The Cape Frio Upwelling effect over the South Brazil Bight northern sector shelf waters: a study using AVHRR images

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ABSTRACT

Daily Sea Surface Temperature (SST) maps derived from AVHRR HRPT data have been produced and analysed for the SE coast of Brazil and adjacent oceanic waters since September of 1992. For the summertime and beginning of autumn, strong upwelling events are easily seen in some of these images when cloud coverage permits. A subset of these images was analysed together with *in situ* hydrographic, nutrients, and phytoplankton biomass data collected during an oceanographic cruise of COROAS (Oceanic Circulation in the Western Region of the South Atlantic) project done in the central sector of the South Brazil Bight (SBB). For well developed upwelling events lasting for more than 10 days, the SST maps show very extensive tongues of cold upwelled water being advected southwestward and reaching the center of the SBB. The plumes of upwelled water are spatially very well correlated with the upwelled nitrate and phytoplankton. It is postulated in this report that the horizontal advection of cold upwelled waters can be one of the important factors affecting the chemical and biological characteristics of the shelf ecosystem in regions up to 400 km distant from CaboFrio in the central area of the SBB.

1. INTRODUCTION

The South Brazil Bight (SBB) is defined as the area of the Brazilian Southeastern continental shelf extending from Cabo Frio (23°S; 42°W) to Cabo Santa Marta (28.5°S; 48.6°W) (Fig. 1). At the northern limit of this region, and a few hundred kilometers north of it, a common feature present on the inner and mid-shelf is a seasonal signal of a wind driven coastal upwelling. This upwelling is primarily forced by the prevailing NE wind, associated with the large scale atmospheric high pressure center present over the South Atlantic.

The negative surface temperature anomalies associated with the upwelling build up during early spring (September) and lasts throughout the summer and a few months later (March and April). During the fall and winter seasons, there is a relaxation of the upwelling (Stech et al., 1995). It has been speculated that the seasonality of the Cabo Frio upwelling is associated with the onshore/offshore seasonal migration of the South Atlantic Central Water (SACW) at the continental slope. Recent studies have shown that the SACW is the source of the cold waters that crop up near the coast in this region (Valentin et al., 1987, Gaeta et al., 1994). In some cases of strong NE winds, persisting for several days, strong upwelling can be developed with surface temperatures dropping to 13-14°C near the coast, close to Cabo Frio. These temperatures are about 10°C cooler than the mid and outer shelf surface waters. For the synoptic time scale of 6 -11 days, with the passage of cold fronts over the region, the surface winds rotate counterclockwise and blow for a few days from the southern quadrant inhibiting the upwelling.

Western boundary regions of the oceans are dinamically quite different from the regions along eastern ocean boundaries. In the South Atlantic waters off Brazil, low nutrient, biomass and productivity levels are typically associated with the warm, high salinity surface water mass, the Tropical Water (TW). The oligotrophic TW occupies the upper 200 m of the water column, being carried by the Brazilian Current (BC) along the 200 m isobath and is characterized by temperatures higher than 20°C and salinities greater than 36 PSU (Signorini, 1978). Increased plankton biomass and productivity observed in the SBB are linked to an increase in nitrogen concentrations caused by intrusions of SACW along the bottom of the continental shelf and inshore areas (Valentin *et al.*, 1987, Brandini, 1990, Gaeta *et al.*, 1996).

In this paper, a set of AVHRR infrared images for the SBB are compared with surface variations in the mesoscale distribution of chemical (nitrate) and biological properties (phytoplankton biomass) to show that an observed increase in productivity was caused by the horizontal advection of a cold water mass originating at Cabo Frio due to a strong upwelling event.

2. THE DATA SET

2.1 Satellite Data

Daily images from the Advanced Very High Resolution Radiometer (AVHRR) aboard the TIROS-N/NOAA satellites have been recorded in the High Resolution Picture Transmission (HRPT) mode by INPE in the level 1-B NOAA format (Kidwell, K.B., 1992) since September of 1992. The digital satellite data were processed using the SEAPAK software (McClain et al., 1992) to generate the Sea Surface Temperature (SST) maps used for analysis. The digital processing of this data set involved: a) image ingestion with the separation of the five channel images from the interleaved original data; b) application of one of the Multichannel Sea Surface Temperature (MCSST) NOAA algorithms for atmospheric correction and generation of the SST images (McClain et al., 1985); c) remaping to a common map projection (Mercator) and geographical gridding; and d) digital image enhancement to increase the contrast and to facilitate interpretation of the thermal features present.

2.2 Biological and Nutrient *in situ* data

A total of 51 stations were occupied from January 25 to February 04, 1993 (Fig.2). Along each of the cross shelf transects, hydrography (CTD with rosette system), nutrients, and phytoplankton biomass data were obtained at indicated stations. In addition, 3-4 of the stations occupied along each transect were chosen to make *in situ*-simulated diurnal experimental observations of primary productivity. Vertical distributions of nutrients and phytoplankton biomass were based on samples collected at (standard) depths: 0, 25, 50, 75, 100, 125, 200, 300 m. Nutrient concentrations were determined according to Grasshoff (1983) and chlorophyll *a* concentrations were measured by fluorescence (Yentsch and Menzel, 1963). Primary productivity was determined by the ^{14}C tracer technique of Steemann-Nielsen (1952).

3. RESULTS AND DISCUSSION

Fig. 3a shows that by the mid part of January of 1995, a strong upwelling event had been stablished in the Cabo Frio area. Two upwelling centers (18°C) can be observed, one at Cabo Frio and other near Cabo São Tomé. It is also clear that the former surface center is being advected southwestward, with the upwelling plume reaching the southern vicinity of São Sebastião Island (23.8°S; 45.6°W), the northernmost part of the oceanographic survey area (See Fig. 2). A gradual increase in temperature with distance is observed, probably resulting from mixing and solar heating. Figure 3b shows that the upwelling event was sustained until the end of the January, with even lower surface temperature at the Cabo Frio upwelling core. Again, the upwelling plume is seen being advected to the area near São Sebastião.

Figure 4a shows the surface nitrate concentration with two maxima (1.5 to 2.0 μM) present on the northernmost inner shelf and slope areas. Comparing the surface nitrate field with the SST maps, it is clear that the very extensive tongues of cold water advected southwestward and reaching the center of the SSB, are spatially correlated with the upwelled nitrate. Thus, the phytoplankton biomass bloom observed at the surface (Fig. 4b) on the mid-shelf (100-150 m depths) was influenced by nutrient enriched waters from Cabo Frio 300 km distant from this region.

Values of chlorophyll *a* integrated over the euphotic zone (not shown) revealed that there is not a monotonic decline in the seaward direction, but rather shows a trend, with the highest values occurring in two sites: one at the shelf on the northernmost sections and the other at the slope near the southern corner of the sampled region. The former, as previously stated, was enriched by cold waters from Cabo Frio and, in addition, showed maximum chlorophyll *a* at the surface. On the other hand, the later showed maximum chlorophyll *a* at 25 m depth. Probably, this last maximum is due to a different dynamical forcing, being caused by divergent isobaths and frontal meandering of the BC resulting in shelf break upwelling. In fact, at these two sites there were blooms of the colonial diatom *Hemialus sinensis* which yielded values of 62.9 and 62.2 mg m^{-2}, respectively.

4. CONCLUSIONS

The results of this study clearly indicate that strong upwelling events occurring from September through March and April in the Cabo Frio region can influence the chemical and biological fields on the SBB shelf at distances of up to 300-400 km. As a result, significant enhancements on phytoplankton biomass and productivity are observed. This is the first reporting in the literature of the remote influence of the Cabo Frio upwelling at such distances in the SBB. This remote influence was made evident through the processing of several AVHRR infrared images for the region, which were then jointly analysed with *in situ* data collected simultaneously during an oceanographic cruise. The large synoptic view provided by the satellite images was crucial in linking the *in situ* high nutrient and chlorophyll *a* patches observed to the upwelling phenomenon occurring at the northern extreme of the SBB.

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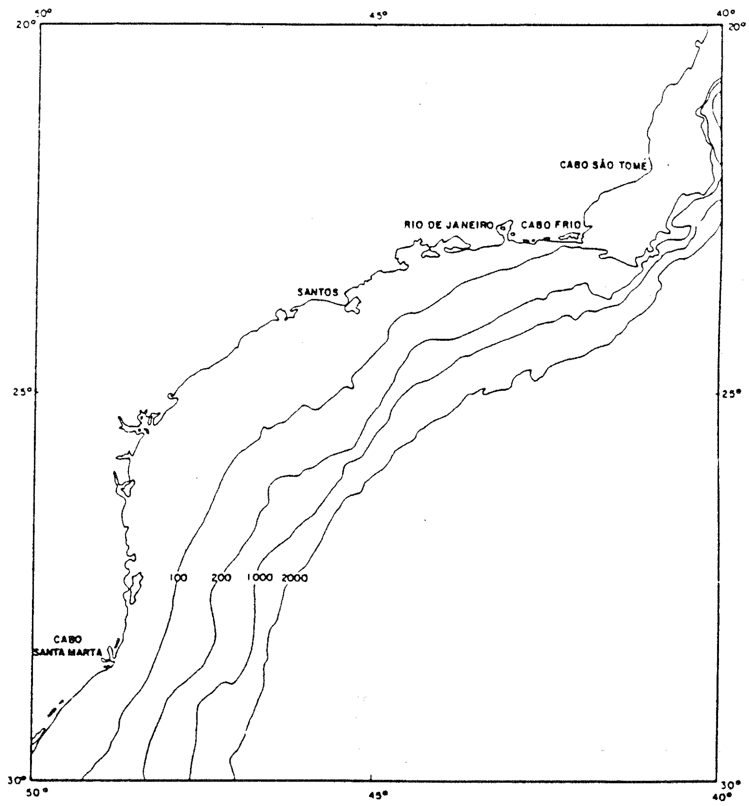

Fig. 1. Map of the South Brazil Bight showing the bathymetry (in meters).

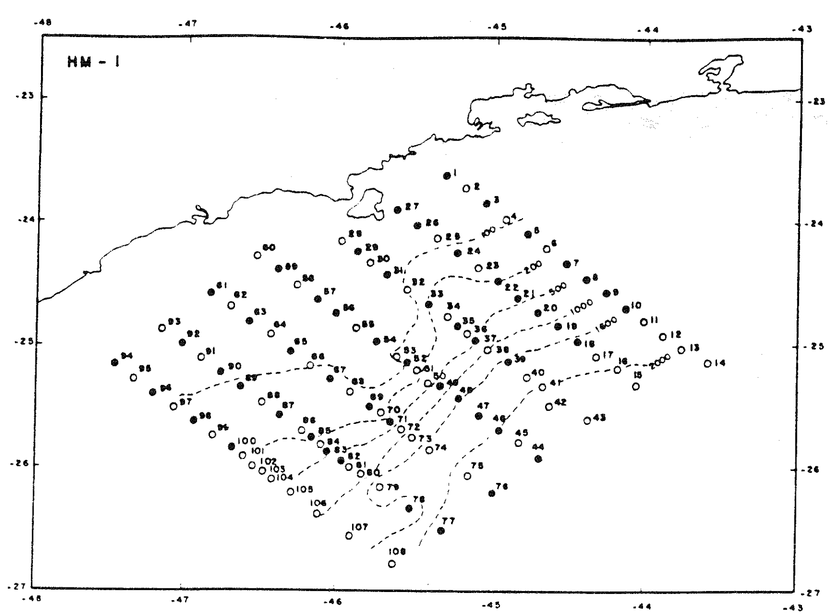

Fig. 2. Map of the SBB region surveyed during COROAS project with bathymetry (dashed lines) and the distribution of CTD (•) and CTD plus chemical (nutrients) and phytoplankton (o) stations.

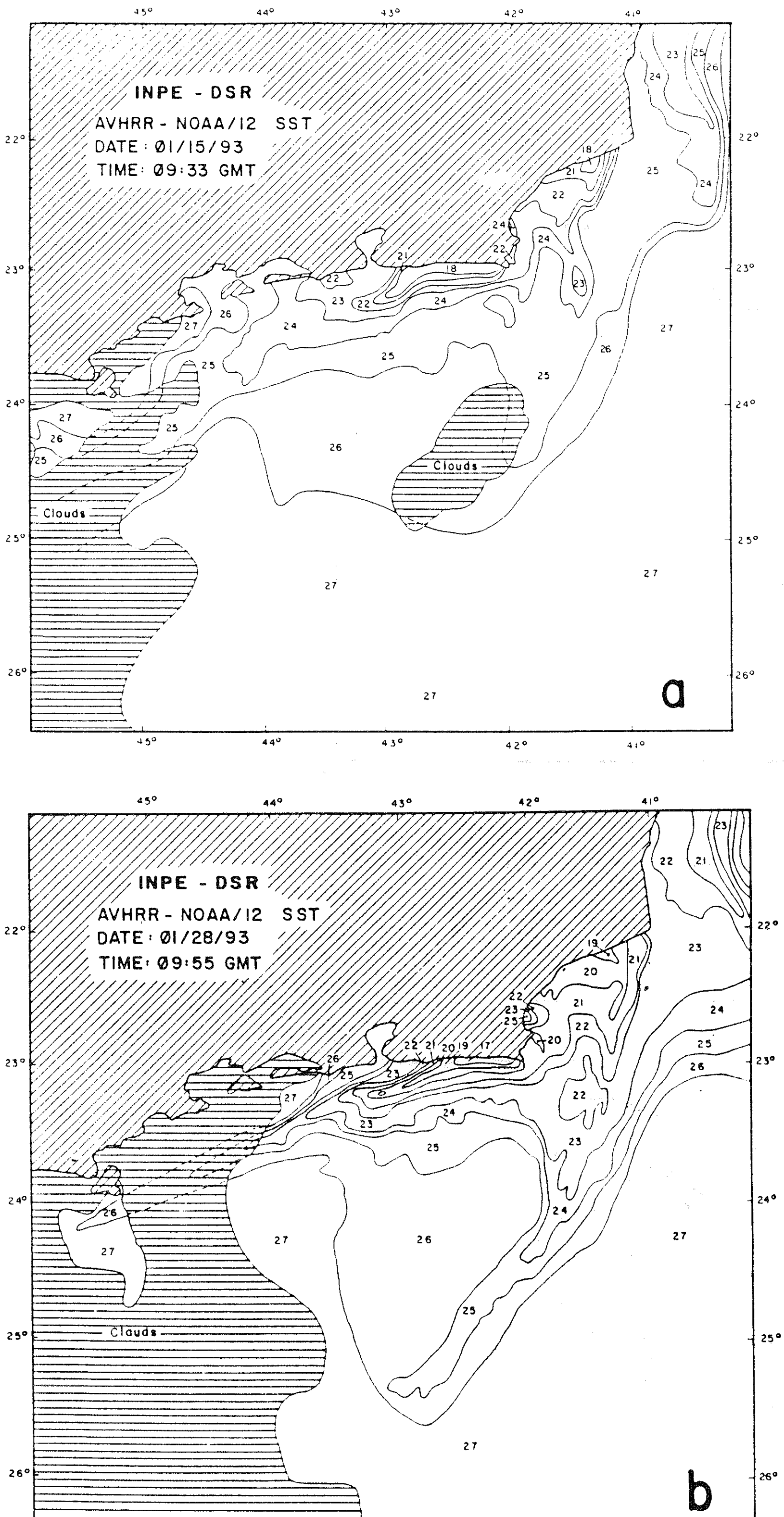

Fig. 3. Sea Surface Temperatures (in °C) from satellite IR imagery, (a)January 15, 1993 and (b) January 28,1993. Horizontal and inclined hatched areas indicate clouded and continental/island areas, respectively. Dashed lines represent analyst interpretation.

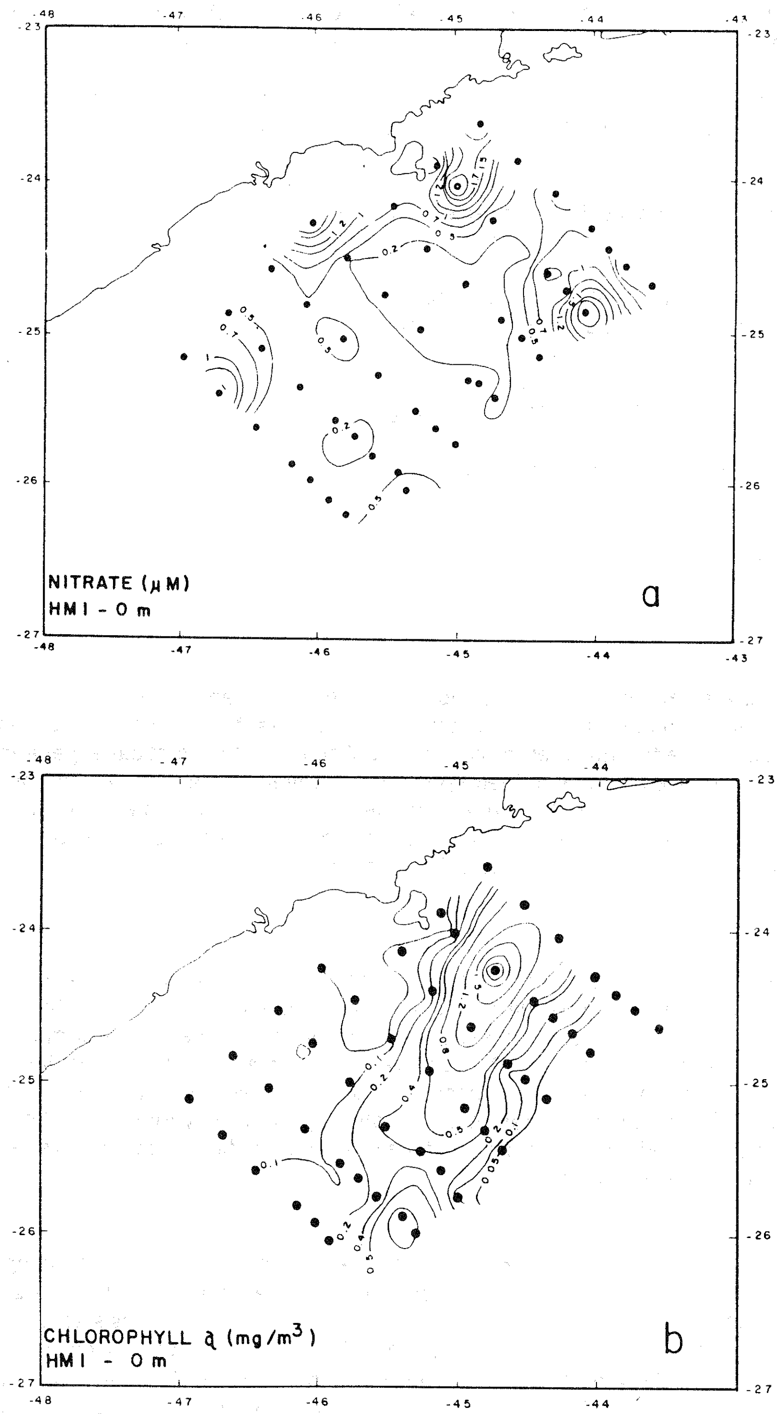

Fig. 4. Surface fields of *in situ* observed (a) Nitrate and (b) chlorophyll *a* concentrations. Data collected during COROAS project from January 25 to February 04, 1993.