Rotating dipole and tripole vortices in polar regions

Oleg Derzho[1,2], Yakov Afanasyev[1] and Brad de Young[1]

[1]Department of Physics and Physical Oceanography, Memorial University of Newfoundland, St. John's, A1B3X7, NL, Canada
[2]Institute of Thermophysics, Russian Academy of Sciences, Novosibirsk 630090, Russia

An important dynamical effect for large scale flows on a rotating planet is a variation of the Coriolis parameter with latitude. An approximation where linear variation of the Coriolis parameter with distance in the North-South direction (beta plane approximation) is widely used to describe many mid-latitude processes. In the polar regions the Coriolis parameter varies quadratically in the first approximation (gamma plane approximation). It is important to examine the dynamics of fundamental modes of vortical structures waves in this circumstance. Herein we show the existence of a fundamental mode of a large-scale motion in the form a system of multiple vortices rotating anticyclonically as a whole. We investigate the problem from both experimental and theoretical points of view.

In this contribution, we shall show the existence of multipole structures on the gamma plane in the form of a vortex dipole or tripole in the center with vortical gyres of alternating sign farther away from the pole, which rotate in the same direction. Our findings show that intense compact vortex structures can exist under condition that they rotate around the pole with a particular angular velocity. The theoretical approach adopted in our study relies on the standard gamma plane vorticity equation for the barotropic flow. We use a slightly nonlinear relation between potential vorticity and the streamfunction and were able to derive one nonlinear equation, which defines the dependence on the angular coordinate combined with one linear equation for the dependence on the radial coordinate. The theoretical technique we use is similar to the approach proposed by Derzho and Grimshaw (Stud. Appl. Math, 115 (4), 387-403, 2005) for the case of large amplitude Rossby waves on a beta plane. We analytically define the angular velocity that ensures the compactness of the vortical structure.

Results of the theoretical findings were confirmed experimentally. The experiments were performed in a rectangular tank with a circular insert. The tank was filled with water and rotated in an anticlockwise direction. The flow was generated using an electromagnetic method. For this purpose we added some salt to the water to increase its conductivity. Three large rectangular permanent magnets were placed under the bottom of the tank one after another with alternating polarities. The electrodes were placed in the water at the sides of the tank such that when the electric current is flowing between the electrodes in the horizontal direction its interaction with the magnetic field of the magnets results in the Lorentz force on the fluid. The force acts on the fluid in the horizontal direction perpendicular to that of the electric current and generates vortices. To visualize the flows and to measure the velocity and surface elevation fields the Altimetric Imaging Velocimetry (AIV) method was employed (Y. D. Afanasyev, P. B. Rhines and E.G. Lindahl, J. Atmos. Sci., 65, 250-262, 2008). The AIV measures the slopes of the perturbation of the free surface height; velocity and vorticity fields were then reconstructed using the appropriate inversion procedure.

Typical tripole vortical structure is presented in the Figure. It is clearly seen that the pattern is quite different from the tripole vortex experimentally observed by G.J.F. van Heijst, R.C. Kloosterziel and C. W. M. Williams (Fluid Mech., 225, 301,1991).