Non QG effects in rotating stratified turbulence

Roullet Guillaume (1), Klein Patrice (1), Hua Bach Lien (1), Le Gentil Sylvie (1) and Sasaki Hideharu (2)

(1) Laboratoire de Physique des Oceans (UMR 6523, CNRS-IFREMER-UBO-IRD), Brest, France
(2) Earth Simulator Center, JAMSTEC, Yokohama, Japan

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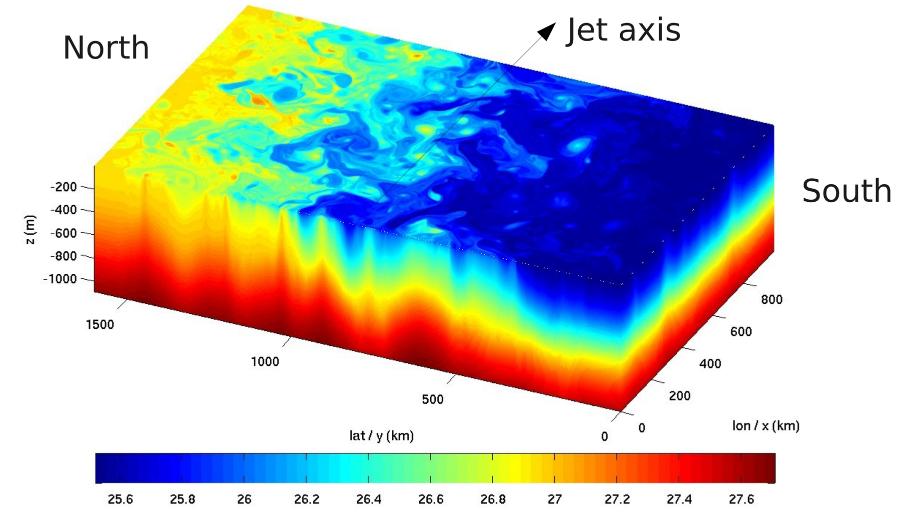
1 / Motivations

In the real ocean, observations claim for a dominance of cyclones at the sea surface and a dominance of anticyclones in the interior. Several mechanisms have been proposed to explain this asymmetry (Polvani et al. 1994, Hakim et al. 2002) but none is able to explain in a unified manner the different behavior observed at surface and in the interior. What is certain is that QG models are unable to break the symmetry and so, any mechanism should include non QG physics. **In terms of potential vorticity, the main followed directions consist in including addition of a nonlinear term in the vorticity. Here, we suggest not to neglect the nonlinearity of the stretching.** This work, based on very high resolution simulations of a PE model, aims to provide new insights on the mechanism yielding to this asymmetry

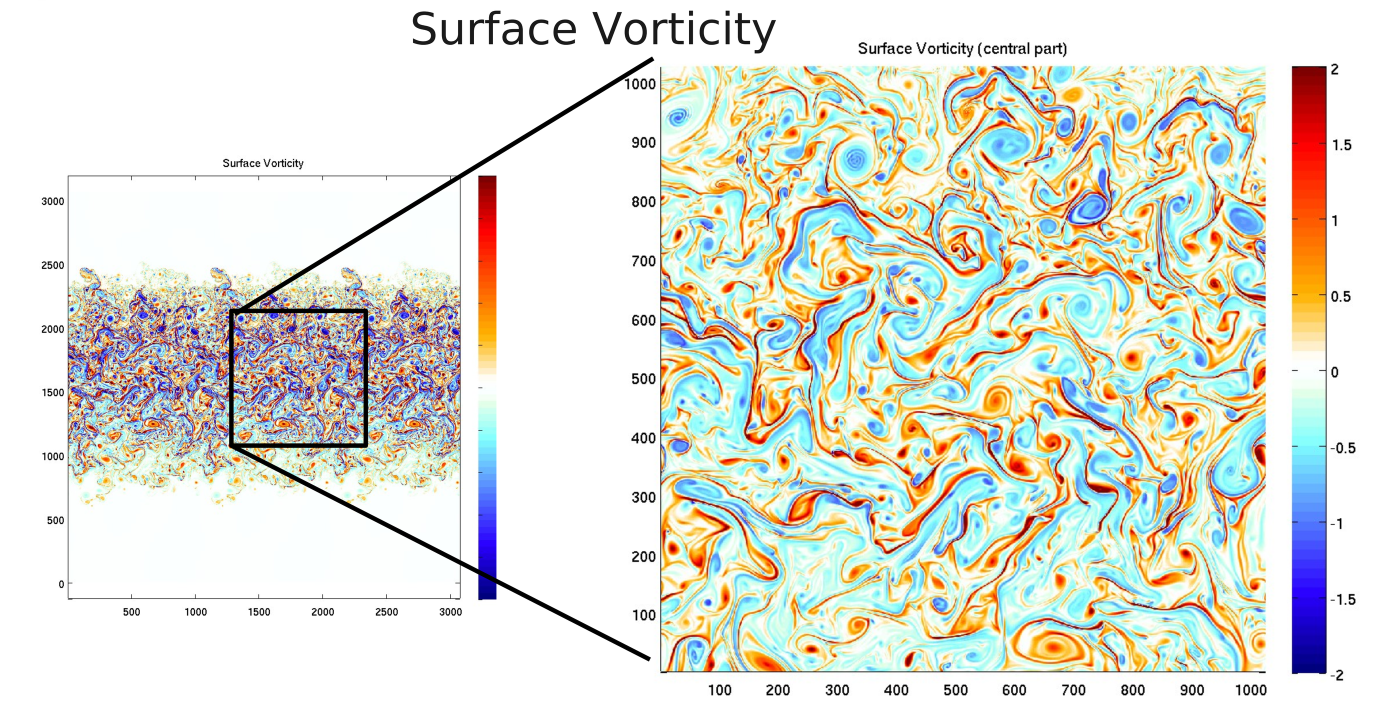
2 / PE Simulations

- Zonal channel on the β plane, forced by baroclinic instability, **no wind, no heat-flux**, restoring time= 50 days, statistical equilibrium (600 days of integration)
- **ROMS model** (PE), 3000x1000x200 (dx=1km), runs performed on the Earth Simulator (Japan)
- The simulation is described by Klein et al. (2008).



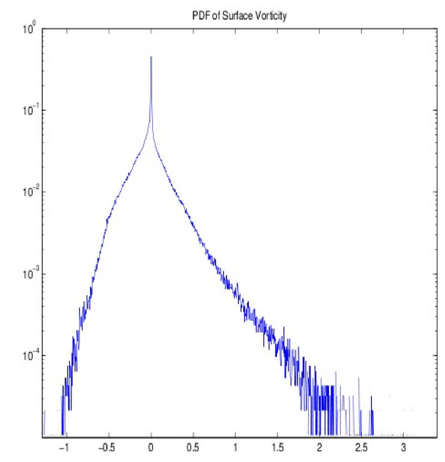
3 / Results

Surface Vorticity

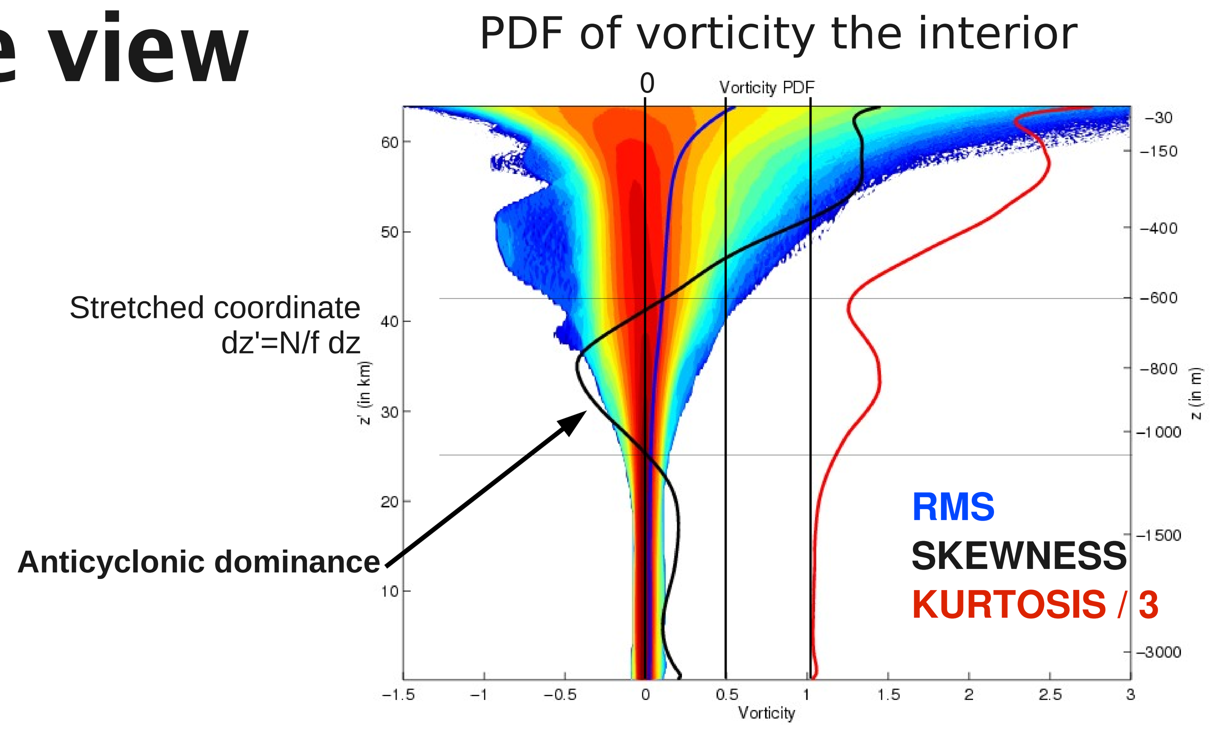


z-coordinate view

PDF of surface vorticity



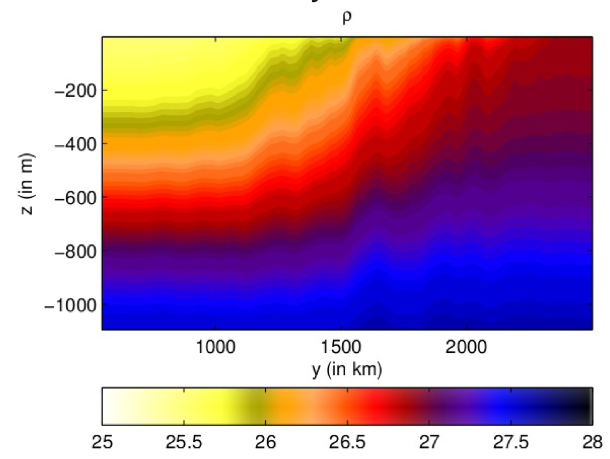
PDF of vorticity the interior



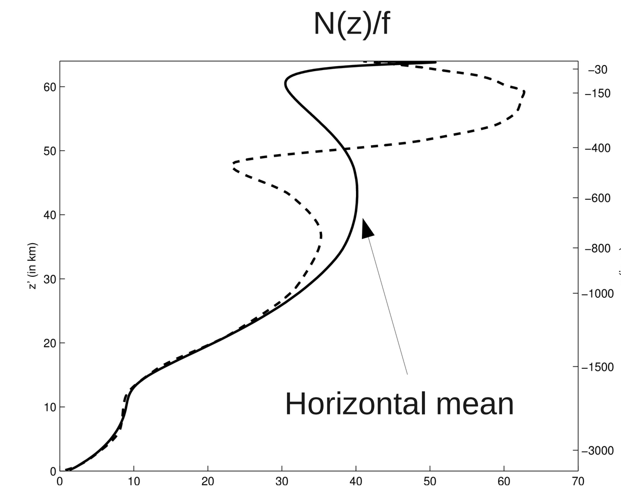
The spatial resolution allows for a full development of meso and submesoscale activity. The surface vorticity has a lot of fine scale structures such as eddies and filaments. Ageostrophic dynamics plays a crucial role, it is responsible for a direct cascade of energy for length scale smaller than 20 km (Klein et al. 2008). Another very important feature is the non symmetric **probability density function (PDF) of surface vorticity (positive skewness) showing a dominance of cyclones**. Its lower value -f is limited by symmetric instability, its maximum value reaches +3f.

The pdf of vorticity is computed for each z-level and plotted vs. the so-called "stretched coordinate" z' to ensure a proper zoom on every part of the vertical (squeezing of the abyss and stretching of the thermocline). The rms (blue curve), i.e. the Rossby number, is high at surface (~0.6) indicating non QG regime (with importance of nonlinearities in the vorticity) and decreases with depth (corresponding to the surface intensification).The asymmetry of the pdf is very clear for all depths smaller than -1100m. Skewness (black curve) is positive for upper layers **(z>-600m) indicating cyclone dominance**. It is negative below the thermocline **(-1100m<z<-600m) revealing anticyclone dominance** there and almost zero below with kurtosis (~3) compatible with normal distribution.

Density zonal mean



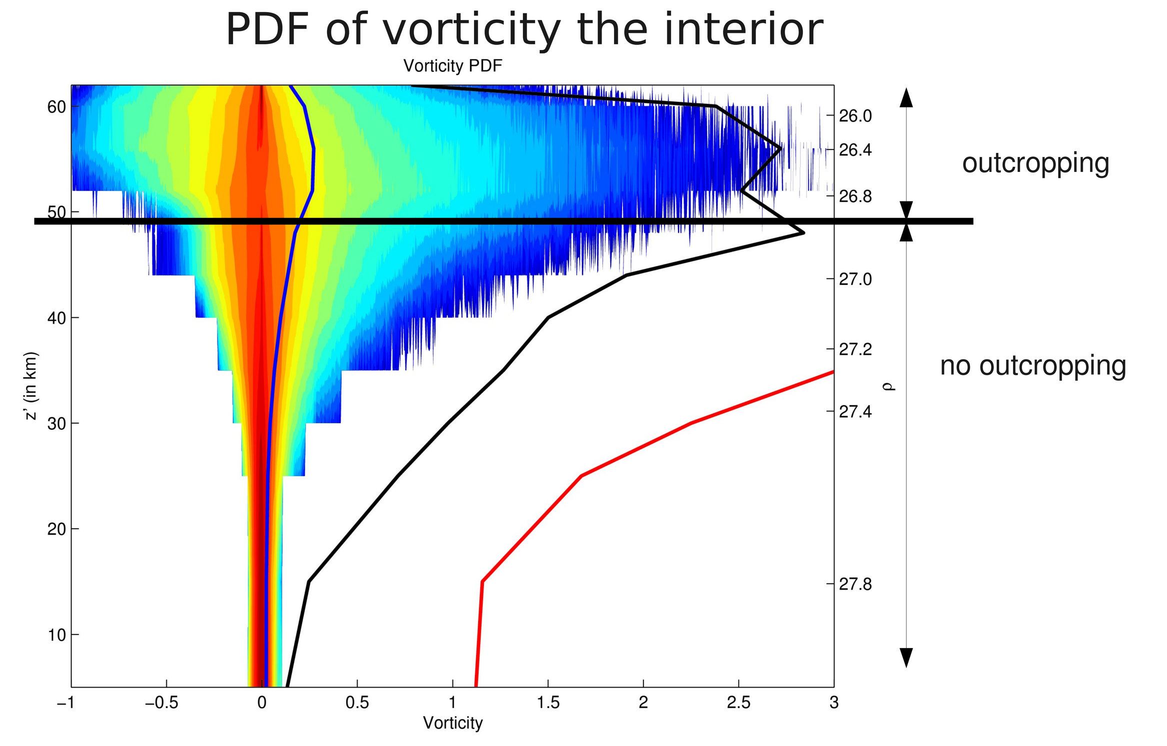
N(z)/f



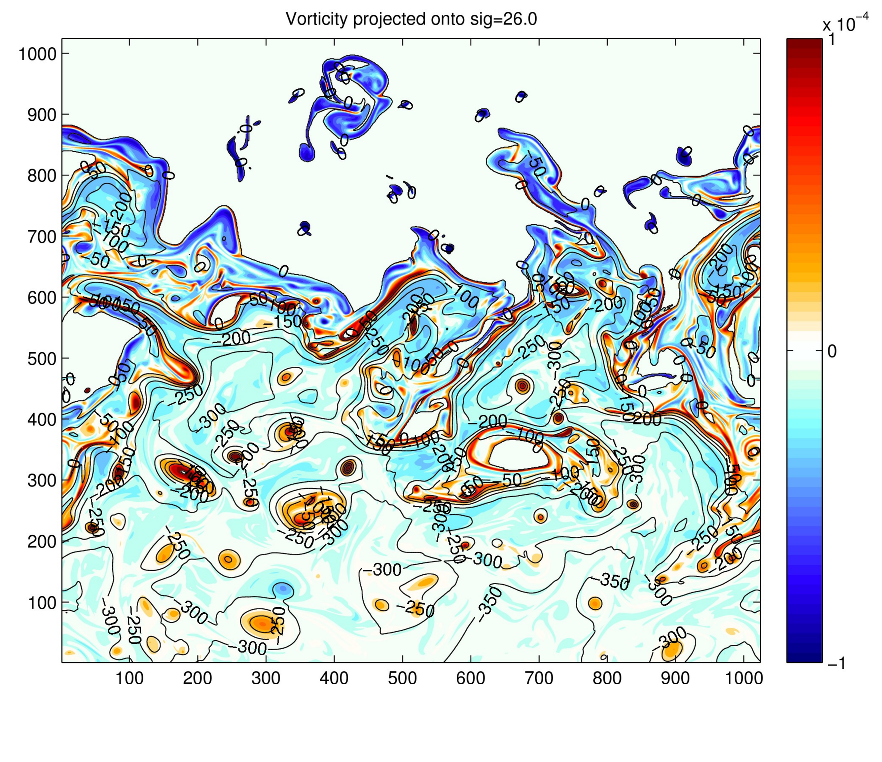
In this simulation, **isopycnal vertical displacement** are important (several hundreds meters). Lightest isopycnal (ρ<27.0) are outcropping, they experience frontogenesis. Densest isopycnals (ρ> 27.0) are flatter with no direct impact of the surface boundary. **We expect a transition regime between these two density classes, therefore we investigate the vorticity statistics in ρ-coordinate.**

ρ-coordinate view

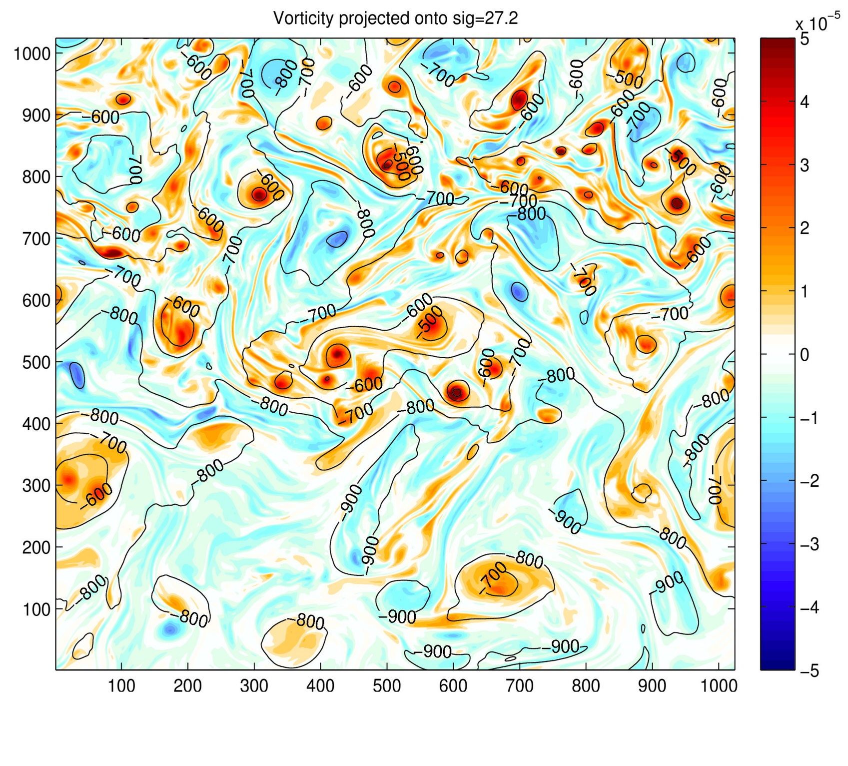
PDF of vorticity the interior



ρ = 26.0 / outcropping isopycnal

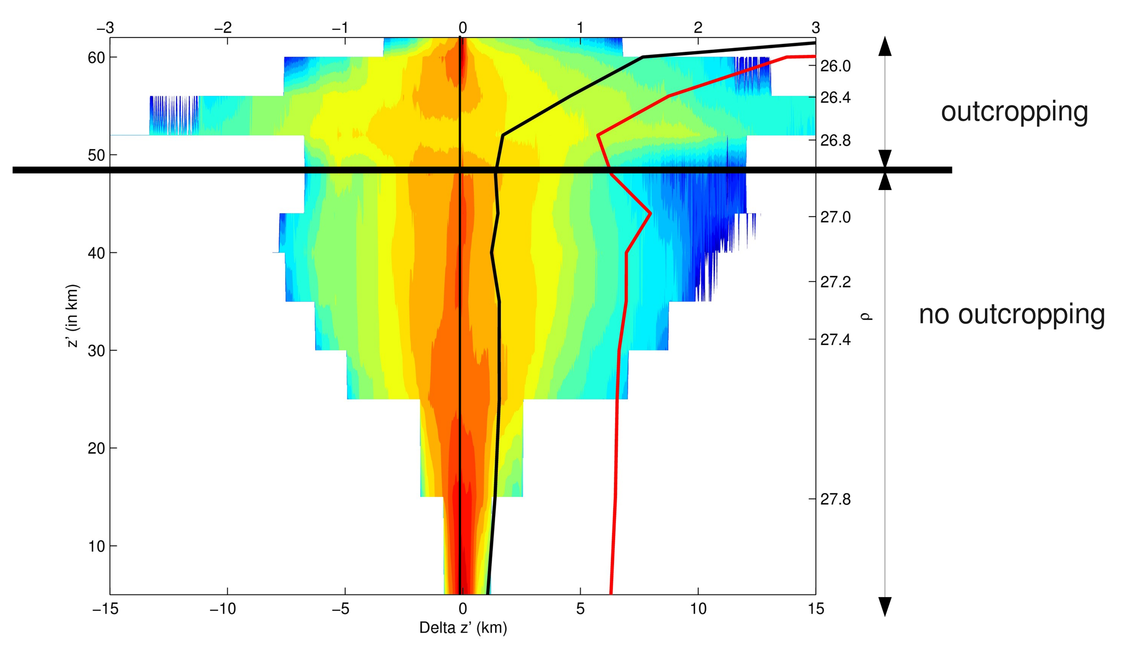


ρ = 27.2 / no outcrop



Vorticity projected on isopycnal (figure on the left) **looks very different than vorticity at a z-level** (compare with figure above). **There is a qualitative difference between outcropping and non-outcropping isopycnals.** For the former, extremes values (-f / +3f) occur, anticyclones and cyclones are spatially segregated with anticyclones preferentially stacked along the outcropping line. For the latter (no outcrop), the values decrease as density increases, there is no spatial segregation but instead a spatial uniformity. These qualitative differences are assessed by the vorticity PDF in ρ-coordinate (above). In this coordinate, cyclones dominate for all densities.

PDF of vertical displacement



What is clear is an asymmetry of cyclones-anticyclones for all the upper layers (z>-1000m). Near the surface it is associated with high Rossby numbers but in the interior, **Rossby is small and consequently nonlinearities on the vorticity.** So this essentially non QG effect should be explained by other means. **We suspect nonlinearity on the stretching to be a good candidate**. On the right figure we plot the PDF of the vertical displacement of isopycnal (weighted by N/f). The skewness is everywhere positive indicating that upward displacements are favored. Vorticity and vertical displacements are linked. If one PDF is skewed the other also is.

4 / Conclusions & Outlook

Vorticity is skewed: cyclones dominate above 600m depth. Beneath anticyclones dominate in z-coordinate but cyclones dominate in r-coordinate. This asymmetry is a non QG characteristic. In the interior, Ro is small, thermal wind balance is fulfilled.

What causes the asymmetry ?

• **Nonlinearity in the vorticity ?**

$$\zeta = \Delta\phi + \epsilon J(\phi_x, \phi_y)$$

This is the route followed by most intermediate models (balance equation model, semigeostrophic, SQG+1 etc). Maybe yes near the surface where Ro is large locally (especially at submesoscale) but likely no in the interior where Ro is quite small.

• **Vertical dependance of N(z) ?** in itself N(z) won't break the symmetry because it can be included in a QG model.

Another hint:
N(z) causes the available potential energy (APE) to be asymmetric and consequently the stretching. In terms of density anomaly Δρ , APE includes a cubic term (and higher ones) (Roullet & Klein 2009)

$$\text{APE} = \frac{1}{2}\rho^2 + \epsilon\rho^3$$

The important isopycnal deviations, associated with this energy asymmetry could be a candidate to rationalize the vorticity skewness. We are investigating this aspect.

References

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