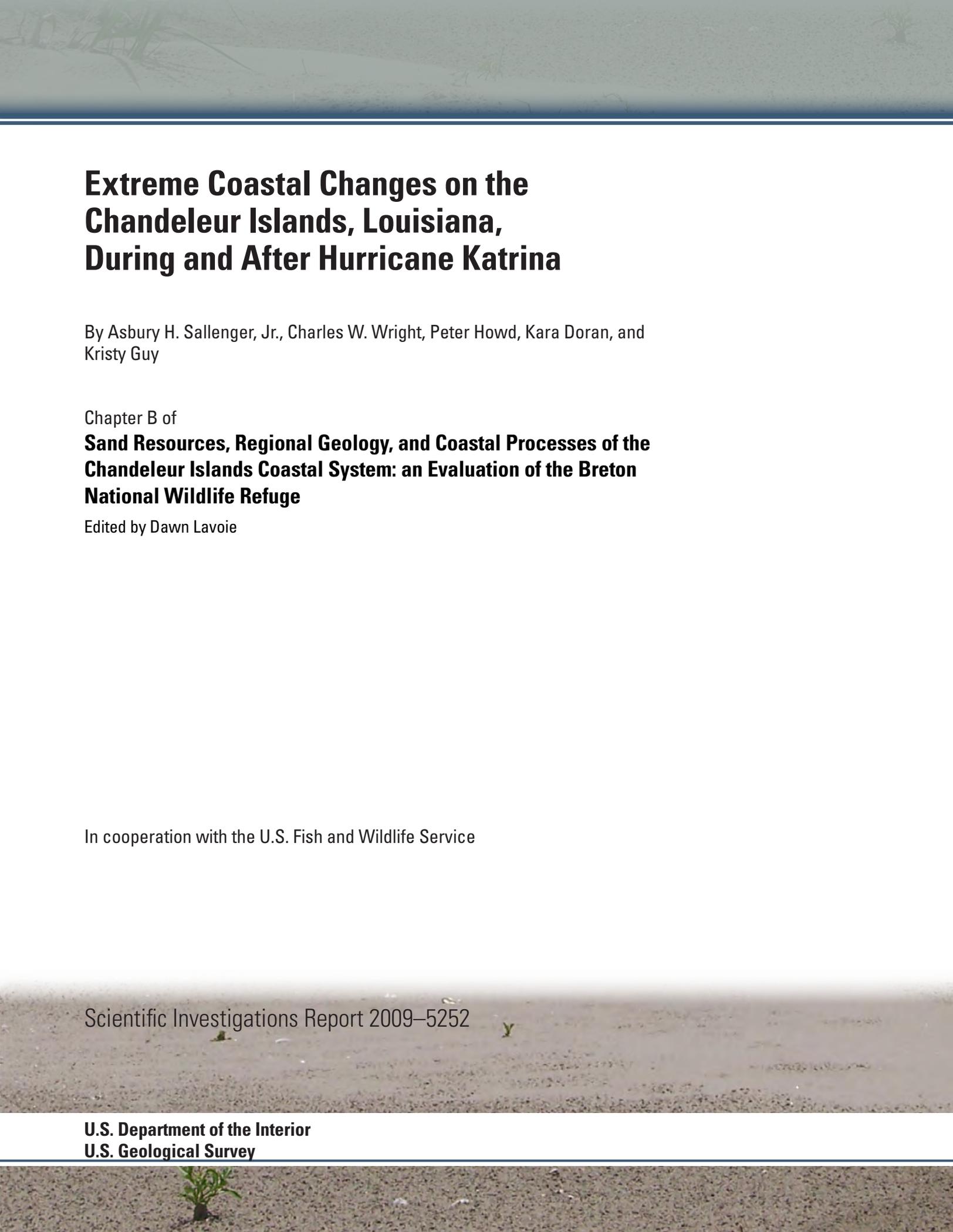


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Chapter B of
**Sand Resources, Regional Geology, and Coastal
Processes of the Chandeleur Islands Coastal
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Scientific Investigations Report 2009–5252



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Edited by Dawn Lavoie

In cooperation with the U.S. Fish and Wildlife Service

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Chapter B. Extreme Coastal Changes on the Chandeleur Islands During and After Hurricane Katrina

By Asbury H. Sallenger, Jr.,¹ Charles W. Wright,¹ Peter Howd,¹ Kara Doran,¹ and Kristy Guy¹

Abstract

For nearly 2 years after Hurricane Katrina in 2005 removed 86 percent of the surface area of Louisiana's Chandeleur Islands, most of the island chain continued to erode rapidly. Feedback processes triggered by the hurricane enhanced this erosion even under relatively mild, poststorm conditions and pushed the system towards failure. During the storm, the Chandeleurs were completely submerged by storm surge as if they had become shoals. When such submergence occurs locally, it can lead to differences in sea level across an island, forcing currents to erode a narrow breach, or inlet, connecting sea and bay. In this chapter, we show that during total island submergence the Gulf of Mexico-front shores were eroded landward an average of 268 m, likely the largest storm-induced shoreline retreat ever reported. Peak elevations on the islands decreased from more than 6 m to less than 3 m, and all of the sand visible from the air was stripped from the islands, exposing remnant marsh platforms to continued degradation by relatively small waves following Katrina. Twenty-two months later, some sand had returned to the islands, although elevations had not rebuilt appreciably, leaving the Chandeleurs vulnerable to inundation by weak storms. These islands are conditioned for extreme erosion and ultimate disappearance because of small sand supply and rapid sea level rise induced on the Mississippi River Delta by subsidence.

Introduction

Barrier islands undergo overwash when the elevation of wave runup periodically exceeds the elevation of the foredune or, in the absence of a dune, the elevation of the beach berm (see for example Sallenger, 2000). The portion of runup that overtops this crest of the active beach system is driven by gravity down the landward slope of the berm or dune as overwash. In general, under these conditions, gradients in landward flow erode sand seaward of the crest and deposit sand landward of the crest, forcing a landward migration of the beach system. Should the cross-shore width of this system

approach the width of the barrier island, and assuming no system losses or gains of sand, the island migrates landward while maintaining its form and size.

This simple overwash model of barrier island response to storms did not apply to the Chandeleur Islands during Hurricane Katrina in 2005. Rather, the 36-km-long island chain on the eastern flank of Louisiana (fig. 1) was not periodically overwashed by waves but, during the latter stages of the storm, was completely and continuously inundated by storm surge, the increase in sea level due primarily to onshore wind stress, reduced barometric pressure, and wave setup. During the storm, the Chandeleurs were no longer barrier islands; rather, they became shoals that underwent landward retreat and area losses of scales not previously observed.

In this chapter we show how the Chandeleur Islands changed when subjected to this inundation regime. Further, we show how feedback processes from these changes forced continued erosion of the islands during the relatively low waves following the storm, erosion that persisted for nearly 2 years after Katrina's landfall, and pushed the islands toward failure.

Airborne Lidar Surveys

The topography of the Chandeleur Islands was surveyed before and several days after the landfall of Hurricane Katrina and then resurveyed four additional times over the following 22 months by using airborne lidar. The surveys were intercompared to detect changes to the islands during the storm and during the recovery period of nearly 2 years.

These lidar surveys were part of a cooperative research program on the coastal impacts of extreme storms in the United States involving the U.S. Geological Survey, the National Aeronautics and Space Administration (NASA), the U.S. Army Corps of Engineers, and in Louisiana, the Louisiana Department of Natural Resources (see for example Sallenger and others, 2002, 2006; Stockdon and others, 2007). Three systems were used to acquire the different surveys: NASA's Airborne Topographic Mapper (ATM; see Brock and others, 2002), NASA's Experimental Advanced Airborne Research Lidar (EAARL; see Wright and Brock, 2002), and the U.S. Navy and U.S. Army Corps of Engineers' Compact

¹U.S. Geological Survey, St. Petersburg, Fla.

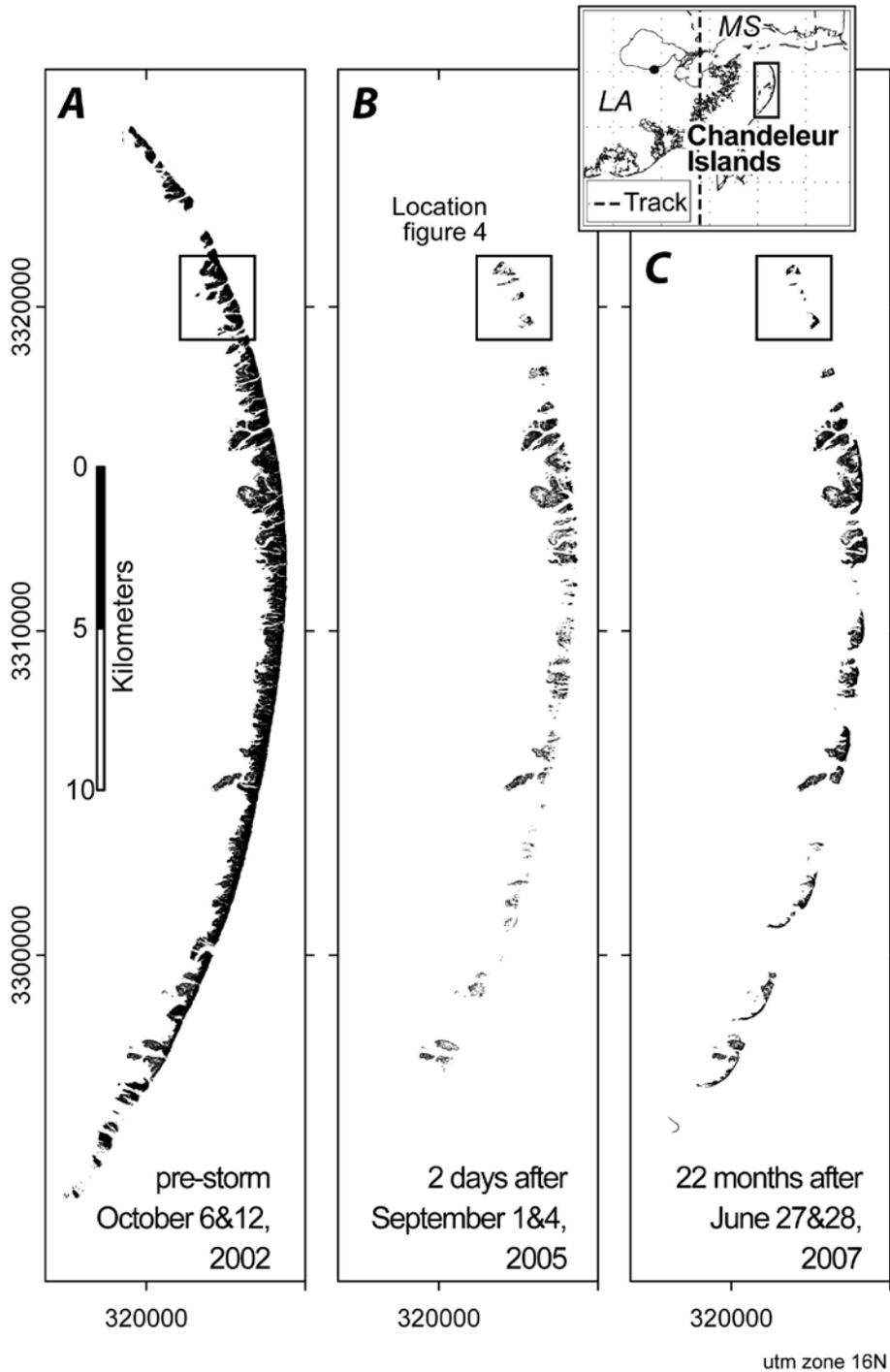


Figure 1. Maps of the Chandeleur Islands on the eastern flank of Louisiana from before and after Hurricane Katrina in August 2005. The maps are based on airborne lidar data; elevations above mean high water (MHW) are shaded black, and elevations below MHW are white. *A*, Lidar survey from before Hurricane Katrina acquired by using the National Aeronautics and Space Administration's (NASA) Airborne Topographic Mapper on October 6 and 12, 2002; referred to in the text as the "prestorm" survey. *B*, Survey within several days of the landfall of Katrina taken by using NASA's Experimental Advanced Airborne Research Lidar (EAARL) from September 1 and 4, 2005; referred to in the text as the survey 2 days after. *C*, Survey nearly 2 years after landfall taken by using NASA's EAARL on June 27 and 28, 2007; referred to in the text as the survey 22 months after.

Hydrographic Airborne Rapid Total Survey (CHARTS; see Heslin and others, 2003).

Multiple surveys of a 70-km-long reach of beach in North Carolina taken within a single day showed the vertical accuracy of ATM over unvegetated sand to be about 15 cm root mean square (RMS) (Sallenger and others, 2003). The other two systems provide topography data of similar vertical accuracy (for EAARL, see Wright and Brock, 2002; for CHARTS, see <http://shoals.sam.usace.army.mil/Charts.aspx/>). With their capability to survey a swath several hundred meters wide with estimates of elevation every 1–2 m² and over hundreds of kilometers of coast in several hours, lidar systems have revolutionized the quantification of coastal change.

EAARL has the only topographic lidar of the three that records the full waveform of reflected light from the ground. (CHARTS records the full waveform for its bathymetric sensor but, at this time, not for its separate topographic sensor. EAARL uses the same laser for both topography and bathymetry.) Hence, EAARL is the only system that can effectively discriminate vegetation, such as the marsh grasses found on the sound side of the Chandeleurs, to produce bare earth topography of the islands. EAARL was tested for its accuracy in determining bare earth elevations on the Chandeleurs by comparing bare earth elevations of a vegetated area with a ground survey of the same area completed at about the same time (Doran and others, 2008). The mean error (or bias) was 8 cm, and the random error was 14 cm, similar to the vertical accuracies determined for ATM over unvegetated sand by Sallenger and others (2003).

Observations

On August 29, 2005, Hurricane Katrina came ashore on the Mississippi River Delta in central Louisiana at Category 3 intensity on the Saffir-Simpson Hurricane Scale with sustained winds of 204 km/h (110 kn; Knabb and others, 2005). During the peak of the storm, a deepwater buoy in the Gulf of Mexico southeast of the Chandeleur Islands reported a significant wave height of 16.9 m and peak period of 14.3 s (National Oceanic and Atmospheric Administration [NOAA] buoy 42040). As the hurricane moved inland, its track passed parallel to, and about 70 km west of, the Chandeleurs (fig. 1), sweeping at least a portion of the storm's powerful right-front quadrant across the islands. (Hurricane-force winds extended to the right, or east, from the track about 195 km.) With the storm's track parallel to the island trend and its counterclockwise swirl, wind direction over the islands changed progressively as the storm moved north: approaching the islands, the winds were onshore (east to west); abreast of the islands, the winds were alongshore (south to north); and leaving the islands, the winds blew offshore (west to east).

Prior to Hurricane Katrina's landfall, a survey recorded the Chandeleurs as a chain of barrier islands 35.9 km long

(Oct. 2002; fig. 1A). This prestorm survey was acquired several days after a low-intensity hurricane (Category 1 Hurricane Lili) made landfall about 250 km to the west of the Chandeleurs. As shown in figure 1A, the islands appeared relatively continuous, although the lidar data detected 21 islets separated by narrow breaches. The islets averaged 1.6 km in length; the longest was 20.8 km. The mean high water contour determined from gridded lidar data defines the limits of the subaerial islands, whose surface area was 13.9 km².

By 2 days after landfall, the surface area of the islands had decreased to 2.5 km², a reduction of 82 percent (fig. 1B). The islands had been breached in many locations; the lidar data now detected 45 islets. Lengths of islets now averaged only 0.31 km; the maximum length was 3.1 km. These changes are cumulative between the prestorm survey and the survey taken 2 days after the storm, although we assume that the bulk of the observed changes can be attributed to Katrina, which was by far the most intense storm to impact the islands during the period between surveys.

Historically, the Gulf of Mexico-front shores of the Chandeleur Islands have undergone net erosion, retreating landward an average of 6.5 m/yr based on comparisons of surveys from 1855 and 1989 (McBride and others, 1992). During the same period, the islands' bayside shores accreted, building landward an average of 2.9 m/yr from repeated storm overwashes. During Katrina, however, massive erosion occurred on the gulf front with no concomitant deposition of sand on the sound side. In fact, aerial reconnaissance 2 days after landfall could detect no visible sand on the islands. What remained were fragments of marsh that before the storm served as platforms on which sand beaches and dunes of the islands had lain. The average gulf-front erosion for the Chandeleurs was 269 m (fig. 2A). Maximum measured shoreline retreat was 1.37 km. Assuming that during the 3-year interval between the prestorm survey and the landfall of Katrina the islands eroded at their historical rate, the average gulf-front erosion during the storm would have been roughly 250 m, which we believe to be the largest barrier island erosion ever reported for a storm.

Further, with massive erosion on the gulf side and no sand deposition on the sound side, the islands significantly narrowed (fig. 2B). The prestorm survey indicated that the widths of the islands were on average 415 m. Two days after Katrina, the average width was only 167 m, a decrease of 60 percent.

Prior to the storm, peak elevations (which were determined within adjacent bins that spanned the width of the islands and were 5 m wide along the length of the islands) were 4–6 m along the northern half of the islands (fig. 3A), indicating the presence of dunes. The islands' southern half had lower elevations, indicating the absence of prominent dunes; there the highest ground elevations would have been at the crests of beach berms. These elevations were first-return lidar data from NASA's ATM and, hence, may be biased high by the laser reflecting off island vegetation, such as the

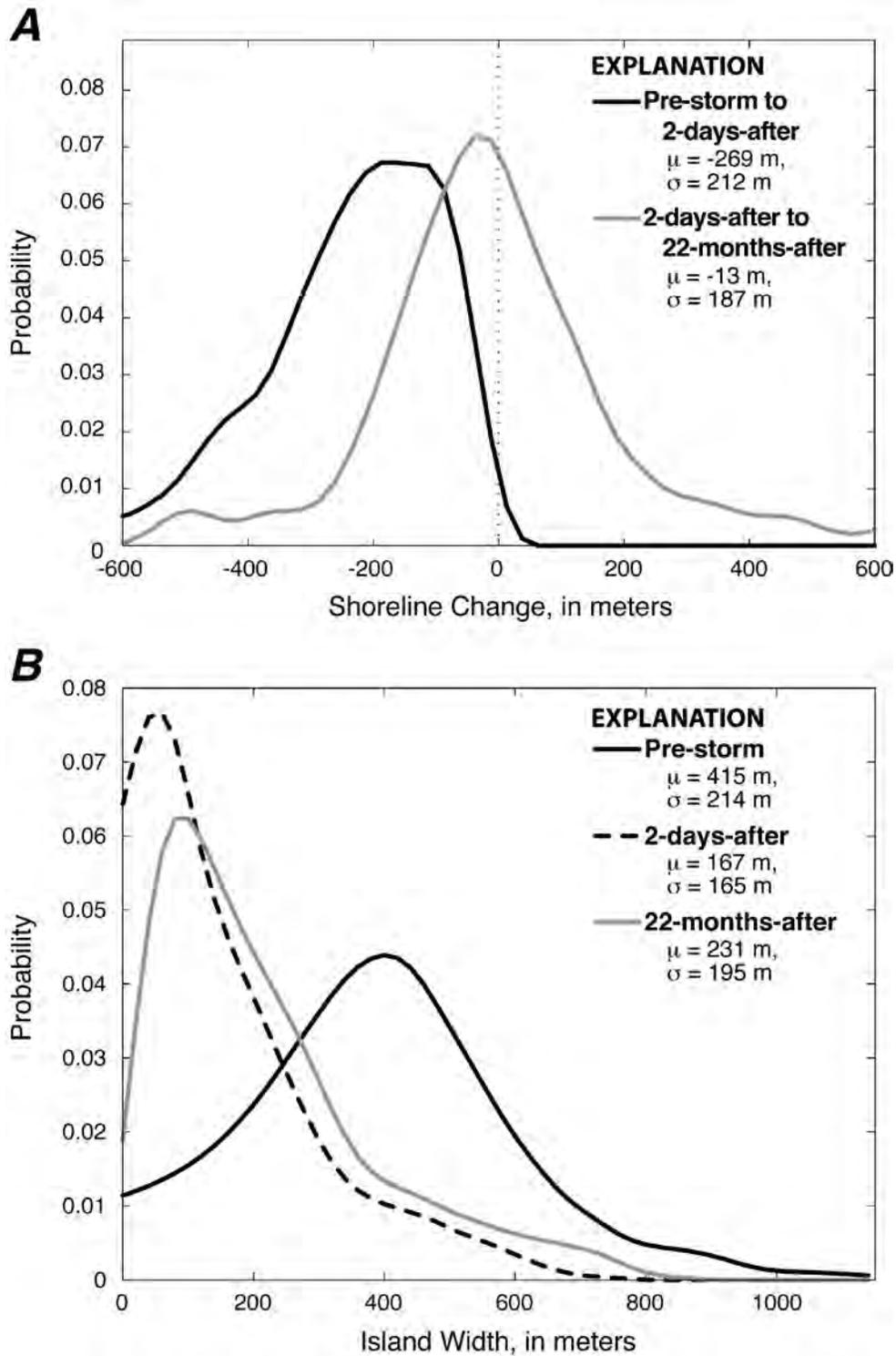


Figure 2. Changes in the shoreline and width of the Chandeleur Islands, La., before Hurricane Katrina in August 2005 (“prestorm”), 2 days after the storm, and 22 months after the storm. *A*, Distribution of shoreline changes determined every 50 m along the 35-km length of the Chandeleur Islands between lidar surveys taken prestorm and 2 days after and between surveys taken 2 days after and 22 months after Katrina. *B*, Distribution of island widths determined every 50 m along the Chandeleurs for surveys taken prestorm, 2 days after, and 22 months after Katrina.

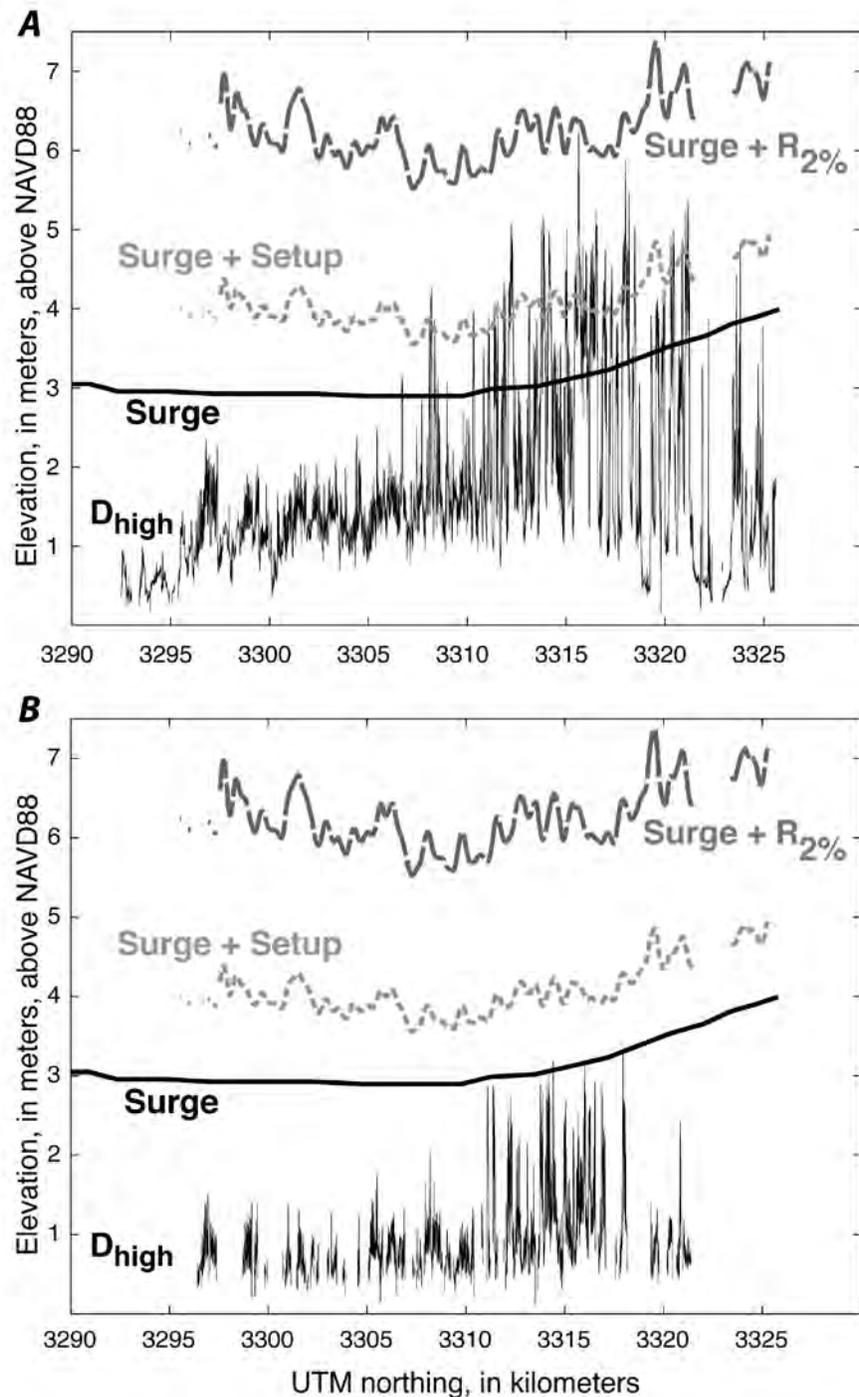


Figure 3. Peak elevations (D_{high}) determined every 20 m along the length of the Chandeaur Islands, La., by using lidar data processed for first return. Only first return is available for the prestorm survey, so even though bare earth data are available for 2 days after Hurricane Katrina in 2005, we show first return here to be comparable with prestorm data. Also shown are storm surge elevations along the shore as determined by the National Oceanic and Atmospheric Administration (NOAA) using the SLOSH model, surge plus calculated wave setup, and surge plus extreme (2%) wave runup. *A*, Prestorm (merged 2001 and 2002) D_{high} determined from lidar data acquired with the National Aeronautics and Space Administration's (NASA) Airborne Topographic Mapper. *B*, D_{high} from 2 days after the storm determined from lidar data acquired with NASA's Experimental Advanced Airborne Research Lidar.

roughly 1-m-high beach and marsh grasses, rather than the sand surface.

Peak surge during the storm was determined by NOAA's National Hurricane Center by using the SLOSH model (Jarvinen and Lawrence, 1985); the plotted values (fig. 3) were extracted from grid cells immediately offshore of the gulf front of the Chandeleurs. This surge was added to wave setup to provide an estimate of still water level during the storm and to $R_{2\%}$ to provide an estimate of the total vertical reach of the highest 2 percent of wave runup. Setup and $R_{2\%}$ runup were found from parameterizations by Stockdon and others (2006) and by using wave data modeled at a shallow-water NOAA buoy location in 13.4 m of water off the northern tip of the Chandeleurs (lat 30.09 N., long 88.77 W.). The buoy stopped operating before the peak of the storm; the peak conditions were provided by modeled data and presented in Interagency Performance Evaluation Task Force (2007).

Storm surge along the Mississippi coast approached 10 m. (According to Knabb and others, 2005, the highest measured water mark was near Bay St. Louis, Miss., at 8.5 m.) The peak surges along the Chandeleurs were smaller, ranging from about 3 m in the south to nearly 4 m in the north. Setup associated with wave breaking on the gulf front of the Chandeleurs added approximately an additional 1 m of still water level. This level was sufficient to submerge the southern half of the island chain; in the northern half, peak island elevations emerged through the combined surge and setup (fig. 3A).

The total elevation of wave runup on the beach, however, was sufficient to overtop prestorm peak elevations along the entire length of the islands (fig. 3A). Hence, during the early stages of the storm, the entire area of the islands was periodically overwashed by waves, driving sand on beaches and dunes from the gulf side of the islands towards the sound side.

During the storm, the topography of the islands was, of course, not static; because of inundation and overwash, peak elevations during the course of the storm were reduced (compare fig. 3A with 3B). With these lower peak elevations along the islands, the still water level during the peak of the storm was sufficient to completely submerge the islands in what Sallenger (2000) called the inundation regime. During such a regime, the Chandeleur Islands became shoals, and differences in sea level between gulf and sound drove mean currents across the island shoal. These mean currents likely contributed to the net transport of beach and dune sand from the islands and exposed the underlying marsh platforms.

Following storms, beaches usually recover naturally, at least to some extent, with sand migrating onshore in swash bars, for instance, and welding onto the beach in the weeks and months after the event (for example, Owens and Frobel, 1977). Over a 22-month period after Katrina's landfall, however, repeated lidar surveys showed that the islands did not uniformly recover. In fact, between 2 days and 22 months after landfall, 56 percent of the gulfside shore continued

to retreat landward (fig. 2A). Within an example reach of shore, the islands progressively retreated landward between successive lidar surveys (fig. 4A); the total retreat at one location approached 500 m.

The composition of the poststorm gulf shore likely contributed to the continued rapid retreat. With the sand stripped from the islands, the muddy marsh fragments that remained were exposed to the surf of the Gulf of Mexico and were vulnerable to erosion even by the relatively low post-Katrina waves. These marsh fragments contained some sand, however. As the marsh shore eroded landward, this sand was released and made available to form incipient beaches, while the fine sediments in the eroded marsh continue to disperse. Over time, these beaches will likely buffer the marshy shore from continued rapid erosion.

The 44 percent of the gulf shore that did not continue to erode over the 22 months after the storm showed the development of spits and welded swash bars that advanced the shore seaward. Within an example reach of this shore, a beach developed seaward of the shoreline position from 2 days after the storm, prograding the shoreline as much as 100 m seaward. This accretion along the 44 percent of the gulf shore was sufficient to widen the islands from an average of 167 m (2 days after) to 231 m (22 months after; fig. 2B). The mean shoreline change for the islands over the same period, though, was 13 m of erosion (fig. 2A).

Bare earth elevations (vegetation removed) are available for the surveys taken 2 days after and 22 months after the storm; these can be used to assess the recovery of peak elevations on the islands. Immediately after the storm, elevations averaged about 1 m (fig. 5A); 22 months later they had increased by only 0.3 m (figs. 5B and 5C). Also shown on these plots are the worst case (maximum of the maximum) storm surge elevations for Category 1 through Category 3 hurricanes, as well as the surge simulated by NOAA using SLOSH for Katrina conditions. Immediately after the hurricane, the islands were vulnerable to complete submergence (inundation regime) by a Category 1 hurricane. Nearly 2 years later, the elevations of the islands had recovered vertically only enough that a portion of the northern half of the islands would be emergent through a Category 1 surge. The implication is that the islands in 2008 remained highly vulnerable to inundation and to having all of their sand swept from the marsh platforms again, which would expose the muddy fragments to further degradation.

Discussion

The Chandeleur Islands are sand starved. Their original source of sand was the Mississippi River, which deposited a delta lobe from which the islands originally formed (Penland and others, 1985). When the Mississippi River switched to a new course about 1,800 to 2,000 years before present, the source of sand building the lobe was cutoff, and the lobe

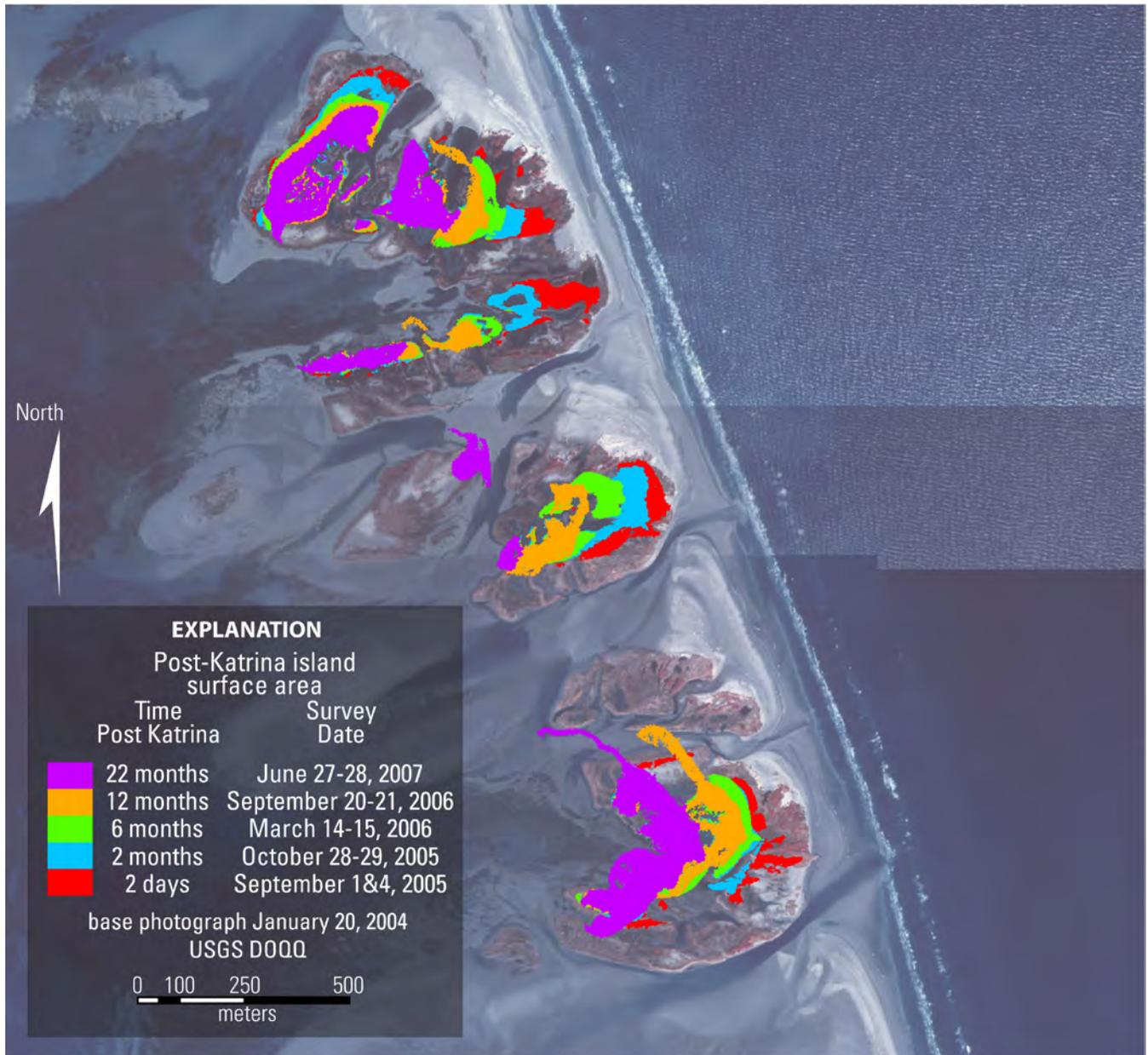


Figure 4. Changes to a 2.5-km-long reach of the Chandeleur Islands, La. (see fig. 1), showing persistent erosion during and for 22 months after Hurricane Katrina's landfall. The base map is a rectified, vertical photograph from before the storm, January 20, 2004. Subsequent lidar maps are stacked on top of the photograph; more recent surveys are overlaid on previous surveys. If no change occurred, only the last (22 months after) survey (indicated in purple) would be visible, as the other surveys would be underneath it. Since red is exposed along the gulf side of the islands, erosion is indicated between 2 days after (red) and 2 months after (blue). Note that each color of the five successive surveys can be seen along the gulfside shore and that together the lidar surveys indicate persistent landward erosion of the gulfside shore.

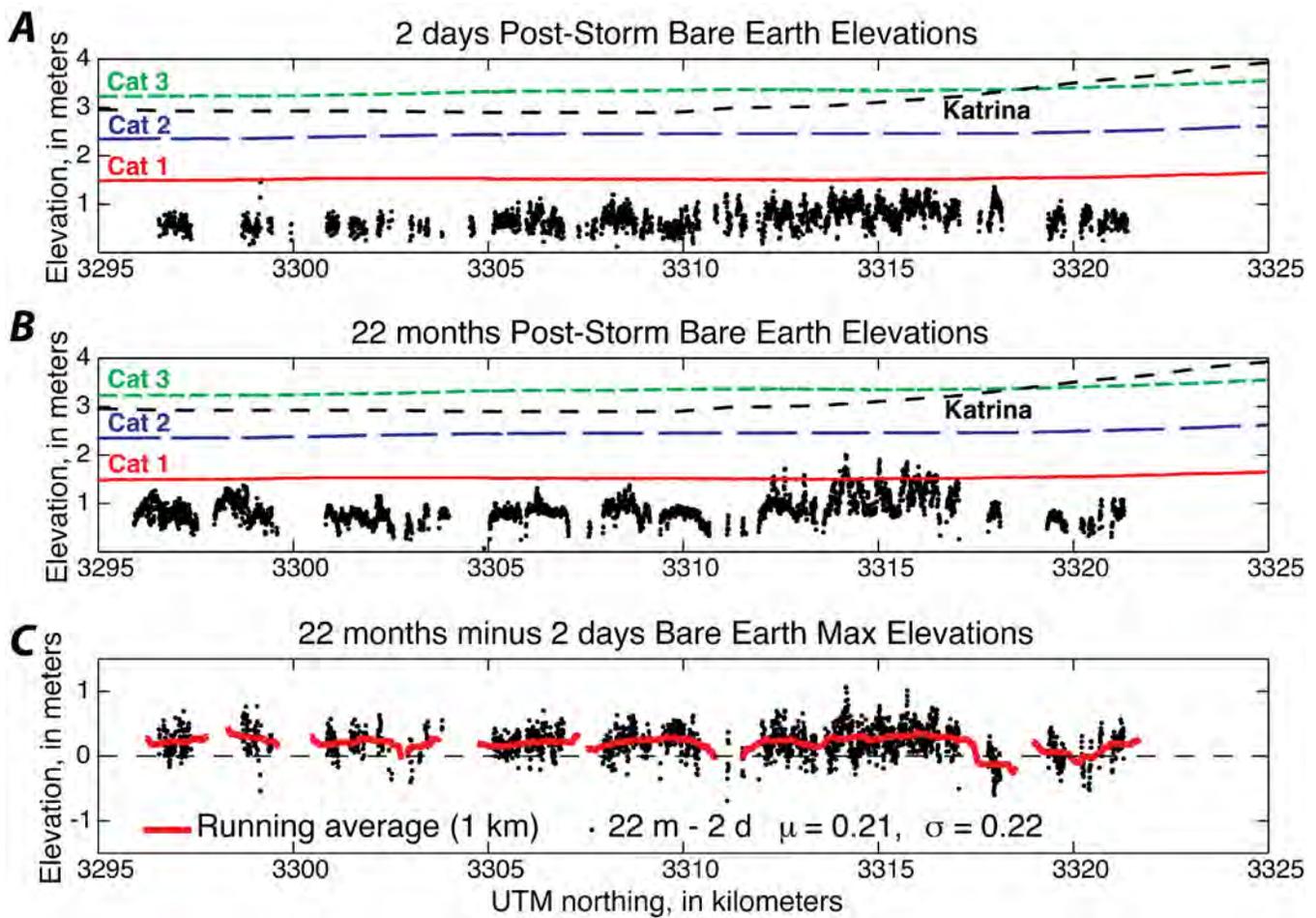


Figure 5. Bare earth peak elevations (D_{high}), maximum of the maximum storm surge elevations for different categories ("cat") of hurricanes, and storm surge for Hurricane Katrina computed by using the SLOSH model. *A*, 2 days after. *B*, 22 months after. *C*, Change in D_{high} between 2 days after and 22 months after.

began to erode landward because of the lack of new sediments and the subsidence from the weight of the already deposited sediments. Waves reworked the lobe, concentrating sand into a headland beach and transporting additional sand to either side of the headland into spits. With the subsidence, the beach detached from the mainland, thereby forming the Chandeleur Islands. Ultimately, with continued subsidence and sand starvation, the islands are forecast to become smaller and lower and eventually sink beneath the sea (see four-step model in Penland and others, 1985).

The lidar observations of the response to, and recovery from, Hurricane Katrina reveal failure modes that may ultimately contribute to the demise of the Chandeleur Islands. The hurricane stripped sand from the islands' marsh platforms along the entire island chain, leaving the muddy platforms exposed to waves. For over 50 percent of the shore, the

marsh platforms continued to erode rapidly. Their ultimate disappearance will increase the potential for island failure because additional sand, from the local sand budget, will be required to rebuild islands vertically from the sea floor. If the available sand is insufficient, the islands will become subaqueous.

Conclusions

Hurricane Katrina caused massive changes to Louisiana's Chandeleur Islands. An extreme storm that impacts a barrier island that is already stressed from low sand supply and rapid sea level rise may trigger failure by both degrading the island during the event and exposing the island to continued extreme erosion following the event.

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Appendix B–1. Chandeleur Islands Grids (See Index Page To Access Data)

