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Generation of Zonal Flow and Magnetic Field by Finite-Amplitude Electromagnetic Waves in the E Ionospheric Layer

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Planetary waves are large-scale modes with wavelengths $\lambda \sim 10^3 km$ having several days period. They are of interest because of their significant influence on the global atmospheric circulation. It is known that similar perturbations can exist in the ionospheric conductive layers. Observational data verifies the permanent existence of ULF EM planetary scale perturbations in the ionosphere. The majority of the ionospheric phenomena such as volcano eruptions, earthquakes, etc. are in the frequency range of planetary waves. Recently, forced oscillations of such kinds observed during magnetospheric storms. The presence of charged particles in the ionosphere enrich the class of possible low-frequency wave modes in the ionosphere.

We consider the weakly ionized ionospheric gas of the E-layer to consist of electrons, ions, and neutral particles. The E layer gas satisfies the condition n/N << 1 where n and N are the number densities for the charged particles and neutrals. The effects of the spatially inhomogeneous along latitudes geomagnetic field and Coriolis parameter must take into account, both of which are essential in case of ULF EM planetary waves.

The system of equations is obtained by taking the z-component of momentum equation (vorticity equation) and Maxwell's equations (magnetic induction equation) by taking into account the plasma conditions for the E-region allow to make some simplifications of the expression for the generalized Ohm's law. First, the ratio of the ion cyclotron frequency to the ion-neutral collision frequency is small, and thus the ions can be considered as unmagnetized. However, the electrons are magnetized.

We introduce a local Cartesian system of coordinates (x, y, z) with latitudinal and longitudinal coordinates. The z-axis coincides with the local vertical direction. The x-axis is directed from west-east, and the y-axis is directed from south-north. The local components of the geomagnetic field vector are $\boldsymbol{B}_0 = (0, B_{0y}, B_{0z})$. For the angular velocity of the Earth's rotation in the local system of coordinates, $\boldsymbol{\Omega}_0 = (0, \Omega_{0y}, \Omega_{0z})$.

We consider the initial nonlinear equations to find the possibility of zonal flow and magnetic field generation by the EM coupled Internal-Gravity-Alfvén (IGA), Rossby-Khantadze (RK), Rossby-Alfvén-Khantadze (RAK) waves in the E-layer. The nonlinear Jacobian terms in these equations permit us to consider three-wave interaction, in which the coupling between the pump EM waves and side-band modes generates LF large-scale modes, so called zonal flows. Since the zonal flow varies on a much longer time scale than the comparatively small-scale coupled IGA waves, so one can use a multiple-scale expansion, assuming that there is a sufficient spectral gap separating the large- and small-scale motions.

The possibility of the generation of sheared zonal flow and sheared magnetic field in the weakly ionized conductive ionospheric E-layer is investigated. The propagation of coupled Internal-Gravity-Alfvén (IGA)[1], Rossby-Khantadze (RK)[2] and Rossby-Alfvén-Khantadze (RAK)[3] waves is analyzed. Under prevalent effect of Hall conductivity for such waves the latitudinal nonhomogeneity of both the Coriolis parameter and the geomagnetic field becomes essential. Linear dispersion relations for the coupled finite-amplitude IGA, RK, RAK waves are obtained. It is shown that owing to latitudinal nonhomogeneity of the geomagnetic field slow and fast waves can couple and form coupled Rossby-Khantadze waves. It is shown that Internal-gravity and Alfven waves can be coupled through the z-component of wave vector. Simplified set of nonlinear equations describing the dynamics of mentioned coupled EM modes is obtained. Nonlinear instability of short wavelength turbulence of mentioned coupled Internal-Gravity-Alfvén[1], Rossby-Khantadze[2], and Rossby-Alfvén-Khantadze[3,4] EM planetary modes with respect to the excitation of low-frequency and large-scale perturbations of sheared zonal flow and magnetic field is revealed. The nonlinear mechanism of the instability is driven by the advection of vorticity and is based on the parametric excitation of zonal flow by three finite-amplitude coupled modes leading to the inverse energy cascade toward the longer wavelength. The corresponding driving forces along with the Reynolds stresses are stipulated by Maxwell's stresses also. The growth rates of the corresponding instability and the conditions for driving them are determined. The possibility of generation of the intense mean magnetic field is shown. Obtained results can be used to elucidate different laboratory and space experiments.

References

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