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Dipole evolution in rotating two-dimensional flow with bottom friction

Viatcheslav Georgievich Makarov

The evolution of a dipolar vortex in a quasi-two-dimensional rotating flow of barotropic fluid over a flat surface with a no-slip condition in the Ekman bottom layer is considered. The vorticity equation in this case becomes nonlinear. An effect of bottom friction is displayed mainly in cyclone-anticyclone asymmetry, which results in the expansion (diminution) of cyclonic (anticyclonic) local structures and in the stronger decay of positive vorticity. When a lateral viscosity is omitted, the vorticity equation has a solution in the form of vortex patches and hence a contour dynamics method may be used for numerical simulation. An approach of point vortices with decaying strengths is also discussed. In an approximation of two patches of opposite uniform vorticity, a three-parameter family of stationary (in an ideal fluid) orbital dipoles [V. G. Makarov and Z. Kizner, "Stability and evolution of uniformvorticity dipoles," J. Fluid Mech. 672, 307 (2011)] consisting of patches with unequal areas and absolute values of vorticity is considered. A three-dimensional domain of instability for this family is numerically constructed. It is shown that the evolution of such dipoles in a flow with bottom friction is described with good accuracy by a properly matched trajectory in parameter space of ideal-fluid steady states. Explicit time-dependent formulae for this phase trajectory are obtained. All characteristics (including the patch's shapes) of the evolutionary dipole, and the same characteristics for the corresponding ideal-fluid stationary dipole, almost completely coincide, at least while the phase trajectory remains in the stability region. The evolution of stationary translating dipoles (with zero net circulation) that have continuously distributed vorticity inside a quasi-elliptical finite region is also examined. When the circular Lamb dipole is used as the initial condition, good qualitative agreement is observed between the asymmetric dipoles obtained during evolution and the chain of the exact solutions from the known one-parameter family of non-symmetrical Chaplygin dipoles.