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Spatial and temporal variability of suspended sediments and their correlation with optical measurements in the Mayagüez Bay, Puerto Rico

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Abstract

Suspended sediments are responsible for changing the water optical properties in coastal areas. Therefore, in order to apply remote sensing in these areas is necessary to understand their variability. Based on this importance this work had determined the spatial and temporal variability of suspended sediments in the Mayagüez Bay. Such variability has been correlated with the optical measurements taken with the GER 1500 and Hydroscat-6. Three bands were identified to be potentially affected by sediments, 595-615nm, 655-675 and 680-700. When the concentration of sediments was more than 15mg/L, the Rrs of those bands were proportional to the concentration (higher the concentration, more reflectance). The future goal is to develop site-specific algorithms to measure suspended sediments using remote sensing. Part of the data was collected last semester, but additional data was collected during a research cruise in February 2002.

Introduction

In this study suspended sediments are define as all suspended particulate matter retained in the GF/F filters. Samples were taken in October 2-4, 2001 and in February 26-28, 2002. The results were compared with the measurements taken by two optical instruments (HydroScat-6 and GER 1500) in order to evaluate how the remote sensing signal is affected. Both instruments were used in October, but only data from the GER 1500 was collected in February due to problems with the Hydroscat-6. Hydroscat-6 measures the backscattering coefficient at six wavelengths and the GER-1500 measures the remote sensing reflectance from 300 to 1100 nanometers. This is important because if site specific algorithms for estimation of suspended sediments can be developed we will be able to measure it from a satellite. This will reduce the cost and time of field work and will allow sampling the Bay more frequently.

Study Site

The Mayagüez Bay is located in the west coast of Puerto Rico between the latitudes of 18.16° and 18.28° (figure 1). There are three main rivers discharging into the bay: Añasco, Yagüez, and Guanajibo Rivers. The basin of Guanajibo and Añasco River are mainly for agriculture use, having the Añasco River the largest catchments. Rio Yagüez basin is mainly urbanized. The Añasco-Mayagüez area has an average annual precipitation range of 200-250 cm (Morlock et al., 1983). Rainfall fluctuates seasonally with a maximum river discharge between the months of September and November (wet season) and a minimum flow from February to April (dry season). Recorded values of discharge for the Añasco and Guanajibo rivers range from 0.88 to 3960 m^3s^{-1} and 0.13 to 3620 m^3s^{-1} respectively (US Geological Survey, 1991).

Coastal currents are the driving force in the transport and distribution of the shelf sediments and act along in concert with wave energies. The most influential components in the distribution of fine sediments in the area are wave-driven and tidal. Only waves from the northwest contribute sufficient energy to the shelf to have an effect on sediment distribution. Measured current speeds range from 2 to 38 cm/sec (Morelock 1983). The effects of rivers discharge, current patterns, and waves are responsible for the distribution of suspended sediments in Mayagüez Bay.

Materials and Methodology

Field Work

1. Sampling was performed on board of the R/V Sultana during February 2002 between Añasco Bay and Punta Guanajibo (figure 1). Twelve stations were sampled at surface and middle depth (up to 23 m depth). These include suspended sediments concentration and many other data that will not be used in this work.
2. The GER-1500 spectroradiometer was used to measure the remote sensing reflectance (Rrs), ***Rrs = Lw / Ed*** ; were Lw is the water-leaving radiance, and Ed is the downwelling irradiance entering the water.
3. The HydroScat-6 is a six wavelength in-situ backscattering sensor that is calibrated to provide measurements of b_b, the backward scattering coefficient. This instrument is part of an optical rosette that was be deployed. Only data from October was used because during the February sampling it got broken.
4. Water samples were collected at surface and at middle depth (middle depth between the surface and the seafloor of the sampling station) to measure the total suspended particles matter (or suspended sediments).

Laboratory Work

1. Analysis of samples toke place in the Bio-Optical Laboratory at the CID (Centro de Investigación y Desarrollo). Horizontal sampling bottles were used to collect the sample in duplicates. The water samples were filtered using a vacuum pump. The filtered volume was measured with a rinsed graduate cylinder, keeping track of obtaining a uniform layer of material on the filter without clogging it.

2. Water samples were put in an oven to let them dry in order to know the amount of particles that were suspended in a known volume of water.
3. The concentration of suspended sediments was obtained from the difference of the filter weight before and after filtering.
4. Statistical analyses (correlation) were made between suspended sediments and the optical measurements.

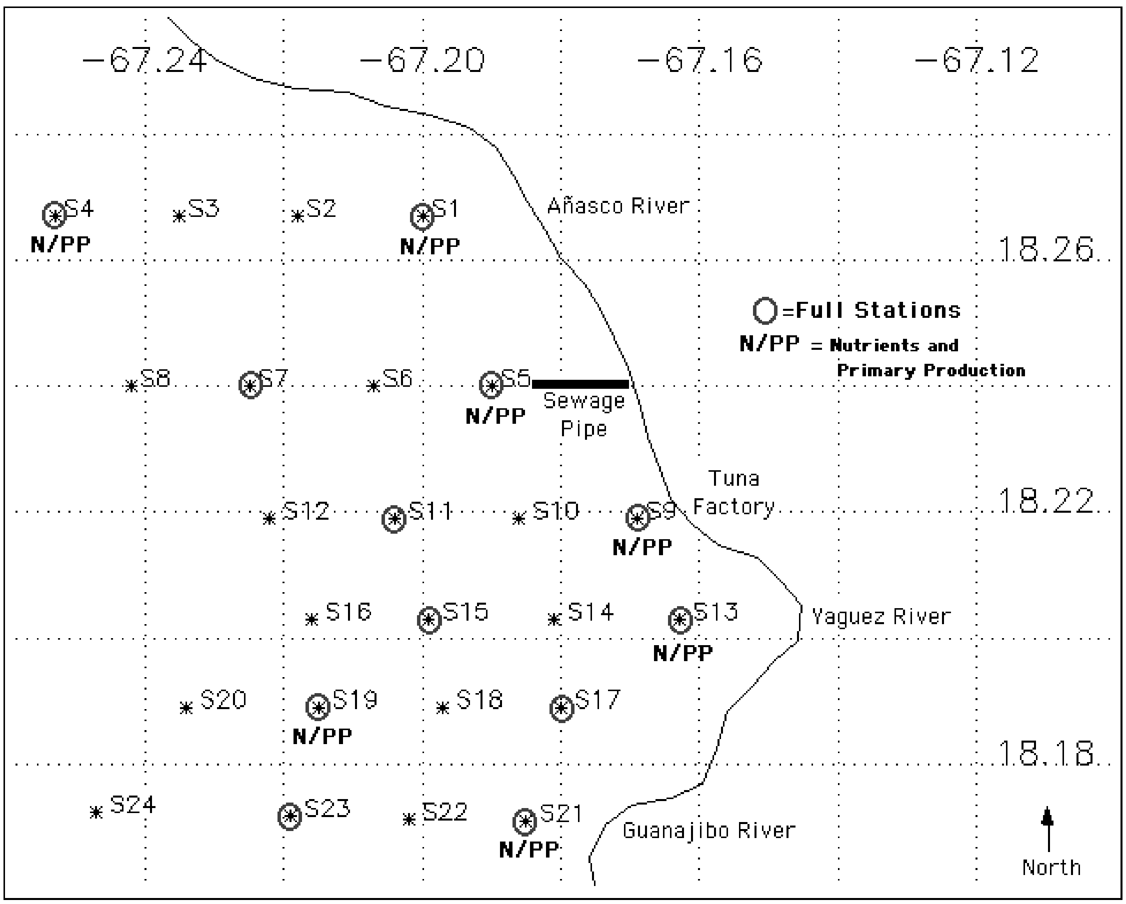


Figure 1 Mayagüez Bay area. Stations within the circle were sampled for all parameters, including suspended sediments.

Results and Discussion

Spatial and temporal variability of suspended sediments

Suspended sediments concentrations were sampled in October 2001 and February 2002 at stations S1, S4, S5, S7, S9, S11, S13, S15, S17, S19, S21 and S23 (figure1). The results are shown in figure 2 and 3. Station 17 was not considered for October because its analysis was not reliable due to a procedure error. The average value from the replicates was used for the correlation with the optical measurements. The highest sediments concentrations were found in the stations closer to the coast (Figure 2 and 3). In October, high values were found especially in Rio Grande de Añasco and Yagüez, but also near the Tuna Factory and the sewage pipe. The values of the stations close to the Tuna Factory and sewage pipe do not vary much from October to February. Añasco had the highest suspended sediment concentration in October with a value of 22.2 mg/L; while Guanajibo had the highest concentration in February with 38.3 mg/L.

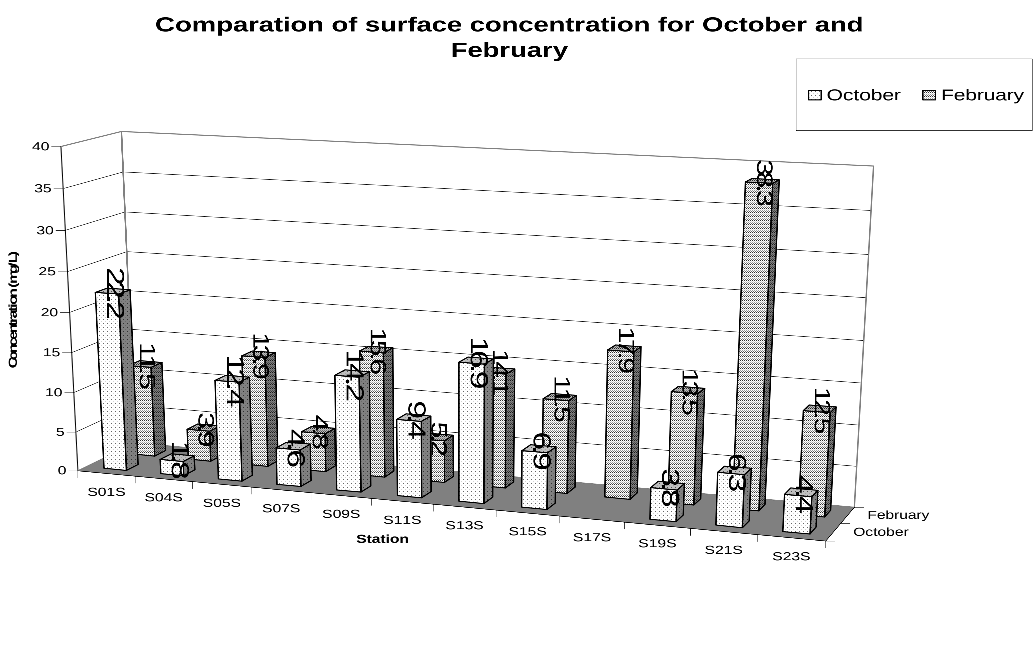


Figure 2

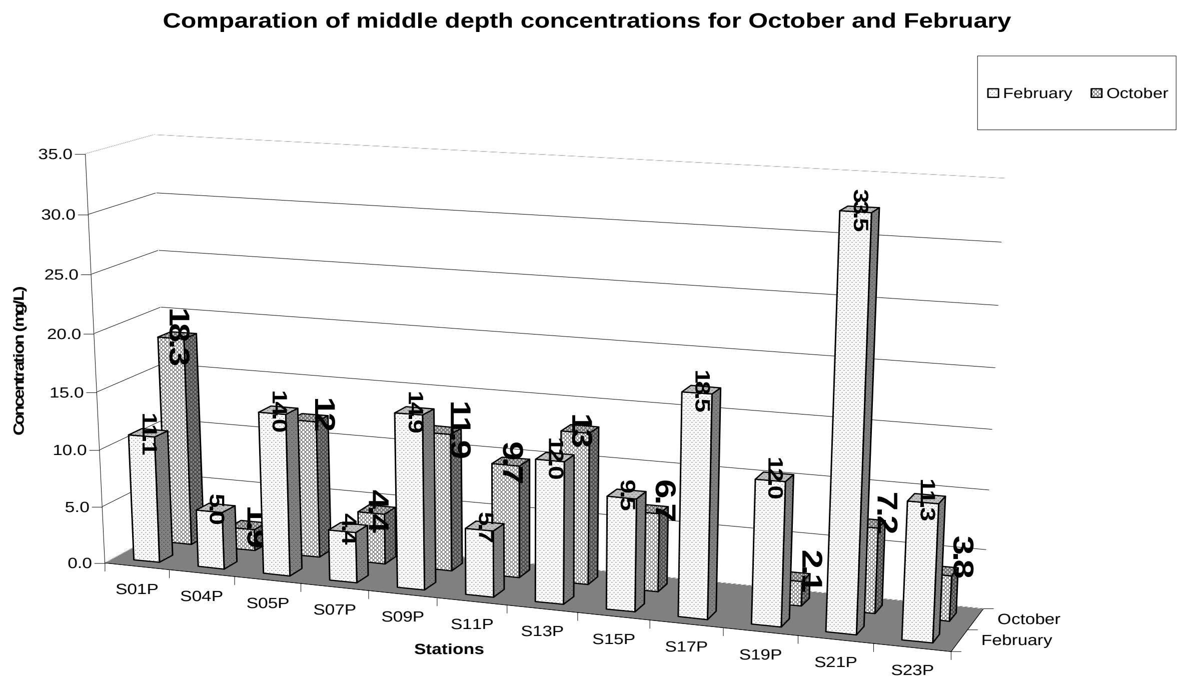


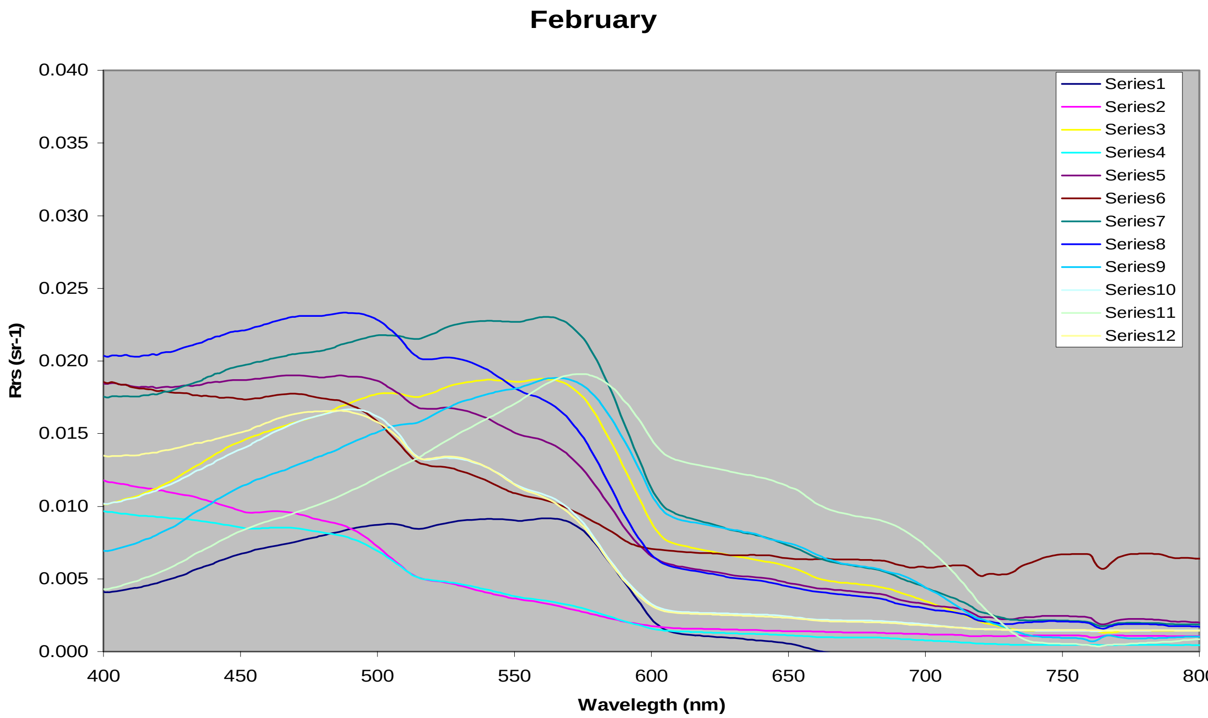
Figure 3

In the northern stations the concentrations of sediments are higher in October than those in the south; while is the opposite occurs in February (Figure 4). Considering that February is dry season less sediments were expected to be found during that month due to a reduced input. There might be three possible explications: That a storm event affected the southern drainages that reach the bay a couple of days prior to the sampling, that there is a local seasonal current in the bottom of the bay that might rise sediments and put them in motion again or a combination of both. In February there were 4 stations that had higher concentrations at middle depth than at surface (figure 4). Far from the coast there are stations S5 and S11. In their case as sediments travel away from the coast they can settle on the seafloor. Station S5 is close to the sewage pipe outlet and the station S17 is at a discrete distance of Guanajibo and Yagüez rivers. In October, the middle depth had higher concentrations of suspended sediments in S4, S11 and S21. Stations S4 and S11 had been already explained but for S21 most of the time surface currents in the Mayagüez Bay travel to the north (F.G. Lowman). This might explain a marked difference in the coastal stations for surface and middle depths samples during October. If data of S17 for this period were available it may support this idea considering that is the closest station north of Guanajibo. Other graphs and tables associated with the variability of sediments are in the appendix A.

GER 1500 measurements and their correlation with suspended sediments:

Six bands were preliminary identified based on the observations of the Remote Sensing Reflectance (Rrs) vs wavelengths for October and February (figure 5). Those were 595-615nm, 655-675nm, 680-700nm, 710-730nm, 755-775nm and 810-830nm. Correlations between the surface suspended sediments of each station and the Remote Sensing Reflectance were made (Figure 6). Details results of the analysis are in Appendix B.

The highest correlation value was 0.81 with a regression of 0.70. In general, correlation improved as the band got smaller (red area, 605nm) getting the best results for October with the highest values. The fallowing bands were discarded: 810-830nm and 755-775nm. In February those two bands were discarded and also 710-730nm. These could be comprehensive considering that water tends to absorb wavelengths higher than 500nm but also lower than 700nm and reflect more in the blue part of the electromagnetic spectrum. Phytoplankton reflects more in the green part of the spectrum (550nm) absorbing also in the red area. S1 was eliminated from the February data in order to have a better correlation and regression. However, when it was removed from the October analysis the correlation and regression decreased. This might happen if one of the two values of the station (Rrs or Tss) was wrong.



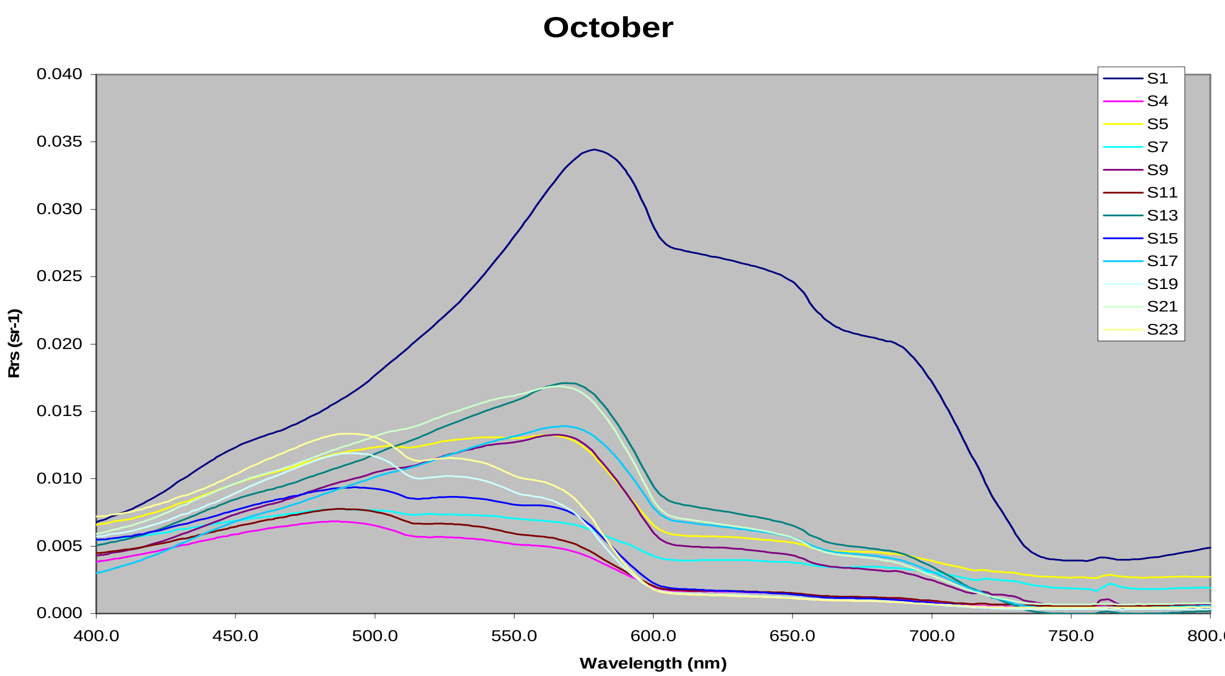


Figure 5 Visible and near infrared data obtained with the GER 1500

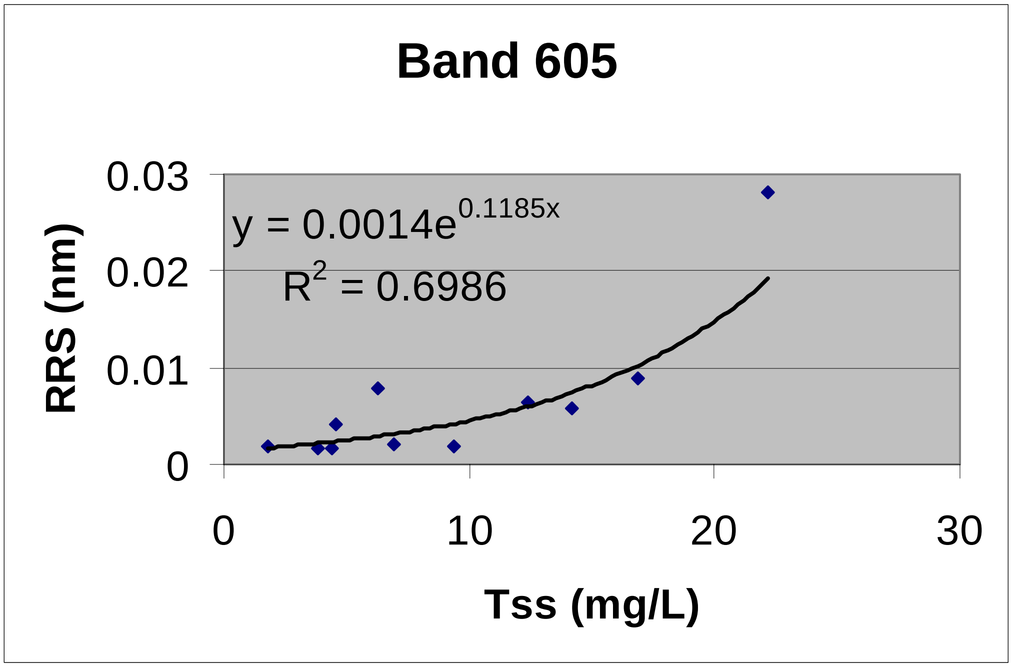
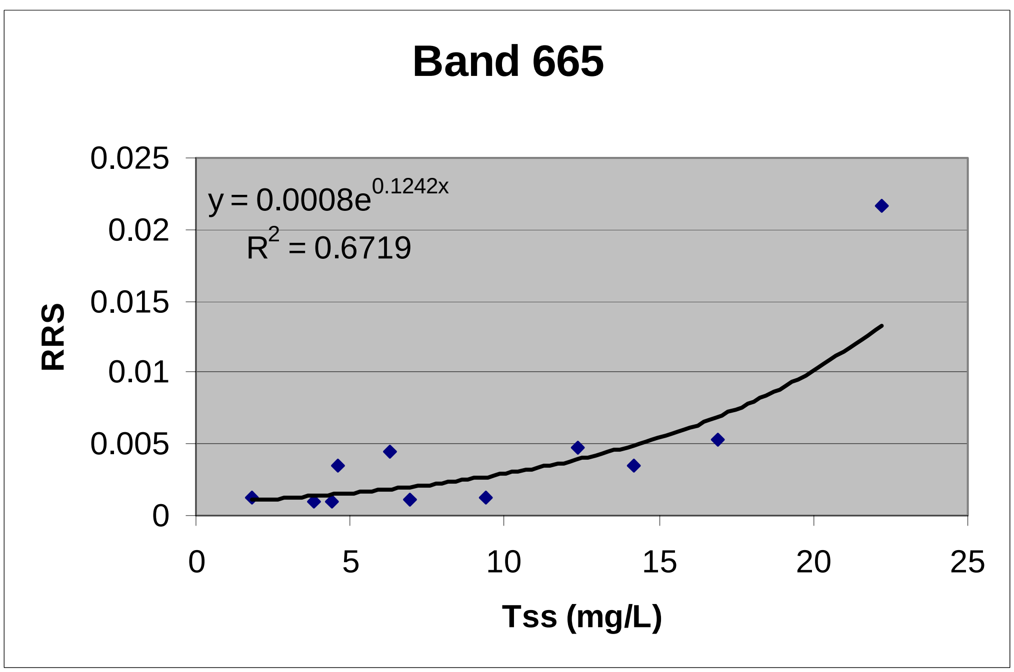


Figure 6. Here are some examples of the correlations done for the month of October. Other Graphs and information related to this are in appendix B.



The correlation of sediments in October coincides proportionally with Rrs of 5 stations in the first two identified bands (605nm and 665nm) and 3 stations in February.

Above 15mg/L of Tss the increase in the concentration is proportional with the reflectance. In general for October the decreasing order of Rrs for a given station within the considered bands (605nm, 665nm, and 690nm) is two position away maximum of the Tss concentration decreasing order. This is not the case for February were this patterns are not so clear. The reasons for that are unclear.

Hydroscat-6 measurements and correlation:

Due to failure of the equipment only backscattering data was collected in October, but from the six bands that the instrument has (bb442, bb470, bb510, bb589, bb620 and bb671) the bb620 was not working. Only the first meter depth was considered in order to compare the results with the obtained from GER 1500. See appendix C for graphs and calculus. Several correlations were done between the backscattering coefficients (bb) of various bands with the total suspended sediments but no good relationships were found. As the bb decreases the Rrs also decreases for the band 671nm (6 values coincide and 3 differ for only from one position). The data obtained with the Hydroscat-6 should still be analyzed in other different ways in order to test if there is any relation that can be suggested.

Conclusion

Costal stations showed higher concentrations of sediments closer to the river mouths or anthropogenic features. Differences in the amounts of Tss in surface water and middle depth were appreciated especially in the oceanic sewage pipe station. Concentrations of sediments changed from wet to dry season and from north to south. Sampling and collection of more data during other periods in the year should give more accuracy for a better comprehension in the temporal and spatial variability of Tss in the Mayagüez Bay.

A positive correlation was found between the Tss and the Rrs from the GER 1500. Three bands were identified to be potentially affected by sediments, 595-615nm, 655-675 and 680-700. I recommend increase the spectral resolution of these bands in order to see if they correlate more. I suggest the development of algorithms using these three bands in order to get an estimation of suspended sediments in the bay using remote sensing. A new band may be tested close to 580nm to see how much the green part of the spectrum may be affected by sediments. Phytoplanktons from the same station need to be recognize to see how it might affect the Rrs with respect of Tss. When the concentration of sediments was more than 15mg/L, the Rrs of those bands were proportional to the concentration (higher the concentration, more reflectance). In order to support or denied this statement more sampling and data should be collected with more than 15mg/L of suspended sediment. Although no relation was immediately found between the backscattering coefficient and the suspended sediments, further analyzes need to be made until all possibilities are discarded or more evidence of a relation between optical instrumentation data and field work is found. .

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Appendix A

October samples

Station	Localization	Filter number	Weight before	Weight after	Weight of suspended Sediment	Water volume	Concentration (mg/L)	Average
S01	SUP	46	0.09068	0.09603	5.35	250	21.4	23.6
S01	SUP	57	0.09341	0.09985	6.44	250	25.8	
S01	PROF.	11	0.09389	0.09751				22.2
S01	PROF.	29	0.09181	0.09735	5.54	250	22.2	
S04	SUP	19	0.09784	0.10138	3.54	1875	1.9	1.9
S04	SUP	3	0.09282	0.09649	3.67	1870	2	
S04*	PROF.	2	0.09195	0.1029				1.8
S04	PROF.	32	0.09366	0.09689	3.23	1815	1.8	
S05	SUP	12	0.092	0.10419	12.19	1000	12.2	12.4
S05	SUP	33	0.09116	0.10065	9.49	750	12.7	
S05	PROF.	28	0.09315	0.10434	11.19	1000	11.2	12
S05	PROF.	40	0.09014	0.09981	9.67	750	12.9	
S07	SUP	49	0.09406	0.09696	2.9	500	5.8	4.6
S07	SUP	16	0.09287	0.09458	1.71	500	3.4	
S07	PROF.	36	0.09	0.09457	4.57	850	5.4	4.4
S07	PROF.	4	0.09394	0.09678	2.84	850	3.3	
S09	SUP	21	0.09433	0.10589	11.56	750	15.4	14.2
S09	SUP	42	0.09579	0.10871	12.92	1000	12.9	
S09	PROF.	52	0.09222	0.10343	11.21	1000	11.2	11.9
S09	PROF.	37	0.09399	0.10348	9.49	750	12.7	
S11	SUP	6	0.09123	0.10149				9.4
S11	SUP	15	0.09381	0.10319	9.38	1000	9.4	
S11	PROF.	59	0.09225	0.10273	10.48	1000	10.5	9.7
S11	PROF.	13	0.09239	0.10139	9	1000	9	
S13	SUP	41	0.09374	0.10599	12.25	750	16.3	16.9
S13	SUP	25	0.092	0.10516	13.16	750	17.5	
S13	PROF.	7	0.09356	0.10488	11.32	750	15.1	13
S13	PROF.	24	0.08955	0.10038	10.83	1000	10.8	
S15	SUP	30	0.09254	0.10324	10.7	1500	7.1	6.9
S15	SUP	50	0.09299	0.10466	11.67	1750	6.7	
S15	PROF.	22	0.09328	0.10521	11.93	1750	6.8	6.7
S15	PROF.	23	0.09465	0.10632	11.67	1750	6.7	
S17	SUP	31	0.09436	0.10075				
S17	SUP	60	0.09532	0.09542				
S17	PROF.	47	0.09469	0.09711				
S17	PROF.	44	0.09444	0.10082				
S19	SUP	55	0.0947	0.09985	5.15	1250	4.1	3.8
S19	SUP	54	0.09235	0.09669	4.34	1250	3.5	
S19	PROF.	38	0.09228	0.09436	2.08	1250	1.7	2.1
S19	PROF.	43	0.09449	0.09777	3.28	1250	2.6	
S21	SUP	10	0.09524	0.09893	3.69	700	5.3	6.3
S21	SUP	9	0.0947	0.09985	5.15	700	7.4	
S21	PROF.	5	0.09366	0.099	5.34	800	6.7	7.2
S21	FROF.	58	0.09476	0.10097	6.21	800	7.8	
S23	SUP	53	0.09318	0.09623	3.05	1800	1.7	3.8
S23	SUP	14	0.09484	0.10547	10.63	1800	5.9	
S23	PROF.	35	0.09229	0.10212	9.83	1750	5.6	4.4
S23	PROF.	8	0.0942	0.09963	5.43	1750	3.1	

February Samples

Station	Localization	Filter number	Weight before	Weight After	Weight of suspended sediment	Water volume	concentration (mg/L)	Average
S01	SUP	2	0.08937	0.09796	8.59	750	11.5	11.5
S01	SUP	3	0.08862	0.09733	8.71	750	11.6	
S01	PROF.	4	0.09024	0.09803	7.79	750	10.4	11.1
S01	PROF.	5	0.09000	0.09879	8.79	750	11.7	
S04	SUP	6	0.09030	0.09702	6.72	2000	3.4	3.9
S04	SUP	7	0.09027	0.09912	8.85	2000	4.4	
S04	PROF.	8	0.09333	0.10271	9.38	2000	4.7	5.0
S04	PROF.	9	0.09300	0.10354	10.54	2000	5.3	
S05	SUP	34	0.09467	0.10458	9.91	750	13.2	13.9
S05	SUP	35	0.09363	0.10457	10.94	750	14.6	
S05	PROF.	36	0.09365	0.10433	10.68	750	14.2	14.0
S05	PROF.	37	0.09330	0.10361	10.31	750	13.7	
S07	SUP	10	0.09279	0.10198	9.19	2000	4.6	4.8
S07	SUP	11	0.09284	0.10304	10.20	2000	5.1	
S07	PROF.	12	0.09315	0.10202	8.87	2000	4.4	4.4
S07	PROF.	13	0.09324	0.10193	8.69	2000	4.3	
S09	SUP	14	0.09264	0.10437	11.73	750	15.6	15.6
S09	SUP	16						
S09	PROF.	18	0.09265	0.10361	10.96	750	14.6	14.9
S09	PROF.	19	0.09336	0.10476	11.40	750	15.2	
S11	SUP	20	0.09357	0.10258	9.01	1750	5.1	5.2
S11	SUP	21	0.09370	0.10299	9.29	1750	5.3	
S11	PROF.	22	0.09382	0.10327	9.45	1650	5.7	5.7
S11	PROF.	26	0.09445	0.10369	9.24	1650	5.6	
S13	SUP	24	0.09620	0.10827	12.07	750	16.1	14.1
S13	SUP	27	0.09459	0.10367	9.08	750	12.1	
S13	PROF.	28	0.09357	0.10472	11.15	900	12.4	12.0
S13	PROF.	29	0.09346	0.10399	10.53	900	11.7	
S15	SUP	30	0.09307	0.10334	10.27	850	12.1	11.5
S15	SUP	31	0.09607	0.10529	9.22	850	10.8	
S15	PROF.	32	0.09674	0.10537	8.63	900	9.6	9.5
S15	PROF.	33	0.09490	0.10334	8.44	900	9.4	
S17	SUP	38	0.09356	0.10854	14.98	825	18.2	17.9
S17	SUP	60	0.09500	0.10961	14.61	825	17.7	
S17	PROF.	40	0.09664	0.11188	15.24	800	19.1	18.5
S17	PROF.	57	0.09514	0.10957	14.43	800	18.0	
S19	SUP	39	0.09600	0.10793	11.93	825	14.5	13.5
S19	SUP	51	0.09492	0.10529	10.37	825	12.6	
S19	PROF.	56	0.09427	0.10467	10.40	875	11.9	12.0
S19	PROF.	53	0.09300	0.10357	10.57	875	12.1	
S21	SUP	41	0.09448	0.11334	18.86	500	37.7	38.3
S21	SUP	55	0.09443	0.11387	19.44	500	38.9	
S21	PROF.	59	0.09538	0.11343	18.05	500	36.1	33.5
S21	PROF.	50	0.09494	0.11040	15.46	500	30.9	
S23	SUP	58						11.3
S23	SUP	43	0.09438	0.10425	9.87	875	11.3	
S23	PROF.	54	0.09333	0.10457	11.24	875	12.8	12.5
S23	PROF.	52	0.09526	0.10555	10.29	850	12.1	