INCT-TMCOcean

# National Institute of Science & Technology of Materials Transfer at the Continent-Ocean Interface

## Scientific Highlights

CNPq - INCT - TMCOcean

INSTITUTO NACIONAL DE CIÊNCIA E TECNOLOGIA DE TRANSFERÊNCIA DE MATERIAIS CONTINENTE-OCEANO

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**National Institute of Science & Technology of Materials Transfer at the Continent-Ocean Interface (INCT-TMCOcean)**

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The results presented here were selected from the extensive literature produced by the researchers of the INCT-TMCOcean between 2009 and 2013, and available at *www.inct.tmcocean.com.br*

# Introduction

The transfer of materials from the continents to the ocean is a key step to understand the global biogeochemical cycles. Along this continuum, organic matter, nutrients and contaminants suffer physical chemical changes which eventually result in their accumulation in coastal areas, export and cycling in continental shelf environments and, under certain scenarios their export to the deep sea. The processes involved in such changes, their drivers and the fate of the materials involved are the study subjects of the INCT-TMCOcean. The research is focused on the Brazilian coast along a climate and land use gradient ranging from sub-tropical humid, in the urbanized and industrialized southeast; to the mostly agricultural tropical semi-arid, in the northeast. This gradient allows the comparison of processes and their drivers to be assessed under different environmental settings.

The project is a research network involving 10 universities, 3 research institutes and a research company, totaling 34 senior researchers and about 78 postdocs, graduate and undergraduate students. The project is endorsed by IMBER and LOICZ and has strong cooperation links with France, Germany and Argentina. Four major questions orient the objectives of the project: i) Are river basins sources or sinks of biogenic matter to the coastal zone? ii) How the net metabolism of the systems is being altered by human interventions and how it changes fluxes and balance of materials? iii) What is the spatial and temporal diversity of fluxes and functioning in relation to regional typology? iv) What are the consequences of changes in the coastal zone in terms of water and material fluxes in a scenario of global change?

To address these questions, the INCT-TMCOcean research network quantifies similarities and dissimilarities of contamination, eutrophication and carrying capacities of different areas along the NE and SE Brazilian coast, integrating and modeling them in order to construct appropriate scenarios for their sustainable utilization. This includes the geological, biological and chemical frameworks as well as the anthropogenic emissions of nutrients and trace metals. Special attention is given to changes in sediment, nutrients, organic matter and pollutants fluxes from the continent downriver to estuaries, where most water-dependent activities are taking place, including the contributions from river damming, irrigated agriculture, urbanization and aquaculture. Particular attention is given to changes in basin morphology, erosion and sedimentation of the estuary. A hierarchical typology of major drivers is achieved in order to balance future planning actions watersheds, while actions to control and minimize impacts are made based on these scenarios. A detailed, comparative, description of the major biogeochemical processes is performed, taking into consideration the different regional geochemical backgrounds, in gradient from humid climate (SE) to semi-arid (NE).

Environmental impacts derived from global climate changes are evaluated by changes in biodiversity proxies of global and land use changes, including changing cover of natural key ecosystems and their biodiversity, the spectrum of fisheries and monitoring species already identified for the basin. The alteration in biogeochemical proxies together with the other major lines of research is used to drawn consistent scenarios of sustainable utilization

of coastal zone goods and services in the reality of the Anthropocene.

The project also aims to evaluate the social-economic impacts on the productive chains of artisan fisheries, aquaculture, irrigated agriculture and husbandry due to water use conflicts, soil erosion and waterways sedimentation. Participation of stakeholders is sought by the organization of workshops to transfer the generated knowledge and how it can be applied in policy making and sustainable development. The project also evaluates the generation and dependence of income and jobs of the local population on the environmental conditions, based on a joint evaluation of environmental and socioeconomic indicators. This dimension is complemented by large efforts in building human capacity and training in all education levels.

## 1 - Relative contribution from natural and anthropogenic sources from non-industrialized areas to the continental runoff of nutrients and trace metals to the ocean

A comparative analysis of the average relative importance of natural processes and anthropogenic sources to the total emissions of nutrients and metals to 21 studied estuarine basins in northeastern Brazil is shown in Figure 1. It is easily observed that in the majority of the estuaries, notwithstanding their low status of urban and industrial development, the anthropogenic sources are by far the most important contributor of nutrients (N and P) and some metals (Cu, Zn and Hg) to their basins.

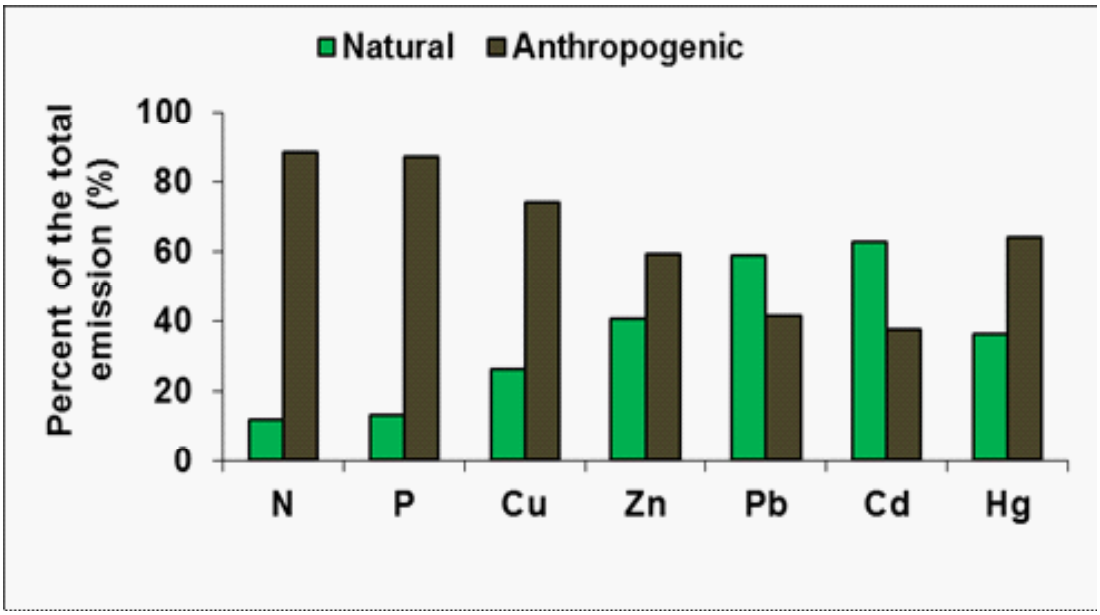


**Figure 1.** Average relative importance of natural processes and anthropogenic sources to the total emissions of nutrients and metals to estuarine basins in northeastern Brazil.

The present situation of most estuaries along the northeastern coast of Brazil is worrisome. Although only a few estuaries show obvious environmental impacts such as eutrophication or severe contamination of the biota, the large contribution of anthropogenic sources is certainly decreasing their support capacity and corroding their natural capital, as well as affecting ecological interrelationships and biogeochemical balances. Also preoccupying is the absence of continuous inventorying of nutrient and metal emissions from these activities and the erratic monitoring programs, when existing at all. We hope the obtained results will

help local and regional environmental agencies to establish such practices.

One of the major anthropogenic activities in these estuaries if intensive shrimp aquaculture. Although relatively recent, the activity in the semi-arid coast of NE Brazil, had less than 300 ha of ponds in 1998 while in 2008, pond area has increased to nearly 12,000 ha. Production peaked in 2005 at 90,000 $t.yr^{-1}$, but reduced and stabilized to 65,000 $t.yr^{-1}$ today, with an average productivity of about 4,200 $t.ha^{-1}$. The semi-arid northeastern coast harbors 93% of this area and 96% of the total Brazilian production. The abundance of potentially usable coastal areas for future farm construction, annual export revenues of US$ 240 million, and a highly job-demanding productive chain, plus a well establish technology and a constantly growing market, forecast a continuous growth of the activity in NE Brazil. Notwithstanding its socioeconomic importance, intensive shrimp aquaculture may cause significant environmental impacts to coastal ecosystems. Effluents are enriched in nutrients and organic matter, from excess fertilizers, aquafeeds and animal excreta, and suspended matter due to erosion of pond walls by the aerators. Also, contrary to most other sources of contaminants, which includes agriculture, husbandry, waste waters and solid waste disposal from urban areas, which effluents are released on soils prior to reaching the estuary, shrimp farming effluents are released directly into estuaries (Table 1). Today, the activity is the most important source of N and P to many estuaries. Little is known however, on the emission of other pollutants such as trace metals, present as impurities in most consumables used in the activity, especially in aquafeeds.

| Driver | Emission Factor ($gCu\ /gHg.ha^{-1}.yr^{-1}$) | Annual Emission ($kgCu/gHg.yr^{-1}$) |
|---|---|---|
| **Wastewater disposal** | 2.5 / 0.2 | 430 / 75 |
| **Solid wastes disposal** | 3.2 / 0.4 | 550 / 150 |
| **Urban runoff** | 0.2 / n.d. | 20 / n.d. |
| **Agriculture** | 45.5 / n.d. | 7,890 / n.d. |
| **Husbandry** | 1.5 / n.d. | 250 / n.d. |
| **Shrimp farming** | 386.4 / 0.37 | 490 / 0.35 |

**Table 1.** Cu and Hg EFs and annual discharges from shrimp ponds and other anthropogenic sources to one of the major shrimp farming area in NE Brazil, the Jaguaribe estuary.

Our project has demonstrated that, although not as visible and obvious as for nutrients, shrimp farming has proved a potential source of trace metals to estuaries, in particular of Cu and Hg, which are present as natural components in aquafeeds, as impurities in fertilizers or as active principles of algaecides. Cu and

Hg emission factors (EFs) range from 386.4 $gHg.ha^{-1}.yr^{-1}$ for Cu to 0.37 $gHg.ha^{-1}.yr^{-1}$ for Hg. These EFs are comparable and even higher than those from other anthropogenic sources and urge environmental authorities worldwide to include trace metals in their monitoring programs of emissions from intensive shrimp farming.

Figure 2 shows the Cu balance calculated for a typical intensive shrimp aquaculture farm in the Jaguaribe estuary, where most of shrimp farms (2,640 ha) of Ceará State, NE Brazil is located. It is clear that the major sources of Cu, as well as other metals, are aquafeeds and chemicals, such as lime and fertilizers, used in the production process. A small fraction of the added metals are exported as shrimp biomass and accumulated in bottom sediments. The large excess is exported to adjacent estuarine waters. Most is exported as particulate species, accumulating in sediments of tidal creeks and in mangroves.

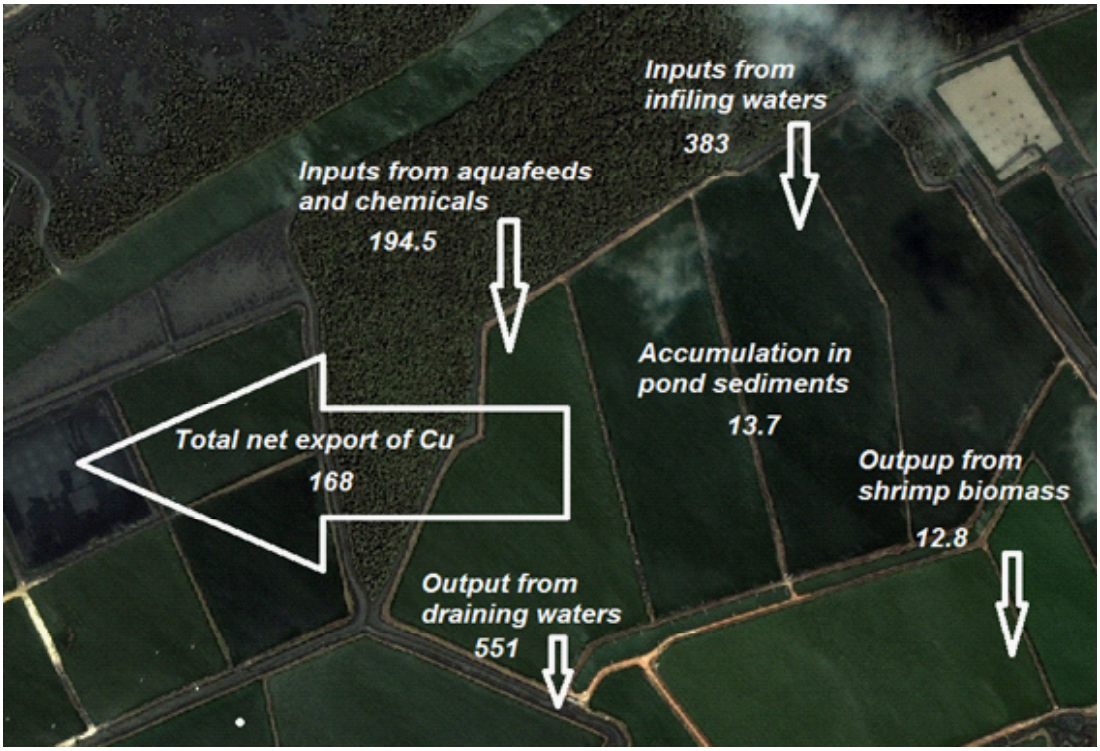


**Figure 2.** Copper balance in a typical intensive shrimp aquaculture farm in the Jaguaribe Estuary, NE Brazil

## 2 - Changes in environmental proxies due to regional land use and global climate changes

Analysis of remote sensing information, photographs and maps performed by several studies, and comparison of satellite data from the various dune fields and estuaries dating back to pre-anthropogenic time showed large-scale response to climate variability and land use change. Selected proxies associated with these envi-

ronmental changes are the velocity of the annual displacement of barchan dunes, and the increasing area of mangrove forests. These were quantitatively linked to alterations in the region's climate, precipitation and fluvial discharges.

The climate in the semiarid coast of NE Brazil is characterized by a relatively short wet season (4-5 months) and a relatively long dry season (7-8 months), with wind intensity determined by the southern shift of the Intertropical Convergence Zone (ICTZ). Wind power is negatively correlated with precipitation, and precipitation is negatively correlated with the difference between sea surface temperatures of the tropical Atlantic Ocean north and south of the equator (Figure 3). The littoral harbors vast fields of sand dunes, in part constituted by parabolic formations stabilized by vegetation, whereas another group of dunes not covered by vegetation is active and moves freely forming barchans and transversal dunes. Wind power determines the mobility and stability of these dunes, moving during dry periods of high wind power and stabilizing when wind power is lowest during the wet season.

When barchan dunes move, residual ridges are often left behind (the so called cuspidate marks shown by the arrows in Figure 3). These are formed by vegetation growing along a line some distance upwind of the lower slope of migrating dunes, due to growing of vegetation along the edge of flooded interdune areas when water level rises during the rainy period. Each cuspidate mark corresponds to the position of the dune during the wet period in each year. Therefore, variations in the distance between these residual dune ridges could be potentially used to monitor climatic fluctuations in rainfall and wind.

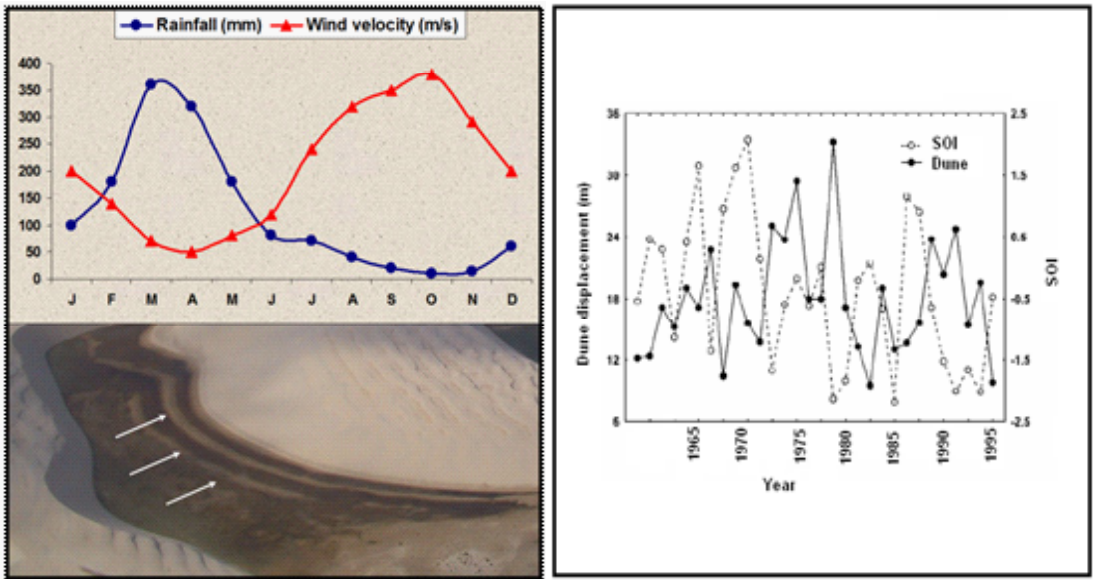


**Figure 3.** Seasonal changes in precipitation and wind power in the semiarid NE coast of Brazil and residual dune ridges (cuspidate marks) left from the displacement of dunes (arrows) and time series of the Southern Oscillation Index (SOI)* and the corresponding displacement of sand dune in Jericoacoara, Ceará State, NE Brazil. *SOI data were obtained from USNOAA.

We have shown that there is a correlation between the intensity of the ENSO events and the displacement of sand dunes in the coast of Ceará, NE Brazil. So it is possible that dune migration could also be used to monitor global climate changes. It was formulated a model that simulates the major varying conditions of wind, rainfall and evaporation rates to examine the potential use of these residual dune ridges for the reconstruction of past climatic fluctuations, at least for the past 40 years. The model was tested for sensitivity to climatic variability in NE Brazil and validated against residual dune ridge displacements as measured in the field and from high spatial resolution satellite images. Unfortunately the results showed that residual dune ridges may not form in years which are exceptionally dry, as may happen during El-Niño events, due to the extreme lowering of the water table. When this type of event happens, the distance between adjacent residual dune ridges may correspond to more than one year and, therefore, the correlation between dune displacements and wind power becomes weak or even disappears. Additionally, because of biotic, aeolian and hydrological processes, cuspidate marks may not preserve their initial shape for long periods, making its potential use in some areas, to reconstruct past climates on a yearly basis or to identify past El-Niño events is limited when up scaled to the regional level.

The hydrodynamics of rivers draining the semiarid NE of Brazil is dependent on climate and the regional land use changes. These rivers are mostly affected by global climate changes and their effects on fluvial flows are maximized by damming and water withdraws for human uses. An average decrease of 5.3 $mm.yr^{-1}$ in annual rainfall over the Ceará State from the late 1960's was reported and confirms previous results from modeling exercises by the IPCC. Also, during the past century

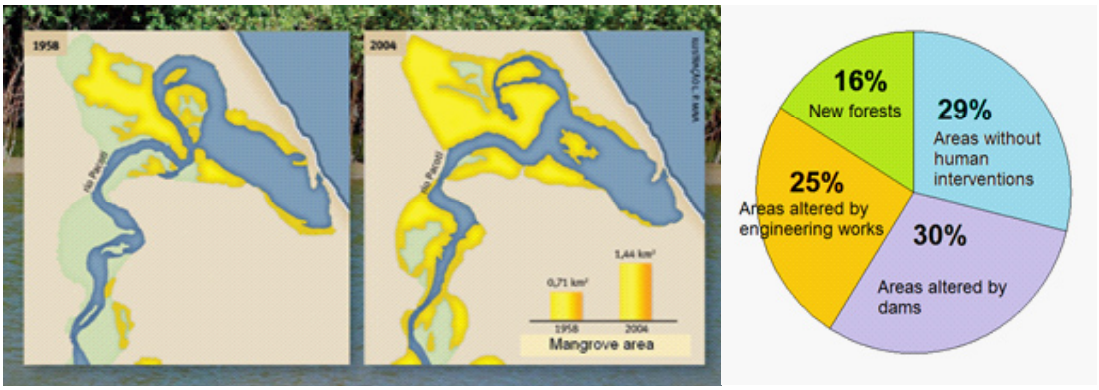


**Figure 4.** Mangrove area expansion at the Pacotí River estuary, Ceará State, NE Brazil, from 1958 to 2004 and major drivers of augmenting mangrove area (as percentage of the net expansion) in 27 estuaries along the semiarid northeastern coast of Brazil, based on remote sensing mapping from 1999 to 2006 using Landsat, SPOT & Quickbird de 1999 a 2006.

human intervention on the semiarid watersheds was mostly the construction of dams for providing freshwater to human uses. These two major drivers contributed to a general decrease in the continental runoff to the ocean, resulting in widespread erosion of the coastline, increasing saline intrusion and sedimentation of estuaries in the NE Brazil.

Mangroves rapidly respond to changes in hydrodynamic and sedimentation-erosion equilibrium and therefore can

be used as monitors of environmental changes occurring in estuaries. Thus a comparative analysis of detailed remote sensing information, aerial photographs and maps of the semi-arid coastline of NE Brazil were performed to the detailed mapping of mangrove forests. Images treated using standard methodology (e.g. GIS, ARCView etc...) to derive graphic scenarios of the recent regional changes of the mangrove areas and their eventual correlation with water and material fluxes as well as the evolution of landscape.

Figure 4 compares, as an example, the mangrove extension in the Pacotí River estuary from 1958 to 2004. Mangrove area increased about 49% in the period following the enlargement of river beaches and creation of new fluvial islands due to accelerated sedimentation, as a result of damming of the river and a 20-fold decrease in the rain season river discharge, when most accumulated sediments during the dry season would have been moved to the ocean. This situation repeats along most estuaries of the semi-arid coast of NE Brazil.

Comparing the expansion of mangrove areas in 27 river basins along NE Brazil from 1999 to 2006, with and without human interventions, made possible to evaluate the relative importance of global climate change (where no direct human intervention was verified) and regional land use changes (mostly river damming and coastal engineering works) as the major drivers to ecosystem changes. The results strongly suggest that global climate change is a major driver of mangrove expansion. At least in 46% of the expansion occurred where no local alteration in land use were detected, although we cannot rule out global change from acting on the other areas affected by regional land use drivers. Mangrove expansion therefore, is an excellent proxy to the effects of global climate change in the semiarid coast of northeastern Brazil.

Other proxies of environmental changes occurring along the NE Brazilian coast under study are beach erosion and river morphology. These processes are accelerating along most of this littoral, in particular the building up of new island in river lower courses and estuaries, enlarging of fluvial beaches and loss of beach volume. All these are interrelated complex processes but that can be correlated to a single major driver which is the decreasing continental runoff.

## 3 - Oceanography of the continental shelf-deep ocean continuum in the Equatorial Western Atlantic Ocean

Seasonal and inter-annual variability of temperature, salinity and density, so called state parameters, and their horizontal and vertical distribution in the water column are fundamental aspects to study ocean-atmosphere heat transfer in tropical and equatorial latitudes. In the Equatorial Western Atlantic Ocean the presence of warm, high salinity tropical water (TW) occurs at the surface, over a layer flowing at the pycnocline with a large variability of temperature and salinity of the South Atlantic Central Water (SACW). The SACW is characterized by lower temperatures and salinity. The isopycnal ($\sigma\theta$ = 27.1) in the tropical regions defines the transition between the SACW and the Intermediate Antarctic Water (AAIW) flowing just below and towards the Equator. The AAIW water mass is relatively cold, enriched in oxygen and with low salinity. It is defined as occurring between the thermo-haline: 3º - 6 ºC and 34.2 - 34.6 PSU. Below the AAIW there is the North Atlantic Deep Water (NADW) characterized by lower temperatures (3º - 4 ºC) and higher salinity (34.6 to 35.0 PSU), this water mass flows southward between depths of 1,500 m to 3,000 m to approximately 32 ºS, where at least part

of this current goes back to the Equator.
The intrusion of TW on the continental shelf drives a water mass with lower oxygen content to shallower waters. The displacement of this mass may be related to an intensification of the Ekman transport towards the coast and/or to the upwelling of deeper water masses carried by the heat accumulation in the South Atlantic, enhanced by global climate changes. Particularly in the during the dry season, a higher influence of the TW is observed in the continental shelf (Figure 5), most likely due to the space-time variability of the North Brazil Current (NBC) and the role of anticyclonic eddies that meander from the adjacent ocean towards the continental shelf.
In the inner shelf region, a marked presence of the coastal waters (CW) was observed, whereas the continental influence (cw) is restricted to the estuaries, most likely due to the limited competence of the continental runoff to reach the continental shelf. In the middle and outer shelf regions, a higher influence of the TW was observed, most likely influenced by the existence of space-time variability in the behavior of the NBC and the role of anticyclonic eddies that meander along the adjacent ocean towards the continental shelf. Even in low latitudes, the baroclinic adjustment of the NBC may contribute to TW intrusion on the northeastern continental shelf. This choking of the continental runoff during the dry season is of high significance to the hydrodynamics and biogeochemistry of estuaries.

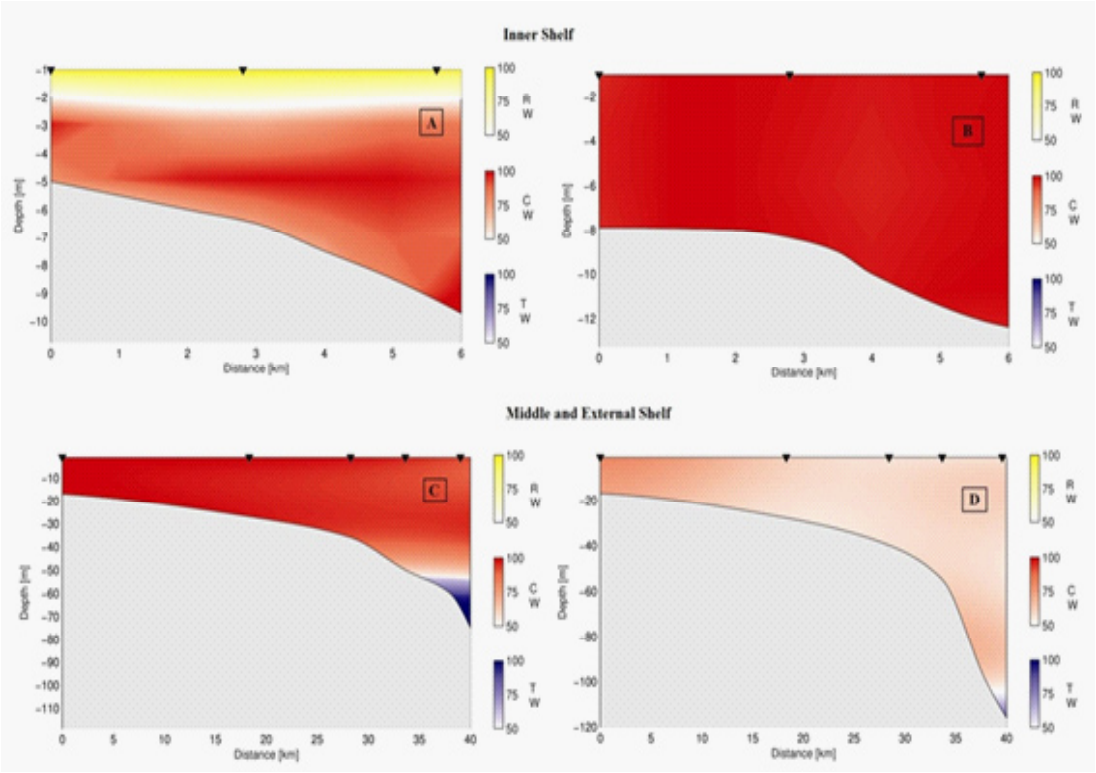


**Figure 5.** Vertical distributions of water masses over the inner shelf (profile A) during the rainy (7A) and dry (7B) seasons and in the middle and outer shelf regions (profile B) during the rainy (7C) and dry (7D) seasons.

Along the shelf-slope continuum we found from the 20 m isobaths to the breaking of the continental shelf, high salinity and temperature waters characterized by high oxygen concentrations, ($\geq$ 6 mg $L^{-1}$), always separated by the $\sigma\theta$ = 23.5 isopycnal. Beyond this region to the open ocean, low salinity and temperature waters, which decrease with depth showed lower oxygen content. Preliminary results based on an integration of the vertical distribution of salinity and temperature through a scattered T-S diagram, show the mixing and stratification of water masses based on the correlation between these variables. The 23.5 isopycnal ($\sigma\theta$) characterizes the Costal Water (CW), extending to a depth of 50 m within the continental shelf. Subsurface layers with isopycnals of 25 and 26.5 characterize the nucleus of two important water masses with, the Tropical Water (TW) and the South Atlantic Central Water (SACW). The depth of the two masses is 60 to 120 m for TW, and 150 to 600 m for SACW. Immediately below the SACW, deeper than 700 m, a water mass separated by a isopycnal of 27, characterizes the Antarctic Intermediate Water (AAIW), with depths ranging between 700 and 950 m. Below this depth we observed a water mass characterized by 3 °C < T < 4 °C and 34.5 < S < 35 PSU, in agreement with the thermo saline indexes of the superficial layer of the North Atlantic Deep Water (NADW), at 1,000 m of depth. This is corroborated by the oxygen concentrations found in this water mass. The present knowledge of the vertical variability of water masses in the South Atlantic Ocean suggests the presence of (NADW) between 1,500 m and 3,000 m. Therefore our results imply the top layer of the NADW at such shallower depths (~1,000 m). If these results proved true, the rising of the NADW may be caused by the present heat accumulation in the South Atlantic and the increasing freshwater inflow in the North Atlantic due to global climate changes. This movement of deep water masses may increase the effects on the continental runoff already observed during the dry season and therefore enhance its significance to the hydrodynamics and biogeochemistry of estuaries.

## 4 - The Arctic Paradox

Hydrodynamics and Hg fluxes are being measured, since 2005, in the dry and rain seasons at the Jaguaribe River estuary, the largest watershed of the semiarid in NE Brazil, which discharges into the Equatorial Atlantic Ocean. During rain periods water fluxes to the ocean with short water residence time within the estuary (0.8 days). During dry periods seawater chokes the fluvial discharge, resulting in longer water residence (3.1 days). Dissolved (<0.7 μ) and particulate Hg concentrations and fluxes were higher from river to estuary than from estuary to sea, accumulating mostly particulate Hg in the estuary. Particulate Hg export (1.8 to 12.6 $mg.s^{-1}$) to the ocean occurred in extremely rainy periods while dissolved Hg exports were near zero in rain periods but reached up to 0.45 $mg.s^{-1}$ during dry periods (Figure 6). The hydrodynamics of the Jaguaribe River estuary is finally dependent on the regional climate and regional land use changes. The Northeastern Brazilian coast is one most affected by global climate changes and their effects on fluvial flows, strongly maximized by damming, are already significant. A decrease was observed in the annual rainfall over the region from the

late 1960's of 5.6 mm.yr$^{-1}$, the resulting progressive decrease in basin runoff is further accelerated by the construction of 5 large size (> $10^6$ km$^3$ water storage capacity), and over 80 small to medium size reservoirs, along the Jaguaribe basin in the past 50 years.

The impacts of global climate change on Hg export to the sea from the semi-arid NE of Brazil, may find a parallel with what is presently occurring in rivers draining into the Arctic Ocean, another region of Earth extremely affected by global change. In the Arctic, increasing continental runoff and breaking of the ice cover in estuaries result in increasing export of Hg to the Arctic Ocean, leading to higher incorporation by the phytoplankton, higher deposition in shelf sediments and increasing concentrations in the Arctic biota. In the semi-arid region of Brazil, on the contrary, global climate changes decrease the freshwater contribution to the estuarine region and eventually the continental runoff to the sea, and therefore it should have resulted in decreasing Hg export to the sea. Paradoxically, however, similar to the Arctic, high Hg concentrations in fish from the northeastern continental shelf off the Jaguaribe River have also been reported, as well as Hg and organic matter concomitant increase in sediment profiles. Reducing continental runoff has, thus, resulted in augmenting the residence time of waters in the estuary and flooding of marginal plains, dominated by mangroves, and slack water conditions. During these periods larger Hg mobilization was simultaneously observed, and resulted in high export of dissolved more bioavailable Hg to the sea.

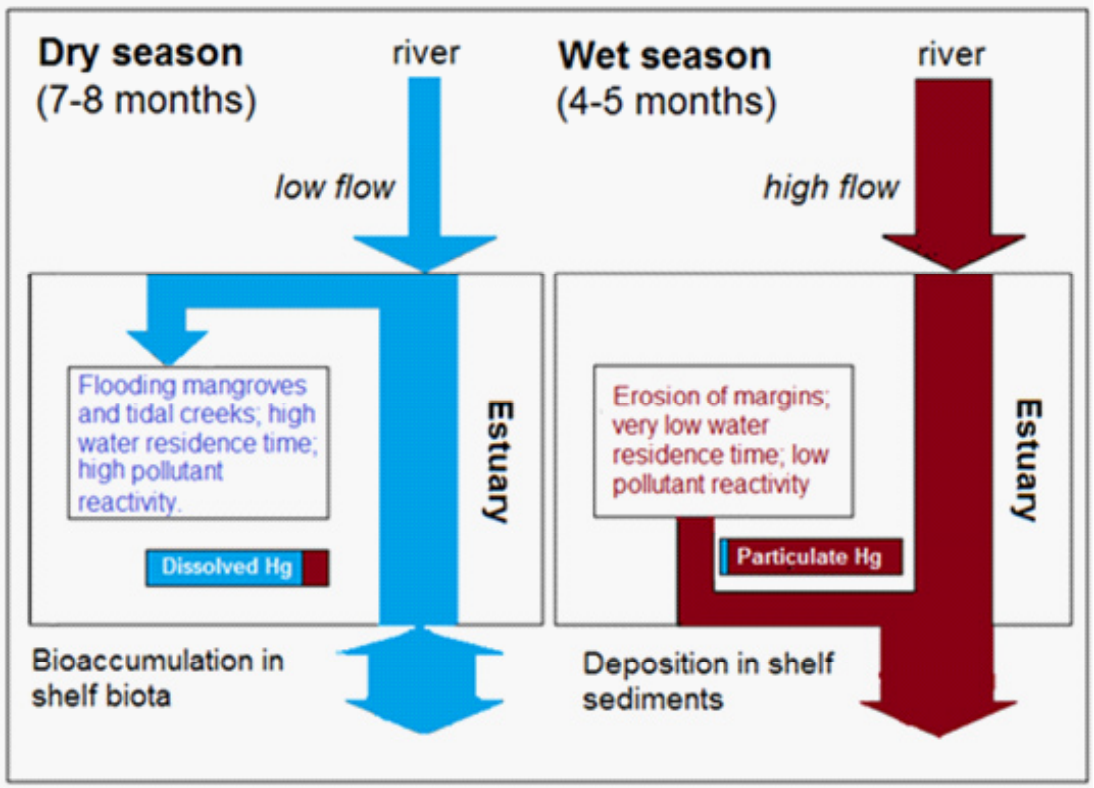


**Figure 6.** Estuarine hydrodynamics under semiarid climate and the effects on Hg export to the sea.

Although based on ongoing observations, one could expect larger Hg mobilization when water residence time in the estuary increases, and this may became more frequently as the continental runoff decreases. If this "Arctic Paradox" holds true, the scenario is probably getting worse, since global climate changes will keep reducing continental runoff in the semi-arid NE Brazil and water withdrawn for human uses will also expand. Therefore, it is possible that Hg reactivity will augment in the estuary even further and when eventually exported to the adjacent coastal sea by the rarer freshwater flux peaks. These mechanisms will increase Hg bioavailability to coastal food webs, similarly to, but paradoxically with, what is presently occurring and is also expected to worsen, in the Arctic.

## 5 - Carbon from a vanished tropical forest biome

The slash-and-burn destruction of Brazil's Atlantic forest, which once covered over 1.3 million $km^2$ and was one of the largest tropical forest biomes on Earth, is a prime example of unsustainable use of tropical forests. Two groups of the INCT-TMCOcean in cooperation with the Max Planck Research Group for Marine Geochemistry at the University of Oldenburg, estimated the amount of black carbon generated by the burning of the Atlantic forest, using historical records of land cover, satellite data and black carbon conversion ratios. It was estimate that before 1973, destruction of the Atlantic forest generated 200–500 million tons of black carbon. The amount of black carbon exported from this relict forest between 1997 and 2008, using measurements of Bezene Polycarboxilic Acid "black carbon" collected from a large river draining the region, and a continuous

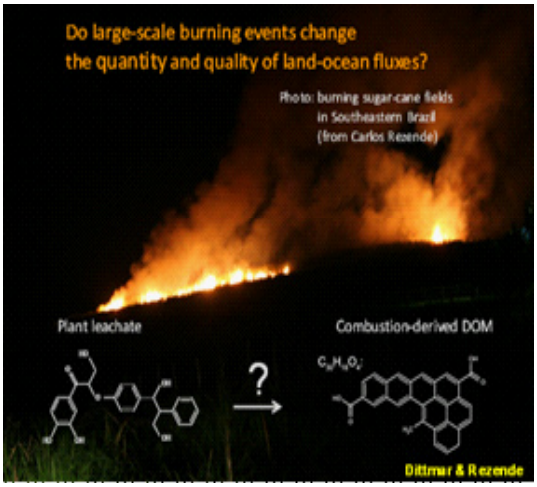


**Figure 7.** Black carbon (polycyclic aromatic fraction) production from the Paraíba do Sul River to the sea for the past 200 years. Black carbon was mainly produced by slash-and-burn clearing of the Atlantic forest. Today's production is mainly due to pasture management (80-320 $t.yr^{-1}$) and pre-harvest burning of sugarcane 110-420 $t.yr^{-1}$). The right photo was a courtesy from Gustavo Luna (ICMBio).

record of river discharge, showed that dissolved black carbon (DBC) continues to be mobilized from the watershed each year in the rainy season, despite the fact that widespread forest burning ceased in 1973. We estimate that the river exports 2,700 tons of DBC to the ocean each year. Scaling our findings up, we estimate that 50,000–70,000 tons of DBC are exported from the former forest each year. We suggest that an increase in black carbon production on land could increase the size of the refractory pool of dissolved organic carbon in the deep ocean. The disappearance of the Atlantic forest provides a worst-case scenario for tropical forests worldwide, most of which are being cleared at an increasing rate. The comparably fast mobilization of DBC from soils and its apparent recalcitrance in the deep ocean suggest that an increase of black carbon production on land may alter the size of the refractory dissolved organic matter pool in the deep ocean on the long term.

# Concluding remarks

The original research that resulted in the selected scientific highlights presented here was mostly supported by the National Research council (CNPq). However, the establishment of a research network provided the necessary framework to multiply human and financial resources; and as an output of this successful initiative of promoting scientific research, many other funding agencies in Brazil and abroad helped in maintaining the INCT-TMCOcean activities. We would like to thank in particular CAPES from the Ministry of Education and the local agencies FAPERJ, FUNCAP and FAPESP, for financing researchers form their States. PETRBRAS and EMBRAPA also participated in the research efforts of the network. The host universities and research institutions, in particular the Universidade Federal do Ceará provided most of the local facilities needed to carry on with the projects objectives. The IRD-France; the Max Planck Institute Germany, IADO-Argentina, IAEA-Monaco, IGBP-LOICZ and IMBER have been our major international partners, and we would like to thank them for this support.

All the original research described here, as well as all other INCT-TMCOcean production and activities are available in the project's website www.inct-tmcocean.com.br

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*Fortaleza, 15 June 2013*

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