Coherent vortices, vertical velocities and the marine ecosystem

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Ocean mesoscale flows are characterized by the presence of intense coherent structures such as vortices, jets and fronts.

Coherent vortices in the open ocean are associated with strong vertical velocities which can reach values comparable to those along fronts.

Along coastal slopes, the interaction between the coherent eddies and the bathymetry induces strong vertical velocities and can generate intense topographic Rossby waves.

The strong vertical velocities provide a communication pathway between deep, nutrient-rich waters and surface waters in the euphotic layer, potentially affecting the functioning of the marine ecosystem. In particular, primary productivity depends on the size and fragmentation of the upwelling regions.

We are interested in studying the interaction between coherent vortices, vertical velocities, sea ice and the marine ecosystem in Arctic regions, by using both simplified modelling approaches and realistic ocean models.

Vertical velocities and coherent vortices

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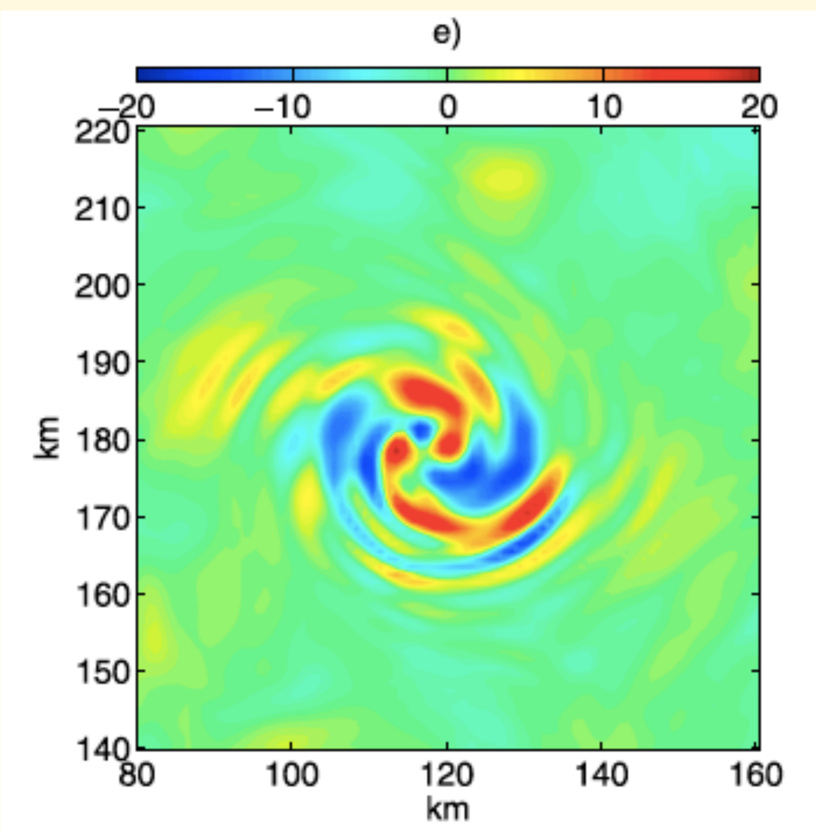

Vertical velocity in m/d at 78 in and around a coherent vortex simulated by a primitive-equation model (ROMS) in a idealized configuration representing the open ocean. The field is averaged over 1 day, thus removing near-inertial motion.

The numerical study of mesoscale turbulence in idealized, primitive—equation settings with simplified wind forcing has revealed that many properties of the horizontal motions are similar to those of two-dimensional and quasi-geostrophic turbulence. The main differences are a strong cyclone-anticyclone asymmetry linked to the straining field exerted by vortex Rossby waves, which is also found in shallow water flows, and the complex structure of the vertical velocity field. Locally, the motion can become strongly ageostrophic, and vertical velocities associated with vortices can reach magnitudes and levels of spatial complexity akin to those reported for frontal regions. Particles released in the pycnocline undergo large vertical excursions because of the vertical velocities associated to the vortices, with potentially important consequences for marine ecosystem dynamics.

Vortices, upwelling, primary productivity

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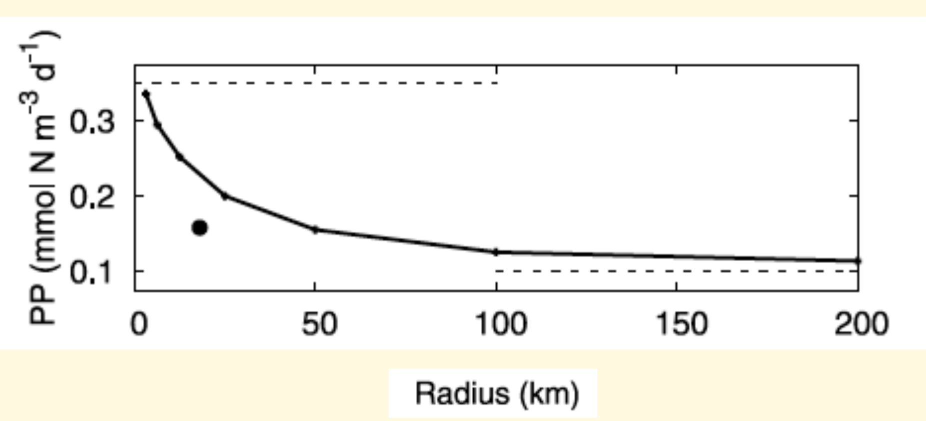
Numerical simulations in a simplified 2D turbulence setting and a NPZ ecosystem model indicate that primary productivity is affected by the form of the nutrient input. For a restoring flux, used to parameterize nutrient input by upwelling, primary productivity depends on the size and/or temporal duration of the upwelling events. For a fixed-flux nutrient input, high-nutrient, low-chlorophyll (HNLC) regions can easily appear, without necessarily implying the lack of some micronutrient.



Domain-averaged primary productivity as functions of the size of individual active regions, R, for restoring flux. Thin dashed horizontal lines indicate two asymptotic values at large and small values of R. Solid points indicate the values obtained when strong upwelling is correlated with the eddy field.

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Vertical velocities along slopes

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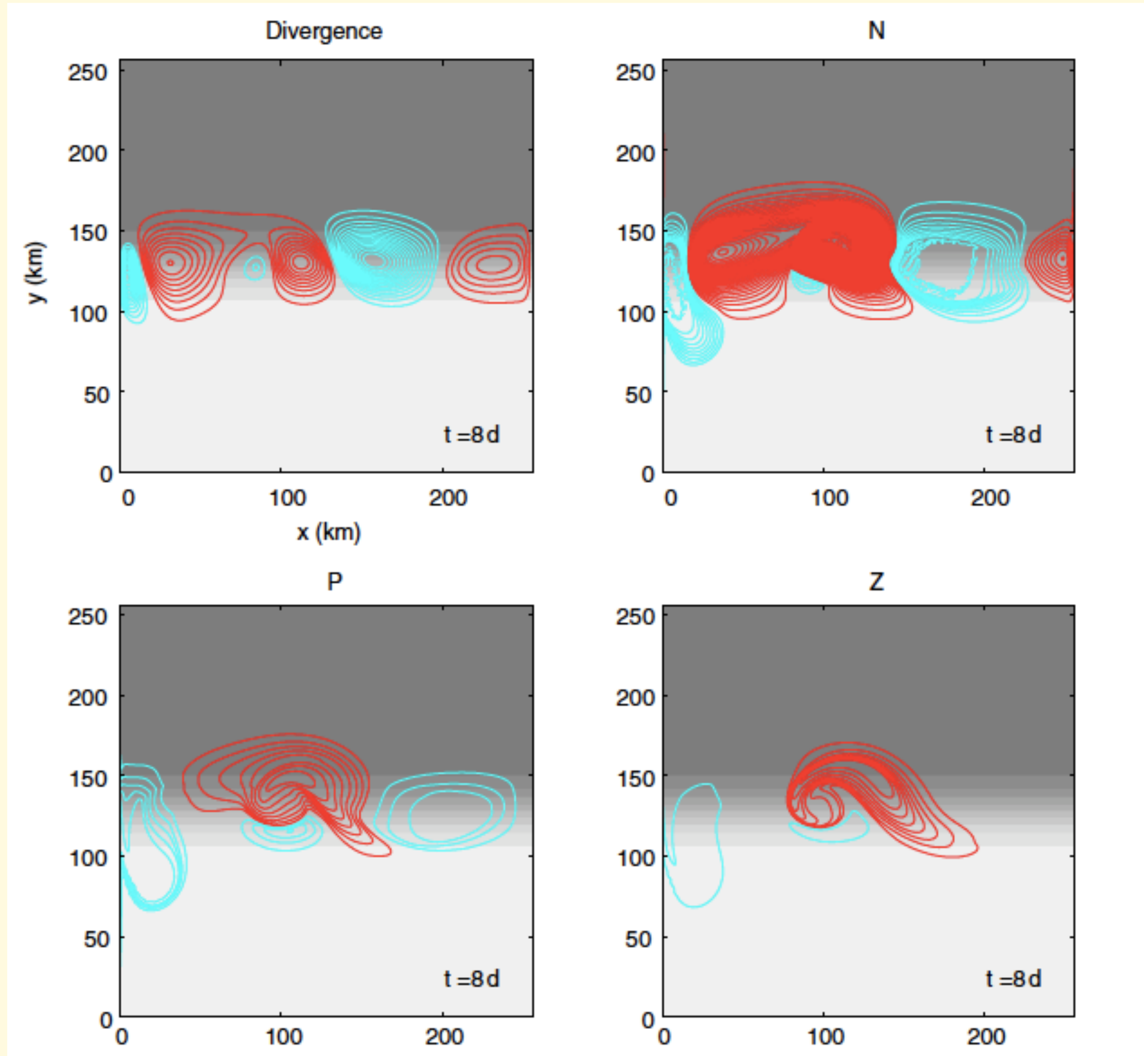
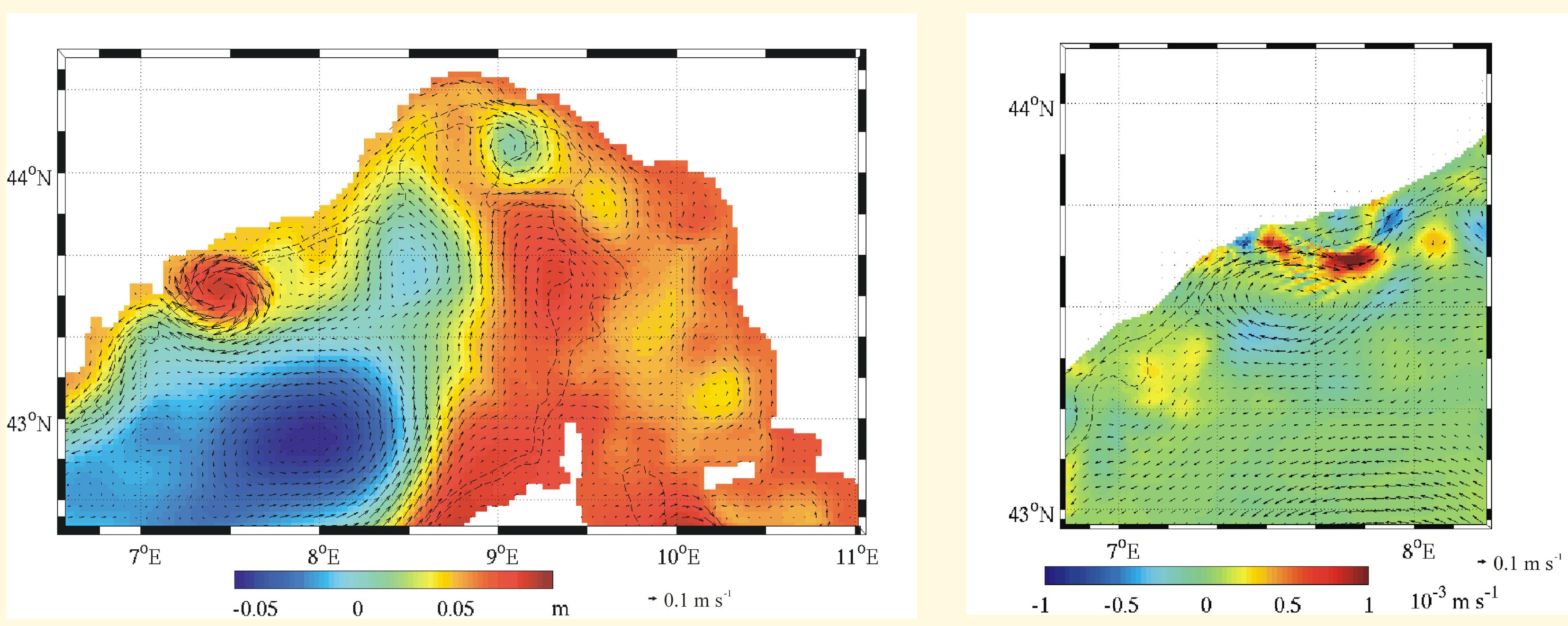
E. Casella, A. Molcard, A. Provenzale

The numerical study of the dynamics of a cyclonic vortex over a steep escarpment shows that plankton abundance over the escarpment is modulated by the passing of topographic Rossby waves, generated by the vortex-topography interaction. In such configuration, advection effects driven by the flow over the escarpment are of limited relevance for the dynamics of biological fields. By contrast, we find that the flow resulting from the interaction of a vortex with a seamount is sufficiently strong and persistent to allow for a remarkable increase of nutrients, and a corresponding enhancement of phytoplankton and zooplankton concentrations. Over the seamount, advection effects associated with trapped flow perturbations around the summit play an essential role.



Contours of horizontal divergence (upper left), nutrient (upper right), phytoplankton (lower left) and zooplankton (lower right) concentrations over an escarpment after 8 days past the time when the vortex first impinged on the escarpment. Positive (negative) contours are plotted with black (gray) lines. For the biological fields we have plotted the anomalies from the equilibrium values.

Numerical simulations and SST satellite images indicate that coastal anticyclonic eddies are of common occurrence in the Ligurian Sea (NW Mediterranean Sea), with several events per year, mainly concentrated in autumn and winter. The eddies are characterized by a complex pattern of intense vertical velocities and induce strong, long-lasting coastal upwelling events. For this reason, anticyclonic vortices in the coastal area can generate bursts of nutrient input in the euphotic layer, contributing to the fertilization of the Ligurian Sea.



Left: SSH field (in meters) on 16 November 2006 from a ROMS simulation with spatial resolution 3 km and 32 vertical levels. Vectors indicate current direction at a depth of 10 meters. Right: Vertical velocity field, at a depth of 150 meters, associated with the coastal vortex on 8 November 2006, for a nested simulation with resolution 1 km.

References:

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