Monthly Variations of Physical and Chemical Properties Observed in Santos Bay and Santos Estuarine Channel

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Abstract — *Vertical profiles of physical (temperature and salinity) and chemical (ammonium, phosphate and silicate) properties were monthly obtained in seven oceanographic stations located in Santos Bay and in Santos channel, as part of a project which aims to determine the influence of the Santos estuarine system on the adjacent continental shelf. The fieldwork was carried out during the spring tides, from November/2004 until December/2005. Hydrographic measurements were made by a CTD and data were interpolated at 0.5 m depth intervals. Hydrographic structure was analyzed by the vertical profiles and T-S Diagram. Nutrients were sampled at surface, midwater and close to the bottom. The time-space variation of the average values obtained at each station was analyzed based on the hydrographic data. The channel waters represented an important source of nutrients to the bay. Whatever the hydrographic structure, these inputs occurs through the channel plume along the whole year, enhanced by rainfall events.*

Index Terms — *hydrographic structure, inorganic nutrients, Santos Bay, Santos estuary, monthly variations*

INTRODUCTION

The estuarine system of Santos and São Vicente, located in the middle portion of São Paulo state coast, is a complex area in geomorphologic terms and moreover in land use and occupation. The original configuration of the main channels (Santos and São Vicente) and of several tributaries that reach the area has been drastically altered in the last decades. Consequently the discharge patterns was also altered. The industry development, land reclamation, inputs of domestic and industrial sewage, harbor and dredging activities and tourist exploitation are some of the factors which has been enhancing the eutrophication in the area.

Eutrophication is an important matter of concern for the governments and environmental management. Nutrient over-enrichment in many coastal areas around the world is causing pervasive ecological effects on coastal ecosystems, including reduction of dissolved oxygen and subsequent impacts on living resources [1].

The present work aims to analyze the monthly variations of ammonium, phosphate and silicate related to hydrographic structure in Santos Bay and along the Santos channel (Fig. 1).

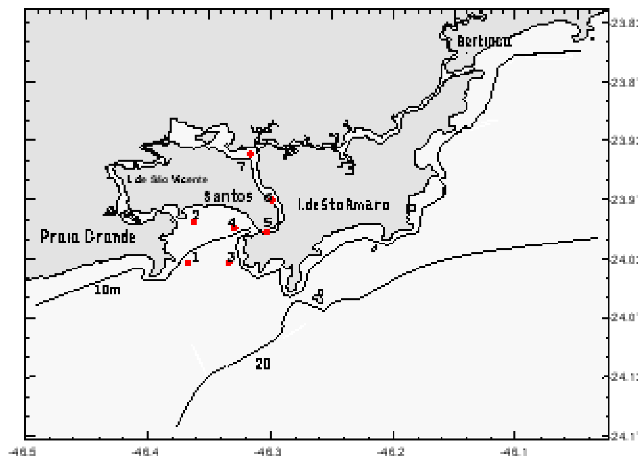

FIGURE 1.
MAP OF THE ESTUARINE SYSTEM OF SANTOS AND SÃO VICENTE AND THE LOCATION OF THE SAMPLING STATIONS IN THE BAY (ST. 1 TO 4) AND IN SANTOS CHANNEL (ST. 5 TO 7).

MATERIAL AND METHODS

Monthly vertical profiles of the hydrographic and chemical properties were determined during the spring tides, from November 2004 up to December 2005, in seven oceanographic stations located in the Santos Bay (four stations) and along the Santos Channel (three stations) as shown in Figure 1.

Hydrographic properties were measured with a Falmouth CTD and the data were interpolated at 0.5 m depth intervals. Conductivity data were converted into salinity according to the Practical Salinity Scale (PSS-1978) [2].

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Monthly variations of thermohaline properties were analyzed by means of vertical profiles and scatter T-S Diagram; stability of the water column was qualitatively analyzed by the crossing angle between the T-S curves and the isopicnals (σt=cte). Water samples for inorganic nutrients (ammonium, phosphate and silicate) were taken in each station from surface, midwater and close to the bottom. Water was filtered onto AP-40 [3] filters and the filtrate was frozen until laboratory processing according to the spectrophotometric methods described in [4] for ammonium and in [5] phosphate and silicate. Data here reported are related to the period from November 2004 up to October 2005. Rainfall data were provided by CODESP (Companhia Docas do Estado de São Paulo).

Results and Discussion

Thermohaline properties observed in Santos Bay during January, February and March (austral summer), exhibited seasonal deep thermoclines and shallow haloclines. The T-S scatter diagram (Fig. 2) indicated temperature and salinity variations in the intervals: ≈22.5^o C - ≈28.0^o C and ≈22.8 - ≈35.8, respectively. The lowest temperature, detected near the bottom, was associated with salinities close to 35.8, representing a signal of the contribution of the South Atlantic Central Water (SACW), as previously observed offshore of Santos [6]- [7].

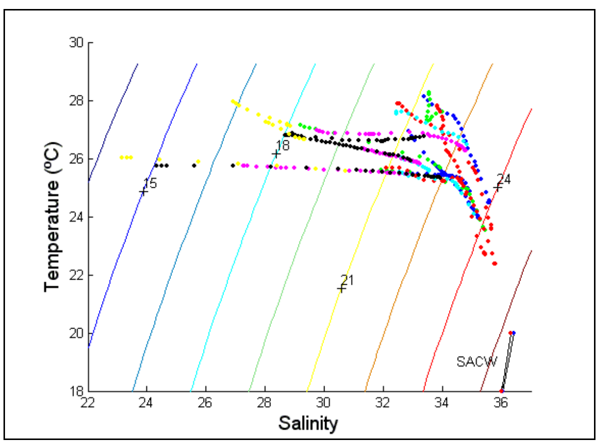

FIGURE 2
SCATTERED T-S DIAGRAM FROM JANUARY, FEBRUARY AND MARCH. STATIONS 1 TO 7 HAVE THE FOLLOWING LEGENDS: BLUE (1) GREEN (2), RED (3), CYAN (4), MAGENTA (5), BLACK (6) AND YELLOW (7). THE DENSITY FIELD IS INDICATED BY THE SIGMA-T ISOLINES.

This diagram also shows a weak vertical stability in the water column and the striking convergence of the T-S curves to the highest density values (σ_t>24) which is a further indication of the SACW influence in the bottom layers of the bay.

Along the Santos channel (st. 5, 6 and 7) the water column was nearly isothermic ≈26.0^{o}C to ≈27.5^{o}C. The highest stability was due to the stronger salinity gradient on the surface layer, which varied from 22.8 to 34.8 (Fig. 2). The sharpest stratification of the water column occurred in the stations 6 and 7, along the mainstream channel, under the influence of the rivers discharge originated by the highest precipitation in this season (Fig. 3); both river discharge and bottom intrusion of water from oceanic origin contributed to this water mass formation.

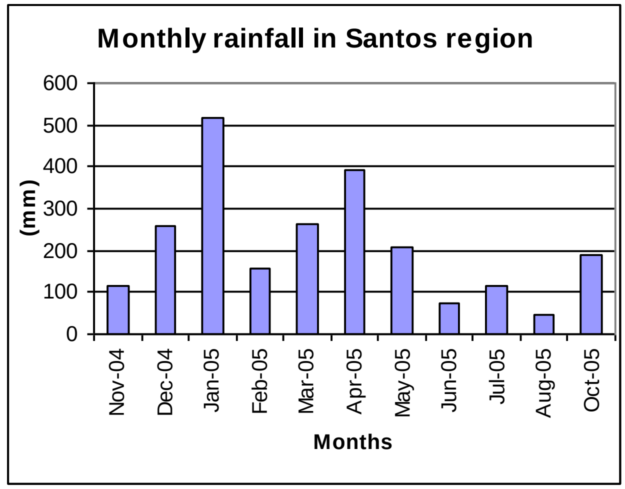

FIGURE 3
MONTHLY RAINFALL (MM) MEASURED AT CODESP METEOROLOGIC STATION IN SANTOS REGION.

The results of April, May and June (Fig. 4) show three distinct groups of thermohaline characteristics, with temperatures decreasing as a result of the seasonal winter cooling. The highest temperatures observed in this diagram were observed on April (≈27.0^{o}C) associated to salinities ranging from ≈27.7 to ≈32.5, with a great vertical stability.

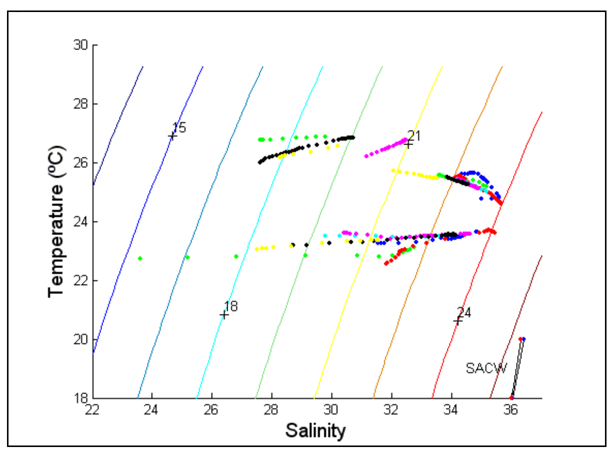

FIGURE 4
SCATTERED T-S DIAGRAM FROM APRIL, MAY AND JUNE. STATIONS 1 TO 7 HAVE THE FOLLOWING LEGENDS: BLUE (1) GREEN (2), RED (3), CYAN (4), MAGENTA (5), BLACK (6) AND YELLOW (7). THE DENSITY FIELD IS INDICATED BY THE SIGMA-T ISOLINES.

Due to bad weather conditions, the samplings at the bay stations could not be done in April. In May the overall temperature and salinity variations were from ≈24.5°C to ≈25.7°C and ≈32.1 to ≈35.6, respectively. In June bay waters presented temperatures still lower and almost isothermal conditions (from ≈22.6°C to ≈23.6°C), coupled with strong salinity stratification (from ≈24.0 to ≈35.4).

The lowest values of salinity were observed in st. 2, nearby the São Vicente channel mouth (Fig. 1) while the highest ocurred in bottom waters in the east side of the Santos Bay (st. 3), indicating the contribution of the SACW for its formation (waters with $\sigma_t \approx 24$). Comparing the group of T-S pairs of May with the previous T-S diagrams (Fig. 2), an increase of approximately 5 units in the salinity may be observed. In stations 6 and 7, the upper fresh water flow imposed a trend to stability in the water column.

The thermohaline features undertaken within the months of July and August (austral winter) are shown in Figure 5. It was not possible to carry out the samplings in September due to the bad weather conditions over the region. Both months showed a weak vertical stratification of the water column along the system, due to the lower rainfall (Fig. 3) the salinity range was relatively small: 31.7 - 34.9 and associated to low temperatures (21.4°C - 21.9°C) due to seasonal cooling.

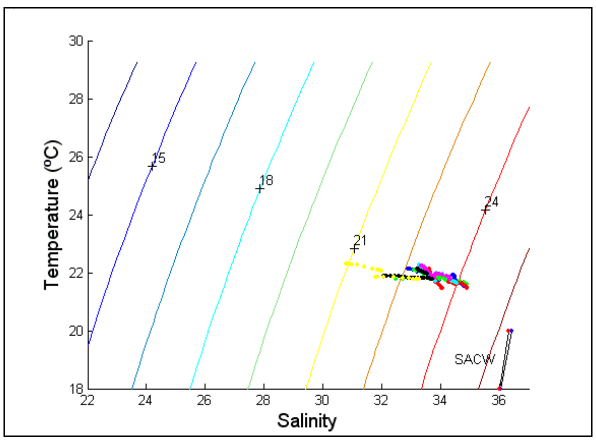

FIGURE 5

Scattered T-S Diagram from July and August. Stations 1 to 7 have the following legends: blue (1) green (2), red (3), cyan (4), magenta (5), black (6) and yellow (7). The density field is indicated by the Sigma-t isolines.

Closing the annual cycle the thermohaline properties of October, November and December are presented in Figure 6. As a result of the seasonal heating and the increase of the freshwater discharge in the estuary (Fig. 3), it was observed a great spreading of T-S pair of points compared to the winter features obtained (Fig. 5), although the temperature range still be smaller than the observed in summer (Fig. 2).

Similar to June and July, temperatures in October were low (varying from 20.2°C to 21.8°C) but the salinity range was wider (from ≈25.5 to ≈33.3) than the observed in the winter. Temperature increased in November and December (up to 25.7°C) and salinities ranged from ≈23.6 to ≈35.9. The convergence of the T-S characteristics in bottom waters of Santos Bay (to low temperatures, T≈22.0°C, and higher salinities S≈36.00) is again an indication of the SACW contribution to these waters. Further features observed through the scattered T-S Diagram (Fig. 6) were the spreading of temperatures from ≈21.0°C to ≈26.7°C and the salinity varying in the interval ≈26.6 to ≈35.9 (the lowest salinities were observed in stations 6 and 7, in the upper reaches of the Santos channel).

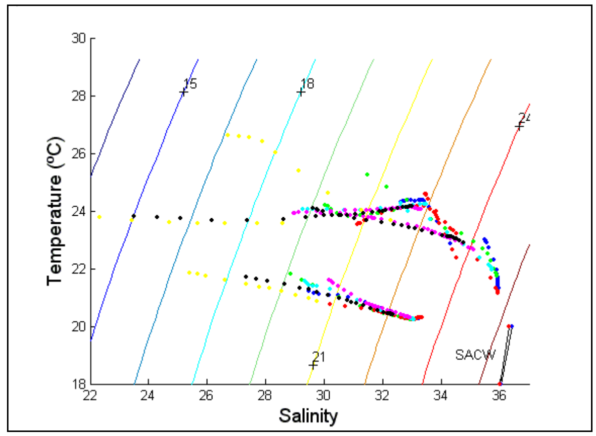

FIGURE 6

Scattered T-S Diagram from October, November and December. Stations 1 to 7 have the following legends: blue (1) green (2), red (3), cyan (4), magenta (5), black (6) and yellow (7). The density field is indicated by the Sigma-t isolines.

The concentrations of ammonium, phosphate and silicate (Figs. 7, 8 and 9) presented as a common feature greater values in channel waters compared to Santos bay. Also, average values obtained for st. 7 (the inner station) are usually the highest, meaning that the inner estuarine waters are important nutrient source for the bay. Comparing the time evolution of nutrients with the monthly rainfall (Figure 3) a positive relationship between these both variables became evident for Santos channel data, mainly considering ammonium and silicate.

The ammonium mean concentration ranged from 0.07 to 21.5 μM in Santos bay and from 0.01 to 32.35 μM in Santos channel (Fig. 7). However, in Santos channel these values were mostly above 3 μM along period of study, revealing the eutrophic condition of these waters. A negative correlation between ammonium and salinity (r^2 = -0.59) and a positive one between ammonium and rainfall (r^2 = 0.67) indicate that the inner waters of Santos channel are an important source of ammonium to the system, with seasonal variations influenced by the hydrological cycle [8].

Phosphate time evolution in the bay (0.06 -11.31 μM) was quite different from those observed in Santos channel (0.28 - 8.38 μM) as can be observed in Figure 8.

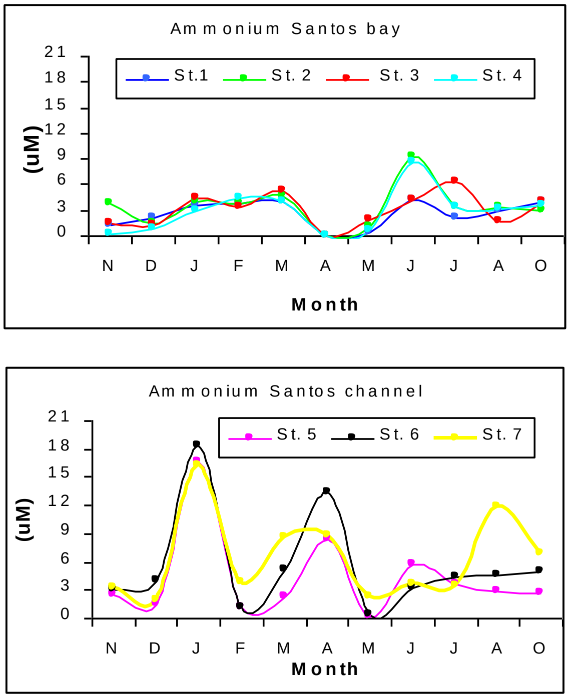

FIGURE 7

MONTHLY MEAN AMMONIUM CONCENTRATION OBSERVED IN STATIONS AT SANTOS BAY (ABOVE) AND IN SANTOS CHANNEL (BELLOW)

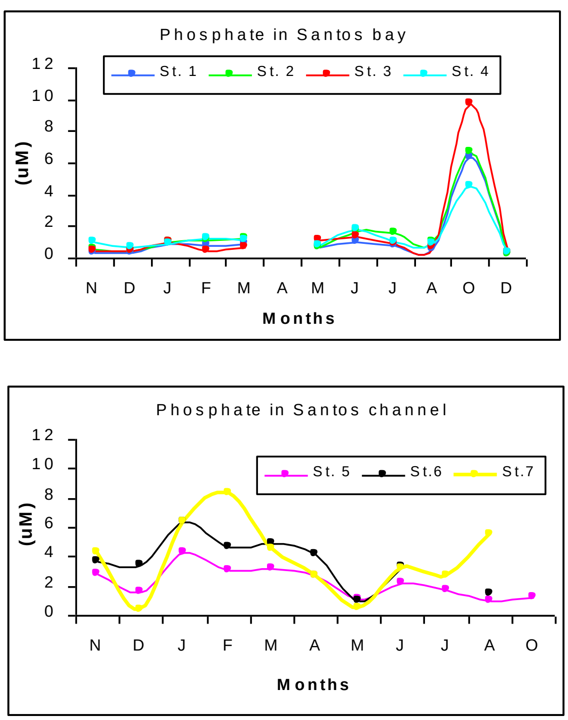

FIGURE 8

MONTLHY MEAN PHOSPHATE CONCENTRATION OBSERVED IN STATIONS AT SANTOS BAY (ABOVE) AND IN SANTOS CHANNEL (BELLOW)

Apparently, estuarine plume are also an important phosphate source to the bay since surface channel waters contained more than 2.0 µM of phosphate most of the year. In the inner channel station (st. 7) high concentrations are observed also in bottom waters meaning that the estuarine water column is entirely phosphate-rich. A conspicuous increase was observed in all bay stations during October, not related to channel input, as the concentrations in channel waters were much lower than the bay. As the greater values occurred in st.3, it could be considered that the phosphate could be originated from other sources (e.g. submarine sewage outfall or a plume from the disposal of dredged sediments).

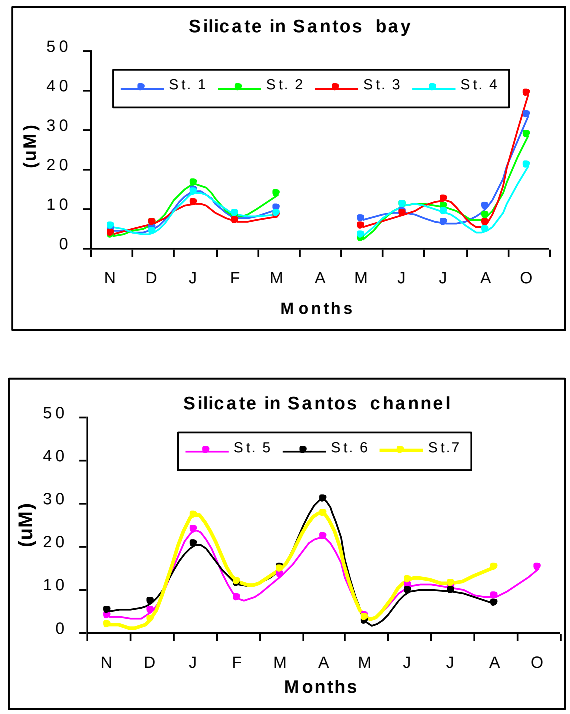

FIGURE 9

MONTHLY MEAN SILICATE CONCENTRATION OBSERVED IN STATIONS AT SANTOS BAY (ABOVE) AND IN SANTOS CHANNEL (BELLOW)

Silicate concentration in Santos bay ranged from 1.03 to 47.21 µM while the observed range in channel waters was from 1.06 and 34.44 µM. The distribution pattern in the bay was quite similar to the observed for phosphate, including the enhancement in October (Fig. 9). In Santos channel the mean values obtained in stations 5 to 7 were always similar indicating a seasonal pattern with higher concentrations between January to April, coinciding to the higher rainfall.

A first attempt to quantify the contribution of the São Vicente and Santos estuarine channels to the eutrophication of Santos bay was assessed through the measurements of instantaneous transport of salt, dissolved inorganic nitrogen (DIN), phosphate, organic and inorganic suspended matter (ISM and OSM) and chlorophyll-a, during dry and rainy seasons [9]. The results indicated a great contribution of the waters of Santos and São Vicente estuaries to the eutrophication of Santos bay, especially in the rainy season.

In spite of transport data are not being presented in this study, the high nutrient concentrations found in the inner waters of Santos Channel corroborate these first transport evaluations. Our expectation is to determine the transport balance of salt and inorganic nutrients for some of the periods here presented based on time-series data obtained during this project at Santos Channel mouth.

CONCLUSIONS

By the present data it was possible to identify the influence of SACW in the composition of the bottom waters of Santos Bay. Also, it was possible to state that, whatever the hydrographic condition of the Santos channel and bay, the channel plume brings nutrients to the bay during whole year. Such inputs are enhanced by rainfall events, giving a certain seasonal pattern to the nutrient variability.

ACKNOWLEDGMENT

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