

# **MONITORING THE DYNAMIC OF THE AMAZON COAST (PARÁ, BRASIL AND FRENCH GUIANA) USING A COMMON METHODOLOGY BASED ON A SPATIAL ANALYSIS COUPLED TO A SIMULATION TOOL**

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## **Abstract:**

Submissive to relatively low degree of human impacts, the Amazonian coastal region presents great ecological wealth associated to high ecosystem diversity, pointing out the needs of understanding regionally both physical and ecological processes in interactions. Particularly, the study of the coastline geomorphology changes and its consequences on the development of littoral vegetation, i. e., must be considered. Our work focuses on two regions of contrasted geomorphology located on both sides of Amazon river: 1) the Peninsula of Bragança located NE of Belém, Pará, Brasil and 2) French Guiana. A remote sensing based methodology is then explained considering the main coastal surfaces changes observed at both sites. Finally, the interest of a simulation tool taking into account geomorphologic and ecologic aspects is discussed.

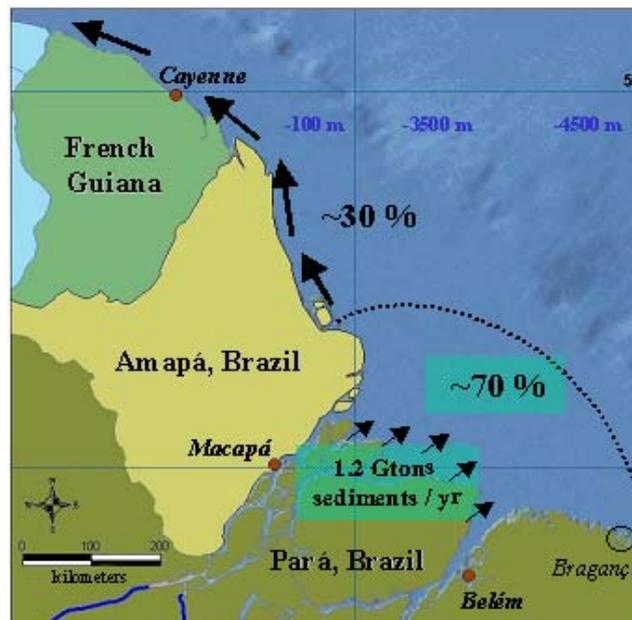
## **Introduction**

The understanding of coastal dynamics in the wet tropics has broad scientific interests as well as social and economic importance (Nittrouer, 1995). Apart the largest flow in the world of around 0.2 billions m<sup>3</sup>/s at the origin of its strong influence to climatic and oceanographic conditions upon the Atlantic ocean (Nittrouer and DeMaster, 1996; Masson and Delecluse, 2001), the Amazon river discharges is estimated in 1.2 x 10<sup>9</sup> tons per year of sediments (Meade et al., 1985) playing a leading role in both hydro-sedimentological and ecological dynamics of the 2500-km

coastline from its mouth to the Orinoco river's one (Allison et al., 1995; 2000). Submissive to relatively low degree of human impacts, the Amazonian coastal region presents great ecological wealth associated to high ecosystem diversity, pointing out the needs of understanding regionally both physical and ecological processes in interactions. Particularly, the study of the coastline geomorphology changes and its consequences on the development of littoral vegetation, i. e., must be considered. Our work focuses on two regions of contrasted geomorphology located on both sides of Amazon river: 1) the Peninsula of Bragança located in the NE of Pará, Brazil and 2) French Guiana. A remote sensing based methodology is then explained considering the main coastal surfaces changes observed at both sites. Finally, the interest of a simulation tool taking into account geomorphologic and ecologic aspects is discussed.

### Study sites on the Amazon littoral

Even if mangroves can be seen as a landscape link between Brazilian and Guianas coasts, the sedimentologic and geologic contexts of their growth are rather different.



**Figure 1:** Amazon coastal region. Main discharge of sediments occurs at the Amazon mouth. The differential part migrates as mudbanks to NW along North Amapá and French Guiana coasts.

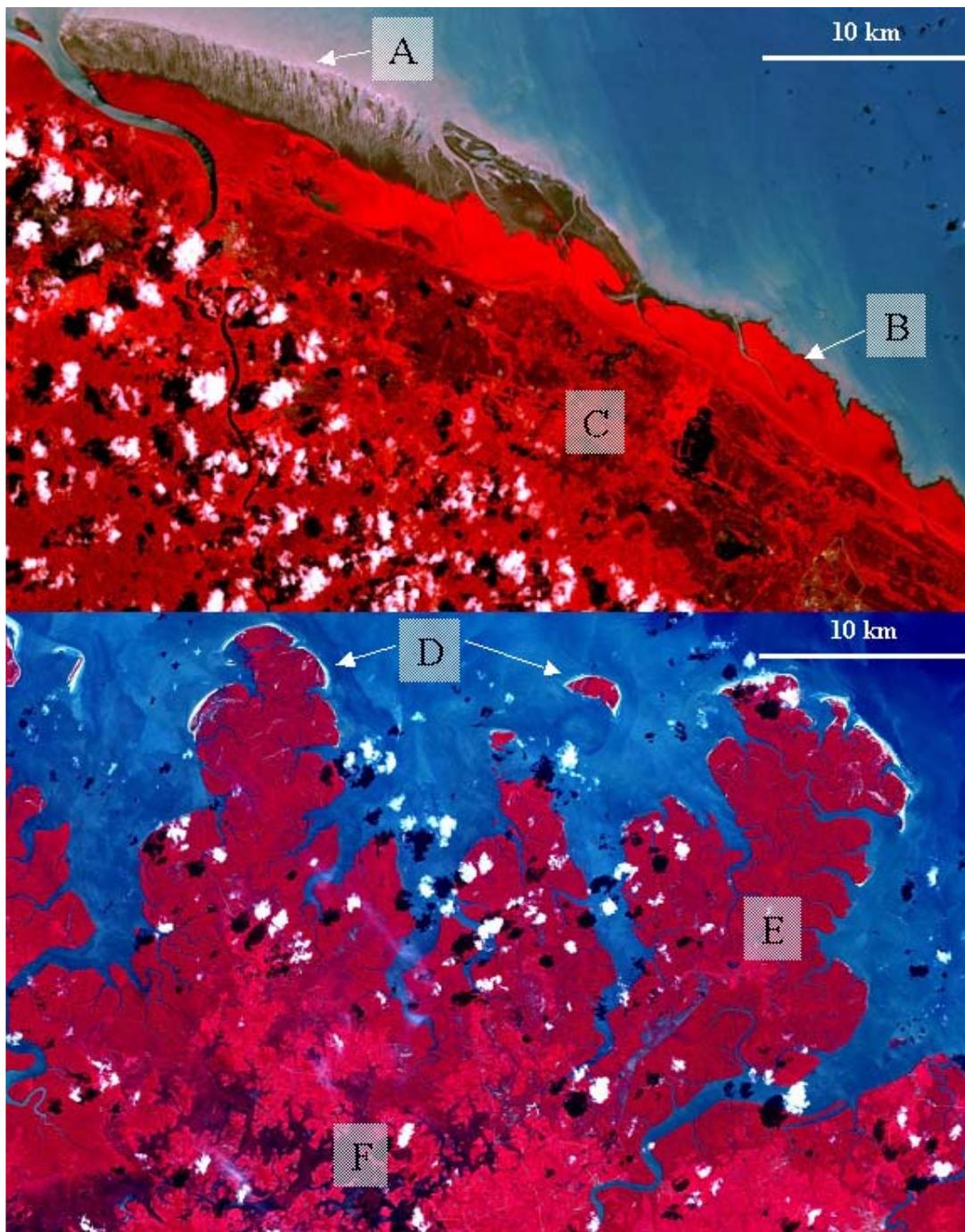
### *Coast of French Guiana*

Towards the NW, the migration of giant 10-40 km wide mudbanks generate alternate phases of intense accretion and spectacular erosion of the relative straight coastline as shown in figure 2 (Froidefond et al., 1988). The morphologic features are related to accretionary lines, such as straight lines along the river and arc lines in front of the cape. According to Allison *et al.* (2000), each accretionary line represents a stage into the evolution of the mudcapes, showing a progradational process of the muddy capes from Amapá to Guianas coasts. The guianese mangroves stretch over 350 km long with a total extent of 600 km<sup>2</sup> and only 1 to 3 km wide. They are characterized by the highest growth rates and structural dynamics, with biomass and tree height increased progressively from the seaward edge inland (from 10 t DM ha<sup>-1</sup> to 500 t DM ha<sup>-1</sup>) while tree density decreased (Fromard *et al.* 1998). Species diversity is relatively low, i.e., three main species; *Laguncularia racemosa* (Lr), *Avicennia germinans* (Ag) and *Rhizophora species* (Rssp.). According to Lugo and Snedaker (1974), the guianese littoral system consists of both fringe shoreline mangroves affected by swell causing breakage during erosion phases and basin inland mangroves where influence of the daily remains low. In our study, the French Guiana coast will be considered as a whole and its dynamics will be studied from 1950 to now.

### *Coast of Pará*

At the other side of the Amazon mouth, in the Brazilian state of Pará, the coastline presents an extremely jagged and irregular morphology consisting of numerous estuaries as shown in figure 2 (Souza Filho and El-Robrini, 1996; Souza Filho and Paradella, 2002; Kjerfve et al., 2002). Here, the mangroves grow over 8.900 km<sup>2</sup> to a distance greater than 30 kilometers from the shoreline, consisting of the one of the largest area of mangroves worldwide. These mangroves are characterized by well-developed forests with tree height reaching 20 m and more. According to Lugo and Snedaker (1974), the system can be described as a riverine/fringe mangroves where occur strong bidirectional flux of tide. The mangrove species diversity is relatively low too, e.g., three main species are *Rhizophora mangle*; *Avicennia germinans* and *Laguncularia* (Matni et al. 2002). This vegetation cover has been affected by anthropogenic activities, such as roads and human settlements. Mangrove forest is found on the tidal flat, grasses occur along the marshes and arbustive vegetation

occupies the chenier sand ridges, dunes and backshore zone of the barrier-beach ridges (Souza Filho and El-Robrini 1996).



**Figure 2:** Comparison of the coast geomorphology of French Guiana (top image, 2 sep-99) and Pará (bottom image, 7 jun-00). Images are plotted at the same scale. A: mudbank, accretion area, B: adult mangrove, erosion area, C: savanna area, D: sand beach, E: adult mangrove, F: savanna area.

Topographically, the study site is a low relief terrain. The tidal flat, including a mangrove system, is characterized by local slopes varying around 1:3000 (0.033%) with topographic breaks dissected by creeks. Salt marshes constitute the highest areas of the coastal plain with a topographic relief reaching 3 m above the mean tidal level, while intertidal mangroves are related to relief variations from 2 to 2.6 m. Supratidal mangroves are associated with altitude variations from 2.6 to 2.8 m above the mean tidal level. Consequently, according to Cohen et al., (2001), salt marshes are inundated only 28 days/year, while mangroves remained flooded from 51 days/year (supratidal mangrove) to 233 days/year (intertidal mangrove).

## Data

### *Ground data*

In French Guiana, measurements on mangrove forests and observations of the sedimentological context are continuously performed since 1993. Detailed description of the ground data collection on mangroves is given in Fromard et al. (1998) and Mougin et al., (1999).

In Bragança, Pará, measurements of mangrove forest, sedimentology, inundation frequency and shoreline changes has been collected since 1998 (Matni et al. 2002, Cohen et al., 2001; Souza Filho and El-Robrini, 2000; Souza Filho and Paradella, 2002).

### *Remote sensing data*

For both sites, a large number of satellite and airborne images is collected. Special effort is conducted to acquire same types of data, e.g. SPOT data, on both sites (Fig. 2). Current work is devoted to the georeferencing of SPOT, Landsat and IGN photographs time series and integration into a GIS database.

Data	Observed regions		Spatial resolution (m)
	French Guiana	Bragança, Pará	
SPOT	1986, 1988-1989, 1991- 2002	1986, 2000	20
LANDSAT	1987, 1988, 1992	1985, 1988, 1990, 1990, 1996	30
RADARSAT	F1 Mode 2001	F1 Mode 1998	10, 10
IGN Photographs	1950*, 1981, 2001		2*,1

**Table 1:** Main remote sensing data used to monitor changes in coastal surface types.

### *Spatial, time and spectral resolution scales*

When classical satellite data (SPOT, LANDSAT) are used, pixel spatial resolution scale ranges from 10 to 30 meters. This resolution doesn't allow small specific areas of less than 2 ha to be distinguished from surrounded large areas. Other limit concerns the poor level of discrimination of mangrove stages. Indeed, only pioneer stages can be distinguished from all the others using these data

Metric data like aerial photographs or Ikonos satellite images appear useful to improve performance of the visual classification. However, at this time, the monitoring of coastal changes remains of very high cost using high spatial resolution data.

Radar data have demonstrated their capability to provide accurate classification of the main surface types of a littoral region (Proisy et al., 1996; Souza Filho and Paradella, 2002). Besides, multifrequency or low frequency radar data can be used to produce quantitative maps of the main mangrove parameters (Mougin et al., 1999; Proisy et al., 2000; 2002).

### **Cartography of littoral surfaces changes**

#### *Methodology and surface types considered*

Our methodology takes benefits from the demonstrated capabilities of the remote sensing data listed above for discriminating the main coastal ecosystems and surface types. The originality of this work lies in the systematic multi-temporal analysis of data mosaics, i.e., covering a whole region and/or several sites of diversified characteristics

Based on good field knowledge, a simple visual interpretation of these remote sensing images is performed to produce numeric delineation of the main ecosystems and areas types encountered in French Guiana and in Pará regions at any observation dates. We consider water areas, mud and sand surfaces, coastal vegetation types (table 2).

The mangrove class can be also divided into sub-classes describing the development stages of the forest, e.g., pioneer, young, adult, mixed, decaying using high resolution data and low frequency radar data (Proisy et al., 1996). Broken mangroves correspond to adult mangrove trees that swell pulls down during erosion phases.

Coastal surface types	Mangrove types
Ocean, Estuaries, River	Pioneer mangrove
Mud and sandbank	Young mangrove
Sand dune, sand beach	Adult mangrove
Mangrove	Mixed mangrove
Swamp forest	Decaying mangrove
Marsh, savanna	Broken mangrove
Others (cities, roads, clouds, etc.)	

**Table 2:** Coastal surfaces and mangrove types considered.

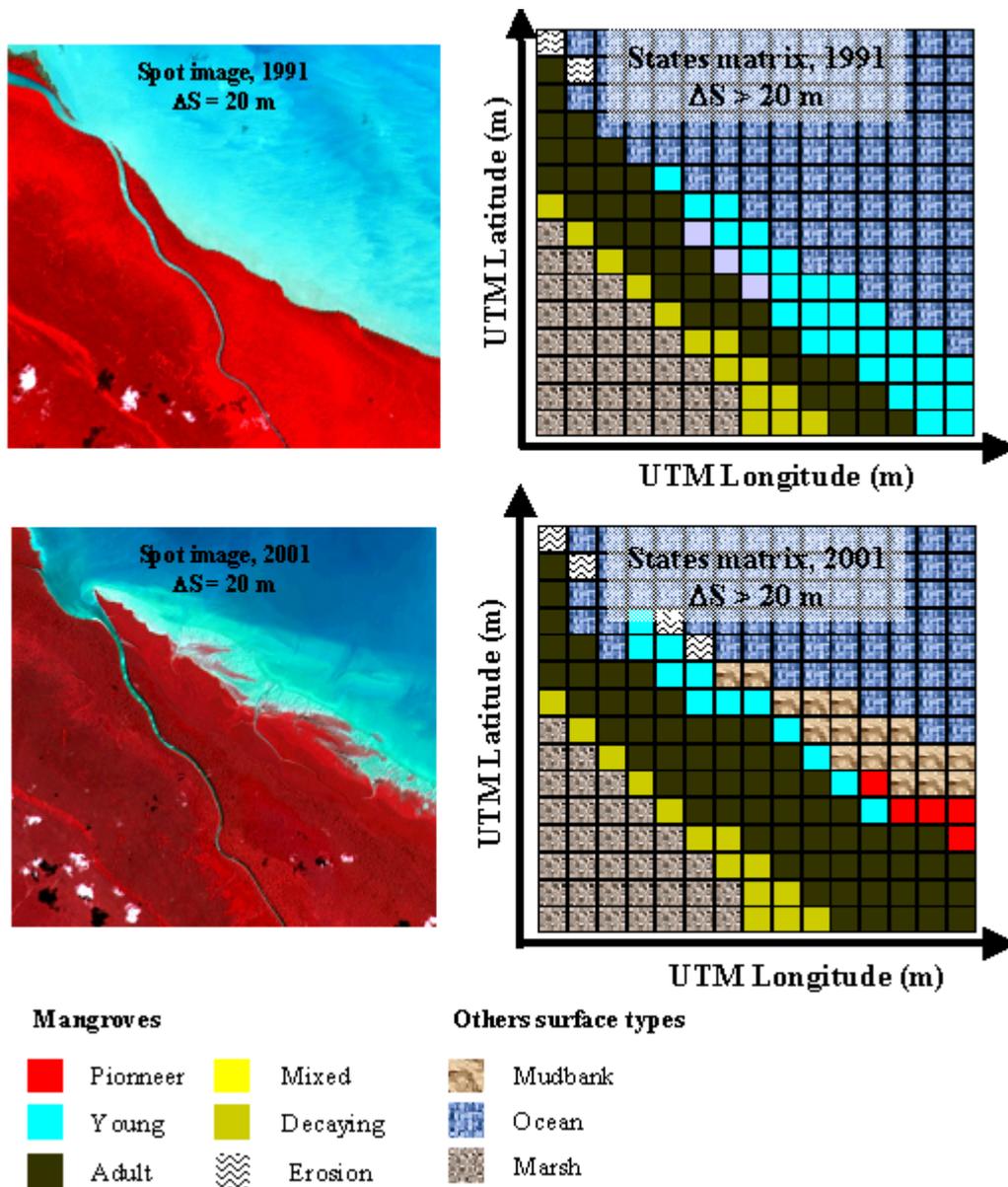


Figure 3: Left side: 10-years shift Spot observations. Right side: Corresponding states matrices at a lower spatial resolution.

## **Towards a modeling approach piloted by remote sensing observations**

### *CAPSIS approach*

To our knowledge, no model describing coastal geomorphology and ecosystems changes still exists. This lack reveals the difficulty of collecting information extensively and continuously. Our effort tends to fill the gap between specific works locally dependant and global understanding of regional processes by proposing a basis of helpful documents showing the dynamics of the littoral in terms of geomorphology and ecology characteristics changes.

Within this context, a spatial model driven and validated by remote sensing observations and aiming to simulate the dynamics of Amazonian littoral is currently developing in collaboration with the Research Unity, named "AMAP" (Botanic and Bioinformatic of Plant Architecture; <http://amap.cirad.fr>). The objectives are twofold: 1) to study the coastal geomorphology changes 2) to simulate growth trajectories of mangroves stands after detection of mudbanks colonization by mangrove.

This two modules will be connected within a global model to be integrated into the CAPSIS plat-form where several forest dynamics have been already implanted (de Coligny et al., 2002). The computing language Java used in CAPSIS programs allows each simulation scenario to be described using interconnected objects which can be easily improved or shared.

### *Cells matrix representation and computing tools*

According to the nomenclature given previously for both sites, cells matrices are constructed for any observation date. Each cell has geographic properties, i.e., latitude, longitude expressed in Universal Transverse Mercator projection (meters) and one temporal property corresponding to the observation date. In addition, the cell dimension depends only of the spatial resolution of the image. There is no limitation by the model. A visualization interface of images and matrices is currently implemented. In addition, computing tools associated to figures plotting results must be adapted from numerous tools already operational on CAPSIS. They must calculate and present clearly surface areas evolution, migration phases, changes occurring in one fixed littoral point.

### Coastal changes to be analyzed

With these analyzing tools, we aim to study, particularly, 3 evolution types in geomorphology, including, accretion, consolidation and erosion and as well 2 ecological processes: colonization and growth (table 3).

<b>Evolution type</b>	<b>Starting state</b>	<b>Final state</b>	<b>Java programs</b> (after the input of a new states matrix)	<b>Processes to be described and monitored</b>
<b>Accretion (mud / sand)</b>	Ocean	Mudbank / <i>Sandbank</i>	Temporal interpolation (1 pixel) Spatial interpolation (n pixels)	Wind, currents. Surface area, direction and speed of migration of mudbanks
<b>Consolidation</b>	Mudbank	Consolidated mudbank / <i>Sandbank</i>	Temporal interpolation (1 pixel) Spatial interpolation (n pixels)	Oxydation process related to exondation time
<b>Colonization</b>	Consolidated mudbank <i>Sandbank</i>	Mangrove	Start of the growth model of mangrove trees	Seed dispersal, Germination time
<b>Erosion</b>	Mangrove	Ocean / <i>Sand dune</i>	Temporal interpolation (1 pixel) Spatial interpolation (n pixels)	Direction and speed of annual erosion
<b>Transformation</b>	Mangrove	Other type of vegetation	Temporal interpolation (1 pixel) Spatial interpolation (n pixels)	Not studied

**Table 3:** Available changes for each cell of states matrix, description of the process and parameters for which evolution must be described into one specific module. In italic are noted evolution types occurring on Pará coasts.

Coastal changes will be studied using interpolation computed programs versus temporal and spatial axes. When colonization by mangroves will be detected on images or calculated by the model, the cell state will change from “consolidated mudbank” to “mangrove” state. The module 2 “mangrove” will be then launched to simulate growth trajectories of mangrove stands. Further details on this module are given in Gardel et al., (2002).

### Conclusion

The Amazonian coastal dynamics must be considered at any observation scales using common tools helping, particularly, geomorphologic and ecologic processes to be better understood. Use of temporal series of remote sensing images can provide objective maps providing an analysis basis for specific studies (Gowda et al., 1995; Kushwaha et al., 2000; Cracknell, 1999). Benefits increase when the derived spatio-

temporal observations piloted a simulation tool dedicating to the study of both geomorphologic and ecologic processes. Efforts are devoted to the development of automatic procedures for 1) coastal wet tropical ecosystems classification and 2) quantitative maps of mangrove structural parameters (Singhroy, 1996; Proisy et al., 2002). To achieve this latter objective, the capabilities of both high resolution optical data and multifrequency radar data must be investigated in preparation of operational uses of the future ALOS/NASDA satellite combining both stereoscopic high resolution optical sensor and low frequency radar system.

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