Land Cover Change of Louisiana and Mississippi produced by Hurricane Katrina

WILMA N. PABÓN RAMÍREZ^{1,*}, AND SOL M. CRUZ RIVERA^{1,*}

¹Department of Electrical and Computer Engineering, University of Puerto Rico, PO Box 9042, Mayaguez, P.R. 00681-9042

*Correspondence authors: <u>wilma.pabon@ece.uprm.edu</u>, <u>sol.cruz@ece.uprm.edu</u>

ABSTRACT. – Remote Sensing is useful tools that allow us to extract information of a scene or object without interact physically with it. Remote Sensing imagery can be acquired using a variety of sensors mounted in diverse platforms like satellite and airborne, and could be aerial photography, multispectral or hyperspectral imagery. This type of data is frequently used to monitor important biophysical characteristics on Earth, to detection and target recognition and also in land cover classification. Using remote sensing techniques, we study and analyze the environmental impact of one of the strongest and most devastating hurricanes in the history of the United States: *the hurricane Katrina*. The regions of interest in this work were New Orleans at Louisiana and the gulf coastal region of Mississippi from St. Louis Bay to Pascagoula, including Long Beach, Gulfport, and Biloxi areas. The images were acquired using the Thematic Mapper (TM) sensor on the Landsat 5 satellite. Different methods of unsupervised and supervised classification were applied. Also the normalized difference vegetation index was calculated to select training samples for the supervised classifications, and to do a change detection of vegetation. Results reveals that forest regions, and Wetlands received the higher environmental impact.

INTRODUCTION

Hurricane Katrina is the sixth strongest Atlantic hurricane ever recorded and is the third strongest hurricane on record that made landfall in the United States. It was the costliest and one of the deadliest hurricanes in the history of the United States. It was formed as the tropical depression number twelve on August 23, 2005 at the southeastern of the Bahamas. It began to intensify and the next day was upgraded to a tropical storm named Katrina. On August 25, 2005 it strengthened to hurricane category 1 few hours before its first landfall at the south Florida. It weakened to a tropical storm after landfall and continued its path along the Gulf of Mexico, where it rapidly intensified to a hurricane category 3 on August 27, 2005 becoming the third major hurricane of the 2005 Atlantic season. One day later, Katrina became a category 5 hurricane with maximum sustained winds of 175 mph becoming the sixth strongest Atlantic hurricane ever recorded. It started to weakened and at 6:10



http://www.ncdc.noaa.gov/oa/climate/research/2005/kat

FIG. 1. Hurricane Katrina Path.

a.m. on August 29, 2005 it makes its second landfall near Buras-Triumph, Louisiana, as hurricane category 3 with sustained winds of 125 mph. Few hours later, hurricane Katrina makes its third landfall near the Louisiana/Mississippi border as a category 3 with sustained winds of 120 mph. Katrina continued its path to the north through the central United States until it was dissipated near the Great Lakes. Figure 1 presents the hurricane Katrina's path as described previously.

Hurricane Katrina caused severe damages along much of the North-Central Gulf coast area, being New Orleans at Louisiana and Mississippi the most affected regions, with an economic impact that may exceed the *\$150 billion* of dollars. Hurricane Katrina brought heavy rain, approximately between eight to ten inches (8 -10 in.). In its wake Katrina caused 53 different levee breaches in the city of New Orleans, causing that at least 80% of this city was under flood water on August 31, 2005. Floodings were the major reason to most of the reported fatalities: 1,836 people lost their live, mainly from the state of Louisiana (1,577) and Mississippi (238). However, 705 people remain categorized as missing in Louisiana. In Figure 2 and 3 we present some photos of the damages caused by hurricane Katrina in the states of Louisiana and Mississippi.

Being probably the worst catastrophe in the country's history, many studies were being made about it. The research project described below had as its main objective study and analyzes the environmental impact of the hurricane Katrina in certain regions of Louisiana and Mississippi using remote sensing techniques. We have as secondary objective familiarized with one of the widely used software for image processing and remote sensing: ENVI 4.3¹.

MATERIALS AND METHODS

Data of Study Areas

The affected areas that we selected to make the study are certain regions of Louisiana and Mississippi shown in Figure 4. The region of interest for those states was chosen based on the most affected areas reported in literature. The data was obtained at no cost from the US Geological Survey (USGS) Earth – Explorer application². The images used are from Path: 21-22 and Row: 39, which corresponds to New Orleans, LA and Mississippi respectively. The available

¹ Environment for Visualizing Images (ENVI) developed by ITT Visual Information Solutions, formerly Research Systems, Inc. is widely used software for remote sensing and image processing. http://www.ittvis.com/envi

² *Earth Explorer* is a USGS application to order and download satellite images, aerial photographs and cartographic products from USGS database.

http://edcsns17.cr.usgs.gov/EarthExplorer/



FIG. 2. A Photo collage of hurricane Katrina devastation in the New Orleans, LA region.

images for the study were acquired on February 14, 2005 (pre) and September 7, 2005 (post) for Louisiana region, and on October 15, 2004 (pre) and October 18, 2005 (post) for Mississippi region. The images were acquired using a Thematic Mapper (TM) sensor system on-board Landsat 5 satellite. Landsat 5 was launched on March 1, 1984 and continues collecting data although on November 26, 2005, data collection was suspended for a time due to platform backup solar array satellite problems. The TM is an optical-mechanical whiskbroom sensor that records energy in the visible, near infrared (NIR), middle wave infrared (MWIR), and thermalinfrared regions of the electromagnetic spectrum. The spectral resolution of this sensor is 7 bands: bands 1-3 in the visible region (0.45- 0.52 µm, 0.52-0.60 µm, and $0.63 - 0.69 \ \mu m$), band 4 in the NIR (0.76-0.90 µm), bands 5 and 7 in the MWIR (1.55-1.75 µm, 2.08-2.35 µm), and band 6 in the thermal infrared (10.4-12.5 µm). It provides a spatial resolution of 30 meters for bands 1 to 5 and band 7. Band 6 provides a spatial resolution of 120 meters. It passes over the same point on the Earth every 16 days. The sensitivity of detectors to small differences in electromagnetic energy is 8 bits (radiometric resolution). A standard worldwide reference system (WRS) scene covers a land area of approximately 185 km (across-track) and 180 km (along-track).

Methodology

Typically, the land cover and land use studies are related, the first one with the surface features and the last one with the economic function. The land cover indicates the physical features that occupy the surface of the Earth, such as water, forest, and urban structures. Land use refers to the principal economic enterprises that characterize an area of land: agriculture, manufacturing, commerce, and residential. Our research project only study the land cover change of certain regions of Louisiana and Mississippi based on remote sensing techniques.



Α

B



FIG. 3. A. A man carries a baby through the flooded streets of New Orleans outside the cities Super Dome football stadium. Tens of thousands of displaced citizens sought shelter at the dome, before, during and after Hurricane Katrina, but have been forced to evacuate as floodwaters continue to rise throughout the area. B. A picture from a region of New Orleans, LA on September 5, 2005. The deep water still remains in the city. C. A floating casino in Biloxi, MS. The picture was taken on April 1, 2006. What remained of a floating casino after Hurricane Katrina is undergoing demolition. D. The Highway 90 bridge from Biloxi to Ocean Springs in MS lies in a twisted mass as result of catastrophic wind and storm surge from Hurricane Katrina. E. This picture of September 3, 2005 illustrates the intensity of damages and destruction to houses in Biloxi, MS. F. A picture of Keesler Air Force Base in Biloxi, MS.

Figure 5 shows a block diagram of the methodology used to achieve the results. For this research project, four multispectral TM images taken before and after the landfall of hurricane Katrina in certain regions of LA and MS were analyzed using the available tools in ENVI 4.3. Basically, the methodology consisted in apply a preprocessing to the four multispectral images, generate the Normalize Difference Vegetation Index (NDVI) outputs, produce a land cover of LA and MS study areas using supervised image classification algorithms, and analyze the vegetation change detection using NDVI outputs. The land cover change will be analyzed using image classification procedures.

In the pre-processing step, we performed a spatial subset, a geometric correction, and atmospheric correction. The spatial subset was performed to select the study areas of LA and MS based on the most affected areas reported in the literature. Those areas include New Orleans in LA and the gulf coastal region of Mississippi from St. Louis Bay to Pascagoula areas, including Long Gulfport, Beach, and Biloxi. The atmospheric correction was generated using Dark Subtract - Band Minimum algorithm available in ENVI. This is a uniform atmospheric correction that finds out the minimum value of water in the infrared bands because in that region of electromagnetic spectrum, water absorbs a



FIG. 4. A,B,C,D. False color composite using bands 5,4,3 for channels R,G,B. A and B. Study regions of Louisiana from Pre-Katrina imagery (A) acquired on February 14, 2005 and Post-Katrina imagery (B) acquired on September 7, 2005. C and D. Study regions of Mississippi from Pre-Katrina imagery (C) acquired on October 15, 2004 and Post-Katrina imagery (D) acquired on October 18, 2005.

lot of the incident energy that arrive to surface resulting in approximately all contribution from atmosphere. After the initial image processing, we generated the NDVI to detect where were the areas of vegetation that received the most environmental impact and observe the intensity of it. NDVI is a modulation ratio of the Simple Ratio index (SR). It is a normalized difference of green leaf



FIG 5. Conceptual diagram of the research project methodology.

scattering in NIR and chlorophyll absorption in red band. It is a widely used index to monitoring changes in the amount of green biomass. This vegetation index produces data range values from -1 to 1. Negative values corresponds to materials which have a higher reflectance values in red region than near infrared region like water that absorb a lot of the infrared energy The common range for green vegetation is from 0.2 to 0.8. We adopted this common range to our study because after histogram inspection we found that values higher than 0.8 are not present in pre and post images. We applied a mask to eliminate values out of that range of 0.2 - 0.8, assigning a mask value of "0". The "0" value was chosen to avoid problems when image differentiation, a change detection algorithm, was applied to images. The NDVI can be calculated as follows (Jensen 2007):

$ND \forall I = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$

ENVI has already a standard routine to produce NDVI outputs. This procedure recognizes data from Landsat TM & MSS, SPOT, AVHRR, and AVIRIS sensors. In our case, we are using a TM data and the standard routine detects that band 3 corresponds to red reflectance and band 4 corresponds to NIR reflectance.

The use of NDVI outputs had two reasons in our methodology: (1) monitoring changes in the amount of green biomass using change detection algorithms explained later and (2) help as a tool in the process of selecting training samples for supervised classification algorithms. Image classification was a key point in a land cover generation of LA and MS study areas. Image classification is the process to produce thematic maps where each pixel in the scene is assigned to one class or cluster depends on the type of classification (Campbell 2006). Usually each pixel is treated as an individual unit composed of values in several spectral bands.

There are two primarily types of imagery classification: supervised and unsupervised classification. The unsupervised classification consists into the identification of natural groups, or structures, within multispectral data using sophisticated algorithms without the necessity to select training samples by image analyst. It is useful because human error can be minimized but in some cases the spectrally homogeneous clusters identified do not necessary correspond to the categories that are of interests to the analyst. ISODATA and K-means were the unsupervised classifiers applied to both set of images. It calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. At each iteration, the algorithm recalculates means and reclassifies pixels with respect to the new means. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iteration is reached. The default parameters were modified.

On the other hand, K-mean uses a cluster analysis approach which requires the analyst to select the number of clusters to be located in the data, arbitrarily locates this number of cluster centers, and then iteratively repositions them until optimal spectral separability is achieved. In our research, the use of unsupervised classification algorithms was a further tool to select representative training samples for supervised classification procedures.

Supervised classification can be defined as the process of using samples of known identity, common named as training data, to classify pixels of unknown identity. In this case, the image analyst needs to have an extensive prior knowledge of the scene to be It is important to select and analyzed. defined carefully the training data in order to classify remotely sensed data successfully into land-use and/or land-cover information. The USGS provides a classification system, "Land -Use/Land-Cover Classification System for use with Remote Sensor Data" (Anderson 1976), with classification levels (I-IV) depend on the nominal spatial resolution of the sensor used to acquire the scene of interest. For our project we used several tool to select a near training samples, which were representative of each class. We used the National Land Cover Database (NLCD) 2001, shown in Figures 6, as a land cover reference. This land cover provides a lot of sub level classes according with Anderson (1976) table. In our case, we only selected training samples for 5 classes: water, forest, agriculture, wetlands, and urban regions, which correspond to level 1 -Use/Land-Cover in the "Land Classification System for use with Remote Sensor Data" (Anderson 1976) due limitations of spatial resolution. With the ENVI link function we can observe the same area of different display and outputs. It was useful to the selection of training samples because allow the comparison between



FIG 6. USGS - National Land Cover Dataset 2001 Subset of (A) Louisiana and (B) Mississippi Region.

NDVI outputs, unsupervised thematic maps, false color composite of bands 4,3,2 which enhance vegetation, and the NLCD 2001. Minimum Distance (MD), Maximum Likelihood (ML), and Mahalananobis classifiers were the supervised algorithms used for this task.

The MD classifier uses the mean vector of each training class specified in the region of interest (ROI) of ENVI and calculates the Euclidean Distance from each unknown pixel to the mean vector for each class. All pixels are classified to the closest ROI class unless the user specifies standard deviation or distance thresholds, in which case some pixels may be unclassified if they do not meet the selected criteria (ENVI 4.3 Help).

ML classifier assumes that the statistics for each training class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class that has the highest probability. The training parameters are the mean and covariance matrix of each training class specified in the ROI (ENVI 4.3 Help).

Mahalanobis classifier, the third supervised classifier used to produce the land cover change, is similar to the ML classification but assumes all class covariances are equal resulting in a faster method. All pixels are classified to the closest ROI class unless you specify a distance threshold, in which case some pixels may be unclassified if they do not meet the threshold (ENVI 4.3 Help). As a final stage of the project, we used change detection techniques such as image differentiation to produce a change detection of vegetation and analyze the land cover change of LA and MS using image classification procedures.

Difficulties

We found several difficulties along the research project. Especially in obtain the data images at no cost, use a mosaic of regions from two different paths, and get a land cover updated for recent years after hurricane Katrina. On a NASA website we found several remote sensing centers that provide images at reduced or no cost such as the Global Land Cover Facility (GLCF) at the University of Maryland which provides Pre-Katrina orthorectified high-quality images but they does not has available data for Post-Katrina imagery. For that reason, this center was ruled out from our options. Our second fail attempt in get data images occurred when we try to get ETM+ images from Landsat 7. USGS provides ETM+ Landsat 7 imagery at no cost but in Scan Line Corrector (SLC) – off format. The SLC consists of a pair of small mirrors that rotate about an axis in tandem with the motion of the main ETM+ scan mirror. The purpose of the SLC is to compensate for the forward motion (along-track) of the spacecraft so that the resulting scans are aligned parallel to each other. Landsat 7 had a SLC failure on May 31, 2003. Due to the geographic area that we would like to study, the use of Landsat 7 in SLC-off format it was not an option for us. Finally, we found TM Landsat 5 images on the Earth Explorer database from USGS which provide pre and post Katrina images.

Originally, we wanted to generate a pre and post mosaic comprised of New Orleans, LA and coastal region of MS instead of the use of four spatial subsets images separately. Due the available images were taken in different time of the year and conditions, the brightness tone in the images affected the performance of supervised and unsupervised classification algorithms resulting in a confusion of classes. We applied several methods of histogram stretching available in ENVI in order to reduce the tone brightness effect into images from different paths but the result was not optimum. For that reason, we decided to make a spatial subset of each region and analyzed images separately. This alternative produces a lot of results but avoid the incorporation of further uncertain and variability to data imagery.

RESULTS AND DISCUSSION

Results of Louisiana

In the following section the results obtained from the study area of Louisiana are presented.

We start presenting the results obtained from NDVI. Figure 7 shows the results of the NDVI for the pre and post Katrina images. Areas with high biomass of green and healthy vegetation have higher NDVI values (near 0.8) and are colored with intense green. By the contrary, areas in where vegetation is not healthy or abundant have lower values of NDVI (near 0.2). These areas are colored in light green to white. Areas colored in black are the areas that are masked which imply that vegetation is not present. As we see in Figure 7, there are regions that are colored as intense/medium green in Fig. 7 (A) that in Fig.7 (B) appears



FIG 7. NDVI results of (A) pre and (B) post Katrina for the Louisiana region

as completely black, especially in the New Orleans area. To see most clearly the effect of the change in vegetation, a pixel is randomly selected in the New Orleans area as shown in Figure 6. This pixel has a high value of NDVI in the pre-Katrina image: 0.766 (see the red arrow in Fig. 6 (A)), and a masked value (see the red arrow in Fig. 6 (A)) in the post-Katrina image. It implies that the area associated with this pixel suffer greater damages. The same pixel is assigned to the wetland class in the NLCD 2001. In literature, we found that the selected pixel is part of the Bayou Sauvage National Wildlife *Refuge*, a large patch of forest, which suffered heavy tree mortality caused by hurricane Katrina as seen in Figure 8.



FIG 8. *Bayou Sauvage National Wildlife Refuge*, a large patch of forest, which suffered heavy tree mortality (areas in red in the right side image) caused by hurricane Katrina.



FIG 9. New Orleans Maximum Standing Floodwater Levels as seen on September 1, 2005



FIG 10. NDVI Change Detection for the affected study region of Louisiana

But also the region New Orleans was very affected by floodings, as shown in Figure 9. Therefore there are pixels that were masked as consequence of the floodwater levels. Figure 10 shows the NDVI change detection. As we can see there are regions that suffer loss of vegetation but there were other regions that gain vegetation. Probably these were agricultural/pasture areas. Table 1 summary the results obtained in the NDVI change detection.

The results of the different types of classifications for the Louisiana region are shown below. We start with the unsupervised classification. Figure 11 and 12 shows the results of the ISODATA and k-Means classifications respectively. There is not a big difference between the outputs of these classifiers. When compared the pre and post images for the two unsupervised classifiers we can see that great difference especially in the New Orleans region. Figure 13 shows the results of the Maximum Likelihood, Mahalanobis and Minimum Distance supervised classifiers. As we can see, ML classifier, classify well the urban areas if we compared with the NLCD 2001 (Fig. 6 (A)). MD classifier was better classifying the water bodies, but was not good with the urban areas. Finally, Mah.D compared with MD, classifies better the urban areas (pre), but no so well compared with ML. In the case of the water it did well compared with ML that only found those areas in where there were maximum floodwater levels (post). Comparing the results of the three classifiers pre and post Katrina, we can see that all of them found significant changes in the New Orleans area, and associates these changes with water. ML classifier found these areas of New Orleans that had the maximum floodwater levels comparing with the Fig.9.



FIG 11. ISODATA Results of the affected study region of Louisiana, (A) pre and (B) post Katrina



FIG 12. k-Means results of the affected study region of Louisiana, (A) pre and (B) post Katrina



FIG 13. Results obtain from supervised classifiers: (A) Maximum Likelihood, (B) Mahalanobis Distance and (C) Minimum Distance of the affected study region of Louisiana pre (left) and post (right) Katrina



FIG 14. Comparison between the Maximum Likelihood classification and the standing floodwater levels map. As we can see regions that were classified as water (that before were land) in the ML thematic map corresponds to the maximum floodwater levels of the New Orleans city (over 10 feet of floodwater).

TABLE 1. Summary	of LA NDVI	Change Detection
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Vegetation Change	Number of	-	Coverage Area	
Detection	Pixels	Percent (%)	(Km ²)	
	Loss			
High (68-100%)	1,100	0.016	1	
Medium (34-67%)	244,846	3.55	220	
Low (0-33%)	1,798,892	26.07	1619	
Total Loss	2,044,838	29.63	1840	
	No Cha	nge		
No change (masked				
values)	3,487,925	50.54	3139	

In conclusion, we can say that in the Louisiana region, the most affected area was the New Orleans city. The major damages in this region were caused by floodings that reaches levels over the 10 feet.

Results of Mississippi

This section explain the results obtained in the study area of Mississippi using diverse remote sensing techniques such as NDVI, vegetation change detection, unsupervised and supervised classifications to produce a land cover change of the most affected areas of MS reported in the literature.

NDVI

The NDVI outputs for MS pre and post Katrina images are shown in figure 15 A,B. As we know, the NDVI produces values from -1 to 1. We adopted a common range of vegetation of 0.2 to 0.8 and values out of that range were masked because are not vegetation pixels. For instance, water and urban pixels which produce negative values or less than 0.2 absorb a lot of incident energy in NIR band resulting in a higher reflectance of red band in comparison with NIR band. The NDVI masked product resulted in a useful and effective tool to help in the selection of vegetation (NDVI values) and high urban (inland NDVI masked values) training samples for supervised classification procedures. A higher NDVI

values which represent a green and healthy vegetation pixels has darker green tone and lower NDVI values are represented with lighter green tone in figure 15 A,B.

In MS NDVI post Katrina output, figure 15B, it is possible to observe an intensive biomass change of green vegetation along the gulf coast of MS including the regions of St. Louis Bay, Gulfport, Biloxi, and Pascagoula. Deer and Cat Island received great biomass damage in forest and wetlands regions. Table 2 shows three random pixels of those regions and St. Louis Bay and comparing their NDVI pre and post values with the class assigned for this region in the NLCD 2001.

TABLE 2. Pre and Post Katrina NDVI values of random pixels

Pixel Location	Mississippi Region	Pre-Katrina NDVI value	Post-Katrina NDVI value	Class in the NLCD 200
30°22'43.44" N,				
88°51'24.51" W	Deer Island	0.6486	0.1860	Wetland
30°19'17.43"N.				
89°21'21.12" W	St. Louis	0.6986	0.2973	Forest
30°13'25.22"N.				
89°5'0.32" W	Cat Island	0.6429	0.1628	Forest

Figure 15 C illustrates a MS NDVI change detection of vegetation generated using an image differentiation technique. As you can observe in figure 15 C, the most vegetation biomass change occurred along gulf coastal region of MS from St. Louis Bay to Pascagoula. Those areas are represented in red in the change detection results (Figure 15C). The total vegetation loss was near 49% as you can see in Table 3 which summarize the change detection results in terms of percentage, number of pixels, and approximate of area coverage for each category (gain or loss). Taking into consideration that approximate 49.6% of study area are water and urban pixels (masked values), the vegetation loss in MS



FIG 15. A and B. NDVI of a Pre (A) and Post-Katrina (B) MS region. C. Vegetation change detection using NDVI results of pre and post Katrina images of MS region. There was applied a mask to A and B in order to keep values in the common green vegetation range of 0.2 to 0.8.

study region was near to 98%. The damages along the coastal region of MS was caused primarily by strong winds and surge storms and the interior inland further biomass change was caused mainly by tornadoes accordingly with literature reports.

TABLE 3. Summary of MS NDVI Change Detection

Description of Vegetation Change Detection	Number of Pixels	Percent (%)	Coverage Area (Km²)
	Loss	4	
High (68-100%)	6,611	0.138	5.95
Medium (34-67%)	162,383	3.39	146.14
Low (0-33%)	2,159,903	45.09	1943.91
Total Loss	2,328,897	48.62	2096
	Gain	1	
High (68-100%)	66	0.001	0.059
Medium(34-67%)	2,990	0.062	2.69
Low (0-33%)	82,118	1.71	73.91
Total Gain	85,174	1.77	76.66
	No Cha	nge	
No change (masked values)	2.375.937	49.60	2138.34

Unsupervised Classifications

ISODATA and K-means unsupervised algorithms were applied to MS pre and post Katrina images in order to use their results as tool for the selection of representative training samples for supervised classification procedures. The unsupervised thematic maps produced by ISODATA and K-means algorithms are shown in figures 16 A,B and 17 A,B, respectively. We are not found a significant difference between both unsupervised methods. As you can observe, both results shows the same pattern change observed in NDVI results along the coastal region of MS primarily in the regions assigned to forest and wetlands in the NLCD 2001 (Figure 6).

Supervised Classifications

Minimum Distance (MD), Mahalanabis Distance, and Maximum Likelihood (ML) were the supervised classification algorithms applied to pre and post Katrina images in order to analyze the MS land cover change after the landfall of hurricane Katrina.

The ML results are shown in Figure 18 A,B. As you can observe, ML classified so well pixels assigned as urban regions in the NLCD 2001 but we concluded that not provide a good land cover for coastal regions, which were one of the most affected areas of MS. NLCD 2001 defined four sublevel classes as urban regions: developed high, low, medium, and open space. Typically urban spectral reflectance signatures are comprised primarily of concrete and asphalt roads, parking areas, shingles, and bare soil which generally reflects some portion of the incident green, red, and near infrared radiant flux. Also those pixels have the major problem of mixed pixels that could be with forest, agriculture, and others. For that reason, if supervised classifiers like ML assigns areas of open space in urban regions that would be tree, vegetation, etc. to urban regions we cannot detect a significant change in vegetation biomass.

The pre and post Katrina thematic maps produced by Mahalanobis classifiers are shown in figures 19 A,B. As you can observe, this classifier defined very well rivers and other water bodies but forest regions are over estimated because confused some wetlands regions. This behavior is not completely bad because several wetlands areas are comprised for aquatic vegetation. Those areas in literature are reported as regions which received а great environmental impact produced by Katrina.



FIG. 16. A and B. Thematic maps of pre (A) and post (B) Katrina images using ISODATA unsupervised classifier.



FIG. 17. A and B. Thematic maps of pre (A) and post (B) Katrina images using K-means unsupervised classifier.



FIG. 18. A,B. Thematic maps of pre (A) and post (B) Katrina images using a Maximum Likelihood supervised classifier.



FIG. 19. A,B. Thematic maps of pre (A) and post (B) Katrina images using a Mahalanobis supervised classifier.



FIG. 20. A and B. Thematic maps of pre (A) and post (B) Katrina images using a Minimum Distance supervised classifie

Minimum Distance NDVI Open Water Perennial Ice/Snov ۲ Developed, Open Space Ρ Developed, Low Intensity **National Land Cover** R Database 2001 Developed, Medium Intensity Developed, High Intensity Е Barren Land (Rock/Sand/Clay) Unconsolidated Shore Deciduous Forest Evergreen Forest Mixed Forest Dwarf Scrub (AK only) Shrub/Scrub Shrub/Scrub Grasslands/Herbac-cous Sedge/Herbaceous (AK only) Lichens (AK only) Ρ Moss (AK only) Pasture/Hay Cultivated Crops 0 S Woody Wetlands Emergent Herbaceous Wetlands Т

FIG. 21. Comparison between a Land cover change of a St. Louis Bay, MS generated using a Minimum Distance supervised classifier, pre and post NDVI, and the National Land Cover Database 2001 of the same region.

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For MS study area, Minimum Distance classifier (figure 20 A,B) was the best supervised algorithm to produce a land cover change taking into consideration of a 30m of spatial resolution (medium resolution) and the available tools for this research which not included field work validation. MD classified so well water bodies and also only assign high developed urban region in the NLCD 2001 to urban class allowing us to analyze the vegetation change in areas of urban open space along the coastal region of MS. A subset of St. Louis Bay, MS thematic map produced by MD is shown in figure 21. This figure also compares the pre and post Katrina NDVI results and NLCD 2001 with the MD classification map for the same region of St. Louis Bay, MS. As you can observe in figure 21, the higher NDVI values (pre and post images) which are represented with darker green tones are the same regions that MD assigned as forest regions.

After evaluate NDVI and land cover change results, the most affected areas of Mississippi were the coastline from St. Louis Bay to Pascagoula including Long Beach, Gulfport, and Biloxi. These results are similar with most affected regions reported in literature which received greater damages caused by strong winds, tornadoes, and storm surges.

CONCLUSION

The results of Mississippi and Louisiana study areas reveals that forest regions, and Wetlands received the higher environmental impact and severe change in vegetation biomass. Wetlands are essential wildlife habitat, massive natural water filters, and "natural sponges" that hold water when it rains, then release it slowly. For that reason, wetlands loss means a significant danger and risk for many different species of fish, birds, and insects which depends of wetland habitats.

FUTURE WORK

As part of this research project, it could be interesting to extend the land cover change work using different multispectral sensors at different spatial resolutions. The use of a low spatial resolution sensor like MODIS would be useful to extend the geographic area for the study. On the other hand, the use of a high spatial resolution sensor like IKONOS would be useful to study in more details specific cities.

The use of a hyperspectral sensor it could be valuable if it is interested in extend the number of classes in more details of informational classes such as types of vegetation, wetlands, etc. Hyperspectral sensors have a high spectral resolution and are valuables to discriminate between materials and objects.

Further point that could be study is the analysis of recent images in years 2006 and 2007 to observe the process of vegetation recovery in those areas.

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