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14. ABSTRACT

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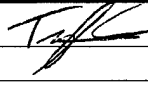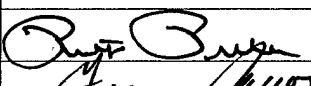This subject paper (has ____) (has never __X__) been incorporated in an official NRL Report.
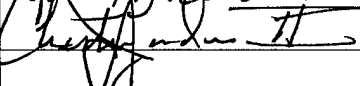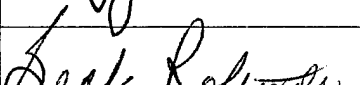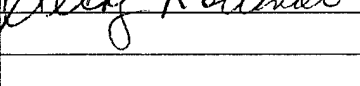
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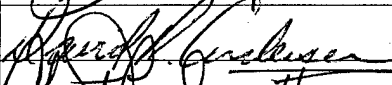**Timothy R Keen, 7322**
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Coastal Sediments '03 Conference Proceedings

BARRIER ISLAND EROSION DURING A WINTER COLD FRONT IN MISSISSIPPI SOUND

Timothy R. Keen[1], Gregory Stone[2], James Kaihatu[1], and Y. Larry Hsu[1]

Abstract: The present study uses high-resolution hydrodynamic and sedimentation models to evaluate the sedimentation patterns inferred in the previous study. This work is examining the sensitivity of erosion on the sound side of West Ship Island to the tidal stage and changes in coastline due to beach replenishment. Water levels and mean currents for a range of tidal conditions and typical cold front winds are being computed using POM. Waves within Mississippi Sound are being calculated for a typical cold front using the SWAN (Simulating Waves Nearshore) model. Surf zone waves and longshore currents are being computed using the SHORECIRC hydrodynamic model. The waves and currents calculated by SWAN, POM, and SHORECIRC are being used to drive a three-dimensional sedimentation model, the Littoral Sedimentation and Optics Model (LSOM), which computes wave and current interaction using a modified version of the Grant and Madsen bottom boundary layer model. LSOM calculates bed roughness and suspended sediment concentrations in addition to bed load. The models are being used to simulate waves, currents, and sedimentation during other cold fronts as well.

INTRODUCTION

The Mississippi bight (Fig. 1) encompasses Mississippi Sound and Chandeleur Sound, which are bounded by the Ship Island to Dog Island barrier island chain and the Chandeleur Islands, respectively. Ship Island was breached by Hurricane Camille in 1969 and again by Hurricane Georges in 1998. Despite the impact of tropical cyclones, approximately 30-40 cold fronts occur each year (Stone et al., 1999), making them the most common meteorological events in this region. Although the waves and currents during cold fronts are weaker than during tropical cyclones, they occur more frequently and thus can be important for the evolution of low energy coasts.

In a previous study, the SWAN (Simulating Waves Nearshore) wave model was used to predict waves and the Princeton Ocean Model (POM) was used to hindcast water levels and currents during a cold front that passed over the region (Keen, 2002). Predicted waves along the sound-sides of the barriers reached heights of 0.9 m with wave periods less than 4 s. Currents near the barrier islands within Mississippi Sound were dominated by tidal flow. This suggests that beach erosion within this estuary is sensitive to the tidal stage as well as the wind direction and strength. The model results have been used to infer sediment transport paths during the cold front. The mean currents predicted by POM suggest that sediment transport on the

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shoreface would have been westward at West Ship Island during frontal passage, which is in opposition to inferred eastward wave-driven longshore drift in the surf zone. Current-driven shoreface transport would have been westward throughout the length of Ship Island after the wind shifted to more northerly during the post-frontal phase. The predicted steady currents also suggest that sediment would have been continuously eroded from West Ship Island and transported into Ship Island Pass to the west. Such a transport system during cold fronts would partly explain the long-term erosion at the western end of Ship Island (Chaney and Stone, 1996).
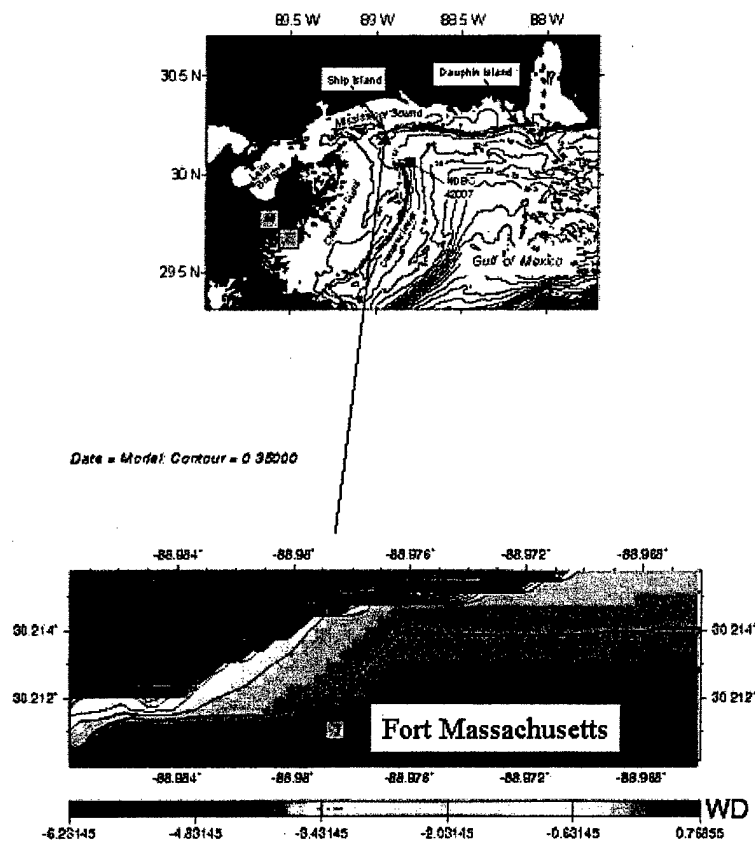

Fig. 1. Location of West Ship Island in the Missisippi Bight.

This study further investigates sediment transport and its effect on beach profile evolution at West Ship Island using higher resolution hydrodynamic models and a high-resolution sedimentation model. The objective of this work is to determine the transport paths and fate of sediment eroded from the beach during a cold front, especially with respect to across-shore location. We propose to test the hypothesis that sediment is transported to the west by wave-driven longshore currents and ultimately is deposited in the channel to the west of the island; however, sediment is also carried to the lower foreshore by undertow and transported by tidal and wind-driven currents, leading to a complex time-dependent sediment transport regime.

METHODS

Field Measurements

The monitoring program along the soundside coast of West Ship Island was established in June 1996 (Stone, 1998). Eight profile markers were established at regular intervals (approximately 600 m) along the beach. Each profile was consistently surveyed from the crest of the foredune to a distance of at least 100 m offshore, except at the western tip where the water depth was too great. A U. S. Army Corps of Engineers (COE) benchmark at the base of the fort was used to determine all elevations relative to NGVD. Surveys were completed in June, October, and December of 1996, and in February, March, April, and June of 1997.

Hydrodynamic measurements were made east of the pier at Fort Massachusetts between 17 February and 8 March, and between 13 March and 1 April 1997. The instrumentation package included high-accuracy, quick-response, and programmable self-recording sensors measuring wind speed and direction, current velocity and direction, water level fluctuations. Wave height, period, and direction as well as low-frequency water level changes were derived from the water level record.

Model Grid Generation

Accurately modeling the shoreface is a difficult problem because of the importance of small-scale variations in water depth and coastline. One location where detailed modeling is possible is Duck, North Carolina, where monthly surveys are made. However, this is a costly and time-consuming procedure that cannot be applied everywhere. The nearshore database for West Ship Island consists of the profiles measured as part of previous work (Stone, 1998). The grid used for this study is based on the profiles collected in June 1996. The model grid in Figure 1 was generated using the profile data; the coastline digitized from NOAA chart 11373; and the 3.8 m (12 foot) contour from the same chart. The across shore profiles are interpolated to the offshore contour where a hyperbolic tangent function is used to transition from the shallow water (< 1.5 m) near the coast to the deeper water (7 m) in the central part of the sound. Alongshore water depths are interpolated between profiles.

The most complete set of profile data were collected in June 1996. These profiles are used to construct a model grid, rather than the incomplete data set from 1997, because this study is preliminary and examines the contribution of different mechanisms to erosion and deposition along the soundside of the barrier island. It was felt to be more important to have a consistent shoreline and foreshore for the entire island rather than the most up-to-date for the selected simulation period. Note that the simulation period was determined by the availability of wave and current data.

Hydrodynamic Modeling

Three numerical models are used to calculate the high-resolution flows required for a detailed sedimentation study at West Ship Island: (1) The Princeton Ocean Model (Mellor, 1993) is used to compute low-frequency water levels and steady currents in Mississippi Sound; (2) The SWAN model (Booij et al., 1999) is used to calculate regional wave fields; and (3) the SHORECIRC model (Svendsen and Putrevu, 1990) calculates very high resolution quasi-three-dimensional flows on the shoreface and in the surf zone.

The steady currents are calculated by the Princeton Ocean Model (hereinafter called POM) (see OEY and CHEN, 1992). The POM solves the primitive equations for momentum, as well as salinity, temperature, turbulent energy and a turbulent length scale (MELLOR and YAMADA, 1982). This model uses split modes; a small time step is used to solve for the depth-integrated flow (external or barotropic mode) and a larger time step is used to compute three-dimensional variables (internal or baroclinic mode). The model uses a terrain-following σ coordinate system in the vertical. The input to POM consists of bathymetry, initial three-dimensional salinity and temperature fields, heat and momentum fluxes at the surface, and the water surface anomalies, transports, and temperature and salinity values at open boundaries.

The POM model requires both initial conditions and boundary forcing to operate. The atmospheric forcing for this study is supplied by the hourly winds measured at NOAA buoy 42007 (Figure 2). The Naval Oceanographic Office compiled the bottom topography from a variety of sources, including the National Ocean Service 3 second database. Three barotropic POM simulations were used in this study. The first uses tidal forcing with an open boundary condition that includes tidal elevations and depth-integrated transports from the ADCIRC database for the East Coast and Gulf of Mexico (LEUTTICH et al., 1992). A second barotropic model is used to examine the wind-driven water levels within the region. This model uses only wind forcing and closed boundaries. The third model uses both tidal boundary conditions and wind forcing. No river inflow is used for these short simulations. The POM simulations were calculated on a Cartesian grid with a horizontal resolution of 777 m along the x axis and 898 m along the y axis. The external time step is 6 seconds and the internal time step is 180 seconds. The model was spun up for 48 hours with tidal forcing only and run for the hindcast interval of 0000 GMT 13 March to 3 April 1997.

A SWAN 69 km by 33 km grid with 500m resolution is set up. The modeling domain reaches the Northern shore of the Mississippi Sound to ensure proper fetch is included. The irregular wind and water level data are interpolated to provide input to the model. Since the main event is coming from the Northwest, no wave boundary conditions are applied at side boundaries. The model is set up in spherical coordinate and includes all shallow water physics such as bottom friction. Both nonstationary and stationary runs were conducted.

In the nearshore, the dynamics of breaking waves exchanges momentum into the water column, forcing wave-drive currents. The SHORECIRC model simulates these currents by propagating offshore waves over the nearshore domain, calculating gradients of radiation stress (momentum flux), and using this information as a depth-integrated body force to generate the current fields. The model is quasi-3D, allowing incorporation of the dynamics inherent in depth-varying currents (in particular, enhanced dispersive mixing) without explicit model discretization in the vertical. While the eventual system will incorporate initial wave conditions from SWAN, we used measured wave conditions to generate the nearshore waves and currents over the domain.

The nearshore grid measured 1.2 *km* offshore by 5 *km* longshore, with a resolution of 6 *m* in both directions. Waves, winds and water levels measured near Fort Massachusetts (see Figure 1 for location) were used as initial and tidal conditions for the model; waves were assumed to be in line with the wind direction and to have a peak period of 3 seconds. Since detailed directional spectra were unavailable, parameterized spectra based on measured wave conditions were used, with the frequency and directional spreads assumed to be quite broad (as is typical of wind-generated wave conditions). Closed lateral boundaries were used, though periodic boundary conditions will be investigated in future implementations. Five conditions spanning the period from March 20, 1997 at 12 noon (pre-frontal) to March 21, 1997 at 7am (after frontal passage) were simulated. Nearshore waveheights, directions and generated currents were saved and passed to the sedimentation model.

Sedimentation Modeling

Sediment entrainment and transport is calculated by the coupled bottom boundary layer-sediment transport model called TRANS98 (KEEN and GLENN 1998), which includes suspended load and bed load transport terms (KEEN and SLINGERLAND, 1993). This model is coupled to a bed conservation model. Several wave, current, and sediment parameters must be given at each grid point in the domain. The significant wave height H_s, peak period T, and mean propagation direction θ are supplied by the SHORECIRC model. The wave orbital speed u_b and diamete4r A_b are computed using linear wave theory. The reference currents u_r are also supplied by SHORECIRC; these currents come from mid-depth and thus represent the mean flow only. The angle between the steady current and wave

directions φ_r is calculated. The eddy diffusivity and resuspension coefficients used in calculating the suspended sediment profiles are based on previous observations and modeling work (Styles, 1998). The model also requires the grain size distribution at each grid point. For this study, fine sand with a mean of 1.25×10^{-6} m (3 ϕ units) is represented by 20 size classes.

In addition to calculating the wave-current bottom shear stresses, the TRANS98 model computes the velocity and suspended sediment concentration profiles, the ripple height η, and the near-bed transport layer height h_{TM}. The model explicitly includes bed armoring as finer material is preferentially removed because the remaining bed sediment is coarser. The depth of entrainment is restricted by the active layer h_A, which represents that part of the bed that interacts with the flow during one time step. The active layer height is given by $h_A = \eta + C \cdot h_{TM}$, where C is a proportionality constant for the average concentration in the near-bed transport layer. When low flow conditions exceed the initiation of motion criteria, the active layer is proportional to the ripple height (GRANT and MADSEN, 1982). During high flow conditions, it is proportional to h_{TM}. When the depth of resuspension for a sediment size class exceeds h_A at a grid point, the reference concentration is reduced and new sediment concentration profiles are calculated. This iterative procedure is applied at each grid point for each sediment size class. Sediment transport as bed load is evaluated using two formulations (VAN NIEKERK et al., 1992; SOULSBY, 1997), which are compared in the discussion. The sedimentation model calculates changes in bed elevation from horizontal sediment transport fluxes using a bed continuity equation.

The numerical model is being used to simulate sediment transport, erosion, and deposition on the shoreface at the time and spatial scales of the observed mean currents, which are on the order of 1 hr and 5 m, respectively. The resulting changes in bed elevation are a consequence of the conservation of mass in the continuity equation. The model is run on a Cartesian grid with a horizontal resolution of 12 m, which covers the West Ship Island area (Figure 3) using 100 grid points in the across-shore dimension and 425 grid points along shore. The minimum water depth used is 0.1 m and the seaward limit of the grid is at 7 m. The model is integrated in time from 0000 GMT 13 March to 3 April 1997 using a time step of 1 hour.

RESULTS

Observations

The field deployment in late March 1997 captured two cold fronts, which are identified by the rapid change from southerly to northerly winds on March 14 and 19-20 (Figure 2). The wind speed was slightly higher during the second front, with a peak of almost 12 m/s. The winds measured at Fort Massachusetts have been shown to correlate well with offshore NDBC buoy 42007 (Stone, 1998). Thus, the wind is uniform near Mississippi Sound during these fronts. This discussion and the following modeling report will focus on this cold front only.
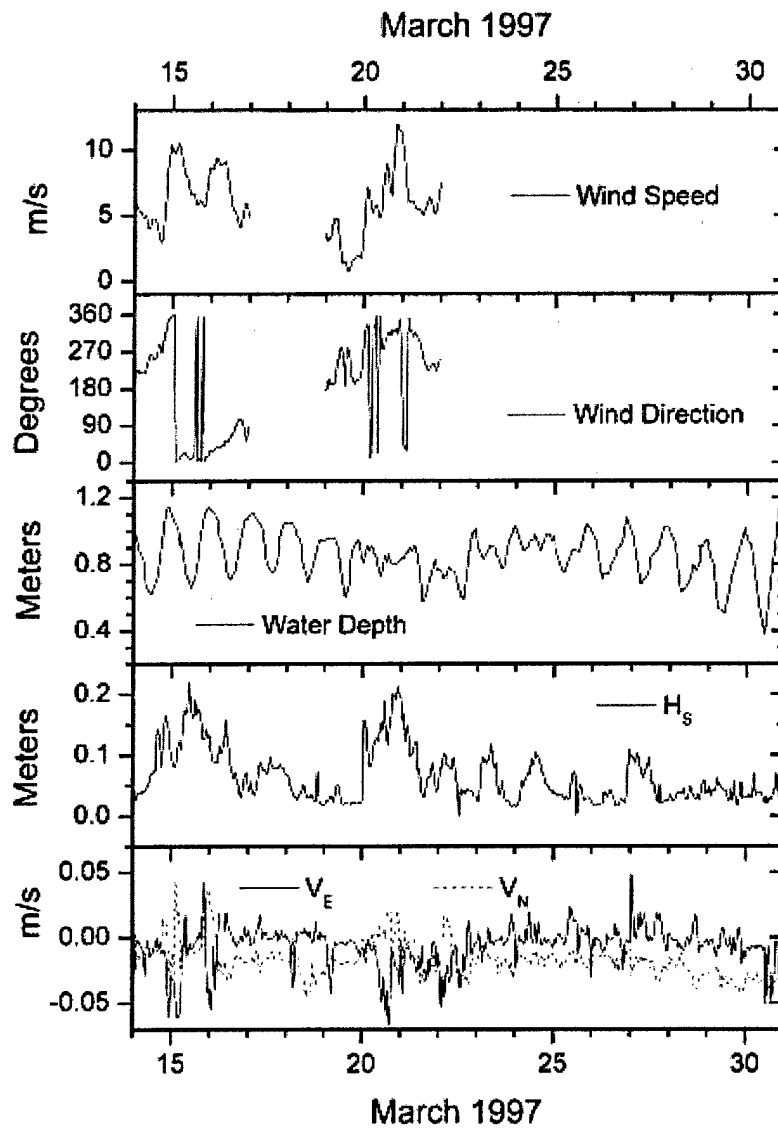
March 1997

Fig. 2. Measurement made at Fort Massachusetts during March 1997.

The pressure instrument measured both wave and low frequency changes in water depth, which can be used to identify the contribution of waves and tides to the physical forcing at Fort Massachusetts. The water depth history seen in Figure 2 is

the result of tides, low-frequency coastal waves, and local wind stress. It is seen that even during cold fronts, the water level is dominated by the astronomical tides; however, there is a perturbation of water level on March 20 during frontal passage, when the tidal signal is reduced. The water depth at this time is very near the mean of 0.86 m at this location. The significant wave height H_S shows a strong increase during the front, with a maximum of 0.2 m at 2300 Central Standard Time (CST) on March 20. At this time, the wind was blowing from the northeast and the fetch within the sound was a maximum.

A peak alongshore current of –0.06 m/s at West Ship Island (solid line in the lower panel of Figure 2) occurred in the afternoon of March 20. Note that negative velocities are westward and southward for easting and northing currents, respectively. However, because of a northward component of 0.02 m/s, the resultant flow was obliquely offshore to the west at this location. This nearshore current was thus opposed to the wind and wave directions. The tide was ebbing at this time, as seen in the water depth record. Although the general ebb tide flow pattern in this area is to the southeast, previous model results suggest divergence of coastal flow at West Ship Island and westward flow along the sound side of the island (Keen, 2002). This model prediction is in agreement with the current measurements at Fort Massachusetts.

The sequence of measured beach profiles has been analyzed for erosional trends by Stone (1998). The June 1997 survey indicates annual changes in beach width and volume of –0.14 m and –0.17 m^3, respectively. Individual profiles showed the following annual changes in beach width and volume: (1) S1 gained 5.16 m and lost 1.59 m^3; (2) S2 eroded 1.26 m and gained 6.57 m^3; (3) S3 gained 5.62 m in width and lost 9.13 m^3; (4) S5 eroded by 0.96 m and lost 2.99 m^3 of sand; (5) S6 eroded 1.33 m and lost 2.95 m^3; and (6) S7 eroded by 8.07 m and lost 9.17 m^3 of sediment. Tropical Storm (TS) Josephine passed southeast of Ship Island on October 7-8, 1996; the October 1996 survey revealed that the average beach width and volume increased 3.75 m and 2.28 m^3, respectively, after the storm because of erosion of the backshore and foredunes along the soundside coast. Following the storm, however, erosion became prevalent and the beach volume decreased substantially. Much of this erosion occurred between the October and December 1996 surveys. Surveys in February 1997 indicated sediment deposited along the lower foreshore by TS Josephine was eroded from the profile. By June 1997, distinctive changes observed along the soundside of West Ship Island included erosion along the lower foreshore and the development of a nearshore bar at profile S1, landward retreat of the foreshore and disappearance of a post-Josephine foreshore ridge at profiles S2, S5, and S6, and development of an upper foreshore ridge at profile S3. However, S3 was probably influenced by nearby beach renourishment near Fort Massachusetts. The June 1997 survey at profile S7 revealed erosion along the foreshore and the seaward face of a nearshore bar, and deposition seaward of the bar on the nearshore shelf. The profile at

S8 was influenced by local sediment supply associated with overwash deposits by TS Josephine and the effect of wave shadowing by the recurved tip of West Ship Island.

The surveys at profiles S6 and S8 suggest offshore transport of sediment during non-storm conditions. These observations suggest that there is a mechanism for transporting sediment offshore, as was suggested by Stone (1998). We will evaluate this hypothesis using the numerical a sedimentation model in section 3.3. The likely contribution of spatially and temporally variable waves and currents to the range of morphological responses seen in the survey data will also be examined.

Modeled Waves and Currents
Due to the relatively small size of the domain, no significant difference is found between these runs. The stationary run result at an output depth of 4 m near the measurement point is shown in Fig. xxx. It has a similar growth and decay shape as the field data, i.e. a pressure transducer at a shallower depth of 0.8 m, but the significant wave height is generally higher. This difference in wave height may be due to the resolution of the grid and difference in depths. A nested run at 90 m resolution is being setup to investigate the impact of bathymetry resolution.
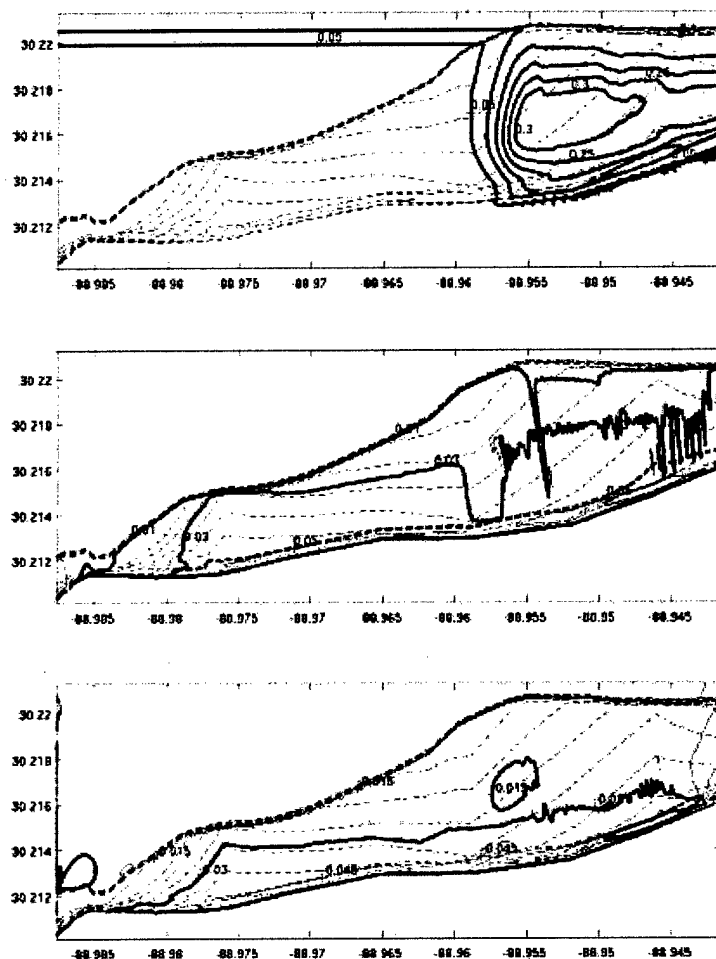
Nearshore wave fields for the five cases modeled are generally marked with very low wave heights on the west side of the island and higher wave heights to the east. Wave arrival directions for the five cases ranged from about 288 degrees azimuth to 325 degrees azimuth, thus arriving from a general northwest direction. The shelf break in the bathymetric grid imparts a severe refractive effect on incoming waves, causing them to swing eastward. This causes a very strong westward gradient in the wave energy field. The resulting radiation stress gradients cause the longshore flow to be eastward. However, due to the overall weakness of the wave forcing (caused by small wave heights and low peak periods), the magnitudes of the mean wave-induced currents rarely exceed 15 *cm/s*. Figure 3 shows the wave heights and offshore and longshore current fields for the conditions during March 20, 1997 at 6pm CST.

The POM was used to simulate tidal currents that were superimposed on the currents computed by SHORECIRC. The currents at the maximum passage of the cold front show moderate flow offshore as the tide was ebbing. This flow is overprinted on the nearshore flow to produce a mean offshore flow at this time (Figure 4A). The front passed too quickly to for frontal flow to interact with a range of tidal stages and flows.

Sedimentation
The TRANS98 model is designed to resuspend sand and silt sized sediment and thus it should be applicable to the nearshore soundside of West Ship Island. However, the transport during the peak of frontal passage is very weak, with a maximum bed load transport rate of 6×10^{-5} kg/m/s (Figure 4B). Suspended sediment transport is an order of magnitude higher (Figure 4C). The maximum transport rates

are directed offshore, however, in keeping with the southerly wind at this time. As the wind shifts to easterly, longshore drift becomes more important (not shown). Both bed load and suspended transport rates are highest near Fort Massachusetts, as indicated by the square in Figure 4. This suggests that this is a focal point of beach erosion, at least during this cold front. Note the displacement of the coastline that is included as part of the graphics package. This coast is inaccurate and is for general reference only.

Figure 3. Predicted Wave heights from SHORECIRC during the peak frontal passage.

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CONCLUSIONS

The wave and sedimentation climate in Mississippi Sound is moderate, with wave heights well below 1 m. However, observed erosion at the eastern end of West Ship Island indicates that even in this physical environment, there is sufficient sediment mobility to produce significant results over monthly to annual time scales. The water depths near the soundside of Ship Island are less than 1 m, especially near the eastern end at Camille Cut. Thus, wave effects are nonexistent at this location as indicated by the profile data. However, as can be seen in the results from this study, when the wind blows from the northeast as during the post-frontal phase of cold front passage, waves can reach greater heights and the period can exceed 3 seconds. These waves cause erosion at the western end of the island. Because of the low wave heights used in driving SHORECIRC, the wave driven longshore currents are very weak, not exceeding 0.1 m/s even during the strongest winds. However, the tidal currents predicted by POM increase the mean currents in the model grid to more than 0.2 m/s. Thus, the critical shear stress to suspend the fine sand used in these simulations is exceeded if the tidal currents are high when waves are present.

The TRANS98 model does not explicitly calculate surf zone erosion and an estimate must be used instead. In this case, we restrict ourselves to examining grid cells where high transport rates are predicted at the coast. This will indicate the path of sediment eroded from the coast without producing a quantitative erosion rate. The results from this study suggest that the physical driving mechanism for erosion at the western end of West Ship Island is the interaction of the tidal flow and the wave driven longshore current at the coast. Additional work will examine the details of this interaction for a number of different tidal and frontal regimes.

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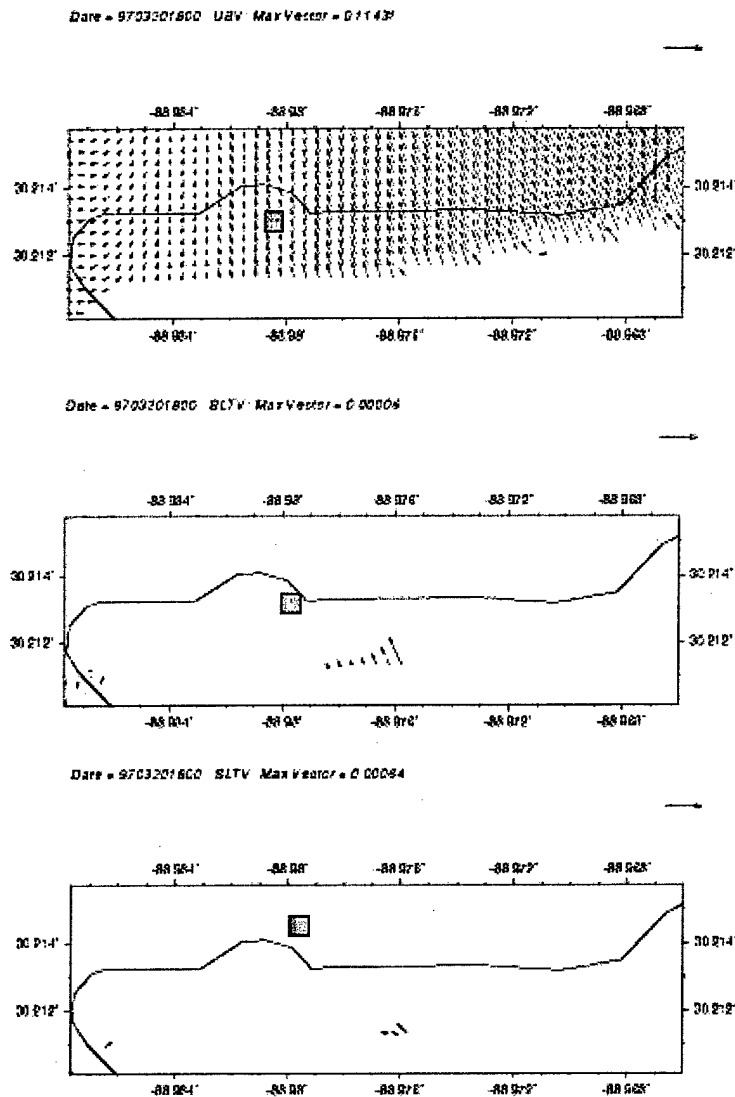
Figure 4. (A) POM currents for the frontal peak. (B) TRANS98 bed load transport rate (C) Trans98 suspended transport rate at frontal peak.

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