Final Report on NASA contract NAG5-9688

Application of Remote Sensing to Assess the Impact of Short Term Climate Variability on Coastal Sedimentation

for the period of

15 June 2000 to 14 June 2004

submitted by

Christopher C. Moeller

W. Paul Menzel

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

University of Wisconsin

1225 West Dayton Street

Madison, Wisconsin 53706

and

Oscar K. Huh

Nan Walker

Coastal Studies Institute (CSI)

Louisiana State University

308 Howe-Russell Geoscience Complex

Baton Rouge, Louisiana 70803

December 2004

Table of Contents

I. INTRODUCTION

The purpose of this joint University of Wisconsin (UW) and Louisiana State University (LSU) project has been to relate short term climate variation to response in the coastal zone of Louisiana in an attempt to better understand how the coastal zone is shaped by climate variation. Climate variation in this case largely refers to variation in surface wind conditions that affect wave action and water currents in the coastal zone. The primary region of focus was the Atchafalaya Bay and surrounding bays in the central coastal region of Louisiana. Suspended solids in the water column show response to wind systems (Roberts et al., 1987; Moeller et al., 1993) both in quantity (through resuspension) and in the pattern of dispersement or transport. Wind systems associated with cold fronts are influenced by short term climate variation. Wind energy was used as the primary signature of climate variation in this study because winds are a significant influence on sediment transport in the micro-tidal Gulf of Mexico coastal zone.

Using case studies, the project has been able to investigate the influence of short term climate variation on sediment transport. Wind energy data, collected daily for National Weather Service (NWS) stations at Lake Charles and New Orleans, LA, were used as an indicator of short term climate variation influence on seasonal time scales. A goal was to relate wind energy to coastal impact through sediment transport. This goal was partially accomplished by combining remote sensing and wind energy data. Daily high resolution remote sensing observations are needed to monitor the complex coastal zone environment, where winds, tides, and water level all interact to influence sediment transport. The NASA Earth Observing System (EOS) era brings hope for documenting and revealing response of the complex coastal transport mosaic through regular high spatial resolution observations from the Moderate resolution Imaging Spectrometer (MODIS) instrument. MODIS observations were sampled in this project for information content and should continue to be viewed as a resource for coastal zone monitoring.

The project initialized the effort to transfer a suspended sediment concentration (SSC) algorithm to the MODIS platform for case 2 waters. MODIS enables monitoring of turbid coastal zones around the globe. The MODIS SSC algorithm requires refinements in the atmospheric aerosol contribution, sun glint influence, and designation of the sediment inherent optical properties (IOPs); the framework for continued development is in place with a plan to release the algorithm to the MODIS direct broadcast community.

II. RESEARCH ACCOMPLISHMENTS

A. Data Collection and Observations

Data collected during this project includes the following:

- NWS surface wind speed and direction at Lake Charles and New Orleans, LA for the period October 1999 – June 2004.
- MAS reflectance and thermal band radiances for ER-2 flights on March 21, 2001 and November 23, 2002.
- In situ water quality measurements (Table 1) for two ER-2 missions with MODIS underflight (March 21, 2001; November 23, 2002) and for two MODIS overpasses (May 20, 2001; Oct 30, 2003).

- Sediment pipe vertical accretion measurements on November 15, 2000 and April 3, 2002 in the Chenier Plain muddy coast region.
- MODIS L1B data from the GSFC DAAC and from direct broadcast readout at the University of Wisconsin.
- ROS-512 hand held radiometer measurements of remote sensing reflectance for March 21, 2001 MODIS overpass.
- Aerial photography of Chenier Plain prograding coast on four dates.

B. MAS Suspended Sediment Concentration (SSC) Algorithm Development

The MODIS Airborne Simulator (MAS) SSC algorithm produced good quality maps of SSC for the case 2 waters of the central Louisiana Gulf coast. A case study for March 21, 2001 yielded a high quality regression when subsurface reflectance was trained by in situ SSC measurements collected by LSU. The relationship shows nonlinear behavior as the sediment load increases, and demonstrates a reduction of sensitivity as SSC increases. This is documented in the Year 2 progress report for this project.

There are several external influences beyond sediment characteristics that may affect subsurface reflectance. To investigate these, a number of sensitivity exercises were undertaken assuming that the appropriate sediment type was brown earth with a fixed backscatter to total scatter ratio of 2% (a commonly accepted value for scattering by sediments). Hydrolight (Mobley and Sundman, 2001) model runs indicate that the subsurface reflectance for case 2 waters is virtually independent of wind speed, cloud cover and air mass (aerosols, water vapor) variation, although these quantities do affect water leaving radiance and the atmospheric correction (important factors when estimating subsurface reflectance from MAS or MODIS top of atmosphere observations). Subsurface reflection does display some latitudinal and seasonal dependence as expected on the basis of changes in the solar zenith angle. For lower sediment load (< 100 mg/l) the subsurface reflectance does exhibit some dependence on other water column components such as chlorophyll and CDOM (colored dissolved organic matter), and some dependence on water depth and bottom reflection but these are insignificant for the typical SSC, chlorophyll, and CDOM amounts in the case 2 waters of the Atchafalaya Bay, LA.

C. Suspended Sediment Transport from MAS

MAS repeat overpass data collected on March 21, 2001 (Day 01080) were used to estimate water motion vectors and sediment transport. The vectors are manually generated by animating MAS repeat pass imagery and tracking observable reflectance features using feature tracking software. Sediment transport is defined as the quantity (kg/s) of sediment that passes through a 50 m wide by 1 m deep vertically oriented window in the water column. This frame of reference represents the MAS footprint size and water penetration depth of the light observed in the MAS red spectral band.

The response of sediment transport to external forcings is of interest. The influences of surface wind, water level, and river discharge were reviewed. Figure 1 shows subsurface reflectance with SSC transport vectors superimposed for two case studies. The data suggest, as expected, that surface winds alone are not responsible for SSC transport.

Table 1. LSU Field Data Collection Program: NASA Atchafalaya Project

I. Field trip 1: 21 March 2001 Atchafalaya River, Four-league Bay and coastal ocean
Field measurements: temperature, salinity, secchi depth, radiometer
Lab measurements: Inorganic sediment concentration
Organic sediment concentration
Total organic carbon
Total inorganic carbon
Chlorophyll a
Phaeophytin a
Stations: 12; Water samples: 22

II. Field trip 2: 23 November 2002 Atchafalaya River and main navigation channel (water levels too low in FLB)
Field measurements: temperature salinity (from CTD), secchi depth
Lab measurements: Inorganic sediment concentration
Organic sediment concentration
Stations: 19; Water samples:38

III. Field trip 3: 30 October 2003 Atchafalaya River and main navigation channel
Field measurements: temperature, salinity from CTD
Lab measurements: Inorganic sediment concentration
Organic sediment concentration
Total organic carbon
Total inorganic carbon
Chlorophyll a
Phaeophytin a
Stations: 13; Water samples 37

IV. Chenier Plain: 20 May 2001
Field measurements: temperature, salinity, secchi depth, waves, met data
Water samples: Inorganic sediment concentration
Organic sediment concentration
Water samples: lots

Surface winds contribute to sea roughening, sediment resuspension, and transport but cannot completely explain the variation in transport seen in the day 95024 (January 24, 1995) and day 01080 cases. These cases show very different transport patterns. The sediment transport vectors are larger on 01080 (about a factor of 2 or more) because SSC is generally higher during the spring flood season (discharge is about twice as large on day 01080). Strong northerly surface winds on 01080 contributed towards sediment transport southward and eastward out over the continental shelf; however, similar winds (though not as strong) on 95024 resulted in transport within but not out of the coastal bay region. U.S. Army Corp of Engineers (ACOE) water level data at Eugene Island shows that water level was rising sharply in the hours before the ER-2 overflight on 95024 and probably acted to constrain the SSC transport in the coastal bay region, despite the offshore winds. Unfortunately, the ACOE water level data was missing on day 01080; however, MAS imagery suggests that water level was not changing rapidly during the ER-2 overpasses on day 01080. These are but snapshots of SSC transport. A capability to monitor sediment transport is needed to further the understanding of SSC transport in response to external forcings such as surface winds, tides, coastal floods, etc. Planning, for example, is underway in NOAA to develop a Coastal Water Imager (CWI) as part of the Hyperspectral Environmental Suite (HES) for the GOES-R series (launch ~ 2012).

D. Short Term Climate Variability Relationship to Coastal Change

Short term climate variability was represented in this study by surface wind energy variation at NWS sites in Lake Charles and New Orleans, LA. It is accepted that winds influence SSC patterns and water level along the micro-tidal Louisiana coast (e.g. Walker et al., 2000). Short term climate variability occurs for various reasons, including the influence of El Nino and La Nina events in the equatorial Pacific Ocean region. The relationship between El Nino events and surface wind energy along Louisiana's Gulf Coast appears complex. A brief investigation was used to compare the Multivariate ENSO Index (MEI) to wind energy along the Gulf Coast (Figure 2). El Nino winters (arbitrarily defined as MEI > 0.75), which are typically cooler and wetter along the Gulf coast, tend to show a unimodal or weakly bimodal energy distribution with peak in the northerly wind energy. La Nina winters (arbitrarily defined as MEI < -0.75), which are typically warmer and dryer along the Gulf coast, tend to show a pronounced bimodal distribution with comparable northerly and southerly wind energy. Winters that are not classified as either El Nino or La Nina winters (not shown) show a range of energy distributions but tend to have a bimodal distribution with a peak in the northerly wind energy. While not an objective of this study, this finding suggests that factors other than El Nino/ La Nina are clearly affecting the weather patterns along the Gulf Coast.

The variation of winter season wind energy from year to year is clear evidence that short term climate variability is occurring along the Gulf Coast. It is known that northerly winds drive turbid coastal waters out over the continental plain (Walker et al., 2000), dispersing the supply of suspended sediment to offshore regions where it is either transported downdrift or sinks to the subaqueous bottom. This would suggest that years of strong northerly energy result in greater sediment transport out of the estuarine environment onto the continental shelf. Strong northwesterly winds have been observed in remote sensing data sets to reverse the westward downdrift current of the coastal zone,

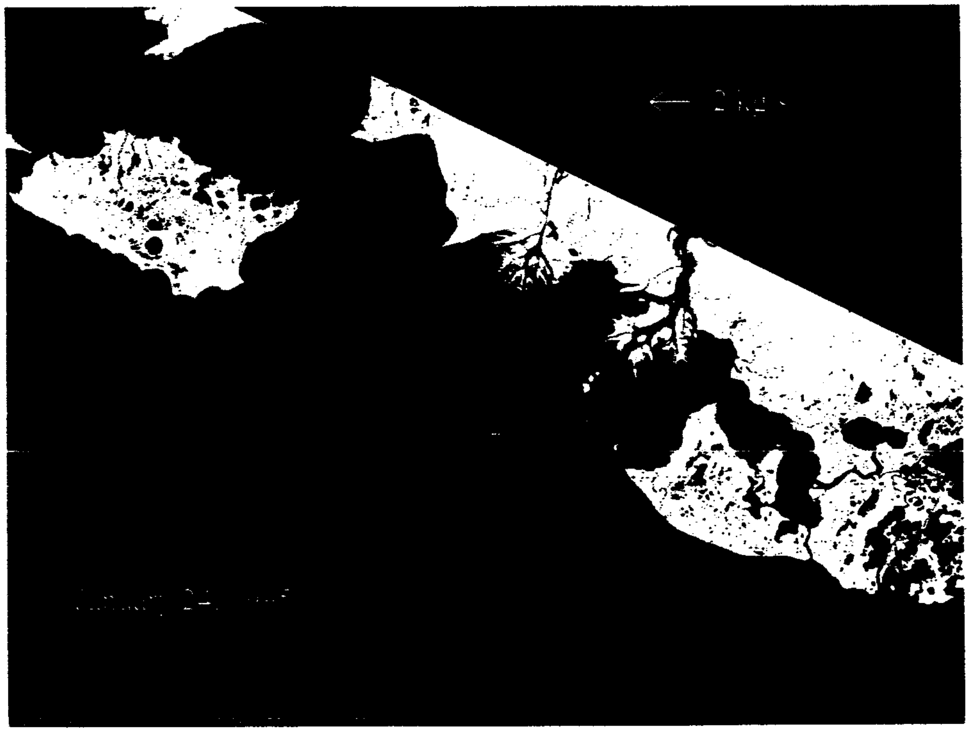


Figure 1. MAS visible imagery with sediment transport vectors (red) for the Atchafalaya Bay region of the Louisiana coast. These examples show small scale circulation and transport patterns under the combined atmospheric and tidal forcings.

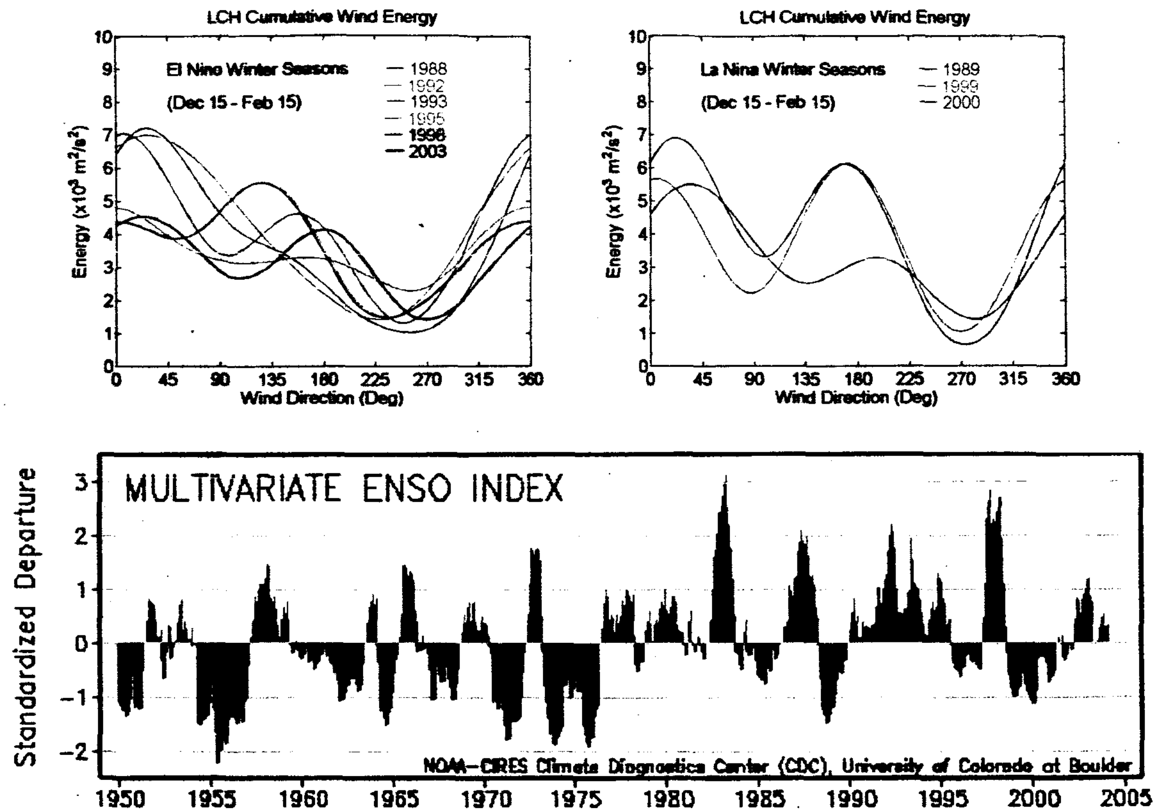
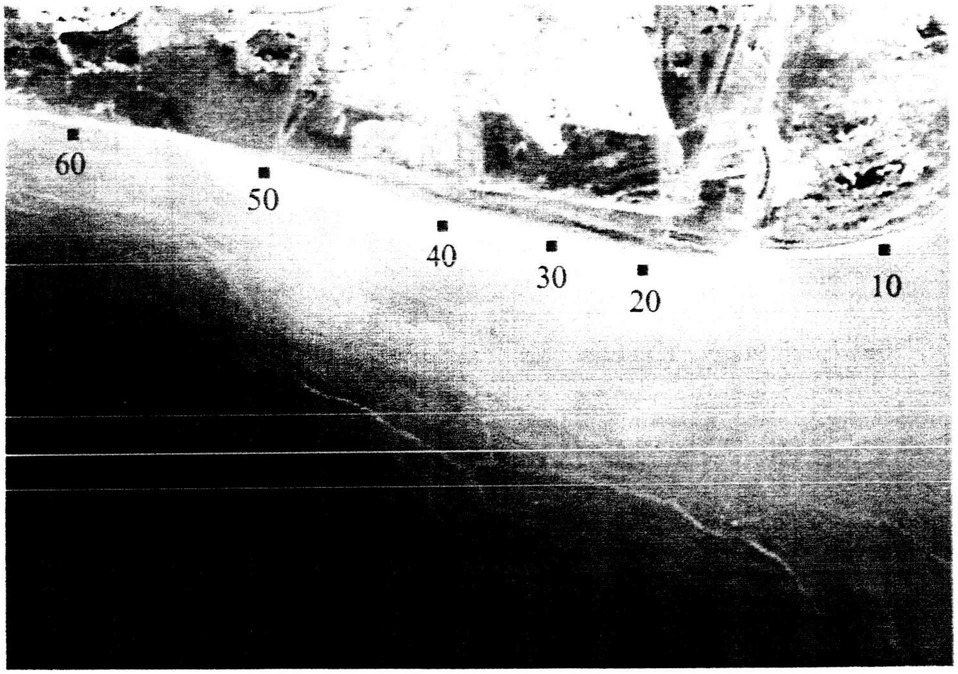


Figure 2. Wind energy ($m^2 s^{-2}$) at Lake Charles, LA for the winter season (Dec 15 - Feb 15). The years are separated into El Nino and La Nina years (based on MEI, bottom, from NOAA CIRES Climate Diagnostics Center) to demonstrate the influence of each on the short term climate of the region. The wind energy variability from year to year is a signature of short term climate change along the U.S. Gulf Coast.

temporarily blocking sediment transport to the prograding coasts west of the Atchafalaya Bay region. The westward drift is restored when winds switch to easterly and southerly components. Years of stronger southerly energy would tend to trap the sediment plume in the Atchafalaya Bay and result in sediment transport westward and shoreward for resuspended sediments. Therefore, La Nina winter seasons are likely to be the most effective seasons at transporting sediment to prograding coastlines downdrift of the Atchafalaya Bay region. However, at existing frequencies of monitoring, the remote sensing data of this study are unable to quantitatively measure sediment transport over the annual cycle. On-going monitoring from an orbiting platform capable of providing high spatial (250 m or better) and temporal (2-3 hours) resolution is desired.

Topographical change along the muddy Chenier Plain coast has been monitored by measuring vertical accretion at sediment burial pipe sites. Metal pipes were installed at six sites (Figure 3) along the coast in the mid 1990's. The pipes were sunk deep (15 – 30') into the strata until reaching a firm subsoil surface for anchoring. It is believed that the pipes have remained anchored throughout the last decade. Measurements from 1997



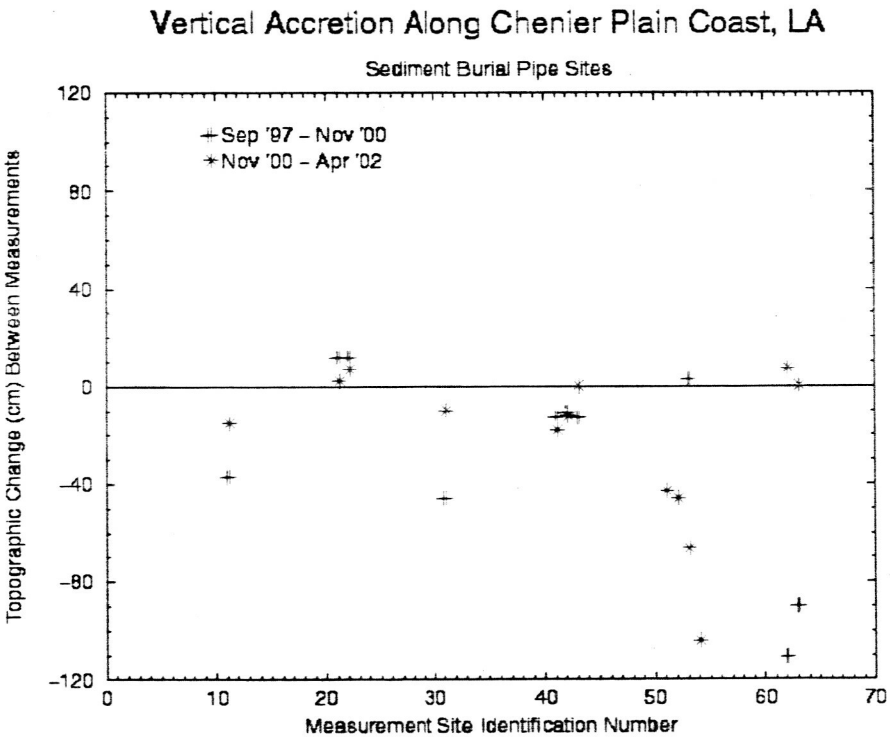


Figure 3. Sediment burial pipe locations (top) with measurement site ID (in red) and change estimates (bottom). Several measurement sites include multiple pipes; these are designated in bottom figure in single units place of ID number. Measurements show a loss of material in the vertical at many sites, with a few sites showing marginal gains.

through 2002 suggest that there is little vertical accretion along the muddy coast (Site IDs 20, 30, and 40 in Figure 3). The measurements show that in sediment starved regions, as indicated by shell beach, significant erosion has taken place (Site IDs 10, 50, 60). These findings underscore the necessary presence of suspended sediment and fluid mud to restore, sustain, and enhance coastal progradation in the face of coastal subsidence and the erosion forces of water and wave action. Field expeditions (See Field Notes for November 15, 2000 and April 03, 2002) have shown that erosion is affecting shell beach as well as vegetated shoreface regions.

E. Applications of MODIS Data

1. Transfer of SSC Algorithm to MODIS

The spatial resolution required to characterize the coastal zone is higher than is generally available on space-borne ocean color sensors, these being typically around 1 km. The highest spatial resolution MODIS bands are the two 250 m bands that observe radiation centered at approximately 650 nm and 850 nm. These bands are, to differing extents, sensitive to sediments suspended in near-surface waters but are also affected by the intervening atmosphere. A common approach to over-ocean atmospheric correction is to characterize the atmospheric contribution to observed reflectance in a spectral region where the ocean water column reflectance can be assumed zero and then to apply the inferred atmospheric characteristics to the wavelengths of interest. MODIS has 500 m resolution bands at 1.6 μm and 2.1 μm where we may safely assume that the water column reflectance is zero except, perhaps, where marine biota have congregated on the water surface as in the case of coccolithophore blooms and red tides. We have employed these two 500 m resolution bands to effect an atmospheric correction and to retrieve estimates of the water column reflectance in the two 250 m resolution bands. Inverting the relationship between water column reflectance and suspended sediment concentration (using sediment inherent optical properties for brown earth provided by the Hydrolight model) permits water column reflectance in the MODIS 250 m bands to be transformed into estimates of suspended sediment concentration. The suspended sediment concentration can also be cast in terms of the ratio of the two retrieved water column reflectances and this may offer more robust estimates of sediment concentration, especially at higher concentrations and where the sediment optical properties are not known with precision. Figure 4 shows the match-up with in-situ data on March 21, 2001 where a single band (660 nm) was used for low (<50mg/l) concentrations and a band ratio used for high (>200 mg/l) concentrations.

The ROS-512 hand-held radiometer measurements that were collected on March 21, 2001 are also plotted in Figure 4 against the MODIS retrieved remote sensing reflectance, Rrs. This comparison eliminates the uncertainty of the sediment inherent optical properties and provides insight on the MODIS Rrs retrieval. The MODIS co-located Rrs is plotted along with the range of Rrs for the neighboring MODIS pixels at the in situ measurement site. The scatter about the 1:1 line suggests uncertainty in the atmospheric correction (assuming perfect calibration of the ROS-512). Some of the departure is likely caused by pixel adjacency effects near land/water interfaces in the MODIS 1.6 μm and 2.1 μm data used for the atmospheric correction.

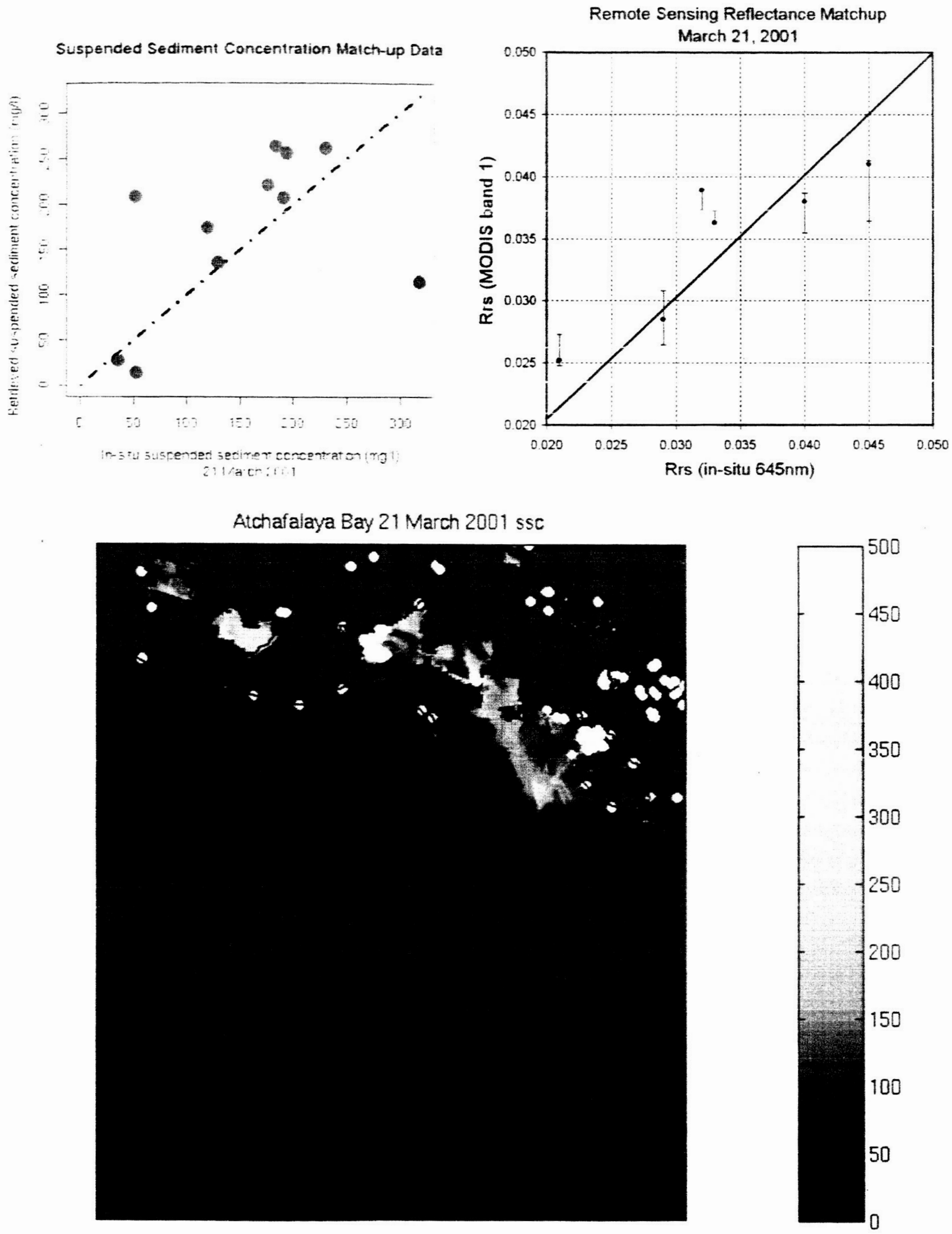


Figure 4. The MODIS retrieved Suspended Sediment Concentration, SSC, (upper left) and Remote Sensing Reflectance, Rrs, (upper right) match-ups with in-situ data on March 21, 2001. One SSC data point, which retrieved at over 1000 mg/l, is omitted. The derived MODIS Rrs are compared for the limited number of in situ sites at which Rrs was measured using a hand held radiometer. The vertical bar shows the range of derived MODIS Rrs for the 3x3 pixel domain centered at each in situ site (represented by dot in the range). An example of the MODIS SSC retrieval is shown at bottom.

2. Multi-day Case Study

MODIS data collected over a six day period provided insight on the monitoring capability of MODIS for coastal processes. During the November 2 – 7, 2001 time period, four MODIS daytime overpasses captured the suspended sediment pattern along the central Louisiana Gulf coast (Figure 5). These images demonstrate the short time scale of the variation of the suspended sediment plume in response to atmospheric wind forcing. The pattern of the suspended sediment plume appears to evolve slowly over the six day period; however, the sediment concentration appears to evolve significantly in response to wind energy variation. The strongest winds occurred in the 24 hours preceding the November 5 image. These winds contributed to resuspending sediment into the water column, making it available for transport. High temporal resolution (hourly) imagery would be useful to reveal the evolution of the sediment transport during this period.

3. Other MODIS Days

MODIS imagery has proven to be a useful resource to gain insight on the variability of suspended sediment patterns under varying atmospheric forcing conditions. Gif images of MODIS daytime overpasses of the Louisiana coast were stored during the lifetime of the project. These show high resolution (500 m) examples of the coastal sediment pattern in the presence of various atmospheric wind conditions. For example, spring season flood conditions bring large sediment loads into the central Louisiana Gulf coast. Westerly component winds drive the plume towards the east. Easterly component winds result in flow towards western Louisiana. These also yield information on timescales associated with sediment transport, however, it was not practical to set up an in situ experiment within the framework of this project.

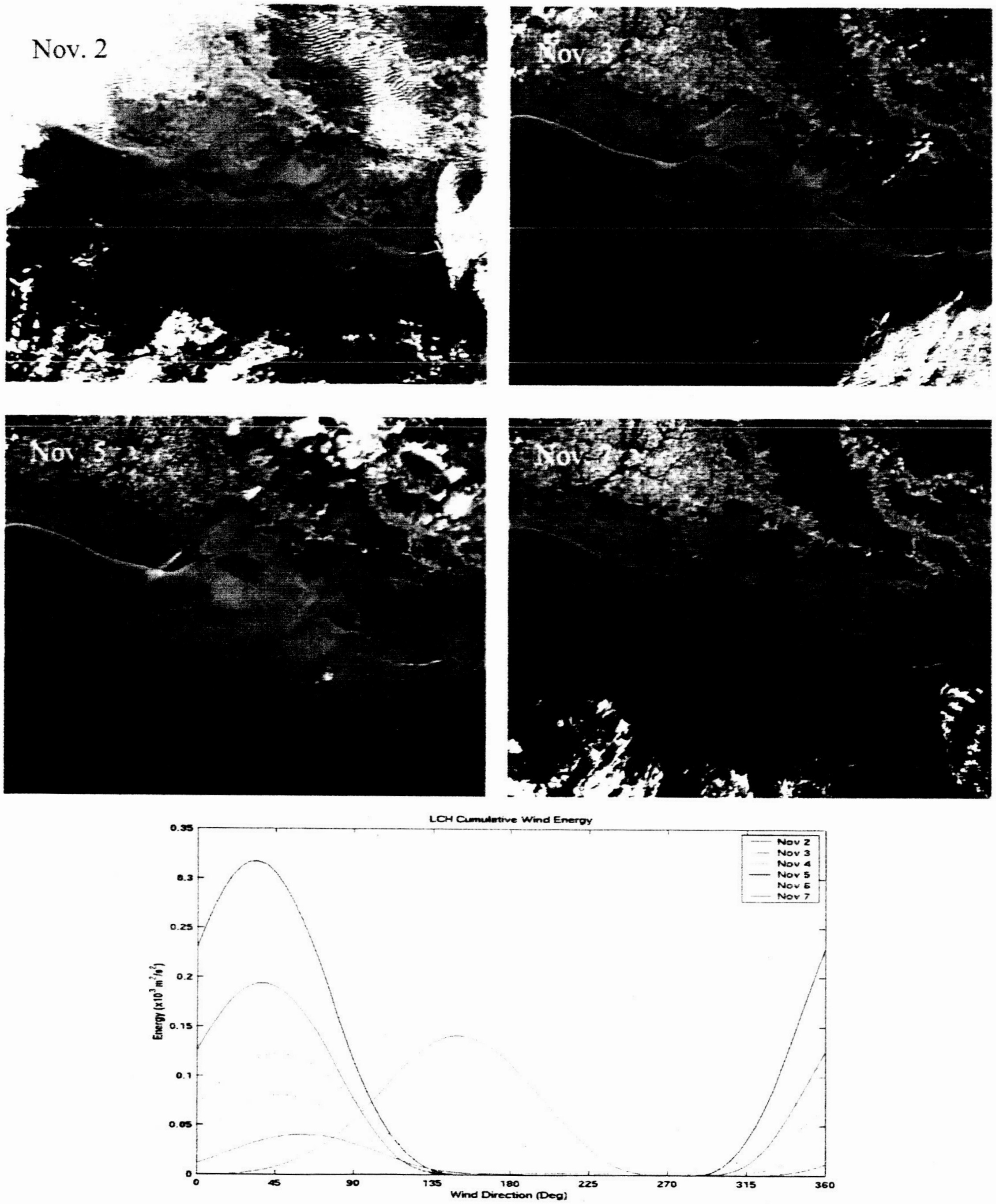


Figure 5. MODIS 650 nm (band 1) 250 m resolution remapped imagery for Nov. 2, 3, 5, and 7, 2001. The images show the evolution of suspended sediment conditions along the central Louisiana Gulf coast over the six day period. Wind energy (bottom) is shown for each day. On November 2, SE winds stirred up coastal waters, adding suspended sediment through resuspension. Strengthening northeasterly winds followed a cold front passage on November 3 causing a peak of suspended sediment in the MODIS imagery on November 5. Weakening winds on Nov 6 and 7 resulted in sediment settling out of the water column and much reduced suspended sediment levels in the November 7 MODIS image.

III. PUBLICATIONS RESULTING FROM NAGW5-9688

Davies, J., C. C. Moeller, M. M. Gunshor, N. D. Walker, W. P. Menzel, "Estimating coastal turbidity using MODIS 250m band observations". Accepted for presentation at the Ocean Optics XVII conference. Freemantle, Australia, October 25-29, 2004. *

Draut, A. E., Kineke, G. C., Huh, O. K., Grymes, J. M. III, Westphal, K. A., and Moeller, C. C. Coastal mudflat accretion under energetic conditions, Louisiana chenier-plain coast, USA. Marine Geology, 214, pp. 27-47, 2005. *

Myint, S. and N. Walker, Quantification of surface suspended sediments along a river dominated coast with NOAA AVHRR and SeaWiFS measurements: Louisiana, USA, *International Journal of Remote Sensing*, Vol. 23, no. 16, 3229-3249, 2002. *

Walker, Nan, Harry Roberts, Gregory Stone, Samuel Bentley, Oscar Huh, Alexandru Sheremet, Larry Rouse, Masamichi Inoue, Susan Welsh, S.A. Hsu, and Soe Myint, Satellite-based assessment of sediment transport, distribution and resuspension associated with the Atchafalaya River discharge plume, *Gulf Coast Association of Geological Societies Transactions*, Vol. 52, 967-974, 2002. *

Roberts, H.H., S. Bentley, J.M. Coleman, S.A. Hsu, K. Rotondo, M. Inoue, L.J. Rouse, A. Sheremet, G. Stone, N. Walker, S. Welsh, and W.J. Wiseman, Jr., Geological Framework and Sedimentology of recent mud deposition on the eastern Chenier Plain Coast and adjacent inner shelf, western Louisiana, *Gulf Coast Association of Geological Societies Transactions*, Vol. 52, 849-859, 2002.

Sheremet, A., G.W. Stone, N.D. Walker, H.H. Roberts and O.K. Huh, The influence of fine-grained sediments on wave propagation, west Louisiana coast, *Gulf Coast Association of Geological Societies Transactions*, Vol. 52, 899-907, 2002

Huh, O. K., N. D. Walker, and C. C. Moeller, "Sedimentation along the Eastern Chenier Plain Coast: downdrift impact of delta complex shift". J. Coastal Res., V17, No. 1, pp. 72-81, 2001. *

Moeller, Christopher C., M. M. Gunshor, W. P. Menzel, O. K. Huh, N. D. Walker, and L. J. Rouse, "Recent monitoring of suspended sediment patterns along Louisiana's coastal zone using ER-2 based MAS data and Terra based MODIS data". 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, 15-18 October 2001 (preprints). Boston, MA, American Meteorological Society, 65-68, 2001. *

* copy included in Appendix A of this report.

IV. REFERENCES

Curtis D. Mobley and Lydia K. Sundman, "HYDROLIGHT 4.2 Users' Guide", Sequoia Scientific, Redmond, WA 98052, 2001.

Moeller, C. C., O. K. Huh, H. H. Roberts, L. E. Gumley, W. P. Menzel: Response of Louisiana Coastal Environments to a Cold Front Passage. J. Coastal Res., Vol. 9, 434-447, 1993.

Roberts, H. H., O. K. Huh, S. A. Hsu, L. J. Rouse Jr., and D. A. Rickman: Impact of cold-front passages on geomorphic evolution and sediment dynamics of the complex Louisiana coast. American Society of Civil Engineers Proceedings of Coastal Sediments '87, 1950-1963, 1987.

Walker, N. D., and A. B. Hammack: "Impacts of Winter Storms on Circulation and Sediment Transport: Atchafalaya-Vermilion Bay Region, Louisiana, U.S.A.", J. Coastal Res., Vol. 16, No. 4 , pp. 996-1010, 2000.

APPENDIX A. – NASA Supported Publications and Field Trip Reports

Estimating Coastal Turbidity using MODIS 250 m Band Observations

James E. Davies, Christopher C. Moeller, Mathew M. Gunshor,
W. Paul Menzel[+] and Nan D. Walker[#]

Cooperative Institute for Meteorological Satellite Studies (CIMSS), Madison, WI
[+] NOAA/NESDIS/ORA
[#] Coastal Studies Institute (CSI), Louisiana State University (LSU)

ABSTRACT

Terra MODIS 250 m observations are being applied to a Suspended Sediment Concentration (SSC) algorithm that is under development for coastal case 2 waters where reflectance is dominated by sediment entrained in major fluvial outflows. An atmospheric correction based on MODIS observations in the 500 m resolution 1.6 and 2.1 micron bands is used to isolate the remote sensing reflectance in the MODIS 250m resolution 650 and 865 nanometer bands. SSC estimates from remote sensing reflectance are based on accepted inherent optical properties of sediment types known to be prevalent in the U.S. Gulf of Mexico coastal zone. We present our findings for the Atchafalaya Bay region of the Louisiana Coast, in the form of processed imagery over the annual cycle. We also apply our algorithm to selected sites worldwide with a goal of extending the utility of our approach to the global direct broadcast community.

INTRODUCTION

Monitoring suspended sediment distribution in the coastal zone is challenging. Accessibility and comprehensive sampling are two significant challenges making it impractical to monitor coastal zones using surface based efforts. Use of aircraft such as the NASA ER-2 is helpful for research activities but impractical for continuous monitoring. Satellite based observations provide the best possible source of data for operational monitoring. The advent of MODIS [1] on the Terra (launched in Dec. 1999) and Aqua (launched in May 2002) platforms has provided well calibrated 250 m resolution radiances useful as a test-bed for sediment concentration estimates and daily global monitoring. These bands (Table 1) are well positioned for monitoring high sediment concentration in case 2 waters.

Previous work using Multi-spectral Atmospheric Mapping Sensor (MAMS) remote sensing observations from the ER-2 platform showed that spectral bands located in the red and near infrared portion of the spectrum are useful for discriminating the reflectance of various suspended sediment concentrations (SSC) found in case 2 waters along Louisiana's Gulf coast [2]. The in-water portion of the at-sensor signal received in these bands originates in the few meters of the water column, largely eliminating sub-aqueous bottom reflectance as a source. A SSC algorithm was generated using the MODIS Airborne Simulator (MAS) [3] observations at 660 nm [4]. This paper investigates the use of similar bands on MODIS for estimating SSC along the Louisiana Gulf Coast. The algorithm developed depends upon the sediment inherent optical properties (IOPs) of a specific sediment type. In-water radiative transfer modeling was performed with Hydrolight [5], a code for computing radiance distributions and derived quantities for natural water bodies. Atmospheric correction is achieved with the assistance of look-up tables generated by 6S [6], an atmospheric radiative transfer code designed to simulate the radiance reflected by the earth-atmosphere system as observed by a range of satellite sensors.

Primary purpose	Band [spatial resolution]	Bandwidth (nm)	Signal to noise ratio	Clear water penetration depth	SSC algorithm
Land/Cloud/Aerosols Boundaries	1 [250 m]	620 - 670	128	2.4 m	Low sediment concentration
	2 [250 m]	841 - 876	201	22 cm	High sediment concentrations
Land/Cloud/Aerosols Properties	3 [500 m]	459 - 479	243		
	4 [500 m]	545 - 565	228		
	5 [500 m]	1230 - 1250	74		
	6 [500 m]	1628 - 1652	275	1.6 mm	Atmospheric correction
	7 [500 m]	2105 - 2155	110	0.41 mm	Atmospheric correction

Table 1. Characteristics of MODIS 250 m and 500 m bands [1]. The clear water penetration depths are computed from the complex refractive index data of Kou et al. [11].

BACKGROUND

The Atchafalaya Bay (Fig. 1) receives the effluent of the Atchafalaya River, a distributary of the Mississippi River. The Atchafalaya River carries about 33% of the total discharge from the Mississippi River distributary system to the Gulf of Mexico. The effluent provides the building material to form delta lobes in the Atchafalaya Bay, as well as supplying a persistent, yet varying quantity of material (suspended load concentrations up to 1000 mg/l or more) for transport in the coastal zone. The coarse grained material settles to the sub-aqueous bottom; fine-grained material is generally transported to sites down-drift of the Atchafalaya Bay. The sediment represents a resource valuable to combat the ongoing natural subsidence of the Louisiana coast region. Subsidence causes loss of wetland habitats by allowing salt water to invade coastal freshwater environments. Sediment transport (or lack of it) is responsible for hazards to industries, including siltation of navigation channels, destructive saltwater intrusion into freshwater environments, and destruction of forests, wetlands and nursery grounds important to commercial fisheries. Coastal fisheries management techniques in Louisiana's fresh and brackish marsh environments depend in part on sediment transport dynamics. For example, in Louisiana where about 31% of the total U.S. commercial shrimp harvest is landed [7], nursery habitat is threatened by increasing erosion of tidal marshes and reduced access to nursery habitat through construction of water control structures [8]. Marsh surfaces must vertically accrete by gaining new marsh soil if they are to counter submergence and salt water intrusion [9]. Also, shifting patterns of fresh, salt and brackish waters affect productivity and survival of oyster beds.

In the micro-tidal Louisiana coastal zone, sediment plume distribution is strongly affected by local winds, especially associated with frequent cold front passages [4]. These winds vary on the scale of hours to days, modulating the direction and speed of the near-shore currents that transport the suspended sediment. Monitoring sediment loads and transport reveals information on the distribution of the resource in the coastal zone and on the natural processes that drive the distribution.

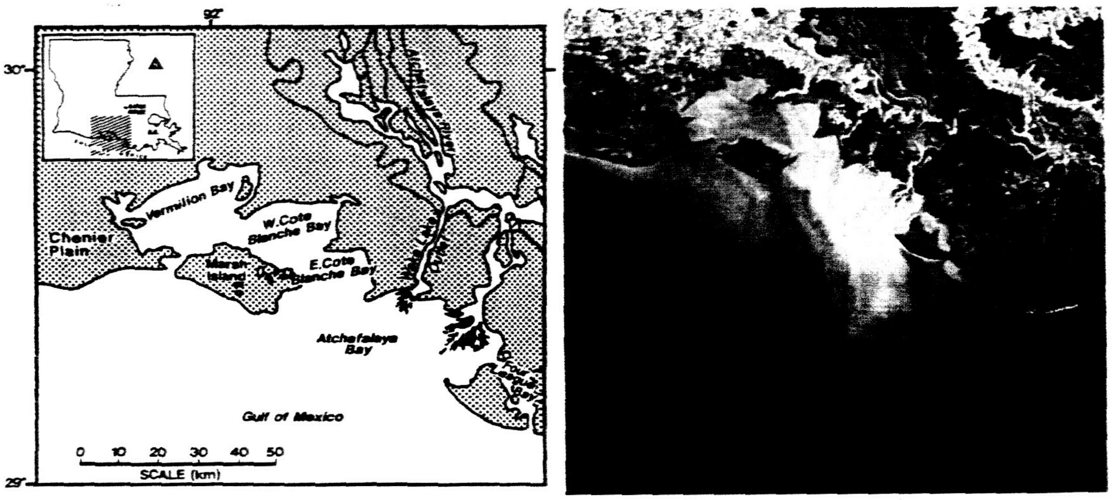


Figure 1. Atchafalaya Bay Region of Louisiana Coastal Zone. True color Terra MODIS image shown at right depicting sediment plume distribution on March 21, 2001.

ATMOSPHERIC CORRECTION

The ultimate goal of this work is to provide to the direct broadcast community an algorithm for estimating coastal suspended sediment concentrations that can be adjusted for local sediment IOPs. Central to this task is the retrieval of the water column reflectance in MODIS channels sensitive to the presence of suspended sediment. In the coastal zone spatial resolution is important and we choose to work with the two 250 m MODIS bands centered at approximately 650 nm and 850 nm (Table 1). A common approach to over-ocean atmospheric correction is to characterize the atmospheric contribution to observed reflectance in a spectral region where the ocean water column has zero reflectance. MODIS has 500 meter resolution bands at 1.6 μm and 2.1 μm where we may safely assume that the water column reflectance is zero except, perhaps, where marine biota have congregated on the water surface as in the case of coccolithaphore blooms and red tides.

For radiative transfer we employ the same formalism as Tafkaa [10], that is,

$$\rho^*_{obs} = T_g \left(\rho^*_{atm} + \rho^*_{sfc} + \frac{\rho_w \, t_u \, t_d}{1 - s \, \rho_w} \right), \tag{1}$$

where ρ^*_{obs} is the apparent reflectance observed by the satellite sensor, T_g is the gaseous transmittance along the sun-surface-satellite path, ρ^*_{atm} is the atmospheric path reflectance, ρ^*_{sfc} is the ocean surface apparent reflectance, t_u and t_d are the upwards and downwards scattering transmittances, respectively, s is the atmospheric spherical albedo and ρ_w is the reflectance of the ocean water column. Equation (1) can be inverted to provide ρ_w only if certain other quantities can be estimated from model computations. We have used the 6S radiative transfer model to compute values for T_g, ρ^*_{atm}, ρ^*_{sfc}, t_u, t_d and s for three aerosol models (continental, maritime and urban) and five optical depths. Presently these computations are performed for spatial domains within each MODIS overpass, each domain defined as 2 scan lines along-track by 2 degrees of scan angle cross-track. Ozone and water vapor column amounts, required for the calculation of the gaseous transmittance, are taken from global TOVS and GDAS1 gridded forecast fields for the time closest to the satellite overpass. The wind speed and direction are also taken from the GDAS1 file, estimates of these being needed to compute ρ^*_{sfc}.

For MODIS bands 6 and 7, ρ^*_{obs} is computed on the assumption that ρ_w is zero. For each pixel, the squared distances between observed and model apparent reflectances are computed. That is, for each aerosol atmosphere *k*,

$$d_k = \left(\frac{\rho^k_{obs}(6) - \rho^*_{obs}(6)}{T_g(6)} \right)^2 + \left(\frac{\rho^k_{obs}(7) - \rho^*_{obs}(7)}{T_g(7)} \right)^2, \tag{2}$$

where ρ^k_{obs} indicates the model predicted apparent reflectance for aerosol model *k* (in contrast to the satellite measured reflectance ρ^*_{obs}). Each of the unknown quantities in equation (1) (ρ^*_{atm}, ρ^*_{sfc}, t_u, t_d and s for MODIS bands 1 and 2) are computed as *X* in,

$$X = \frac{\sum_{k=1}^{m} X_k / d_k}{\sum_{k=1}^{m} 1/d_k}, \tag{3}$$

where the summation is over the *m* aerosol atmospheres defined for model simulations. Inverting equation (1) and substituting these estimates of ρ^*_{atm}, ρ^*_{sfc}, t_u, t_d and s provides, for each 250 m pixel, the water column reflectance ρ_w in MODIS bands 1 and 2. Fig. 2 shows ρ_w of Louisiana coastal waters on March 21, 2001.

A difficulty that remains is the removal of sun glint in regions where it is a significant contributor to the total reflectance. The current atmospheric correction relies entirely on modeled values of ρ^*_{sfc} which is adequate only for regions of low sun glint. A data driven correction based on combined visible, 4 µm and 11 µm observations will be investigated in the future.

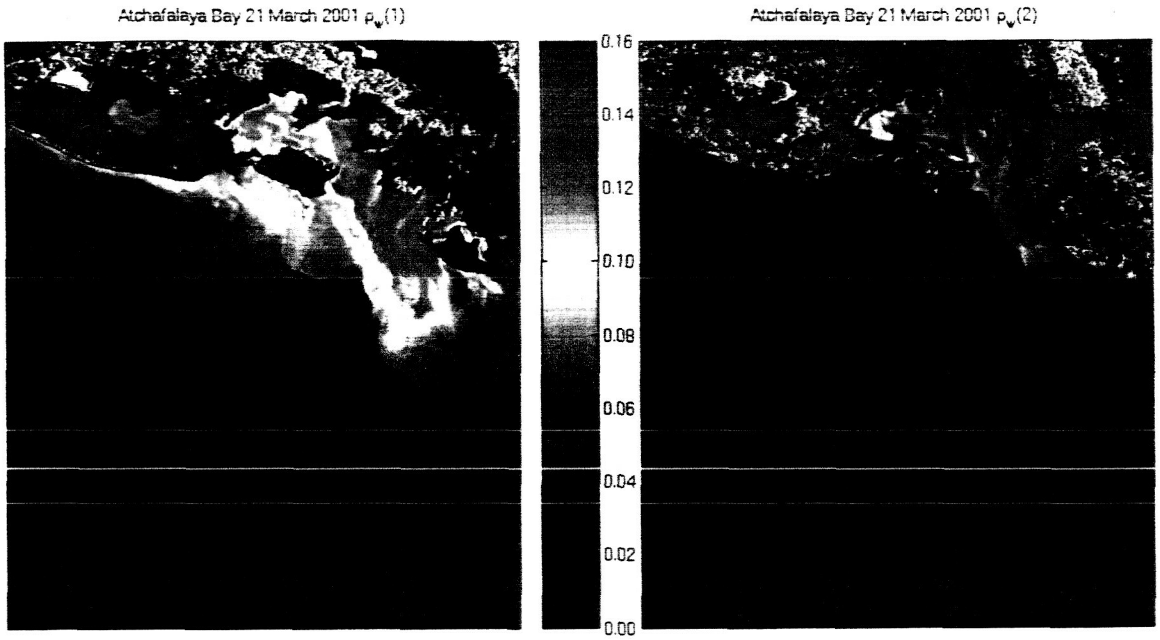


Figure 2. Retrieved ρ_w for coastal waters in the Atchafalaya Bay region of the Louisiana coast on March 21, 2001. Band 1 water column reflectance (left) is greater than for band 2 (right) primarily due to a larger backscatter coefficient and a greater penetration depth.

SEDIMENT CONCENTRATION RETRIEVALS

The absorption and scattering coefficients of the suspended sediment are computed from specific absorption and scattering coefficients, a^* and b^* respectively, of dimension area per unit mass. Multiplication by sediment concentration yields absorption and scattering coefficients (a_s and b_s) of dimension inverse length, that is,

$$a_s = S\,a^* \qquad \text{and} \qquad b_s = S\,b^* \quad , \tag{4}$$

where S is the sediment concentration in milligrams per liter. Using aircraft based observations from previous work [12] we have found that the Atchafalaya Bay sediment is similar to the Hydrolight sediment model denoted "brown earth". Sediments scatter anisotropically and, in this work, we assume that the ratio of sediment backscatter to total scatter is 0.02. The total absorption coefficient, a, and the total backscattering coefficient, b_b, are given by,

$$a = a_w + a_s \qquad \text{and} \qquad b_b = 0.5\,b_w + 0.02\,b_s \quad , \tag{5}$$

where a_w and b_w are the absorption and scattering coefficients for water. We wish to estimate the remote sensing reflectance for both MODIS bands 1 and 2 in order to retrieve a suspended sediment load. Hydrolight simulations, however, are limited to the wavelength range 350 to 800 nanometers. Fig. 3 shows the remote sensing reflectance, R_{rs}, versus b_b/a for "brown earth" simulated by Hydrolight for MAS bands 3, 4 and 5

(662, 709 and 751 nm respectively). A line of best fit, with slope 0.052 and zero intercept, is also shown. Based on these simulations we choose to estimate R_{rs} via,

$$R_{rs} = 0.052\,\frac{b_b}{a} \quad , \tag{6}$$

and we further assume that $\rho_w = \pi R_{rs}$. Equations (4) to (6) permit an estimate of S from ρ_w for each of MODIS bands 1 and 2 provided that water and sediment inherent optical properties are known. Inverting equation (6) leads to,

$$S = \frac{50\pi\, a_w\, \rho_w - 0.052 \times 25\pi\, b_w}{0.052\, b^* - 50\pi\, a^*\, \rho_w} \quad , \tag{7}$$

We used values from Kou et al. [11] for a_w and for b_w we used the empirical relation $b_w = 2.935\,(\lambda/100)^{-4.3}$. Values for a^* and b^* were taken from the "brown earth" model in Hydrolight for MODIS band 1, and were extrapolated to provide estimates for MODIS band 2. The ratio of MODIS band 2 ρ_w to MODIS band 1 ρ_w is also a function of suspended sediment concentration,

$$\left(\frac{\rho_w(2)}{\rho_w(1)}\right) = \left(\frac{0.5\, b_w(2) + 0.02\, b^*(2)\, S}{a_w(2) + a^*(2)\, S}\right)\left(\frac{a_w(1) + a^*(1)\, S}{0.5\, b_w(1) + 0.02\, b^*(1)\, S}\right) \quad , \tag{8}$$

and is not affected by the angular distribution of the ocean water column radiant exitance which is similar in MODIS bands 1 and 2. Fig. 4 shows $\rho_w(1)$ and $\rho_w(2)/\rho_w(1)$ as a function of S for the Hydrolight "brown earth" sediment model. It is clear that $\rho_w(1)$ provides good sensitivity at low sediment concentrations whereas $\rho_w(2)/\rho_w(1)$ has good sensitivity at higher concentrations.

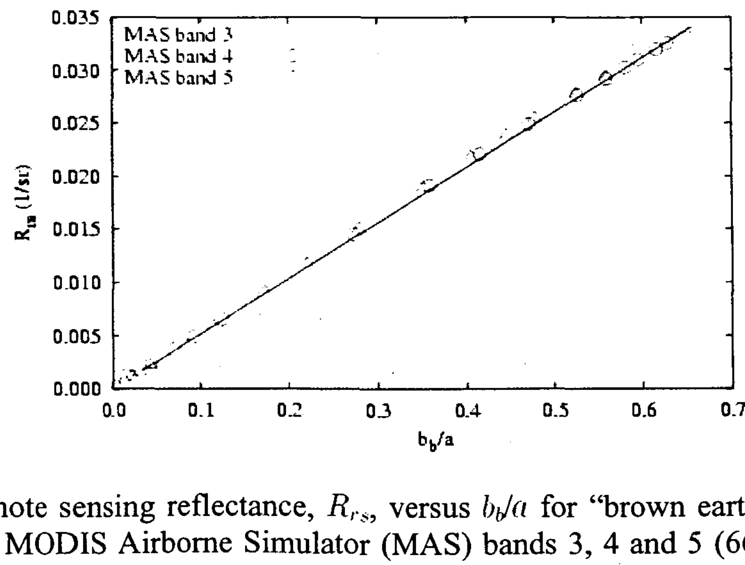


Figure 3. Remote sensing reflectance, R_{rs}, versus b_b/a for "brown earth" simulated by Hydrolight for MODIS Airborne Simulator (MAS) bands 3, 4 and 5 (662, 709 and 751 nm respectively). The line of best fit has slope 0.052 and passes through the origin. Hydrolight simulation results are for nadir view with the sun at 40 degrees from zenith.

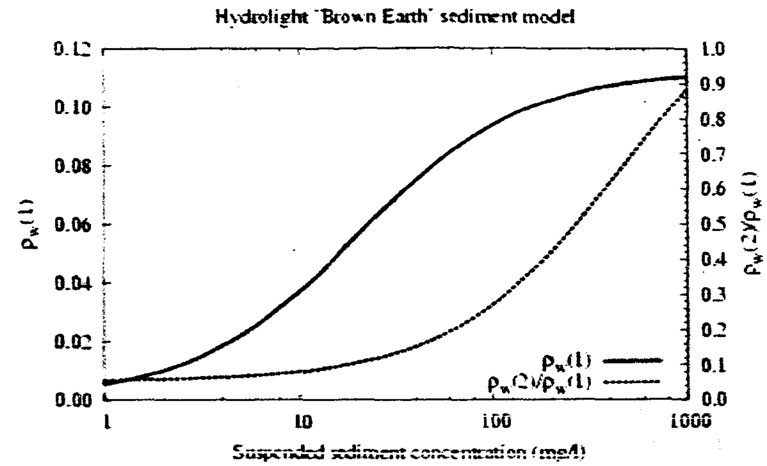


Figure 4. MODIS $\rho_u(1)$ as a function of suspended sediment concentration (left axis) and $\rho_u(2)/\rho_u(1)$ as a function of suspended sediment concentration (right axis) for the Hydrolight "brown earth" sediment inherent optical properties.

For present purposes we set $\rho_u(1)$ thresholds at 0.04 and 0.08. Pixels with $\rho_u(1) < 0.04$ use the MODIS band 1 sediment concentration retrieval, pixels with $\rho_u(1) > 0.08$ use the MODIS band 2/1 ratio retrieval. For $0.04 < \rho_u(1) < 0.08$ a linear combination is returned as the sediment concentration.

Fig. 5 shows Atchafalaya Bay sediment concentrations retrieved in this way from four MODIS overpasses chosen to represent each of the four seasons of the year 2001. Because of its greater water penetration depth, the results of a MODIS band 1 only suspended sediment retrieval are also shown in Fig. 5. The SSC retrieval for these 4 days is indicative of the annual cycle of turbidity along the Louisiana coast. Springtime snowmelt and rain increase discharge from the Mississippi River distributary system and sediment loads in the Atchafalaya Bay region (March 21 case). As spring runoff subsides, the Atchafalaya Bay sediment diminishes into the summer (May 24 case) and fall (Sept. 29 case) seasons. At the onset of winter, cold front passages return, increasing wave activity and sediment re-suspension in the coastal zone (Dec. 30 case). Cold fronts swell and subside the suspended sediment load during frontal passages and the quiet interim periods, respectively.

The MODIS band 1 only retrieval in Fig. 5 is "saturated" (red region) in the high SSC regions for the March 21 and Dec. 30 cases. This occurs because the MODIS band 1 calculated value for $\rho_u(1)$ exceeds the maximum value of $\rho_u(1)$ based on the "brown earth" model in Figure 4. This suggests that the IOPs for brown earth are not matching the IOPs of the Atchafalaya Bay suspended sediment. Raising the backscatter to total scatter ratio from the assumed 0.02 up to 0.03 or 0.04 would raise the brown earth model $\rho_u(1)$ to include the MODIS band 1 calculated value for $\rho_u(1)$ in the saturated regions. However, no firm evidence is available at this time to substantiate adjusting the IOPs in the model for the Atchafalaya Bay suspended sediment retrieval. In the future, the use of in situ measurements of SSC in the Atchafalaya Bay will be investigated for deriving IOPs for the region.

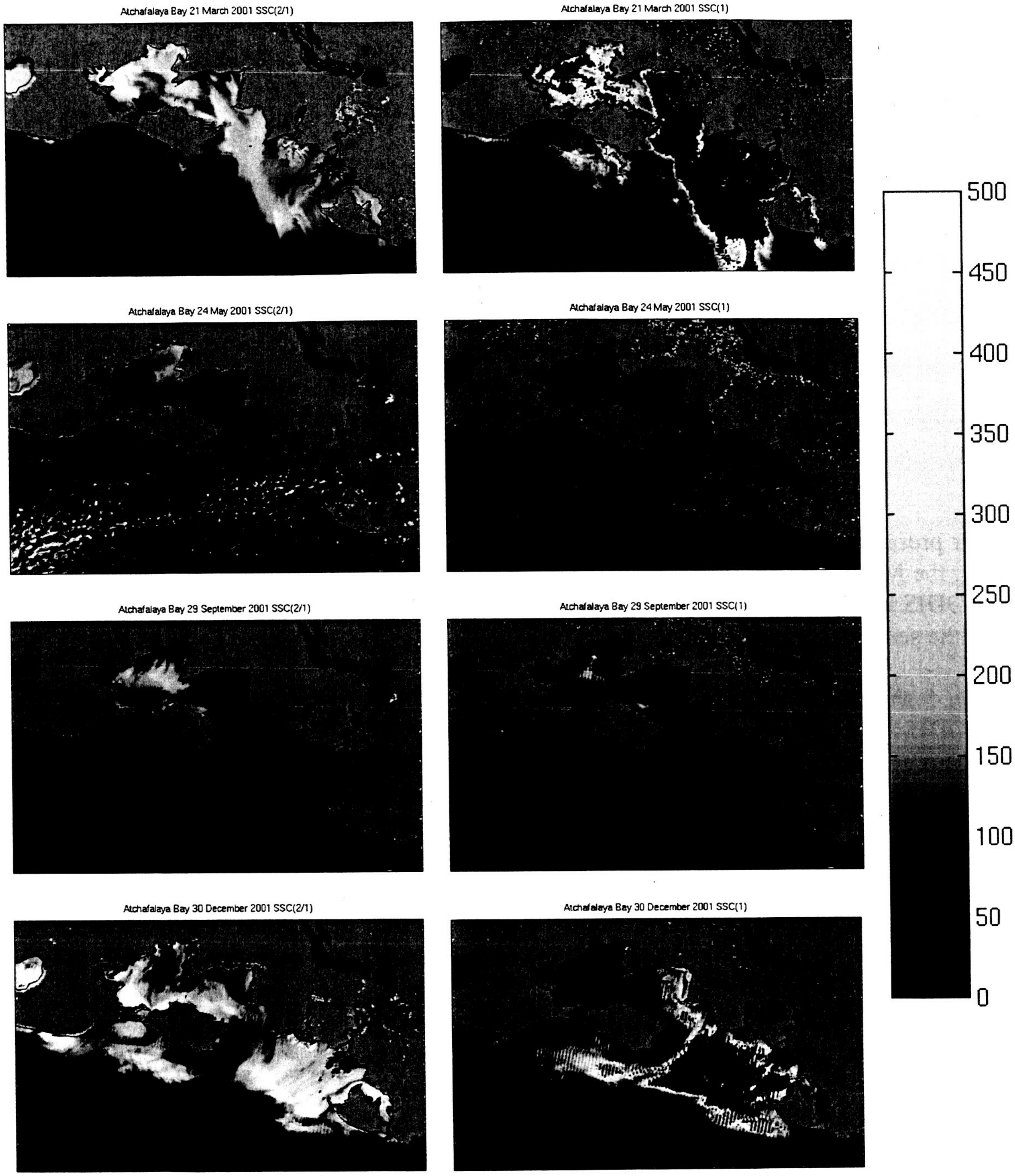


Figure 5. Suspended sediment concentration in mg/l retrieved for the Atchafalaya Bay region from four MODIS overpasses chosen to represent each of the four seasons. The leftmost images are derived using the combined band 1 and band 2 approach, the rightmost images use only band 1. In the 21 March and 30 December at right, the algorithm fails when $\rho_w(1)$ values exceed the maximum predicted by the in-water model (red regions). This indicates that the assumed IOPs for band 1 may be underestimated for the Atchafalaya Bay region.

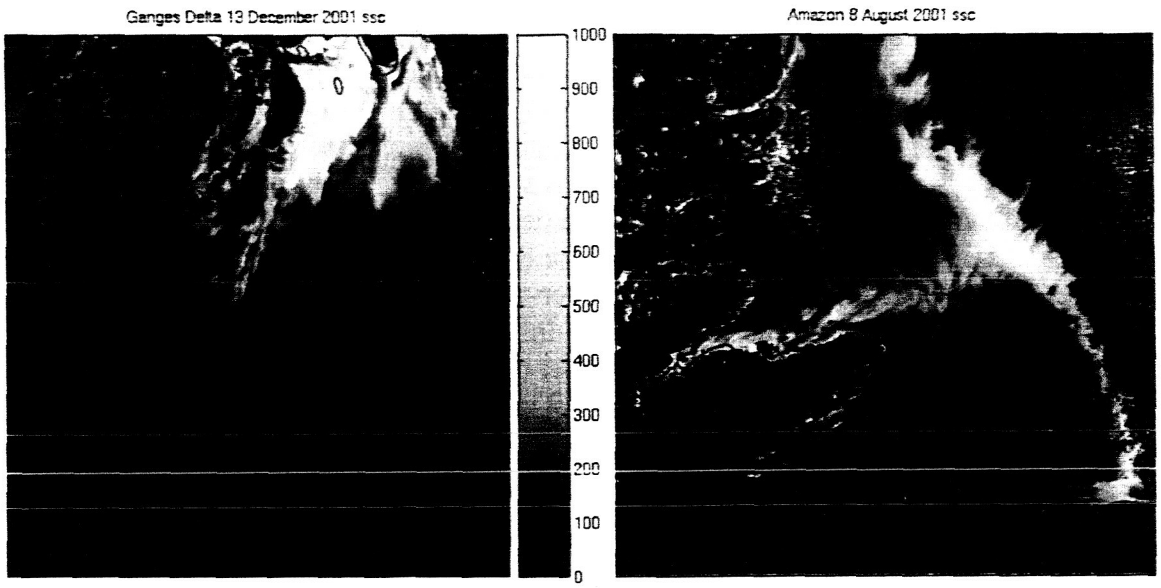


Figure 6. Suspended sediment concentration in mg/l retrieved for the Ganges Delta on December 13, 2001 (left) and for the Amazon Delta on August 8, 2001 (right).

Fig. 6 gives a first look at the application of the MODIS SSC algorithm to other prominent world deltas. The products, which use the same IOPs as used for the Atchafalaya Bay region, are interesting for the relative variability in the scenes but are not intended to be used for SSC quantity comparisons between delta regions. These examples are presented as initial test cases for extending the application of the SSC algorithm to the global domain, the goal of this effort. The SSC retrieval at sites around the globe is a function of the IOPs at each site. The IOPs at each site must be substantiated by in situ sampling before the SSC quantity at different sites can be meaningfully compared. It is envisioned that local users of a MODIS SSC direct broadcast product will apply their knowledge of local drainage basin conditions to specify appropriate IOPs. The first step of making the MODIS SSC retrieval product available to local users for their evaluation is being undertaken by this project.

CONCLUSIONS AND FURTHER WORK

A suspended sediment concentration estimation algorithm has been tested using MODIS observations of case 2 waters along the Louisiana coast. MODIS provides well calibrated on-orbit observations of the globe on a daily basis, including 660 and 865 nm bands at 250 m resolution. The MODIS 250 m resolution observations are used to estimate SSC. MODIS 500 m observations at 1.64 and 2.13 μm are used to constrain the atmospheric correction of the 660 and 865 nm data. Atmospheric modeling of aerosol is based upon the 6S model. Inherent optical properties for relating the remote sensing reflectance to SSC are provided in the Hydrolight model. Early testing indicates that low (< 50 mg/l) SSC is best retrieved using the MODIS 660 nm band; however, the sensitivity of the 660 nm band to SSC diminishes at high concentrations and so a ratio technique of the 865 and 660 nm bands is used. SSC "snapshots" of the case 2 waters in the Atchafalaya Bay region show a large range of SSC both on given days and through the annual cycle. The algorithm was also applied without adjustment to scenes of the Ganges and Amazon River deltas for a first look at the SSC variability at these sites.

Further work is necessary to mature the SSC algorithm. A key element is to better understand the IOPs of the sediment at given delta sites around the world. Observations in the Atchafalaya Bay region suggest that the backscatter to total scatter ratio of 0.02 is an underestimate. Co-incident aircraft observations and in situ measurements in the Louisiana coast region will be used to gain insight on this ratio for that region. Such measurements are needed and sought for other deltas around the world, with a goal of a daily MODIS global product of SSC for case 2 waters.

REFERENCES

[1] http://modis.gsfc.nasa.gov/about/specs.html

[2] O. K. Huh, C. C. Moeller, W. P. Menzel, L. J. Rouse Jr., and H. H. Roberts (1996), "Remote sensing of turbid coastal and estuarine water: a method of multispectral water-type analysis". *J. of Coastal Research*, Vol. **12**, No. 4, pp. 984-995, 1996.

[3] King, M. D., W. P. Menzel, P. S. Grant, J. S. Myers, G. T. Arnold, S. E. Platnick, L. E. Gumley, S-C. Tsay, C. C. Moeller, M. Fitzgerald, K. S. Brown, and F. G. Osterwisch, "Airborne scanning spectrometer for remote sensing of cloud, aerosol, water vapor, and surface properties," *Journal of Atmospheric and Oceanic Technology*, **13**, pp. 777-794, 1996.

[4] Moeller, C. C., O. K. Huh, H. H. Roberts, L. E. Gumley, and W. P. Menzel, "Response of Louisiana coastal environments to a cold front passage". *J. Coastal Res.*, Vol. **9**, No. 2, pp. 434-447, 1993.

[5] Curtis D. Mobley and Lydia K. Sundman (2001), "HYDROLIGHT 4.2 Users' Guide", Sequoia Scientific, Redmond, WA 98052.

[6] E. Vermote and D. Tanre and J. L. Deuze and M. Herman and J.J. Morcrette (1997), "Second Simulation of the Satellite Signal in the Solar Spectrum (6S)", 6S User Guide Version 2, July 1997.

[7] U.S. National Marine Fisheries Service. "Fisheries of the United States, 1994". U.S. National Marine Fisheries Service Current Fisheries Statistics 9400, 1995.

[8] E. E. Knudsen, B. D. Rogers, R. F. Paille, W. H. Herke, and J. P. Geaghan,. "Juvenile white shrimp growth, mortality, and emigration in weired and unweired Louisiana marsh ponds". *North American Journal of Fisheries Management*, **16**, pp. 640-652, 1996.

[9] J. A. Nyman, R. D. DeLaune, H. H. Roberts, and W. H. Patrick Jr., "Relationship between vegetation and soil formation in a rapidly submerging coastal marsh". *Marine Ecology Progress Series*, **96**, pp. 269-279, 1993.

[10] Marcos J. Montes, Bo-Cai Gao, and Curtiss O. Davis (2003), "Tafkaa atmospheric correction of hyperspectral data", Proceedings of SPIE -- Volume 5159, Imaging Spectrometry IX, Sylvia S. Shen, Paul E. Lewis, Editors, December 2003, pp. 188-197.

[11] Linhong Kou, Dabiel Labrie and Peter Chylek (1993), "Refractive indices of water and ice in the 0.65- to 2.5 μm spectral range", Applied Optics, vol. 32, no. 19, pp. 3531-3540.

[12] Moeller, Christopher C., M. M. Gunshor, W. P. Menzel, O. K. Huh, N. D. Walker, and L. J. Rouse, "Recent monitoring of suspended sediment patterns along Louisiana's coastal zone using ER-2 based MAS data and TERRA based MODIS data". 11th Conference on Satellite Meteorology and Oceanography, Madison, WI, 15-18 October 2001 (preprints). Boston, MA, American Meteorological Society, 65-68, 2001.

Field Notes Nov. 15, 2000
Chenier Plain Sediment Burial Pipe Measurements

Chris Moeller, Mat Gunshor, Oscar Huh
Dale Winch, airboat pilot
University of Wisconsin – Madison
Louisiana State University

Equipment: Field notebook and pens, quadrangle maps, make-shift measuring stick (see "Lock" section), 35mm camera with telephoto lens (Huh), and the digital camera with zoom lens from CIMSS (Moeller, Gunshor). The meter stick was actually a wooden broomstick or mop handle obtained from the U.S. Army Corps of Engineers employee stationed at the lock near the boat launch. Using a red marker and measuring tape, Chris marked off feet and inches on the stick. For distances longer than the measuring stick we assumed the pipes were approximately 30m apart and judged distances based upon that estimate. We did not have a GPS device on this trip so latitude/longitude locations listed here are from the September 1997 trip. Future equipment suggestions: Sechi disk, echosounder, fathometer, small binoculars for finding pipes inshore, a long firm measuring device (longer than a meter or yard stick, if possible), a GPS device, replacement clamps, and blue and orange (perhaps red would be better) spray paint for remarking the pipes where necessary. We should also bring a measuring tape or something else (rope?) that we could use to measure the distance between adjacent pipes. Finally, red reflective tape for additional marking of pipes.

Weather: Cool (upper 50's), overcast (mid level), and relatively dry. There were light (7-10 mph) easterly winds when we started out, progressing to southeasterly in the afternoon and picking up (10-12? mph) in the afternoon. Seas were fairly calm and did not prevent us from visiting any of the pipes. We were somewhat concerned most of the trip that we needed to be fast since winds were expected to increase from the southeast in a prefrontal mode in the afternoon. There had been a cold frontal passage about 36 hrs previous. In the end, the afternoon winds did not become a hindrance.

<u>Dock</u> 10:20am CST

Notes: Loaded and launched airboat from a side inlet of Freshwater Bayou Canal. Freshwater Bayou is now referred to as Freshwater City. Headed out of Freshwater Bayou Outlet into the Gulf and turned west alongshore toward the Western Erosion Site.

<u>Lock</u> 10:30am CST

Notes: When loading the boat we discovered that we forgot a measuring stick. We stopped at the lock to ask the man (Greg or Craig?) working there if he had something. We ended up using a long (about 5') wooden broom stick or mop handle, which Chris marked off with a red marker using measuring tape. We left the lock at 10:38am CST.

<u>Western Erosion Site (WES)</u> 11:08am CST

- Pipe #3 WES #3 3rd pipe in (shoreward) from the south at WES.

29°33.894' N 92°29.698' W

Measurements:

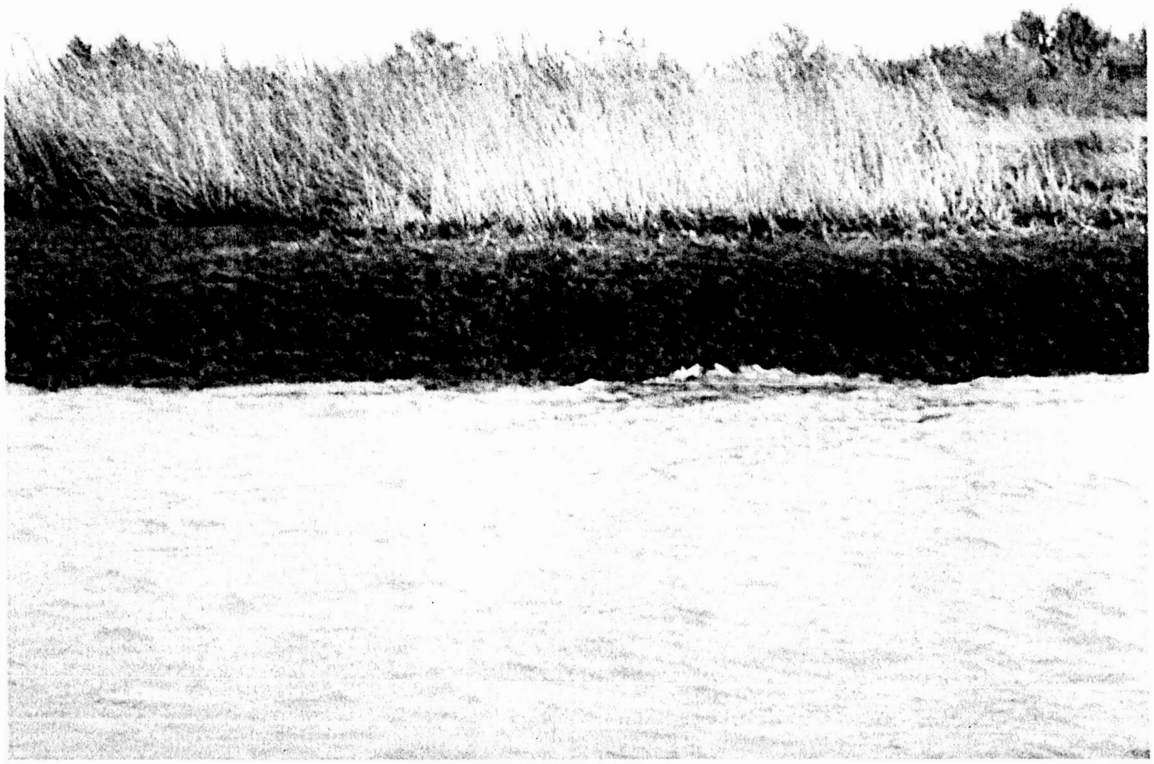
From water level to surface of sedimentation: 26 in
From clamp to water level: 72 in

Description: Pipe standing in about 2' of water. The subaqueous bottom was described as being hard or solid at this point. While tied to the pipe we estimated that it was approximately 30 to 40 yards from the pipe to the sand ridgeline. There were clumps of grass in the mud. The mud onshore appeared very firm and was heavily pocked or tunneled (1-2" diameter). It gave the appearance of a lava field to Chris. We later conjectured that the tunnels were the pathways of former root systems of vegetation which had since been eroded away.

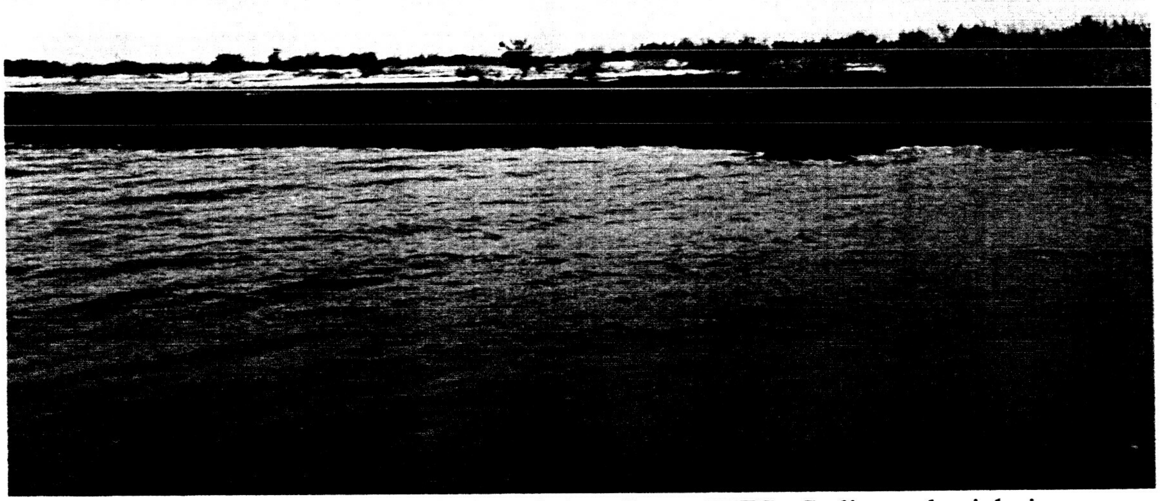
Note: Pipe WES#3 is almost certainly the pipe that Huh et al placed at the shell beach ridge line in 1994. Through eroding forces, it now is about 30-40 yards seaward of the beach ridge and stands some 8 – 10' above the water line (i.e. much of the pipe that was once submerged in the shell beach ridge is now exposed by erosion.) – ed.

Pictures:

1. Oscar displaying our make-shift measuring stick. (Dscn0004.jpg)



2. Firm mud ridge at Western Erosion Site. Note pockmarked surface, possible remnant pathways of vegetation root systems. Erosional forces seem to be cutting the beach and stranding the vegetation. (Dscn0005.jpg)



3. Sand Ridge beyond pock-marked mud shoreline at WES. Sediment burial pipe positions suggest that the beach ridge has eroded back since 1994. (Dscn0006.jpg)

- Pipe #2 WES #2 2nd pipe in (shoreward) from the south at WES.

Measurements:

From water level to surface of sedimentation: 32 in
From water level to clamp: 4 ft 6 in

Description: Pipe standing in about 2.5' of water. The subaqueous bottom here was described as firm and wet. An outer clamp on this pipe has broken loose from rust, exposing an inner clamp that is itself severely rusted (as well as the pipe).

Pictures:

4. Pipe at WES #2. Note broken outer clamp hanging on pipe and exposing severely rusted inner clamp about 3 inches above. (Dscn0007.jpg)

- Pipe #1 WES #1 Southernmost pipe at WES.

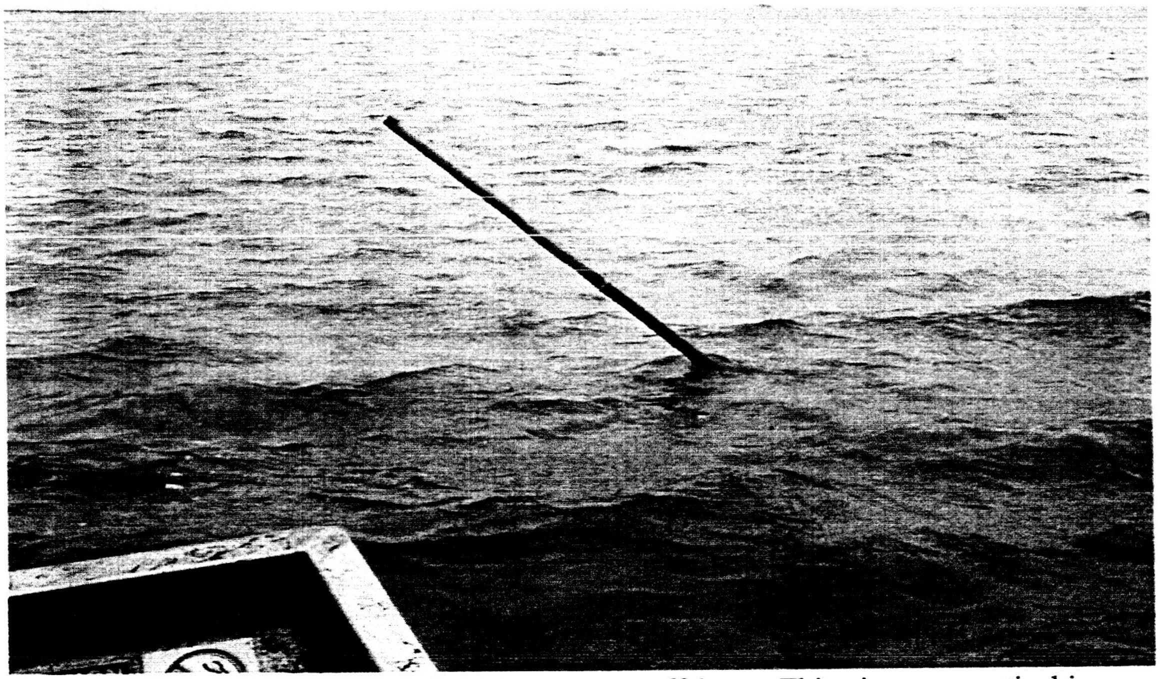
29°33.813' N 92°29.640' W

Measurements:

From water level to surface of sedimentation: 3 ft 6 in

Description: This pipe is bent at about a 45-degree angle (was not bent in Sept 1997). Due to this fact we were unable to make a meaningful measurement from the clamp.

Pictures:



5. Bent pipe at WES #1 some 50 meters or more offshore. This pipe was vertical in Sept 1997. A measurement from the surface of sedimentation to the approximate water level at the pipe was recorded. Note light seas. (Dscn0008.jpg)

Notes: Chris roughly estimated the shell beach extended about ½ mile eastward from WES. Pipes are numbered so the #1 pipe is the farthest south - in this case, the farthest out into the gulf since they are in water. We visited the #3 first, then #2, followed by #1 last. We left this site and headed eastward to the Dewitt Canal Site.

Dewitt Canal Site (DCS) 11:39am CST

5 pipes seen at this site, 4 were visited. We also saw the red and white triangle marker installed inland by Rouse in 1994.

- Pipe #1 DCS #1 Southernmost pipe (farthest toward the Gulf)

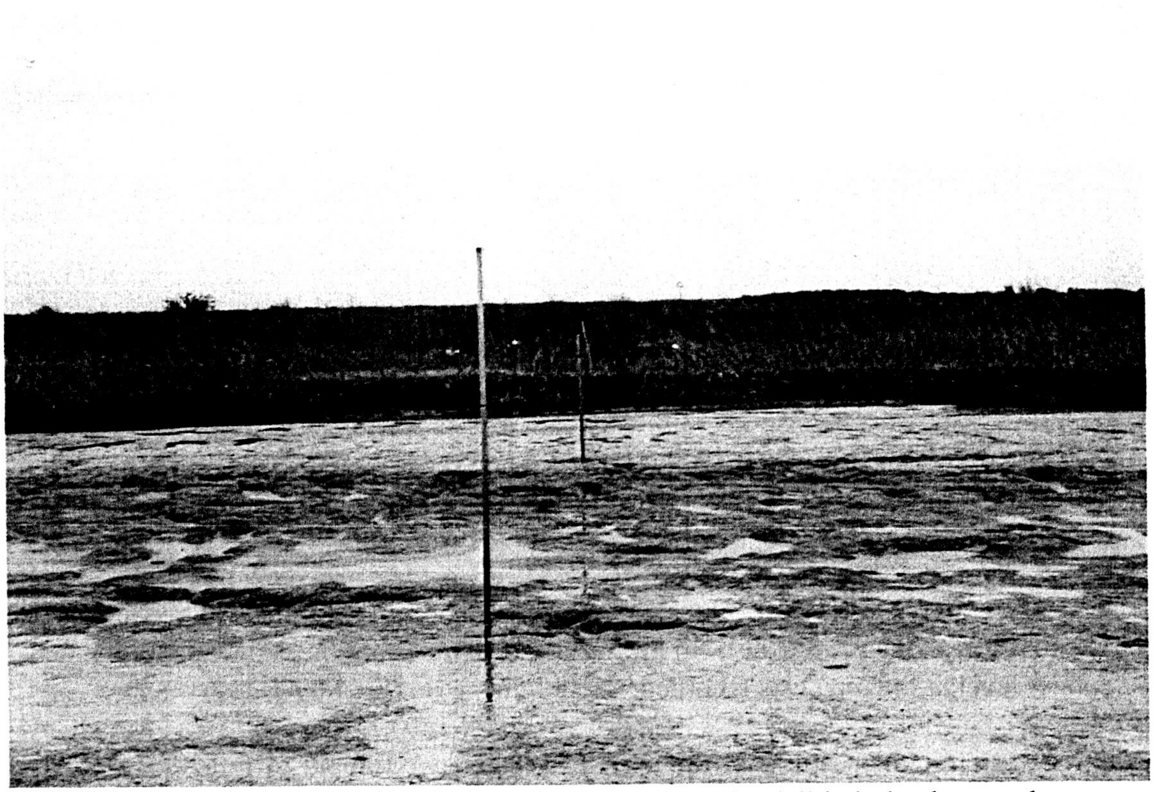
29°33.357' N 92°26.454' W

Measurements:

From clamp down to the surface of sedimentation: 6 ft
From clamp up to the top of the sediment pipe: 27 in

Description: The surface was fluid mud here which looks eroded and pocked. There were bird prints in the mud near the pipe. Mud flat extends approximately 20m south from this pipe. This pipe was not painted in Sep. 1997.

Pictures:



6. Looking North from DCS#1. DCS#2, #3, & #4 clearly visible in background. (Dscn0010.jpg)

7. Chris measuring at DCS#1. The broomstick is sitting on the mud surface at the base of the pipe and the total distance to the clamp on the pipe (visible at the very top of picture) is being measured. Note puddling of surface water. The area immediately at the base of the pipes tended to be a bowl shaped depression, often several inches deep. Water level appeared to be quite low, and was observed rising later in the day. (Dscn0138.jpg)

8. Chris completing the measurement to the clamp on DCS#1. The total distance in feet and inches from the surface of sedimentation to the clamp was recorded by Mat. The measuring process was generally completed within 1 minute. Error bars for this measurement procedure are estimated to be about +/- ½ to 1 inch. For some pipes, the distance from the upper clamp to the top of the pipe was also measured and recorded to complete a documentation process begun with the Sept 1997 field trip. (Dscn0139.jpg)

- Pipe #2   DCS #2

Measurements:

From upper clamp down to the surface of sedimentation: 4ft 8in
From upper clamp up to the top of the sediment pipe: 5ft
From upper clamp to lower clamp: 3ft 10in

Description: The surface was fluid mud here. Here at 11:54am. This pipe was not painted in Sep. 1997.

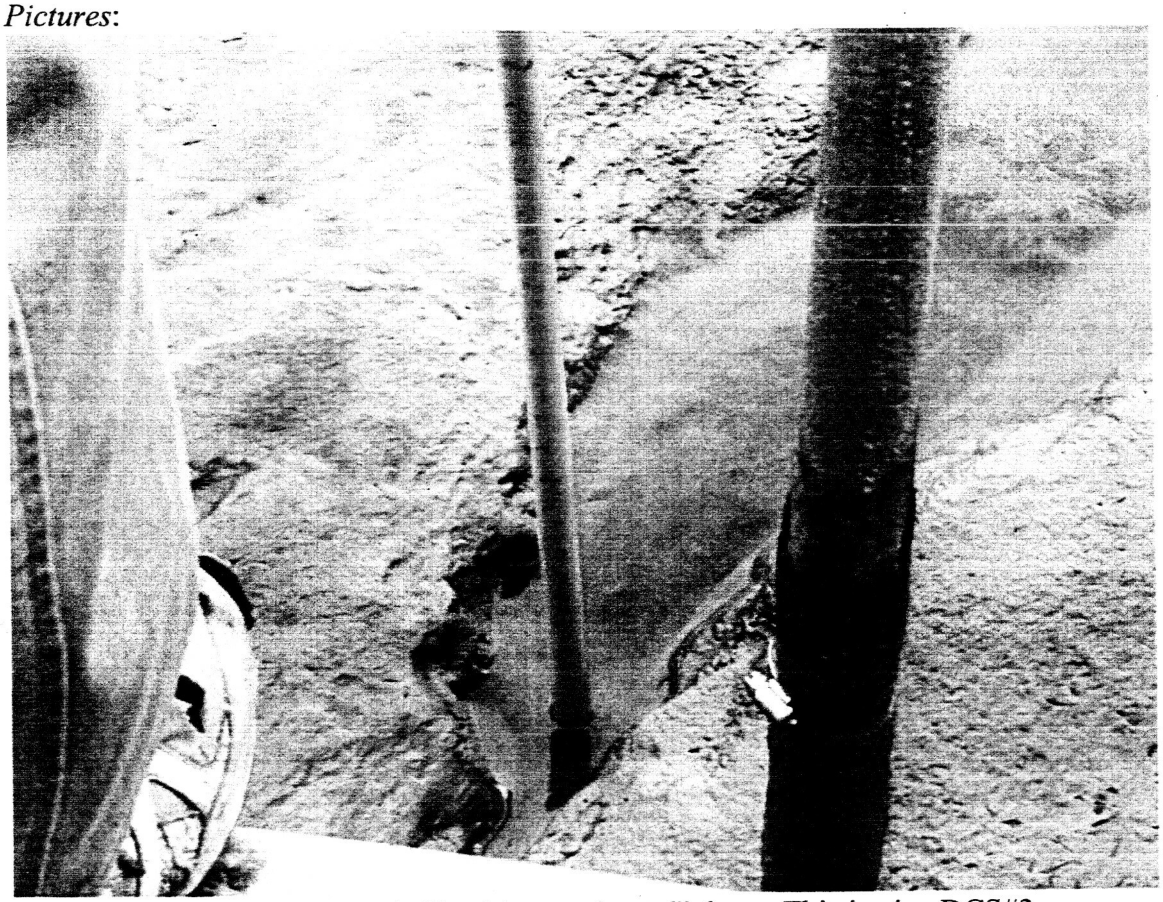
- Pipe #3   DCS #3

Measurements:

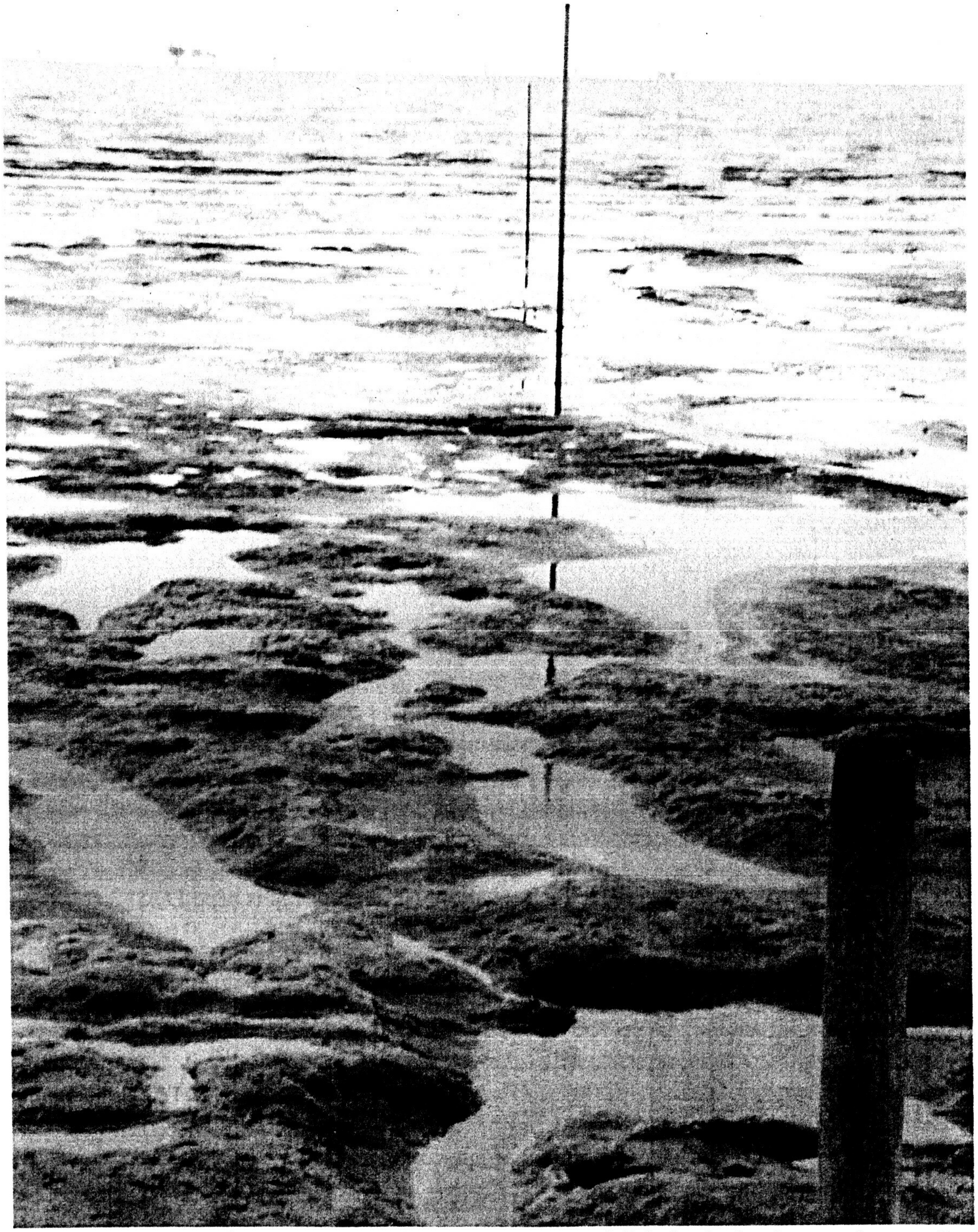
From upper (?) clamp down to the surface of sedimentation: 5ft 2in

Description: We're assuming this measurement is from the upper clamp if there was more than one clamp since it was the only clamp visible. There were 6-10in deep shore normal rills here. This pipe is approximately 20m from the mud edge (or mud "escarpment"). Oscar described the mud surface here as "hummocky."

Pictures:



9. One of many shore normal rills, this one about 6" deep. This is pipe DCS#3. (Dscn0140.jpg)



10. Facing seaward from DCS#3, DCS#2 and DCS#1 visible in the background, as well as several oil platforms. Significant puddling at DeWitt Canal site is evident. Oil platforms in background. (Dscn0141.jpg)

11. Facing shoreward from DCS#3, DCS#4 visible above escarpment just north (2 meters) of the edge of vegetation which reaches to the escarpment. A fifth pipe (DCS#5) is barely evident in the photo just at the edge of the taller vegetation in the background. The line between DCS#4 and DCS#5 is a former fence line. The

vegetation on the escarpment was severely matted for about 20 meters, suggesting overwash during a high water event. (Dscn0142.jpg)

- Pipe #4   DCS #4

Measurements:

From clamp down to the surface of sedimentation: 2ft 8in
From clamp up to the top of the sediment pipe: 1ft 7in

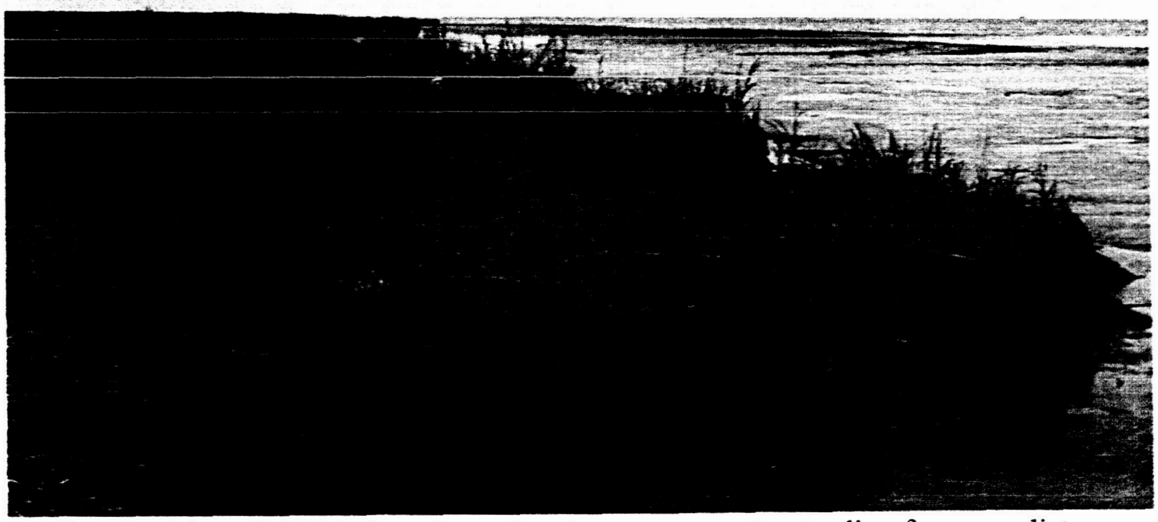
Description: This pipe was not painted in Sep. 1997. Pipe is about 10m north of the mud escarpment. The surface here was firm mud with grass. We debarked from the airboat to make these measurements and were able to walk easily. Much of the grass here looked to be flattened, we assumed by some high water event. The thick areas of grass were difficult to walk on.

Pictures:

12. Seaward from DCS#4. DCS#1-3 are resting in exposed fluid mud. The exposed mud flat (water edge to escarpment) was estimated at about 100m at this time, based in part on an assumption that the sediment pipes were placed at 30m spacing. (Dscn0143.jpg)

13. Oscar walking northward on large log near fence line between DCS#4 and DCS#5, which is visible near the edge of the matted vegetation. Note some trash (left side) is also present at extent of matted vegetation. (Dscn0144.jpg)

14. Mat measuring mud escarpment, about 2' high near DCS#4. The escarpment appears to be a purely erosional feature. (Dscn0145.jpg)



15. Eastward from DCS#4 alongshore showing escarpment extending for some distance. Mat providing scale. (Dscn0146.jpg)

16. From DCS#4. Airboat parked at escarpment. Time for a lunch break. (Dscn0148.jpg)

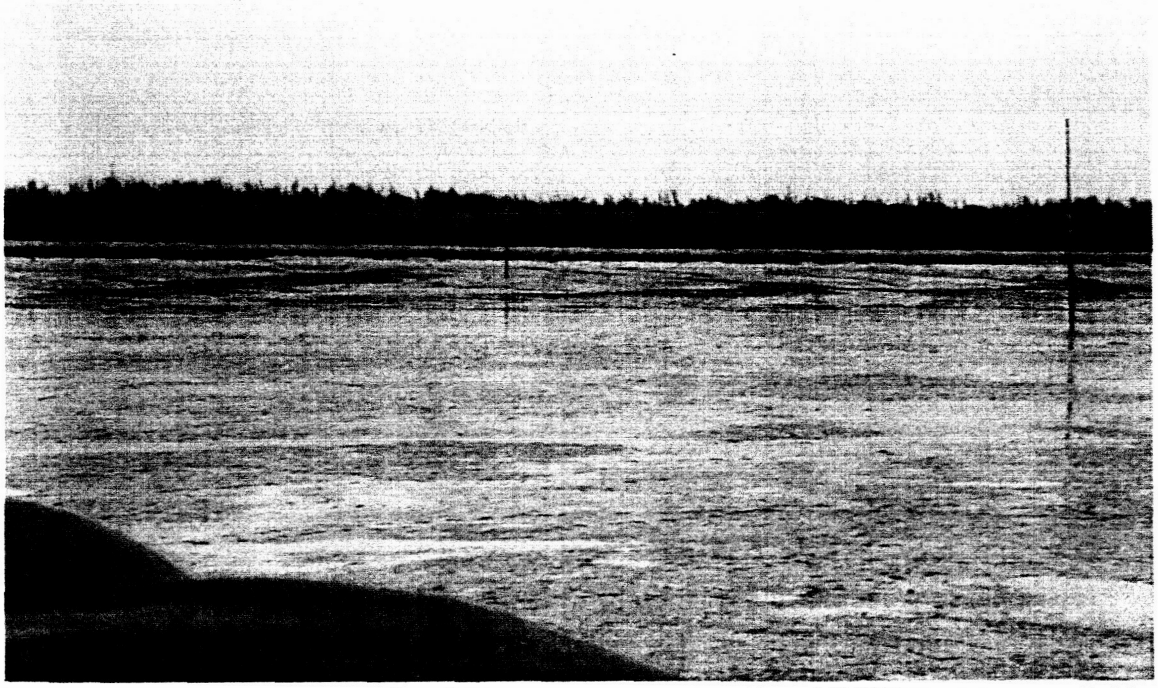
Notes: There was a mud flat about 100m long extending seaward from a mud escarpment at this site. At the base of pipes there often were 6" or so diameter bowls (2-3" deep below the surrounding surface of sedimentation) that were scoured out. We measured the mud escarpment to be about 2 feet high from the surface of the mud flat. From DCS#4 we could see a fifth pipe to the north and Oscar made his way through the thick grass to see it but made a hasty retreat from the mosquitoes. We saw a fence here that starts between pipes 4 and 5 and extends northward. There was also a long log, which was approximately 3-4 feet in diameter and lying next to the fence oriented north/south. The grass here was flattened northward for 20m inland from the escarpment and the grass was colonized all the way to the edge of the escarpment. There was trash on the flattened grass. We could see the triangle that Larry Rouse put here about 200m north of the escarpment.

After exploring this area we ate lunch here in the boat at 12:30pm CST. Then we continued east alongshore toward the Exxon Canal West Site.

<u>Exxon Canal West Site (ECW)</u> 1:05pm CST

Dale called the pipeline here the Transco pipeline. Transco is now Williams so maybe a more appropriate name is the Williams Pipeline. He said that as an area dries up the big oil companies sell off their sites to little oil companies who then pump them dry. There are 7 pipes at this location, according to Oscar, but we could only see 5 of them, each at regular spacing of about 30m between pipes. The pipes are buried in a straight line extending seaward from a fenceline, which is used for holding grazing cattle. North of the northernmost pipe is an orange/red (reflective?) triangle marker to help locate the site from the sea. Larry Rouse remembers putting it here and we did see it well inland on this day. On this day we measured the southernmost 4 pipes.

Pictures:



16.1 Approaching the Exxon Canal Site pipe array, ECW#2 and ECW#3 visible on fluid mud surface. (Dscn0149.jpg)

- Pipe #1 ECW #1 Southernmost pipe at ECW - farthest from shore.

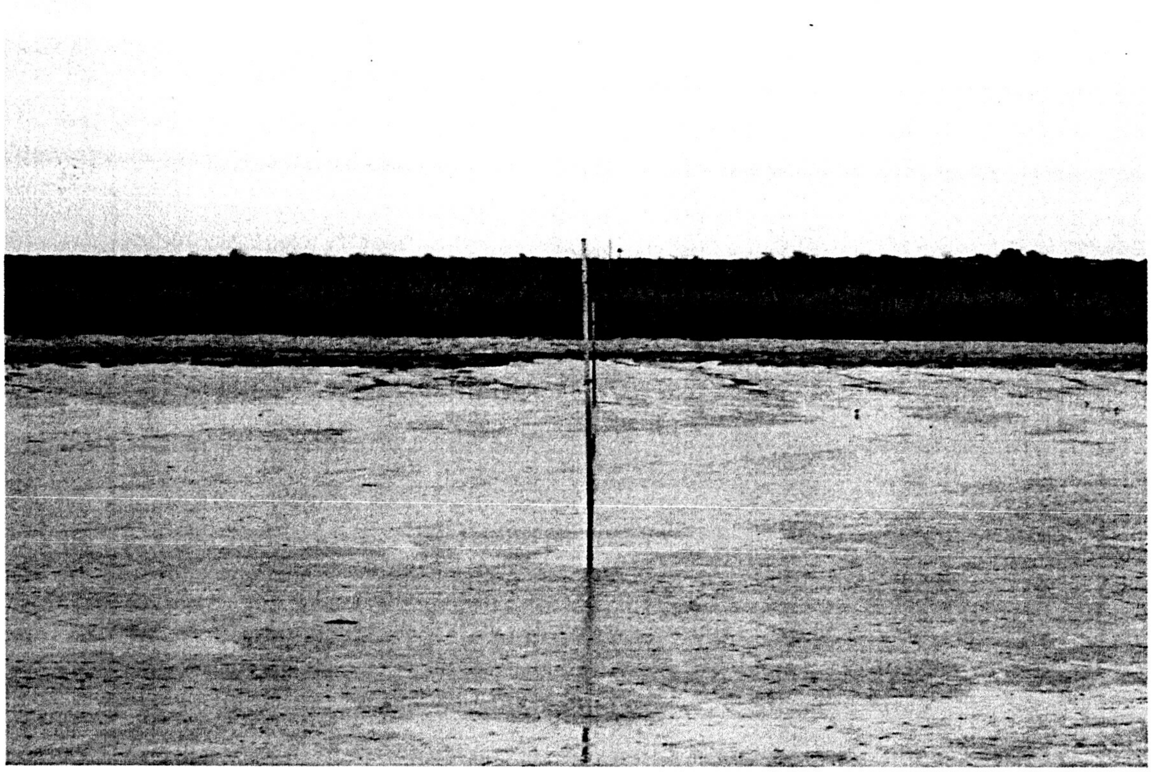
29°32.605' N 92°23.410' W

Measurements:

From clamp down to the surface of sedimentation: 4ft 6in
From clamp up to the top of the sediment pipe: 35in

Description: Fluid mud surface. We could see long (> 100m) linear 1-2" tall wavelets rolling in and as the water moved back out it was mostly clear, with little or no sediment in it. It looks like the mud flat (from the grass edge) is about 80-90m here.

Pictures:



16.2 Shoreward from ECW#1, ECW#2 and ECW#3 visible. ECW#5 visible in the vegetation and the triangle is far in the distance. (Dscn0150.jpg)

- Pipe #2 ECW #2 Second pipe shoreward from the Gulf

Measurements:

From clamp down to the surface of sedimentation: 4ft 7in

Description: Noticed that the paint marks from 9/97 were still here, although the blue paint is much more vibrant than the orange. This is pretty much the case at all pipes we visited today.

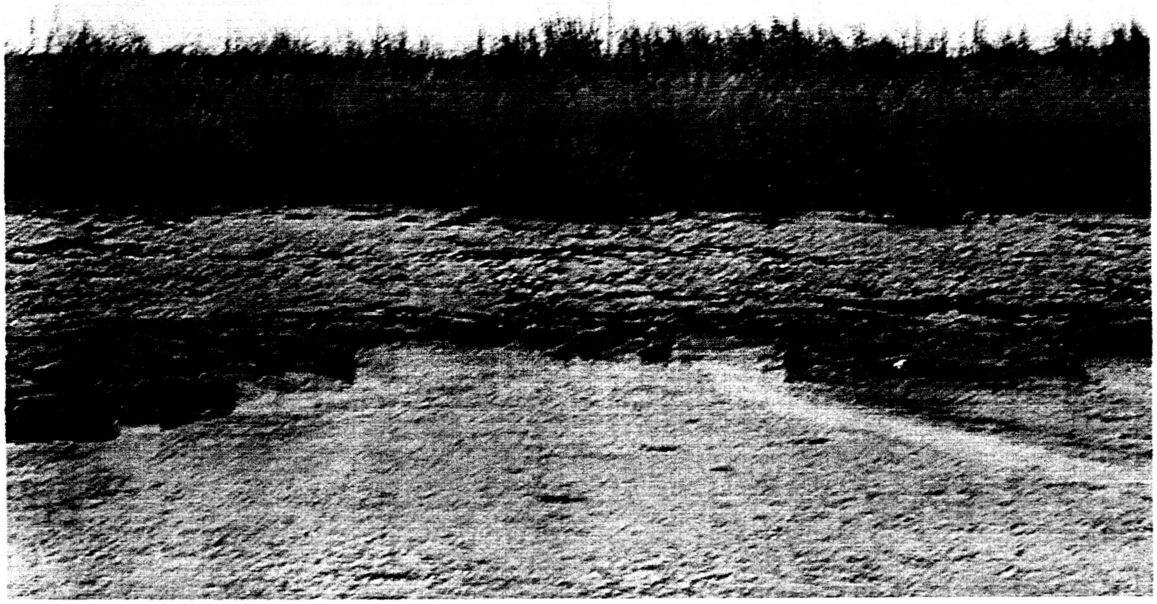
- Pipe #3 ECW #3 Third pipe shoreward from the Gulf

Measurements:

From clamp down to the surface of sedimentation: 4ft 2in

Pictures:

17. ***Picture 17 (Seaward from ECW#3) came out black (forgot to remove lens cap)*** (Dscn0151.jpg and Dscn0152.jpg)



18. Shoreward from ECW#3. Note mud ridge, about 6-10" tall in foreground. ECW#4 stands about 18" tall on the mud ridge in the center of the photo about 2 meters seaward of the vegetation line. The mud ridge itself is roughly 6-8 meters front to back in the center of this photo. Note: This picture is out of focus and Paint Shop Pro was used to sharpen the image somewhat. (Dscn0153sharp.jpg)

- Pipe #4 ECW #4 Fourth pipe shoreward from the Gulf.

29°32.652' N 92°23.406' W

Measurements:

From top of pipe down to the surface of sedimentation: 18in

Description: We were here at about 1:30pm CST. The pipe is sheared off at a former pipe joint low to the ground (18"), probably weakened by rust. The clamp was apparently on the on the missing (upper) part of the pipe as no clamp is now visible on this pipe.

- Pipe # 2 TCS #2 Second pipe shoreward from the Gulf.

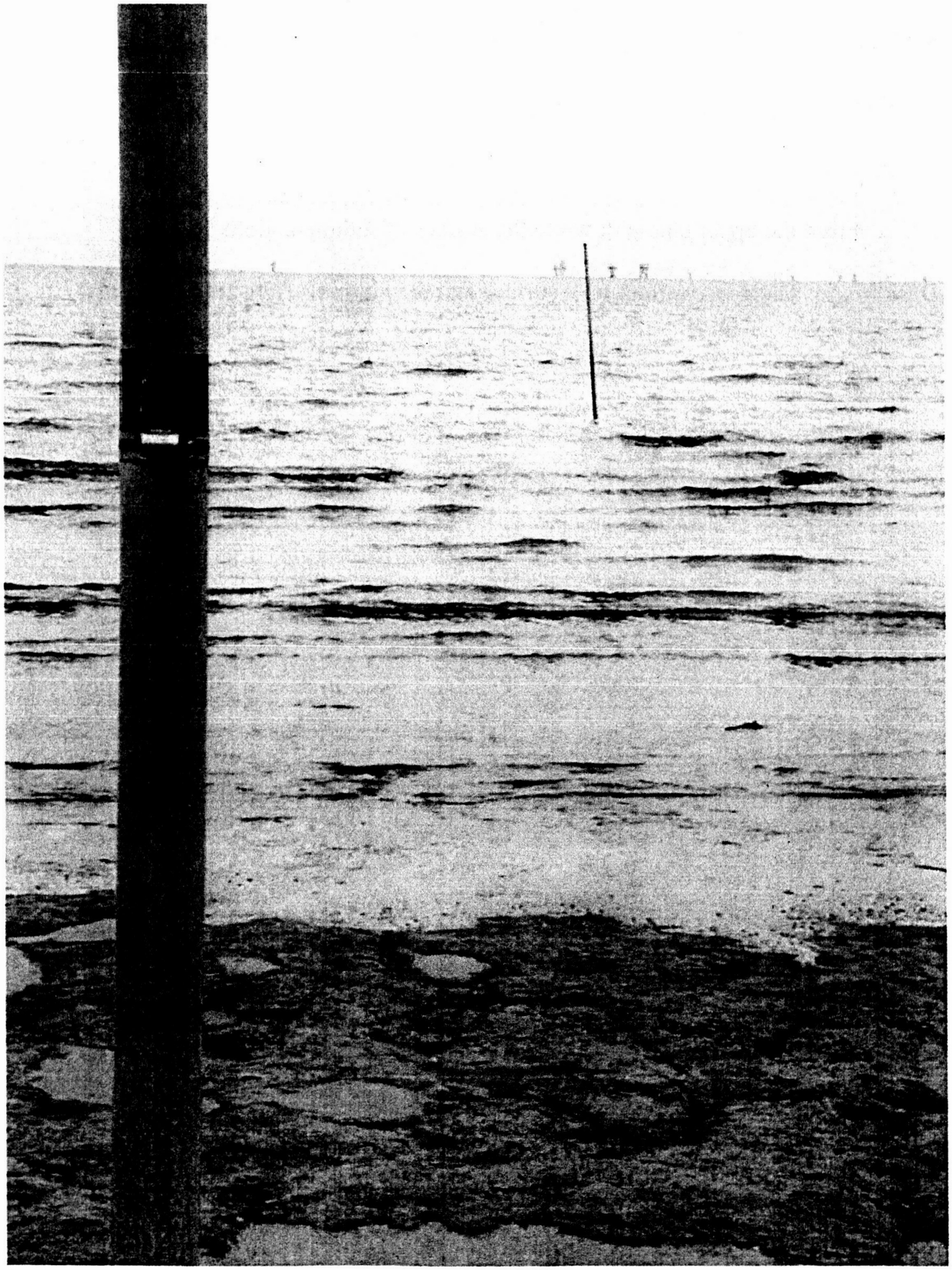
29°32.003' N 92°20.054' W

Measurements (2 clamps):

From the lower clamp down to the surface of sedimentation: 1ft 3in
From the upper clamp down to the surface of sedimentation: 5ft 2in

Description: There was a fluid mud surface and the pipe was right at the edge of vegetation.

Pictures:



25. Seaward from TCS#2, TCS#1 visible in the background. Texture of fluid mud surface at TCS#1 evident in foreground. (Dscn0161.jpg)

Notes: The vegetation here was approximately 4-5 feet high. We were unable to get further in shore but we could see a pipe approximately 200 yards north, inline with the other pipes. There is a large advertisement sign many hundred yards inland that our boat driver, Dale, said was placed at the shoreline many years ago. We left this site and headed east across Freshwater Bayou Outlet to the Eastern Erosion Site.

Eastern Erosion Site (EES) 2:17pm CST

- Pipe #1 EES #1 Southern-most pipe at EES

29°32.004' N 92°17.028' W

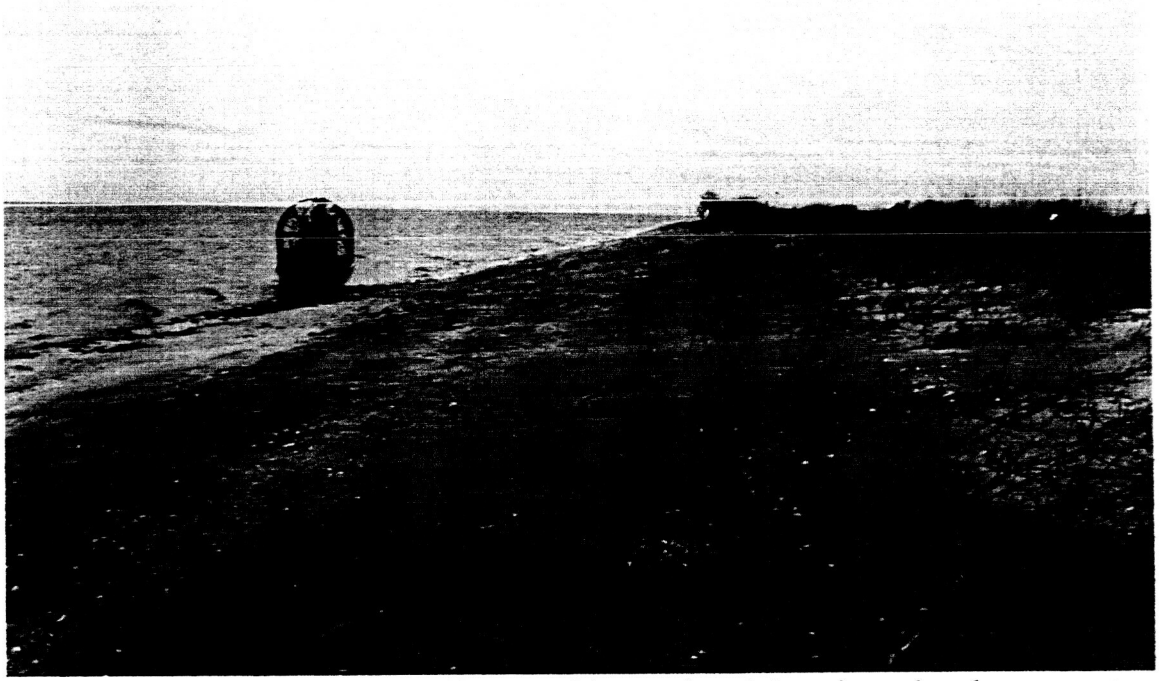
Measurements:

From clamp down to the surface of sedimentation: 5ft 5in

Description: In approximately 2ft of water here. The bottom was firm mud.

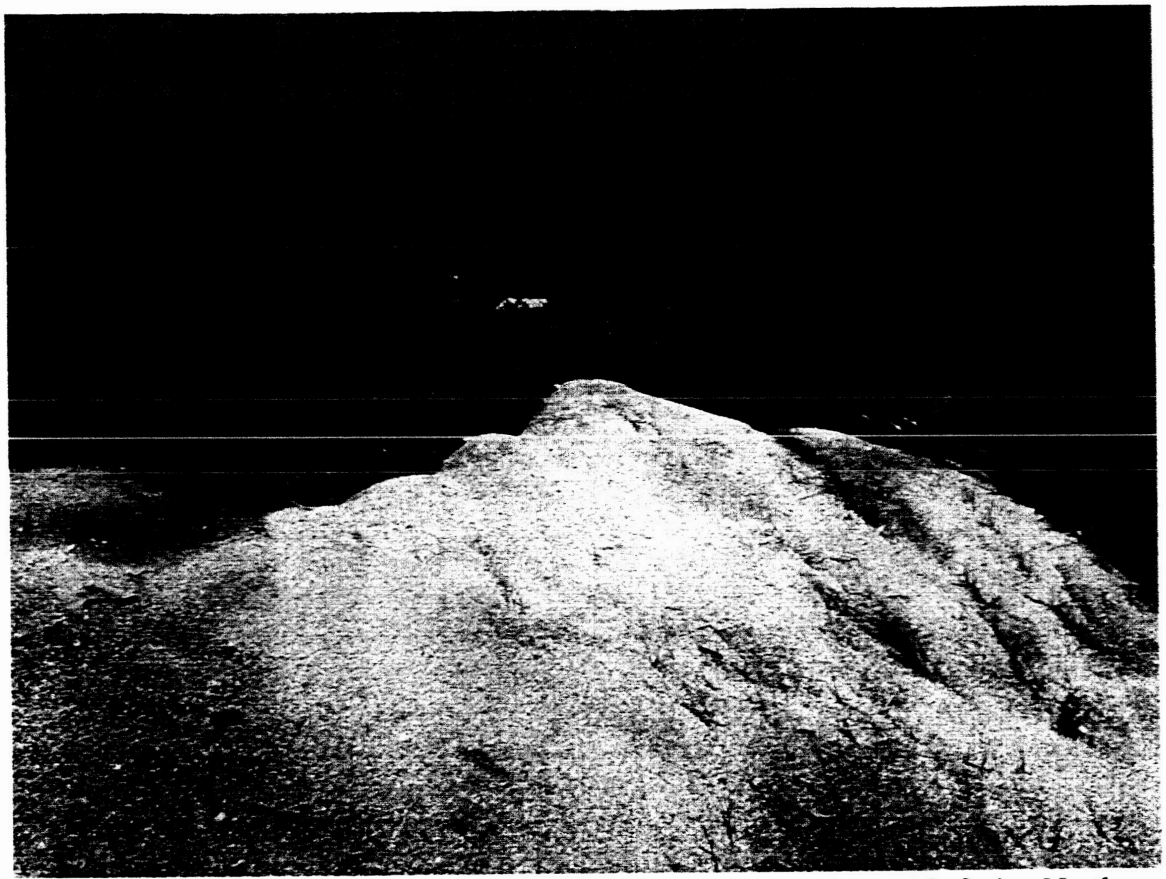
Pictures:

26. Facing pipe from shell beach at Eastern Erosion Site. In 1994, two pipes were installed at this site, reportedly one at shell beach ridge and a 2nd some 25 meters seaward. At this time, there is no evidence of a 2nd pipe at this site. Based on description given in the Nov. 1994 report, it is likely that erosion toppled the shell beach ridge pipe (only sunk about 1meter into ridge) and that the remaining pipe is the seaward pipe, now some 50 meters from the shell beach ridge. (Dscn0162.jpg)



27. Facing west along beach at EES. No evidence of mud deposits on beach. (Dscn0163.jpg)

28. Facing inland some 15 meters inland of shell beach ridge at EES. Mat is standing on a shell beach overwash lobe. The grassy lowland region beyond contained some standing water. In the background is a chenier populated by Oak trees. (Dscn0164.jpg)



29. Shell beach overwash lobes, taken from Mat's position in picture 28, facing North. (Dscn0165.jpg)

farther onshore. A few sprigs of vegetation are growing from the overwashes, suggesting aging (Ed. Note: overwashes were unvegetated in Nov 2000). We all believed it looked like there was less shell beach here now than when we were here last in November 2000 (Ed. Note: confirmed by Nov 2000 trip report).

Fig EES-2. Mosaic photo looking west along shell beach at EES. Vegetation becomes dominant at beach ridge line. Note sediment burial pipe extending upward from water about 1/6th of the photo width from left edge of photo. Estimated distance from pipe to shoreline was about 7 airboat lengths (airboat is 16' long). (Photo EES_mosaic_west.jpg)

Fig EES-3. Looking west from a position about 15' landward from beach ridgeline at EES. Several shore normal overwashes are visible, somewhat chopped up by cattle traffic (note cattle path extending from position of photographer). (Photo EES_6_overwash_west.jpg).

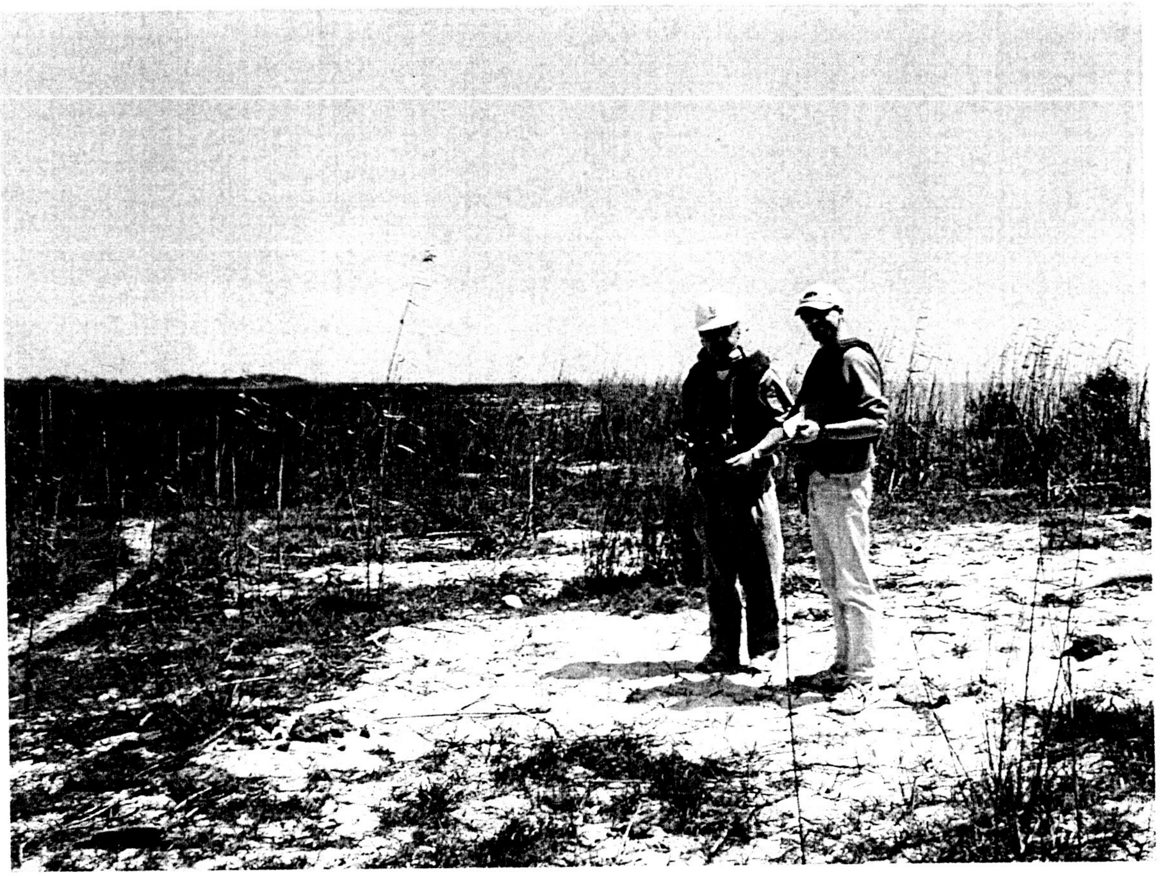


Fig EES-4. Looking east from same position as Fig EES-3. Overwash appears downtrodden, with some new vegetation on it, suggesting it is aging. Cattle path extends into the distance on the left. In Nov 2000, the observed overwashes at this site were devoid of any vegetation. (Photo EES_7_overwash_east.jpg)

Figure EES-5. Vegetation at beach ridge line at EES, about 4' high. Sediment burial pipe visible in background at center of photo. (Photo EES_8_vege.jpg).

While motoring along the coast in this area we saw dozens of cows running along, inland from the ridgeline. There was a path, new since November 2000, inland from the ridgeline, which was apparently created by the cattle. Robert says sometimes airboat captains get called to drive out there and help herd the cattle. When we left this site we headed west alongshore, passed Freshwater Bayou, and headed for the Western Erosion Site.

Western Erosion Site (WES) 1:00pm CST

2 pipes (WES #2 and WES #3) were seen at this site. WES #1 was leaning severely in November 2000 and is now not found.

- Pipe #2 WES #2 Now the southernmost pipe (farthest offshore).

Measurements:

From clamp impression to surface of sedimentation: 83 inches

Description: Water level was about 49 inches here. The pipe is badly rusted and the clamp is missing. There is still an indentation where the clamp was, so we used that for our measurement. Because of the water depth we had to use a length of rope weighted at the end to make these measurements. Because we couldn't reach the surface of sedimentation, we could not make a judgement on what its composition was.

Pictures:

- Pipe #3 WES #3 Northernmost pipe (farthest onshore).

29°33.918 N 92°29.686 W

Measurements:

From clamp to surface of sedimentation: 98 inches

Description: Water level is 46 inches here. Again, we needed to use the rope to make these measurements and could not determine bottom composition. The red tape is still present on this pipe. This pipe stands some 10' above the water line.

Pictures:

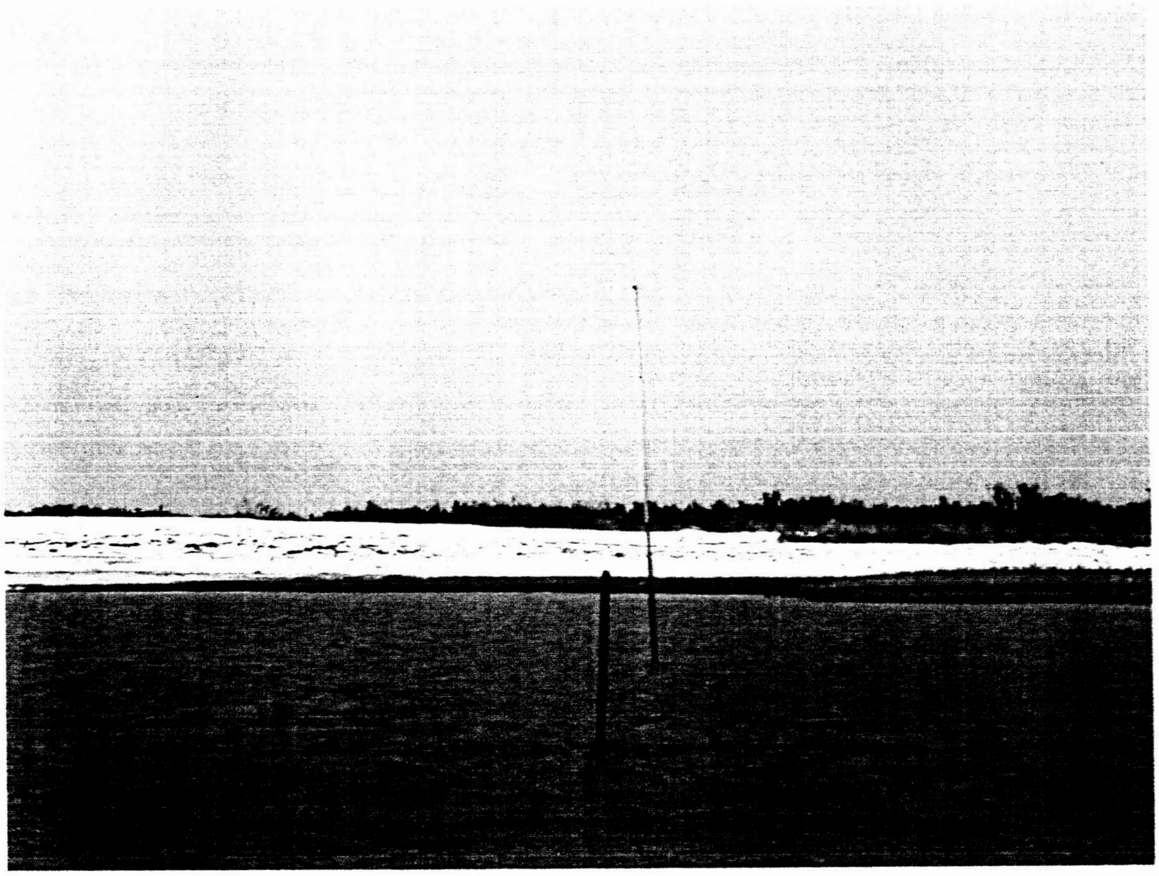


Fig WES-1. The two remaining pipes (WES #2 and WES #3 in back) at WES. It is almost certain that WES #3 was rooted at the shell beach ridge line in 1994. Beach ridgeline, some 40-50 yards from WES #3 in background, is steep and tall (~6'). (Photo WES_2_pipe.jpg)

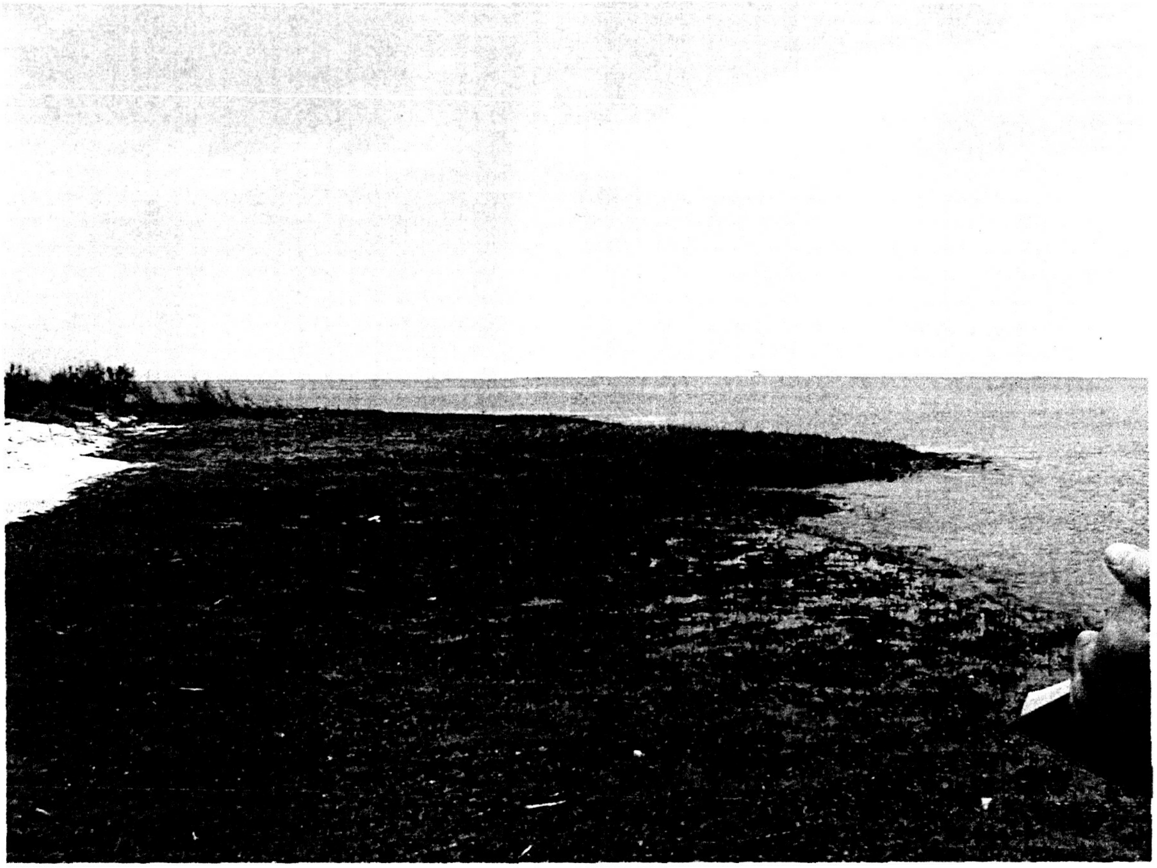


Fig WES-2. Looking east from strand line at WES. Eroded mud field in foreground is pock-marked and mostly devoid of vegetation. An ongoing erosion appears to be taking place here. Shell beach at left. (Photo WES_4_east.jpg).

Fig WES-3. Looking west along shell beach. Note height (~6') and steep nature of beach up to ridgeline. This beach is undergoing erosion, pushing the beach ridgeline landward as indicated by measurement. (Photo WES_6_west.jpg)

Notes: WES #1 was not found. It stood tilted at a nearly 45 degree angle in November 2000 at our last visit. #1 was the farthest offshore and now #2 is the farthest – we will continue to call it #2. There was more erosion apparent here. The beach is all shell with some, but not much, mud present. Pock-marked mud surface extended 10 to 30 feet seaward from the shell beach line (fig WES-2,-3). Mud is not clumped, it is a flattened area with sparse vegetation and relatively firm. It is approximately 40-50 yards from WES #3 to ridgeline. Oscar said "lots of shell ridges" as he walked around here. (Ed. Note: In Sept 1997, the distance from WES#3 to beach ridgeline was estimated at 20 yards, in Nov 2000, estimated at 30-40 yards).

At 1:24pm CST we ate lunch here.

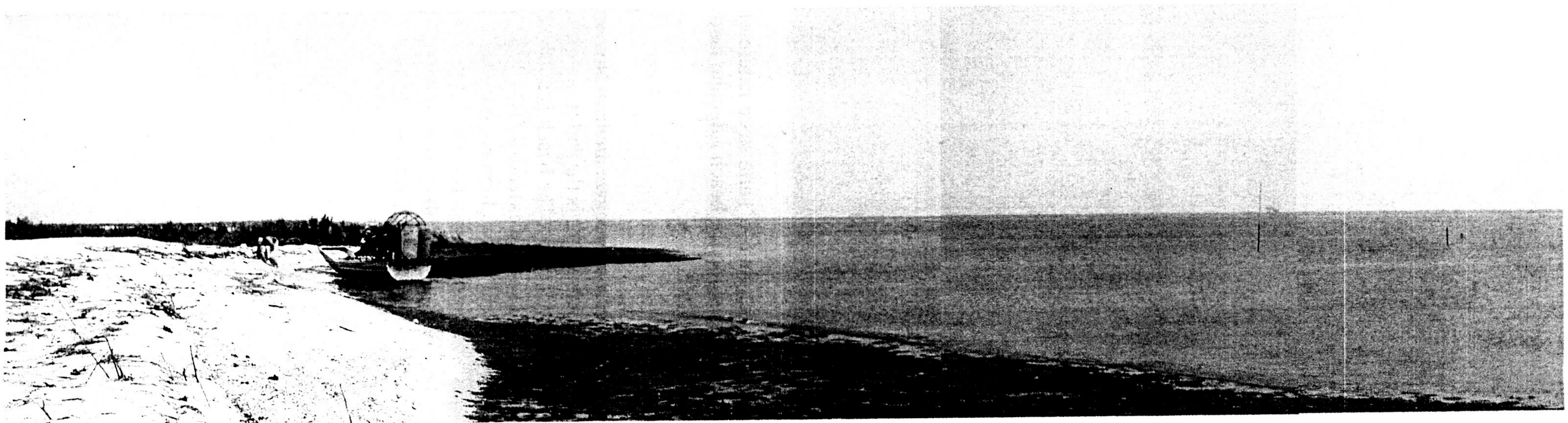


Fig WES-4. Mosaic looking east at Western Erosion Site. Two remaining sediment pipes are visible at right in the water. The tallest pipe (WES#3) is presumed to have been placed at the beach ridge line in November 1994. Today it sits some 40-50 yards seaward of the April 2002 beach ridge line. (Photos WES_7_east.jpg + 8, 9, & 10_east.jpg merged into WES_mosaic.jpg)

Pocket Beach (WS 1) 2:11pm CST

29°33.588 N 92°27.397 W

Notes: As we motored back east towards the Dewitt Canal Site we saw some interesting features along the coast that we had not seen in the September 1997 or November 2000 trips. There were "pocket beach" (like pockets on billiard table) areas where it appeared a shell beach area was carved in an arc out of the muddy coast. There was a clay wall and sand layer with some grass near shore. The reach of the pockets (front to back) was about 20 feet. It was a different plant growing here than in other areas – and the plant appeared healthier farther from shore. This area appeared to be experiencing erosion based on the cut mud banks and the pocket features..

Pictures:

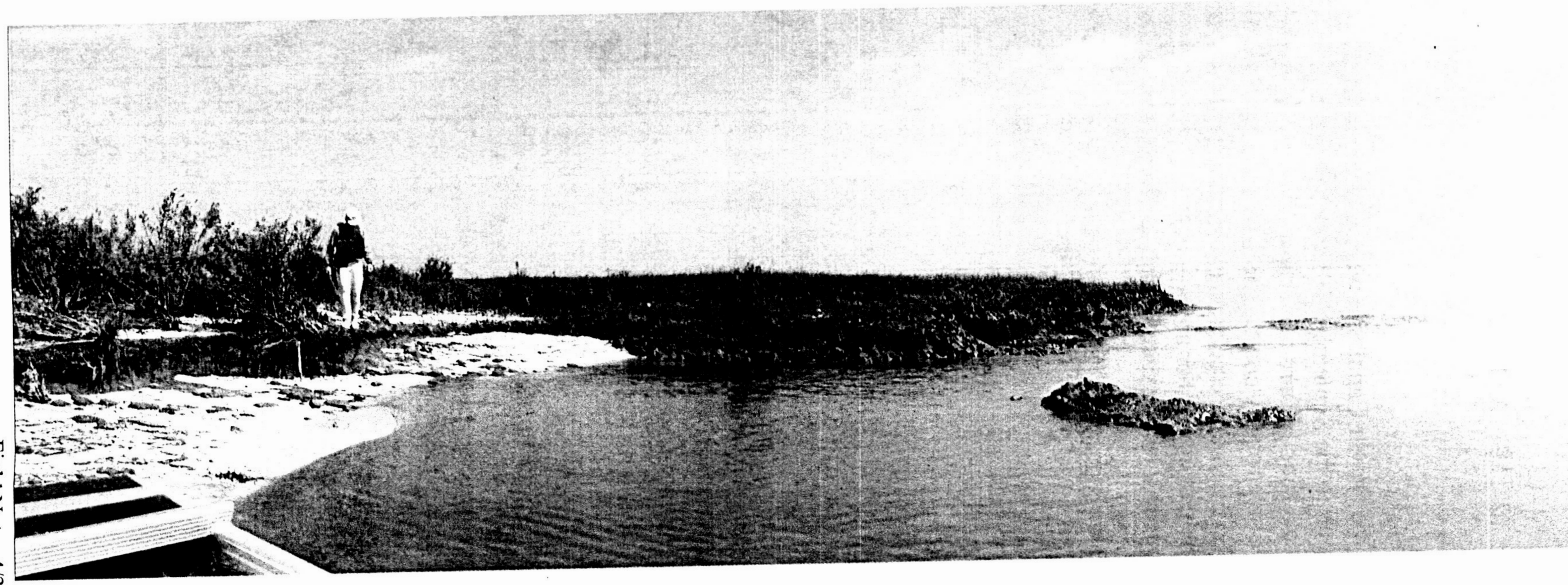


Fig WS1-1. Looking eastward from inside "pocket" beach. Photo shows shell deposition at back (left) of "pocket" and the cut mud bank eastern side of the pocket. (Photo WS1_mosaic.jpg)

Fig WS_1-2. Mat giving scale to cut mud bank on eastern side of "pocket" beach. Cut mud embankment is 16–20" high. (Photo WS1_1_ledge.jpg)

Fig WS_1-3. Looking west from inside "pocket" beach. Clumping of mud and cut mud banks suggest erosion is underway. Cut mud bank extends to left of photo out into water (similar to eastern side shown in Fig WS_1-2. Vegetation is more of a bush than a grass, suggesting a long colonization period (years?). This vegetation was also present at EES (see Fig EES-5). (Photo WS1_4_clumps.jpg)

Dewitt Canal Site (DCS) 2:18pm CST

5 pipes seen at this site, 4 in water and 1 inland. Made measurements of 4 pipes in water. In November 2000 we also saw 5 pipes here, 3 in water and 2 inland. We also saw the red and white triangle marker installed inland by Larry Rouse in 1994. There is an old fence row here which erosion is now threatening.

- Pipe #1 DCS #1 Southernmost pipe (farthest toward the Gulf)

Measurements:

From clamp down to the surface of sedimentation: 89 inches

Description: The water level was 38 inches here. The bottom surface was soft mud. This pipe was not painted in Sep. 1997. The clamp is still on the pipe.

Pictures:

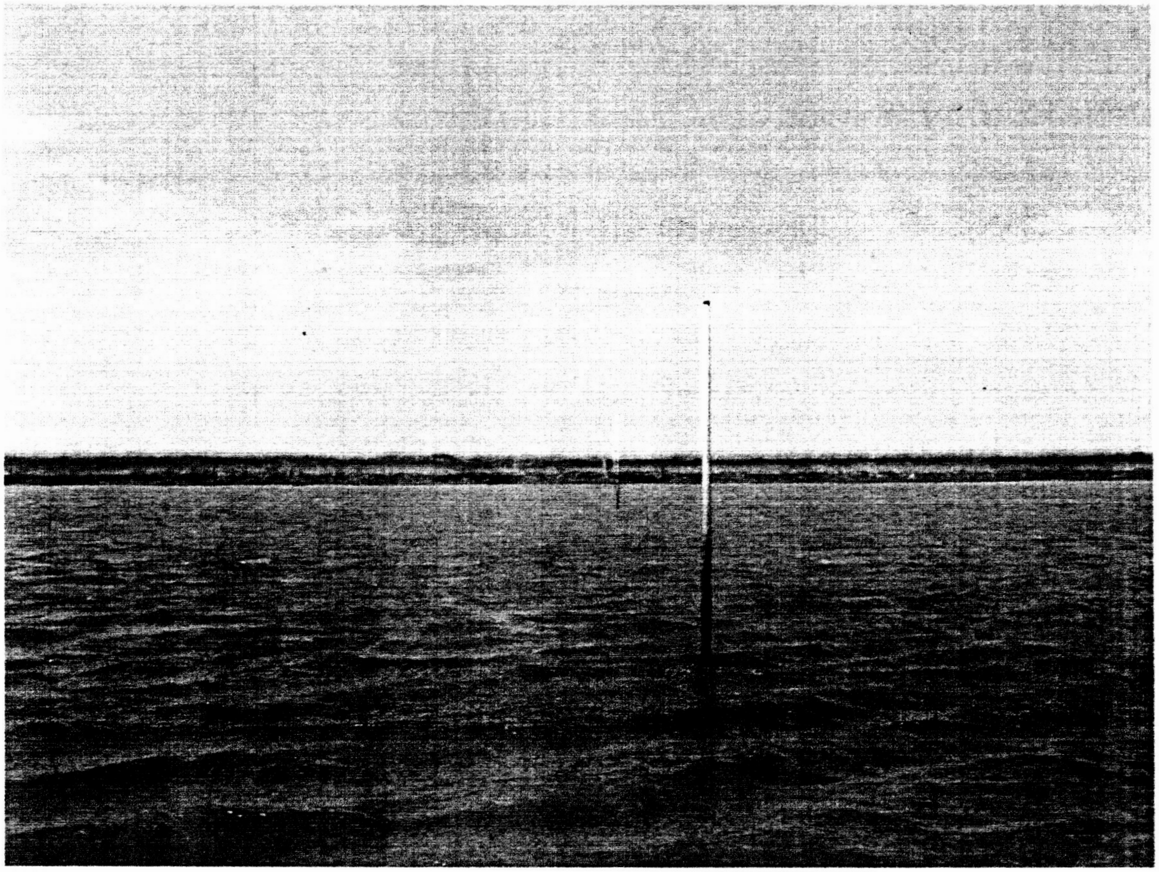


Fig DCS-1. Looking north at DCS#1. Four pipes (DCS#1-4) of 5 pipe array are visible, the 5th being inland and partially hidden by vegetation. (Photo DCS_2_Pipe.jpg)

- Pipe #2 DCS #2 2 clamps at this pipe

Measurements:

From upper clamp down to the surface of sedimentation: 74 inches
From lower clamp down to the surface of sedimentation: 28 inches

Description: Water level was 29 inches here. The bottom surface was soft mud. This pipe was not painted in Sep. 1997.

- Pipe #3 DCS #3 2 clamps

Measurements:

From upper clamp down to the surface of sedimentation: 88 inches
From lower clamp down to the surface of sedimentation: 48 inches

Description: The water level was 29 inches here. The bottom surface was soft mud. The red tape placed on this pipe in 1997 was still present at this time.

- Pipe #4 DCS #4 2 clamps

29°33.375 N 92°26.459 W

Measurements:

From upper clamp down to the surface of sedimentation: 73 inches
From lower clamp down to the surface of sedimentation: 29 inches

Description: This pipe was not painted in Sep. 1997. Water level was 13 inches here. This pipe is slightly bent. This pipe is approximately 7 feet seaward of the vegetation line. In November 2000 this pipe was on vegetated land, but now is in water (i.e. erosion has removed the land surface that once existed.

Pictures:

Fig DCS-2. Looking southward from land towards DCS#4,3,2,1, resp. Note DCS#4 (foreground) is in water. In November, 2000 DCS#4 was up on the land/vegetation platform. Seaward-most post of old fence row just visible at right edge of photo. (Photo DCS_9_Pipe.jpg)

Fig DCS-3. Oscar making measurements at DCS#4. Note eroded mud bank of background and position of fence row post to ongoing erosion. (Photo DCS_3_pipe.jpg)

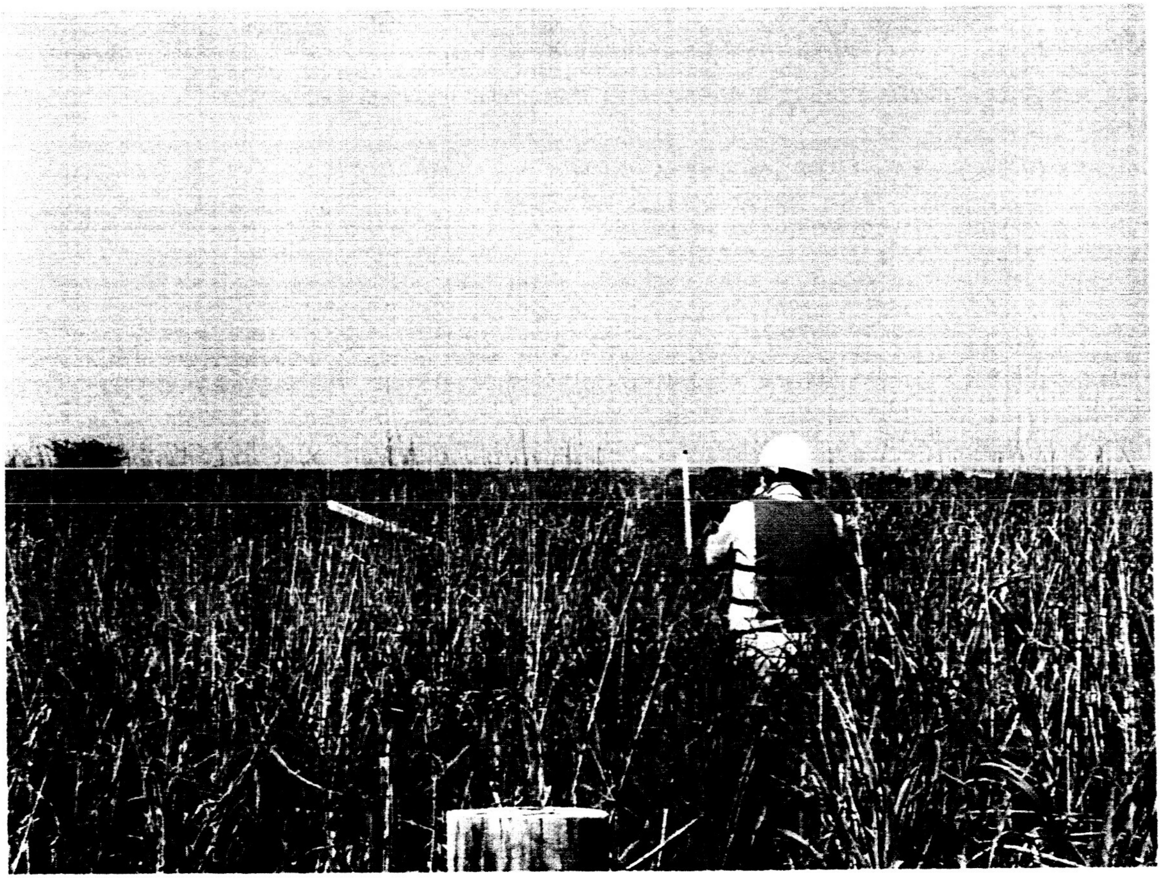


Fig DCS-4. Oscar photographing pipe DCS#5 in its inland position. The post in the foreground is the landward most (3^{rd} of three) post of the old fence row at DeWitt Canal. Grasses are the predominant vegetation at this site. (Photo DCS_8_pipe.jpg)

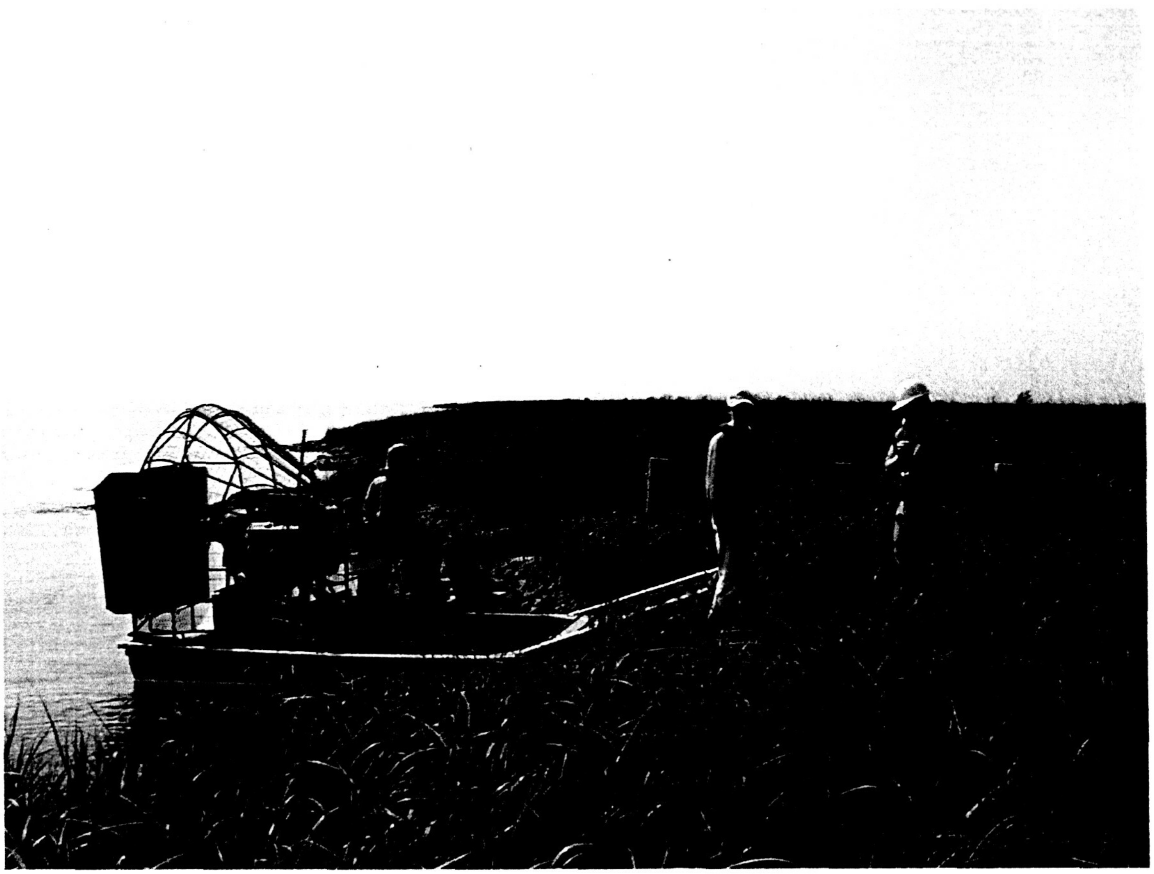


Fig DCS-5. Looking west at three posts of old fence row at DeWitt Canal. The southernmost (leftmost) post is less than 5' from the mud embankment and may soon be undercut. DCS#4 visible behind airboat. (Photo DCS_11_west.jpg)

Fig DCS-6. Mat measuring the 30" high embankment at DeWitt Canal. This site had similar sized embankments in November 2000. (Photo DCS_10_ledge.jpg)

Fig DCS-7. Looking east from DeWitt Canal Site. Embankment continues eastward to mud flats. (Photo DCS_13_east.jpg)

Notes: This site seems to have eroded quite a bit since the November 2000 trip. Pipe #4 is no longer on land and the old fence here is just a few feet from the shoreline. In November 2000 there was a large (3-4' diameter) log here oriented N-S next to the fence which is no longer here. The grass was colonized all the way to the shoreline. We could see the triangle that Larry Rouse put here about 200m north of the escarpment.

<u>New Grass Colonization (WS 2)</u> 2:46pm CST

Notes: We stopped at this spot because the coastline seems to be transitioning from an erosional setting to the west to a depositional setting to the east. There was a mud flat extending approximately 40 yards seaward of the old, established vegetation line. Short, 6 inch, new vegetation was growing on the mud flat, extending about 20-30 yards seaward of the old vegetation line.

29°33.000 N 92°24.986 W

Pictures:

Fig WS2-1. Established (background) and new (foreground) vegetation between DCS and ECW pipe array sites. This region appears to be in the transition zone between ongoing erosion at DeWitt Canal to the west and static or prograding conditions at Exxon Canal West to the east. Note the structure in the mud in the foreground is suggestive of recent erosion activity of mud deposits while the new vegetation is a further colonization of this mud flat. However, there are no cut mud banks in this region, suggesting that erosion is not the dominant force. Westward the mud flats become less extensive and eventually give way to cut mud embankments. Eastward lie fluid mud flats. (Photo WS2_1_vege.jpg)

<u>Exxon Canal West Site (ECW)</u> 2:55pm CST

There may have been 7 pipes here originally but today we only saw 4 (3 in water, 1 inland, presumed #5). In November 2000 we saw 5, one of which (#4) only extended about 18" above the fluid mud line (probably broken off). On this trip we estimated #4 must be slightly (5'?) inland, obscured by tall grass (it wasn't inland in November 2000). The pipes are arrayed in a straight line extending seaward from a fenceline, which is used for holding grazing cattle. North of the northernmost pipe is an orange/red (reflective?) triangle marker to help locate the site from the sea. Larry Rouse remembers putting it here and we did see it well inland on this day. On this day we measured the southernmost 3 pipes.

- Pipe #1 ECW #1 Southernmost pipe at ECW – farthest from shore.

Measurements:

From clamp down to the surface of sedimentation: 61 inches

Description: Soft mud bottom here. Water level was 16 inches. There was one clamp and the red tape was still on it.

Pictures:

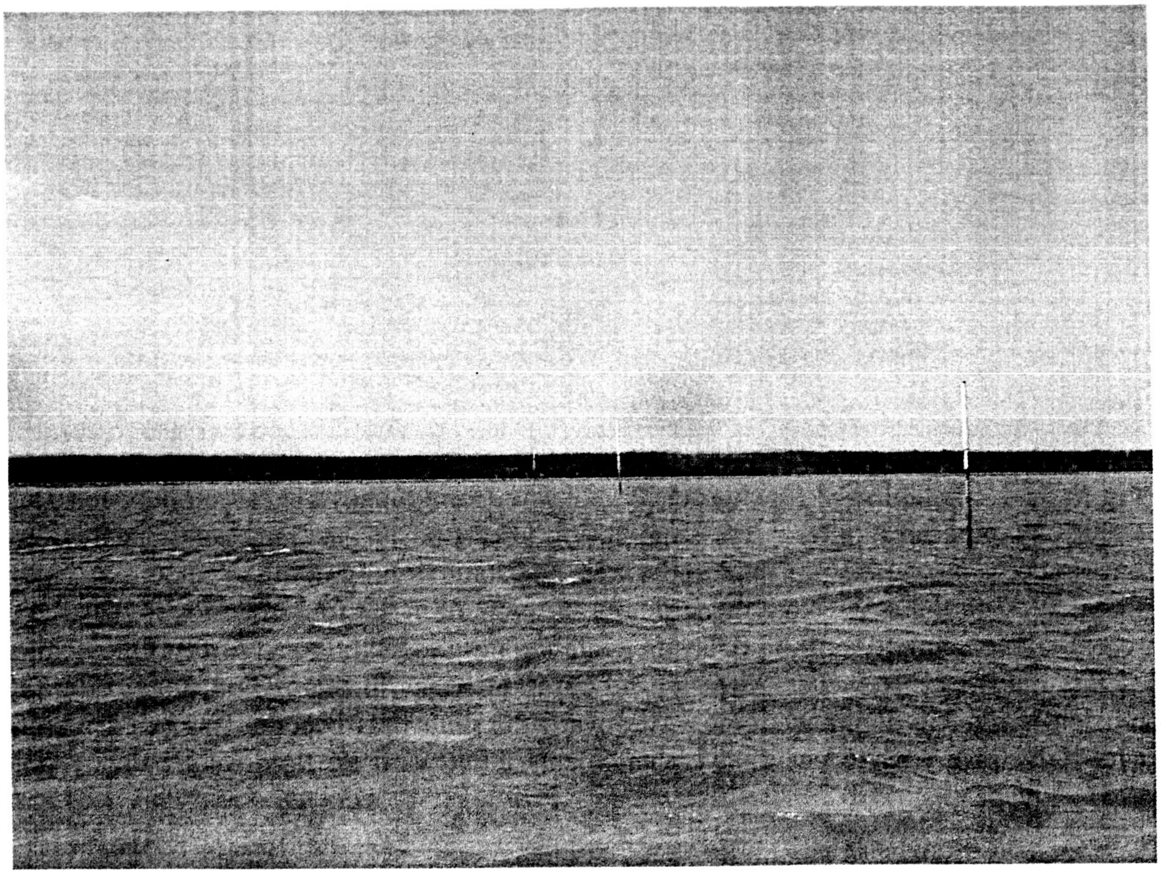


Fig ECW-1. Array of pipes at Exxon Canal West site. Three pipes are visible (#1, 2, 3) in the water. Nov 1994 trip report suggests these pipes are spaced 30 m apart. A stub of a fourth pipe (#4) is likely just inland in vegetation. A fifth pipe (#5) was later observed inland. (Photo ECW_1_pipe.jpg)

- Pipe #2 ECW #2 Second pipe shoreward from the Gulf

Measurements:

From clamp down to the surface of sedimentation: 60 inches

Description: Water level was 11 inches here. Very fluid mud bottom. This pipe also has its clamp and red tape still. The paint markings on this pipe from 1997 are still recognizable and it could be seen that this was marked as pipe #2.

Pictures:

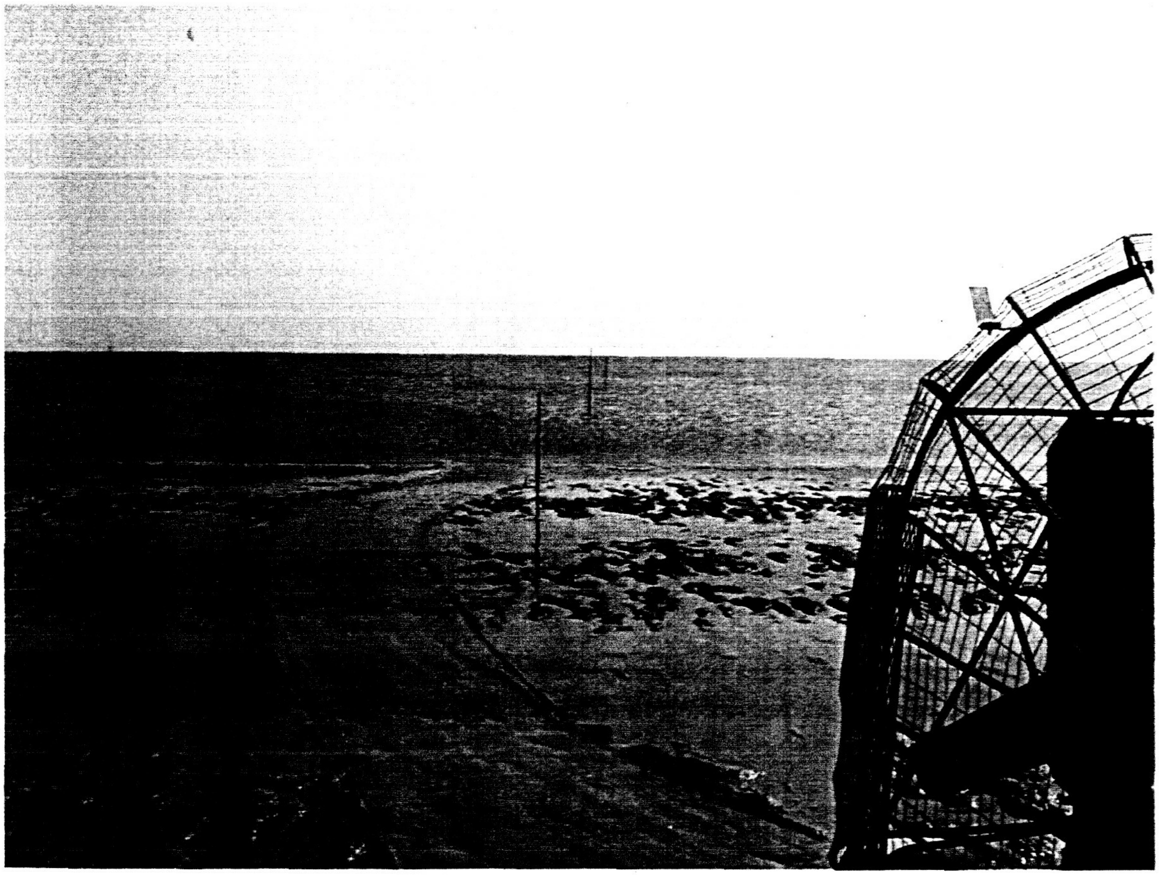


Fig ECW-2. Looking south at ECW#3, 2, 1 (resp.) from about vegetation line. Pipe #1 and #2 were in shallow water (< 1') while ECW#3 was on fluid mud surface in standing water. (Photo ECW_8_south.jpg)

- Pipe #3 ECW #3 Third pipe shoreward from the Gulf

Measurements:

From clamp down to the surface of sedimentation: 50 inches

Description: Water level was 3 inches here. Clumpy looking mud-flat here, approximately 25 yards to vegetation line. The clamp was still on the pipe along with the red tape.

Pictures:

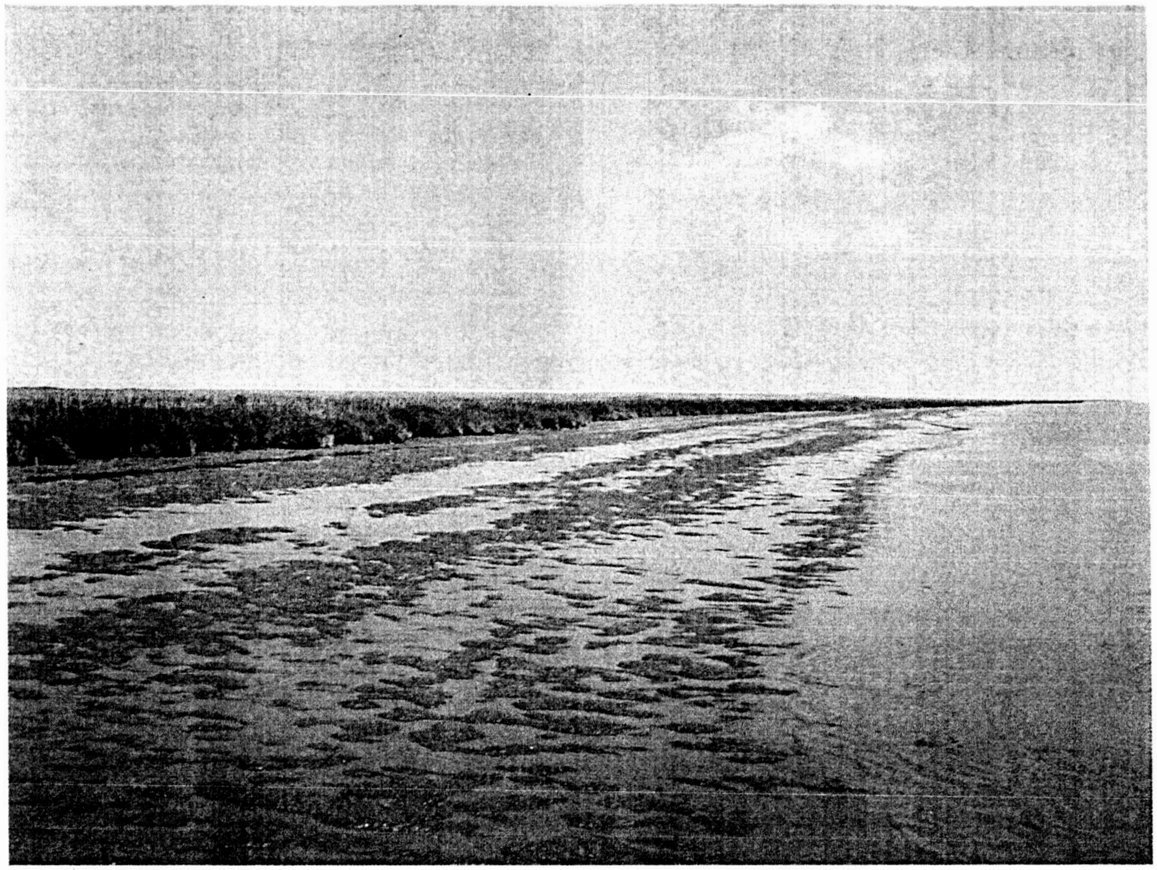


Fig ECW-3. Looking east from position of pipe ECW#3. Mud flat extends about 30-40 yards, slightly overrunning vegetation line. (Photo ECW_5_east.jpg)

Fig ECW-4. Looking west from ECW#3. Choppy nature of mud suggestive of pathways created by water flowing in and out over mud flats(????). (Photo ECW_6_west.jpg)

- Pipe #4 ECW #4 Fourth pipe shoreward from the Gulf.

Description: This pipe may still be here, but we could not see it. During the November 2000 trip we found this pipe was sheared off at a joint low to the ground – about 18" above the mud flat – and the clamp was gone. In November 2000 this pipe was about 2-3m seaward of the vegetation line. Currently, the pipe appears to be on land and hidden by tall grass. Estimating the mid-point between pipes #5 (observed inland) and #3 (in mud flat) would put pipe #4 about 10 feet into the vegetation. We took a way point at the vegetation line.

29°32.647 N 92°23.410 W

Pictures:

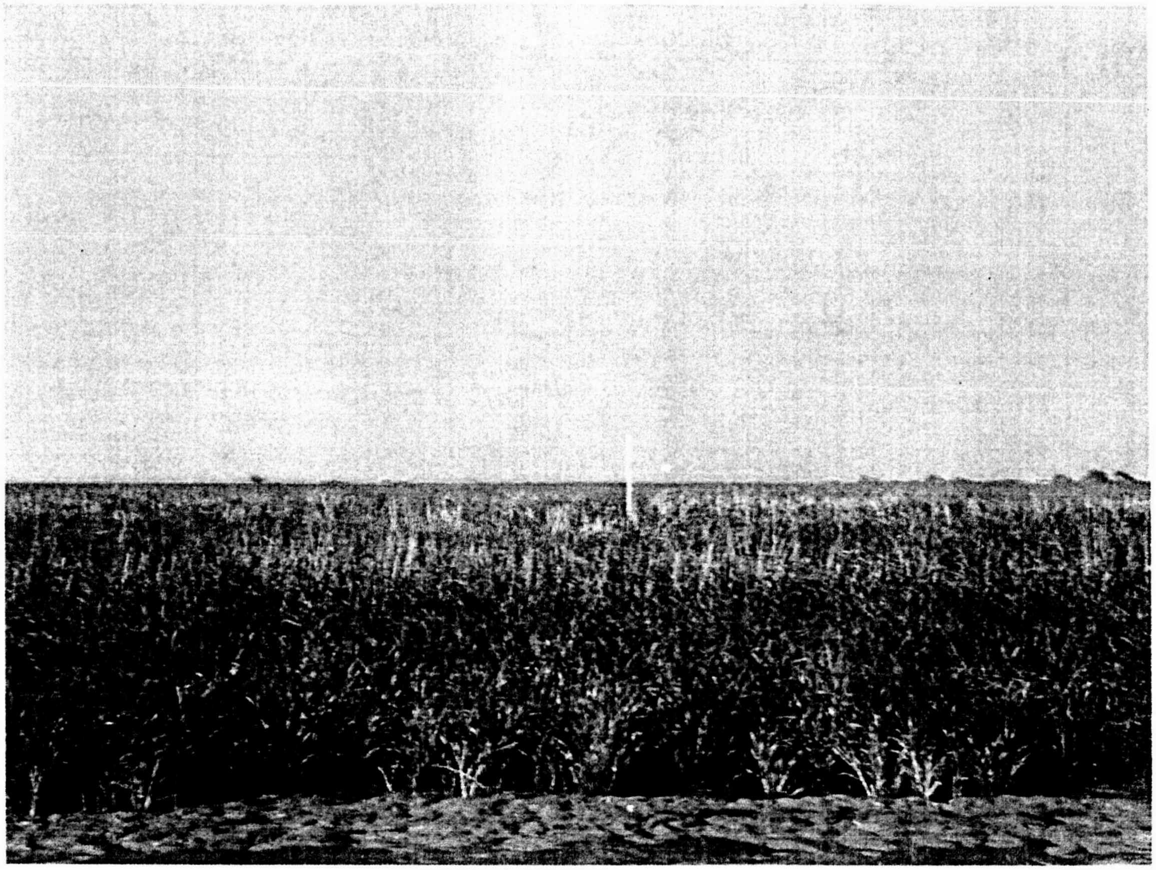


Fig ECW-5. Looking south from mud flat near vegetation line. Pipe ECW#5 is visible in center. No evidence was found of ECW#4, though it could be hidden by vegetation. Fluid mud extends up to vegetation line, in part overrunning plants at front. Pipe #5 is roughly 35 yards into vegetation. (Photo ECW_4_pipe5.jpg)

- Pipe #5 ECW #5 Fifth pipe shoreward from the Gulf.

Description: This pipe is too deep into thick vegetation for us to reach with the airboat or by foot but we can see it.

Notes: We rode the airboat about 25 yards up the mud flat right to the vegetation line. The grass here was a rich, healthy green color about 3 feet high. We realized at this point that the water level was coming up. After 5 minutes we looked back and our airboat track in the mud was already mostly filled with water.

Solitary Pipe Site (SPS) 3:21pm CST

- Pipe #1 SPS #1 Only pipe at site – 2 clamps, still painted.

29°32.278 N 92°21.565 W

Measurements (2 clamps):

From lower clamp to the surface of sedimentation: 29 inches
From upper clamp to the surface of sedimentation: 65 inches

Description: The water level was 10 inches here. The bottom was soft mud. The vegetation line was about 30-35 yards from the pipe. Up to here there was not much of a mud flat evident. There was a 6 inch ledge at the vegetation line. Despite northerly winds and small capillary waves moving south, there was an occasional solitary wave that come onshore – perhaps due to the rising tide. Oscar wanted to see some wave action.

Pictures:

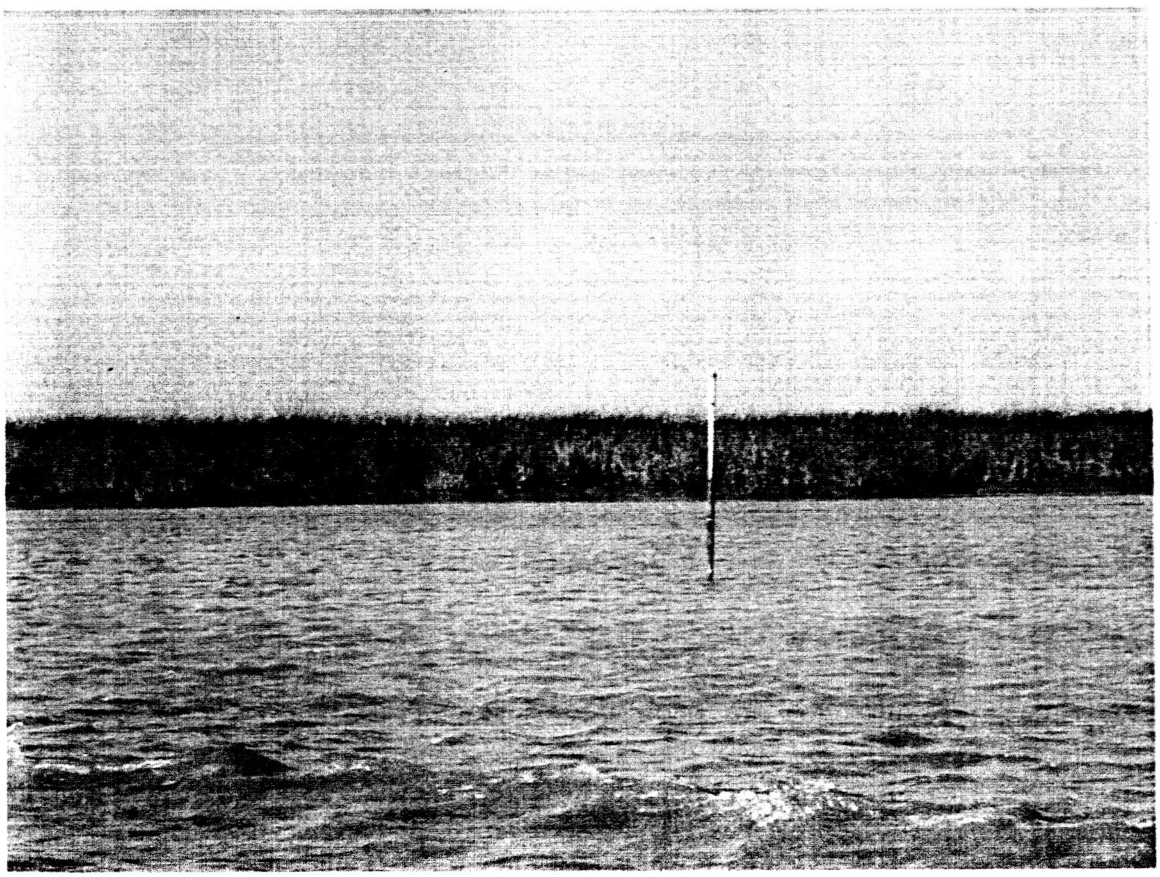


Fig SPS-1. Solitary pipe site. There is a small (6") embankment at the vegetation line. In November 2000, this site had fluid mud right up into vegetation. The distance of 30-35 yards to the vegetation line is very similar reported in the November 2000 trip report. (Photo SPS_1_pipe.jpg)

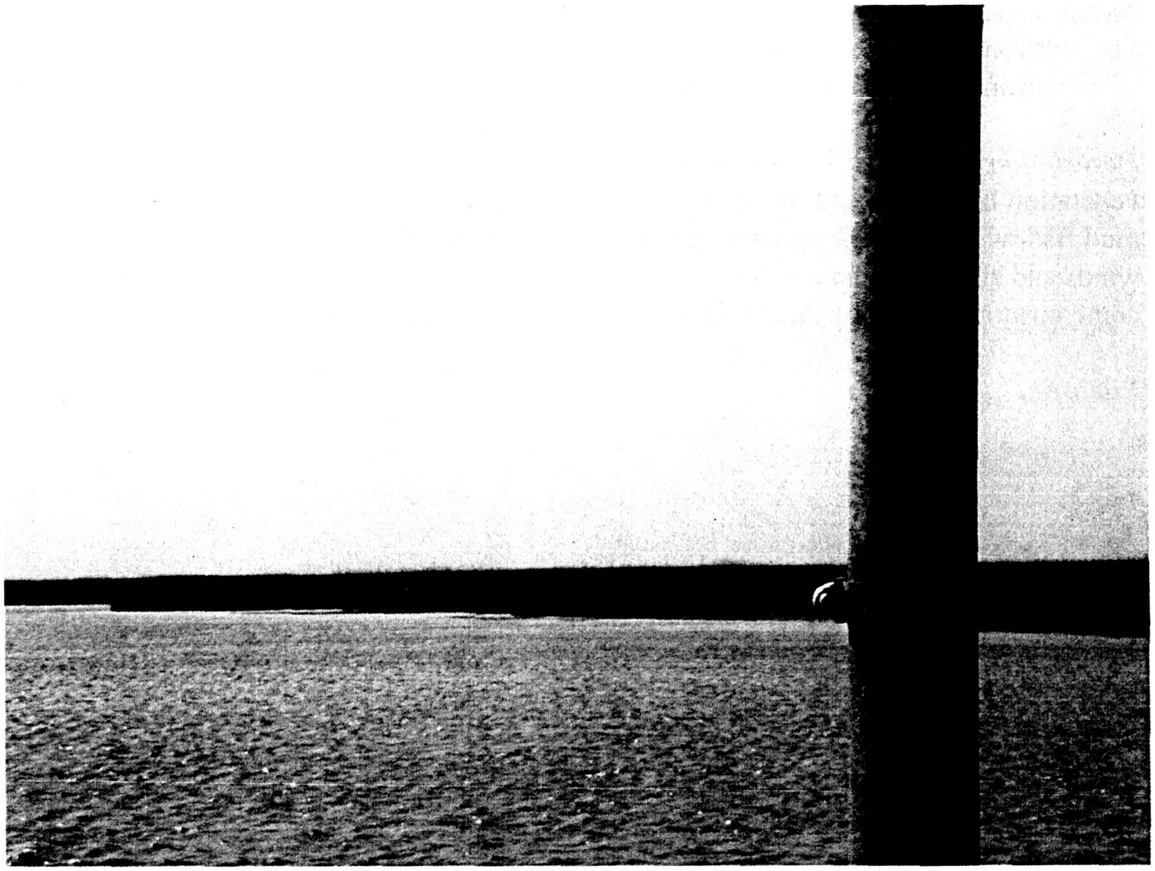


Fig SPS-2. Looking west from SPS pipe. (Photo SPS_4_west.jpg).

Wave Observations 3:28pm CST

29°32.272 N 92°21.427 W

We stopped here in shallow (<6") water over fluid mud surface because it looked like a good place to observe the small waves near the strand line. Oscar wanted to see if sediment transport was evident in terms of how clear the water looked retreating from the coast, as opposed to approaching. There were small, perhaps 2-3 inch, solitary waves coming on shore here. Capillary waves were going off shore since we still had light northerly winds. The most interesting observation was that the turbidity didn't really travel with the waves, it was observed moving more alongshore, in a sort of drift through which the waves ran towards shore. The turbidity would move east for a while (< 10 seconds), then start moving west again with no net transport evident and there was not a strong current. We could see small scale eddies and other features in the suspended sediment as we watched water drain away from the coast between solitary incoming waves.

Triple Canal Site (TCS) 3:41pm CST

In September 1997 we could only see 2 pipes here. In November 2000 we found those 2 pipes but also could see a third approximately 200 yards or more north of TCS#2. This trip we only saw the 2 pipes.

- Pipe #1 TCS #1 Southernmost pipe at Triple Canal Site

Measurements:

From clamp down to the surface of sedimentation: 85 inches

Description: Water depth was about 10 inches here. The pipe still had red tape near the 1 clamp. We could see 1 red painted line between 2 blue ones, which would mark this as pipe #1 from 1997. It was approximately 7 boat lengths, or 112 feet, to TCS#2.

Pictures:

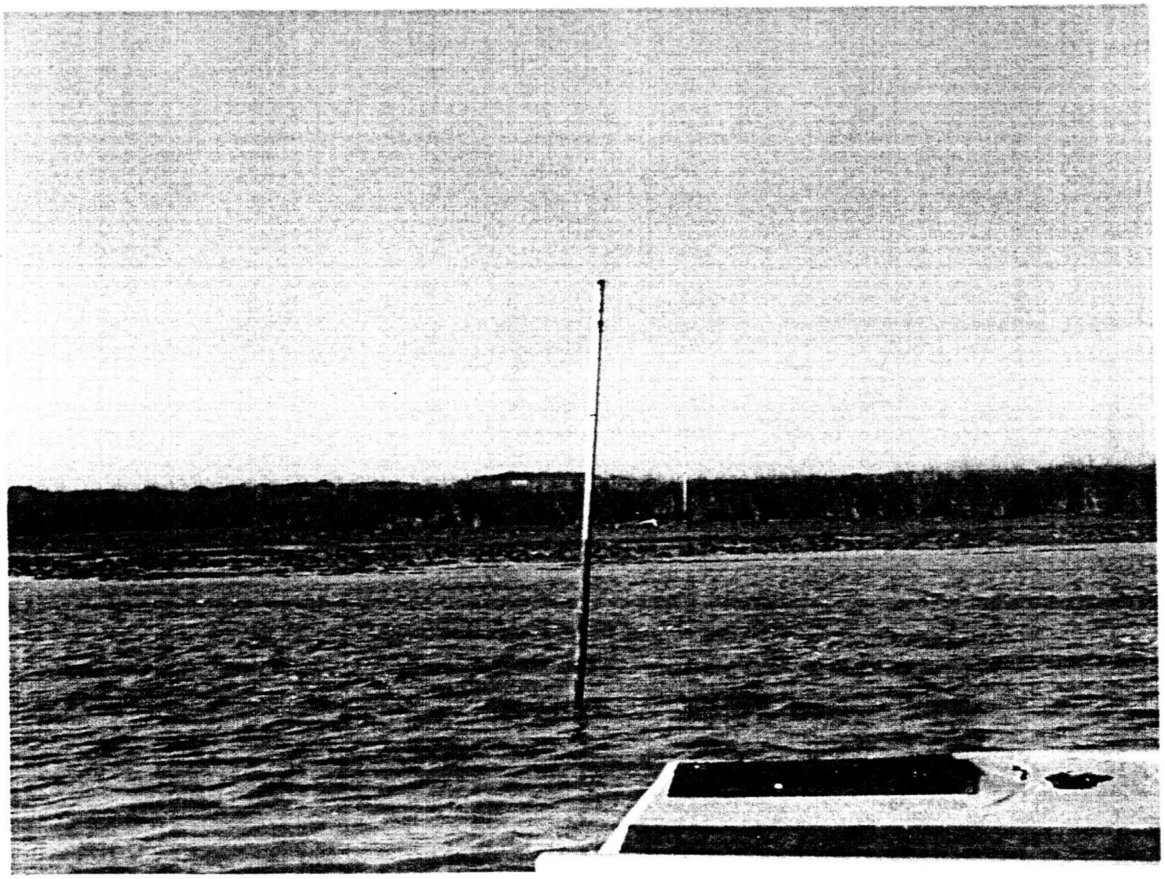


Fig TCS-1. Looking north at two pipes, TCS#1 (foreground) and TCS#2, observed at Triple Canal Site. A mud flat of about 25 yards is seen in the background. (Photo TCS_2_pipe.jpg).

- Pipe # 2 TCS #2 Second pipe shoreward from the Gulf.

29°31.925 N 92°20.041 W

Measurements (2 clamps):

From the lower clamp down to the surface of sedimentation: 12 inches
From the upper clamp down to the surface of sedimentation: 59 inches

Description: Soft, fluid mud surface here. The pipe is about 6 yards from the vegetation line and we were on a mud flat. The red/orange paint marked this pipe as #2. The lower clamp here was rusted badly.

Pictures:

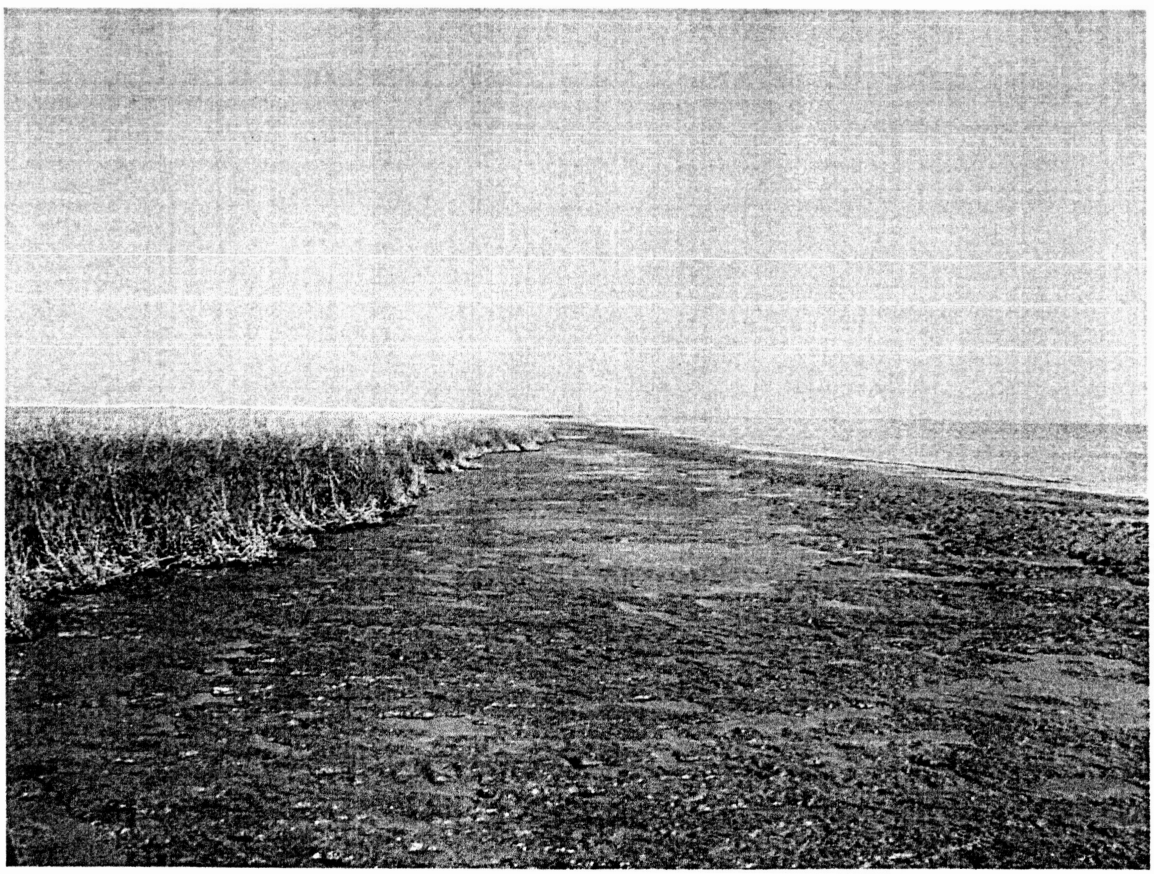


Fig TCS-2. Looking east from TCS#2. 25 yard mud flat extends up to vegetation line. (Photo TCS_3_east.jpg)

Fig TCS-3. Looking west from TCS#2 at mud flat. This mud flat has similar patterns to that observed at ECW. (Photo TCS_5_west.jpg)

Notes: There was approximately 25 yards of exposed fluid mud at this site. The grass was about 3 feet high. We did not look for the pipe we saw here in November 2000 which was much farther inland. There is a large advertisement sign many hundred yards inland that our boat driver in November 2000, Dale, said was placed at the shoreline many years ago. We left this site and headed east to Freshwater Bayou Outlet and to the dock.

Dock 4:30pm CST

Notes: Boat launch site (i.e. Dock) was the same as in Sept. 1997 and November 2000. Here we unloaded our equipment and supplies from the boat and packed up Oscar's Nissan Pathfinder. We were fortunate to have no mosquitoes during this excursion. On the way back out we were slowed significantly by a herd of cattle being tended to by about a dozen cowboys on horseback. We followed Robert, hauling his airboat, through the herd – amazed at the size of some of the cows, which were looking us eye to eye in the Pathfinder. At about 5:00pm CST we visited a man named Simmes Lynch (not sure about the spelling) who lives nearby in Pecan Island. He owns Acadiana Marina and seems very knowledgeable about the geomorphology of the area. We stopped in Breaux Bridge for dinner at Mulate's, "The Original Cajun Restaurant."

Pictures:

Fig Get-along-little-doggy. Many challenges must be met to return to civilization on a trip to Bayou country. (Photo Cattle2.jpg)

Notes:
ES 1 = Easter Site 1, East of Eastern Erosion Site
EES = Eastern Erosion Site
WES = Western Erosion Site
WS 1 = Western Site 1, Pocket Beach
DCS = Dewitt Canal Site
WS 2 = New Grass Colonization
ECW = Exxon Canal West
SPS = Solitary Pipe Site
TCS = Triple Canal Site

Sediment Burial Pipe Measurements at a Glance
April 3, 2002

Site	Measurement Description	Measurement Inches	Measurement cm
WES #1	Water Level to SoS	-99	-99
WES #2	Clamp to SoS	83	210.8
WES #3	Clamp to SoS	98	248.9
DCS #1	Clamp to SoS	89	226.1
DCS #2	Upper Clamp to SoS	74	188.0
DCS #3	Upper Clamp to SoS	88	223.5
DCS #4	Upper Clamp to SoS	73	185.4
ECW #1	Clamp to SoS	61	154.9
ECW #2	Clamp to SoS	60	152.4
ECW #3	Clamp to SoS	50	127.0
ECW #4	Top of pipe to SoS	-99	-99
SPS #1	Upper Clamp to SoS	65	165.1
TCS #1	Clamp to SoS	85	216.0
TCS #2	Upper Clamp to SoS	59	149.9
EES #1	Clamp to SoS	71	180.3

SoS – Surface of Sedimentation

Waypoint List

Waypoint #	Latitude (North)	Longitude (West)	Note
1	29°32.206	92°15.931	Eastern Site 1
2	29°32.039	92°17.042	EES #1
3	29°33.918	92°29.686	WES #3
4	29°33.588	92°27.397	Pocket Beach (WS 1)
5	29°33.375	92°26.459	DCS #4
6	29°33.000	92°24.986	New Grass Colonization (WS 2)
7	29°33.647	92°23.410	ECW #5
8	29°32.278	92°21.565	SPS
9	29°32.272	92°21.427	Wave Observations
10	29°31.925	92°20.041	TCS #2