REMOTE SENSING AND COASTAL ECOSYSTEM MONITORING IN FRENCH GUIANA: RESEARCH AND ACHIEVEMENTS OVER A DECADE

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ABSTRACT:

The coastal ecosystems of French Guiana are very complex and changing due to the presence of huge quantities of mud originating from the Amazon. have been studied for more than a decade. Due to access difficulties through both land and sea, the use of remote sensing has always been essential, and the understanding of the complex landscapes was greatly improved when airborne and spaceborne imaging sensors began to be systematically used. However, the implementation of remote sensing techniques has to face specific difficulties due the typical geographical characteristics of humid tropical landscapes (cloud cover, complexity, rapid changes) and to the lack of infrastruture. In this paper the geographical and scientific context of French Guiana are presented with emphasis on coastal environment, and the result of research efforts over a decade are summarized. Two important aspects are considered, namely, remote sensing data acquisition and coastal landscape characterization in the humid tropics.

1. INTRODUCTION

The Amazonian coast ranges over almost 2000 km from the Amazon mouth (Northern Brasil) to the Orinoco delta (Venezuela), through French Guiana, Suriname and Guyana. The muddy sediments originating from the Amazon are transported along the shoreline by oceanic currents, generating a highly instable coastal environment. In spite of the need for a better understanding of these phenomena, the Amazonian coast has never been very attractive for science as compared with inner Amazonia. This has considerably limited the study and monitoring of coastal ecosystems in French Guiana. However, the use of remote sensing in the last two decades has contributed to the knowledge of these areas in spite of there severe access difficulties. The permanent evolution of this environment is a concern for decision makers, since the population and the economic activity of this region are concentrated along the coast. Sea defense operations and coastal infrastructure management (polders, harbours), as well as ecosystem preservation programs, require a better understanding and a regular monitoring of the coast line evolution. A state-of-art review of the knowledge and methods at the end of the 80s has been presented by Prost (1989). During the nineties, an increased scientific cooperation with neighboring countries, in particular Brazil, and the creation of a remote sening research group, created conditions for a real improvement of coastal research in this region. This paper briefly presents the research performed in the field of coastal environment and stresses the role of remote sensing. The geographical context of the area is firts presented. The organization of research is described and the results achieved over a decade are reviewed. The difficulties inherent to the humid tropics are considered for the two main aspects of this research, namely, access to remote sensing data and coastal landscape characterization. As concluding remarks, some suggestion are given for further achievements.

2. GEOGRAPHICAL CONTEXT

French Guiana is a small Amazonian territory located on the North coast of South America, between Suriname and the Amapa Brazilian state. Its area is about 84,000 km2 and its population is less than 200,000 people, concentrated along the coast. The largest part of the territory is covered by dense rain forest. The coastal plain is bordered by huge mud banks on which mangrove periodically grows and dies. This is due to the influence of the Amazon river, first in the world in terms of freshwater and sediment volumes brought to the ocean. The sediments are transported by coastal currents along the Brazilian coast on the left bank of the Amazon estuary, generating highly turbid coastal waters (figure 1). Beyond the Oyapock estuary which is the border with French Guiana, the sediments are organized in huge mud banks (20-30 km) that migrate westwards with an average velocity of 1 to 2 km per year. These banks cause difficulties for navigation, especially in estuaries where silting limits the access to harbours and requires permanent dragging which is very costly. Under favourable oceanic and climatic conditions the mud banks become stable and the mangrove growth is very rapid. Figure 2 shows the arrival and stabilization of a mud bank at the entrance of the Kourou estuary as seen by SPOT in 1996 and 2001.

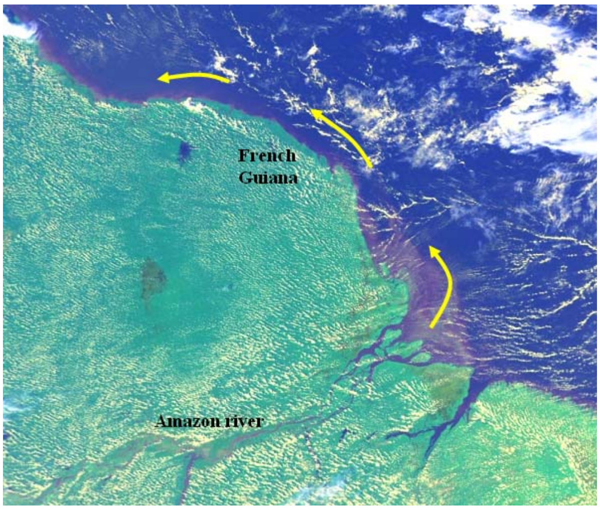

Figure 1. Amazonian sediment migration along the coast of the Guianas (background : NOAA-AVHRR, source IRD).

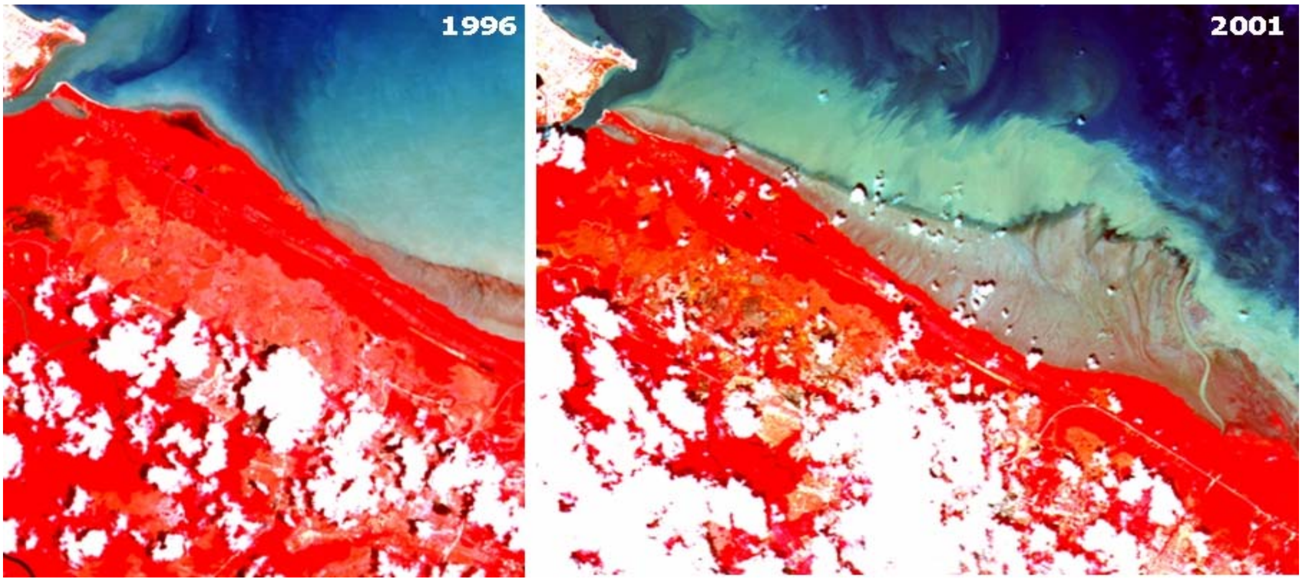

Figure 2. Displacement of a mud bank near Kourou over 5 years (SPOT images, ©CNES 1996, 2001)

The unstable coastal floodplain is unsuitable for infrastructure implementation. However, most human settlements are located along the coast, where they generally take advantage of local geological characteristics. The two major towns, Cayenne and Kourou, are built on the two unique rocky promontories. The motorway that crosses the country from border to border runs along stable geological structures such as cheniers. In the west, huge polders were established for rice cultivation between the road and the sea, but the mangrove belt that protected the polder against the sea was recently destroyed by oceanic erosion, so that it remained unprotected and was partially invaded by salt water.

In this context, coastal processes and particularly sedimentation and erosion, are major concerns for decision makers, both on the short term for risk management and on the long term for planning. Therefore, the scientific community is challenged to bring short term responses and predict evolutions to support industry and public policies.

3. SCIENTIFIC CONTEXT

Amazonia offers a great scientific interest to most fields of research, from vegetal and animal biodiversity to ethnolinguistics. However, the coastal area differs from inner Amazonia in terms of scientific attractivity. Before the XIXth century, the exploration of South America by European scientists was mainly coastal, and the maps of this period provide very rich information on coastal and estuarine areas with bathymetry and detailed description of natural landscapes and human settlements, while the interior still contains erroneous or even fantastic information such as Parimae lake and a variety of mythic creatures. After the Age of Enlightenment, a new generation of explorers such as Alexander von Humboldt had a more rational approach and the scientific attractivity of the coast seems to have moved towards the interior. This is still the general trend nowadays, and the lack of prestige of the coast for research is worsened by severe operational constraints such as field access difficulties, which are much worse in mangrove than in Amazonian rain forest. This had a decisive influence on the use of remote sensing methods. Indeed, scientists who had to face these difficulties have developed a tradition of photointerpretation over several decades. Aerial photographs acquired for official topographic mapping were used for soil mapping, hydrology, geomorphology and ecological research in coastal wetlands. This contributed to promote a multidisciplinary approach in this complex and changing environment.

In the last two decades, most economic activities undertaken along the coast (fishery, agriculture, quarries as well as the Kourou space center) were jeopardized by rapid and unexpected variations of the environment, and stimulated research programs in which remote sensing was often essential. This research involved both local teams (mainly from ORSTOM – the former name of IRD), and French scientists who organized field trips with local support, to study sedimentary dynamics (Froidefond et al. 1988), mangrove ecology (Fromard et al. 1998), hydrology of coastal wetlands (Lointier 1996) and other topics likely to improve the understanding of coastal ecosystems. Similar studies were performed in neighboring countries, namely, Suriname (Augustinus 1989) and Amapá, Brazil (Silveira 1998) to understand the evolution os the coastline at different time scales.

On the basis of existing skill in photo interpretation a remote sensing laboratory was established in ORSTOM in the early 90s with the aim of providing remote sensing capability for both science and local development, particularly for coastal ecosystem monitoring. At the same time, the Brazilian geomorphologist Maria Thereza Prost created the ECOLAB network in which scientists from French Guiana, Suriname and Brazil could work together in the field of Amazonian coastal ecology and meet in periodical workshops that are still organized with a two year period. A regional map of Amazonian coastal ecosystems was produced in the frame of this network. This map covered the coast of Suriname, French Guiana and the two Brazilian states of Amapá and Pará (figure 3).

Until the end of the 90s this research remained very close to the economic world and it was mostly stimulated by development concerns. It was also limited by the lack of remote sensing data and important efforts were dedicated to the acquisition of images from airborne and spaceborne systems as exposed below.

By 1999-2000 the coast of French Guiana was selected as a study area within the PNEC (Programme National d'Environnement Côtier) to observe the behaviour of Amazonian sediments transported along the coast and understand their impact on local ecosystems at different time scales. Remote sensing was involved in most aspects of this research : coastline evolution, mud bank monitoring, mangrove structure and dynamics, water colour as a sedimentation indicator etc. These studies took advantage of an increasing quantity of images acquired. For instance, Gratiot et al. (2005) demonstrated the potential of high revisit frequency to derive intertidal bathymetry of a mud bank from a series of SPOT images aquired at different tide levels over a few weeks.

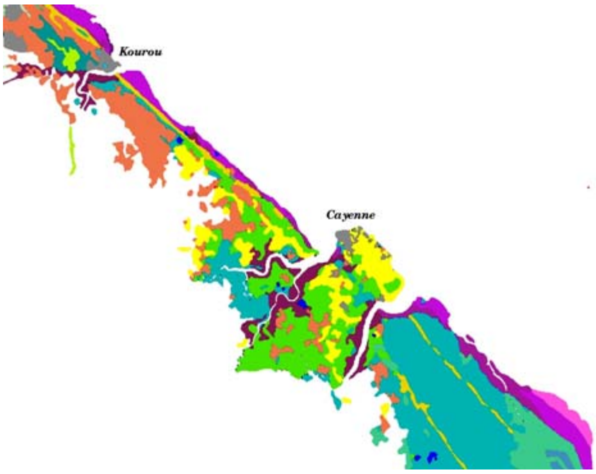

Figure 3. A regional map of coastal ecosystems : detail over French Guiana

In parallel, the remote sensing laboratory already mentioned undertook more fundamental research on remote sensing methods, taking into account local requirements but without an aim of immediate response. Three PhD theses followed this approach in the frame of three relevant tropical application fields: urban growth monitoring (Gardel 2000), deforestation monitoring (Tsayem 2002) and dengue epidemiology (Tran 2004).

A recent evolution that is worth noting here is the integration of societal sciences in environmental research. This is a worldwide tendency, and it was confirmed by the local group who successfully applied remote sensing techniques for urban demography (Faure et al 2004) and dengue epidemiology (Tran et al. 2002).

4. ACCESS TO REMOTE SENSING DATA

One of the main challenges of environmental research in the humid tropics has always been the access to up-to-date information. This has long been the case in French Guiana, where important efforts were dedicated to improving the access to airborne and spaceborne remote sensing images.

Local companies provide remote sensing data for a non-scientific market, e.g. aerial photography and laser altimetry. Some research projects made use of those data when needed.

Geometric accuracy is not always needed and the immediate availability of data may be preferred in some cases. This led to the implementation of cheap solutions with weak quality requirements but allowing an autonomous access to the information for the research teams. In 1997, surveys were performed with an airborne video camera in agricultural areas is response to urgent needs for cadastral data updating, although with poor geometric accuracy. The same method was used in coastal areas for monitoring the beaches of Cayenne (Anthony et al. 2002) and natural ecosystems in northern Brazil (Timouk et al. 2001).

As far as satellite remote sensing is concerned, most observation systems have a lower coverage density in tropical areas. Figure 4 shows the distribution of SPOT-5 imagery after 2 years, for a cloud cover lower than 10%. The lack of data observed in tropical areas is due to the lower density of receiving stations, to the lower rate of requests and to the important cloud cover in the humid tropics.
An L-band receiving station was implemented in Cayenne to receive NOAA-AVHRR images, and more recently SeaWiFS. In 2005 an X-band receiving station was also implemented to receive data from SPOT and ENVISAT-ASAR. Both stations cover the north of south-America and the caribbean region.

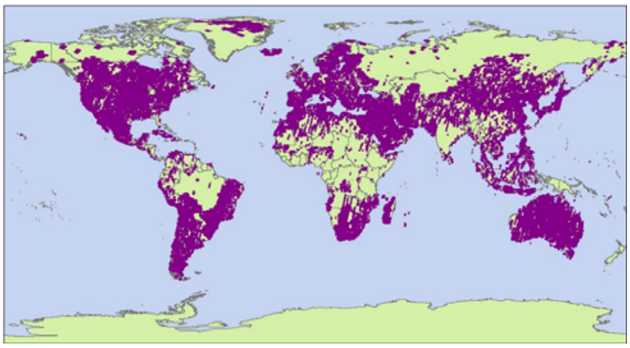

Figure 4. Worldwide coverage of SPOT-5 images after 2 years.

5. COASTAL LANDSCAPE CHARACTERIZATION IN THE HUMID TROPICS

An important aspect of remote sensing research in complex and changing environments consists in studying the behaviour of different sensors, with different scales and wavelengths, over these ecosystems.

In parallel with experimentations involving images from spaceborne optical scanners (Landsat TM or SPOT HRV) in response to short term environmental concerns, several research projects were undertaken to deal with less classical sensors . Beyond the need for better understanding of tropical environmental processes, this approach has a technological interest as it contributes to assessing the potential and the limitations of a new sensor in a more complete way. Besides, this a often a request from space agencies. Several studies were carried out with radar images, including over wetland and mangrove ecosystems in the frame of the SAREX experiment (Mougin et al. 1994, Prost et al. 1994), and a multidisciplinary study was performed in an ESA pilot project based on a ERS-1 mosaic of French Guiana (Rudant 1994), with emphasis on the characterization of coastal ecosystems (Lointier et al. 1994). The same approach was followed to test airborne sensors in a tropical context, e.g. hyperspectral images from the CASI sensor, and laser altimeter data. In both cases data were acquired over natural and agricultural landscape around Cayenne to allow accuracy budgets and an analysis of the response of these sensor in the very peculiar ecosystems of the Amazonian coast. Very wide field images were analysed with the same approach (Eva 2002), i.e. with the aim of establishing landscape signatures for low resolution image sampling.

On the basis of theoretical knowledge and local experiments, several state-of-art reviews could be produced to clarify the actual potential of remote sensing methods for specific environmental studies, either to characterize specific ecosystems such as Amazonian rainforest (Polidori et al. 2003) of coastal wetlands (Tran et al. 2000), or to answer environmental questions in the frame of societal or economical issues, such as mercurial pollution in gold extraction areas (Polidori et al 2001).

One of the main challenges of tropical environment research is to adapt classical remote sensing techniques to the peculiarities of the humid tropics (Polidori & Proisy 2003). Indeed, most techniques are designed (or are more efficient) for landscapes that are structured with regions, each region having a homogeneous content and discontinuous borders. Such a structure allows the description of each land parcel as an object with topological properties and a limited amount of parameters. However, most lanscapes of the humid tropics do not fit this model, and even the coastline can hardly be considered as a line in topological terms. For the same reason, the modelling approach that correlates radiometries or indices with ecological parameters (such as water sediment concentration, leaf area index or population density) are less relevant in the presence of very heterogeneous surfaces. This makes the signature concept less relevant and requires the identification of other indicators for surface characterization.

These limitations imply that interpretation methods developed elsewhere cannot be imported without care and that specific research is needed locally to make the best use of remote sensing technologies is these very peculiar environments. New approches are being discussed that could take advantage of improved data access and existing experience in French Guiana and neighboring countries (Proisy et al. 2003). The theoretical background needed to reinforce local research capabilities were discussed at regional level, they will be considered when a new Master degree is implemented in the local university (Polidori 2002).

6. CONCLUSION

Although the remote sensing team it quite small in French Guiana, a long experience in photo-interpretation and the scientific achievements of the last decade in the field of coastal ecology and remote sensing led to the implementation of a SPOT-ENVISAT receiving station and of a Master degree with a remote sensing option in order to strengthen local research capabilities. These achievements have been recognized at a regional scale in the frame of scientific networks such as ECOLAB (dedicated to Amazonian coastal ecosystems) and SELPER (Latin-American society of remote sensing experts) which received French Guiana as a new member country.

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