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Magnetized Rossby waves in mid-latitude ionosphere F-layer

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We present the results of study of the ionosphere quasi-periodic perturbations on the basis of the analysis of the critical $f0F2$ frequency variations. The temporal scales of the perturbations are about 7 days and relative amplitude of the $f0F2$ perturbations are up to 40% of the averaged electron density value. It is assumed from the temporal scale and position that the critical $f0F2$ frequency variations are caused by Rossby wave-like disturbances with magnetic field influence on the ions. We studied the spatial and temporal scales of the waves at the F-layer altitudes on the basis of the mid-latitude ionosonde network measurements (Millstone Hill, Dyess, and Point Arguello stations data). The generalized Charney-Obukhov equation is proposed to describe the dynamics of the perturbations. We present the numerical model based on the full reduction algorithm for numerical solution of the dynamics equation.

Key words: plasma waves and instabilities, ionospheric disturbances, wave propagation

INTRODUCTION

The large-scale wave structures (Rossby waves) play an important role in energy balance and circulation of the atmosphere and in the oceans. Similar scale structures are often observed in the ionosphere as the quasi-periodic disturbances of the electron density and magnetic field variations [1, 6, 11, 12, 14]. We focus on the large-scale zonal ionospheric disturbances which propagate at fixed magnetic latitude [12]. These waves are mainly observed during the magnetic storms, substorms [5], earthquakes [8, 13] as well as during man-made explosions [4, 9].

Magnetic field ionospheric wave disturbances (MFIWD) are observed in the F-region of the ionosphere at mid-latitudes. They propagate along the magnetic parallels [8, 12]. Amplitudes of geomagnetic pulsations can vary from several units to several tens of nT in these waves. The atmospheric planetary waves are generated in the troposphere and in the stratosphere. Their penetration into the F-region is difficult because of the strong shielding effect of stable ionospheric zonal winds (especially in summer) [7], so that the source must exist in the F-region of the ionosphere. In [7] such source is discussed to be located in the ionosphere. The fundamental factor for the processes of global scale is the latitudinal inhomogeneity of the geomagnetic field, and MFIWD is a new branch of natural oscillations of F-layer caused by this mechanism. These disturbances manifest themselves in a form of background oscillations for natural conditions.

The Rossby waves are often observed in the neutral Earth's atmosphere. Usually they are observed as pressure variations with periods of 2, 5, 10 and 16 days [2]. The seasonal modulation of planetary waves activity is also observed [3]. Rossby waves usually propagate westward. But under some conditions the Rossby waves can have stationary nature (velocity along latitude is almost zero) or even can be driven to the east. Their appearance is observed in South Polar Region total ozone data [2]. The model and physical interpretation of ionosphere parameters variations (e. g. electron density) remains among the central problems of the Earth's ionosphere study. The critical frequency ($f0F2$) of F2 ionosphere layer is the mostly reliable measure of a maximum electron concentration (N_m) in F2 layer [1]: $N_m = 1.24 \cdot 10^4 (f0F2)^2$, where $f0F2$ is expressed in MHz, N_m in cm^{-3}. Due to the wide application of ionospheric sounding method a huge amount of data on seasonal, daily, latitudinal variations of the electron concentration has been accumulated.

In the present paper we propose the theoretical model of large-scale atmosphere waves to explain periodic changes of critical frequency, observed by ionospheric sounding.

MAGNETIC FIELD IONOSPHERIC WAVE DISTURBANCES

The analysis of f0F2 variations shows the existence of the waves with periods about 7 days with relative amplitude up to 40% of the unperturbed value

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of f0F2. Their behaviour can not be explained by solar or geomagnetic activity. Taking into account a temporal scale, time dynamics and theoretical statements, it is possible to assume that $f0F2$ modifications are stimulated by Rossby-like waves. We analysed the spatial and temporal properties of planetary waves at heights of ionospheric F layer on the basis of wide ionosonde array. The types of the waves have been defined. Numerical model for study of the electron concentration dynamics in ionosphere F-layer in the geostrophic approximation is proposed.

Initial equations of planetary electromagnetic waves in F-region on the equator under the condition of 2-liquid MHD with mechanical movements have the following form:

$$\begin{cases} \frac{\partial \vec{U}}{\partial t} = \frac{1}{4\pi\rho_0}\left[\left[\vec{\nabla}\times\vec{H}\right]\times\vec{H}\right] + \\ \qquad +2\left[\vec{U}\times\vec{\Omega_0}\right] - \left(\vec{U}\vec{\nabla}\vec{U}\right), \\ \frac{\partial \vec{H}}{\partial t} = -c\,rot\vec{E} = rot\left[\vec{U}\times\vec{H}\right] - \\ \qquad -\frac{c^2}{4\pi}\left[\vec{\nabla}\times\left[\hat{\sigma}^{-1}\times rot\vec{H}\right]\right], \\ div\vec{V} = 0, \\ div\vec{H} = 0, \end{cases} \quad (1)$$

where $\vec{U}$ and $\vec{V}$ are the velocities along x and y directions (Fig. 1), $\vec{H} = \vec{H}_0 - \vec{h}$, where $\vec{H}_0$ is the intensity of the Earth's geomagnetic field, $\vec{h}$ - is the variation of intensity of Planetary Electro-Magnetic Waves (PEMW), $\hat{\sigma}$ is the conductivity tensor, Ω_0 is the planet rotation frequency, $F_A = \frac{1}{c}\left[\vec{j}\times\vec{H}\right] = \frac{1}{4\pi}\left[\left[\vec{\nabla}\times\vec{H}\right]\times\vec{H}\right]$ is the Ampere force, $rot\vec{H} = \frac{1}{c}\frac{\partial\vec{E}}{\partial t} + \frac{4\pi}{c}\vec{j} \approx \frac{4\pi}{c}\vec{j}$, then $\vec{j} \approx \frac{c}{4\pi}rot\vec{H} \equiv \frac{c}{4\pi}\left[\vec{\nabla}\times\vec{H}\right]$. In the moving coordinate system $\vec{E} = \vec{E} + \frac{1}{c}\left[\vec{U}\times\vec{H}\right]$, from which one can get: $\vec{j} = \hat{\sigma}\left(\vec{E} + \frac{1}{c}\left[\vec{U}\times\vec{H}\right]\right)$.

The final dimensionless output system has the form:

$$\begin{cases} \frac{\partial\bar{\Omega}_z}{\partial t} - r_1\frac{\partial\bar{\xi}}{\partial\bar{x}} - r_2H_0\frac{\partial\bar{h}_z}{\partial\bar{x}}\left[\frac{\partial\bar{\xi}}{\partial\bar{y}}\frac{\partial\bar{\Omega}_z}{\partial\bar{x}} - \frac{\partial\bar{\xi}}{\partial\bar{x}}\frac{\partial\bar{\Omega}_z}{\partial\bar{y}}\right] + \\ \qquad +r_2\left(\bar{H}_0\bar{J}_{exty} + \bar{H}_{0y}\frac{\partial\bar{J}_{extz}}{\partial\bar{y}}\right), \\ \frac{\partial\bar{h}_z}{\partial t} - H_0\frac{\partial\bar{\xi}}{\partial\bar{x}} - D\frac{\partial^2\bar{h}_z}{\partial\bar{y}^2} = \\ \qquad = \left(\frac{\partial\bar{\xi}}{\partial\bar{y}}\frac{\partial\bar{h}_z}{\partial\bar{x}} - \frac{\partial\bar{\xi}}{\partial\bar{x}}\frac{\partial\bar{h}_z}{\partial\bar{y}}\right) + D\frac{\partial\bar{J}_{extx}}{\partial\bar{y}}, \\ \bar{\Omega}_z = -\Delta_{\perp}\bar{\xi}, \end{cases} \quad (2)$$

where $\Omega_z = \left(rot\vec{U}\right)_z = \frac{\partial U_y}{\partial x} - \frac{\partial U_z}{\partial y}$, $U_x = \frac{\partial\xi}{\partial y}$, $U_y = \frac{\partial\xi}{\partial x}$, ξ is the stream function, J_{ext} is the external current, $D = \frac{c^2}{4\pi\sigma_\perp}\frac{H_0}{L_0^2}\frac{t_0}{H_0} = \frac{c^2/U_0^2}{4\pi\sigma_\perp t_0}$, $H_0 = -2\frac{L_0}{R}$, $r_1 = \frac{2}{R}\Omega_0 t_0 L_0$, $r_2 = \frac{V_{AL}^2}{U_0}$, $U_0 = \frac{L_0}{t_0}$, $L_0 = 1000\,\mathrm{km}$, $t_0 = 100\,\mathrm{s}$.

We used (2) to study numerically the dynamics of MFIWD with the total reduction algorithm presented in [10]. The linear approximation gives planetary waves, which propagate along the fixed magnetic latitude. In case of taking into account the nonlinearity the robust vortex solution is present.

EXPERIMENTAL STUDY

We analysed the properties of planetary scale waves propagation of ionosphere F-layer altitude by use of the critical frequency $f0F2$ observations. We used observations from 3 ionospheric stations: Dyess, Millstone Hill and Point Arguello. Geographic coordinates of the stations are listed in Table 1.

Table 1: Locations of the ionosphere sounding stations.

Station	URSI code	Latitude	Longitude
Dyess	DS932	32.4	260.3
Millstone Hill	MHJ45	42.6	288.5
Point Arguello	PA836	35.6	239.4

We observde a significant increase of the low-frequency wave activity during the summer time. We analysed the manifestations of the low-frequency wave activity with typical periods of 5–7 days during May–September 2005. Analysis of the simultaneous observations by three ionosphere sounding stations allowed us to estimate the spatial scale of the planetary waves, their wave-vector, and phase velocity. We estimated the spectral power of the signal by use of the Morley wavelet and the Blackman-Turkey algorithm.

Fig. 2 (left) shows the F2-layer critical frequency $f0F2$ values obtained during May 2005 by use of the observations on the ionosphere sounding station Dyess. Spectra of the $f0F2$ fluctuations are shown in Fig. 2 (centre). Results of the wavelet transform application for these measurements are shown in Fig. 2 (right). Periods obtained for different stations are 4.7–6.2 days (Fig. 3). The phase shift for a signal filtered near wave frequency enables the estimation of spatial scales wave activity. The analysis of the phase shift shows that the longitudinal wave with a wave number 2 is observed. A phase velocity is

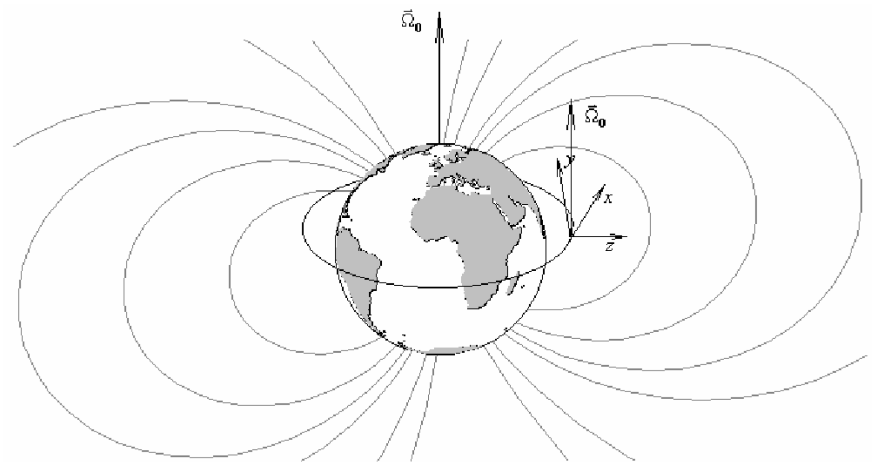

Fig. 1: Magnetic dipole coordinate system and the local coordinate system used with the β-plane approximation.

32.3°/day, or about 150 km/hour. The wave amplitude can achieve 40% from unperturbed frequency $f0F2$.

RESULTS AND CONCLUSIONS

We obtained and analysed the system of equations for the plasma dynamics at the F-layer by use of β-plane approximation with the magnetic field influence on ions. The generalized Charlie-Obukhov equation is obtained by use of the geostrophic approximation with effects of the charged particle motion and electromagnetic forces. We used the conservative numerical simulation algorithm based on the total reduction technique to study the Planetary Electro-Magnetic Waves dynamics at the middle magnetic latitudes [10]. The considered observed waves seem to be slow magnetized Rossby-like waves.

The obtained simulation results are verified by the ionosphere sounding stations measurements of the $f0F2$ critical frequency. We present the results of the analysis of the three ionosphere sounding U.S. stations: the periods are from 4 to 7 days; the wavelength is from 0.5 to 1 R_E; perturbation amplitude is up to 40% of the averaged electron density value. Wave properties show that the observed variations can be caused by wave-like disturbances at the F2-layer altitude similar to Rossby waves in the Earth's atmosphere but with interaction of charged particle with magnetic field.

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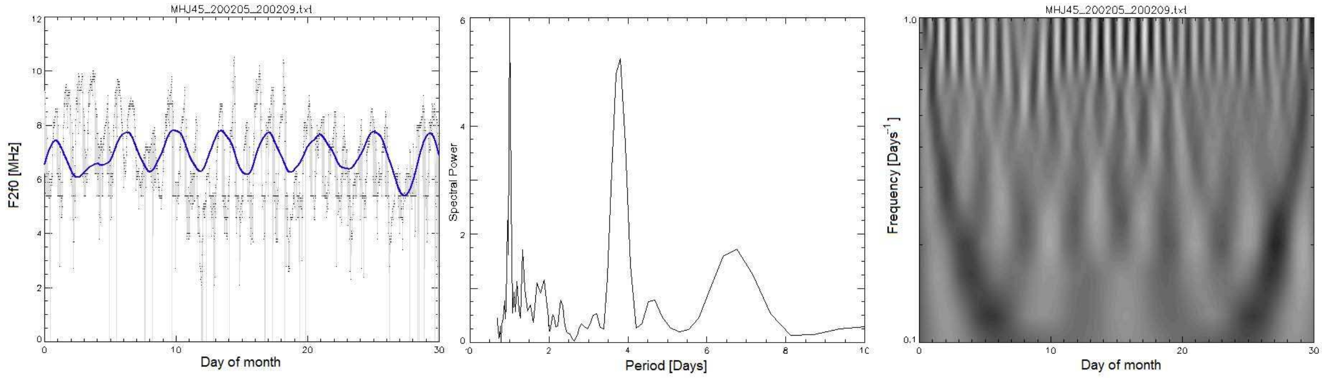

Fig. 2: Left: dynamics of the critical $f0F2$ frequency detected during May 2002 by ionosphere sounding at Millstone Hill (shown by dots); solid line shows the value averaged on two days interval. Centre: spectra of the $f0F2$ fluctuations. Right: wavelet spectra of the $f0F2$ perturbations (the real part of wavelet transform is shown).

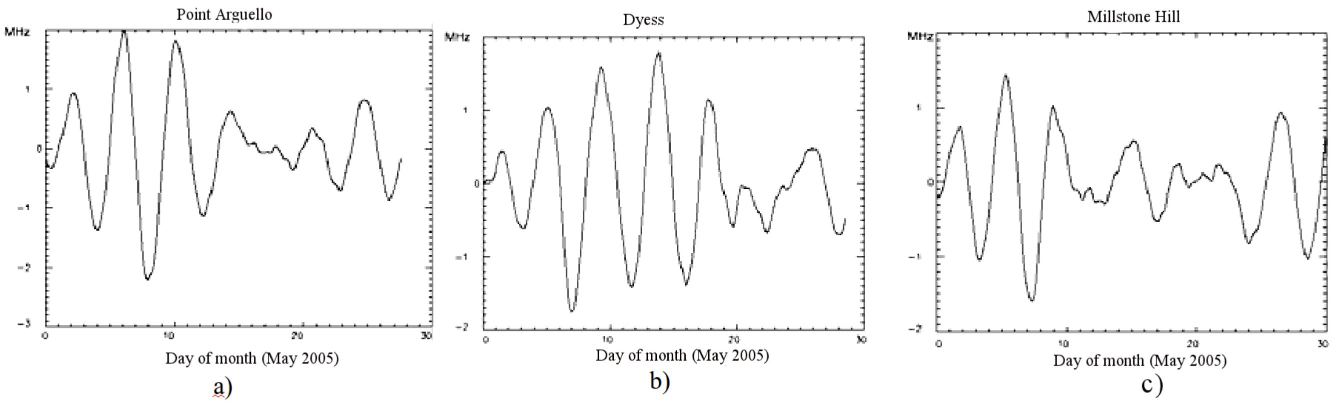

Fig. 3: Signal, filtered by the period of 5.5 days. a) Point Arguello, b) Dyess and c) Millstone Hill respectively. May 2005