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AN INVESTIGATION OF THE NIGHT-TIME INCREASES OF THE PLASMA DENSITY IN THE MIDDLE-LATITUDE IONOSPHERIC F2-LAYER BY THE MATHEMATICAL MODELING METHOD

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Abstract. The forming mechanism of the night-time increases of the plasma density in the middle-latitude ionospheric F2-layer has been investigated using the global numerical Upper Atmosphere of the Earth Model (UAM). The model calculation results show that main cause of the occurrence of these increases is the equatorward thermospheric wind. The dependence of these increases on seasons and solar activity has been investigated. The enhanced plasma density regions can extend up to the heights of the plasmasphere of the Earth. The electromagnetic drift influences on the latitudinal location of the high-latitude sides of these regions, moving them to the lower latitudes.

Introduction

The anomalous plasma density increases in the night-time middle-latitude ionospheric F2-layer have been found in the observed data of the F2-layer critical frequency (f_0F2), electron density maximum (*NmF2*) and total electron content (*TEC*) obtained by many basic methods of the ionospheric measurements such as radio sounding [Gilliland, 1935; Mikhailov et al., 2000; Richards et al., 2000], radio transmission [Bertin and Lepine, 1970; Balan et al., 1991], Doppler measurements [Horvath and Essex, 2000] and incoherent scatter [Richards et al., 1994; Richards et al., 2000].
The anomalous night-time middle-latitude plasma density increases appear in the form of the maxima on the plots of the latitude or local time dependences of f_0F2, *NmF2* and *TEC*. These increases are observed in the pre-midnight and/or post-midnight hours at the local time dependence [Mikhailov et al., 2000]. The night-time middle-latitude maxima of the *TEC* appear in the form of the *enhanced electron density regions* (EEDR's) on the two-dimensional plots (maps) of the latitude-longitude or latitude-time dependence of the *TEC* at the night side [Brunini et al., 2003].
The review of the experimental data shows that the occurrences of the EEDR's are a peculiarity of the quiet nighttime middle-latitude F2-layer of the ionosphere [Bertin and Lepine, 1970; Horvath and Essex, 2000; Mikhailov et al., 2000]. These regions are forming in all seasons under the different solar activity levels. The season and solar activity level variations of the EEDR's become apparent in the time period of the appearance, durability and amplitude of the increases [Balan et al., 1991; Horvath and Essex, 2000; Mikhailov et al., 2000].
The plasma density increases in the night-time middle-latitude ionospheric F2-layer were investigated by means of the mathematical modeling methods. These increases were reproduced by using the one-dimensional theoretical models FLIP [Richards et al., 1994], SUPIM [Bailey et al., 1993] and [Mikhailov and Schlegel, 1997].
There are two primary interpretations of the EEDR's observations and results of the mathematical modeling: the hypothesis about the forming role of the *electromagnetic* $\mathbf{E}\times\mathbf{B}$ *drift* (due to either the low-latitude dynamo origin electric field [Horvath and Essex, 2000] or the electric field of the magnetospheric convection [Mikhailov and Förster, 1999]) and the *neutral wind* [Mikhailov et al., 2000].
The first type of the interpretation has a qualitative character, and does not allow estimating the role of each taken separately transfer processes. The second interpretation allows quantitatively estimating the EEDR's forming roles of the electromagnetic drift and thermospheric wind but it does not take into account the peculiarities of this problem: 1) the three-dimensionality of the transfer processes at the heights of the ionospheric F2-layer and plasmasphere of the Earth and 2) integration of the thermosphere, ionosphere and plasmasphere in the interrelated system.
Here we investigate the problem of the forming of the night-time middle-latitude EEDRs mechanism by means of the global Upper Atmosphere of the Earth Model (UAM) which takes into account the peculiarities of this problem.
This model describes the thermosphere, ionosphere and plasmasphere of the Earth as a single system by the numerical integration of the corresponding time-dependent 3D equations of the continuity, momentum and heat balance for the neutral and electron gases and equation for the electric field potential [Namgaladze et al., 1998].
The empirical model of the neutral atmosphere NRLMSISE-00 [Picone et al., 2002] has been integrated into the UAM. This version of the UAM allows to get the neutral gas densities and temperature directly from the empirical thermosphere, to calculate the pressure gradients and thus to solve the momentum equations for the horizontal thermospheric winds.

The influence of the meridional wind on the EEDR's

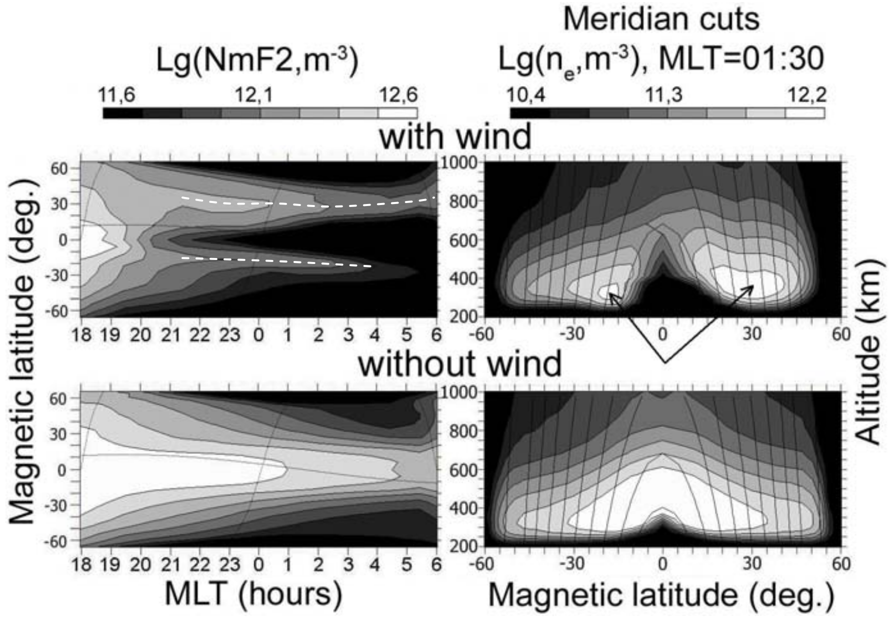

Fig. 1. At the *right column* – the geomagnetic latitude-time distributions of *Lg(NmF2)* for the 24:00 UT (16.04.2002). At the *left column* – the meridional cuts of the *Lg(n$_e$)* for the 24:00 UT and 01:30 MLT (16.04.2002) for the altitude range *h*=200÷1000 km. At the *top* – the results of the UAM version calculation with the thermosphere wind. At the *bottom* – the results of the model calculation without wind. The white broken curves and black pointers indicate to the EEDR's.

We present two versions of the model calculations of the electron density distribution by using the UAM with the empirical thermosphere model NRLMSIEE-00 for estimating the relative role of the thermospheric wind in the EEDR's forming: 1) with thermospheric wind and 2) without wind.
The horizontal wind velocity is calculated from the empirical neutral gas pressure data by the NRLMSISE-00 in the version of the model calculation with wind (1). In the version 2 the switching-off of the thermospheric wind is realized by means of the model calculation in which momentum equations for the neutral gas are not solved, but in other equations for the charged particles the thermospheric wind velocity is taken equal to zero.
The selected day (16.04.2002) represents the quiet conditions near the equinox under high solar activity.
The initial conditions are the same for all model calculations. To obtain them we integrate the modelling equation system until the results of integration do not differ under continuating integration (steady state solution).
The calculated geomagnetic latitude-longitude distributions of *Lg(NmF2)* at the night longitudinal sector (18:00-06:00 MLT) (left column) and latitude-altitude distributions of *Lg(n$_e$)* along the geomagnetic meridian 01:30 MLT for the altitude range from 200 to 1000 km (right column) are presented in Fig. 1 for the UT moment 24:00. The midday-midnight geographic meridian, the terminator line and geographic equator are drawn at the left maps. The geomagnetic force field lines are drawn at the right maps. The versions of the model calculations are presented top-down in Fig. 1.
The night-time middle-latitude EEDR's are well expressed at the map of the distribution of *Lg(NmF2)* corresponding to the version (1) of the model calculation with the thermosphere wind. These regions are absent at the map corresponding to the version (2) without wind.
The EEDR's are clearly visible at the meridional cuts of *Lg(n$_e$)* corresponding to the version 1 also. These regions represent the electron density isolines aligned along the geomagnetic field lines. They extend to altitudes of the Earth's plasmasphere along the geomagnetic field force lines.
These regions are absent at the meridional cuts corresponding to the version 2 without wind.

The influence of the electromagnetic drift on the EEDR's

We present four versions of the model calculations of the electron density distribution by using the UAM with the empirical thermosphere model NRLMSIEE-00 for estimating the relative role of the electromagnetic $\boldsymbol{E}\times\boldsymbol{B}$ drift in the EEDR's forming: 1) with thermospheric wind and drift, the across polar cap potential is constant and equal to $\Delta\varphi=20$ kV; 2) without wind, but with drift and $\Delta\varphi=20$ kV; 3) with wind, drift and $\Delta\varphi=60$ kV; 4) without wind, but with drift and $\Delta\varphi=60$ kV.
The calculated latitude-altitude distributions of *Lg(n$_e$)* along the geomagnetic meridian MLT=01:30 for the altitude range *h*=800÷3000 km for 24:00 UT (16.04.2002) are presented in Fig. 2. The corresponding to the versions of the model calculations (1, 2) with the constant across polar cap potential $\Delta\varphi=20$ kV meridional cuts are presented at the left column, corresponding to the versions of the model calculations (3, 4) and $\Delta\varphi=60$ kV ones are presented at

the right column. The results of the model calculations with the thermosphere wind (1, 3) are presented at the top, those without wind (2, 4) are presented at the bottom.

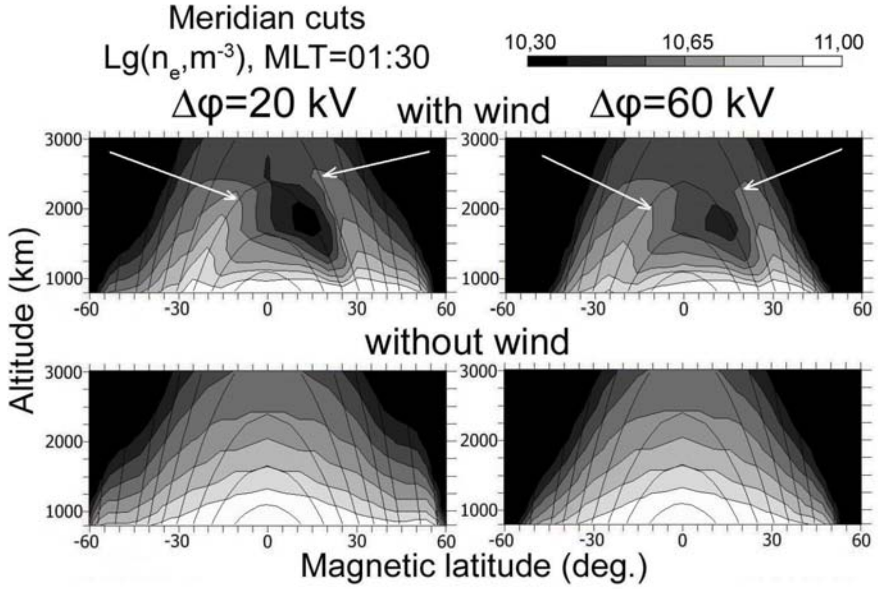

Fig. 2. The latitude-altitude plots of Lg(n_e) along the geomagnetic meridian MLT=01:30 for the altitude range *h*=800÷3000 km for 24:00 UT (16.04.2002) for the constant across polar cap potential $\Delta\varphi=20$ kV (*left column*) and for the $\Delta\varphi=60$ kV (*right column*). At the *top* – the results of the UAM version calculation with the thermospheric wind. At the *bottom* – the results of the model calculation without wind. The white pointers indicate to the EEDR's.

As in the previous calculations, the EEDR's are better expressed at the cuts corresponding to the versions (1, 3) of the model calculations with the thermospheric wind and these regions are absent at the cuts corresponding to the versions (2, 4). The comparison of the results of the model calculations with the constant across polar cap potential 20 kV and 60 kV shows that the electric field influences to the EEDR's at the high-latitude: the higher velocity of the electromagnetic drift the stronger compressing of the electron density isolines from poles due to the equatorward displacement of the main ionospheric trough.

The investigation of the season and solar activity level EEDR's variations

The differences in seasons are caused by the location of the subsolar point relatively the geographic equator. The season effects are better expressed at the solstice conditions when the subsolar point is maximally displaced relatively the geographic equator to the summer hemisphere.

We present the model calculations of the electron density by the UAM with the NRLMSISE-00 for two selected quiet days representing the solstice under low (23.06.1986, F10.7=69.6) and high (20.06.1990, F10.7=161.2) solar activity levels. The calculated geomagnetic latitude-longitude distributions of the northward wind at *h*=300 km (left column) and the corresponding distributions *Lg(NmF2)* (right column) at the night longitudinal sector (18:00-06:00 MLT) are presented in Fig. 3 for the 18:00 UT. The corresponding to the solstice under low solar activity maps are presented at the top row, the corresponding to high solar activity ones are presented at the bottom row (Fig. 3). The midday-midnight geographic meridian, the terminator line and geographic equator are drawn at the maps. The negative meridional wind is southward, the positive one is northward.

It is seen that the northward wind is equatorward at the summer hemisphere at the middle latitudes under both solar activity levels. Such distribution of the wind results the EEDR's in the form of the "ridge" with monotonically decreases of the *NmF2* when going from evening to morning hours.

The meridional wind is poleward at the winter hemisphere at the middle latitudes at the pre-midnight MLT sector. It changes the direction near midnight and becomes equatorward at the post-midnight MLT sector. The poleward wind drives F2-layer plasma to the lower altitude where the ion loss rate increases and results in the disappearance of the EEDR's at the pre-midnight sector. Accordingly the EEDR's are represented in the form of the "hill" which expressed at the post-midnight MLT sector at the winter hemisphere.

The comparison between the solar activity levels shows that the EEDR's are better expressed under low solar activity. The values of the electron density in these regions are larger under high solar activity than under low activity.

Conclusions

Thus our investigation shows that the main cause of the occurrence of the EEDR's is the equatorward thermospheric wind driving the F2-layer plasma to the higher altitudes where the ion loss rate decreases.

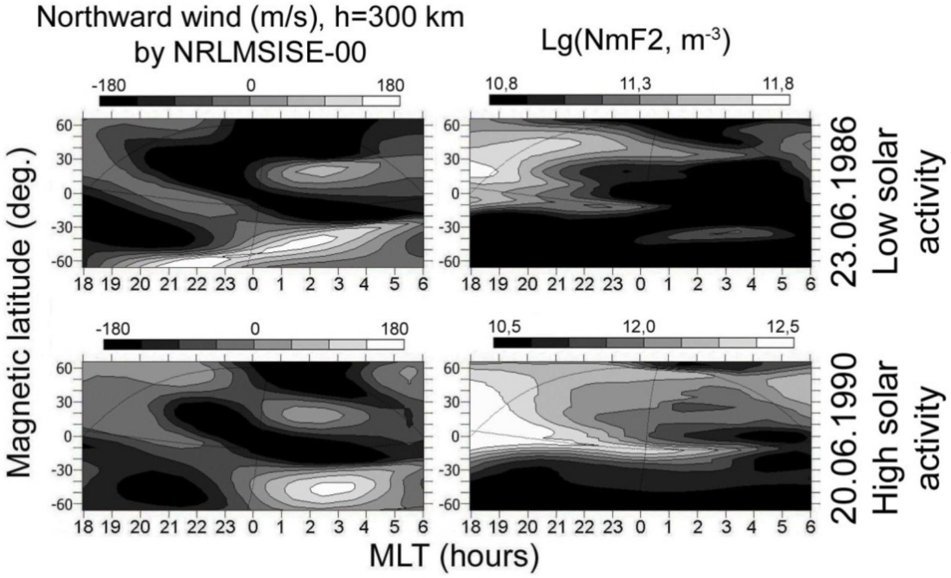

Fig. 3. The latitude-longitude plots of the northward wind at h=300 km (*left column*) and the corresponding distributions *Lg(NmF2)* (*right column*) at the night longitudinal sector (18:00-06:00 MLT) for the 18:00 UT. The corresponding to the solstice under low solar activity maps are presented at the *top*, the corresponding to high solar activity ones are presented at the *bottom*.

The enhanced electron density regions are extended to the plasmasphere along the geomagnetic force lines. Their form is controlled by geometry of the geomagnetic field lines.

The season and solar activity variations of the enhanced electron density regions are formed by the corresponding variations of the thermospheric wind velocity. In summer the EEDR's are visible in form the "ridges" with decreases of the *NmF2* when going from evening to morning hours. In winter these regions are visible in form the "hills". The EEDR's are better expressed under low solar activity.

The electromagnetic drift influences on the latitudinal location of the high-latitude sides of the EEDR's, moving them to the lower latitudes. The displacement of these regions from poles is proportional to the drift velocity value.

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