The Impact of Physical Processes along the Louisiana Coast

Ioannis Y. Georgiou\(^\ddagger\)\(^\ddagger\), Duncan M. FitzGerald\(^\ddagger\), and Gregory W. Stone\(^\ddagger\)

\(^\ddagger\)Pontchartrain Institute for Environmental Sciences and FMI Center for Environmental Modeling
University of New Orleans
2000 Lakeshore Drive
CERM Building, Suite 349
New Orleans, LA 70148, U.S.A.

\(^\ddagger\)Department of Earth Sciences
Boston University
685 Commonwealth Avenue
Boston, MA 02215, U.S.A.

\(^\ddagger\)Coastal Studies Institute and Department of Oceanography and Coastal Sciences
Louisiana State University
Baton Rouge, LA 70803, U.S.A.

ABSTRACT


The present-day coast of Louisiana is undergoing unprecedented change when compared with other coastal regions of the United States. Whereas most of its shoreline is retreating and its coastal bays expanding at the expense of wetlands, the Wax Lake and Atchafalaya deltas are prograding and forming new delta plains. Coastal processes responsible for reworking the lower delta plain and modifying the coast are modest, including very low-wave energy and a microtidal regime. However, occasional hurricanes and more frequent frontal systems produce elevated water levels and large waves (heights >1 to 2 meters), which produce erosion, overwash, and barrier breaching. High subsidence rates coupled with eustatic sea-level rise and wave erosion are converting wetlands to open-water bays. Along barrier shorelines, this process is increasing tidal exchange, which is enlarging tidal inlets and the volume of sand captured in ebb-tidal deltas. Sequestration of sand in offshore ebb shoals depletes sand resources to the barrier chain. The segmentation, landward migration, and overall decrease in size of the barriers are a product of relative sea-level rise and the lack of contribution of new sediment to the system. Restoration of the barriers should be planned with an understanding that the Louisiana coast is evolving in a transgression.

ADDITIONAL INDEX WORDS: Louisiana Coast, wetland loss, waves, subsidence, sediment transport, storms.

INTRODUCTION

The coastal barrier chains in Louisiana form the first line of defense in protecting abutting wetlands, inland bays, and mainland regions from the direct effects of wind, waves, and storm surge. These barriers efficiently mitigate the surge and wave field during tropical cyclones (STONE and McBRIDE, 1998; STONE et al., 2003; STONE et al., this volume). As such, they function to significantly reduce erosion of marshes and wetlands fringing adjacent bays. In addition, their presence helps to maintain gradients between saline and freshwater, thereby preserving estuarine systems.

The morphology and integrity of barrier islands along the Louisiana coast are directly related to the supply of sediment contributed to the coast and the physical processes operating in this region. The same processes that built the barriers are also partly responsible for their erosion, segmentation, and migration onshore. Today, many of the barrier chains are highly fragmented and are rapidly disappearing as a result of recent and past hurricanes, subsidence, eustatic sea-level rise, and longshore transport gradients (STONE and ZHANG, in press). Because of their rapid disintegration over short time scales, restoration projects such as the Coastal Wetland Planning, Protection, and Restoration Act Coast 2050 and the Louisiana Comprehensive Coast-wide Ecosystem Restoration Feasibility Study have been enacted. The success of these programs in reestablishing the integrity of the barrier coast is enhanced when the processes related to wave-generated sediment transport, hurricanes, tropical and extratropical storms, tidal inlet hydraulics, coastal bay circulation, and subsidence and eustatic sea-level rise are well known. This article summarizes the more salient coastal processes that pertain to the Louisiana coast and discusses how these processes are affecting the barriers, tidal inlets, and backbarrier environments.

WAVE CLIMATE

The wave climate along the Louisiana coast is a product of seasonal wind patterns and the passage of tropical and extratropical storms. The distribution of deepwater wave energy is known from several National Data Buoy Center arrays located in deep water (Figure 1). The nearshore wave climate is less well known, and data come primarily from time series collected at WAVCIS (Wave-Current-Surge-Information System) operated by the Coastal Studies Institute at Louisiana State University (Figure 1).

Deepwater Waves

A summary of deepwater wave characteristics for the Louisiana coast is given in Table 1. The period of record ranges
widely, from 1 to 20 years, but the trends are fairly consistent. Mean annual deepwater significant wave height varies from a low of 0.75 meters off the central Louisiana coast (Station 42017) to a high of 0.95 meters offshore of both Holly Beach (Station GCBL1) and Head of Passes (Station LNEL1). An exception to this trend occurs at Station 42007, northeast of northern Chandeleur Islands, where the average annual wave height is 0.50 meters. The lower average wave height measured at this site as compared to other stations is due to the protection afforded by the Chandeleur Islands and Belize Delta to waves propagating from the southwest.

Wave periods at all stations exhibit similar trends (Table 1). Mean annual wave period ranges from 4.5 to 5.9 seconds, with the longest average period recorded at the station offshore Holly Beach (GCBL1) and the shortest period measured at the northern Chandeleur Islands location (42007). Dominant wave energy flux cannot be determined from the NOAA data buoys because they are not directional gauges. However, other studies have shown that the distribution of dominant deepwater wave energy is similar to energy fluxes determined from nearshore gauges.

Nearshore Waves

Nearshore wave data for the WAVCIS (CSI-5) station, located approximately 2 kilometers off Timbalier Island at the 5-meter isobath (Figure 1), demonstrate a high correspondence between dominant wave approach and wind direction (Figure 2). For the period between midspring and midfall, winds are predominantly from the south to southwest. Likewise, the dominant wave approach is from the southwesterly quadrant, having a 40% probability of occurrence. During late fall to early spring, the wind regime is controlled by the passage of cold fronts, which commonly produce winds blowing from the northeasterly to southerly quadrants. However, northeasterly winds blow offshore in central Louisiana, and the fetch is too small to generate large waves at the WAVCIS station (Figure 2). Therefore, the dominant waves (probability ~80%) propagate from the southwesterly quadrant and subsequently control sediment transport patterns along the central Louisiana coast. Significant wave height data from WAVCIS station CIS-5 illustrate the seasonality in wave energy in coastal Louisiana (Figure 3). Typically, waves vary from approximately 0.07 meters to 0.8 meters, the latter being a function of weak storms in the Gulf. However, tropical cyclones generate considerably larger waves during summer months as shown here for a period in early June 2001, where waves over 1.9 meters in height were recorded. During winter months the effects of cold-front passages over the Louisiana coast produce immediate increases in wave height. During the 4-month period from November 2001 to February 2002, 20 cold-front passages were identified, with 6 events resulting in energetic sea states and wave heights ranging from ~1 to 2 meters. Therefore, with the exception of infrequent tropical cyclone activity in summer months, the high frequency of frontal passages over the Louisiana coast plays a critical role in generating and sustaining higher waves during winter months.

STORMS

The Gulf Coast region is affected by a high incidence of tropical cyclones (MULLER and STONE, 2001). During the
Georgiou, FitzGerald, and Stone

past 100 years, 55 hurricanes and tropical storms have made landfall along the Louisiana coast, with the highest incidence occurring in September (Stone et al., 1997). Extratropical storms associated with cold fronts form above the tropics (above the Tropic of Cancer in the Northern Hemisphere) and occur more frequently, regardless of their lower intensity, than hurricanes or tropical storms. For example, in an average year 20 to 30 cold fronts will pass through coastal Louisiana (Chaney, 1998).

**Cold Fronts**

Cold fronts are defined as narrow transition zones (25–250 kilometers) between two air masses of different densities; polar air from Canada moves south meeting the warm, often moist, air mass of the southwestern and southeastern regions. Cold fronts move west to east and commonly extend to the Gulf of Mexico. They are characterized by spatial and temporal changes in wind speed, direction, barometric pressure, temperature, and humidity (Mossa and Roberts, 1990). The pressure gradient at the front controls the intensity of the system and the transfer of energy to the coast. This energy is manifested in the form of strong winds, large waves, low water levels, and abnormal rates of shoreline erosion and sediment transport and deposition (Pepper and Stone, 2002, 2004).

The frontal system can be oriented oblique or parallel to the east-west trend of the coast depending upon the initial position of the air masses and how the weather system evolves. As illustrated in Figure 4, an eastward-migrating low-pressure system will generate an oblique frontal system. Alternatively, when a deep arctic air mass descends toward the Gulf of Mexico, a frontal system parallel to the coast develops. The type of cold front controls the duration of the storm and the magnitude of coastal processes.

In relation to coastal erosion, in some coastal segments of Louisiana, cold fronts are more important than the occasional hurricane, primarily because of their high frequency of occurrence (Mossa and Roberts, 1990). Typically, cold fronts have a duration of 12 to 24 hours depending on the storm speed. Studies by scientists at Louisiana State University's Coastal Studies Institute characterized cold-front passage in three phases: the prefrontal, the frontal passage, and the postfrontal stage (Roberts et al., 1987). Initially, a prefrontal phase occurs during which strong, warm, moist winds blow from the southerly quadrant. The resulting frontal phase is characterized by a sudden drop in air pressure; erratic winds; and short-lived, but occasionally intense, rain squalls. Finally, a postfrontal phase occurs, during which time temperature and humidity drop, air pressure rises, and winds are strong and northwesterly to northeasterly. The resulting response in the nearshore is water-level setup along the coast, which causes high-energy waves to break higher on the beach, overwashing low barriers. Elevated water levels also increase tidal exchange to and from the bays and marsh systems behind the barriers; in turn, this can enlarge existing tidal inlets as well as establish incipient tidal inlets. The passage of fronts may produce strong northerly winds generating short-period waves in the major bays. This is a
frequent condition and is believed to be responsible for the chronic shoreline erosion along the back side of many unprotected barriers (STONE et al., 2004; WATZKE and STONE, in press.)

Data collected in 1988 at an offshore production platform (28.3° N, 93.0° W) illustrate the effect that frontal systems have on the coastal zone (Figure 5). Prior to the cold front, the wind was from the north at 10.3 m/s, and the significant wave height was 0.6 to 1.2 meters. As the front approached, the winds shifted to the south at 10 m/s but subsided as the front moved past the station. Water levels increased by 0.3 to 0.4 meters. Immediately following the passage of the front, during a 5-hour period, winds blew strongly from the north at 18 to 23 m/s. During this time the wave energy increased, reaching a peak significant wave height of 2.7 meters. Within 12 hours seas decreased to 1.5 meters maintaining this height for another 24 hours.

Hurricanes and Tropical Storms

Coastal Louisiana is low-lying with many areas of moderate population containing numerous dwellings, buildings, and other infrastructure. This combination presents a highly vulnerable situation to a major storm. Over the years, many hurricanes have passed through coastal Louisiana. A graph of the spatial and temporal distribution of large-magnitude storms for the period between 1901 through 1996 indicates that hurricanes occur slightly less frequently than tropical storms, and they affect the southwest, south-central, and southeast sections of the coast more than eastern Louisiana (Figure 6). The graph also demonstrates that during the past 100 years, hurricane activity has peaked in September, which is consistent with hurricane activity in the Gulf of Mexico and central Atlantic Ocean (STONE et al., 1997). Similarly, 60% of tropical storms making landfall along Louisiana take place during the months of August and September, and 80% of hurricane landfalls occur during the same period (STONE et al., 1997).

Factors affecting the severity of a storm and the magnitude of morphological change to barrier coasts, headlands, and wetland areas include the strength, speed, and size of the storm. For example, a satellite image taken on 26 September 1998 shows Hurricane Georges covering much of the Gulf of Mexico and the coastal states of Louisiana, Mississippi, Alabama, and Florida (Figure 7). The size of Hurricane Georges ensured that much of the northern Gulf of Mexico was affected by this storm. The most important factor governing the degree of erosion and amount of damage is wind velocity, which is the criterion used to categorize storm intensity (Saffir-Simpson Scale). For instance, note the good correlation between the category of a hurricane and its storm surge as measured at the Gulfport, Mississippi, tide gauge station (Figure 8). Hurricane Camille was a Category 5 storm that had wind velocities in excess of 322 km/h producing a surge of 6.7 meters. In contrast, Hurricane Georges was a Category 2 storm with wind velocities less than 160 km/h, and it generated only a 2.2-meter surge. Another function of wind ve-
Figure 3. Time series of wave height data from WAVCIS station CIS-5. The top graph is for the May 2001–August 2001 period, and the bottom graph is for the November 2001–February 2002 period.

Locity associated with hurricanes is wave energy. The higher the wind magnitude and fetch, the larger the wave heights. Waves are primarily responsible for most of the coastal erosion during a storm (STONE et al., 2004).

Recently, Louisiana experienced the impact of two major storms that caused widespread flooding, beach erosion, barrier overwash, and breaching. Tropical Storm Isidore made landfall along the Caminada Morau headland near Fourchon on 26 September 2002, and 7 days later, on 3 October, Hurricane Lili made landfall west of Marsh Island in western Louisiana. Sea state during these storms was recorded at WAVCIS stations (CIS-5) (Figure 9A, B). Because Isidore was
Figure 4. Cold fronts affecting coastal Louisiana. (A) Weather maps illustrating the end member types of Gulf Coast cold-front passages: (i) eastward-migrating cyclone-type, and (ii) arctic surge-type cold fronts. (B) Types of cold fronts produced by each of these weather systems, respectively (Mossa and Roberts, 1990).

Figure 5. Wind, wave, and tidal elevation data measured at a production platform off the Louisiana coast.
a relatively weak storm, its storm surge was only 0.6 meters, whereas Hurricane Lili produced a 1.2-meter storm surge along the coast (Figure 9A). Likewise, the significant wave height for Isidore was 2.3 meters, compared with 2.8 meters for Lili (Figure 9B). Hurricane Lili produced significant erosion and overwash along the Isles Dernieres and Timbalier Islands (Figure 10). The severity of overwash was due to the fact that Tropical Storm Isidore had already eroded much of the barriers and removed the protective beach. The temporal proximity of the two events resulted in much greater change to the coast than would have been predicted if Hurricane Lili had been the only landfalling storm. Western Louisiana experienced minor erosion even though Hurricane Lili made landfall in the vicinity. This is attributable to the presence of fluid mud on the inner continental shelf and the dissipation effect on both the wave and surge field as measured at CSIT3 (STONE et al., 2003).

LONGSHORE SEDIMENT TRANSPORT

In coastal Louisiana, direct measurements of longshore transport are limited. The rates of transport are typically based on historical studies of erosional and depositional trends as demarcated by shoreline change analyses, sedimentation patterns in the vicinity of coastal structures, and numerical wave refraction modeling. An overview of the general trends of sand movement along the Louisiana coast is shown in Figure 11 and Table 2. Sediment transport trends along the coast are discussed in terms of shoreline segments based on barrier island arcs and other geomorphic features.

West Louisiana—Holly Beach (Calcasieu Sabine)

In western Louisiana, longshore sediment transport rates are known from studies of the coast between Calcasieu Pass to Sabine Pass. In this region sediment is moving predominantly westward with the exception of localized reversals at both passes. Transport reversals are attributed to wave refraction caused by offshore shoals (Sabine Bank) and the dredge mounds on the flanks of the channels (UNDERWOOD et al., 1999). Transport rates generally increase west of Calcasieu Pass toward Constance Beach, where a maximum rate of 30,000 m³/y occurs (Figure 11). A general decreasing trend in sand transport occurs westward of Sabine Pass.
Isles Dernieres

Sediment transport along the Isles Dernieres is complex given its fragmented nature. Overall, sediment moves in a westerly direction along the Isles Dernieres island chain, although local bidirectional transport occurs on Trinity and Whiskey Islands. Sediment movement around Whiskey Pass is largely nonexistent. Waves propagating through the passes break along the marsh shoreline in Lake Pelto (STONE and ZHANG, 2001, in press). The dominance of wave-generated and flood-tidal currents controls landward sand transport at many of the inlets, thereby minimizing inlet sediment bypassing and sand nourishment of the downdrift barrier shorelines. Although net transport rates are variable, net westward transport of approximately 60,000 m$^3$/y has been derived numerically (STONE and ZHANG, 2001, in press).

Timbalier Islands

Net sediment movement along the Timbalier Islands is to the west, and the rate increases from east to west. Subscale transport trends are evident on both islands. East Timbalier

Figure 7. Satellite view of Hurricane Georges before landfall on 27 September 1998 off coastal Louisiana.
Island is dominated by westward transport, with a net increase in rate to the west attaining a maximum of approximately 50,000 m³/y. However, the sand transport system along the island has been greatly diminished because of the extent of coastal structures in the area. The potential for transferring sand from the Caminada Moreau headland to East Timbalier Island is minimal, given the large width of Raccoon Pass and the net landward movement of sand to its flood-tidal delta. 

KULP et al. (2002) have documented extensive growth of the Raccoon Pass flood-tidal delta during the past 10 years. This suggests that little sand bypasses the inlet but rather is moved onshore into Timbalier Bay. Similarly, transport trends occur along Timbalier Island with a net increase in the rate along the eastern flank of the barrier to approximately 50,000 m³/y. Conversely, the rate decreases to the western end of the island. This pattern suggests that sand eroded from the eastern flank is transported to the west where it is deposited along the west flank of the barrier as well as in Cat Island Pass. Bypassing of sand across Little Pass Timbalier is minimal. Waves propagate through this inlet prior to breaking in Timbalier Bay. In addition, dense armoring along East Timbalier Island decreases the longshore export of sediment to the west.

Chandeleur Islands

Sediment transport along the Chandeleur Islands has been determined primarily from wave modeling studies by ELLIS (1998) and STONE and ELLIS (2005). A sediment transport nodal point exists on the south-central portion of the island chain. North of this point sand moves northward for 25.5 kilometers along the barrier system, and south of this point the sediment moves southward for 16.5 kilometers along the island complex (STONE and ELLIS, unpublished data). The magnitude of predicted sediment transport is greater in the southern cell than the northern cell and is attributed to an increase in breaker angle and not breaker height. This finding underscores the control that wave refraction exerts on longshore transport trends along the island. A maximum rate of 88,000 m³/y was calculated for the southern cell and 66,000 m³/y for the northern cell.

Barataria Bay

For the Barataria Bay, coastal segment estimates of longshore transport are based on shoreline erosional-depositional trends. Approximately 146,000 m³/y is calculated to move eastward along Grand Isle. Similarly, an estimated 10,000 m³/y of sediment moves westward from Sandy Point toward Barataria Bay. The Caminada Moreau headland contains a drift divide midway along the headland.

CROSS-SHORE SEDIMENT DISPERSAL

Cross-shore movement of sediment includes the material that is eroded from the beach and transported offshore during storms, as well as that material moved onshore by the process of overwash and wave-current interactions in the bottom boundary layer. One mechanism of offshore transport occurs during setup along the coast, which results in downwelling on the inner shelf, during which resuspended sediments may be transported offshore. At the same time, storm waves...
breaking over low barriers wash sand into backbarrier marshes. This process provides a mechanism for the barriers to migrate onshore and to reestablish sand platforms that are colonized by marsh vegetation. Another important process of cross-shore sediment transport occurs during the passage of cold fronts in the vicinity of the Atchafalaya Delta. The strong offshore winds that accompany cold fronts suspend mud off the bottom that was recently deposited by the Atchafalaya River. Wind stresses and river discharge produce seaward-directed currents that transport the suspended clays to the outer shelf (ROBERTS et al., 2003).

The measurement and documentation of onshore sediment transport is a complex process that is not well understood. However, some examples do occur along the Louisiana coast, indicating that this phenomenon is taking place. For example, the accumulation of sand in the lee of several of the breakwaters along the eastern end of Raccoon Island is a direct result of onshore sand transport. This sand may be derived through the process of inlet sediment bypassing, or the sand may be moving onshore from remnants of Raccoon Island, which used to be situated more seaward than it is today (Figure 12). Bottom boundary layer and sediment transport measurements made on the ebb delta indicate a net onshore mean current and sediment flux during both fair-weather and storm conditions (STONE et al., 2003). Sand not only is deposited in the lee of the structures but has, as shown in
Figure 10. Lidar images post-Hurricane Lili showing the net accretion and erosion at the western part of Raccoon Island.

the figure, accumulated between the breakwater gaps and seaward of them (STONE et al., 1999, 2003).

Another large-scale example of the transfer of sediment on the inner continental shelf has been documented in the region offshore of the eastern delta plain (LIST et al., 1994).

Bathymetric change maps for the area seaward of the Bayou Lafourche shoreline eastward to the Plaquemines for the 1878–1989 time period reveal a pattern of large-scale sediment redistribution on the inner shelf (Figure 13). As seen in Figure 13, since 1878 there has been widespread erosion in

Figure 11. Longshore sediment transport estimates in coastal Louisiana. Rates are in cubic meters per year (m³/y). Arrows indicate net dominant transport direction, and closed circles indicate the section that the given rate applies to.
the vicinity of Bayou Lafourche headland and the Plaquemines delta region seaward to the 15-meter isobath. The greatest amount of erosion occurred closest to shore (>2.5 meters) and decreased seaward. In contrast, the embayments fronting Barataria Bay and Terrebonne Bay have been depositional over the same time period with more than 2.5 meters of vertical accretion in certain areas (Figure 13). The erosional and depositional trends suggest that there has been transport of sediment from headlands toward the intervening embayments. The path and mechanisms of sediment erosion, transport, and deposition are not well understood. Shoreline and nearshore promontories are sites of wave focusing and erosion, whereas embayments are commonly areas of wave dispersal and sedimentation (Jaffe, List, and Salenger, 1997).

TIDES

Tides along the coast of Louisiana change in a systematic manner with an overall decrease in tidal range from the western chenier plain eastward toward Mississippi Sound (Figure 14). At Calcasieu Pass in western Louisiana, the tides are mixed, having a strong diurnal component \( TR = 100 \) centimeters. In the delta region including Raccoon Point (west), Grand Isle (central), and the northern Chandeleur Islands (east), tides are strongly diurnal. At Raccoon Point, the tidal range varies from a low of 15 centimeters during equatorial tidal conditions to a high of 100 centimeters during tropic tides. In the central and eastern portion of the delta, the tidal wave is damped, resulting in smaller equatorial tidal ranges \( TR = 12 \) centimeters) and smaller tropic tidal ranges \( TR = 64 \) centimeters) as compared to the Calcasieu tides.
Figure 13. Sea-floor changes from 1878 to 1989 in coastal Louisiana. (Reproduced from List et al., 1994.)

Figure 14. Typical tidal signature along coastal Louisiana from west (top) to east (bottom).
Figure 15. Potential effects of the withdrawal of fluids from the delta region. Prolonged or rapid production of oil, gas, and formation water (2) causes subsurface formation pressures to decline (3). The lowered pressures (3) increase the effective stress of the overburden (4), which causes compaction of the reservoir rocks and may cause formerly active faults (1) to be reactivated (5). Either compaction of the strata or downward displacement along faults can cause land-surface subsidence (6). Where subsidence and fault reactivation occur in wetland areas, the wetlands typically are submerged and changed to open water (7). Figure is not to scale. D = down, U = up. (From USGS Fact Sheet FS-091-01; after MORTON and PURCELL, 2001.)

SEA-LEVEL RISE AND SUBSIDENCE

Subsidence of the Mississippi River delta is related to natural processes such as sediment compaction, faulting, and isostatic adjustment to regional crustal loading. Anthropogenic-related subsidence is caused by the withdrawal of fluids (gas, oil, and water) by the petroleum industry (JURKOWSKI, N., and BROWN, 1984; KOLB and VAN LOPIK, 1958; MORTON and PURCELL, 2001; PENLAND et al., 1989). Recent work by the US Geological Survey (USGS) suggests that fluid withdrawal has the cumulative effect of decreasing pore pressure, which can initiate formerly active faults. The down-faulted side of the fault, which has subsided more than a meter in some regions, can convert a dry land surface to open water (Figure 15, MORTON and PURCELL, 2001).

The relative role of natural vs. anthropogenic factors on net regional subsidence has not been well established, despite the potential significance of these mechanisms on patterns of coastal erosion and depositional processes. Historic sea-level curves exist for Eugene Island along the west delta coast and for Grand Isle along the central delta coast (Figure 17). The curve for Grand Isle extends from the late 1940s to the present time, whereas the Eugene Island curve covers only the period between the early 1940s and the mid-1970s. Data for Grand Isle indicate that relative sea level is rising at a rate of 1.03 cm/y (PENLAND and RAMSEY, 1990). This is the
highest rate along the contiguous United States, which helps explain coastal evolution in Louisiana (Figure 16). Without the influx of substantial new sediment to the lower delta plain, marsh and other wetlands are not able to keep pace with rising sea level and are therefore being drowned. Subsidence and rising sea level are also largely responsible for coastal erosion and the transgressive nature of most barriers in Louisiana. The historical decrease in size and segmentation of Louisiana's barrier systems as well as the loss of wetlands have greatly increased the vulnerability of mainland areas to major hurricanes (Stone and McBride, 1998; Stone et al., 2003).

TIDAL INLETS AND TIDAL PRISM DYNAMICS

The morphological evolution of barrier islands along the Louisiana coast is the result of river avulsion and the subsequent reworking of distributaries (Penland, Suter, and Boyd, 1988). The size and number of tidal inlets along the barrier coast are controlled, in part, by the volume of water (tidal prism) moving into and out of backbarrier bays. The historical evolution of these tidal inlets is a product of changes in extent and configuration of the backbarrier bays. Detailed geomorphic and bathymetric changes of the lower delta plain between the 1880s and the 1990s, including the barrier and tidal inlet systems, are contained in a two-atlas set published by the USGS (List et al., 1994; Williams et al., 1992). Levin (1993) also discusses historical development of the inlets. Generally, tidal exchange between backbarrier bays and the Gulf of Mexico has increased along the delta plain since at least the 1880s because of widespread conversion of wetlands and saltmarsh to open-water areas. For example, in the mid-1800s the Isles Dernieres were backed by Lake Pelto. At that time, the lake was surrounded by a nearly uninterrupted expanse of marshland. During the next hundred years, land subsidence, wave erosion of the marsh shoreline, and dredging activity transformed the lake into a large continuous sound having an open connection to Caillou Bay to the west and Terrebonne Bay to the east. The historical changes that have occurred to the Isles Dernieres are symptomatic of wetland loss and barrier evolution along the entire delta plain coast. Extensive engineering along the lower Mississippi River and confinement of its discharge have dramatically decreased sediment influx to much of the lower delta plain, reducing the ability of the marsh to keep pace with rising sea level. Thus, the hypsometry of the backbarrier has evolved toward greater subtidal environments and less intertidal and supratidal area. This trend has strongly affected tidal inlet geometry and sediment dispersal along the barrier complexes.

Tidal prism dynamics and the pattern of tidal exchange strongly affect the occurrence and geometry of tidal inlets along the various barrier chains. The northern and southern Chandeleur Islands front Chandeleur and Breton Sounds, respectively. Both of these broad bays are connected to the Gulf of Mexico, and thus most of the tidal waters pass around the barrier chain rather than flowing through tidal inlets. Many of the inlets along the Chandeleur Islands are formed during storms and are ephemeral in nature. Generally, inlets of this
section of coast are small in size due to small tidal prisms. Tidal inlets along the Timbalier Islands and Isles Dernieres have highly variable geometries because of the segmented nature of these barrier systems. Much of the tidal exchange between the backbarriers of Caillou Bay, Terrebonne Bay, and Timbalier Bay and that of the Gulf of Mexico occurs through broad shallow channels where the transgressive barriers have undergone extensive erosion. However, there are several relatively deep passes (6 to 10 meters) that are maintained by strong tidal currents (~1.0 m/s).

The barrier chain that has formed between the Caminada-Moreau headland region and the Plaquemines delta lobe is somewhat different from the other barrier chains, because it is more robust and less segmented, and tidal flow into and out of its backbarrier occurs entirely through well-defined tidal inlets. During the past half-century, rapid relative sea-level rise (~0.3 cm/y; Penland and Ramsev, 1990) and other erosional processes within Barataria Bay have led to substantial wetland loss, converting more than 775 square kilometers of wetlands to open water (Figure 17; Barras, Bourgeois, and Handley, 1994). As the open-water area increased, so has the bay tidal prism and tidal exchange. Between 1880 and 1990 the enlarging tidal prism produced a 44% increase in the combined cross-sectional areas of the major tidal inlets of Barataria Bay (Figure 18). The increase in size of the tidal inlets was at the expense of the adjacent barrier islands. During the same period of time there was concomitant progradation of the ebb-tidal deltas. For example, since the 1880s the ebb delta at Barataria Pass built seaward more than 2.0 kilometers. Shoreline erosion and increasing bay tidal prism also facilitated formation of new tidal inlets, including Pass Abel (FitzGerald et al., 2005, in press).

ESTUARINE CIRCULATION

Inland bays and estuaries in Louisiana are shallow and are composed of interconnected cascading shallow lakes with numerous streams, bayous, passes, and a chain of barrier islands and tidal inlets in the lower basin that separate the bay from the Gulf of Mexico. The areas inside the bay are shallow with large regions of marsh and intertidal flats. Hydrodynamics, transport, and mixing processes in coastal Louisiana are complex in nature. They are driven by wind stress, waves, astronomical tides, atmospheric pressure gradients, density flows, freshwater inflow, and periodic surges due to storms in the Gulf of Mexico (Sikora and Kjerve, 1985). Circulation and water levels in the Barataria Basin are strongly influenced by astronomical tides, winds, and precipitation (Inoue and Wiseeman, 2000; Mashriqui and Kemp, 2004; Mashriqui et al., 2002). Tides in the region are small and diurnal. Monthly mean sea-level variations at the four main passes (Caminada Pass, Barataria Pass, Pass Abel, and Quatre Bayou Pass) are reported to be between approximately 27 and 38 centimeters (Marmier, 1954). Since the basin was disconnected from the Mississippi River, freshwater inflow is primarily from precipitation, runoff, and man-made diversion structures. These structures provide a controlled flow of freshwater from the Mississippi River into the basin. These diversions directly affect the salinity structure of the basin as well as local circulation patterns once active. Another effect of salinity distribution in inland bays coastwide is wind stress (Mashriqui et al., 2002; Sikora and Kjerve, 1985). Tidal currents also contribute significantly to the exchange of salt between estuaries and the adjacent Gulf of Mexico, as does the lower-frequency, atmospherically driven flows. Because of their predictability, these tidal currents and flow exchange between the barriers, tidal inlets, and tidal passes are particularly important during the summer months, when wind forcing is weak. These control factors on salinity, water levels, freshwater exchange, and inlet hydraulics create a complex and dynamic system with feedback between processes, which in turn can play an important role in

Journal of Coastal Research, Special Issue No. 44, 2005
the long-term effects of the basin circulation and morphology (McCorquodale and Georgiou, 2004).

The Pontchartrain Estuary, located on the east bank of the Mississippi River, has similar characteristics of a shallow estuary to that of Barataria Basin. Although the inland lakes (Maurepas, Pontchartrain, and Borgne) do not have intertidal flats except for the Biloxi marshes, they are surrounded by deteriorating flats. Circulation and transport in the estuary is driven by similar forcing to that in Barataria Basin. Studies in the estuary reported salinity stratification often exceeding an area of 250 square kilometers near the bottom.

Studies in the estuary reported salinity stratification often exceeding an area of 250 square kilometers near the bottom waters of Lake Pontchartrain, with dissolved oxygen values nearing anoxic conditions of less than 2 mg/L (Fournier, 1978). The salinity plume causing this problem was identified at the interconnection of the lake to the Mississippi River Gulf Outlet; it was dynamic in nature and was primarily driven by currents near the bed (Georgiou and McCorquodale, 2000). Numerical hydrodynamic studies of this density indicated that stratification in the basin affects circulation patterns near the bed and in the vicinity of the tidal passes (Georgiou and McCorquodale, 2002).

SUMMARY AND CONCLUSIONS

Because of the low-lying nature of the lower Louisiana delta plain, coastal processes have a strong influence on erosional and depositional trends and the stability of the barriers, distributaries, marshes, bays, and coastal wetlands. The degree of reworking of the delta framework is remarkable given the overall low wave and tidal energy of the northern Gulf of Mexico. Subsidence and the combined impact of occasional tropical cyclones and frequent cold fronts are largely responsible for coastal change.

The coast experiences low-energy waves having deepwater heights ranging from 0.5 to 1.0 meters and periods of 5 to 6 seconds. Eighty percent of waves approach from the southeast. Tides are mixed in western Louisiana and become diurnal in the central and eastern sectors. Cold fronts are significant geological agents, because they produce nearshore wave heights of 1 to 2 meters, they occur approximately 20 to 30 times a year, and they are responsible for reworking the baysides of barrier islands. Hurricanes and large tropical storms are the primary driving force causing barrier rollover (with the exception of the Chandeleurs, the barriers of which are not rolling over but thinning in space), tidal inlet formation, and wave erosion of marshes.

The reworking of former deltaic headlands supplies sediment to the longshore transport system. Longshore transport rates vary widely along the coast because of differences in shoreline orientation, nearshore wave energy gradients, and sediment availability. The average rate is in the 60,000 to 90,000 m³/y range. The highest reported rate occurs along Grand Isle (146,000 m³/y), but this rate is based on sediment accumulation updrift of a jetty, which may have been partially sourced from sand moving onshore from the adjacent ebb-tidal delta. Historical bathymetric surveys indicate that large quantities of sediment (mud and silty sand) have been displaced along the coast, such as the >2.5 meters of vertical erosion that occurred off the Lafourche Headland (from 1880s to 1980s), whereas 2.5 meters of vertical accretion has taken place over the same period of time offshore of the Barataria Bay barriers.

During the past century, subsidence and eustatic sea-level rise have combined to convert expansive areas of coastal wetlands to open-water regions. Substantial land loss in the backbarrier has led to increased tidal exchange, which has produced larger-sized tidal inlets and the growth of ebb-tidal deltas. The sequestration of sand on ebb shoals has removed sand from the littoral system, resulting in barrier erosion, breaching, and formation of new tidal inlets.

Hurricanes and tropical storms, subsidence, and the lack of new contributions of sediment to the littoral system have produced the highly dynamic and transgressive nature of the Louisiana coast. Successful reconstruction of the barrier system requires a plan that is in compliance with the long-term sedimentological trends, including high rates of relative sea-level rise. Acknowledging that barriers will continue to thin in space, backbarrier wetlands will continue to be converted to open water, and tidal inlets will continue play an important role in sediment dynamics are important lessons in re-establishing the integrity of the barrier island systems.

LITERATURE CITED


