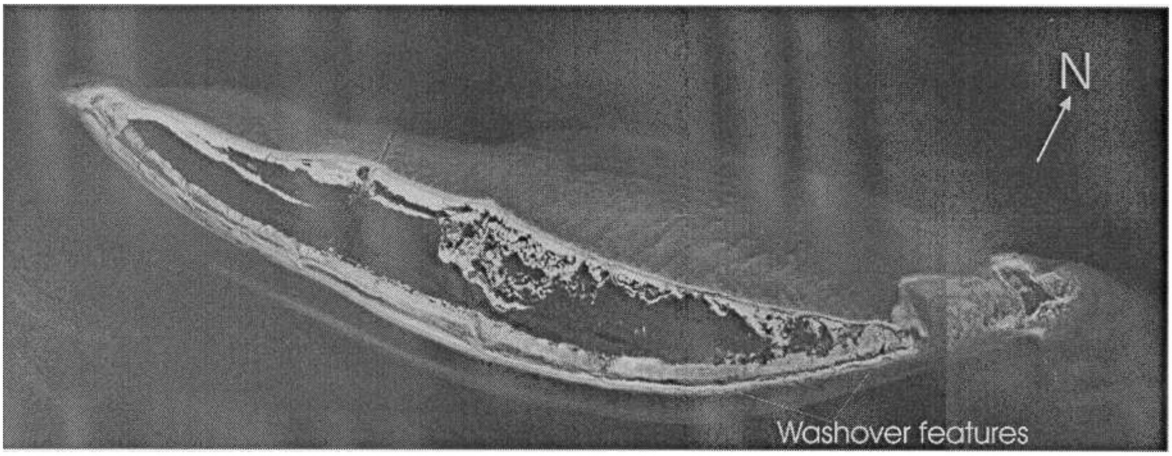
West Ship Island Evolution, Morphology, and Hurricane Response -- 1995 to 2000

By Keil **Schmid**



Mississippi Department of Environmental Quality
Office of Geology
Open-File Report 133

S. Cragin Knox
State Geologist

Coastal Section
Energy and Coastal Geology Division
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ABSTRACT

West Ship Island is part of the Gulf Islands National Seashore in Mississippi; it is a popular tourist destination and is the site of historic Fort Massachusetts. Hurricane Georges passed just to east of the island *in* late September 1998. This report has combined new shoreline data including LIDAR, Global Positioning System (GPS) surveys, and cross-shore profiles with traditional data sources such as aerial photography, sediment cores, and bathymetry to describe island change in the period preceding Hurricane Georges, change caused by the hurricane, and change during recovery-

Island evolution prior to the storm's passage had been described as rotational, with the island actually moving southward toward the Gulf of Mexico (regressive)- During the hurricane the island retreated and portrayed typical transgressive (toward shore) behavior. Following the hurricane, the island regained much of the 39 acres lost during the storm-

One key feature of the island's overall evolution seems to be Loggerhead Shoal to the east of the island. To the west of the shoal longshore transport and low elevations dominate- Cross-shore transport and hummocky dunes are associated with the island landward of the shoal- The location of Loggerhead Shoal appears to be a result of earlier Pleistocene topography.

INTRODUCTION

The evolution of the Mississippi barrier islands from shoals (Otvos, 1970a;b;1979) to the present configuration is driven by natural interactions between relative sea level, sediment supply, and meteorological - oceanographic conditions (McBride and Byrnes, 1995), and by human induced changes from dredging, sediment diversion, and habitat control (Shabica et al., 1984)- As meteorological conditions (energy) vary by orders of magnitude over short durations, changes in barrier island position and morphology typically happen at irregular and exaggerated rates (Byrnes et al., 1989)- The Mississippi barrier islands are no exception, with average shoreline position changes in some areas as high as 90 meters/year (McBride and Byrnes, 1995; McBride et al., 1995)-

These high rates make simple Global Positioning System (GPS) shoreline surveys, with accuracies of better than five meters (Hutchins and Oivanki, 1994), a viable way to document island evolution at yearly to semi-yearly scales- This is an important milestone in the study of hurricane change along the Mississippi barrier islands; at no time before could shoreline evolution be as densely and completely quantified prior to and following a hurricane's passage without incurring high costs. Previous studies have documented short temporal changes; however, they have been mainly qualitative (Byrnes et at., 1989). Temporally dense data also help highlight fine-scale spatial trends and possibly the mechanisms that taken in total are important ingredients in island morphology and evolution.

Beyond satellite based surveying, the availability of Light Detection and Ranging (LIDAR) data to researchers has brought highly accurate elevation data sets to the greater research community. LIDAR has been successfully used in documenting seasonal change in coastal California as well as the Atlantic Coast (Morgan et al., 1999; Sallenger et al., 1998).

This report focuses on West Ship Island and is part of a series covering recent change on the Mississippi barrier islands in response to Hurricane Georges. West Ship was originally part of Ship Island, which was breached during Hurricane Camille in 1969. The two islands now appear to be evolving separately. As West Ship is a relatively "new" island, being separated from East Ship several times and then permanently during Hurricane Camille (Nummedal et al., 1980), it also offers some insight on inter-island processes and formation mechanisms.

Study Site

Coastal Mississippi stretches from Louisiana in the west to Alabama in the east (Figure 1) and contains five nearly shore-parallel barrier islands. The Mississippi barrier islands are an elongate east - west chain, located 15 to *20* kilometers *from the* mainland coast. From east to west, the islands are Petit Bois, Horn, East Ship, West Ship, and Cat (Figure 2). Petit Bois, Horn, East Ship, and West Ship are presently part *of* the Gulf Islands National Seashore and Cat is in the stages of being acquired. All of the islands in Mississippi are broadly considered high profile, regressive barrier islands (Nummedal et al., 1980), although each island has extensive low profile areas that change rapidly. The eastern islands appear to exhibit a shoal to island geology (Otvos, 1970a;b) with the main source of sediment *from* the Alabama mainland coast (Otvos, 1985). Their early formation into islands has been placed in the Mid-Holocene (about 3-4 thousand years ago) (Otvos, 1979). Historically, within the last 300 years, the eastern islands (Petit Bois and Horn) have had a dominantly translational - longshore drift movement, such that they are not moving landward but rather along the coast. Cat Island, the westernmost island, has had very little translational movement and is instead eroding in place. The two Ship Islands are in the middle of the spectrum. In particular, West Ship Island is a rare island in that it has actually experienced shoreline advance and an area increase between 1966 (prior to Hurricane Camille) and 1986 (McBride and Byrnes, 1995).

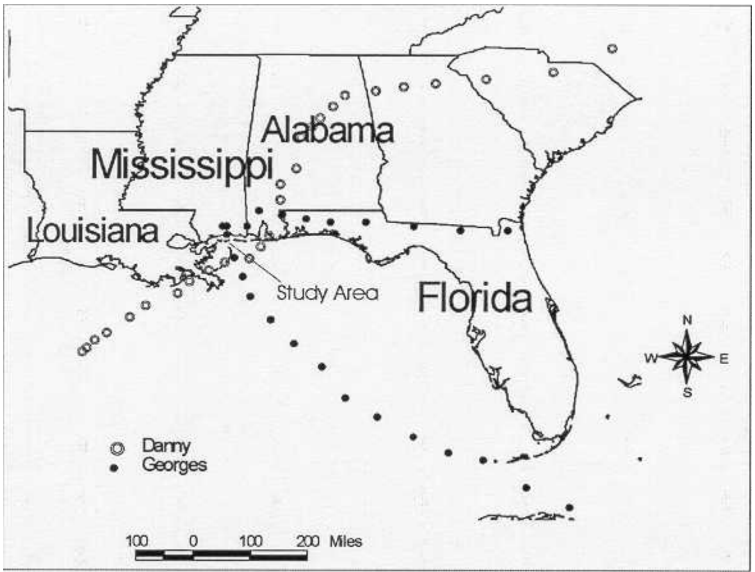

Figure 1. **General study site in southeastern United** *States.*

The importance of hurricanes on the formation and change of gulf coast barrier islands is undeniable (Nummedal et al., 1980). Each hurricane or storm is unique and its effect on individual barrier islands produces a distinct result (Morton, 1999; Sallenger, 2000). The eye of Hurricane Georges entered and passed through the Mississippi Sound between East Ship and Horn islands on September 28, 1998 (Figures 1 and 2)- It was a category 2 storm before making landfall near Biloxi, Mississippi. Although Hurricane Georges was only a category 2 storm when impacting the Mississippi Gulf Coast, its slow forward motion of about 5 mph (Otvos, 1999) caused significant damage to barrier islands in the area. In Louisiana island changes from Georges have been compared to those caused by Hurricane Camille, a category 5 storm (Penland et al-, 1999). The only other tropical storm of note to pass fairly close to Mississippi during the study period was Hurricane Danny in 1997 (Figure 1); however, it only glanced the area and was substantially weaker.

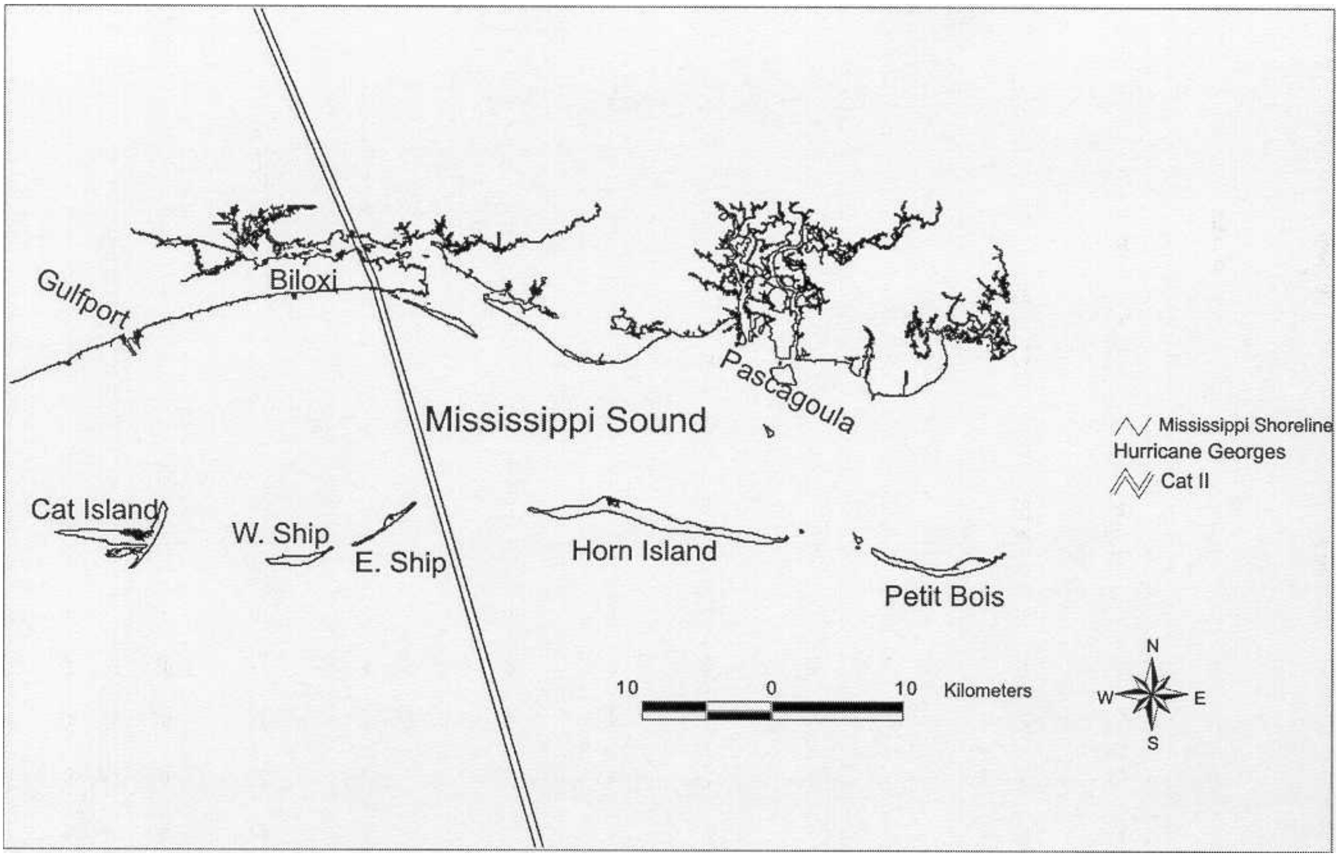

Figure 2. Study area with Hurricane Georges track.

METHODS

Several different methods were used to document island evolution prior to, in response to, and following Hurricane Georges- Kinematic GPS surveying techniques were used to highlight shoreline changes in periods prior to Hurricane Georges (1995-1997), encompassed by Hurricane Georges (1997-1998), and following Hurricane Georges (1998-2000)- To further document island changes, morphology from LIDAR elevation data sets collected following Hurricane Georges was analyzed in relation to hurricane-driven shoreline change. At representative locations, cross-shore profiles generated from LIDAR elevations taken in 1998 were compared with profiles measured with conventional survey procedures in 2001 to highlight morphology changes during the period.

Yearly GPS shoreline surveys of the Mississippi barrier islands have been performed since 1993 by the Mississippi Office of Geology and semi-annually by the National Park Service since 1998. In each survey the high tide shoreline was mapped using kinematic GPS techniques. All data were post processed, yielding accuracies on the order of ± 2-5 meters (Hutchins and Oivanki, 1994)- The high tide line, denoted by a wet-to-dry line, beach berm, or wrack line, has been chosen as the most repeatable datum and represents the state-owned boundary. Errors, both in interpreting the high-tide line and from differences in tide range, exist, although effort has been taken to insure a level of consistency between mapping parties. Tides are classified as microtidal and diurnal with a typical range of 0.5 m.

The GPS shorelines in 1995, 1997 and 2000 were surveyed during the June to early August period. The shoreline in 1998 was surveyed in November, following the passage of Hurricane Georges. Three separate time ranges are used to illustrate ambient or pre-hurricane conditions (1995-1997), hurricane-caused change (1997-1998), and the recovery stage (1998-2000)-

Locations of shoreline retreat and advance beyond certain levels were computed using buffers on GPS shorelines. The buffer width was chosen to highlight areas of significant change within the confines of the survey accuracy. Otvos (1976) suggested that areas with more than 1.2 m/yr are changing significantly. Any portions of the compared (later) shoreline landward of the base (earlier) shoreline buffers were highlighted as retreat; portions seaward of the buffers were highlighted as advance-

Buffer widths for each island were based on historic levels of shoreline change reported in Byrnes et al- (1991). West Ship Island has an average shoreline change of roughly 1-6 m/yr (rounded up to 2-0 m/yr for accuracy considerations) and a high of 3-2 m/yr (rounded up to 4.0 m/yr for accuracy considerations). Buffers were assigned using average change (years x 2.0) and high change (years x 4-0) during the ambient and recovery periods. The high change buffer was doubled for the hurricane period to account for this rare, high-energy event. During this period only major changes (years x 8-0) are highlighted; the average value was not used for the hurricane period analysis- Buffers help highlight areas of targeted change levels; they do not represent all areas of change, which would, in most cases, include the entire shoreline.

Total island area changes were also computed using GPS shorelines. This technique is especially useful in describing changes on the eastern end of the island, which is a very low-elevation spit with high shoreline change rates compared to the rest of the island. The buffer technique is too sensitive to the changes on this type of environment. The boundary between the eastern spit and the main island was established as the end of the main island following Hurricane Georges.

Shoreline configurations prior to 1993 were taken from National Ocean Service (NOS) T-sheets and aerial photography (Byrnes et al., 1991). The maps were digitized by the Louisiana Geological

Survey. These data are less accurate than GPS survey; they have accuracies on the order of ± 10 meters (Oivanki and Yassin, 1994) and are used only to document broad historic trends spanning several tens of years.

General analysis of morphology was preformed using LIDAR data flown in November 1998 (U.S. Geological Survey et at., 1998). Horizontal accuracies are on the order of 1 meter; vertical accuracies are ±15 to 20 centimeters. For general analysis of morphology, a 10 x 10 meter grid and the minimum value within each grid was used. The minimum value in the grid was specifically chosen to reduce the effects of vegetation. Elevation values were imported into AUTOCAD MAP (AutoDesk, 1998) and 10 x 10 meter gridded surface was generated using QUICKSURF (Schreiber Instruments, 1998). A triangulated grid method was chosen based on the normal spacing of data points (Schreiber Instruments, 1998).

Areas with representative morphology and shoreline change were further analyzed with a higher density of LIDAR elevation points; for these areas 2 x 2 meter grids and surfaces were chosen. The high-density data were used to produce cross-shore profiles. These LIDAR profiles were then compared to conventional profile surveys taken with a total station in 2001. Survey benchmark locations were GPS'ed and elevations taken from the 2 x 2 meter LIDAR grid. At some locations the benchmark elevation taken from the 1998 LIDAR survey was not completely accurate for 2001. In these cases, the benchmark elevations were adjusted vertically so that measured beach face morphology was consistent with respect to its elevation. LIDAR elevations over the subaqueous portions of the profiles (below sea level) are suspect so interpretations of the bathymetry changes are limited and tenuous.

Baseline historical wind and bathymetry data were obtained from the National Data Buoy Center (NDBC) and the National Geographic Data Center (NGDC). Both data sources were internally checked for errors by the providing agencies. Bathymetric data points were taken between 1935 and present and were provided in roughly 90 meter grids (6 arc seconds). The data were then contoured using 50 x 50 m grids-

DATA

Ship Island

East and West Ship islands, located ten miles (16 km) offshore of Biloxi, Mississippi, are quickly evolving Gulf Coast barrier islands that still bear the scars from Hurricane Camille (1969). Ship Island (both East and West) has experienced rapid evolution in its extent (Figure 3), especially since being breached by the 1947 Hurricane and then permanently by Camille (Schmid, 1999)- In fact, Ship Island has been breached five times since 1850 (1852, 1893, 1947, 1965, and then permanently in 1969) (Nummedal et al., 1980). Beyond change brought about by natural forces, an important factor in the island's evolution since 1948 has been maintenance of Ship Island channel. Sediment that would form the sand platform to the west of the island is lost into the channel. Subsequent dredging removes sand from the system, unless it is pumped back onto the island, as it was in the 1970's (Henry and Giles, 1975).

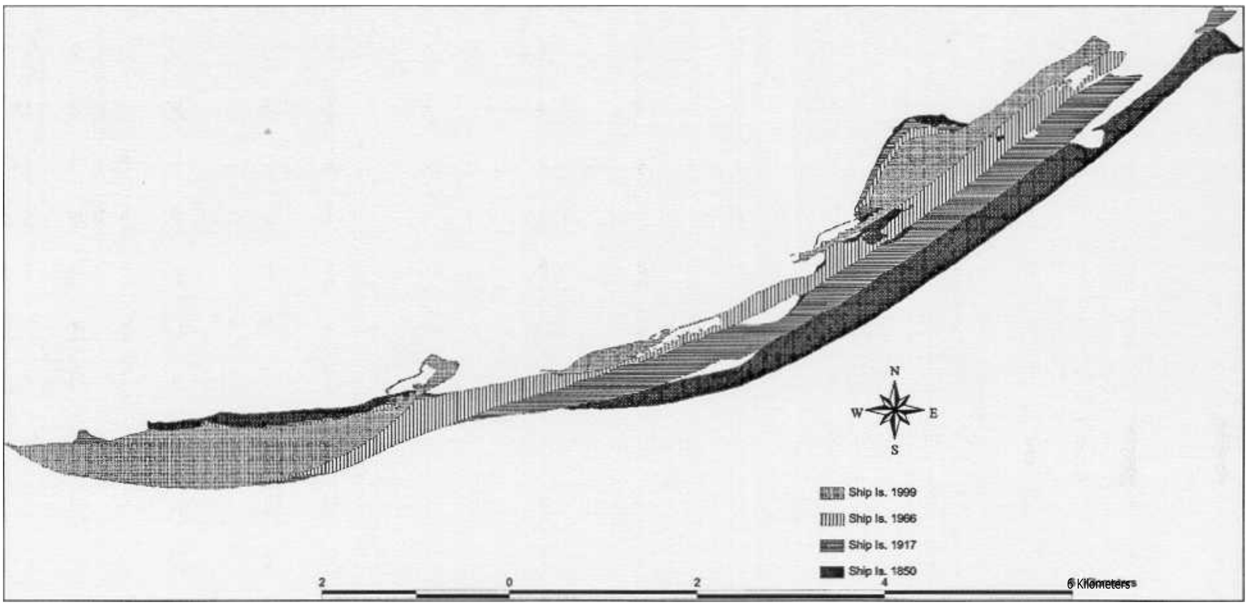

Figure 3. Historic positions and size of West Ship Island.

Ship Island is the most visited of the Gulf Islands National Seashore islands in Mississippi and has the most infrastructure. Visitors are ferried there to enjoy the beach and wildlife, and tour historic Fort Massachusetts. The fort was built to protect the approaches to New Orleans and the natural harbor on the island's northwest side (Oivanki, 1994)- Fort Massachusetts was originally built on the western tip of the island, but is now over one kilometer from the west tip (Figure 4). Erosion has threatened the fort for many years; several renourishment projects have been undertaken to protect it-

Ship Island is also important to the safety of the mainland as it shelters the highly developed Gulfport coastline and port.

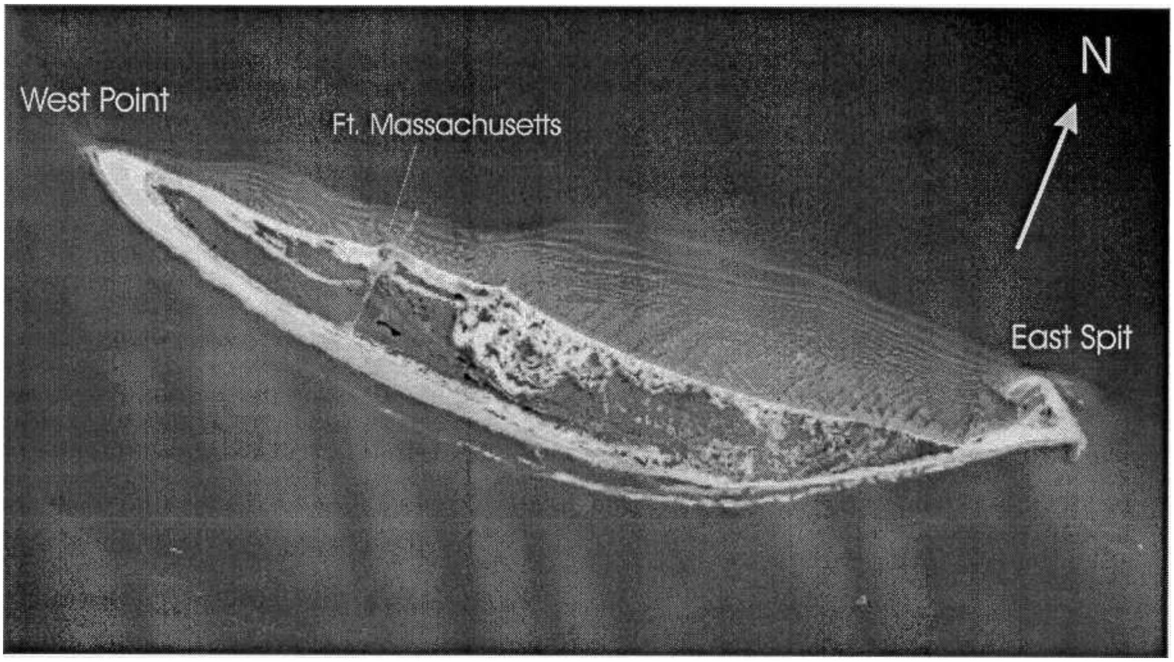

Figure 4. West Ship Island in 1996. (Photo courtesy of NOS)

Since Ship Island was severed, the two resulting islands seem to have evolved independently. West Ship Island has a higher elevation and a larger sand resource (dunes) than East Ship and is a more stable island. East Ship has experienced significant shoreline retreat (Figure 3)- Neither island is moving laterally at rates comparable to Horn and Petit Bois islands.

Yearly wind patterns from 1995 to July 2000 show little change (Figure 5), although the shapes of the wind roses are slightly different during each period. The southern shoreline (broken lines in Figure 5) has two dominant orientations that are about 30 to 35 degrees apart; the eastern segment is perpendicular to the southeast direction, the western is perpendicular to the south. The northern shoreline runs east to west (perpendicular to the north). As far as overall patterns might affect longshore drift, it would seem that during the 1995-1997 and 1998-2000 periods there is more potential for east to west longshore transport on the southern shoreline than during the 1997-1998 period. On the north side, the same pattern is also observed, as a higher percentage of time the wind was blowing from the NE as opposed to the NW in the 1995-1997 and 1998-2000 periods- Average overall wind speeds during the 1995-2000 period are highest from the northeast to northwest (about 14 knots), and lowest from the south (about 10 knots)-

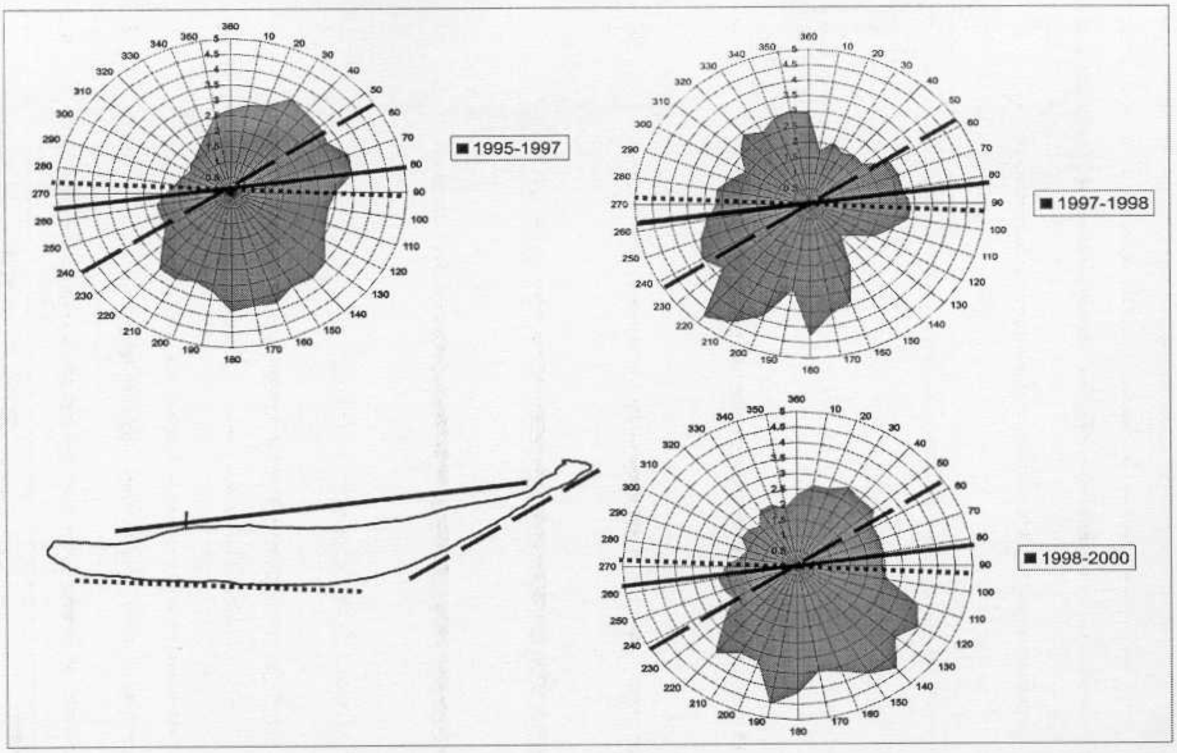

Figure 5. **Wind data taken from National Data Buoy Center - buoy #42007, approximately 10 miles southwest of Ship Island. Shaded area is the percent of time the wind was from the specific direction.**

The bathymetry works in tandem with the wind patterns (Figure 6) to shape the amount of energy . reaching the shore. Bathymetry is both an important factor in the evolution of West Ship Island and a direct result of it. One of the most striking features is the shoal, known as Loggerhead Shoal, on the southeast side of the island. It appears to influence the orientation of the southern shoreline and it forms nearly a 90 degree angle with the southeast shoreline. To the east of the start of the shoal the shoreline is oriented SW - NE, to the west it is oriented E-W. On the north side of the island there is a noticeable thinning of the shallow flats at the point east of Fort Massachusetts and a deep natural harbor to the west of Fort Massachusetts (Figures 4 and 6).

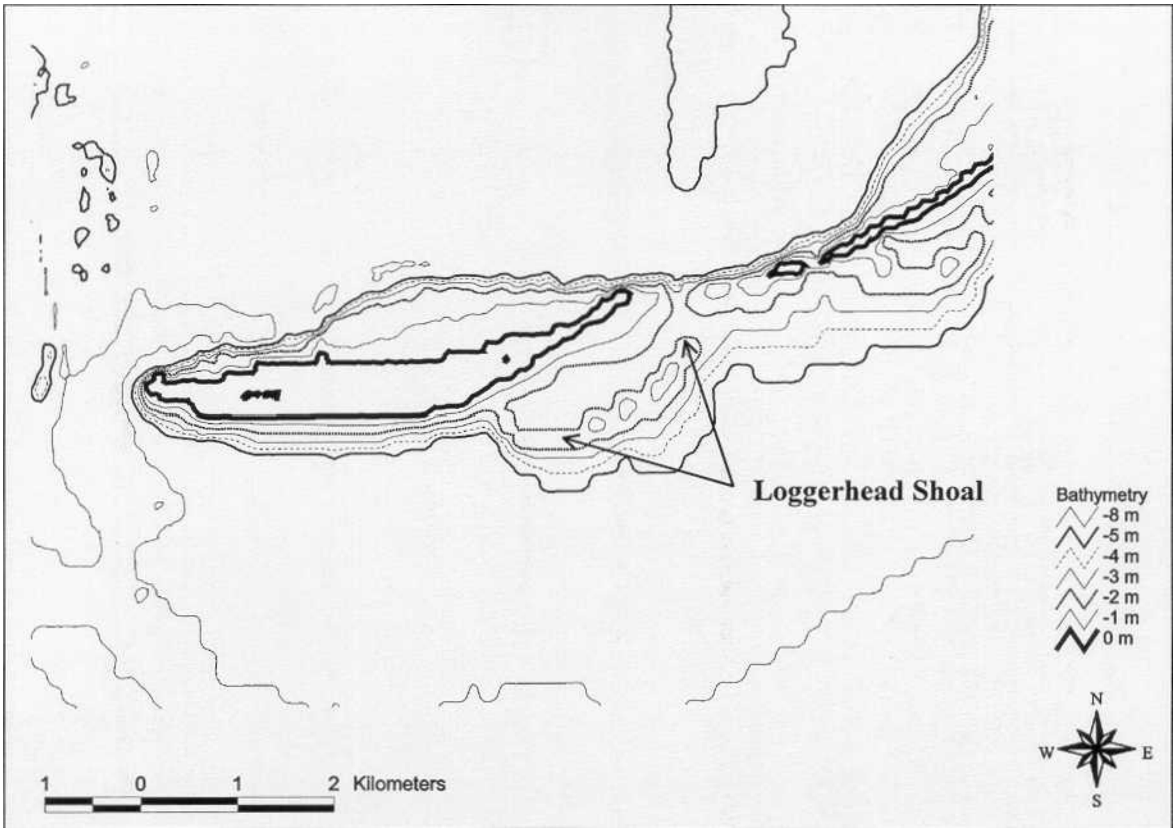

Figure 6. Bathymetric map of the West Ship Island area; zero elevation is a rough outline of island location during the survey.

Shoreline Change

Historically, Ship Island has been associated primarily with rotational instability (Figure 3) as opposed to translation (Byrnes et al., 1991; McBride et al-, 1995). Ship Island is the only northeastern Gulf of Mexico barrier island with this type of geomorphic classification, which was originally described by Leatherman (Leatherman et al., 1982). West Ship Island has an average shoreline change of roughly + 1.6 m/yr and a high of + 3.2 m/yr (Byrnes et al., 1991); each value was rounded up for the purpose of buffer analysis (Table 1). Buffer analysis was performed on the entire island. Change on the eastern and western ends of the island is also documented with changes in area, as the spits change at higher rates than the rest of the island.

Shoreline	Change (high, ave)
July, 1995	Baseline
July, 1997	8 m, 4 m
November, 1998	8 m
August, 2000	8 m, 4 m

Table I. West Ship Island shoreline inventory

1995 -1997 GPS

Comparison of the 1995 and 1997 shorelines using the average and high change buffers shows that a large part of the southern (Gulf side) shoreline is changing at more than an 8 m/yr level (Figure 7). The shoreline retreat change at the west end of the island and advance adjacent to Fort Massachusetts is the result of dredging the Ship Island channel and using the sand to renourish the beach in front of Fort Massachusetts in 1996 (Trembanis and Pilkey, 1998).

The island as a whole shows a balance between shoreline retreat and advance, and on the southern shoreline there appears to be a spatial cyclicity in it. The cyclicity is evident in long, 1 km, segments- The western end is associated with advance, which is consistent with the idea of rotational instability and a westward migration of the island- The northern shoreline (Sound side) is stable, except at the very eastern end adjacent to the spit, where there is a segment of shoreline retreat. The shoreline change highlights the spit's recurvature to the northwest. The area of renourishment near Fort Massachusetts is the only segment on the north side of the island showing shoreline advance.

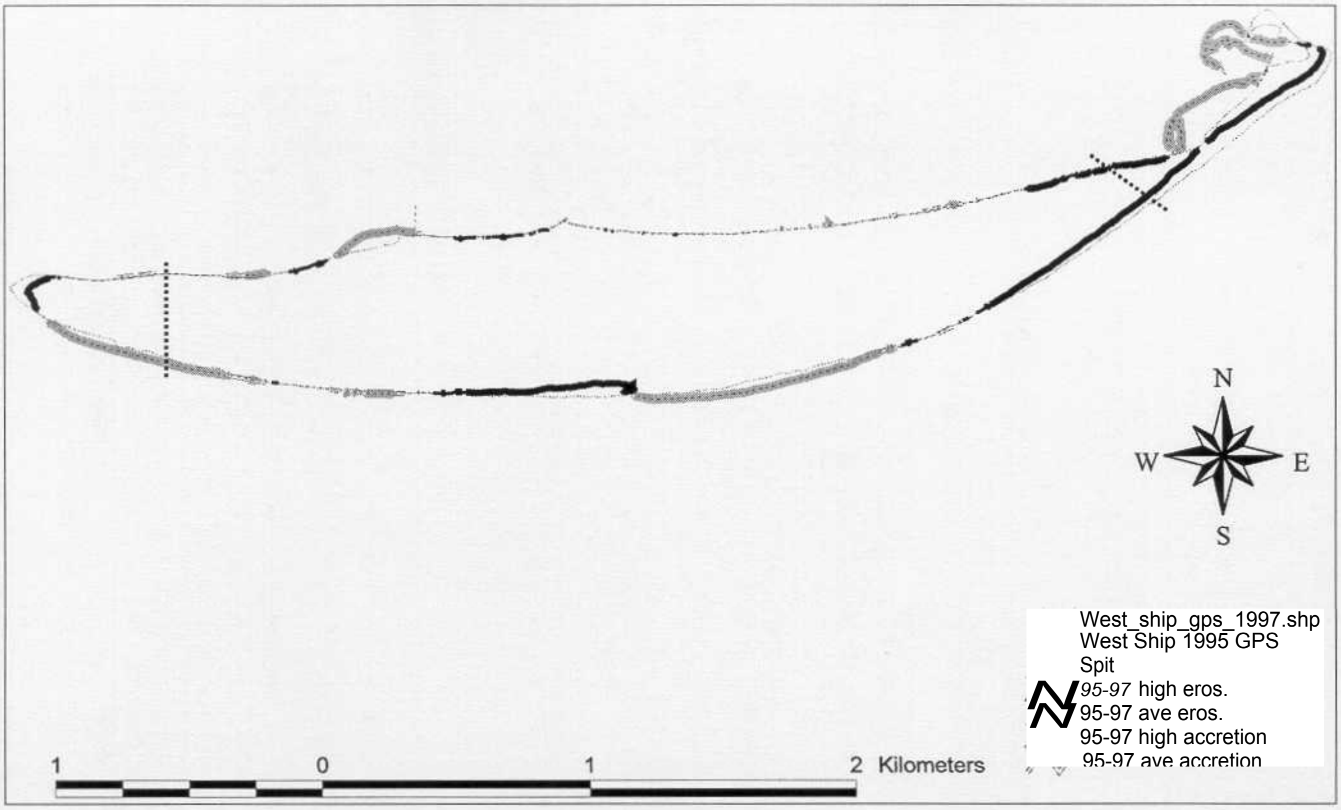

Figure 7. **Shoreline change patterns during the 1995 to 1997 period; levels of change are given in Table 1.**

Based on the average buffers, 47% of the shoreline is advancing (Table 2) and 44% is retreating on the southern shoreline at rates considered significant (Otvos, 1976). In contrast, only 21% of the northern shoreline is advancing and 26% of the shoreline is retreating. This highlights the relative change in energy conditions between the Sound and Gulf shorelines, and is further illustrated by the amount of shoreline changing at double the average yearly rate (high change). A total of 78% (retreat + advance) of the southern shoreline has shown a high level of change, while only 24% has shown similar levels on the northern shoreline.

Table 2. Shoreline distances with certain levels of change forthe island in meters

1995-1997 Shorelines	total shoreline length (m)	retreat		advance	
		high	ave	high	ave
Southern	4660	1786	2056	1852	2200
Northern	4010	506	1033	456	857

Despite the fact that much of the southern shoreline and 71% of the island (excluding the west end and most of the eastern spit) changed at more than two m/yr, only 4 acres of change (Table 3) occurred on the island, including spits. This is a negligible change. The eastern spit gained 2.5 acres and the western spit gained 1.1 acres. Taken in total this accounts for about 90% of the area change over the two-year period.

Table 3. Island area change from 1995 to 1997

1995-1997	1995 (sq m)	1997 (sq m)	change (sq m)	change (acre)
total island	2033996	2050555	16559	4.1
east spit	105269	115390	10121	2.5
west spit	119206	123723	4517	1.1

1997 – 1998 Post Georges GPS

During this period, which was slightly longer than one year, only very high change (2 x high yearly change) areas are highlighted (Figure 8). The data clearly show that most of the southern shoreline retreated during the storm. Only the small middle island spit (knuckle) showed advance. This feature has remained nearly fixed for over three years, which suggests that it is controlled by the preexisting geology or structural feature. For example, the knuckle on the south side of the island corresponds to the location where there is a dramatic change in the width of the Ship Island flats on the north side of the island and is close to the beginning of Loggerhead Shoal (Figure 6).

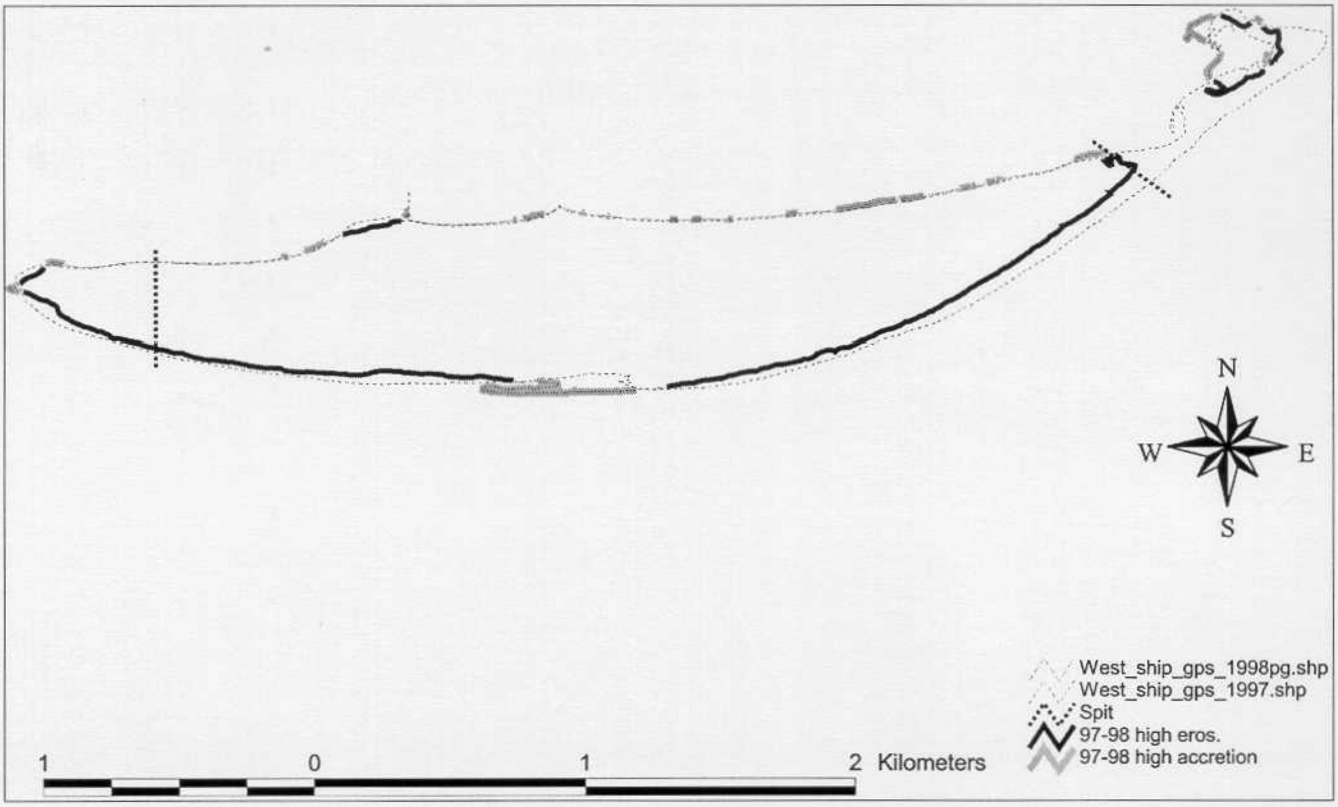

Figure 8. Shoreline change patterns during the 1997 to 1998 period; levels of change are given in Table 1.

During the storm the eastern spit lost a significant portion of its area and, as during the previous period, has rotated northwestward with what is left of the southern portion retreating and the northern shoreline advancing. The island's northern shoreline actually shows an overall advance signature. The advance appears to be associated partially with washover as it occurs mainly on the eastern portion of the island, which is the thinnest and shows a distinct signature of overwash morphology in aerial photos (Figures 9 and 10)- The notable exception is near Fort Massachusetts where retreat was prevalent. The high loss near the fort, despite the overall advance pattern on the northern shoreline, suggests that the shoreline there is dramatically out of equilibrium.

Figure 9. West Ship Island in 1997, before Hurricane Georges. (Photo courtesy of NOS)

Figure 10. West Ship Island in 1998 after Hurricane Georges. Notice the washover features on the eastern end and the change in the eastern spit. (Photo courtesy of NOS)

Taken in total, 84% of the southern shoreline retreated by more than 8 m (26 ft) while only 14% advanced (Table 4). Conversely, on the northern shoreline only 8% retreated by 8 m, while 23% advanced. The previous pattern (1995-1997) of equal retreat and advance on the southern shoreline and higher retreat on the northern shoreline has flip-flopped during the hurricane period. During this period the northern shoreline became the advancing side; this is similar to the transgressive nature of most Atlantic barrier islands-

Table 4. Shoreline distances with certain levels of change for the island in meters

1997-1998 Shorelines	total shoreline length (m)	retreat high	retreat ave	advance high	advance ave
Southern	4777	4000		667	
Northern	4286	335		973	

From 1997 to 1998 the island lost over 38 acres (Table 5), a dramatic change from the previous period when there was only about 4 acres of change. Of the 38.5 acres, 15 acres were lost on the eastern spit and 4 acres on the western point; thus, the two ends of the island account for about half of the total area lost. Most of the remaining area loss is on the southern shoreline, which is the opposite of what was documented in the previous period. This suggests that the island's evolution is driven by transgressive phases in conjunction with rotational instability (McBride and Byrnes, 1995; McBride et al., 1995).

Table 5. Island area changes from 1997 to 1998

1997-1998	1997(sq. m)	1998 (sq. m)	change (sq. m)	change (acre)
Total island	2050555	1894580	-155975	-38.5
East spit	115390	55073	-60317	-14.9
West spit	123723	107773	-15950	-3.9

1998 Post Georges - 2000 GPS

The most noticeable change from 1998 to 2000 is regrowth of the eastern spit (Figure 11)- Regrowth of the eastern spit occurred quickly following its overwash during Hurricane Georges; it returned to pre-hurricane form in about 8 months. The dominant northwest migration of the eastern spit as seen in the past two periods is less evident during this period and may be a result of the significant amount of regrowth. The western tip of the island also migrated over 150 meters (75 m/yr) during the period.

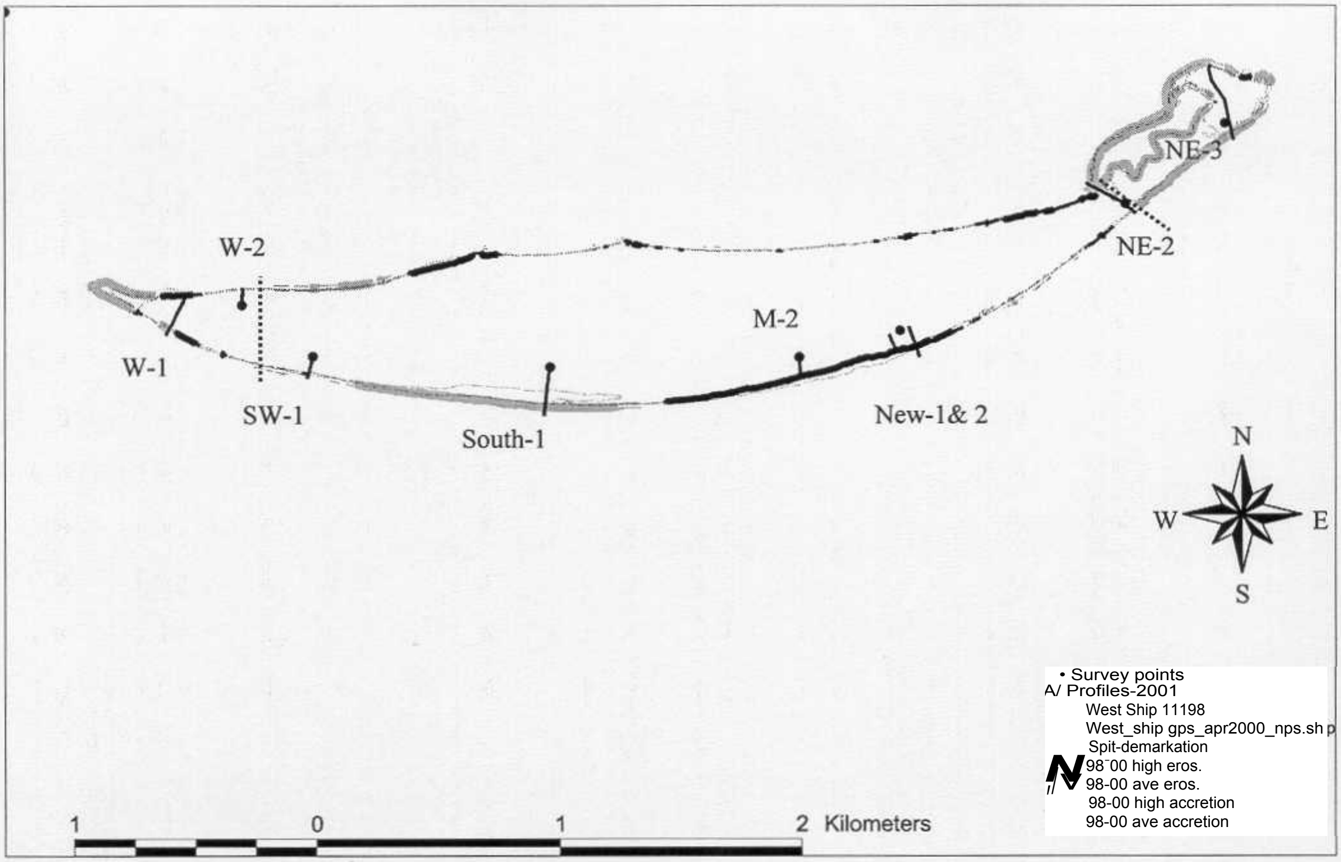

Figure 11. Shoreline changes from 1998 (after Hurricane Georges) to August 2000. Profile locations taken in 2001 are also included.

During the recovery period, retreat and advance on the southern shoreline was very nearly balanced (Table 6). A total of 34% of the shoreline advanced at more than 4 meters (2 m/yr) and 36% retreated. The northern shoreline differed from the southern shoreline as 35% retreated and only 20% advanced. It is interesting that the northern shoreline, which is a lower energy coast, has the same percentage of retreat as the high-energy southern shoreline. This process is consistent with, and provides evidence for, the island's general trend towards rotational instability and southwestward translation-

Table 6. Shoreline retreat numbers from 1998 to 2000

1998-2000 Shorelines	total shoreline length (m)	retreat		advance	
		high	ave	high	ave
Southern	4777	1367	1712	1155	1609
Northern	4286	819	1484	527	867

From November 1998 to August 2000 West Ship Island gained 26 acres (Table 7), which is two-thirds of the acreage lost during the previous period. Nearly 20 of the 26 acres gain occurred on the eastern spit, where elevations are extremely low. It only takes modest volume changes to increase the island area here; however, the rapid regrowth of the spit indicates a steady source of sediment from the updrift East Ship Island. In contrast, growth of the western point must first fill a relatively deep area (Figure 6), which causes the island to thin. For example, although the western point extended 150 m (about 500 ft) beyond the previous shoreline it only gained 2 acres (Table 7).

Table 7. Area change from 1998 to 2000

1998-2000	1998 (sq m)	2000 (sq m)	change (sq m)	change (acre)
Total island	1894580	2000109	105529	26.1
East spit	55073	135376	80303	19.8
West spit	107773	115600	7827	1.9

A suite of shoreline surveys taken between November 1998 and August 2000 suggests that the bulk of the recovery occurred between November 1998 and June 1999 (Figure 12) when the island gained about 25 of the 26 acres gained in total during the nearly two year period. In fact, it appears that after a 7 month recovery period the island evolved on a seasonal basis. The recovery process is different from the seasonal pattern in that the gain occurred during the winter.

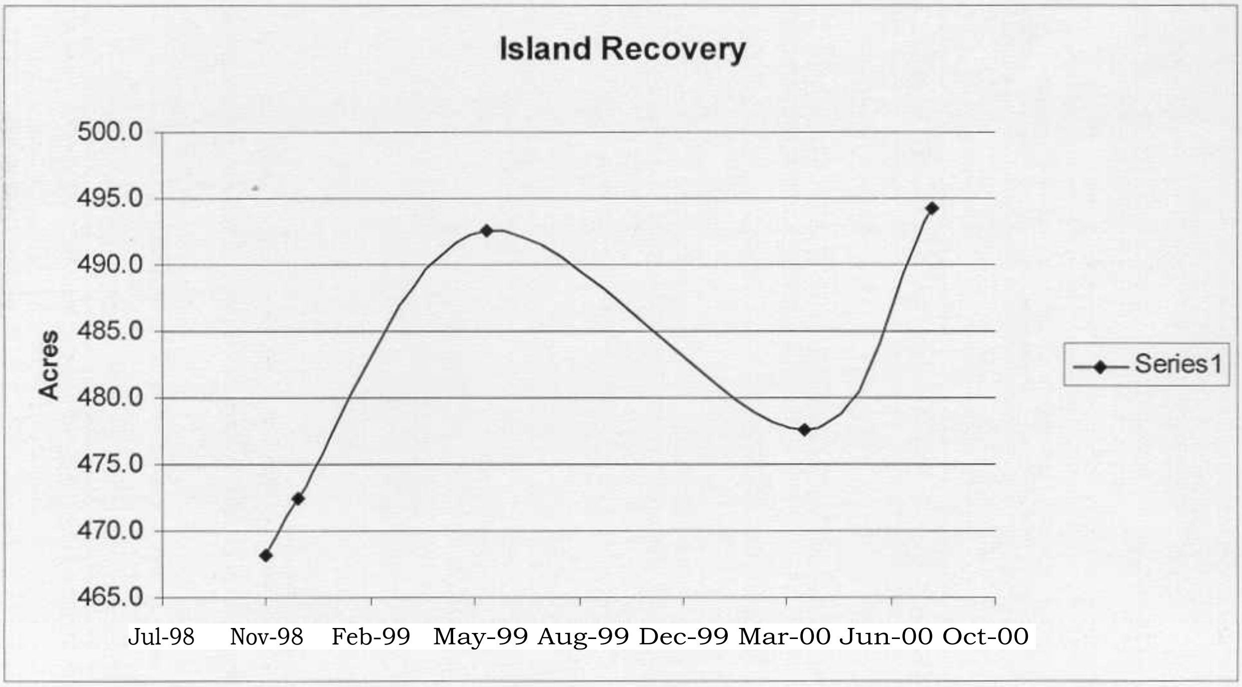

Figure 12. Island change between Hurricane Georges and August 2000.

Elevations

LIDAR elevation data further indicate that a general change in island morphology occurs near the lighthouse (Figure 13). Again, this location is consistent with the dramatic thinning of Ship Island flats to the north of the island and the start of Loggerhead Shoal south of the island. To the west of the lighthouse the island is dominated by low central elevations with a surrounding line of dunes. To the east of the lighthouse the island is dominated by higher elevations and a hummocky interior.

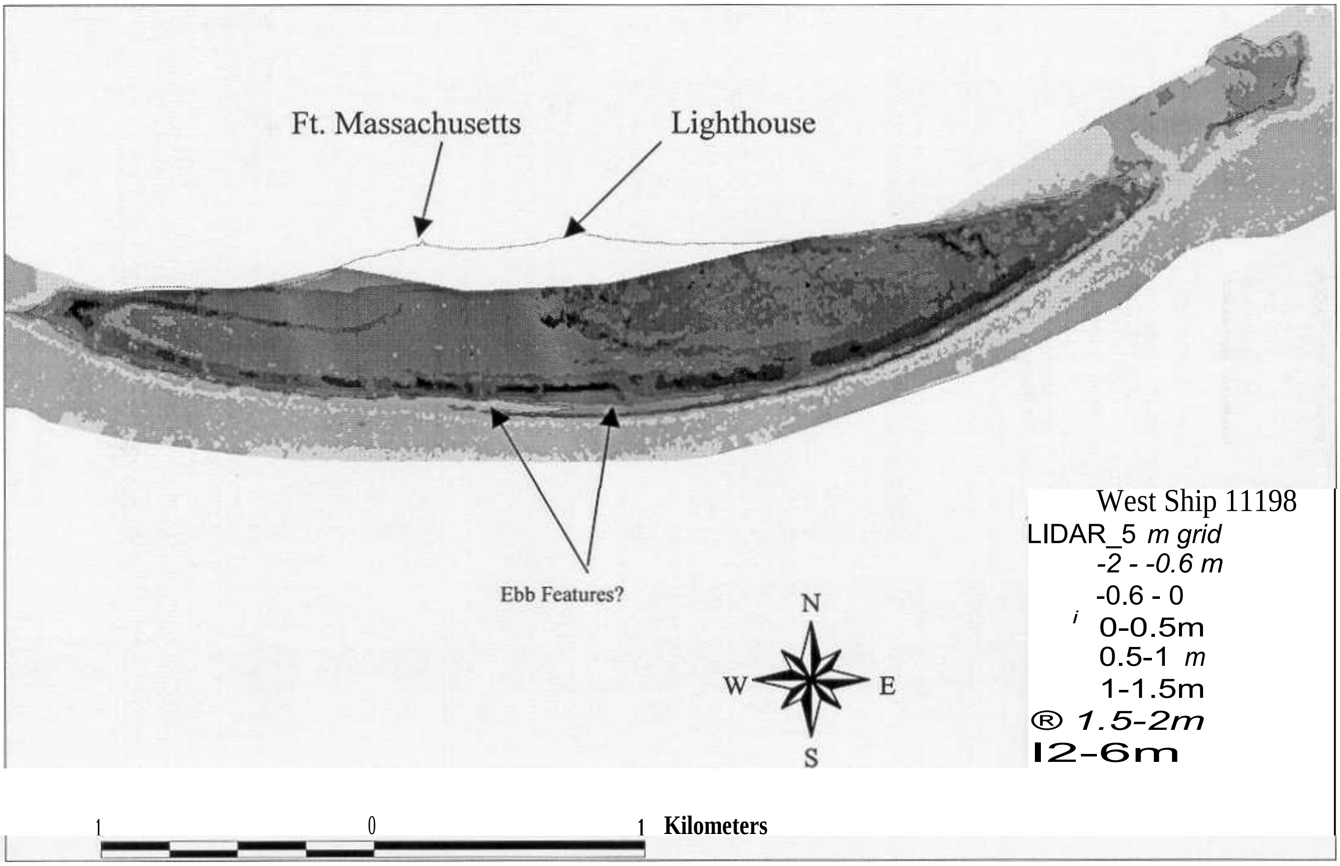

Figure 13. LIDAR elevation (m) for West Ship Island.

The northwestern portion of the island has an inland dune ridge that is nearly continuous from about the lighthouse to the west end of the island, where the inland dunes join the southern dune line. This inland dune line is also evident in aerial photos (Figures 4, 9, and 10). The trace of these dunes corresponds roughly to the 1966 shoreline (Figure 14), and probably reflects the natural shoreline on the northwest side of the island before beach renourishment was used to combat erosion in front of and around Fort Massachusetts. The interior of the island west of the old lighthouse has a low elevation, although close inspection of aerial photographs and LIDAR shows several subtle ridges that appear to have links to older shorelines. Generally, it appears that west of the lighthouse the island is sand starved, as if lateral movement became more dominant than vertical aggradation and/or the depth west of the lighthouse was such that more sediment was deposited below sea level. This is addressed in more detail in the Morphological Regions portion of the Discussion section.

The eastern portion of the island, beginning just east of the lighthouse, has an overall higher elevation, a more robust southern dune line, and a hummocky dune interior. The southern dune line is nearly continuous; however, there are several breaches and what appears to be at least one ebb flow signature (see Figures 13 and 14). The ebb features formed during Hurricane Georges are located adjacent to the beginning of the hummocky dune morphology, very near where a spit developed on the southern shoreline. It appears that the ebb flow across the island during Georges was controlled by the change in the island's interior morphology.

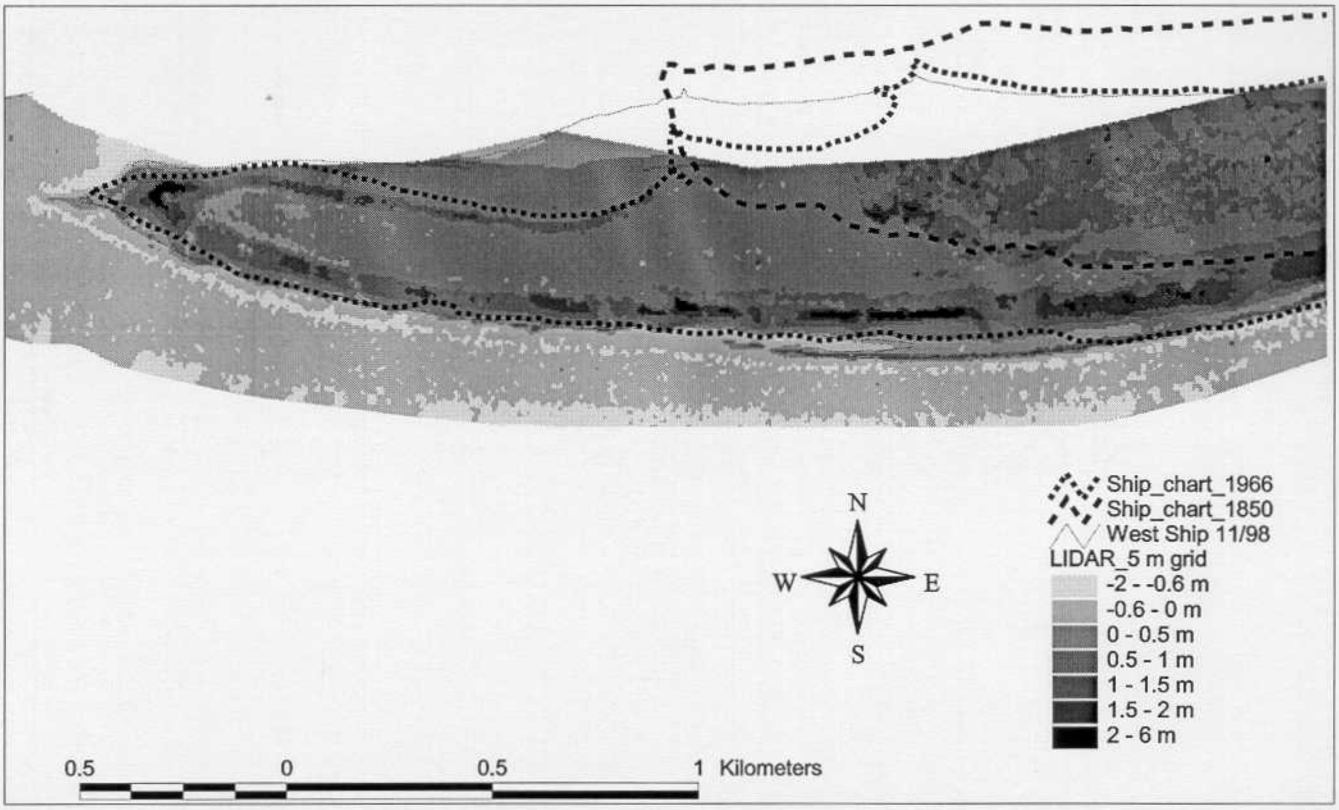

Figure 14. LIDAR elevation data on the western half of the island with historic shorelines superimposed.

The southern extent of the hummocky interior morphology roughly corresponds to the circa 1850 shoreline. The relationship between the two suggests that if there is indeed a temporal change in the island's evolution it may have occurred around 1850-

Profiles

Nine profiles were surveyed on Ship Island in April and June 2001; they were compared to LIDAR-generated profiles following Hurricane Georges (Figures 15, 16, 17, and 18). Seven (W-l, W-2, SW-1, South-1, M-2, NE-2, and NE-3) of the locations were chosen based on LIDAR-generated morphology and shoreline change as defined by GPS surveys. Two profiles (New-1A and -1B) were added in the field based on recent shoreline morphology change. The locations fall into three categories: western spit, southern shoreline, and eastern spit.

Table 8. Volume change at profiles in cubic yards per linear foot of shoreline

Profile #	Volume Change (c.yds/ft)
W-1	8.8
W-2	0.4
SW-1	-4.1
South-1	20.0
M-2	-5.9
New-1A	-8.8
New-1B	-8.6
NE-2	5.0
NE-3	7.7

The western spit profiles (Figure 15; W-1 and W-2) include a cross island and a northern shoreline profile. Unfortunately, W-2 is not a complete profile - the LIDAR data do not fully cover the entire length. The cross-island profile (W-1) begins in the north and ends on the southern shoreline- Both profiles had positive volume change between 1998 and 2001 (Table 8), which would be expected on the western portion of the island- In each case, however, the trend is for vertical accretion on the inland section, and slight loss on the active wave-influenced portion of the profile. Given the timing of the LIDAR overflights, several weeks after Hurricane Georges' passage, there was probably significant onshore movement of sediment that was previously transported offshore during the storm, i.e., the natural recovery cycle. This would tend to increase the sand volume resident on the low-elevation (wave-influenced) beach. A prominent subaerial beach ridge, probably an onshore migrating bar, in the W-1 LIDAR profile suggests that this was occurring to a large degree.

W-1 W-2

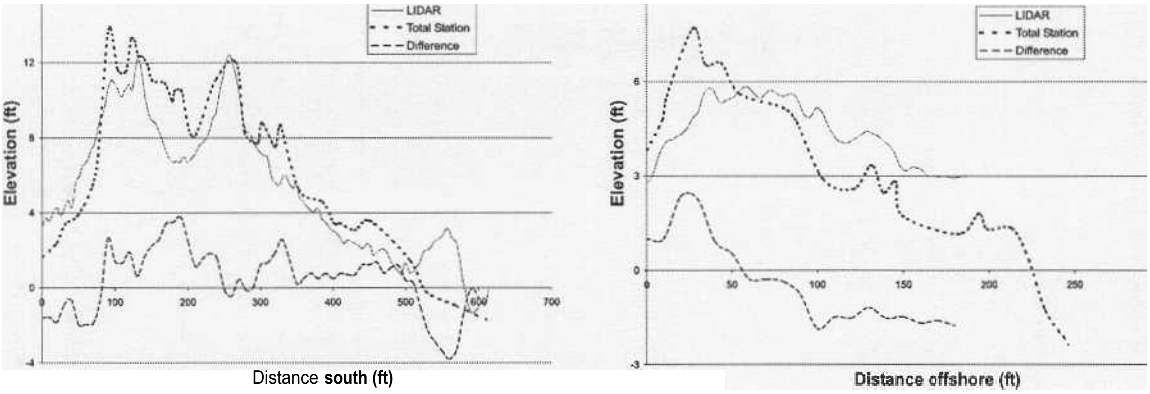

Figure 15. Profiles on the west spit portion of the island.

The profiles on the southern shoreline (Figure 16; SW-1, M-2, New-1A, and New-1B) are more surprising, as there is a predominance of negative volume change (Table 8). Unfortunately, most of the profiles were in areas that had negative shoreline changes (Figure 8); thus, the representativeness of the southern shoreline as a whole is limited. Only one profile (Figure 17; South-1) was in an area of shoreline advance and coincides with the island's "knuckle". It had a distinctly positive volume change (Table 8). The representativeness of the profiles notwithstanding, the agreement of shoreline retreat/advance and profile volume change is an important finding-

In each profile there was little change in the onshore/upland portion of the profile. The active wave-dominated portions of the profiles, excluding South-1, were, like the western two, distinctly negative. The pervasive negative volume change signature on the southern shoreline is contrary to the areal recovery following Hurricane Georges.

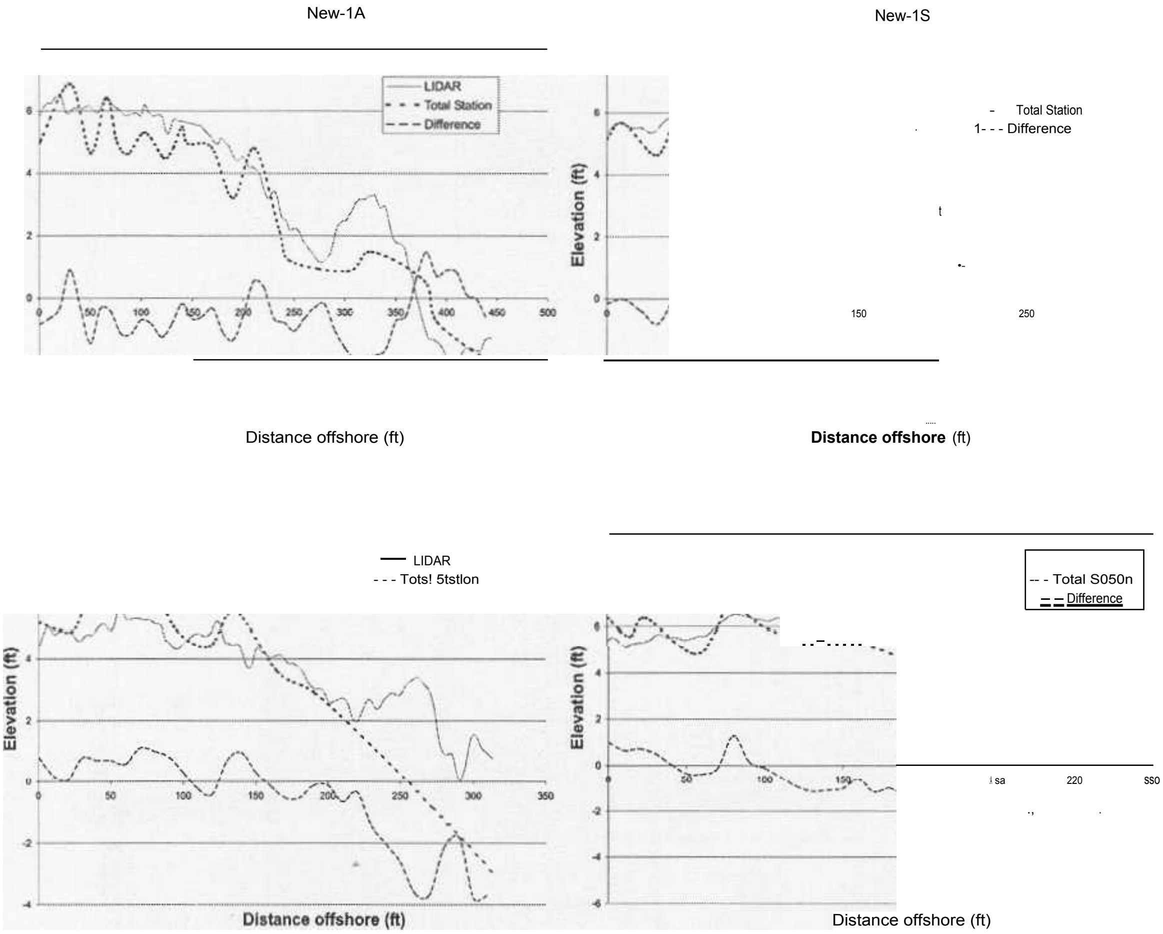

Figure 16. Profiles on southern shoreline with negative volume and shoreline change.

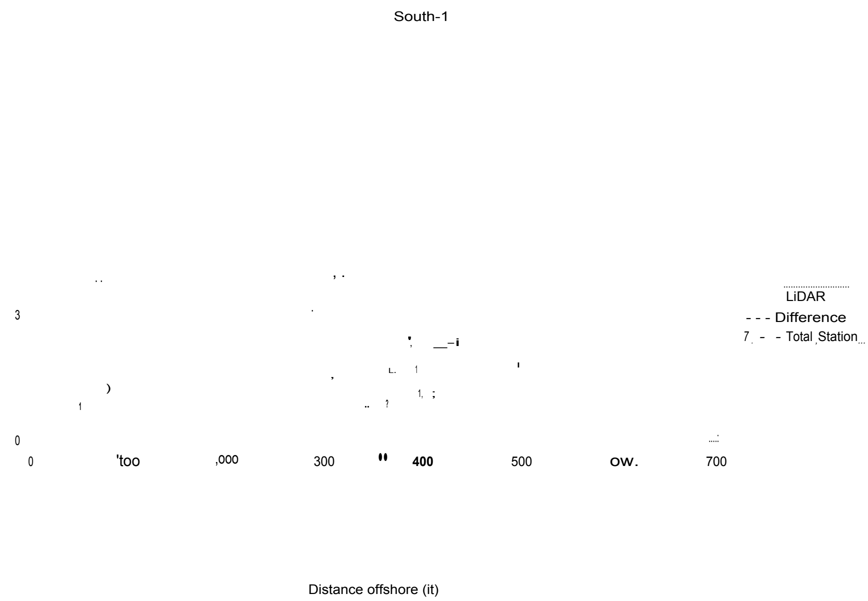

Figure 17. Profile on southern shoreline with positive volume and shoreline change.

The eastern profiles are more in keeping with the regrowth of the island (Figure 18; NE-2 and NE-3) and show positive volume changes (Table 8). The NE-2 profile is located where the east end of the island was located immediately following Hurricane Georges; it is also at the border between the low eastern flats with the associated sand spit and the hummocky dunes on the main portion of the island. The NE-3 profile runs across the small 'it island' that was above sea level following Hurricane Georges. Both profiles begin in the north and end on the southern shoreline.

As would be expected -- given the dramatic areal change on the eastern end of the island - the profiles have a positive volume change over the period. The NE-2 profile shows the development of small subaerial beach ridge running seaward of the island; this is a fairly permanent feature, having re-established itself shortly after the hurricane's passage. Although the elevation of this feature above sea level is subtle (6"), the volume change occurring here is the highest along the profile. Like the western profiles, the dunes have grown vertically, but the wave-influenced portions of the profile show negative volume changes. The basic patterns seen in NE-2 are similar to NE-3; the northern shoreline has aggraded significantly, while the southern has changed little. These changes are consistent with **the** northerly recurvature of the spit through the five-year period.

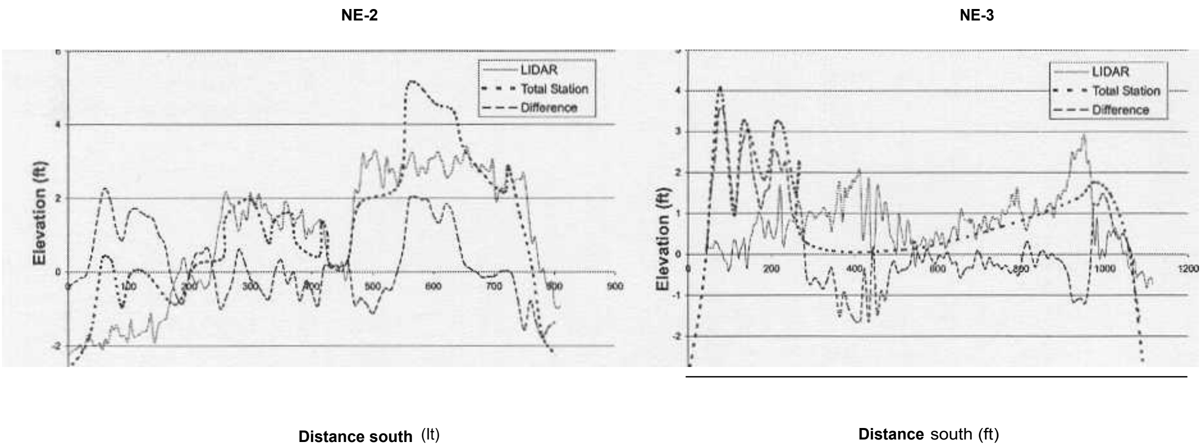

Figure 18. Profiles on eastern spit.

DISCUSSION

Shoreline survey data taken on West Ship Island between 1995 and 2000 suggest that the island's evolution can be separated into two phases: a transgressive phase during the hurricane period and a regressive-translational phase during the other two periods. In addition to the temporal evolution, there are three distinct spatial changes associated with different morphological regions separated by two consistent linear boundaries. Overall five year spatial change patterns in shoreline retreat-advance are consistent with the morphological regions, and are probably a contributing factor in producing the different morphology. These three temporal and spatial characteristics combine to create a geomorphic response signature unique to the Mississippi barrier islands (McBride and Byrnes, 1995; McBride et al., 1995)

Temporal Phases

Predictably, the transgressive and regressive-translational periods correspond to hurricane and non-hurricane periods respectively. The difference between the recovery (1998-2000) and pre-hurricane periods (1995-1997) is more subtle; it appears to be associated with a change from rotation (pre-hurricane) to translation (recovery).

In terms of morphological response types (McBride and Byrnes, 1995; McBride et al., 1995), the calculated shoreline change percent values (Table 9) are good indicators of overall response type. For example, between 1997 and 1998, 23% of the northern shoreline was classified as highly advancing while only 8% classified as highly retreating, which gives a net of 15% advancing. If the northern shoreline is inspected closely (Figure 8), the overall trend is toward advance and is consistent with the percent value. In contrast, the northern shoreline during the 1995-1997 period was nearly balanced in terms of retreat and advance (Table 9) and on close inspection (Figure 7) the overall shoreline changed little.

Table 9. Percentage of total shoreline with change at the specified levels (Table 1).

1995-1997	Retreat (%)		Advance (%)	
Shorelines	High	Ave	High	Ave
Southern	38	44	40	47
Northern	13	26	11	21

1997-1998	Retreat (%)		Advance (%)	
Shorelines	High	Ave	High	Ave
Southern	84	0	14	0
Northern	8	0	23	0

1998-2000	Retreat (%)		Advance (%)	
Shorelines	High	Ave	High	Ave
Southern	29	36	24	34
Northern	19	35	12	20

Using the idea that the overall percent of shoreline change (advance - retreat) can be used to describe the entire shoreline trend, the two phases highlight the changes in island evolution. During the transgressive phase, the southern shoreline shows a total retreat of 70%; the northern shoreline has an overall advance of 15%. These trends would roughly characterize the process as landward rollover (Figure 19) (McBride and Byrnes, 1995; McBride et al., 1995). However, since the threshold value is the same in both cases (8 m; Table 1), a point can be made that, while the northern shoreline is advancing and the southern shoreline retreating, the magnitude of difference (70% to 15%) would put the response type on a continuum between rollover (% advance on northern shore / % retreat on southern shore = 1) and retreat (% advance on northern shore I % retreat on southern shore = 0). Using similar logic, the two non-hurricane periods show in-place narrowing (1998 to 2000) and advance (1995-1997) response types (Figure 19)-

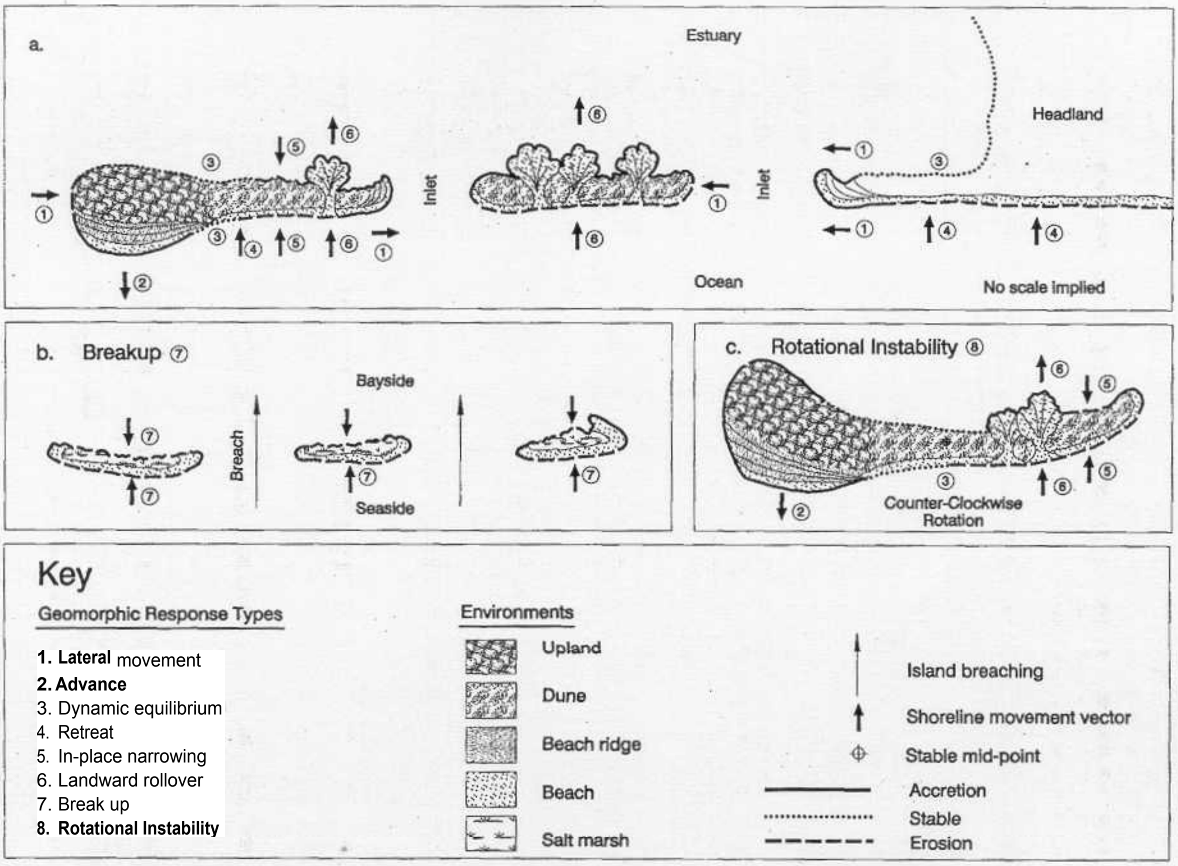

Figure 19. Geomorphic response types of McBride (taken from McBride et al., 1995)

These categories were determined using only shoreline change on the main part of the island; it does not include the east spit, or east-west translation. Further analysis using island area change and more specifically area change at the ends of the island can help modify the afore-mentioned categories and account for lateral movement. Based on this, West Ship Island does not show strong east to west translation and actually has a larger area increase on the east as compared to the west from 1995 to 2000. The influence of a maintained ship channel contributes to the lack of a westerly translation (Table 10) (Oivanki, 1994). The shallow depths surrounding the eastern portion of the island (Figure 6) also facilitates island growth there.

Table 10. Island area in square meters from 1995 to 2000

Year	Total island (sq m)	East spit (sq m)	West spit (sq m)
1995	2,033,996	105,269	119,206
1997	2,050,555	115,390	123,723
1998	1,894,580	55,073	107,773
2000	2,000,109	135,376	115,600

The overall change in island area is significantly higher during the 1998-2000 period than during the 1995-1997 period as would be expected, but does not equal the loss during Hurricane Georges (1997-1998). It should be noted that the percentage of area change on the spits as compared to the entire island (spit area change/total change x 100) during non-hurricane periods is higher than during the hurricane period, which is consistent with a rotational or translational response during ambient periods. Using shoreline change differences along with area changes, especially on the ends, the 1995-1997 period may be classified as a continuum between advancing and rotation, the 1997-1998 period as a continuum between landward rollover and retreat, and the 1998-2000 period as a continuum between rotation and in-place narrowing.

A comparison of the profiles taken in 1998 and 2000 (Figures 15, 16, and 17) shows some trends of both narrowing and rotation. The westernmost profile (W-1, Figure 15) narrowed, grew vertically, and translated southward during the period, which is consistent with the trend as indicated by shoreline surveys. The eastern profiles (Figure **18)** have distinct growth on the north side of the island and little or none on the south side, which is consistent with rotation. Profiles on the southeastern shoreline show a clear trend of shoreline retreat that may be associated with in-place narrowing. Profile South-1 (Figure 17) has a clear profile volume increase that in tandem with the southeastern profiles may further suggest a rotational nature.

The shoreline surveys and profiles highlight an interesting aspect of the island: its large recurved eastern spit. Both Petit Bois and Horn islands have developed recurved eastern spits, but they are significantly smaller sized. The persistence, size, and growth of the spit through time raises questions about the influence of East Ship, less than 1 kilometer to the east, both temporally and spatially, and/or the influence of geologic structural control. The interrelation of the two islands is an issue that should be addressed to predict and plan for the future changes, which may be vastly different than present as East Ship Island continues to evolve quickly (Schmid and Yassin, 1999). The influence of pre-Recent geologic features on island evolution is discussed below-

Morphological Regions

There are three distinct morphological regions on West Ship Island: the eastern spit, the hummocky dune eastern portion of the island, and the low elevation western portion of the island. The boundary between the eastern island and eastern spit (A in Figure 20) is associated with a decrease in elevation and a change from hummocky dunes to sand flats; it is represented by the line marking the beginning of the east spit on shoreline change figures (Figure 7, 8, and 11). This boundary also represents the eastern end of the island following Hurricane Georges (Figures 8 and 10)- The reason for the dramatic change in morphology at this boundary is not entirely clear and the significance of this morphology change, in terms of the island's longer-term evolution, has yet to be seen. The persistent nature of the eastern spit, however, is clearly related to the existence of a shallow platform surrounding the area (Sand Flats and Loggerhead Shoal). The lack of such a shoal area on the northwestern end and the existence of a deep channel mean that much more sediment is needed to create the same amount of island area. Noticeable thinning of the island west of Fort Massachusetts, especially before the renourishment following the 1966 map (Figure 14), is probably related to the naturally deep water to the west. Maintaining a stable shoreline adjacent to the deep channel will be difficult as the island will naturally look for an "easier" place to grow - to the southwest. The variations in bathymetry from one end of the island to the other have created the very different spit morphologies on West Ship Island: a low, wide, recurving spit and a straight, narrow spit. East Ship does not show the same difference in spit configurations.

The boundary between the hummocky eastern (from A to B in Figure 20) and low elevation western portions of the island (west of B in Figure 20) is consistent with a change from hummocky dunes to flat, low elevation in the interior of the island. This boundary can also be extended offshore; it forms a nearly straight line with the west edge of Loggerhead Shoal (Figures 6 and 20). To the north, the boundary is also consistent with the dramatic thinning of Ship Island Flats (Figure 4). This boundary appears to be important in the island's evolution, as it seems to control the orientation of the island, and thus the mode of sediment transport- To the east of the boundary the island is aligned perpendicular to the dominant SE wind direction (Figure 5) where cross-shore transport (onshore-offshore) should dominate. West of the boundary the island is aligned perpendicular to the south, or about 20 to 30 degrees from the dominant SE direction; here the transport should have a larger alongshore component (longshore transport). A recent study (Cipriani and Stone, 2001) also shows an increase in longshore transport from east to west on the island. The alignment of the eastern portion of the island appears to have a direct impact on the sediment transport and may explain the hummocky dune interior- If sediment is moved inland instead of alongshore, by both wind and waves, the island should grow vertically; in fact, this portion of the island has the highest overall elevation (Figure 20).

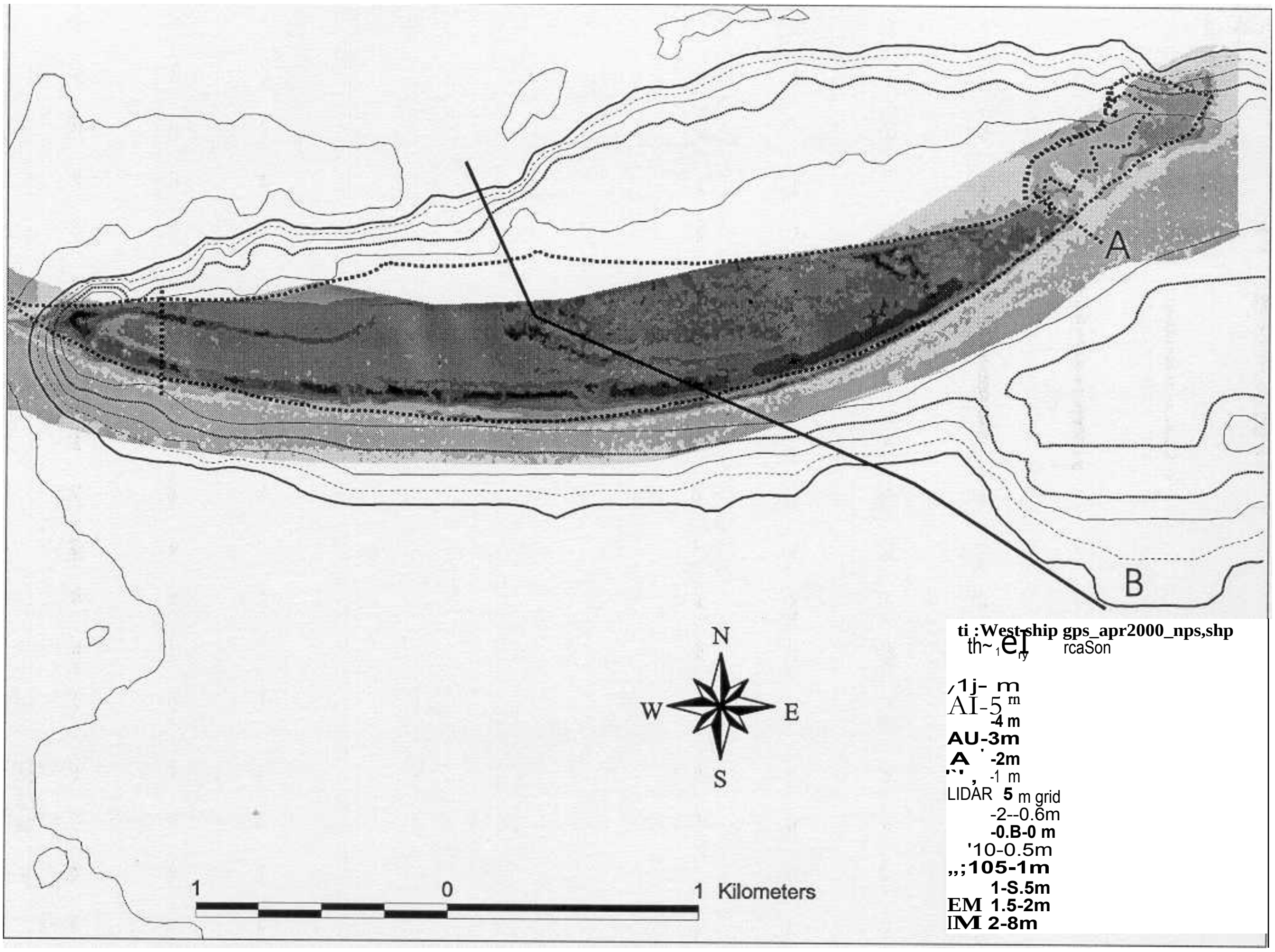

Figure 20. Geomorphic boundaries based on island morphology.

Loggerhead Shoal changes the wave incidence on the shoreline behind it by refraction (Carter et at., 1990) and in doing so may also set up littoral transport cells (longshore cells) that perpetuate the change in shoreline evolution and produce the observed rotational instability. The growth and movement of the shore-parallel spit on the southern shoreline (compare Figures 7 and 8) suggests that the shoreline west of the boundary is in fact dominated by longshore sediment transport-

Looking more thoroughly at the origin of Loggerhead Shoal and development of the morphological boundary, there are several deep cores (greater than 50 ft deep) that were drilled on and around West Ship Island and analyzed by Ervin Otvos (Otvos, 1986)- Mapping Pleistocene depths (Figure 21) adopted from his core analysis suggests that the morphological boundary and/or formation of Loggerhead Shoal have a structural component- Contours of the Pleistocene surface show a depression running at an angle to the island and very nearly in line with the boundary line drawn using surface topography and the edge of Loggerhead Shoal. The interrelation of Loggerhead Shoal, island morphology, and Pleistocene surface appears to be a prime example of how pre- Holocene topography influences coastal morphology and thus island evolution.

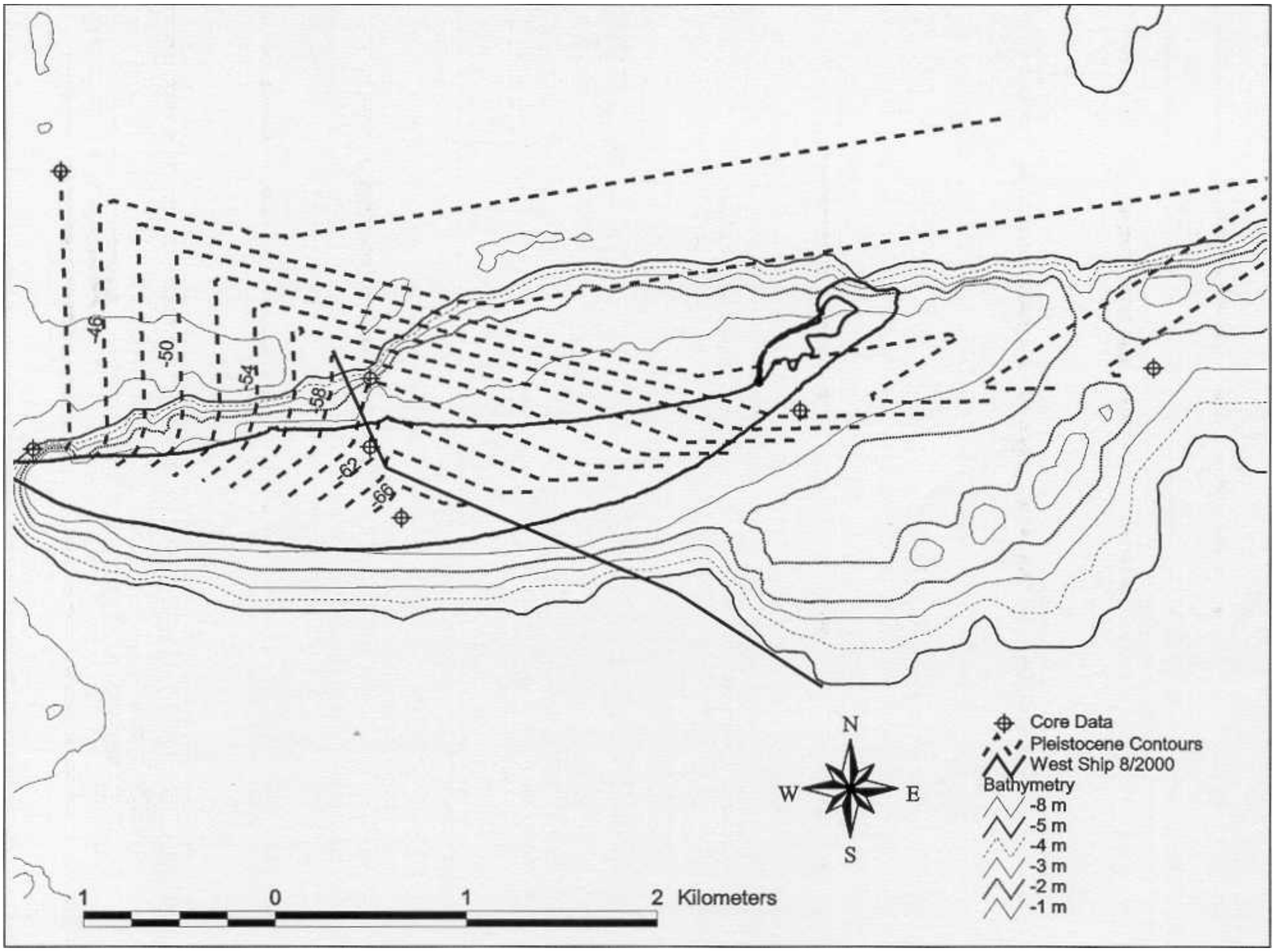

Figure 21. Geomorphic regions and Pleistocene surface contours.

Morphological Regions and Shoreline Change

West Ship Island's shoreline change over the five-year study period (1995 to 2000) is consistent with the morphological regions as determined from LIDAR-generated topography, NGDC bathymetric data, and Pleistocene paleo-topography.

To show the areas with the highest change, shoreline segments with more than 24 m (78 ft) or about 5 m/yr (16 ft yr.) change are highlighted in Figure 22. It is evident that the southern shoreline east of the morphological boundary has the highest retreat signature on the island. Much of the retreat occurred during the hurricane (Figure 8), when large overwash features were created (Figure 10)- This further supports the idea that the morphology of the island east of the boundary is controlled by shore-normal sediment transport, resulting in higher shoreline retreat but greater interior vertical growth. It is difficult, however, to determine weather Loggerhead Shoal is a function of the shore-normal sediment transport (i.e. onshore and offshore) or if it has created this situation- Loggerhead Shoal appears to be an important factor in the island's long-term evolution, and may warrant a more in-depth investigation.

The only area with a large positive shoreline change is on the north side of the eastern spit. This represents the five year trend for the spit to re-curve to the northwest while changing in area very little- The low elevation of the spit and the northwest movement suggest that sediment overwashed by waves coupled with longshore transport on the north side of the island are important in the area's shoreline evolution and migration signature. Aeolian (wind-created) features (dunes, ripples) are limited on this spit as much of the area is associated with algal-bound sediments that form a wind-impervious pavement. The overwash signature stops at the boundary separating the eastern spit from the island and wind transport becomes dominant. The eastern spit is associated with and is a result of the island's rotational nature.

Shoreline change on the west end of the island is difficult to assess as dredging and renourishment have disrupted natural progression. During the five year period the island's west tip has migrated westward at rates very near the long term average (9.6 m/yr) even with a dredging operation included. The westward migration rate is, however, an order of magnitude lower than the western ends of either Horn *or* Petit Bois islands (Byrnes et al-, 1991).

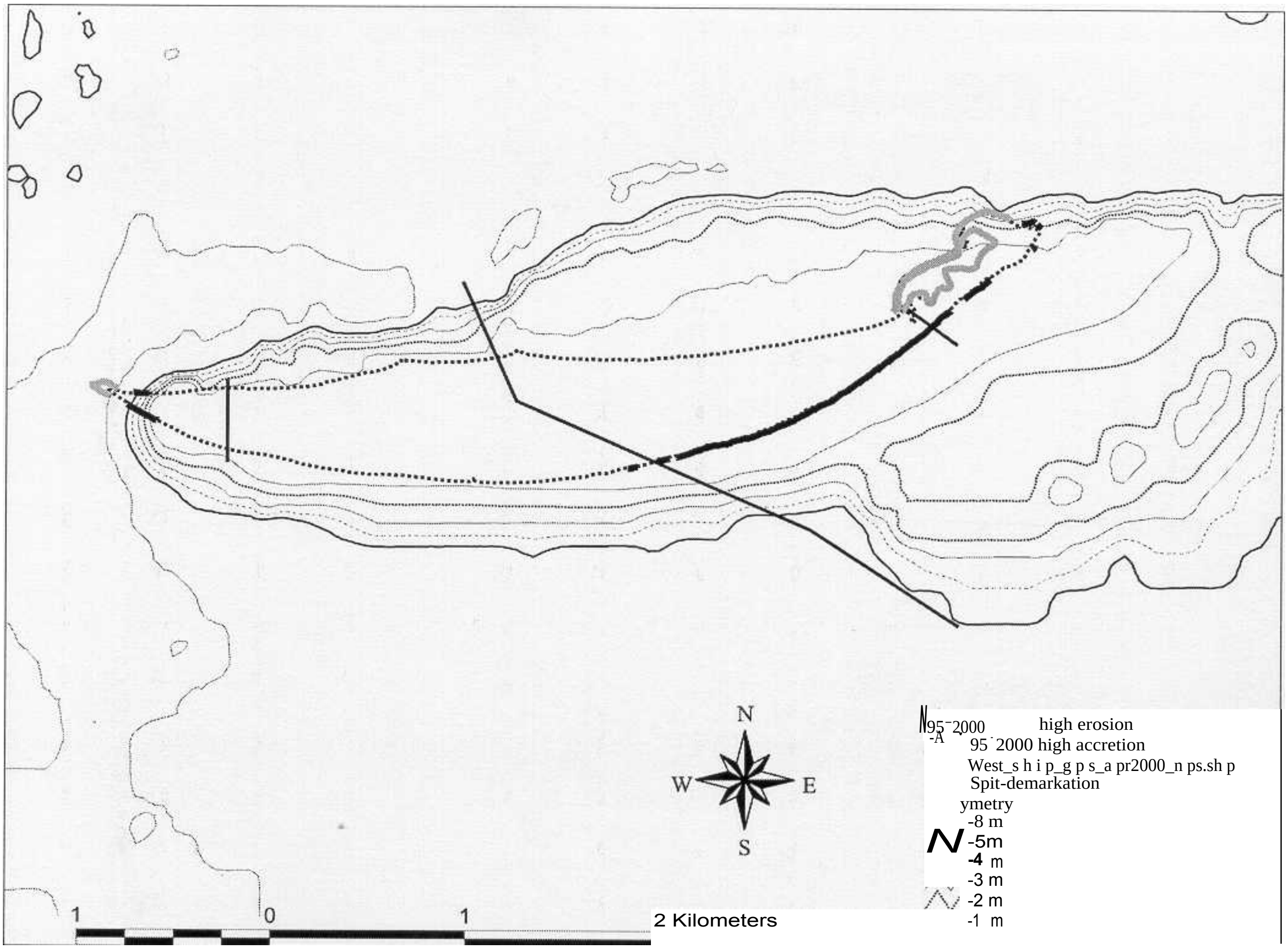

Figure 22. Areas with high change and the morphological regions of the island.

CONCLUSION

West Ship Island is unique among most northeast Gulf of Mexico barrier islands in that it is dominated by rotation as opposed to lateral movement or retreat. Overall area change during the five-year period was minimal despite passage of Hurricane Georges; however, shoreline change beyond the average yearly level is widespread in all periods analyzed. The highest shoreline retreat is associated with the southeastern portion of the island and it appears to be related to Loggerhead Shoal. In fact, Loggerhead Shoal may be the controlling factor in the island's rotation and overall morphology-

Findings and suggestions for future studies based on the data collected include:

- Yearly and semi-yearly GPS surveys are a simple and economical way to study island evolution in temporally short periods with high accuracy- Given the long-term average shoreline change rate for West Ship Island (1.6 m/y) the accuracy of the technique limits year to year comparisons of shoreline position, but is useful for two to three year comparisons. Area comparisons can probably be done at shorter intervals. Storm-related changes are well within the technique's accuracy.

- West Ship Island shows different morphological responses through the five-year period. During the hurricane period the island exhibits a rollover to retreat pattern that can be broadly described as a transgressive phase. When ambient conditions prevail the island shows little change and may be considered a regressive phase. As with most barrier islands, storms appear to be the driving force in West Ship Island's evolution, and may in this case be considered a natural progression rather than erosion, as the island shows a strong tendency to recover. The recovery process may be at the expense of East Ship Island; the relationship between these two islands should be examined.

- West Ship Island has several morphological regions that correspond with unique sediment transport modes. The eastern spit is separated from the island by a dramatic change from hummocky dunes to low-elevation sand flats. Sediment transport here is associated with overwash and longshore drift on the northern shoreline- The southeastern portion of the island is associated mainly with onshore-offshore sediment transport. Cross-shore sediment transport builds up the interior dunes, but also has created higher shoreline retreat. West of the hummocky interior dunes the island is dominated by a single dune line, low interior elevations and longshore sediment transport. The north side of the island generally shows little change through the period. Areas near Fort Massachusetts, however, have a higher retreat signature. This area is being artificially widened and may have a high sediment transport rate directly offshore (toward the north).

- An important factor in the island's evolution is Loggerhead Shoal; it appears to control sediment transport on the southern side of the island. The Pleistocene surface mapped from previously taken cores suggests that the formation of the shoal is associated with the underlying Pleistocene morphology. More generally, the bathymetric changes and the size of the sediment platform from one end of the island to the other play an important role in determining island and spit morphology- Further work is needed to understand the relationship between platform shape and its control.

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