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THE EFFECT OF IONOSPHERE INHOMOGENEITY ON MAGNETIC PULSATION POLARIZATION. 1.

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1. Introduction

When in the ionosphere a dipole source appears which electric field changes in time with frequency in the range of geomagnetic pulsations, the polarized magnetic disturbances on the ground can be detected. This source may be a patch of enhanced conductivity in the ionosphere. It may be formed in a natural way, for example, due to the electron precipitations [*Maltsev et al.*, 1974; *Oguti et al.*, 1984] or artificially, for example, due to the ionospheric heating by the modulated powerful HF radio wave [*Stubbe and Kopka*, 1985; *Lotz-Iwen*, 1983].

Authors investigating the geomagnetic pulsations usually suggest that pulsation generation happenes in the horizontally homogeneous ionosphere what simplifys the problem. Presence of an ionospheric inhomogeneity can influence essentially the polarization characteristics of the magnetic pulsations. *Glassmeier* [1984] studied numerically the influence of one kind of ionospheric inhomogeneity for the incident Alfven wave.

The aim of this work is to study the ground distribution of the polarization ellipses of the magnetic pulsations generated by an ionospheric dipole source for the case of the inhomogeneous conductivity of the ionosphere.

2. Magnetic pulsations generated by the dipole source in the inhomogeneous ionosphere: a case of large-scale strip

At first let the ionosphere be divided by a straight line into two parts with different height-integrated ionospheric conductivities Σ_0 and Σ_2. When in any part the dipole source appears, at the separating boundary the supplementary polarization electric charges arise. The supplementary polarization electric field generating additional currents inside and outside the source region arises as well. As a result the distribution and magnitude of the total ionospheric current disturbance changes and hence, so does the magnetic effect on the ground.

2.1. In the ionosphere

Lyatsky and Maltsev [1983] have solved this problem on the ionosphere level and have got the potential of electric field and current function of equivalent ionospheric currents for this case. The "method of reflection" was used. It is convenient to choose in the ionosphere the complex coordinate system w=x+*i*y according to Lyatsky and Maltsev [1983]. Then the conductivities are written in the complex form $\Sigma=\Sigma_p - i\Sigma$, where Σ_p and Σ_H are the Pedersen and Hall conductivities correspondingly. Let the line, separating the ionosphere into two regions with different conductivities coincide with the real axis, and the source being a circle with radius a and conductivity disturbances $\Delta\Sigma_1$ be at a distance of d_0 from the coordinate centre (Fig.1). The polarization of the ionospheric source is assumed to be circular. In each region we search for a potential φ and a current function ψ as follows: $\varphi = Re\ F$, $\psi = Im\ (\Sigma^* F)$, where F is a complex potential determined by the dipole moment of the source and the moments of the "reflected" dipoles, and the symbol $*$ means the complex conjunction. The expressions for F in each region are determined from the continuity equations for φ and ψ on the border of the regions (Eqs.(5.100) and (5.101) in *Lyatsky and Maltsev* [1983]. We shall use for analysis the difference between them and the potentials and current functions calculated for the homogeneous ionosphere. This difference defines the disturbance due to inhomogeneity.

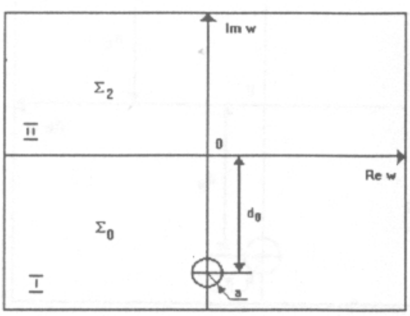

Fig.1. Scheme of considering ionosphere region with complex coordinate system.

The distributions of the disturbances of ψ in the ionosphere are calculated for the case: Σ_0(S)=5-5*i*; Σ_2(S)=30-30*i*; for conductivity of the source Σ_1(S)=5-5.1*i* and for wave conductivity of the magnetosphere Σ_w=0.05 S; for the radius of the source a=10 km, and its distance from the border d_0 = 50 km. The distributions of ψ disturbances are symmetrical relatively the boundary and have a form of two vortices with focuses located at the boundary. The position of these vortices depends on the source polarization.

2.2. On the ground

In Fig.2 the hodograms of the magnetic effect on the ground calculated from ψ disturbance are presented. The disturbance on the ground is symmetrical respectively to the strip border and to the line crossing the source projection point and perpendicular to the strip border. It is seen that on the ground far from the boundary the disturbance of ΔB has usual circular polarization, then the total magnetic vector is polarized as for the homogeneous ionosphere. It is because of additional current sources associated with the inhomogeneity are situated on the boundary, and far from it the influence of these sources is negligible.

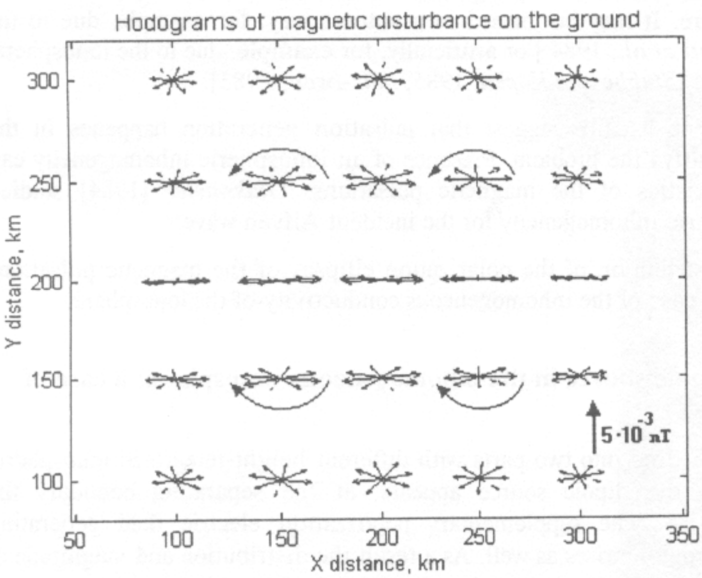

Fig.2. Distribution of magnetic disturbance vectors on the ground calculated for 8 time moments. The separating line is at y=200 km, the coordinats of source (x, y) are equal to (200, 150) km. The rotation sense is indicated by arrows.

When one moves to the boundary, the polarization becomes elliptical and then linear with dominating direction of ΔB along the boundary. Here polarization vector changes rotation sense. Inside the source region on the ground the disturbance of ΔB has the same rotation sense as in the source in the ionosphere, but it has contrary sense of rotation on the other side from the boundary.

The calculations show that for the values of ambient conductivities (outside and inside the strip) $\Sigma_{P0} = \Sigma_{H0} = 5$ S; $\Sigma_{P2} = \Sigma_{H2} = 30$ S the maximum magnetic effect on the ground due to the ionosphere inhomogeneity reaches up to 40% of the magnetic disturbance generated by the same source in the homogeneous ionosphere with conductivities Σ_{P0} and Σ_{H0}

These results are valid for the case of a finite but sufficiently large width of the ionospheric region with enhanced conductivity. So we called this case as large-scale strip case.

3. Magnetic pulsations generated by the dipole source in the inhomogeneous ionosphere: a case of meso-scale strip

3.1. In the ionosphere

Let the ionospheric inhomogeneity in form of a strip with d_s width and Σ_2.conductivity stretches parallel to the real axis of the complex coordinate system and be located at a distance of d_0 from the source centre (Fig.3.).

For determination of the complex potentials in each ionosphere region we use also the "method of reflection". Now the potential in each region I, II and III we look for as a series of the potentials of dipoles obtained by successive "reflections" of the initial dipole from each boundary of the strip: The coefficients of these series, that are the dipole moment values, are constructed such so that on the strip boundaries the continuity conditions for electric potential and current function were met. For considered case the complex potentials and current functions for the regions I, II and III can be written in the form:

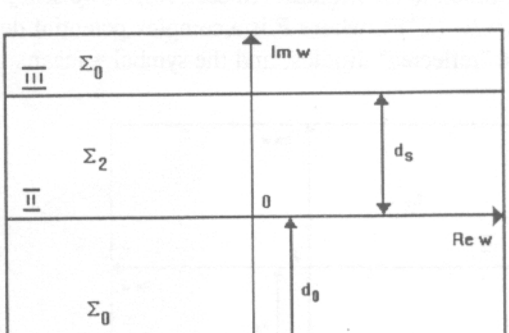

Fig.3. Scheme of ionospheric region of interest with complex coordinate system.

$$F_I = \frac{q_0}{w+id_0} + \frac{q_r}{w-id_0} + \sum_{n=1}^{\infty} \frac{\left|\Sigma_2-\Sigma_0\right|^{2(n-1)}\left(\Sigma_2-\Sigma_0\right)\left(\Sigma_0+\Sigma_0^*+2\Sigma_w\right)\left(\Sigma_2+\Sigma_2^*+2\Sigma_w\right)q_0^*}{\left|\Sigma_0+\Sigma_2^*+2\Sigma_w\right|^{2n}\left(\Sigma_2+\Sigma_0^*+2\Sigma_w\right)\left(w-i\left(2nd_s+d_0\right)\right)}$$

$$F_{II} = \frac{q'}{w+id_0} + \sum_{n=1}^{\infty} \frac{\left|\Sigma_2-\Sigma_0\right|^{2(n-1)}\left(\Sigma_2-\Sigma_0\right)\left(\Sigma_0+\Sigma_0^*+2\Sigma_w\right)q_0^*}{\left|\Sigma_0+\Sigma_2^*+2\Sigma_w\right|^{2n}\left(w-i\left(2nd_s+d_0\right)\right)} +$$

$$+\sum_{n=1}^{\infty} \frac{\left|\Sigma_2-\Sigma_0\right|^{2n}\left(\Sigma_0+\Sigma_0^*+2\Sigma_w\right)q_0}{\left|\Sigma_0+\Sigma_2^*+2\Sigma_w\right|^{2n}\left(\Sigma_0+\Sigma_2^*+2\Sigma_w\right)\left(w+i\left(2nd_s+d_0\right)\right)}$$

$$F_{III} = \frac{q''}{w+id_0} + \sum_{n=1}^{\infty} \frac{\left|\Sigma_2-\Sigma_0\right|^{2n}\left(\Sigma_0+\Sigma_0^*+2\Sigma_w\right)\left(\Sigma_2+\Sigma_2^*+2\Sigma_w\right)q_0}{\left|\Sigma_0+\Sigma_2^*+2\Sigma_w\right|^{2(n+1)}\left(w+i\left(2nd_s+d_0\right)\right)}$$

$$\psi_I = \mathrm{Im}\left[\left(\Sigma_0^*+\Sigma_w\right)F_I\right];\ \psi_{II} = \mathrm{Im}\left[\left(\Sigma_2^*+\Sigma_w\right)F_{II}\right];\ \psi_{III} = \mathrm{Im}\left[\left(\Sigma_0^*+\Sigma_w\right)F_{III}\right]$$

We calculated these values numerically for the case: the undisturbed conductivity Σ_0(S)=5-5i; the wave conductivity Σ_w = 0.05 S; the conductivity of the strip Σ_2(S) = 30-30i; the disturbed conductivity in the circle Σ_1(S) = 5-5.1i; a=10 km; d_0 =50 km; ds =40 km. For this case the currents are concentrated into the narrow strip where the current streams are formed. The spatial distribution of ψ becomes strongly asymmetrical with respect to the strip boundary unlike the previous large-scale case. Now the currents have four vortices structure in contrary to two vortices one for the case of large-scale strip.

3.2. On the ground

The described distribution of the currents produces a complicated picture of the magnetic variations on the ground.

In Fig.4 the calculated hodographs of the magnetic disturbances on the ground for the dipole source with the circular polarization are shown. The distribution of the polarization ellipses becomes rather complicated indeed. The line separating the regions of the different rotation senses does not coincide now with the strip border as it did in the previous case. The main axes of the polarization ellipses near the separating line are directed almost along it.

We obtained that for the strip of 40 km width with conductivities $\Sigma_{P2}=\Sigma_{H2}$ =30 S in the ionosphere with conductivities $\Sigma_{P0} = \Sigma_{H0}$ = 5 S the maximum magnetic effect due to the inhomogeneity reaches up to 30%.

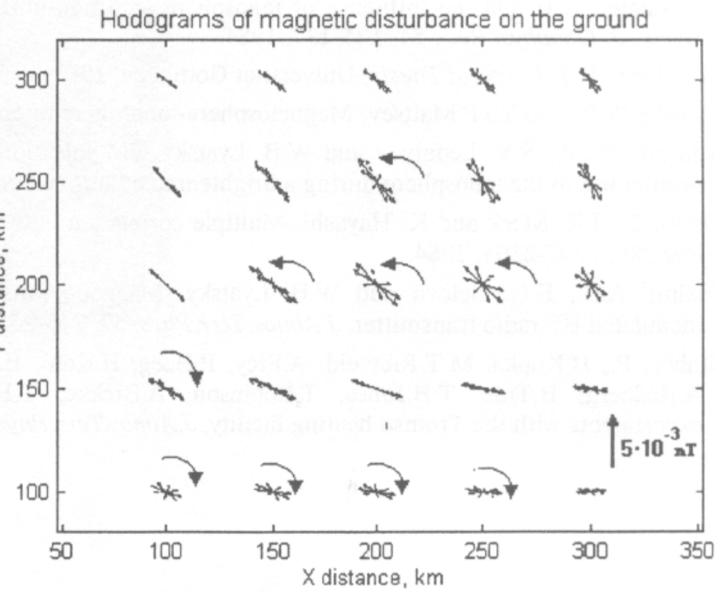

Fig.4. Distribution of magnetic disturbance vectors on the ground calculated for 8 time moments. The separating line is at y=200 km, the coordinats of source (x, y) are equal to (200, 150) km. The rotation sense is indicated by arrows.

4. Results and discussion

In the paper the magnetic disturbance polarization in the ionosphere and on the ground from a dipole circular polarized source in the inhomogeneous ionosphere has been considered for two cases.

In the case of large-scale strip the difference current and magnetic disturbances have the following features:

a) The polarization ellipse distribution in the ionosphere and on the ground is symmetrical relatively to the strip boundary.

b) On the ground this boundary is a line separating the regions with different vector polarization rotation sense. Outside the strip the polarization vector rotates as inside the source; inside the strip this vector rotates in the opposite direction.

c) The polarization on this line is linear, and the polarization vector ΔB is directed along the line. While moving away from the separation line, the polarization becomes elliptical and then circular.

For the meso-scale strip the difference magnetic disturbance on the ground has the following characteristics:

a) The magnetic polarization ellipse distribution on the ground becomes essentially asymmetrical relatively to the strip .

b) The line separating the regions with different rotation senses of the polarization vector becomes curved with respect to the strip projection on the ground.

In the paper the expressions for potentials of polarization electric field and current functions of ionospheric disturbed currents are obtained for the ionosphere with strip inhomogeneity.

The results of the paper may be important both for interpretation of data of natural magnetic pulsation polarization and for study of artificial magnetic pulsations generated by the ionosphere heating. It should be mentioned that the "method of reflection" used here and, consequently, the obtained results are valid for the case when the dimensions of the source (patch) are sufficiently small.

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