Feature-Oriented Regional Modeling of the Brazil Current System

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Introduction

The Brazil Current (BC) develops intense meso-scale activity and large meanders as it flows off the SE Brazilian coast (20°S-25°). These meanders sometimes enclose eddies that pinch off from the BC and are either shed to the Subtropical Gyre interior or be reabsorbed by the current. Also in this latitude range, the South Atlantic Central Water (SACW) upwells near the coast.

The finite-amplitude BC meanders are recurrently formed in the surroundings of Cape São Tomé (22°S) and Cape Frio (23°S). The cyclones may grow seaward and the anticyclones penetrate the continental shelf. Therefore, there are physical bounds for the anticyclone growth. On the other hand, the cyclonic meander growth can be easily observed from AVHRR images. There are also observational evidences that the cyclonic meanders interact with the continental margin and may influence the coastal upwelling phenomenon (Figure 1). It seems that these interactions cause an asymmetric temperature-salinity structure both radially and azimuthally in the eddy structure.

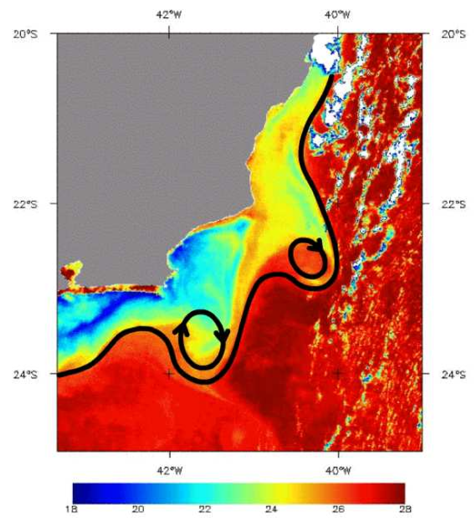

Figure 1: *AVHRR image of Brazil current eddies (Cape Frio and Cape de São Tomé) in February 2001- Courtesy of J.A. Lorenzzetti (INPE,Brazil).*

A multi-scale synoptic circulation system in the SE Brazil region is being developed, using the feature-oriented approach proposed by *Gangopadhyay and Robinson* (1997) to investigate the this complex oceanic region dynamics as well as to target future ocean prediction. This work presents the preliminary results related to development of one of the components of such scheme: the feature models (FMs) for the BC system.

Methods

Gangopadhyay and Robinson (2002) stated that every oceanic region is unique in terms of its dynamic behavior and can be expressed in terms of the evolution and the interactions of dominant features over many scales. These authors suggested that those features can be represented by their signature in the water properties, such as temperature and salinity.

Building on these ideas, the prevailing synoptic circulation features were identified from previous observational efforts. These features consist of the southward flowing Brazil Current, the cyclonic eddies off of Cape São Tomé (CST) and Cape Frio (CF), the surrounding coastal upwelling region among others (Figure 2). Their synoptic water-mass (T-S) structures are characterized and parameterized via analytical/empirical formulation to develop the temperature-salinity FMs. These synoptic-scale feature models are then merged with climatology via objective mapping to generate initialization fields for numerical simulations. This whole procedure has been referred in the literature as the "Feature-Oriented Regional Modeling System-FORMS" (*Gangopadhyay and Robinson*, (2002)).

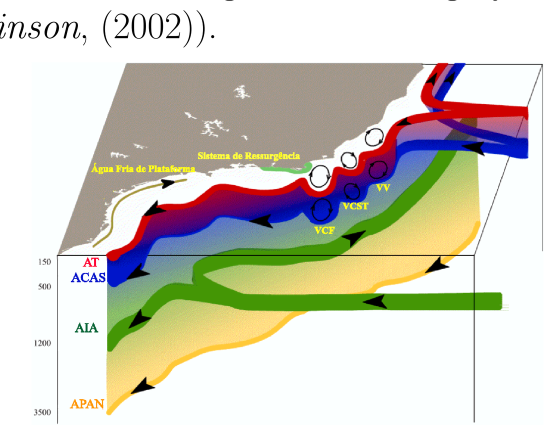

Figure 2: *An schematic representation of the boundary currents and associated water masses, the main eddy-like structures and the upwelling region off Southeast Brazil.*

◁ The Brazil Current Feature Model (BCFM) ▷

The Brazil Current FM follows the formulation developed by *Gangopadhyay and Robinson* (2002). We obtain the along-stream component of BC geostrophically via parameterized 3-D temperature and salinity fields. The generic expression of the temperature (or salinity) structure at a given location (x,y,z) is

$$T_i(x,y,z) = [T_{i_s}(x,y) - T_{i_b}(x,y)]\Phi(x,y,z) + T_{i_b}(x,y); \qquad (1)$$

where the index i denotes the $inshore$, $core$, and $offshore$ positions of typical profiles of both oceanic and coastal edges as well as center of the BC front. The sub-indexes s and b refer to surface and bottom values of the hydrographic property. $T_i(x,z)$ is constructed using a synoptic data set available from observational data sets. In our case, we applied the methodology to the "*Dinâmica do Ecossistema de Plataforma da Região Oeste do Atlântico Sul* (DEPROAS)" CTD set. The choice of such typical profiles is made by identifying the location of the BC front via mapping of the geostrophic streamfunction and extracting the synoptic temperature and salinity profiles at these three positions. $\Phi_i(x,y,z)$ is the non-dimensional profile of the property, which will be used as a vertical structure function in the three locations.

Figure 3 shows both an sketch of the BCFM formulation and the three-dimensional temperature field produced by using the *Levitus et. al,* (1994) climatology for the T_{i_s} and T_{i_b} values along its path throughout the oceanic area adjacent to Southeast Brasil and the $\Phi_i(x,y,z)$ estimated from the DEPROAS data set

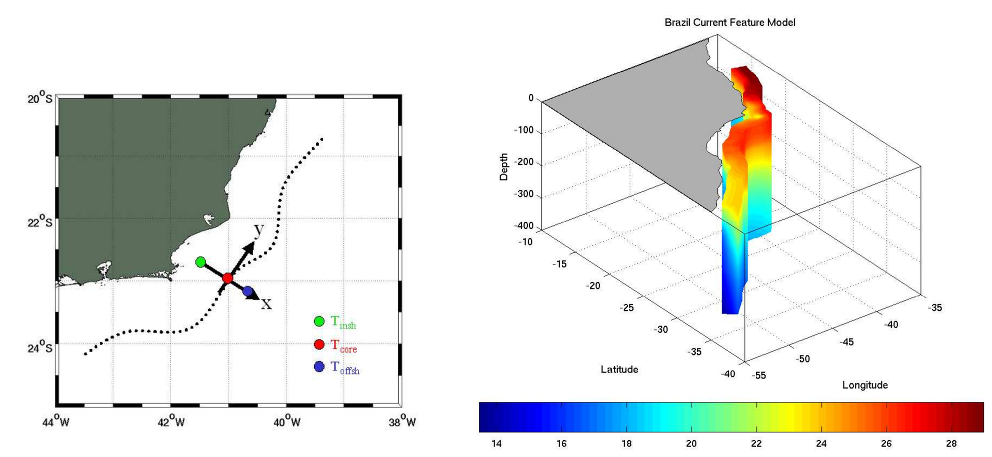

Figure 3: *The Brazil Current Feature Model: an schematic FM representation and an exercise of its application using climatological T_{i_s} and T_{i_b}.*

◁ The Eddy Feature Model (EFM) ▷

We here propose a simple asymmetric parametric characteristics model to describe the EFMs, which will be useful for understanding the interaction between the coastal upwelling, the eddies and the BC front.

The water mass distributions within the eddies off of CST and CF (and possibly off of Vitória as well) set up an asymmetric configuration. The inshore part of the meander (as seen in Figure 2) will have water mass characteristics closer to the upwelling region (i.e., relatively colder and fresher), while the offshore part of the eddy would have water masses akin to the shoreward side of the BC meander (i.e., relatively warmer and saltier).

We developed this new parametric model by modifying the *Gangopadhyay and Robinson* (2002) formulation of a symmetric eddy. In their parameterization, the edge temperature salinity profiles are uniform, a characteristic of the Gulf Stream rings. Therefore, for such symmetric eddies, the hydrographic property profiles are identical along the whole eddy edge. For the EFMs, we must consider varying T-S profiles by adopting the tracer formulation given by

$$T(r,z,\theta) = T_k(z,\theta)(1 - e^{-r/R}) + T_c(z)e^{-r/R}; \qquad (2)$$

where $T_c(z)$ is the core profile input, r is the distance between the center to the border of the eddy and $R = 3R_0$, where R_0 is the internal Rossby deformation radius. $T_k(z,\theta)$ is the border profile value. This latter quantity can be written as

$$T_k(z,\theta) = [T_i(z) + \frac{(T_o(z) - T_i(z))}{2}e^{\theta/\gamma}(1 + cos\theta)]; \qquad (3)$$

where θ ranges from 0 to 2π. T_o is the temperature/salinity profile of the offshore part of the eddy edge. We establish T_o position to be at $\theta = 0$ in the model. T_i is the temperature/salinity profile of the inshore edge part where $\theta = \pi$. Hence, by such configuration, the location $\theta = 0$ along the eddy border is where get the highest temperature (due to the T_o profile) (Figure 4).

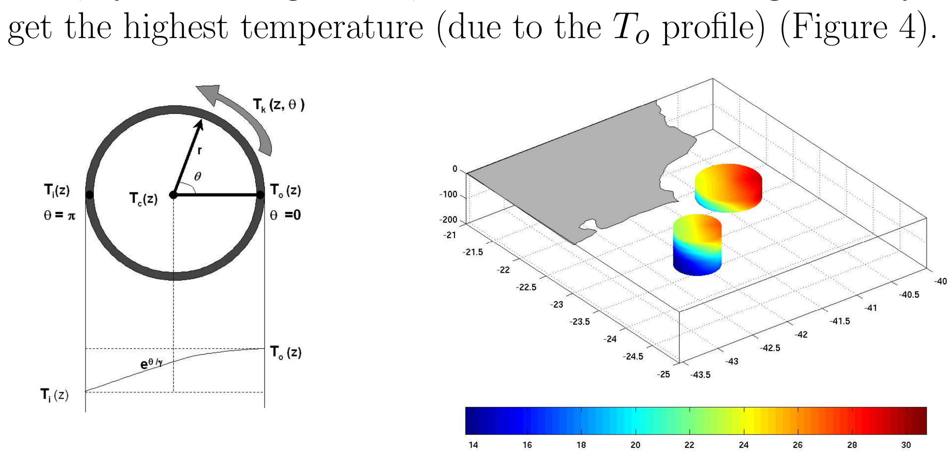

Figure 4: *The asymmetric EFM parameters and an exercise of its application using climatological T_{i_s} and T_{i_b}.*

The function $e^{\theta/\gamma}$ provides the azimuthal distribution between inshore and offshore borders of the eddy. In fact, the gradient between T_i and T_o in the EFM border varies with this "asymmetry" function. Therefore, γ can be called the asymmetry parameter and determines how the exponential function azimuthally varies (Figure 4). If γ is a high positive value, temperature and salinity tend to vary linearly from T_o and T_i along the edge. On the other hand, γ also establishes the percentual contribution of coastal/SACW upwelled waters and oceanic waters within the eddy. If $\gamma > 0$ as θ increases, T_o contributes to a general warming of the eddy edge. Thus, through the γ parameter, we can also control how warmer or colder the eddy is.

◁ The Coastal Upwelling Feature Model (CUFM) ▷

During the summer period, where coastal upwelling is more common and robust due to favorable wind conditions, the surface temperature difference between the BC front and upwelled waters near coast is most of the time grater than 8°C. The upwelling region off Southeast Brasil is more intense around Cape Frio and Cape São Tomé. As coastal upwelling occurs, the SACW "climbs" the shelf break and the isotherms (as well as isopycnals) bend upwards in the vicinities of the continental slope.

A schematic representation of this feature near CF and CST is shown in Figure 5. This sketch synthesizes the first-step towards developing the CUFM. It is derived from the continental shelf front FM developed by *Gangopadhyay and Robinson* (2002). The formulation is then given by

$$m(\eta,z) = \frac{1}{2} + \frac{1}{2}tanh\left[\frac{\eta - \Theta \times z}{\gamma}\right]; \qquad (4)$$

where $m(\eta,z)$ is a meld function, $\Theta = h/x$ is the slope angle, defined by h, the thermocline depth, and x, the front distance, γ is half-width of the front, η is the cross-frontal distance and L is the total distance between inshore non-dimensional profile (T_i) and T_o.

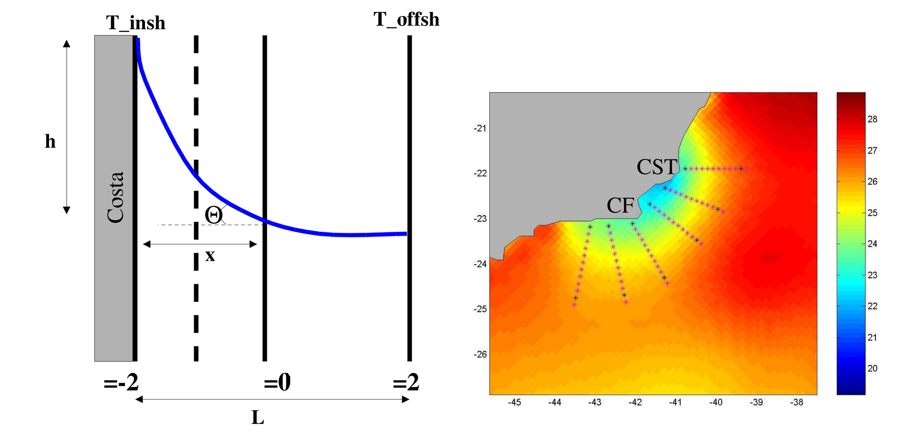

Figure 5: *An schematic representation of the Coastal Upwelling FM and an exercise of its application using climatological T_{i_s} and T_{i_b}.*

The function m is hence applied on two non-dimensional profiles (obtained from the DEPROAS observations) given by

$$\Phi_i(x,z) = \frac{T_i(x,z) - T_{i_b}(x)}{T_{i_s}(x) - T_{i_b}(x)}, \qquad (5)$$

where the index i refers again to the $offshore$ and $inshore$ positions.

Results and Discussion

As an example, we apply the tree FMs described above by performing a numerical simulation with a regional implementation of the full Princeton Ocean Model (POM) version. The model domain is the oceanic area adjacent to the SE Brazil coastline.

First, we employ the methodology as described above. The surface temperature extracted from the DEPROAS set and climatology. Salinity is inferred from T-S climatological relationships. We then re-dimensionalize the profiles and generate the 3-D structure for the features. After that step, we merge the FM with the appropriate background climatology via multi-scale objective analysis (*Lozano et al.*, 1996). Concluding such procedure, initial temperature and salinity fields, as well as the derived geostrophic velocity fields, are used to initialize the numerical simulation (Figure 6A) with a BC dynamically adjusted to the mass field. In this particular test simulation, we did not apply any other forcing.

Figures 6A to D show the temporal evolution of the experiment. After 6 days of simulation, the CFE pinches off as a cyclonic eddy. By day 9 (Figure 6D), moves offshore of the BC and other eddy is forming ((40^o W, -24.5oS). Obviously, sensitivity studies and both statistical and dynamical inter-comparison analysis with observations are needed to validate, calibrate and verify such dynamical statistics.

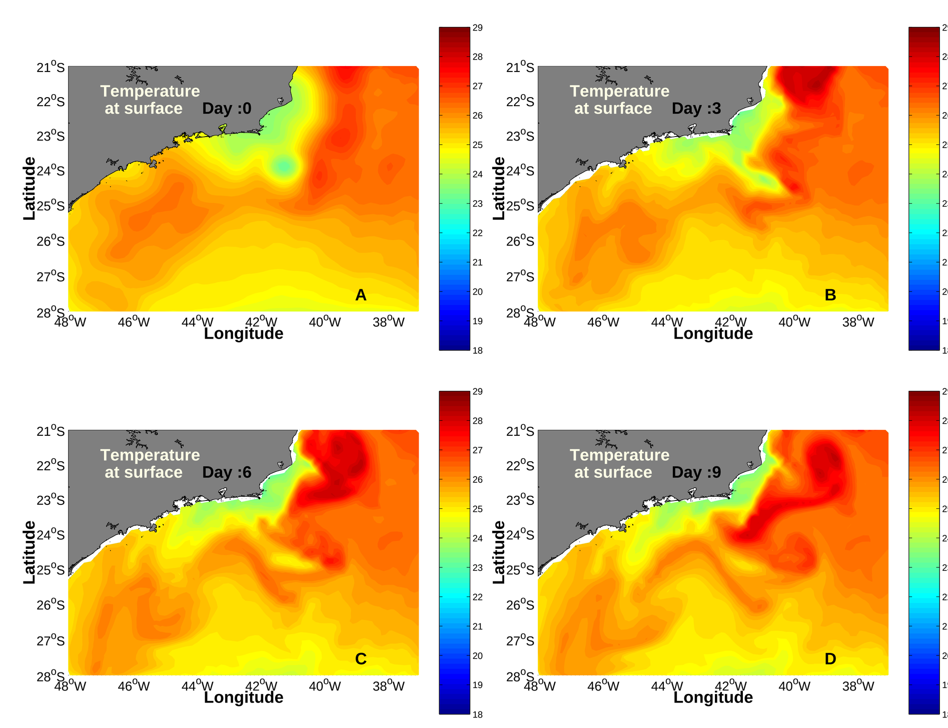

Figure 6: *A numerical model application for the FORMS technique using three FMs of the BC system.*

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Acknowledgments

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