Dynamics of the Brazil-Malvinas Confluence: Energy Conversions

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Abstract. In this work, we investigated the mesoscale dynamics of the Brazil-Malvinas Confluence (BMC) region. Particularly, we were interested in the role of geophysical instability in the formation and development of the mesoscale features commonly observed in this region.

We dynamically analyzed the results of numerical simulations of the BMC region conducted with ‘Hybrid Coordinate Ocean Model’ (HYCOM). We quantified the effect of barotropic and baroclinic energy conversions in the modeled flow and showed the dominance of the latter in the region.

1. Introduction

The confluence of the warm waters of the Brazil Current (BC) flowing S-SW with the cold waters of the Malvinas Current (MC) flowing N-NE generates a region of strong potential vorticity gradient around 36ºS, in the Atlantic Basin, as can be seen from AVHRR images obtained by [1], containing meanders, eddies and filaments, known as the Brazil-Malvinas Confluence (BMC).

Figure 1 shows a series of sea surface temperature images from the BMC region, obtained by [3]. We can clearly observe the signature of the confluence region in the thermal front, as also the formation of coherent structures in the flow.

The processes that lead to the formation of the retroreflection and eddy-shedding patterns are akin to occur via geophysical instability processes. Moreover, analytical contour dynamics models constructed by [2], allowing only the baroclinic instability mechanism, exhibited the development of both retroreflection pattern and baroclinic vortical dipole formation.

These authors verified that dipoles were pinched off from either the retroreflection lobe (i.e., the primary crest of the wave train) or the primary trough when the baroclinically unstable current system was perturbed. Particularly, their results showed that dipole formation occurs at the vicinities of the continental boundary when unstable waves propagate phase westward.

The processes responsible for the formation and development of these instabilities, although, are not yet fully understood.

2. Model formulation.

As the theoretical results obtained by [2] pointed that the baroclinic instability effect could be the main source of meander growing in the BMC region, we performed, in this study, an energy conversion analysis of the flow using the numerical simulation outputs of HYCOM. Our aim was
Figure 1. Images obtained by [3], showing weekly sea surface temperature averages, between 09-06-2002 and 12-10-2002. The red circle identifies a warm ring that was generated and absorbed by the current.

to account for the effects of both baroclinic and barotropic instability, not possible in [2] more idealized study.

The implementation of HYCOM, for the BMC region, followed [4]. First, a 21-layers coarser resolution (1/3-degree) version for the entire Atlantic Basin, from 65°S to 60°N, was forced with monthly mean winds, obtained from COADS base, and initialized with climatological hydrography from [5]. This initial configuration was run for 25 years. After such period a one-way nesting with 1/12-degree resolution and 21 layers was implemented for the western South Atlantic region delimited by the latitudes 30°S and 45°S and the longitudes 60°W and 45°W, as showed in figure 2.

The nested model was run for one full year, forced with the same COADS climatological data and lateral boundary conditions provided by the coarse resolution model, using a 20 grid-points relaxation.

The BMC flow was obtained using the nested modeled year average and the corresponding 26th year data of simulation of the whole domain generated by HYCOM, for the fields of velocity, temperature and salinity. Those fields compared well with observed data.
Figure 2. High resolution domain, delimited by the red square.

The surface long-term velocity field is showed in figure 3, in IS units.

Figure 3. Mean surface velocity field, in IS units. The color scale represents the absolute values of velocities.

We clearly observe the BMC front located around 41°S, in accordance with observations performed by [6], as a result of the confluence between the BC flowing in the S-SW direction and the MC flowing N-NE. We also identify the zonal current extension, corresponding to the
South Atlantic Current (SAC).

The maximum absolute value of the velocities in the BC flow occur around 0.55 m/s, closely to the ones observed by [7] at 28°S. Maximum velocities associated with the MC flow are approximately 0.3 m/s, with mean velocity values around 0.17 m/s, higher than the geostrophic values measured by [8] at 36.5°S.

The flow associated with the BC weakens with increasing depth due to its baroclinicity, while the MC flow, dominated by the barotropic dynamics, presents small variability. These characteristics can be observed in figure 4, where we present the results for the velocity field around 650m.

![Figure 4. Velocity field, in IS units, for the 650m depth. The color scale represents the absolute values of velocities.](image)

Particularly, the velocity field calculations clearly show the intense vortical activity associated with the BMC front, showing the presence of two large anticyclonic structures in both sides of the confluence.

With the dynamical fields of the modeled BMC we performed the energy conversion calculations utilizing the method developed by [9], obtaining both baroclinic and barotropic energy conversion maps for all depths of the flow.

3. Energy conversions
To perform the energy conversion calculations we used the quasigeostrophic framework, following [9] and decomposed the three-dimensional flow into a leading order geostrophic flow component $\mathbf{u} = (u, v, 0)$ and a small ageostrophic component $\mathbf{u}_a = (u_a, v_a, w_a)$.

In order to calculate the eddy energetics we need to decompose the instantaneous fields into mean and eddy fields, which is done by defining the mean field as the long term average and the eddy field as the deviations from it.

According to [9] we can define the barotropic energy conversion, representing momentum advection associated with the flow, as

$$ BT = -u' u'' \frac{\partial u}{\partial x} - u' v'' \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) - v' v'' \frac{\partial v}{\partial y}, $$

(1)
where the mean terms are denoted by an over bar and the eddy terms are denoted by primes.

The baroclinic energy conversion, which is relevant to baroclinic instability, representing a mechanism that lowers the center of mass of the fluid is defined as

\[ BC = \frac{g\alpha}{\theta_z} \left( \overline{u^' T^'} \frac{\partial \bar{T}}{\partial x} + \overline{v^' T^'} \frac{\partial \bar{T}}{\partial y} \right), \]  

with \( \alpha \) being the specific volume and \( \theta \) a \( z \) coordinate function representing a purely vertical temperature field given by \( T = \theta(z) + \delta T(x, y, z, t) \), with \( \delta T(x, y, z, t) = \Delta T(x, y, z) + T^'(x, y, z, t) \) and \( \bar{T} = \theta(z) + \Delta T(x, y, z) \).

The energy conversion rates were calculated for all vertical levels of the simulation, showing the same dynamical characteristics, being less effective with increasing depths. Furthermore, it is important to note that only positive values of the conversion rates represent truly energy conversions.

The surface barotropic and baroclinic energy conversion rates are showed in figure 5 and figure 6, respectively.

**Figure 5.** Surface barotropic energy conversion rate, in m\(^2\)s\(^{-3}\).

We can observe in figure 5 that regions where barotropic conversions occur are associated with the retroflection region within the boundaries of the flow and the boundaries of the anticyclones. The maximum values of the barotropic conversions reach 2 \( \times \) 10\(^{-6}\) m\(^2\)s\(^{-3}\), located around 39\(^\circ\)S and 51\(^\circ\)W.

In figure 6 we observe that the baroclinic energy conversions are also more effective in the retroflection region. Maximum values of baroclinic conversion are 14 \( \times \) 10\(^{-6}\) m\(^2\)s\(^{-3}\). The zonal flow extension, corresponding to the SAC, also presents positive baroclinic energy conversions corresponding due to the meandering formation in this current.

The energy conversion rates associate with the BMC are of the same order of those calculated for the Gulf Stream by [9], although in the BMC the conversion process decays quickly with increasing depth.
4. Conclusions

We reproduced, in this work, the dynamic flow patterns observed in the BMC region, using an
hybrid coordinate ocean model (HYCOM), to study the origin and development of the intense
eddy activity commonly observed in this region. We were particularly interested in quantifying
the importance of geophysical instability in the dynamics of the flow.

This was achieved through the calculation of the energy conversion rates, following [9]
quasigeostrophic eddy energetic formulation, using HYCOM output fields for the region
delimited by the latitudes between 30°S and 45°S and the longitudes between 60°W and 45°W.

The results of the energy conversion calculations showed the dominance of the baroclinic
conversions over the barotropic ones, although these process do not always occur at the same
locations.

The dominance of baroclinic energy conversion mechanism suggest that heat fluxes are more
efficient to destabilize the flow than are the momentum fluxes. The conversion of the available
potential energy to kinetic energy in the BMC seems to be the main cause for the growing of
instabilities, while the barotropic conversions seems to be important in regions of intense shear
flow, particularly in the boundaries of the anticyclones.

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