SELF SIMILAR EVOLUTION OF AN ANTICYCLONE IN A ROTATING STRATIFIED FLOW - APPLICATION TO MEDDIES

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We present a theoretical model for the time evolution of an isolated vortex in a rotating stratified flow. We support our study with both laboratory experiments and numerical simulations. This work is motivated by the existence of huge coherent vortical structures [1] observed to form at the exit of the Gibraltar straits. These anticyclonic vortices, known as Meddies, show a strikely long lifetime of the order of years.
We consider the axisymmetric Navier-Stokes equations in the Boussinesq approximation. We initialize the system with a vortex whose density and velocity anomalies fulfill the quasi-geostrophic equilibrium solution derived by Hassanzadeh et al [3] and verified in experiments by Aubert et al [2]. In the limit of small Rossby and Ekman numbers the velocity and density equations can then be linearised and reduced to a single equation for the pressure. In the region of the parameter space explored by experiments the pressure equation further simplifies to a radial diffusion equation which admits a self similar solution. Depending on the initial velocity and density profiles (e.g. an isolated Gaussian vortex), the time evolution of the velocity and density anomalies can be explicitly predicted.

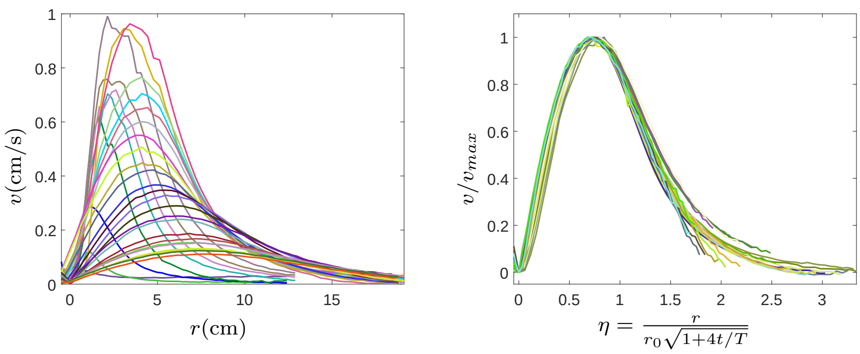

Figure 1. On the left: the radial profile of the tangential velocity at different times during one hour of experiment. Here the control parameters are $f = 2\,\mathrm{rad/s}$ and $N = 1.23\,\mathrm{rad/s}$. On the right: rescaled version of the left diagram. The velocity is divided by its max. The radius is rescaled according to a diffusive law.

We perform laboratory experiments with the same apparatus as [2]. We generate anticyclones injecting a small amount of neutrally buoyant fluid at the center of a rotating tank filled with salty water linearly stratified in density. The fluid motion is investigated using PIV techniques, providing the velocity field in a plane orthogonal to the vorticity vector. We also perform numerical experiments with initial conditions similar to experiments using a finite elements code. Our two control parameters are the background Coriolis parameter f and Brunt-Väisälä frequency N. We consider the radial profile of the tangential velocity and observe that it evolves in a diffusive self-similar way (see figure 1). This result which is common to experiments and simulations is predicted by the model with no adjustable parameter. We remark that, according to the model, a radial diffusion occurs irrespective of the initial aspect ratio (e.g. even for an initial vortex elongated in the radial direction). We claim that this is a consequence of the critical role played by the recirculation inside the vortex, which in general should not be neglected.
Real Meddies occupy a region of the parameter space which is difficult to reach with laboratory experiments but according to the model their evolution should follow the same mechanism. Using an effective value for the deep ocean viscosity we can roughly estimate the lifetime of a Meddy with the right order of magnitude.

References

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