Study of Hurricane Sandy Coastal Impacts and Shorelines changes in New Jersey using Aerial Photographs

Nin-Hernandez, G and Torres-Váquez, A

University of Puerto Rico, Mayaguez Campus: Physics. Geology and Marine Sciences Building

Mayaguez, Puerto Rico 00681

Abstract. – Hurricane Sandy was a high impact tropical and extra-tropical storm that affected the East Coast of the United States on October 27- 31, 2012. Aerial photographs taken before and after the passage of the hurricane were selected in order to be analyzed and processed with the purpose of identifying shoreline changes and significant coastal impacts. In order to determine shoreline changes, images representing the same areas before and after were selected; the estimated average of erosion was approximately 15, while the estimated deposition was approximately 11 meters. For the purpose to identify coastal impacts two different image classifications were implemented: Unsupervised (Isodata) and Supervised (Maximum likelihood). Coastal impacts determined by these classifications were lower than expected, probably due to cleanup and restoration efforts taking place before the capture of the images. Nonetheless, maximum likelihood was the best and most accurate classification to determine the coastal impacts.

Keywords: Hurricane Sandy, Coastal Impacts, Shoreline, Envi-Classic, Aerial Photographs

Introduction

Hurricane Sandy was a late-blooming storm that formed in October 22, 2012 in the western Caribbean Sea, south of Jamaica. It strengthened, crossed through Jamaica and Cuba, and continued its path through the Atlantic Ocean, showing signs of heading towards the United States. The emergence of a warm pattern blocking the North Atlantic Ocean and the development of a trough in Central US affected the storm as it moved north, steering it towards Northeastern US. Its move north influenced its internal structure, giving it mid-latitude - instead of tropical - identifiers. As the trough in Central US intensified and moved east, it interacted with the baroclinic structures of the hurricane. Hurricane Sandy made landfall near Brigantine, New Jersey (Figure 1) on October 29, 2012 as an extra tropical storm (Blake,2013).

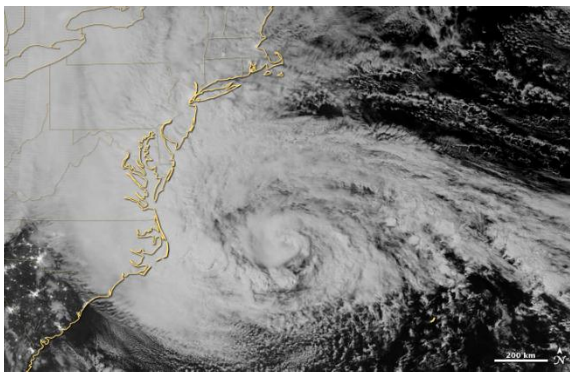

Figure 1: Visible satellite image showing the position and the structure of Hurricane Sandy on October 28, 2012

The New Jersey coast extends 209 km from Sandy Hook to Cape May, and is construed of numerous islands. New Jersey's tourism is dependent on the health of coastal locations like Atlantic City and Long Island Beach.

Some geological features present along the coast are groins and barrier islands (Psuty, 1983). Groins (Figure 2) are low walls constructed perpendicular to the shoreline and function as traps to the transportation of sediments along the long-shore current (Morelock, 2005).

Figure 2: Image showing groins presents along the New Jersey coast. (Image from: Department of Environmental protection, State of New Jersey).

The torrential rains and intense wind field associated with Sandy had a considerable impact on Jamaica, Cuba and the East Coast states. However, the most significant effects were those caused by storm surge. According to the National Hurricane Center (NHC), storm surge is the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. It should not be confused with the regular tides, which are caused by astronomical patterns, or with storm tide, which combines the regular tides and storm surge.

The National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) Center for Operational and Oceanographic Products and Services (CO-OPS) has tidal gauges that measured storm tides across the Atlantic sea-board at the time of Hurricane Sandy's passage. Storm surge in New Jersey ranged from 1m in Cape May to 3m in Sandy Hook; the values could be higher, given that fact that many stations, Sandy Hook included, malfunctioned and stopped recording information during the storm (Fanelli, 2013). Nonetheless, these values were both record setting, as were many along the New Jersey and New York Coast (see Appendix for detailed data table).

According to reports gathered by NOAA, the number of deaths caused by Sandy were 117, 72 of those in the United States, 41 of those attributed directly to storm surge (~30%). The New Jersey's Governor Office estimated that approximately 346,000 housing units were damaged or destroyed, with 22,000 of those made inhabitable. Total losses were estimated above $8 billion.

Remote sensing is the science of deriving information about the Earth's surface using images that register reflected or emitted radiation in one or more regions of the electromagnetic spectrum (Campbell and Wyene,2011). Coastal impacts and shorelines changes are commonly quantified using techniques of remote sensing, specifically aerial photographs (Figure 3).

Figure 3: Aerial photograph from New Jersey showing the impacts and changes on the shorelines.

Objectives

The main purpose of this research was to identify coastal impacts and shoreline changes caused by the passing of Hurricane Sandy along the New Jersey coast. This would be achieved by downloading, analyzing and processing aerial photographs from before and after the passing of the storm.

Methodology

The methodology for this research consist of three principal stages: (1) downloading, analysis and processing of aerial images, (2) the delineation of shoreline before and after the passage of hurricane and (3) the identification of coastal impacts using different classification methods.

(1)Downloading, Analysis and Processing of aerial images

Approximately 12 images from before the hurricane and more than one hundred from after the hurricane were downloaded. Three different images were selected for the same areas for before and after the hurricane. The images selected were analyzed, preprocessed and processed with Environment for Visualizing Images (ENVI) Classic. Preprocessing of the images consisted of the atmospheric correction using dark subtract and a spatial subset in New Jersey along the coastline.

Images from before the passage of the hurricane were downloaded from: http://earthexplorer.usgs.gov/. These aerial images were taken with a digital frame camera (DCM) on March 2012 with a spatial resolution of 3 bands (RGB) (24 bits) and a pixel size of 30 meters. The before images are geo-referenced with UTM projection for Zone 18. On the other hand, images from after the passage of the Hurricane Sandy were downloaded from the Hurricane Sandy Response Imagery Viewer: http://storms.ngs.noaa.gov/storms/sandy/, and were taken during the period of October 30 to November 5 of 2012. Images from after the hurricane were taken using the DSS 500 sensor which has a radiometric resolution of 3 bands (RGB) and a pixel size of 30 meters. Images of DSS 500 sensor were not geo-referenced.

In order to register (geo-reference) the image after the hurricane, a tool in Envi Classic was used: Registration Image to Image using Ground Control Points. Five different Ground Control Points (Figure 4) were used to apply the reference for the after image.

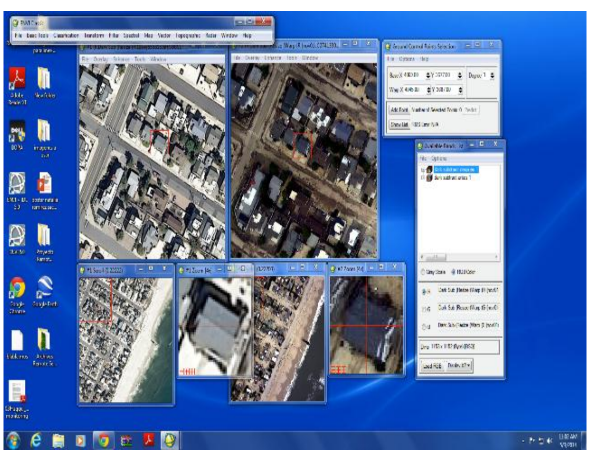

Figure 4: Image showing the different ground control points created in order to geo-reference the image after the hurricane.

(2) Shoreline delineation

Shoreline is defined as the position of the land-water interface at one instant of time (Morelock, 2005). For the purpose of this research the shoreline was established at the interface between the wet and dry elements on the image with the purpose to see the coastal evolution before and after the passage of the hurricane. Using the ENVI classic ROI Tool (polyline features), the shoreline was created on the image before and after the passage of the hurricane. Using the measurement tool, areas of erosion and depositions were identified and average of them was calculated.

(3) Coastal Impacts: Images Classification

In order to have an assessment of the coastal impacts (storm surge) along the New Jersey coastline, different image classification methods (Supervised and Unsupervised) were utilized. Unsupervised classifications (K-means and Isodata) were applied for all the three images of before and after the passage of Sandy. Only one of those classification (Isodata) was selected for the purpose of the study. On the other hand, a supervised classification (Maximum likelihood) was applied for the same three images. For this specific classification 4 different classes (region of interest) were established in order to run the classification. The classes created are: Oceans, Sand, Vegetation and City (which includes houses and streets).

Results and Interpretations

The first images to be studied were taken in Branch Beach, Long Beach Island. Figure 6 is an image taken on November 1, 2012 after the passage of the storm. It showed significant changes to the coastal environment. The residential community shows signs of storm surge impact, evident by the presence of sand as much as 100 meters inland. The displacement (in some cases partial, in some cases complete) of residential units and other human-made elements is also indicative of strong storm surge. Other evident features in the after image are the emergence of two small islets some meters off the shore.

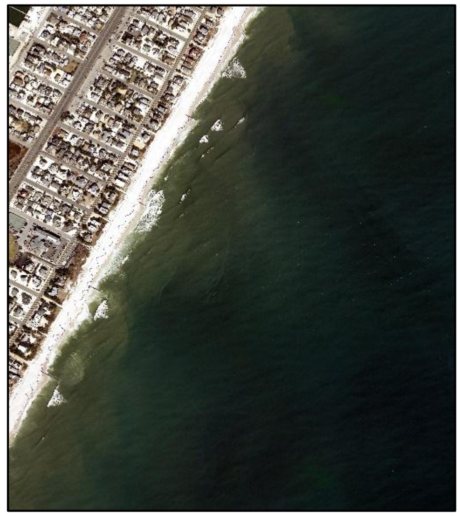

Figure 5: Long Beach Island Aerial Photograph taken in March, 2012.

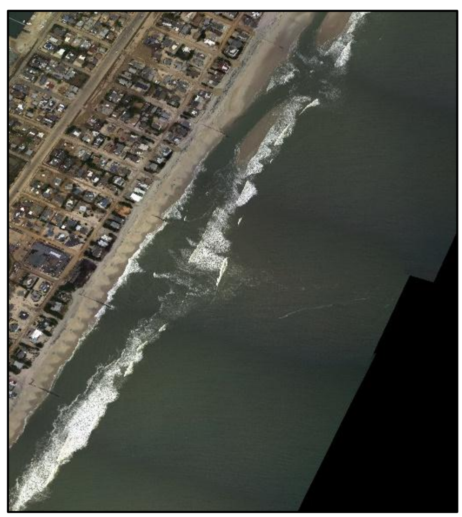

Figure 6: Long Beach Island Aerial Photograph taken after the storm, in November 2012.

The shorelines found before and after the storm showed both erosion and deposition along the beach front (Figure 7). The shoreline measurement after the hurricane also showed signs of dune formation in the beach, another clear sign of high storm surge activity. When the differences between the two shorelines were measured, the average deposition was 15.07 m (Figure 8), while the average erosion was 17.7m (Figure 9). The localization of the erosion and deposition of the beach was determined by the groin features present in the beach; deposition was found north of the groins, erosion was found south.

Figure 7: Close-up shot of the shoreline delineation in Long Beach Island. The red line represents the "before" shoreline, the blue line is the "after" shoreline.

Figure 8: Snap-shot of the deposition measurements. The red line represents the "before" shoreline, the blue line is the "after" shoreline.

Figure 9: Snap-shot of the erosion measurements. The red line represents the "before" shoreline, the blue line is the "after" shoreline.

The two image classification methods used to study the images in this project, Isodata and Maximum Likelihood, provided some interesting, albeit inconclusive results. Isodata provided a first approximation to the coastal impacts caused by the storm. The classes used in each image bear no relationship in terms of color, but there was clear evidence in the “after” image that some of the elements found in the shore area were also present in the residential sector (Figure 11). Nonetheless, the classes represented were ambiguous at best and bear no relationship with clear informational classifications (that is to say, while the colors in the shore area can be found in the residential area, establishing that sand was found in said area is pure speculation.) Thus, using unsupervised classification methods was found to be of little help when conducting such a study.

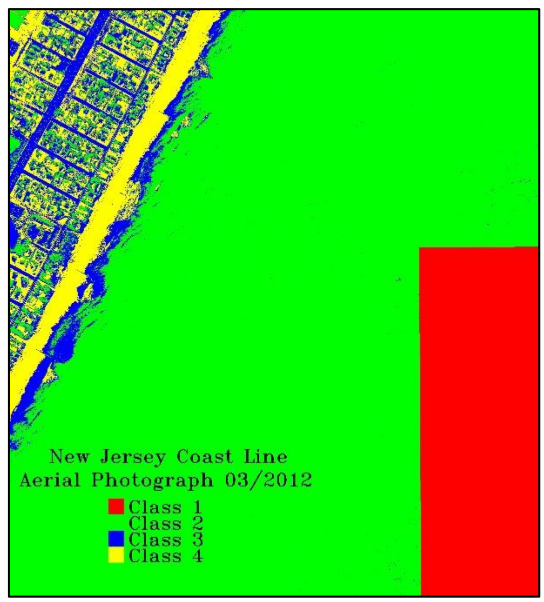

Figure 10: Isodata classification of Long Beach Island image taken on March 2012.

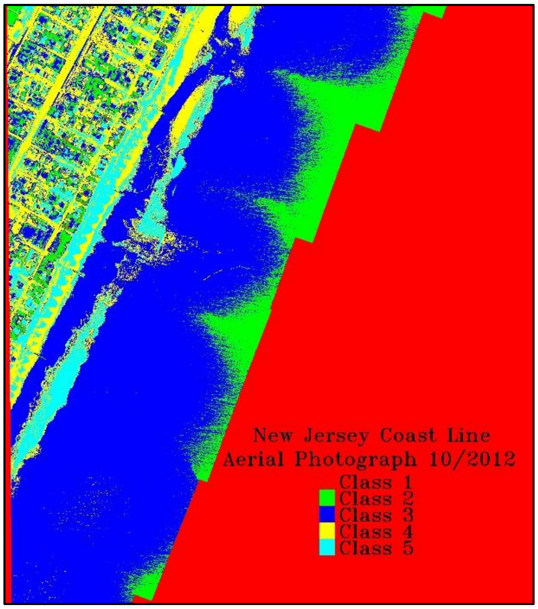

Figure 11: Isodata classification of Long Beach Island image taken on November 2012.

The supervised classification method used in this study was able to provide better results than Isodata. The classes represented in both images have direct relationship to the elements they represent, and are the same in both images; this allows easier comparison of features between the two images. When examining the two images, it was clear that the "after" image shows evident presence of sand in unexpected areas, like streets, avenues and residences (Figure 13). This helps give an idea of how far the storm surge went. There was also a decrease in vegetation presence which could be due to strong winds that felled trees and other shrubbery.

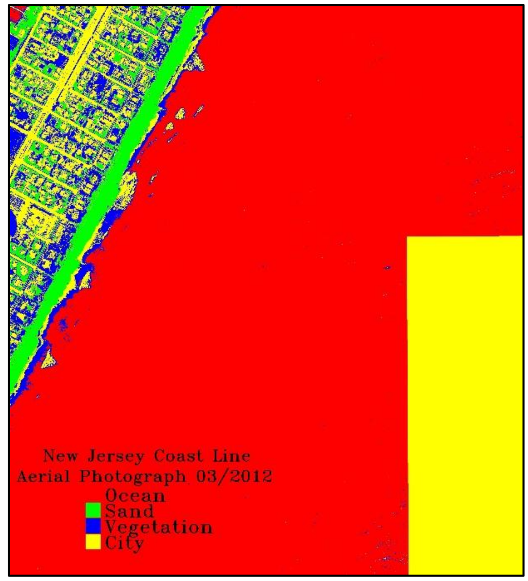

Figure 12: Maximum likelihood classification of Long Beach Island image taken on March 2012.

Figure 13: Maximum likelihood classification of Long Beach Island image taken on November 2012.

Similar results were observed when analyzing the second and third locations represented by the images. Both sets of images were taken over Northern Long Beach, New Jersey. The first set (Figures 14 & 15) shows a before image taken in March 2012 and an after image taken on November 1, 2012, two days after the storm made landfall. The aftermath image shows significant storm surge impact: there are visible changes in the location and position of a variety of housing units as well as clear evidence of displaced sand in the residential and commercial areas.

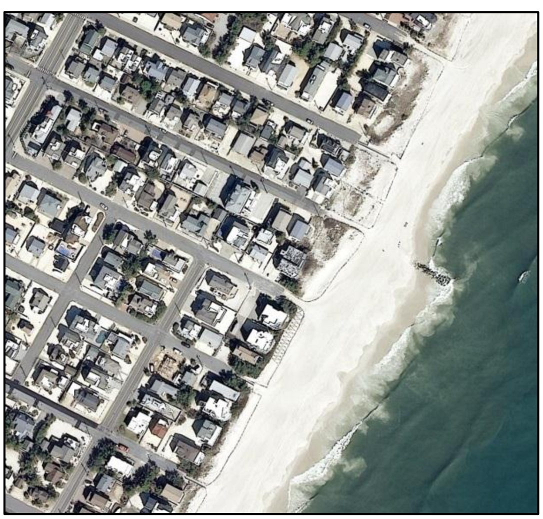

Figure 14: North Long Beach Aerial Photograph taken in March, 2012.

Figure 15: North Long Beach Aerial Photograph taken after the storm, in November 1, 2012.

The shoreline study conducted on this area showed signs of erosion and deposition. There is also evidence of dune formation due to the storm tide, visible in the sinusoidal pattern of the post-storm shoreline (Figure 16).

Figure 16: Close-up shot of the shoreline delineation in North Long Beach. The red line represents the "before" shoreline, the blue line is the "after" shoreline.

Classifying the North Long Beach images yielded similar results to Branch Beach. Isodata shows a lack of skill in accurately representing the environment, and makes image interpretation harder than it would be if it was unprocessed.

Figure 17: Isodata classification of North Long Beach image taken on March 2012.

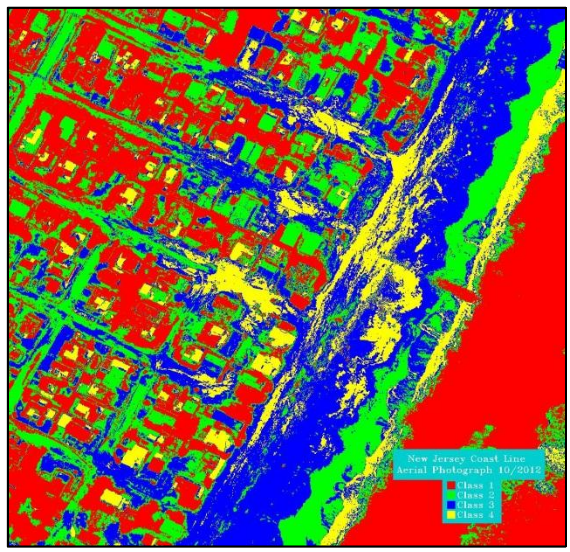

Figure 1: Isodata classification of North Long Beach image taken on November 2012.

Right off the bat, it is evident there is no color correspondence which makes the image interpretation and analysis more challenging. Furthermore, in the image of the aftermath, correspondence between objects represented in the image is also incongruent: the ocean and the residential units share a class, as does the wet sand and other residential aspects. The continuing trend of unskilled Isodata classifications cements the futility of the method when considering aerial images of this kind.

The maximum likelihood supervised classification was more successful in accurately representing the visual elements of the image. The March 2012 classified image shows a remarkable amount of detail that seems to be missing in the post-storm image. Nonetheless, the aftermath image concisely captures the storm surge impact cause by Sandy; sand was deposited along the residential avenues and penetrated hundreds of meters beyond its delineated perimeters.

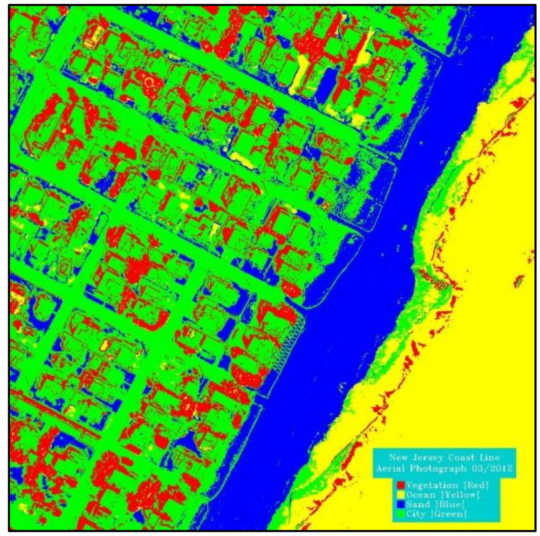

Figure 19: Maximum likelihood classification of North Long Beach image taken on March 2012.

Figure 20: Maximum likelihood classification of North Long Beach image taken on November 2012.

The final image was taken on October 31, 2012, one day after Sandy, and it shows the most damage of the three.

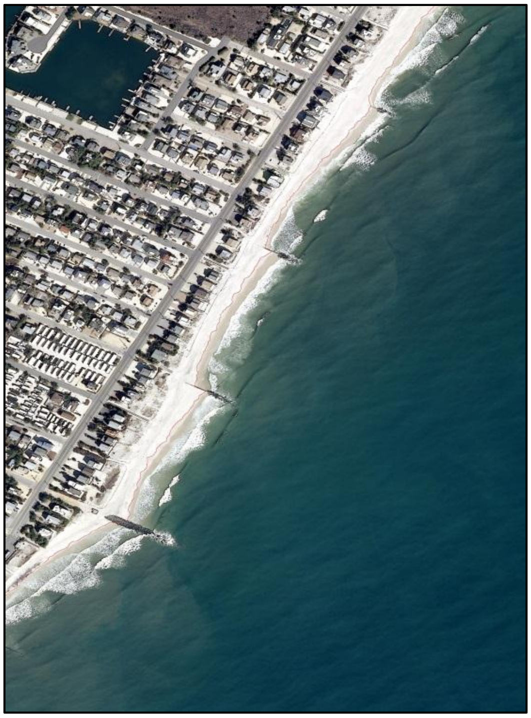

Figure 21: North Long Beach Aerial Photograph taken in March, 2012.

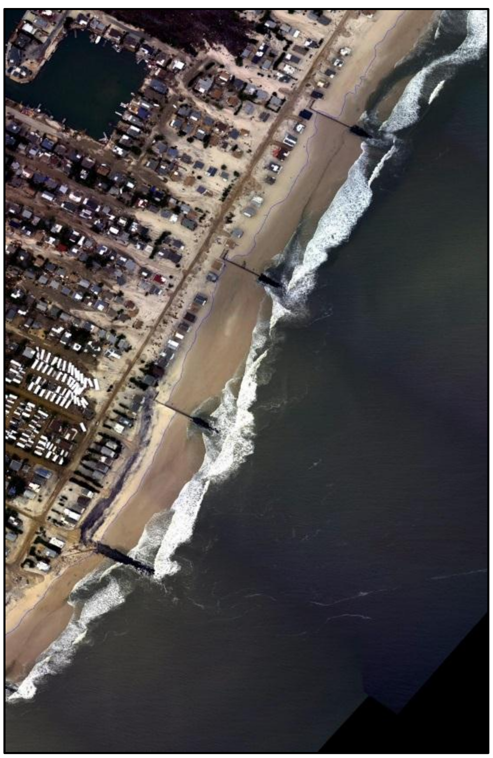

Figure 22: North Long Beach Aerial Photograph taken in October, 2012.

This might be due to the timing of clean up and recovery efforts: in the other two images, the efforts to clean up and restore the area to its previous conditions are more advanced than in this case. This means that, to a certain degree, this image gives the most accurate idea of the true aftermaths of Sandy.

Shoreline comparisons were similar to those established with the previous two images; erosion and deposition were present and quantifiable, with a 12.28 meter loss and 6.78 gain in isolated areas. The erosion caused by the storm is most noticeable in the top strip of Figure 23, where the shoreline almost touches the residential area. This indicates that water entry in this area was significant and very impactful during the duration of the hurricane. This image also shows significant signs of groins at work; we see the deposition and the erosion clearly localized on top and bottom of a groin near the center of the previous Figure 23.

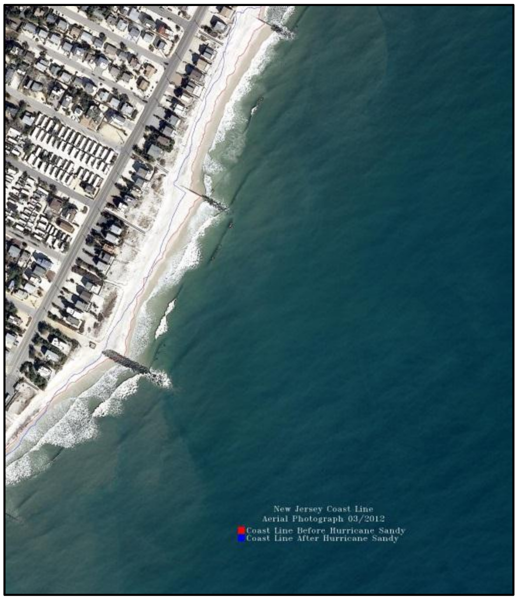

Figure 23: Close-up shot of the shoreline delineation in North Long Beach. The red line represents the "before" shoreline, the blue line is the "after" shoreline.

Figures 24 and 25 show the efforts that went into classifying the image using Isodata. As is to be expected, the images are inaccurate in their representations and allow for little interpretation and analysis. Nonetheless, they provide more data to support the study.

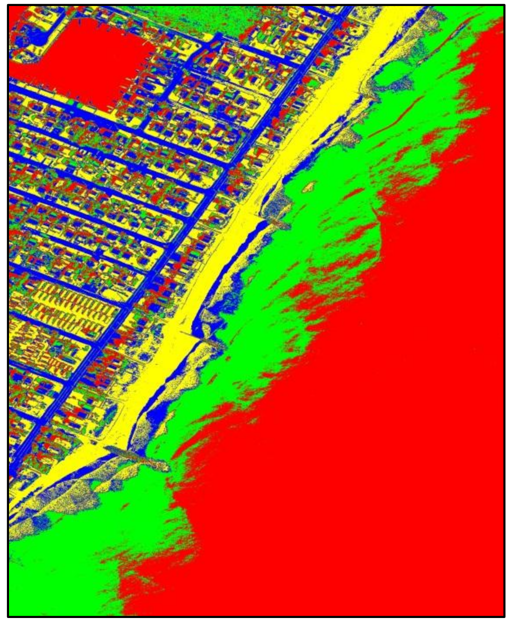

Figure 24: Isodata classification of North Long Beach image taken on March 2012.

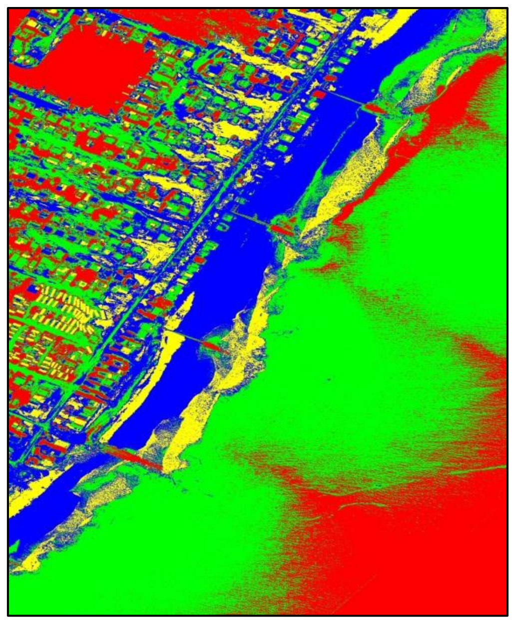

Figure 25: Isodata classification of North Long Beach image taken on October, 2012.

The starkest, most impressive results gathered from classified images were acquired when the October 31 image was classified using Maximum Likelihood. The stark contrast that can be seen in terms of sand deposition is astounding and a true testament to the power that storm surge can carry and the effects in can have in coastal communities.

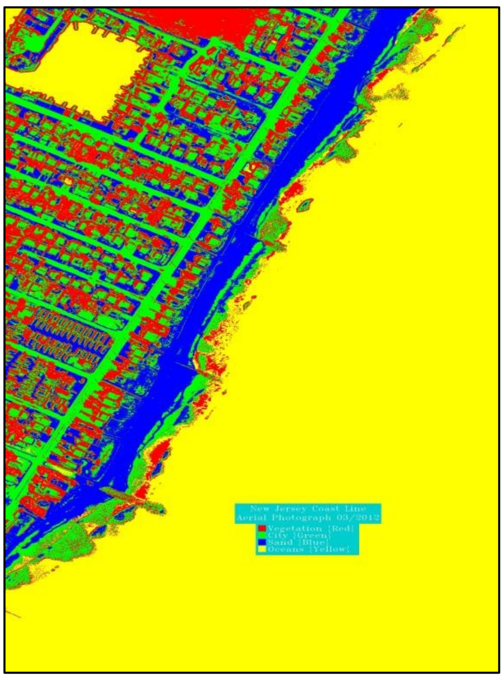

Figure 26: Maximum likelihood classification of North Long Beach image taken on March 2012.

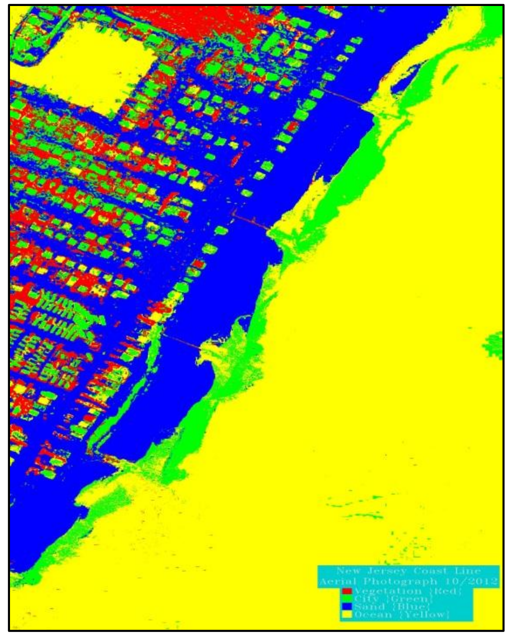

Figure 27: Maximum likelihood classification of North Long Beach image taken on October, 2012.

This image presents clear evidence of the extent of sand deposition caused by the storm surge. It also shows a diminished vegetation presence and the power that the storm surge waters carried with it: in the bottom left corner of Figures 22 and 23 it's evident that trailers were displaced, some completely.

Conclusions

According to the results obtained from this research we concluded that aerial photographs are ideal for studying coastal changes and tidal impacts. With the results of the shoreline changes, the deposition and erosion along the coast of New Jersey was in the order of 10 to 15 meters; these processes were mainly affected by the presence of groins along the coast. In term of the image classification, to have an assessment of the coastal impacts, the best classification was Maximum likelihood in comparison with Isodata, mainly due to the resolution of the image and the region of interest chosen to run the classification.

Recommendations/ Future Works

In order to have more consistency on the results, make a more comprehensive study covering larger zones along the coastline, including Sandy Hook and Mantoloking area. In order to expand more the project, realize the same study of coastline changes for longer period (more than 10 years) of time to see global and local changes on sea level. Finally with the purpose of compare these results, process satellite images **(Figure 27**) with the best resolution to see differences on the results.

Figure 27: Satellite image showing the New Jersey coastline in 2000**.**

References

Campbell, J.B and Wyene R.W., 2011: Introduction to Remote Sensing: Fifth edition. The Guilford Press: London and New York. 666 pages.

Department of Environmental protection, State of New Jersey, Webpage: http://www.nj.gov/dep/shoreprotection/structures.htm

Environment for Visualizing Images (Envi) Classic: Envi Classic.ink

Hurricane Sandy Response Imagery Viewer: http://storms.ngs.noaa.gov/storms/sandy/

Morelock, Jack. 2005: Coastal erosion in Puerto Rico, Department of Marine Sciences University of Puerto Rico, Mayaguez, Puerto Rico Webpage: http://geology.uprm.edu/Morelock/erosPR.htm

Psuty, N. P. 2008. Plumb Beach: A problem of losses and gains of sediment. Unpublished report, Institute of Marine and Coastal Sciences, Rutgers University, Highlands, NJ.

"Storm Surge Overview." Storm Surge Overview. National Hurricane Center. Web. 15 Apr. 2014. <http://www.nhc.noaa.gov/surge/>.

U. S. Department of the Interior, U. S. Geological Survey, USGS: EarthExplorer: http://earthexplorer.usgs.gov/

United States. National Oceanic and Atmospheric Administration. Center for Operational and Oceanographic Products and Services. *Hurricane Sandy Water Level and Meteorological Data Report*. By Colleen Fanelli, Paul Fanelli, and David Wolcott. N.p., 24 Jan. 2013. Web. 15 Apr. 2014. <http://www.tidesandcurrents.noaa.gov/publications/Hurricane_Sandy_2012_Water_Level_and_Meteorological_Data_Report.pdf>.

United States. National Oceanic and Atmospheric Administration. National Hurricane Center. Tropical Cyclone Report - Hurricane Sandy. By Eric S. Blake, Todd B. Kimberlain, Robert J. Berg, John P. Cangialosi, and John L. Beven, II. 12 Feb. 2013. Web. 15 Apr. 2014. <http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf>.