



In cooperation with National Park Service Gulf Coast Network Inventory and Monitoring Program and National Aeronautics and Space Administration

The Use of Lidar in Monitoring Barrier Island Volumetric Change and Shoreline Position at the Gulf Islands National Seashore, MS

By J.M. Bonisteel-Cormier, Amar Nayegandhi, C.W. Wright, and J.C. Brock

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List of Abbreviations and Acronyms

ALPS – Airborne Lidar Processing System

CIR – Color-infrared

DEM – Digital Elevation Model

EAARL – Experimental Advanced Airborne Research Lidar

ESRI – Environmental Systems Research Institute

GEOID03 – Conterminous U.S. geoid model

GIS – Geographic Information Systems

GPS – Global Positioning System

GUIS – Gulf Islands National Seashore

I & M – Inventory and Monitoring

INS – Inertial Navigation System

LIDAR – Light Detection And Ranging

NAD83 – North American Datum, 1983

NASA – National Aeronautics and Space Administration

NAVD88 – North American Vertical Datum, 1988

NPS – National Park Service

RMSE – Root Mean Square Error

UTM – Universe Transverse Mercator

USGS – United States Geological Survey

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter (m ²)	0.0002471	acre
square kilometer (km ²)	247.1	acre
square meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
cubic meter (m ³)	35.31	cubic foot (ft ³)
cubic meter (m ³)	1.308	cubic yard (yd ³)
cubic kilometer (km ³)	0.2399	cubic mile (mi ³)
cubic meter (m ³)	0.0008107	acre-foot (acre-ft)

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

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Executive Summary

The U.S. Geological Survey (USGS), in collaboration with the National Park Service (NPS) Inventory and Monitoring (I&M) Program and National Aeronautics and Space Administration (NASA), used the Experimental Advanced Airborne Research Lidar (EAARL) to collect topographic data for ecological monitoring, storm-event assessment, habitat mapping, and evaluating geomorphic change. In this study, 1-m, 5-m, and 10-m digital elevation models (DEMs) were created from EAARL data to assess and monitor morphologic change at Gulf Islands National Seashore, MS. Multiple, repeat surveys designed for the conservation and monitoring of critical coastal habitat were conducted over the study area. Lidar data were collected in September 2005; June 2007; and September 2008 to capture impacts from storms and major anthropogenic modifications that occurred during those times. Morphologic change was determined between each of the acquisition periods by calculating net volumetric change per unit area (m) and identifying shoreline position variation as well.

Each survey did not cover the same extent of the barrier island; the net volumetric change was normalized by dividing by unit area. Results from the volumetric change analysis illustrated that a 1-m resolution DEM provided the most detailed representation of morphologic change, while the volumetric change rates remained about the same regardless of the transformation in DEM resolution. The justification could be made for a coarser resolution for future barrier island volumetric change rate studies. At the larger resolutions, however, a grid cell can be much larger than the features in that area causing the local variance to increase. Therefore, measurements will not be correlated with their neighbors resulting in a loss of topographic detail.

Datum referenced shorelines were extracted for each study area in 2005, 2007, and 2008. Using a contour datum-based shoreline provides unbiased repeatability. The study sites have a constant value shoreline of 0-m North American Vertical Datum of 1988 (NAVD88) Geoid03 that has been established. Not all years of collection covered the full barrier island and as such the shoreline areas were absent in those sections. Each barrier island with the exception of Cat Island had shoreline progression measurements from 2005 to 2008.

The ability of lidar to collect high-density measurements of topography and bathymetry over large areas shows the capacity of lidar surveys in capturing ever-changing morphology, especially when natural influences play a considerable role in shaping the environment at the five Mississippi barrier islands. Insight into the processes that determine the “long-term” barrier island modification will increase with additional lidar collection.

Introduction

Barrier islands are valuable natural resources that provide recreational areas and coastal ecosystems as well as protect marshes and coastal environments during storms. These dynamic and rapidly changing islands characterize most of the areas along the U.S. Atlantic and Gulf Coasts. It is a

challenge to document the barrier island change-producing processes that are occurring or likely to persist into the future. Continuously measuring and monitoring these changes allows better management of natural and anthropogenic modification and protects coastal resources (Stockdon and others 2007).

Mobile platforms such as lidar make it possible to quickly collect accurate and dense data over larger areas (Stockdon and others, 2007). Lidar point densities are on average one laser shot per square meter; such densities permit the creation of high-resolution digital elevation models (Stockdon and others, 2007). In addition, lidar surveys often provide full island coverage that may not be obtained with other remote sensing techniques. A full island survey allows for the assessment of barrier island width and changes in barrier island area (Stockdon and others, 2007). EAARL is an example of an airborne lidar instrument that has the ability to collect coastal topography and shallow submerged bathymetry simultaneously in a single seamless coverage, which can be another limitation with other techniques for delineating the shoreline (Nayegandhi and others, 2006; Nayegandhi and others, 2009).

This study demonstrates the capacity of lidar surveys in capturing ever-changing morphology, while examining volumetric change and shoreline position for the Mississippi barrier islands (fig. 1). Raster geographic information system (GIS) methods were used to conduct volumetric change and shoreline position analyses based on lidar data collected in September 2005, June 2007, and September 2008. The specific intentions of this paper were to evaluate the change in shoreline position, calculate barrier island erosion and deposition, examine how volumetric measurements varied with different spatial resolutions, and identify areas of significant change. 

Insert figure 1 here

Study Area

The barrier islands in Mississippi are considered recent features, presumably less than 5,000 years old (Otvos, 1979; Otvos and Giardino, 2004). These features were thought to have originated as

submerged sand shoals that aggraded as sea level rose forming a barrier island chain (Otvos, 1979; Morton, 2007). The westward-directed littoral drift had a primary influence on the vertical build-up of the sandy barrier platforms (Otvos, 1985). Downdrift progradation contributed in a secondary capacity but deep, wide inlets between the barrier islands truncated the growth of the spit platforms (Otvos, 1985).

Historical analysis from the mid 1800s shows the Mississippi barrier islands sustaining rapid land loss and modification (Morton, 2007). Even more focus has been drawn to the morphological changes to the Mississippi barrier islands after the impact of Hurricane Katrina on this area in late August, 2005. The primary causes for this land loss include more frequent, intense storms, a relative rise in sea level and a diminished sediment supply (Morton, 2007). The barrier islands are on average three meters or less in elevation and the intervening inlets are wide, however, the islands and underlying shoal platforms are able to dissipate some of the wave energy generated in the Gulf before it reaches the mainland (Morton, 2007; Stockdon and others, 2010).

Methods

Data Acquisition

Three EAARL topographic lidar surveys were conducted between 2005 and 2008 over the Mississippi barrier islands (fig. 1). The September 2005 dataset were collected on September 1, 3, 4, 7, and 8 after Hurricane Katrina made landfall on the Louisiana-Mississippi border on August 29, 2005. Hurricane Katrina caused extensive beach erosion along the coast of Mississippi (Knabb and others, 2005). High water observations of the storm surge from along a 32 km swath of the Mississippi coast, centered around Bay St. Louis, MS, indicate that the storm surge was about 7.3 m to 8.5 m. The maximum high water observation of storm surge was about 8.5 m at Pass Christian, MS, roughly 40 km

northwest of the study area (Knabb and others, 2005). The 2005 EAARL survey occurred to capture the effects of Hurricane Katrina on the study area. The second data acquisition mission was flown on June 27, 28, 29, and 30, 2007. Hurricane Gustav made landfall over the southwestern portion of Louisiana on September 1, 2008 (Beven and Kimberlain, 2009). As Gustav approached the Gulf Coast, water levels rose with storm surge values of 3.01 m recorded at the Bay-Waveland Yacht Club, Mississippi, by NOAA operated coastal tide gages (Beven and Kimberlain, 2009). The third data collection occurred on September 8, 2008 for the Mississippi Gulf islands to acquire the possible aftereffects of Hurricane Gustav.

Data Processing and Analysis

The tool used for the post-flight processing of EAARL data is the custom-built Airborne Lidar Processing System (ALPS), a software package developed by a NASA-USGS collaboration. ALPS has the ability to combine the laser return backscatter with aircraft positioning information. Processing algorithms are then used to convert raw waveform lidar data acquired by the EAARL system into geo-referenced point (x, y, z) returns for first surface and bare earth topography (Nayegandhi and others, 2006; Nayegandhi and others, 2009).

Data acquired in cooperation with NPS and NASA over the Mississippi GUIS study sites between 2005 and 2008 were projected in Universal Transverse Mercator (UTM) coordinates. This data were converted to horizontal positions referenced to North American Datum (NAD) 1983 and North American Vertical Datum (NAVD) 1988 vertical elevations using the GEOID03 model.

1-m resolution DEMs or gridded continuous surface elevation maps of the study areas were produced using Delaunay triangulation from the geographically-referenced elevation measurements collected in 2005, 2007, and 2008. The DEMs were then resampled in Environmental Systems Research Institute (ESRI) ArcGIS 9.x to 5-m and 10-m cell resolutions.

Elevation-difference maps were created and a cut-fill analysis was performed to determine topographic change; both analyses were performed by use of the ArcGIS 9.x software package. Elevation-difference maps were created by subtracting the older dataset from the most recent dataset. This facilitated the spatial analysis of topography and topographic change (i.e., erosion, deposition, or no change) between time intervals for each study area. Cut-fill analysis was also performed to estimate the sediment volumetric change of the barrier island sections between successive time-series. To perform the analysis, the DEMs must have the same cell size resolution, for example, both DEMs must have a 1-m resolution to analyze change. From the difference calculation a volume database table displayed the volume of each polygon and whether a negative (cut), zero, or positive (fill) volumetric value (m^3) was assigned to each cell. All of the positive and negative volumetric values of the cells were added to determine the net change for each barrier island segment. Spatial patterns of deposition and erosion of sediment were studied between each time interval. Since, each survey did not cover the same extent of the barrier islands, the net volumetric change was normalized by dividing by unit area. The normalized value ($\text{m}^3/\text{m}^2 = \text{m}$) allows for volumetric change comparison regardless of the size of the area chosen.

Datum referenced shorelines were extracted for each study area over the three acquisition years. The study sites have a constant value shoreline of 0-m NAVD88 (Geoid03) that has been established. The shoreline was determined by generating contours in ArcGIS 9.x. The contours do not extend beyond the spatial extent of the raster and they are not generated in areas of no data. The 0-m contour was exported from ArcGIS 9.x and imported into GlobalMapper 11.x for modification of erroneous contours. Using a datum based shoreline allows consistent and repeatable measurements of the features (Stockdon and others, 2002). Not all years of collection covered the full barrier island and as such the shoreline areas were absent in those missing sections.

The potential error in the analysis can be mainly attributed to laser rangefinder error, global positioning error (gps) position errors, inertial navigation system (ins) orientation error, and interpolation error of point data (Crane and others, 2002; Sallenger and others, 2003). Data collected by the EAARL have shown to be vertically consistent within +/-15 cm and to be within 1 meter in horizontal accuracy (Nayegandhi and others, 2006). The interpolation process may introduce some error but it is usually considered negligible (Crane and others, 2002).

Results and Discussion

The topographic lidar surveys at the Mississippi barrier islands revealed that all five islands experienced extensive changes in shoreline position and volumetric change from Post-Katrina in September 2005 to Post-Gustav in September 2008 (table 1)

Table 1. Volumetric change per unit area (m) for the Mississippi barrier islands. Rates are in meters/year where positive number indicates accretion of the barrier island.

Period	Cell Resolution (m)	Cat Island	West Ship	East Ship	Horn Island	Petit Bois
2005-2007	1	0.22	0.15	0.27	0.11	0.12
2005-2007	5	0.22	0.15	0.27	0.11	0.12
2005-2007	10	0.22	0.15	0.27	0.11	0.12
2007-2008	1	*	0.08	0.21	0.23	0.20
2007-2008	5	*	0.08	0.20	0.23	0.20
2007-2008	10	*	0.08	0.21	0.22	0.20

* Lidar survey data was not collected over Cat Island in 2008.

Cat Island

The volumetric analysis shows Cat Island experienced a post-storm recovery period after Hurricane Katrina in 2005 (table 1, fig. 2). The shoreline position analysis however, indicated minimal change between 2005 and 2007 (fig. 3), but it can be determined that there was an overall build-up of the interior of Cat Island (table 1, fig. 2). Areas of erosion were primarily focused on the perimeter and

in the middle of the island (fig. 2) where channels of water exist. The patterns of erosion suggest that the island is narrowing around the perimeter and there is a possible deepening of the water channels from 2005 to 2007.

It is unknown if Cat Island continued the post-storm recovery from 2007 to 2008 since it was not surveyed again after Hurricane Gustav. It is possible that Cat Island continued to accumulate sediment; past analysis has shown Cat Island to be primarily protected from extreme-storm processes like those produced by Hurricane Gustav (Rosati and Stone, 2009). The northern and southern spits and the east-west orientated beach-ridges of Cat Island absorb the storm-destructive waves (Morton, 2008).

Volumetric change rates for the barrier island remained the same regardless of the DEM resolution, demonstrating that a 10-m-DEM resolution for this particular barrier island study area was sufficient (table 1). If a finer representation of geomorphic features is required as it would be for dune areas then the volumetric change would be best obtained with 1- or 2-m-resolution DEMs (Woolard and Colby, 2002). A site on the backshore of Cat Island was chosen (figs.2, 4) to demonstrate volumetric change between 1-, 5-, and 10-m-resolution DEMs (fig.). Deposition was evident for this specific area for all DEM resolutions, with the 10-m-resolution DEM yielding the least increase (table 2, fig. 4). This analysis demonstrates that at finer resolutions the grid cell is smaller than the coastal backshore region it was representing therefore it well describes the details of that feature (Woodcock and Strahler, 1987; Woolard and Colby, 2002). The coarser resolution grid cells approximate the size of the backshore topography resulting in a loss of topographic change detail (Woodcock and Strahler, 1987; Woolard and Colby, 2002). There is a need to determine resolution where maximum variability occurs for a specific region and select the resolution just below that level to provide proper characterization of topographic features (Woodcock and Strahler, 1987; Cao and Lam, 1997; Woolard and Colby, 2002). 

Insert figure here 2

Insert figure here 3

Insert figure here 4

Table 2. Cat Island backshore region volumetric change (m³).

Change	1 m	5 m	10 m
Erosion	-30.02	-31.77	-3.50
Deposition	3360.26	3432.46	3176.21
Net Change	3330.25	3400.69	3172.72

West Ship Island and East Ship Island

West Ship Island volumetric change showed areas of alternating erosion and deposition along the perimeter while there was rapid aggradation of the spit (fig. 5). Erosion was mainly focused on the area west of Fort Massachusetts and along the southern section of the spit (fig. 5). The wave energy that causes this erosion is focused onto the island by local topographic and bathymetric conditions (Morton, 2007). The West Ship and East Ship Islands ENE–WSW shore orientation are normal-to storm-waves that approach from the S-SSE further facilitate erosion (Morton, 2007). Despite perimeter erosion, West Ship is still accreting with buildup of sediment along the interior (fig. 5). Shoreline position shows West Ship is elongating but also becoming narrower particularly along the western end of the island as sediment moves westward alongshore (fig. 6).

Insert figure here 5

Insert figure here 6

Depositional magnitudes of volumetric change were greater for East Ship Island than West Ship Island (table 1). East Ship experienced prominent erosion along the Gulf of Mexico perimeter (fig. 7) while alternating erosion and deposition was seen on the Mississippi Sound side. Development further inland on East Ship can be seen particularly from 2007 to 2008 (fig. 7). Stockdon and others (2010) reported extensive shoreline retreat and large losses of beach volume this could be attributed to possible

overwashing and erosion of East Ship by waves and currents from Hurricane Gustav. The overwashing of the beach could lead to the interior aggradation of East Ship (fig. 7). Shoreline position shows East Ship is lengthening but also becoming narrower particularly along the barrier island core (fig. 8). The spits on either side of the island core however are widening (fig. 8).

Insert figure here 7

Insert figure here 8

This analysis supports that in response to the dominant littoral movement, East and West Ship Islands migrate in a westward direction, the Gulf shoreline along the eastern end erodes, supplying sand to the advancing western tip (figs. 5 and 7). The islands however, also face waves from the S-SSW causing East and West Ship Islands to experience occasional drift reversals resulting in eastward prograding and recurving spits on the eastern tips (Otvos and Carter, 2008).

Volumetric change rates for West Ship barrier island remained the same regardless of the DEM resolution, this was not the same for East Ship island (table 1). The 2007 to 2008 East Ship volumetric change analysis showed that a 5-m-resolution DEM had different volumetric change than the 1- and 10-m-resolution DEMs. The narrowing and lengthening of East Ship Island from 2005 to 2008 could have changed how the volumetric change analysis was calculated. The 5-m-resolution DEM would have reduced the number of pixels in the image to represent many topographic causing the local topographic variance to decrease.

Horn Island

Volumetric change along Horn Island was variable along the perimeter with areas of erosion and accretion (fig. 9). Horn Island experienced a buildup of the interior core that increased between June 2007 and September 2008 (table 1, fig. 9). Shoreline analysis shows the elongation of spits and the narrowing of Horn Island (fig. 10). Historical analysis has determined that the eastern section of Horn

Island erodes to transfer sediment to western tip of island that to strengthens the growth of the lateral spit (Morton, 2008).

The 2007 to 2008 volumetric change analysis for Horn Island showed that a 10-m-resolution yielded slightly different results than the 1- and 5-m-resolution DEMs (table 1). The landward migration and lengthening of Horn Island from 2005 to 2008 could have changed how the volumetric change analysis was calculated. It is possible that Horn Island is too narrow to be properly represented by a 10-m-resolution DEM.

Insert figure here 9

Insert figure here 10

Petit Bois Island

Magnitudes and characteristics of volumetric change on Petit Bois were similar to those calculated on Horn Island (table 1). The volumetric change analysis showed that predominately erosive areas from 2005 to 2007 became areas of accretion between 2007 and 2008 or areas of accretion became areas of erosion (fig. 11). The change to erosion particularly along the eastern Gulf shore of Petit Bois was most likely associated with focused wave action from Hurricane Gustav (Stockdon and others, 2010; Morton, 2008). Change to the Petit Bois shoreline shows an accumulation in sediment on both eastern and western spits (fig. 12). Shoreline analysis also illustrates the narrowing of Petit Bois Island, similar to the other Mississippi barrier islands (fig. 12).

Volumetric change rates for Petit Bois remained the constant with the change in DEM resolution. This analysis shows that a 10-m-DEM resolution for this particular barrier island study area was acceptable (table 1).

Insert figure here 11

Insert figure here 12

Conclusions

Detailed, accurate topography is critical in low gradient coastal environments like the Mississippi barrier islands, which often undergo frequent change due to environmental and anthropogenic impacts. This study demonstrates the capacity of lidar surveys in capturing these changes to the morphology. The volumetric change and shoreline position analysis demonstrated that the Mississippi barrier islands continue to migrate from east to west with the exception of Cat Island, which is primarily protected from offshore waves by the Chandeleur and Ship Islands (Rosati and Stone, 2009). The barrier islands are also elongating and becoming narrower on both the Gulf and Mississippi sides in response to shoreline erosion by longshore and cross-shore sediment transport (Morton, 2008). Ship island may indicate the possible future morphological changes for Petit Bois and Horn Islands that consist of island narrowing, unequal lateral transfer, and island segmentation (Morton, 2007; Morton, 2008).

Even though the shoreline perimeter was eroding on many of the barrier islands, the volumetric change analysis measured post-storm recovery. The volumetric change measured a buildup of sediment for the interior of all of the barrier islands during the time of collection. The buildup particularly experienced between June 2007 and September 2008 could be mainly attributed to overwash from Gustav. Stockdon and others (2010) documented that Hurricane Gustav contributed almost as much geomorphic evolution to the Mississippi barrier islands as Hurricane Katrina; when washover deposits were documented (Morton, 2007).

To fully understand the changing morphology of the barrier island system elevation surveys should be collected yearly preferably within the same season. This will attempt to capture changes made on a smaller scale as well as a larger one like a full barrier island survey. When studying volumetric change the type of features that are to be evaluated need to be considered. A 5-meter-resolution DEM

may be too large for particular features but too small to evaluate others. Resolution also depends on the density of data; change cannot be evaluated on a 1-meter-resolution DEM if point elevation values are 4 meters apart. To provide satisfactory characterization of the study area, determine the resolution at which maximum variability occurs and select the resolution occurring just below that level (Woodcock and Strahler, 1987; Woolard and Colby, 2002). Gross landform change over an entire barrier island for example; a larger grid cell size may be sufficient. The coarser resolution will reduce computational demands for processing and storage of the data. 

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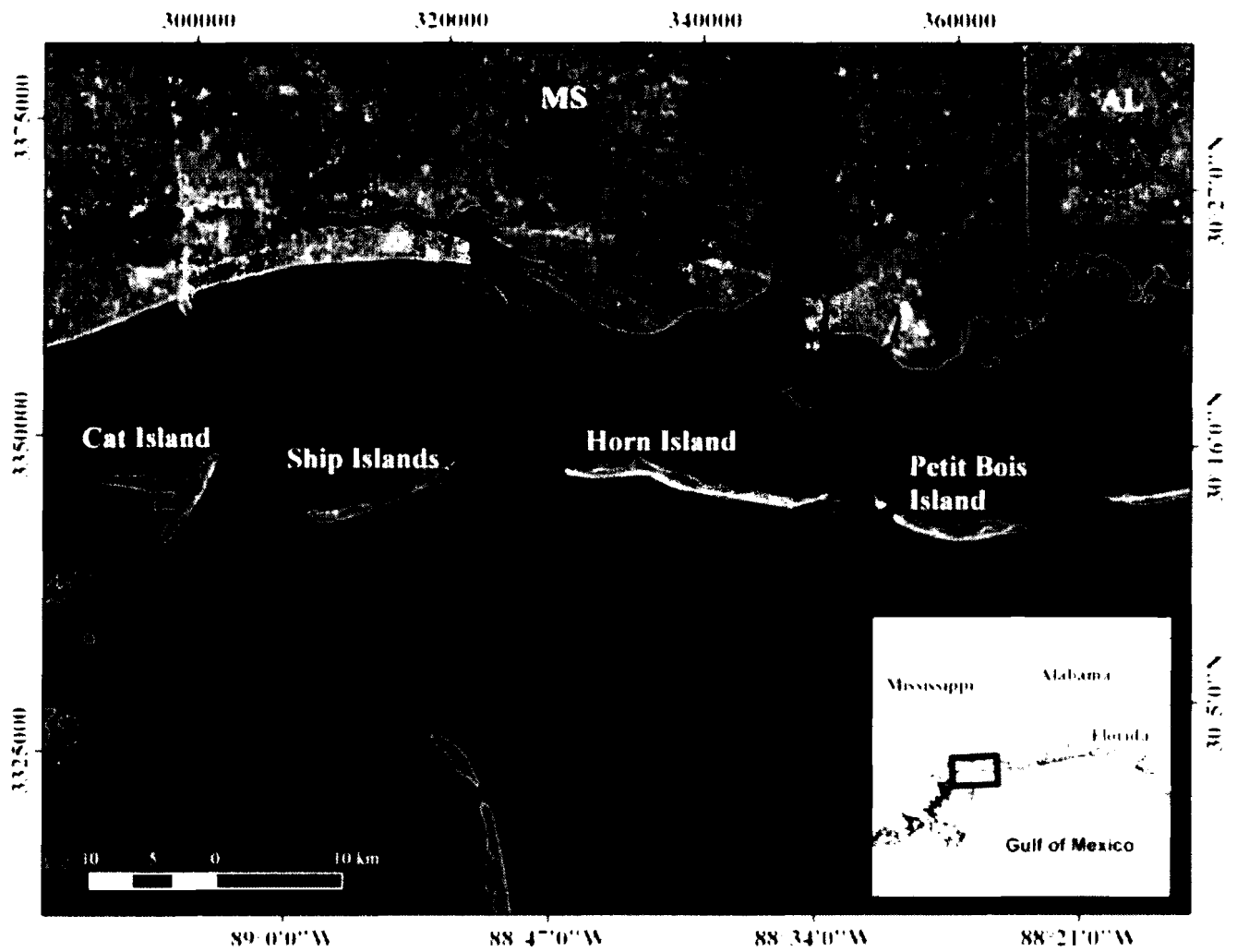


Figure 1. Location map of the Mississippi barrier islands of the Gulf Islands National Seashore.

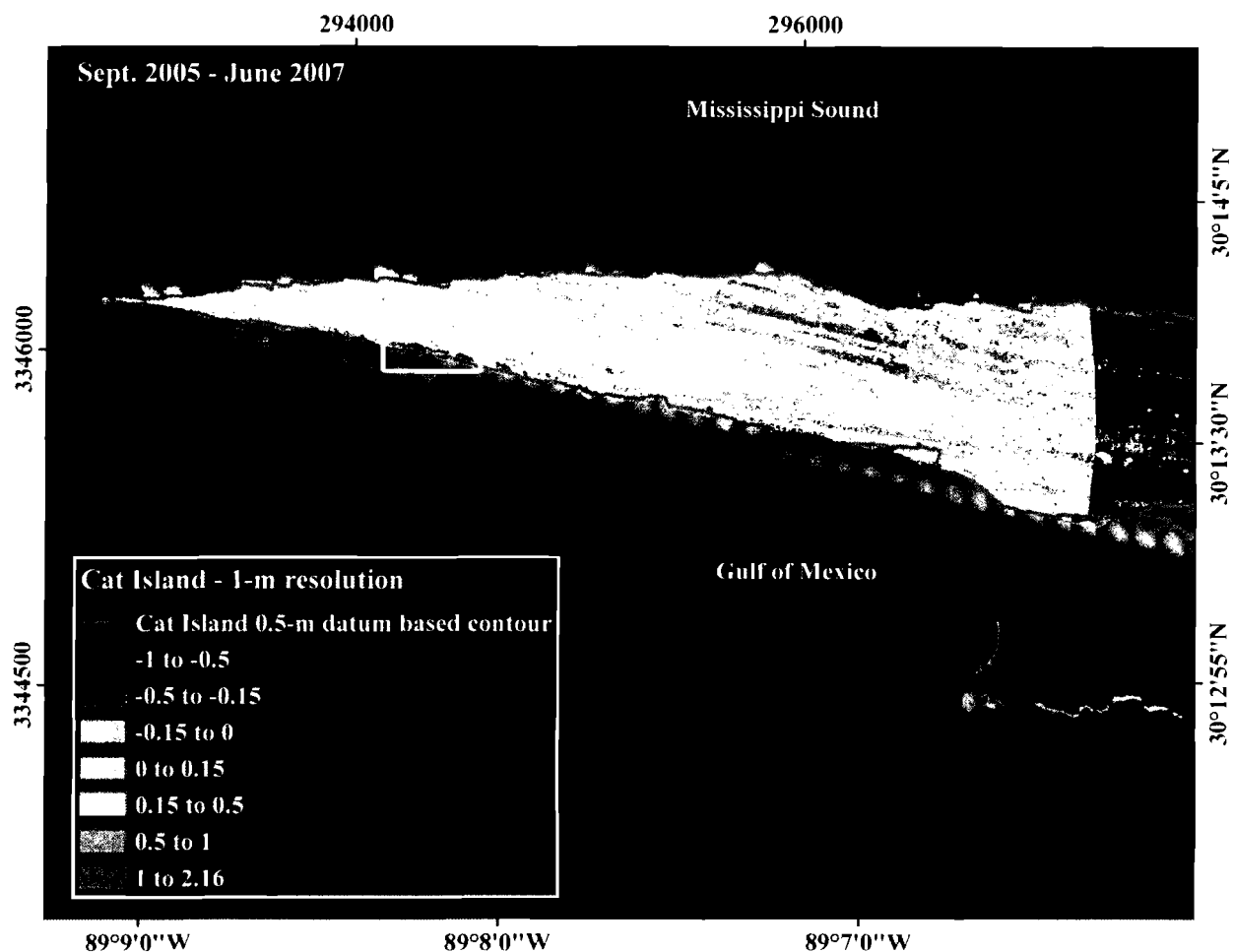


Figure 2. Color-infrared (CIR) aerial photography taken by the EAARL camera on June 29, 2007. 1-m resolution volumetric change analysis at Cat Island calculated between September 2005 to June 2007. The white square represents the section of the backshore region analysis seen in figure 4.

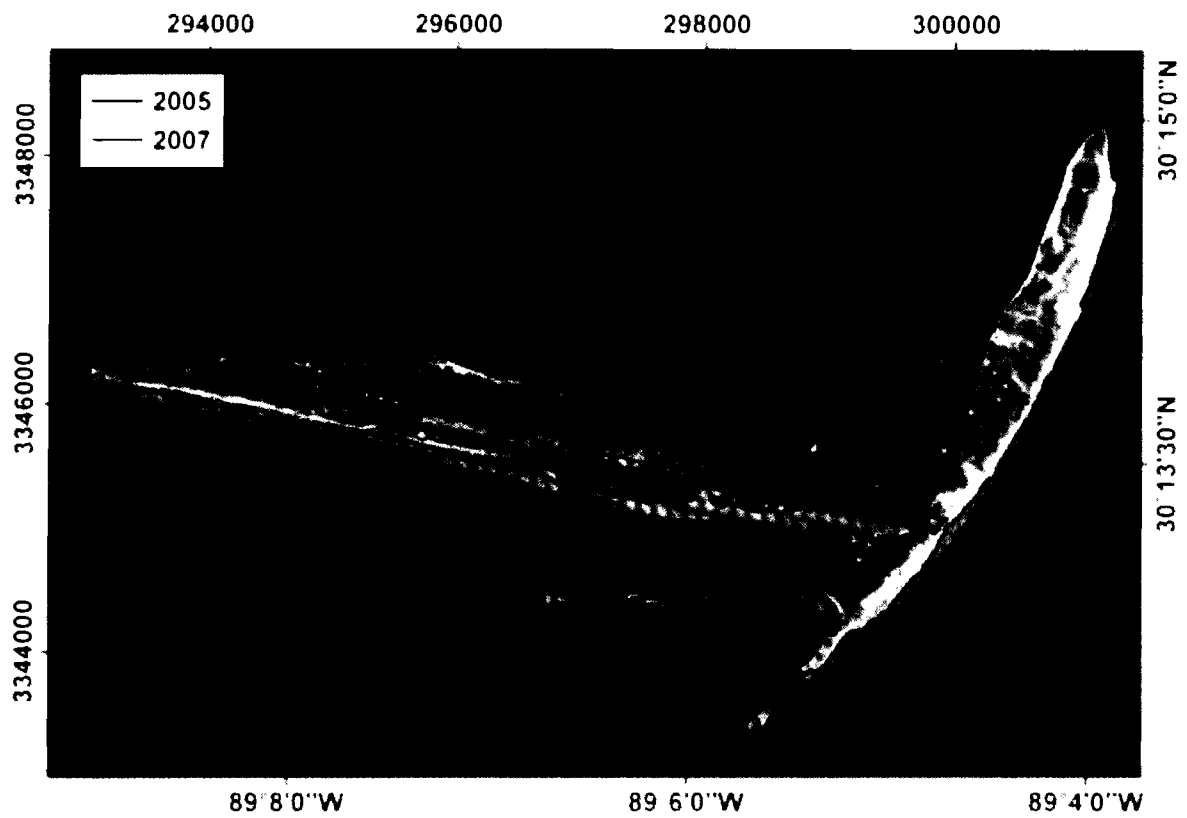


Figure 3. CIR aerial photography taken by the EAARL camera on June 29, 2007. 0-m datum defined shoreline position analysis for Cat Island.

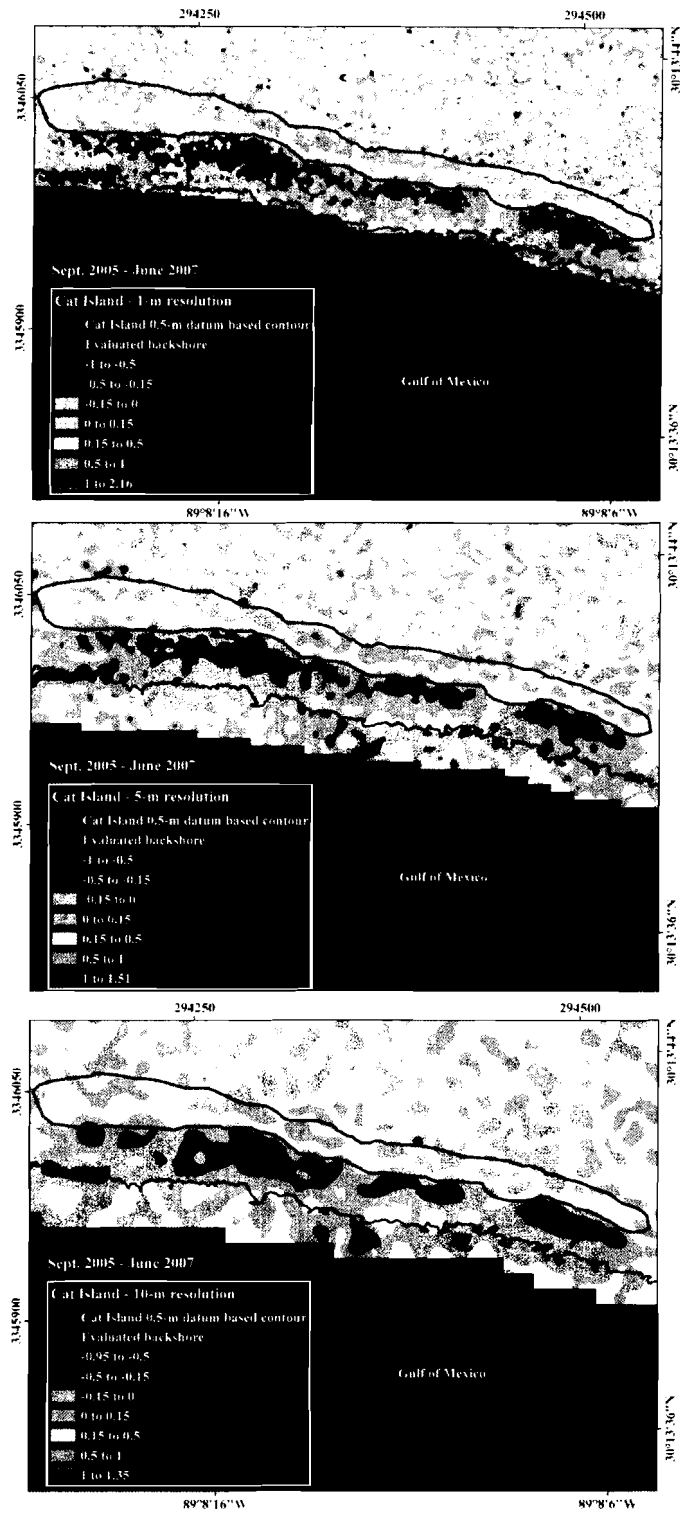


Figure 4. Volumetric change at varying DEM resolutions of a Cat Island backshore region subset between September 2005 and June 2007.

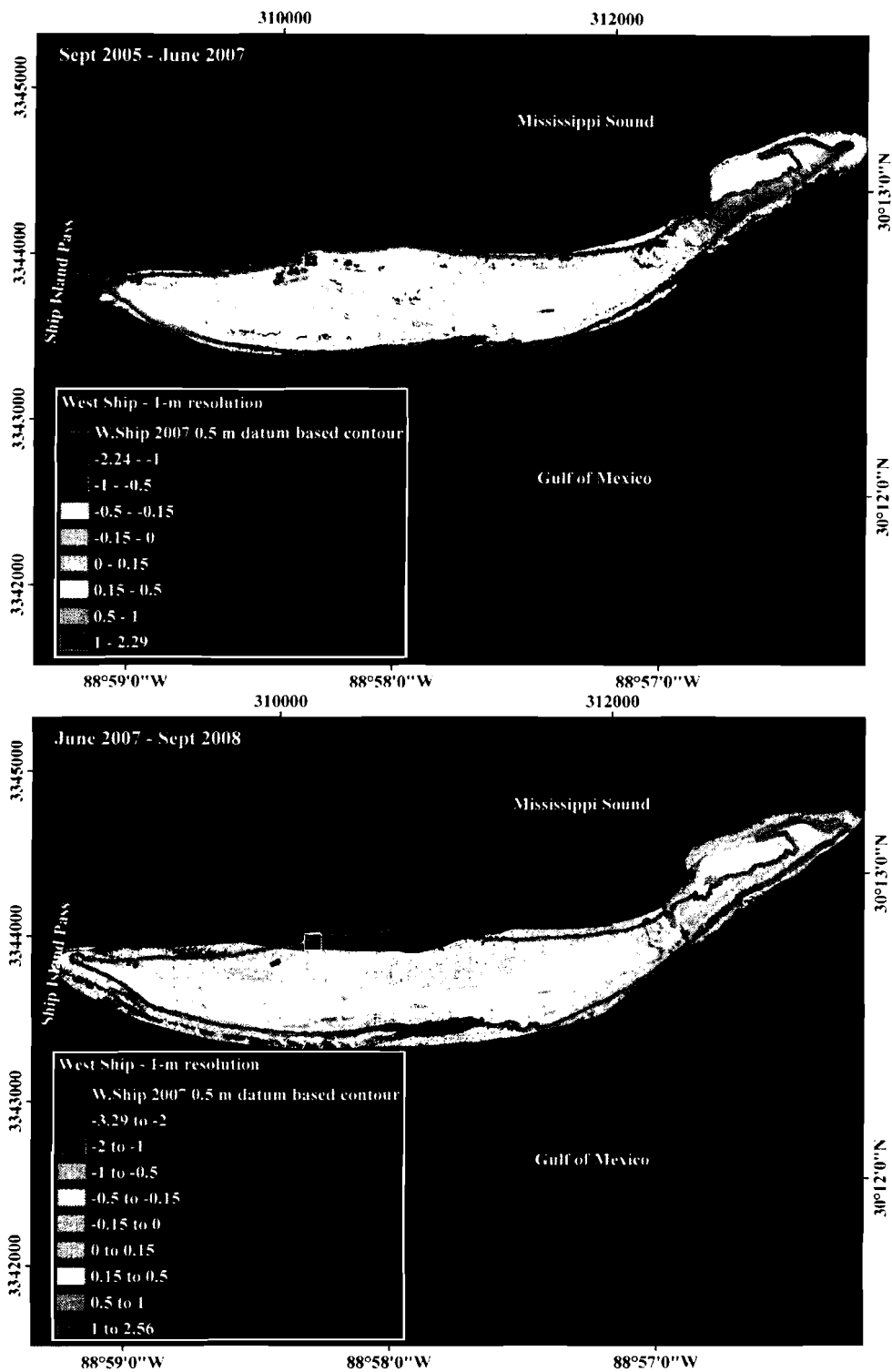


Figure 5. 1-m resolution volumetric change analysis at West Ship Island, calculated from September 2005 to June 2007 (top) and June 2007 to September 2008 (bottom). The white square in each figure represents the location of Fort Massachusetts.

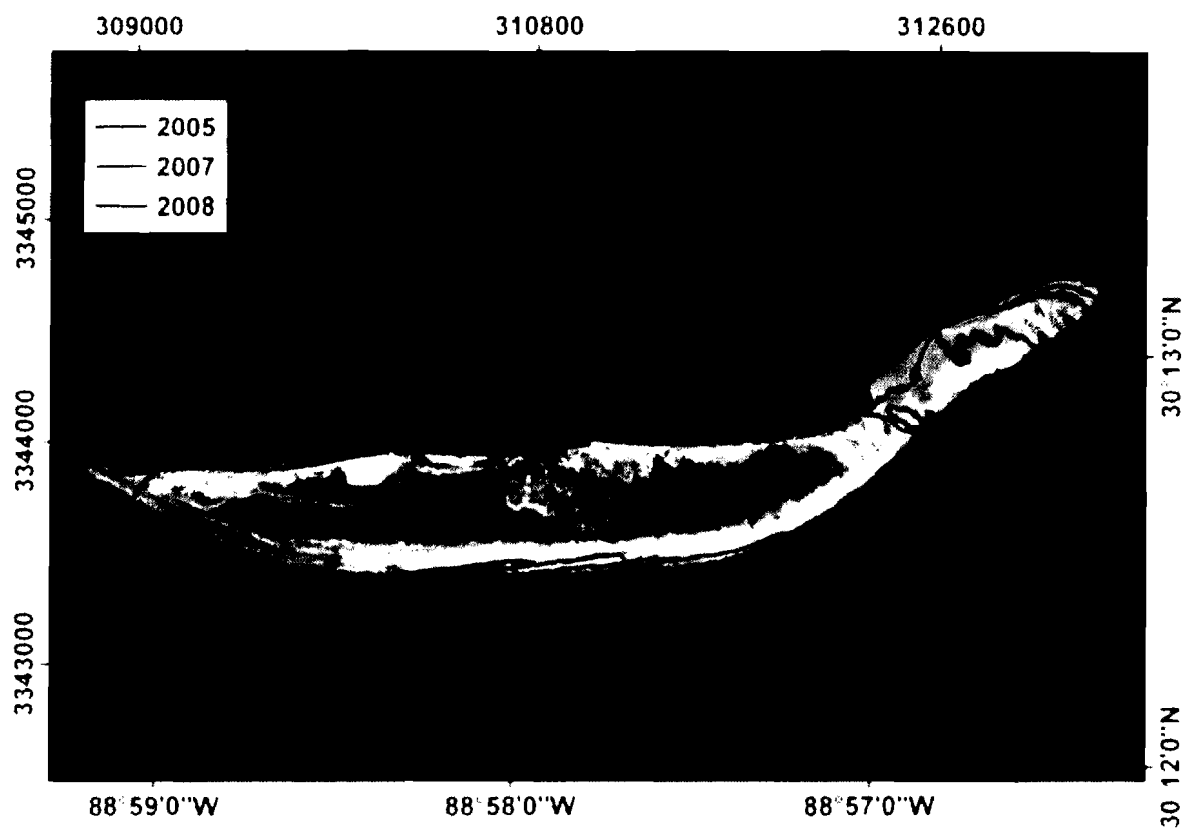


Figure 6. CIR aerial photography taken by the EAARL camera on September 8, 2008. 0-m datum defined shoreline position analysis for West Ship Island.

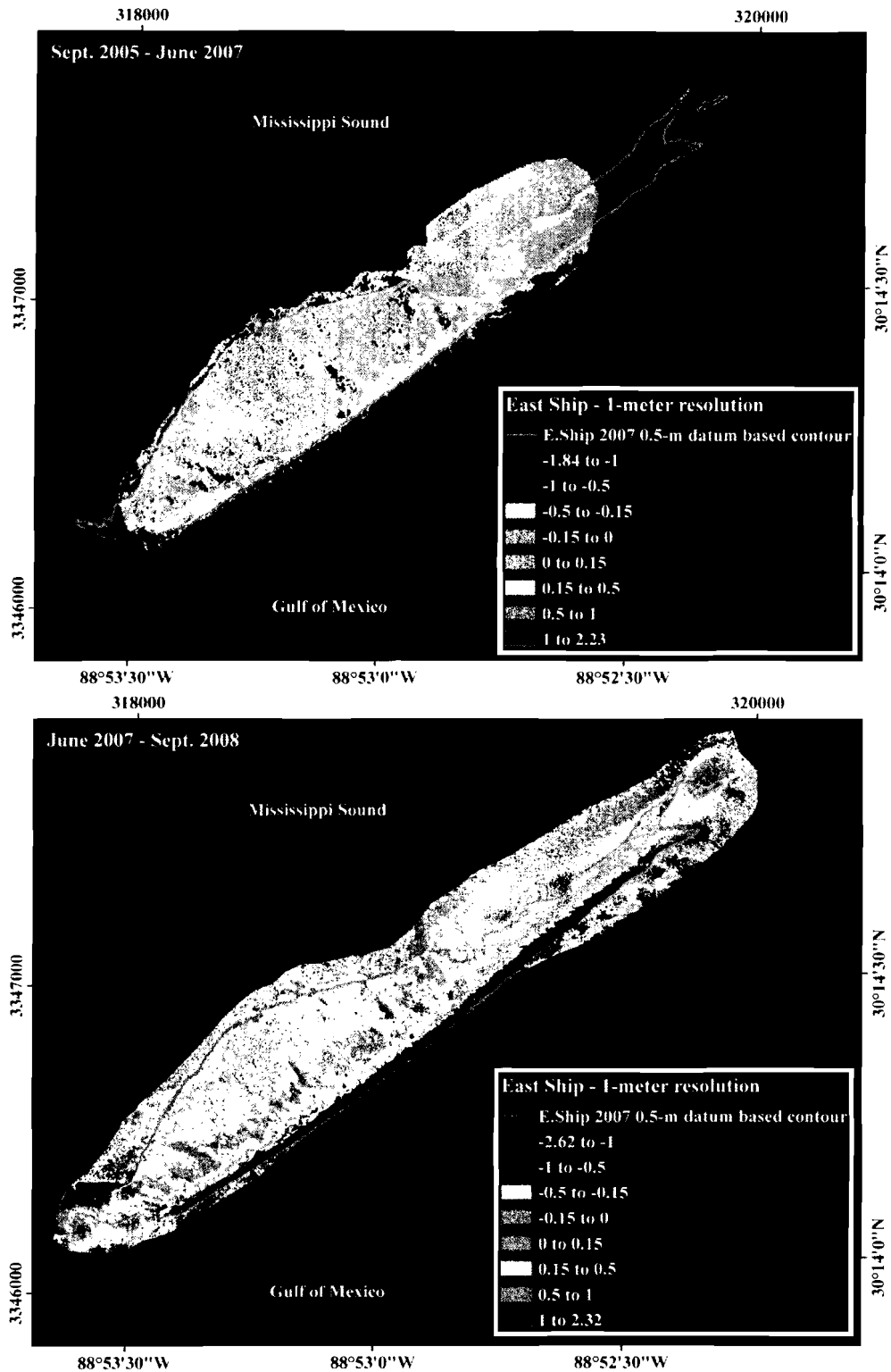


Figure 7. 1-m resolution volumetric change analysis at East Ship Island, calculated from September 2005 to June 2007 (top) and June 2007 to September 2008 (bottom).

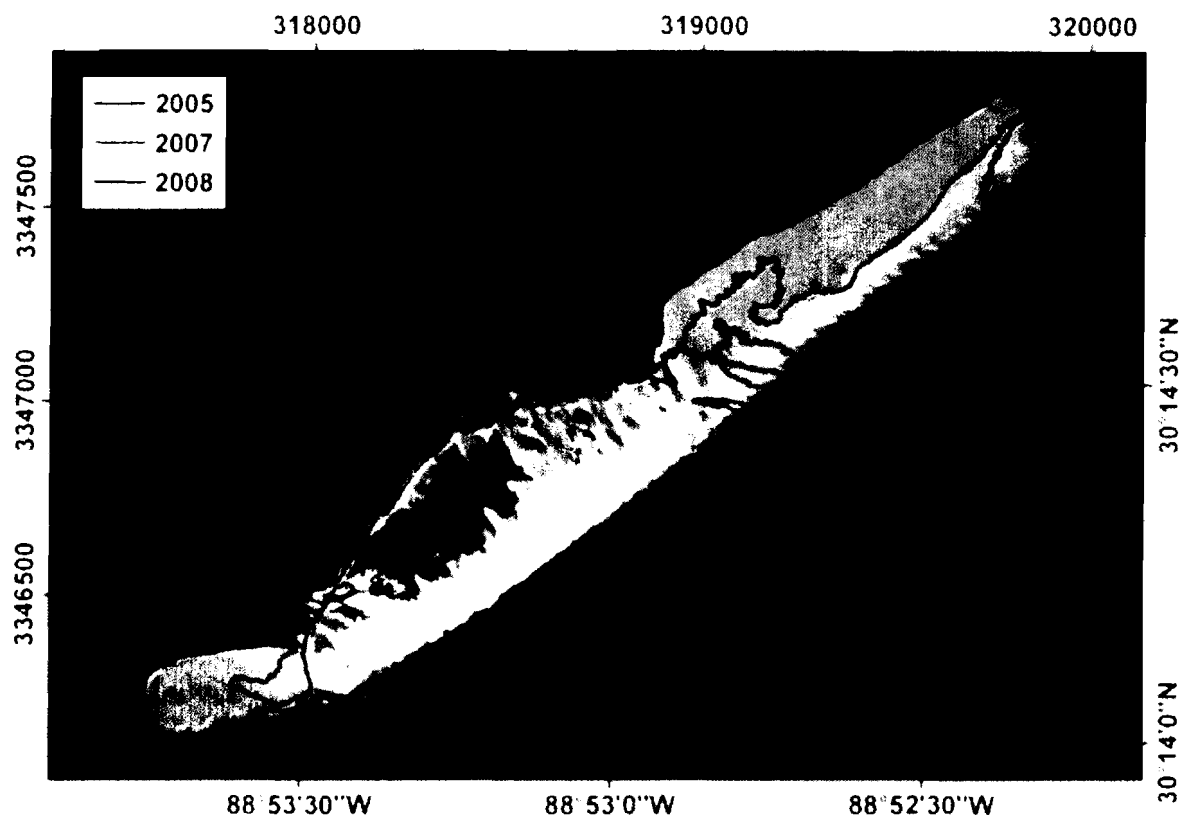


Figure 8. CIR aerial photography taken by the EAARL camera on September 8, 2008. 0-m datum defined shoreline position analysis for East Ship Island.

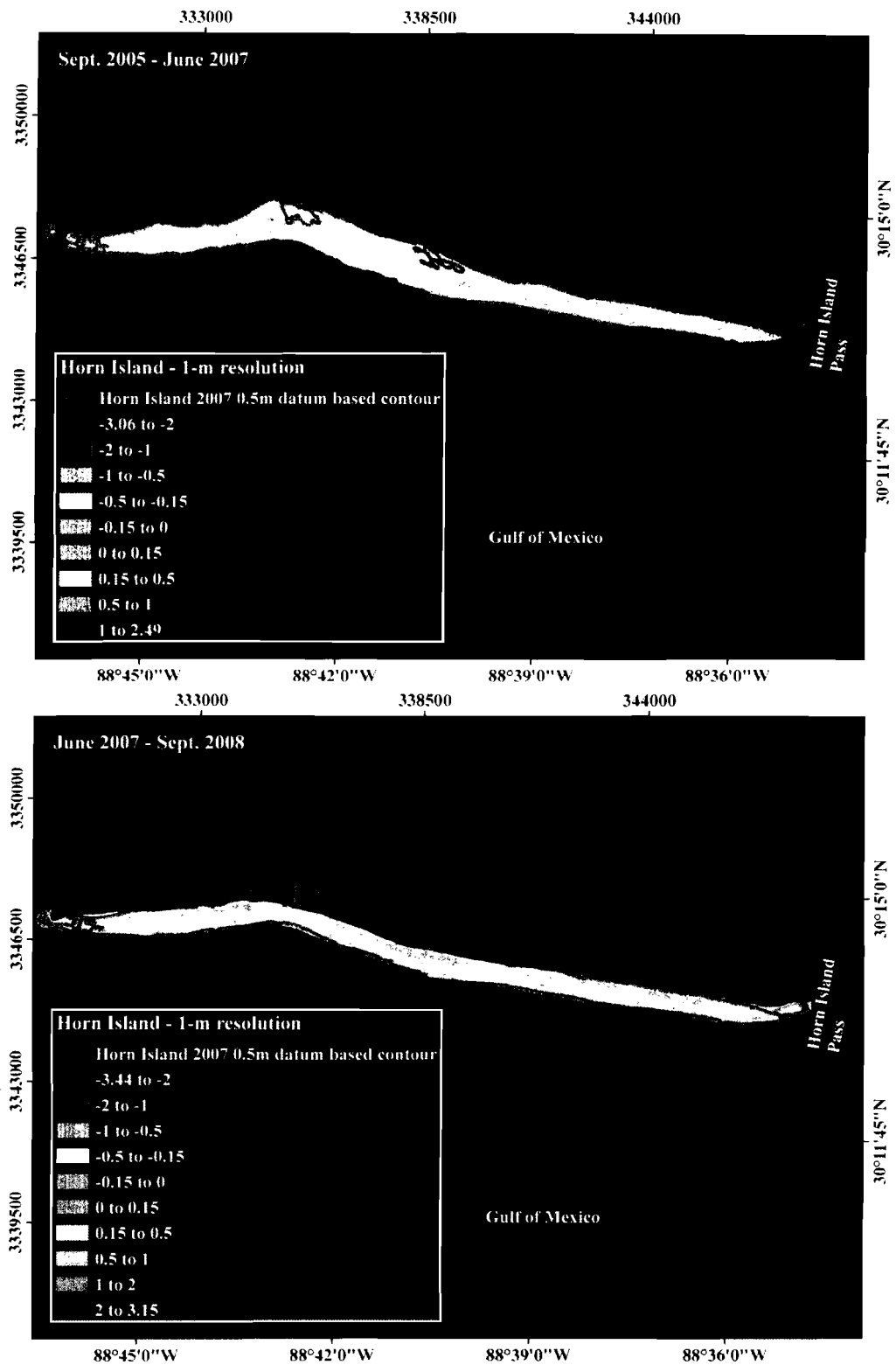


Figure 9. 1-m resolution volumetric change analysis at Horn Island, calculated from September 2005 to June 2007 (top) and June 2007 to September 2008 (bottom).

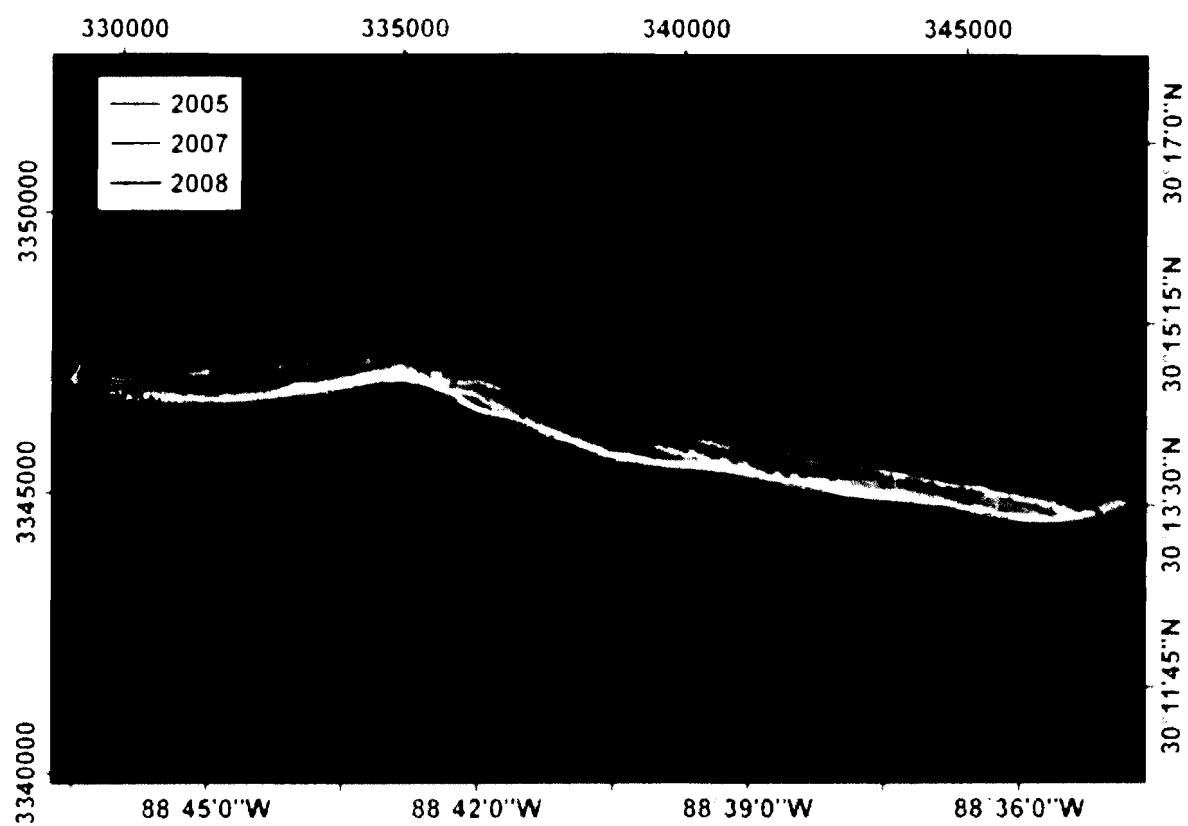


Figure 10. CIR aerial photography taken by the EAARL camera on September 8, 2008. 0-m datum defined shoreline position analysis for Horn Island.

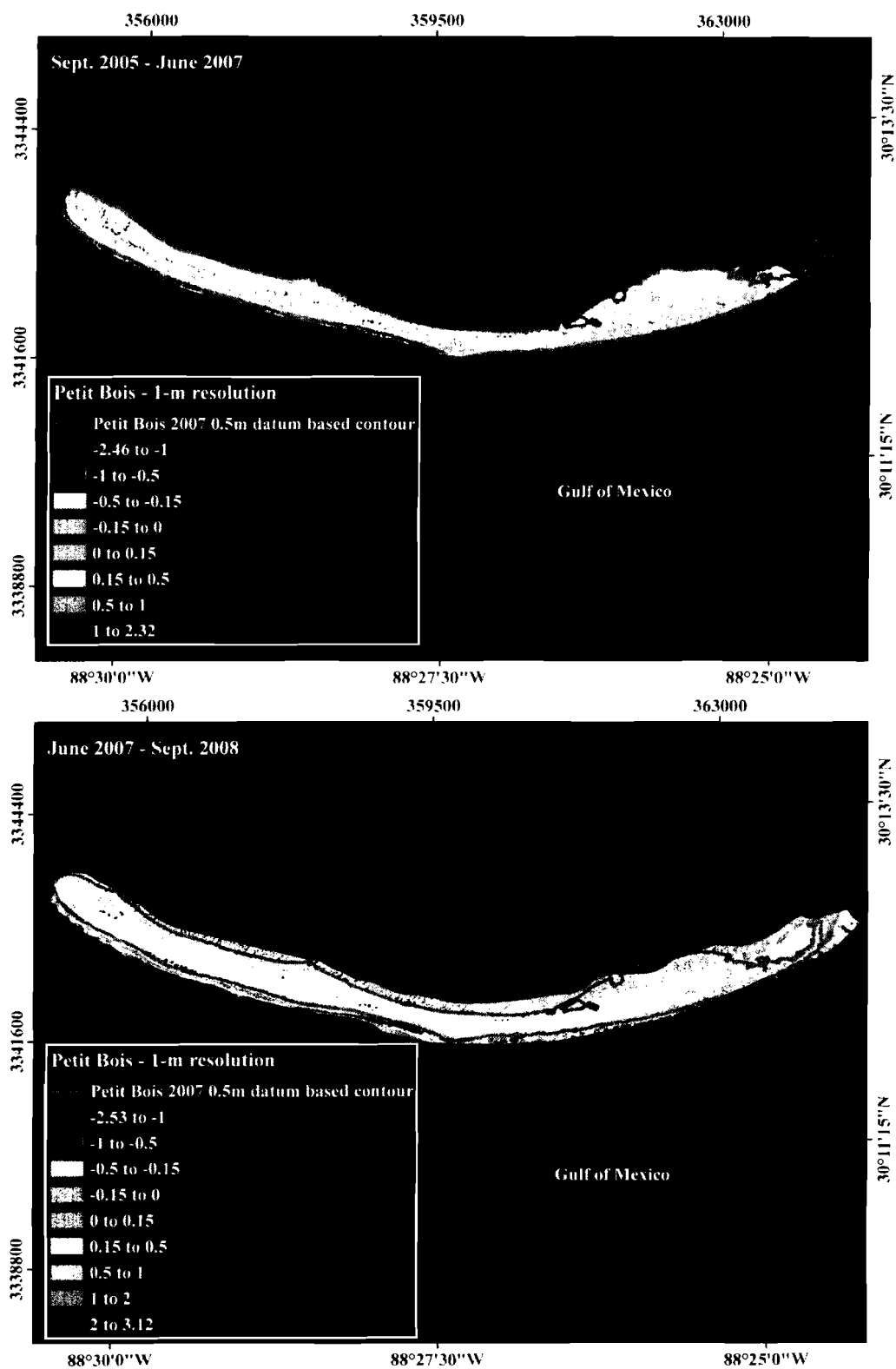


Figure 11. 1-m resolution volumetric change analysis at Petit Bois Island, calculated from September 2005 to June 2007 (top) and June 2007 to September 2008 (bottom).

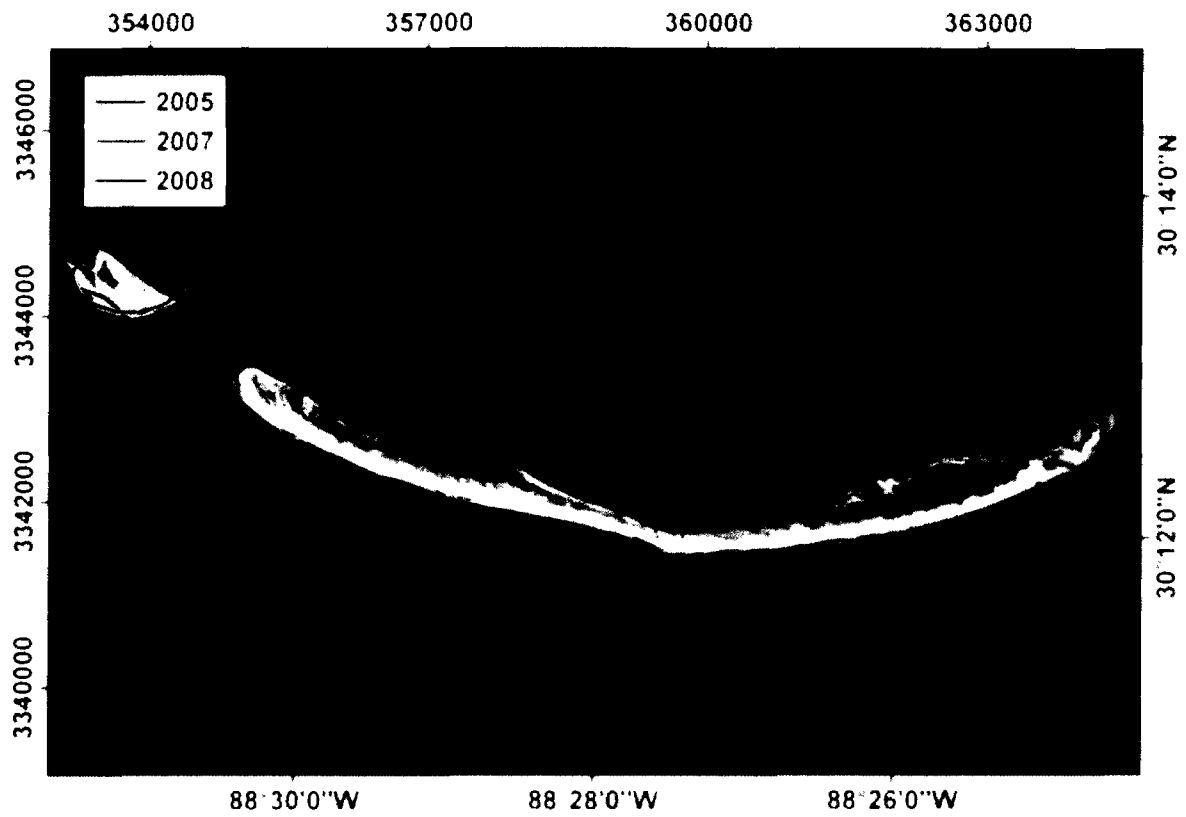


Figure 12. CIR aerial photography taken by the EAARL camera on September 8, 2008. 0-m datum defined shoreline position analysis for Petit Bois Island.