

Homogenization of Potential Vorticity in the Eastern Region of the North Atlantic Subtropical Gyre. A Modelling Approach

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1. Introduction

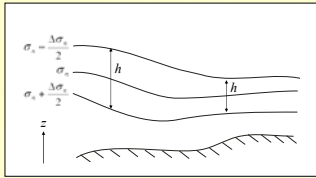
The eastern region of the North Atlantic subtropical gyre is an upwelling favourable region characterized by an intense quasi-permanent southward flowing coastal jet that is fed by the eastern branch of the Canary Current and provides the eastern boundary condition for the interior flow. Laiz et al. (2001) and Machín et al. (2006) specified this boundary drainage by allowing a meridional band of near-constant potential vorticity (Q) near the coastline and used it for a very simple one-layer quasigeostrophic model. The existence of such a constant Q meridional band implies the generation of negative relative vorticity at the eastern boundary, as if induced by the horizontal shear associated to the system of coastal currents, and allows the interior water to exit the numerical domain at the eastern boundary in reasonable agreement with observations.

3. Potential vorticity along isopycnal layers

The potential vorticity (Q) was calculated following the classical definition:

$$Q = \frac{f + \zeta}{h} \quad [1]$$

where f is planetary vorticity and ζ is relative vorticity. In the case of the 10 m depth layer, $h = 10$ m. In the case of the four selected isoneutral surfaces, and since they closely match the corresponding isopycnal layers, h represents the thickness of each layer (see Figure 2) and is calculated as follows:



$$h = -\bar{\rho} \frac{\partial z}{\partial \sigma}$$

where z is the vertical coordinate, σ is potential density and $\bar{\rho}$ is a reference density.

Figure 2. Example of the isopycnal layer σ_θ along which Q is evaluated from the density gradient between the isopycnals $\sigma_\theta - \Delta\sigma_\theta/2$ and $\sigma_\theta + \Delta\sigma_\theta/2$, with $\Delta\sigma_\theta = 0.05$.

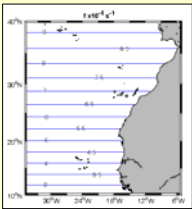


Figure 3. Distribution of planetary vorticity ($f \times 10^{-5} \text{ s}^{-1}$)

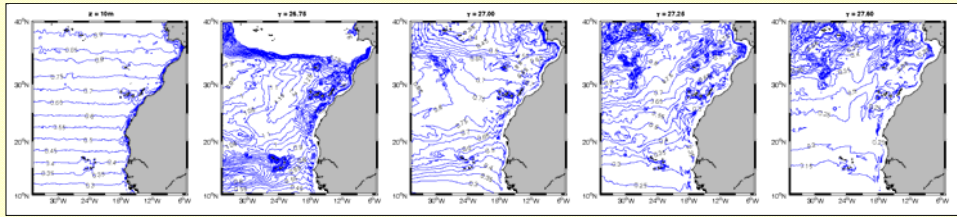
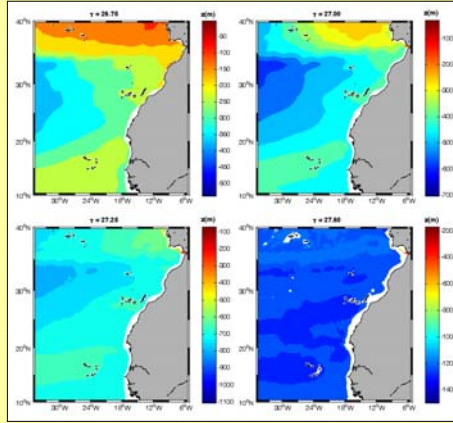


Figure 5. Annual mean distribution of potential vorticity on $z = 10$ m surface ($Q \times 10^{-10} \text{ m}^{-1} \text{ s}^{-1}$), and on $\gamma = 26.75$, $\gamma = 27.0$, $\gamma = 27.25$, and $\gamma = 27.6$ surfaces ($Q \times 10^{-10} \text{ m}^{-1} \text{ s}^{-1}$).

2. High resolution numerical model

The Regional Oceanic Modeling System (ROMS) is a primitive-equation, free-surface model which uses an orthogonal curvilinear coordinate system in the horizontal direction and a generalized terrain-following (sigma) coordinate in the vertical (Shchepetkin and McWilliams, 2005). In this study we use the results from a 50-yr climatological solution of a model configuration for the eastern North Atlantic (Mason, 2009) for the 10 m depth layer and for



four neutral-density layers ($\gamma = 26.75, 27.0, 27.25, 27.6$) in a grid that extends between $10^\circ\text{--}40^\circ\text{N}$ and $6^\circ\text{--}40^\circ\text{W}$ with a horizontal resolution of 7.5 km and 32 sigma-levels in the vertical; see the configuration details in Mason (2009) and Mason et al. (2010). The mean depth for these four neutral-density layers is shown in Figure 1. These isoneutrals are almost indistinguishable from the isopycnals with equal values.

Figure 1. Depth of the neutral density surfaces (annual mean).

A strip of intense anticyclonic vorticity is observed near the coast, more evident at the $z = 10$ m surface. Between this band of negative ζ and the coast there is a narrower band of cyclonic vorticity (Figure 4). The large scale distribution of Q is controlled by the background planetary vorticity, f , mainly at the $z = 10$ m surface. On deeper isopycnals there are regions where Q contours deviate from latitude circles. A band of constant Q is observed near the coast at all levels (Figure 5), in accordance with the observed strip of anticyclonic ζ .

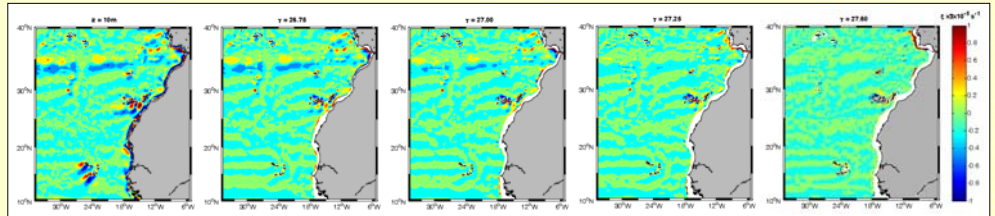


Figure 4. Annual mean distribution of relative vorticity ($\zeta \times 10^{-5} \text{ s}^{-1}$) on $z = 10$ m surface, $\gamma = 26.75$, $\gamma = 27.0$, $\gamma = 27.25$, and $\gamma = 27.6$ surfaces.

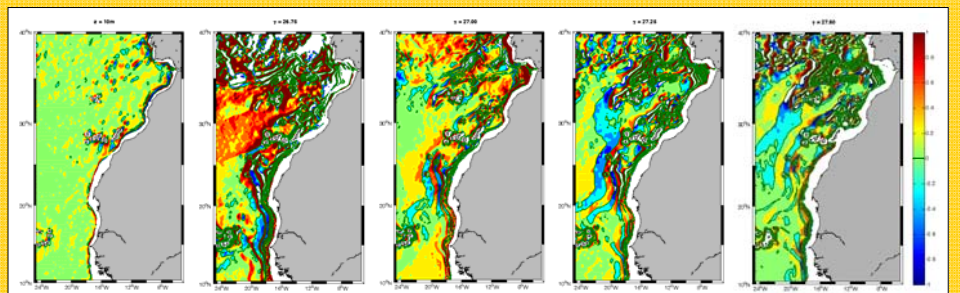
4. Potential vorticity meridional gradient

The meridional gradient of Q is calculated as:

$$\frac{dQ}{dy} = -\frac{(f + \zeta)}{h^2} \frac{dh}{dy} + \frac{\beta}{h} + \frac{1}{h} \frac{d\zeta}{dy} \quad [2]$$

The main contribution to dQ/dy was found to be the first term on the right hand side of equation [2] that is one order of magnitude larger than the other two terms, i.e., the meridional gradients of f and ζ respectively. A narrow band of $dQ/dy \cong 0$ is observed along the coast, indicating meridional homogenization of Q (Figure 6). This clearly points at a boundary adjustment to the large-scale interior flow, i.e. a coupling of the coastal dynamics to the ocean-interior forcing.

Figure 6. Annual mean distribution of dQ/dy on the $z = 10$ m surface ($dQ/dy \times 10^{-11} \text{ s}^{-1}$), and on $\gamma = 26.75$, $\gamma = 27.0$, $\gamma = 27.25$, and $\gamma = 27.6$ surfaces ($dQ/dy \times 10^{-10} \text{ s}^{-1}$). The dark green line corresponds to the contour $dQ/dy = 0$.



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