Assessment of Tropical Cyclone Induced Transgression of the Chandeleur Islands for Restoration and Wildlife Management

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***Abstract*-The Chandeleur Islands are the first line of defense against tropical storms and hurricanes for coastal Louisiana. They provide habitats for birds species and are a wildlife refuge; however, distressingly, they are eroding and transgressing at an alarming rate. In 1998, Hurricane Georges caused severe damage to the chain, prompting restoration and monitoring efforts by both Federal and State agencies. Since then, storm events have steadily diminished the condition of the islands. Quantification of shoreline erosion, vegetation, and land loss, from 1979 to 2009, was achieved through the analysis of imagery from Landsat 2-4 Multispectral Scanner, Landsat 4 & 5 Thematic Mapper, and Advanced Spaceborne Thermal Emission and Reflection Radiometer sensors. QuickBird imagery was used to validate the accuracy of these results. In addition, this study presents an application of Moderate Resolution Imaging Spectroradiometer data to assist in tracking the transgression of the Chandeleur Islands. The use of near infrared reflectance calculated from MOD09 surface reflectance data from 2000 to 2009 was analyzed using the Time Series Product Tool. The scope of this project includes not only assessments of the tropical cyclonic events during this time period, but also the effects of tides, winds, and cold fronts on the spatial extent of the islands. Partnering organizations, such as the Pontchartrain Institute for Environmental Research, will utilize those results in an effort to better monitor and address the continual change of the island chain.**

I. INTRODUCTION

A. *Study Area*

The Chandeleur Islands are located south-southeast of St. Bernard Parish, Louisiana (Fig. 1). They began as a long island that has since been segmented into several islets covering 80 km. The Chandeleurs were formed over 2,000 years ago and are uninhabited [1]. Dozens of hurricanes and other severe storms have fragmented these islands, resulting in severe erosion of the island chain's land mass over time. The islands serve as a migratory stop for birds, provide habitat for nesting bird species, and are part of the second oldest National Wildlife Refuge in the United States.

The Chandeleur Islands are a diverse landscape, composed of beaches, dunes, and marshes. The northern portion of the islands is dominated by beaches that have multiple bars and washover fans that are separated by dune fields. The dunes are vegetated by grasses and shrubs that grade into a high salt marsh, also populated by black mangroves. The southern portion of the islands is more narrow and lower in elevation than the northern portion, leading to shoals separated by tidal inlets and small island fragments.

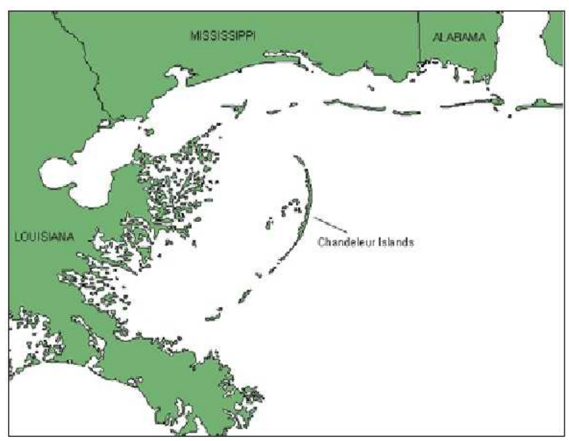

Fig. 1 Study area.

To the west over the St. Bernard Delta surface, the Chandeleur Islands are rapidly transgressing. The long-term Gulf shoreline erosion rates estimate a minimum 2 m/yr loss in the north-central portion and greater than 12 m/yr loss at the northern and southern ends of the islands [2]. The deterioration of the islands is caused not only by the frequency of Gulf storms but also by the subsidence of the St. Bernard Delta sediments and absence of a rejuvenating sediment supply. There have also been sea floor landslides, which may have caused stronger waves and greater erosional impact to the Chandeleur Islands as well. [3].

Over the past decade, tropical cyclones have decimated the Chandeleur Islands, destroying pre-existing vegetation, ruining habitats, and eroding the shoreline. In 2004, when Hurricane Ivan passed approximately 95 kilometers east of the islands, it destroyed the restoration progress of the Chandeleur Islands. Almost all of the vegetation on the islands was lost and the washover channels increased in number from 20 to over 100. The 2005 hurricane season further delayed any rebuilding progress that could have been made in the islands. Hurricanes Dennis, Katrina, Cindy, and Rita all occurred during the 2005 hurricane season, resulting in severe damage to the islands. In particular, Hurricanes Dennis and Katrina reduced and redistributed many terrestrial parts of the islands into sub-surface formations and shoals. Katrina also caused a severe amount of overwash, and consequently all of the planting sites created during previous restoration efforts became open water [3].

The 2008 hurricane season marked another disastrous year of hurricane impacts for the Chandeleur Islands, since they had not recovered from Hurricane Katrina by the time Tropical Storm Edouard passed the islands in August. Immediately following Edouard, two major hurricanes, Ike and Gustav, passed or made landfall near the Chandeleurs, further counteracting the small amount of restoration progress in terms of land accretion that had been made prior to Katrina.

B. *Relevance to National Concerns*

This project pertains to two of NASA's Applied Sciences' applications of national priority: natural disasters and ecological forecasting. Natural disaster applications regard the assessment and prediction of natural disaster impacts and risks to help minimize impact and aid in resource and response planning. Hurricanes are a major threat and source of damage to the Gulf Coast, making it necessary for decision makers to be equipped with accurate and timely data that not only aid in response but also help to minimize losses. The purpose of this project is to assess the impact of tropical cyclonic events on the Chandeleur Islands and provide the potential to aid resource managers in restoration projects that can benefit the islands. The aim of ecological forecasting is to provide decision makers with reliable forecasts of living systems changes and estimations across time through the combination of satellite data, in situ data, and forecasting models [4]. The Pontchartrain Institute for Environmental Sciences (PIES) has not been able to quantify the transgression of the islands or assess impacts of recent hurricanes including Gustav in 2008 because of limited resources. Therefore, this project examined a method for effectively utilizing data acquired from NASA Earth Observing Systems (EOS) to evaluate and analyze the state of the Chandeleur Islands to support the assessment needs of the PIES.

II. Methodology

A. *Data Utilized*

For analysis of island land area change, vegetated area change, and island transgression, Earth observation and ancillary data were acquired from the following sources:

- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard the Terra satellite platform
- Landsat 2-4 MSS
- Landsat 4 & 5 TM
- Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua
- QuickBird
- National Climatic Data Center (NCDC) Hourly Global Surface Data

Landsat 2-4 MSS and Landsat 4 and 5 TM imagery were downloaded using the U.S. Geological Survey (USGS) Global Visualization Viewer (GloVis) at the Earth Resources Observation and Science Center at http://glovis.usgs.gov/. Images were acquired for path 21, row 39 (World Reference System; the images downloaded were over the Chandeleur Islands, cloud-free, and preceding and following 27 tropical cyclonic events that occurred between 1979 and 2009.

ASTER data were downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) at https://lpdaac.usgs.gov/, using the NASA Warehouse Inventory Search Tool.

Post-Hurricane Gustav aerial photography was downloaded from the National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey Web site http://ngs.woc.noaa.gov/gustav/.

MODIS data were obtained from the LP DAAC, which is an organization that collects, processes, and archives data collected by NASA EOS. Images were acquired daily from 2000 to 2008.

A QuickBird image from August 22, 2007, was provided by PIES. This QuickBird imagery was used as ground reference data to conduct an accuracy assessment on a 2007 land/water classified ASTER image.

Hourly Global Surface Data were downloaded from the NCDC Web site. Data were acquired for Buoy 42007 from 01/01/1981 to 06/18/2009. The MATLAB® file Wind_rose was downloaded from the file exchange on the MATLAB Central Web site (http://www.mathworks.com/matlabcentral/fileexchange/). Resulting wind roses are found in Figs. 14 and 15.

B. *Image Processing*

Unsupervised ISODATA (Iterative Self-Organizing Data Analysis Technique Algorithm) classifications were conducted on Landsat and ASTER datasets using ERDAS IMAGINE® on each of the subset images using 150 classes, 150 iterations, and a convergence threshold of .995. The classified images were then manually aggregated into two classes: water and land. The land and water classifications used to determine land area and calculations are found in Figs. 3 and 4. Pixels classified as water were used to create a mask covering the water surrounding the islands for each date to help ensure that Normalized Difference Vegetation Index (NDVI) calculations (as described in Section C) did not include surrounding water areas [5].

MODIS images were processed using the Time Series Product Tool (TSPT), a program created at John C. Stennis Space Center for use in the "automated, rapid, large-scale regional surveillance" of vegetation, free of any atmospheric effects. TSPT, designed for use in MATLAB, provides a means to process MODIS data and other satellite sensor products by automatically correcting for cloud cover and by removing undesirable pixels [6]. It uses a number of modules to create images that are cloud and noise free.

The output of the TSPT includes single image displays of satellite imagery, time-series plots for specific locations, or videos that show single images over a specified time frame [6] [7].

For this project, TSPT was set to apply MODIS data from the Terra and Aqua platforms. Images collected daily from 2000 to 2008 were used. MOD 09 GQ and GA were used to aid in tracking the transgression of the Chandeleur Islands over an 8-year period.

C. NDVI

NDVI is used to measure vegetation health. This project calculated NDVI to assess vegetated area cover change (as described below) and did not include surrounding water areas vegetation coverage of the islands. Landsat and ASTER data calculations were processed in ERDAS IMAGINE spatial modeler. During image analysis, values ranging from 0.0 to 0.02 were classified as sand. In calculating vegetated areas, since most of the vegetation on the Chandeleur Islands is sparse grass and shrubs, pixels with NDVI values greater than 0.02 were assessed as vegetation. Measurements of vegetation in hectares were computed in ERDAS IMAGINE for each image. Vegetated area quantification results are found in Figs. 5 and 6.

D. Land/Shoreline Change

To display shoreline change for the Chandeleur Islands over the past 30 years, a series of maps were created in ESRI ArcMap®. Then water masks from 1979, 1989, 1999, and 2009 were applied to Landsat images of the islands and converted into shapefiles and compared to visualize land area changes. The visualization of these changes is found in Fig. 7.

E. Transgression Methods

After MODIS data were processed using the TSPT, images were displayed in ENVI®. For the analysis of island transgression, three transects were selected in the islands–north, central, and south–as seen in Fig. 2. Horizontal profiles of the near infrared (NIR) value of each pixel in each transect were compared over time to show the transgression of the islands through movement of the maximum NIR value. The maximum NIR value in the first MODIS image was shown as a solid line in graphs; change in peak NIR value was extrapolated to analyze transgression. Transgression results are included in Figs. 8–13 and Table 1.

F. Accuracy Assessment of Classifications

Accuracy assessments evaluate the quality of information derived from a particular dataset and are an essential part of the research to determine how classification methods affect results. Accuracy assessments in remote sensing are performed by selecting a number of points in the classified image and checking them against reference data, such as field survey results or high resolution imagery (usually less than 2 m) of the region [8]. When adequate ground reference data or aerial photography are not available, visual interpretation of the original data by a skilled individual familiar with the land cover types and ground conditions may be the only reasonable option to conduct the necessary accuracy assessments [9]. For this study, thematic map accuracy assessment was based upon visual interpretation of Landsat MSS and TM data as ground reference data [10].

The binomial probability theory equation was used to determine the number of points that should be selected for the accuracy assessment [8]. The equation (1) states

$$N = \frac{Z^2(p)(q)}{E^2} \qquad (1)$$

where N is the sample size, $Z = 2$ from the standard deviate of 1.96 for the 95% two-sided confidence level, p is the expected accuracy for the entire map, $q = 100 - p$, and E is the allowable error [8].

Two hundred four points were randomly placed in each of the classified images. The Equalized Random point selection method was used to distribute the points to ensure that each class received the same number of points. Each land cover type had 102 points that had to be checked against the reference dataset. Each point on the classified image was checked against the reference dataset. Once the process was complete, the accuracy statistics were computed for each land cover type and for the image collectively. Results from the accuracy assessment are found in Tables 2–4.

Fig. 2 Location of transects selected in transgression .analysis

G. Wind Data

NCDC hourly wind speed and wind direction data from 1981 to 2009 were input into MATLAB as the variables D and V, respectively. The command Wind-rose (90-D,V) was used to create a wind rose, which illustrates the wind profiles near the Chandeleur Islands. This process was repeated with seasonal data (April–September and October–March) from the same time period to create summer and winter wind roses.

III. Results

A. Land Area Change

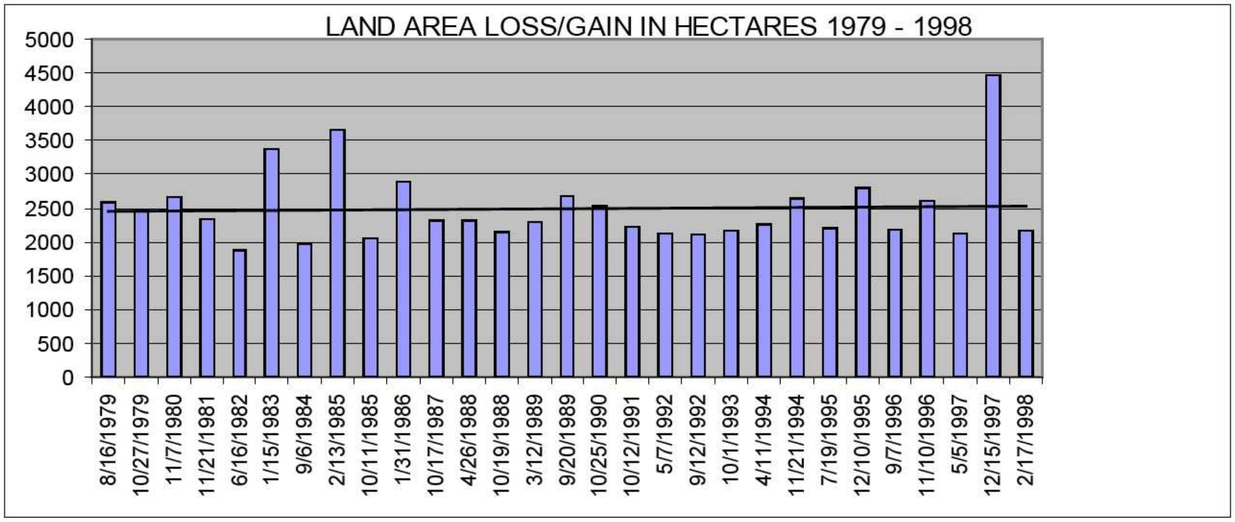

Fig. 3 Land area change from 1979 to 1998. Black line represents trend during time period.

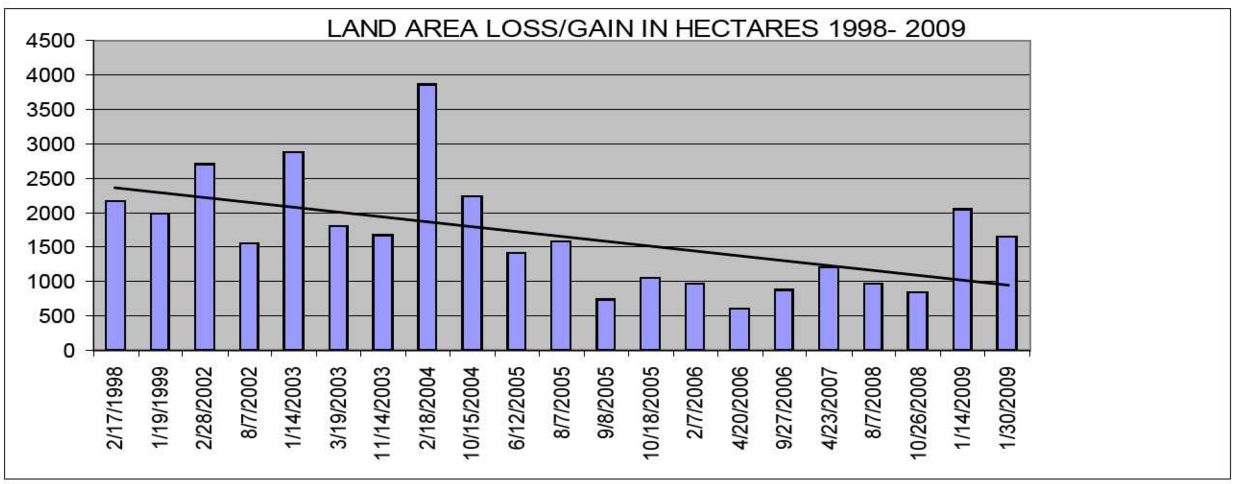

Fig. 4 Land area change from 1998 to 2009. Black line represents trend during time period.

B. Vegetated Area Change

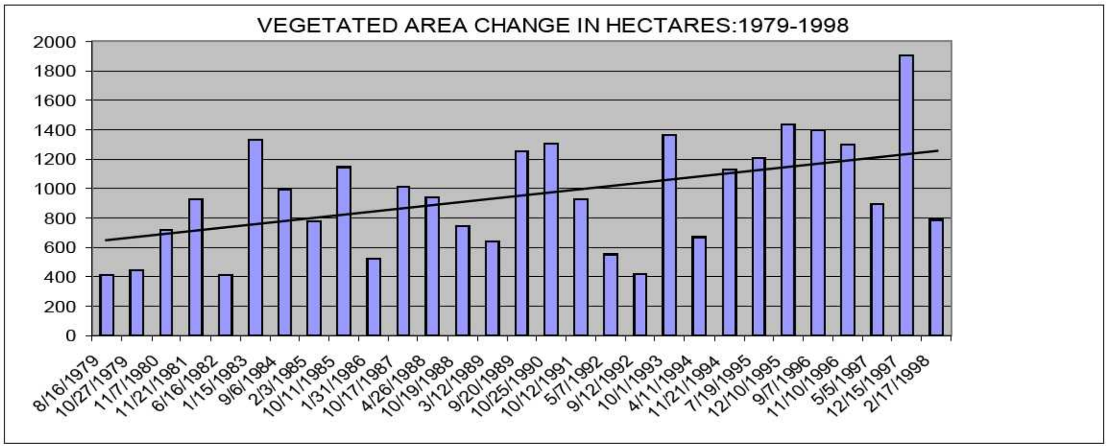

Fig. 5 Vegetated area change from 1979 – 1998. Black line represents trend during time period.

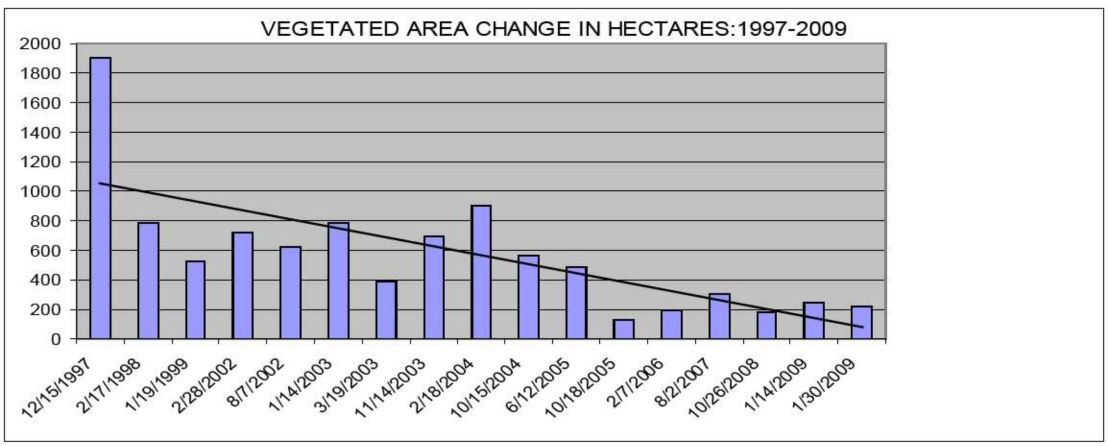

Fig. 6 Vegetated area change from 1997 – 2009. Black line represents trend during time period.

C. Shoreline Change

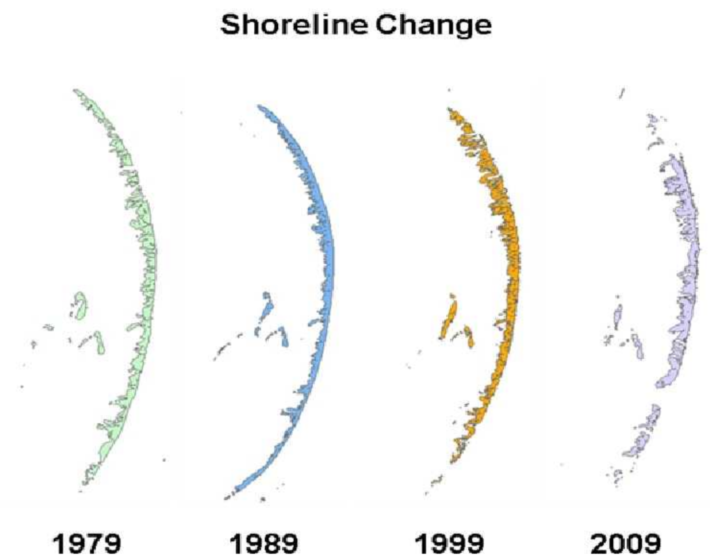

Fig. 7: Visualization of shoreline change from 1979, 1989, 1999, and 2000.

D. Transgression

In Figs. 8–13, the pink line represents maximum NIR reflectance in 2000.

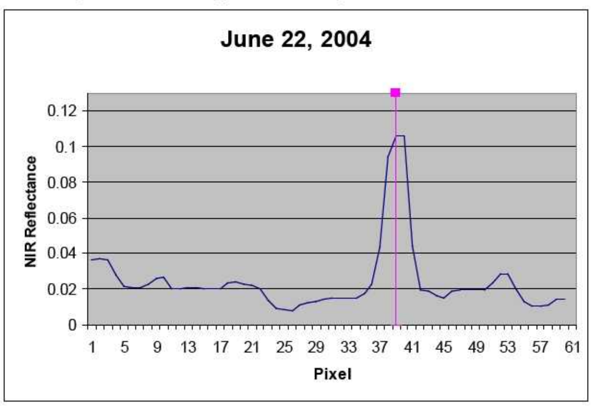

Fig. 8 Northern Transect NIR Reflectance June 22, 2004.

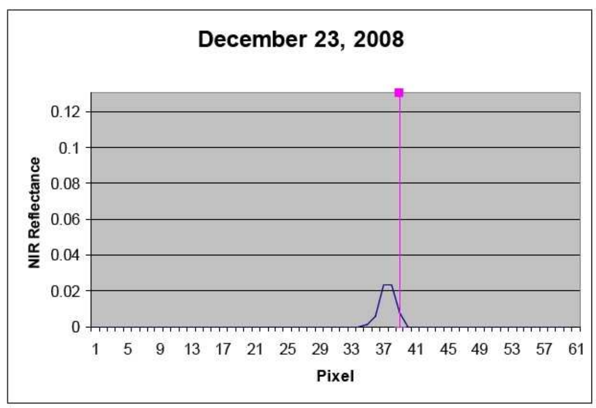

Fig. 9 Northern Transect NIR Reflectance Dec. 23, 2008.

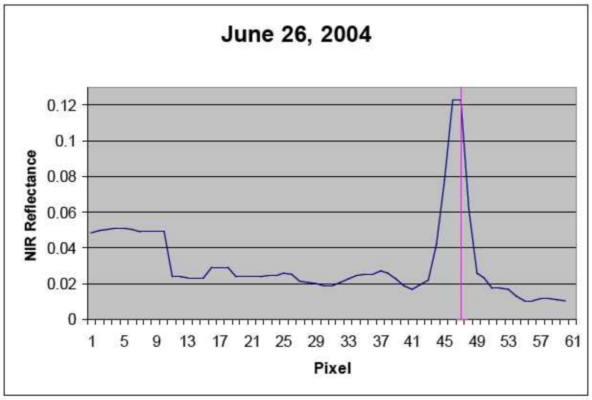

Fig. 10 Central Transect NIR Reflectance June 26, 2004.

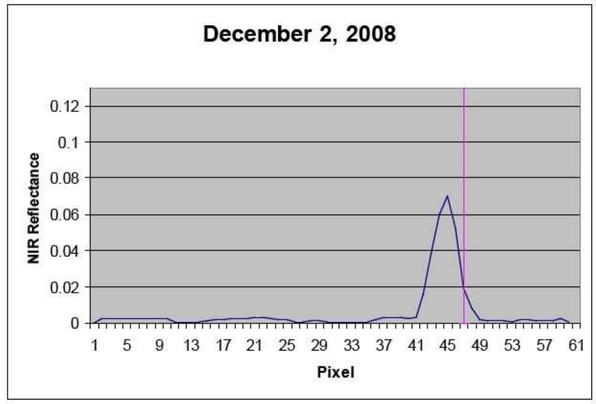

Fig. 11 Central Transect NIR Reflectance Dec. 2, 2008.

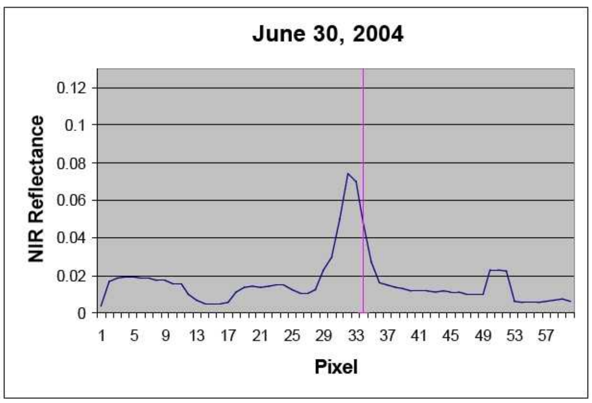

Fig. 12 Southern Transect NIR Reflectance June 30, 2004.

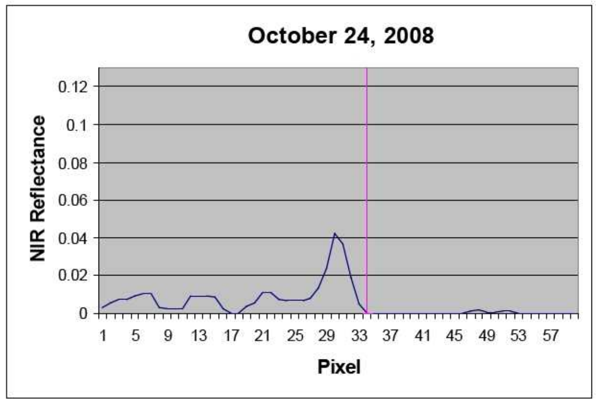

Fig. 13 Southern Transect NIR Reflectance Oct. 24, 2008.

Table 1 Quantification of MODIS transgression analysis based on pixel counts from Figs. 8–11.

Transects	Approximate Transgression
Northern	250 m
Central	250 m
Southern	1,000 m

E. *Accuracy Assessment*

Table 2 Error matrix of classified April 23, 2007, ASTER image using 2 m QuickBird image as reference data.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	118	102	101	85.59%	99.02%
Land	86	102	85	98.84%	83.33%
Overall Classification Accuracy = 91.18%					
Overall Kappa Statistics = 0.8235					

Table 3 Error matrix of classified May 5, 1997, Landsat TM image using unclassified image as reference data.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	94	102	94	100.00%	92.162%
Land	110	102	102	97.73%	100.00%
Overall Classification Accuracy = 96.08%					
Overall Kappa Statistics = 0.9216					

Table 4 Error matrix of classified August 16, 1979, Landsat MSS image using unclassified image as reference data

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water	93	102	93	100.00%	91.18%
Land	111	102	102	91.89%	100.00%
Overall Classification Accuracy = 95.59%					
Overall Kappa Statistics = 0.9118					

D. Wind Roses

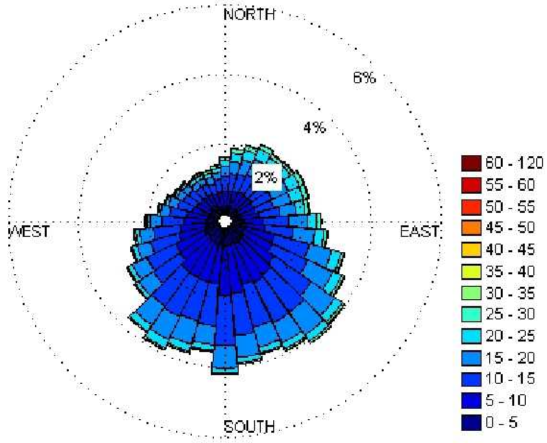

Fig. 14 Summer Wind Rose.

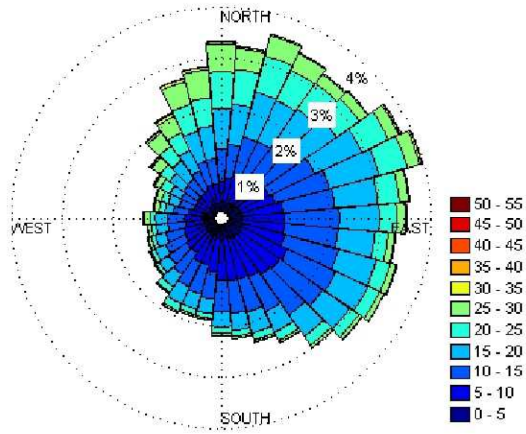

Fig. 15 Winter Wind Rose.

IV. Discussion

A. Land and Vegetation Change

In 1979, the total area of the Chandeleur Islands was assessed at 2588.4 hectares (Fig. 3). In 2009, the total area of the islands was 1663.29 hectares (Fig. 4). This equates to a 35.7% loss of land area over the entire 30-year study period, with 16.0% lost between 1979 and 1998 and 19.7% lost between 1998 and 2009.

In 1979, the total vegetated area of the Chandeleur Islands was assessed to be 412.92 hectares (Fig. 5). In 2009, the total vegetated area of the islands was assessed to be 218.43 hectares (Fig. 6). This equated to a 47.1% loss over the entire 30-year study period, with 89.7% gained from 1979 and 1998 and 136.8% lost from 1998 to 2009.

The graphs for both land area and vegetation change were broken into time periods of 1979 to 1998 (pre-Hurricane Georges) and 1998 to 2009 (post-Hurricane Georges). The 1998 hurricane season marked the beginning of a period of both increased storm frequency and severe degradation to the Chandeleur Islands. The trend lines shown in both graphs of land area and vegetation area support this finding and help to further illustrate this dramatic trend change.

B. Transgression

Figs. 8–11 show that the northern and middle portions of the islands remained mostly stationary throughout the MODIS study period, except for the time period directly following Hurricane Katrina in 2005. After Hurricane Katrina, the northern and middle portions of the island exhibited a slight transgressive movement. However, Figs. 12 and 13 show that the southern portion of the islands steadily transgressed from 2000 to 2008; however, the transgression was accelerated by Hurricane Katrina in 2005.

C. Tides

Tides are an important factor to consider in the study of barrier islands. Tides control the water level and the movement of water around barrier islands and through tidal inlets. Because of the bathometry and the shallow slope of the Chandeleur Islands, the tidal elevations at the islands are greatly influenced by wind. This process, called wind setup, can cause actual tides to be higher or lower than forecasted tides [11]. The ability to accurately measure tides on the Chandeleur Islands is limited. There are no tidal gauges on the Islands, and the closest buoy is located about 9 miles NNE of the islands. The recorded tides at this buoy are not an accurate representation of the actual tides at the Chandeleur Islands. The buoy is located in open water and is not affected by the same near-shore bathometry as the islands. Estimated tidal ranges were acquired through the use of the Tides extension to NOAA's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. The SLOSH Model provides historical predictions of tidal range by hour. The imagery metadata was examined and the nearest hour was used to determine tides; e.g., for an image acquired at 10:25 AM, the 10:00 AM tide was used. The predicted tidal range, as referenced to mean water level (mwl), was obtained for each hour at the time of sensor acquisition (Table 5). This tidal range is a factor in the major peaks in land area in 1997 and 2004. Because of the shallow bathymetry near Chandeleur Island, relatively small changes in water level have the capacity to cover or expose large areas of land, which complicates barrier island remote sensing.

Table 5 Estimated tidal range from SLOSH Model..

Average tide	-0.025 ft
Maximum	+1.1 ft
Minimum	-1.4 ft

D. Winds

Winds affect the erosion of the Chandeleur Islands because seasonal wind patterns greatly influence the wave climate along the Louisiana coast . The direction and speed of the winds can determine the erosive energy of the waves. There is a high correlation between wind direction and direction of dominant wave approach [11]. Southeasterly winds produce waves with the greatest fetch because they can travel the farthest distance. Therefore, waves approaching from the southeast are often the most erosive. The wind profile reflects weather patterns. Fig. 14 shows that during the summer season, the wind is predominately from the south. Fig. 15 shows that during the winter season, the wind is predominately from the northeast. During the winter, because of cold front passage, the wind often comes from a north-northwesterly direction.. This is significant because northwest winds cause waves that erode the back barrier beaches, which are more stable and usually sheltered from erosive forces. Therefore, the Chandeleur Islands are constantly susceptible to wind-driven erosion throughout the year.

V. Conclusion

Over the past several centuries, the Chandeleur Islands have been slowly eroding and moving toward the mainland. As transgressive barrier islands, this is their natural morphology. However this project found that beginning around 1998, vegetated area and land area began dramatically decreasing. An increase in frequency and intensity of storms over the past decade has hindered regeneration of the islands and has made them more susceptible to damage from natural phenomena, such as cold fronts, winds, and waves. Hurricane events, such as Hurricane Katrina in 2005 and Hurricane Gustav in 2008, have accelerated the transgression of the island. The northern and middle portions of the island remained mostly stationary throughout 2000-2008, except directly following Hurricane Katrina in 2005. The southern portion of the islands steadily transgressed landward throughout the entire period, but transgression was accelerated by Hurricane Katrina's impact in 2005. TSPT was instrumental in providing analysis and quantifying transgression of the islands. Without restoration efforts, coastal Louisiana will likely lose its first line of defense from future tropical cyclonic events. Overall, this project benefits the Pontchartrain Institute for Environmental Sciences by providing use of NASA Earth Observation Systems in necessary barrier island research.

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