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SIMULATION OF MAIN IONOSPHERIC TROUGH, LIGHT ION TROUGH AND POLAR CAP PATCHES DURING SUBSTORMS

M.V. Klimenko, V.V. Klimenko (*West Department of N.V. Pushkov IZMIRAN RAS, 41, Pobedy Av., Kaliningrad, 236017, Russia; E-mail: maksim.klimenko@mail.ru)*

Abstract. The given paper is devoted to researches of the main ionospheric trough (MIT) and light ion trough behavior, and the formation of polar patches of ionization during modeling substorms. In model calculations, the MIT stratification is obtained in active and recovery phases of a substorm. At the analysis of calculation results, we have found out the formation of ionization patches in polar caps at heights of *F*-region and external ionosphere. Besides, we have considered the substorm current wedge influence on global distribution of the ionosphere *F2*-layer critical frequency.

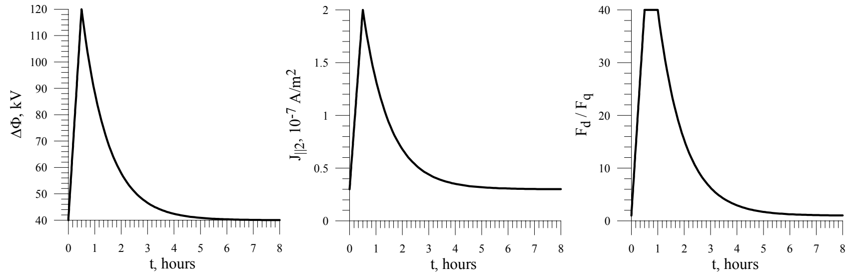

Fig. 1. The behavior of model input parameters: potential difference through polar caps (left), field aligned currents of second region (middle) and ratio of the particle precipitation flux during substorm to the quiet flux (right).

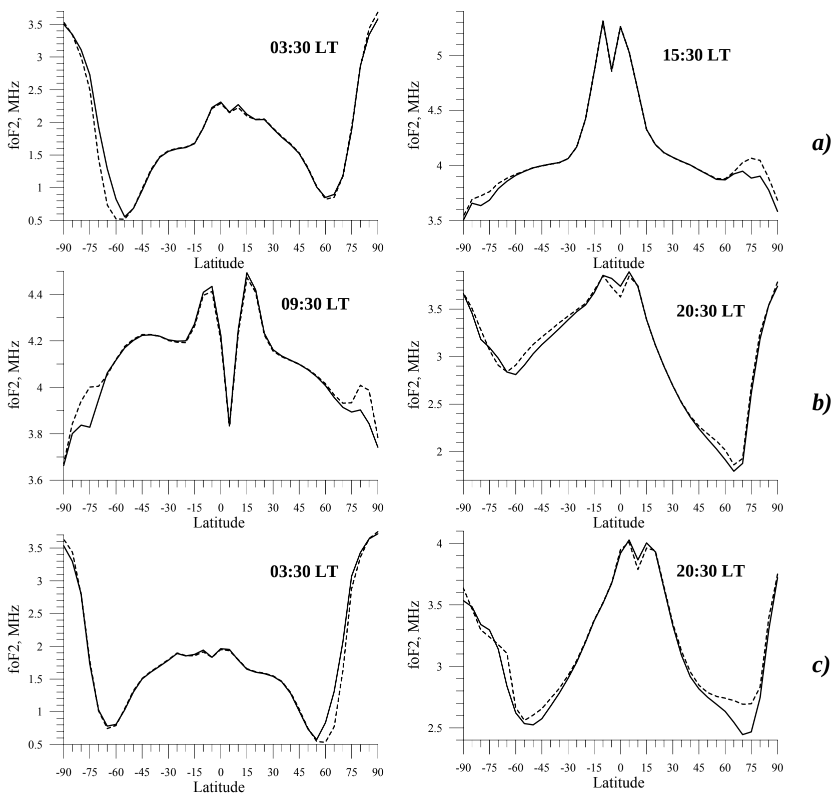

Fig. 2. Model calculated latitudinal profiles of the *foF2* in 0.5 h after the substorm beginning at a) 00:00 UT, b) 06:00 UT and c) 12:00 UT for different LT moments. Dotted lines – quiet conditions, solid lines – substorm.

Introduction

Magnetospheric substorm is the complex phenomenon occurring in near-Earth space. The researches of a substorm are spent many years (Akasofu, 1964; Pudovkin, 1991; Stern, 1996). However, until now unequivocal answers to the many questions are not given. One of them is the question about ionospheric effects of a substorm. The decision of this question is carried out often by mathematical modeling methods (Volkov, Namgaladze, 1996; Schunk et al., 1997; Zhu et al., 2000). It is known that during magnetospheric perturbations there is a strengthening of potential difference through polar caps, field-aligned currents and particle precipitation from magnetosphere. Particle precipitation variations lead to ionosphere conductivity changes and, as consequence, to redistribution of electric fields and currents in the ionosphere. Additional electric fields during disturbances cause additional electromagnetic drifts of thermal plasma in F-region of high-latitude ionosphere, which lead to its density change. Besides the electric fields penetrate from a high-latitude ionosphere into the middle and lower latitudes, causing the global changes of ionospheric parameters. At modeling of ionospheric substorm effects, it is necessary to find out the following. Whether has the time of substorm beginning any significance and if has what is it? Whether is it necessary to take into consideration the substorm current wedge?

In this study, we present the numerical calculation results of ionospheric effects of four modeling substorms that have begun at different UT moments. Calculations for vernal equinox conditions in the minimum of solar activity were executed based on Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP). In calculations, we took into account the magnetosphere convection electric field, dynamo electric field generated by thermospheric winds and particle precipitation. Besides, we have carried out the calculations with taking into account the substorm current wedge (SCW) in two various statements.

The model GSM TIP brief description

The model GSM TIP developed in West Department of IZMIRAN was described in details in (Namgaladze et al., 1988). In this model the numerical decision of the hydrodynamics equations for multi-component gas mixture, consisting of neutral (O_2, N_2, O, H), and charged (the molecular ions O_2^+, NO^+, atomic ions O^+, H^+, and electrons) particles is realized. In the model GSM TIP by the self-consistent manner, it is calculated the thermospheric winds from the equations of neutral gas movement and the electric fields of dynamo and magnetospheric origin. The new calculation block of electric fields was added to the model GSM TIP (Klimenko et al., 2006).

Calculation results and discussion

Fig. 1 shows the time courses of the model input parameters during modeling substorm.

Fig. 2 shows the model calculated latitudinal profiles of the ionospheric *F2*-layer critical frequency, *foF2,* in 0.5 h after the substorm beginning at different UT moments. We have chosen the local time (LT) moments with the greatest effects in the main ionospheric trough (MIT). The substorms cause strong positive disturbances in F-region of ionosphere in the nighttime sector in the MIT region. It leads to the reduction of the MIT depth. Besides, during substorms MIT it is displaced to the equator. The MIT behaviour during the substorms, obtained in calcula-

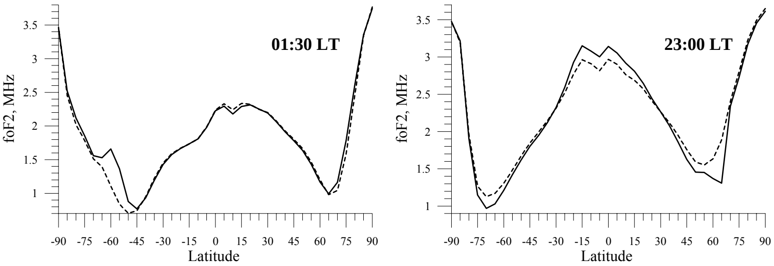

Fig. 3. Model calculated latitudinal profiles of the ionospheric F2-layer critical frequency *foF2* in 0.5 h (left) and 6 h (right) after the substorm beginning at 18:00 UT. Dotted lines – quiet conditions, solid lines – substorm.

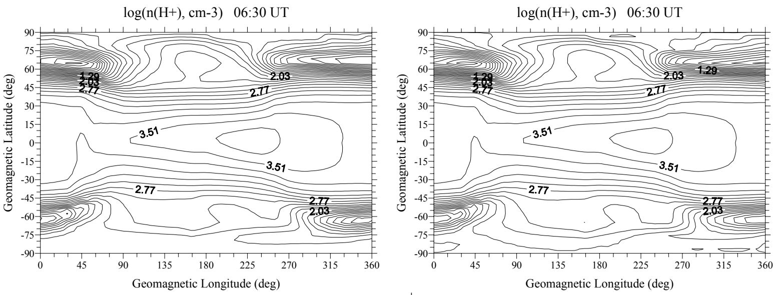

Fig. 4. Model calculated maps of H^+ ion concentration at height of 1500 km. Left – quiet conditions, right – substorm.

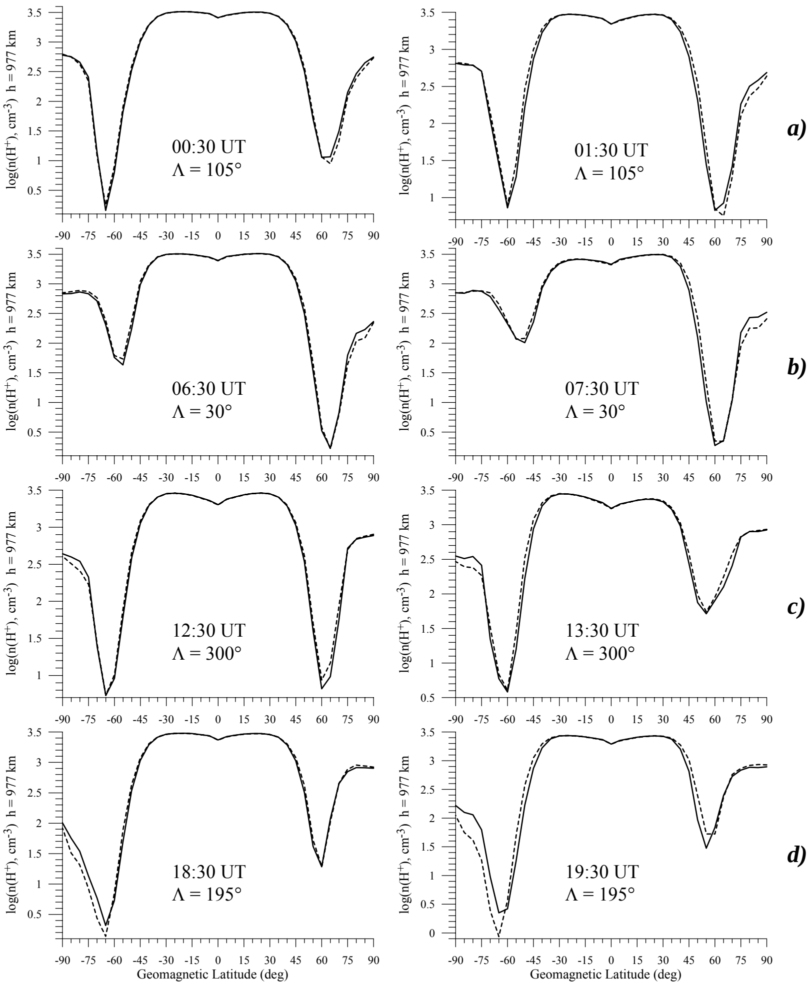

Fig. 5. Model calculated latitudinal profiles of the H^+ ion concentration at height of 977 km in 0.5 h (left) and 1.5 h (right) after the substorm beginning at a) 00:00 UT, b) 06:00 UT, c) 12:00 UT and d) 18:00 UT. Dotted lines – quiet conditions, solid lines – substorm.

tions, is in agreement with experimental data. The substorms cause negative disturbances in the MIT region in daytime, morning and evening ionosphere F-region.

The negative disturbances in the middle and low latitudes are much less then in the MIT region. The calculation results show that in this statement of the problem all substorms cause the strengthening of the daytime equatorial ionization anomaly (EIA). During substorms there is EIA narrowing – the EIA crests press oneself to the equator more closely than in quiet conditions, that is they are formed at smaller latitudes. It is explained by the penetration of the magnetosphere convection electric field to the equator and easing of responsible for the EIA formation eastward electric field generated in the daytime by thermospheric winds.

In addition, we consider the substorm, which have begun at 18:00 UT. Fig. 3 shows the calculated *foF2* latitudinal profiles in 0.5 h after this substorm beginning on the geographical meridian corresponding 01:30 LT and in 6 h after its beginning on the geographical meridian corresponding 23:00 LT. It is visible that in 0.5 h after the substorm beginning the additional high-latitude trough in southern hemisphere which is absent in quiet conditions is formed due to formation of powerful tongue of ionization. Thus, the MIT stratification occurs in a southern hemisphere. Such MIT stratification occurs in northern hemisphere too in 6 hours after the substorm beginning. These stratifications are the consequence of non-stationary magnetosphere convection. The distinction between these events consists that the stratification in a southern hemisphere occurs in active phase of substorm, and in northern hemisphere in recovery phase of substorm. Shapovalova et al., 2003 presented the experimental acknowledgement examples of the MIT stratification existence based on the tomographic reconstructions.

We have considered the effects of the substorm beginning at 06.00 UT in H^+ ion concentration at height of 1500 km. Fig. 4 shows the model calculated global maps of H^+ ion concentration at this height in 0,5 h after the substorm beginning. On an initial phase of substorm the patch in H^+ ion concentration at height of 1500 km is formed. The patch exists during short time and is connected with a non-stationary magnetosphere convection electric field. Plasma drift due to this electric field leads to the tearing off the thermal plasma part from tongue ionization and to its further movement from the day to the night side where it disappears because owing to the recombination processes. The tongue ionization is formed at heights of the ionosphere *F*-region and is stretched into the external ionosphere.

Fig. 5 shows the model calculated latitudinal profiles of the H^+ ion concentration at height of 977 km in 0.5 h and 1.5 h after the substorms beginning. For all substorms calculation results show the displacement of the light ion trough to the equator that is in agreement with observations. It is visible that the different substorms cause both positive and negative effects in the bottom of the light ion trough.

At last, we carried out the calculations of ionospheric substorm effects with taken into account the substorm current wedge (SCW). Fig. 6 shows the behavior of the input parameters at modeling of ionospheric substorm effects with taking into account SCW: field-aligned currents of the first and second region, SCW and the ratio of the particle precipitation flux during substorm to the quiet flux.

We considered two cases of the SCW statement. Fig. 7 shows the longitudinal profiles of the field-aligned currents of the first and second region and SCW in the statement of Rostoker, Friedrich, 2005 and Volkov, Namgaladze, 1996.

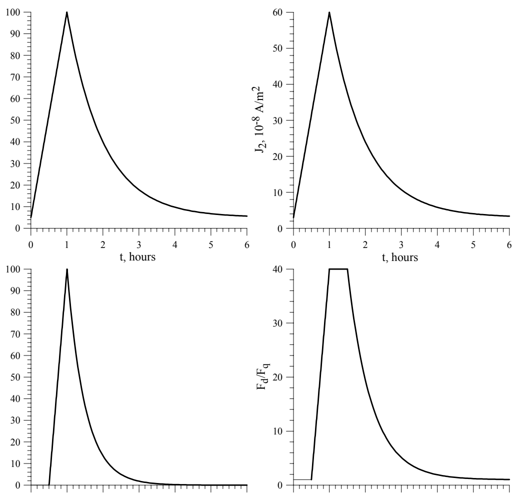

Fig. 6. The behavior of the model input parameters: field aligned currents of the first and second region, SCW and ratio of the particle precipitation flux during substorm to the quiet flux.

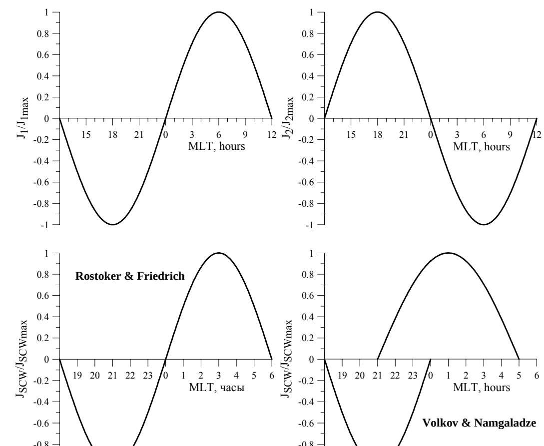

Fig. 7. The longitudinal profiles of the field aligned currents of the first and second region and SCW in the statement of Rostoker, Friedrich, 2005 and Volkov, Namgaladze, 1996.

Fig. 8 shows the model calculated *foF2* global maps in 1 h after the substorm beginning for quiet conditions, without take into account SCW, and with take into account SCW in the statement of Rostoker, Friedrich, 2005 and Volkov, Namgaladze, 1996. It is visible, that the substorm causes the global *foF2* changes. At that, the ionospheric effects depend both on that, whether SCW is considered in calculations or not, and how SCW is considered. The most SCW effects are formed in the high-latitude ionosphere.

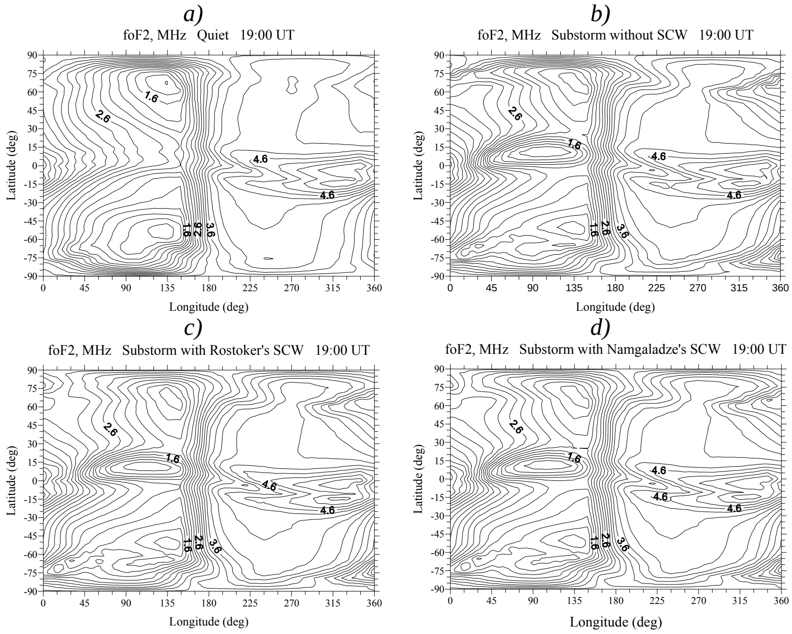

Fig. 8. Model calculated maps of the ionospheric *F2*-layer critical frequency *foF2* in 1 h after the substorm beginning: a) quiet conditions, b) without take into account SCW, c) and d) with take into account SCW in the statement of Rostoker, Friedrich, 2005 and Volkov, Namgaladze, 1996, accordingly.

Summary

1. The most essential changes of electron concentration in the ionosphere *F*-region during geomagnetic disturbances occur in a high-latitude ionosphere.
2. During substorm the stratification of the main ionospheric trough, its displacement to the equator and the deepening of the trough bottom are possible.
3. We shown that the stratification of the main ionospheric trough occurs both on the substorm expansion phase and on the recovery phase.
4. We shown the formation of polar ionization patches during substorm in concentration of hydrogen ions at height of 1500 km.
5. During substorm the displacement of light ion trough to the equator and the trough bottom deepening are possible.
6. The novelty of calculation results consists that all parameters of the upper Earth's atmosphere are simulated self-consistently. It allows describing adequately the observable phenomena existent in the nature owing to the account of the magnetospheric convection electric field penetration to the middle and low latitudes, the disturbances of dynamo electric field, the variations of global thermospheric circulation and neutral atmosphere structure, and heat balance of upper atmosphere.

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