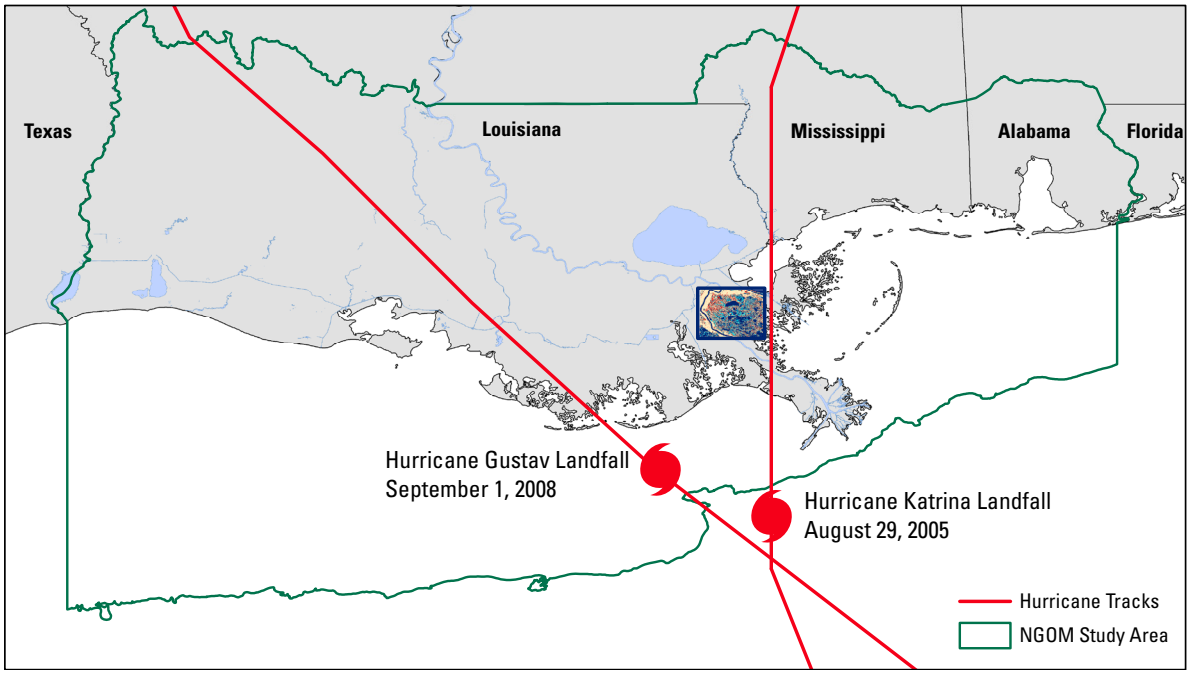
USGS
science for a changing world

Land Area Change Analysis Following Hurricane Impacts in Delacroix, Louisiana, 2004–2009

By Monica Palaseanu-Lovejoy, Christine Kranenburg, and John C. Brock



Pamphlet to accompany
Scientific Investigations Map 3207

U.S. Department of Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this report is in the public domain, permission must be secured from the individual copyright owners to reproduce any copyrighted materials contained within this report.

Suggested citation:
Palaseanu-Lovejoy, M.E., Kranenburg, C.J., Brock, J.C., 2012, Land Area Change Analysis Following Hurricane Impacts in Delacroix, Louisiana, 2004–2009, U.S. Geological Survey, Scientific Investigations Map 3207, 9 p.

Contents

Introduction 1
Methodology 1
Discussion.....1
Conclusions 5
Acknowledgements 9
References.....9

Figures

1. Map of study area. 1
2. Satellite imagery sources, dates, and extents of imagery used. 2
3. Change analysis map 2004–2006. 4
4. Highlighted section from figure 3–Hurricane Katrina change analysis. 5
5. Change analysis map 2006–2008. 6
6. Change analysis map 2008–2009. 7
7*A*. Change analysis map 2004–2009.....8
7*B*. Change analysis interpretation. 9

Tables

1. Independent and dependent variable predictors for fractional-water maps ..3
2. Evaluation indices for maximum Kappa coefficient of agreement. 3

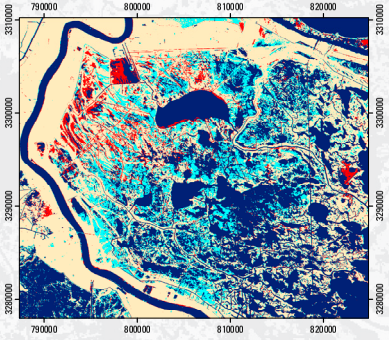
Scientific Investigations Map 3207
Pamphlet accompanies map

Land Area Change Analysis Following Hurricane Impacts in Delacroix, Louisiana, 2004–2009

By Monica Palaseanu-Lovejoy,[1] Christine Kranenburg,[1] and John C. Brock[2]

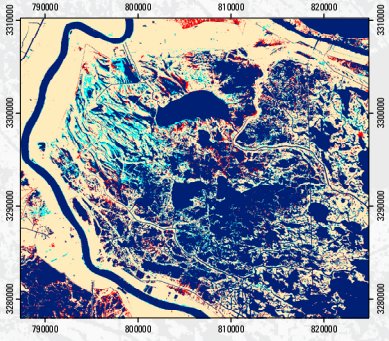
[1]Jacobs Technology, contracted to U.S. Geological Survey, [2]U.S. Geological Survey

Land Change Analysis 2004–2006:
Hurricane Katrina (Aug. 2005)



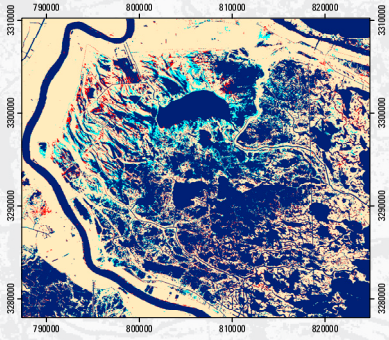
Mar. 2004	Sept. 2006	Change Analysis Interpretation
Land	Land	Unchanged land areas (44.92%)
Water	Land	New land areas (5.60%)
Land	Water	New water areas (11.81%)
Water	Water	Unchanged water areas (37.67%)

Land Change Analysis 2006–2008:
pre-Hurricane Gustav (Sept. 2008)



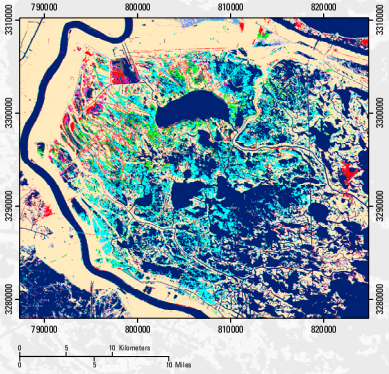
Sept. 2006	Mar. 2008	Change Analysis Interpretation
Land	Land	Unchanged land areas (46.75%)
Water	Land	New land areas (3.75%)
Land	Water	New water areas (3.76%)
Water	Water	Unchanged water areas (45.73%)

Land Change Analysis 2008–2009:
Hurricane Gustav (Sept. 2008)

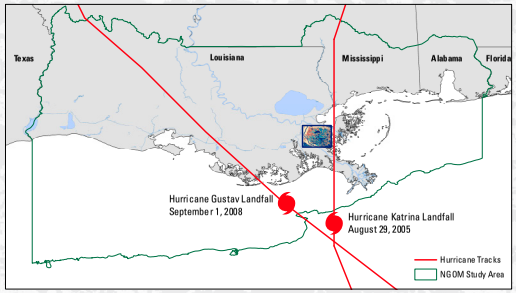


Mar. 2008	Nov. 2009	Change Analysis Interpretation
Land	Land	Unchanged land areas (46.67%)
Water	Land	New land areas (3.94%)
Land	Water	New water areas (3.84%)
Water	Water	Unchanged water areas (45.56%)

Land Change Analysis 2004–2009



Mar. 2004	Sept. 2006	Mar. 2008	Nov. 2009	Change Analysis Interpretation
Land	Land	Land	Land	Unchanged land (41.37%)
Water	Land	Land	Land	Permanent land Katrina (3.25%)
Land	Water	Land	Land	Temporary water Katrina (1.48%)
Water	Water	Land	Land	Drained fields after 2006 (0.55%)
Land	Land	Water	Land	Water-level fluctuation 2008 (1.32%)
Water	Land	Water	Land	Vegetation seasonality (0.69%)
Land	Water	Water	Land	Drainage after 2008 (1.18%)
Water	Water	Water	Land	New land Gustav (0.75%)
Land	Land	Land	Water	New water Gustav (1.39%)
Water	Land	Land	Water	Erosion Gustav (0.74%)
Land	Water	Land	Water	Post-storms flooding/seasonality (0.97%)
Water	Water	Land	Water	Drainage in 2008 (0.74%)
Land	Land	Water	Water	Dead vegetation, after 2006 (0.84%)
Water	Land	Water	Water	Temporary new land Katrina (0.92%)
Land	Water	Water	Water	Permanent new water Katrina (8.17%)
Water	Water	Water	Water	Unchanged water (35.63%)



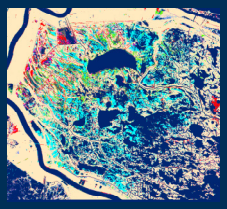
Northern Gulf of Mexico (NGOM) study area showing the track of hurricanes Gustav and Katrina in relation to the land change study area of this map.

Image sources:
Base maps derived from USGS Landsat imagery 2004, 2006, 2008, and 2009
30 meter pixel resolution
Projected using WGS 84 datum and Universal Transverse Mercator (UTM) Zone 15 North
Longitude of Central meridian: -93.00000

U.S. Department of the Interior
U.S. Geological Survey

April 2012

Land Area Change Analysis Following Hurricane Impacts in Delacroix, Louisiana, 2004–2009



By Monica Palaseanu-Lovejoy[1], Christine Kranenburg[1], and John C. Brock[2]

[1]Jacobs Technology, contracted to the U.S. Geological Survey, [2]U.S. Geological Survey

Introduction

In this study, we estimated the changes in land and water coverage of a 1,208-square-kilometer area surrounding Delacroix, Louisiana (fig. 1), that was impacted by hurricanes Katrina (Aug. 29, 2005) and Gustav (Sept. 1, 2008). The objective of this study is twofold: (1) to provide pre- and post-Hurricane Katrina and pre- and post-Hurricane Gustav moderate resolution 30-meter (m) fractional-water maps based upon multiple source images, and (2) to quantify land and water coverage changes due to the recent hurricanes. Tropical Storm (TS) Cindy also moved over the study area on July 6, 2005, less than 2 months before Hurricane Katrina impacted the area. Thus, any effects from TS Cindy will be included in the changes attributed to Hurricane Katrina in the following analysis. Although TS Cindy took a more direct path across the study area, the peak wind speed was only 50 knots, compared to 110 knots for Hurricane Katrina.

Methodology

The U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center provided the following imagery for this project: three *QuickBird* images and four Landsat 5 Thematic Mapper (TM) scenes for Path 22, Row 39. One *Geoeye-1* image was provided by the National Geospatial-Intelligence Agency (NGA). Figure 2 shows imagery dates and extents.

The aim of this study is to improve estimates of wetland land loss in Delacroix, La., due to extreme storms impacting the region between 2004 and 2009. The estimates developed in this study are based on change-detection-mapping analysis that incorporates pre- and post-landfall (Hurricanes Katrina and Gustav) fractional-water classifications using a combination of high-resolution (< 5 m) *QuickBird* and *Geoeye-1* images, and medium-resolution (30 m) Landsat images. The fractional-water maps are the result of regression-tree modeling in which the dependent variables are derived from high-resolution imagery and the independent variables from 30-m resolution Landsat imagery. The continuous fractional-water maps are classified into land and water categories using the maximum Kappa coefficient as an optimizer. Palaseanu-Lovejoy and others (2010) provide details on the fractional-water methodology.

The list of independent and dependent variables that were useful predictors for the final maps selected for each year is shown in table 1. The optimum threshold and associated accuracy metrics derived from each year's selection point dataset are shown in table 2.

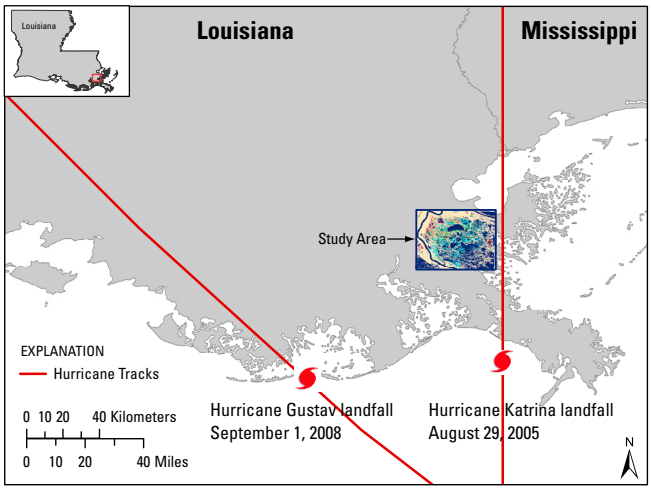


Figure 1. Map showing location of study area.

Discussion

The Delacroix region is composed of a relatively unmanaged (few artificial water diversions present) marsh in the central and eastern sections that is bounded by residential and agricultural areas to the north and west. Each of these distinct land-use types responds to, and recovers differently from, an extreme storm event. Land/water changes detected after an extreme storm event reflect both permanent and temporary changes and are affected by both natural and artificially controlled drainage, land-recovery projects, and the time elapsed since the storm impact. These changes are superimposed on a very dynamic environment in which land/water architecture is influenced by seasonality and water levels (microtidal fluctuation, precipitation, water-management practices). For this study, we consider permanent

EXPLANATION

High resolution

Quickbird - (04/04/2004) Yellow

Quickbird - (09/29/2006) Color Infrared (CIR)

Quickbird - (11/07/2007) Purple

Geoeye-1 - (11/16/2009) Greyscale

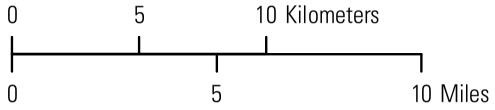
Moderate resolution

Landsat 5 - (03/12/2004)

Landsat 5 - (09/26/2006)

Landsat 5 - (03/23/2008)

Landsat 5 - (11/05/2009)



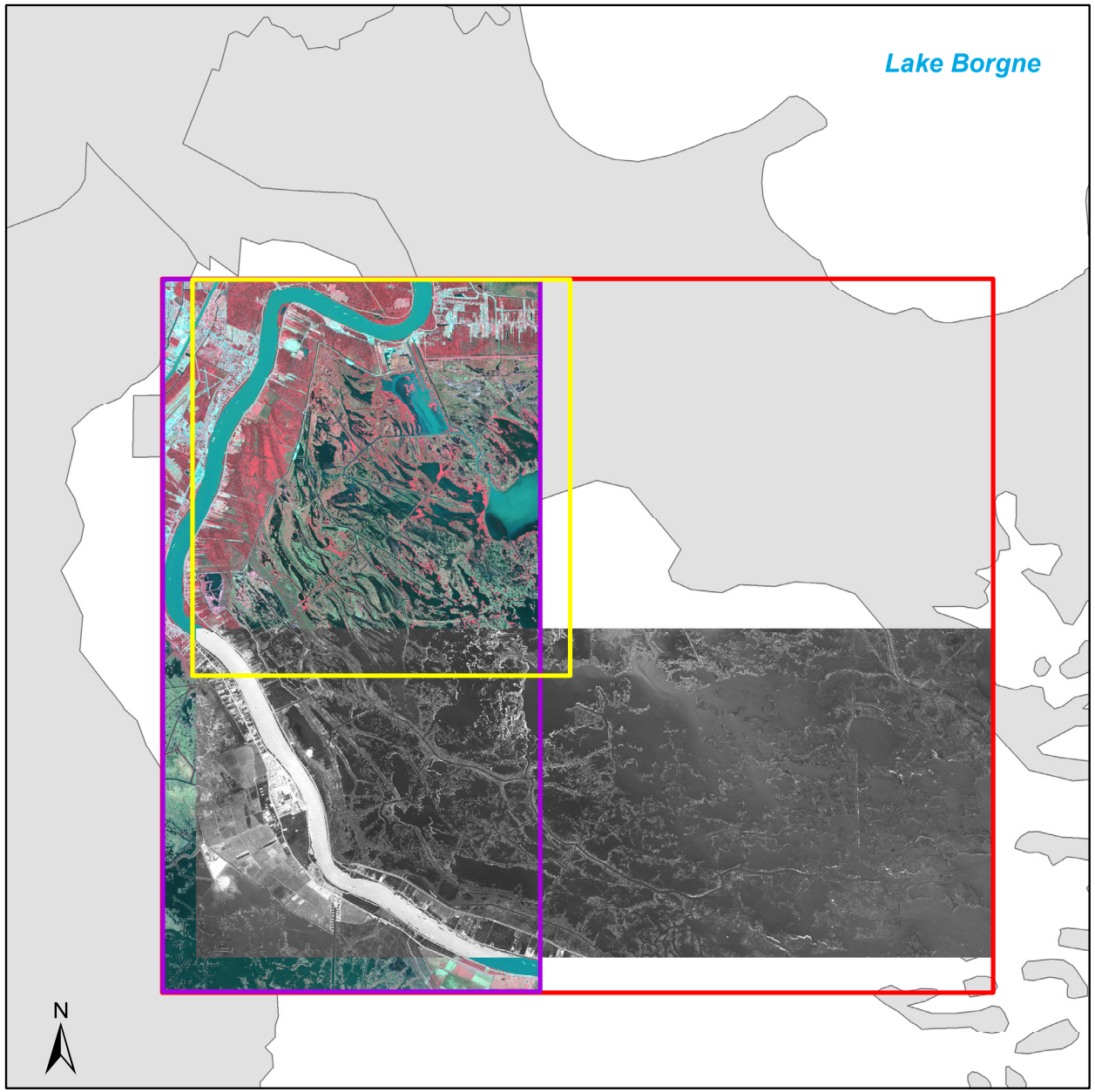


Figure 2. Sources, dates, and extents of satellite imagery used.

Table 1. Independent and dependent variable predictors for fractional-water maps.

[Abbreviation of spectral bands and acronyms used: b1, blue; b2, green; b4, IR, infrared; VIS, visible bands; PCA, principal components; ICA, independent components; GNDWI, green normalized difference water index.]

Year	Idependent variable	Dependent variable
2004	Landsat bands: 1 to 6	Water Index: PCA
	Texture: Homogeneity (bands 1 to 6) Principal Components: 2 to 6	
	Water Index: Braud	
2006	Landsat bands: 1 to 6	Water Index: Braud (sum(VIS)-sum(IR))/(sum(VIS)+sum(IR))
	Texture: Entropy (bands 1 to 6) Principal Components: 2 to 6	
	Water Index: GNDWI	
2008	Landsat bands: 1 to 6	Water Index: GNDWI (b4-b2)/(b4+b2)
	Texture: Variance (bands 1 to 6) Independent Components (log): 1 to 3	
2009	Landsat bands: 1 to 6	Water Index: GNDWI (b4-b2)/(b4+b2)
	Texture: Contrast (bands 1 to 6) Principal Components: 2 to 6	
	Water Index: GNDWI	

Table 2. Evaluation indices for maximum Kappa coefficient of agreement.

PCC-percent correctly classified, AUC-area under the curve. All values are percentages.

Year	Threshold	PCC	PCC water	PCC land	Kappa	AUC	Commission	Ommission
2004	40	97.75	96.88	98.63	95.50	99.52	1.37	3.12
2006	35	99.64	99.52	99.76	99.29	99.73	.24	.48
2008	40	98.10	99.10	97.24	96.33	99.54	2.71	.91
2009	51	99.31	99.46	99.14	98.62	99.52	.78	.54

new water areas to be those new water areas that appear after a storm and persist through time. They are the result of direct removal of wetlands by storm surge and appear mostly connected to existing bodies of open water, but also emerge in marsh-fringing areas.

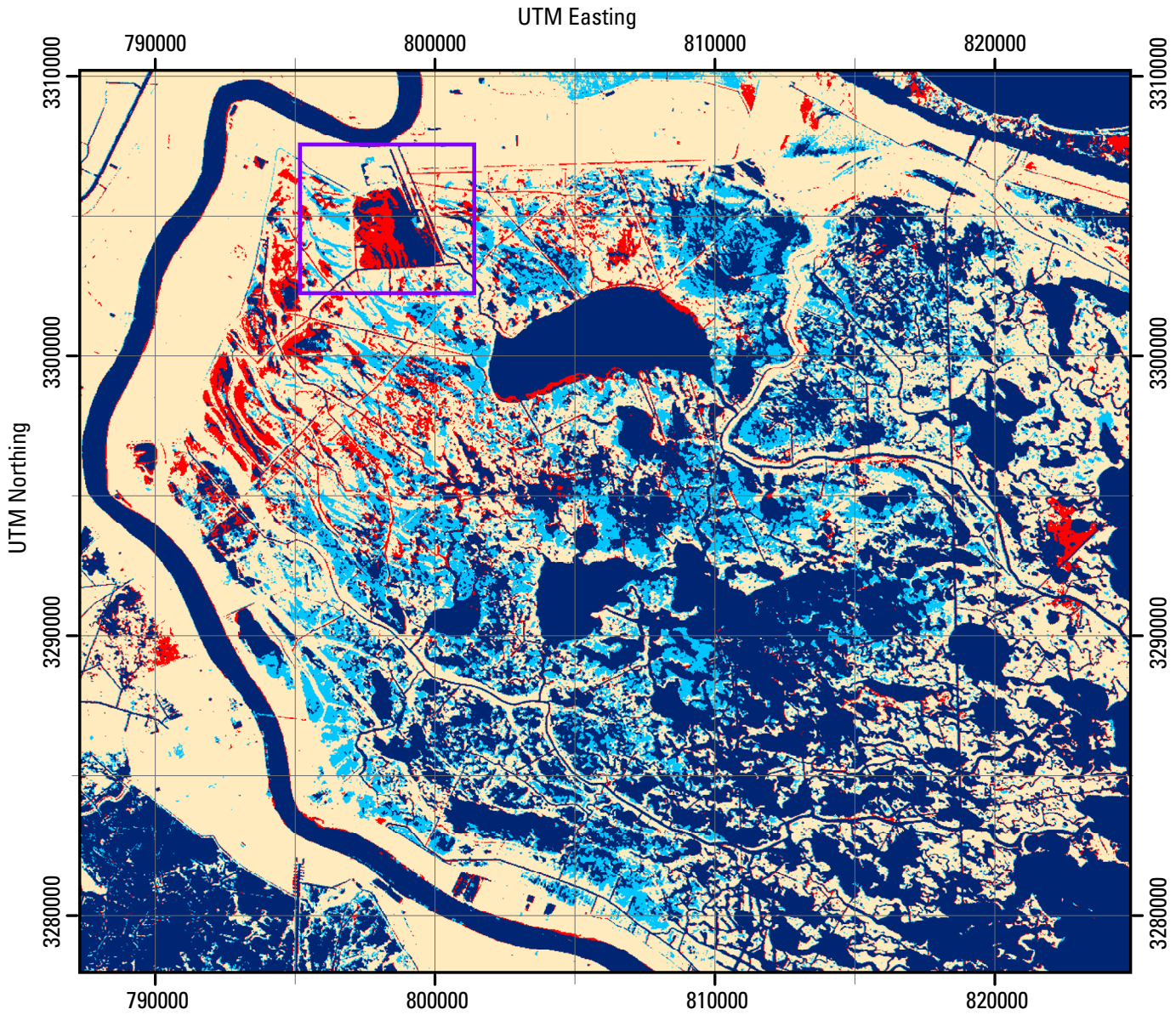
Temporary new water bodies are usually the result of flooding and water entrapment in impounded areas, removal or scouring of floating and submerged vegetation, or are caused by water-level fluctuation due to tidal or meteorological variations between images. Temporary new water bodies usually revert to their original classification (land) after a suitable period of recovery.

Land gain in the Delacroix area is mostly transitory and is the effect of storm-debris deposition, displacement of aquatic vegetation to different locations, drainage, seasonality, or nitrate nutrient input. Most of the land gain observed along rivers, canals, and beaches is a direct result of variations in water levels caused by tidal or meteorological influences.

Hurricane Katrina made landfall on the eastern border of the Delacroix study area on August 29, 2005. Many of the new water areas (11.81 percent) created by this hurricane formed around existing bodies of open-water. (fig. 3).

Extensive marsh scarring is evident in the numerous elongated finger-like new water features in the west-central part of the study area (fig. 3). At present, it is difficult to distinguish between flooded marsh and marsh removed by storm surge. The new land areas (5.60 percent) are largely due to vegetation seasonality, drainage, or possible nitrate pollution from the adjacent agricultural areas to the west or the golf course to the north. Scarring, vegetation seasonality, displacement, and probable nitrate pollution are apparent in Big Mar, the impounded pond, and its vicinity in the northwestern part of the study area (fig. 3, highlighted in purple; fig. 4). Individual changes cannot be confirmed as transitory or permanent until later in the time series.

Between September 2006 and March 2008, no extreme storm events impacted the area. The changes that occurred represent normal variability in a very dynamic environment and were due to vegetation seasonality and water-level fluctuation (tidal and meteorological) (fig. 5). Most of the new



Base maps derived from USGS Landsat imagery 2004 and 2006.

Mar. 2004	Sept. 2006	Change Analysis Interpretation
Land	Land	Unchanged land areas (44.92%)
Water	Land	New land areas (5.60%)
Land	Water	New water areas (11.81%)
Water	Water	Unchanged water areas (37.67%)

0 5 10 Kilometers

0 5 10 Miles

Projected using the WGS 84 datum and the Universal Transverse Mercator (UTM) Zone 15N coordinate system.

Figure 3. Change analysis map 2004–2006—Hurricane Katrina.

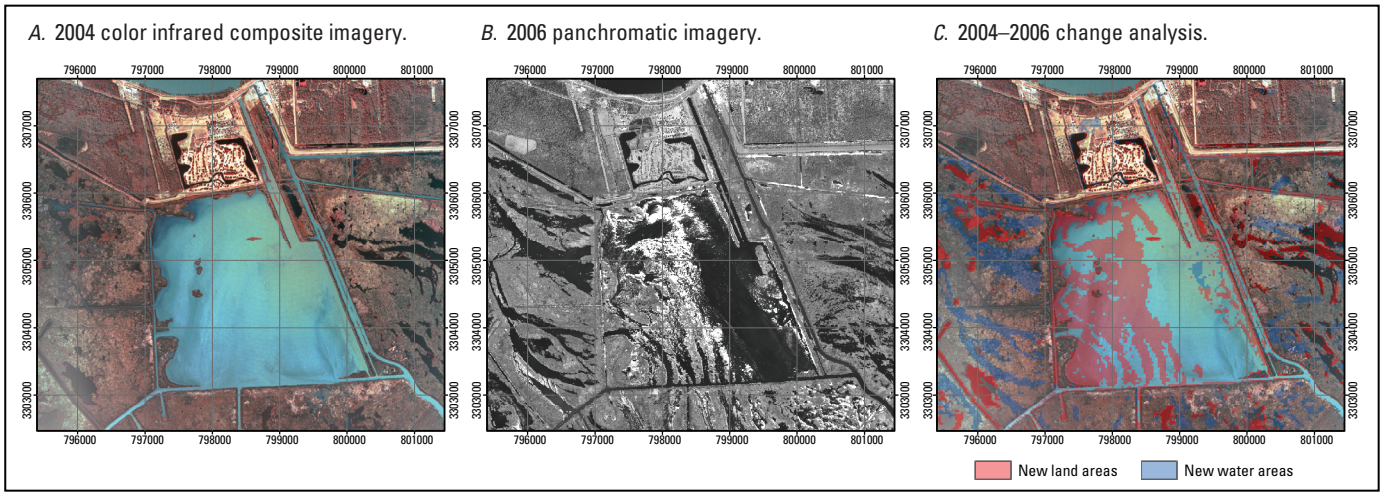


Figure 4. Highlighted section from figure 3—Hurricane Katrina change analysis.

water areas (3.76 percent) that developed between September 2006 and March 2008 are the result of aquatic vegetation loss due to seasonality, while the new land areas (3.75 percent) are mainly the result of water-level fluctuations and drainage.

Hurricane Gustav made landfall on September 1, 2008, approximately 80 to 100 kilometers (km) west of the study area and had minimal impact compared to that of Hurricane Katrina. Most post-Hurricane Gustav new water (3.84 percent) and new land (3.94 percent) areas (fig. 6) are more comparable to those in the March 2008 change analysis map (fig. 5) in both magnitude and spatial distribution than to those in the Hurricane Katrina change analysis map (fig. 3). This indicates that these changes are more closely related to the environment's natural variability than to Hurricane Gustav (fig. 6). This interpretation is supported by analysis of the time series change in the Delacroix area, from 2004 to 2009 (fig. 7).

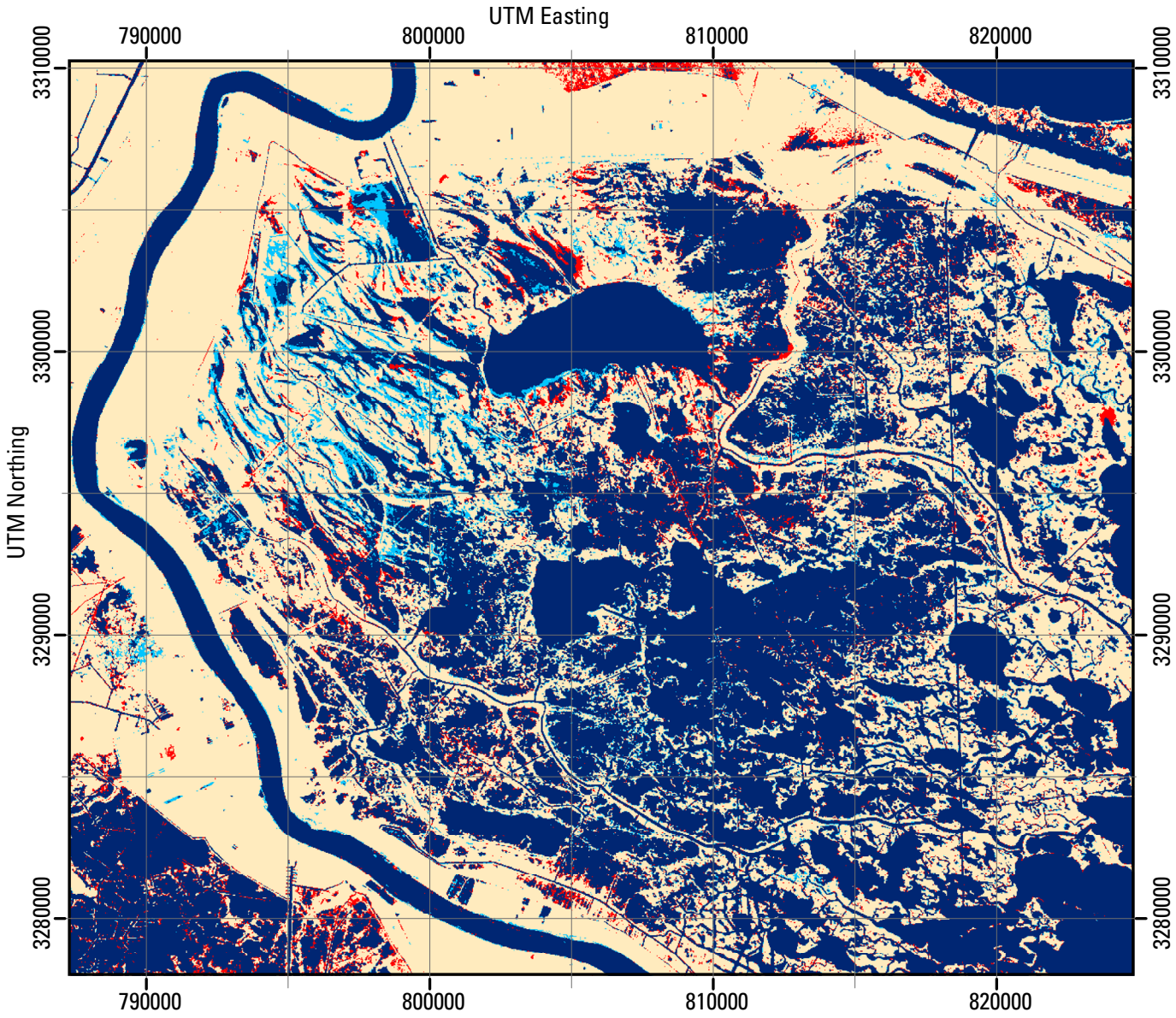
The interpretation of figure 7 involves determining the classification (land or water) of each pixel of the study area for each year's imagery. The change analysis interpretation is based on the change in class of a particular pixel through time. For example, if a pixel is classified as land in 2004, changes to water in 2006 and remains water in 2008 and 2009, it is assigned to the class "Permanent new water due to Katrina." A pixel that toggles between water in Spring 2004 imagery, land in Fall 2006 imagery, back to water in Spring 2008 and then back to land in Fall 2009 is attributed to vegetation seasonality. The left half of figure 7*B* indicates the 16 possible classification combinations over a 4-image set.

Time series change analysis reveals the permanent changes due to Hurricane Katrina, namely the permanent new water (8.17 percent) and permanent new land areas (3.25 percent) (fig. 7*B*). Temporary fluctuations in land/water classification due to seasonality, drainage, flooding, and water-level oscillations are perceptible as well. Collectively, these leave only 0.75 percent as new land areas and 1.39 percent as new water areas due to Hurricane Gustav, and these categories include both permanent and temporary changes. A further 0.74 percent of the area then changed from water in March 2004 to land in September 2006 and March 2008 reverted to water after Hurricane Gustav.

Spatially, a clear pattern emerges in which marshes in the east and southeast of the study area are almost unaffected; damage then gradually increases to the north and west, up to and until the boundary with the agricultural/urban areas. This trend closely follows the salinity gradient of the marshes in the study area. Saline marshes robustly withstood the effects of the hurricanes despite being closer to the eye of Katrina than the brackish and intermediate marshes farther inland. Howes and others (2010) attribute this robustness of high-salinity marshes, relative to their fresher counterparts, to their deeper root systems and higher shear strength of the soil on which they reside. Fresh marshes display a highly sinusoidal land-loss trend-line, indicating the variation is dominated by short-term vegetation seasonality and meteorological conditions, which conceal hurricane impacts.

Conclusions

Most of the permanent new water areas (8.17 percent) due to Hurricane Katrina occur around existing bodies of open water and in marsh fringing areas, but they are also present in historically stable areas. The presence of scarring in stable marshes is discernible as newly formed, elongated finger-like ponds, especially in the central-western part of the study area. Storm-debris deposition, small reclamation projects and permanent drainage can result in small new land areas, but



Base maps derived from USGS Landsat imagery 2006 and 2008.

Sept. 2006	Mar. 2008	Change Analysis Interpretation
Land	Land	Unchanged land areas (46.75%)
Water	Land	New land areas (3.75%)
Land	Water	New water areas (3.76%)
Water	Water	Unchanged water areas (45.73%)

0 5 10 Kilometers

0 5 10 Miles

Projected using the WGS 84 datum and the Universal Transverse Mercator (UTM) Zone 15N coordinate system.

Figure 5. Change analysis map 2006–2008—no storm events.

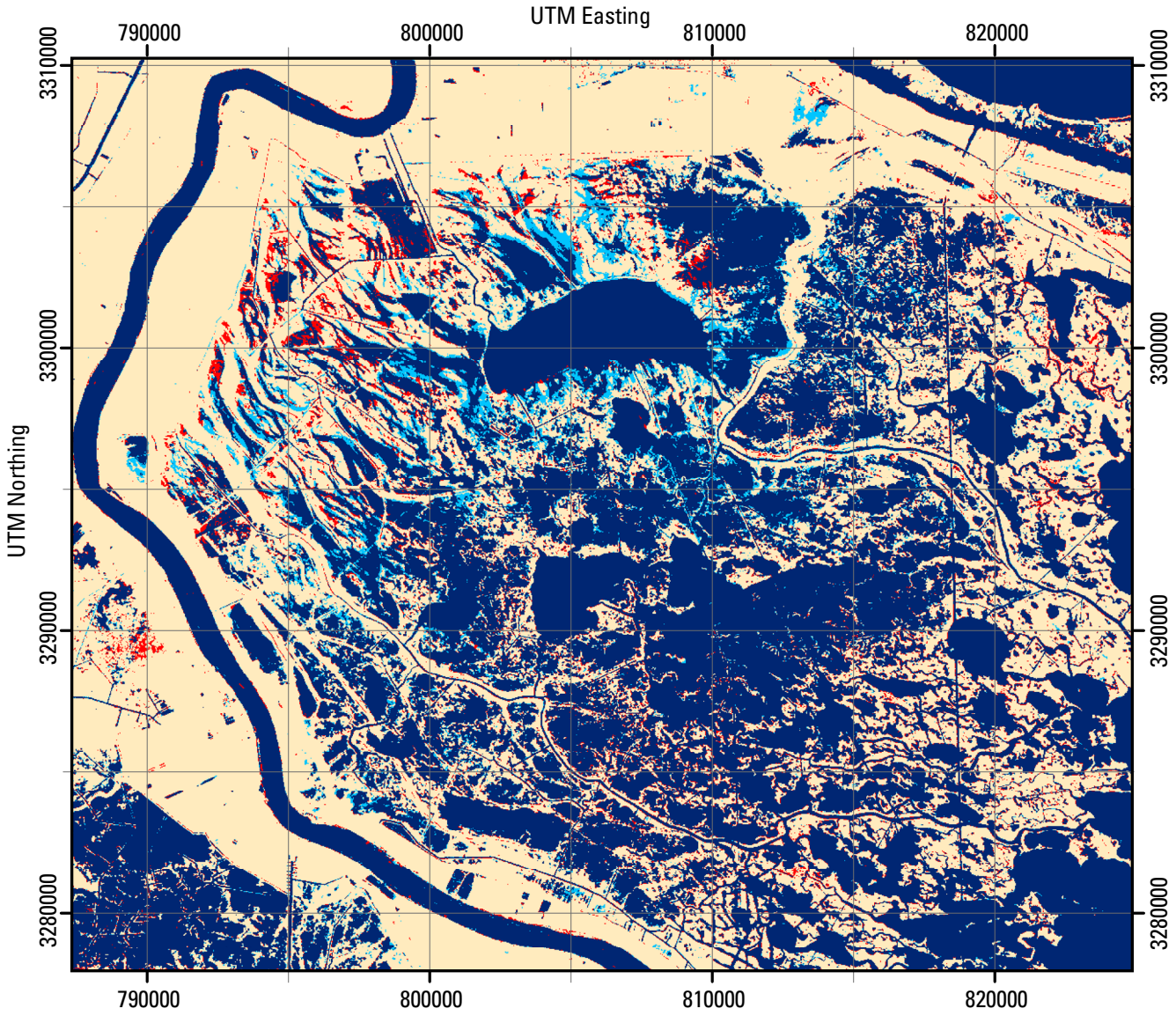
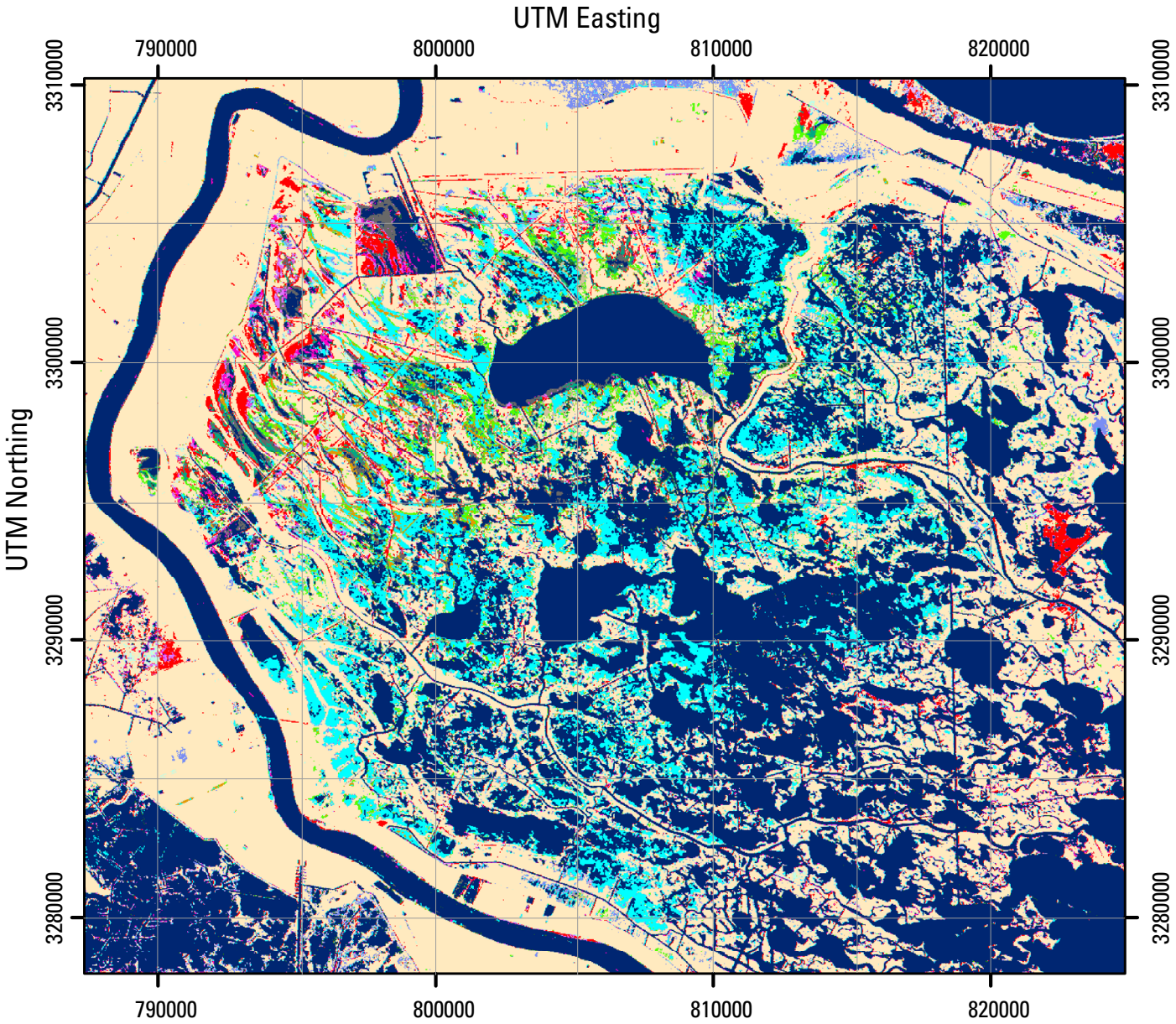
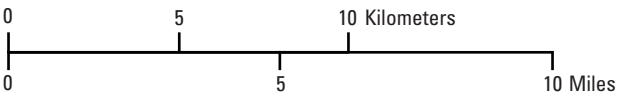


Figure 6. Change analysis map 2008–2009—Hurricane Gustav.

A



Base maps derived from USGS Landsat imagery 2004, 2006, 2008 and 2009.



Projected using the WGS 84 datum and the Universal Transverse Mercator (UTM) Zone 15N coordinate system.

Figure 7. Change analysis (*A*) map 2004–2009 and (*B*) interpretation chart.

B

Mar. 2004	Sept. 2006	Mar. 2008	Nov. 2009	Change Analysis Interpretation
Land	Land	Land	Land	Unchanged land (41.37%)
Water	Land	Land	Land	Permanent land Katrina (3.25%)
Land	Water	Land	Land	Temporary water Katrina (1.48%)
Water	Water	Land	Land	Drained fields after 2006 (0.55%)
Land	Land	Water	Land	Water-level fluctuation 2008 (1.32%)
Water	Land	Water	Land	Vegetation seasonality (0.69%)
Land	Water	Water	Land	Drainage after 2008 (1.18%)
Water	Water	Water	Land	New land Gustav (0.75%)
Land	Land	Land	Water	New water Gustav (1.39%)
Water	Land	Land	Water	Erosion Gustav (0.74%)
Land	Water	Land	Water	Post-storms flooding/seasonality (0.97%
Water	Water	Land	Water	Drainage in 2008 (0.74%)
Land	Land	Water	Water	Dead vegetation, after 2006 (0.84%)
Water	Land	Water	Water	Temporary new land Katrina (0.92%)
Land	Water	Water	Water	Permanent new water Katrina (8.17%)
Water	Water	Water	Water	Unchanged water (35.63%)

Figure 7. Change analysis (*A*) map 2004–2009 and (*B*) interpretation chart. ---Continued

land gain along waterways and beaches is considered to be the result of temporary variations in water levels caused by tidal or meteorological influences.

Saline marshes suffered far less hurricane damage than their fresher counterparts. In fresh marsh vegetation, seasonality has a considerable effect on land-loss variation, obscuring hurricane impacts.

Estimation of permanent losses (or gains) due to Hurricane Gustav cannot be made until the transitory impacts are identified and quantified. However, it is expected that the permanent losses will be relatively small, probably less than 1 percent of the area. Overall, 77 percent of the area remained unchanged between 2004 and 2009, and over 11 percent of the area was changed permanently by Hurricane Katrina (both land gain and land loss). Less than 3 percent was affected, either temporarily or permanently, by Hurricane Gustav.

Acknowledgments

The USGS St. Petersburg Coastal and Marine Science Center acknowledges the support and assistance of the USGS Land Characterization team at the Earth Resources Observation and Science (EROS) Center, in Sioux Falls, South Dakota, and the USGS National Wetlands Research Center, in Baton Rouge, La., in the development of this dataset.

References

Howes, N.C., FitzGerald, D.M., Hughes, A.J., Georgiou, I.Y., Kulp, M.A., Miner, M.D., Smith, J.M., and Barras, J.A., 2010, Hurricane-induced failure of low salinity wetlands. Proceedings of the National Academy of Sciences, v. 107 no. 32, p. 14014-14019.

Palaseanu-Lovejoy, M.E., Kranenburg, C.J., and Brock, J.C., 2010, Land area change and fractional-water maps in the Chenier Plain, Louisiana, following Hurricane Rita, (2005): U.S. Geological Survey, Scientific Investigations Map 3141, 6 p. pamphlet.