ELLIPTICAL BAROTROPIC f-PLANE DIPOLES IN A ROTATING FLUID

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Barotropic f-plane dipolar vortices were generated in a rotating fluid and a comparison was made with the so-called supersmooth f-plane solution which – in contrast to the classical Lamb–Chaplygin solution – is marked by an elliptical separatrix and a continuously differentiable vorticity field. Dye-visualization and high-resolution particle-tracking techniques revealed that the separatrix aspect ratio and the vorticity versus streamfunction relationship are in close agreement with those of the supersmooth f-plane solution for the entire lifespan of the dipolar vortex.

Background

Dipolar vortices play an important part in large-, meso- and small-scale geophysical flows due to their self-propelling motion and robustness. The long lifespan and stability of these coherent structures have motivated researchers to look for explicit stationary solutions (see Meleshko and van Heijst, 1994). In theoretical studies by Kizner and Khvoles (2004) and Khvoles, Berson and Kizner (2005), stationary solutions for barotropic f- and β-plane dipole modons with elliptical separatrices were suggested (Fig. 1) and tested for stability numerically. Among the possible solutions there exist the so-called supersmooth solutions whose vorticity derivatives are continuous at the separatrix. Such solutions are characterized by a specific separatrix aspect ratio. Because of the uniqueness of the supersmooth solutions and their remarkable stability, these dipoles are good candidates for being attractors for dipoles of other forms in the presence of dissipation. Inspired by these, the present research aims at finding such structures in the laboratory.

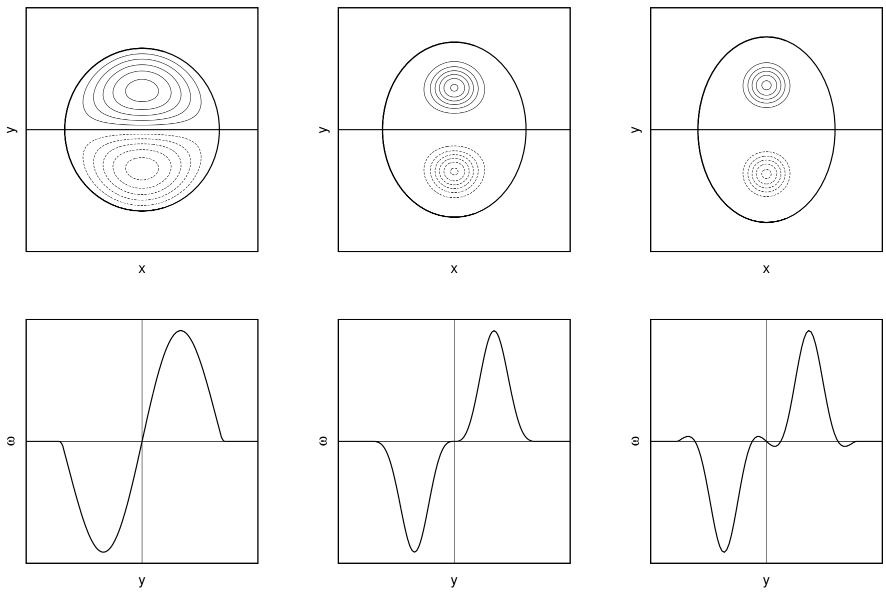

Fig. 1. Family of elliptical barotropic f-plane dipoles with separatrix aspect ratios $\epsilon = 1$ (Lamb–Chaplygin solution), $\epsilon = 1.16$ (supersmooth f-plane solution) and $\epsilon = 1.30$. Upper panels: vorticity fields. Lower panels: vorticity along a straight line passing through the dipole vorticity extrema.

Method and results

The laboratory experiments were performed in a rotating fluid in which the flow is quasi-two-dimensional. Although a β-plane can be easily established in the laboratory, attention was restricted to the f-plane for which, in non-dimensional variables, only a single supersmooth solution exists (see Fig. 1). A dipolar vortex was created by dragging a vertical plate through the fluid in the horizontal direction. After the plate was removed, a well-defined quasi-steadily translating dipolar vortex emerged within a few rotation periods. The initial flow characteristics were controlled by variation of the drag speed and the drag distance of the plate. Dye-visualization and high-resolution particle-tracking techniques were used to obtain qualitative and quantitative information about the horizontal flow field (see Figs 2 and 3). Both the separatrix aspect ratio and the vorticity versus streamfunction relationship were investigated in detail and appeared to be in close agreement with those of the supersmooth f-plane solution. This agreement was monitored for the entire lifespan of the dipolar vortex, confirming above-cited numerical simulations which demonstrated the longevity of the supersmooth dipoles.

Fig. 2. Dye visualization of a dipole propagating through a line of dye. The dye eventually demarcades the interior region of the dipole which provides an indication of the separatrix aspect ratio.

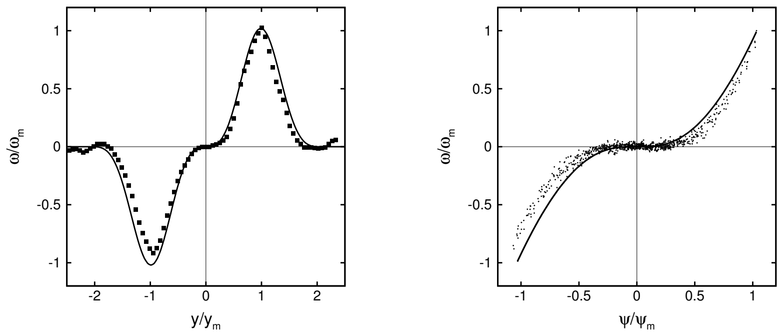

Fig. 3. Left panel: cross-sectional vorticity distribution along a straight line passing through the dipole vorticity extrema. Right panel: vorticity versus streamfunction relationship for the interior dipole region. The supersmooth f-plane solution is indicated by the solid lines.

References

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