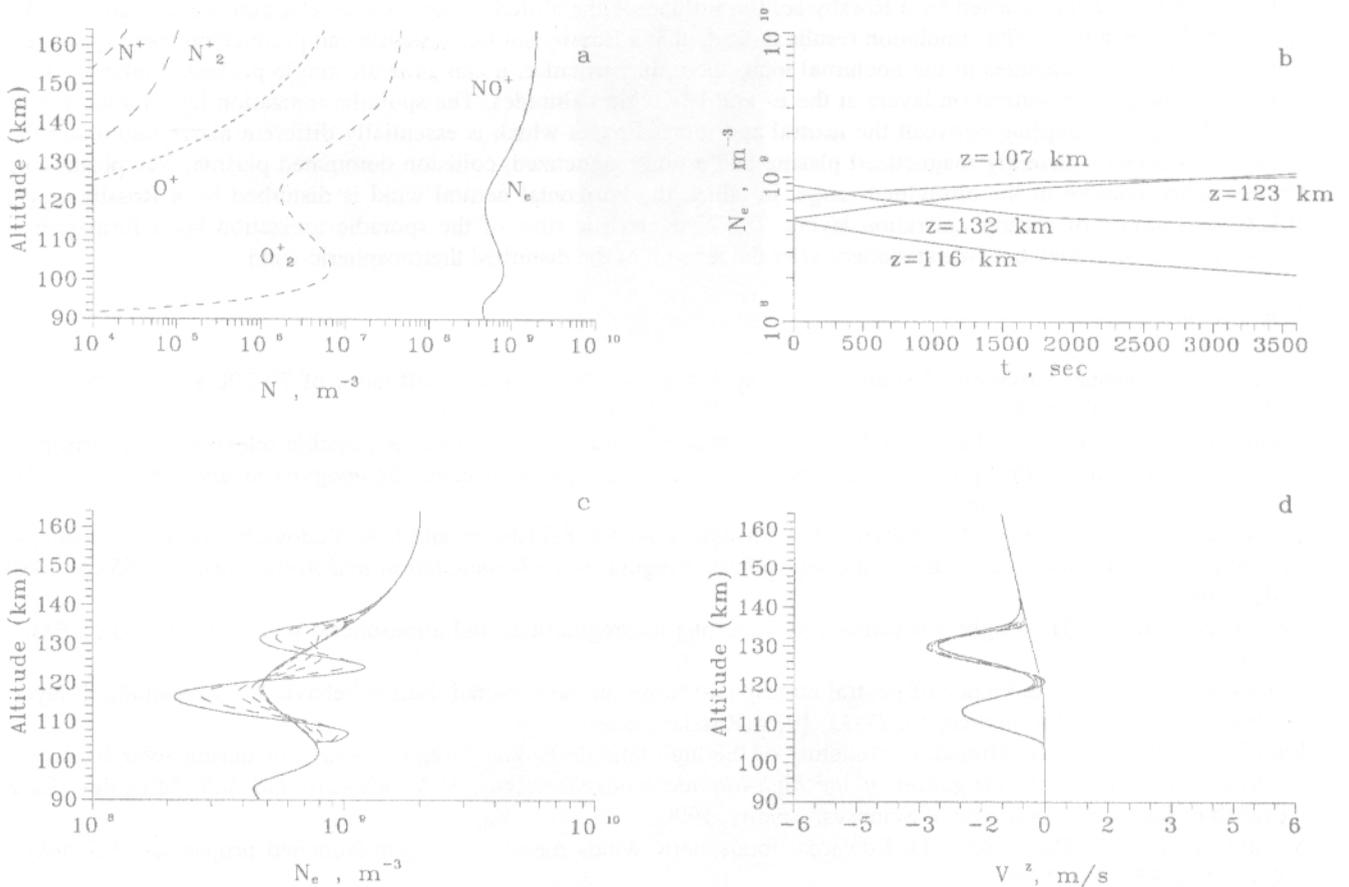


Fig.2. **a** Steady-state profiles of the number densities of ions of different types and electron concentration N_e at the initial moment in absence of the neutral wind. **b** The time variations of the electron concentration at different levels after the turn-on of the disturbed neutral wind. **c** Altitudinal profiles of the electron concentration at different moments after the turn-on of the disturbed neutral wind : 0, 30, 60, 300, 600, 1800, and 3600 s. **d** Altitudinal profiles of the vertical component of the ion drift velocity at different moments after the turn-on of the disturbed neutral wind. The moments are the same as in **c**.

In addition, we have investigated how the altitude of height range in which the thermospheric wind is disturbed and direction of the wind affect the ionospheric response to a Rossby wave. From this investigation it has been found that a Rossby soliton structure can produce single-peaked, double-peaked, and even triple-peaked ionization layers at the E- and F1- region altitudes. The number of the peaks on an altitudinal profile of the electron concentration depends on the location of a Rossby wave on the vertical axis and direction of the horizontal thermospheric wind inside a Rossby soliton structure. Sporadic ionization layers are generated due to the origin of peaks on the altitudinal profile of the vertical component of the ion drift velocity. The number of such peaks depends on the altitude of a Rossby wave location relative to the boundary between a strongly magnetized plasma and a non-magnetized collision - dominated plasma.

It should be noted that a triple-peaked ionization layer at the E-region altitudes has been numerically simulated by *Korenkov* [1979]. In that paper the effect is achieved due to the action of a diurnal harmonic of an atmospheric tidal wind with a short vertical wavelength and the maximum amplitude of 30 m/s at 110 km. The ionospheric response to a Rossby wave has not been investigated by *Korenkov* [1979].

4. Conclusions

A mathematical model of the high-latitude ionosphere, which enables to calculate the composition of the ionosphere in the 90-164 km height range has been briefly described. Using this model, we have investigated how the horizontal neutral wind disturbance caused by a Rossby soliton influences the altitude profile of the electron concentration in the high-latitude ionosphere. The simulation results indicate that a Rossby soliton structure can produce noticeable electron concentration profile changes in the nocturnal ionosphere. In particular, it can generate single-peaked, double-peaked, and even triple-peaked ionization layers at the E- and F1- region altitudes. The sporadic ionization layers arise due to specific dynamical coupling between the neutral and ionized gases which is essentially different above and under the boundary between a strongly magnetized plasma and a non-magnetized, collision dominated plasma. The position of this boundary relative to the altitudinal range, in which the horizontal neutral wind is disturbed by a Rossby wave, affects the number of arising ionization layers. The characteristic time of the sporadic ionization layer formation is about one hour until they become stationary after the turn-on of the disturbed thermospheric wind.

References

- Fraser, G.J., Seasonal variation of southern hemisphere mid-latitude winds at altitudes of 70-100 km, *J. Atm. Terr. Phys.*, 30, 707-720, 1968.
- Ivanov-Kholodny, G.S., V.I. Petviashvili, A. Ya. Feldshtein, and L.A. Yudovich, A possible relevance of geostrophic vortices in the upper atmosphere to the "spotted" structure of the ionosphere, *Geomagnetism and Aeronomya*, 27, 393-397, 1987 (Russian issue).
- Ivanov-Kholodny, G.S., N.V. Petviashvili, G.N. Pushkova, A. Ya. Feldshtein, and L.A. Yudovich, Three - dimensional solitons of Rossby waves and large-scale ionospheric irregularities, *Geomagnetism and Aeronomya*, 28, 55-59, 1988 (Russian issue).
- Kent, G.S., and R.W.H. Wright, Movements of ionospheric irregularities and atmospheric winds, *J. Atm. Terr. Phys.*, 30, 657-691, 1968.
- Korenkov, Yu. N., The influence of neutral atmosphere flows on the seasonal-diurnal behaviour of a sporadic E layer, *Geomagnetism and Aeronomya*, 19, 27-33, 1979 (Russian issue).
- Lukicheva T.N., and V.S. Mingalev, Modeling of the high-latitude E- and F-region behaviour during solar flares (in Russian), pp.4-10, in *Investigation of the high-latitude ionosphere*, eds. V.A. Vlaskov and V.S. Mingalev, Kola Branch of the USSR Academy of Sciences, Apatity, 1990.
- Murphy, C.H., G.V. Bull, and H.D. Edwards, Ionospheric winds measured by gun-launched projectiles, *J. Geophys. Res.*, 71, 4535-4544, 1966.
- Wright, J.W., The interpretation of ionospheric radio-drift measurements. Some results of experimental comparisons with neutral wind profiles, *J. Atm. Terr. Phys.*, 30, 919-930, 1968.