Nonlinear singular Kelvin waves within a barotropic vortex

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Abstract

This study considers the propagation of helical neutral modes within a barotropic and axisymmetric vortex with an arbitrary azimuthal velocity profile. The singular mode/mean flow interaction leads to strongly nonlinear critical layers around the radius where the angular velocity of the mean flow and the disturbance frequency are comparable. Strong analogies can be done with the theory of critical layers in a stratified flow. We formulate a theory valid when the analogous local Richardson number is small at the critical radius but is nevertheless larger than the mode amplitude, and at a long time asymptotic steady state after the formation of the critical layer. The problem is tackled by removing the apparent singularity by retaining nonlinear terms in the equations of motion inside the critical layer. Viscosity is also introduced in order to render the nonlinear critical layer solution unique, but the inviscid limit is eventually taken. The result from the interaction is the emergence of a multipolar vortex whose poles are located on the critical radius, spiral around the basic vortex axis and are embedded in a distorted mean flow caused by a slow diffusion of the three-dimensional vorticity field from the critical layer in a transitional stage due to the very weak viscosity of the flow. This study gives an analytical description of these vortices.

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