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Louisiana Barrier Islands and their Importance in Wetland Protection: Forecasting Shoreline Change and Subsequent Response of Wave Climate

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ABSTRACT

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The role that barrier islands play in mitigating the wave climate in lower energy, bay or lagoonal environments has not yet been addressed in detail. With the exception of one study in which a shallow water wave prediction model (HISWA) (LIST et. al., 1992) was applied to idealized barrier-bay configurations, the critical linkages among barriers, wave energy transmission into bays, regenerated local waves, and subsequent wave climate have not been made. In Louisiana, barrier disintegration is rapid over the short-term (10^2 years) and the mere potential for impacts of barrier loss on the bay wave climate is highly significant. Because of a paucity in scientific data which could be utilized to address this issue, there remains a significant debate as to the value of barrier islands in mitigating wave climate in the bays and along fringing marshes. In this paper we present historical shoreline change data which are used to predict the rapid disintegration of a section of barrier island coast along central Louisiana (Isles Dernieres) and resultant forecasted increases in wave energy in the adjacent bays. The methods associated with shoreline, bathymetric and wave energy forecasting are briefly presented as an example of a larger, ongoing project regarding the feasibility of large-scale barrier island restoration in Louisiana. A brief overview of the magnitude and causal mechanisms associated with wetland loss are provided in addition to the implications associated with barrier island loss and subsequent detrimental impacts on fringing marshes. The example data set presented here indicates that the role of Louisiana's barrier islands comprising the Isles Dernieres in mitigating the wave climate in their adjacent bays and fringing marshes appears critical. Considering only fairweather conditions, the data indicate that the bays adjacent to the Isles Dernieres could experience an increase in wave height of 700% if the barrier chain is reduced to shoals. Although large-scale barrier island restoration will greatly reduce wave energy in Louisiana's bays and along fringing marshes, additional devices capable of absorbing wave energy around portions of the fringing marshes will likely require construction. This may occur in areas where the fetch permits regeneration of incident waves that have propagated across the Louisiana shelf, or locally generated higher frequency waves.

Additional Index Words: *Louisiana, barrier islands, Isles Dernieres, marsh/wetland loss, shoreline change, wave energy, forecasting, numerical modeling.*

INTRODUCTION

Louisiana contains approximately 40% of the nation's coastal and estuarine wetlands within the 48 conterminous states. Combined with their associated bays and estuaries, these wetland environments support a harvest of renewable natural resources with an estimated annual value in excess of $1 billion annually (STONE *et al.,* 1997; WILLIAMS *et al.,* 1997). Since the mid 1950's, these wetlands have been reduced by approximately 2,500 km². When viewed from a national perspective, approximately 80% of the nation's wetland loss has occurred in Louisiana over the last half century. Estimates indicate that at the current rate of wetland loss, Louisiana is expected to lose an additional 4,000 km² over the next half century thereby severely impacting the state's economy and potentially increasing storm wave inundation and flooding threats to New Orleans and surrounding suburban areas (BOESCH *et al.,* 1994; STONE *et al.,* 1997; WILLIAMS, *et al.,* 1997).

The factors responsible for wetland loss have for the most part, been well documented in the literature (see recent reviews in BOESCH *et al.,* 1994; ROBERTS, 1997; COLEMAN *et al.,* 1998) and may be categorized by scale as follows: (1) Geological-province scale (10^4 km²)—isostatic downwarp of the subsurface, sediment compaction, subsurface fluid withdrawal and eustatic sea-level rise; (2) hydrological/hydrodynamic-basin scale (10^2 km²)—high water due to astronomical tides, wave setup, storm surge and rivers in flood; aeolian processes, lightning causing fires; (3) biological-marsh scale (10^1 km²)—vegetation loss due to dieback and herbivory.

It was not until shortly after World War II that the extent

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Figure 1. The study area is located along the northern Gulf of Mexico in coastal Louisiana. The primary geographic focus of this paper is the Isles Dernieres, a barrier island system in south-central Louisiana.

of wetland loss and coastal erosion in Louisiana became apparent, largely through the pioneering work of James P. Morgan and Phillip B. Larimore (MORGAN and LARIMORE, 1957). Their work remains the cornerstone for numerous studies on barrier island and wetland dynamics and is discussed in more detail below. In addition, Morgan's work was the first to recognize that the barrier islands-mainland beaches around Louisiana and vast expanses of marsh, constitute a unified system. His work demonstrated that a critical control on the rate of shoreline retreat is the degree of subsidence the region is experiencing. As discussed in more detail later in this paper, subsidence rates were shown to decrease with delta abandonment resulting in a reduction in the rate of coastal erosion.

The postulate surrounding an interdependence between marsh and barrier-mainland coasts has not been investigated since Morgan's original work, published in the 1950's. Barrier islands and marshes fringing Louisiana's large bays and estuaries have been studied independently. This approach has thwarted our ability to comprehend better the logical interaction among incident wave processes, bay hydrodynamics and at a minimum, marsh response. The objective of this paper is to summarize and demonstrate the significance of Morgan's work on shoreline change around Louisiana's coast. Recent advances in utilizing a detailed, historic (10^2 years) time series of shoreline change will be presented in addition to a discussion of subsequent forecasting of shoreline change trends into the next millennium. In addition, the predicted shoreline change is used as a basis to predict subsequent bathymetric adjustments, for example barrier to shoal trans-

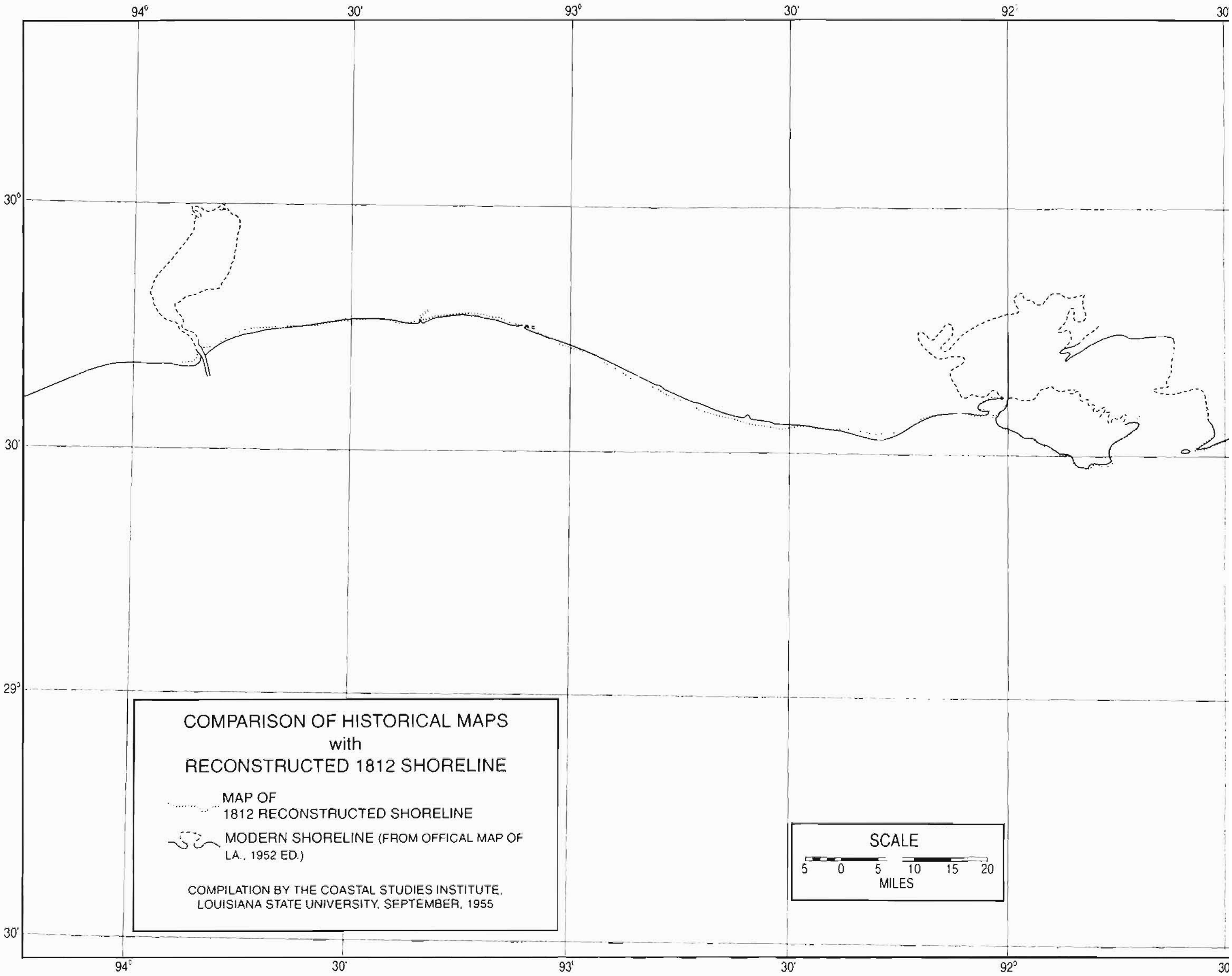


Figure 2. Comparison of the reconstructed 1812 Louisiana shoreline with that of 1952 as originally compiled by MORGAN (1955). The map is a copy of the original and thus, units are expressed in English.

formation, and bay deepening over time. This approach permits a detailed evaluation of the interplay among waves, barrier islands, and marshes fringing the bays and estuaries for present day and future conditions. It is our ultimate objective to demonstrate that as Morgan had surmised one-half century ago, Louisiana's barrier islands play a critical role in mitigating the wave climate in adjacent bays and estuaries, and, therefore, are integral to the longer-term morphological maintenance of saline marshes. In this paper we summarize our findings for one section of coast—Isles Dernieres (Figure 1)—an area where substantial reductions in the subaerial mass of the barrier islands have been documented historically, and considerable predicted loss appears likely. A more comprehensive discussion of the nearshore and bay/estuary wave climate along the entire south-central Louisiana coast is provided in STONE *et al.* (in preparation).

HIGH-RESOLUTION STUDIES OF SHORELINE CHANGE

Only two comprehensive studies of historical shoreline change have been conducted along Louisiana's outer shoreline (see Figure 1 for a regional setting of the State). In both cases, Louisiana State University and the Coastal Studies Institute played pivotal roles. The first investigation was con-

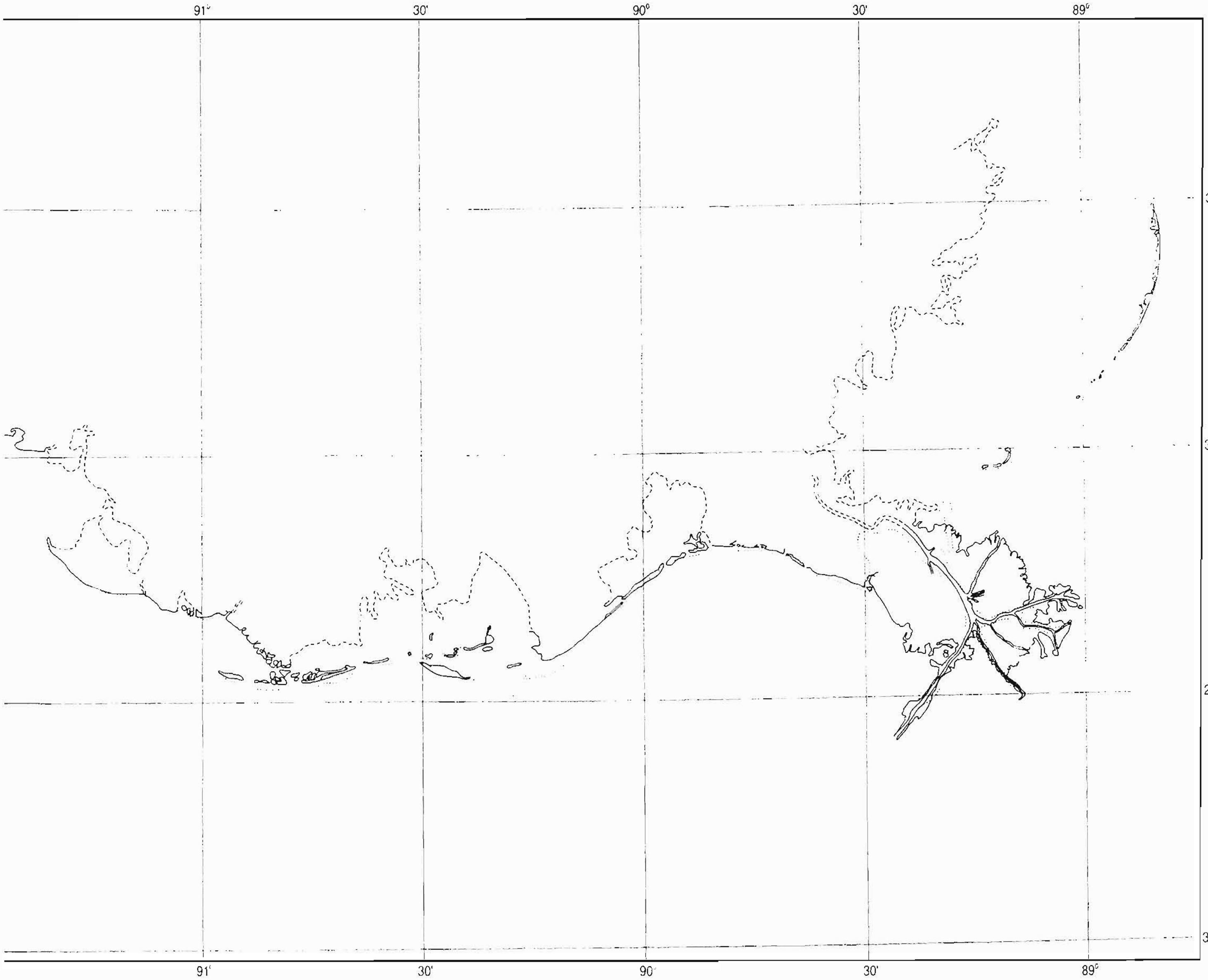


Figure 2. Continued.

ducted in the 1950's by James P. Morgan for the Louisiana Office of the Attorney General (MORGAN, 1955, 1960; MORGAN and LARIMORE, 1957), whereas the second was completed in the 1990's as a series of cooperative research projects with the United States Geological Survey (MCBRIDE and BYRNES, 1995).

Louisiana Attorney General

In the 1950's, the State of Louisiana and the federal government became involved in a lawsuit (tidelands case) regarding the offshore 3-mile boundary, which demarcates state versus federal water bottoms. The exact position of this 3-mile limit had numerous economic ramifications because the boundary determined ownership of, and jurisdiction over, vast quantities of underlying mineral resources, namely large petroleum reserves and sulphur deposits. The complicating issue was that the 3-mile limit was measured from the outer shoreline, which in Louisiana's case, was characterized by rapid changes on an annual basis. It was determined that the 3-mile limit should be based on the 1812 shoreline, the year Louisiana was admitted to the Union. James P. Morgan was responsible for determining historical trends in shoreline change along the entire outer coast in order to reconstruct the position of the 1812 shoreline (MORGAN and LARIMORE, 1957). A reproduction of the original map as produced by MORGAN and LARIMORE (1957) is provided in Figure 2. Note, the reconstructed 1812 and 1952 shorelines are portrayed as they were originally presented.

Using a combination of cartographic data (Topographic Sheets) and aerial photography, MORGAN and LARIMORE (1957) constructed historical shorelines between 1838 and 1954 for three time periods: 1) middle-to-late 1800s, 2) 1930s, and 3) 1950s. All maps were photographically enlarged or reduced to a common scale of 1:20,000. In addition, measurements were taken along 277 shore-perpendicular transects located at one-minute intervals of longitude or latitude from the Texas to Mississippi state lines.

The cartographic technique employed by MORGAN and LARIMORE (1957) to reconstruct the 1812 shoreline was simple but innovative. At each one-minute interval, shoreline change data were plotted graphically (Figure 3). On the graph, the horizontal axis was time plotted as years from 1800 to present, whereas the vertical axis was distance plotted in thousands of feet. Moreover, the distance scale on the graph matched the base map scale (1:20,000), thus allowing direct transfer between the two media. Positive (advance) and negative (retreat) measurements were plotted above or below the zero line, which represented the 1932 shoreline. Where possible, a line of best fit was drawn through the three points, and the slope of the line was used to represent the shoreline change rate for that transect. The intersection of the straight line with the 1812 year line determined the extrapolated distance into the past.

According to MORGAN and LARIMORE (1957), most of the outer Louisiana coast was dominated by erosion with advance occurring only at the mouths of the active bird-foot delta, as well as segments east of Sabine and Calcasieu Passes and the Freshwater Bayou area (mudflat progradation west of Marsh Island) (Figures 4 and 5). Otherwise, shoreline retreat was prevalent for the time period considered. The Late Lafourche delta (Timbalier Island to Caminada Pass) was characterized by the highest erosion rates at 19 m/yr, followed by the Early Lafourche delta (Isles Dernieres) at 8.2 m/yr (Figure 5). The St. Bernard delta (Chandeleur Islands) averaged 4.1 m/yr, and the Barataria delta (Grand Isle to Grand Bayou Pass) was similar at 4.3 m/yr. The areas with the two lowest rates of retreat were the Teche (Pt. Au Fer area) and Maringouin deltas (Atchafalaya and Vermilion Bays) at 2.8 and 2.3 m/yr, respectively.

MORGAN and LARIMORE (1957) recognized a key relationship between the age of individual deltas and shoreline retreat rates. Once deltas become abandoned, rates of subsidence and coastal erosion show a decelerating trend. As such, young deltas subside faster and are characterized by high retreat rates, whereas older deltas tend to subside slower and are dominated by lower retreat rates. Hence, an apparent reverse relationship exists.

MORGAN and MORGAN (1983) updated the original shoreline change data set to include a 1969 shoreline interpreted from aerial photography acquired by the U.S. Army Corps of Engineers. Shoreline change trends along the deltaic plain showed similar trends but the chenier plain experienced major reversals (Figures 4 and 5). According to MORGAN and MORGAN (1983), shoreline change trends along the chenier plain had reversed in two of the areas that were previously advancing and the formerly stable area was retreating (Figure 4). Only one segment (between Calcasieu Pass and the Mermentau River mouth) continued to show advance but the rate had slowed. Overall, MORGAN and MORGAN (1983) documented an accelerating rate of shoreline land loss from 0.54 mi^2/yr (1.40 km^2/yr) between 1932 and 1954 to 0.63 mi^2/yr (1.63 km^2/yr) between 1954 and 1969.

LSU-USGS Cooperative Research

In the 1990s, the second comprehensive study of historical shoreline change in Louisiana was completed as a result of two cooperative research projects between Louisiana State University and the U.S. Geological Survey (MCBRIDE *et al.*, 1992, 1995; BYRNES *et al.*, 1995; MCBRIDE and BYRNES, 1995, 1997). The five-year projects were entitled the "*Louisiana Barrier Island Erosion Study*" and "*Geologic Processes Affecting Coastal Erosion in Western Louisiana*." The goal of both projects focused on developing a better understanding of the processes that cause coastal erosion and wetland loss, particularly the rapid deterioration of Louisiana's barrier islands, estuaries, chenier plain, and associated wetland environments.

Changes in shoreline position for the period 1855 to 1994 were compiled within a geographic information system (GIS) using historical maps, near-vertical aerial photography, and global positioning system (GPS) field surveys (BYRNES *et al.*, 1991, 1994, 1995; MCBRIDE and BYRNES, 1995, 1997). The high water line (HWL) was used or interpreted on the cartographic data, aerial photography, and during GPS surveys. A computer mapping system was used to digitize shorelines, accurately superimpose all historical shorelines, and calculate shoreline change along shore-perpendicular transects. Over 3,000 transects were established at < 500 m intervals along the gulfside and bayside shorelines, and average rates of shoreline movement were calculated by dividing absolute measurements by time elapsed.

Based on quantitative documentation of historical changes in shoreline position, MCBRIDE and BYRNES (1995) classified the outer shorelines of the deltaic and chenier plains according to shore response at megascale (Figures 6 and 7). In contrast to the shoreline classification by MORGAN and LARIMORE (1957), which is based solely on the direction of shoreline movement (i.e., advance, stable, and retreat), MCBRIDE and BYRNES (1995) expanded the classification into eight response types that can address evolution of entire geomorphic features (e.g., barrier islands). Insight to the evolution of barrier islands is possible because both the gulfside and bayside shorelines were analyzed instead of just the gulfside shoreline as done in most previous shoreline change studies. The minimum temporal and spatial scales used for classification were 80 years and 10 km, respectively (except a short segment along the Plaquemines shoreline).

Isles Dernieres Shoreline Changes

The Isles Dernieres have experienced rapid deterioration over the past 100 years evolving from a nearly continuous barrier shoreline in 1887 to a series of barrier island frag-

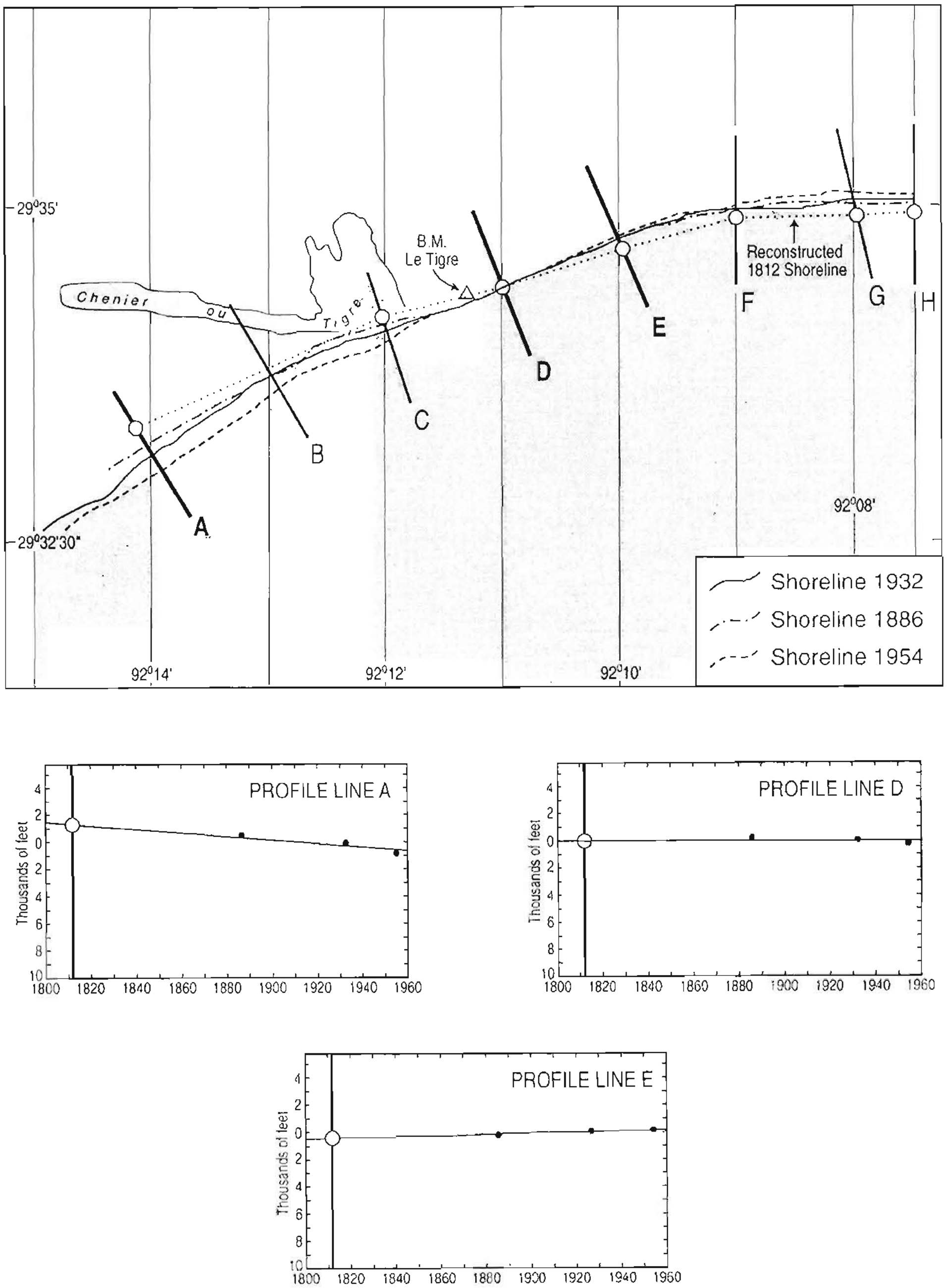


Figure 3. Reconstructing the1812 shoreline of Louisiana (MORGAN and LARIMORE, 1957). Base map showing historical shoreline positions (1886, 1932, and 1954) and shore-perpendicular transects (upper); three graphs depicting shoreline advance (A), shoreline stability (D), and shoreline retreat (E) selected by the present authors to demonstrate the methodology employed by Morgan and Larimore (see text for discussion). Units are expressed in English as originally presented by MORGAN and LARIMORE (1957).

ments in 1988 (Figure 8). The barrier island system has suffered both gulfside (11.1 m/yr) and bayside erosion (2.4 m/yr) causing the island to narrow at a rapid rate (MCBRIDE and BYRNES, 1997). As the island narrowed from an average width of 1,171 to 375 m, it became more susceptible to island breaching during the passage of cold fronts and tropical cyclones. In healthy barrier island settings, most inlets would tend to close fairly rapidly after storm landfall. By contrast, breaches along the Isles Dernieres have not only remained opened (e.g., Coupe Colin, Whiskey Pass, Coupe Juan, and Wine Island Pass) but have widened due to an inadequate sediment supply and high rates of relative sea level rise (~1 cm/yr). Consequently, the Isles Dernieres have been reduced in size from 3532 ha in 1887 to 781 ha in 1988—a decrease

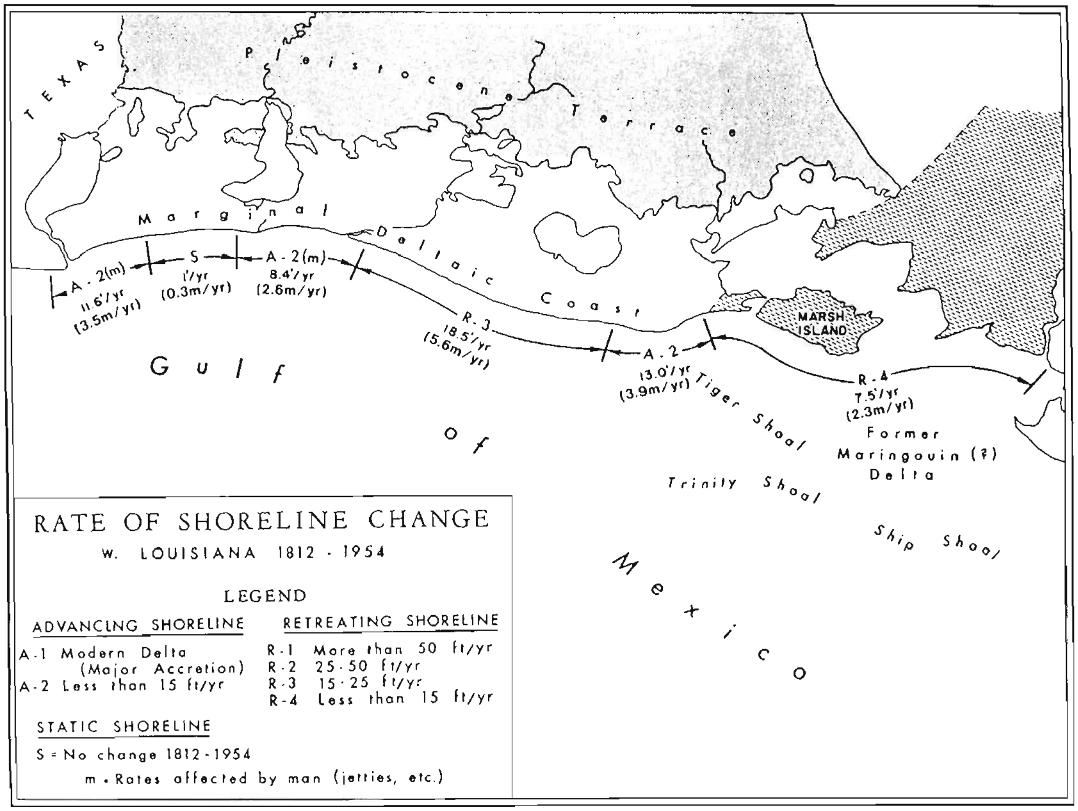


Figure 4. Shoreline change rates for the Louisiana chenier plain (Texas-Louisiana border to Pt. au Fer Island [Teche Delta]) for the period 1812–1954 (from MORGAN and LARIMORE, 1957). Units expressing change rates are presented in both English (original figures) and metric (modified by present authors).

of 78% (MCBRIDE and BYRNES, 1997), and is classified as experiencing island *breakup* (Figure 7).

Future Conditions: 30 and 100-year Forecasts

Using the same concept of extrapolation as MORGAN and LARIMORE (1957), MCBRIDE and BYRNES (1997) constructed shorelines 30 and 100 years into the future based on long-term shoreline change rates at individual shore-perpendicular transects. Thus, Morgan and Larimore extrapolated into the past to reconstruct an 1812 shoreline (Figure 2), whereas MCBRIDE and BYRNES (1997) extrapolated into the future to construct 2018 and 2088 shorelines (Figures 9 and 10). Using these future shorelines, wave modeling was employed to predict future wave conditions in the adjacent estuaries.

QUANTIFYING BATHYMETRIC AND WAVE CONDITIONS

Predicting Future Wave Height Conditions

A large number of wave forecasting methodologies are currently in existence (see O'REILLY and GUZA, 1991, 1993; STONE *et al.*, in preparation). These methods define the wave field as monochromatic or single period waves, one-dimensional spectral waves, two-dimensional spectral waves and shallow water waves. Several of the more commonly used models were evaluated and are reviewed in more detail in STONE *et al.* (in preparation). A finite-difference model (STWAVE) was selected for use in this project. The model is used for near-coast time-independent spectral wave energy propagation simulations (CIALONE *et al.*, 1992) and is based on a simplified spectral balance equation:

$$\frac{\partial}{\partial x}(CC_g E(f, \theta)) + \frac{\partial}{\partial y}(CC_g E(f, \theta)) = 0 \qquad (1)$$

where

$E(f, \theta)$ = spectral energy density
f = frequency of spectral component
θ = propagation direction of spectral component
C_g = group speed
S_i = source terms (shoaling, refraction, wind forcing, bottom interaction)

STWAVE simulation requires a wave energy spectrum specified for the input boundary of the computational grid. It transforms the spectrum across the grid, including refraction

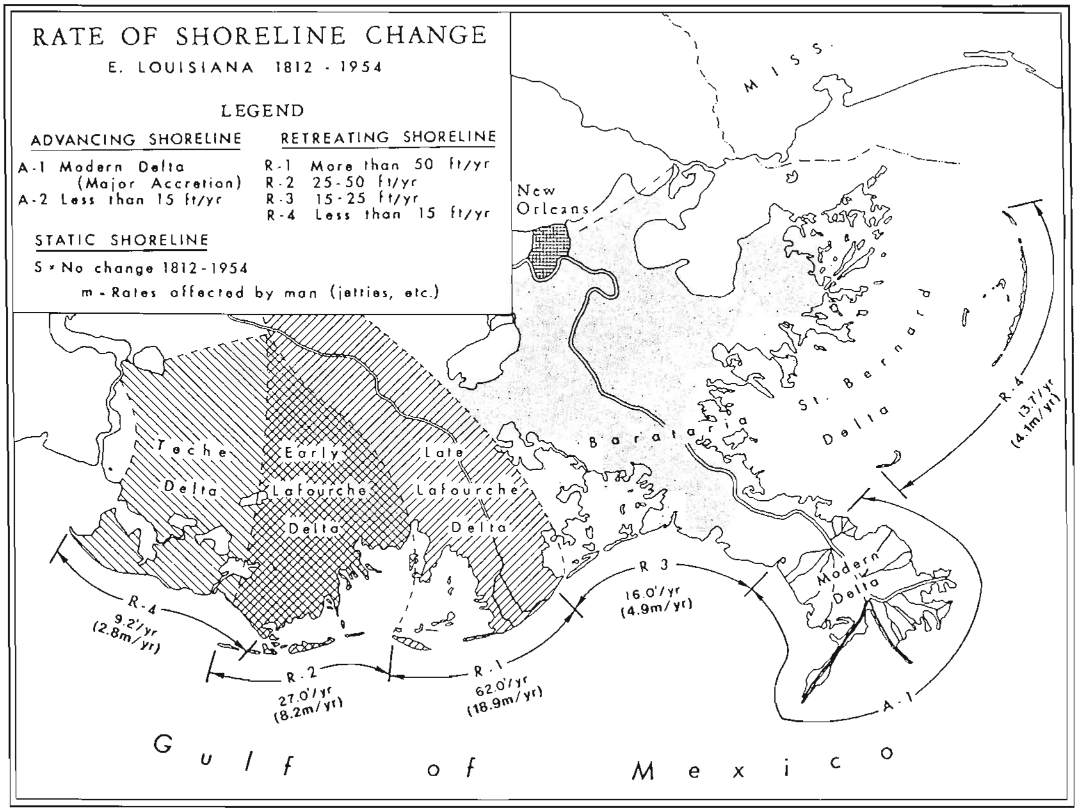


Figure 5. Shoreline change rates for the Louisiana deltaic plain (Pt. au Fer Island [Teche Delta] to the Chandeleur Islands [St. Bernard Delta]) for the period 1812 to 1954 (from MORGAN and LARIMORE, 1957). Units expressing change rates are presented in both English (original figures) and metric (modified by present authors).

and shoaling effects. The spectrum is modified to include the effects of bottom diffraction and the convergence/divergence of energy influenced by the local bathymetry. The model is computationally efficient because of its assumption that only wave energy directed into the computational grid is significant, i.e., wave energy not directed into the grid is neglected. Wind-wave generation, nonlinear energy transfer, wave field and wave-bottom dissipation and wave breaking are also considered (Don Resio, U.S. Army Corps of Engineers, Vicksburg, Mississippi, personal communication). The boundary conditions required for the model include a bathymetric grid and deep water wave conditions.

Two different types of bathymetric grid were generated for this study. The Type I grid is coarser in resolution with a grid size of 500 m in both longitudinal and latitudinal directions, with 96,000 grid cells (400 × 240). Type II includes three finer resolution bathymetric grids with a latitudinal grid size of 50 m and a longitudinal size of 135 m. Bathymetric grids of present (1988), 30-year, and 100-year projections were generated for the study site. The original bathymetric data used as input to STWAVE were generated in a modular GIS environment (MGE). With the projected shoreline configurations, the inner shelf bathymetry was conformed assuming an equilibrium profile. Thus, where the projected shoreline was shown to have transgressed or regressed, the inner shelf profile was adjusted accordingly, maintaining a similar configuration. Historic bathymetric comparisons along the study area (LIST *et al.,* 1994) confirm this trend over the last century or so and validate the approach. Additionally, the rapid landward translation of Ship Shoal (see Figure 4 for location) which approximates 20 m/yr, was incorporated in the 30 and 100 year bathymetric scenarios. Projected changes to the marsh coastline have not been incorporated in the 30 and 100-year scenarios. Although the necessary high resolution data set is not yet available which would allow such an undertaking, omission of these data will not significantly bias the numerically modeled wave climate forecasted for the bays. In addition the primary emphasis of this approach is on the role that the barriers play in mitigating the wave climate in Louisiana's bays.

In the larger study of wave and barrier interactions, a comprehensive deep water wave climate was developed for the Louisiana coast (STONE *et al.,* in preparation). STWAVE was first run over the coarse grid to model the wave height distributions for two input boundary conditions: storm (Hs=6 m, Tp=11 sec., Vwind=20 m/s) and fair weather (Hs=1 m, Tp=5 sec., Vwind=5 m/s). The two predominant wave directions, south (=0) and southeast (=45), were modeled under each condition. Wind was always in the direction of wave propagation. Two hurricane simulations were undertaken,

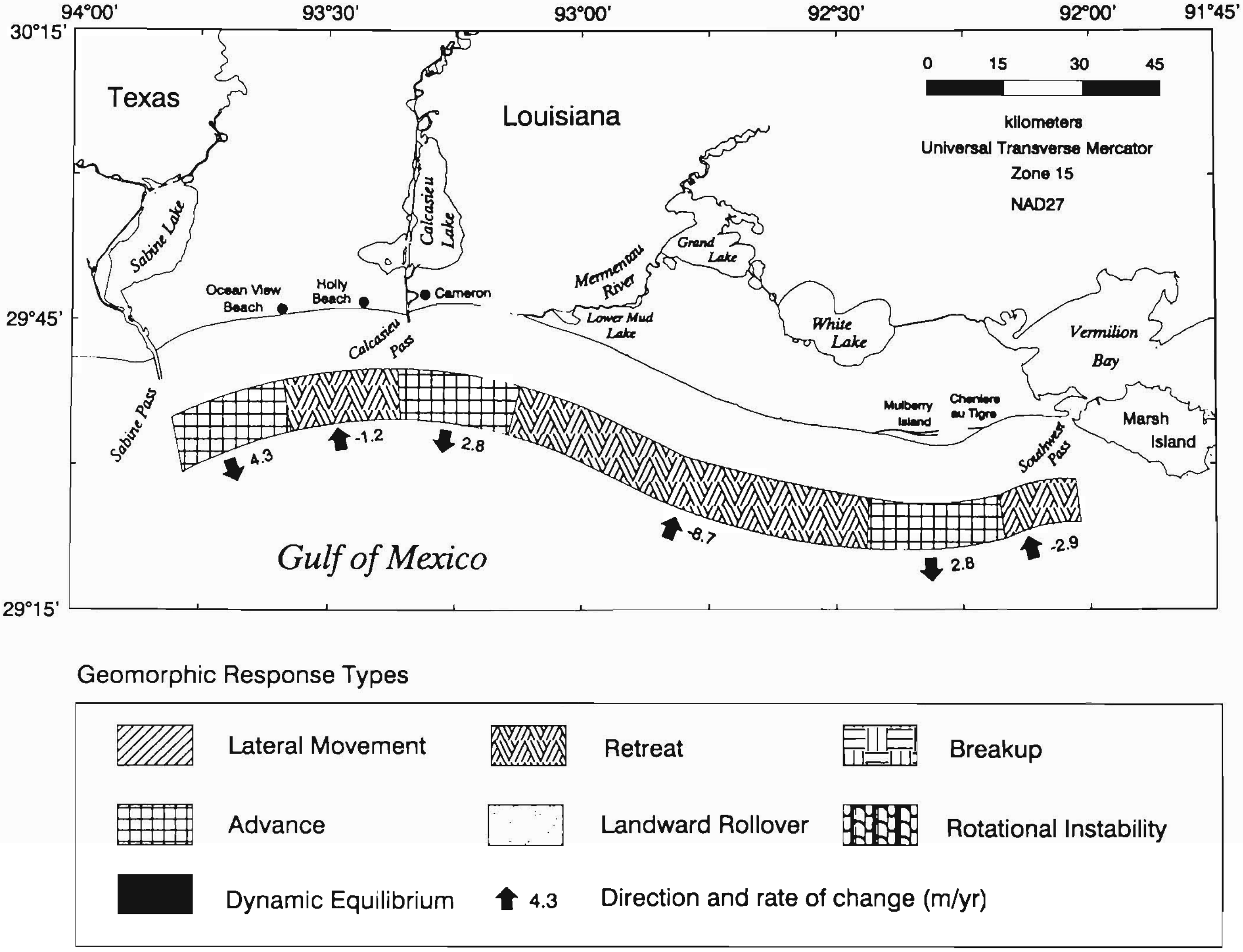


Figure 6. Geomorphic response-types as well as rate (m/yr) and direction (→) of shoreline change for the Louisiana chenier plain for the period 1883/87 to 1994 (from McBride and Byrnes, 1995).

one representing conditions during Hurricane Andrew and the other representing conditions during a Category 5 storm making landfall over Timbalier Island. Respective deep water wave statistics used were Hs=16 m, Tp=18 s, V=40 m/s and Hs=22 m, Tp=18 s and V=75 m/s (Stone *et al.,* 1995). In addition to the wave height output, wave spectra were collected at the middle of the offshore boundary of all three higher resolution grid areas. These directional wave spectra were then used as input boundary conditions in model runs that computed wave height distributions over the three higher resolution bathymetric grids. Thus, each area has three different grids that were generated for present, 30-year, and 100-year scenarios.

ROLE OF BARRIER ISLANDS IN MITIGATING THE BAY WAVE CLIMATE

The modeled wave height distributions are plotted in Figure 11 in which the upper left panel shows the current (1988) barrier configuration and wave height distribution; the upper right panel shows the 30-year forecast; the lower left panel shows the 100-year forecast and the lower right panel shows the wave adjustment to a hypothetical, large-scale barrier island restoration effort. The example provided in Figure 11 pertains to fair weather deep water conditions where the significant wave height is 1 m, the wave period 5 sec., direction of wave approach is from the south and the wind speed is 5 m/sec. from the south.

Under fair weather conditions, wave height increases in both Caillou Bay and Lake Pelto are clearly apparent, and range from 0.2 to 0.8 m. Increases in wave heights in both systems are clearly attributable to shortening of barrier island length, increasing inlet width and nearshore slope steepening for the 30-year forecast. Increases in wave heights are particularly widespread in the bays for the 100-year forecast. Similar trends are evident on simulating waves approaching from the southeast. For both storm and fair weather condi-

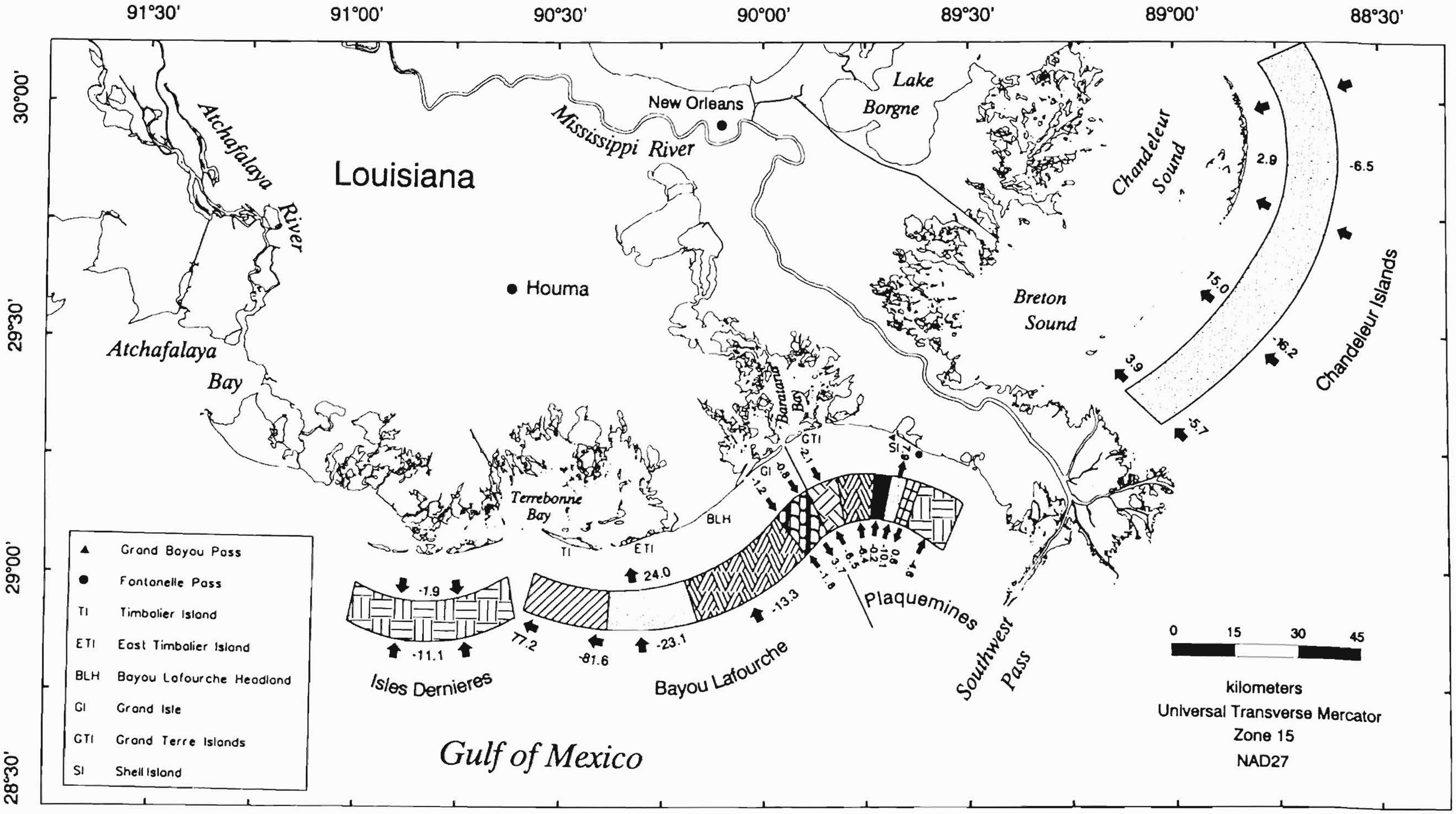


Figure 7. Geomorphic response-types as well as rate (m/yr) and direction (→) of shoreline change for the Louisiana deltaic plain for the period 1855 to 1989 (from McBride and Byrnes, 1995). See Figure 6 for legend.

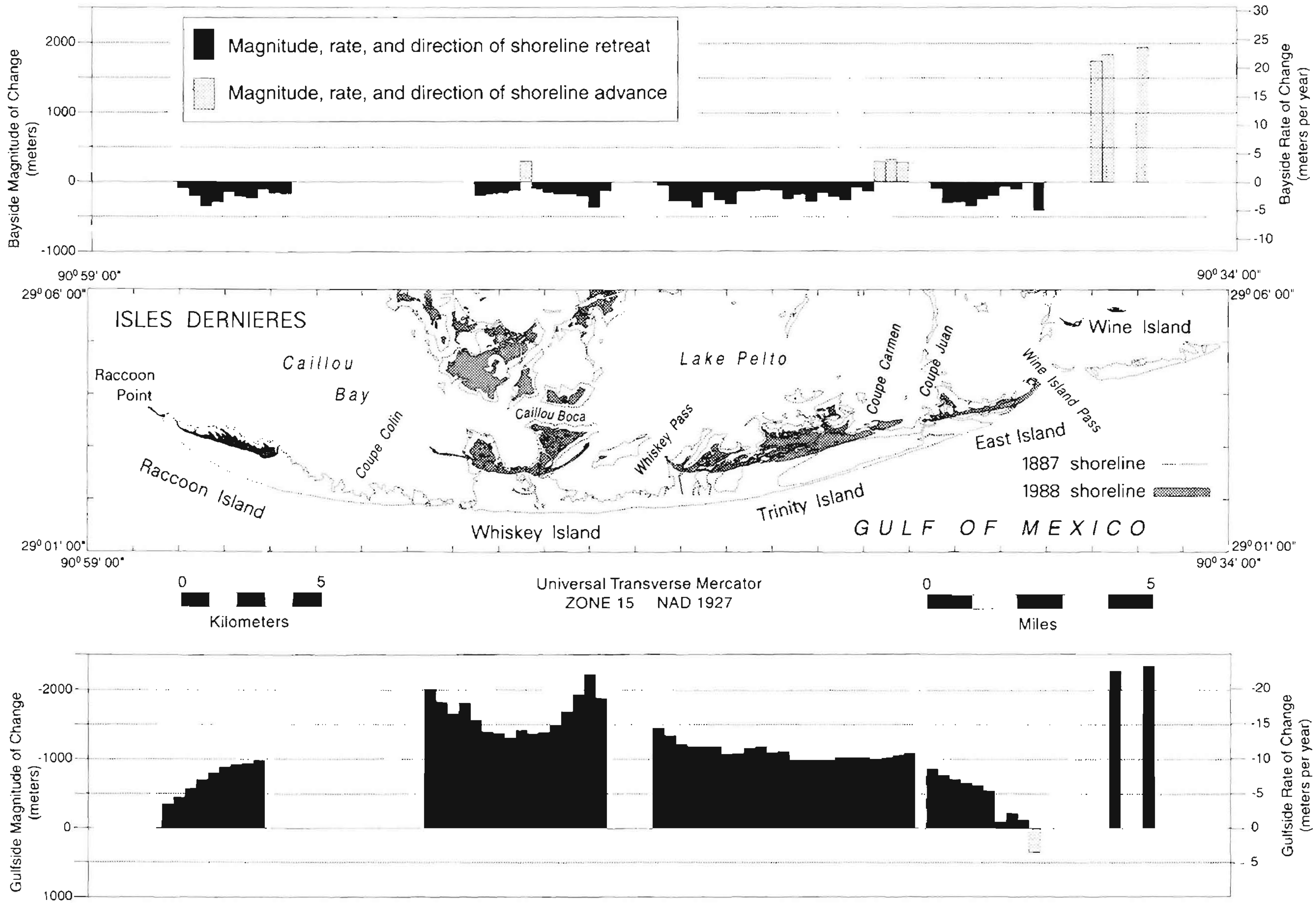
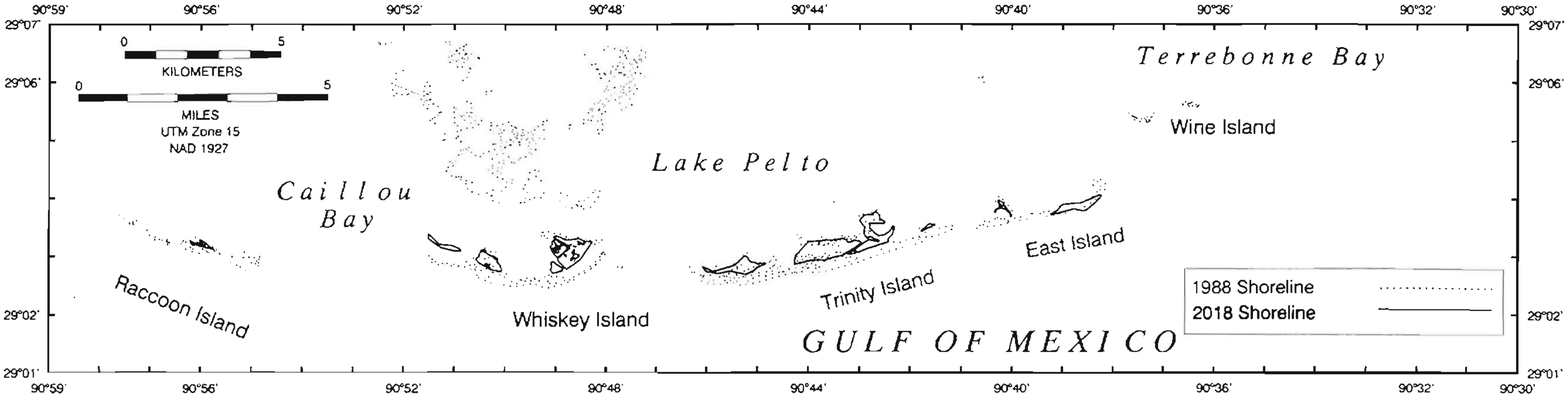


Figure 8. Historical shoreline changes of the Isles Dernieres barrier island system for the period 1887 to 1988. Histograms along the gulfside and bayside shorelines show the magnitude (m), rate (m/yr), and direction of change (from McBride and Byrnes, 1997).



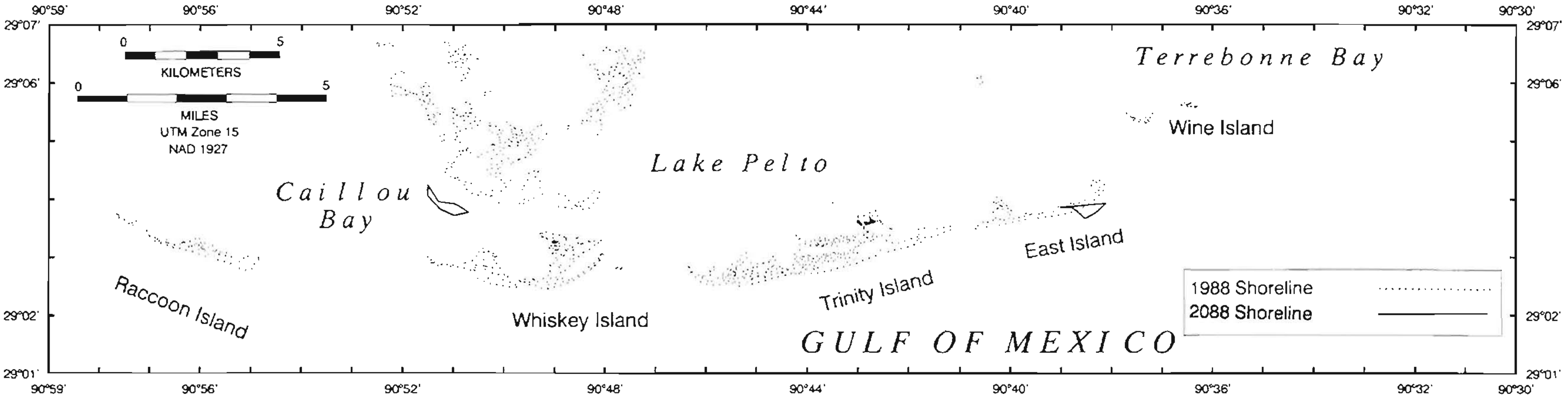


Figure 9. (Above) The Isles Dernieres barrier shoreline extrapolated 30 years into the future (2018 AD) and compared to the 1988 shoreline (dotted) (from McBride and Byrnes, 1997).

Figure 10. (Below) The Isles Dernieres barrier shoreline extrapolated 100 years into the future (2088 AD) and compared to the 1988 shoreline (dotted) (from McBride and Byrnes, 1997).

tions, changes in wave height are due to the transformation of the subaerial mass of the coast to shoals or deepening of the offshore profile. For the 30-year forecast under storm conditions, wave heights increase by 0.3 to 1 m due to the removal of Raccoon Island (most westward located island on Figure 11, upper left panel). A slight (0.2 m) decrease in wave height occurs further north in Caillou Bay which may be due to changes in diffraction/refraction patterns across the expanded portion of the inner shelf due to removal of Raccoon Island. A similar decrease in wave height occurs north of Whiskey Island due to an increase in the island width thereby enhancing the island's capacity to protect and reduce wave energy in the adjacent bay. (This increase in island width is due to a restoration project that was undergoing completion at the time of writing). Along the eastern flank of the Isles Dernieres, Lake Pelto experiences increases in wave heights of between 0.2 and 1.0 m. This is due to the decrease in barrier length, increase in inlet size and steepening of the nearshore slope. It is important to note that this increase in wave height extends considerable distances across Lake Pelto toward the adjacent fringing marsh shoreline. Increases in wave heights are particularly pronounced in Lake Pelto for the 100-year forecast during storm conditions. The magnitude of increase is up to 1 m and occurs over a much greater distance of both Caillou Bay and Lake Pelto. This significant increase in wave height can be primarily attributed to the loss of virtually all of the Isles Dernieres. A decrease in wave height of 1 m is apparent along the east end of East Island due to seaward displacement of the barrier. The trends described above are similar on simulating waves approaching from the southeast.

Interpretation of the numerical model output for the Isles Dernieres area indicate significant increases in wave height, and therefore, wave energy in both Caillou Bay and Lake Pelto for the 30 and 100-year wave forecast during storm and fair weather conditions. The large geographical extent of these increases in height, up to 1 m, are largely due to deterioration of the barrier islands, resulting in transformation of these bays from generally low energy, protected systems to higher energy, coastal embayments.

Hurricane Simulations

A combined storm surge-wave prediction simulation was conducted for Hurricane Andrew which made landfall along the area in 1992. The simulation was undertaken to generally evaluate the performance of STWAVE by comparing model output with field measurement. Details on the impacts of Andrew on the Louisiana coast may be found in Stone and Finkl (1995); Stone *et al.* (1993; 1995); Grymes and Stone (1995). Waves ranging from 2 to 4 m were simulated breaking along the coast, and exhibited a wave height gradient which increased to the east from the Isles Dernieres. This trend has been attributed to an increase in shelf slope to the east and subsequent reduction in the wave energy decay rate (Stone *et al.*, 1995). Landward of the coast within the marshes, predominantly wind-generated waves attained heights of 1 m. The output appears reasonable when compared to observation and *in situ* measurement of water levels during Hurricane Andrew (see Stone and Finkl, 1995). For the current conditions (1988), the barriers are predominantly overtopped by waves approximating 2 m in height. Landward in the bays, waves typically attain heights of around 1 m increasing to 2 m southeast of New Orleans. A gradual landward shift of larger wave heights is noticeable with the disappearance of barrier islands and coastal retreat, particularly for the 100-year scenario.

IMPLICATIONS FOR BARRIER ISLAND RESTORATION

The data presented here for the Isles Dernieres site show conclusively that with the anticipated deterioration of the barrier islands, a substantial increase in wave energy will occur in Caillou Bay and Lake Pelto within the time frames presented. The data also indicate that the marshes fringing these water bodies will also experience a significant increase in wave energy commensurate with barrier disintegration, particularly in Lake Pelto. The precise relationship/s between increased wave energy and marsh response in Louisiana has not yet been established. Clearly, the cohesive properties characteristic of the marsh deposits complicate the anticipated response to wave-current suspension, resuspension and transport during increased energy conditions. In the absence of field data, the assumption made here is that on crossing an energy threshold, the marsh sediments comprising the nearshore profile will undergo transport away from the site, albeit the transport pathways have not yet been determined. This response is set within the context of a much longer temporal scale, where the processes responsible for secular depletion of the marshes are perhaps better understood (*e.g.*, compaction and subsidence). In addition, the likely erosional response of Louisiana's marshes to increasing wave energy is viewed distinctive of episodic marsh surface accretion (aggradation) that has been documented during hurricanes when super-elevated water levels in the marsh play a critical role (see recent reviews by Cahoon *et al.*, 1995).

The example data set presented indicates that the Isles Dernieres play a critical role in mitigating the wave climate in the adjacent bays and fringing marshes. An additional simulation was carried out to quantify the impact of barrier island restoration along the Isles Dernieres on wave climate in the bays. As shown in Figure 11, lower right panel, reestablishing the barriers through large-scale nourishment will reduce energy levels in Caillou Bay and Lake Pelto considerably, up to 800% in certain locations, thereby reducing the potential for wave-induced marsh erosion. The data also suggest that while large-scale barrier restoration will significantly inhibit the ability of waves propagating across the shelf to enter the bays, higher frequency, locally-generated waves will develop in the bays and break along the marsh shoreline. While the amplitude of these waves will remain relatively small—typically 15 cm during winter storms—because of factors including fetch, bay depth, and marsh shoreline orientation, their steepness, and high frequency (periods of 1–3 secs.) enhances their effectiveness in causing erosion. A numerically-derived example of a locally-generated wave in the lee of a barrier island with a fetch of 13 km is shown

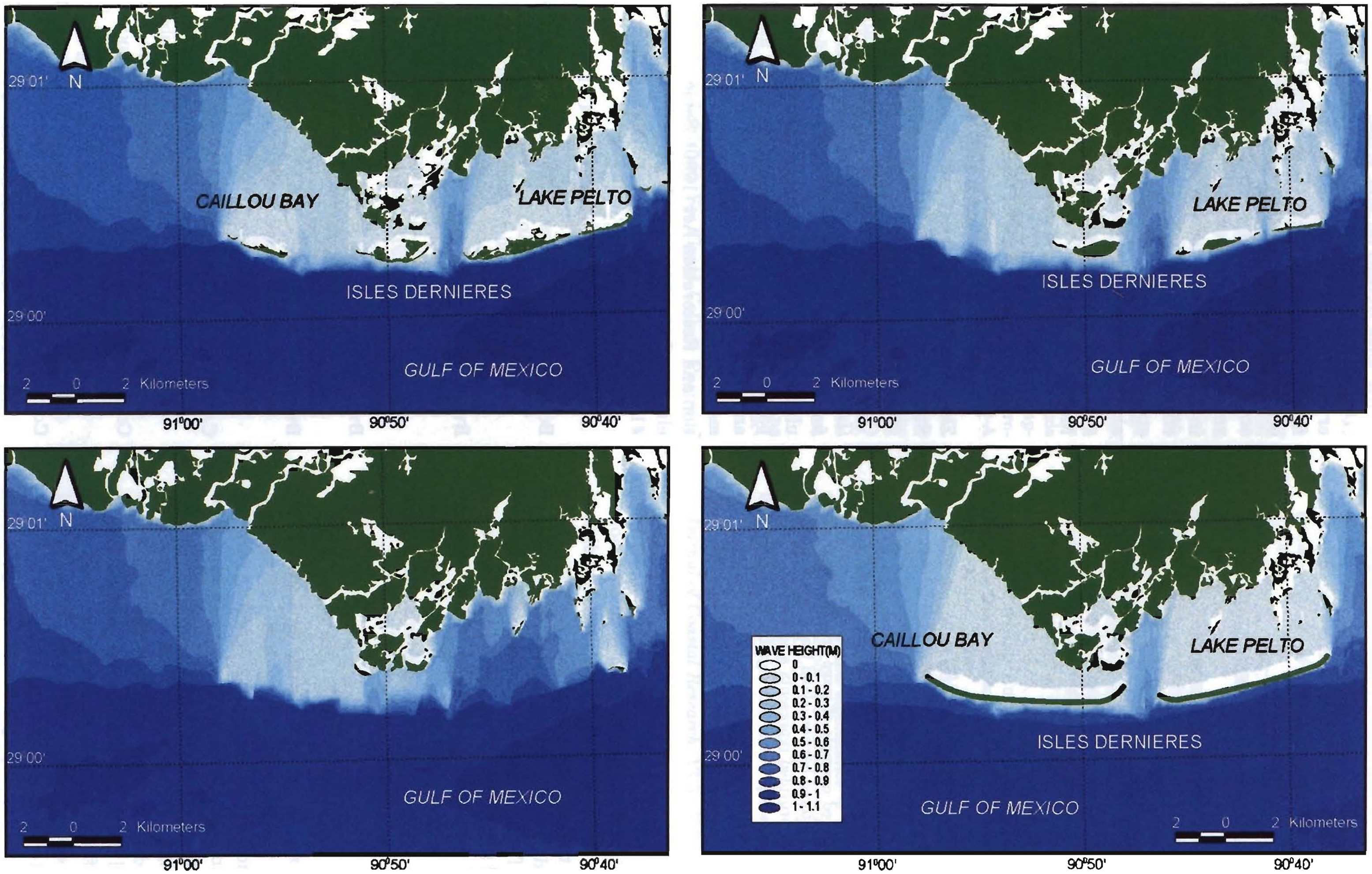


Figure 11. Numerically-modeled wave height (m) distribution on the Louisiana shelf and in Calliou Bay, Lake Pelto, and the Isles Dernieres for present day (1988) conditions (top left); 30-year forecast (top right); 100-year forecast (bottom left) and hypothetical barrier island restoration (bottom right). The data illustrate the projected disintegration of barrier islands and the subsequent increase in wave height in the bays and along the fringing marshes for fair weather waves approaching from the south. (See text for more detailed discussion).

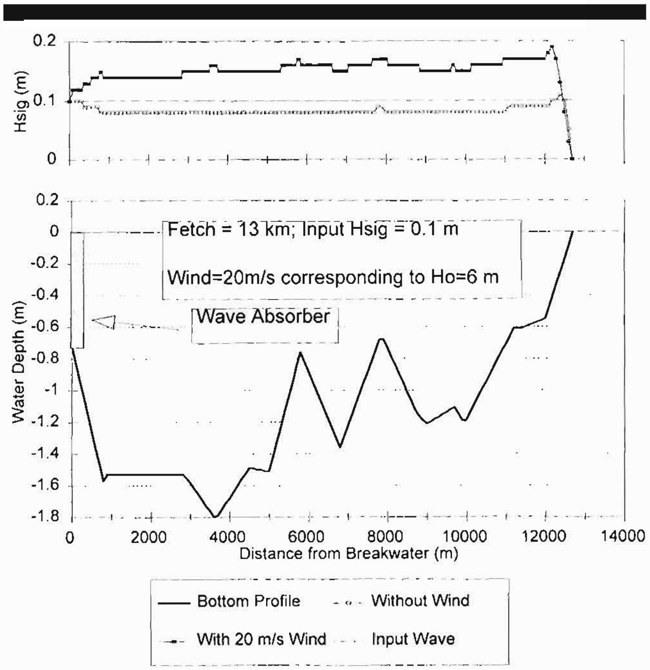


Figure 12. Numerically-derived example of wave growth (upper curve on upper panel) in lee of a restored barrier island fronting a bay with a fetch of 13 km. The example provided represents a severe winter storm during which high frequency, steep waves with significant heights of 20 cm propagate across the bays and are capable of significant erosion along the marsh shoreline.

in Figure 12 to explore this phenomenon further. The wave approaches a significant wave height of near 20 cm prior to reaching the break point at 15 cm. The boundary conditions offshore correspond to a strong winter storm with a wind speed of 20 m/sec and a corresponding deep water significant wave height of 6 m. Thus, in order to maximize the effects of future barrier island restoration efforts in reducing wave energy along the marsh shorelines, an additional wave energy-absorbing device will require construction. A hypothetical device is shown in the numerically-derived example in Figure 12, and is constructed in a water depth of 0.7 m.

CONCLUSIONS

The magnitude of marsh loss and coastal erosion in Louisiana was initially recognized over one-half century ago through the exposition of seminal works conducted by the late James P. Morgan and colleagues. These early studies on shoreline change not only revealed new evidence of the interrelationship among marsh and outer shoreline dynamics, fluvial processes, and sediment supply, but were highly innovative and detailed in their methodological approach. Some 50 years later, significant technological advances permitted expansion of the historical time series and forecasting of shoreline changes into the 21st. Century. These data provide a highly detailed, quantitative projection of the rapid disintegration of numerous Louisiana barrier islands and complete transformation of subaerial to subaqueous sand bodies early in the 21st. Century. In turn, numerical wave modeling suggests substantial increases in wave energy in Louisiana's bays (700% increase during fairweather conditions adjacent to the Isles Dernieres) and estuaries resulting in the rapid (10^1–10^2 years) transformation of these water bodies to higher energy, coastal embayments. The logical extension of these findings is that an increase in marsh loss rates will likely occur commensurate with increasing energy levels. Large-scale barrier island restoration will greatly reduce the adverse effects associated with rapid increases in wave energy in otherwise protected bay and lagoonal environments. This effort will require fine tuning which will likely involve a structural component designed to flank fringing marshes along portions of the bays were the fetch permits local wave growth or propagation of incident waves from the Gulf of Mexico.

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