Vortices in rotating stratified environment: shape, lifetime, and layering

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Ocean Meddies are long-lived anticyclonic pancake vortices of Mediterranean origin evolving in the Atlantic Ocean. They have a saltier and warmer core than the surrounding oceanic water, their diameters go up to 100 km, and they can survive for 2 to 3 years. Besides their characteristic shape and suprisingly long lifetime, their extensive study using seismic images has revealed fine structures surrounding their core, corresponding to layers of constant density (see e.g. Fig. 1 and [1]). These layers are a physical manifestation of an interior route to dissipation in oceans, and as such, they may contribute to the mystery of the oceanic energy cascade from the large climatic scales to the smaller scales, where all of it is dissipated. But the origin of layering is still unsolved: it may be due to salt fingers from a double-diffusive instability of salt and heat, to global modes of the quasigeostrophic instability, and/or to viscous overturning motions induced by a double-diffusive instability of salt and momentum [2].

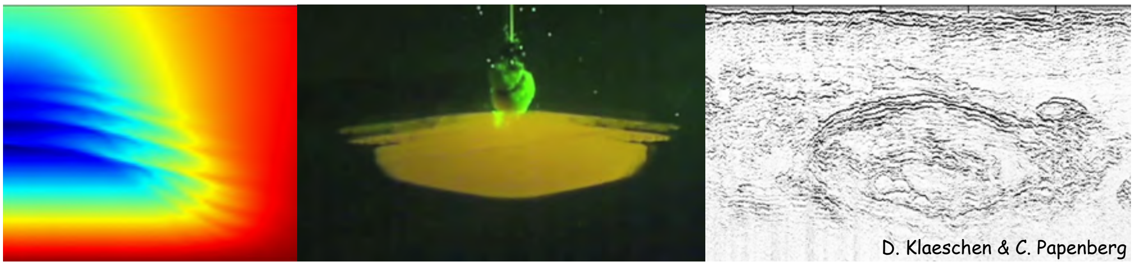

Fig. 1: Layering observed above an anticyclone in a rotating stratified environment, with from left to right: the results of an axisymmetric numerical simulation where the color field shows the density anomaly compared to the linear background; a picture of a laboratory experiment using salty water, where the dyed vortex is created by continuous injection through the pipe and sponge shown in the center; and a real Meddy observed by seismic reflection from the water column in the Gulf of Cadiz.

We have addressed the questions of the shape, lifetime and layering of Meddies using laboratory experiments, in the continuity of the first works by [3] and [4]. Our laboratory anticyclonic vortices are created via injection of isodense fluid in a rotating and linearly stratified layer of salty water. Our experiments are complemented by axisymmetric numerical simulations. Using short injections, we then systematically investigate the time evolution of the resulting pancake structures: their shape is determined by a geostrophic equilibrium, whose quasi-steady evolution is due to a strong interplay between internal recirculation and associated potential energy generation v.s. viscous dissipation, in close agreement with our analytical model. Then using continuous injection to counteract this viscous dissipation, we systematically investigate the appearance of layers depending on the relative values of the Rossby number, of the ratio between the Coriolis parameter and the background buoyancy frequency, and of the Schmidt number. We conclude that the observed layers are due to the double-diffusive instability mechanism of McIntyre [2]. Applying our results to Meddies allows us to indirectly estimate the typical values of turbulent diffusivity and viscosity at the layer scale.

References

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