EPSC Abstracts
Vol. 10, EPSC2015-357, 2015
European Planetary Science Congress 2015

Background Non-Uniform Wind Effect on Large Scale Zonal Flow Generation by ULF Modes

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Abstract

In the present work the features of generation of the large scale flows in the ionosphere on the background of inhomogeneous non-stationary winds is considered. From the equation of magnetized (modified by the geomagnetic field) Rossby type waves using multi-scale expansion the nonlinear equation of interaction of amplitudes of five different scale modes is obtained. These modes are: ultra low frequency (ULF) primary magnetized Rossby wave, its two satellites, long wavelength zonal mode and large scale background mode (inhomogeneous wind). The effects of nonlinearities (scalar, vector) in formation of the large scale zonal flows by magnetized Rossby waves with finite amplitudes in the dissipative ionosphere is studied. For this purpose the modified parametric approach is used. New mechanism of energy exchange between the small scale waves and large scale ones are revealed.

1. Introduction

Recently interest to generation of the large scale zonal flows, influencing the transfer processes in the atmosphere [9], magnetized plasma [10], in some astrophysical objects [11] has increased. Excitation of the anisotropic large-scale structures, such as the zonal flows, streamers and convective cells by comparably small scale turbulence is intensively studied in laboratory plasma [10], as well as in geophysical and astrophysical flows [11].

The different scale wave perturbations undergo amplification/generation at the presence of the background shear flow and the nonlinear effects appear important in their dynamics [19]. Nonlinear interaction of the waves with each other and medium can generate various nonlinear structures - comparably large scale zonal flows among them [17]. Theory of generation of the zonal flows by Rossby waves were developed in works [14,24] using the parametric formalism on the basis of three wave nonlinear interaction.

2. Model Equation for magnetized Rossby wave

For investigation of the interaction of the Rossby type waves with local inhomogeneous zonal wind the nonlinear equation of the dynamics of magnetized Rossby type structures in the ionosphere is used:

$$\left(\frac{\partial}{\partial\tau}+V_0(y)\frac{\partial}{\partial x}\right)(P-\Delta P)+(V_R+V_0^{"})\frac{\partial P}{\partial x}-b_{\perp 0}\frac{\partial^2 P}{\partial y^2} \qquad (1)$$
$$-b_{\perp z}\frac{\partial^2 P}{\partial x^2}+\nu\Delta^2 P=-V_R P\frac{\partial P}{\partial x}+J\left(P,\Delta P\right).$$

Here the following dimensionless variables are used:

$$\tau=2\Omega_{0z}t;\quad P=P/P_0;\ x,y=(x,y)/r_R;\ \alpha+\beta=\partial\overline{\Omega}/\partial y,$$
$$\alpha+\beta=(\alpha+\beta)r_R/\overline{\Omega};\ V_0^{"}=d^2V_0/dy^2;\ V_0=V_0/(2\Omega_{0z}r_R);$$
$$b_{\perp z}=b_{\perp z}/(2\Omega_{0z});\ b_{\perp z}=\sigma_\perp B_{0z}^2/(\rho_0 c^2),\ \nu=\nu/(2\Omega_{0z}r_R^2);$$
$$J(a,b)=\partial a/\partial x\cdot\partial b/\partial y-\partial a/\partial y\cdot\partial b/\partial x;\ b_{\perp 0}=\sigma_\perp B_0^2/(\rho_0 c^2),$$
$$b_{\perp 0}=b_{\perp 0}/(2\Omega_{0z}).$$

Equation (1) represents the generalized Charney-Obukhov-Hasegawa-Mima equation.

3. Multiscale representation of perturbed quantities

In the paper a five wave process is investigated – nonlinear interaction of comparably small scale initial pumping waves (magnetized Rossby waves), its two satellites, large scale zonal modes and more larger shear flows. Using standard decomposition formalism (multiscale expansion) for perturbed values we will have the following representation:

$$\hat{P}(x,y,t) = \hat{P}_0(y,k)e^{i(q_x x-\Omega t)} + \hat{P}_0^*(y,k)e^{-i(q_x x-\Omega t)},$$
$$\tilde{P}_0(x,t) = \tilde{P}_0 e^{i(k_x x-\omega_k t)} + \tilde{P}_0^* e^{-i(k_x x-\omega_k t)},$$
$$\tilde{P}_\pm(x,y,t) = \tilde{P}_\pm(y,k)e^{i(k_\pm x-\omega_\pm t)} + \tilde{P}_\pm^*(y,k)e^{-i(k_\pm x-\omega_\pm t)}.$$

Here $k_\pm = k_x \pm q_x$, $\omega_\pm = \omega_k \pm \Omega$; sign " * " denotes complex conjugate; the pairs $(\omega, \mathrm{k_x}\cdot\mathbf{e_x})$ and $(\Omega, \mathrm{q_x}\cdot\mathbf{e_x})$ – are frequencies and wave vectors of comparably small scale pumping wave and the large scale zonal flow, respectively.

4. Summary and Conclusions

In the presented paper nonlinear generation and further evolution of large scale zonal flows according to the small scale ULF magnetized Rossby waves with finite amplitude in a shear flow driven dissipative ionosphere is studied. Initial nonlinear dynamic Charney – Obukhov equations, containing a scalar as well as vector nonlinearity and describing the features of turbulent behavior of magnetized Rossby waves are obtained. Parametric approach and five wave presentation of the perturbations is used. On the basis of the dynamic equation the system of three connected equations for amplitudes of satellite waves and generated zonal modes at given profiles of pumping waves and background shear flow are obtained. On the basis of theoretical analysis of the corresponding system of equations for amplitudes of perturbations new features of energy pumping from comparably small scale ULF magnetized Rossby waves and shear flows into the large scale zonal flows and of nonlinear self organization of collective activity of the five waves in the ionopsheric medium.

From analysis it follows that comparably small scale magnetized Rossby waves appear modulationally unstable with respect to the large scale flows. This instability is accompanied with excitation of the large scale zonal flows.

This investigation has revealed a possible mechanism of generation, intensification (weakening) of the zonal flows by finite amplitude Rossby waves in the ionosphere by virtue of the local background flows depending on the parameters of this flow. Herewith, the background flow with approximately small amplitude stipulates development of modulation instability and intensification of the zonal flow generation, increasing growth increment. But strong shear flow sufficiently decrease instability increment and accordingly the process of zonal flow generation weakens.

Reinolds stress acts as initial mechanism for instability swinging. Spectral energy pumping from small scale Rossby wave and background shear flow into large scale zonal flow in the ionospheric medium. Thus magnetized Rossby wave type fluctuation can destabilized due to nonlinear five-wave interaction with simultaneous generation of the large scale zonal flows.

Acknowledgements

The work is done by support of grant No 31/14 of Shota Rustaveli National Science Foundation.

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