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BIO-OPTICAL EVIDENCE OF LAND-SEA INTERACTIONS IN THE WESTERN COAST OF PUERTO RICO

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ABSTRACT

Several years ago a joint effort between researchers from the NASA-Stennis Space Center and the University of Puerto Rico at Mayagüez intended to use remote sensing for a better understanding of the land-sea interactions of Mayagüez Bay; a semi-enclosed bay in the western coast of Puerto Rico. However, the complexity of the bay's optical properties and certain limitations of the technology at that time made it very difficult. Recently improved methods and instruments have been used in this bay, allowing a better understanding of such bio-optical variability. A new sampling design with twenty-four stations was performed. Inherent and apparent water optical properties were measured using the NASA ocean optics protocols for validation of satellite ocean color sensors. A custom-made rosette with several optical instruments helped to provide more detailed analyses of the bio-optical properties. In addition, water quality parameters were measured. Our results show that large spatial and temporal variability of the bio-optical properties in Mayagüez Bay are generated by changes in rivers discharge and anthropogenic activities. The new efforts finally show clear bio-optical evidence for land-sea interactions. It also provides an important step for better application of remote sensing in the western coast of Puerto Rico.

INTRODUCTION

The application of remote sensing in coastal environments has been very difficult because of the optical complexity of these waters (Carder et al., 1989). Seasonal river discharge and land run-off increase the concentration of phytoplankton biomass along with colored dissolved organic matter and suspended sediments. Such conditions make that conventional remote sensing techniques do not work properly. Therefore, in order to estimate the water quality parameters, like phytoplankton biomass, in coastal waters is necessary a new approach where all sources responsible for the optical variability are considered in the interpretation of the remote sensing signal.

In Puerto Rico, a large effort has been done during several years in order to better understand the bio-optical properties of Mayagüez Bay. This semi-enclosed bay in the west coast of Puerto Rico suffers spatial and temporal variations in phytoplankton pigments and suspended sediments due to seasonal discharge of local rivers (Gilbes et al., 1996). Several years ago a joint project with researchers from NASA-Stennis Space Center and the University of Puerto Rico at Mayagüez intended to use remote sensing for a better understanding of the land-sea interface in this bay (Otero et al., 1992). However, the complexity of bay's optical properties and certain limitations of the technology at that time made it very difficult. New efforts using improved methods and better instruments are accomplishing the original objectives. This paper shows the latest efforts toward a better understanding of the land-sea interactions in Mayagüez Bay.

MATERIALS AND METHODS

Field data was obtained during several cruises per year to the Mayagüez Bay since 1997. The samplings were planned considering the dry and wet seasons of the region and from inshore to offshore waters, covering the Añasco, Yagüez, and Guanajibo Rivers, and the regions affected by the dumping of a tuna factory and a sewage pipe (Figure 1). Twenty-four (24) stations were sampled with an optical package, in which 12 stations (indicated with a circle in the figure) had ancillary data.

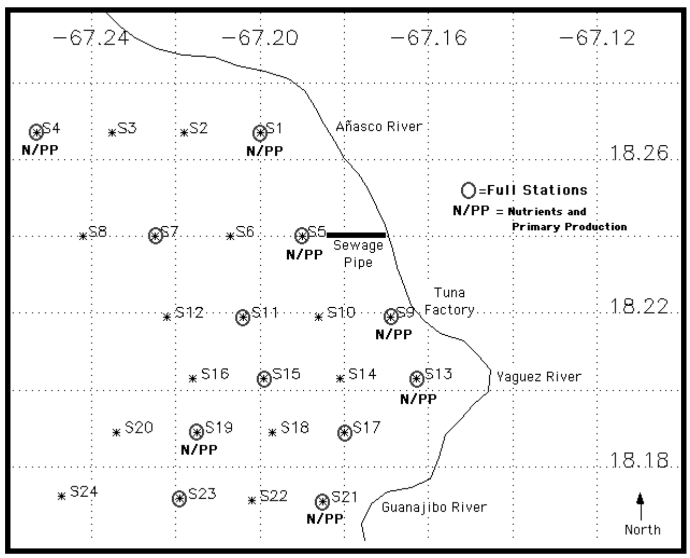

Figure 1: Sampling stations at Mayagüez Bay, Puerto Rico.

An optical rosette with several instruments was used to measure profiles of different water properties (Figure 2). A CTD (Seabird SBE-19 with pump) measured temperature and salinity. A small fluorometer (Model WetStar from Wet Labs) measured chlorophyll fluorescence. The spectral transmittance, $c(\lambda)$, and spectral adsorption, $a(\lambda)$, was measured over nine wavelengths with the AC-9 meter (from Wet Labs). The backscattering coefficient, $b_b(\lambda)$, at six wavelengths was measured with the HydroScat-6 (from Hobi Labs). Upwelling radiance, $L_u(0^-, \lambda)$, and downwelling irradiance, $E_d(0^-, \lambda)$, was obtained using a submersible radiometer (Model OCR-200 from Satlantic). Water-leaving radiance, $L_w(\lambda)$, and the above-surface downwelling irradiance, $E_d(0^+,\lambda)$, was measured using the GER 1500 portable spectroradiometer. $R_{rs}(\lambda)$ was calculated from the ratio between $L_w(\lambda)$ and $E_d(0^+, \lambda)$.

Figure 2: Bio-Optical Rosette for profiling measurements.

The optical measurements from the profilers were compared with water samples measurements collected at several depths. Concentration of phytoplankton chlorophyll-a were obtained using the standard fluorometric method (Yentsch and Menzel, 1963). Total particulate absorption spectra, $a_p(\lambda)$, for samples collected on Whatman GF/F glass-fiber filters were measured with an integrating sphere attached to a GER 1500 portable spectroradiometer using the method developed by Mitchell and Kiefer (1984) and the optical-path elongation factor β from Bricaud and Stramski (1990). Methanol-extractable pigments were removed by slowly passing hot methanol through the filter pad (Roesler et al., 1989). The absorption spectrum of this pad was measured to determine the detritus absorption coefficient, $a_d(\lambda)$. The difference between the particulate and detritus spectra, before and after the methanol extraction, was considered to be the *in vivo* phytoplankton absorption, $a_{ph}(\lambda)$. Optical absorption spectra of the colored dissolved organic matter, $a_g(\lambda)$, was determined with a Perkin Elmer double-beam spectrophotometer following the method described by Bricaud et al. (1981).

RESULTS AND DISCUSSION

Mayagüez Bay is a highly dynamic environment that shows large spatial and temporal variability of bio-optical properties. Trends in Chl-a concentrations measured in this bay during recent years are similar to those measured in the past by Gilbes et al. (1996). A clear Chl-a peak in October (Figure 3) is due to the high river discharge during the rainy season that goes from August to November. Stations 1, 13, and 21 are the closest to the rivers mouth and they show the higher concentrations of Chl-a.

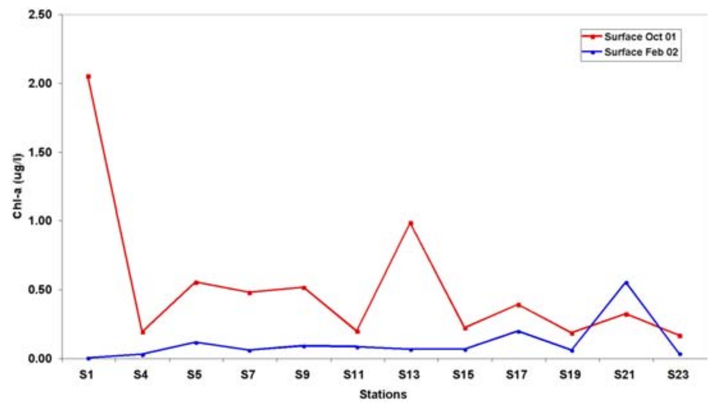

Figure 3: Chlorophyll-a concentrationsin surface waters of Mayagüez Bay.

In addition to the October peak, time series measurements collected by Rosado et al. (2002) identify another peak in April or May at some stations, which is more difficult to explain (Figure 4). The weak correlation between Chl-a and rivers discharge suggest that other factors may also play an important role in the phytoplankton dynamics during times of low river discharge. These factors may include anthropogenic activities, wind-driven organic matter resuspension and internal waves. Figure 4 shows that along the sampled year the station called Atunera maintained the higher concentration of Chl-a. This station is located in an area were a tuna factory is dumping material. The data clearly show the effect of such dumping in the bio-optical properties of the bay.

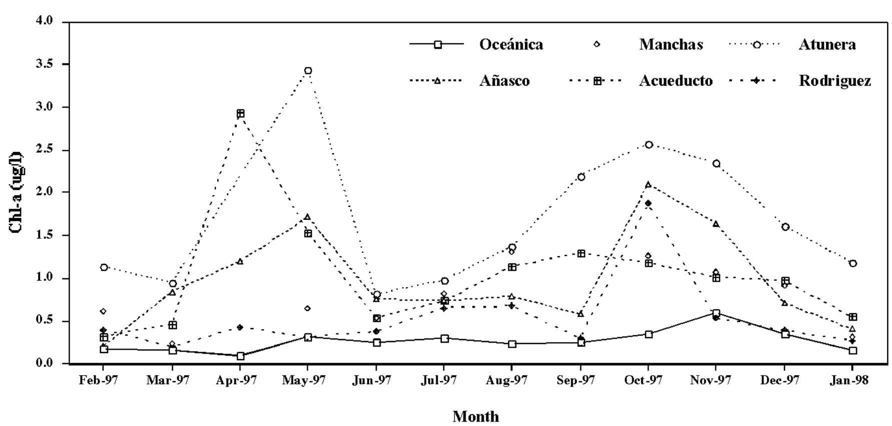

Figure 4: Time series of Chlorophyll-a concentrations at Mayagüez Bay collected by Rosado et al. (2002).

The effect of river discharge on the bio-optical properties of Mayagüez Bay is perhaps more clearly recognize with the data collected by the bio-optical rosette. For example, a contour map of Chl-a fluorescence is presented in Figure 5, showing the higher concentrations closed to the rivers.

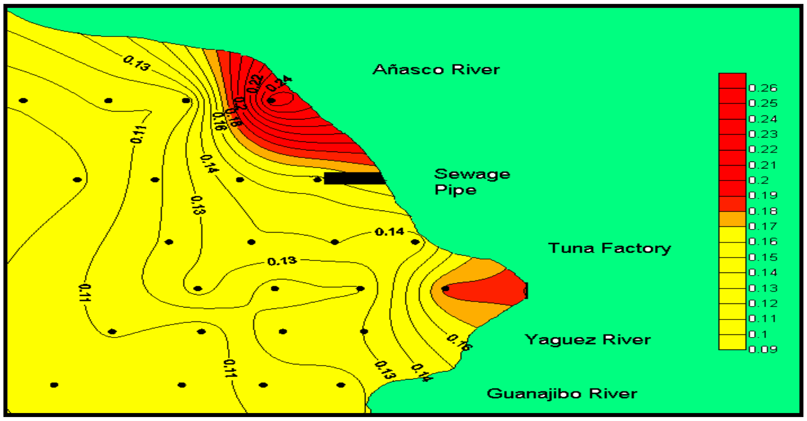

Figure 5: Chlorophyll fluorescence as measured with the bio-optical rosette during October 2001.

Profiles of bio-optical data are another evidence of the effect of river discharge (Figure 6). Lenses of low salinity and high optical properties (absorption, attenuation, and backscattering) are clearly identified on the top of the water column.

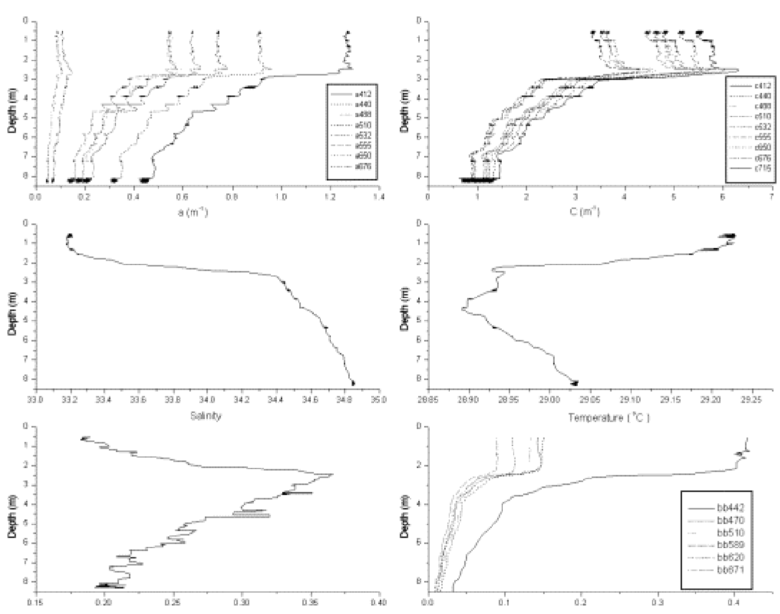

Figure 6: Profiles of water optical properties as measure in one station with the bio-optical rosette.

Changes in bio-optical properties are highly correlated with the riverine input of suspended sediments. The distribution of suspended sediments follows the seasonality and magnitude of river discharge (Figure 7). During the wet season (October) the northern stations of the bay show the higher concentrations and during the dry season (February) the southern stations have the higher concentrations. Perhaps this is another evidence for the possible effect of wind-driven and anthropogenic effects.

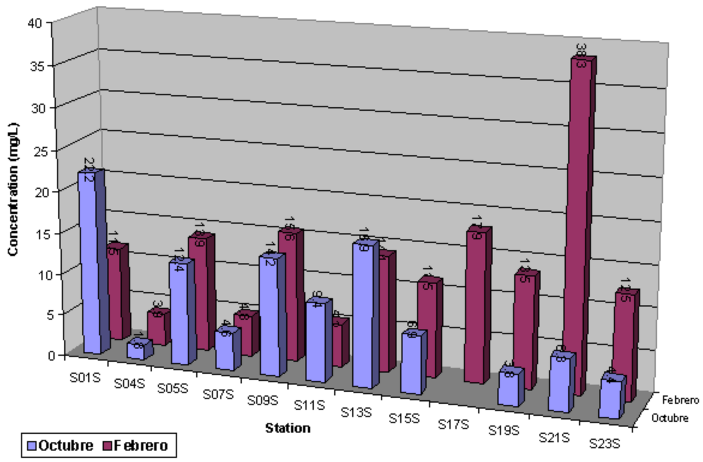

Figure 7: Suspended sediments at surface waters of Mayagüez Bay.

Nutrients concentration is another piece of evidence for the important effect of rivers discharge. Figure 8 shows how the nutrients clearly increase during the wet season, especially at those stations closed to the river mouths.

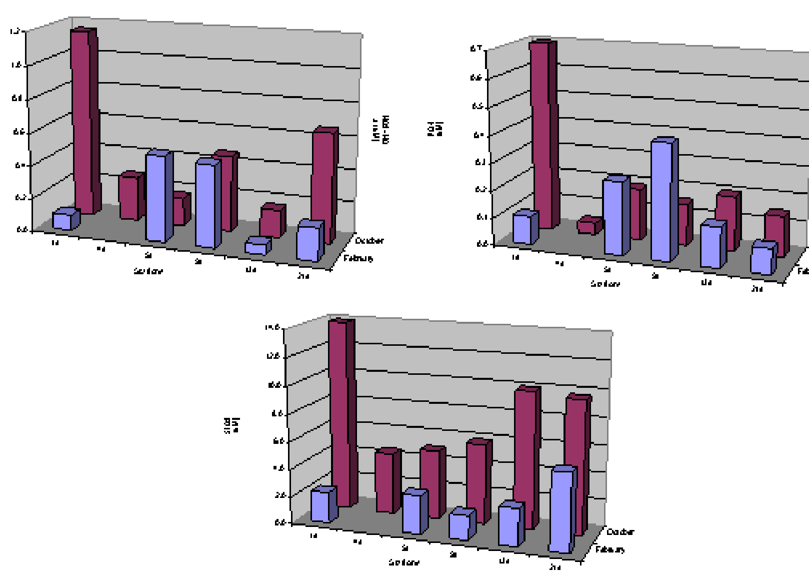

Figure 8: Nutrients concentration at surface waters of Mayagüez Bay. Top left panel shows NO_2+NO_3, top right panel shows PO_4, and bottom panel shows SiO_4.

Land-sea interactions are also shown with the absorption coefficients of particles, detritus, and phytoplankton (Figure 9). The collected data demonstrate that these optical properties are also affected by the rainy season, where October is the peak of river discharge.

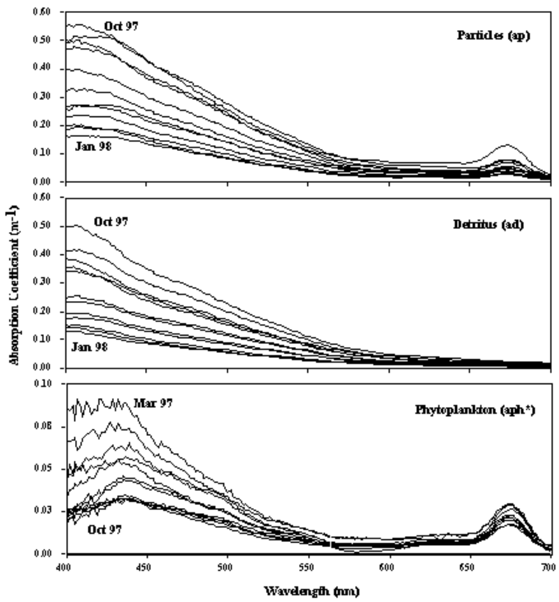

Figure 9: Absorption coefficients of particles, detritus, and phytoplankton at surface waters in an inshore station of Mayagüez Bay.

The absorption of colored dissolved organic matter (a_g) is also affected by all the processes described above. Those stations closed to the rivers, like the Añasco Station in Figure 10, show the higher absorption of CDOM.

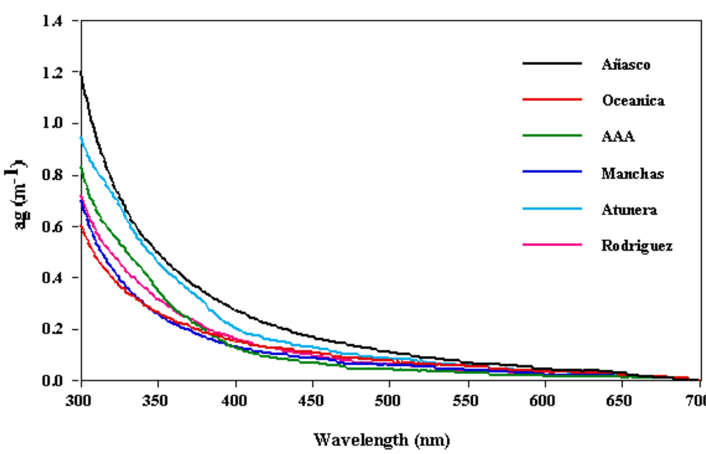

Figure 10: Absorption coefficient of colored dissolved organic matter at surface waters of selected stations in Mayagüez Bay.

As demonstrated, our preliminary analyses of Mayagüez Bay indicate that the bio-optical variability is very large, even though this is a relative small geographic area. Therefore, it must be considered in order to apply ocean color remote sensing. Measurements of remote sensing reflectance clearly show such differences, and at least three different curves have been identified in shape and magnitude (Figure 11).

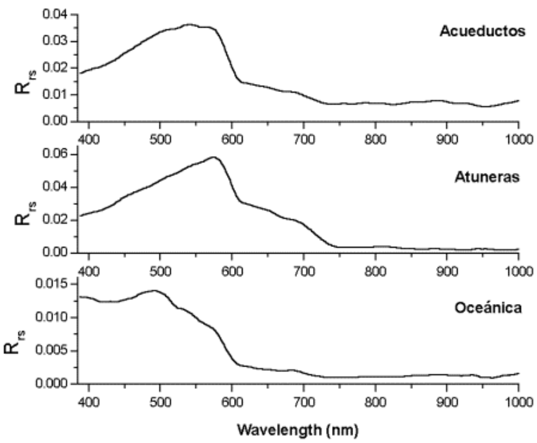

Figure 11: Examples of remote sensing reflectance (Rrs) curves found in the Mayagüez Bay.

The large variability in bio-optical properties at such small geographic region makes the use of current ocean color sensors very difficult. This is the case of SeaWiFS, where the pixels size (1 km) is too large for studying the Mayagüez Bay. However, even under such conditions the land effect on sea conditions are appreciated (Figure 12).

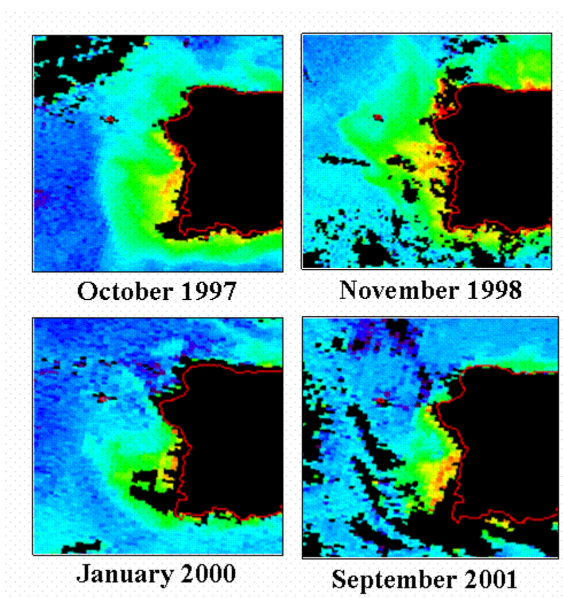

Figure 12: SeaWiFS images showing the Mayagüez Bay.

CONCLUSIONS

The rainy versus the dry seasons, and therefore the river discharge, appear to be the principal factor regulating the bio-optical properties in Mayagüez Bay, including the phytoplankton populations. Anthropogenic activities in the river basins affect the composition of the rivers input in the bay and the characteristics of the water masses entering the bay. The western basin of Puerto Rico is highly developed and deforested, which favors erosion and transference of soil particles into the river waters. These suspended particles increase scattering and absorption, effectively attenuating light, but also increase nutrient concentrations. During the dry season, resuspension of sediments and organic matter by wind and waves seems to be especially important (Alfonso, 1995, Gilbes *et al.*, 1996). Another possibility is the intrusion of internal waves into Mayagüez Bay, suspending sediments and organic matter deposited earlier within the coastal zone (Edwin Alfonso, personal communication; Bogucki and Redekopp, 1999). At smaller spatial scales, the anthropogenic effects of the tuna industry and sewage processing plants may be important. Nutrients in the vicinity of the Atuneras and Acueductos stations were high, especially organic nitrogen (Mónica Alfaro, unpublished data). Phytoplankton populations will respond to increased nutrient supply at these stations. Increased predation of zooplankton by gelatinous plankton (medusae and ctenophores) may be another mechanism accounting for larger phytoplankton biomass in these stations. Large populations of these organisms have been reported in Acueductos and Atuneras stations (Mónica Alfaro, unpublished data). This predation regulates abundance of zooplankton populations, resulting in lower grazing pressure over phytoplankton. This preliminary, but comprehensive, study of the bio-optical properties of Mayagüez Bay is establishing the basis for our next step toward a better understanding of land-sea interactions. It is clear that new and improved techniques of remote sensing are necessary for this region. But we are already working on that.

ACKNOWLEDGMENTS

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