MODIFICATION OF CONDUCTANCE DUE TO THE ACCELERATION OF THE IONOSPHERIC MEDIUM

МОДИФИКАЦИЯ ПРОВОДИМОСТИ В НИЗКОШИРОТНОЙ ИОНОСФЕРЕ, ОБУСЛОВЛЕННАЯ УСКОРЕНИЕМ ПЛАЗМЫ

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Предложен новый метод оценки влияния пондеромоторных сил на глобальное распределение электрических полей и токов в ионосфере Земли. Педерсеновская и холловская проводимости модифицируются для учета влияния ускорения проводящей среды с токами. Показано, что токи в слое F_2 существенно уменьшаются, если процессы длятся несколько часов. Эффект особенно важен для ночной низкоширотной ионосферы. Для количественного анализа эффекта использована Международная справочная модель ионосферы. Эта эмпирическая модель дает область с высокой каулинговской проводимостью не только в слое E, но и в слое F_2 ночной ионосферы. Анализируемый эффект уменьшает проводимость в слое F_2 на порядок, что делает проводимость ближе к наблюдаемым соотношениям между электрическими полями и токами на геомагнитном экваторе.

1. Introduction

The ionosphere is usually considered as a conductor with a given conductivity distribution when global electric fields and currents are simulated. Considering the high conductivity in the direction of the magnetic field, a two-dimensional approach is appropriate. The magnetic field lines are equipotentials and the ionospheric conductor may be represented by Pedersen and Hall conductances which are equal to integrals along magnetic field lines of the corresponding local conductivities s_P, s_H [7].

If the conductor is moving, then Ohm's law is valid in the moving frame of reference. An additional term appears in the laboratory frame of reference that is proportional to the velocity. This kind of electric field generator is subject of the dynamo theory. The motion of the medium is mainly defined by neutral winds and it is slightly disturbed by the ponderomotive force in E region of the ionosphere since the density is large there. So, this conductor moves in the magnetic field and works as a magnetohydrodynamical generator. In contrast to the E region, the medium in the F region is guided by ponderomotive force that corresponds to a division of the ionosphere into dynamo and motor regions [8].

Here, we analyze the motion of the conducting medium, whose appearance is due to the electric and magnetic fields, and estimate how the electric current is changed due to its influence. This gives a quantitative description of the ionospherical region in that dynamo is changed by motor.

The concept of defining some effective conductivity which represents a moving conducting medium is not new. It is done by [1] under the assumption of a steady-state motion. But periods of unsteady state processes are often not short. The model [2] represents a modification of the Pedersen conductivity for an electric field which is harmonic in time. Our approach differs mainly in that an unsteady process is regarded as a relaxation to a new steady state after a moment when the electric field is changed. We add an analysis of integrated conductivities which is important for large scale electric fields.

2. The Conductor Motion

Let us consider a homogeneous conductor which moves in magnetic $\vec{B}$ and electric $\vec{E}$ fields. Let us split vectors $\vec{E}$ into field-aligned components $E_{\|}$ parallel to the magnetic field and the normal components $\vec{E}_n$. The Ohm's law is valid in the rest frame of reference,

$$j_{\|} = s_{\|} E_{\|} \tag{1}$$

$$\vec{j}_n = s_P \vec{E}'_n - s_H [\vec{E}'_n \times \vec{B}] / B \tag{2}$$

$$\vec{E}'_n = \vec{E}_n + [\vec{u}_n \times \vec{B}], \tag{3}$$

where $\vec{j}$ is the current density, quantities $s_P, s_H, s_{\|}$ are the Pedersen, Hall and field-aligned conductivities, $\vec{u}$ is the conductor velocity, r is the mass density. We use SI units. In the case of interest, the electric field and velocity are normal to the magnetic field. The equation of motion is,

$$r \frac{d\vec{u}_n}{dt} = [\vec{j}_n \times \vec{B}], \tag{4}$$

If the process under analysis covers time t_0, it is natural to define an average values of the conductivities, which can be calculated on the base of the solution for the problem (1-3) with zero velocity at the moment t_0, as it is done in [5],

$$< s_P >= s_P \frac{t}{t_0}(1 - \exp(-t_0 / t)), \qquad < s_H > = s_H \exp(-t_0 / t). \tag{5}$$

3. Empirical Model of the Main Ionospheric Parameters

Our calculations are based on the following empirical models: The International Reference 2001 (IRI), the Mass Spectrometer Incoherent Scatter 1990 E (MSISE), the International Geomagnetic Reference Field 1945-2010 (IGRF-10). We used Fortran software of these models from the web page of NASA's Space Physics Data Facility [10].

The concentration of the main ions O^+, O_2^+, NO^+, and electrons, as well as their temperatures, we define by IRI. To include the height region of 80-100 km we choose the model [4] among those included to IRI. All other alternatives inside IRI are solved as a choice of standard versions. The main neutral gases N_2, O_2, O concentrations, we define by the MSISE model [9]. The model IRI demonstrates the convergence of electron, ions and neutrals temperatures, when the height decreases to 120 km. This permits to define a common temperature. We use the MSISE model to define the temperature below 120 km because it can not be done by IRI. We calculate the collision rates of the electrons and ions in accordance with [3] and [11]. Then the components of the conductivity tensor by usual formulae e.g. [8].

Typical space distributions of the values of the parameter t in dependance of of the period of acceleration t_0 are presented in [5] as well as modified values of Pedersen and Hall conductivities. Here we concentrate on the modification of their integrals along magnetic field lines, which are refereed to as Pedersen and Hall conductances Σ_P, Σ_H.

4. Modification of the Ionospheric Conductance

In the previous section, the conductances Σ_P, Σ_H are defined for a magnetic field line. We identify a field line by the height h of its position above some point with given geomagnetic coordinates. The conductances Σ_P, Σ_H as functions of h are shown in Fig. 1 a, b, respectively. Midnight values above the point with geomagnetic coordinates $q = 90^o, j = 180^o$ are presented at a taken moment of universal time. Fig. 1 c presents the midnight Cowling conductance $\Sigma_C = (\Sigma_P^2 + \Sigma_H^2) / \Sigma_P$, which is important for theories of equatorial electrojets. Since the height distributions of s_P and s_H differ from each other, Σ_C

is not equal to the integral of the local Cowling conductivity $s_C = (s_P^2 + s_H^2)/s_P$ which is sometimes used instead of Σ_C.

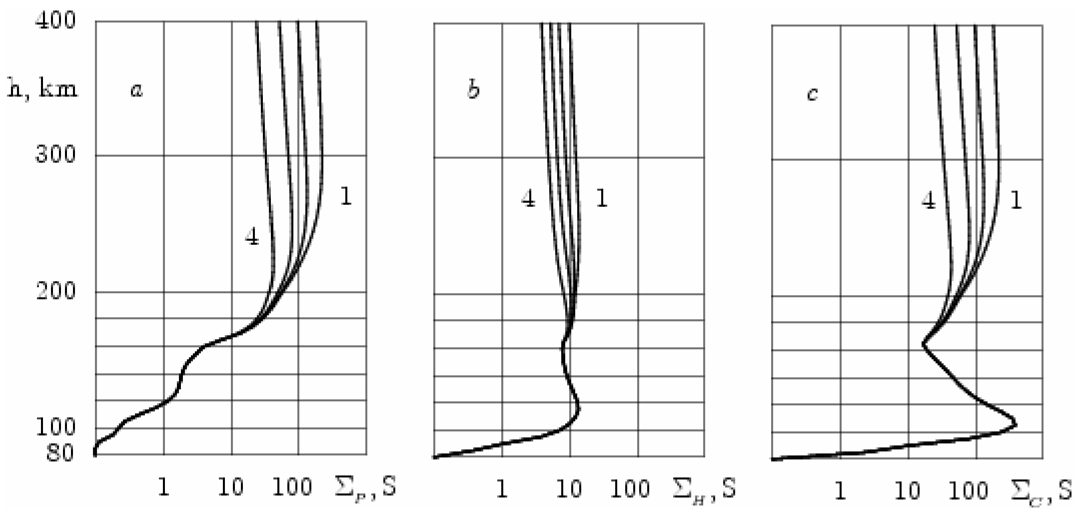

Fig.1. The height distributions of the conductances $\Sigma_P, \Sigma_H, \Sigma_C$. Midnight values above geomagnetic equator. The curves 1 present the original $\Sigma_P, \Sigma_H, \Sigma_C$ and the curves 2, 3, 4 correspond to the processes with $t_0 = 1/3, 1, 3$ hours. The ordinate h is the height at which the magnetic field line crosses the geomagnetic equator.

The curves marked with number 1 present the original $\Sigma_P, \Sigma_H, \Sigma_C$ and the curves 2, 3, 4 correspond to the processes with $t_0 = 1/3, 1, 3$ hours. As it is seen in Fig. 1 all three conductances decrease significantly in the night-side ionosphere. The effect under consideration in fact cancels the second conducting layer, the conductance of which for the short-term processes is larger than the conductance of the layer below 160 km. Since the Pedersen conductance below 160 km is small, its 30 times decrease above 200 km is very important.

Fig. 2 shows the difference between night conductances for short-term and long-term processes. We use a logarithmic scale for the conductances in units of Siemens. The values of Σ to neighboring contours differ $\sqrt[3]{10}$ times which is approximately twice. Conductance distributions at the base surface near the geomagnetic equator are presented. The abscissa is the geomagnetic longitude j_m and the ordinate is the height at which the magnetic field line crosses the base surface. Only the night half of the geomagnetic equator is presented. The left and the right panels of Fig. 2 present $\Sigma_P, \Sigma_H, \Sigma_C$ for short-term and long-term process of $t_0 = 3$ hours.

Fig. 2 shows that the conductances decrease one order of magnitude above 180 km in the whole night-side low-latitude ionosphere for 3 hours long processes as compared to the short-term ones. This is also shown in Fig. 1.

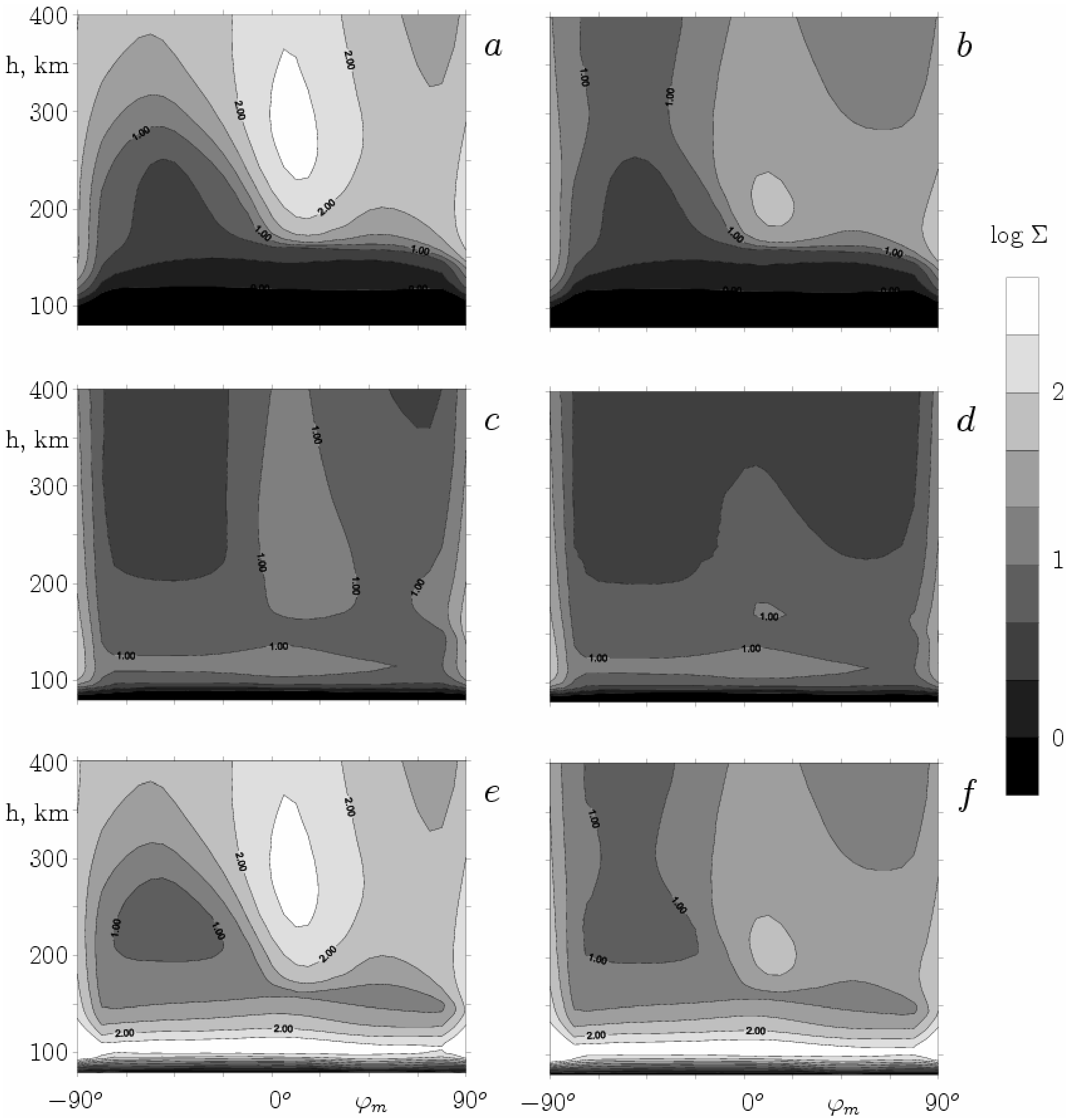

Fig.2. Conductance distributions above the night half of the geomagnetic equator. Left panels show conductances for a short-term process. Right panels show conductances for a long-term process, for which modifications of the conductivities are done for $t_0 = 3$ hours. Panels a, b are for $\log_{10} \Sigma_P$, panels c, d are for $\log_{10} \Sigma_H$, panels e, f are for $\log_{10} \Sigma_C$, where conductances in S units are used. The color scale is common for all panels. Common color is used for $\Sigma < 1\mathrm{S}$ and the contours $\Sigma < 1\mathrm{S}$ are not plotted.

The main result of the analyzed acceleration is that for the long-term processes, the night-side height distributions of the conductances become similar to the day-side ones with 30 times less scale, as it takes place in the middle-latitude ionosphere. This is precisely the property which is used practically in all models of the low-latitude ionospheric conductance. Fig. 2 shows that this is wrong for the short-term processes, but indeed, the analyzed acceleration of the medium permits to ignore the conductance of the higher layer for the long-term processes.

It is also important to note that the conductances in the night-side low-latitude ionosphere are much larger than it can be expected if one extrapolates their properties from the middle-latitudes to low latitudes.

We can summarize the results of the section as the expectation of essential modifications of the model electric fields and currents in the low-latitude ionosphere compared to the models which use less detailed conductivity models than IRI gives. Our models [6] are among the latter.

For the long-term processes the modification of the traditional models may be moderate because on one hand the IRI-2001 model gives the second night-side layer of high conductance, and on the other hand, the acceleration of the medium reduces current in such a layer.

5. Discussion

The proposed modification of the local conductivity according to formulae (5) is based on the assumption (4) that no force but the ponderomotive one accelerates the medium. The ponderomotive force above the geomagnetic equator may be vertical as well as horizontal. The vertical movement of the ionospheric medium can break pressure balance stronger than the horizontal movement. In spite of that, such a motion due to an Eastern or Western electric field is often observed above the geomagnetic equator as the fountain effect or super-fountain effect during storm time [12]. Pressure and friction are supposed to be unchanged in our model. Conversely, the original local conductivities s_P, s_H remain unchanged if the ponderomotive force is negligible. The adequateness of one of these opposite assumptions can be proved only in the frame of a more general model, because of the fact that pressure and other parameters may be changed as a result of the motion.

If we have only the simplified model of the ionosphere that is a global conductor with given conductivity and velocity distributions, it is useful to calculate the electric fields and currents twice, for given s_P, s_H and for effective $< s_P >$, $< s_H >$. If the results are different, a qualitative analysis of acceleration is needed. In special cases, this supports one of the alternatives. For example, a considerable reduction of the effective conductivity in the F_2 layer must be always done. In general, a quantitative simulation of the motion is necessary.

Conclusions

The IRI model gives the second high conductance layer in the night-side low-latitude ionosphere in addition to the main conductor in the E layer. It reduces the electric field and equatorial electrojets, but intensifies the night-side currents in the F_2 layer during short-term events. These currents occupy the regions which are much wider than those of the equatorial electrojets. The local conductivity is to be reduced with formulae (5) to take into account the influence of the ponderomotive force. The corresponding acceleration of the conducting medium reduces the currents in the F_2 layer. The effect is a maximum in low-latitude night-side ionosphere.

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