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Understanding the dynamics of MODIS Chlorophyll-a in Mayagüez Bay and its relationship with suspended sediments

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I. Abstract

The main objective of this project is to validate the MODIS (Moderate Resolution Imaging Spectroradiometer) chlorophyll-a product for the Mayagüez Bay and know the relationship of suspended sediments with this type of data. Comparisons of the chlorophyll-a values directly measured in the field, with MODIS chlorophyll-a and suspended sediments are presented. A correlation coefficient (R^2) of 0.0283 were obtained between MODIS chlorophyll-a from the Terra satellite and the field chlorophyll-a. In the case of Aqua satellite the R^2 was 0.0265. The correlation of the suspended sediments and the Chlorophyll-a, both from the field was 0.0903. The R^2 relations between Chlorophyll-a from Aqua and Terra and the suspended sediments were 0.0267 and 0.2327 respectively. These R^2 values demonstrate that MODIS is not producing good chlorophyll-a values for Mayagüez Bay.

***Keywords**:* chlorophyll-a, suspended sediments, Mayagüez Bay, MODIS

I. Introduction:

The oceans represent around 71% of the Earth, which means that they have a great influence in our lives, including the food. The food chain in the ocean begins with the phytoplankton. These important microscopic plants take up essential nutrients to produce carbohydrates (Stout, 2007), which are also vitals for other marine organisms.

In this research I validated the bio-optical algorithms developed by NASA (National Aeronautics and Space Administration) to estimate phytoplankton chlorophyll and correlated these values with the suspended sediments. Ocean color sensor known as MODIS, onboard Aqua and Terra satellites were used. This satellite has 36 bands, but currently from 8 to 36 (with a spatial resolution of 1Km) is used for the estimation of Chlorophyll-a (Cardwell, 1999). Terra satellites have its orbit around the Earth from north to south across the equator in the morning and Aqua passes south to north over the equator in the afternoon (Cardwell, 1999).

The selected study site is Mayagüez Bay, which is located at 18° 10’ N and 18° 16’ N latitude and the 67° 10’ W and 67° 14’ W for longitude. This Bay is constantly affected by the discharge of the Güanajibo, Yagüez and Añasco rivers (Figure 1). The sediments and nutrients from these rivers affect the phytoplankton dynamics of the Mayagüez Bay.

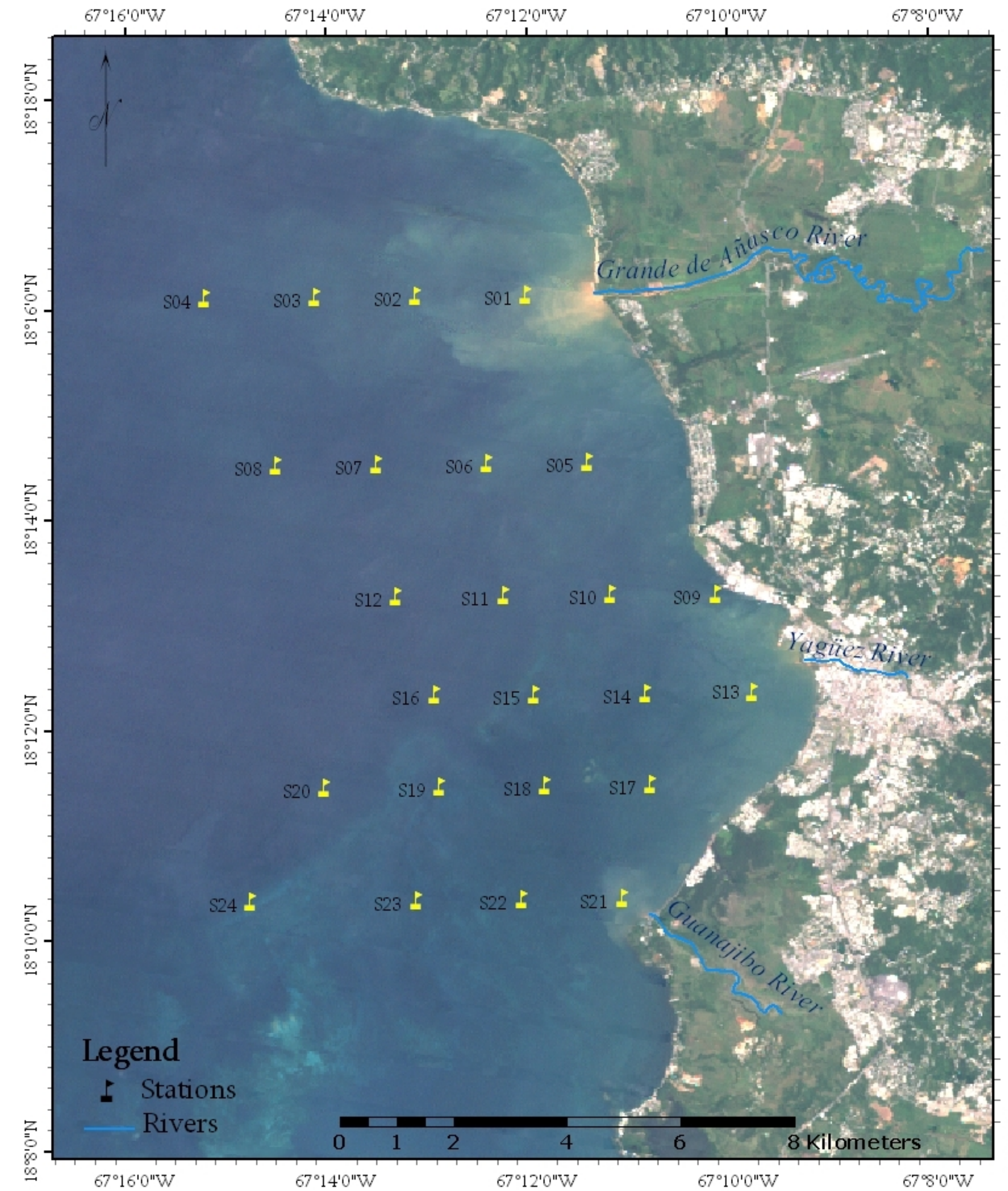


Figure 1: The study area in Mayagüez Bay and the station in which the chlorophyll-a measurements were taken. (V. Rodriguez, Personal Communication).

This research was focused in determining if the standard NASA algorithms applied to the 1 Km spatial resolution bands of the MODIS sensor to measure the chlorophyll concentration are useful in the Mayagüez Bay. Also, I compared the MODIS measurements with the field data collected along the Mayagüez Bay.

The validation of MODIS images will also help to better understand the impact of the sediments on the phytoplankton dynamics. If these satellite measurements are correct we will be able to study the large-scale dynamics of phytoplankton affected by the sediments in the Mayagüez Bay.

The suspended sediments are defined as solid particles transported in a fluid media or found in deposit after transportation by flowing water, wind, glacier and gravitational action. Their concentration in a water body is affected by many factors. In rivers, the concentration depends on the water's flow rate, turbidity, soil erosion, urban runoff, and wastewater and septic system effluent, while in lakes, decaying plants and animals, bottom-feeding fish, wind and wave action play a larger role. Suspended sediments play a key role in shaping the characteristics of a body of water, by transporting adsorbed toxic substances, blocking light from reaching submerged vegetation, which in turn slows down photosynthesis. This effect causes less dissolved oxygen to be released into the water by the plants and in extreme cases, results in death of the plants (Kunkel, 2002).

The geology of the Mayagüez Bay is composed by Alluvium of the Quaternary. But it is not the only formation that is important in this area. The geology of the rivers that discharge into this Bay is also important. One of them is the Güanajibo River located at the south of the Bay. The formations that compose this river basin are from Cabo Rojo, whose most abundant rock is the serpentinite. North to it, we found the Yagüez River, which is composed by the Yauco Formation. The Yauco Formation is composed of volcanic sandstone, siltstones, mudstones, claystone and limestone and the most abundant minerals are calcite, chlorite, epidote and quartz. Another formation that has effects in the clasts and sediments that arrive in the Mayagüez Bay is the Maricao Formation. It is composed by volcanic breccia with large phenocrysts, conglomerates, volcanic sandstone and limestones. The most common minerals are augite, plagioclase, hornblende and magnetite. The last unit through which the Yagüez River cuts is one composed by porphiritic augite basalts. It also has minerals scaprolite, plagioclase, magnetite and olivine (Curet, 1986). Those are the compositions of the sediments that are discharged into the Mayagüez Bay (Figure 2). The concentration of sediments derived from bottom sediment re-suspension or discharge of sediment-laden rivers is highly variable over a wide range of time and space scales (Miller and McKee, 2004). Therefore their changes affect the measured Chlorophyll in these coastal areas.

1:20 000

Figure 2: Geologic Map of the Mayagüez Bay (Curet, 1986)

The MODIS images (Figure 3) collected for this study were processed and analyzed with the SeaDAS computer software. The images were from the same dates that field data were taken. The comparison between MODIS images and field data will allow the validation of the sensor spatial resolution and its algorithm. This study will also determine the problems and limitations of using this technology in the study area. This type of study has not been performed yet in Mayagüez Bay, although it has been done in other places like the Baltic Sea, in which the results obtained do not agree with the hypothesis established (Darecki and Stramski, 2004).

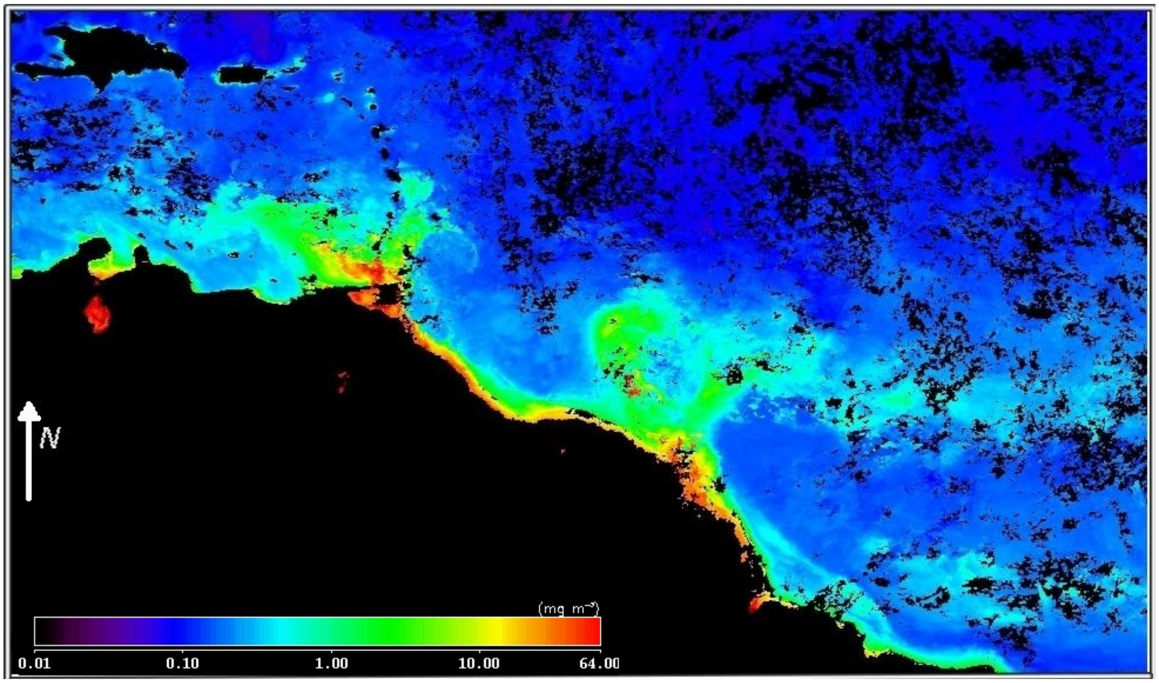


Figure 3: Example of a MODIS chlorophyll image of 1 km of spatial resolution. (F. Gilbes, 2005)

IV: Methodology:

The first step in this research was download the images from the NASA Ocean Color website. The webpage has the capacity to let the users choose the sensor and the satellite, the specific date and the region of interest, in this case, the Caribbean. After all the images from the sampling dates (Appendix 1) were downloaded for the Aqua and Terra satellites, the next step was to process the images.

The used NASA webpage shows the swats files from the specifications provided. Also we have the opportunity to choose the level of the image. They are from level 0 (completely raw), level 1A, level 1B (both partially processed) and level 2 (processed products). I choosed the images at level 1A, which were processed on the NASA-developed SeaDAS software. Here the level 1A images were geoprocessed and change to level 1B and finally level 2 (Figure 4).

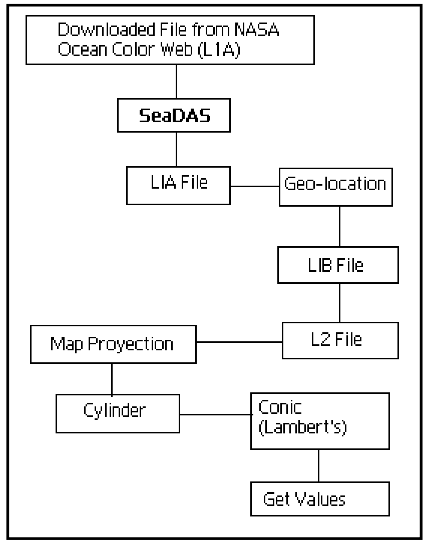


Figure 4: Flow Chart of the steps to get the image values

The next step was to correlate MODIS and field data. Finally, the accuracy of the MODIS images with 1Km of spatial resolution for the Mayagüez Bay was established.

V: Sample Description

The MODIS sensor consists of 36 bands with three different spatial resolutions in the pixels. The bands used in this study were designed to measure the ocean color, which have a spatial resolution of 1Km (Figures 5&6). Images covering the Caribbean region and Puerto Rico were selected for 28 different dates, for each satellite. This means that I am analyzed 56 images. These images had the concentration of phytoplankton chlorophyll-a as calculated with the following algorithm:

$$C_a = 10^{0.283 - 2.753 (R) + 1.457 (R^2) + 0.659 (R^3) - 1.403 (R^4)}, \text{ where}$$

$$R = \log_{10} (R_{rs}\,443 > R_{rs}\,448 / R_{rs}\,551), \text{ (Mc Clain, 2007).}$$

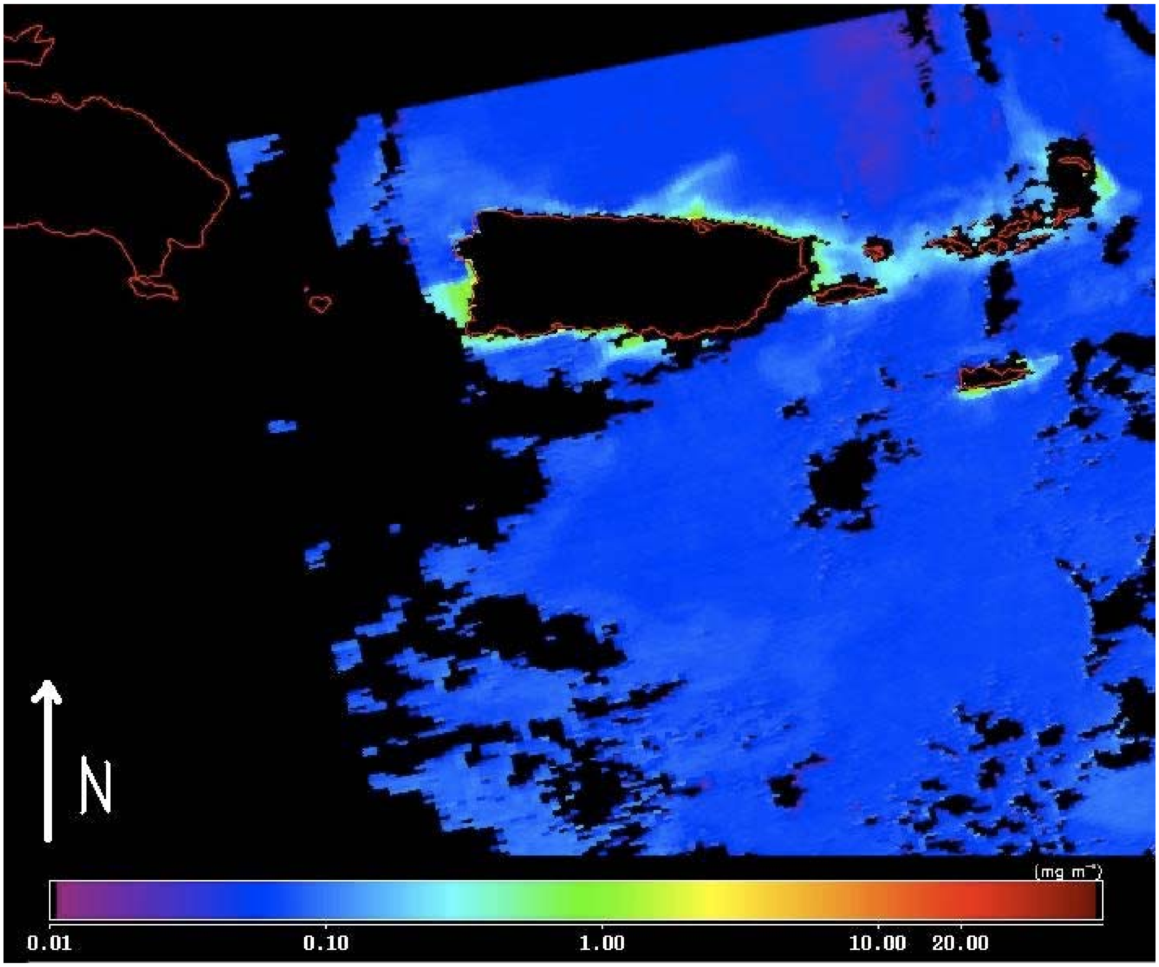


Figure 5: Example of a MODIS image for the Aqua Satellite processed in SeaDAS

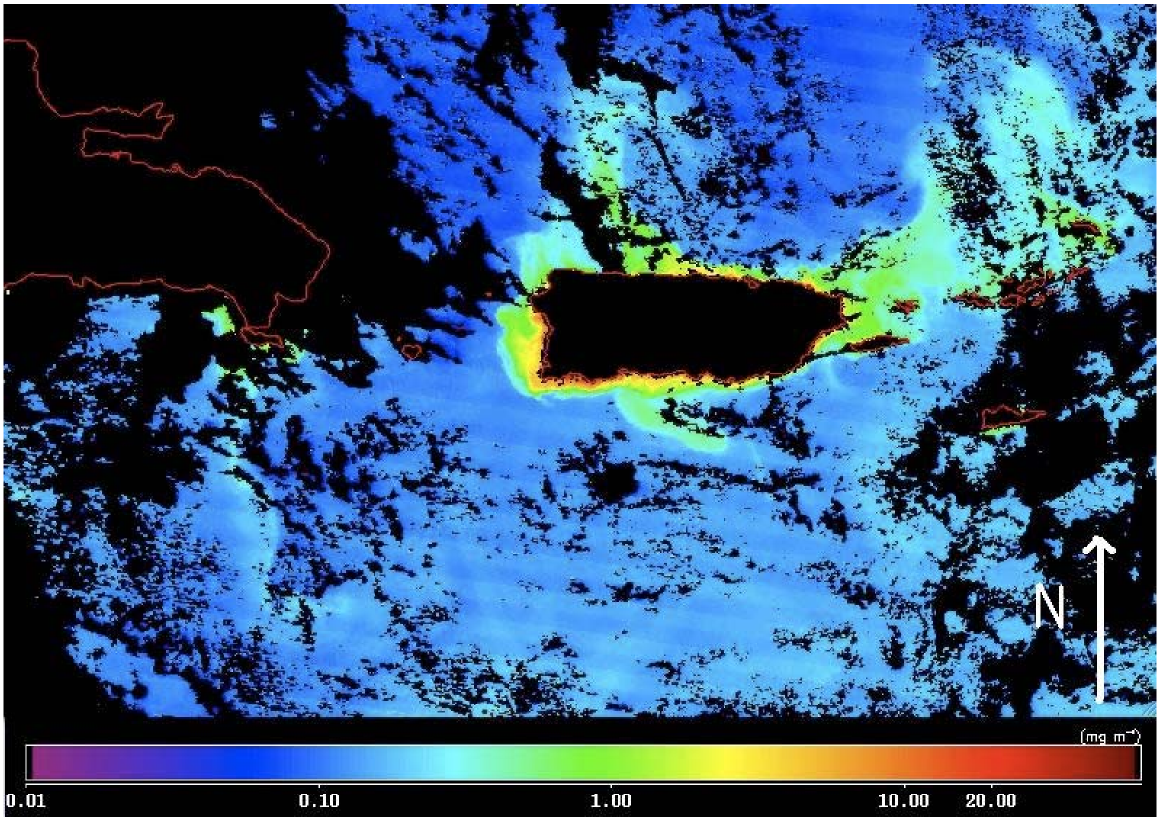


Figure 6: Example of a MODIS image for the Terra Satellite processed in SeaDAS

This algorithm was validated in this study using field measurements of Chlorophyll-a as determined with the standard fluometric method. The data was also compared with field suspended measurements as determined using the standard filtration method.

VI. Results

The results of this project demonstrate that the spatial resolution of the MODIS images is too large to for Mayagüez Bay.

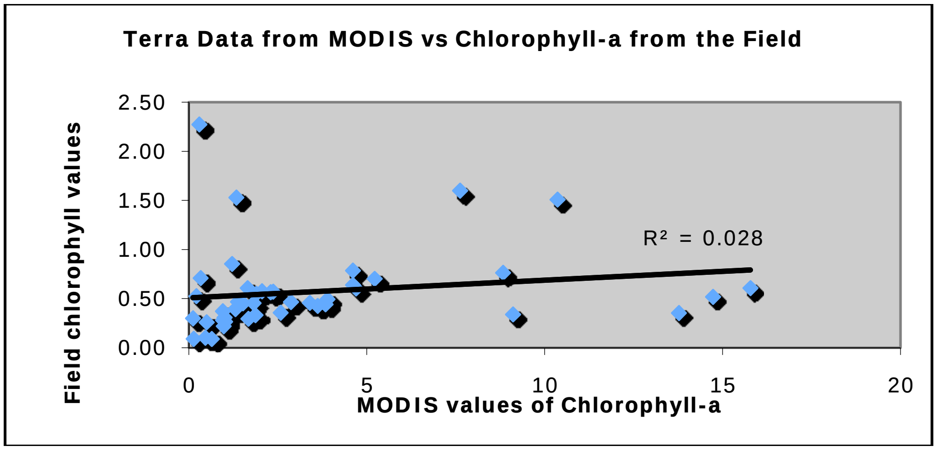
The correlation values were very low due to several reasons. Among the most important are the atmospheric conditions and the fact that we are working in coastal waters, were the optical signal is very complicated.

The average percent of good values for the Aqua satellite was 9% and for the Terra satellite was 39.6% (Table 1).

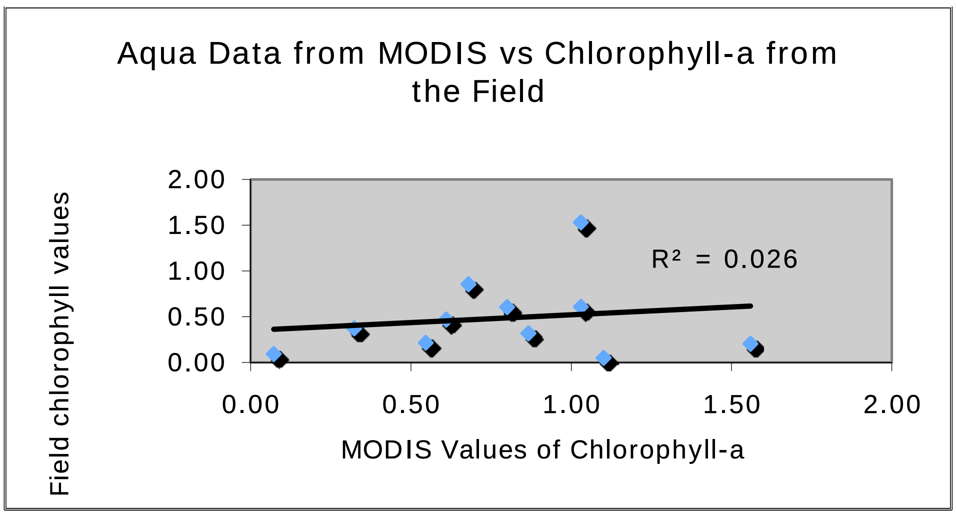
Table 1: Percent of Missing Data

Date	Satellite	Percent of Missing Data	Comments
April 24-26, 2001	Aqua & Terra	100%	Satellite not available
October 2-4, 2001	Aqua & Terra	100%	Satellite not available
February 26-28, 2002	Aqua & Terra	100%	Satellite not available
August 20, 21, 22, 2002	Aqua & Terra	100%	Clouds
February 25, 26, 27, 2003	Aqua	91.7%	Clouds
February 25, 26, 27, 2003	Terra	33.3%	Clouds
October 7, 8, 9, 2003	Aqua	100%	Not image available for Puerto Rico
October 7, 8, 9, 2003	Terra	33.3%	Clouds
January 12, 13, 14, 2004	Aqua	55.6%	Clouds
January 12, 13, 14, 2004	Terra	33.3%	Clouds
12-Feb-04	Aqua	100%	Clouds
12-Feb-04	Terra	30%	Clouds
19-Aug-04	Aqua & Terra	100%	Clouds
10-Mar-05	Aqua	0 %	-
10-Mar-05	Terra	66.7%	Clouds
19-Jul-05	Aqua & Terra	100%	Clouds
17-Aug-05	Aqua	100%	Clouds
17-Aug-05	Terra	83.3%	Clouds
20-Sep-05	Aqua & Terra	100%	Clouds
19-Oct-05	Aqua	100%	Clouds
19-Oct-05	Terra	16.7%	Clouds
6-Dec-05	Aqua	100%	Clouds
6-Dec-05	Terra	33.3%	Clouds
8-Mar-06	Aqua	100%	Clouds
8-Mar-06	Terra	33.3%	Clouds
21-Apr-06	Aqua & Terra	100%	Not image available for Puerto Rico
26-Sep-06	Aqua & Terra	100%	Clouds
26-Oct-06	Aqua	100%	Clouds
26-Oct-06	Terra	50%	Clouds

The correlation coefficient (R^2) between the field chlorophyll-a and the MODIS chlorophyll-a was 0.028 for Terra and 0.026 for Aqua (Graph 1 & 2). Factors that affect this correlation are the lack of values and the big spatial resolution.

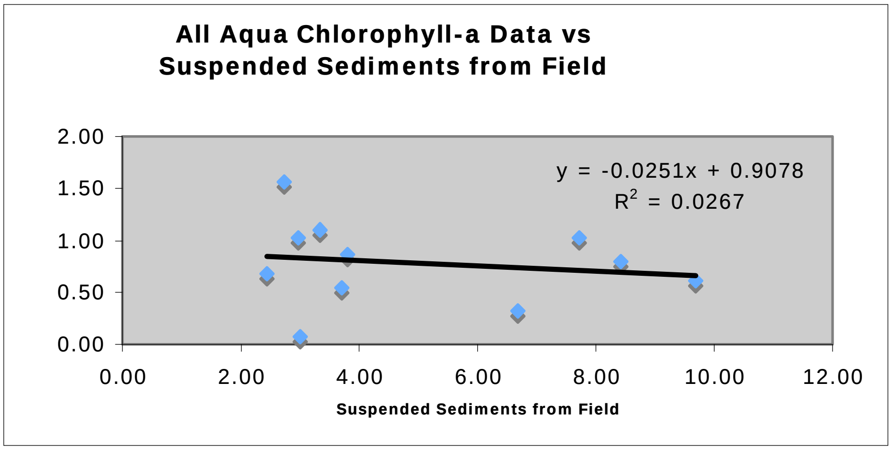


Graph 1: Correlation of the Chlorophyll-a between field and MODIS Terra data.

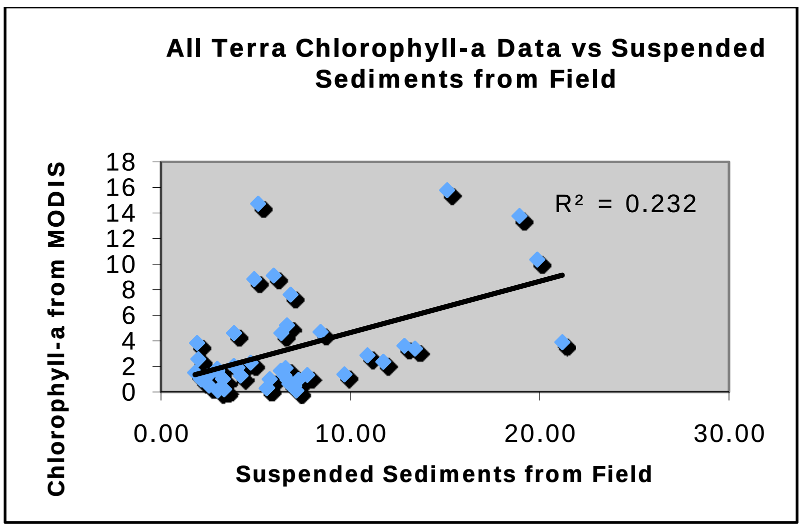


Graph 2: Correlation of the Chlorophyll-a between field and MODIS Aqua data

Correlations for the MODIS Chlorophyll-a and the suspended sediments concentration from the field were also low for the Aqua satellite but they were higher for Terra (Graphs 4 & 5).



Graph 3: Correlation of the Chlorophyll-a as measured with MODIS at Aqua and the field suspended sediments



Graph 4: Correlation of the Chlorophyll-a as measured with MODIS at Terra and the field suspended sediments

VII. Discussion

The correlations values found in this study proved that the MODIS 1Km spatial resolution and the standard NASA algorithms for Chlorophyll are not appropriate for Mayagüez Bay.

Better correlations values were found for MODIS Terra, which cover the Mayagüez Bay during the morning. This has an important implication because of the amount of clouds and the atmospheric conditions of the area. Science Aqua passes the Bay in the afternoon the atmospheric conditions and the cloud cover increases and it makes more difficult to detect a good signal from a satellite sensor.

The correlation values of the suspended sediments and the chlorophyll-a from the MODIS sensor were also low, although for Terra we got a higher regression value. It was expected to find a good correlation with the suspended sediments because they have a big influence in the phytoplankton dynamics. For example, suspended sediments block the sun light reaching the phytoplankton, which therefore reduces their production. More analyses are required to better understand the relationship between suspended sediments and Chlorophyll-a in Mayagüez Bay. Also, suspended sediments have a direct effect in the reflectance signal detected by satellite sensors, which also require more research.

VIII. Conclusion

This project proved that MODIS 1Km spatial resolution does not work effectively in the Mayagüez Bay. This was proved by low correlations values for MODIS mounted in the two satellites. Also this project showed low relationship between suspended sediments and the phytoplankton chlorophyll-a, demonstrating the need of more research in this area.

IX. References:

- Miller, R.L., and McKee, B. A., 2004, Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters, Department of Earth and Environmental Sciences, v. 93, no. 1-2, p. 259-266.

- Carder, K. L., 2004, Performance of the MODIS semi-analytical ocean color algorithm for chlorophyll-a, Department of Marine Sciences, University of South Florida, v. 33, no. 7, p. 1152 – 1158.

- Dareckia, M. and Stramski, D, 2004, An evaluation of MODIS and SeaWiFS bio-optical algorithms in the Baltic Sea, Institute of Oceanology, v. 89, no. 3, p. 326-350.

- Labiosa, R. G., Arrigo, K. R., Genin, A., Monismith, S. G. and Van Dijken, G., 2003, The Interplay between Upwelling and Deep Convective Mixing in Determining the Seasonal Phytoplankton Dynamics in the Gulf of Aqaba: Evidence from SeaWiFS and MODIS, Limnology and Oceanography, v. 48, no. 6, p. 2355-2368.

- Stout, P. K., 2007, Phytoplankton: Plant of the Sea, Sea Grant Facts, p. 637.

- Kunkel, A., 2002, Suspended Sediments in South San Francisco Bay, University of Texas.

- Curet, A.F., 1986, Geologic Map of the Mayaguez and Rosario Quadrangle, Puerto Rico, USGS, scale 1:20 000, 1 sheet.

- Cardwell, S., 1999, About MODIS, NASA Ocean Color WebPage.

- Mc Clain, C., 2007, Empirical chlorophyll algorithms for SeaWiFS and MODIS, NASA Ocean Color Website.

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Appendix 1:

Table 2: Values of the stations measured of the Chlorophyll-a from MODIS, from the field and the suspended sediments and river discharges

Cruise date	Station	Surface Field Chl-a	Terra MODIS Chl-a	Aqua MODIS Chl-a	Surface Suspended Sed.
Sept. -26-06	**A1**	0.76	No Data	No Data	10.45
	A2	0.44	No Data	No Data	2.82
	AAA1	2.20	No Data	No Data	3.93
	Y1	1.24	No Data	No Data	3.65
	G1	1.11	No Data	No Data	4.23
	G2	0.35	No Data	No Data	2.13
Apr. - 26-06	**A1**	1.07	No Data	No Data	10.00
	A2	0.17	No Data	No Data	2.24
	AAA1	0.27	No Data	No Data	2.77
	Y1	0.42	No Data	No Data	4.68
	G1	0.44	No Data	No Data	5.17
	G2	0.26	No Data	No Data	1.97
Marzo 8 06	**A1**	0.64	4.61	No Data	6.35
	A2	0.26	0.5	No Data	2.53
	AAA1	0.55	1.9	No Data	4.03
	Y1	0.67	No Data	No Data	7.10
	G1	1.09	No Data	No Data	24.20
	G2	0.22	0.98	No Data	2.12
December 6 05	**A1**	0.34	9.11	No Data	5.95
	A2	0.33	No Data	No Data	2.42
	AAA1	0.45	1.82	No Data	2.97
	Y1	0.91	No Data	No Data	10.60
	G1	0.70	5.22	No Data	6.65
	G2	0.45	1.52	No Data	1.80
October 19 05	**A1**	0.52	14.73	No Data	5.13
	A2	0.44	3.84	No Data	1.90
	AAA1	0.76	8.83	No Data	4.92
	Y1	1.35	No Data	No Data	8.03
	G1	1.51	10.36	No Data	19.87
	G2	0.36	2.58	No Data	1.97
September 20 05	**A1**	0.42	No Data	No Data	11.35
	A2	0.09	No Data	No Data	1.60
	AAA1	0.27	No Data	No Data	2.63
	Y1	1.34	No Data	No Data	6.93
	G1	0.88	No Data	No Data	6.77
	G2	0.13	No Data	No Data	1.73
July 17 05	**A1**	0.42	No Data	No Data	3.28
	A2	0.23	No Data	No Data	2.82
	AAA1	0.30	No Data	No Data	2.80
	Y1	0.60	No Data	No Data	3.17
	G1	0.77	No Data	No Data	4.67
	G2	0.17	No Data	No Data	1.85
August 17 05	**A1**	0.30	No Data	No Data	24.15

	A2	0.27	1.02	No Data	3.27
	AAA1	0.36	No Data	No Data	6.50
	Y1	0.71	No Data	No Data	6.51
	G1	0.97	No Data	No Data	28.45
	G2	0.09	No Data	No Data	13.37
March 10 05	**A1**	0.32	No Data	0.87	3.80
	A2	0.09	0.1365	0.07	3.00
	AAA1	0.21	No Data	0.55	3.70
	Y1	0.20	No Data	1.56	2.73
	G1	0.05	No Data	1.10	3.33
	G2	0.854	1.215	0.68	2.43
February 12 2004	**1S**	0.608	15.78	No Data	15.11
	2S	0.592	No Data	No Data	2.41
	4S	2.274	0.2949	No Data	5.57
	5S	0.576	2.054	No Data	3.84
	7S	0.526	0.2103	No Data	3.33
	13S	1.254	No Data	No Data	3.09
	15S	0.566	2.298	No Data	4.73
	21S	0.51	No Data	No Data	2.70
	23S	No Data	1.285	No Data	4.20
	24 S	No Data	1.298	No Data	No Data
January 12-14 2004	**S01**	1.54	No Data	No Data	6.79
	S02	0.61	1.652	1.03	2.97
	S03	1.53	1.3345	1.03	7.72
	S13	0.76	No Data	No Data	3.94
	S14	1.60	7.621	No Data	6.84
	S15	0.79	4.61	No Data	3.85
	S21	No Data	No Data	No Data	9.33
	S22	0.60	4.7	0.8	8.42
	S23	0.47	1.381	0.61	9.68
October 7-9 2003	**S01**	0.35	13.77	No Data	18.93
	S04	0.10	0.47	No Data	7.03
	S05	0.43	3.62	No Data	12.85
	S07	0.09	0.64	No Data	6.77
	S09	0.51	No Data	No Data	8.99
	S11	0.33	1.87	No Data	6.57
	S13	0.95	No Data	No Data	9.21
	S15	0.47	2.87	No Data	10.90
	S17	0.49	No Data	No Data	11.75
	S19	0.30	1.67	No Data	6.33
	S21	1.12	No Data	No Data	50.54
	S23	0.31	1.00	No Data	5.74
Febuary 25-27 2003	**S01**	0.49	3.90	No Data	21.19
	S04	0.30	0.12	No Data	7.14
	S05	0.52	No Data	No Data	13.81
	S07	0.71	0.33	No Data	5.60
	S09	0.46	3.40	No Data	13.41
	S11	0.37	0.96	0.323	6.68
	S13	1.04	No Data	No Data	12.71
	S15	0.57	2.37	No Data	11.74
	S17	0.59	No Data	No Data	12.69

	S19	0.39	1.31	No Data	6.51
	S21	0.97	No Data	No Data	16.98
	S23	0.28	0.96	No Data	7.26
August 20-22 2002	**S01**	0.78	No Data	No Data	14.01
	S04	0.37	No Data	No Data	2.89
	S05	0.59	No Data	No Data	11.25
	S07	0.28	No Data	No Data	5.98
	S09	0.82	No Data	No Data	11.85
	S11	0.48	No Data	No Data	6.77
	S13	1.09	No Data	No Data	12.45
	S15	0.51	No Data	No Data	6.93
	S17	0.67	No Data	No Data	10.8
	S19	0.34	No Data	No Data	6.22
	S21	0.65	No Data	No Data	22.1
	S23	0.40	No Data	No Data	11.67
Febuary 26-28 2002	**S01**	0.68	No Data	No Data	11.53
	S04	0.10	No Data	No Data	3.89
	S05	0.30	No Data	No Data	13.90
	S07	0.22	No Data	No Data	4.85
	S09	0.26	No Data	No Data	15.60
	S11	0.25	No Data	No Data	5.23
	S13	0.43	No Data	No Data	14.10
	S15	0.22	No Data	No Data	11.46
	S17	0.42	No Data	No Data	17.93
	S19	0.22	No Data	No Data	13.52
	S21	0.97	No Data	No Data	38.30
	S23	0.19	No Data	No Data	11.30
October 2-4 2001	**S01**	2.05	No Data	No Data	23.6
	S04	0.19	No Data	No Data	1.95
	S05	0.55	No Data	No Data	12.45
	S07	0.48	No Data	No Data	4.6
	S09	0.51	No Data	No Data	14.15
	S11	0.19	No Data	No Data	11.55
	S13	0.99	No Data	No Data	16.9
	S15	0.22	No Data	No Data	6.9
	S17	0.39	No Data	No Data	12.9
	S19	0.18	No Data	No Data	3.8
	S21	0.32	No Data	No Data	6.35
	S23	0.16	No Data	No Data	3.8
April 24-26 01	**S01**	2.38	No Data	No Data	16.07
	S04	0.52	No Data	No Data	2.46
	S05	1.11	No Data	No Data	9.11
	S07	0.26	No Data	No Data	6.53
	S09	0.87	No Data	No Data	10.72
	S11	0.43	No Data	No Data	4.08
	S13	0.87	No Data	No Data	9.40
	S15	0.33	No Data	No Data	3.61
	S17	0.39	No Data	No Data	3.12
	S19	0.29	No Data	No Data	2.12
	S21	0.41	No Data	No Data	7.70
	S23	0.26	No Data	No Data	3.20