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A Modified Korteweg–de Vries equation for Rossby–Khantadze Waves in a Sheared Zonal Flow of the Ionospheric E Layer

L.Z. Kahlon[1], H. A. Shah[1] and T.D. Kaladze[2,3],
[1] Physics Department, Forman Christian College (A Chartered University), Ferozpur Road, 54600 Lahore, Pakistan; lailakahlon@fccollege.edu.pk ; lailakahlon192@gmail.com
[2]I. Vekua Institute of Applied Mathematics of Tbilisi State University, Tbilisi, Georgia
[3]E. Andronikashvili Institute of Physics, I. Javakhishvili Tbilisi State University, 0128 Tbilisi, Georgia

Due to a significant role in the global atmospheric circulation Rossby waves attract special scientific attention in connection with sheared zonal flows. Note that spatial nonhomogeneity of Coriolis parameter alongwith ambient geomagnetic field along the meridians causes the propagation of such coupled Rossby-Khantadze (RK) electromagnetic (EM) waves [1]. The generation of sheared RK EM planetary vortices in the ionospheric E-region also discussed [2]. It was revealed, that propagation of coupled EM RK waves could be self-organized into solitary dipolar vortices and the possibility of the generation of intensive magnetic field is shown. Numerical work on EM RK waves with sheared zonal flow in ionospheric E-plasma was found as well [3]. In this work it was pointed out the splitting of vortices, where the energy is transported by sheared flow into multiple pieces. Equatorial Rossby wave solitons under the action of sheared flows were also discussed and the existence of solitons was confirmed by the observations of *Freja and Viking satellites*. In Jian et al.'s work [4], they investigated the nonlinear propagation of Rossby waves in stratified neutral fluids with zonal shear flow and obtained modified Korteweg-de Vries (mKdV) equation with cubic nonlinearity. Generation of the zonal flow alongwith magnetic field in the ionospheric E-plasma by Rossby-Khantadze EM planetary waves also discussed. Possibility of magnetic field generation of 10^3 nT is predicted. Nonlinear interaction of magnetized electrostatic Rossby waves with sheared zonal flows in the Earth's ionospheric E-layer is discussed in [5] and the authors developed the modified Korteweg-de Vries (mKdV) equation having cubic nonlinearity describing propagation of appropriate solitons.

We consider partially ionized E-ionospheric region consisting of small concentration of electrons, ions and bulk of neutral particles, where such ionospheric plasma is enclosed in a spatially inhomogeneous geomagnetic field $\boldsymbol{B}_0 = (0, B_{0y}, B_{0z})$ and the Earth's angular velocity $\boldsymbol{\Omega} = (0, \Omega_{0y}, \Omega_{0z})$. We consider two-dimensional' wave motion $\mathbf{v} = (u, \mathrm{v}, 0)$, where $u = -\frac{\partial\psi}{\partial y}$, $\mathrm{v} = \frac{\partial\psi}{\partial x}$, and $\psi(x, y, t)$ is the stream function. Then the nonlinear behavior can be narrated by the following 2D system of equations: The first equation describes the evolution of the z-component of vorticity ($\zeta_z = \boldsymbol{e}_z \cdot \nabla \times \mathbf{v} = \Delta\psi$) of the singly fluid momentum equation under the action of the geomagnetic field and the second equation is the z-component of the perturbed magnetic induction obtained through Faraday's law [1, 6].

To derive the nonlinear modified KdV we used the multiple scale analysis technique. From the lowest order of O (ε^0), we get an eigen-value problem with constant eigen-value c_0 along with the boundary conditions. From the next order O (ε^1), by using separation of variables techniques and after doing some mathematical manipulations we arrive at the mKdV equation with cubic nonlinearity of (1+1) dimension. Traveling wave solitary solution of this equation is obtained.

Apart from the ordinary Rossby waves electromagnetic RK perturbations generated by the latitudinal gradient of the geomagnetic field and represent the variation of the vortical electric field $\boldsymbol{E}_\mathrm{v} = \mathbf{v}_D \times \boldsymbol{B}_0$, where $\mathbf{v}_D = \boldsymbol{E} \times \boldsymbol{B}_0 / B_0^2$ is the electron drift velocity. RK waves propagate along the latitude with the velocity $|c_B| \approx 2 - 20\ km/s$. Frequency ($\omega = k_x c_B$) and the phase velocity c_B depend on the number density of the charged particles and vary by one order of magnitude during the daytime and nighttime conditions (which is so suitable for experimental observations). Such perturbations have relatively high frequency $(10^4 - 10^{-1})\ s^{-1}$ and have wavelengths $\sim 10^3\ km$. Compared with the ordinary Rossby waves electromagnetic RK waves accompanied by the strong pulsations of the geomagnetic field 20-80 nT. RK waves are mainly of zonal type and observed mainly during magnetic storms alongwith sub-storms, artificial explosions, earthquakes, etc. Therefore, theoretical investigations of electromagnetic Rossby type oscillations will provide valuable information for further ionospheric experimental investigations.

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