Proposed PhD Research Project:

Isolated Coherent Vortices in Geostrophic Turbulence

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Big Picture. Mesoscale oceanic eddies play an important role in ocean dynamics by affecting horizontal material transport, vertical stratification, large-scale currents, and air-sea interactions (e.g., review by McWilliams 2008). Eddies occur virtually everywhere in the ocean, and their observational evidence comes from in-situ and satellite measurements (e.g., Chelton et al. 2011). Many oceanic eddies behave like planetary waves, but many other eddies are better described as coherent, isolated and long-lived vortices, which are characterized by localized and concentrated vorticity and density anomalies. The Big Red Spot on Jupiter is a famous example of particularly long-lived coherent vortex. Over the last 40 years the subject of isolated coherent vortices was so much favoured by theoreticians that it became a *classical topic* of Geophysical Fluid Dynamics (e.g., McWilliams 1986). Nowadays this topic is ready for significant revision due to the greatly increased computational capabilities. In particular, the time is ripe to consider *nonstationary*, *asymmetric* and *tilted* vortices on large-scale *background flows*, which can provide sustaining energy sources able to compensate for dissipative processes.

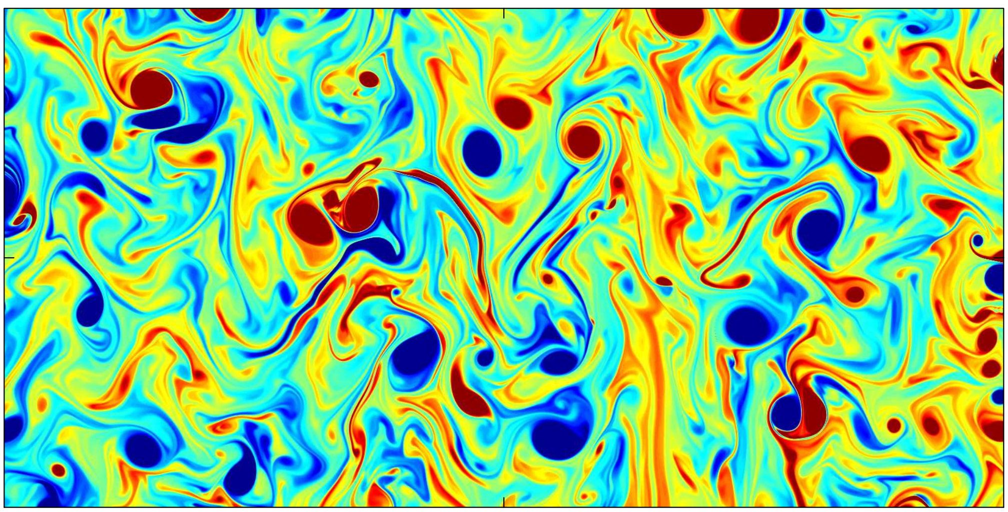

Figure 1: Illustration of the geostrophic turbulence flow regime sustained by vertically sheared, westward background flow and dominated by ensembles of spontaneously generated, isolated coherent vortices. Shown is the surface potential vorticity anomaly, which is a fundamental flow property; intense red and blue anomalies correspond to the cyclonic and anticyclonic vortices. Same-sign vortices tend to merge together, opposite-sign vortices tend to form propagating dipoles; all vortices interact with the background shear and each other, and also propagate due to self-induced drifts. Space around the vortices is filled out by vorticity filaments, planetary waves, and multi-scale turbulent fluctuations. The observed vortices have complicated shapes, vertical tilts and temporal oscillations.

Motivation and Open Questions. Recently, simulations of baroclinic turbulence have captured, for the first time, dynamically consistent generation and consequent evolutions of ensembles of coherent isolated vortices, at an unprecedented level of detail and accuracy (Berloff et al. 2011; see Fig. 1). These simulations raised many open research questions. The Project will focus on understanding the dynamical mechanisms that sustain and govern these flow features, as well as on their stability, variability, material transport and stirring properties, and mutual interactions on an hierarchy of background flows with growing complexity.

Work Plan

The starting point will be statistical and dynamical analysis of the numerical model solutions with naturally generated vortex ensembles. This will require a fair amount of original scientific computation, as well as development of vortex detection and tracking algorithms. Then, we will proceed with taxonomy of the vortex population and systematic statistical description of the structural properties, trajectories, genesis and life cycles, dynamical balances, and Lagrangian transport properties of the vortices. This will be followed by focused high-resolution modelling and precise analyses of various individual vortex solutions. Research agenda includes: linear stability analysis of vortices; mean-flow/vortex and vortex-vortex nonlinear interactions and feedbacks; effects of various background flow configurations; intrinsic variability of vortices. Search for steady-state propagating vortices will be attempted with Newton-Raphson method.

Over the course of Project, the student will acquire multiple skills in Applied Mathematics, Geophysical Fluid Dynamics, Scientific Computing, Applied Statistics and Data Analysis. Interactions with the world-leading theoreticians and theoretical groups working on coherent vortices will be encouraged.

References

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