Estimating Total Suspended Sediments in Tropical Open Bay Conditions using MODIS

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Abstract: - Monitoring and better understanding of sediment flux and processes in coastal environments are important to maintain water quality and geomorphologic balance. This study describes the development and validation of an algorithm to estimate total suspended sediments (TSS) based on remote sensing reflectance (R_{rs}) and MODIS/Terra band 1 data. Three different algorithms were developed by combining two equations: (1) establishing the relationship between TSS with R_{rs} and (2) defining the relationship between R_{rs} and MODIS band 1 reflectance. A significant relationship was defined between TSS and R_{rs} at 645 nm (R^2=0.73). All three algorithms were evaluated by applying resultant equations to two MODIS images from which *in situ* data was available. In the validation analysis the lower error was encountered when using an exponential equation, however linear equations estimations followed better the tendency of measured values. Additional pre-processing routines will be evaluated in order to improve validation results and produce TSS operational products.

Key-words:-Total Suspended Sediments (TSS), Remote Sensing Reflectance (R_{rs}), MODIS, coastal waters, Mayagüez Bay

1 Introduction

Mayagüez Bay is an open bay located at the west part of Puerto Rico where many biological, chemical and geomorphological processes are affected by the distribution and abundance of suspended sediments. This area provides an exceptional laboratory to study inshore processes and coastal dynamics that can be used as baseline for the development of biogeo-optical algorithms for tropical coastal waters. The concentration of Total Suspended Sediments (TSS) is considered one of the most important water quality parameters [1] and can produce non-point source pollution. Spatial and temporal variations of this parameter are affected by both anthropogenic and natural factors. The study of these variations and other associated coastal processes could require plenty of money, effort and time. This limitation is reduced by incorporating remote sensing techniques where desire information can be retrieved from spectral data. This study aimed to establish the relationship between *in situ* measurements of TSS concentration and Remote Sensing reflectance (R_{rs}) as measured with a field spectroradiometer and MODIS band 1. Previous developed algorithms [2] for similar applications have been evaluated in this area with poor results. This is mainly due to the combination of working in a relatively small area (~95 Km^2) and a small range of TSS values. The present study is focused in developing such a site-specific algorithm to estimate TSS based on MODIS reflectance band 1 and validate it using *in situ* TSS measurements.

2 Methodology

2.1 *In situ* measurements

All *in situ* data were collected during research cruises between January 2004 and October 2006 where 6 to 8 permanent stations were visited (Fig. 1). R_{rs} was computed with measurements collected with the GER-1500 field spectroradiometer and using the following equation:

$$R_{rs} = \frac{L_0(\lambda) - (f * L_s(\lambda))}{E_d(0^+, \lambda)} \quad (1)$$

Where f is the Fresnell coefficient equal to 0.028 at 45^o [3]. The curves were corrected for sky-light reflection subtracting the minimum measured value between 900-920 nm, and in a few cases using lower spectral regions (730-900 nm). It was not possible to select a specific wavelength because sampled stations include both clear and turbid waters and these conditions affect the determination of the most appropriate wavelength for this correction [4]. Water samples were collected at approximately 1 meter deep in six stations to measure TSS, which corresponded to all the material larger than 0.7 µm. Concentrations of TSS (in mg/l) was determined with the standard weight difference method [5].

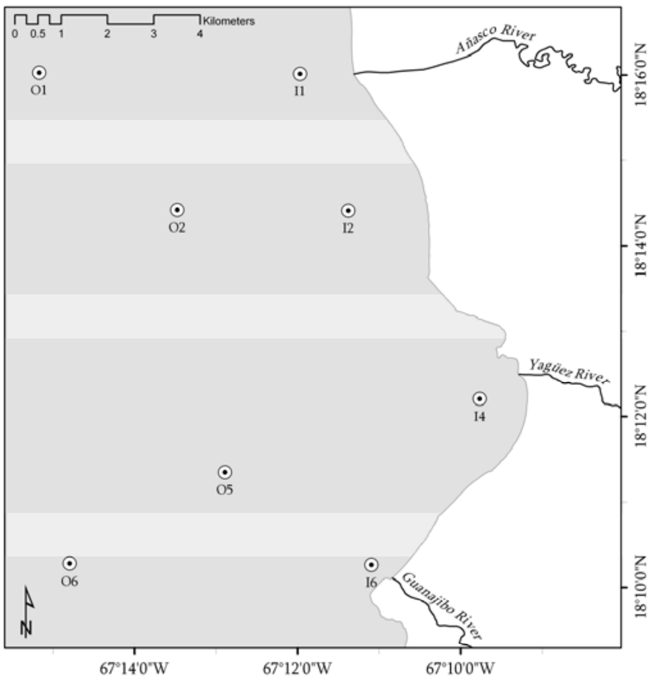

Figure 1. Study area (Mayagüez Bay at western Puerto Rico) showing the location of sampling stations.

2.2 MODIS Data

Images collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) during the same sampling dates were downloaded through a NASA Internet server (Landweb). The product selected was MOD02QKM, which includes reflectance and radiance values of MODIS/Terra band 1 and 2. All images were processed using ENVI (v. 3.4) software with pre-processing routines. They were georeferenced as UTM NAD83 for Puerto Rico region. The atmospheric correction was performed with the routine called "Dark Substract". The darkest value in band 2 was manually identified in each image and used as the "User Value" option.

2.3 Algorithm Development and Validation

The algorithm consisted in the combination of two equations, one that defined the relationship between R_{rs} and TSS, and other to establish the relationship between R_{rs} at 645 nm and MODIS band 1. Data collected during thirteen sampled days were used to develop the first equation, while this number was limited to five for the second equation. This difference was mainly due to the lack of good quality images suitable for analyses, which affected the development of the second algorithm. MODIS reflectance values were extracted from pixels corresponding to stations monitored for R_{rs}. Developed equations were applied to two images that were not incorporated in the previous analysis and *in situ* data was available in order to validate the algorithms. Finally, the proficiency of the algorithms was evaluated by comparing estimated and observed values and computing the root mean square error (RMSE).

3 Results and Discussion

3.1 Algorithm Development

A significant relationship (R^2=0.73; n=72) was defined between TSS (mg/l) and R_{rs} at 645 (Fig. 2a). This result suggests that this region of the spectrum is suitable for TSS estimation using remotely sensed data in these waters. However, it was detected a large unknown variability in this equation that could be reduced by the incorporation of more observations. Two linear equations were defined to establish the relation between TSS (mg/l) and R_{rs} at 645 nm (Fig. 2b) considering the presence of an extreme value. The higher square correlation coefficient (R^2=0.88; n=30; $P<0.0001$) was observed when incorporating such extreme value. The strong relationship observed between these two parameters indicates a high correspondence between MODIS reflectance and *in situ* R_{rs}. A decrease in both, slope and square correlation coefficient (R^2=0.69; n=29; $p< 0.0001$) is observed when that point is excluded. This extreme value could be representative of rare, but real conditions; therefore, more sampling associated to high river discharge is necessary to validate this relationship. It was observed that when working with low reflectance values resultant estimations tended to be negative or extremely low, therefore an exponential equation was incorporated in this analysis in order to minimize this effect (Fig. 2c). The square correlation coefficient of this equation was lower (R^2=0.59) than when using linear equations. Based on these analyses the following algorithms were implemented and tested:

$$TSS = 602.63 * (0.5157 * (\text{MODIS band 1}) - 0.0089) + 3.1481 \quad (2)$$

$$TSS = 602.63 * (0.3043 * (\text{MODIS band 1}) - 0.0036) + 3.1481 \quad (3)$$

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$$TSS = 602.63 * (0.0007e^{47.755 * \text{MODISband1}} + 3.1481 \quad (4)$$

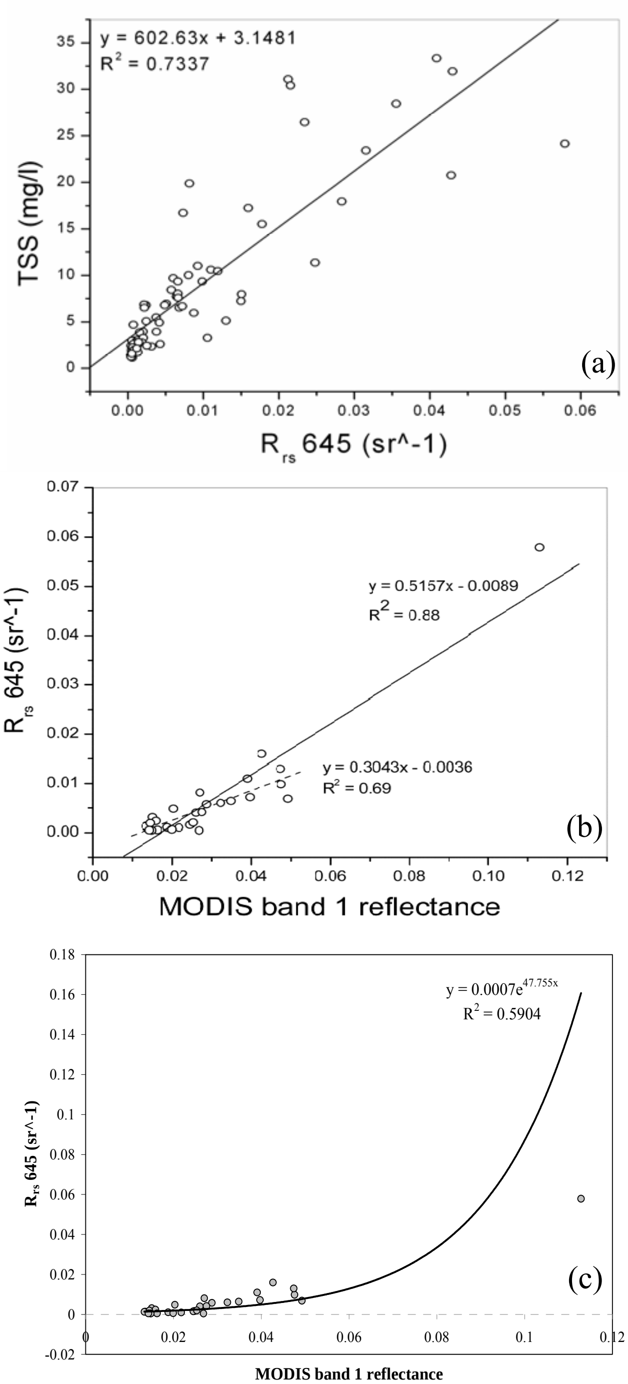
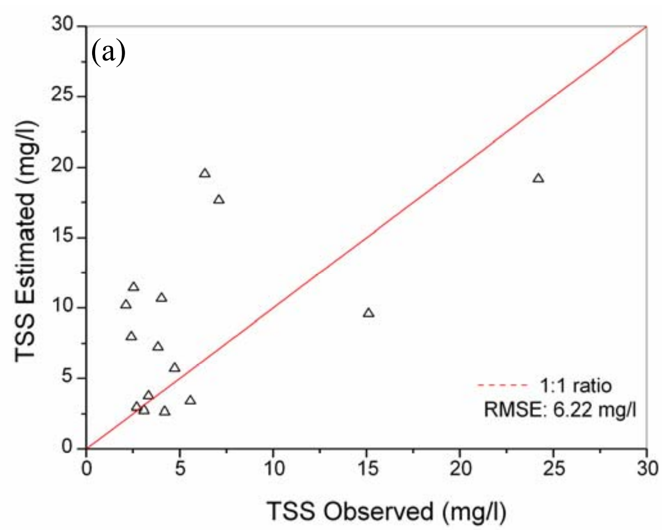


Figure 2. Data used to develop a TSS algorithm for Mayaguez Bay; (a) Relationship between *in situ* R_{rs} at 645 nm and TSS, (b) Two linear and (c) one exponential equations defining the relationship between R_{rs} at 645 nm and MODIS band 1 reflectance.

3.1 Algorithm Validation

For validation purposes, equations (2), (3) and (4) were applied to two images corresponding to cruises dates (Feb 12, 2004 and March 8, 2006) not included in the development of the equations. The spatial variability observed in these products appeared to respond by inshore processes showing higher concentrations in areas closer to the shoreline. The first two algorithms resulted in RMSE higher than 5 mg/l (Fig. 3a-b) while the lower RMSE (3.4 mg/l) was encountered when using equation 4 (Fig. 3c). Comparison between these validation results indicated equation 4 was able to better estimate TSS in lower concentrations, but during higher concentrations it tended to underestimate this parameter. Although equation 2 showed a higher RMSE, estimated values followed better the tendency of observed values. The limitations of these algorithms can be attributed to various factors: (i) limited data representative of high TSS concentrations, (ii) MODIS band 1 is not capable of detecting TSS signal under low concentrations conditions, (iii) the atmospheric correction method is not appropriate, and (iv) the signal effect of the bottom. In order to generate operational products following this approach, additional atmospheric corrections and pre-processing routines will be incorporated in the analysis.



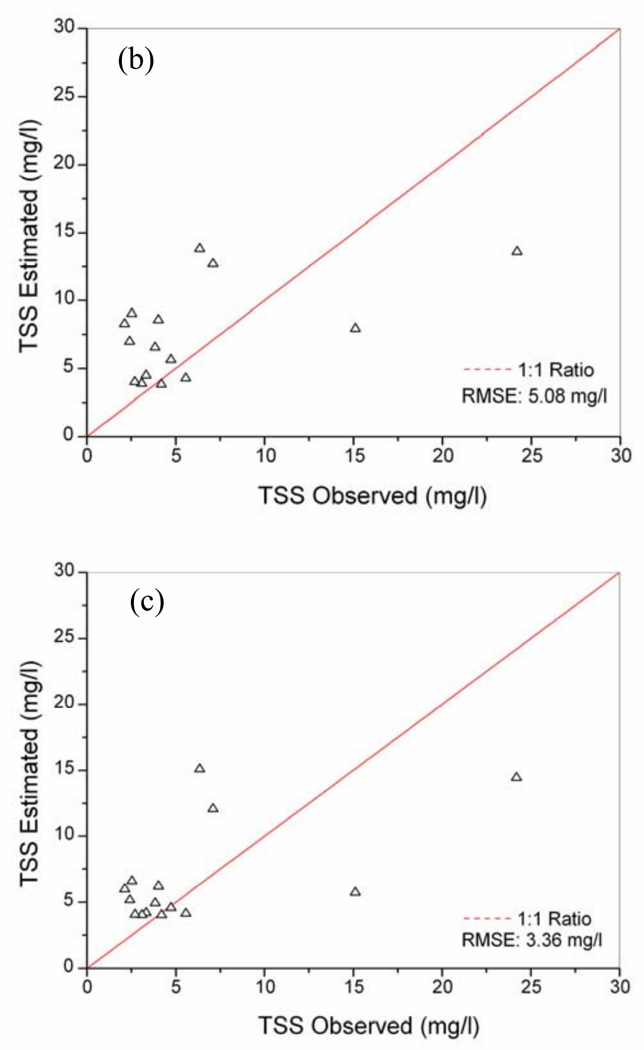


Figure 3. Validation results using (a) equation 2, (b) equation 3 and (c) equation 4.

4 Conclusion

An algorithm to estimate the concentration of TSS in coastal tropical waters will be very useful for the development of coastal studies reducing the amount of field work while covering larger areas. It was determined that the geometric and radiometric corrections that are included during the images pre-processing are crucial for this type of analysis. The algorithm estimations were able to detect spatial variations associated to TSS distribution and the RMSE ranged from 3.36 to 6.22 mg/l. These estimations are within an acceptable range considering the limited amount of data corresponding to high concentrations, the weak signal present in this area, and other factors such as bottom and atmospheric effects.

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