UNDERGRADUATE RESEARCH PROYECT

Submitted to:

Department of Geology

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Suspended Sediments around Puerto Rico as measured with AVIRIS and MODIS

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Abstract:

This study applied a previously developed algorithm for AVRIS to study a number of river plumes throughout the coast of Puerto Rico. This research project used the valuable information obtained by the AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor and MODIS (The Moderate Resolution Imaging Spectroradiometer) sensor. Specific rivers were chosen for analyses of their discharge, annual precipitation, and AVIRIS and MODIS images. The island was divided into three main areas (the western, central and eastern) to quantify the discharge and precipitation. Several rivers were selected in each region based on discharge and cloud coverage. Transects were created long shore and inshore-offshore to obtain suspended sediment concentrations from the images. In the inshore-offshore relationship; the western region showed high amounts of suspended sediment concentration in the Añasco River with 197.66 mg/l. The central region showed the highest amount of suspended sediment in the Manatí River with 31.86 mg/l. The eastern region showed the highest amount of suspended sediment in the La Plata River with 51.76 mg/l. In the long shore relationships; the western region showed the highest amount of suspended sediment in the Añasco River with 119.24 mg/l. The central region showed the highest amount of suspended sediment in the Coamo and Cibuco Rivers with 33.27 mg/l and 33.19 mg/l. The eastern region showed high amounts of suspended sediment concentration in the Espíritu Santos River with 50.93 mg/l.

Keywords: AVIRIS, suspended sediment, sediment dynamics, rivers, discharge.

Introduction and Statement:

The changes in topography, weather, and human activities affect the dynamics behavior of sediments in coastal areas, like the Mayaguez Bay. Sediments from the rivers are deposited on the shore or remained suspended throughout the bay due to high discharge produced by large precipitation.

The relatively short width of Puerto Rico and its east-west running mountain chain does not allow long rivers. Out of 1,200 bodies of water in Puerto Rico, only 50 of them are classified as rivers (Bawiec, 2001). Numerous rivers flow down from the mountains to distinct coastal plains. The Central Range divides the north or Atlantic from the south or Caribbean watersheds. The northern rivers are long, rich and tranquil waters in comparison to the southern rivers. The major rivers are: Grande de Loíza (65 km), Bayamón (40 km), La Plata (80 km), and Grande de Arecibo (55 km). In the west portion of the island the major river basins include the: Culebrinas (45 km), Grande de Añasco (65 km), and Guanajibo (36 km) rivers. The Rio Camuy is a popular river, but not for its length or breadth. It has distinctive geological features. Located in the northwest quadrant of the island, the Camuy River flows north from the mountains and submerges below ground at several locations to become a subterranean river within the karsts regions of Camuy. Subterranean streams are abundant, especially toward the northwest. Many of the rivers draining south run dry most of the year; nonetheless, with heavy rainfall, they can cause flooding (Rivers and Lakes of Puerto Rico, 2006).

Puerto Rico is composed of volcanic and plutonic rocks from the Cretaceous and Eocene covered by sedimentary rocks from the Oligocene and present. The majority of the caves occurs in the Karts region located in the north and are from the Oligocene and present. The oldest rocks are proximally 190 million years old and are located in Sierra

Bermeja, in the southwest part of the island. These rocks represent part of the oceanic crust. The geology of the island influences the sediment distribution that reaches the ocean and remains suspended (Bawiec, 2001).

The rainy season occurs between May and December. A dryer period appears around December and can last till March (Bawiec, 2001). The north region, and especially the mountain areas, receives the most precipitation. The southwestern coastal region is characterized by a dryer period. This disparity is evident in the 189 inches of annual rain that falls over El Yunque Rain Forest in the north and the 40 inches that fall over Ponce city in the south. Annual rainfall averages about 1,550 mm (161 inches) in the north, 910 mm (36 inches) in the south, 101-381 cm (40-150 inches) in coastal regions and 508 cm (200 inches) in the mountains (Bawiec, 2001).

The previous study evaluated the dynamics of three river plumes in Mayaguez Bay and determined the distinct characteristics between them using the AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor. The concentrations of suspended sediments were obtained from water samples collected at 10 stations along the Mayaguez Bay. These samples were compared with reflectance values from AVIRIS images acquired during the same day over the Bay (August 19, 2004). These data were used to develop an empirical algorithm to estimate the concentration of suspended sediment in the Mayaguez Bay using AVIRIS. The image of suspended sediments showed higher concentrations in the Añasco and Guanajibo plumes and smaller amounts in the Yaguez (Figure 1). The Añasco plume spread out farthest into the Bay with concentrations of 15.52 mg/l near the shore and 1.40mg/l farther out into the Bay. The Guanajibo plume had a unique shape because of wave movement that transports the sediments southward along the coast with a concentration of 5.46 mg/l. The Yaguez plume did not spread out far into the bay but remained close to the shore with a concentration of 5.00mg/l (Gonzalez,2005).

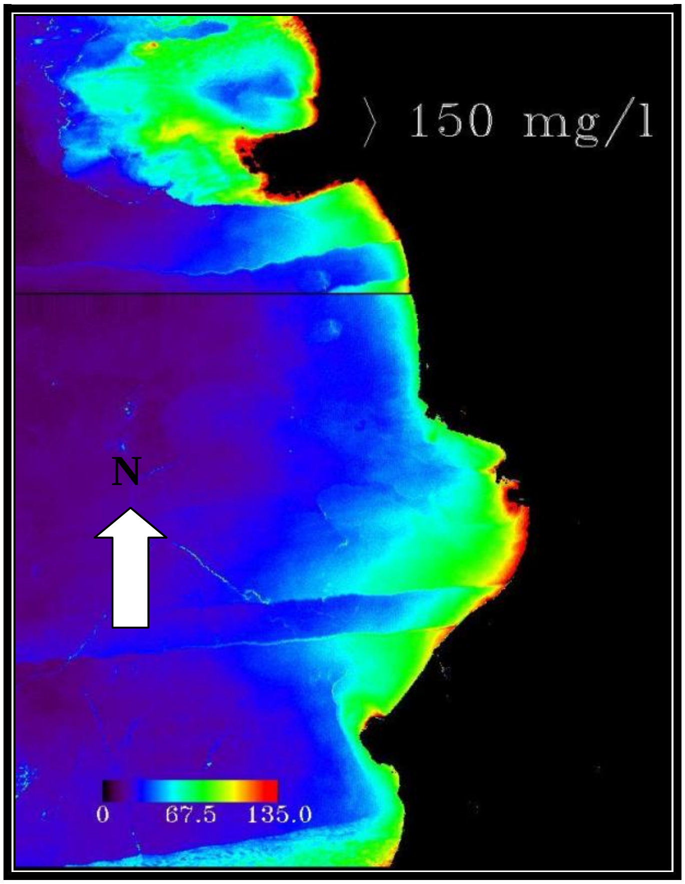


Figure 1. Suspended Sediment Concentration Image of the Mayaguez Bay area.

The main purpose of this research project was to apply the previously developed algorithm for AVRIS to study a number of river plumes throughout the coast of Puerto Rico. This research project used the valuable information obtained by AVIRIS (Airborne Visible/Infrared imagine Spectrometer) sensor and created suspended sediment concentration images for AVIRIS and MODIS. Specific rivers were chosen by analyses of their discharge, annual precipitation, and AVIRIS and MODIS images.

MODIS (Moderate Resolution Imaging Spectroradiometer) is a key instrument on board the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, and a spatial resolution of 250m (bands 1-2), 500m (bands 3-7) ,and 1000m (bands 8-36). Studies should be conducted using other sensors like MODIS because data from this sensor is more available. As well as create an images of suspended sediment concentration for the whole island of Puerto Rico for different periods of time. The results will be used to monitor the discharge and suspended sediment concentration around the coast of Puerto Rico.

As part of this research project the method that included the proper combination of bands to better understand the sediment dynamics in the Mayaguez Bay was applied to the rest of Puerto Rico’s coast. Using the developed algorithm; valuable spectral information was obtained for the rest of the island (González, 2005).

Literature Review:

Since the late 1970’s remote sensing studies of suspended sediments have been made using the fact that suspended sediments increase the radiance leaving from surface waters in the visible and near infrared region of the electromagnetic spectrum (Ritchie and Schiebe, 2000). Most researchers that had large ranges of suspended sediment concentrations (i.e., 0-200+ mg/l) have found a curvilinear relationship between suspended sediments and radiance or reflectance (Ritchie et al. 1976, 1990) They also found that when suspended sediments increase the amounts of reflected radiance tend to saturate. The point of saturation depends on wavelength, with the shorter wavelength saturating at lower concentrations. Ritchie et al. (1976) used *in situ* studies to conclude that wavelength between 700 and 800 nm were most useful for determining suspended sediments in surface waters. Many researchers have studied algorithms that separate turbid areas from shallow water areas using a combination of reflectance differences with 550nm, 660nm, and 860nm channels from MODIS. This sensor has been highly used by researchers studying suspended sediment concentrations. MODIS is widely accepted because it is a multispectral sensor with 32 spectral bands that can be applied to a variety of remote sensing applications.

Olariu (2002) used ASTER data to calculate suspended sediment concentrations in the Red River delta. Transformation of digital numbers yielded estimates of suspended sediment concentrations between 0 and 800 mg/l, but the method has some limitation for concentrations higher than 600 mg/l. The remote sensing data sets they used were obtained during relative low discharge of the Red River, but for high discharge of 3500 ft^3/s (July 2nd, 1997) suspended sediments were visible as far as 8 km away from the delta front.

González (2005) evaluated the dynamics of three river plumes in the Mayaguez Bay and determined distinct characteristics between them using AVIRIS. It was concluded that the principal factor for the diverse dynamics found on the Mayaguez Bay is the river discharge. The applied algorithm for detecting suspended sediment concentrations demonstrated that remote sensing is a useful tool for detecting changes in ocean color produced by suspended sediments.

Studies have been conducted to determine the impact of a Hurricane in the biogeochemistry and productivity of coastal regions due to their large impact on river discharge, land runoff, water circulation, and morphological conditions. Gilbes et al. (2001) studied the impact of Hurricane George on the coast of Puerto Rico using the spaceborne sensor SeaWiFS. The Hydrological data from Puerto Rico were used to evaluate the effect of runoff on ocean color patterns around the island. To better understand the origin and distribution of colored waters documented in the SeaWiFS imagery, we must establish how much water was discharged to the coastal regions of Puerto Rico for the periods preceding each image acquisition (Gilbes et al., 2001). Typically, only a portion of the rain falling on a watershed will discharge directly to the coastal waters as stream flow (Gilbes et al., 2001).

Methodology:

The images collected in Mayaguez Bay were used initially for developing the methodology to study the plumes of the Añasco, Guanajibo and Yaguez rivers (González, 2005). The developed method was applied to images collected around Puerto Rico with AVIRIS to study other river plumes. AVIRIS data was compared with a MODIS (Moderate Resolution Imaging Spectroradiometer) image. The Image processing was performed using the software called ENVI (Environmental of Visualization Images) and ACORN (Atmospheric Correction Now). It included atmospheric correction and application of developed algorithm for estimation of suspended sediment which produced images of suspended sediment concentration for the coast of Puerto Rico. Discharge and precipitation data from each selected river was studied using the USGS Water Resources of the Caribbean real time data. This helped monitor the discharge and suspended sediment concentration around the coast of Puerto Rico during image acquisition.

The island was divided into three main regions (the western, central and eastern) to quantify the discharge and precipitation data (Figure 2). The selected rivers are shown in Table 1 and Figure 3.

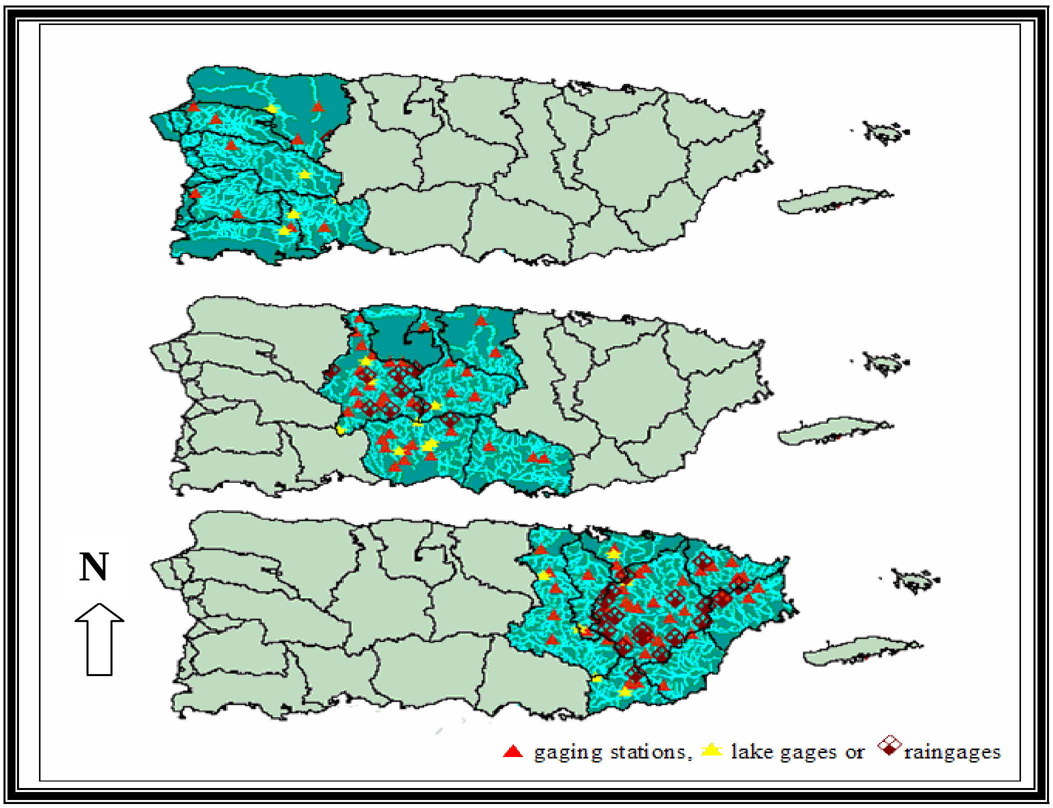
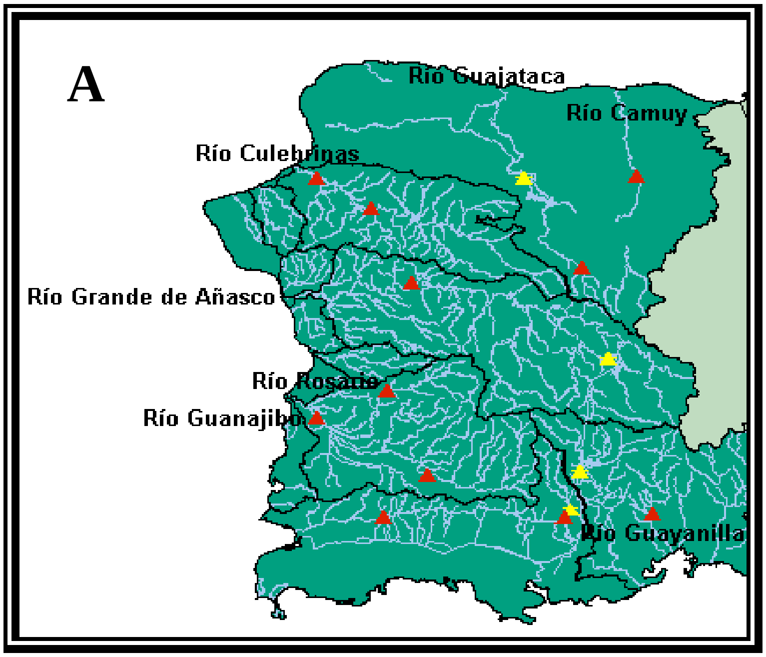
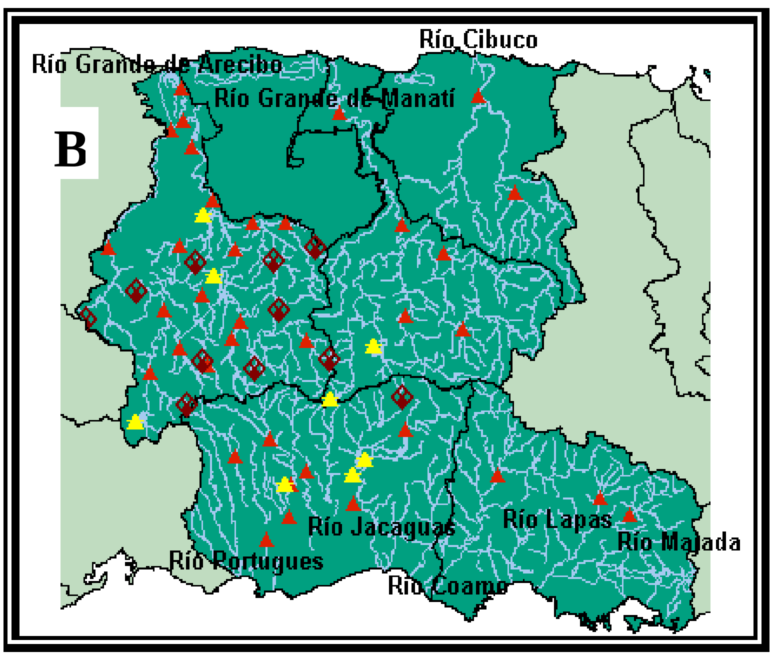


Figure2.Selected regions for this study Upper: western region, Center: central region, and Lower: eastern region (http://pr.water.usgs.gov/, USGS Water Resources of the Caribbean Real Time Data).

Region	***Rivers***
Western	Añasco
	Culebrinas
	Rosario
	Guajataca
	Camuy
	Guanajibo
	Guayanilla
	Yaguez
Central	Grande de Arecibo
	Manatí
	Cibuco
	Jacaguas
	Portuguese
	Majada
	Lapas
	Coamo
Eastern	La Plata
	Piedras
	Fajardo
	Marín
	Quebrada Grande
	Espíritu Santo
	Maunabo
	Mameyes
	Grande de Patilla Rivers

Table 1. Rivers selected for the study (http://pr.water.usgs.gov/, USGS Water Resources of the Caribbean Real Time Data).


A
Río Guajataca
Río Camuy
Río Culebrinas
Río Grande de Añasco
Río Rosario
Río Guanajibo
Río Guayanilla


B
Río Cibuco
Río Grande de Arecibo
Río Grande de Manatí
Río Jacaguas
Río Lapas
Río Majada
Río Portugues
Río Coamo

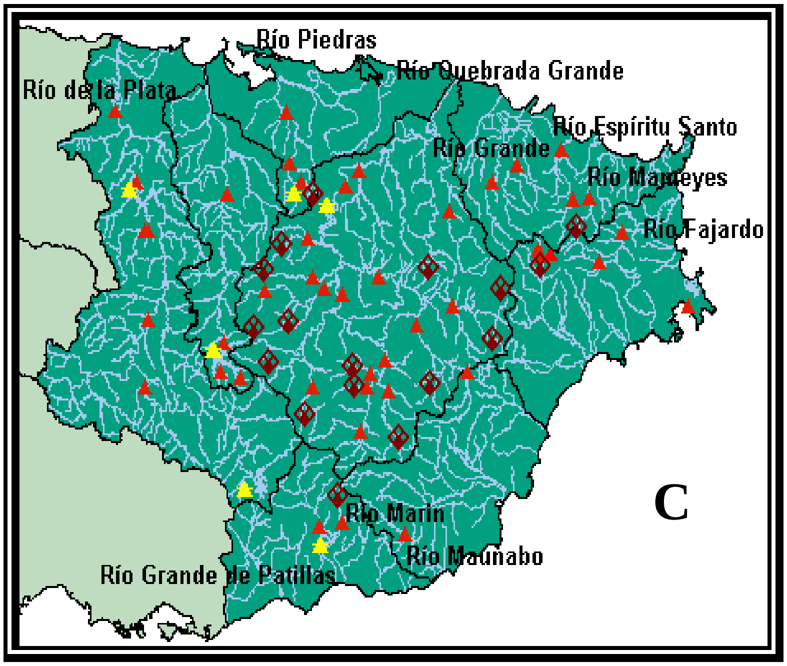


Figure 3. Selected study areas in detail (A) Western region, (B) Central region and (C) Eastern region: Rivers selected for the study (http://pr.water.usgs.gov/, USGS Water Resources of the Caribbean Real Time Data).

MODIS sensor is a high quality sensor for detecting changes in ocean color produced by suspended sediments because it is a multispectral sensor mounted in a satellite which continually orbits the earth acquiring images around the year (Table 2). This characteristic is useful for monitoring suspended sediments concentration in the coast of Puerto Rico.

Table 2. Spectral characteristics between the AVIRIS and MODIS sensors.

Characteristics	AVIRIS	MODIS
Spectral Bands	224	36
Spatial Resolution	4m or 20m	250 m,500 m,or1000 m
Spectral Range	400 to 2500 nm	620 to 14085 nm
Mission Life	5 years	6 years

Laboratory Work:

Image processing:

- Transects A-B, C-D, K-J, L-M, and E-F from the August 19,2004 AVIRIS images of Puerto Rico were selected for this study (Figure 4) as well a August 2,2004 MODIS image of Puerto Rico.

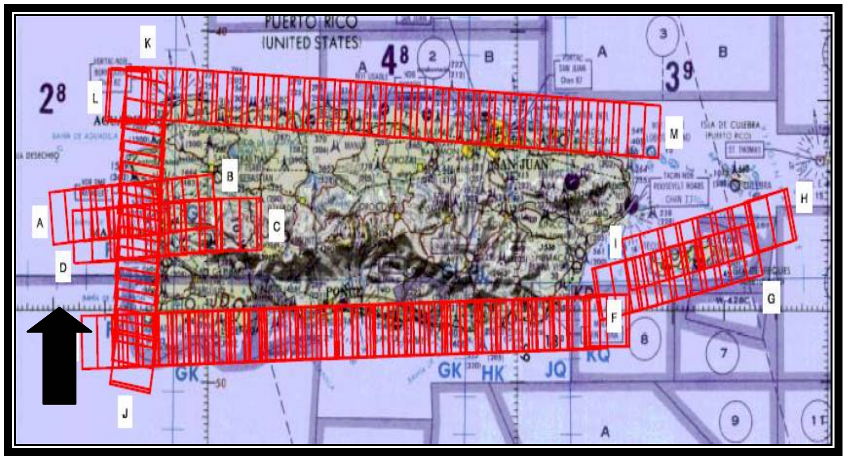


Figure 4. Map of Puerto Rico with the areas covered by AVIRIS in August 19, 2004 (Flight Summary Report Guild, NASA Ames Research Center, 2003).

- Using ACORN (Atmospheric COrrection Now) an accurate atmospheric correction was produced for the five AVIRIS images.
- Using ENVI (Environmental of Visualization Images) regions of interest along two transects were developed in a 3x3 pixel range for each of the selected rivers. Transects were created long shore [C-D] and inshore-offshore [A-B].The transects were 7.4 km long and were perpendicular to each other. Seven points from 0 km to 7.4km were selected for the long shore transect and 5 points every two kilometers for the inshore-offshore transect. Figure 5 shows both transect for Río Camuy. The distance of the transects was chosen based on the extent of the Añasco plume.

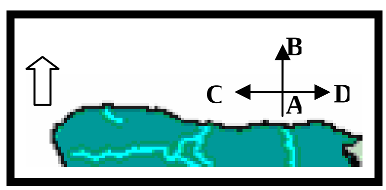


Figure 5. Example of transect for the Río Camuy.

- The discharge and precipitation data for each of the rivers were obtained from the USGS Water Resources of the Caribbean real-time data. This was organized in Microsoft Excel Software.
- The previously developed algorithm for Suspended Sediment Concentration using band 46(777nm) from AVIRIS was entered into ENVI (Environmental of Visualization Images) to generate the images of suspended sediment concentration for the AVIRIS and MODIS images.
- Suspended Sediment Concentration data was obtained from each of the transects in the AVIRIS images.

- A mask for the suspended sediment concentration image was created to distinguish between turbid sediment waters and clear waters for the AVIRIS and MODIS images.
- The AVIRIS images from the western, central and eastern regions were combined using the mosaic module of ENVI to create suspended sediment concentration images for each region.
- The final AVIRIS images were compared with the suspended sediment concentration MODIS image.

Results:

The previously developed algorithm was obtained from multiple graphs that were developed between suspended sediment concentrations from the water samples and reflectance values from each of the 20 bands in the red and infrared region in the Mayaguez Bay area. Only the bands with high correlation values were used to develop the algorithm.

A linear fit was also run with the near infrared spectrum data at 777 nm and a correlation (R^2) of 0.82 was obtained (Figure 6). The fitted line has the following equation: Suspended Sediment Concentration (mg/l) = a (x) + b

Where, **a** = 0.0829

b = 0.0325

x is the reflectance of band 46 (777nm).

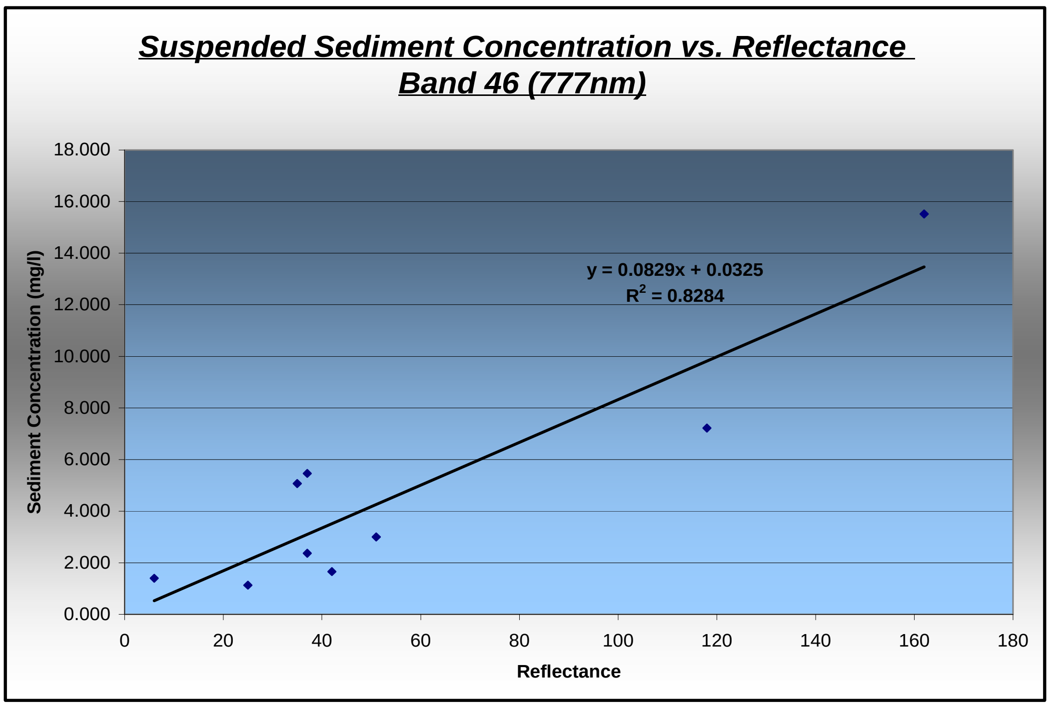
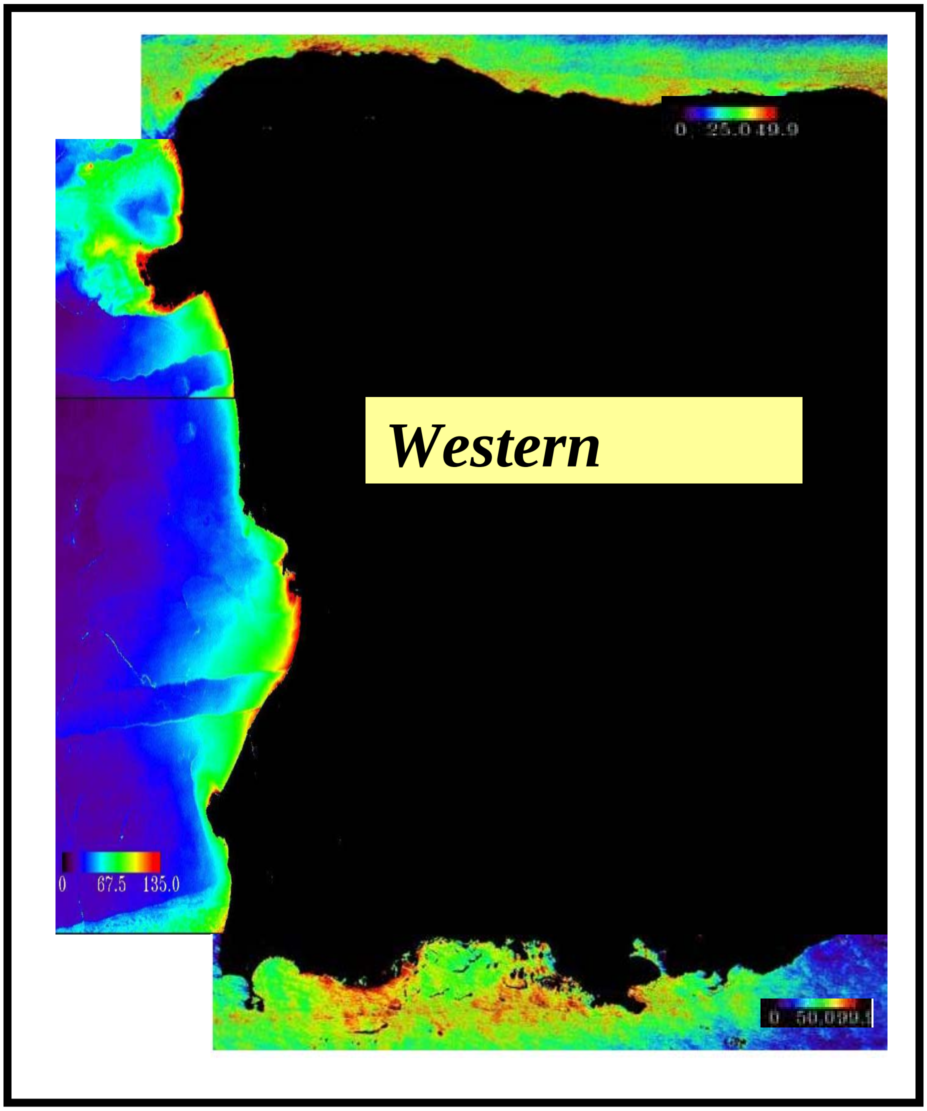


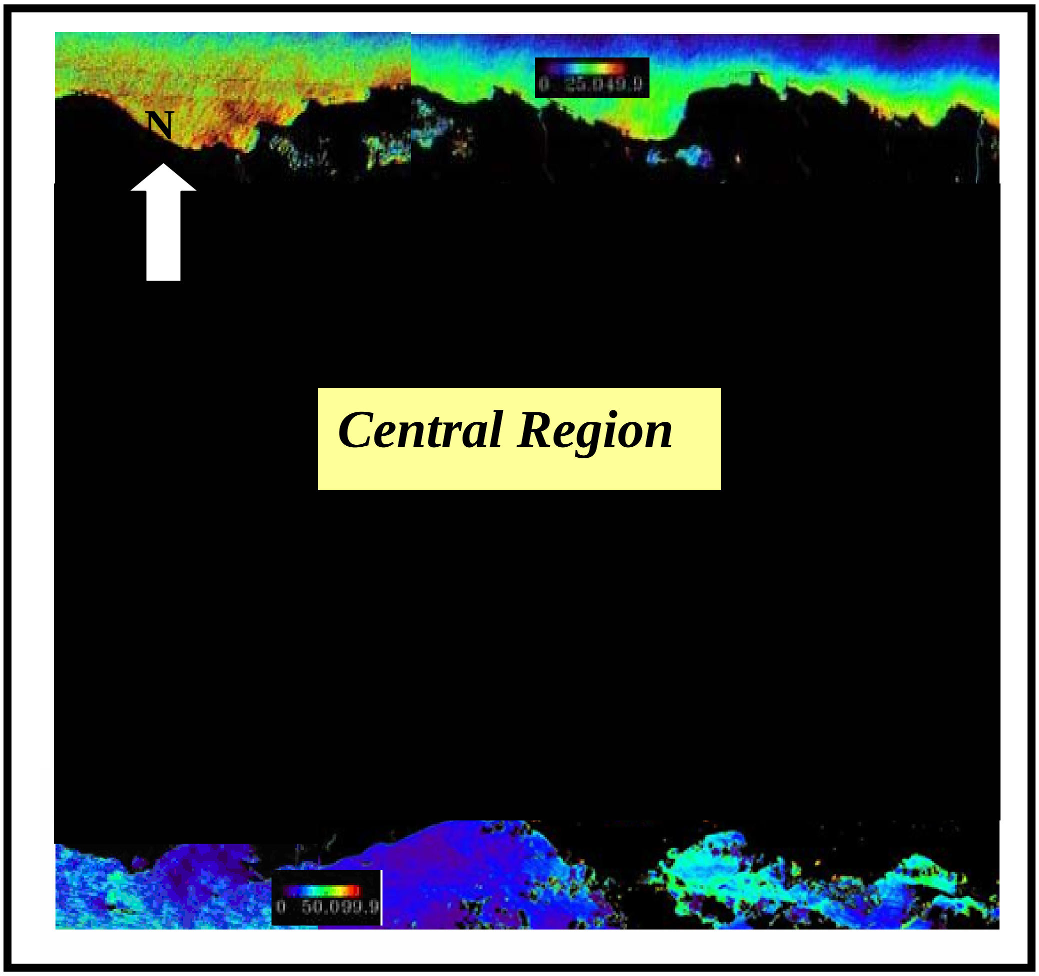
Figure 6. Suspended Sediment Concentration versus Reflectance in Band 46 (777nm).

Finally, AVIRIS images of suspended sediment concentration were developed using the algorithm obtained from band 46 (777 nm) (Figure 7). MODIS images of suspended sediment concentration were developed (Figure 8).

A.



B.



C.

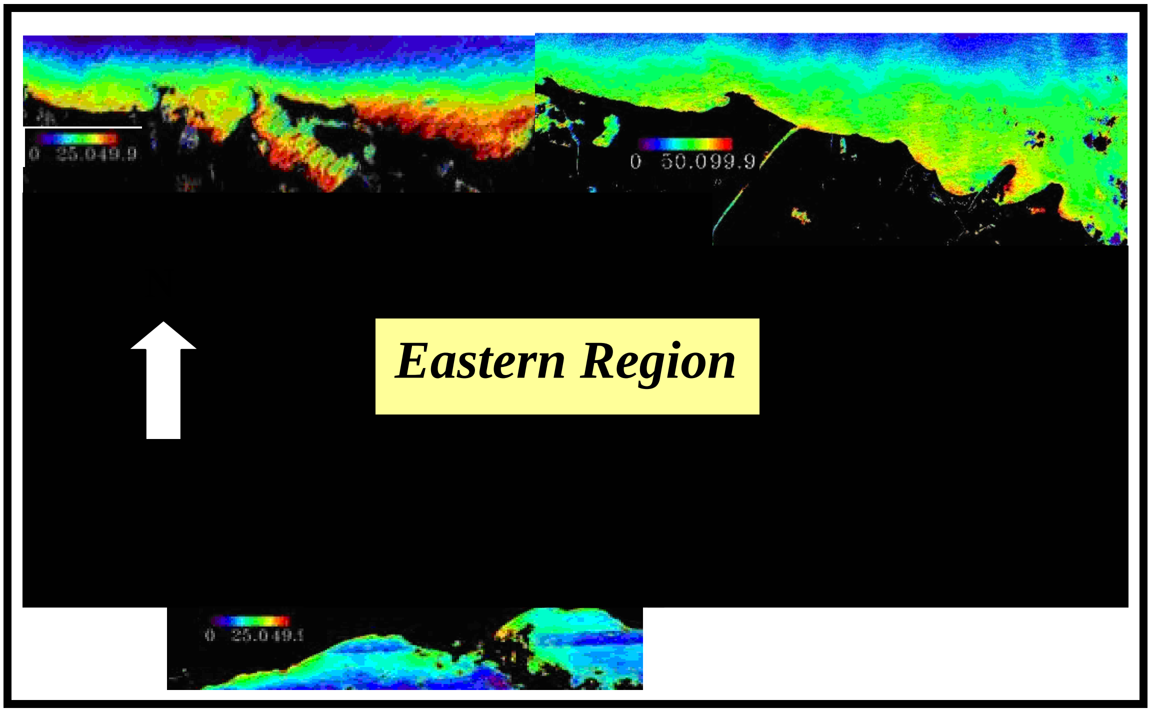


Figure 7. Suspended Sediment Concentration Images of the Western, Central and Eastern Regions.

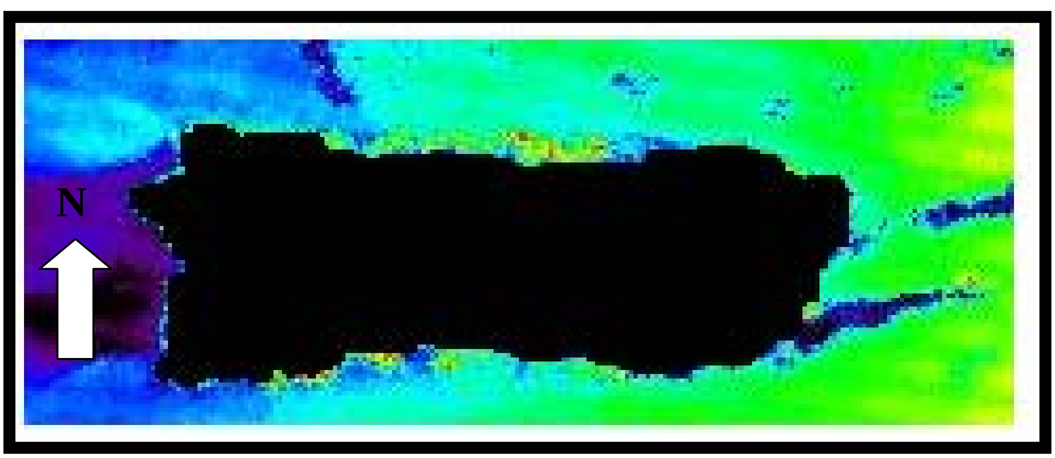


Figure 8. Suspended Sediment Concentration MODIS Image of Puerto Rico (August 2, 2004).

The variability of suspended sediment concentrations along the inshore-offshore and longshore transects in each river is presented in Figure 9. The nearest point to each river mouth is located at 4 km.

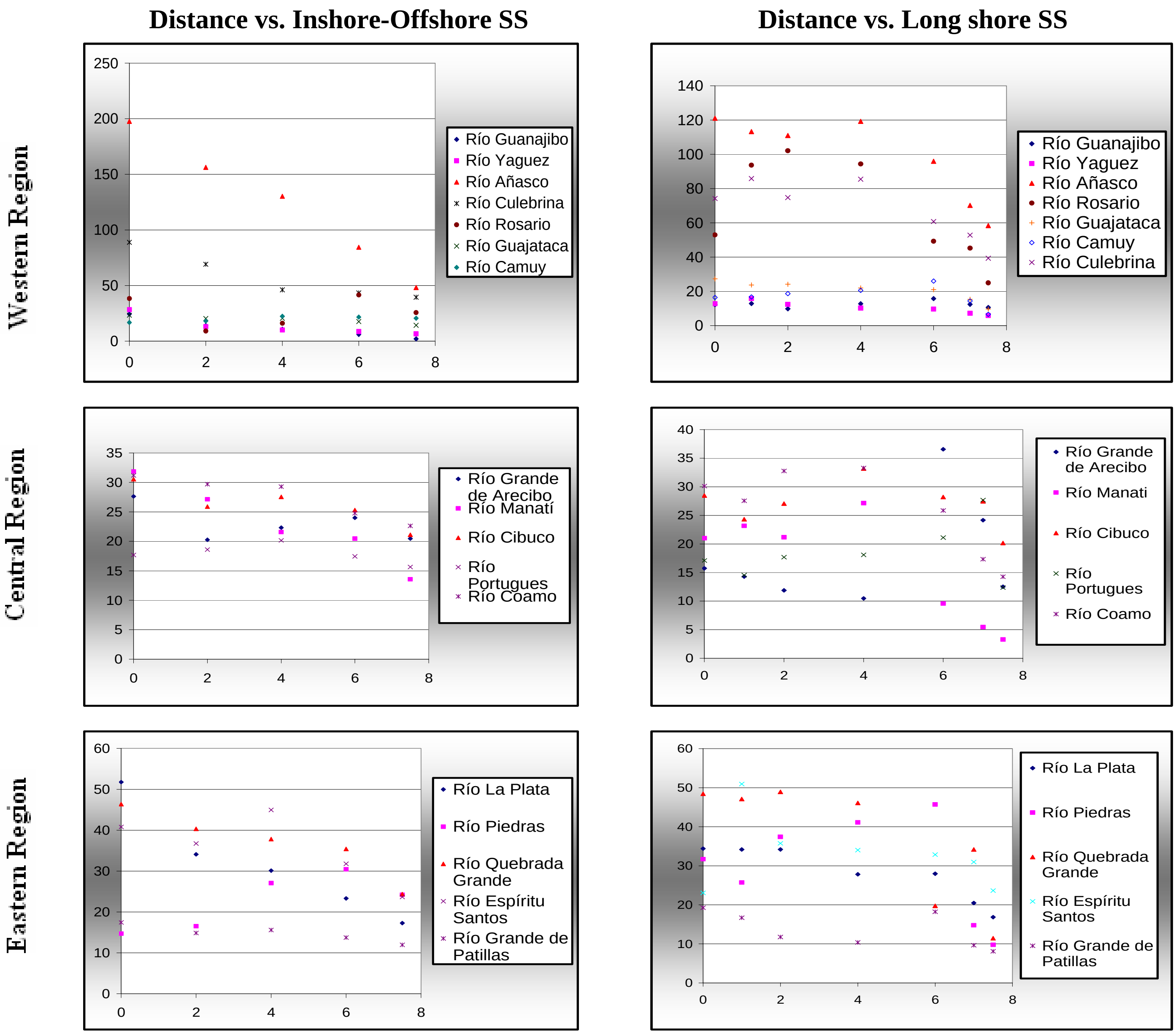


Figure 9. Western, Central, and Eastern region Inshore-Offshore and Longshore suspended sediment concentration data. Note different scales on ordinate axes.

Discharge and precipitation data was acquired for the selected rivers to develop a relationship between suspended sediment concentrations and discharge from the nearest inshore point to the farthest offshore point and precipitation (Figure 10). The precipitation data is a total sum of the amount of inches of rain for each region (Figure 11). For the western region there was no precipitation data available in the USGS Water Resources of the Caribbean Real Time Data Base.

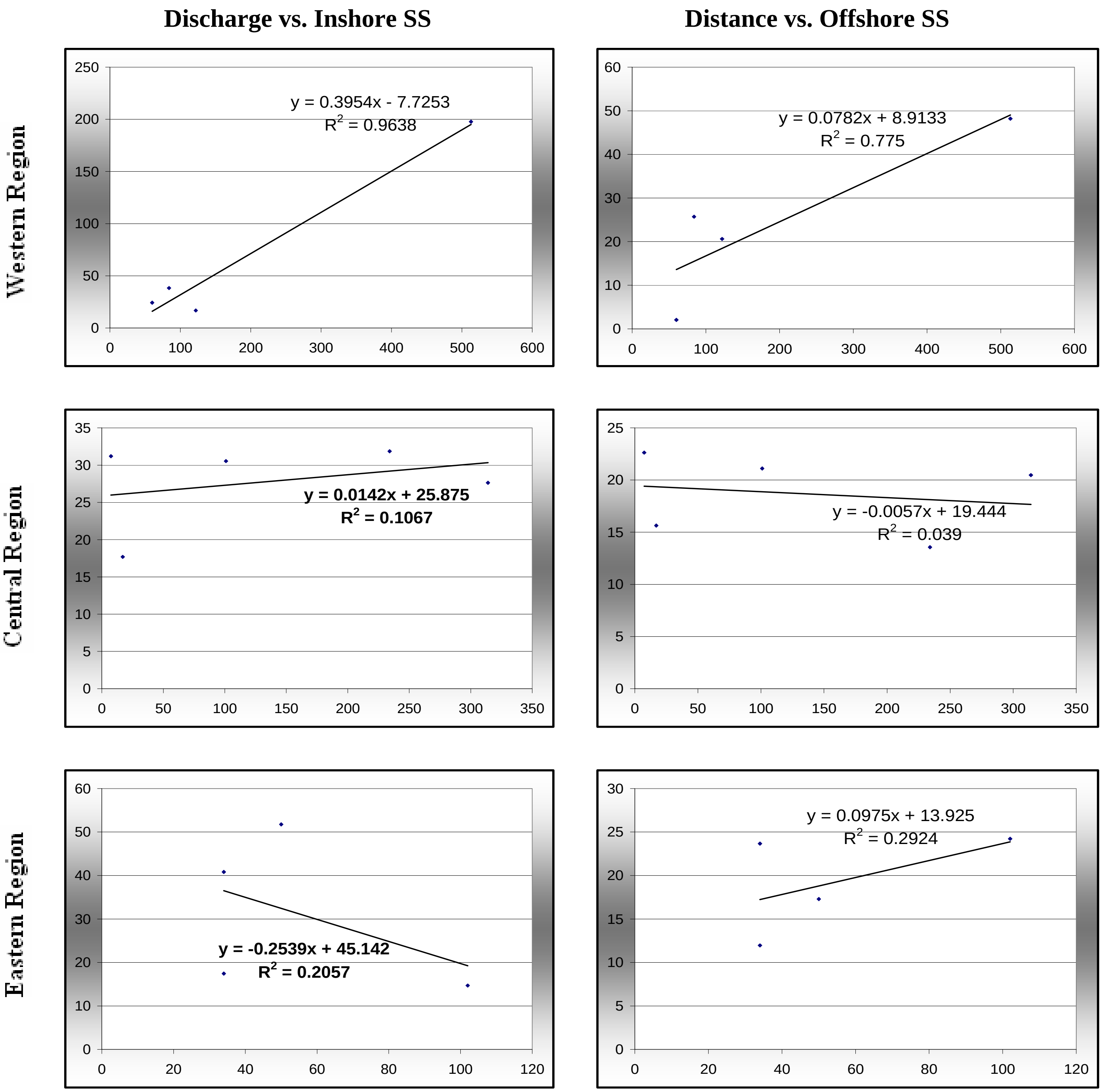


Figure 10. Western ,Central, and Eastern regions inshore and offshore suspended sediment concentration data and discharge relationship. Note different scales on ordinate axes.

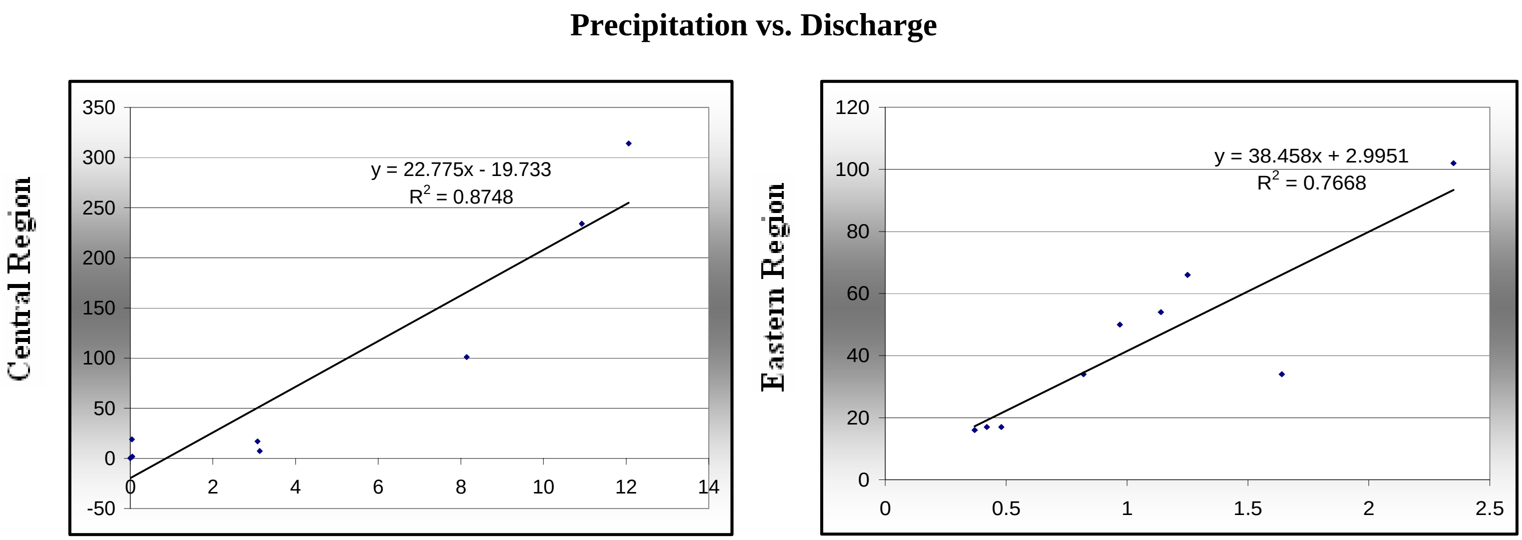


Figure 11. Central and Eastern regions discharge and precipitation relationship. Note different scales on ordinate axes.

Discussion and Interpretation:

The coast of Puerto Rico has a series of dynamic environments that involve the continuous deposition of sediments from its rivers. However, the Añasco River is the main supplier of sediments when compared with the rest of the Island rivers (González, 2005). The river plumes are formed when the amount of sediments transported into the ocean becomes larger than ocean erosion can carry away; especially in periods of heavy rainfall.

The AVIRIS images taken on August 19, 2004 show changes in ocean color especially near the Añasco, Grande de Arecibo, Manatí , and La Plata river mouths; indicating large amounts of discharge. Daily discharge data was obtained for a group of rivers to compare with suspended sediment concentrations from AVIRIS. The USGS daily discharge data shows high discharge from the Añasco, Camuy, Grande de Arecibo, Manatí, Cibuco, and Piedras rivers (Appendix: Table 2).

Relationships between suspended sediment concentrations and distance were developed to see the river plumes behavior. Graphs were created using the inshore and offshore suspended sediment concentration data as well as dividing the data into regions. The western region showed high amounts of suspended sediment concentration near the river mouth at 0 km. The highest amount of suspended sediment was found in the Añasco River with 197.66 mg/l and the lowest amount at the Camuy River with 16.77 mg/l. The western region showed a decrease in suspended sediments moving offshore in all of the selected rivers. The central region showed high amounts of suspended sediment concentration near the river mouth at 0 km. The highest amount of suspended sediment was found in the Manatí River with 31.86 mg/l and the lowest amount at the Portuguese River with 17.69 mg/l. The central region showed a decrease in suspended sediments moving offshore in all of the selected rivers but not as dramatic as the western region. The eastern region showed high amounts of suspended sediment concentration near the La Plata, Quebrada Grande, and Espíritu Santos River mouths at 0 km. However, estrange variations in suspended sediment concentrations in the Piedras River starting inshore with 14.70 mg/l and finishing offshore with 24.22 mg/l. The highest amount of suspended sediment was found in the La Plata River with 51.76 mg/l and the lowest amount at the Piedras River with 14.70 mg/l. The eastern region showed in general a decrease in suspended sediments moving offshore in all of the selected rivers.

A relationship was developed using the long shore suspended sediment concentration data for each region. The western region showed high amounts of suspended sediment concentration in the river mouth at 4 km. The highest amount of suspended sediment was found in the Añasco River with 119.24 mg/l and the lowest amount at the Yaguez River with 10.25 mg/l. The western region showed a decrease in suspended sediments moving north along the coast for all of the selected rivers. Variations in suspended sediment concentration were observed southward because of wave movement. The central region showed high amounts of suspended sediment concentration at the river mouth at 4 km. The highest amount of suspended sediment was found in the Coamo and Cibuco Rivers with 33.27 mg/l and 33.19 mg/l. The lowest amount was found at the Grande de Arecibo River with 10.47 mg/l. The central region showed a decrease in suspended sediments moving eastward along the coast for all of the selected rivers. The Grande de Arecibo plume had a unique shape because of wave movement that transported the sediments eastward along the coast increasing suspended sediments with a concentration of 36.56 mg/l. The eastern region showed high amounts of suspended sediment concentration near the river mouth from 0-2 km. The highest amount of suspended sediment was found in the Espíritu Santos River with 50.93 mg/l and the lowest amount at the Grande de Patillas River with 11.76 mg/l. The eastern region showed a decrease in suspended sediments moving eastward for all of the selected rivers. The Piedras plume increased in suspended sediments eastward but then decreased swiftly this may be caused by wave movement because most of the sediment influx into higher-energy coastlines is distributed laterally along the shoreline by wave action (Easterbrook, 1999).

Discharge data acquired for each river was compared with the inshore suspended sediment concentration. In the western region there was 0.96 value of correlation which indicates high correlation between the suspended sediment data from the image and discharge. For the central region the value of correlation was 0.11 which indicates very low correlation between suspended sediment concentrations and river discharge. This could be caused by the basin size and extent of the rivers when compared with the western region, high energy waves in the north coast and the low amount of rain that fell during August 19, 2004.The eastern region behaved similar to the central region with a value of correlation of 0.21.When compared with the offshore suspended sediment concentrations a similar behavior was found. The western region had a value of correlation of 0.78 which is high but not as good as the inshore data for this region. The behavior of the central and eastern regions was similar with poor correlation values of 0.03 and 0.29. This occurs because of the decrease in suspended sediments from 5-8 km offshore due to the hydrodynamic interactions between the rivers fresh water and seawater as well as differences in density produced by sediment load, and wave and current action in the ocean (Easterbrook, 1999).

The spreading distance of the plumes depend on the frictional inertia between the freshwater and seawater. Because there is limited mixing in the boundaries of the plume, there is relatively little frictional inertia (Prothero, 1996). That is why some river plumes go a long way seaward before freshwater breaks up and mixes with seawater. The shape of the plume will depend on the rate of sediment influx relative to the wave and current energy of the sea (Prothero, 1996).

Precipitation data was also acquired to develop a relationship with discharge. The USGS real-time data had no precipitation data available for the western region. The central and eastern regions showed high correlation values of 0.87 and 0.77 which indicated that the amounts of rain fall will affect the discharge. The central region showed higher amounts of precipitation with a total of 37.43 inches and the eastern region had low precipitation with a total of 9.44 inches.

The precipitation, discharge and suspended sediment concentration data help understand the sediment dynamics along the coast of Puerto Rico. There is an intimate relationship between the amount of rain fall in the three main regions (western, central, and eastern) and the discharge of each selected river. The high amount of rain fall increases discharge that produces higher amounts of suspended sediment concentration.

The AVIRIS images of suspended sediment concentration show higher amounts of suspended sediments in the west and north parts of the island. The western region showed higher suspended sediment concentrations when compared to the central and eastern regions. The MODIS image shows higher suspended sediment concentration in the western region as well. The AVIRIS and MODIS sensors are dependable for understanding the dynamics of suspended sediment around the coast of Puerto Rico because of there ability to show distinct differences in ocean color.

Conclusions:

The principal factor for the diverse dynamics found in the coast of Puerto Rico is river discharge produced by the main rivers that reach the ocean. The coast is influenced by the amount of deforestation and development that favor erosion and transport soil particles into the river. These suspended sediments are transported into the ocean causing turbidity in the water and differences in ocean color.

The AVIRIS image of suspended sediment concentration shows very well the various sediment dynamics throughout the western, central and eastern regions. The three main regions showed distinct characteristics between them; discharge, spreading of the plume and suspended sediment concentrations. The developed images showed higher amount of sediments in the Añasco, Lajas and Culebrina plumes and smaller amounts for the Yaguez, Guanajibo, Rosario, Guajataca and Camuy in the western region. The Añasco plume spread out farthest into the ocean with a high suspended sediment concentration of 197.66 mg/l near the shore and 48.19 mg/l farther out offshore. The developed images showed similar high amount of sediments in the Arecibo, Manatí, Cibuco, and Coamo plumes and smaller amounts for the Portuguese in the central region. For the eastern region the developed images showed higher amount of sediments in the La Plata, Quebrada Grande and Espíritu Santos plumes and smaller amounts for the Piedras and Grande de Patillas. The western region showed the highest amount of discharge and suspended sediment concentrations.

The applied techniques and developed algorithm demonstrated that remote sensing is a useful tool for detecting changes in ocean color produced by suspended sediments. The combination of bands and the value of correlation depend on the amount of field data available. Future studies must include more field data.

Further studies should be conducted using other sensors like MODIS because data from this sensor is more available. The most important factor would be the amount of field data used to compare with reflectance values in the red and infrared range of the spectrum. As well as create an images of suspended sediment concentration for the whole island of Puerto Rico for different periods of time. The results will be used to monitor the discharge and suspended sediment concentration around the coast of Puerto Rico.

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Acknowledgments:

I would like to thank the Space Information Laboratory of the University of Puerto Rico at Mayaguez for providing the MODIS image of Puerto Rico. I have to thank Wilfredo Alequín for helping me with supplies and transferring data to the GERS lab computers. Thanks to my advisor, Dr. Fernando Gilbes for answering all my questions.

Appendix

Table 1. Suspended Sediment Concentrations (mg/l) for each river transect.

Region	River		Transects A-B [ss] (mg/l)	Transects C-D [ss] (mg/l)
Western				
	Río Guanajibo		24.32	12.21
			14.04	12.88
			10.72	9.84
			6.06	12.79
			2.06	15.78
				12.38
				10.59
	Río Yaguez		28.38	12.79
			13.13	15.78
			10.06	12.38
			8.65	10.25
			6.59	9.65
				7.24
				5.89
	Río Añasco		197.66	121.06
			156.29	113.26
			130.27	46.95
			84.42	119.24
			48.197	95.94
				70.16
				58.39
	Río Culebrina		88.90	74.23
			69.17	85.50
			46.2	60.79
			43.39	52.84
			39.47	39.33
				36.50
				39.33
	Río Lajas		95.69	94.87
			98.60	103.35
			35.35	125.46
			32.59	135.06
			28.54	120.27
				115.36
				91.23
	Río Rosario		38.33	12.96
			9.15	93.62
			16.11	102.08
			41.57	94.36

			25.71	54.36
				49.23
				45.24
	Río Guajataca		23.33	27.30
			20.34	23.74
			20.50	24.15
			17.65	21.98
			14.36	20.97
				15.36
				9.67
	Río Camuy		16.77	16.44
			18.18	16.77
			22.33	18.68
			21.66	20.59
			20.61	25.98
				14.37
				6.57
Central				
	Río Grande de Arecibo		27.63	25.73
			20.26	14.29
			22.33	11.88
			23.99	10.47
			20.47	36.56
				24.16
				12.50
	Río Manatí		31.86	21.00
			27.14	23.16
			21.58	21.17
			20.47	27.14
			13.56	9.57
				5.45
				3.28
	Río Cibuco		30.54	28.47
			25.89	24.32
			27.55	27.05
			25.31	33.19
			21.11	28.21
				27.45
				20.16
	Río Portuguese		17.69	17.10
			18.60	14.54
			20.17	17.69

			17.45	18.10
			15.64	21.11
				27.68
				12.37
	Río Coamo		31.20	30.12
			29.71	27.55
			29.29	32.77
			24.78	33.27
			22.63	25.86
				17.33
				14.25
Eastern				
	Río La Plata		51.76	34.4
			34.1	34.18
			30.12	34.19
			23.33	27.80
			17.29	27.96
				20.47
				16.84
	Río Piedras		14.70	31.70
			16.52	25.73
			27.06	37.42
			30.45	41.12
			24.22	45.71
				14.76
				9.77
	Río Quebrada Grande		46.37	48.44
			40.32	47.11
			37.83	48.94
			35.41	46.12
			24.36	19.75
				34.19
				11.44
	Río Espíritu Santos		40.81	23.07
			36.75	50.93
			44.96	35.76
			31.78	34.02
			23.67	32.85
				30.97
				23.64
	Río Grande de Patillas		17.44	19.26
			14.87	16.69

			15.61	14.37
			13.74	11.76
			11.96	10.37
				18.22
				9.65
				8.10

Table 2. Discharge and Precipitation data for the western, central and eastern regions.

Region	River	Date (dd/mm/yyyy)	Discharge (cubic feet per second)	Precipitation (sum of inches)
Western				
	Río Guanajibo	19/08/2004	60	No data available
	Río Añasco	19/08/2004	513	No data available
	Río Rosario	19/08/2004	84	No data available
	Río Camuy	19/08/2004	122	No data available
	Río Guayanilla	19/08/2004	30	No data available
Central				
	Río Cibuco	19/08/2004	314	8.14
	Río Jacaguas	19/08/2004	234	0.04
	Río Coamo	19/08/2004	101	3.13
	Río Lapas	19/08/2004	17	0
	Río Grande de Arecibo	19/08/2004	7.4	12.06
	Río Majadas	19/08/2004	19	0.05
	Río Manatí	19/08/2004	0.3	10.93
	Río Portuguese	19/08/2004	1.9	3.08
Eastern				
	Río La Plata	19/08/2004	50	0.97
	Río Piedras	19/08/2004	102	2.35
	Río Espíritu Santos	19/08/2004	34	1.64
	Río Grande de Patillas	19/08/2004	34	0.82
	Río Mameyes	19/08/2004	66	1.25
	Río Fajardo	19/08/2004	54	1.14
	Río Marin	19/08/2004	17	0.48
	Río Maunabo	19/08/2004	16	0.37
	Río Grande	19/08/2004	17	0.42