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Concurrent Observations of Ocean Color and Sea Surface Temperature between Cabo Frio e Cabo São Tomé

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Abstract Mesoscale oceanographic features can be important mechanisms for enhancing primary production in oligotrophic regions. In this work, we present a 6-day comparison of sea surface temperature (SST) and chlorophyll (chl) estimates by remote sensing. The main oceanographic features observed in the Southeast Brazilian region, were the São Tomé semi-permanent eddy, shelf break upwelling and Brazil Current inshore frontal meanders. A clear response in pigment concentration was observed in the shelf break upwelling. In the center of the meanders and eddy chl remained relatively low, suggesting that the cold signatures also noted in these areas were more related to the entrapment of shelf waters than to upwelling.

Keywords: Ocean color, SST, cyclonic eddy

1 Introduction

The Southeast Brazilian coast has direct influence of the oligotrophic waters from the Brazil Current (BC) (Peterson and Stramma 1991; Stramma and England in press). Waters from BC are saline, warm and oligotrophic (Brandini *et al.* 1997). Primary production and phytoplankton biomass tend therefore to be low, but they can be altered by oceanographic processes that promote injections of nutrients from subsurface waters to the euphotic zone. In this region, a number of physical structures capable of potential enrichment have been reported as cyclonic eddies (Matsuura 1986; Schmid *et al.* 1995; Stech *et al.* 1996; Gaeta *et al.* 1999) frontal regions (Garfield 1990), and upwelling events, both at the coast (Valentin *et al.* 1987; Kampel *et al.* 1997) and at shelf break (Campos *et al.* 2000). The quantification in time and space of mechanisms that promote the enrichment of these waters are thus extremely relevant for the general understanding of the factors controlling primary production, and the resultant impact on biogeochemical cycles and management of ocean's living resources (Mann and Lazier 1996).

The dynamics and spatial scale of the eddies and upwelling events, especially those at higher depths, complicate the study of their impact on biological activity. One has to relay on methods which allow a synoptic view of both physical and biological features. A current possible path is to use remote sensing images of Sea Surface Temperature (SST) and chlorophyll-a (chl) estimates. However, this approach is limited by cloud cover and it is also restricted to surface layers of the ocean.

Here we present preliminary results from a 6-day continuous observation (August 21 to 26, 2000) of both SST and chl estimates between Cabo Frio (23ºS/42ºW) and Cabo de São Tomé (22ºS/41ºW), during a period relatively clear from clouds. Our goal is to illustrate the impact of

the evolution of the semi-permanent eddy off Cabo São Tomé and a shelf break upwelling feature (21º-22ºS) on estimations of surface chl.

2 Methods

From August 21 to August 26 2000, daily Advanced Very High Resolution Radiometer (AVHRR) and Sea-viewing Wide Field-of-view Sensor (SeaWiFs) data were recorded in HRPT mode (level 0) by the Remote Sensing Division at National Institute of Space Research (INPE, Brazil). Both data have nominal 1.1 km resolution at nadir.

SST maps of the region were derived from data collected by the AVHRR flown onboard the NOAA satellites. The raw data were then converted to level 1B-NOAA format (Kidwell 1995). The digital process involved: i) cloud masking using a threshold value of albedo in the channel 2; ii) application of one of the multichannel sea surface temperature NOAA algorithms for atmospheric correction and generation of SST images (McClain *et al.* 1985).

SeaWiFs data were processed with the routines Swl10 (version 3.0) and SeaDAS (version 4.0), both distributed by the SeaWiFs Project (NASA), using respective standard algorithms and masks. Chlorophyll-a values were obtained using a global algorithm (O'Reilly *et al.* 1998) and daily atmospheric data acquired from NASA GSFC's Distributed Active Archive Center (DAAC).

Both SST and chl images were mapped to cylindrical projection and geographically gridded. The images were digitally enhanced and a color slicing was applied to improve the contrast and to facilitate interpretation of the thermal and pigment features present. Chl estimates were scaled to a maximum of 32 $mg.m^{-3}$.

The features were identified on the SST maps and their geographic locations were used to extract the chl values from the SeaWiFs images. In addition, a profile (values from each pixel between the coordinates 21.5ºS/41.2ºW and 22.2ºS/39.5ºW) was extracted from each image north from Cabo São Tomé, in order to monitor a shelf break upwelling event.

4 Results and Discussion

Due to cloud cover and problems during acquisition, data for SST was not available in August 24. Data for chl was not available in August 22. Because of that, we excluded the data from August 24 from the analysis and we will assume that the temperature features observed on August 22 are valid for comparison with the chlorophyll data from August 21.

Visual analysis of the thermal images **(Figures 1 and 2)** clearly show 3 distinct features: i) the development of the Cabo São Tomé eddy (see also **Table 1**), ii) a number of meanders south of Cabo Frio, and iii) a cold water signature north of São Tomé, at the vicinities of the shelf break. The thermal inshore front of the BC was very well delimited throughout the images. Small cold features observed randomly in the images will not be associated with upwelling events due to he possible contamination by water vapor.

Fig. 01

Fig. 02

Tab. 01

The eddy off São Tomé increased progressively in diameter (around 50% in 4 days), stretching meridionally in August 23 and then zonaly in August 25 (**Figures 1 and 2**). The center of the eddy also tended to move inshore (**Table 1**). The temperature inside the core of the eddy remained approximately constant during the 6-day period. Average chl concentrations in the core of the eddy tended to increase with time, but they were not substantially. Chl signatures (around 0.4-0.5 $mg.m^{-3}$) associated with this eddy were spiral-like lines located at the periphery in the offshore side of the eddy. Part of this high chlorophyll segment is visible in the center of the eddy by August 26. These patterns are more likely associated with the entrapment of the

colder surface waters from the shelf than with a response of upwelling in the central portion of the eddy.

Is interesting to note the development of a fairly large chl signature off São Tomé, starting from the coast, and following the inshore side of the São Tomé eddy. This high chl (above 1 mg.m^{-3}) signature extended around 25 km from August 21 to August 23 (**Figure 1**) and progressed to more than 120 km in August 26 (**Figure 2**). This feature may be directly related to the thermal front of BC, probably linked to the front's effects on both advection and concentration of cells, and mechanisms of nutrient transport (Mann and Lazier 1996). The presence of this eddy seem to enhance these mechanisms substantially and that deserves further investigation.

Fig. 02

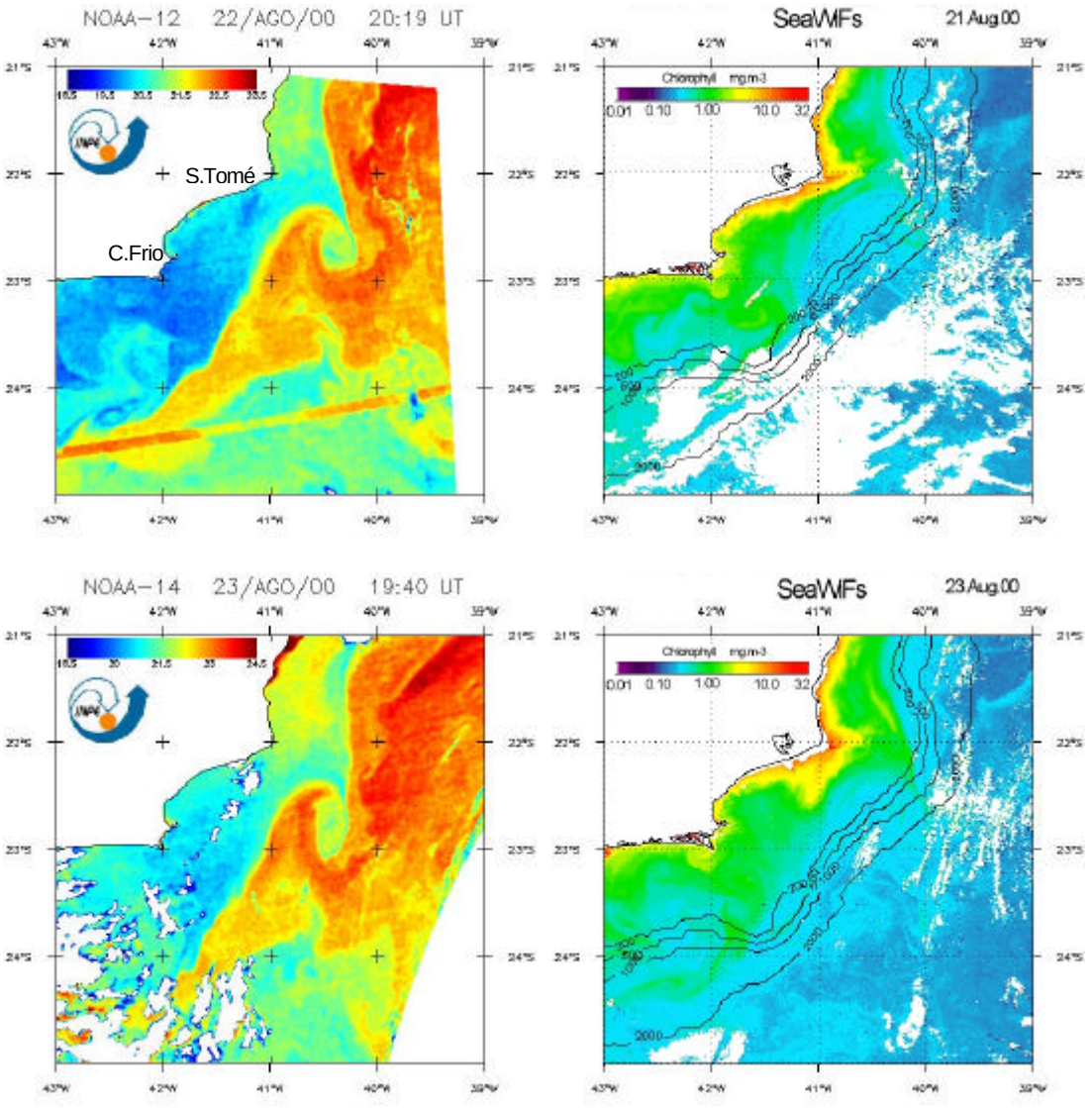

Figure 1. Sea Surface Temperature (SST) and chlorophyll estimates for August 21-22 and August 23, 2000. Note changes in SST scales. Lines on chlorophyll maps are isobaths in meters.

South of Cabo Frio we can also observe a clear correlation between the cold and warm water features and chlorophyll signatures. In this case, the low chlorophyll signatures in the shelf waters are probably related to the dilution of shelf waters by the BC.

A distinct cold water plume is present at the shelf break region, north of São Tomé (around 21.5ºS/40.5ºW) in all images, predominantly on August 25 and 26 (**Figure 2**). It is noted that there is a clear relationship between the decrease in temperature and the increase in chlorophyll concentration. Comparing the evolution of this feature during the 6-day period (**Figure 3**), we observe a 4-fold increase in chl and a migration of the peak towards the coast. On the other hand, SST data decreased around 2ºC and the minimum tended to be displaced offshore. These results show clearly that shelf break upwelling events are indeed can be an important mechanism for enhancing the primary productivity in this ecosystem.

Fig. 03

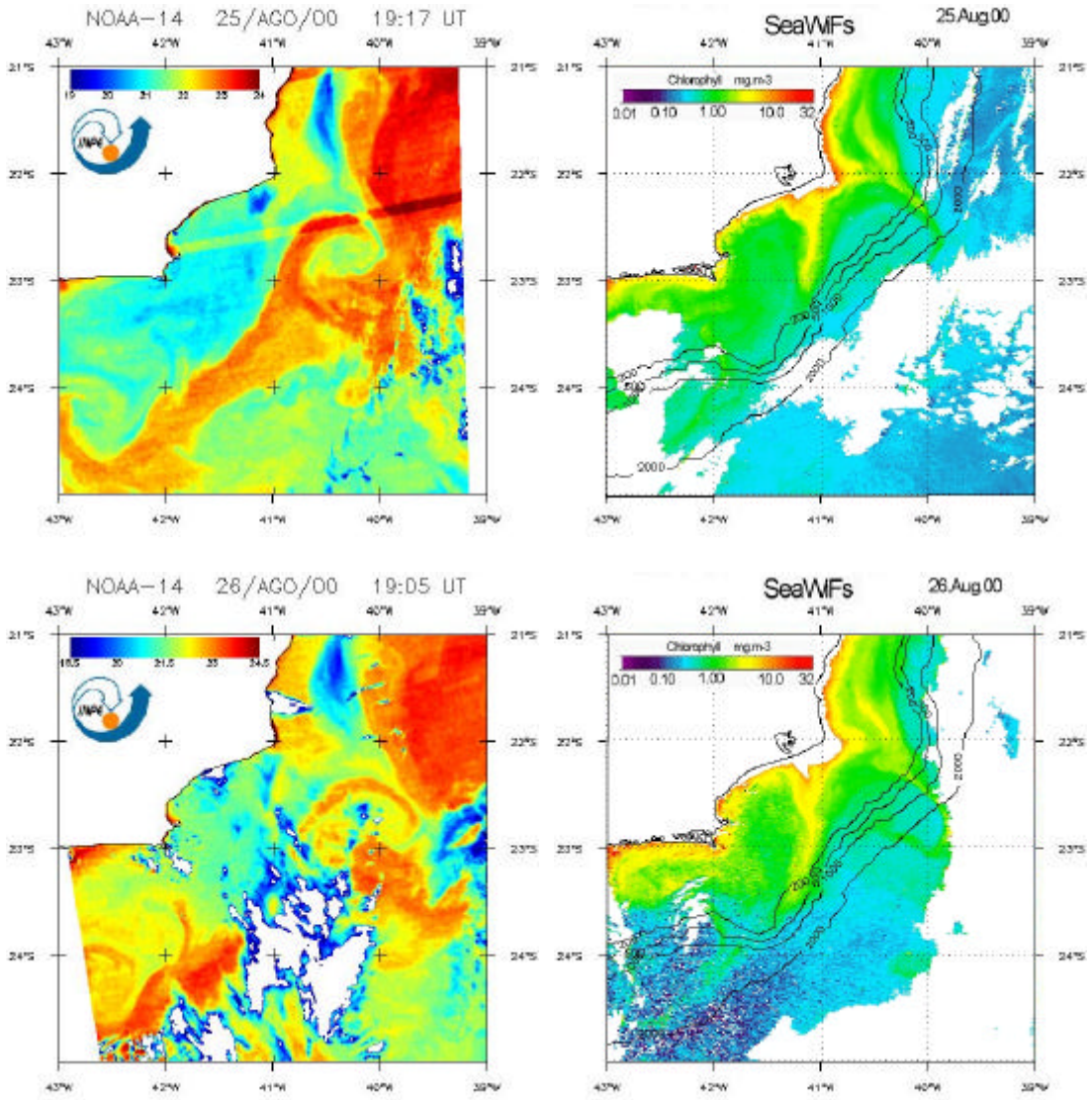

Figure 2. Same as Figure 1 only for August 25 and 26.

Table 1- Approximate position, temperature and chlorophyll concentration on the central region of the cyclonic meander/eddy off Cabo São Tomé

Date	Latitude (°S)	Longitude (°W)	Diameter (Km)	Temperature (°C)	Chlorophyll (mg.m-3)
August 21-22	22.75	40.37	45	21.4	0.16-0.20
August 23	22.78	40.43	50	21.5	0.22-0.26
August 25	22.75	40.23	60	21.5	0.22-0.28
August 26	22.67	40.04	65	21.7	0.24-0.30

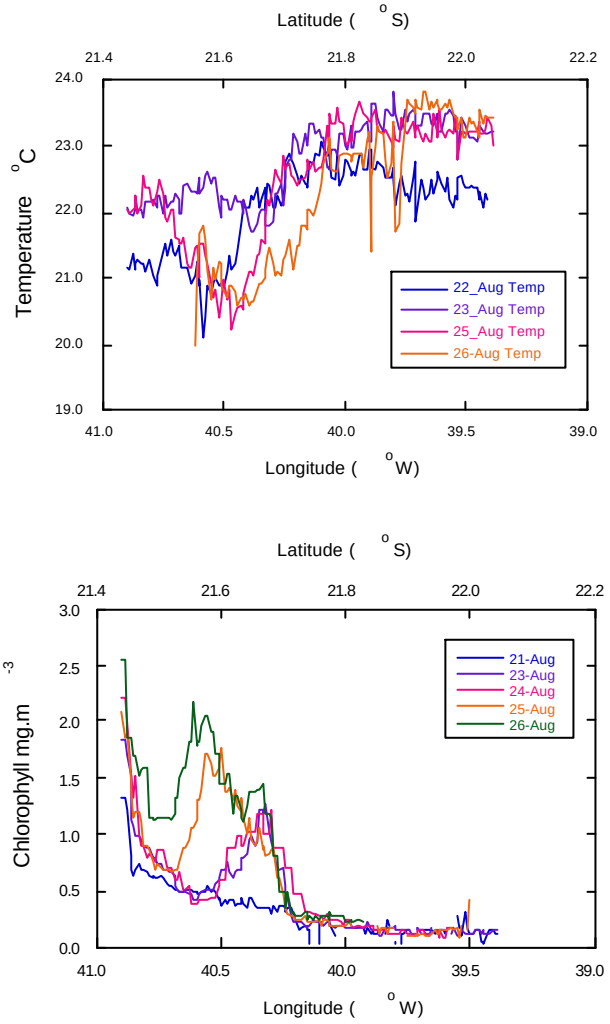

Figure 3 – SST (above) and chl (below) profiles extracted from the AVHRR and SeaWiFS satellite images, respectively.

5 Conclusions and Future Directions

The importance of mesoscale features capable of bringing nutrients into the euphotic zone are well recognized. In this work we observed a reasonable relationship between SST and surface chl fields in the Southeast oceanic region of Brazil.

The main oceanographic features noted through the analysis of the images were: São Tomé semi-permanent eddy, shelf break upwelling and BC inshore frontal meanders. A clear response in pigment concentration was observed in the shelf break upwelling. In the center of the meanders and eddy chl remained relatively low, suggesting that the cold signatures also noted in these areas were more related to the entrapment of shelf waters than to upwelling.

Masking of clouds seems to be rigorous in the chlorophyll images. On the other hand, on SST images there is a need for improvement in these algorithms.

The analysis of chl estimations by remote sensing is still a fairly new line of research in Brazilian waters (Omachi 1999; Ciotti *et al.* 2000; Kampel *et al*. 2000). Is important to note that one of the biggest source of uncertainties for these data is the atmospheric correction (Gordon 1997; Wang 1999), especially over turbid coastal waters, and these corrections have to be properly verified for this study area. The other sources of uncertainties are related to the changes in phytoplankton species composition and the presence of other particles and dissolved material which interferes with the chl algorithm performance (Carder *et al.* 1991; Ciotti *et al.* 1999), thus, field data is still required to validate and or modify the standard algorithm for chlorophyll (Omachi and Garcia 2000).

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