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Physical oceanographic behavior at the Guama/Acara-moju and the Paracauari river mouths, Amazon Coast (Brazil)

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ABSTRACT

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This study was conducted as a part of the Potential Environmental Impacts of the Transport of Petroleum and Derivates in the Coastal Amazonian (PIATAM mar II) project, under the auspices of the Petróleo Brasileiro S/A – PETROBRAS. This paper focuses on the physical oceanographic behavior at the mouth of two tributary systems of the Para River, on the Brazilian Amazonian Coast. The Guamá/Acará–Moju Rivers are connected to the right margin of the Pará River through the Guajará Bay. The Paracauari River is a smaller system, and is connected to the Para along its left margin, via the Marajó Bay. The purpose was to characterize the physical oceanographic behavior at those areas and contribute to emergency contingency actions in occasional accidents related to oil spills. Fieldwork was carried out in the dry season, at the lowest expression of continental drainage and comprised measurements of water temperature, salinity and currents speed and direction; measurements of near surface wind intensity and direction, and the gathering of records of the tidal oscillation. The Guamá/Acará-Moju was classified as type 1b and the Paracauari as type 1a by the Hansen and Rattray classification criteria. In the most inland location, higher fresh water input and greater depth contributes to increase stratification in the system. Distinct hydrodynamical behavior distinctly affects residence time, concentration and transport of foreign substances released into the estuarine environment, and will require specific management.

ADDITIONAL INDEX WORDS: *Amazon Coast, Estuarine Dynamics, Oil Spill*

INTRODUCTION

This study was conducted as part of the Potential Environmental Impacts of the Transport of Petroleum and Derivates in the Coastal Amazonian (PIATAM mar II) project, under the auspices of the Petróleo Brasileiro S/A – PETROBRAS. It focused on the physical oceanographic behavior at the mouth of two tributary systems of the Para River, on the Brazilian Amazonian Coast, with the purpose of contributing to emergency contingency actions in occasional accidents related to oil spills.

Those areas are located in northern Brazil, a region of high mangrove density at which mangrove trees can be 30 m high. Mangrove ecosystems are typical of tropical coasts and present a large biomass and variety of species of microorganisms, macro-algae, crustaceous, mollusks and fishes, well adapted to a periodic oscillation of salinity and fluvial and tidal fluxes. Mangroves serve as grounds for feeding, reproduction and spawning of many aquatic organisms, being of great ecological importance.

At the same time, mangroves occupies intertidal coastal areas, where ports and maritime oil terminals are more likely to be installed, thus requiring studies that could contribute to prevent, minimize and mitigate impacts such as those resulting from oil spills, that would alter physical and chemical properties of waters and sediments and severely affect coastal biota. In the Amazonian region, where the large scales and multitude of systems, impose a special difficulty to research conduction, studies focusing on the hydrodynamics and its implications to pollutant dispersion i.e. Bezerra *et al* (2009b) are still scarce, and urgently need.

METHODS

Study Area

This work was conducted at the mouth of the Guamá/Acará-Moju Rivers, in front of the Miramar Petrochemical Terminal, near the city of Belém (Pará State), and at the mouth of the Paracauari River near the fluvial Port of the city of Soure, in the Extractive Marine Reserve of Soure (Figure.1). The study area is located in northern Brazil, in a region that experiences an equatorial, hot and humid climate (type Afi by the Köppen System), with a mean annual temperature of 25 °C, air humidity above 80% and a rainfall of 2889 mm.y^{-1}.

Rain seasonality is well defined with a dry/hot period from June to November (Bemerguy, 1981) when air temperature can reach 40ºC and monthly rainfall ranges from 11 to 152 mm, and a rainy season from December to May with monthly rainfall volume ranging from 215 to 436 mm (Tempo Agora, 2010).

Atmospheric circulation responds to four major forcing: (1) NE and E winds from the subtropical anticyclone systems of the South Atlantic and the Azores; (2) W winds from the continent; (3) N winds from the Inter Tropical Convergence Zone and (4) S winds from the Polar anticyclone. Prevailing winds blows from NE (29%), N (10%) and E (9%) with mean velocity of 2.6 to 2.9 m.s^{-1} and remain calm in 45% of the time year around (CTA/IAE, 1971).

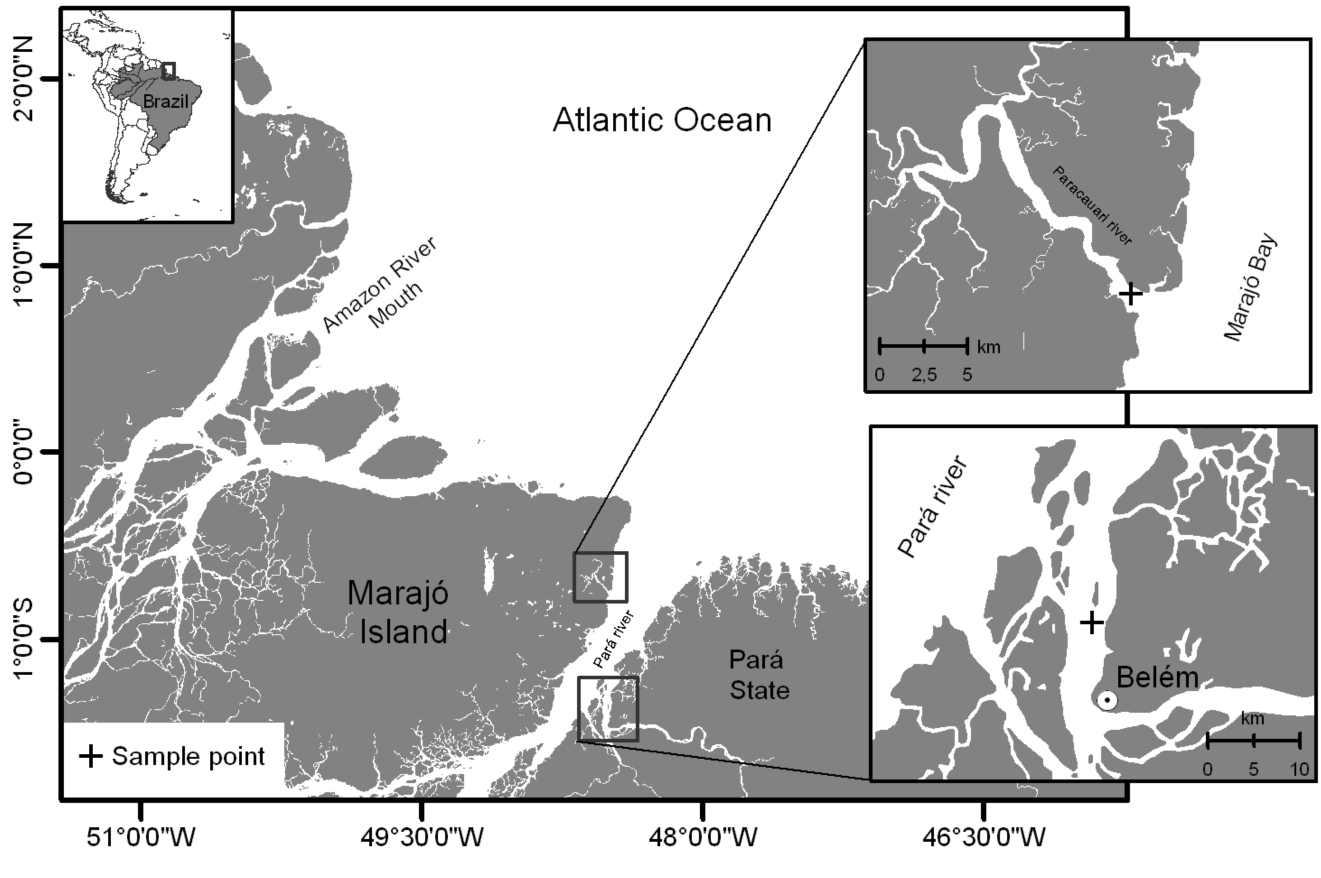

Figure 1.Study area with indication of sampling stations at the mouth of the Guamá/Acará–Moju rivers (Guajará Bay-PA) and of the Paracauari river (Marajó Bay-PA) on the Brazilian Amazonian Coast

Both areas receive large volumes of freshwater discharge and experience macro tidal regime. Tides along the eastern margin of the Marajó Island present an amplitude ranging from 3.6 to 4.7 m (Bemerguy, 1981)

The system formed by the Guamá/Acará–Moju Rivers drains an area of 87.400 km^2 and is connected to the right margin of the Pará River through the Guajará Bay. The Guajará Bay is a highly dynamic area, under the influence of both fluvial and marine forcing (Gregório, 2007; Gregório et al 2009). The Miramar

Petrochemical Terminal is located at the northern shore of the Guajará Bay, 5 km from the city of Belém. Local ship traffic corresponds mainly to tankers of PLG (Petroleum Liquefied Gas), gas, aviation kerosene, diesel oil and mix MF-380. Due to the high cargo traffic and the potential for oil spills the area was considered by Souza Filho et al (2009) of high-priority for conducting studies that could contribute to a better understanding of local hydrodynamics and thus contention of spills.

The Paracauari River is located in the Marajó Island. It's a smaller system, connected to the Para River along its left margin, via the Marajó Bay, in the Golfão Marajoara. Some portions of the river are limited by coastal cliffs. Large areas are surrounded by mangroves, evidencing the tidal influence (Teixeira and Costa, 1992). The system is part of the Extractive Marine Reserve of Soure (Esex Soure) also called Mareianazes (Presidência da República, 2001).

The Paracauari together with the other rivers that drain the Marajó Island is part of the Hydrographic Amazonian Basin (ANA, 2009). Management of island system requires special planning, considering the high population density, high pressure over the natural resources and the vulnerable coastal surrounding where impacts are more likely to reach large proportion (Bezerra et al, 2009a)

Fieldwork

Fieldwork was carried out in the dry season (Oct/07 and Nov/07) at the lowest expression of continental drainage in 25-26 Oct/2007 at the Guamá/Acara-Moju system and in 2-3 Nov/2007 at the Paracauari River.

Oceanographic campaigns were conducted on board of the Denebola, a nautical signalizing barge from the North Sector of Signalization (SSN-4) of the 4th Command of the Naval District of the Brazilian Navy.

Measurements were done hourly, over a 24-hour period. They comprised: (a) salinity and temperature profiles from surface to bottom with a SeaBird SBE37 CTD; (b) surface and bottom currents speed and direction, using a Sensordata SD-6000/30 current meter and (c) wind speed and direction 6.5m above water surface, using an Instrutherm AD- 155 portable anemometer. Were also included tidal oscillation records with a limnigraph, at 15 minutes intervals, at the Miramar Terminal and at IBAMA's (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) pier at Soure.

Once at the lab, all collected data were transferred/digitized to electronic spreadsheets and processed using the instruments software and/or MatLab routines. Estuarine classification was conducted based on salinity and currents measurements, using the Hansen e Rattray (1966) diagram. Adimensional stratification and circulation parameters being computed accordingly Miranda, et al (2002)

RESULTS AND DISCUSSION

Guama/Acará-Moju River Mouth

Measured tidal surface and near-bottom currents at Guama/Acará-Moju river mouth are presented in Figure 2, with direction referenced to the magnetic north and current speed in m.s^{-1}.

Surface and bottom currents flow in the same direction, with current speeds being in general, 0.25 m.s^{-1} greater at surface during flood tide. During ebb tide, this difference increases to 0.70 ms^{-1}, with surface current intensity at times twice as great as bottom currents

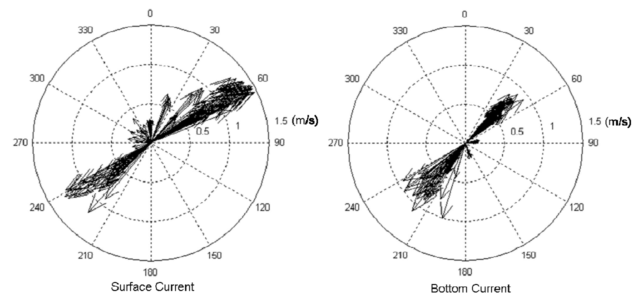

Figure 2. Stick diagrams of currents time series 1m above the bottom.

Tides near Belém are semidiurnal, with a form number of 0.12 and with spring and neap tidal ranges of respectively 3.28 m and 1.78 m. Measured tidal water level oscillation and current speed at surface and near the bottom curves at the mouth of the Guama/Acará-Moju Rivers are presented in Figure 3.

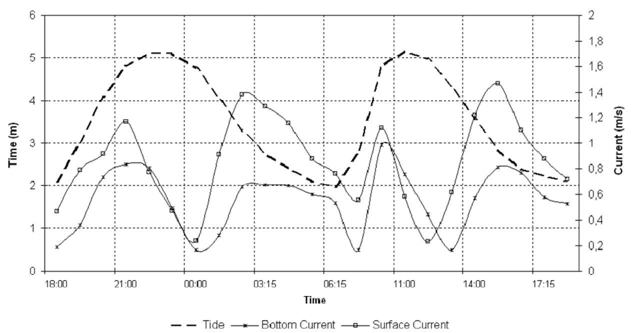

Figure 3. Tidal level and surface and bottom current speed oscillation. 25-26 Oct/2007.

Tides show a flow asymmetry with flooding periods lasting circa 5 hours and ebbing periods lasting circa 8 hours. Current speed and tidal water level oscillation are nearly in phase during low tides but show a phase difference of 80-90 degrees at high tides.

Current patterns at surface and bottom layer are more similar during flood than during ebb tide. During the discharging stage, bottom currents are slightly weaker (0.2 m.s^{-1}) than surface currents, the opposite being verified during flood periods.

Surface currents were stronger (1.5 ms^{-1}) during ebb tide, when tidal and river flows have same direction. During flood tide, when river flow counterpoises tidal excursion, surface currents had magnitude of 1.1 m.s^{-1}. The inverse occurs in the bottom layer.

Salinity was low and remained near constant during the observed period and along the water column. Maximum registered salinity value was of 1.3 during high tide at surface waters and of 1.6 at the beginning of the ebb tide for bottom waters. Similarly, water temperature also remained near constant, oscillating between 28.69 ºC and 29.10 ºC.

Prevailing winds blow from the northeastern sector during the night period and from southeast during daylight period. The temporal variation of surface current and wind intensity are presented in Figure 4.

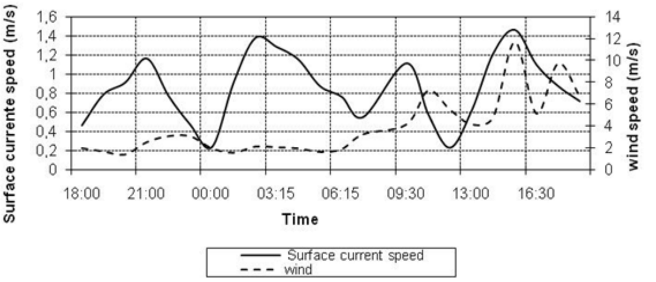

Figure 4. Wind speed and surface currents at the Guamá/Acará-Moju river mouth. Oct., 25-26/2007.

For the first half of the register (from hour 18:00 Oct., 25 to 06:00 Oct., 26) wind speed was lower than 3.0 m.s-1, while for the second half of the register (from hour 06:00 to 17:30 Oct., 26), winds were stronger, oscillating between 4.0 m.s-1 and 12 m.s-1. The transition between weak to strong winds caused an increase in water level (wind setup) around 9:30 of day Oct, 26 (Figure 4), which coincided to a warning of rain storm to the area.

Paracauari River Mouth

Tides at Soure are semidiurnal (F=0.13) with a mean spring tidal amplitude of 3.86 m and a neap tidal amplitude of 2.19 m, with a symmetrical flood/ebb cycle of six hours each.
Current velocity at the surface layer was generally greater than that at the bottom layer, varying from 0,05-0,06 m.s-1 during slack low and high water to 0,60-0.70 m.s-1at the ebbing and the beginning of the flooding stage (Figure 5). Currents are directed along the major channel axis.

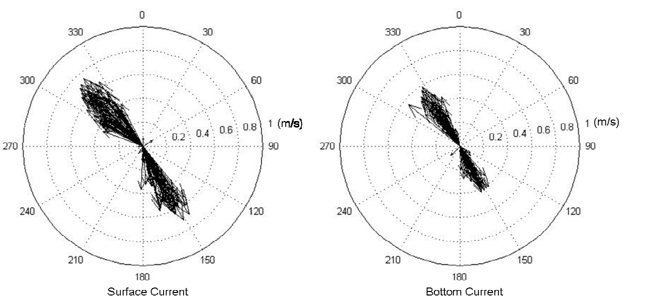

Figure 5. Polar plots of hourly measurements of surface and bottom water currents. November, 2-3/2007.

Oscillations in surface currents speed responded to winds gusts. Prevailing winds were from the NE-E sector with speed from 4.51 ms-1, to 4.7 ms-1 (Figure 6).
Vertical salinity profiles varied little over the tidal cycle, oscillating between 6.4 and 7.7, with bottom salinity higher than surface salinity (Figure 7). Since sampling was conducted during the dry season, salinity values are not expected during other times of the year.
Water temperature was distributed quite homogeneously with thermal amplitude of 0.6 ºC (28.2ºC to 28.8°C).

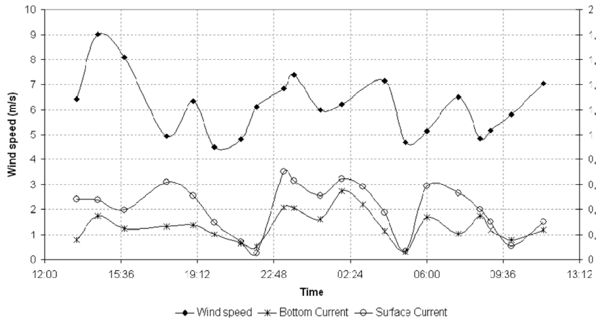

Figure 6. Wind speed and surface and bottom currents at the Paracauari river mouth. November, 2-3/2007

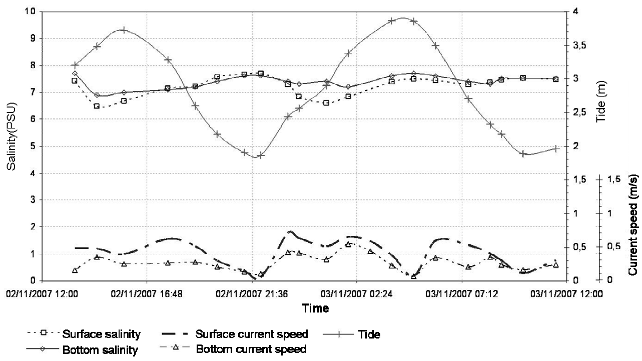

Figure 7. Surface and bottom salinity, current speed and water level tidal oscillation. 2-3 November/2007

Estuarine Classification

In order to allow estuarine classification for both systems, stratification and circulation parameters were computed using measured currents and salinity distributions. Results are presented in the Hansen & Rattray Diagram (Figure 8).

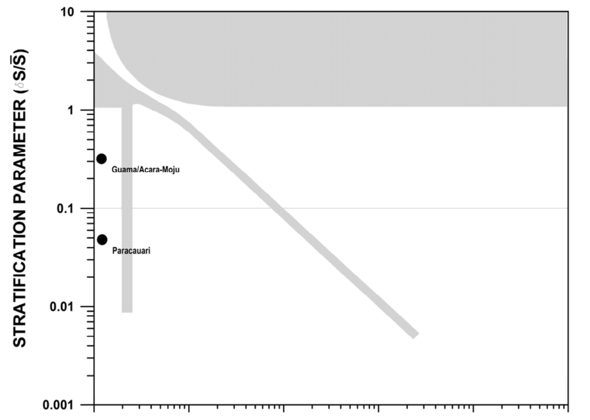

Figure 7. Estuarine classification of the Guamá/Acará-Moju and Paracauari River mouths, accordingly the Hansen and Rattray Diagram

For the period of this study (dry season) the Guamá/Acará-Moju and the Paracauari present a circulation parameter of similar magnitude, but with higher stratification parameter for the Guama/Acará-Moju than for the Paracauari. The Paracauari is classified as type 1a and the Guama/Acará-Moju as type 1b, the first corresponding to a well mixed laterally homogeneous estuary and the second showing a slight stratification.
Circulation and stratification are function of freshwater discharge, which is a buoyancy source, and of the winds and tidal forcing acting on the systems and contributing to stratification breakdown. They are also a function of the estuary morphology that could enhance or reduce the effect of each of those forcings. The larger fresh water discharges received by the Guama/Acará-Moju, and its greater depth and inner location, are more likely to contribute to its higher degree of stratification as observed in this study

CONCLUSIONS

Despite being located under general similar field forcing (climate, tidal oscillation and wind pattern), the Guamá/Acará-Moju was classified as type 1b and the Paracauari as type 1a estuary by the Hansen and Rattray classification criteria. The more inland location, higher fresh water input and greater depth of the Guamá/Acará-Moju contributes to increase stratification in this system. Distinct hydrodynamical behavior distinctly affects residence time, concentration and transportation of foreign substances released into the estuarine environment, and will require specifics management actions.

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