Extreme Coastal Changes on the Chandeleur Islands, Louisiana, During and After Hurricane Katrina

Chapter B of
Sand Resources, Regional Geology, and Coastal Processes of the Chandeleur Islands Coastal System: an Evaluation of the Breton National Wildlife Refuge

Scientific Investigations Report 2009–5252

U.S. Department of the Interior
U.S. Geological Survey
Extreme Coastal Changes on the Chandeleur Islands, Louisiana, During and After Hurricane Katrina

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

Chapter B of Sand Resources, Regional Geology, and Coastal Processes of the Chandeleur Islands Coastal System: an Evaluation of the Breton National Wildlife Refuge
Edited by Dawn Lavoie

In cooperation with the U.S. Fish and Wildlife Service
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.
asp/). 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, retreated
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 ($D_{\text{high}}$) determined every 20 m along the length of the Chandeleur 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) $D_{\text{high}}$ determined from lidar data acquired with the National Aeronautics and Space Administration’s (NASA) Airborne Topographic Mapper. B, $D_{\text{high}}$ from 2 days after the storm determined from lidar data acquired with NASA’s Experimental Advanced Airborne Research Lidar.
after landfall, 56 percent of the gulfside shore continued
however, repeated lidar surveys showed that the islands did
1977). Over a 22-month period after Katrina’s landfall,
bars, for instance, and welding onto the beach in the weeks
least to some extent, with sand migrating onshore in swash
currents across the island shoal. These mean currents likely
differences in sea level between gulf and sound drove mean
such a regime, the Chandeleur Islands became shoals, and
what Sallenger (2000) called the inundation regime. During
storm was sufficient to completely submerge the islands in
along the islands, the still water level during the peak of the
(3
The peak surges along the Chandeleurs were smaller,
from 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. 3.4).

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. 3.4). 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. 3.4 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. 4.4); 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.
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.
Acknowledgments

We thank Karen Morgan (U.S. Geological Survey [USGS]), Kristy Guy (USGS), Dennis Krohn (USGS), Virgil Rabine (National Aeronautics and Space Administration [NASA]), Billy Reynolds (USGS), Charlene Sullivan (formerly of the USGS), and Richard Mitchell (EG&G) for data processing and field support related to the 2005 lidar dataset and William Krabill (NASA), Robert Swift (EG&G), and the air and ground crews of NASA’s ATM during acquisition of the 2002 lidar dataset.

References


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