LANDSCAPE MODIFICATIONS BY HURRICANE ISABEL, FISHERMAN ISLAND, VIRGINIA

T.R. Allen[1] and G.F. Oertel[2]

[1]Department of Political Science and Geography, Old Dominion University, Norfolk, VA 23529
[2]Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA 23529

ABSTRACT

Fisherman Island, an emergent barrier island situated at the southern tip of the Delmarva Peninsula and the entrance to the Chesapeake Bay, is the most rapidly accreting barrier on the Virginia coast. The island has developed in the past 200 to 250 years in a sequence of emergence, divergence, and bipolar spreading. Past storms have left records of accretion events, punctuated by truncation from overwash and channel plugging. This study sought to assess the impact of Hurricane Isabel on the geomorphology and vegetation of the island. Hurricane Isabel produced a 1.3-m storm surge and 3-m wave runup in the vicinity, resulting in submergence of much of the island during elevated water levels. Augmenting a long-term spatial study of island evolution, Landsat Enhanced Thematic Mapper images collected pre- (3 September 2003) and post-Isabel (20 October 2003) were classified for analysis of changes to island morphology and vegetation. Results document localized accretion, interdune flooding and overwash, and minor erosion from Isabel. The island subaerial surface area increased by 3.3%, an observation bolstering its emergent nature, although significant changes were also noted *between* terrestrial cover types (15% of the pre-storm island changed among landform and vegetation types). The greatest morphological changes were spit development, overwash sediment deposition from the beach to shrub-dune areas, and redistribution and accumulation of wrack and storm debris. The island maintained its pre-storm record of sequence morphodynamics.

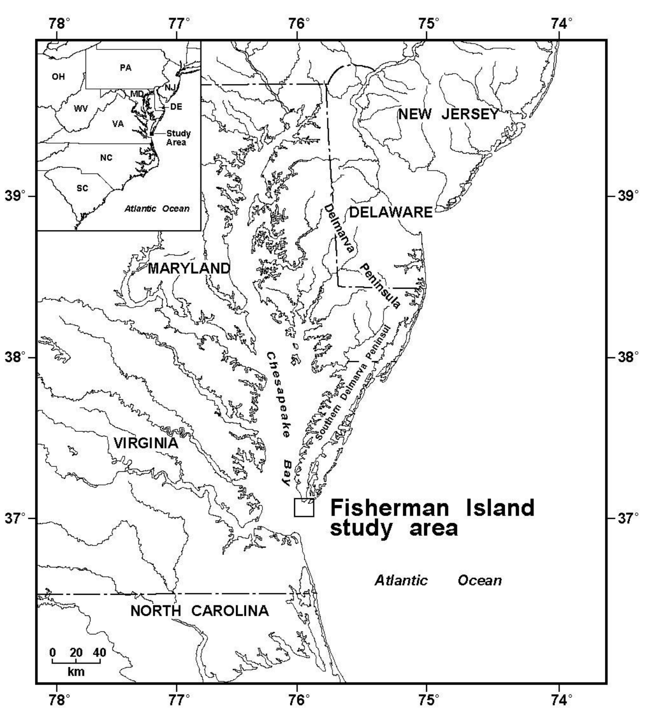

Figure 1. Study area location, Fisherman Island, southern Delmarva Peninsula.

INTRODUCTION

Fisherman Island is the southernmost island in the Delmarva Peninsula chain of barrier islands and marks the northern boundary of the Chesapeake Bay entrance (Figure 1). The island exhibits landscape features distinct from other islands in the Delmarva coastal compartment. The paleogeography and emergence of Fisherman Island from the shoreface are detailed in Oertel and Overman [1]. The distinguishing landscape features of the island complex today reflect its emergence, bipolar spreading and divergence, and modern and periodic hiatus in the depositional record caused by

K.G. Sellner (ed.). Hurricane Isabel in Perspective. 2005. Chesapeake Research Consortium, CRC Publication 05-160, Edgewater, MD.

truncation from storm overwash and erosion. The ultimate sand sources of this emergent island are thought to be relatively deep shoreface environments. Deep bay and coastal currents seaward of the nearshore breaker zone transported and deposited sand in a convergence zone at the Chesapeake Bay mouth. This accumulation rose to the level of wave base, resulting in wave refraction of ocean swell. Refracting wave crests are primarily responsible for driving sand onto the Fisherman Island shore [1]. The present-day morphology of the island is a unique emergent pattern with a "collar" shape due to wave refraction recurving spits at both ends of the major axis of the island.

Fisherman Island forms part of the U.S. Fish and Wildlife Service's (FWS) Eastern Shore of Virginia National Wildlife Refuge and is bisected by Route 13 and the causeway of the Chesapeake Bay Bridge-Tunnel. The landscape provides habitats for endemic and migratory waterfowl, shorebirds, and summer nesting waterbirds [2]. Habitat diversity on a relatively low elevation and youthful emergent island is substantially controlled by geomorphic processes. The landform mosaic includes shorelines, ridges, swales, ponds, subaerial flats, tidal flats, sand bars, and spits. In addition, part of the island was developed during World War II and contains relic installations.

Prompted by experience with the site and the opportunity to study potential rapid changes on an emergent barrier island, a remote sensing analysis of surficial and land cover change was initiated. Although shoreline delineation from remote sensing is problematic even using aerial photographs [3], satellite remote sensing to detect change of coastal environments is useful in characterizing and measuring changes of erosion and accretion [4] or zonal variations over moderate distances [5]—particularly where changes are rapid and a long history of shoreline observations is available [6].

METHODS

Isabel Surge, Wave, and Profile Analyses

Observations of the storm event on the uninhabited island are not available, but water-level monitoring stations and buoy data are useful proxy sources. Beach profile measurements were also taken as part of an annual observation program, including 2003 and updated in 2004. First, to characterize Isabel's storm surge on Fisherman Island, water level monitoring data from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) (*http://tidesandcurrents.noaa.gov/data_res.html*) were acquired. Although no direct storm surge measurements were made on Fisherman Island, the proximity to Kiptopeke (a long-term, water-level monitoring station) and numerous tidal benchmarks in the vicinity suggest an appropriate surrogate. In addition, detailed wave observations from the National Data Buoy Center (*http://www.ndbc.noaa.gov/*), primarily from the nearby Chesapeake Light Tower (station # CHLV2) located on the inner shelf, were analyzed. Wind direction, sustained wind speed, and peak gusts were recorded.

Detailed wave data included the wind- and swell-wave significant wave heights (Ho), swell direction (azimuth), and dominant wave period(s). Given the swell height, the breaker height and distance from shore was approximated using an assumed nearshore gradient. Wave runup elevation could be estimated from these data and compared to surface observations and aerial photograph interpretation of the storm's effects. Beach profiles have been collected annually at a site on the western, leeward bayside of Fisherman Island over the past few years as part of a study of the island's morphodynamics and for a course on coastal landscape ecology at Old Dominion University in Virginia. In addition to profiles from 2001 and 2002, a profile was obtained immediately before Hurricane Isabel in September 2003 and again in September 2004.

Remote Sensing

Remote sensing was used to measure shoreline accretion/erosion and net changes in the landscape composition of Fisherman Island. Erosion/accretion is analyzed in a discrete fashion with the classification and movement of shorelines, controlling for tidal asynchrony in the imagery.

Shifts in vegetation and geomorphic features of the island require a more complex analysis using remote sensing, including complementary field data or high-resolution aerial photography (both available in only limited extent). Two cloud-free Landsat-7 ETM+ satellite images were acquired from the USGS Eros Data Center. The pre-Isabel image was taken 3 September 2003 with the post-Isabel image taken 20 October 2004. Both images were geometrically corrected to <0.5 pixel RMS error and co-registered to a common earth coordinate system (UTM WGS84). Since change detection requires consideration of exogenous effects such as atmosphere, solar illumination, and viewing geometry, the images were radiometrically corrected by converting the digital numbers to radiance and then reflectance values. Thus, true reflectance data could be analyzed and corrected for between-scene atmospheric differences with calculation of a set of spectral enhancements that highlight changes on the island. Prior to analyzing changes, the imagery was subset to the general area of Fisherman Island, focusing on nearshore and terrestrial features.

The remote sensing approach used three methods of change detection: image differencing, change vector analysis (CVA), and post-classification change detection. Image differencing —along with multi-image display— highlighted macro-changes on the island, including major erosional/accretional areas, overwash, and ecological changes to vegetated features. Change vector analysis was chosen to refine the basic changes identified by image differencing and to classify pixels into types of change that would typify storm impacts (areas of erosion, accretion, denuded dunes, or overwash areas). Finally, post-classification change detection was used as a discrete, albeit coarse, measurement tool to derive measures of net change on the island (land loss or accretion and amount of change between vegetation and landform types). Post-classification requires the separate classification of two or more images and subsequent overlay analysis. Although this method is the most straightforward change-detection method and is useful for showing discrete changes, it also potentially compounds errors in the individual classified images.

RESULTS AND DISCUSSION

Surge, Wave, and Beach Profiles

The Kiptopeke water levels (Figure 2) deviated markedly from predictions, reflecting the impact of storm surge on the area. Located several kilometers northwest of the island on the eastern Chesapeake Bay shore, Kiptopeke indicated a storm surge maximum of 1.3 m. As a proxy for storm overwash observations, detailed wave data were acquired from Chesapeake Light Tower (CHLV2), which is located approximately 20 km southeast of the island. Wave observations included dominant wave heights (H_o) of 5–6 m over 16 hours, dominant period of 16 sec, and surface winds of 72 mph (116 $km \cdot hr^{-1}$) sustained with gusts to 93 mph (150 $km \cdot hr^{-1}$). Using the wave data, we estimated breaker heights of up to 7 m, approximately 250 m offshore, which could produce a wave runup height of approximately 3 m. This runup would be superimposed upon the storm surge, approximately equal to the Kiptopeke water level observation (Figure 2). The combination of moderate storm surge and extreme wave action upon the island and its nearshore area prompted further study of the pre- and post-storm landscape. The annual beach profiles (Figure 3) on the southern left-hand spit near the Chesapeake Bay Bridge-Tunnel indicate only moderate shoreline retreat and possible net accretion on the dune, but a more synoptic view via satellite images would complement this observation.

Change Detection

Pre- and post-Isabel images showed a variety of spectral changes owing to geomorphic processes and vegetation disturbance. Image differencing highlighted areas of gross spectral change, identifying areas for more detailed investigation. These areas included: right-hand spit progradation on the northern end of the island; areas of erosion, overwash, and accretion; and inundated dune swales. Change vector analysis was used to

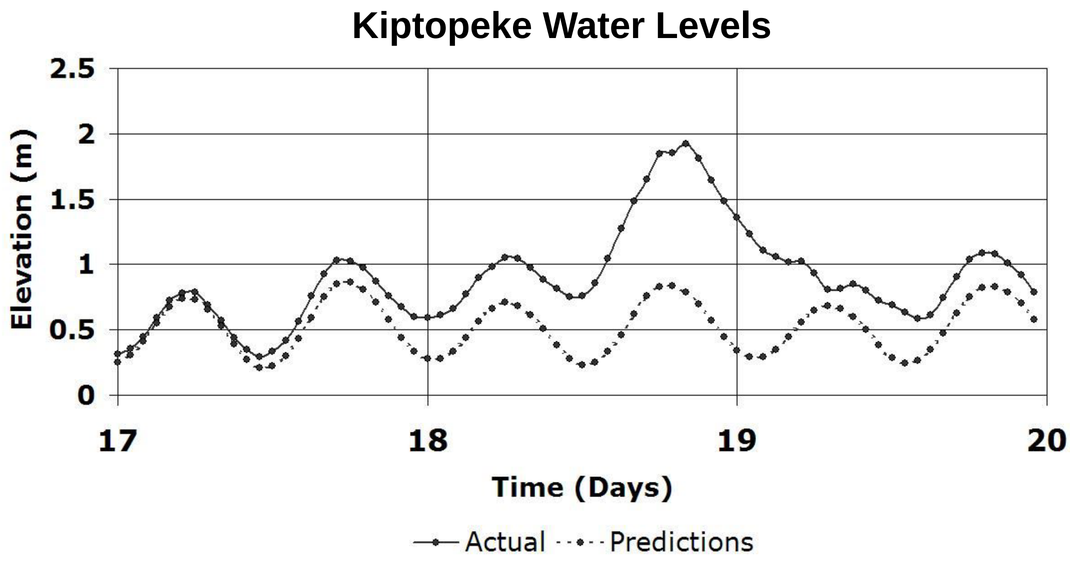

Figure 2. Kiptopeke water levels showing an estimated 1.3 m storm surge.

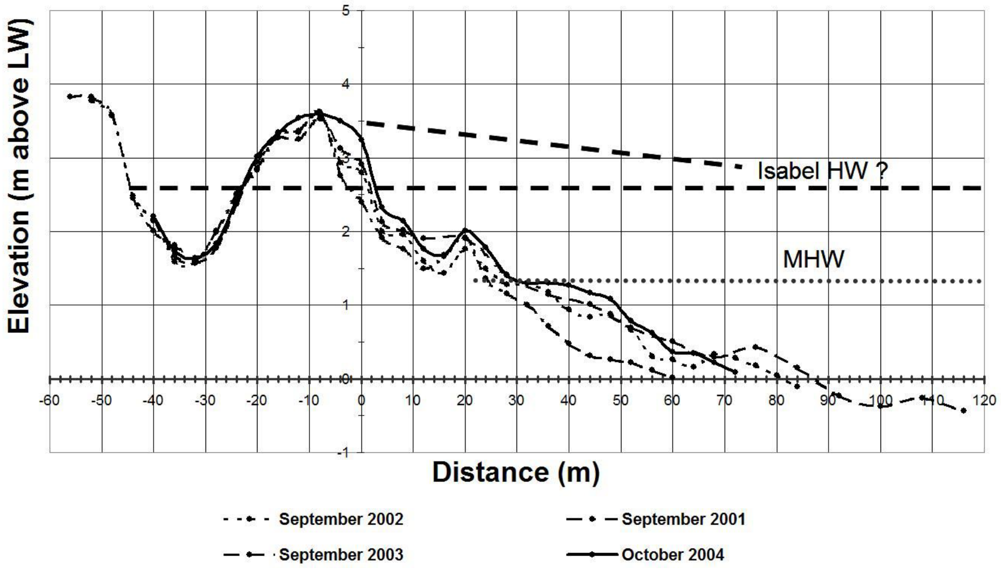

Figure 3. Annual beach profiles taken on the leeward, bay side of Fisherman Island in September 2001, 2002, and 2003 as well as October 2004.

delineate training sites for these areas of known change and to classify the remainder of the image into change/no-change. These areas are depicted as overlays of accretional sands (Figure 4) and eroded beaches and denuded dunes overwashed during the storm (Figure 5). Observations were confirmed by visual image interpretation, ground observations, and oblique aerial photographs of sites (e.g., Figure 6).

For post-classification change detection, we sorted each image into one of four classes using an ISODATA unsupervised classification algorithm (water, marsh/wrack/forest, dune/shrub/grass, and sand/bare). Pre-/post-storm images were overlaid as raster grids and a tally matrix used to tabulate class change/no-change. Table 1 shows the result of classified changes in terms of land area of classes (hectares). Table 2 reports the percentage change for each class. In both tables, cells in the diagonal represent no change. On the northeast side of the island, significant erosion of the beach was indicated, with additional adjacent overwash and

Figure 4. Accretion areas identified by supervised CVA, vectorized into polygons, and displayed over Landsat satellite data (ETM+ 4 September 2003 band 1). Polygons on the island would be overwashed and denuded from vegetated to bare sand. The offshore bars south and east of the island were substantially eroded. The large spit platform on the northern side of the island would subsequently expand longitudinally downdrift (e.g., Figure 5 and Figure 6).

deposition of wrack from possible submerged aquatic and dune vegetation (Figure 6). In terms of percentage change, the island accreted 3.3% additional sand area (~32 ha that were water were

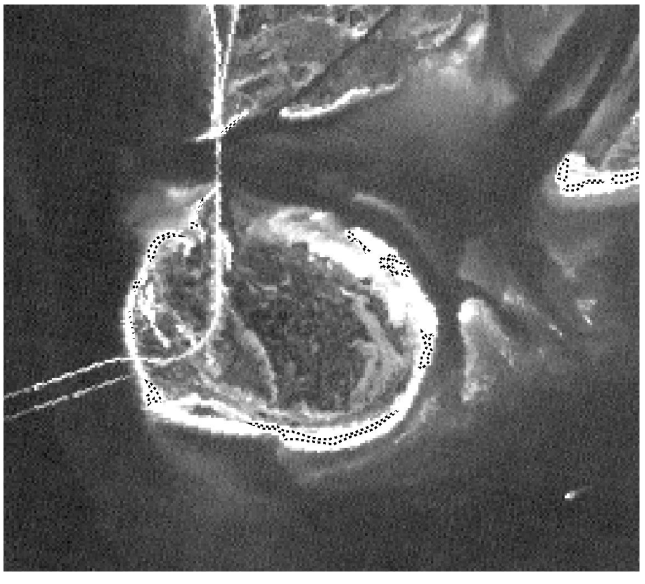

Figure 5. Overwash and erosional areas classified by supervised CVA, displayed over Landsat ETM+ 20 October 2003 band.

classified as bare sand after the storm). A shift also occurred from marsh to water, however, as a result of ponding or possible mixed pixels (accounting for 3.5% of the change or ~34 ha). Erosional and denudational changes were indicated by a shift from marshes, shrub, and dune vegetation to bare sand (3.9% or ~37 ha). Overwash caused the change from bare, sandy beach to wrack and shrub-dune debris deposits (3.7% or ~35 ha).

The pattern of interdune flooding suggests inundation from the landward/mainland side of the island, with surge water backing up from the interstitial marshes. Northeast winds and the lack

Figure 6. Oblique aerial photograph of eastern Fisherman Island looking south-southeast after Hurricane Isabel illustrating overwash, erosion, and accretion patterns (Photo courtesy of John Porter, University of Virginia, Virginia Coast Reserve LTER).

of major breaching of primary dunes corroborate this interpretation. This interpretation of change requires the significant caveat that only casual field observations were available to "groundtruth" the changes prior to Isabel and immediately afterward. However, the oblique aerial photography and long-term familiarity with processes and vegetation patterns on the island nonetheless provide confidence in the interpreted results. In addition, accuracy assessment of the individual land cover classifications yields overall accuracy in the 90–95% range among classes (with the lowest being marsh and the highest water).

Table 1. Area change/no-change matrix (hectares) for Fisherman Island landscape classes.

From 2 Sept '03 \ To 20 Oct '03	Water	Marsh/wrack/forest	Dune/shrub/grass	Sand/bare
Water	210	11.8	0.9	32.7
Marsh/wrack/forest	34.1	247.2	6.4	14.5
Dune/shrub/grass	0	20.6	205.9	22.4
Sand/bare	3.9	11.1	24.1	134.9

Table 2. Percent change/no-change matrix for Fisherman Island landscape classes.

From 2 Sept '03 \ To 20 Oct '03	Water	Marsh/wrack/forest	Dune/shrub/grass	Sand/bare
Water	21.4	1.2	0.1	3.3
Marsh/wrack/forest	3.5	25.2	0.6	1.5
Dune/shrub/grass	0.0	2.2	21.7	2.4
Sand/bare	0.4	1.2	2.5	14.2

SUMMARY AND CONCLUSIONS

This project sought to quantify the impact of a hurricane on an emergent barrier island and to gauge the utility of alternative remote sensing change-detection algorithms. Changes between land-surface types represented processes that are typical of other barrier islands, including overwash, erosion and accretion downdrift along inlets and recurved spits, and backbarrier flooding. Despite the high wave energy and moderate surge estimated to have impacted the island, no major breach of primary dunes occurred. Even with significant alterations in vegetation and geomorphic surfaces, the island retained its record of sequence morphodynamics. The project also demonstrated that rather than the application of stand-alone algorithms for change detection, sequential analyses using image differencing, CVA, and post-classification change detection can provide complementary information. Image differencing excels as an exploratory technique. Change Vector Analysis allows for specific process, state, or gradational changes to be mapped. Post-classification provides an overall synoptic assessment of landscape structure and change among island surfaces.

ACKNOWLEDGMENTS

The authors wish to thank Dr. John Porter of the University of Virginia and the Virginia Coast Reserve Long-Term Ecological Research station for sharing aerial photographs taken after Hurricane Isabel.

REFERENCES

1. G.F. Oertel and K. Overman. 2004. Sequence morphodynamics at an emergent barrier island, middle Atlantic coast of North America. *Geomorphology* 58: 67–83.
2. Fish and Wildlife Service. 2004. Eastern Shore of Virginia National Wildlife Refuge (*http://easternshore.fws.gov/*).
3. R.A. McBride, M.W. Hiland, S. Penland, S.J. Williams, M.R. Byrnes, K.A. Westphal, B.E. Jaffe, and A.H. Sallenger Jr. 1991. Mapping barrier island changes in Louisiana: Techniques, accuracy, and results. *Proc. Coast. Sed. '91*, American Society of Civil Engineers, New York. 1011–1026.
4. M. El Raey, S.H. Shawat El-Din, A.A. Khafagy, and A.I. Abo-Zed. 1999. Remote sensing of beach erosion/accretion patterns along Damietta-Port Said, Egypt. *Int. J. Remote Sens.*, 20: 1087–1106.
5. O.E. Frihy, S.M. Nasr, M.M. El Hattab, and M. El Raey. 1994. Remote sensing of beach erosion along Rosetta promontory northeastern Nile Delta, Egypt. *Int. J. Remote Sens.* 15: 1649–1660.
6. F.J. Anders and R.J. Byrne. 1991. Accuracy of shoreline change rates as determined by maps and aerial photographs. *Shore Beach*, 591: 17–26.