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Plume analysis in six rivers of Puerto Rico using MERIS

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Abstract

This research evaluate the relationship between rainfall events, river discharge, and the dynamics of river plumes (specifically, their effect on suspended sediments and chlorophyll) in coastal areas of Puerto Rico. More precipitation in the island, and large river discharge, is shown from August to November (Gilbes et al., 1996). Therefore, maximum values of total suspended matter (TSM) and chlorophyll (CHL) has been registered (Gilbes et al., 1996). Consequently, during the wet season more concentration of TSM and CHL will be registered during this research and will affect the coastal ecosystem and carbonate production. The Medium Resolution Imaging Spectrometer (MERIS), a sensor on the ENVISAT-1 of the European Space Agency that has a spectral resolution of 300 meters was used to determine the TSM and CHL concentrations.

Keywords: Total suspended matter, River discharge, River plumes, MERIS,

Introduction

Storms and strong rainfall events are responsible for the majority of the total suspended matter (TSM), and nutrient fluxes in the streams that eventually go to the ocean (Hoover and Mackenzie, 2009). Storms also cause landslides, which are a source of soil erosion and sediments yield in the catchments (Hone-Jay et al., 2013). The land use will affect and make some changes in the fluvial fluxes, specifically in the TSM, the nutrients and the water (Hoover and Mackenzie, 2009). A storm or a strong rainfall event will bring to the ocean large inputs of dissolved nutrients and could be unfavorable to photosynthetic organisms because there will be low light, turbidity increase, rapid mixing of plumes which result in dilution of nutrients (Hoover and Mackenzie, 2009; Devlin et al., 2012). This factors could cause medium to long term impacts, such as reduce the densities of juvenile corals, changes in community composition, decreased species richness and changes to communities that are dominated by more resistant coral species and macroalgae (Devlin et al., 2012). Also, turbidity inhibits carbonate production due it reduces the amount of light reaching the sea floor affecting the growth of calcareous algae, sea grass and any photosynthetic organism such as phytoplankton which needs light for photosynthesis (Tucker and Wright, 1991). Therefore, it is important to know the relationship between storm or strong rainfall events with the river discharge and the dynamics of river plumes around the coast of Puerto Rico. From August to November, there is more precipitation in the island, and large river discharge, therefore maximum values of total suspended matter (TSM) and chlorophyll (CHL) are registered (Gilbes et al., 1996). Consequently, during the wet season more concentration of TSM and CHL will be registered during this research and will affect the coastal ecosystem and carbonate production (Tucker and Wright, 1991).

Flood plume waters are buoyant freshwater masses and are found in the surface layer until it dispersed or it mixed into the water column (Devlin et al., 2012). This is why water sampling is collected on the top surface layer of the flood plumes, and remote sensed data recovered from surface water can be used to describe flood plumes (Devlin et al., 2012). Based on water quality parameters that can be measured from space, ocean colour satellite imagery offers large scale information of the flood plume spatial and temporal distribution (Devlin et al., 2012). Remote sensing methods are relatively cost effective and detects, monitor and gather a variety of information (Devlin et al., 2012).

The ocean colour sensor which will be use in this study is the Medium Resolution Imaging Spectrometer (MERIS), on board the ENVISAT-1 satellite of the European Space Agency and had a spatial resolution of 300 m which made it the first ocean colour sensor adequate for monitoring coastal areas (Kratzer et al., 2008). The sensor has a spectral resolution of 15 programmable spectral bands (Kratzer et al., 2008). After atmospheric correction, the MERIS Case 2 water algorithm uses the logarithm of remote sensing reflectance above surface in eight of the fifteen bands (Kratzer et al., 2008). The eight bands used for deriving the level 2 products are centered at 412, 442, 490, 510, 560, 620, 665 and 708 nm (Kratzer et al., 2008). The software called BEAM (http://www.brockmann-consult.de/cms/web/beam/) will be used for processing the MERIS data, which is an open source application to visualize, analyze and process the data (Kratzer et al., 2008).

The objectives of this research are: (1) learn and use the software BEAM to process the MERIS images, (2) determine the concentration of total suspended matter (TSM) and phytoplankton chlorophyll-a (CHL) in six streams of Puerto Rico during five strong rainfall events in a 10 years period, (3) compare TSM and CHL concentration during before and after the strong rainfall events; (4) and finally, establish a relationship between rainfall, river discharge and the plume dynamics in the coast of Puerto Rico.

Study Sites

The area of interest is all the rivers in Puerto Rico that discharge into to the Atlantic Ocean and the Caribbean Sea. But since there are too many rivers in Puerto Rico, the island will be divided into four sections (North, South, East and West), and the rivers selected for this study will be *Río Grande de Arecibo, Río La Plata*, *Río Jacaguas*, *Río Grande de Patillas*, *Río Grande de Añasco* and *Río Fajardo*. Figure 1 presents the six streams and Table 1 shows the GPS coordinates for each stream. Figures 3 to 7 show their location separately.

As the name suggest Rio Grande de Arecibo is in the town of Arecibo. The valley floor of the Rio Grande de Arecibo has a gently slope with an elevation approximately of 80 feet above sea level. Throughout the Arecibo- Manatí region alluvial, blanket sand, swamp and beach deposits of Quaternary age overlie the limestone formations. The alluvial deposits are composed of moderately well sorted stratified sand, gravel, silt and clay. The thickness of the alluvial deposits within the Rio Grande de Arecibo valley average about 130 feet thick in the southern part of the valley. Also, the river deposits blanket sands, which are composed of quartz and clay varying greatly in proportions (Veve and Taggart, 1996). The other river in the North which will be study is the longest river (62 miles) in Puerto Rico, the Río La Plata, in which its flood plain is in the Vega Baja Town. The headwaters of Rio La Plata are at an elevation of 2,960 feet. Alluvial deposits of 110 feet thick are found along stream valley, and in the coastal plain are swamp and marsh deposits. Pleistocene silica sand deposits form most of the ridge of the coastal terrace deposits, along the edges of the coastal plain (Veve and Taggart, 1996).

In the South one of the rivers that shall be studied is Rio Grande de Patillas in the town of Patillas. Quaternary alluvial deposits overlap the Juana Diaz Formation and are composed of layers of unconsolidated to poorly consolidated clay, sand, gravel and rounded to angular boulders. These deposits are the most important lithologic units in this region because it contains a considerable acquire (Veve and Taggart, 1996). The river is Rio Jacaguas in the Juana Diaz town. Alluvial deposits of Quaternary in age overlie the Juana Diaz Formation and Ponce Limestone. These deposits consist of poorly bedded and sorted gravel, sand, silt, and some clay. The thickness of these alluvial deposit ranges from 200 to 2,000 feet (Veve and Taggart, 1996).

In the West side the Rio Grande de Añasco will be analyzed, which is locating in the Añasco town. In its valley are volcanic and volcaniclastic rocks of Cretaceous age which are overlain by Quaternary alluvial deposits. The alluvial fill in the valley is composed of clay, silt, and sand with gravel deposits also thin corridors of alluvium have been deposited along the Rio Grande de Añasco. Swamp deposits are present in the valley (Veve and Taggart, 1996).

In the East the selected river is Rio Fajardo and the flood plain alluvium is mostly unconsolidated, poorly sorted to moderately well sorted, commonly thick bedded sand, gravel and clay. In the valley of Rio Fajardo the flood plain forms piedmont plains with a thickness of 35 m (Briggs and Aguilar-Cortés, 1980).

Methods

The study period covered 5 of the 10 years of MERIS operation, from April 2002 until April 2012. In this period strong rainfall events were selected and an image from before the events was chosen. To identify the selected events a combination of rainfall data from the National Weather Service (NWS) and the available cloud-free images from MERIS was used. Preliminary, 18 rainfall events were chosen, then while selecting the cloud-free images from MERIS this number was reduced to 5 events. The events days are: Nov 23, 2007; Oct 19, 2008; Sep 18, 2009; Nov 17, 2009 and Oct 18, 2010.

After the events were selected, the images from MERIS were downloaded from NASA website (http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=me&typ=FRS). Once the images from MERIS were downloaded they were processed from raw image (level 1) to final products (level 2) using the BEAM software and MERIS Case 2 Regional Processor, which has 3 different algorithms and the final products were the concentration of total suspended matter (TSM), and phytoplankton chlorophyll-a (CHL), as decribed in Aceituno (2013).

Also, the stream discharge data from the available USGS gauging stations in selected streams were downloaded from the USGS website (http://pr.water.usgs.gov/). The USGS gauging stations were: USGS 50144000 *Río Grande de Añasco* in San Sebastián, USGS 50029000 *Río Grande De Arecibo* at Central Cambalache, USGS 50046000 *Río De La Plata* At Hwy 2 Nr Toa Alta, USGS 50071000 *Río Fajardo* Nr Fajardo, USGS 50092000 *Río Grande De Patillas* Nr Patillas, and USGS 50111500 *Río Jacaguas* at Juana Diaz. The discharge, which is measured in the middle of the basin and not in the mouth of the river, was an essential consideration at the time of the analysis. Statistical analyses were performed using the rainfall from NWS, the stream discharge from the USGS, and the dynamics of the plume from MERIS data (TSM and CHL concentration).

Sample description

The island of Puerto Rico will be divided into four sections, North, South, East, and West to carry out the sampling of the plumes. Two rivers from North and South were designated. The *Río Grande de Arecibo* and *Río La Plata* in the North, and *Río Jacaguas* and *Río Grande de Patillas* in the South. In the East and West of the island one river is proposed due to the short dimension of those sections. The *Río Grande de Añasco* in the West and *Río Fajardo* in the East.

Results and Discussion

The selected events starting with November 20, 2007 showed a 24-hr accumulated precipitation ranging from 0.01 to 4.0 inches approximately (Figure 8). On October 16, 2008 the accumulated precipitation varied from 0.01 to 2.5 inches (Figure 9). The third event on September 18, 2009 the data collected range from 0.01 and in some areas achieved 6 inches (Figure 10). Then on November 17, 2009 the 24hr accumulated precipitation was from 0.01 to 6 inches in some areas of the island (Figure 11). On October 16, 2010 a total precipitation was reported ranging from 0.01 and in some areas 6 inches (Figure 12). The date with less accumulated precipitation was February 4, 2009 where was almost no precipitation accumulated except in some areas where 0.01 inches was registered (Figure 13).

After processing the MERIS images with the Case 2 Regional Processor, the level 2 images were obtained. A visual analysis was made for the TSM and CHL concentrations (Fig. 15 and 16). Using BEAM's color manipulation tool and applying a color palette called gradient 8 the high concentrations were identified (Fig. 14). When the color palette is selected instantaneously the colors represents the maximum and minimum values. The red color is for the high concentration and the light blue is for les concentration. Comparing the accumulated precipitation of the events with the river discharges the highest values are registered during the rainfall dates. These highest discharges agree with the highest values which are seen in the MERIS images. Also if a visual analysis and a comparison are made between the TSM and CHL concentration in both images it can be said that they are intrinsically related because where the TSM concentration is high the CHL concentration is also high. However, a quantitative analysis is required, so further research will be done next semester to corroborate this statement.

Conclusion

The Medium Resolution Imaging Spectrometer (MERIS), a sensor on the ENVISAT-1 of the European Space Agency that has a spectral resolution of 300 meters was used to determine the TSM and CHL concentrations. Using MERIS and a software called BEAM maximum values of total suspended matter (TSM) and chlorophyll (CHL) has been registered (Gilbes et al., 1996). Consequently, during the wet season more concentration of TSM and CHL was registered during this research and will affect the coastal ecosystem and carbonate production. Further quantitative analysis will be done next semester.

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Table

Table 1. Location and GPS coordinates of the six streams.

Stream	Location	GPS Coordinates
Río Grande de Arecibo	North	(18.266007, -67.188817)
Río La Plata	North	(18.475475, -66.254453)
Río Jacaguas	South	(17.974300, -66.539842)
Río Grande de Patillas	South	(17.979625, -66.016892)
Río Grande de Añasco	West	(18.472761, -66.710607)
Río Fajardo	East	(18.328218, -65.627234)

Figures

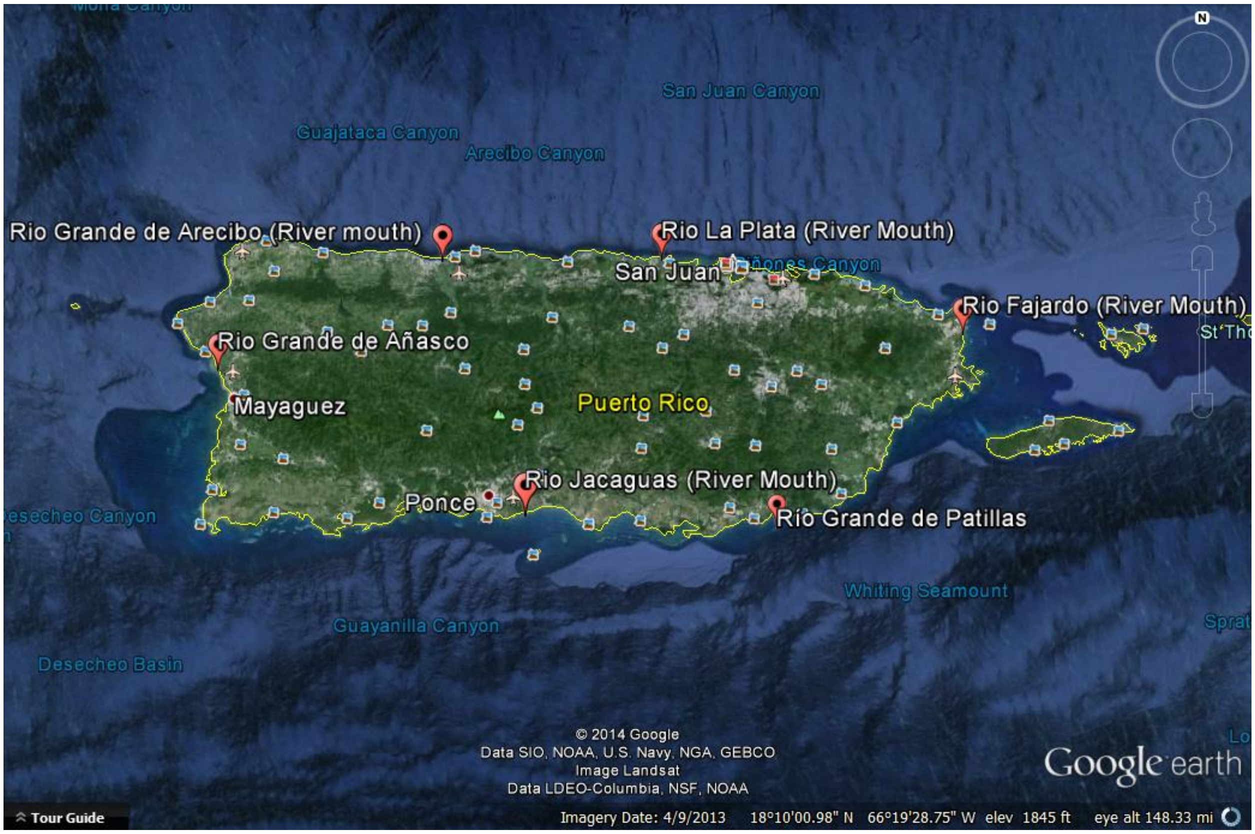


Figure 1. Locaction of the six streams of Puerto Rico: *Río Grande de Arecibo* (North), *Río La Plata* (North), *Río Jacaguas* (South), *Río Grande de Patillas* (South), *Río Grande de Añasco* (West), and *Río Fajardo* (East).

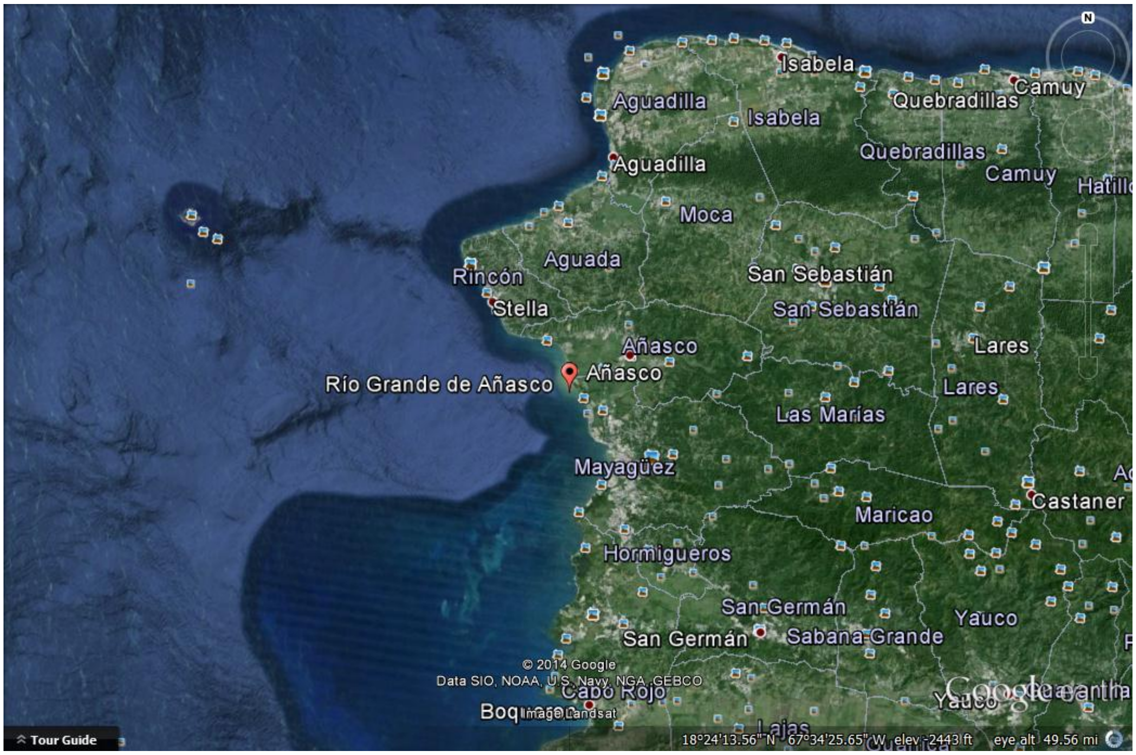


Figure 2. Location of Río Grande de Añasco in the West of Puerto Rico.

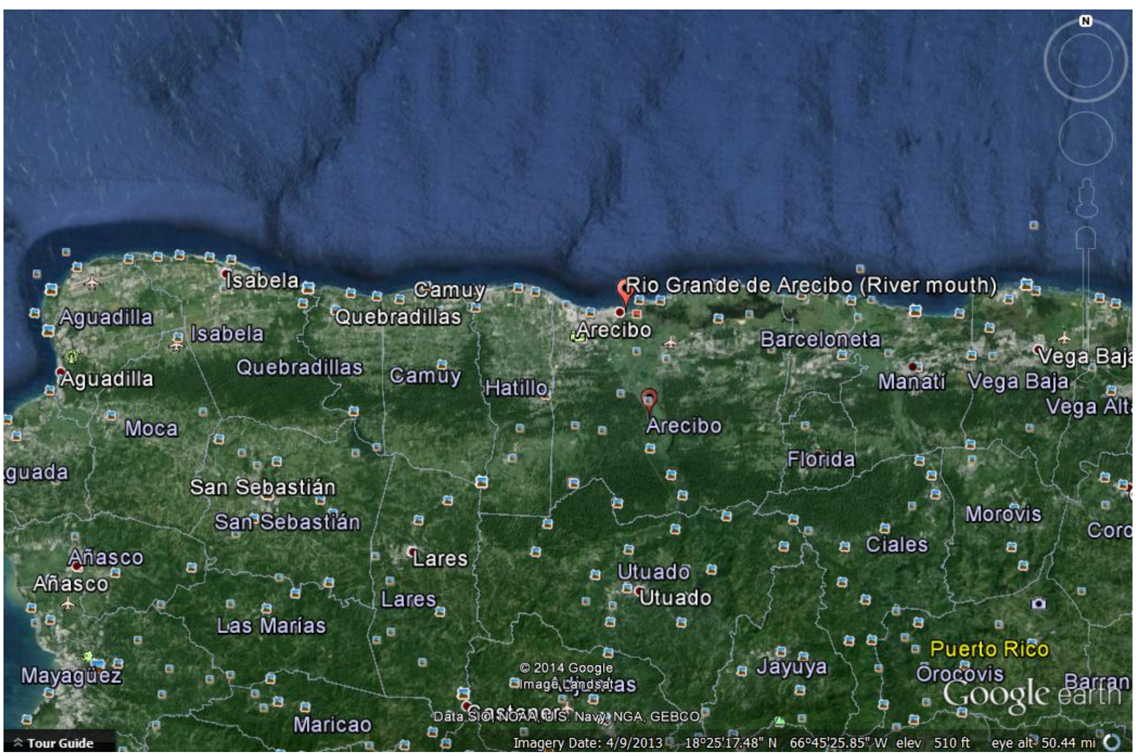


Figure 3. Location of Río Grande de Arecibo in the North of Puerto Rico.

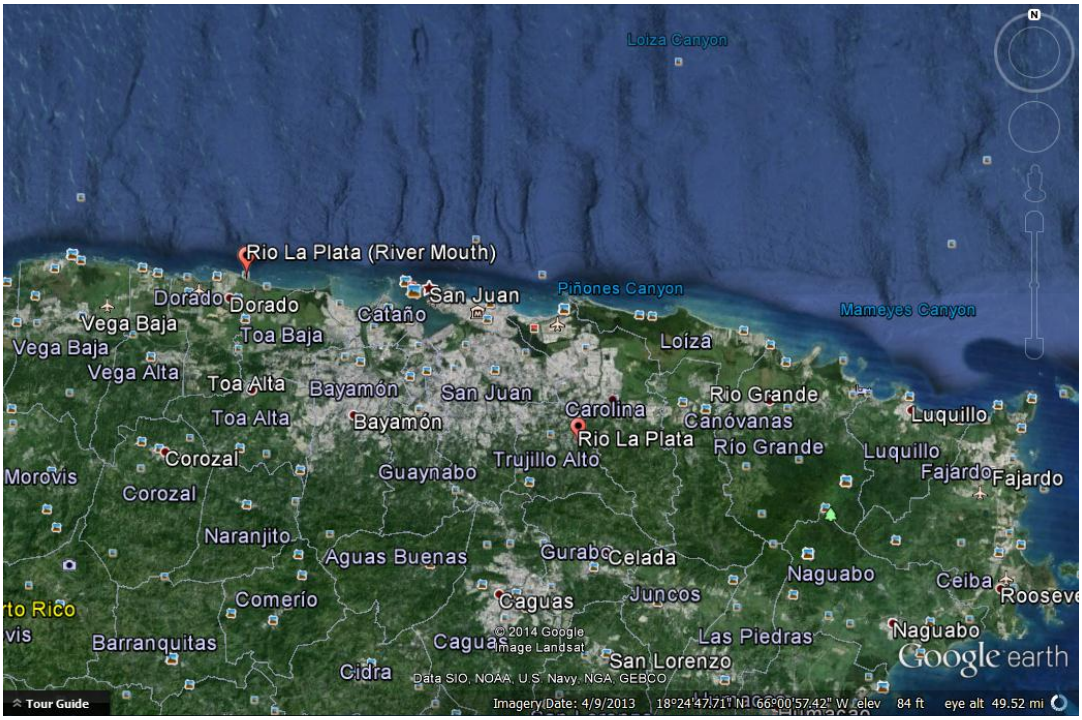


Figure 4. Location of Río La Plata in the North of Puerto Rico.

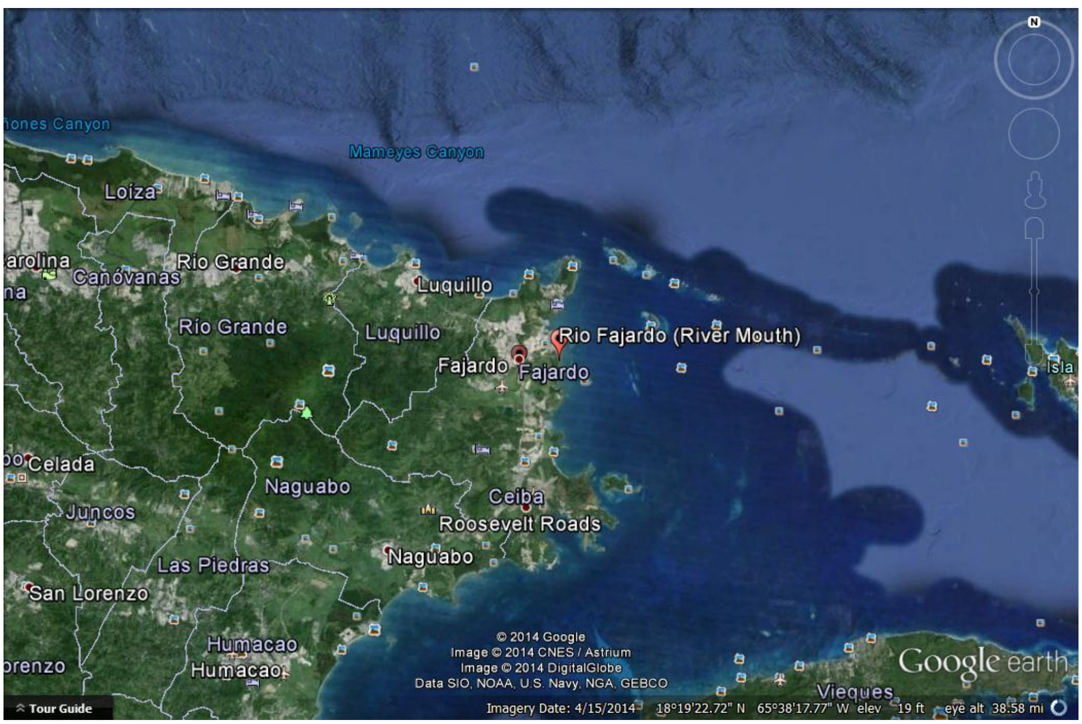


Figure 5. Location of Río Fajardo in the East of Puerto Rico.

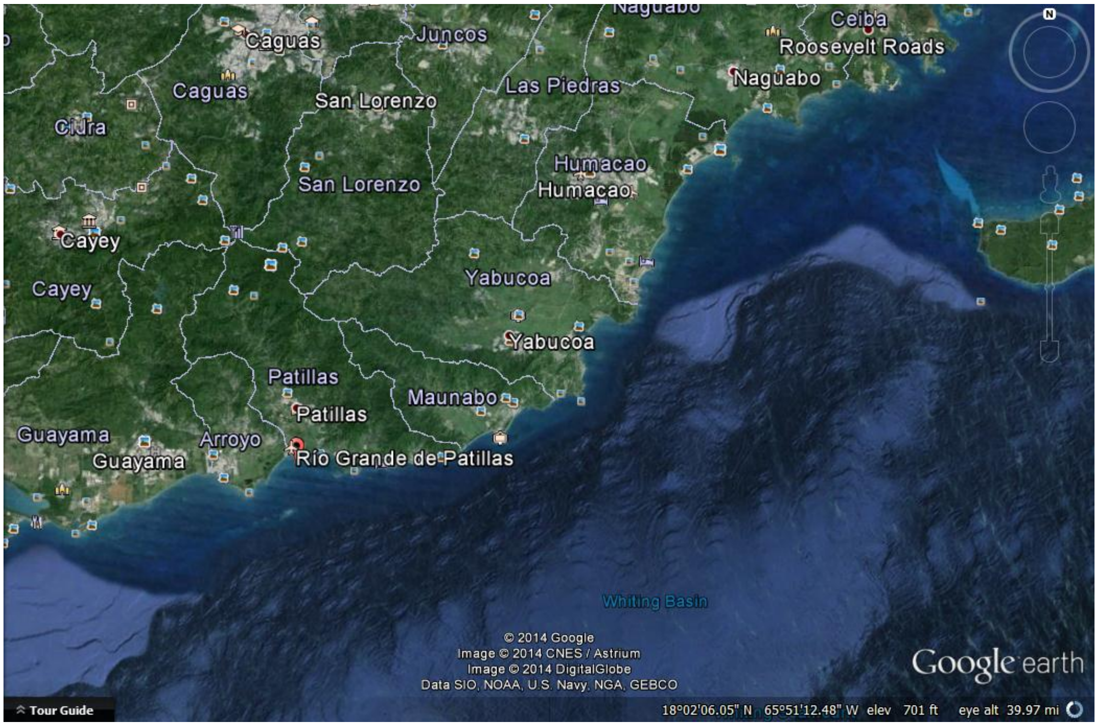


Figure 6. Location of the Río Grande de Patillas in the South of Puerto Rico.

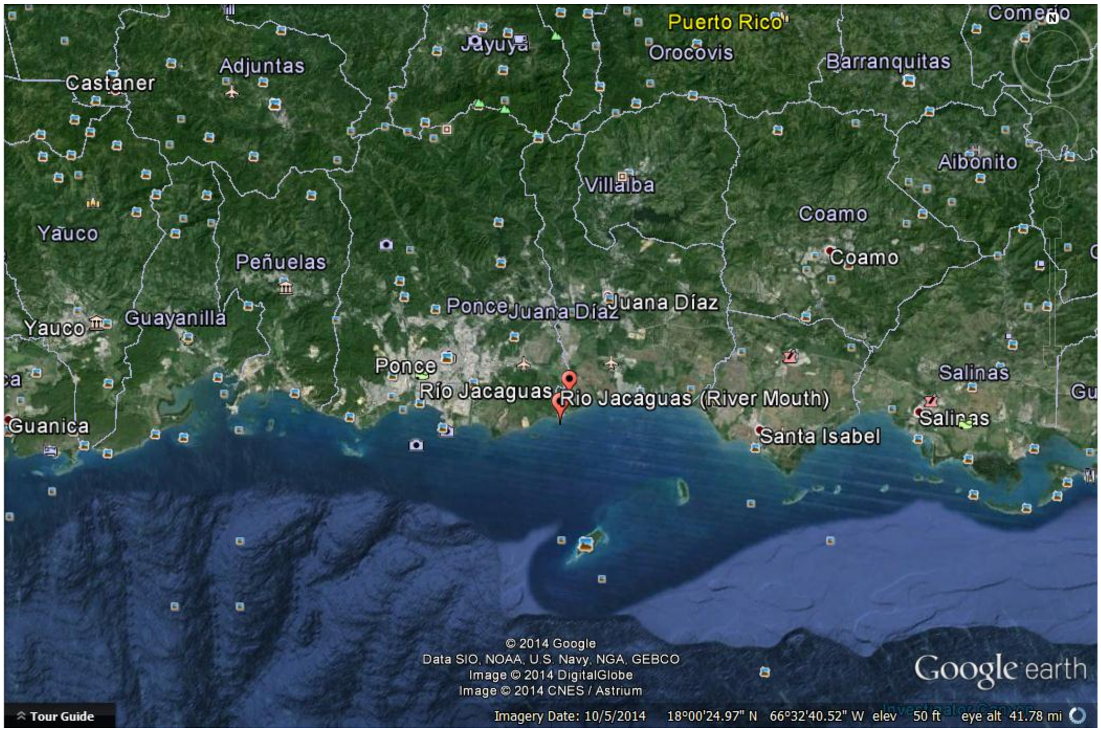


Figure 7. Location of the Río Jacaguas in the South of Puerto Rico.

Precipitation Data:

Figure 8. Precipitation data of Event #1: Nov 20, 2014

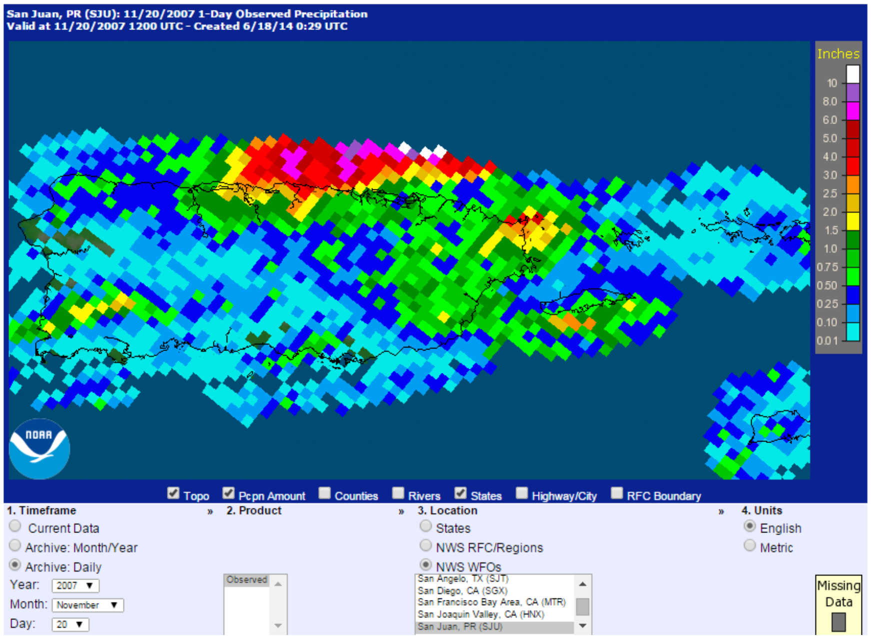


Figure 9. Precipitation data of Event # 2: October 16, 2008

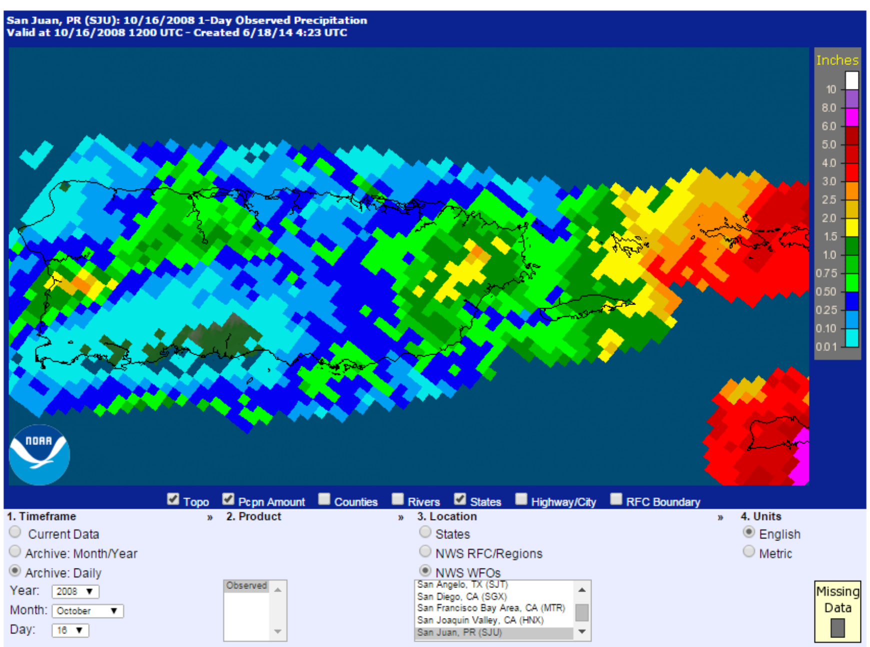


Figure 10. Precipitation data of Event #3: September 18, 2009

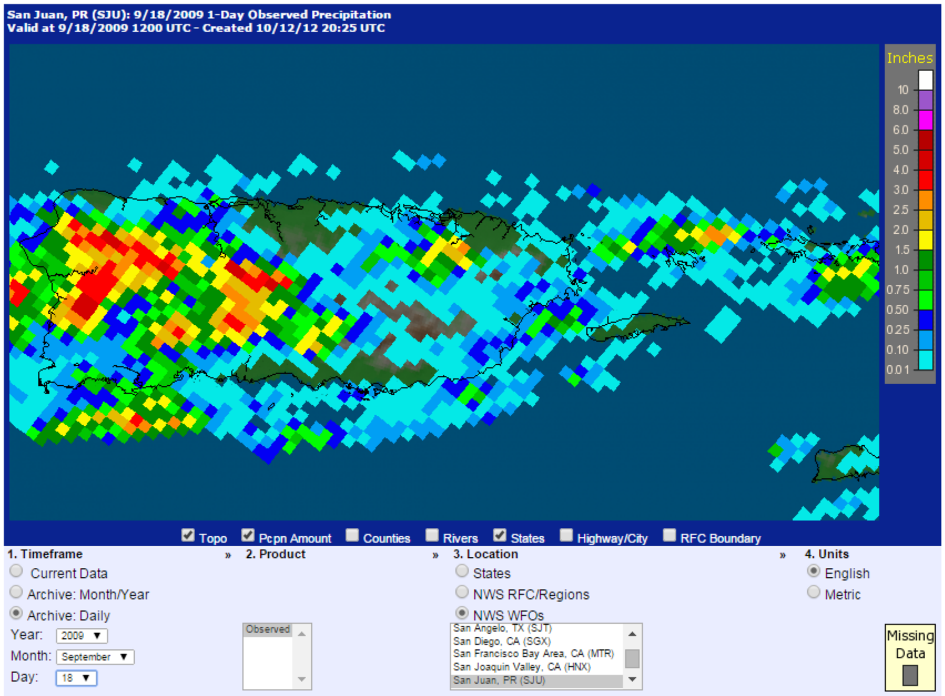


Figure 11. Precipitation data of Event #4: November 17, 2009

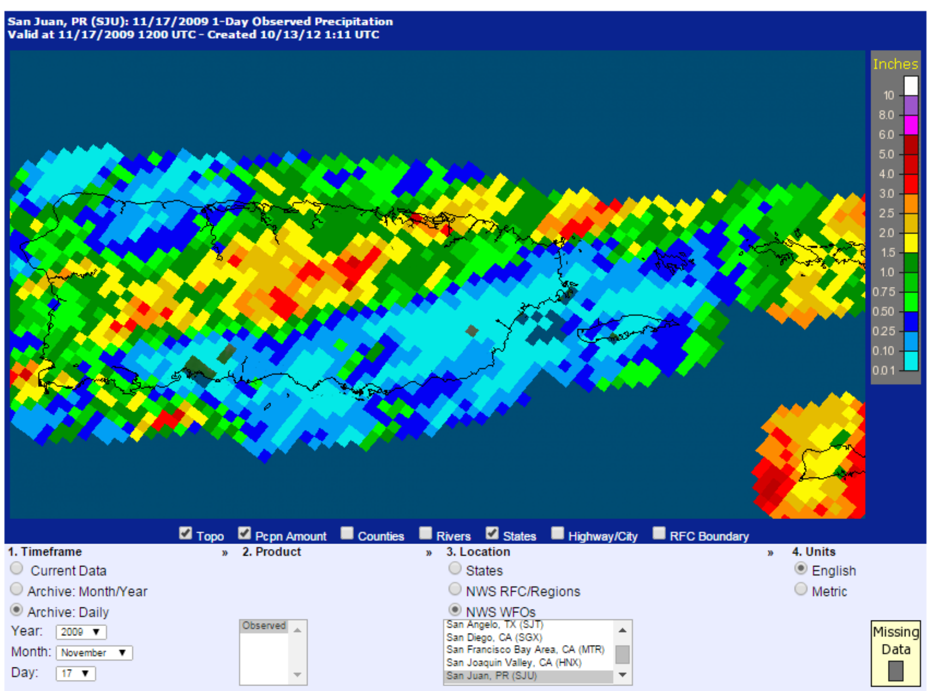


Figure 12. Precipitation data of Event # 5: October 16, 2010

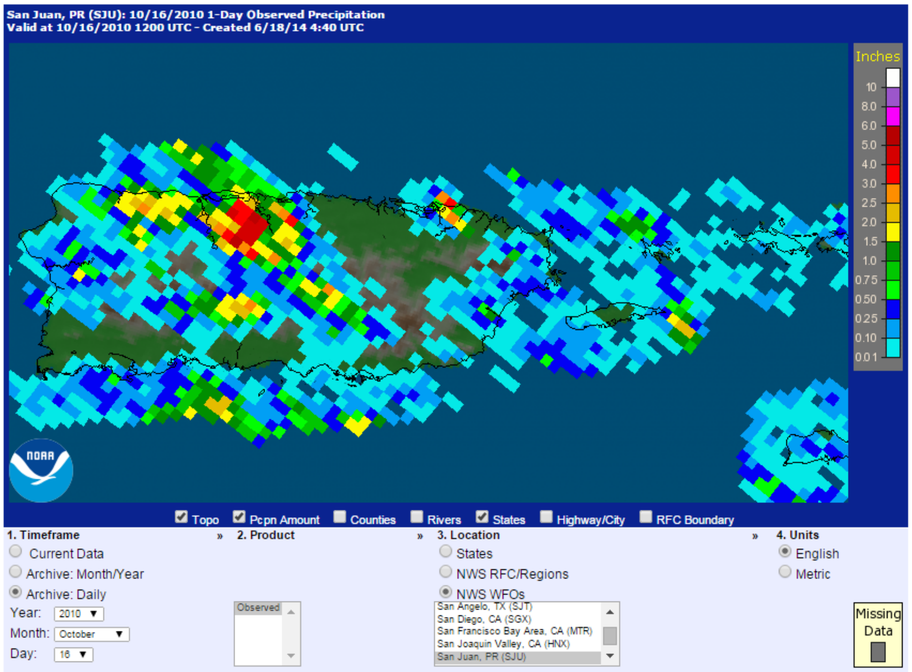
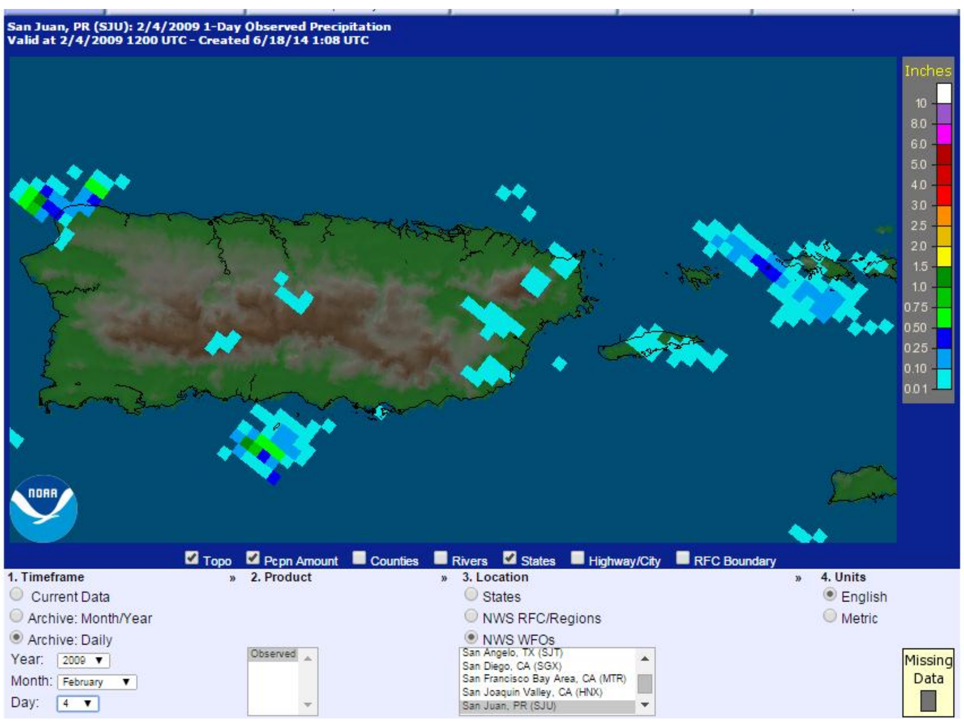


Figure 13. Precipitation data of Event # 6: February 4, 2009



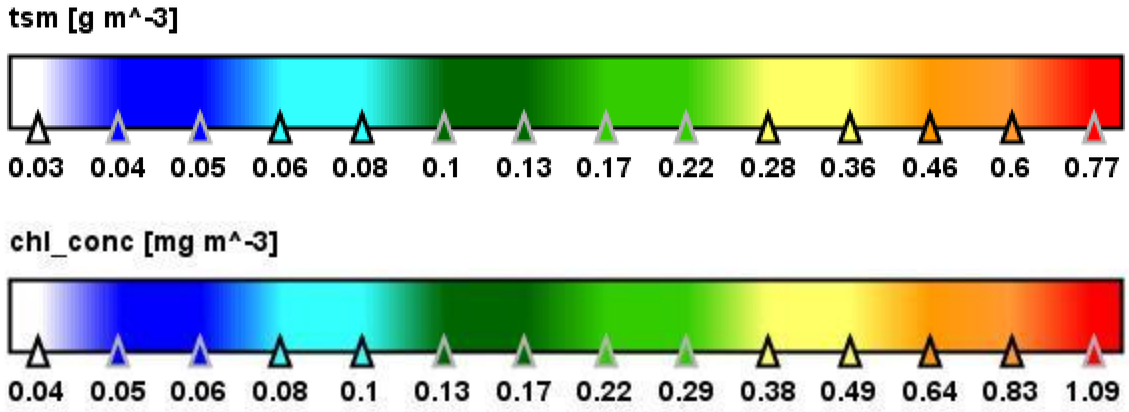
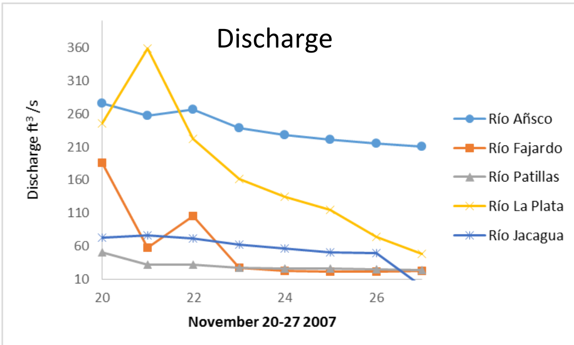
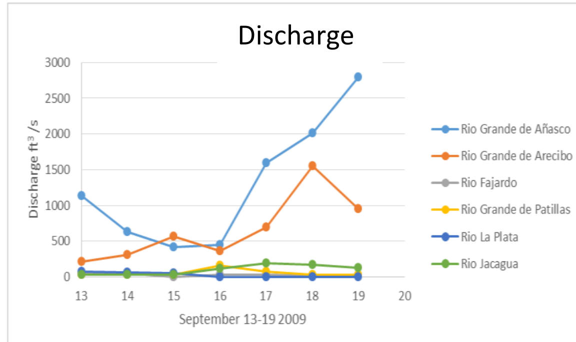
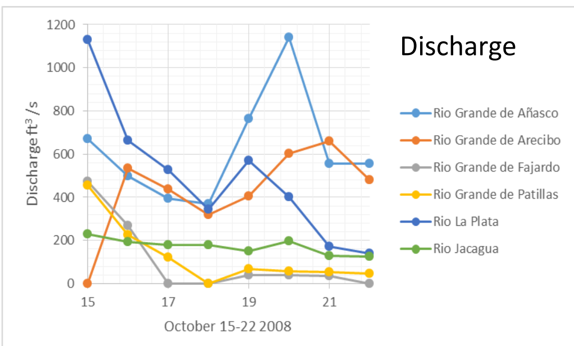


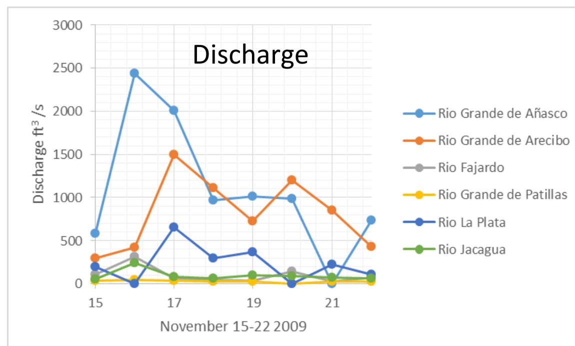
Figure 14. Color palette.

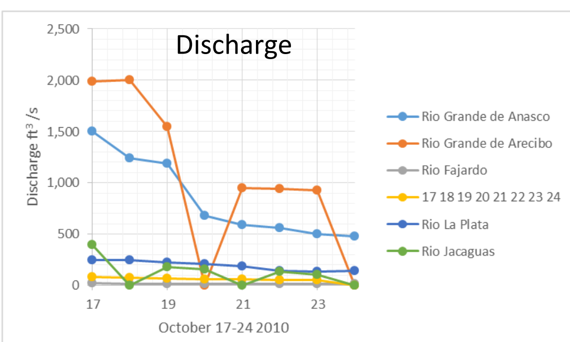
Graph 1: River discharge of every stream during the 5 strong rainfall events and the event with almost none precipitation.

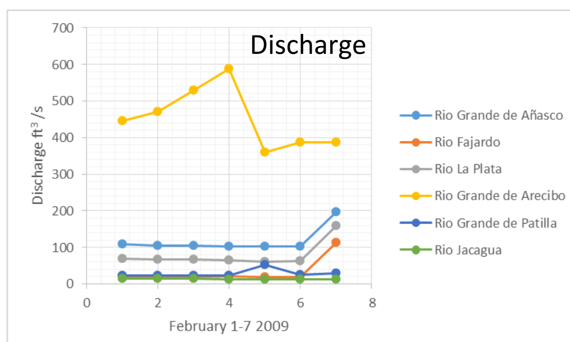












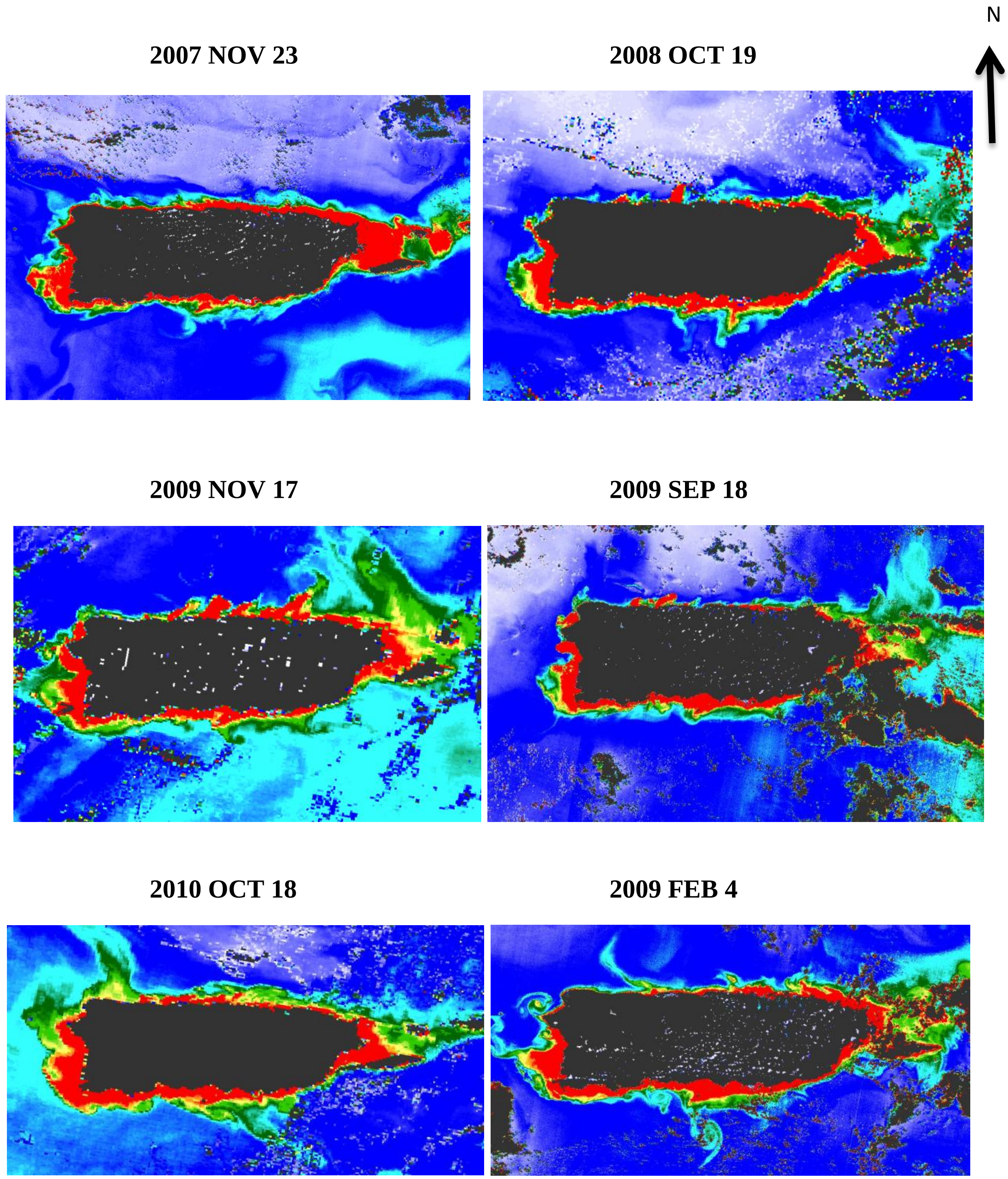


Figure15. MERIS images showing the total suspension matter during the six strong rainfall events.

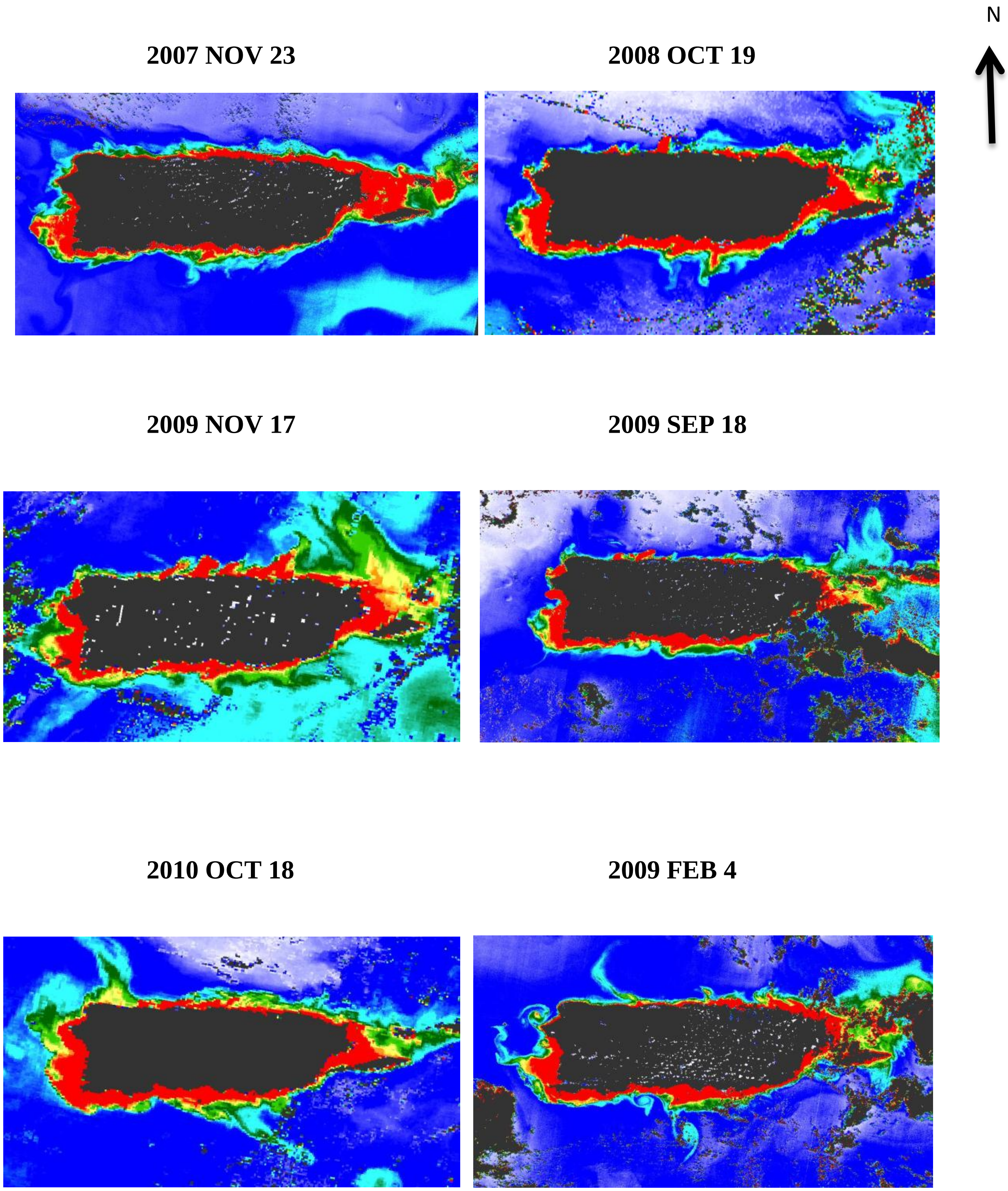


Figure 16. MERIS images showing the chlorophyll concentration during the six strong rainfall events.