A MESO-SCALE BRAZIL CURRENT FRONTAL EDDY: OBSERVATIONS BY ASAR, RADARSAT-1 COMPLEMENTED WITH VISIBLE AND INFRARED SENSORS, IN SITU DATA, AND NUMERICAL MODELING.

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Abstract

During a week of November 2004 a series of microwave, infrared and visible satellite images were acquired over the oceanic area of Campos Basin, at the SW South Atlantic off Brazil in conjunction with a hydrographic campaign. The main oceanographic feature present during that period was a well-developed cyclonic Brazil Current (BC) frontal eddy. An oil seepage was present in the same region and the surface slick was captured by the clockwise circulation of the eddy. The thermal contrast between the offshore warm waters of BC and the shelf cooler waters, which is frequently enhanced by the presence of cold upwelling plumes, seems to modulate the atmospheric stability and $\sigma_o$ values in the region, making the BC front and the eddy clearly visible in the ASAR and Radarsat-1 images. The presence of the oil film in the eddy also facilitated its detection in the microwave images. AVHRR SST, MERIS, CBERS and ASTER images clearly confirm the analysis of the eddy made with SAR images. A numerical simulation of the three-dimensional circulation in the region for the observed period was implemented using the POM model. The model was able to generate the BC frontal eddy at the location observed in the satellite images. The model results are used to get the 3D view of the eddy and its velocity field. The offshore upward slope of the pycnocline at the outer shelf and shelf break obtained from CTD casts confirms the presence of the northward inshore branch of the eddy.

1. Introduction

The Campos Basin, located at the SW South Atlantic near Rio de Janeiro, Brazil (Fig. 1), is the most important continental shelf and adjacent deep ocean area for the oil production in the country. This is a region of about $10^5$km$^2$ in which 64 platforms operate generating 89% of the total Brazilian oil production of $1.847 \times 10^9$ barrels per day as of today (March 2006). It is estimated that about 40,000 people work in the area. Despite all the investment put into safety measures to minimize the risk of accidents and environmental impacts to the coastal and oceanic ecosystems of the region the offshore oil industry is intrinsically a risk prone activity. To prevent problems and to mitigate the consequences of accidents, there is a continuous demand of environmental data for monitoring the region and to support engineering projects and scientific studies. As part of a network of environmental data acquisition system, the Brazilian oil company Petrobras operates several in situ platforms in the region. Complementing this data set, the company acquires routinely remote sensing orbital data of a series of satellite sensors, encompassing the visible, infrared and microwave electromagnetic spectrum. In general, most of the satellite data is made available in near real time basis.
The most important oceanic surface feature of the region is the Brazil Current (BC), the western boundary current of the South Atlantic gyre (Fig. 2, left). BC is formed as the southern branch of the South Equatorial Current (SEC) in the bifurcation present at about 10 – 15oS. This is warm and high salinity water that moves southward along the shelf break [3]. Considering that most offshore industry activities are concentrated in the outer shelf and shelf break regions it is expected that any passive contaminant in the surface layers in the region will drift southwards. This flow pattern in fact prevails most of the time but high energy oceanic meso-scale activity can develop in the region with the generation of strong BC meandering and formation of frontal eddies. Historical hydrographic data shows that Intermediate Water Boundary Current (IWBC) flows northwards underneath the Tropical Water of BC, which flows to the south in the area (Fig. 2, right). BC-IWBC velocity field is 75 – 80% baroclinic over the slope according to [6]. Some preliminary studies indicate that baroclinic instability associated with the vertical stratification and current shear feeds energy from the basic flow to the perturbations.

Taking into account the meso-scale flow field, it is seen that the presence of BC inshore cyclonic frontal eddies can reverse the basic flow. At the inshore side of these eddies water flows from S to N. It is, therefore, quite clear that the fate of any contaminant in the water in this region will depend heavily on the prevalence of normal conditions of BC flowing southward or the presence of eddies. In the Campos Basin, two eddies have been observed quite frequently. One is located SE of Cabo São Tomé (CSTE) and another SE of Cabo Frio (CFE) (Fig. 2, right).
In order to get a better understanding of the effect of eddy activity over the circulation in Campos Basin, Petrobras is sponsoring a scientific project involving in situ hydrographic data collection, acquisition of satellite data and numerical ocean modeling. The objective of this paper is to show the first results of this project with the focus in the last week of November 2004, when the São Tomé Eddy was present in the area modulating the surface flow. A natural, but relatively strong, oil seep event happened during the period of the experiment. The cyclonic circulation of the Cabo São Tomé eddy captured the surface expression of the seep and it was visible in most of the satellite imagery collected.

2. Available data set
For the experiment carried out at the Campos Basin, satellite data were available from the following sensors: a) ENVISAT/ASAR; b) Radarsat-1; c) MERIS; d) ASTER, e) CBERS-2/WFI [1], f) AVHRR; g) GOES-W; and h) QuikScat winds. CTD (Conductivity/Temperature/Depth) hydrographic casts were done to verify the field of mass at the Cabo São Tomé region. A numerical simulation of the three-dimensional circulation in the region for the observed period was implemented using the Princeton Ocean Model (POM) [3]. The model was initialized using the results of the Ocean Data Assimilation Experiment (GFDL/Univ. Princeton) and it was forced with winds simulated for the region by AVN model of NCEP.

3. Results
Soon before the beginning of the hydrographic campaign it was reported the presence of a large surface oil slick in the area. A ROV sent to the bottom (1200 m) showed that the origin of this surface film was an intense oil seep. Total cloud cover associated with the passage of a cold front prevented the use of any visible or infrared satellite image at this time. Fig. 3 (left) shows that the acquisition of Radarsat-1 image was important to map the feature. QuikScat wind data revealed that part of dark features observed in that image was a low wind region. The circular pattern of the slick and the BC front, observed by SST differences between cooler shelf and warm BC waters, allowed the mapping of the CSTE. Two days later (Fig. 3 – right), the ENVISAT/ASAR image gave another view of the eddy revealing that the oil film had moved NW with the clockwise cyclonic circulation of the eddy. Eddy size estimated from these images is about 60 – 70 km.

With the clearing of sky at November 23th it was possible to get the first visible and IR images of the eddy. Fig. 4 shows a zoom of the eddy in three channels of ASTER sensor. Possibly due to appropriate sun illumination conditions, one can see the oil seep in the visible channel. Different responses inside of the seep area can be visualized which seem to be related to different thickness of the film. A better view of the seep was possible in the NIR channel. At the thermal IR channel it is possible to get a good view of the eddy size (65 km). Darker areas represent cooler shelf waters. White spots in the TIR image are oil platforms with operating flares. Fig. 5 (left) shows the visible image acquired by the Brazil-China satellite CBERS about 30 minutes after ASTER image shown before. Sun illumination was even better to show the oil seep and give a good signal of the eddy. Distinct oil characteristics inside the seep area are clearly observed in this image. The thermal field at this time is shown in Fig. 5 (right). Red colors show the warm waters of BC separated from the cooler shelf waters (green). The CSTE is clearly visible in this AVHRR image. Blue colors show the surface expression of the coastal upwelling, quite common in the area this time of the year [5].
Fig. 4 ASTER view of the CSTE and oil seep: 2004/11/23 12:55 GMT. (left) Band 1 (0.56 µm); (center) Band 7 (2.26 µm); (right) Band 13 (10.66 µm).

Fig. 5 View of CST eddy and oil seep. 2004/11/23; Left: CBERS-WFI 13:30 GMT Color composite 2R1G1B; Right: SST AVHRR NOAA-15

Fig. 6 shows ENVISAT/ASAR (left) and MERIS (right) images of the eddy at day 25 of November. The area extent of oil has decreased, being visible mostly at the S/E parts of the eddy. Although MERIS image captured only part of the eddy, it is possible to get sense of it. The interpreted BC circulation seems to match the position of the oil film in the SAR image.

A numerical simulation of the three-dimensional circulation in the region for the observed period was implemented using POM model. Fig. 7 (left) shows that the simulation was able to generate the BC frontal eddy at the location observed in the satellite images. Eddy size of the model is also very similar to the size extracted from the images. This result gives us some confidence in using model results to get a 3D view of the eddy and its velocity field. Model results indicate that over the outer shelf up to the 100 m isobath the northward flow of the inshore portion of the eddy spans the whole water column (Fig. 7, right). Maximum water velocities of 0.5 ms⁻¹ and 0.3 ms⁻¹ were modeled for the offshore and inshore extremes of the eddy, respectively. For one vertical hydrographic CTD section which sampled the inshore part of the eddy, the upward slopes of the temperature, salinity and pycnocline lines at the outer shelf and shelf break (Not shown) confirm the presence of the geostrophic balanced northward circulation of the inshore branch of the eddy.
Fig. 6 2004/11/25 Left: ASAR 01:00 GMT; Right: MERIS Band 1 12:00 GMT. VST:Cabo São Tomé Eddy; dark arrows indicate probable CB surface circulation.

Fig. 7 POM results for Nov. 23th, 2004. (Left): surface circulation. (Right) Vertical section plot of meridional velocity (cm/s) through line AB at left. Green/blue/white colors represent southward currents; remaining colors are northward circulation.

4. Conclusion
The results presented indicate that through a synergistic approach of using a set of visible, infrared and microwave satellite images it was possible to obtain a good view of the Cabo São Tomé Eddy, which sometimes develops at the Campos Basin oil field. It is very important to monitor this feature and to understand its formation mechanism and life cycle considering its influence over the normal southward circulation of the Brazil Current at the outer shelf. Considering the potential of SAR images to monitor the eddy, results show that, both VV ENVISAT-ASAR and HH Radarsat-1 instruments were able to capture the feature. The presence of the oil seep and the thermal contrasts between cooler shelf and warm BC waters, which seem to modulate atmospheric boundary layer stability, are considered the main mechanisms modulating Bragg scattering and making the eddy visible in the SAR images.

The use of visible and infrared images was important to complement the information extracted from SAR images. The use of such images is, however, totally dependent on cloud coverage in the region. Unfortunately, cloud coverage in the area is relatively high throughout the year, making SAR data a fundamental tool for operational and near-real time monitoring of Campos Basin. The satellite data was important for checking the ability of the numerical model in capturing the eddy, its position and surface size. On the other hand, after this test of model’s skill, numerical model results can be used to obtain a reasonable estimate of the circulation of the eddy and its three dimensional characteristics, an information difficult to extract from remote sensing.

References
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