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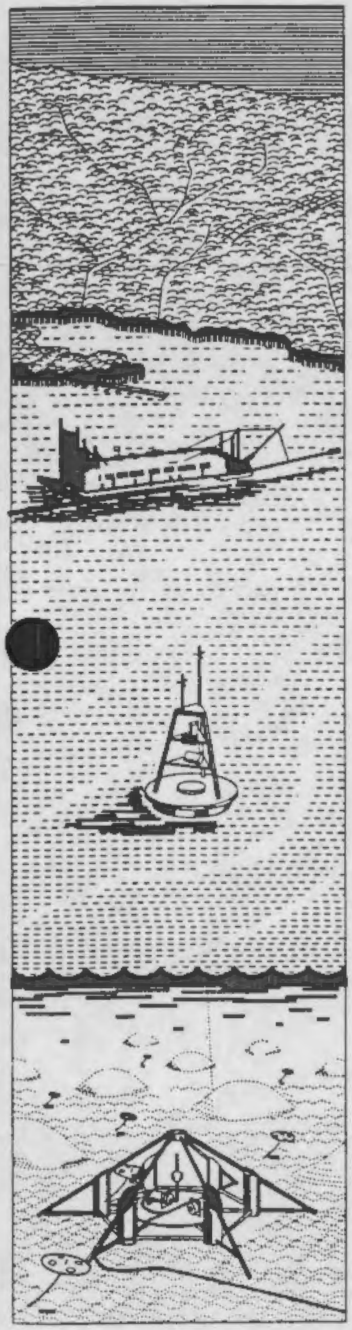

DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-95-6

IMPACT OF NEAR-BOTTOM CURRENTS ON DREDGED MATERIAL MOUNDS NEAR MOBILE BAY

by

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Final Report

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Prepared for DEPARTMENT OF THE ARMY
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Washington, DC 20314-1000

Under Work Unit No. 32466

The Dredging Research Program (DRP) is a seven-year program of the US Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Waters
- Area 2 - Material Properties Related to Navigation and Dredging
- Area 3 - Dredge Plant Equipment and Systems Processes
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
- Area 5 - Management of Dredging Projects

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US Army Corps of Engineers
Waterways Experiment Station

Dredging Research Program Report Summary

Impact of Near-Bottom Currents on Marine Dredged Material Disposal Mounds (TR DRP-95-6)

ISSUE: The Corps of Engineers is responsible for managing hundreds of millions of cubic meters of sediment that annually accumulate in the Nation's waterways. After dredging the material to maintain navigability, much of it is placed offshore in open water. In 1987, the Corps initiated a National Berm Demonstration Program (NBDP) off the Alabama coast. The purpose of NBDP was to better understand the long-term fate of dredged material and improve ancillary benefits possible with its correct placement. The long-term fate of mounded material, its environmental impacts, and results from environmental monitoring at the NBDP site have been documented in a series of reports. This report uses NBDP wave and bottom current measurements to investigate fundamental ways that natural forces can disperse material placed on the seafloor.

RESEARCH: The Corps' Dredging Research Program (DRP) and the U.S. Army Engineer District, Mobile (CESAM) have continued monitoring dredged material deposits (berms) and environmental factors at the NBDP site. Repeated bathymetric surveys have documented gradual loss of material from the crests of two shallower sand berms. For 4 years, these berms remained as distinct forms, but migrated persistently north northwest, toward the coast. Surface wave buoys and bottom-mounted gauges recorded wave and current forces over this 4-year period. Instrument stations were maintained offshore, just seaward, and on top of the berms. This is the first report using measured waves and currents to investigate how large berms move.

SUMMARY: Several fundamental berm movement mechanisms are proposed and evaluated against the Alabama field measurements. The collected data are sufficient to reject some concepts of sediment movement that were previously relied on. The data suggest that two other proposed mechanisms are important. These findings help focus work on new mechanisms to better understand and predict long-term, large-scale sediment movement in open coastal environments.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. The report can be borrowed from the WES Library or purchased from the National Technical Information Service (NTIS). To purchase a copy, call NTIS at (703) 487-4650.

About the Authors: Dr. Scott L. Douglass is a professor in the Civil Engineering Department, University of South Alabama, Mobile. During most of the period of report preparation, Dr. Donald T. Resio was a professor in the Department of Oceanography, Ocean Engineering, and Environmental Sciences at Florida Institute of Technology in Melbourne, FL. Dr. Resio has since joined the U.S. Army Engineer Waterways Experiment Station as the senior scientist at the Coastal Engineering Research Center (CERC), Vicksburg. Mr. Edward B. Hands is a research physical scientist in the Coastal Structures and Evaluation Branch, CERC. Mr. Hands' number is (601) 634-2088; for further information about the Dredging Research Program (DRP), contact Mr. E. Clark McNair, Jr., Manager, DRP, at (601) 634-2070.

Dredging Research Program

Technical Report DRP-95-6
July 1995

Impact of Near-Bottom Currents on Dredged Material Mounds Near Mobile Bay

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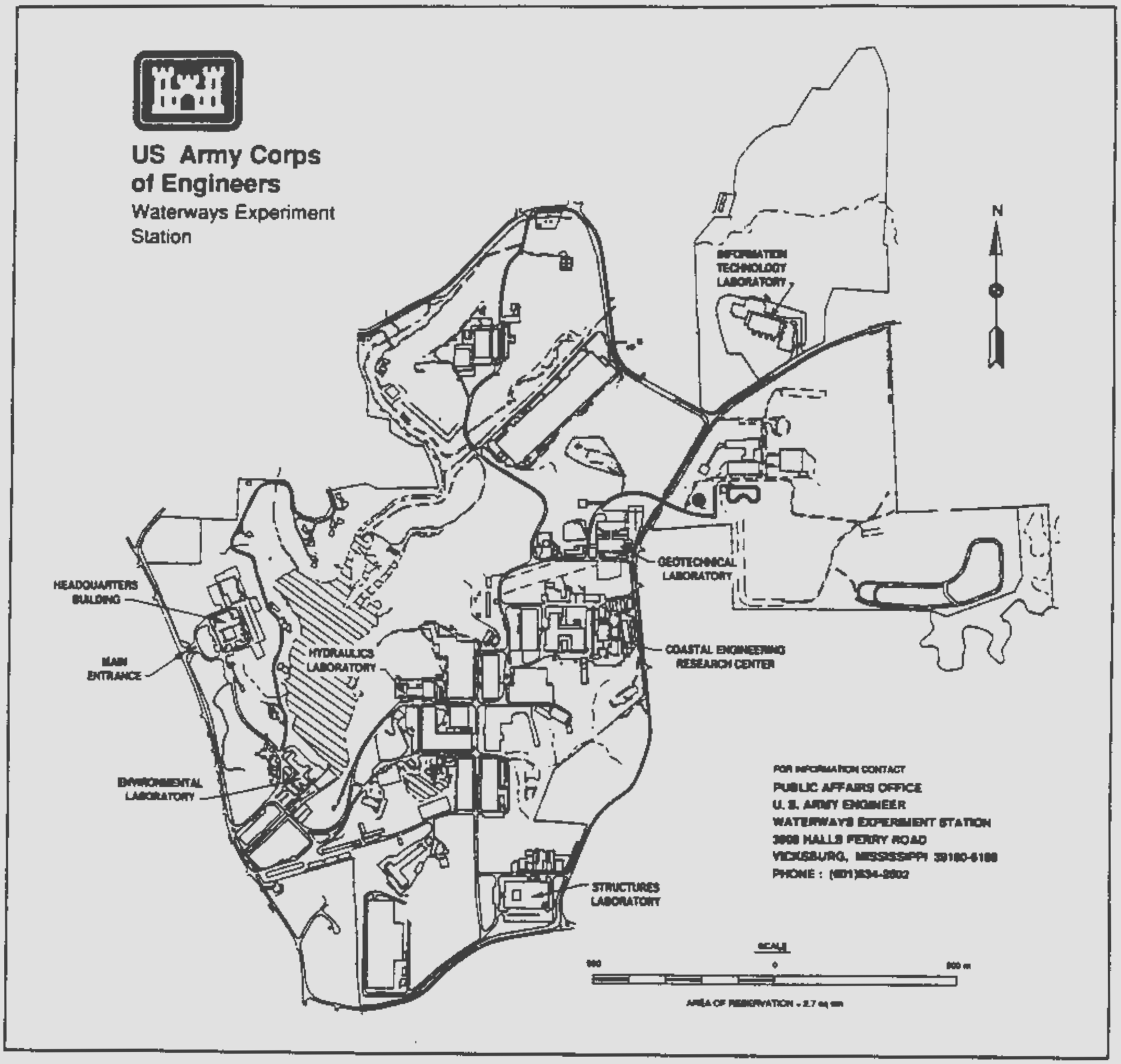

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Contents

List of Figures

List of Tables

Preface

The work described herein was authorized as part of the Dredging Research Program (DRP) by Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Work Unit 32467, "Field Techniques and Data Analysis to Assess Open Water Disposal Deposits." HQUSACE Chief Advisor for the DRP was Mr. Robert Campbell. Mr. John H. Lockhart was HQUSACE Advisor for DRP Technical Area 1 (TA1), which included Work Unit 32467. Additional HQUSACE DRP Technical Monitors were Messrs. Gerald Greener, Barry W. Holliday, M. K. Miles, John Sanda, and David B. Mathis. Mr. E. Clark McNair, Jr., Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station (WES), was DRP Program Manager. Dr. Lyndell Z. Hales (CERC) was the DRP Assistant Program Manager.

Drs. Nicholas C. Kraus, Senior Scientist, CERC, and Billy H. Johnson, WES Hydraulics Laboratory, were Technical Managers of TA1. Work was conducted under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively. Mr. Edward B. Hands, Engineering Development Division (EDD), CERC, was the contracting officer's representative and the Principal Investigator for Work Unit 32467. Mr. Hands worked under the direct supervision of Mr. Thomas W. Richardson, Chief, EDD; Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch (CDS); and Dr. Yen-hsi Chu, Engineering Applications Unit. The final report was written by Dr. Scott L. Douglass, University of South Alabama, Dr. Donald T. Resio, Florida Institute of Technology, and Mr. Edward B. Hands, CERC. Mr. Douglas M. Pirie, U.S. Army Engineer Division, South Pacific, provided helpful comments and suggestions on report modifications.

Field measurements were taken by WES personnel with assistance from the WES, the U.S. Army Engineer District, Mobile (CESAM), the Dauphin Island Fishery Research Branch of the U.S. Public Health Service, the U.S. Coast Guard (USCG) District, Mobile; the National Data Buoy Center (NDBC) of the National Oceanic and Atmospheric Administration (NOAA); and Dauphin Island commercial fishermen Messrs. Clinton Collier and Billy Sprinkle. Survey contractors were Pyburn & Odom, Inc., Baton Rouge, LA; Browning, Inc., Jackson, MS; and John E. Chance and Associates, Inc., Lafayette, LA. Mr. James W. Reaves, CESAM, was contract monitor for surveys.

Special thanks are extended to Mr. William L. Murden, retired Chief of the former Corps Dredging Division. His push for innovative management of dredged material was critical in initiating the National Berm Demonstration Program.

At the time of publication of this report, COL Bruce K. Howard, EN, was Commander of WES. Dr. Robert W. Whalin was Director.

For further information on this report or on the DRP, please contact Mr. McNair, Program Manager, at (601) 634-2070, or Mr. Hands, Principal Investigator, at (601) 634-2088.

Summary

This study analyzes measurements of waves and currents off the Alabama coast to assess what mechanisms are responsible for long-term landward movement of large submerged sand bodies. Wave gauges and near-bottom electromagnetic current meters monitored flow conditions around berms that have been persistently migrating landward. Horizontal components of flow were sampled at 1-sec intervals over 17-min bursts repeated either four or six times per day. Instruments operated in this mode for months; they were then replaced or moved to a new station. Seven stations were monitored over a period of 4 years. Three of these stations were a few miles offshore, two were just seaward of the berms, and two were on top of these migrating sand bodies.

A simple conceptual model guides testing of sediment transport mechanisms. This conceptual model includes five fundamental transport possibilities. Each is evaluated against collected data. For simplicity, the possible mechanisms are referred to as:

a. Dominant advection by mean currents.

b. Net migration due to nonlinearities of wave oscillations.

c. Other aspects in the temporal organization of oscillations such as lags among acceleration, speed, and boundary layer development on scales of wave periods.

d. Strong correlation of entrainment and advection on the scales of storms.

e. Feedback between the berm and flow field that could alter mean currents, nonlinearities, or temporal organization of wave oscillations.

At several sites around the United States dredged material placement has been relocated landward toward the breaker zone to economically conserve sand within the littoral system. The Alabama berms, like other successful feeder deposits, are migrating landward on the scale of months to years. At this test site, steady currents were almost always small and had no constant or even strongly dominant direction of flow near the berms. Because measurements extended over such a long time during which the

berms maintained a simple pattern of migration, the first and fourth potential mechanisms (advection and entrainment-advection correlations) can definitely be rejected at this site. The data fail to provide any clear support for the third mechanism. The fifth mechanism is addressed by only a small percent of the measurements because so few were made at the same time on and in front of the berms. The few simultaneous measurements show only small differences in currents that do not lend credence to the fifth mechanism. The second mechanism, nonlinearities, is clearly seen throughout the data and increases with wave intensity. Thus, faster peak speed under wave crests appears to be the dominant mechanism moving Alabama berms persistently landward. Feedback between waves and berm shape may amplify this tendency.

Nonlinear wave oscillations are pervasive in shallow wave-dominated environments, which suggests that feeder deposits could be widely effective in mitigating coastal erosion problems. The dredged material and erosive forces at the Alabama site are typical of many coastal dredging situations; however, site differences should be considered. Mean currents, for example, can be more important than wave nonlinearities in situations of strong tidal or surge dominance.

This investigation, the first to test potential processes responsible for berm migration, has implications for future quantification efforts. Having collected current data over such a long period at this site, field work can focus on shorter periods at other locations. Measurements should cover a range of environments where berms are exposed to different modes of transport and dispersion. Spatially denser data are needed across berms to define feedback mechanisms and establish expected rates of berm movement.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
knots (international)	1.852	kilometers/hour
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers

1 Introduction

The U.S. Army Corps of Engineers (USACE) dredges hundreds of millions of cubic yards of material from the nation's waterways each year. Underwater placement is often the preferred disposal choice. The ability of currents and waves to disturb, resuspend, and transport bottom sediments is a concern in planning and managing coastal open-water dredging disposal sites.

The primary design variable controlling the impact of surface water waves on bottom sediments is water depth. USACE places material in different depths to encourage or discourage movement of the material, but there is often a tradeoff between depth and haul distance.

Sediment motion in the nearshore is an extremely complex phenomenon. Wave motion; bottom slope; three-dimensional circulation cells; wind, tide, and density-driven currents; turbulence; and the interactions of these processes contribute to sediment motion. Nonetheless, those tasked with solving problems and making decisions in this environment make the best use of available technology while pursuing a better understanding of the physics involved in order to develop improved methodologies. Presently, it is assumed for some applications that mean currents are responsible for net mound movements. As will be shown later in this report, such an assumption appears to be inconsistent with measurements off the coast of Alabama.

The USACE has been monitoring several submerged mounds of dredged material (berms) offshore of the mouth of Mobile Bay, Alabama. As part of this monitoring, bottom-mounted, directional wave, tide, and current gauges were maintained by the Coastal Engineering Research Center of the U.S. Army Engineer Waterways Experiment Station for several years. This research uses these data to assess potential mechanisms by which near-bottom currents displace berms.

The objectives of this research were to analyze the characteristics of the currents and to examine their potential to move sediments in the nearshore and on the USACE disposal sites. Specific goals were: (a) characterization of the currents in the measurement area, including determination of the relative magnitudes of mean currents and wave-induced perturbations around the mean in the area of the Alabama berms, (b) analysis of the potential role of nonlinearities in the combined wave-current regime relative to sediment transport in preferential directions, and (c) assessment of the effect of the presence of the berms on the near-bottom currents.

In light of ongoing efforts to employ a combination of multivariate statistical techniques, numerical models, and field measurements to estimate the fate of dredged material, the information obtained from this study could play an important role by specifying a possible coupling between physics and statistics. This study complements the bathymetric surveys of the offshore dredged material disposal berms in Alabama (Hands and Bradley 1990; Hands 1991; Hands and Allison 1991; Hands 1992; Hands 1994). While the surveys give an idea of what happened to the material, this study investigates why it happened. The analyses performed in this study could be used to extrapolate into the future and to other locations. The practical engineering implications of these results address the methodology of assessing depths, locations, and configurations of future disposal berms.

2 Theoretical Perspective

Background

Sediment transport

Sediment movement and near-bottom water velocities responsible for sediment movement in water depths of interest have been investigated by geologists, oceanographers, and engineers. The depths of interest are those depths beyond the daily surf zone but within a reasonable haul distance for the dredge contractor from shore. Typically, these depths will experience wave-generated currents during major storm events. Although the actual depths vary with wave climate, in general, they range from 2 to 60 m (7 to 197 ft).[1] For the geologist or oceanographer accustomed to considering the deep ocean, these depths might be referred to as the "inner continental shelf" or the "shoreface." For the coastal engineer accustomed to considering the surf zone, these depths of interest might be referred to as "offshore."

Mechanisms that can transport sediment include tidal currents, waves, wave groups, wind-generated currents, wave-current interactions, density-gradient-driven currents, rip currents, shelf circulation patterns driven by barometric pressure gradients, turbulent eddies and gravity. The relative importance of these mechanisms probably varies in time and with location. Wright (1987) and Wright et al. (1991) present a cross-disciplinary literature review focussed on what moves sediments in the cross-shore direction in these depths off the mid-Atlantic coast and specifically questions models for sediment transport which focus exclusively on the wave field while ignoring other current-generating mechanisms. One example of a wave-based conceptual model is Dean's equilibrium profile concept for the surf zone with its explanation based on wave energy dissipation. Another example is the general concept that the asymmetry of the wave orbital velocity field as predicted by nonlinear wave theories can preferentially move sediment onshore. The strong point of such models, their simplicity, is also their potential weakness since the dominant processes driving the phenomenon of

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1 A table of factors for converting non-SI units of measurement to SI units can be found on page xi.

interest should be contained in an appropriate model. In this paper, the phenomenon of interest is the behavior of submerged mounds. Thus, this is a more specialized problem than sediment transport on the shelf and perhaps the most appropriate model is one of less complexity.

Constructed berm movement

A number of investigations of the behavior of specific constructed underwater mounds have recently been reported (Hartman, Ogston, and Hanson 1991; Healy, Harms, and deLange 1991; Andrassy 1991; Hands 1991). Hands and Allison (1991) collocate information on 11 different mounds constructed at sites around the United States since 1935 and present an empirical methodology for predicting the stability or activeness of proposed sand mounds. This methodology is based on two parameters proposed by Hallermeier (1981) for the inner and outer limits of sand transport initiation and a third parameter based on an estimate of the near-bottom peak oscillatory wave velocities. These three parameters are functions of the wave climate, water depth, and grain size. A PC model, EBERM, has been developed to evaluate these parameters and compare them to a database of well-documented berm responses (Hands and Resio 1994).

Alabama berm monitoring results

The dredged material disposal project near the mouth of Mobile Bay has been monitored by USACE since 1987. Hands (1991) presents an overview of the monitoring of the underwater constructed mounds. The mounds are south of Dauphin Island on the edge of the Mobile Pass ebb-tidal delta (Figure 1). The largest mound, the Mobile Outer Mound, is the farthest offshore at a depth of 15 m (49 ft) and contains about 13 million m^3 (17 million yd^3) of primarily fine-grained material. A smaller mound with about 355,000 m^3 (464,000 yd^3) of primarily sand was constructed closer to shore in depths of about 6 m (20 ft). Detailed monitoring of the behavior of this shallower sand berm, hereafter called the Sand Island Bar, is reported in Hands and Bradley (1990). Near the Sand Island Bar, another mound was found during the bathymetric surveys which was smaller and was apparently built during development of a gas well at about the same time. The smaller berm will be referred to as the Sand Island Mound.

The two constructed bathymetric features in shallower depths, the Sand Island Bar and the Sand Island Mound, migrated towards the north during the first few years after construction. The Sand Island Bar site was surveyed 21 times from December 1987 to February 1991 to document the behavior of the constructed bar. Hands (1991, 1994) describes and shows the bathymetric changes which occurred. During the first year after construction, 1987, the peaks of the mound around -3.7 m (-12 ft) mean low water (mlw) were planed off and the seaward tip of the bar was removed. During the next 2 years, the bar moved landward as a distinct feature. By 1990, the western portion of the bar, which is oriented in the northwest-southeast

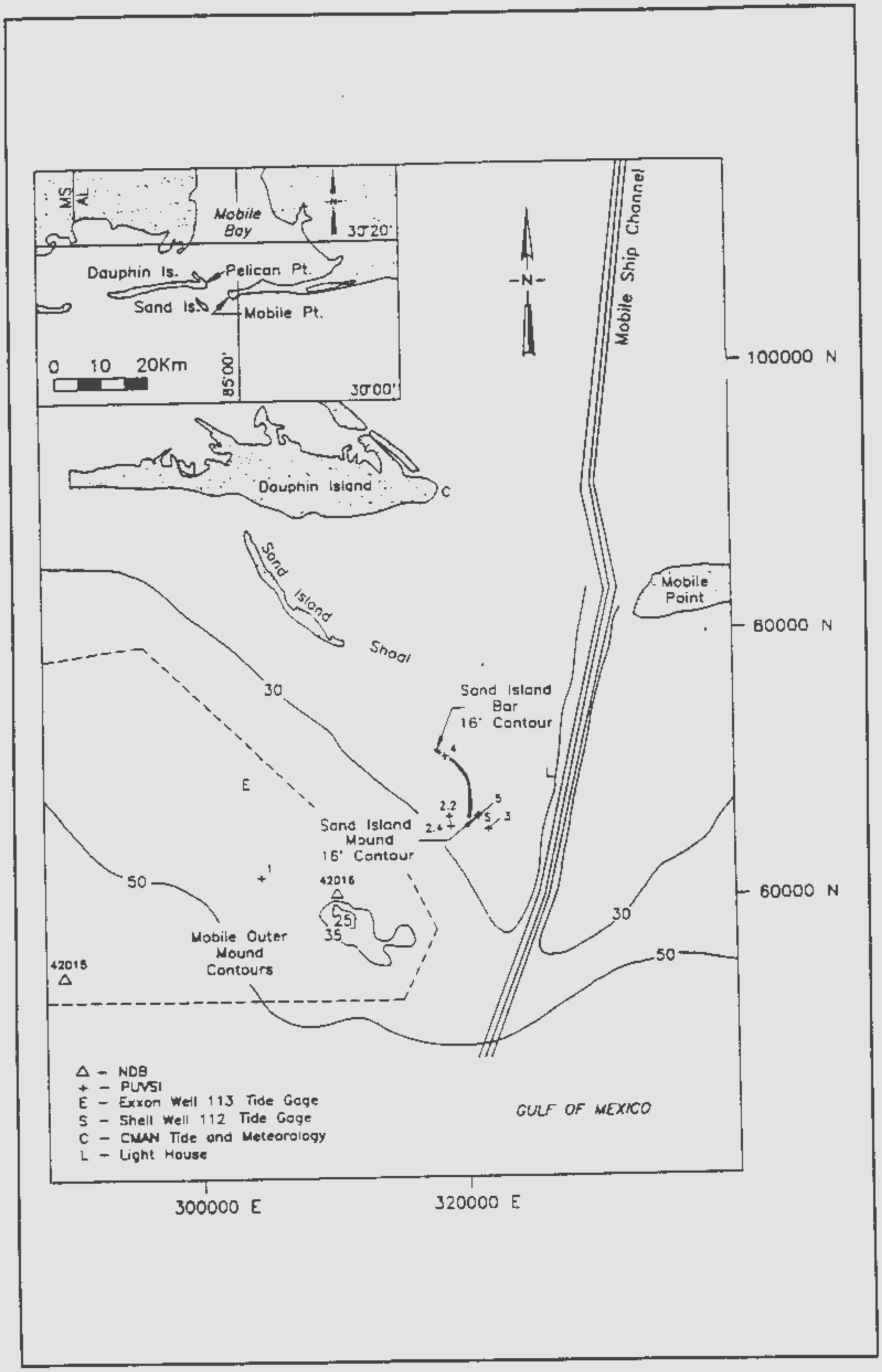

Figure 1. Location of constructed submerged features and gauges (from Hands and Allison (1991))

direction, had migrated almost into the adjacent contours of the Mobile ebb-tidal delta.

The nearby Sand Island Mound moved to the north-northwest (Hands and Allison 1991). The nearly circular shape of the mound makes documentation of the motion via individual contour changes more straightforward than the much larger Sand Island Bar. As shown in Figure 2, the mound migrated about 100 m (328 ft) to the north over a 3-year period. There was a small component of westerly movement. The ratio of northward movement to westward movement was about 5:1.

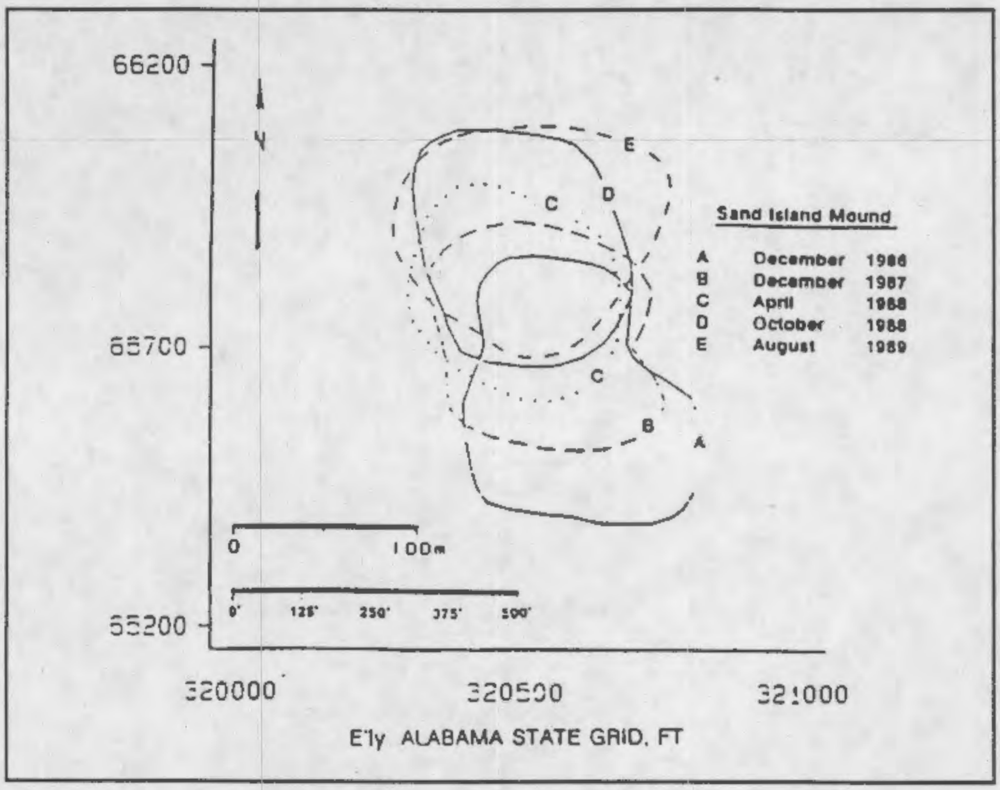

Figure 2. Migration of Sand Island Mound (from Hands and Allison (1991))

Characteristics of Currents Related to Net Sediment Transport

In order to understand the implications of current measurements considered here, relative to the observed evolution of the disposal mound, it is helpful to have a simple conceptual model of the basic mechanics of sediment transport. In the conceptual model for sediment transport considered here there are four basic components:

a. **Bottom source.** If a "critical" shear stress is exceeded, material will be injected into the water column from the underlying sediment surface. In other words, in this situation the water-bottom interface acts as a sediment source at the lower boundary. Since the sediment source is at the bottom of the water column, there should almost always exist a mean gradient of sediment concentrations which decrease as one moves upward.

b. **Turbulent fluxes**. If turbulent flow exists and a gradient of sediment concentration exists in the vertical, a net transport in the vertical can result. The governing form for this transport is similar to typical turbulent transports in nature, i.e.,

$$T(z) = \overline{\rho'(z)w'(z)} \tag{1}$$

where $T(z)$ is the rate of vertical sediment flux past a unit horizontal area at a level z above the bottom, $\rho'(z)$ represents a deviation from the mean volumetric sediment concentration at level z, and $w'(z)$ represents the deviation in vertical velocity around some mean value at level z.[1] In other words, w' represents turbulent velocity fluctuations in the vertical. Most researchers have assumed that the turbulent transport mechanism is the dominant vertical transport mechanism, which implies that the mean vertical velocity is very small. This assumption is part of the foundation of depth-integrated surge/current models and follows from basic scale considerations.

Net horizontal turbulent transports can also exist in situations where there are mean gradients in sediment concentration in the horizontal plane. The form of the turbulent transport equation dictates that transport will be directed away from regions of high turbulence and/or high sediment concentration and into regions of low turbulence and/or sediment concentration.

c. **Gravitation settling**. A continual downward flux of sediments will exist in a water column due to gravitational effects. Settling velocity in still water is a function of density and grain size. A dynamic equilibrium for sediment concentration will exist when the transport upward due to turbulent transport is balanced by gravitational settling.

d. **Advection**. A horizontal transport of material is produced by mean currents. In this context, sediment transport is definable as the flux of material (due to the mean current) within the water column through an area along one side of a rectangular water column. It should be recognized that deposition and erosion will relate to the divergence of these fluxes and not directly to the fluxes themselves (i.e., a constant flux, no matter how large, produces no net deposition or erosion).

All four components of the sediment transport model described above follow from basic considerations of conservation of mass, related constraints

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1 For convenience, symbols and abbreviations are listed in the Notation (Appendix A).

on mass fluxes, and transport phenomena in turbulence. In this context, a positive divergence of mass flux will result in erosion and a negative divergence will result in deposition.

In light of the conceptual model described above, certain aspects of currents which might produce a net sediment transport can now be examined. This will serve to guide the analyses in subsequent sections and will help interpret results in terms of potential for affecting the disposal mound. In effect, any differences between current characteristics measured at on-mound sites and those measured at off-mound sites are being isolated, at least relative to what is perceived as contributing to differences in sediment transport characteristics. This is motivated by the fact that observed bathymetric changes indicate that the mound is migrating northward.

In order to obtain a net northward migration of the mound, a positive divergence of transport must exist on the southerly slope and on the top of the mound; and a convergence (or negative divergence) must exist in the region immediately north of the mound. For this effect to be related directly to observed currents, we can hypothesize that one of the following five mechanisms is occurring:

a. Northward currents at on-mound sites are larger than at off-mound sites.

b. A positive correlation exists between sediment entrainment and northward currents (for example, as might be produced by the combination of large wave heights and northward currents). This would result in more sediment being in the water column when mean currents are moving northward than when moving southward.

c. Nonlinearities in the currents exist, which produce an increased northward transport at on-mound sites. Possibly nonlinearities at on-mound sites could be different from those at off-mound sites.

d. The temporal organization of the currents is different at on-mound sites than at the off-mound sites. For example, if transient effects such as the time to create a fully developed boundary layer were important to the net transport, the distribution of flow durations could influence net transport.

e. Feedback exists between currents and transport which relates to large-scale deviations from an equilibrium profile.

3 Current Measurements

The near-bottom water velocity data evaluated in this report were collected as part of the monitoring of the hydrodynamics in the immediate vicinity of the Mobile dredged disposal berms. Gauge locations are as shown with the "PUVSI" designation in Figure 1. The gauges used in this report collected simultaneous, instantaneous samples of pressure (P) and the two orthogonal, horizontal components of the water current velocity (u, v). Pressure was sampled with a pressure transducer and the current was measured with an electromagnetic current meter. This arrangement, the PUV gauge, is used to measure directional wave spectra. Current values can be time-averaged to calculate the mean currents at the site. Both waves and mean currents were estimated using the data. Wave and mean current results are summarized in McGehee et al. (1994), are used in Hands and Allison (1991), and are the basis for this report. Guza, Clifton, and Rezvani (1988); Guza (1988); and Aubrey and Trowbridge (1988) review earlier field measurements of wave oscillatory currents and assess the accuracy of electromagnetic current meters to measure instantaneous currents.

This study focused on current observations on and near berms. Gauges were sampled in bursts every 4 or 6 hr for 1,024 sec at a sampling rate of 1 Hz. Data were checked by the field personnel responsible for data collection (Coastal Engineering Research Center's Prototype Measurement and Analysis Branch) and for data quality problems such as fouled probes, power failures, and pressure spikes (McGehee et al. 1994).

The earlier current measurement stations, gulfward of the berms, (PUVSI-1.1 through PUVSI-3A and PUVSI-3B) were instrumented with internally recording commercial SeaData-9 and SeaData-12 gauges. The SeaData gauges were mounted above concrete anchors with pressure port elevations between 110 and 137 cm (43 and 54 in.) above the seabed. Elevations of electromagnetic current sensors ranged from 122 to 152 cm (48 to 60 in.) above the seabed.

Gauges designed and assembled at WES for this study were installed on top of the two active berms (McGehee et al. 1994). Data from these two stations were automatically telemetered to Vicksburg on a daily schedule. Station PUVSI-4 was on the Sand Island berm and PUVSI-5 was on the

Sand Island mound (Figure 1). These on-berm instruments were mounted in trawler-resistant pods. Divers clamped the pods to three 1-in.-diam (0.4-cm-diam) galvanized pipes jetted 3 m (10 ft) into the bottom. Elevations of pressure ports and current sensors for these real-time gauges were 10 and 40 cm (4 and 16 in.) above the bed, respectively.

Wave gauges were also installed 1.5 and 3 km (0.8 and 1.6 miles) farther offshore. The National Data Buoy Center (NDBC) installed 3-m (10-ft) buoys for this study and maintained them over the 4-year study period. The now standard 3-m (10-ft) pitch-roll-heave wave buoy is described by Steele et al. (1990). All wave and current measurements occurred between 1987 and 1990.[1] The structural members of the pod were 1.5-in.-diam (0.6-cm-diam) steel with none of the members closer than 1.5 ft (0.5 m) to the current meter sensor. McGehee et al. (1994) postulate that the turbulence induced by vortices shedding from the frame are high in frequency relative to the wave orbital motions. McGehee et al. (1994) also report that in unidirectional flow tests, the trawler-resistant mounting did not affect velocity measurements at any detectable level.

One problem identified in the analysis of the PUV data was the lack of re-calibration of the gauges after deployment. Significant drifts in mean velocities were observed in other studies using similar gauges, indicating that the zero-point had changed artificially through time. However, in reviewing the data from the Alabama gauges, no intervals with significant long-term departures in the mean could be found. This fact, plus the fact that many different gauges were used over tbe duration of this project, suggest that the data are representative of actual currents at the Alabama berm sites.

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1 Archived data from the NDBC buoys are available from the National Oceanographic Data Center (NODC), 1825 Connecticut Avenue, NW, Washington, DC 20235. Digital ASCII files from other instrument stations include wave and current time series and summary statistics based on analyzed directional spectra. These files are available from the Dredging Research Program Manager at CERC.

4 Data Analysis

Analysis of Current Climatology

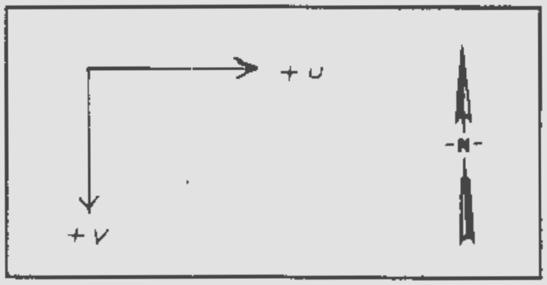

Figure 3. Definition of *u*-*v* directions

Since data were collected at several stations over varying time intervals, it is somewhat difficult to interpret the overall data set in terms of a climatology. Figure 3 gives the definitions of current sign used in the data report (McGehee et al. 1994) and adopted in this report. The east-west component of current is "*u*" and is positive towards the east. The north-south component of current is "*v*" and is positive to the south. All currents are depicted in terms of the direction toward which the water is flowing. Figure 4 reproduces a typical joint *u*-*v* current distribution. This shows the typical distribution of currents in this region. From these figures it appears that higher current velocities tend to move primarily in the alongshore direction. Table 1 shows calculated mean velocities for all sites. These data indicate that the overall mean velocity in this region is toward the southeast. Note that this is parallel to the bottom contours as would be expected from conservation of mass near the coast.

Evaluation of Tidal Constituents

Harmonic analysis of the time series of *u* and *v* currents is not very conclusive for the data collected in this study. Primary energy-containing frequencies are spread over a fairly large range, including some significant peaks in the 2- to 5-day range. This suggests that a substantial part of the energy may be driven by synoptic meteorological forcing rather than tidal forcing. Analyses indicate that typical alongshore (*u*-direction) tidal currents in this area are in the range of 5 to 15 cm/sec (2 to 6 in./sec) with maximums of about 30 cm/sec (12 in./sec). Onshore tidal magnitudes are smaller than alongshore, indicating that the gauge sites are not directly in the path of the tidal jet from Mobile Pass. The main ebb-tidal jet is located to the east of the gauge sites.

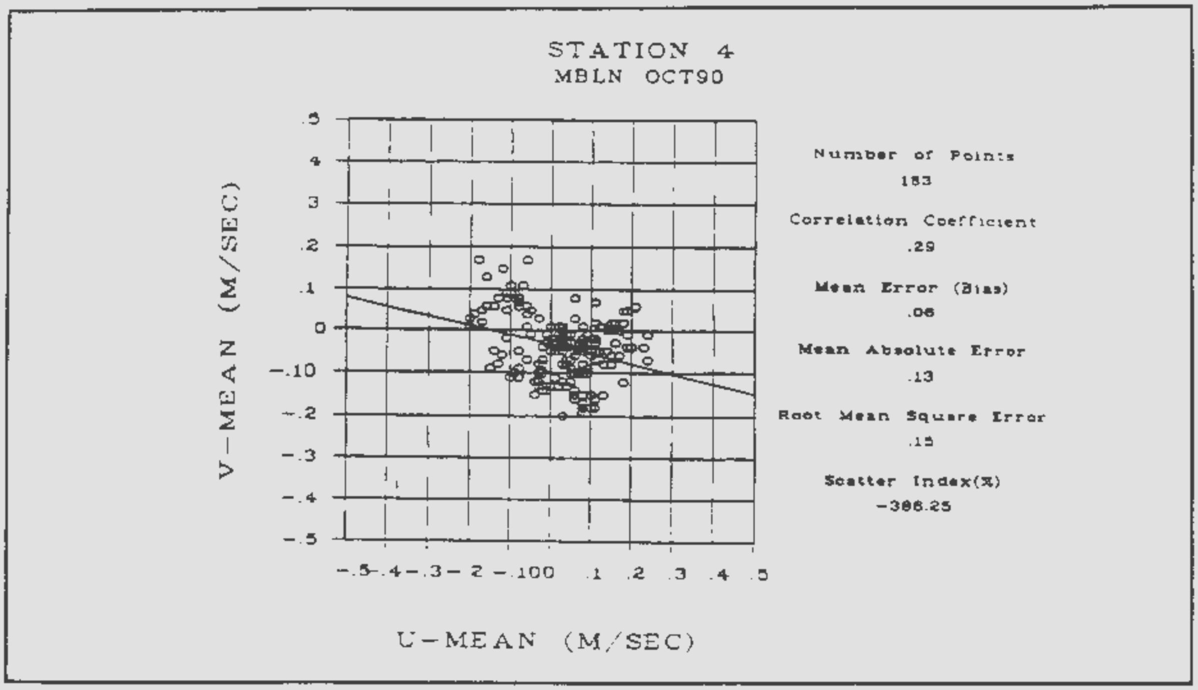

Figure 4. Typical bidirectional current distribution

Table 1
Mean Current Statistics

FILE NAME	INSTRUMENT STATION	NO OF BURSTS	START DATE YYMMDDHHNN	END DATE YYMMDDHHNN	<u> m/sec	<v> m/sec
Offshore						
MO3703	PUVSI-1.3	27	8704302220	8705071020	0.011	-0.030
Near seaward side of the berms						
MO0304	PUVSI-2.2	163	8709281631	8711020431	0.018	0.005
MO3206	PUVSI-2.4	135	8802262030	8803310830	0.034	0.045
MO2801	PUVSI-3A	318	8808181700	8811052300	0.000	0.006
MO0305	PUVSI-3A	235	8812051830	8902020630	0.023	-0.074
MO0115	PUVSI-3A	360	8906272100	8909251500	0.035	0.030
MO1901	PUVSI-3B	272	8904202300	8906271700	0.176	0.009
MO5605	PUVSI-3B	216	8906272100	8908201500	0.061	0.046
MO2807	PUVSI-3B	316	8901311745	8904201145	0.051	0.051
On Top of Sand Island Bar						
AUG89	PUVSI-4	250	8908250000	8910101300	-0.067	-0.001
NOV89	PUVSI-4	175	8911242100	8912290100	-0.030	-0.022
JAN90	PUVSI-4	121	9001100400	9001301600	-0.032	-0.032
FEB90	PUVSI-4	69	9002092000	9002282000	0.033	0.023
MAR90	PUVSI-4	28	9003230000	9003311600	0.033	0.044
APR90	PUVSI-4	64	9004011600	9004302000	0.039	0.050
MAY90	PUVSI-4	49	9005010000	9005310400	0.017	0.060
JUN90	PUVSI-4	69	9006031600	9006300800	0.085	0.080
AUG90	PUVSI-4	186	9008010000	9008312000	0.062	0.007
OCT90	PUVSI-4	184	9010010000	9010311200	0.025	-0.038
On Top of Sand Island Mound						
MBSAUG89	PUVSI-5	242	8908250000	8910090900	0.054	-0.006

Current Characteristics and Sediment Transport

In a previous section it was suggested that various climatological characteristics of currents might contribute to the net migration of the disposal mound. In this section, these characteristics will be investigated via the extensive set of measurements near the disposal mound. Since the primary concern is mechanisms which may influence the northward migration of the disposal mound, analyses will concentrate on the v-component (north-south component) of motion.

As mentioned previously, the primary data consist of bursts of 1,024 samples taken at 1-sec intervals. If we were to attempt to use these raw data directly for our climatological characterizations, it would be quite cumbersome and would likely produce little insight into the sediment transport processes in this area. On the other hand, if we only investigated mean currents, we would lose all information on velocity fluctuations (waves and turbulence) and any nonlinear aspects of these fluctuations. We thus began our analyses by investigating distributions of fluctuations. From a loose application of the central limit theorem and the knowledge that linear waves produce velocities which are approximately normally distributed, it is expected that measured currents will be approximately normally distributed. Consequently, we take as our normalization form for the "burst" velocities

$$\hat{u}' = \frac{u - \bar{u}}{\sigma_u} = \frac{u'}{\sigma_u}$$

$$\hat{v}' = \frac{v - \bar{v}}{\sigma_v} = \frac{v'}{\sigma_v} \qquad (2)$$

where

$\hat{u}', \hat{v}'$ = normalized velocities

σ_u, σ_v = rms measures of the current distributions

Figure 5 shows plots of typical distributions of $\hat{u}'$ and $\hat{v}'$ for selected gauge sites. From this figure it appears that the distributions of velocities in the x and y directions could be reasonably represented by normal distributions. For a first approximation, it might be tempting to use only the mean u and v values and the σ_u and σ_v values to characterize the currents for this study. However, this would only be strictly valid if higher order moments of the distribution were negligible and would essentially neglect certain nonlinear aspects of currents which could influence sediment transport. An analysis of statistical moments up through the fifth moment indicated that the third statistical moment (skew) was in fact not negligible for much of the data, whereas fourth moments (kurtosis) and higher appeared to be consistently very small.

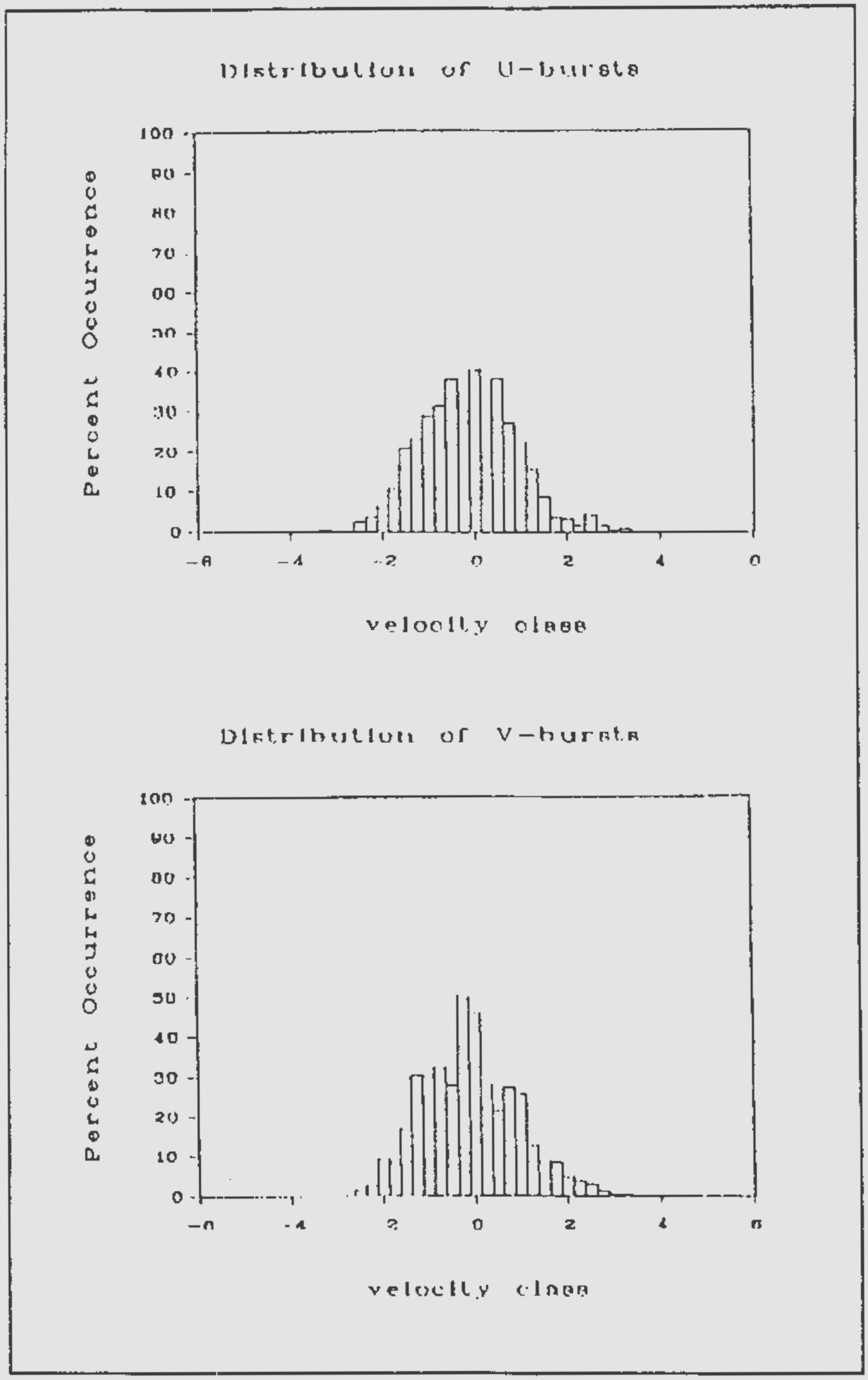

Figure 5. Distributions of standardized velocity components (dimensionless) during a typical "burst"

A set of four parameters (mean, rms, and skew of u and v) can be used to characterize the climatology of currents in place of using the actual current distributions themselves. Mean values will control advection, rms values will influence the turbulence intensity and vertical transport of sediments, and coefficient of skew values will provide a good measure of nonlinearity in the distributions of instantaneous velocities.

Analyses of mean currents

Table 1 gave a listing of the mean u and v currents for all of the sites at which data were taken, partitioned into off-mound and on-mound sites. The mean north-south (v) velocities are small and the differences between mean v-velocities at the on-mound and off-mound sites do not appear to be significant. Furthermore, the on-mound mean v-velocities tend to move slightly in the offshore direction; consequently, they are not likely to be related (in a straightforward advective fashion) to the onshore migration of the mound.

Another problem with the interpretation of a mean-current forcing of mound migration is the fact that variations in the mean north-south velocities are much larger than the long-term average velocity. If the mound were able to respond to a small net mean velocity, it should exhibit considerable fluctuations in position during times when the mean varied. Such fluctuations would show up in the surveys as apparent random onshore-offshore movements of the mound. Also, such fluctuations would cause significant dispersion of the mound material in the north-south direction *and* particularly in the east-west direction (where the fluctuating mean currents are considerably larger). We do not find random displacements in survey positions, but instead find a slow continual migration toward the north. This persistent direction of displacement means that fluctuations in mean currents are not reflected in fluctuations in mound positions. Also, significant dispersion of the mound material is not found. Based on these arguments, it is not likely that mound migration is related directly to a simple mean current.

Correlations between v and σ_v

If a persistent correlation existed between v and σ_v, it could produce a net transport, since more sediment would be in suspension when the mean velocity was headed in one direction than when it was headed in the opposite direction. Plots of v versus σ_v were made for each measurement site. Figures 6 and 7 show typical results from two sites. Two notable aspects are particularly evident in these plots. First, low values of σ_v appear to be independent of v. Second, above some threshold of σ_v, there exists a tendency for larger values of σ_v to be associated with positive values of v (offshore flow). This may have a physical interpretation in that low wave conditions, presumably with low wave periods, will not produce significant mass transport; whereas

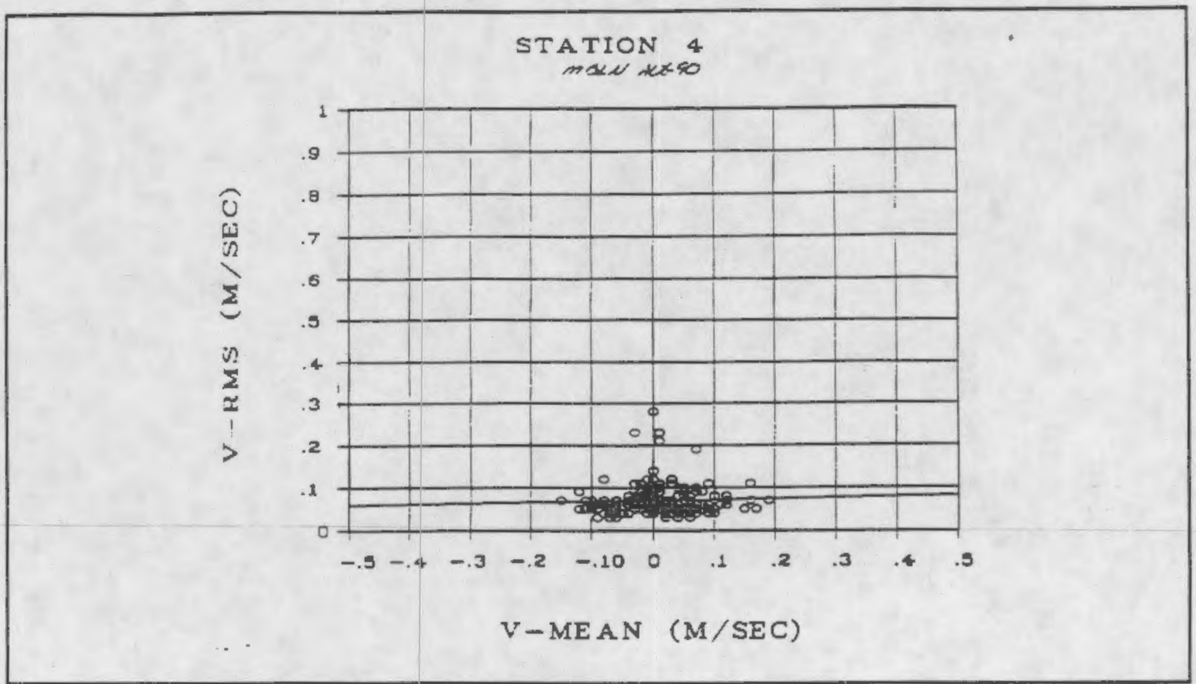

Figure 6. Joint distribution of v and σ_v at site PUVSI-4

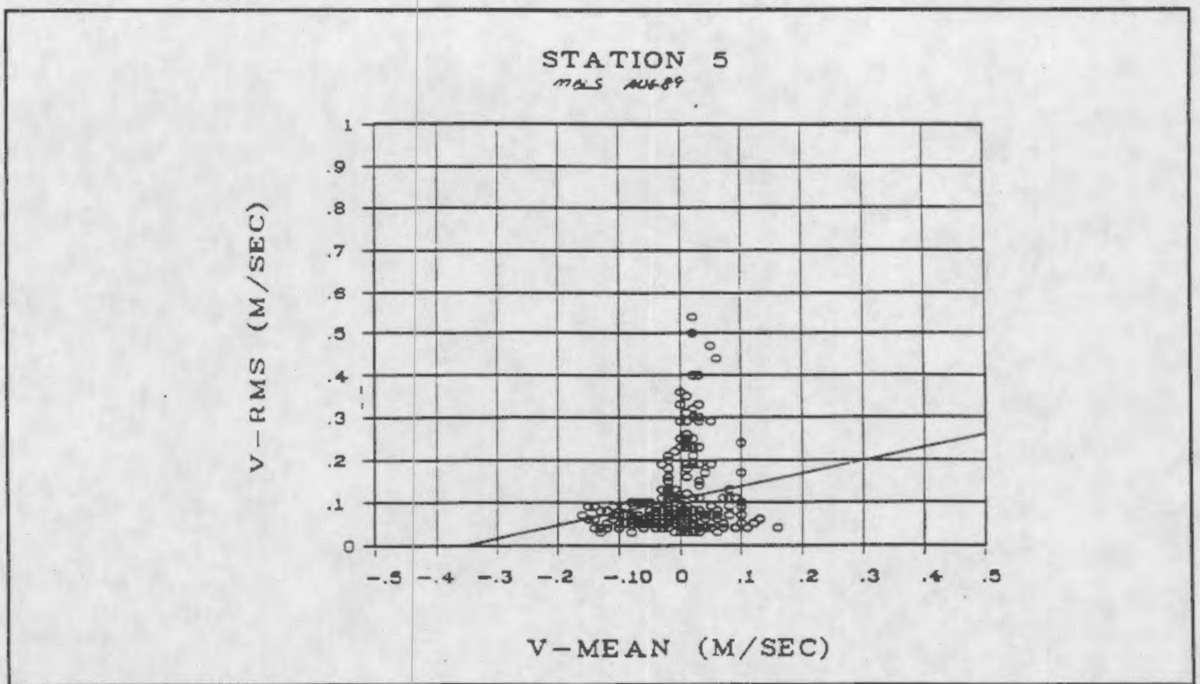

Figure 7. Joint distribution of v and σ_v at site PUVSI-5

higher waves approaching the shore will usually produce a net mass transport in the upper region of the water column and a return flow near the bottom where the gauges are located. Another possibility could be that large waves are coincident with winds blowing toward shore, which also produces net downwelling and return flow in the near-bottom region.

Nonlinearities in velocities

In a steady-state flow, the rate of suspended sediment transport can be related to the cube of the velocity. In the combined wave-current regime present at the measurement sites used in this study, steady-state conditions are unlikely, due to the irregular wave-induced oscillations. In this case, one would expect net transport to occur in the direction of the predominance of higher velocities. The coefficient of skew provides a measure of the asymmetry of a distribution which can be used to investigate the possibility of such nonlinear influence. If the skew is zero or very small, then the distribution is symmetric and there are just as many high velocities moving toward the north and the south. In the coordinate system used in this study if the skew is positive, then more high velocities move toward the south than the north. If the skew is negative, then more high velocities move toward the north. This would be consistent with our concept of nonlinearities in shallow- and intermediate-depth waves, since higher velocities are expected toward the coast under the wave crest than away from the coast under the wave trough.

In order to explore the role of nonlinearities, plots of the coefficient of skew versus mean *v* velocity and versus rms *v* velocity were constructed. Typical results are shown in Figures 8 (on-mound) and 9 (off-mound) for the former case, and in Figures 10 (on-mound) and 11 (off-mound) for the latter case. It can be seen from these figures that there is only a weak (possibly small negative) correlation between mean *v*-velocities and the *v* coefficients of skew. This suggests that the cases with pronounced negative skew (northward) tend to occur slightly more often with positive (southward) mean currents. This is consistent with the previous interpretation that higher waves (which should produce larger negative skews) tend to be associated with net offshore near-bottom flows at the measurement sites used in this study. It should be noted that the weakness of the correlation in the relationship between *v*-mean and *v*-skew suggests that caution should be used in any inferences based on this relationship.

A high correlation exists, however, between *v*-rms and *v*-skew especially for σ_v values greater than 0.1 m/sec (0.3 ft/sec). This high correlation between the negative coefficients of skew and the rms *v*-velocities strengthens the previous interpretation, since it indicates that large rms (wave-induced) velocities are associated with higher nonlinearities (i.e., a larger proportion of high velocities moving toward the north). Larger waves thus seem to be associated with higher mean velocities directed offshore and greater skewness of velocities toward the land.

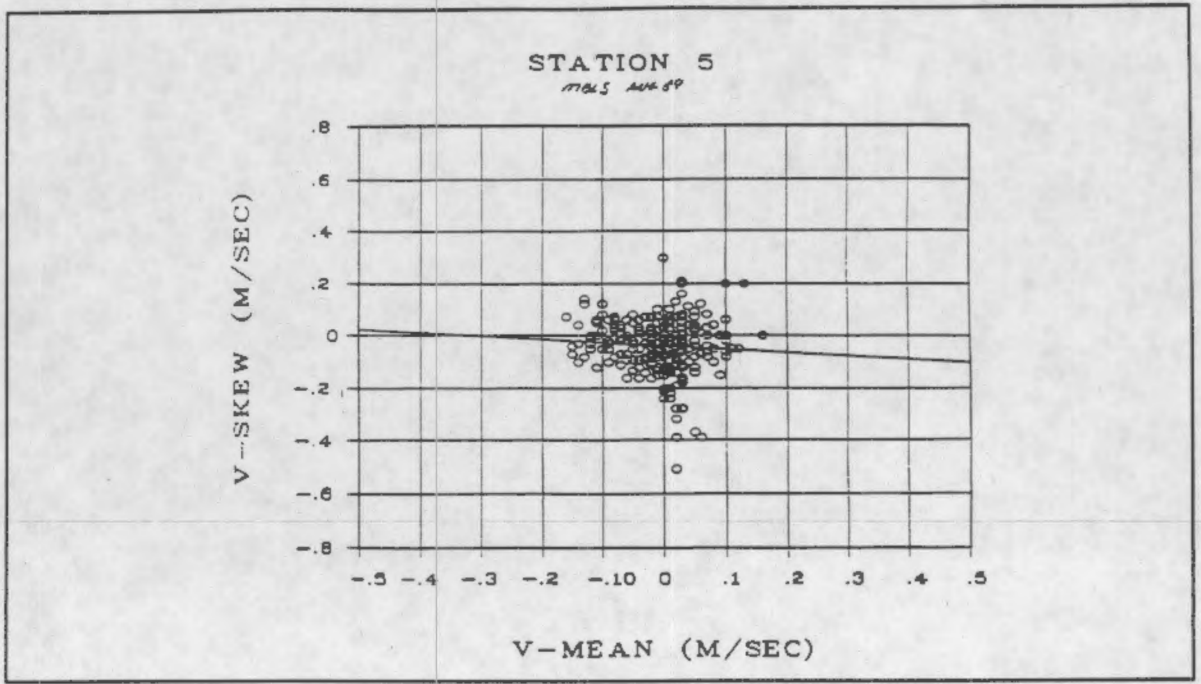

Figure 8. Joint distribution of mean v and σ_v at site PUVSI-5 (on-mound)

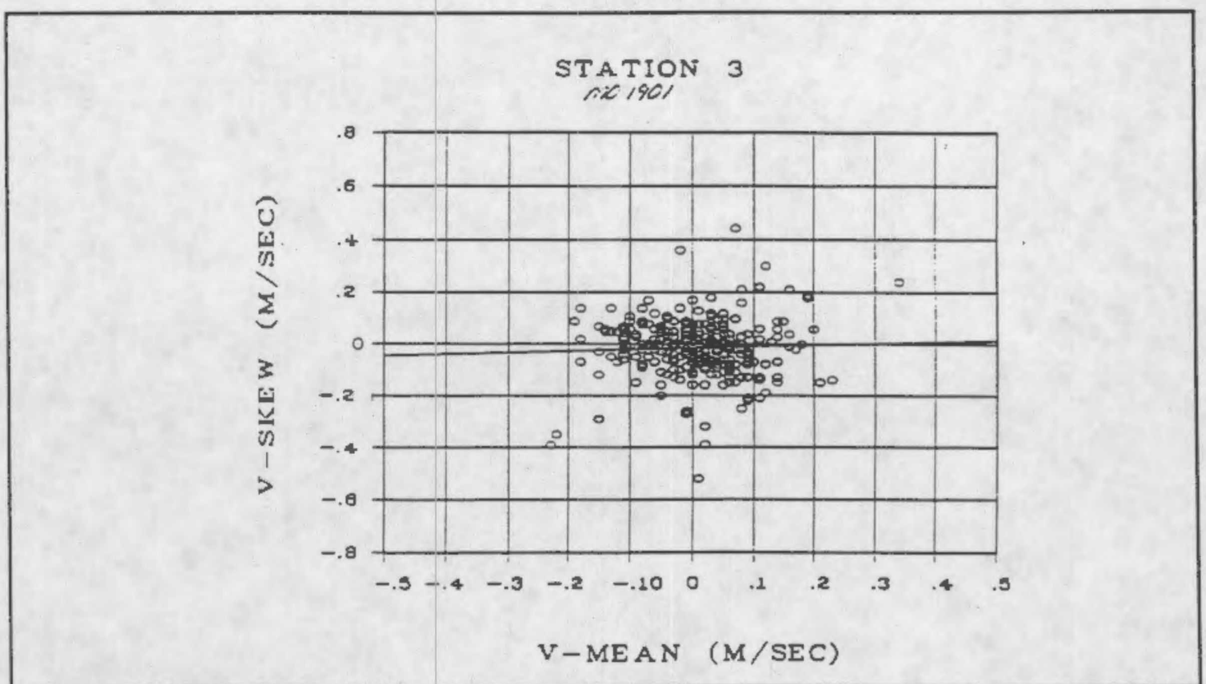

Figure 9. Joint distribution of mean v and σ_v at site PUVSI-3 (off-mound)

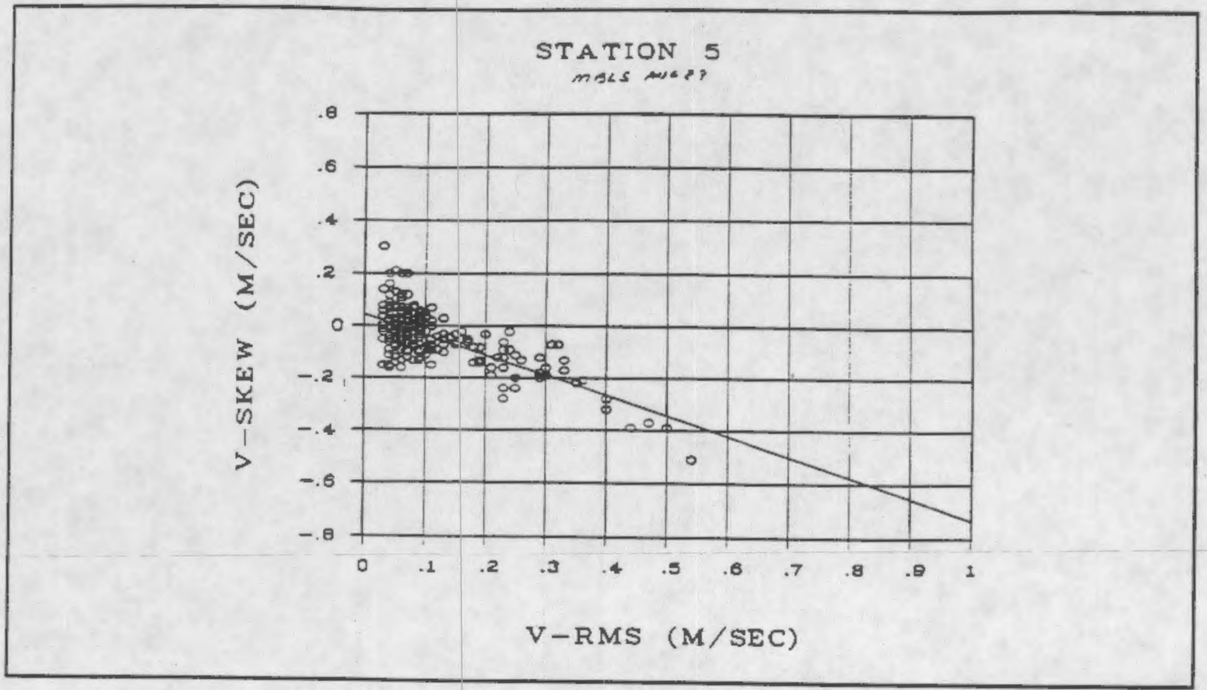

Figure 10. Joint distribution of skew and σ_v at site PUVSI-5 (on-mound)

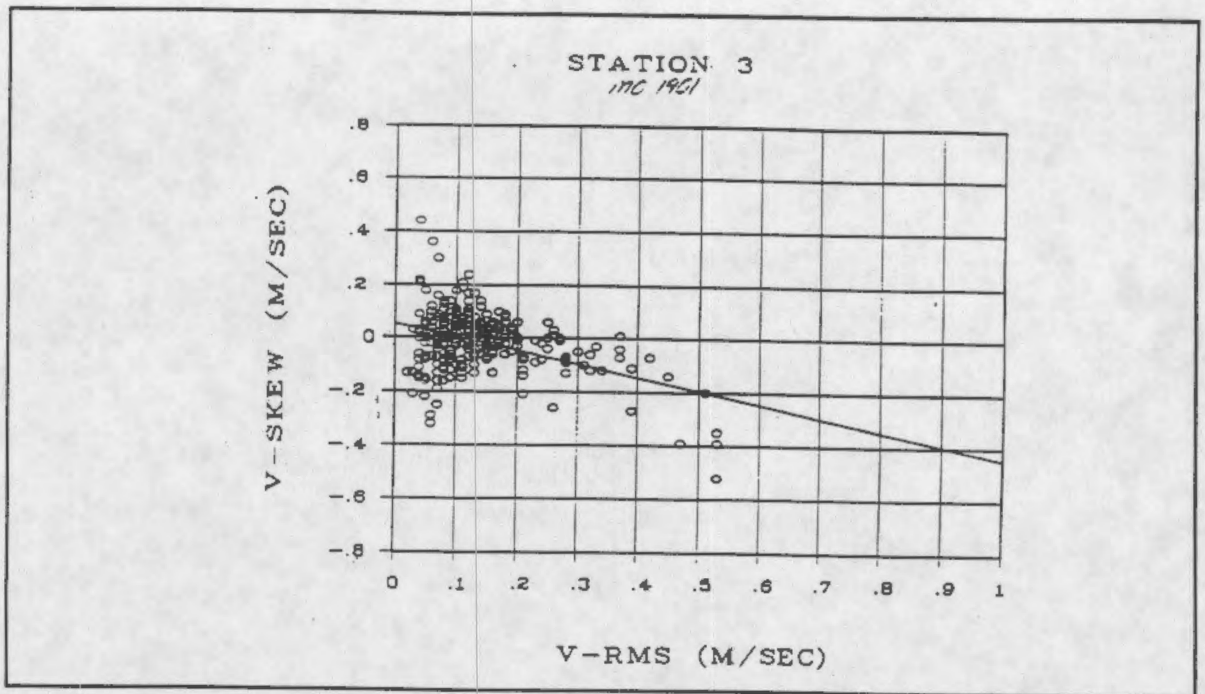

Figure 11. Joint distribution of skew and σ_v at site PUVSI-3 (off-mound)

Temporal organization of velocities

If a correlation existed between current direction and stage of boundary layer development, it might be possible to affect a net motion toward the direction with the more developed boundary layer, even though mean motions were not in that direction. In order for such a correlation to exist, the temporal organization of currents must be asymmetric on the time scale commensurate with boundary layer development (1 to 2 sec or less). No significant asymmetries were found on this scale; however, some variabilities at a longer scale were detected.

It is typically assumed that velocities in nature due to combined waves and currents can be regarded as a simple (constant) mean current with a short-term oscillatory current superposed. In this context, one would expect that if the mean current is subtracted from the total velocities in a "burst," the resulting record would only contain information on wave-induced velocities. In this context, if the net displacement of a hypothetical water particle is plotted, one would expect that it would oscillate around zero, with excursion lengths on the order of the orbital velocity ellipses. For waves typical of the Mobile measurement sites, this yields excursions in the range of 0.25 to 2.5 m (0.8 to 8.2 ft) for monochromatic, unidirectional waves.

If the maximum excursion is calculated for each "burst" and plotted against expected displacements due to the mean current over the sample time (as shown in Figures 12 and 13), the maximum excursion is consistently much larger than would be expected by a homogeneous wave train. This suggests that a significant component of motion with a frequency somewhere between the waves and mean currents exists. These are likely due to eddies and other nonstationarities in the overall velocity field. It is interesting to note here that these large excursions exist even when the mean current is near zero. In these cases, the excursions could become dominant contributors to the water motions. In fact, this scale of motion is likely to be very important to dispersion of waterborne materials (contaminants, organic materials, etc.). However, due to the fact that this scale of motion is considerably longer than the characteristic time for development of the near-bottom boundary layer, it is unlikely to contribute significantly to sediment transport (other than in the sense that they contribute to the overall mean velocity).

Feedback mechanisms

Concepts of equilibrium offshore slopes have long been advanced by scientists and engineers. In these concepts, the form of the offshore slope is such that it establishes a dynamic balance between onshore and offshore sediment transport. Since no form-independent mechanism has been found in the current data which readily explains the preferential movement of sediment on the mound toward the north, it is possible that a form-dependent mechanism might be responsible for this migration. This implies that feedback exists between bottom slope and net sediment transport. In this context, sediment transport on the southerly slope could in fact be quite different than transport on the northerly slope.

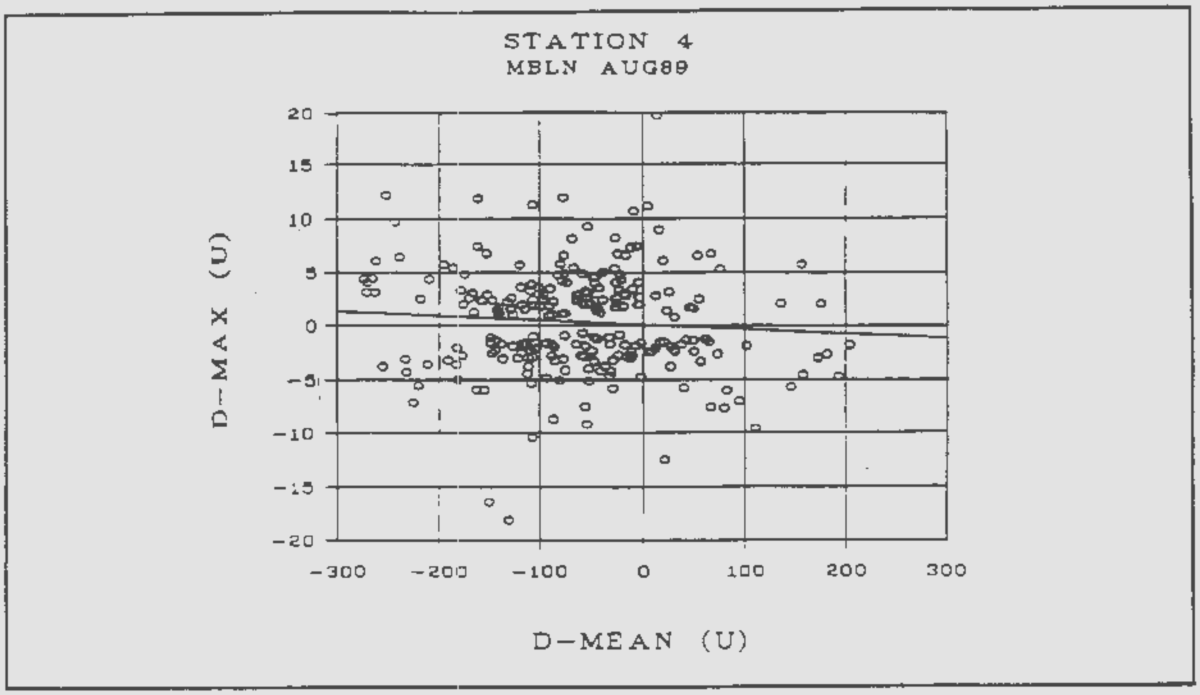

Figure 12. Cumulative east-west displacement of a hypothetical water particle, site PUVSI-4, 25 August-10 October 1989

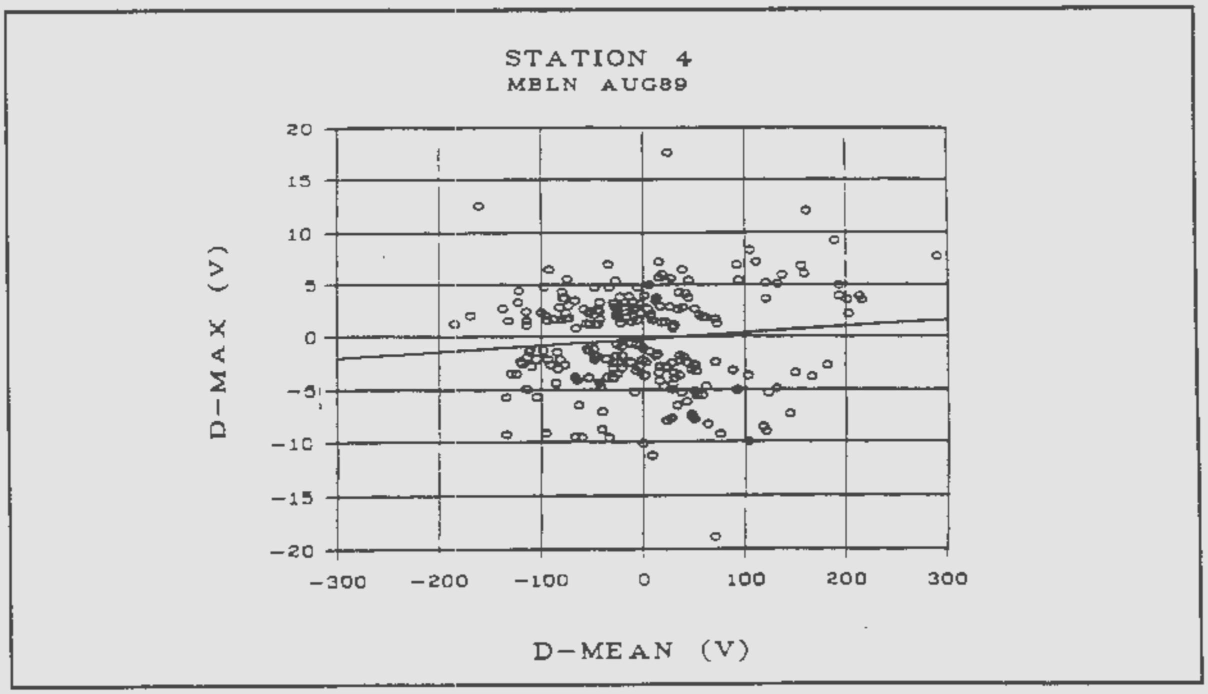

Figure 13. Cumulative north-south displacement of a hypothetical water particle, site PUVSI-4, 25 August-10 October 1989

No direct evidence was found in the data to support the hypothesis that a feedback mechanism plays an important role in the northward migration of the mound. However, the following argument might be used to support the existence of such a mechanism. First, mean currents on the mound are toward the offshore direction and, hence, cannot explain a preferential northward transport of mound sediment (i.e., direct advection cannot explain the northward migration of the mound). Second, there is a small negative correlation between high waves and mean currents in the offshore direction; hence, correlations between mean currents and turbulence intensities cannot explain a northward sediment transport. Third, the lowest order of motion with a pronounced asymmetry that might explain a northward transport is the shoreward skew in current ("burst") distributions that increases during intervals of large waves. Thus, asymmetries in wave motions constitute the lowest order mechanism which appears to be capable of moving sediment toward the north. However, these asymmetries exist in comparable magnitudes at both on-mound and off-mound sites; so unless sediment in all areas where wave asymmetries exist is moving toward the coast (essentially all coastal areas of the world), it is likely that some other factor is also involved in determining the direction of net motion. The exact specification of this feedback is beyond the scope of this effort; therefore, no further discussion is included here.

Specific Events

Details of the near-bottom currents during four sample climatological events are discussed in this section. The four events are a distant tropical storm passage, a strong-mean dominated current flow, a southerly wind, and a frontal passage. The full time series of 1-Hz near-bottom velocities is considered in the time domain. Detailed examination of the data shows some interesting characteristics of the current field that relate to sediment-transporting ability and reinforce the conclusions in the statistical treatment above.

Hurricane Chantal

Chantal developed in the southern gulf on 30 July 1989 and moved northwest, eventually making landfall near the Texas-Louisiana border as a mild (Category I: maximum windspeed of 130 km/hr (70 knots)) hurricane on 1 August 1989. The hurricane's eye formed 1,600 km (994 miles) south of Mobile and passed 800 km (487 miles) southwest of the Alabama gauges.

Waves and mean currents recorded at PUVSI-3A between 31 July and 2 August 1989 are summarized in Figure 14. Data from PUVSI-3B indicate essentially the same results. A wave height H_{mo}, wave period T_p, and mean current vector are shown for each of the 17.1-min (1,024-sec) bursts. Within 24 hr, wave heights increased from less than half a meter

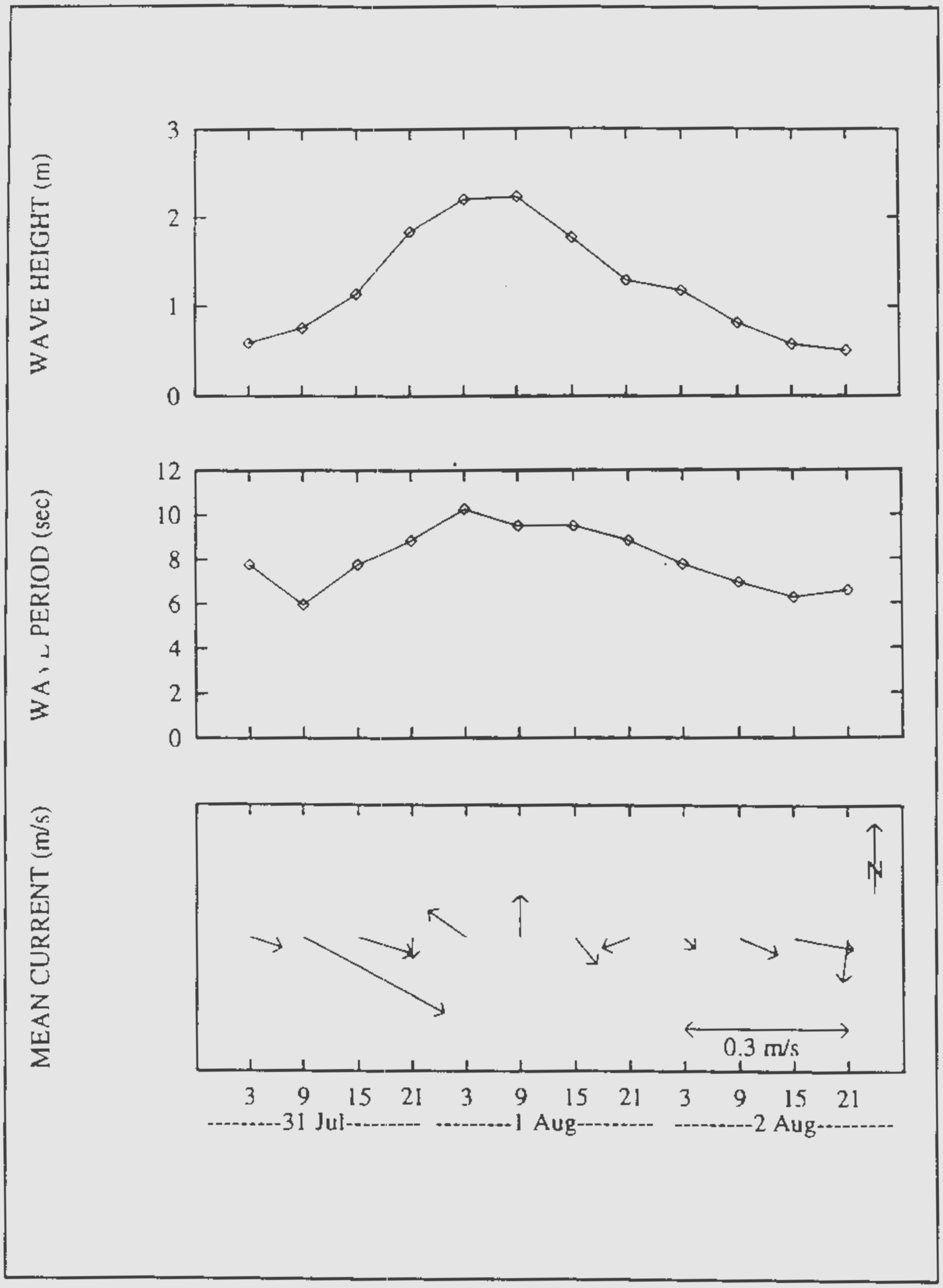

Figure 14. Wave and mean current conditions during passage of Hurricane Chantal

(1.6 ft) to over 2 m (6.6 ft) by 0300 hr (GMT) on 1 August 1989. The depth of the water was roughly 6.2 m (20.3 ft).

The maximum mean current occurred 18-24 hr prior to the largest waves. At 0900 hr on 31 July the average of the current data samples was toward the east-southeast at 0.29 m/sec (1.0 ft/sec). Six hours previously and six hours later, the mean current was moving in the same direction but with a much reduced magnitude. At the time of the largest waves, 0300 and 0900 hr on 1 August, the mean current was much smaller, 0.09 m/sec (0.3 ft/sec) to the northwest and 0.08 m/sec (0.26 m/sec) to the north. Although there was positive correlation between the large waves and northward mean currents for these two time periods, statistical summaries presented earlier indicate that such occurrences are not dominant (see Figures 6 and 7).

Samples of the 1-Hz current data for 31 July and 1 August are shown in Figure 15. Data are plotted as current vectors with direction arrows from a baseline where each observation is offset to the right of the previous second's observation. Only 1 min of each record is shown. Patterns of the current records vary as the storm waves begin to hit the Alabama coast. At 0300 hr on 31 July, currents were very weak and somewhat oscillatory in nature. By 0900 hr, the currents were all moving in roughly the same direction, east-southeast, at roughly the same magnitude, 0.2 to 0.4 m/sec (0.66 to 1.3 ft/sec). This indicates a relatively strong, steady east-southeast current modified by a wave-driven oscillatory flow. By 1500 hr, the oscillatory flow is more dominant and the steady background current is reduced but still evident. This trend of increasing oscillatory flow and decreasing steady flow continues through 2100 hr. By 0300 hr on 1 August, the wave-driven oscillatory flow is most strongly developed and the steady, background current is almost gone. The current oscillates from northeast to southwest with a period that corresponds with the period of the waves, 10 sec. This is the near-bottom current field due to the swell forerunner of the hurricane.

Figure 15 also shows that the current field has some asymmetric aspects associated with finite-amplitude waves. Swell waves are propagating from the hurricane, which is located to the southwest. Under the wave crests, currents are toward the northeast: under the wave troughs, currents are reversed toward the southwest. Forward currents are stronger but of shorter duration as would be expected under finite-amplitude waves.

At 0900 hr on 1 August, the currents still show a strong oscillatory nature. This clear oscillatory motion continues through the 1500 and 2100 hr observations, but is clearly decaying in magnitude as the wave heights decayed.

Current values measured during the passage of Hurricane Chantal were sufficient to entrain and move sand. The single maximum current measured during each 17-min observation increased from 0.25 m/sec (0.82 ft/sec) at 0300 on 31 July to 1.02 m/sec (3.35 ft/sec) at 0300 on 1 August, and then

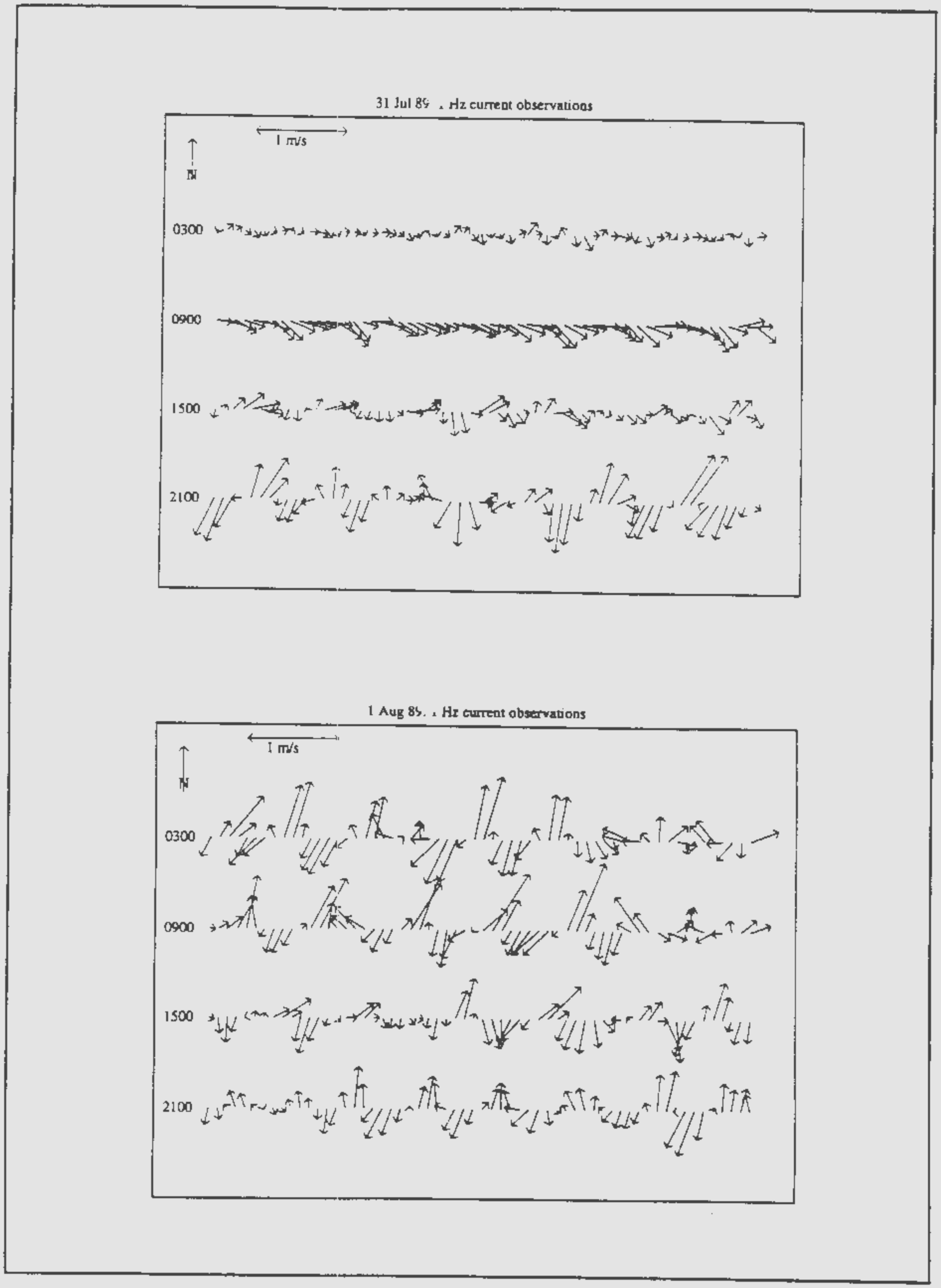

Figure 15. Instantaneous current vectors measured at 1 Hz during passage of Hurricane Chantal (Continued)

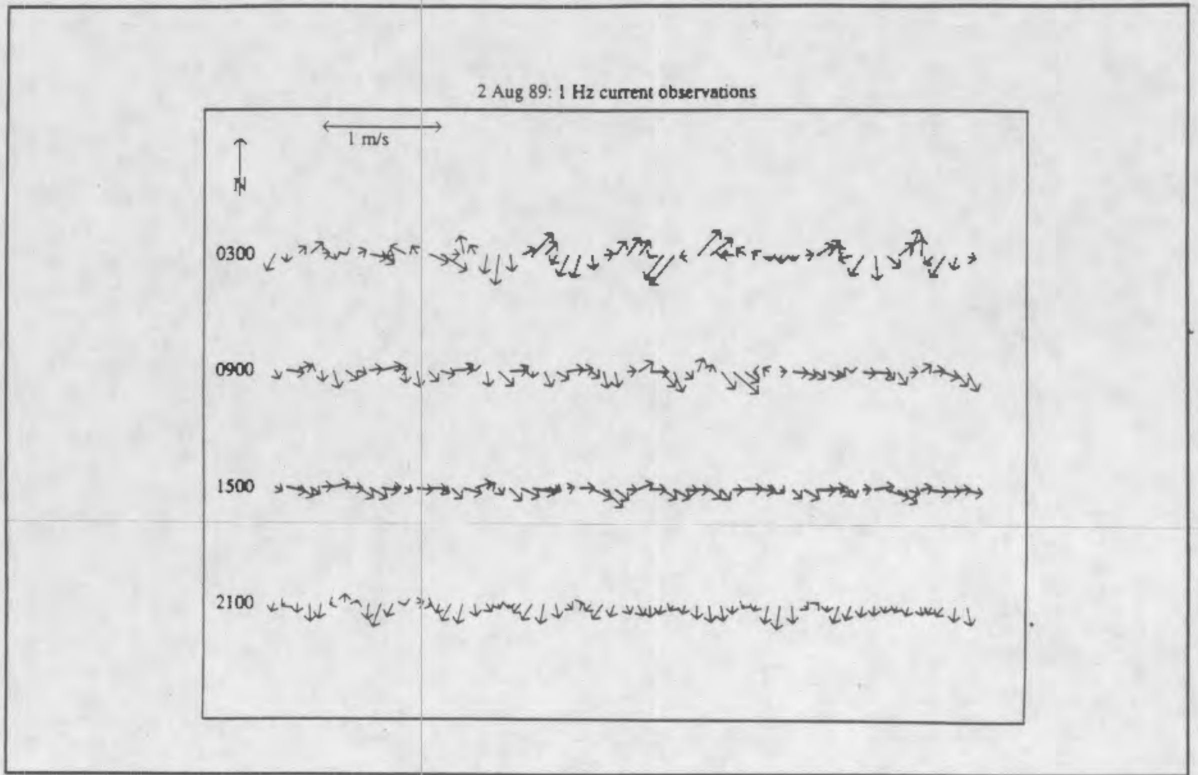

Figure 15. (Concluded)

decreased to 0.58 m/sec (1.9 ft/sec) at 2100 on 1 August. It continued to decrease to 0.26 m/sec (0.85 ft/sec) by 1500 on 2 August.

Asymmetry of the near-bottom currents

The asymmetry of the 0300 data on 1 August 1989, the oscillatory near-bottom current caused by the Chantal swell forerunner, is considered in detail in this section. The 1,024 current samples are plotted together in Figure 16 with the two components of velocity referenced to actual compass direction that the current was flowing toward. Values are aligned along an axis that runs roughly 30 deg east of north. This corresponds with the angle of wave approach computed by the full PUV data analysis and roughly with the location of the storm at the time these waves were generated. This direction is also approximately perpendicular to bottom contours at the site. Currents are greater to the east-northeast, or onshore, than they are to the south-southwest, or offshore. This is consistent with the asymmetry shown in the currents in Figure 15. Magnitudes of the forward velocities under the wave crests exceed the magnitudes of the backward velocities under the wave troughs.

To document this asymmetry further, the cumulative distribution of the 1,024 current values is plotted in Figure 17. The 1,024 individual current values are given signs, positive or negative, based on whether the individual

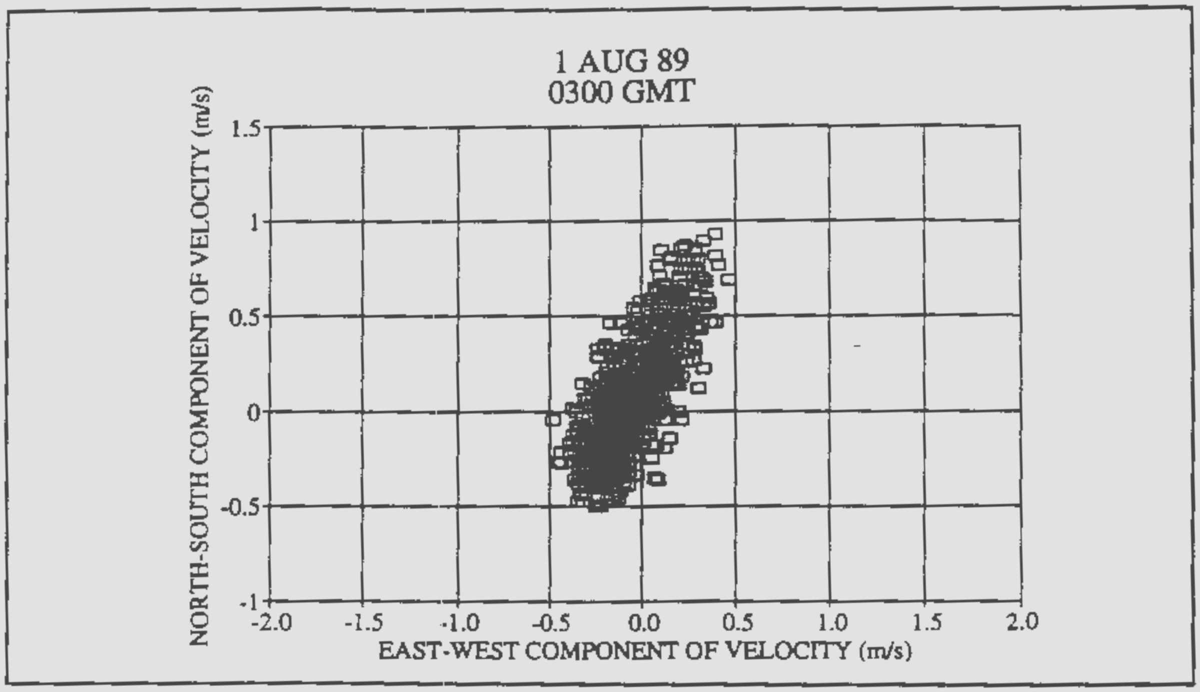

Figure 16. Scatter plot of instantaneous currents measured due to swell from Hurricane Chantal (0300-0317 hr GMT, 1 August 1989 (1,024 values))

current is moving in the "onshore" or "offshore" direction. Definitions of onshore and offshore correspond with the direction of wave propagation, not the actual shoreline. "Onshore" is taken as the direction of wave propagation, 30 deg east of north, and "offshore" is taken as the opposite direction. The total individual current magnitude is retained, i.e., a component in the "onshore" or "offshore" direction is not calculated. Assigning the signs in this manner to the original current magnitudes is equivalent to drawing a line through the origin of Figure 16 rotated clockwise 30 deg from horizontal and assigning a positive value to currents falling above the line and negative values to those below the line.

Figure 17 shows that onshore velocities occurred less frequently than offshore velocities during the 17-min record but that the largest velocities were "onshore." Roughly 45 percent of the time, the current was flowing "onshore." Roughly 55 percent of the time it was flowing "offshore." Another demonstration of the asymmetry of the oscillatory current field is the skewness of the distribution in the tails. Only 2 percent of the velocities exceed 0.5 m/sec (1.6 ft/sec) in the "offshore" direction, while 11 percent of the velocities exceed it in the "onshore" direction.

All of the presentations of the 0300 1 August 1989 data indicate an asymmetry of the oscillatory wave-driven, near-bottom current field. The cumulative probability distribution shown in Figure 17, the scatter plot of the 1,024 velocities shown in Figure 16, and the sample of the data plotted with time in Figure 15 all support the concept that forward velocities under

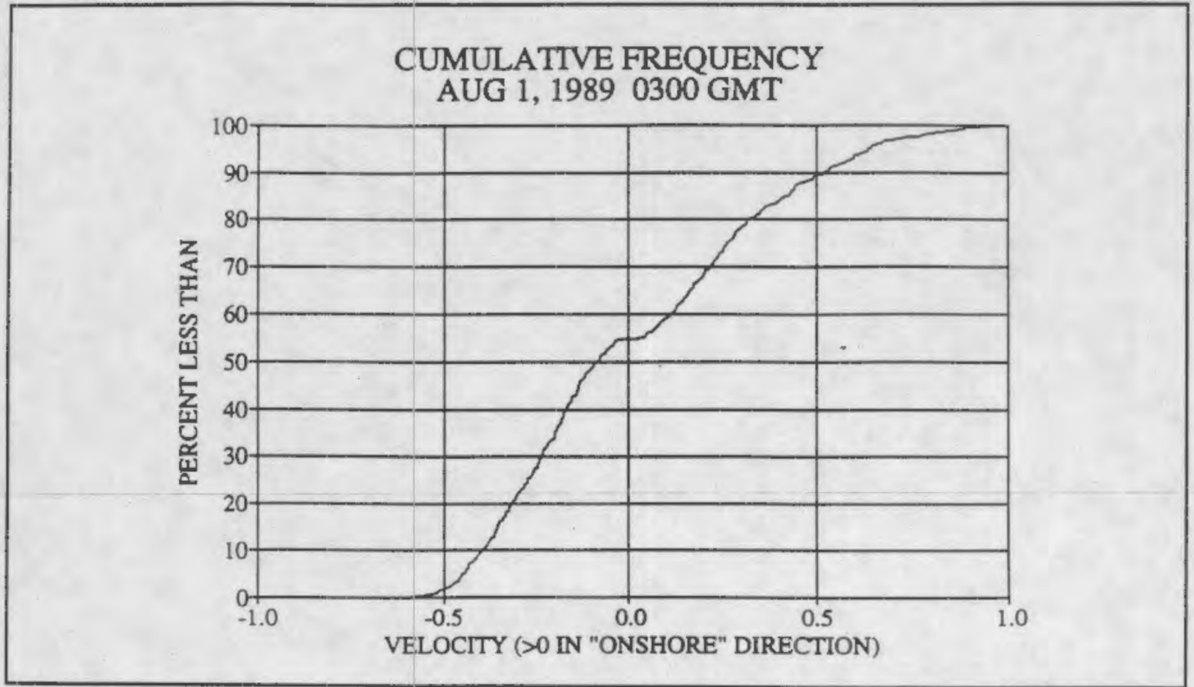

Figure 17. Cumulative distribution of instantaneous velocity vectors resolved along the axis of wave propagation during Chantal swell (0300-0317 hr GMT, 1 August 1989)

the wave crests exceed the return flow under the wave troughs for the selected burst.

In summary, the wave-dominated episode from the passage of Chantal produced near bottom velocities which clearly were sufficient to move the sand on the berm, even when the mean currents were very small. Also, the asymmetry of the currents indicates a preference for onshore movement during the storm, which corresponds with the observed direction of mound migration. Given the measured currents during Chantal and the fact that the highest mean currents during the 4-year study occurred when Tropical Storm Florence passed nearby, it is clear that tropical storms and hurricanes are likely to play an important role in berm migration for this area. However, it should be recognized that extratropical storms occur with a much greater climatological frequency. Thus, frontal systems may actually play a greater role in mound migration in this area. Available data are insufficient to determine objectively which type of storm is actually dominant. Neither can be neglected.

Strong-mean dominated event

The 0900 31 July observation at the beginning of the Chantal record discussed above will be used here as an example of a near-bottom current field which is dominated by a strong uni-directional component. The magnitude, direction, and steady nature of the 0900 31 Jul current observations are apparently not unusual for the site. During the previous month, the mean current was exceeded once and was almost equaled several times. Obviously, the presence of a tropical storm in the gulf would have affected the mean currents at the gauge in late July-early August. Thus, this strong, near-steady flow may be due to a shelf circulation response with some contribution from a strong-mean driven event. Magnitudes and directions correspond with those of roughly 28 days earlier, at 1500 on 2 July. Specifically, the mean currents were 0.33 m/sec (1.08 ft/sec) to the east-southeast and 0.29 m/sec (0.95 ft/sec) to the east-southeast, the maximum single current observations were 0.52 m/sec (1.71 ft/sec) and 0.53 m/sec (1.74 ft/sec), the wave heights and periods were H_{mo} = 0.76 m (2.79 ft) and 0.82 m (2.69 ft), T_p = 5.95 sec and 5.02 sec, at 1500 on 2 July and 0900 on 31 July, respectively. Instantaneous current records for 1500 on 2 July and 1500 on 3 July (not shown) appear very similar to that shown for 0900 on 31 July. In conclusion, the currents at 0900 on 31 July 1989 are not abnormal for the area. Regardless of the cause of the currents, the 0900 July 1989 data show a strong mean current with wave-driven oscillations.

Because berm surveys did not show any east-west or offshore berm movement, it is evident that mean currents are not the dominant mechanism controlling berm fate at this site. This finding contrasts with that of Scheffner (1991) who inferred that berm migration at this site was controlled by a hypothesized landward mean current. The extensive current data used in this report do not contain a landward current as hypothesized. However, these data were not available when Scheffner performed his work.

Comparison of the strong-mean and wave-dominated currents

This section compares and contrasts two of the records discussed above in terms of their ability to move sediment. The two records provide a convenient comparison between strong-mean and wave-induced bottom currents. The record for 0900 on 31 July is assumed to be typical of strong-mean flows which occur several times per month. The 0300 1 August record is assumed to be a single representation of long-period waves which occur aperiodically. The following discussion compares the two records using a number of different parameters including mean currents, typical current magnitudes, maximum instantaneous currents, mean current directions, net currents above a threshold velocity, and higher moments. The values of the parameters discussed below are summarized in Table 2. Results indicate that some of the simpler, more common, parameters (such as mean current) give different pictures of sediment-moving capabilities than the more complex parameters. For simplicity throughout the following discussion, the 0900 31 July record is referred to as the "strong-mean flow example" and the 0300 1 August record is referred to as the "storm-wave example."

Table 2
Summary of Parameters Comparing "Strong-Mean" and "Storm Wave" Example Events

Parameter	Example Events	
	July 31, 0900 (Strong-Mean)	August 1, 0300 (Storm Wave)
Mean velocity	0.28 m/sec (0.92 ft/sec)	0.08 m/sec (0.26 ft/sec)
Typical velocity	0.31 m/sec (1.02 ft/sec)	0.30 m/sec (0.98 ft/sec)
Max. velocity	0.53 m/sec (1.74 ft/sec)	1.02 m/sec (3.35 ft/sec)
Direction of mean velocity (full burst)	ESE	NW
Direction of mean velocity (V>0.4 m/sec (1.31 ft/sec) only)	ESE (no shift)	ENE (70° shift)
$<V^3>$	0.033 m^3/sec^3 (0.04 yd^3/sec^3)	0.060 m^3/sec^3 (0.08 yd^3/sec^3)
$<V^3>$ (V>0.3 m/sec (0.98 ft/sec) only)	0.025 m^3/sec^3 (0.03 yd^3/sec^3) (75% of total)	0.055 m^3/sec^3 (0.72 yd^3/sec^3) (90% of total)
$<V^3>$ (V>0.4 m/sec (1.31 ft/sec) only	0.004 m^3/sec^3 (0.01 yd^3/sec^3) (12% of total)	0.047 m^3/sec^3 (0.06 yd^3/sec^3) (80% of total)

Considering mean currents, the strong-mean flow example mean currents (0.30 m/sec (0.98 ft/sec)) are larger than the storm-wave example mean currents (0.08 m/sec (0.30 ft/sec)). However, the mean current is apparently misleading when considering the sediment-moving capabilities of the current field. Figure 15 shows much wave-induced oscillation that would "agitate" the bottom and suspend sediments.

Considering the typical current, the average magnitude of the instantaneous current observation, the storm-wave example currents (0.30 m/sec (0.98 ft/sec)) are about the same as the strong-mean flow example currents (0.31 m/sec (1.02 ft/sec)). Magnitudes of the instantaneous velocities are calculated as the square root of the sum of the squares of the two velocity components, $V = (u^2 + v^2)^{0.5}$. These instantaneous speeds are thus not affected by the directions of the instantaneous velocities. The average of these values is a measure of the typical bottom velocity during the 17-min burst record.

Considering the maximum instantaneous current measured during the 17-min burst, the storm wave example currents (1.02 m/sec (3.35 ft/sec)) are about twice as large as the strong-mean flow currents. The maximum instantaneous current was the largest single value in the 1,024-sample record of the magnitudes.

Considering the direction of the mean currents, the storm wave example currents are in a different direction (northwest) than the strong-mean flow example currents (east-southeast).

Considering a velocity threshold criteria for sediment motion changes the inferred direction of net motion for the storm wave example, but not the strong-mean flow example. Assuming sediment does not move when the instantaneous measured magnitude $V = (u^2 + v^2)^{0.5}$ is below some threshold value V_{crit} is a first approximation of the effects of threshold concepts. As V_{crit} is increased through 0.2 to 0.4 m/sec (0.66 to 1.31 ft/sec), the direction of inferred net sediment transport during the storm wave example period changes from northwest through north to east-northeast. This shift in inferred net direction of sediment transport occurs because the smaller current values drop out of the analysis, leaving only the forward and reverse flows under the crest and troughs of the swell, which are propagating in a direction 30 deg east of north. Interestingly, the small mean current during the wave-dominated event is roughly at right angles to the direction of wave-induced oscillations. Changing assumed threshold values does not change the inferred direction of sediment transport during the more steady, strong-mean flow example.

This simple approximation of threshold effects does not account for several physical aspects such as bottom shear stress or the time history of currents. Although there are a number of different proposed relationships between transport and water velocity, all give transport as a function of some form of higher order moment such as velocity squared or cubed. The average values of the instantaneous velocity magnitudes cubed are $<V^3> = 0.033$ m^3/sec^3 and 0.060 m^3/sec^3 for the storm-mean flow and storm wave examples, respectively. Assuming transport to be a function of $<V^3>$, the storm-wave event has about twice the sediment-moving capability of the strong-mean event.

The two concepts discussed above, higher moments and a threshold velocity, can be combined. Assuming no sediment motion when V does not exceed V_{crit} dramatically affects the velocity-cubed results given above. For the strong-mean flow example, the values of velocity cubed are very sensitive to this V_{crit} assumption. For a threshold of 0.3 m/sec (0.98 ft/sec), the mean of the cubed value is 0.025 m^3/sec^3, or 75 percent of the full value. For a V_{crit} = 0.4 m/sec (0.66 ft/sec), $<V^3> = 0.004$ m^3/sec^3, or 12 percent of the full value. The storm wave example is not nearly as sensitive to the V_{crit} assumption; $<V^3> = 0.055$ to 0.047 m^3/sec^3, or 90 to 80 percent of the full value as V_{crit} is varied from 0.3 to 0.4 m/sec (0.98 to 1.31 ft/sec). Thus, considering a realistic range of V_{crit} for the known grain size, the storm event had between twice and ten times the sand-moving ability of the strong-mean event.

White (1989) found that although threshold considerations do not significantly affect sand transport in the energetic surf zone, they are needed to properly model direction of transport just beyond the surf zone. Alabama current measurements indicate that threshold considerations are important to both direction and magnitude of transport at berm sites.

Southerly seas followed by frontal passage

On October 21-22, 1990, PUVSI-5 captured two flow conditions typically encountered during the fall and winter at the Sand Island Berm. Because the NDBC buoys had been removed the previous month, winds from the Bates' Field Airport, located 70 km (37.8 miles) north are used as indicative of the general wind changes during this event. On 21 October, winds between 5.1 and 7.7 m/sec (10 and 15 knots) blew from the southeast, creating a choppy sea condition with wave heights between 0.75 and 1.0 m (2.5 and 3.3 ft) for over 24 hr. The next day the wind shifted around from the north as a cold front moved into the area from the central United States. This meteorological condition is typical for this area in the fall and winter. Wave heights on the berm decayed from 0.84 to 0.73 to 0.58 m (2.76 to 2.4 to 1.9 ft) from 0400 to 0800 to 1200 on 22 October and continued to decrease to 0.39 m (1.28 ft) by 2400. These changes are consistent with expectations for a rapid, frontal shift to an opposing wind which decays the sea. As the front passed, and the wind shifted from blowing from the south to blowing from the north, the average currents measured near the bottom switched from flowing toward the south to flowing toward the north. This shift is consistent with coastal upwelling/downwelling being driven by mass transfer due to winds and waves.

Plots of eight 1-min records of the instantaneous current observations are shown in Figure 18 for 1600 to 1607 on 21 October when the wave heights were at their maximum, 0.98 m (3.22 ft). The wave agitation is visible. The records also show some "surf beat" or wave-group-like phenomena as components of the wave field got into and out of phase. Figure 19 shows the same information after the northerly wind has knocked the wave heights down to 0.51 m (1.67 ft).

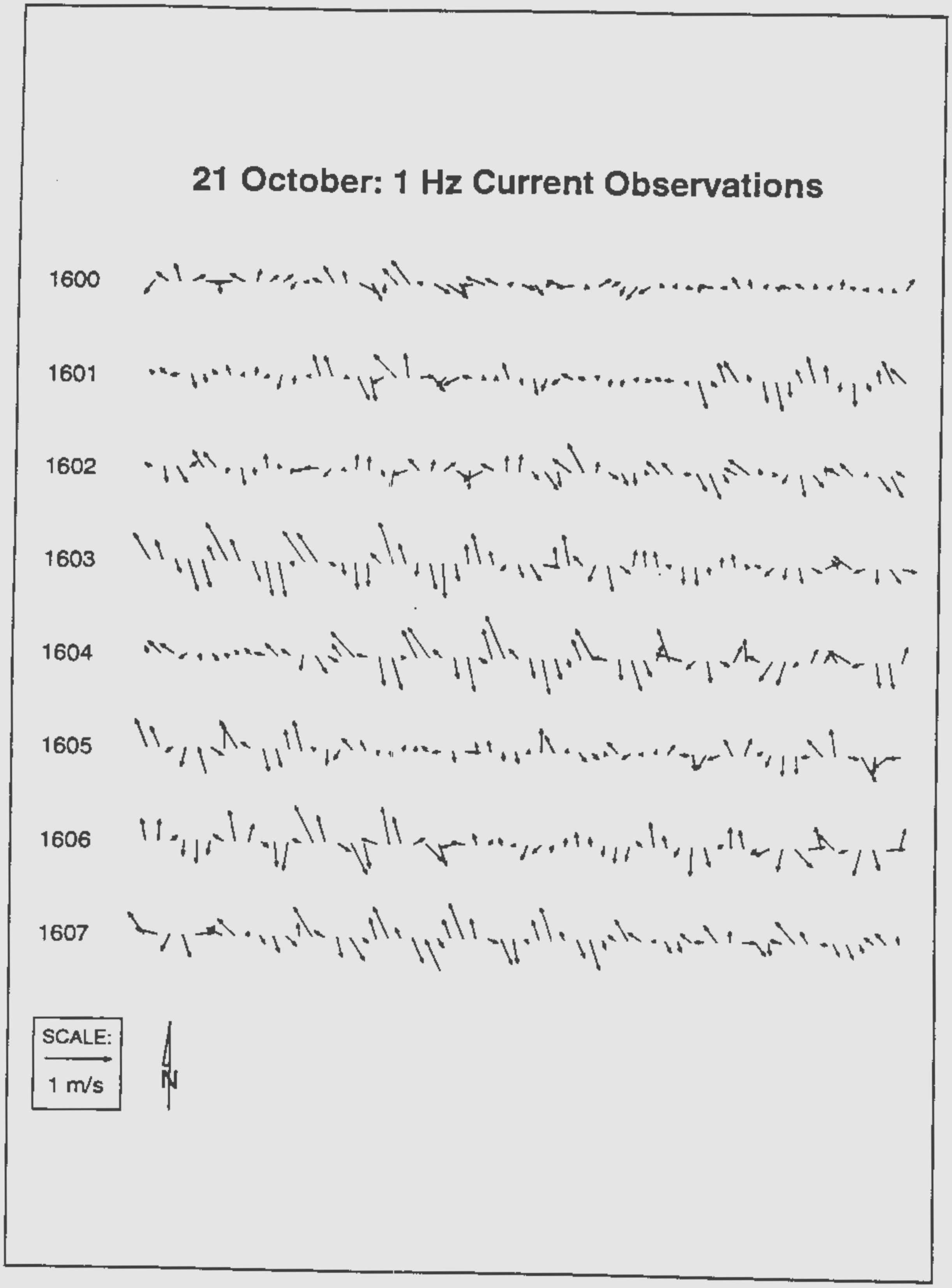

Figure 18. Instantaneous current vectors measured at 1 Hz at 1600-1607 on 21 October 1990 (southerly wind sea)

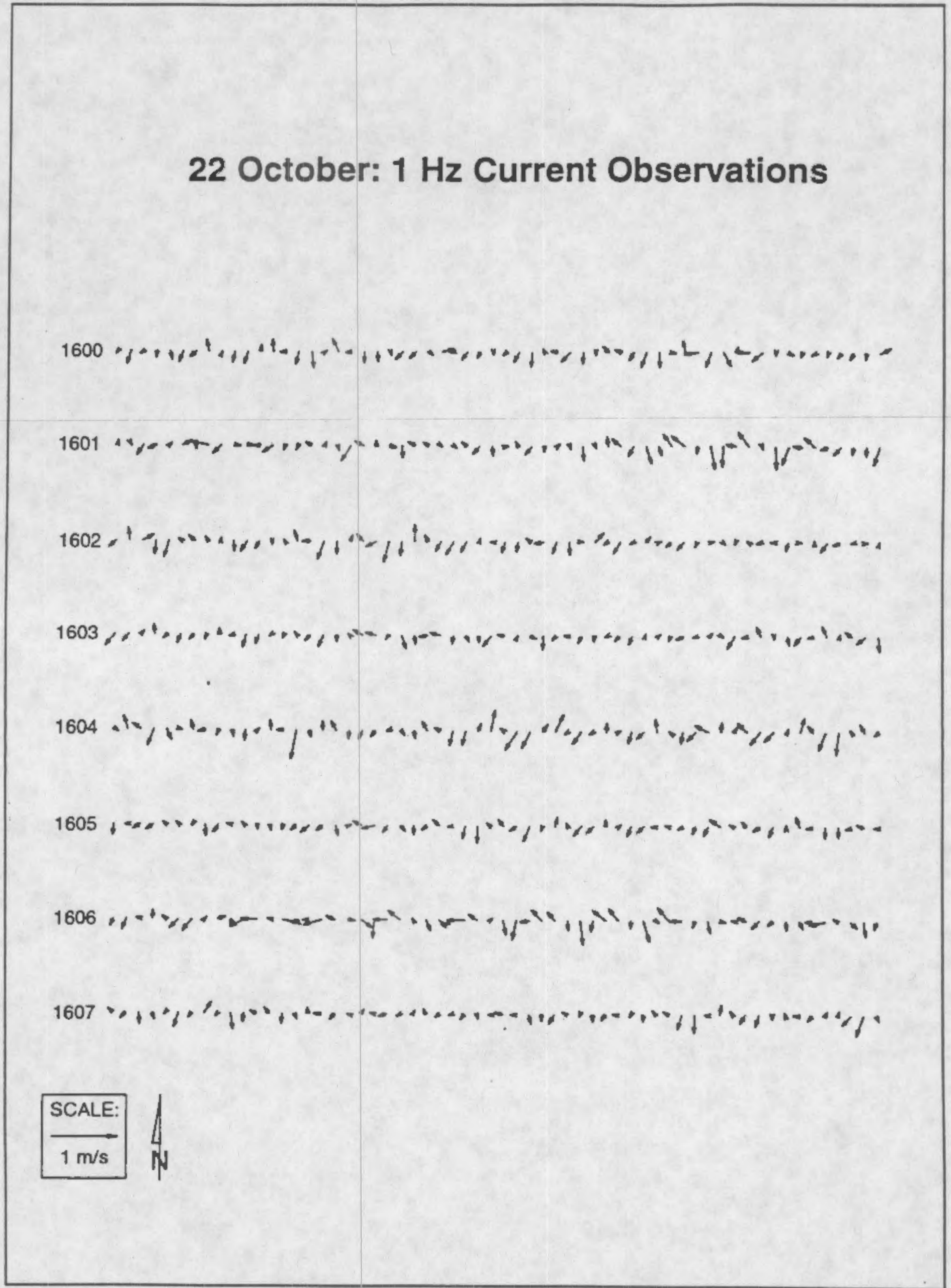

Figure 19. Instantaneous current vectors measured at 1 Hz at 1600-1607 on 22 October 1990 (northerly frontal winds)

5 Conclusions

McGehee et al. (1994) provide details on the gauges and collection of wave and current data analyzed in this report. Conclusions reached here regarding the dominant mechanisms affecting mound stability are based on analysis of these process measurements plus movement of the Sand Island Mound and the Sand Island Bar toward the north-northwest, as reported earlier (Hands 1991, 1992, 1994). Examples of this progressive mound migration are shown in Figure 2 of this report. This motion is toward the coast and in the general direction of large wave propagation. Relative to the five hypothesized mechanisms discussed earlier, the following results have been found.

a. Related to the possibility that northward currents at on-mound sites are larger than at off-mound sites, it was found that *mean currents were directed toward the offshore at both on-mound and most of the off-mound sites.* Alongshore mean currents were somewhat larger than the on-offshore currents; so if mean currents play a dominant role in mound migration, the mound should not simply migrate shoreward as reported. *Furthermore, there was no overall mean current directed toward shore to support the hypothesis that mean currents controlled the landward migration of the berms.*

b. Concerning a positive correlation between sediment entrainment and northward currents, *large waves were found more likely to be accompanied by mean currents in the offshore direction. This means that the observed correlation also fails to explain northward mound migration.*

c. Concerning nonlinearities in currents, coefficients of landward skew were found to increase for larger waves. This could explain a tendency for northward sediment transport. Specific events with skew were the passage of a hurricane and southerly seas related to typical winter weather patterns. *However, coefficients of skew at off-mound sites were equivalent to those at on-mound sites; consequently, this mechanism by itself would be expected to result in northward sediment transport at all depths along this entire stretch of coast.*

d. *Regarding the possibility that temporal organization of the currents is different at on- and off-mound sites, little or no difference was found.*

e. Concerning the possibility that feedback between currents and transport exists which relates to large-scale deviations from an equilibrium profile, *it is hypothesized* that such a mechanism, with or without the landward skew in near-bottom orbital velocities, could explain observed mound migration. If verified, this concept could be used to design disposal mounds to maximize or minimize landward transport depending on which berm benefits were appropriate for the specific site and materials under consideration. However, *this is only speculative at present* and deserves additional study. If such a feedback mechanism plays a large role here, it's probably a fairly universal mechanism.

6 Recommendations

Additional analysis of the Alabama long-term process data should further investigate nonlinearities in peak orbital speeds, feedback with the berm, and the relationship of nonlinearity and feedback to rates of berm movement.

Additional data are needed to document how nonlinearities change spatially over berms. Obtaining these data will require simultaneous field measurements across a berm, followed by verification of gradients over different geometries in the laboratory or field.

Until the feedback mechanism is better understood, it seems prudent to include high relief as a design feature of any feeder berm. Not only will high relief allow smaller footprints, less expensive monitoring, and easier tracking of berm movement, but initial analysis suggests that higher relief will increase landward movement. Smaller relief diminishes wave attenuation because the sediment is exposed to slower orbital speeds. Smaller berm relief also results in diminished feeder benefits because the berm is exposed to more linear wave oscillations. Conservation of sediment in the berm form and preferential landward berm migration may be related to feedback between the current and artificially steepened slopes on seaward and leeward flanks of high-relief berms.

References

Andrassy, C. J. (1991). "Monitoring of a nearshore disposal mound at Silver Strand State Park." *Proceedings of Coastal Sediments 91 Conf.* American Society of Civil Engineers, New York, 2, 1970-1984.

Aubrey, D. G., and Trowbridge, J. H. (1988). "Reply: Comment on kinematic and dynamic estimates from electromagnetic current meter data," *Journal of Geophysical Research* 93(C8), 1344-1346.

Guza, R. T. (1988). "Comment on kinematic and dynamic estimates from electromagnetic current meter data," by D. G. Aubrey and J. H. Trowbridge, *Journal of Geophysical Research* 93, 1343-1347.

Guza, R. T., Clifton, M. C., and Rezvani, F. (1988). "Field intercomparisons of electromagnetic current meters," *Journal of Geophysical Research* 93(C8), 9302-9314.

Hallermeier, R. J. (1981). "A profile zonation for seasonal beaches from wave climate," *Coastal Engineering* 4(3), 253-277.

Hands, E. B. (1991). "Wide-area monitoring of Alabama berms," *Proceedings of the Offshore Technology Conference.* Marine Tech. Soc., New Orleans, LA, 1, 98-105.

________. (1992). "Monitoring of Alabama berms," *Dredging Research Technical Notes* DRP-1-08, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

________. (1994). "Shoreward movement and other 5-year changes at Sand Island, Alabama." *Proceedings of the Western Dredging Association Conference, San Diego, CA.* Center for Dredging Studies, College Station, TX, 223-235.

Hands, E. B., and Allison, M. C. (1991). "Mound migration in deeper water and methods of categorizing active and stable depths," *Proceedings of Coastal Sediments 91 Conf.* American Society of Civil Engineers, New York, 2, 1985-1999.

Hands, E. B., and Bradley, K. P. (1990). "Results of monitoring the disposal berm at Sand Island, Alabama: Report 1, Construction and first year's response," Technical Report DRP-90-2, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hands, E. B., and Resio, D. T. (1994). "Empirical guidance for siting berms to promote stability or nourishment benefits," *Proceedings of the 2nd International Conference on Dredging and Dredged Material Placement, Buena Vista, FL.* American Society of Civil Engineers, New York, 220-228.

Hartman, G. L., Ogston, A., and Hanson, M. (1991). "Analysis of transport processes on ocean disposal mound." *Proceedings, Coastal Sediments 91 Conf.* American Society of Civil Engineers, New York, 2, 2027-2036.

Healy, T., Harms, C., and deLange, W. (1991). "Dredge spoil and inner shelf investigations off Tauranga Harbour, Bay of Plenty, New Zealand." *Proceedings of Coastal Sediments 91 Conf.* Amer. Soc. of Civil Engineers, New York, 2, 2037-2051.

McGehee, D., McKinney, J. P., Grogg, W. E., and Hands, E. B. (1994). "Monitoring of waves and currents at the dredged material mounds offshore of Mobile, Alabama," Technical Report DRP-94-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scheffner, N. W. (1991). "A systematic analysis of disposal site stability." *Proceedings, Coastal Sediments '91.* Seattle, WA, 2012-2026.

Steele, K. E., Wang, D. W., Teng, C., and Lang, N. C. (1990). "Directional wave measurements with NDBC 3-meter discus buoys," U.S. Department of Commerce, National Data Buoy Center, Stennis Space Center, MS.

White, T. E. (1989). "Using sediment-threshold theories in waves and currents." *Proceedings, Sediment Transport Modeling, New Orleans, Aug 1992.* American Society of Civil Engineers, New York, 248-253.

Wright, L. D. (1987). "Keynote address to Coastal Sediments 87: Shelf-surfzone coupling: Cross-shore transport mechanisms on the shoreface." *Proceedings of Coastal Sediments 87 Conf.* American Society of Civil Engineers, New York, 1, 25-40.

Wright, L. D., Boon, J. D., Kim, S. C., and List, J. H. (1991). "Modes of cross-shore sediment transport on the shoreface of the Middle Atlantic Bight," *Marine Geology* 96, 19-51.

Appendix A
Notation

D	Water particle displacement
H_{mo}	Spectral significant wave height
P	Instantaneous pressure
$T(z)$	Rate of vertical sediment flux past a unit horizontal area at a level z above the bottom
T_p	Period of the peak of the energy density spectrum
U	East-west component of the water current velocity (see Figure 1)
$\bar{u}$	East-west mean current velocity
u'	Demeaned east-west instantaneous current velocity
$\hat{u}'$	Normalized current velocity in the east-west direction
V	Magnitude of instantaneous velocity vector
v_{crit}	Threshold velocity for sediment transport
v	North-south component of the water current velocity (see Figure 1); mean current vector
$\bar{v}$	North-south mean current velocity
v'	Demeaned north-south instantaneous current velocity
$\hat{v}'$	Normalized current velocity in the north-south direction
$w'(z)$	Deviation in vertical velocity around some mean value at level z (i.e., turbulent velocity fluctuations in the vertical)
x	Horizontal distance
y	Horizontal distance
z	Vertical distance

$\rho'(z)$	Deviation from the mean volumetric sediment concentration at level z
σ_u	Root-mean square of east-west velocities
σ_v	Root mean square of north-south velocities

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13. ABSTRACT *(Maximum 200 words)*

Repeated bathymetric surveys have shown persistent movement of hundreds of thousands of cubic meters of sand at two submerged berms off the Alabama coast. Over a 4-year period, bidirectional current measurements were made on top of and offshore of these migrating sand berms. These process data are used here to assess fundamental transport mechanisms that potentially could account for such berm movement.

A simple conceptual model of sediment mechanics is proposed with five fundamental transport mechanisms that are evaluated against flow measurements. Certain transport mechanisms were, as a result, eliminated from further consideration. Other mechanisms were supported by the measurements and deserve further study.

14. SUBJECT TERMS

Berms	Monitoring disposal sites	Sediment fate predictions
Bottom currents	Mounds	Velocity asymmetries
Dredged material uses	Nearbed hydrodynamics	Wave measurements

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