

Impacts of Fluvial Fine Sediments and Winter Storms on a Transgressive Shoal, off South-Central Louisiana, U.S.A.

D. Kobashi[†], F. Jose[‡] and G. W. Stone[§]

[†]Coastal Studies Institute,
Dept. of Oceanography and
Coastal Sciences, Louisiana
State University, Baton
Rouge, LA 70803, U.S.A.
dkobas1@lsu.edu

[‡]Coastal Studies Institute,
Louisiana State University,
Baton Rouge, LA 70803,
U.S.A. felixjose@lsu.edu

[§]Coastal Studies Institute,
Dept. of Oceanography and
Coastal Sciences, Louisiana
State University, Baton
Rouge, LA 70803, U.S.A.
gagreg@lsu.edu



ABSTRACT

KOBASHI, D., JOSE, F., AND STONE, G.W., 2007. Impacts of Fluvial Fine Sediments and Winter Storms on a Transgressive Shoal, off South-Central Louisiana, U.S.A. *Journal of Coastal Research*, SI 50 (Proceedings of the 9th International Coastal Symposium), 858 – 862. Gold Coast, Australia, ISSN 0749.0208

Ship Shoal, a transgressive sand shoal off South-Central Louisiana and one of the potential sand resources that will likely be used to restore rapidly eroding barrier islands in coastal Louisiana, has a unique, complex sediment exchange with fluvially introduced sediments during high river discharge and a high energy wave climate associated with frequent winter storms. The result of a recent field survey, undertaken from April 4th to May 25th, 2006 showed that the bottom sediment distribution was strongly affected by fine-grained sediment outputs from Atchafalaya River and the prevailing wind and wave conditions, changing from mud to fine sand for roughly two months, which was also supported by satellite imagery and river discharge data. The data from the pulse-coherent Doppler profiler (PCADP) showed the existence of a fluid mud layer during the deployment, which was associated with the interaction of waves and the fluvial sediments. An observed fluid mud layer of 10-15 cm in thickness was conspicuously influenced during a storm in late April, in which a maximum wind speed of 17 m/s and significant wave height of 2.3 m were recorded. Waves strongly reworked bottom sediment during the pre-frontal phase, vertical mixing occurred due to strong vertical velocity and finally, after the storm passed, the re-suspended and the mixed sediments settled out and the fluid mud layer was re-established during the waning phase of the storm. The above results show the influence of fluvial fine sediments and winter storms on Ship Shoal sediments and its feedback relationship with hydrodynamic processes, which is likely to affect benthic habitat of the shoal and future sand mining.

ADDITIONAL INDEX WORDS: *fluid mud, cold fronts, wave climate, bottom boundary layer, sediment resuspension, deposition, transport, Ship Shoal*

INTRODUCTION

The Louisiana coast has (i) geologically, (ii) physically and (iii) meteorologically unique features. The Mississippi River and its distributaries have developed deltas at the river mouths, discharging large amounts of fine-grained sediment onto the Louisiana continental shelf (ROBERTS, 1997). The deltas are characterized by regressive and transgressive phases: The regressive phase is characterized by delta progradation switched approximately every 2000 years as the river meanders and switches its course (ROBERTS, 1997). The transgressive phase is characterized by three stages: (1) erosional headland and flanking barriers, (2) barrier island arc, and (3) submerged inner shelf shoals (PENLAND ET AL., 1986). The study area, a submerged inner-shelf sand shoal parallel to the coast, called Ship Shoal, is thought to be a remnant of the Maringouin delta, which was active 7500-5000 years BP (PENLANDS ET AL., 1986; ROBERTS, 1997). The Louisiana coast has been facing tremendous coastal land loss due to subsidence, shortage of sediment supply from the Mississippi River, occasional hurricane landfalls, frequent passages of winter storms, and human intervention such as dam constructions (ROBERTS, 1997) etc. This has culminated in a loss of approximately 0.4 ha of land every 35 minutes. The state and

federal governments are seeking potential sources of sand to restore rapidly eroding beaches and barrier islands (DRUCKER ET AL., 2004). The study area, Ship Shoal is thought to have 1.2 billion cubic metres of potential high quality quartz sand (KULPET AL., 2001). In addition, although the northern Gulf of Mexico is characterized by a low-energy micro-tidal environment, frequent winter storms and rare hurricane landfalls will continue to impact Louisiana's coastal environment tremendously (cf ALLISON ET AL., 2000; STONE, 2000; WALKER AND HAMMOCK, 2000; SHEREMET ET AL., 2005). Particularly, winter storms characterized by the front between an Arctic polar cold air mass and a tropical warm air mass could substantially impact the coastal environment in terms of physical and biological processes due to their frequencies (i.e. 20-30 times a year) (STONE, 2000; PEPPER, 2000). The wave-climate, bottom boundary layer, and subsequent sediment transport studies have been conducted extensively based on the analysis of non-cohesive sediments (e.g. PEPPER, 2000; STONE, 2000). However, although Ship Shoal is a sand shoal, the result of the previous survey suggests the existence of mud on the sand bottom, which could affect physical and biological processes. The purpose of the paper is to show the complexity of the shoal sedimentary environment and the factors that could affect them

based on the result of the recent field survey undertaken during winter storm and spring flood season in 2006.

FIELD SURVEY

The field survey was undertaken from April 4th through May 25th, 2006 at the eastern flank of the shoal, which is a proposed sand mining area (Figure 1).

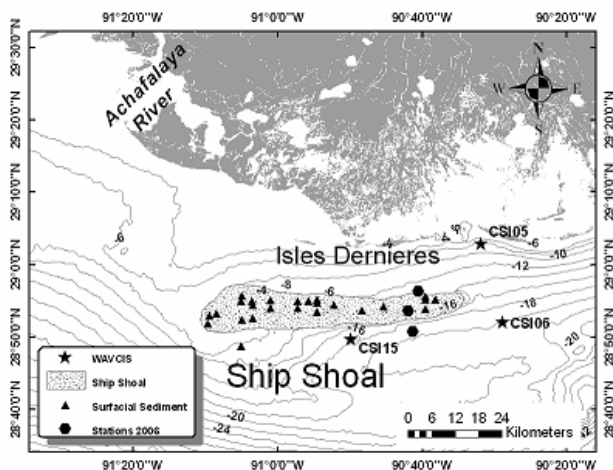


Figure 1 Map of the study area

The survey consisted of the deployment of the oceanographic instruments and repeated bottom sediment sampling. Two SonTek[®] acoustic Doppler velocimeters with a Paroscientific[®] pressure sensor and two D&A[®] optical backscatter sensors (only at the onshore station) were deployed at both onshore and offshore edges of the shoal. SonTek[®] pulse-coherent Doppler profiler (PCADP) coupled with a Druck[®] pressure sensor (1.16 mab) and two D&A[®] optical backscatter sensors (30 and 60 cmab) was deployed on the crest of the shoal (Figure 1). The data from the PCADP deployment are presented in this paper. The instrument was set up in burst mode, a discontinuous measurement with a sampling frequency of 2 Hz with 2048 records every 1 hour burst. Bottom sediment samples were collected by a diver, using a ponar grab at each station, and also by box cores for the entire shoal during a benthic survey cruise (Figure 1). The samples were analyzed by granulometric analysis and sedigraph for sand and mud samples, respectively. The optical backscatter data were calibrated using bottom sediments and water samples to estimate the suspended sediment concentration (SSC). The data analysis and discussions are given in the following section. Detailed analytical methods are provided by STONE ET AL (2006).

RESULTS AND DISCUSSION

Heterogeneous Sedimentary Environment

One important characteristic of the Louisiana coast is the large concentration of fluvial fine-grained sediment output from the Mississippi River and the Atchafalaya River. The Atchafalaya River, a Mississippi River distributary located roughly 150 km northwest of Ship Shoal, discharges a tremendous amount of fine-grained sediments onto the Louisiana continental shelf, especially during the spring flood season. The river sediments are usually transported to the west as alongshore coastal current (WELLS AND

KEMP, 1981); however, during the spring flood season, the sediments are occasionally transported to the southeast due to northwesterly and southwesterly winds caused by winter storms (WALKER AND HAMMOCK, 2000). Terra-1 MODIS satellite images obtained during the deployment period, captured at the Earth Scan Laboratory, Louisiana State University, clearly showed the plumes of the fluvial sediments transported further southeast, down to the shoal during winter storms. This has also been reported by WALKER AND HAMMOCK (2000). Grains size distribution of the sediment samples shows that the sediment on the shoal was coarser at the eastern part of the shoal than at the western shoal, suggesting the influence of the river discharges from the Atchafalaya River (Figure 2).

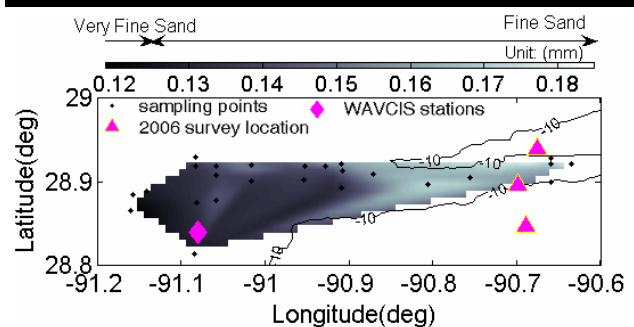


Figure 2 Grain size distribution on the shoal

Moreover, additional sediment sampling at the eastern shoal region shows the impacts of winter storms on the shoal sediment (Figure 3). The grain size data for the crest of the shoal showed that the sediment changed drastically from mud to fine sand during a rough two month period (Figure 3), suggesting the influence of fluvial fine sediments and sediment reworking during winter storms.

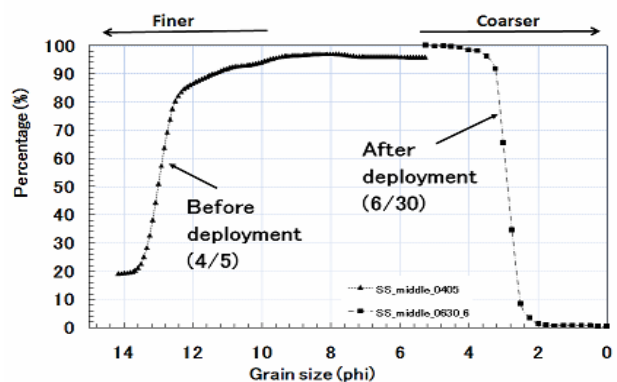


Figure 3 Cumulative weight percentage of the sediment before and after the deployment

Bottom elevation change obtained from the PCADP is also associated with river discharges and winter storms (Figure 4b). River discharge data at Simmesport, Louisiana (91°47'54"W, 30°58'57"N) from U.S. Army Corps of Engineers (USACE), New Orleans District show two high river discharge periods during and before the deployment (Figure 4a). High river discharge is defined as higher than 5,666 m³/s suggested by WALKER AND HAMMOCK (2000) (Figure 4a, dash line).

Before the deployment, high river discharge was measured at Simmesport with a maximum discharge of 8,785 m³/s. Bottom elevation on the crest of the shoal increased approximately 15 cm, which matched the high river discharge, adding a time lag because of the distance between Simmesport and Ship Shoal. Terra-1 MODIS true colour images during the period clearly showed the river sediment was transported southeast and reached the shoal. The same situation happened again around May 10th, which was another high river discharge period. While, during late April, a storm hit the survey area and a substantial reduction in the bottom

elevation was measured. Detailed mechanisms of re-suspension and depositional processes that affect the elevation change during the period are discussed in a later section of this paper.

Bottom Boundary Layer and Sediment Transport Processes

The sediment distribution pattern discussed above was strongly influenced by the wave climate as well as the river discharge. During the deployment period, a total of 7 winter storms passed the survey area with a maximum wind speed of 17 m/s and associated wave height of 2.3 m in April 30th (Figure 5). Time series data during the period show that the waves substantially re-suspended bottom sediment. A current velocity profile shows that the horizontal velocities were strengthening up to the sensor height (i.e. 1.16 m) during the pre-frontal phase (Figure 5c). Vertical velocities were also high during the pre-frontal phase (Figure 5d), suggesting that the re-suspended sediment was mixed up to the sensor height, probably up to the water surface, because of the sharp temperature increase reported by STONE ET AL (2006) during the period.

The shear stress exceeded the threshold for sediment re-suspension on April 29th, which matched the sharp increase in the bottom turbidity (Figures 5e,f). Maximum shear stress reached 0.76 N/m² on April 30th which matched the high turbidity values during the re-suspension period (i.e. April 29th ~ April 30th). Substantial vertical mixing could have happened because of high

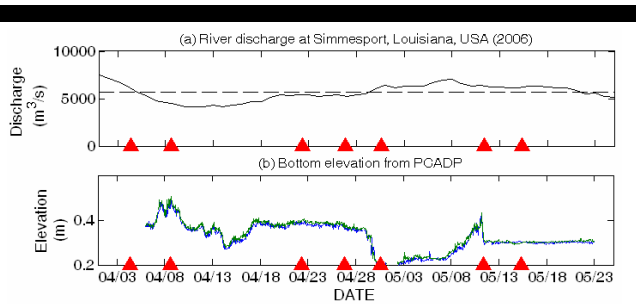


Figure 4 (a) River discharge of Simmesport and (b) bottom elevation on the shoal crest. Shaded triangles show passages of winter storms.

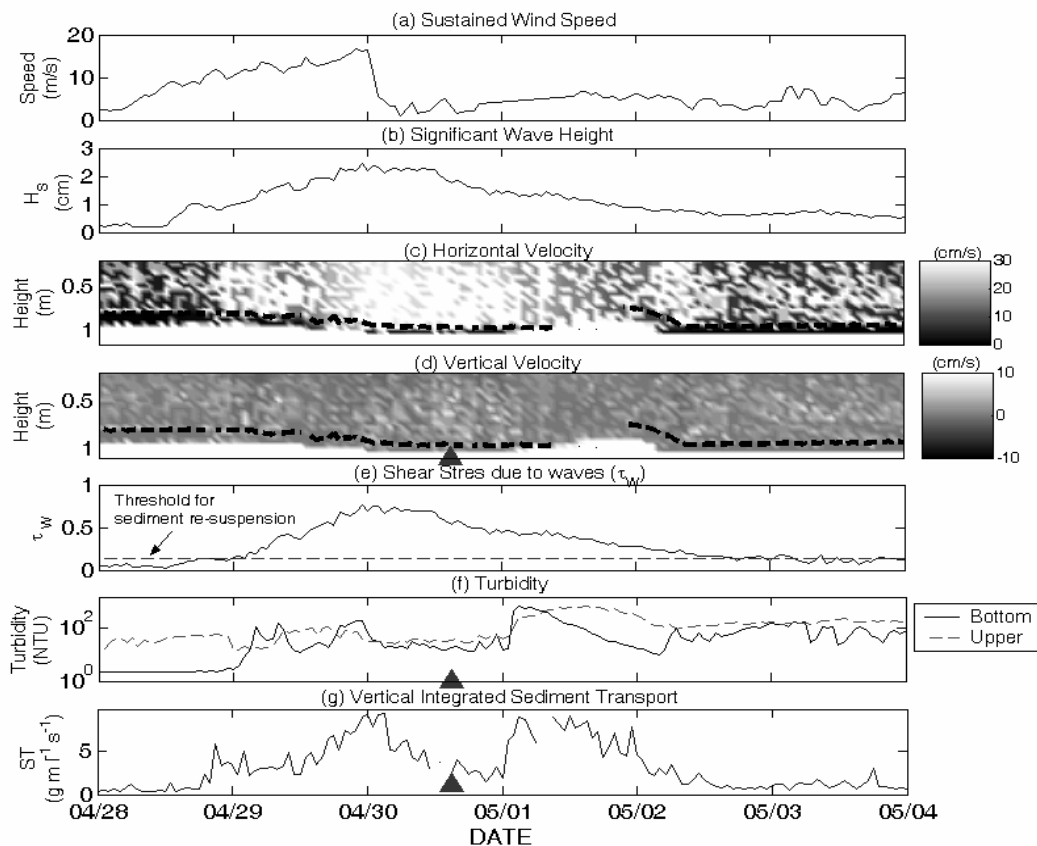


Figure 5 Time series of (a) sustained wind speed, (b) significant wave height, (c) horizontal current profile with bottom elevation (dash line), (d) vertical current profile with bottom elevation (dash line), (e) shear stress with the threshold for sediment re-suspension (dash line), (f) turbidity, and (g) depth-integrated sediment transport. Shaded triangle shows a passage of a cold front

vertical mixing usually associated with the occurrence of sediment re-suspension (mixing period). After the storm passed, the wave height decreased as did the shear stress. However, the turbidity had the highest value during this post-storm period because the re-suspended sediment settled gradually during the waning phase of the storm (settling period) (Figure 5f). Depth-integrated sediment transport from the bottom (0 m ab) to the sensor height (1.16 m ab) shows the important combination of velocity and sediment concentration to the transport (Figure 5g). During the re-suspension period, high horizontal velocity and high SSC triggered high sediment transport. During the mixing period, lower SSC and lower horizontal velocity in spite of high vertical velocity caused low transport. During the settling period, the sediment transport rate had the highest value because of the high SSC, despite lower horizontal velocity.

Sediment Exchange on the Shoal

One of the biggest issues for this study is the existence of mud/fluid mud over the consolidated sand layer, confirmed by a diver before and after deployment. Fluid mud layers have already been reported by several researches off western Louisiana and near the Atchafalaya River (e.g. KEMP AND WELLS, 1987; ALLISON ET AL., 2000; SHEREMET ET AL., 2005), but not on the sand shoal, off south-central Louisiana. The fluid mud layer is a fluffy gel-like high concentration layer defined by $10 \text{ g/l} < \text{SSC} < 400 \text{ g/l}$ (MEHTA ET AL., 1994; TRAYKOVSKI ET AL., 2000). It is also characterized by a sharp change of the sediment concentration between upper water and the fluid mud layer (lutocline). Figure 6 shows the schematic illustration of Ship Shoal sediment exchange.

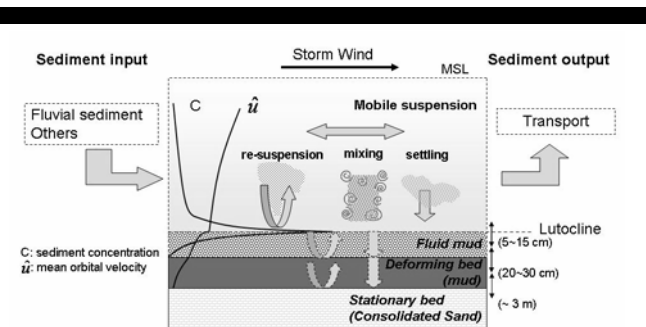


Figure 6 Schematic illustration of sediment exchanges on Ship Shoal

Ship Shoal appears to receive high inputs of fluvial sediments from the Atchafalaya River possibly in the form of gravity driven density flow, wave-induced currents, or both during high river discharge (WALKER AND HAMMOCK, 2000; BENTLEY, 2002). Moreover, waves during storms strongly rework the bottom sediments and cause high vertical mixing. The re-suspended sediment is then transported by mean currents from the shoal or deposits on the shoal during the waning phase of the storms (Figure 6).

Figure 7 clearly illustrates this scenario. Relative suspended sediment concentration (SSC) profile (Figure 7b) obtained from the PCADP acoustic backscatter intensity shows the sediment re-suspension and depositional processes during a storm. Before the storm passage (i.e. April 29th), the shear stress was less than the threshold for sediment re-suspension and the bottom sediments were not re-suspended. The peak of the SSC near the bottom (i.e. lutocline), which is about 10 g/l , was detected during this period (Figure 7c). The SSC is dramatically reduced below the peak because of the attenuation of acoustic backscatter intensity, which

is also reported by TRAYKOVSKI ET AL (2000) on the Eel River shelf off California. The fluid mud layer could be 10~15 cm in thickness (Figure 7c).

Shear stress exceeded the threshold as the storm approached and the sediment was re-suspended (Figures 5e,f). After the storm passage, the high value of the SSC disappeared and the SSC peak was shifted upward due to strong vertical diffusion (Figure 7d). A few days after the storm passed, the shear stress decreased and a substantial amount of sediment deposition occurred in spite of the highest sediment transport during the period (Figures 5g and 7e, May 1st-2nd). After the storm, the fluid mud layer was re-established with approximately 10 cm of thickness.

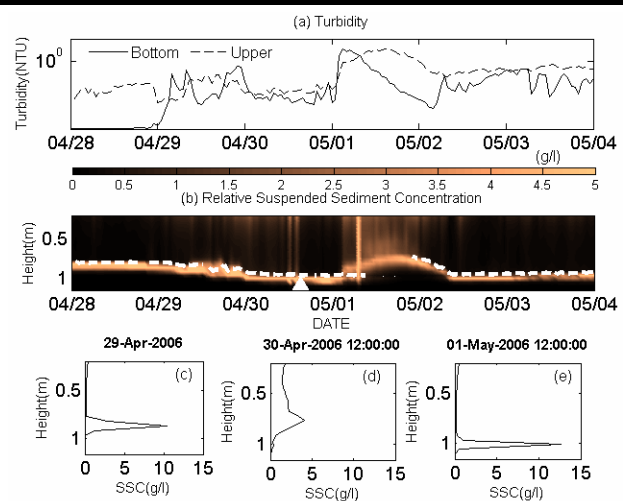


Figure 7 Time series of (a) turbidity, (b) sediment concentration profile, and (c-e) suspended sediment concentration profile before and after a storm

The above results clearly suggest the interaction of the fluid mud with waves and currents. Off western Louisiana, fluid mud has been detected based on field surveys and a numerical model implementation (e.g. WELLS AND KEMP, 1987; BENTLEY, 2002; SHEREMET ET AL., 2005). Ship Shoal has a unique and complex sedimentary environment characterized by winter storms and episodic fluvial sediment inputs which could occur when the high river discharge and the winter storms occur concurrently, compared to other inner-shelves along western Louisiana, which have frequent fluvial sediment inputs. However, the dispersal mechanism of the Atchafalaya mud plume to the shoal and wave-mud bottom interaction are little known because of the lack of available data. BENTLEY (2002) studied, by means of radiochemical analysis, the Atchafalaya flood deposit along the western Louisiana inner-shelf during spring flood season and showed the influence of Atchafalaya river sediments on the inner shelf off western Louisiana. Also, ALLISON ET AL (2000) show the hyperpycnal flow from the Atchafalaya River onto the inner shelf off western Louisiana based on a field survey. SHEREMET ET AL (2005) show the wave-mud bottom interaction and the formation of fluid mud affected by waves and currents during Hurricane Claudette based on *in-situ* observation and a numerical model off western Louisiana. However, for the heterogeneous sand shoals along south-central Louisiana, such research has never been undertaken and all of the available research is limited to the analysis of non-cohesive sediment (e.g. PEPPER, 2000; STONE, 2000). The heterogeneous sediment will likely affect local hydrodynamics and benthic habitat on the shoal (FLEEGER J., pers.

com.). Integration of field work, laboratory experiment, satellite imagery, and numerical model implementations will enable us to demonstrate detailed mechanisms of how the waves and the fluvial sediment outputs affect the shoal environment, which is likely to become a critical issue for future sand mining of the study area.

CONCLUSION

A field survey was undertaken from April 4th to May 25th, 2006 to examine the effects of fluvial fine sediments and storm waves on the heterogeneity of sediments on the surface of the sand shoal; the following results were obtained. Sediments sampled before and after the deployment of instrumentation changed from clay to fine sand for over a period of approximately 2 months, suggesting the importance of fluvial sediment inputs from the Atchafalaya River and sediment reworking due to winter storms. Time series data obtained using the bottom boundary layer array, coupled with river discharge data, showed strong correlations between bottom elevations, winter storms and the river discharge. Data from a pulse-coherent Doppler profiler in addition to satellite imagery, allow us to conclude that (1) fluid mud was occasionally derived from the Atchafalaya River during post-frontal events, that material being deposited on the shoal during fair weather and was approximately 10~15 cm in thickness, (2) the fluid mud layer was strongly reworked by storm waves during pre-frontal conditions, consistent with the highest wave heights and shear stress, resulting in a maximum of 20 cm of vertical erosion, and (3) the fluid mud was mixed during storm passages due to strong vertical velocity and sediment deposition was apparent during the waning phase of the storms. Ship Shoal, although comprised primarily of sediment in the sand range, appears to undergo significant changes in sediment type in the bottom boundary layer. Data presented here suggest that the Atchafalaya River debouches fine-grained sediment (silts and clays) onto the inner shelf, a considerable amount of which is deposited on the surface of the shoal. The resuspension of fine-grained material from offshore during storms may also be a second mechanism integral to this phenomenon. The implications associated are significant for several reasons including; (1) cohesive effects on hydrodynamic modeling (e.g. frictional effects on waves, currents, etc.) and (2) benthic habitat. Both of these have critical implication for potential future sand mining in large scale coastal restoration in coastal Louisiana.

ACKNOWLEDGEMENTS

The research has been funded by the U.S. Minerals Management Service, Dept. of Interior under contract # 1435-01-04-CA-35162 and by Louisiana Department of Natural Resources under contract #2513-04-02. Authors would like to thank CSI field support group for the invaluable help to the field survey and Richard Condrey, John Fleegeer and their students who helped us collect bottom sediment samples during a benthic survey cruise. Invaluable comments to the manuscript from Amy Spaziani and three anonymous reviewers are greatly appreciated. Yuliang Chen assisted with cartography.

LITERATURE CITED

- ALLISON, M.A., KINEKE, G.C., GORDON, E.S., GONI, M.A., 2000. Development and reworking of a seasonal flood deposit on the inner continental shelf off the Atchafalaya River. *Continental Shelf Research* 20 (16), 2267-2294.
- BENTLEY, S.J., 2002. Dispersal of fine sediments from river to shelf: process and product, *Transaction, Gulf Coast Association of Geological Societies*, v.52, 1055-1067.
- DRUCKER, B.S., WASKES, W., AND BYRNES, M.R., 2004. The U.S. Mineral Management Service Outer Continental Shelf Sand and Gravel Program: Environmental studies to assess the potential effects of offshore dredging operations in federal waters, *Journal of Coastal Research*, 20 (1), 1-5.
- KEMP, P. AND WELLS, J.T., 1987. Observations of shallow-water waves over a fluid mud bottom: Implications to sediment transport. Proceedings of *Coastal Sediments '87*. 363-378.
- KULP, M.A., PENLAND, S., AND RAMSEY, K.E., 2001. Ship Shoal: sand resource synthesis report. Prepared by the Coastal Research Laboratory, Department of Geology and Geophysics, University of New Orleans, LA. 70pp. + Appendices.
- MEHTA, A. J., LEE, S.C., AND LI, Y., 1994. Fluid mud and water waves: a brief review of interactive processes and simple modeling approaches. Final report DRP-94-4, Department of Army, U.S. Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, 92p, ill; 28 cm.
- PENLAND, S., SUTER, J.R., AND MOSLOW, T. F., 1986. Inner-shelf shoal sedimentary facies and sequences: Ship Shoal, Northern Gulf of Mexico, SEPM Core Workshop No.9, Modern and Ancient Shelf Clastics, 73-123.
- PEPPER, D.A., 2000. Hydrodynamics, Bottom boundary layer processes, and sediment transport on the south-central Louisiana shelf: The influence of extra tropical storms and bathymetric modification. Unpublished Ph.D. dissertation, Louisiana State University, Baton Rouge, 159p.
- ROBERTS, H.H., HUH, O.K., HSU, S.A., ROUSE JR., L.J., AND RICKMAN, D., 1987. Impact of cold-front passages on geomorphic evolution and sediment dynamics of the complex Louisiana coast, Proceedings of *Coastal Sediments '87*, 1950-1963.
- ROBERTS, H., 1997. Dynamic changes of the Holocene Mississippi River Delta Plain: The Delta Cycle, *Journal of Coastal Research*, 13(3), 605-627.
- SHEREMET, A., A.J. MEHTA, B. LIU, G.W. STONE, 2005. Wave-sediment interaction on a muddy inner shelf during Hurricane Claudette. *Estuarine, Coastal and Shelf Science*, v.63, 225-233.
- STONE, G. W., 2000. Wave climate and bottom boundary layer dynamics with implications for offshore sand mining and barrier island replenishment in south-central Louisiana. OCS Study MMS 2000-053. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, La. 90 p.
- STONE, G.W., CONDREY, R., AND J. FLEEGER, 2006. Environmental Investigation of the Long-Term Use of Ship Shoal Sand Resources, Year 2 Annual Report to U.S. Minerals Management Service and Louisiana Department of Natural Resources, 62pp.
- TRAYKOVSKI, P., GEYER, W.R., IRISH, J.D., AND LYNCH, J.F., 2000. The role of wave-induced density-driven fluid mud flows for cross-shelf transport on the Eel River continental shelf. *Continental Shelf Research*, Vol. 20. 2113-2140.
- WALKER, N.D. AND HAMMACK, A. B., 2000. Impacts of Winter Storms on Circulation and Sediment Transport: Atchafalaya-Vermilion Bay Region, Louisiana, U.S.A., *Journal of Coastal Research*, 16(4), 996-1010.
- WELLS, J.T. AND KEMP, P., 1981. Atchafalaya mud stream and recent mudflat progradation: Louisiana chenier plain. *Transaction, Gulf Coast Association of Geological Society*, v.31, 409-416.