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Relative Sea-Level Rise in Louisiana and the Gulf of Mexico: 1908–1988

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ABSTRACT

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Louisiana is experiencing the most severe wetland loss and barrier island erosion in North America. Rates of land loss exceed 100 square kilometers per year in the Mississippi River delta and chenier plains. Rapid sea-level rise induced by delta-plain subsidence and a deficit of terrigenous wetland sediment are the primary factors driving the rapid deterioration of the Louisiana coastal zone.

Within the Mississippi River delta plain, the Houma tide gage documented a relative sea level rise rate of 1.09 cm/yr from 1946 to 1988, based on U.S. Army Corps of Engineers tide gauge records. On the coast, the Eugene Island tide gage documented a slightly higher relative sea level rise rate of 1.19 cm/yr. When other tide gages in Louisiana with 30-year records or more are compared to the record of the Houma tide gage station, relative sea level appears to rise faster in the Terrebonne Parish area than anywhere else in Louisiana. Representative water level histories from the Chenier plain, Teche basin, Terrebonne delta plain, Barataria basin, Balize delta plain, St. Bernard delta plain, and Pontchartrain basin indicate the regional rates of relative sea level rise decrease to the east and the west from the Terrebonne coastal area.

In comparison with other National Ocean Survey tide gage records throughout the U.S. Gulf Coast, Louisiana is experiencing the highest relative sea level rise rate at 1.04 cm/yr for Grand Isle, the rates decrease from 0.63 cm/yr at Galveston, Texas to 0.15 cm/yr at Biloxi, Mississippi. Mean relative sea-level rise in Louisiana is more than five times the Gulf of Mexico average. A comparison of the Grand Island relative sea level rise rate (1.04 cm/yr) with the global relative sea level rise rate (0.12 cm/yr) indicates that, on the average, relative sea level is rising 10 times faster in Louisiana than in the much of the rest of the world.

The rapid rate of relative sea level rise observed in Louisiana can be attributed to subsidence of the Mississippi River delta plain due to sediment compaction. Louisiana directly overlies the entrenched Pleistocene valley of the Mississippi River, which is filled with Holocene deltaic sediments more than 150 m thick.

ADDITIONAL INDEX WORDS: *Sea-level rise, tide gauge, coastal zone, land loss, coastal erosion, Louisiana, Gulf of Mexico.*

INTRODUCTION

Louisiana is faced with a catastrophic land loss problem, a rapid rise in relative sea level is one of the primary processes driving barrier island erosion, the loss of valuable marshes, and the potential destruction of a vast estuarine resource base. Louisiana contains 40% of this nation's coastal wetlands and 80% of the coastal wetland erosion is occurring here. In order to understand the rate and magnitude of relative sea level rise, two tide gauge networks in Louisiana and the northern Gulf of Mexico were analyzed to determine temporal and spatial trends of relative change. The U.S. Army Corps of Engineers (USACE) maintains a network of 83 tide gauge stations throughout coastal Louisiana, which were used to determine the local and regional character of relative sea level rise in Louisiana. The National Ocean Survey (NOS) maintains nine tide gauge stations throughout the northern Gulf of Mexico in Texas, Louisiana, Mississippi, Alabama, and Florida and these were used to determine the character of relative sea level rise throughout the region (LYLES *et al.*, 1987).

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Coastal Erosion in Louisiana

Louisiana is experiencing the most severe land loss and barrier island erosion in North America (Figures 1, 2). Land loss rates in the

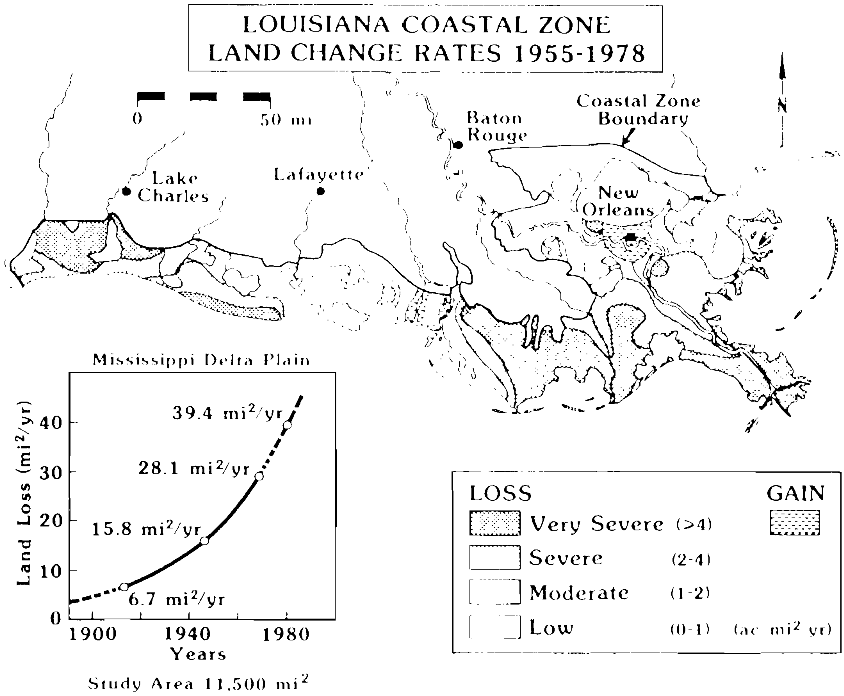


Figure 1. Diagram illustrates the pattern of coastal land loss in Louisiana (van Beek and Meyer-Arendt, 1982).

Mississippi River delta plain exceed 102 square kilometers per year (GAGLIANO *et al.*, 1981). Louisiana experienced a decrease in total barrier island area of about 37%, from 92.4 km^2/yr to 57.8 km^2, between 1880 and 1979 (PENLAND and BOYD, 1981). Current predictions based on a land loss rate of 27.7 km^2/yr indicate that Terrebonne Parish will be converted into open water within 102 years (GAGLIANO *et al.*, 1981). Between 1887 and 1979, the Terrebonne Parish barrier islands decreased in area from 48.3 km^2 to 18.3 km^2 (PENLAND and BOYD, 1981). At a loss rate of 0.326 km^2/yr, these islands will be converted to submerged sand shoals in 56 years. Rapid relative sea level rise induced by delta-plain subsidence and a deficit of terrigenous wetland sedimentation are the primary factors driving the rapid deterioration of the Louisiana coastal zone.

Previous Sea-Level Rise Studies

Previous investigations have documented that the analysis of tide gauge records is a valid technique for measuring relative sea level rise in Louisiana and the Gulf region (GORNITZ *et al.*, 1982; HICKS *et al.*, 1983; MARMER 1954; PIRAZZOLI 1986; GORNITZ and LEBEDEFF 1987; HICKS and HICKMAN 1988; PENLAND *et al.*, 1988a). An early comparison of relative sea level rise rates for Louisiana revealed rates as high as 4.3 cm/yr (SWANSON and THURLOW 1973). That study used 11 years (1959–1970) of tide gauge records from the Mississippi River delta plain. A comparison of the SWANSON and THURLOW (1973) data set with other, more recent data sets (BOESCH *et al.*, 1983; BYRNE *et al.*, 1976, 1977; DELAUNE *et al.*, 1985; PENLAND *et al.*, 1988a; PIRAZZOLI 1986) suggests that the 4.3 cm/yr rate of relative sea level rise is anomalous because the short period of record (1959 to 1970). Typically, the longer the period of record for a tide gauge station, the lower the rate of relative sea level rise calculated from the data. HICKS (1968) suggests that the period of record should exceed two lunar nodal tide cycles to yield accurate results. A nodal tide cycle is the 18.6-year period that it takes for the moon to complete its nodal cycle. Using tide gauge records of 20-year

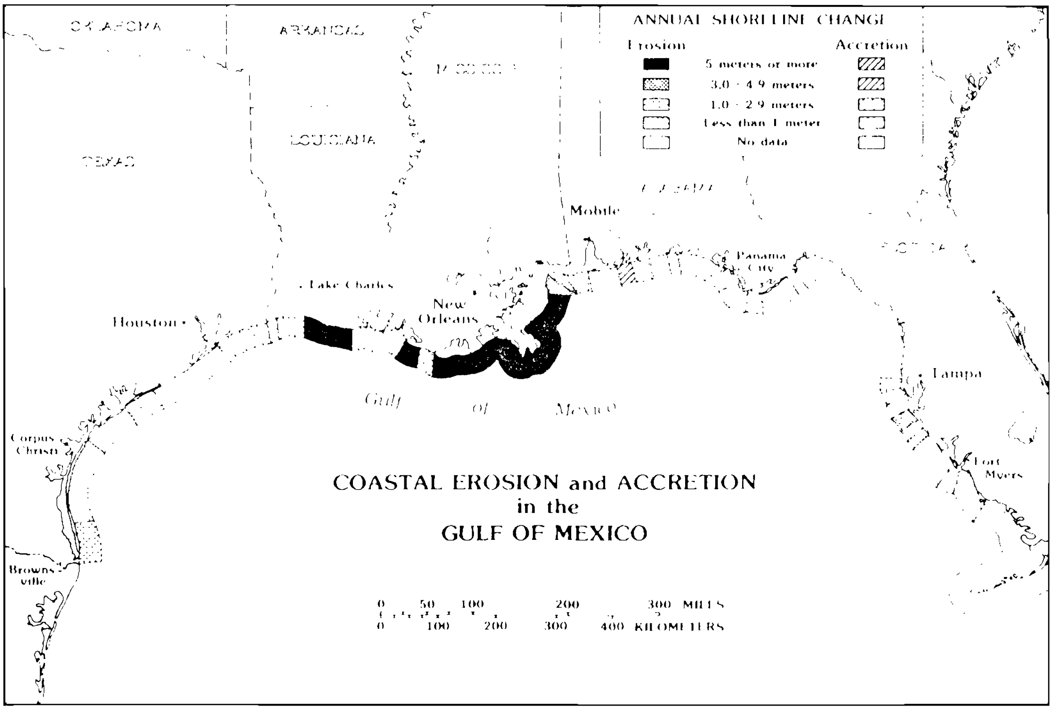


Figure 2. Annual shoreline change rates in the northern Gulf of Mexico (after U.S. Geological Survey 1989).

periods or more accounts for any water level variations resulting from this astronomical phenomenon as well as nontidal effects such as wind, direct atmospheric pressure, river discharge, currents, water temperature, and salinity (HICKS 1968).

TIDE GAUGE DATA ANALYSIS

Database and Analysis

Two tide gauge networks exist in the Gulf of Mexico region. Both of these were analyzed to determine the rates of relative sea level rise affecting Louisiana (Figure 3). The USACE has maintained tide gauges in Louisiana since 1933, when it established the first station at Morgan City on the Intracoastal Waterway. Today, the USACE maintains 83 tide gauges in coastal Louisiana; however, only 20 of these have records that exceed two lunar node tidal cycles. The oldest NOS tide gauge station in Louisiana is the Eugene Island station, which was established in 1939. The other NOS station in Louisiana is at Grand Isle. The oldest NOS tide gauge station in the Gulf of Mexico is located at Galveston, TX and was established in 1908. The NOS network provides a comparative data set for the U.S. Gulf coast while the USACE network provides readings only for Louisiana.

The NOS tide gauge stations at Grand Isle and Eugene Island are considered to have the best resolution of all Louisiana stations. These tide gauges record water levels every six minutes, 24 hours a day at locations with direct tidal exchange with the Gulf of Mexico. The Eugene Island station has a period of record from 1939 to 1974. In 1974 NOS stopped maintaining the station and the USACE began keeping the records. The Grand Isle station at Bayou Rigaud has 40 years of records (1947–1987). NOS maintains this station and sends the 8:00 a.m. readings to the USACE for their records. The NOS provided summaries of daily mean, high and low water levels at each station (HICKS *et al.*, 1983). These data were averaged

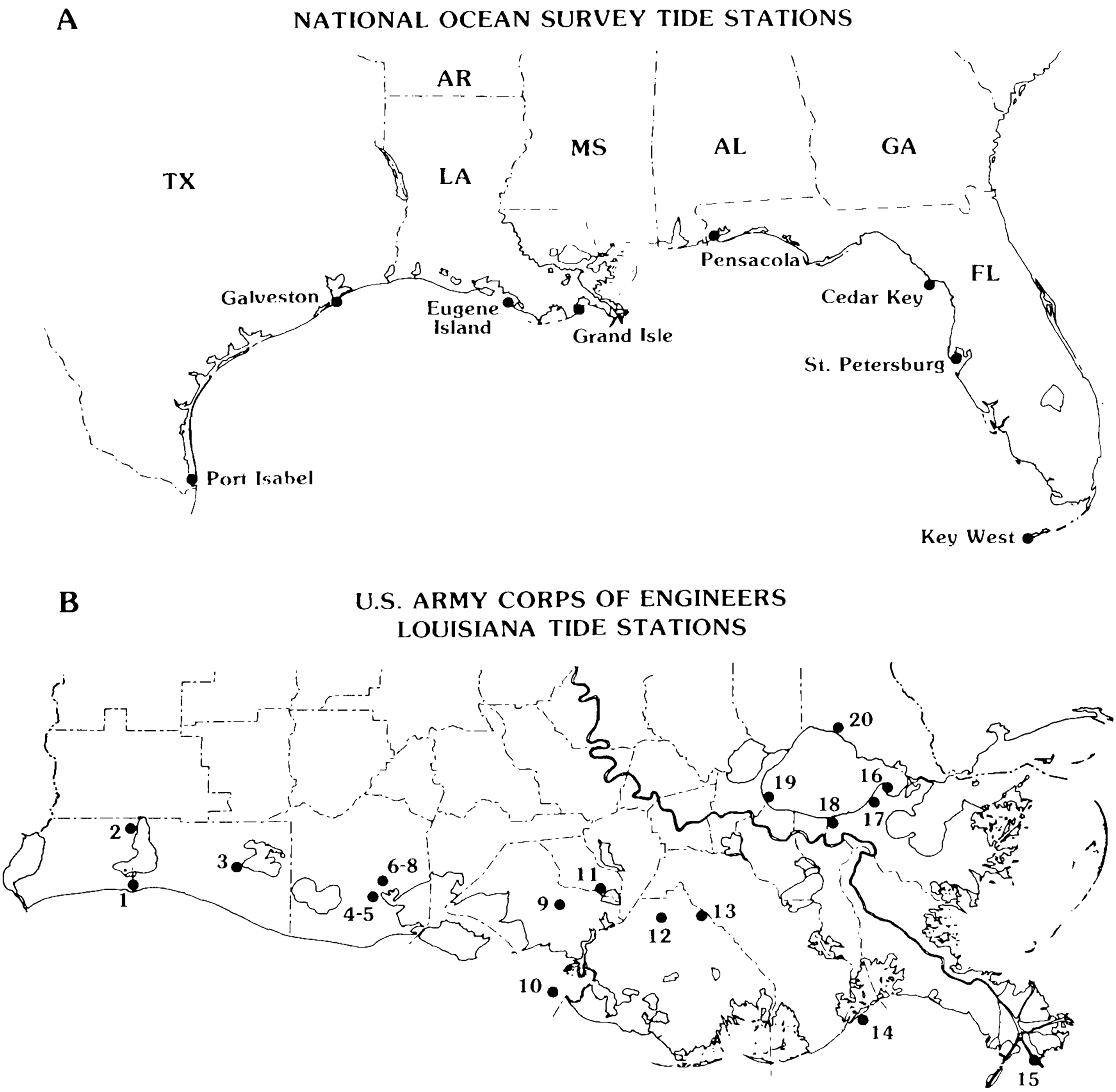


Figure 3. (A) Location of the National Ocean Survey tide gage stations in the Gulf of Mexico (Lyles *et al.*, 1987). (B) Location of the U.S. Army Corps of Engineers tide gauge stations in Louisiana (U.S. Army Corps of Engineers, 1931–1988).

into monthly summaries of mean monthly and annual water levels. For each station, a time-series plot of annual water levels was constructed. A linear regression was performed on the complete data set in order to produce a best-fit straight line with a slope equal to the rate of relative sea-level rise. In this way, a relative sea-level rise rate based on the entire record was obtained. The maintenance history for each station was reviewed to remove any errors in the data that may have resulted from re-positioning or damage to the station. This same procedure was performed for the NOS tide gauge stations in Texas, Mississippi, and Florida. The tide gauge stations with sufficient record included Port Isabel and Galveston in Texas and Pensacola, Cedar Key, St. Petersburg, and Key West in Florida. USACE maintains a station in Biloxi, Mississippi which was used with the NOS stations to complete the comparison in the Gulf of Mexico.

Data from 20 U.S. Army Corps of Engineers tide gauge stations in the Louisiana coastal region were analyzed for this study. Daily USACE water level measurements were averaged and summarized in mean monthly and mean annual tables. The mean annual water-level history was then plotted against time. A linear regression was performed to produce a best-fit straight line with a slope equal to the rate of change in sea-level. This analysis was performed for the entire record. The maintenance record for each tide gauge was examined to identify errors in the data set. The USACE stations were grouped into seven geomorphic regions: (1) the Chenier plain, (2) the Teche basin, (3) the Terrebonne delta plain, (4) the Barataria Basin, (5) the Balize delta, (6) the St. Bernard delta plain, and (7) the Pontchartrain Basin (Figure 4).

NOS Tide Gauge Results—Gulf of Mexico

Louisiana. The Eugene Island station lies on the Point au Fer shell reef system 8 km south of the prograding Atchafalaya River delta (Figure 3A). This station has a good maintenance record, but recently has become more and more affected by Atchafalaya River flooding, notably the spring floods of 1972 and 1973. An analysis of the entire record (1939–1974) indicates a relative sea-level rise rate at Eugene Island of 1.19 cm/yr (Table 1). The Bayou Rigaud tide gauge station at Grand Isle lies behind the barrier island on the Exxon Dock adjacent to Barataria Pass (Figure 3A). After the Bayou Rigaud station was destroyed, NOS established a new station at the U.S. Coast Guard station and renamed it East Point. The records show that, between 1947 and 1987, relative sea-level rose steadily at a rate of 1.04 cm/yr (Table 1, Figure 5). The water-level time series appears to have been contaminated very little by Mississippi River flooding.

Texas. The Galveston tide gauge station is located at the east end of Galveston Island on the Texas coast (Figure 3A). This site is connected to the Gulf of Mexico by the Houston Ship Channel. The period of record ran from 1908 to 1986 and the rate of relative sea-level rise was analyzed to be 0.63 cm/yr (Table 1, Figure 6).

The Port Isabel tide gauge station lies on the mainland shoreline of Laguana Madre at the south end of Padre Island (Figure 3A). Relative sea-level rise was 0.31 cm/yr between 1944 and 1986 (Table 1, Figure 6).

Florida. The Pensacola tide gauge station

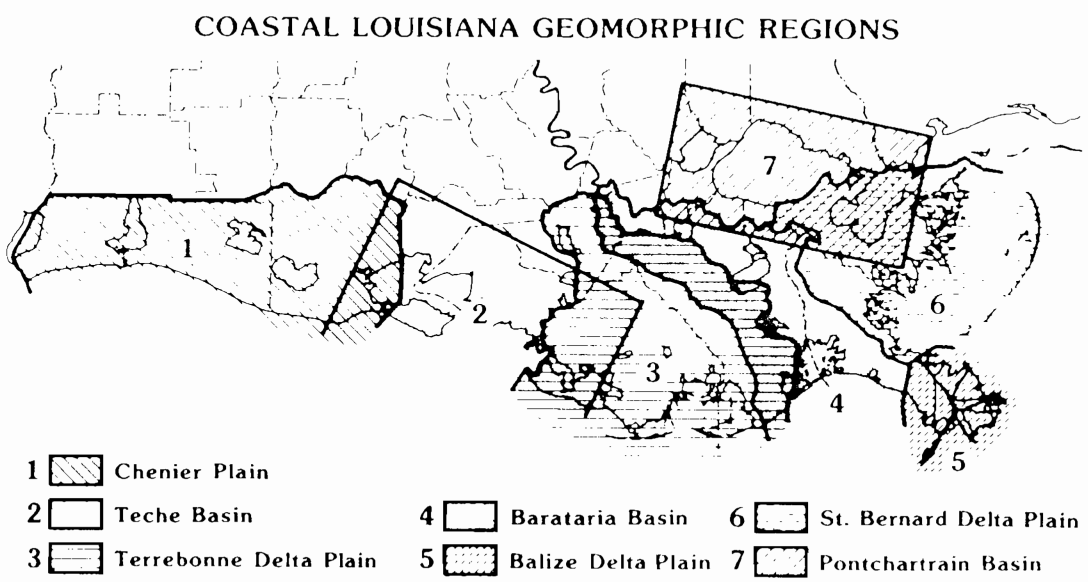


Figure 4. Geomorphic regions in coastal Louisiana.

Table 1. *National Ocean Survey (NOS), Gulf of Mexico Tide Gage Stations.*

Station Name	Station Location	Record Period	RSL (cm/yr)
Eugene Island	Louisiana	1934–1974	1.19
Grand Isle	Louisiana	1947–1987	1.04
Galveston	Texas	1908–1988	0.63
Port Isabel	Texas	1944–1979	0.31
Pensacola	Florida	1923–1988	0.23
Cedar Key	Florida	1914–1986	0.17
St. Petersburg	Florida	1947–1986	0.24
Key West	Florida	1913–1986	0.22

lies on the mainland shoreline of Escambia Bay near the west end of Santa Rosa Island (Figure 3A). The station is connected to the Gulf of Mexico by Perdido Pass. An analysis of the entire period of record, 1923 to 1986, reveals a rate of relative sea-level rise of 0.23 cm/yr (Table 1, Figure 7).

The Key West tide gauge station lies at the extreme western end of the Florida Keys in the southeastern Gulf of Mexico (Figure 3A). The relative sea-level rise rate for the period of record, 1913 to 1986, was calculated to be 0.22 cm/yr (Table 1, Figure 7).

The St. Petersburg tide gauge station is on the western shore of Tampa Bay and the locale is connected to the Gulf of Mexico by a series of tidal inlets along the Tampa Bay barrier shoreline (Figure 3A). Its period of record runs from 1947 to 1986 and yielded a relative sea-level rise rate of 0.24 cm/yr (Table 1, Figure 8).

The Cedar Key tide gauge station lies on a

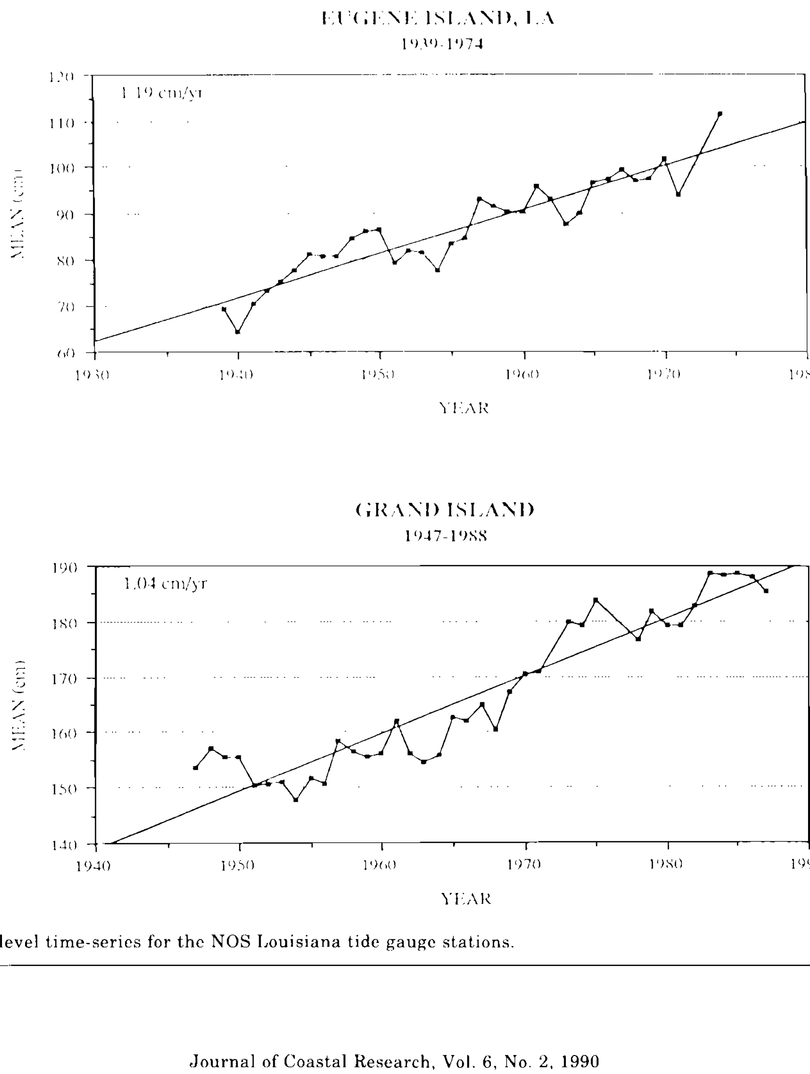


Figure 5. Water level time-series for the NOS Louisiana tide gauge stations.

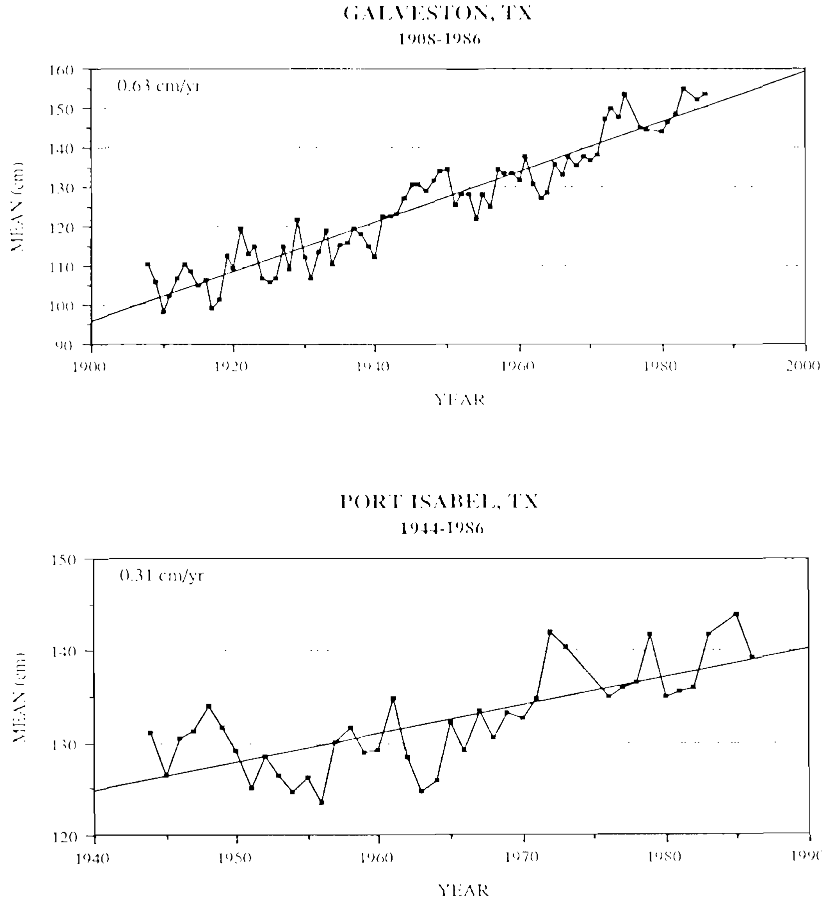


Figure 6. Water level time-series for the NOS Texas tide gauge stations.

coastal island between Suwannee Sound and Waccassa Bay in the Big Bend region of Florida (Figure 3A), directly on the Gulf of Mexico. A relative sea-level rise rate of 0.17 cm/yr was calculated for the period of record 1914 to 1986 (Table 1, Figure 8).

USACE Tide Gauge Results—Louisiana

Chenier Plain. The Chenier Plain in western Louisiana is a marginal delta plain composed of a series of transgressive shell or sand ridges separated by regressive mud flats (Figure 4). The Chenier Plain is about 2,500 years old (GOULD and McFARLAN 1959; PENLAND and SUTER, 1990). It began prograding seaward when sea-level rise slowed at the approximate end of the Wisconsinan glacial period. This coastal deposit pinches out landward about 49 km inland on the Pleistocene Prairie terrace and reaches a maximum thickness of about 10 m along the shoreline. The USACE maintains 12 tide gauge stations on the Chenier Plain. A review of these water-level time series indicate that only eight of the tide gauge stations have periods of record sufficient for analysis (Table 2).

The Calcasieu Pass tide gauge station lies about 3 km from the coast near Cameron which is connected to the Gulf of Mexico via Calcasieu Pass (Figure 3B). Of the Chenier Plain stations, it is most directly connected to the Gulf of Mexico and thus should have the most accurate measurements (Figure 9). The rate of relative sea-level rise for the station's entire period of record is 0.57 cm/yr (Table 2).

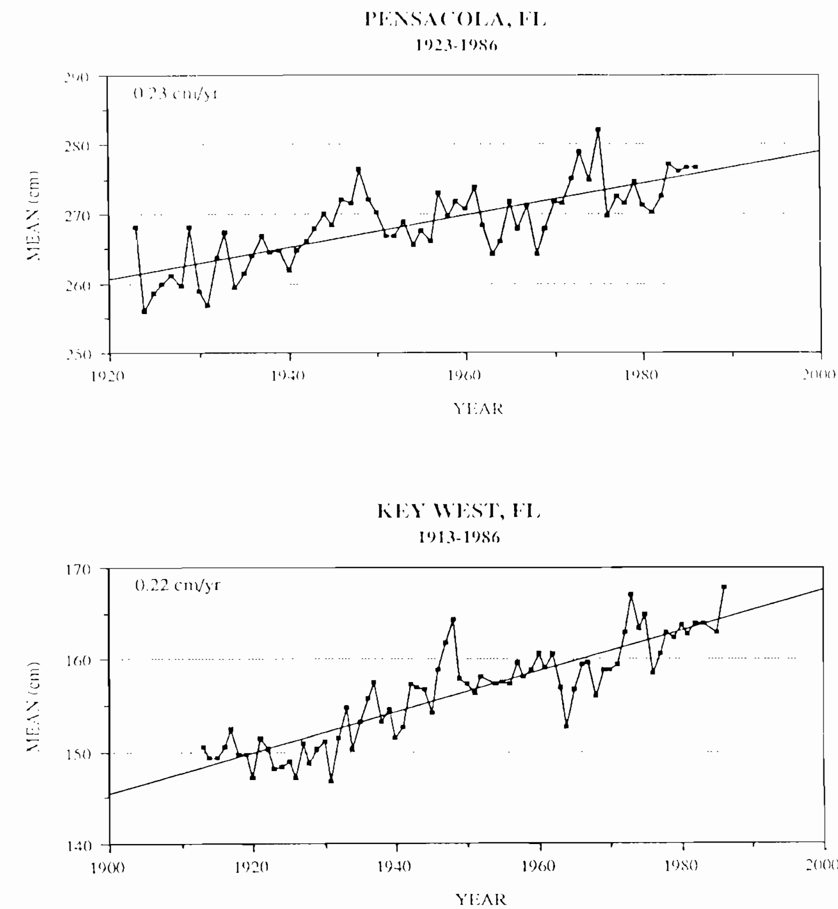
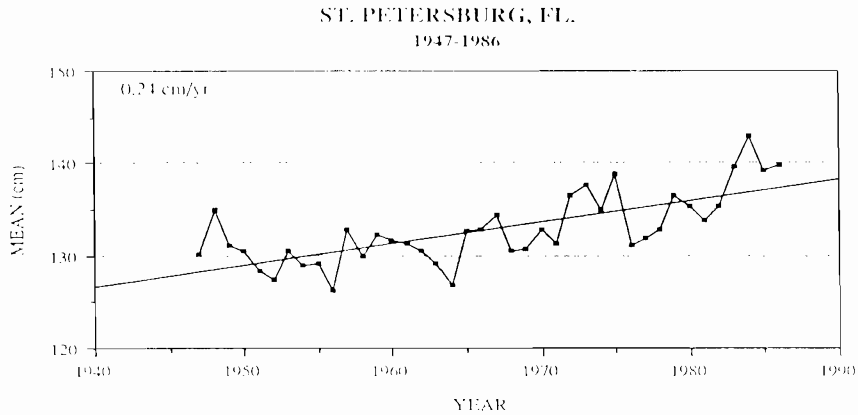


Figure 7. Water level time-series for the NOS Pensacola and Key West, Florida tidal stations.

The rates of relative sea-level rise for the Chenier Plain stations with complete records range between 0.34 cm/yr and 0.69 cm/yr for the period of record (Table 2). The average rate of relative sea-level rise, based on all eight Chenier Plain tide gauge stations, is 0.57 cm/yr.

Teche Basin. The Teche Basin is a marginal deltaic basin that developed within the erosional remnants of the Teche delta complex in the late Holocene delta plain when sea-level stood 4-6 m below present (Figure 4). Submergence of this delta complex over the last 4,000 years has generated a series of interconnected bays between the old Teche distributaries (PENLAND *et al.*, 1987). These bays are partially separated from the Gulf of Mexico by Marsh Island, Atchafalaya Bay shell reefs, and Point au Fer Island. The thickness of the Holocene section increases from west to east in the Teche basin because it overlies the western wall of the infilled Pleistocene valley of the Mississippi River (KOLB and VAN LOPIK 1958). Holocene sequences range from 10–15 m thick near Chenier au Tigre to over 100 m thick near Morgan City. Vermilion Bay, West Cote Blanche Bay, East Cote Blanche Bay, and Atchafalaya Bay make up the Teche Basin.

The water-level regime in the Teche Basin is complicated by the growth of the Atchafalaya River delta complex into the basin. Increasing seasonal flooding combined with high rates of sedimentation associated with delta growth tend to amplify the effects of relative sea-level rise. The tide gauge stations in the Teche basin measure the combined effects of eustatic



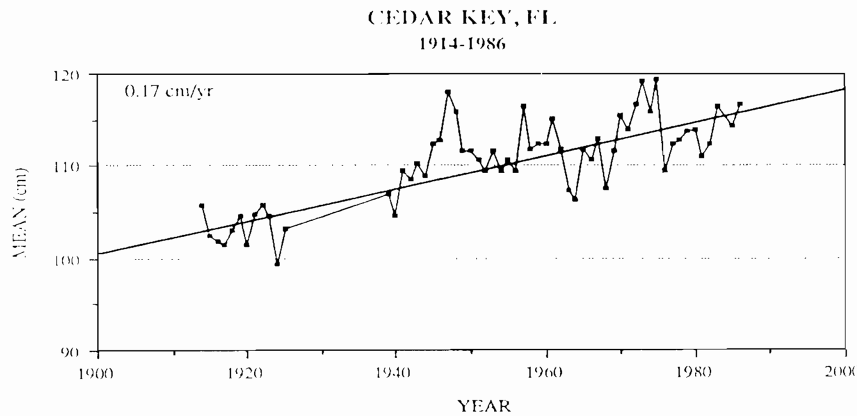


Figure 8. Water level time-series for the NOS St. Petersburg and Cedar Key, Florida tidal stations.

changes and subsidence with the added effect of rising Atchafalaya River stages.

The USACE maintains 23 tide gauge stations throughout the Teche Basin. A review of their water level histories indicates that only three of these stations have sufficient periods of record or clean enough records to make them suitable for analysis (Table 2). These stations are Calumet, Eugene Island, and Morgan City. The rates of relative sea-level rise were measured at 1.77 cm/yr, 1.17 cm/yr, and 1.26 cm, respectively, for the periods of 1942–1988, 1942–1988 and 1933–1987, respectively (Figure 10). The average relative sea-level rise rate for the entire period of record for all three Teche Basin stations is 1.40 cm/yr. It is important to note the variable and erratic character of these tide gauge records as compared to records from other stations in Louisiana. These erratic, and rapid water level changes can be attributed to several years of flooding associated with the growth of the Atchafalaya River delta (Table 2).

Terrebonne Delta Plain. The Terrebonne delta plain represents the depositional surface of the Teche and Lafourche delta complexes of the Mississippi River delta plain (Figure 4). This delta plain consists of several small deltas that are truncated by a series of transgressive barrier shorelines generated by multiple episodes of distributary switching (PENLAND *et al.*, 1987; PENLAND *et al.*, 1988c). The Terrebonne delta plain directly overlies the infilled Pleistocene valley of the Mississippi River. The thickness of the Holocene section in this region ranges between 100 m and 200 m. The western

Table 2. *U.S. Army Corps of Engineers, Louisiana Tide Gage Stations.*

Station Name	Parish Location	Record Period	RSL (cm/yr)
Chenier Plain			
Cameron	Cameron	1942–1988	0.57
Hackberry	Cameron	1943–1988	0.34
Mermentau River	Cameron	1949–1988	0.69
Schooner Bayou-East Auto	Vermilion	1942–1988	0.61
Schooner Bayou-East Staff	Vermilion	1942–1988	0.58
Vermilion Lock-East Auto	Vermilion	1942–1988	0.53
Vermilion Lock-East Staff	Vermilion	1943–1988	0.54
Vermilion Lock-West	Vermilion	1942–1988	0.68
Teche Basin			
Calumet	St. Mary's	1942–1988	1.77
Eugene Island	St. Mary's	1942–1988	1.17
Morgan City	St. Mary's	1933–1987	1.26
Terrebonne Delta Plain			
Greenwood	Terrebonne	1942–1986	0.98
Houma	Terrebonne	1946–1988	1.09
Barataria Basin			
Grand Isle	Jefferson	1949–1986	1.11
Balize Delta Plain			
Port Eads	Plaquemines	1944–1988	0.94
St. Bernard Delta Plain			
South Shore	Orleans	1949–1986	1.01
Little Woods	Orleans	1931–1977	1.09
Pontchartrain Basin			
West End	Jefferson	1931–1987	0.40
Frenier	St. John the Baptist	1931–1984	0.36
Mandeville	St. Tamany	1931–1988	0.45

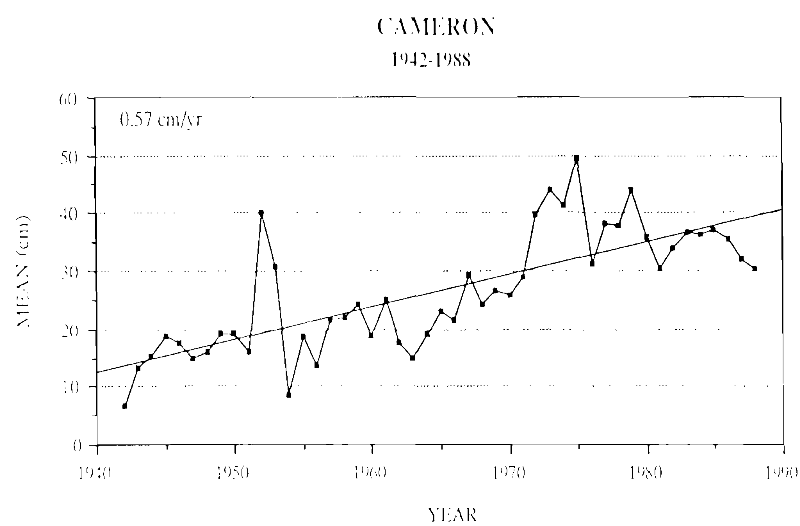


Figure 9. Water level time-series for U.S. Army Corps of Engineers Chenier plain.

margin of the Terrebonne delta plain is adjacent to the prograding Atchafalaya River delta and is experiencing higher and higher river stages as a result. In contrast, the eastern portions of the Terrebonne delta plain are not affected by the Atchafalaya River.

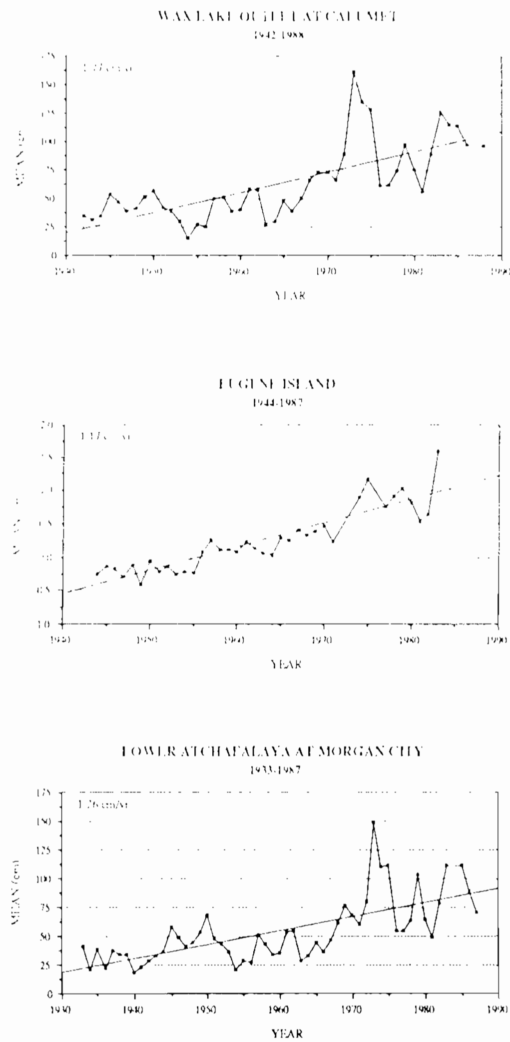


Figure 10. Water level time-series for U.S. Army Corps of Engineers Teche basin.

The USACE maintains eight tide gauge stations in the Terrebonne delta plain. A review of the water-level histories from these stations indicates that only two locations had periods of record suitable for analysis. The Greenwood tide gauge station is located in the western portion of the Terrebonne delta plain in the zone influenced by Atchafalaya River flooding (Figure 3B). The Houma tide gauge station lies in the central portion of the Terrebonne delta plain (Figure 3B).

The Greenwood tide gauge station is in Bayou Black 25 km east of the Atchafalaya River. The period of record analyzed for this station ran from 1942 to 1986. The analysis indicated a relative sea-level rise rate of 0.98 cm/yr (Table 2, Figure 11).

The Houma tide gauge station lies 70 km inland on the Intracoastal Waterway and is connected to the Gulf of Mexico by the Houma Navigation Channel. The period of record analyzed was from 1946 to 1988. The rate of relative sea-level rise was calculated to be 1.09 cm/yr during this interval (Figure 11). The average

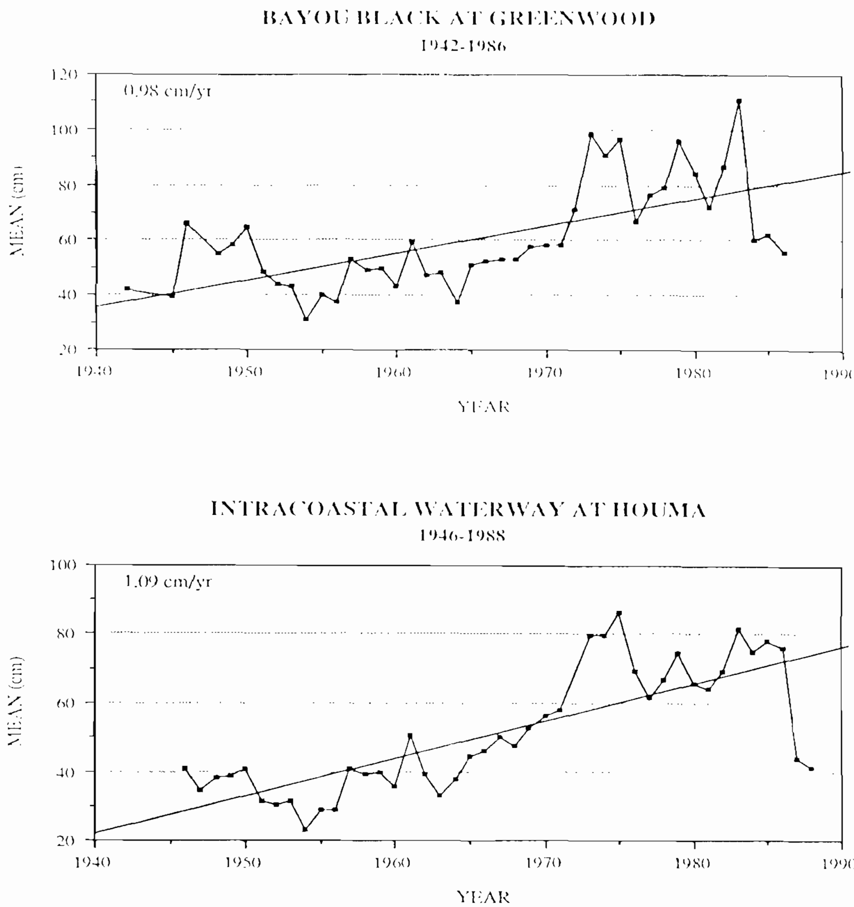


Figure 11. Water level time-series for U.S. Army Corps of Engineers Terrebonne delta plain.

relative sea-level rise rate for the two Terrebonne delta plain tide gauge stations is 1.04 cm/yr.

Barataria Basin. The Barataria Basin is an interdistributary wetland system located between the abandoned Lafourche and Plaquemines delta complexes (Figure 4). The basin consists of Lac Des Allemands, Lake Salvador, Little Lake, Caminada Bay, and Barataria Bay. The seaward margin of this deltaic estuary is formed by the Caminada-Moreau coast, Grand Isle, Grand Terre Islands, and Cheniere Ronquille. Caminada Bay and Barataria Bay are connected to the Gulf of Mexico via Caminada Pass, Barataria Pass, Pass Abel, Quatre Bayoux Pass, and Pass Ronquille. The Barataria Basin lies over the eastern wall of the infilled Pleistocene valley of the Mississippi River. The thickness of the Holocene section in the Barataria Basin increases from 10–15 m in the upper basin to over 100 m at Grand Isle (KOLB and VAN LOPIK 1958).

The USACE maintains seven tide gauge stations in the Barataria Basin. A review of the water level histories for these tide gauge stations revealed that only one site has a record suitable for analysis. The Grand Isle tide gauge station is located at the U.S. Coast Guard station on Bayou Rigaud, less than 1 km from the Gulf of Mexico via Barataria Pass. The period of record analyzed ran from 1947 to 1986. The analysis of the entire record yielded a relative sea-level rise of 1.11 cm/yr (Table 2, Figure 12).

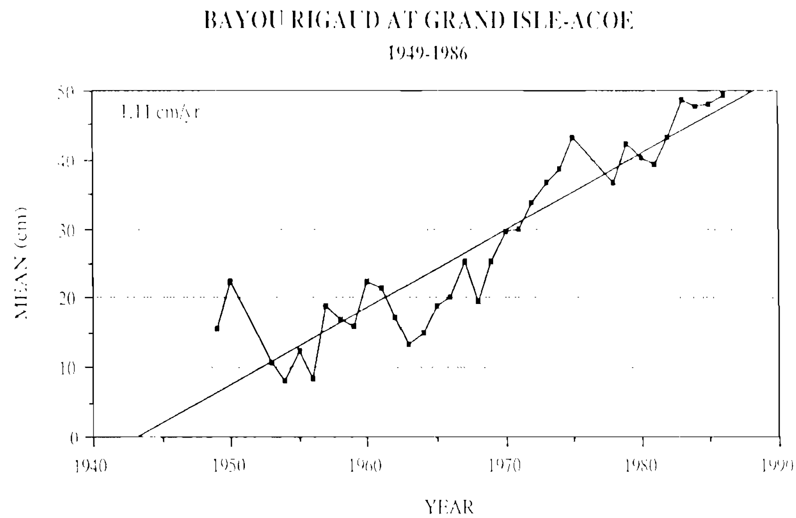


Figure 12. Water level time-series for U.S. Army Corps of Engineers Barataria basin.

Balize Delta Plain. The Balize delta plain is a smaller, active deepwater delta of the larger Modern delta complex (Figure 4). This delta lies south of Venice and consists of seven major distributaries. The delta has been building toward the edge of the continental shelf for approximately 400 years (COLEMAN, 1988). Termed the "bird-foot," the Balize delta consists of a sequence of subdeltas that have overlapped to form the depositional surface. The thickness of the Holocene section exceeds 100 m. The main distributaries of the Balize delta are Southwest Pass, South Pass, Southeast Pass, Northeast Pass, North Pass, Pass a Loutre, and Main Pass. The tidal regime in this coastal region is heavily influenced by the stages of the Mississippi River.

The USACE maintains 10 tide gauge stations in the Balize delta plain and adjacent Mississippi River. A review of these stations indicated that only one station has records of sufficient quality and duration for analysis. The Port Eads tide gauge station is located at South Pass about 4–5 km north of the Gulf of Mexico. The erratic character of the records reflects repeated flooding. The period of record analyzed was between 1944 and 1988. The analysis indicated a relative sea-level rise rate of 0.94 cm/yr (Table 2, Figure 13).

St. Bernard Delta Plain. The St. Bernard delta plain represents the depositional surface of the abandoned St. Bernard delta complex, which is more than 3,000 years old (Figure 4). The transgressive submergence of this delta complex over the last 2,000 years has generated the Chandeleur barrier island arc, which is separated from the mainland by Chandeleur Sound (PENLAND *et al.*, 1985). Numerous large passes and tidal inlets connect the St. Bernard wetlands and Chandeleur Sound with the Gulf of Mexico. The Holocene section in this area increases in thickness from 15–20 m near Little Woods to over 100 m near Breton Island.

The USACE maintains 10 tide gauge stations in the St. Bernard delta plain. Only two of these stations had records suitable for analysis, these stations are South Shore and Little Woods, located on the Bayou Sauvage delta of the St. Bernard delta complex, which separates Lake Pontchartrain and Lake Borgne. The Rigolets connects Lake Pontchartrain with the Gulf of Mexico.

The South Shore tide gauge station lies immediately west of Point aux Herbes. Its period of record runs from 1949 to 1986. The analysis of the entire water-level history yielded a relative sea-level rise rate of 1.01 cm/yr (Table 2, Figure 14).

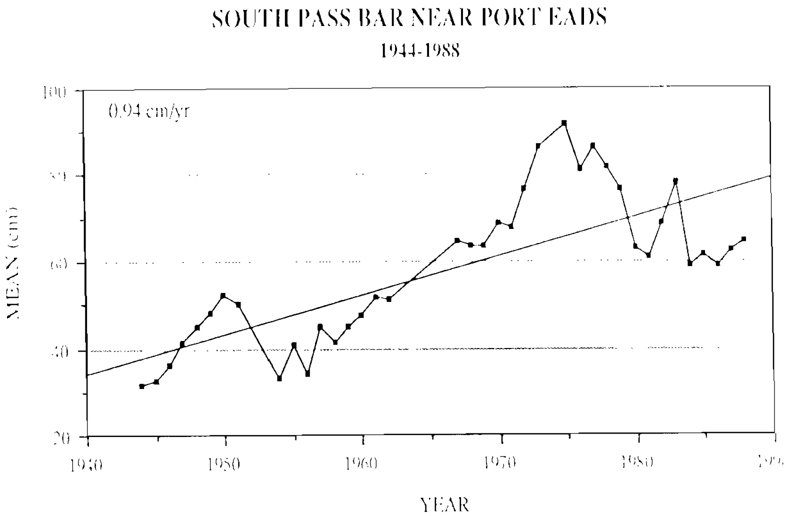


Figure 13. Water level time-series for U.S. Army Corps of Engineers Balize delta plain.

The Little Woods tide gauge station is 10 km southwest of the South Shore station. It has records dating from 1931 to 1977. A relative sea-level rise rate of 1.09 cm/yr was calculated for the entire period of record (Table 2, Figure 14).

Pontchartrain Basin. The Pontchartrain Basin is a marginal deltaic basin located between the Pleistocene terraces in the Florida Parishes and the St. Bernard delta complex (Figure 4). The progradation of the St. Bernard delta complex 2,500 years ago along the eastern side of the Mississippi River delta plain enclosed the Pontchartrain Basin, which consists of Lake Maurepas connected to Lake Pontchartrain by Pass Manchac, Lake Pontchartrain connected to Lake Borgne by The Rigolets, and Lake Borgne connected to the Gulf of Mexico by Mississippi Sound. The Holocene section of the basin pinches out against the Pleistocene terraces to the north and thickens to 10–15 m toward the south adjacent to the St. Bernard delta plain. The USACE maintains 11 tide gauge stations in the Pontchartrain Basin. Of these only three have records suitable for analysis: the West End, Frenier,and Mandeville tide gauge stations.

The West End tide gauge station lies at the western end of Lake Pontchartrain (Figure 3B). Its records date back to 1931 and continue to 1987. The analysis of the West End water-level history revealed a relative sea-level rise rate of 0.40 cm/yr (Table 2, Figure 15).

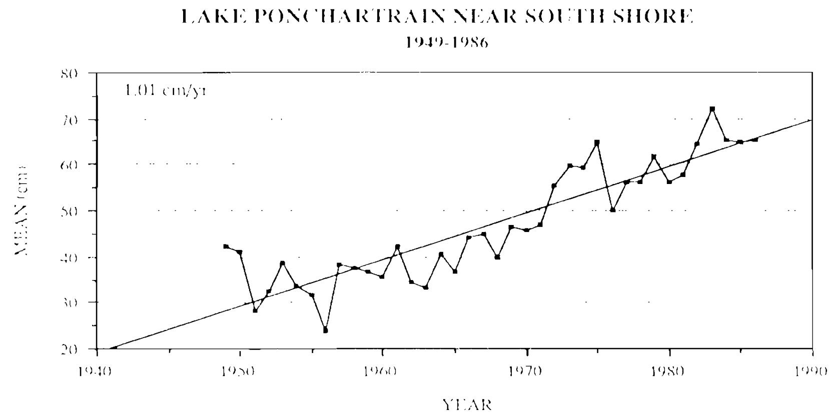
The Frenier tide gauge station is located south of the West End station on the southwest shore of Lake Pontchartrain (Figure 3B). Its period of record runs from 1931 to 1984. The water-level history analysis yielded an average relative sea-level rise rate of 0.36 cm/yr (Table 2, Figure 15).

The Mandeville tide gauge station, located on the north shore of Lake Pontchartrain (Figure 3B), has a period of record from 1931 to 1988. The analysis of its water-level history indicates a relative sea-level rise rate of 0.45 cm/yr for the entire record (Table 2, Figure 15).

REGIONAL COMPARISON

Gulf of Mexico—NOS Tide Gauge Stations

Louisiana is experiencing a higher rate of sea-level rise than any other state on the Gulf Coast. The zones of highest sea-level rise are associated with the Mississippi River delta plain, while the rates along the Chenier Plain to the west and the Pontchartrain Basin to the east decrease to levels comparable to those of adjacent coastal states (Figure 16). The highest rate of relative sea-level rise in Louisiana,



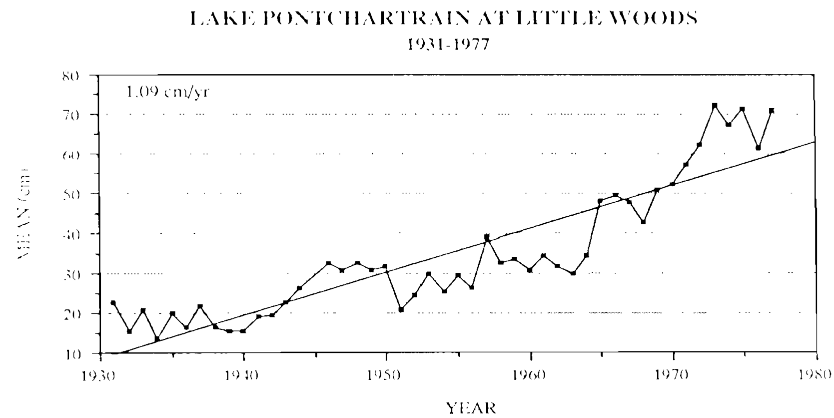


Figure 14. Water level time-series for U.S. Army Corps of Engineers St. Bernard delta plain.

according to NOS tide gauge data, is at Eugene Island, where the average rate for the period 1939–1974 has been calculated to be 1.19 cm/yr.

In Texas, the rate of relative sea-level rise ranges from 0.31 cm/yr in Port Isabel to 0.62 cm/yr at Galveston. The Galveston rate is nearly identical to the rate for the Chenier Plain in western Louisiana. In the eastern Gulf of Mexico, the Mississippi, Alabama, and Florida tide gauges recorded the lowest rates of relative sea-level rise. For Florida, the relative sea-level rise rates averaged between 0.17 cm/yr at Cedar Key and 0.23 cm/yr at Pensacola. Biloxi recorded the lowest relative sea-level rise rates in the Gulf of Mexico with an average of 0.15 cm/yr for the entire period of record.

Louisiana—USACE Tide Gauge Stations

Of the seven geomorphic regions identified in Louisiana, the Teche Basin is experiencing the highest rate of relative sea-level rise based on the USACE tide gauges (Figure 17). The average rate of relative sea-level rise recorded from the three tide gauge stations indicate a rate of 1.31 cm/yr in the Teche Basin. The Calumet tide gauge station had the highest relative sea-level rise rate, 1.77 cm/yr. However, the rapid apparent relative sea-level rise rate in the Teche Basin is anomalous due to the impact of Atchafalaya River flooding and delta building. When the measurements that were taken during the years of major flooding are omitted from the analysis, the rate of relative sea-level rise

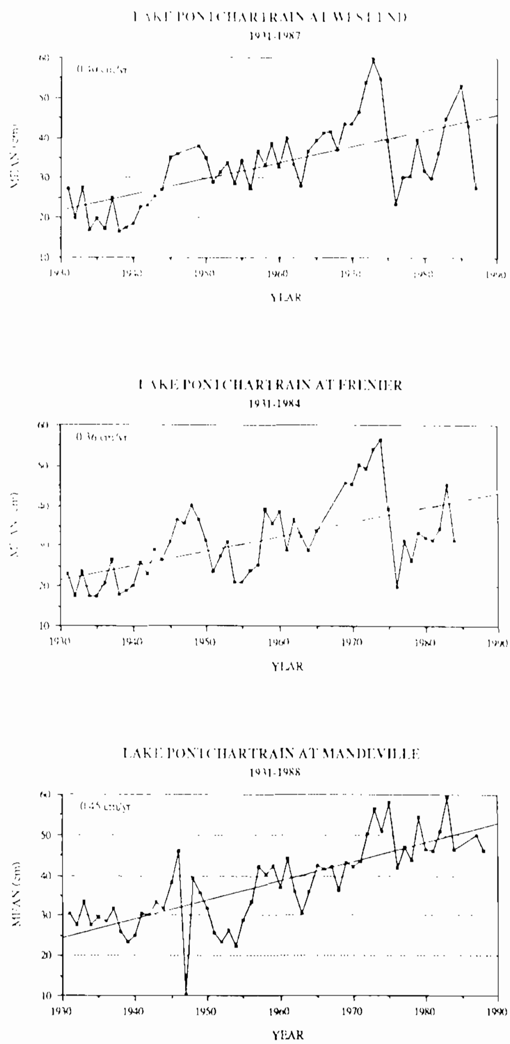


Figure 15. Water level time-series for U.S. Army Corps of Engineers Pontchartrain basin.

is reduced. For example, when this procedure was followed for the Eugene Island tide gauge station records, the overall rate of relative sea-level rise at that station fell from 1.61 cm/yr to 0.81 cm/yr. High rates of relative sea-level rise are to be expected in the Teche Basin because of the thick underlying sequence of Holocene valley fill. Even so, the Teche Basin records do not accurately depict the effects of subsidence and eustatic changes because of the Atchafalaya River flooding. Similarly, Mississippi River floods contaminate the Balize delta plain tide gauge station readings.

The second-highest rate of average relative sea-level rise, 1.04 cm/yr, is found in the Terrebonne delta plain and is based on an average of the Greenwood and Houma stations. These high rates of relative sea-level rise are to be expected because the Terrebonne delta plain directly overlies the thickest portion of the Mississippi River delta plain where the Holocene section is more than 250 m thick. Because there is minimal contamination from the Atchafalaya River, the Terrebonne delta plain measurements should represent accurately the combined effects of eustatic change and compac-

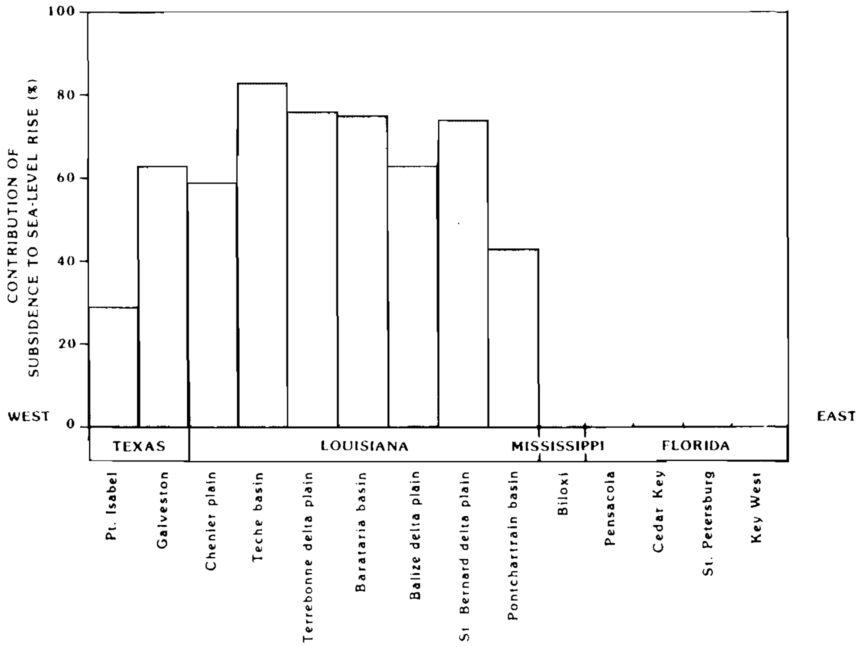


Figure 16. Relative sea-level rise histogram for the NOS Gulf of Mexico.

tional subsidence. On either side of the Teche Basin and Terrebonne delta plain the average rates of relative sea-level rise decrease. Eastward lie the Barataria Basin, the Balize delta plain, the St. Bernard delta plain, and the Pontchartrain Basin, with rates of 1.11cm/yr, 0.94 cm/yr, 1.05 cm/yr, and 0.41 cm/yr, respectively. To the west of the Teche Basin lies the Chenier plain, which is experiencing an average relative sea-level rise rate of 0.57 cm/yr. This pattern of relative sea-level rise is the result of impaction, which related to the varying thickness of the underlying Holocene Mississippi River delta plain (ROBERTS 1985; PENLAND *et al.*, 1988b).

Compactional Subsidence

In the Louisiana coastal zone, the natural compaction of Holocene deltaic sediments is viewed as the primary factor driving relative sea-level rise. Contour maps of the Pleistocene/Holocene boundary associated with the Mississippi River delta and chenier plains were constructed by FISK (1948) and KOLB and VAN LOPIK (1958) showing the entrenched Pleistocene valley filled with more than 150 m of Holocene sediments. We compared the thickness of the Holocene sequence and the rate of relative sea-level rise at each tide gauge station. Figure 18 illustrates this relationship between relative sea-level rise and Holocene sequence thicknesses for the Mississippi River delta and chenier plains. For the chenier plain, where the Holocene sediment thickness is less than 10 m, the lowest relative sea-level rise rates are observed. For the delta plain, where the Holocene sediment thickness is greater than 50 m, the highest relative sea-level rise rates are found. This relationship indicates that the rapid rate of sea-level rise observed in Louisiana can be attributed to the natural compaction found in the Mississippi River delta plain.

CONCLUSIONS

(1) The analysis of National Ocean Survey tide gauge records from nine stations along the U.S. Gulf Coast indicates that Louisiana is experiencing the highest rates of relative sea-level rise in the Gulf of Mexico. Maximum relative sea-level rise rates in Louisiana ranged

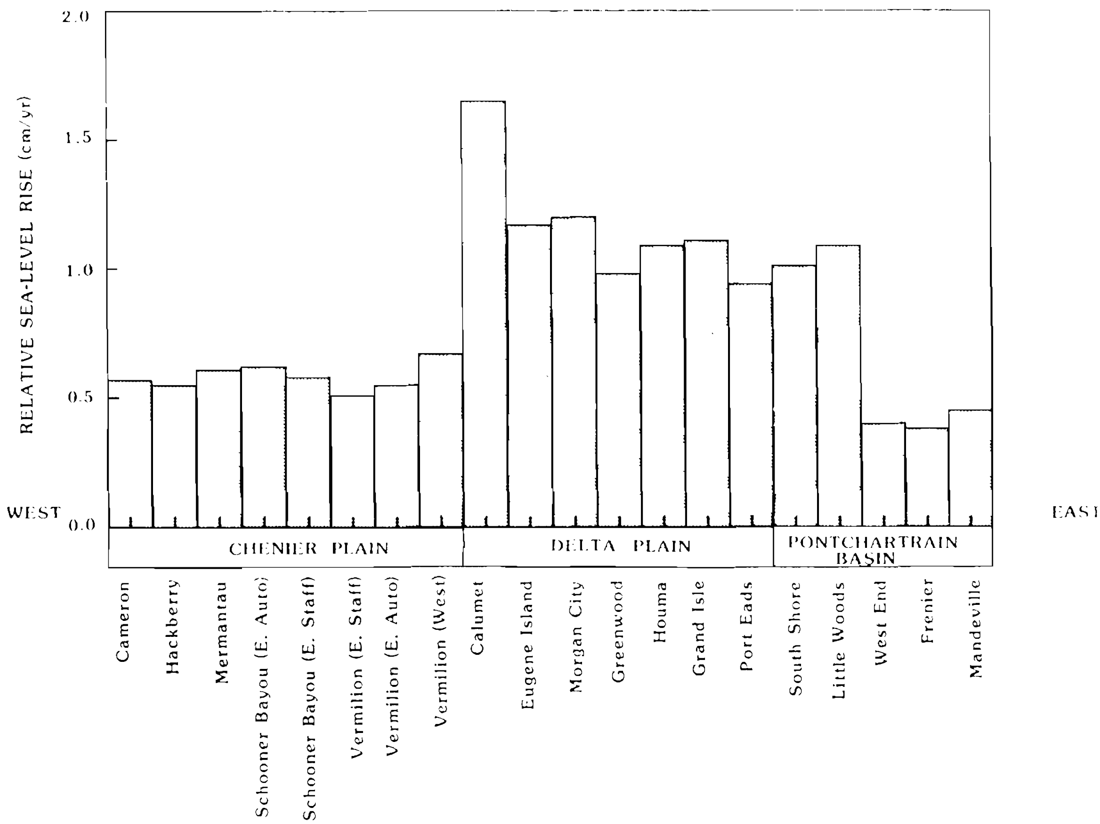


Figure 17. Relative sea-level rise histogram for the U.S. Army Corps of Engineers Louisiana stations.

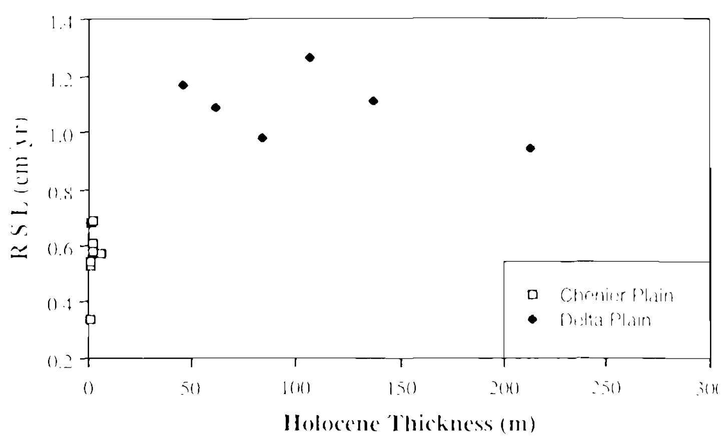


Figure 18. Relationship between relative sea-level rise and the thickness of the Holocene sediments in the Mississippi River delta and chenier plains.

between 1.04 cm/yr and 1.19 cm/yr. Texas ranks second with rates ranging between 0.31 cm/yr and 0.63 cm/yr, followed by Florida with rates from 0.17 cm/yr to 0.24 cm/yr, and Mississippi-Alabama with a rate of 0.15 cm/yr.

(2) An analysis of U.S. Army Corps of Engineers tide gauge records from 20 stations in coastal Louisiana indicates that the highest rate of relative sea-level rise not *contaminated* by the discharge of the Mississippi River is 1.11 cm/yr at Grand Isle within the Barataria Basin. Relative sea-level rise rates up to 1.77 cm/yr can be found within the Teche Basin, but the average rates from these stations have been artificially elevated by readings taken during the flood stages of the Atchafalaya River. Relative sea-level rise rates decrease east and west away from the Terrebonne delta plain. East of the delta plain lies the Pontchartrain Basin where relative sea-level rise rates range from 0.36 cm/yr to 0.45 cm/yr. West of the delta plain, the rates range between 0.34 cm/yr and 0.69 cm/yr.

(3) The regional pattern of rapid relative sea-level rise observed for Louisiana is related to the thickness of the underlying Holocene sediments. The greatest rates of relative sea-level rise are associated with the Mississippi River delta plain where the underlying Holocene section reaches a maximum thickness of about 150–200 m. East and west of the delta plain, the thickness of the Holocene section decreases to less than 20 m. In some cases the Holocene section pinched out completely as it does in Florida. The rates of both relative sea-level rise and subsidence decrease east and west of Louisiana.

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RÉSUMÉ

La Louisiane connait actuellement les plus sérieuses pertes de sables et érosions rencontrées sur les îles barrières d'Amérique du Nord. Ces pertes affectent plus de $102 km^2$ par an dans le delta du Mississippi, et $0,326 km^2$ par an de la surface des îles barrières. Les facteurs essentiels conduisant à la déterioration de la frange côtière de Louisiane sont: la rapide montée du niveau de la mer induite par la subsidence du delta, et un déficit des apports terrigènes sur les zones humides.

La montée moyenne du niveau de la mer entre 1946 et 1988 est de 1,09cm par an dans la plaine du Mississippi à Houma; sur le littoral, à l'île Eugène, elle atteint 1,19cm par an. La comparaison de l'ensemble des données montre que le niveau de la mer monte plus vite dans la zone de Terrebonne Parish que partout ailleurs en Louisiane. Les faits historiques concrétisant cette montée du niveau de la mer (plaine de Chénier, bassins de Teche, Baratavia et Ponchartrain, deltas de Terrebonne, Balize et St. Bernard) indiquent que la hausse moyenne du niveau de la mer décroît d'est en ouest à partir de la zone littorale de Terrebonne. Comparées à celles du golfe, ces données montrent que la Louisiane connait une montée relative de 1,04 cm par an à Grand Isle, que ce chiffre décroît à 0,62cm par an à Galveston (Texas), pour atteindre 0,15cm par an à Biloxi (Mississippi). La montée moyenne du niveau de la mer en Louisiane est plus de 5 fois supérieure à celle du golfe du Mexique. Comparée à la montée globale du niveau de la mer (0,12cm par an), celle qui est enregistrée à Grand Isle (1,04cm par an) montre que la mer monte dix fois plus vite en Louisiane que dans les autres parties du monde.

La rapidité de cette montée peut être attribuée à la subsidence du delta du Mississippi par compaction sédimentaire. En effet, la Louisiane s'étend sur la vallée pléistocène du Mississippi, recouverte par les sédiments du delta holocène de plus de 150m d'épaisseur.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*