Down to Submesoscale in the Laboratory Experiment with Optical Altimetry

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Introduction

Unbalanced processes, often accompanied by spontaneous wave radiation, lead to forward energy cascade, thus playing an instrumental role in dissipating energy in the ocean (McWilliams, 2016). It was shown numerically that the forward energy cascade at submesoscale is dominated by the ageostrophic flow, and the energy spectrum have a -2-like slope rather than the familiar -3 slope of 2D turbulence. Cyclonic vortices prevail over anticyclonic vortices since the latter are subject to centrifugal instability. In this study, we model the submesoscale dynamics in the laboratory.

Experiment Setup

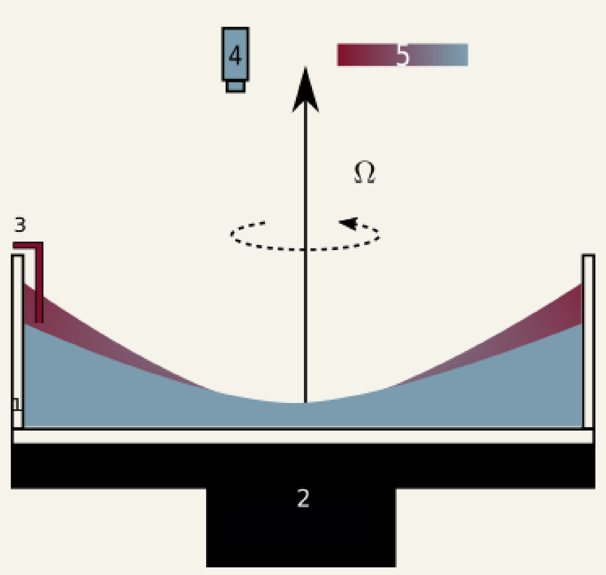


Fig.1. Experiment setup. A cylindrical tank (1) 110 cm in diameter, is filled with 10 cm salty water and is rotated at a rate of **Ω**=2.4 rad/s (period of rotation *T* = 2.7 s). A video camera (4) observes the surface perturbations reflecting a light source with color mask (5).

The water in the tank was preheated to 70 ºC in order to reduce its viscosity and generate thermal convection due to evaporative cooling from the surface. Freshwater (red) was injected through a pipe (3) into the tank along the wall; it formed a baroclinically unstable coastal (wall) current.

Relative vorticity skewness

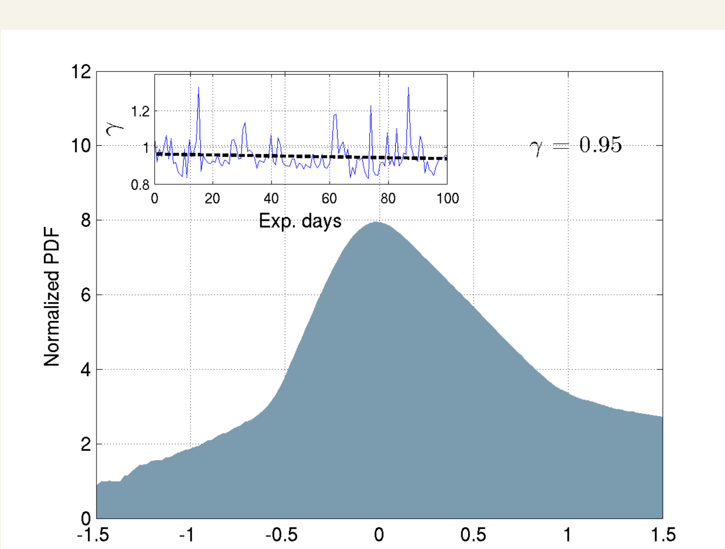


Fig.3. PDF of the relative vorticity normalized by the "planetary" vorticity, Ro = ζ/f_0, showing a positive skewness favouring cyclones in the cooling period. The insert shows that the skewness slowly declines with time as the surface evaporation weakens.

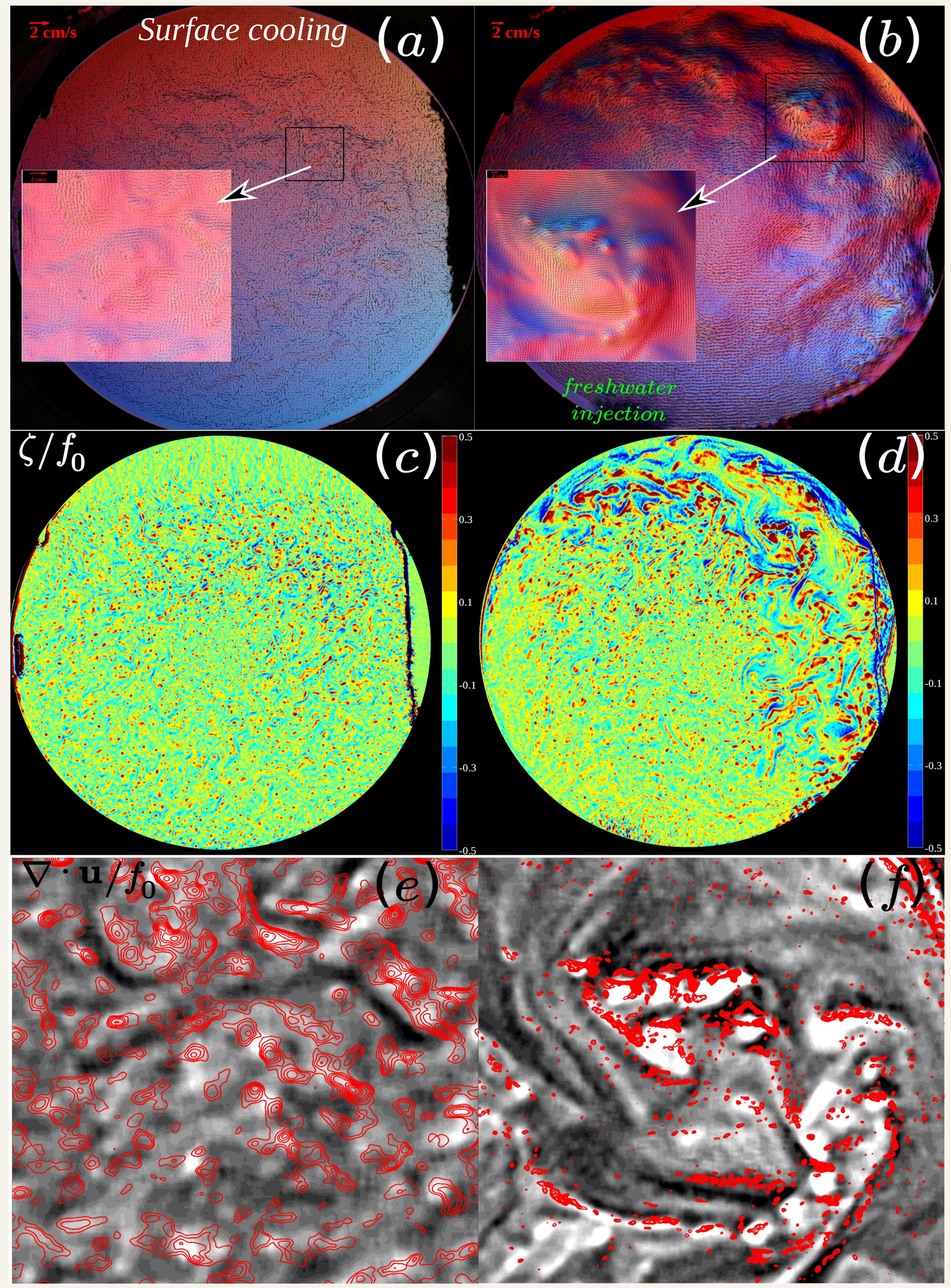


Fig.2 The velocity vector fields (arrows) superposed on the altimetric images, captured before (a) and during (b) the injection of freshwater. An abundance of submesoscale structures is observed. Before the injection the flow is in a quasi-equilibrium state, driven by convection due to surface cooling, An example of a mesoscale cyclone wrapped by thin filaments which contain smaller (submesoscale) cyclones, is shown in (b, f). Panels (c, d) show normalized relative vorticity Ro=ζ/f_0 before and during the injection respectively. The horizontal convergence (negative divergence, red contours) in (e, f) is superposed on grayscale Ro. Panels (e, f) show that areas of strong convergence are mainly cyclonic (white).

Altimetry and Ageostrophic Current

An optical altimetry system (Afanasyev et al. 2009) is employed to measure the perturbations of the surface slope $\nabla\eta$ relative to the parabolic surface when in a solid-body-like rotation. The perturbations are created by the pressure perturbations in the flow.

Velocity of the flow can be derived from the equation for the horizontal motion

$$\mathbf{u}_t + (\mathbf{u}\cdot\nabla)\mathbf{u} + f_0\boldsymbol{k}\times\mathbf{u} = -g\nabla\eta, \quad (1)$$

where g is the gravitational acceleration, $f_0 = 2\Omega$, and $\boldsymbol{k}$ is the vertical unit vector. A first approximation is the geostrophic velocity

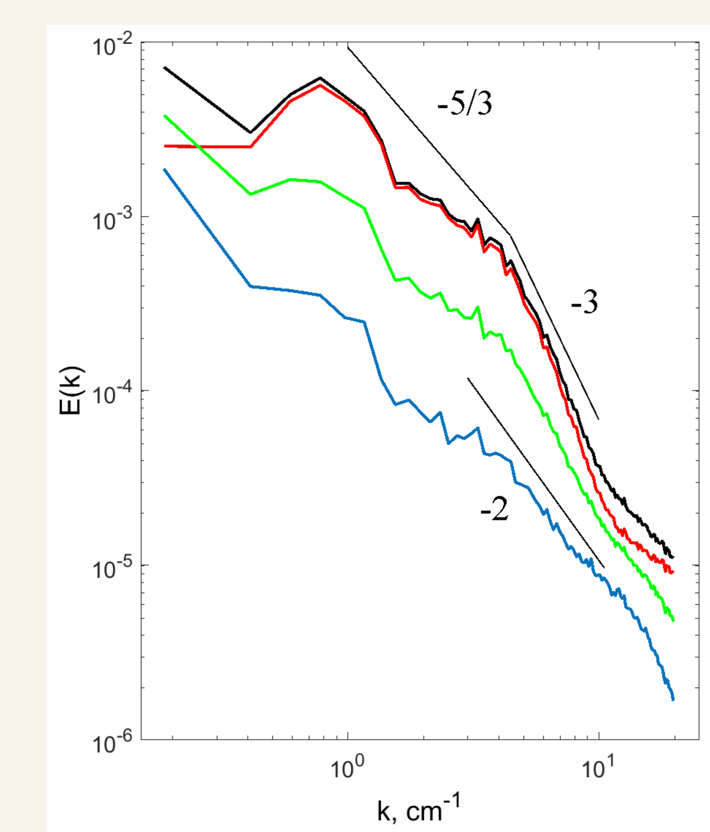
$$\boldsymbol{u_g} = \frac{g}{f_0}\boldsymbol{k}\times\nabla\eta\ , \quad (2)$$

The Helmholtz decomposition is employed to extract the solenoidal component of $\boldsymbol{u_g}$, i.e. a "true" non-divergent geostrophic current. Further approximations can be obtained by an iterative procedure (Arnason et al., 1962). The resulting total velocity contains geostrophic and ageostrophic components

$$\boldsymbol{u} = \boldsymbol{u_g} + \boldsymbol{u_a}\ . \quad (3)$$

Energy spectra

Fig 4. Energy spectrum of the total $\boldsymbol{u_g}$(black), geostrophic $\boldsymbol{u_g}$(red), and ageostrophic $\boldsymbol{u_a}$(blue), velocities. The coupling, $\widetilde{u_g}\widetilde{u_a}^* + \widetilde{u_a}\widetilde{u_g}^*$, between $\boldsymbol{u_a}$ and $\boldsymbol{u_g}$ is shown in green.



Conclusions

- Cyclones prevail over anti-cyclones.
- Strong cyclones are accompanied by convergence.
- The ageostrophic energy spectrum has a -2 slope at submesoscales.

References

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