Remote Sensing of the SW South Atlantic Using Satellite Tracked Drifters and AVHRR images

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Abstract. INPE and Petrobras are conducting since July, 1997 a collaborative program (Project SATBOIA) of monitoring the SW South Atlantic through the use of surface drifters tracked by satellite. In this paper it is presented an analysis of the data collected by the first nine drifters launched. Drifters trajectories and sea surface temperature time series collected by these platforms are discussed. To help the interpretation of such data, some sea surface temperature maps derived from the AVHRR sensor are also presented.

Keywords: Remote Sensing, Drifters, AVHRR, Ocean Monitoring.

1 Introduction

The monitoring and the study of the oceans is one of the most challenging tasks of the so-called environmental sciences of today. The routine acquisition of ocean variables, at surface or at depth, is very difficult and expensive. The harsh, large and remote ocean environment poses a technological complexity for obtaining operational ocean data. This task becomes impractical using only ships and anchored platforms. Especially in the last few years, the technologies of satellite tracked ocean drifters and environmental satellites have been advanced to the point of becoming fundamental tools in the ocean monitoring arena. The costs of drifters were reduced to values that made them expendable platforms. It is now possible to deploy a fair number of this kind of drifters, covering very large oceanic areas for extended periods of time at a moderate costs. The most important oceanic variables such as surface winds, wave amplitude and spectrum, sea surface temperature, topography and ocean color can now be daily and globally obtained through a constellation of environmental satellites.

As part of its mission, the Brazilian Institute for Space Research (INPE) is engaged in national and international projects aiming at the ocean monitoring using space technology. Since 1990, INPE has been developing and deploying satellite tracked low cost drifters (LCD) in the South Atlantic. More than two dozen of such drifters were built and deployed during this period, mostly during the project COROAS in the SW South Atlantic and in project MEDICA in the Antarctic Circulation portion of the Atlantic. These measurements are complemented by thermal infrared data collected by the Advanced Very High Resolution Radiometer (AVHRR), flying on board the environmental NOAA satellites. Maps of Sea Surface Temperature (SST) are produced from these data.

More recently, starting in July 1997, the Project SATBOIA was initiated with the deployment of a new series of LCD's as part of the Brazilian Buoy Program - PNBOIA, which is the national segment of the Global Ocean Observing System – GOOS. These deployments have the objective of monitoring the thermal structure of the surface waters of the SW South Atlantic and associated circulation using satellite tracked Lagrangian drifters. In this paper we present an analysis of some drifter data and SST maps obtained since the beginning of the Project SATBOIA.

2 The Data

2.1 Low Cost Drifters

The drifting buoys, developed at INPE, closely follow the design described by Sybrandy and Niiler (1991). A schematic representation of these drifters is presented in **Fig. 1**. In the surface float are installed the battery pack, the ARGOS transmitter, an antenna, a salinity switch to cut off transmission in cases of submersion and a thermistor to measure water temperature 12 cm beneath the mean water line. These surface temperatures are measured with a nominal accuracy of 0.12º C (YSI, 1993). The drogue element, made of dakron cloth, is adjusted for 15 m depth. Therefore, the drifter is considered to provide data about the mean horizontal currents for the upper 15 m water layer. Additional details about these drifters can be found in Niiler *et al.* (1987).

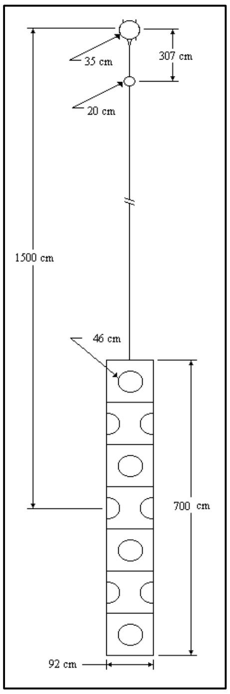

Fig. 1 – Schematic representation of the drifting buoys developed by INPE

The drifters are tracked by the Data Collection and Location System (DCLS) ARGOS, on board the operational NOAA-N satellites. The geographic positions of the buoys are determined by the Service ARGOS in Toulouse, France, by a processing of the recorded Doppler shift of the received signal introduced by the relative movement of the satellite with respect to the drifter.

The LCD transmits every 90 seconds, so that up to 9 Doppler observations are possible during one overflight of the satellite. A buoy position calculation is done only if a minimum of four good transmissions are received by the satellite. The positional data are considered to be known at best to about 111 m (±0.001º latitude), depending on the quality of data being transmitted, the sea state etc. Although up to nine temperature data are transmitted during an overflight, only one drifter position is computed for each satellite pass. As a consequence, while the displacement and temperature series extend over the same time period, the number of geographic positions is always less than the number of temperature observations. After being received via telephone modem, the drifter time series are subjected to a routine quality control to eliminate spurious temperature and position values.

Table 1 contains the coordinates of deployments of the first nine drifters and related information.

Table 1 - Information about the drifters at deployment sites

LCD	DAY (1997)	TIME (Local)	LATITUDE	LONGITUDE	TSM *in situ* (ºC)
3195	07/13	16:58	19º30'55.0"S	39º01'08.0"S	24.0
9001	07/14	07:35	19º30'03.6"S	37º30'20.4"W	24.6
3197	07/14	14:54	19º30'00.0"S	36º30'52.0"W	25.3
32440	10/15	07:30	19º30'04.0"S	39º00'34.0"W	25.0
32441	10/15	19:30	19º30'01.0"S	37º31'35.0"W	25.8
32442	10/16	02:40	19º29'56.9"S	36º30'06.0"W	25.0
32443	12/11	16:30	19º30'03.0"S	37º30'04.0"W	26.0
32444	12/11	05:30	19º30'04.0"S	39º00'03.0"W	26.3
32445	12/12	01:40	19º29'56.9"S	36º30'06.0"W	26.5

With the exception of drifter 9001, all other drifters were configured to transmit in the continuous mode of the ARGOS system. This mode allows up to seven position fixes per day at these latitudes. The 9001 drifter uses a version of ARGOS transmitter programmed for large scale studies. In this mode, it transmits continuously during eight hours and sleeps for the remaining 16 hours of each day. This mode allows a longer duration for the power pack of the buoy at the expense of a lower temporal sampling of up to 4 fixes per day in the region.

2.2 Satellite SST Data

The SST maps of the region were derived from data collected by the AVHRR flown onboard the NOAA-12 satellite. This data were recorded in the High Resolution Picture Transmission (HRPT) mode by INPE´s station located at 22.40ºS and 45.01ºW. The raw data were then converted to the level 1-B NOAA format (Kidwell, 1995) and were processed using the SEAPAK software (McClain *et al.*, 1992). The digital processing involved: a) image ingestion with the separation of the five channel files from the interleaved original data; b) cloud masking using a threshold value of albedo in the channel 2; c) 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); d) remaping to Mercator projection and geographical gridding; and e) digital image enhancement to increase the contrast and color slicing to facilitate interpretation of the thermal features present.

3 Results and Discussion

3.1 Drifters Trajectory Data

All drifters were launched south of the Abrolhos Bank in the Vitória-Trindade ridge seaward of the shelf break. This is a region where the Brazil Current (BC) reorganizes after interacting with the ridge. **Fig. 2** (**a, b, c**) presents the trajectories of the three groups of drifters launched since the beginning of the project. As expected for a region under the influence of the Brazil Current, a general S/SW drift is observed for most of the floats.

FIG. 2a
FIG. 2b
FIG. 2c
FIG. 3

For the deployments that took place in October and December of 1997 (See **Figs. 2b , 2c**), an anomalous northward drift is observed for two buoys (32442 and 32445). The buoy 32442, launched in October, shows an anticyclonic loop, while buoy 32445, launched two months later, presents a cyclonic trajectory in the same region (35 to 37ºW and 18 to 20ºS). An indication of an anticyclonic circulation in that region is presented by Stramma *et al*. (1990), see **Fig. 3**. In that paper, this circulation was estimated from geostrophic calculations and extends from 15 to 20ºS and from 32 to 35ºW. Near 20ºS, BC flow of Stramma, *op. cit*. shows two southward branchs; one along the shelf break following the 1000m isobath and another east of deep channel between the shelf and the first bank. The drifter data shows a similar pattern, with some of the drifters also flowing along the channel. No evidence of the small anticyclonic circulation sketched by those authors centered at about 20ºS and 38ºW is present in the buoy data. It is true though, that drifter series do not sample the area with the spatial resolution necessary to capture that circulation if it had been present at that time.

Near 20ºS, drifter 3195 displacement series shows maximum and average speeds of 62cm s^{-1} and 19 cm s^{-1}, respectively. The maximum speed recorded by this drifter quite exceeds the values of 10.8, 23.9 and 18.7 cm s^{-1} observed around 20ºS for the coastal branch of the BC by the R.V. Saldanha (Mar. 1957 and Jan. 1975) and Atlantis (Mar. 1959), as reported in Table 1 of Strama *et al*. (1990). A high speed of 50 cm s^{-1} for the coastal branch was, however, reported by Luedemann (1975) through the analysis of drift bottle releases and recovery sites.

FIG. 2a
FIG. 2c

A few days after its release, the drifter 3195 (**Fig. 2a**) interrupted its southwestward motion and was caught during 10 days in a cyclonic circulation of about 60 km of diameter centered at about 20ºS and 39ºW. The maximum tangential velocity observed in this period was 39 cm s^{-1}, and the average velocity was 17 cm s^{-1}. The initial trajectory of drifter 3244 (**Fig. 2c)**, five months later, also shows a cyclonic circulation in the same area. This seems to be the surface manifestation of the so-called Vitória eddy, first reported by Schmid *et al*. (1995) at the same position and for the months of February and March of 1991. Drifters released in the eddy by those authors indicated a circulation with a diameter ranging from 48 to 120 km, and with swirl velocities ranging from 30 to 45 cm s^{-1}. The presence of this eddy at almost the same position for the month of May of 1995 is reported by Gaeta *et al*. (1997). These authors show the importance of this coherent feature on the phytoplankton biomass and the primary productivity in the area.

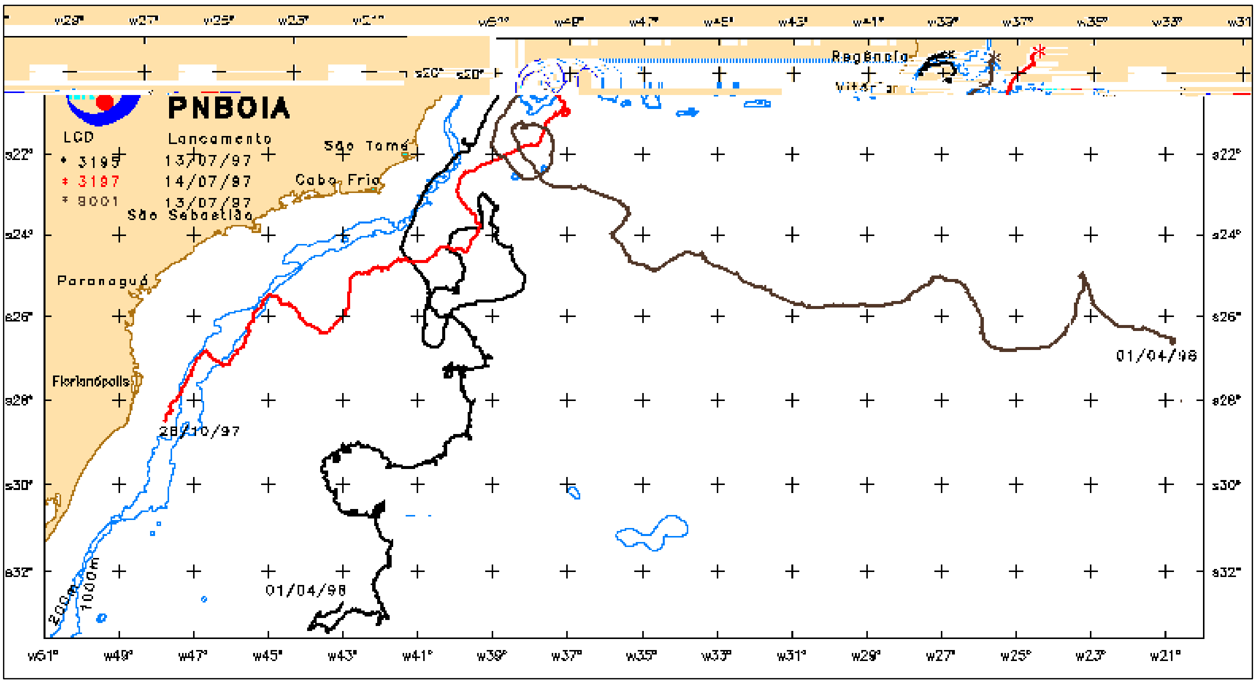

Fig. 2 a – Map of the region with drifters (3195, 3197, 9001) trajectories from July 13, 1997 to April 01, 1998. Light blue continuous lines are isobaths of 200 and 1000 meters.

It is interesting to note in **Fig. 2a** the trajectory of buoy 3197 crossing the anticyclonic loop of buoy 9001. The time analysis of the position of these two buoys show, however, that buoy 3197 crossed the loop when buoy 9001 was on the SE portion of it. A possible interpretation is that buoy 3197 passed by the northern portion of this gyre but was not caught by it, and it continued to flow on the normal BC trajectory to SW.

A large anticyclonic recirculation cell centered about 25ºS is indicated by the trajectory of buoy 3195. This recirculation cell starts SE of Cabo Frio where the BC feels the abrupt change of orientation of the coastline and the shelf break. This is a region where perturbations on the BC flow are a conspicuous phenomenon.

One of the most striking features present in **Fig. 2a** is the abrupt curve of buoy 3195 trajectory at the 26.7ºS and 40.8ºW at its most southern portion of the recirculation. An average speed of 40 cm s-1 and a radius of curvature of 25 km is observed for the curved portion of the path. A Rossby number Ro = U/fr=0.4/(0.65x10^{-4} x2.5x10^{4})=0.25 is obtained, where U is the velocity scale, f is the Coriolis parameter and r is the length scale, here the radius of curvature. Calculating the relative vorticity ζ_r = U/r with the same values, one obtains $\zeta_r = 0.16 \times 10^{-4}\ s^{-1}$. The ratio of ζ_r to f, another interpretation for Ro, also gives Ro= 0.25 as expected, indicating that the geostrophy assumption is weak in this part of flow. The relative vorticity in this case is not negligible in comparison with the planetary vorticity.

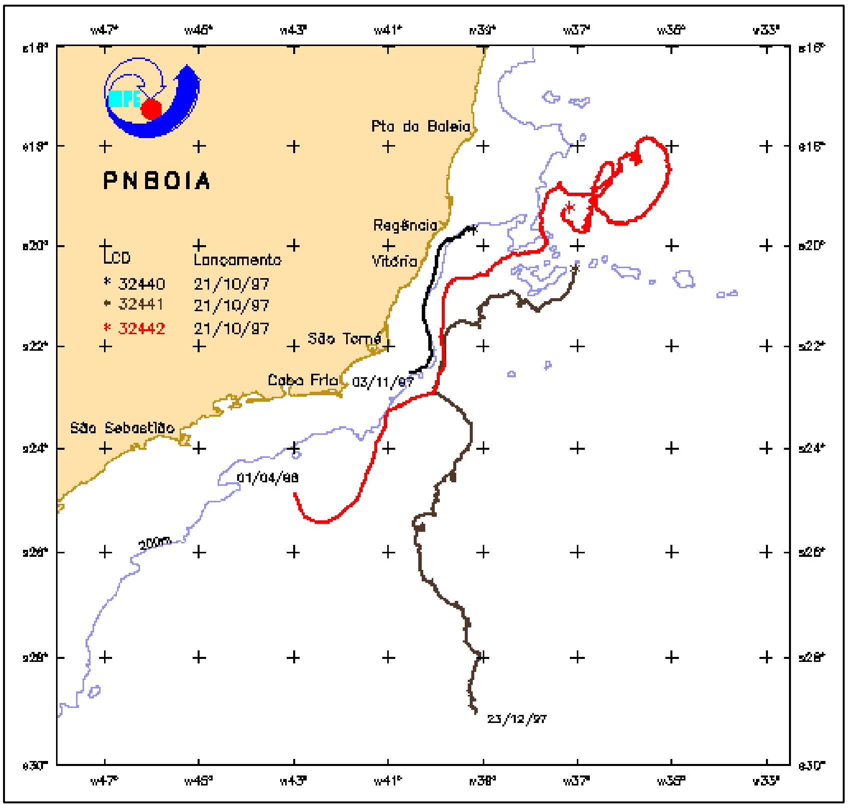

Fig. 2 b – Trajectories of drifters 32440, 32441, 32442 from October 10, 1997 to April 01, 1998.

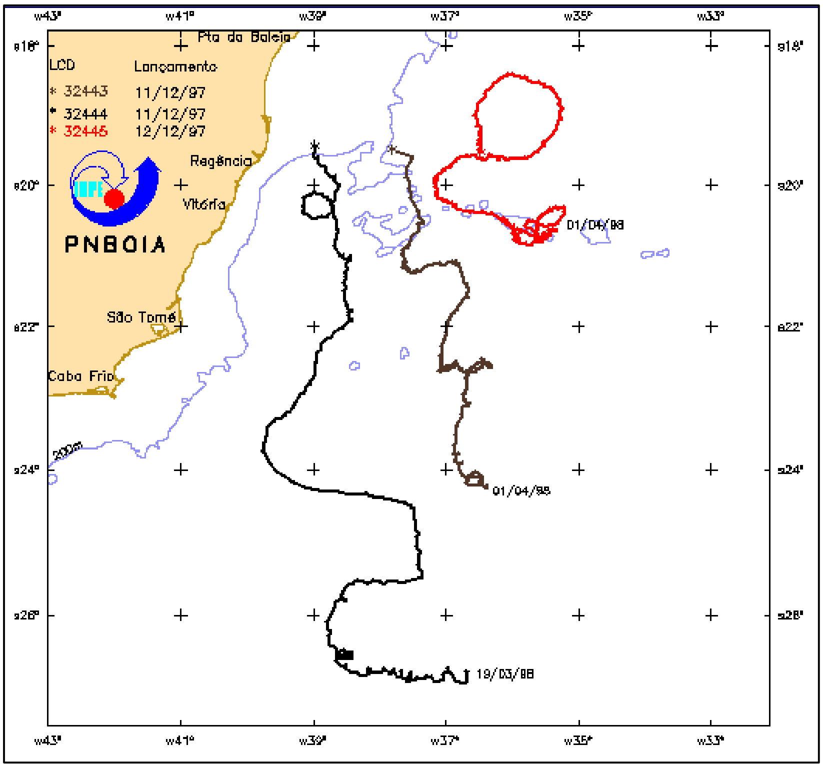

Fig. 2 c - Trajectories of drifters 32443, 32444, 32445 from December 10, 1997 to April 1, 1998.

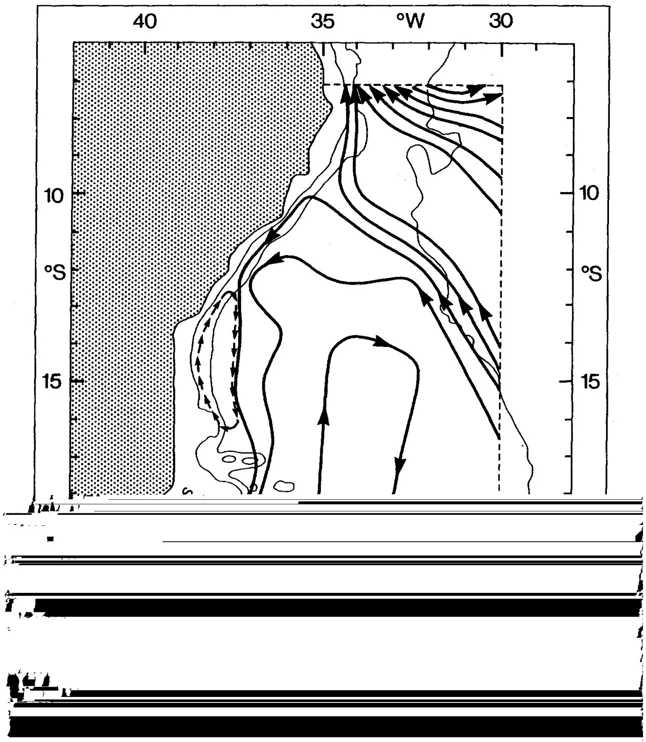

Fig. 3 – Schematic representation of the geostrophic flow field in the upper 500 meters. Reproduced from Stramma *et al.* (1990).

The trajectory of all buoys show the presence of meandering motion of large amplitude. These meandering trajectories are also revealed in the SST maps derived from AVHRR data and are related with BC frontal instabilities. A striking example of a large amplitude meandering is present in the trajectory of buoy 32444 (**Fig. 2c**).

Perhaps the most remarkable feature present in all these figures is the continuous eastward displacement of drifter 9001(**Fig. 2a**). According to the traditional view of the large scale subtropical gyre of the South Atlantic, such eastward drift was supposed to occur at much higher latitudes. In the next few months it will be possible to evaluate if this eastward displacement is the southern limb of a large scale anticyclonic gyre. FIG. 2a

At several places, the drifter trajectories show the presence of inertial motion loops. One such case is present in the initial northward motion of drifter 32442 (**Fig. 2b**) and another was observed in the trajectory of buoy 3195 (**Fig. 2a**) along the large loop centered at 29.5ºS and 42.5ºW. The period of the looping trajectories in these cases match the inertial period at those latitudes. FIG. 2b

3.2 Drifters Temperature Time Series Data

Fig. 4 presents the sea surface temperature, latitude and longitude time series for eight drifters. Low and high frequency temperature variations are observed for all drifters. The high frequency component is mostly associated with the diurnal cycle of solar radiation. This diurnal FIG. 4

temperature signal is sampled by the early morning and mid-afternoon passages of the NOAA-N satellites. Some high amplitude spikes observed in these figures should not be taken as noise. They correspond to several contiguous measurements of similar value. Noise spikes, consisting of one or only a few adjacent anomalous values are removed in the processing of the data. The low frequency component is easily observed to be associated with the seasonal cycle of sea surface temperature combined with a net north or south mean displacement of the buoy.

3.3 Infrared Satellite Data

During the project, daily AVHRR images were recorded. However, due to extensive cloud cover and a few technical problems, only a small number of images were utilized for data analysis and comparison with drifter trajectories.

As observed in **Fig. 5** (SST field for August 20, 1997), warm waters (red colors) of tropical origin associated with the BC dominate most of the oceanic region. The strong thermal front between the BC and the cooler shelf waters (blue, green and yellow), defines a frontal region easily observed in the image. It is interesting to note the coastal upwelling at Cabo Frio with a surface core of 18ºC. Note the long plume of cold upwelled waters near São Tomé was pushed offshore by an intrusion of the BC warm waters onto the shelf. This cold plume is in contact with the western BC front, enhancing the thermal gradients there. Strong upwelling events such as this one are infrequently observed in this region in the winter season. The black line plotted in the image represents the trajectory of drifter 3195 for the period of 18 to 22 of August. The drifter flows to southwest with velocities as high as 90 cm s^{-1}, staying close to the BC western border. The drifter position time series indicates an acceleration of the BC flow near Cabo Frio. FIG. 5

The **Fig. 6** shows the SST field for September 09, 1997. The high temperature contrast between the cooler shelf waters and the BC tropical waters defines a very sharp front in this image. Cold upwelled water plumes (blue colors) are observed near Vitória, São Tomé and Cabo Frio, with temperature cores as low as 18ºC. The BC intrusion onto the shelf north of São Tomé noted in the previous figure (**Fig. 5**) is now restricted to only a thin layer hugged against the coast, immediately north of the Cape. A mushroom like feature (a pair of opposite vortices) is present south of Cabo Frio formed of BC waters. The two black lines plotted in this image represent part of the trajectories of drifter 3195 (from August 20 to September 09) and drifter 3197 (from September 07 to 20). The SE deflection of drifter 3195 close to 24.5ºS – 41.5ºW, is associated with the anticyclonic cell of the mushroom. The thermal field suggests that to the south of the mushroom head the BC makes another large cyclonic loop towards the coast. The sharp curve seen at the southern extreme of 3195 trajectory in this figure must be associated with an anticyclonic eddy not observed in the image due to cloud cover in the region. FIG. 6 FIG. 5

In **Fig. 7** it is presented the SST map of the region for the February 03, 1998. As observed very frequently in this area, a large offshore meandering of the BC inshore front is detected at the latitude of Cabo de São Tomé. The black line plotted in this figure represents the trajectory of drifter 32440 for the month of November of 97. The very good fit of the drifter trajectory with the BC front shows that this meandering was persistent throughout that period. A large plume of cold upwelled water is being advected from the Vitória region in the direction of the BC front. FIG. 7

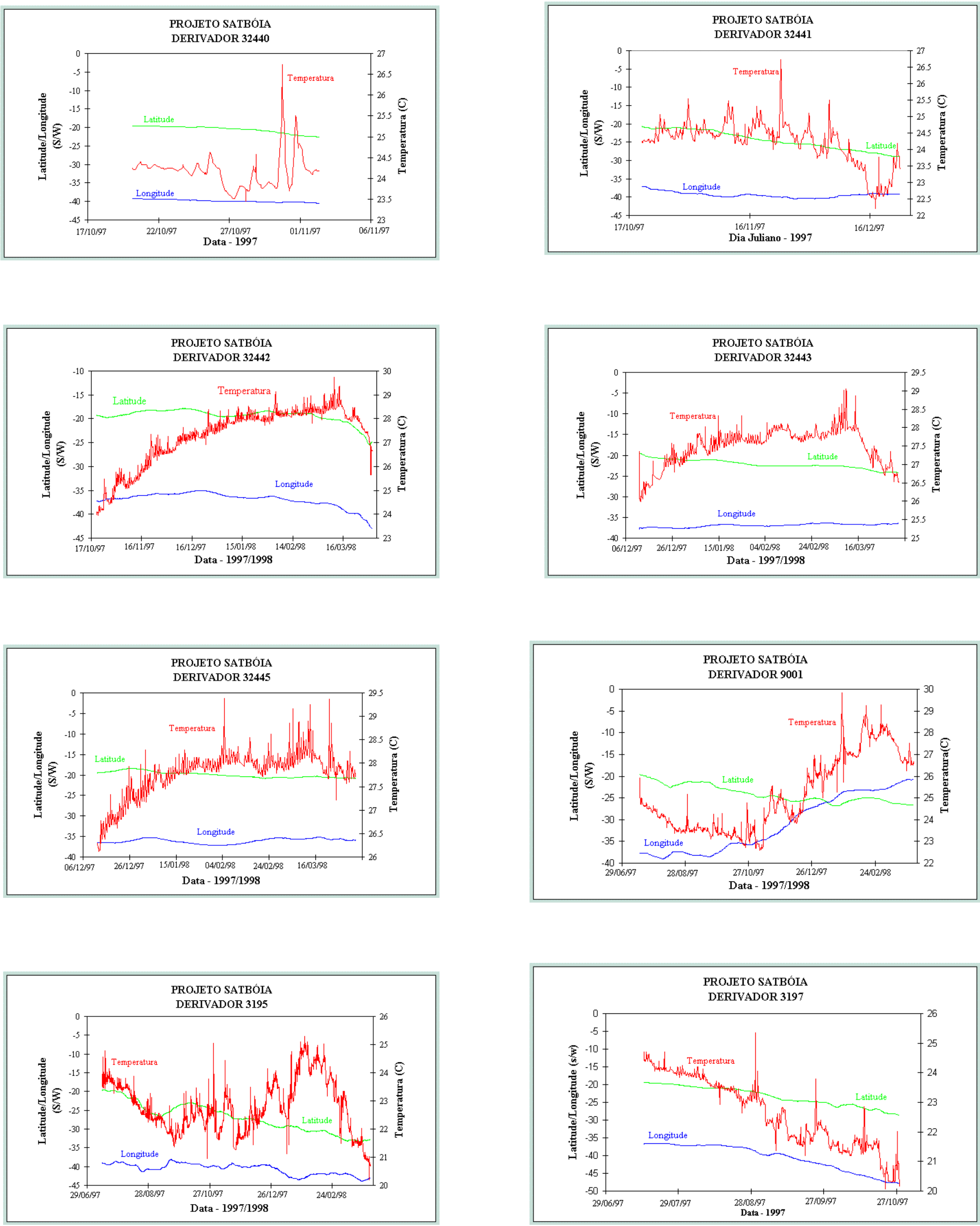

Fig. 4 – Temperature, latitude and longitude time series for eight drifters.

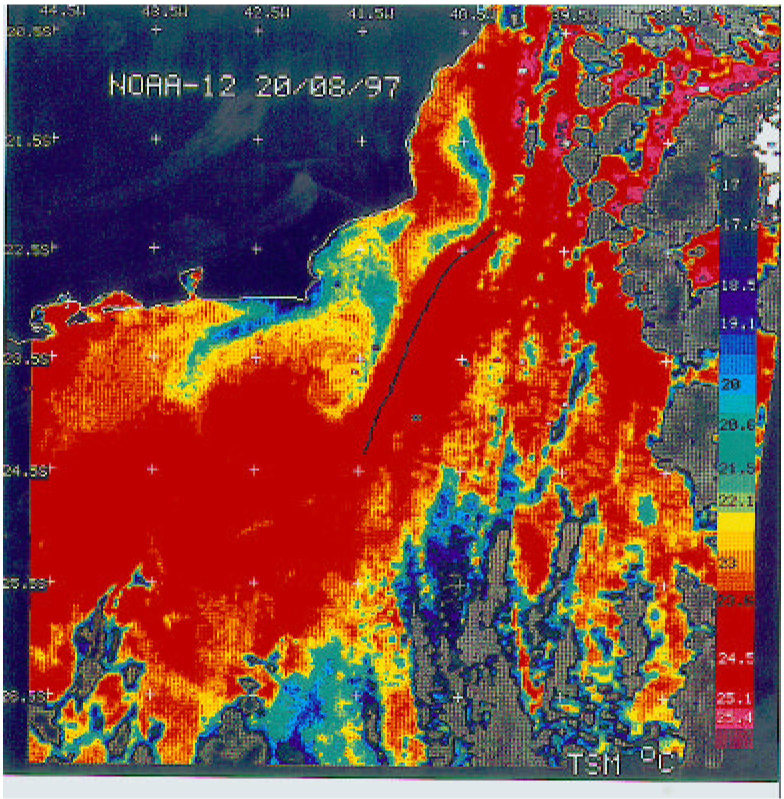

Fig. 5 – Map of SST for August 20, 1997. Clouds are marked by the dark blue and gray colors.

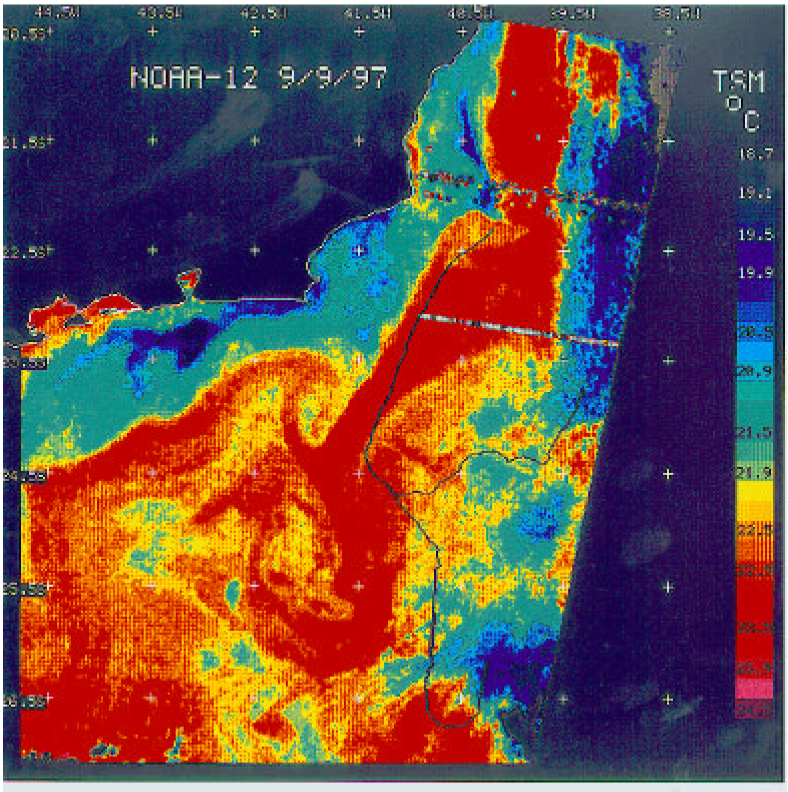

Fig. 6 – Map of SST for September 9, 1997. Clouds in the eastern part are in blue and green.

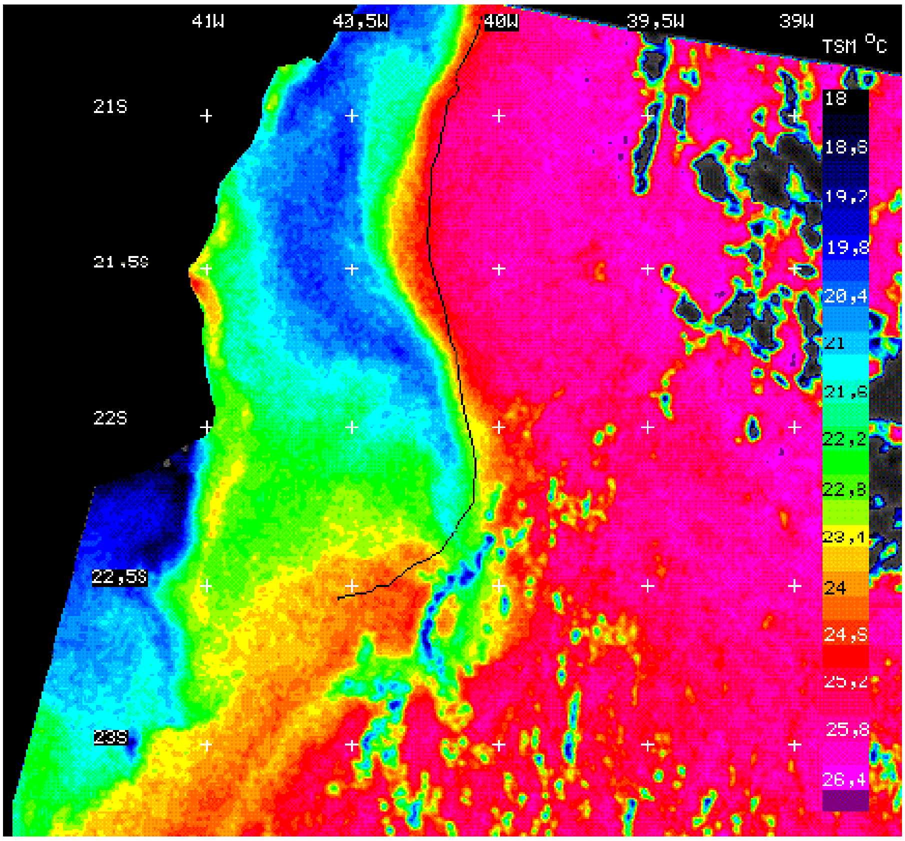

Fig. 7 – Map of SST for February 02, 1998. Clouds are marked by the dark blue color in the northeastern part of the image.

4 Summary and Conclusions

Since July of 1997, INPE and Petrobrás are conducting a collaborative program (Project SATBOIA) of monitoring the SW South Atlantic through the use of surface drifters. Of the planned 24 drifters, by the time of this writing, nine were already launched. In this paper we present a simple analysis of the data acquired by these buoys. As it is possible to see, the data collected by the drifters can be used to infer a number of important parameters of the flow. In particular, considering that these drifters are Lagrangian floats, that is, they can be considered as water following devices, they are ideal platforms to validate oil spill models and ocean numerical models. The temperature data collected by the buoys are also the best source for validation and development of atmospheric correction algorithms for infrared SST data processing. The instantaneous velocities extracted from buoy positions can be used for studies of energy distributions.

A weekly updated version of all these plots can be reached by the interested reader at the following Internet site: http://serp.atsme.inpe.br/dsr/satboia/lev2satb.htm.

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