Vertical velocities in quasi-geostrophic floating vortices

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Fine-scale oceanic structures, such as vortices and fronts, escape the classical two-dimensional geostrophic description and exhibit ageostrophic vertical motions. Measurements and understanding of these fine-scale vertical velocities are one of the main open questions among the oceanography community, as they are most likely responsible for ocean mixing or other transport of scalar quantities.

Geophysicists have derived the $\omega-$Equation [1] to diagnose these vertical velocities from their horizontal data. Assuming a flow is quasigeostrophic and divergence free, this equation states that vertical velocities will arise in order to compensate the loss of geostrophic balance and to conserve potential vorticity along streamlines. However, the difficulty to measure velocity and scalar fields at sea on horizontal extended domains make the use of this equation challenging. The $\omega-$Equation reads:

$$N^2\nabla_h^2\mathbf{w} + f^2\frac{\partial^2\mathbf{w}}{\partial z^2} = 2\nabla_h\cdot(\nabla_h\boldsymbol{u_g}\cdot\nabla_h\rho) \tag{1}$$

with $\mathbf{w}$ the ageostrophic vertical velocity, $\boldsymbol{u_g}$ the geostrophic horizontal velocity field, ρ the density, f the Coriolis frequency, N the Brunt-Väisälä frequency and ∇_h the horizontal gradients.

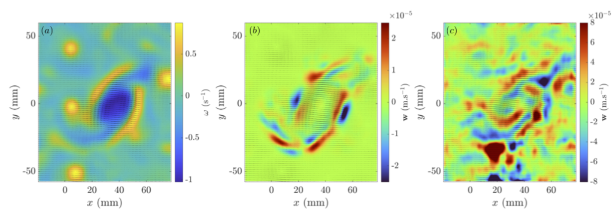

Figure 1. (a) Vorticity map of our ellipitical floating vortices obtained from PIV measurements. (b) Resulting $\mathbf{w}$ (m.s^{-1}) field obtained from the $\omega-$Equation model (equation 1). (c) Resulting $\mathbf{w}$ (m.s^{-1}) field obtained from integrated horizontal divergence of $\boldsymbol{u_g}$.

Here, we propose to test the predictions of the $\omega-$Equation on laboratory experiments with actual measurements of vertical velocity $\mathbf{w}$. These experiments aim to reproduce typical oceanic configurations using a rotating table and density stratification of the fluid layer. We focus here on non-axisymmetric floating vortices (figure 1 a), resulting from the balance between the Coriolis force and the density gradients. Vertical velocity is reconstructed from our PIV measurements using the continuity equation between different vertical position in the vortex. As shown by figure 1, these vertical velocities obtained from our measurements of the horizontal divergence (panel c) are in fair agreement with the prediction calculated from the $\omega-$Equation (panel b). While their magnitude is quite small ($\simeq 40$ μm.s^{-1}), these upward and downward motions appear specifically on the edges of our vortex where the vorticity sign changes, and serve to reestablish the flow stratification. These results were further completed through the use of theoretical models of oceanic vortices, with the aim of helping oceanographers in identifying regions of upwelling and downwelling in the ocean.

References

1. BJ. Hoskins & I. Draghici & HC. Davies, A new look at the ω-equation, *Quarterly Journal of the Royal Meteorological Society*, **104**, 31-38 (1978).