CHANGES TO GEOMORPHIC AND BATHYMETRIC FEATURES DUE TO EXTREME STORM EVENTS NEAR EAST PASS INLET, FLORIDA

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Abstract: The impact of coastal regions to storm induced geomorphic and bathymetric change can be efficiently monitored using three-dimensional spatial data. Having multiple surveys of a coastal region, specifically when coastal projects are present, is invaluable for the assessment of the resiliency of the region to extreme storm events. Methods to identify geomorphic features and assess the navigable conditions through a maintained inlet have been developed to assist in the monitoring efforts. Spatial variation for the beach system, including the dune peak elevations, width from the shoreline to the dune peak, and volume, are monitored for several surveys for change detection. For all the surveys analyzed, morphological changes to the shoal system may significantly impact the safe navigability of the channel through the inlet.

INTRODUCTION

Beaches and barrier islands are vulnerable to extreme storm events that can cause severe erosion and overwash to the system. Having dunes and a wide beach in front of coastal infrastructure can provide protection during a storm, but the erosion to the dunes and shoreline can be severe and cause the system to be more vulnerable, especially when multiple storms impact the region before the beach recovers. Also, changes in bathymetric features, such as shoals, can cause serious problems when a navigation inlet is present. The movement of sediment can shoal in the channel compromising the functional performance of the navigation inlet. Assessing the morphology of bathymetric features is very important to provide a quick evaluation of the impact to the inlet. Pre- and post-storm surveys are vital to the assessment of damage caused by extreme storm events. The use of airborne lidar (light detection and ranging) to collect topographic and bathymetric data has greatly improved the efficiency and accuracy of monitoring morphological changes as compared to traditional survey methods.

Several studies have shown that lidar data can be used to extract features, such as dunes, to assess the vulnerability of the region (Houser et al., 2008; Saye et al., 2005; Stockdon et al., 2009), monitor beach nourishment projects (Gares, et al., 2006), and identify the shoreline and change rates (Stockdon et al., 2006). Similarly, lidar has been used to monitor inlets to determine the processes affecting navigation, such as movement of the ebb shoal (Irish and Lillycrop, 1997; Wozencraft, 2001).

Engineering projects that are constructed in the coastal environment must perform to the design specification while being resilient to extreme storm events. Shore protection and navigation projects are designed to provide improved protection under normal conditions as well as maintain resiliency during storm events. Mapping the spatial variation for a coastal region is invaluable for monitoring coastal engineering projects. High-resolution elevation and imagery data is collected along the U.S. coastline as part of the National Coastal Mapping Program (NCMP) which is funded by the U.S. Army Corps of Engineers (USACE) Headquarters. The NCMP is executed by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTCX) and the data products are intended to support the coastal engineering and research needs within USACE. Three-dimensional spatial data can be used to enhance the assessment of projects which are typically monitored using two-dimensional profiles.

The objectives of this research are to utilize the three-dimensional spatial data for the development of methods to efficiently monitor geomorphic change and bathymetric morphology at a navigation project site. To show the applicability of using lidar for change detection and monitoring coastal projects, the inlet at East Pass, Florida and the 2 km length of coast to the west of the inlet is used to demonstrate the procedure.

METHODS

Study Area

The study area along the Florida panhandle exhibits complex geomorphic and bathymetric features which include dunes and a shoal system (Morang, 1992). The East Pass inlet in Okaloosa County, FL provides access to Choctawhatchee Bay. The dunes provide a natural defense to the upland area, but the narrow beach width of this coastal region makes the area vulnerable to erosion and overwash. The hurricane seasons of 2004 and 2005 were extremely active with Hurricane Ivan (2004), Hurricane Dennis (2005) and Hurricane Katrina (2005) impacting the area and causing erosion and shoaling of the navigation channel. The west side of East Pass, FL is primarily undeveloped; however, US98 provides access to the highly developed Destin area on the east side of the inlet. The analysis was performed on the west section of the coast to prevent results being influenced by upland structures. Figure 1 is an aerial photograph of East Pass, FL taken during the 2010 NCMP survey. The East Pass inlet is maintained at a width of 55 meters (180 ft) and 3.65 meters (12 ft) mean lower low water (mllw). Two rubble mound jetties are constructed on both the east and west side of the inlet to provide channel stability.

Figure 1. Aerial image from the 2010 NCMP survey of the East Pass inlet study area.

Data

The surveys conducted as part of the NCMP provide complete coverage of the coastal zone on a recurring basis and therefore are ideally suited for monitoring changes to geomorphic and bathymetric features. The data used for this analysis was collected by the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system which is shared between the USACE and U.S. Naval Oceanographic Office (NAVOCEANO). The CHARTS system includes a 3 kHz bathymetric laser, a 20 kHz topographic laser, an Itres Compact Airborne Spectrographic Imager (CASI)-1500, and DuncanTech-4000 RGB digital camera (Wozencraft and Lillycrop, 2006). The lidar and imagery data collected by the CHARTS system is processed into Geographic Information System products and include bathymetric and topographic Digital Elevation Models (DEMs), RGB orthomosaics, North Atlantic Vertical Datum 88 (NAVD88) shorelines, building footprints, and bare earth grids (Wozencraft et al., 2007). This data is uniquely available to address the need for three-dimensional analysis of shore protection and navigation projects.

The surveys of East Pass, FL used for this analysis were flown for 1) April-May 2004 (Pre-Ivan), 2) November-December 2004 (Post-Ivan), 3) July 2005 (Post-Dennis), 4)

November-December 2005 (Post-Katrina), and 5) January-March 2010. This data is uniquely available to assist in the storm event assessment when pre- and post-storm surveys exist as well as aid in change detection to identify trends for a complete understanding of the impacts of the coastal zone due to storm events.

Data Analysis

The data analysis for the changes in geomorphic features and bathymetry through the inlet is processed separately. The analysis for the geomorphic metrics will be discussed first. Transects were extracted from the 1 m grids using the auto-profiler tool within the suite of Coastal Engineering Tools (C.E. Tools) developed by the USACE Mobile District Spatial Data Branch (OP-J, 2010). The resolution of the spot elevation is 1 m with 30 meter spacing interval between profiles. A series of MATLAB codes were written to find the zero shoreline, peak of the dune, width of the beach from shoreline to dune peak, and volumetric changes for the distance from shoreline to dune peak. The transects are analyzed profile-wise within MATLAB. The data is not smoothed since the raw lidar data is processed before the grids are generated to remove noise. The peaks are found by using the MATLAB signal processing function, "findpeaks" which compares neighboring data points and classifies the local maxima. The volumetric change is determined for each transect for the length of the study area using trapezoidal integration from the shoreline to the dune peak. The multiple surveys are compared to the 2004 Pre-Ivan NCMP survey to show the impact from storm events from the 2004 and 2005 hurricane season as well as show the changes occurring after 6 years with the 2010 NCMP survey.

Similarly, the condition of the navigation inlet is assessed by extracting cross-sections perpendicular to the channel centerline for the 55 m width of the channel. The cross-sections were extracted every 30 meters. The maintained depth of the navigation inlet is 3.65 m (12 ft) mllw and the lidar data has a vertical projection of North Atlantic Vertical Datum 1988 (NAVD88), so the depth was converted to NAVD88 by using the National Oceanic Atmospheric Administration's (NOAA) Vertical Datum (VDatum) tool for the NCMP 1m grid (NOAA VDatum, 2010). The difference of the NAVD88 and mllw datums was minimal for locations within the inlet, so an average of the converted depth values was used for the analysis (3.69 m NAVD88). The cross-sections were analyzed with a series of MATLAB codes to find the channel condition by finding locations that have a depth that is equal to or below the maintained depth and then determining the length of the navigable channel cross-section to be used for the percent ranking. Table 1 provides the condition ranking as adopted from the USACE Great Lakes Division Guidelines for Coastal Navigation and Navigation Structures Draft Proposal.

While East Pass inlet is maintained for smaller vessel traffic, the methods developed for this study could be applied at any navigation inlet that has sufficient lidar coverage. The volumetric change of the width from dune to shoreline, and bathymetric morphology are determined to assess the impacts of extreme storm events to the coast and navigation inlet to assist in the recovery efforts and understanding of the movement of sediment. Having multiple surveys for the area allows for change detection of geomorphic features and areas of concern through the navigation inlet to be identified.

Table 1. Ranking criteria for navigable channel

Navigation Channel Condition Ranking	
Condition Ranking	Condition Description
Good	95% Channel Navigable
Moderate	75% Channel Navigable
Poor	50% Channel Navigable
Failing	25% Channel Navigable
Failed	0% Channel Navigable

RESULTS

Geomorphic Metrics

As mentioned previously, having dunes and a wide beach can provide increased protection during a storm event, so being able to assess these geomorphic metrics and compare the results for multiple surveys is invaluable to understanding the condition and vulnerability of the region. Dunes with the highest elevation also typically have a wider beach. The 2004 pre-Ivan survey is used as the base survey to compare the 2004 Post-Ivan, 2005 Post-Dennis, 2005 Post-Katrina, and the 2010 NCMP surveys. Table 2 gives the average dune peak elevation, average distance from shoreline to dune peak, and the maximum dune peak for the 2000 m coast to the west of the East Pass inlet. The 2004 NCMP survey is shown to have the highest average dune peak elevation as well as the widest distance from shoreline to dune peak. After Hurricane Ivan 2004, the average dune peak elevation was reduced by 0.5 meters. The dune peak elevations continue to decline after the region is impacted by both Hurricanes Dennis and Katrina in 2005. However, the results show that the average dune peak elevations begin to recover during the relatively calm period from 2005 to the latest survey in 2010. The beach width from shoreline to dune peak also follows the erosional trend where the average is at its narrowest following Hurricane Dennis.

Figure 2 shows the results for the changes in dune peak elevation, distance from shoreline to dune peak, and volume change from the 2004 NCMP base survey and the post-storm surveys. The significant loss in dune elevation occurs for all post-storm surveys near the 1500 m location. This area is beside a low lying region that was likely overwashed during the hurricanes causing the dunes to erode. The area with the most retreat of the distance from shoreline to dune peak occurs near the location where the road curves toward the ocean. The loss of beach width from this location could be significant to the impacts of the infrastructure.

Table 2. Geomorphic metric statistics for surveys at East Pass, FL

Survey Period	Mean Dune Height, m	Mean Distance from Shore to Dune, m	Maximum Dune Height, m
2004 Pre-Ivan	6.59	172.48	15.19
2004 Post-Ivan	6.09	155.37	11.66
2005 Post-Dennis	5.86	124.70	11.83
2005 Post Katrina	5.89	161.25	9.77
2010 NCMP	6.10	159.10	9.45

The 2004 Pre-Ivan NCMP survey is compared to the 2010 NCMP survey to show recovery of the area after the relatively calm coastal storm seasons following the busy 2004 and 2005 hurricane seasons. Figure 3 shows the changes in distance from shore to dune peak and volume for the survey six years after the 2004 Pre-Ivan NCMP survey. The change in distance from shore to dune peak from the 2004 Pre-Ivan survey and 2010 NCMP survey has loss for the majority of the study area except near the 2000 m distance alongshore. This result is likely due to the merging of sediment from the ebb shoal. Volume change for the area has a majority of loss with the exception of gain at the 2000 m distance alongshore location. Table 3 shows the net gain and net loss for the area comparing each survey to the 2004 Pre-Ivan survey. The results show that there is net loss for the region for all surveys. The most substantial volume loss occurs for the 2005 Post-Dennis and 2010 NCMP surveys. There is a 95% increase in net volume loss for the 2010 NCMP survey as compared to the 2004 Post-Ivan survey.

The width of the beach from the shoreline to the highest dune peak is an important geomorphic metric to consider since having a wide beach can provide increased protection during a storm event. The elevation of the dune is also important because the dunes act as a barrier during a storm event helping to protect upland portions of the coast. The distances from shore to dune peak as well as the elevations of the dune peaks are important geomorphic metrics that can be used to assess the condition of the region and the vulnerability to extreme storm events. Retreat and dune loss are the primary results for the post-storm surveys; however, the 2010 NCMP survey shows areas of advancement and dune gain where the ebb shoal connects to the shore. While the movement of sediment from the ebb shoal to the beach is beneficial to the upland area, navigation can be compromised when sediment fills in the channel.

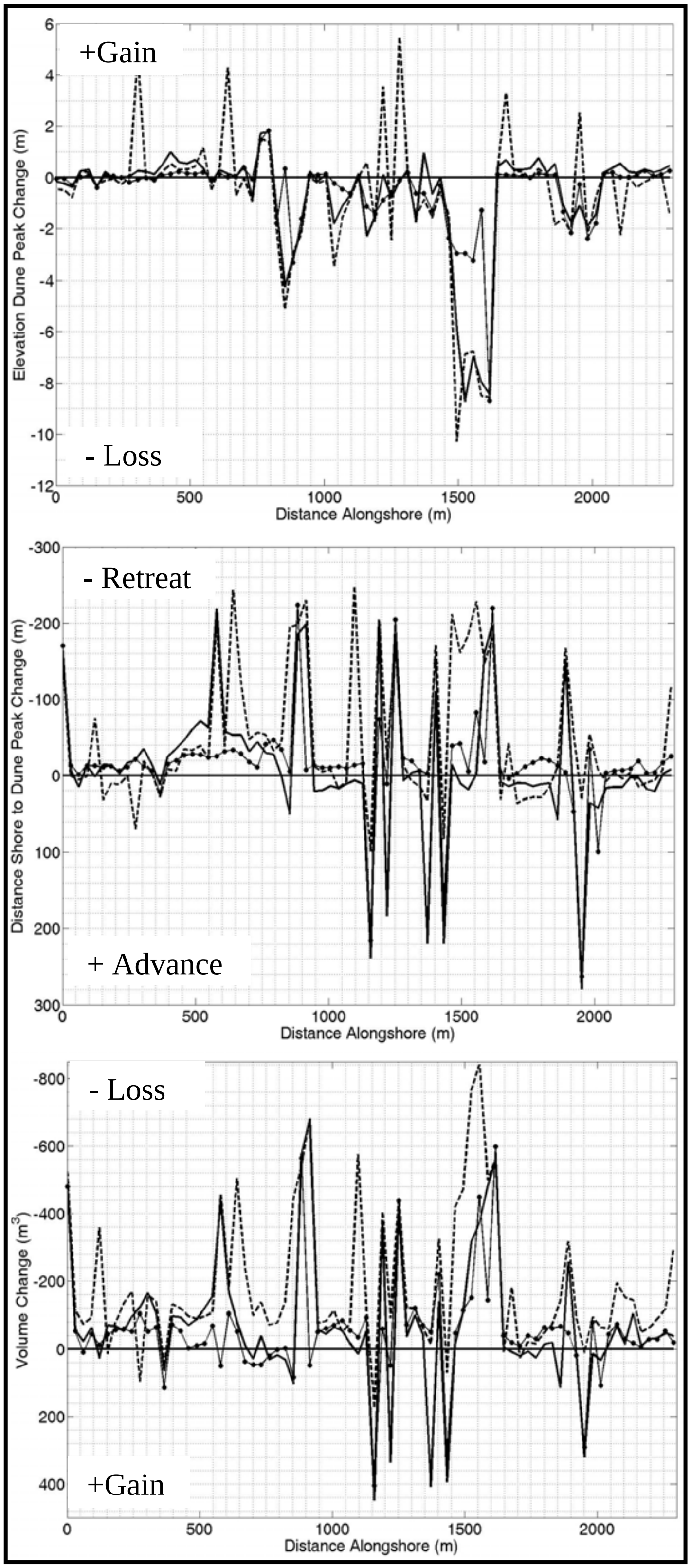

Figure 2. Change in geomorphic metrics from the 2004 Pre-Ivan NCMP survey, elevation of dune peak, distance from shore to dune peak, volume change, to the 2004 Post Ivan (dotted line), 2005 Post-Dennis (dashed line), and 2005 Post Katrina (solid line) on the west side of East Pass, FL

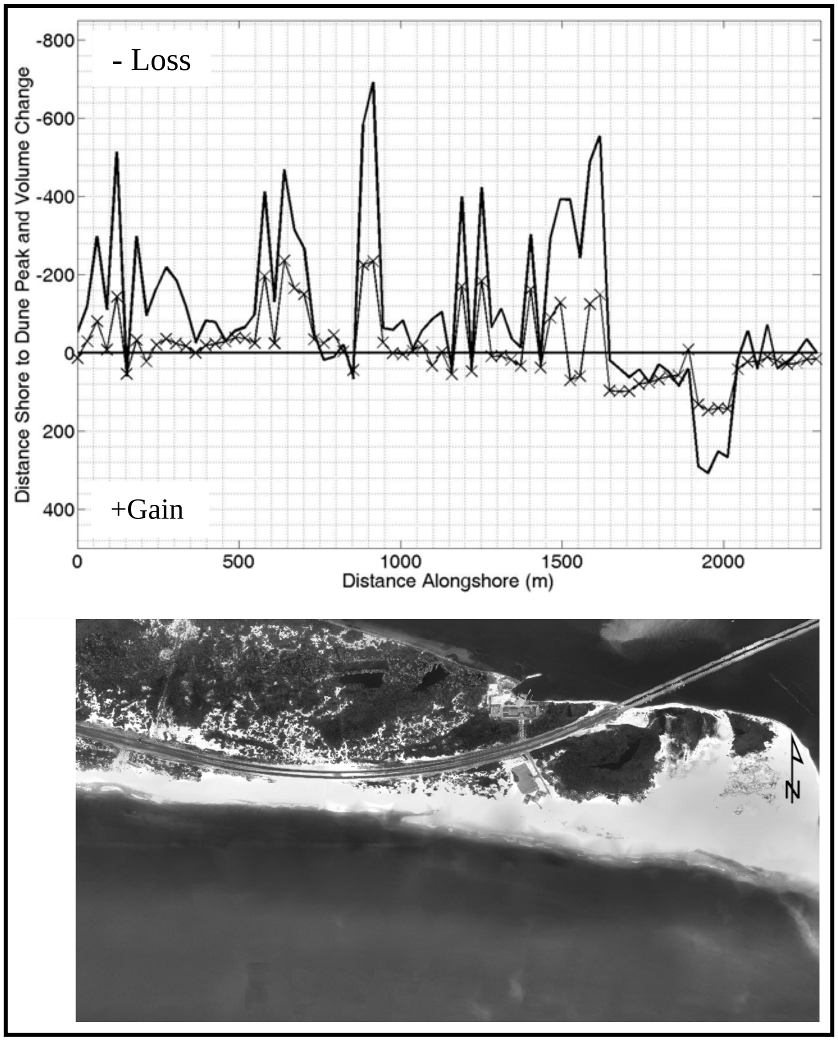

Figure 3. Change in distance shore to dune peak m (crossed line) and volume change m^3/m (solid line) from the 2004 Pre-Ivan NCMP survey and the 2010 NCMP survey

Table 3. Geomorphic changes from 2004 Pre-Ivan survey at East Pass, FL where Net Loss is Negative (-) and Net Gain is positive (+)

Survey Period	**Mean Dune Height, m**	**Mean Distance from Shore to Dune, m**	**Mean Volume Change, m^3/m**
2004 Post-Ivan	-0.50	-17.10	-53.42
2005 Post-Dennis	-0.72	-47.78	-184.81
2005 Post Katrina	-0.70	-11.23	-70.05
2010 NCMP	-0.48	-13.41	-104.47

Navigation Channel
The main portion of the channel that is south of the US 98 bridge is considered for the analysis to determine the impact from multiple storm events and to identify areas that are more vulnerable to shoaling and are therefore hazardous to safe navigation (Figure 4). The condition of each cross-section is assessed to identify the percent of the channel available for navigation and then using the information to assign a rank (Table 2).

Figure 5 shows the percentage of the channels that are navigable for the 2004-Pre-Ivan NCMP, 2004 Post-Ivan, 2005 Post-Katrina, and 2010 NCMP surveys. There are areas of no data from the 0+00 station to the 20+00 station for the 2004 Pre-Ivan NCMP survey. The no data areas are likely due to water clarity issues which can be a concern when using airborne lidar to monitor navigation channels. The results show that the stations near 50+00 and 80+00 have zero percent navigable conditions (Failed Ranking) for the 2004 Pre-Ivan, 2004 Post-Ivan, and 2005 Post-Katrina surveys. These areas of concern are located near the bounds of the ebb shoal (station 80+00) and the spur jetty on the east side (50+00).

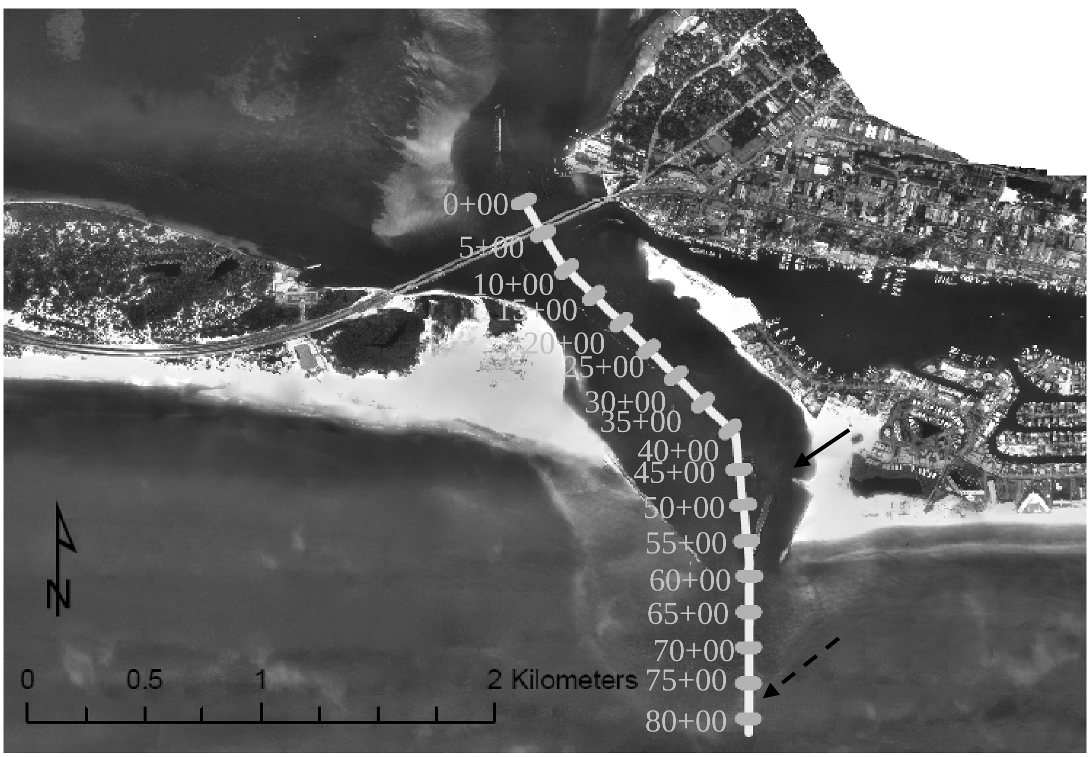

Figure 4. Aerial image from the 2010 NCMP survey of the navigation channel through East Pass inlet with stations and location of spur jetty (solid arrow) and bounds of ebb shoal (dashed arrow) are identified

The condition ranking of the percentage of the navigable channel is shown in Figure 6 for all of the surveys. The 2004 Pre-Ivan NCMP and 2004 Post-Ivan surveys have approximately 50% of the channel cross-sections that are at least 95% navigable.

There are some areas with no data available for the 2004 Pre-Ivan NCMP and 2005 Post-Dennis surveys which are due to insufficient lidar coverage caused by unfavorable water clarity. The 2005 Post-Katrina survey has 70% of the channel cross-sections that are at least 95% navigable while the 2010 NCMP survey has approximately 85% of the channel cross-sections with this ranking. The only area of concern for the 2010 NCMP survey is near the bounds of the ebb shoal near station 80+00.

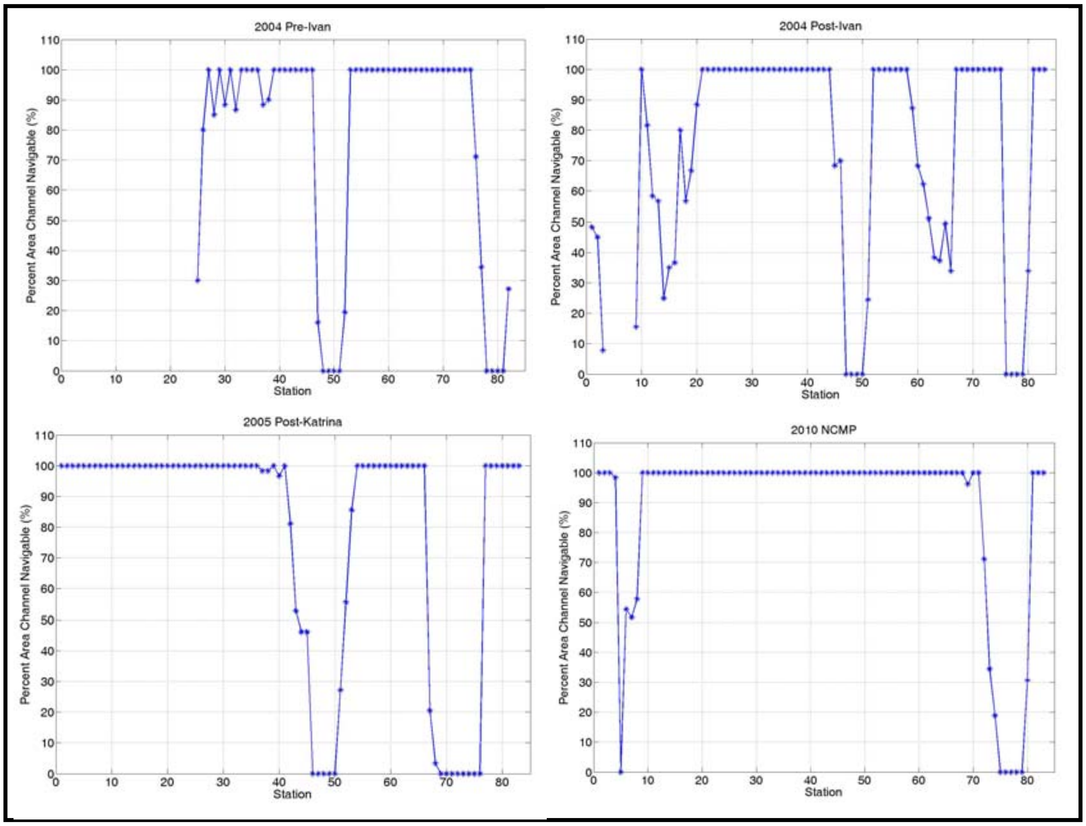

Figure 5. Percent area of each cross-section of the channel that is navigable for the 2004 Pre-Ivan NCMP (top left), 2004 Post-Ivan (top right), 2005 Post-Katrina (bottom left), and 2010 NCMP (bottom right)

Being able to quickly assess the condition of the navigation channel is vital to maintaining safe transportation. For small areas, such as near inlets, the JALBTCX can survey after extreme storm events as part of emergency management efforts. It takes a few hours for the area to be flown and the data can be processed within a week. The timeliness of the deliverable data depends on the size of the survey area; however, once the data is available, coastal planners and managers can use the products for storm damage assessment.

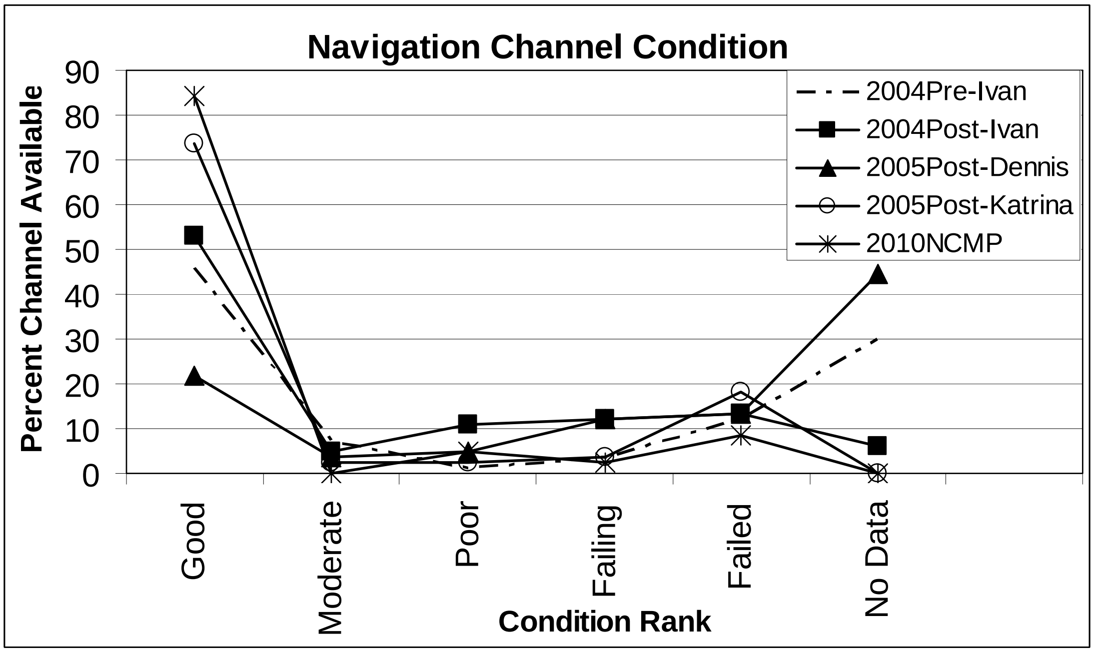

Figure 6. Condition ranking of the percent of the navigation channel for the 2004 Pre-Ivan NCMP, 2004 Post-Ivan, 2005 Post-Dennis, 2005 Post-Katrina, and 2010 NCMP surveys

CONCLUSIONS

The volumetric and shoreline change, and changes in nearshore bathymetric morphology are quantified to assess the performance of the projects and the vulnerability to extreme storm events using lidar derived products from the NCMP. The trend for the beach width and dune system is erosional except where the ebb shoal joins the beach near the inlet. Some recovery can be seen in the average dune elevation during the relatively calm period 5 years after Hurricane Katrina. Comparing multiple surveys shows that morphological changes to the shoal system may significantly impact the navigation inlet. Being able to quickly assess the condition of the navigation inlet is vital to maintaining safe transportation.

The methods developed using three-dimensional data will enable planners and engineers to assess the condition of the coastal region and navigation projects, evaluate the vulnerability of these areas and projects to extreme storm events, and predict future conditions for the project life-time. Future goals to improve the procedures and applicability of these methods include limiting the analysis to only include geomorphic metrics seaward of any infrastructure, determining the navigable half channel condition since presumably the channel can be reduced to single lane traffic, increasing the study area reach to show trends on a larger scale, and performing the study at several shore protection and navigation project sites.

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REFERENCES

Gares, P.A., Wang, Y., and White, S.A. (2006). "Using LIDAR to monitor beach nourishment project at Wrightsville Beach, North Carolina, USA," Journal of Coastal Research, 22(5), 1206-1219.

Houser, C., Hapke, C., Hamilton, S. (2008). "Controls on coastal dune morphology, shoreline erosion and barrier island response to extreme storms," Geomorphology, 100, 223-240.

Irish, J.L. and Lillycrop, W.J. (1997). "Monitoring New Pass, Florida, with High Density Lidar Bathymetry," Journal of Coastal Research, 13(4), 1130-1140.

Morang, A. (1992). "A study of geologic and hydraulic processes at East Pass, Destin, Florida'" U.S. Army Corps of Engineers, Washington DC.

NOAA VDatum (2010). http://vdatum.noaa.gov/welcome.html

Saye, S.E., van der Wal, D., Pye, K., and Blott, S.J. (2005). "Beach-dune morphological relationships and erosion/accretion: An investigation at five sites in England and Wales using LIDAR data," Geomorphology 72, 128-155.

Stockdon, H.F., Doran, K.S., and Sallenger, A.H., Jr. (2009). "Extraction of lidar-based dune-crest elevations for use in examining the vulnerability of beaches to inundation during hurricanes," Journal of Coastal Research, 53,

Stockdon, H.F., Holman, R.A., Howd, P.A., and Sallenger, A.H., Jr. (2006). "Empirical parameterization of setup, swash, and runup," Coastal Engineering, 53 (7), 573-588.

USACE Mobile District Spatial Data Branch (2010). "C.E. Tools User's Guide," http://ecoastal.usace.army.mil/tools.asp

Wozencraft, J.M. (2001). "The coastal zone revealed through SHOALS lidar data," Proceedings Hydro 01, Norfolk, Virginia, USA

Wozencraft, J.M. and Lillycrop, W.J. (2006). "JALBTCX Coastal Mapping for the USACE," International Hydrographic Review, 7(2), 28-37.

Wozencraft, J.M.; Macon, C.L., and Lillycrop, W.J. (2007). "CHARTS-Enabled Data Fusion for Coastal Zone Characterization," Proceedings of the Sixth International Symposium on Coastal Engineering and Science of Coastal Sediment Processes 2007 (Reston, Virginia, USA, ASCE), 1827-1836.