CHAPTER ONE HUNDRED TWENTY EIGHT

DUCK82 - A COASTAL STORM PROCESSES EXPERIMENT

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Abstract: In October, 1982, a multi-agency nearshore processes experiment was conducted at Duck, NC to measure the nearshore morphological response to storm-induced waves and currents. The experimental setting for a series of companion papers is described, as are the oceanographic and meteorological characteristics of the storms. Rapid changes to the nearshore bar system occurred during the early stages of the first storm, and the bar developed a pronounced crescentic configuration during subsequent periods of high waves. Much of this activity is attributed to the effects of infragravity waves having periods greater than 30 seconds.

Introduction

Background. In recent years, several field experiments have been conducted to define nearshore processes and sediment transport patterns under "normal" wave and wind conditions. Large arrays of wave and current measuring sensors, combined with bathymetric surveys, have provided preliminary evidence of complex relationships between forcing processes and sediment response. To date, however, lack of both rugged instrumentation and a means to survey nearshore areas during high wave conditions have precluded measurements of storm-related nearshore processes.

To document the response of a typical East Coast site to extratropical storms (northeasters), a cooperative experiment known as DUCK-82, was conducted in October, 1982 at the Field Research Facility (FRF) of the U. S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, Miss. Participating in the experiment were investigators from the FRF, the U. S. Geological Survey, Oregon State University, and the University of Washington. Newly developed sensors and equipment were deployed which, for the first time, allowed a comprehensive analysis of the processes affecting the magnitude and time scale of short-term nearshore response.

The objectives of the experiment were to define the two and three-dimensional response of a coastal area extending from a well developed

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fore-dune system to about the 7 m (22 ft) water depth; to measure the waves, currents, winds, and other forces producing this response; and to determine the relative importance of these forces in controlling the observed sedimentary response.

This paper discusses the experimental setting and methods, the meteorological and oceanographic characteristics of two storms affecting the study area, and the resulting nearshore morphological response. Finally, five ICEE-84 papers addressing other aspects of the experiment are introduced. Birkemeier (3) provides perspective for these short-term studies by describing long-term changes to selected profiles at the same site.

Experiment Description

Site. The Field Research Facility is located near Duck, NC on the northern end of North Carolina's Outer Banks (Figure 1), a long narrow string of barrier islands fronting the Atlantic Ocean. Offshore contours (6 to 15 m, 19 to 49 ft, water depths) in the vicinity of the FRF are generally straight and shore-parallel, although there is a deep trough in the immediate vicinity of the FRF research pier (1). Along the beaches and in water depths less than about 6 m (19 ft), changes in morphology can be large and rapid.

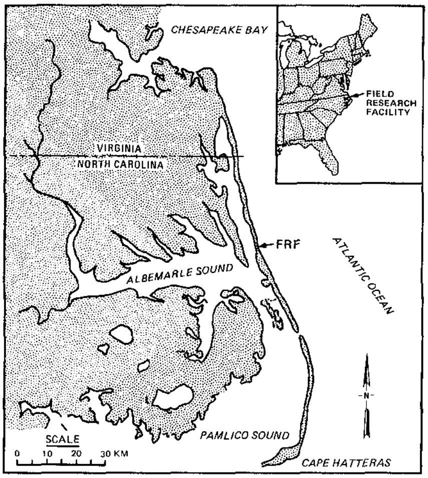


Figure 1. Location of study area

Sediments in the area vary greatly in size. The foreshore typically exhibits a bi-modal size distribution comprised of a coarse (~1 mm) fraction interspersed with finer (~0.3 mm) sands, with a median size of about 0.75 mm. Offshore, sands decrease in median size from about 0.2 mm on the nearshore bar to less than 0.1 mm in 20 m (65 ft) of water.

Experimental Design

Nearshore Process Data Collection. The experimental design required a wide variety of instrumentation to be operated simultaneously and at frequent intervals during storms. Four Marsh-McBirney electromagnetic current meters and seven Baylor staff wave gages were located on the FRF pier (Figure 2), and a Waverider[R] buoy wave gage was located 3 km (2 mi) offshore in 20 m (65 ft) of water. A Weathermeasure anemometer located on the FRF building at an elevation of +19 m (+62 ft) MSL provided wind speed and direction information.

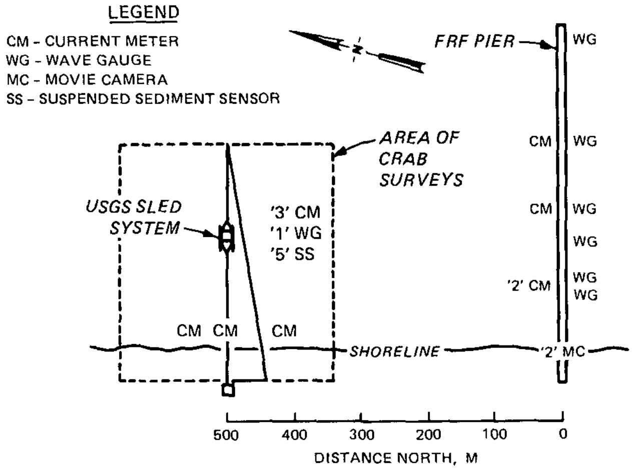


Figure 2. Experiment configuration

A large sea sled specially designed for storm use (9), Figure 3, was towed by a double-drum winch and triangular line arrangement along a shore-normal transect about 457 m (1485 ft) north of the pier to measure storm-induced waves, currents, and suspended sediment. Mounted on the sled was a vertical array of electromagnetic current meters (0.5, 1.0 and 1.75 m, 1½, 3 and 5½ ft, above the bottom), a pressure wave gage, and an optical suspended sediment meter. Data from these instruments were telemetered to a shore-based data collection system. Movie cameras at the shore end of the pier provided data for measurement of wave runup (5).

Nearshore Surveys. Fifteen profile lines were established within the survey area near the north boundary of the FRF (Figure 2) to determine the three-dimensional morphological response to storms. The profiles were 23 m (75 ft) apart, over 300 m (975 ft) long, and extended over a longshore distance of 320 m (1040 ft). The southernmost profile was 340 m (1105 ft) north of the FRF pier, sufficiently distant to be outside any pier influence. The center profile was surveyed with the USGS sled system using a Hewlett-Packard infrared total station and optical prisms on top of the sled's 10 m (33 ft) mast. Approximately 20 minutes were required to measure each profile. Since the sled had

Figure 3. USGS sea sled

previously operated in plunging breakers in excess of 5 m (16 ft), it was anticipated that profiles could routinely be obtained throughout any storm expected to occur at the site.

The other 14 profiles were measured using the FRF's Coastal Research Amphibious Buggy (CRAB), Figure 4, and Zeiss Elta-2 total station system (2). The CRAB is a motorized 10.6 m (35 ft) high wheeled tripod supporting an operating platform and a set of optical prisms which reflect the Zeiss' infrared beam. Vertical and horizontal accuracy of this system is about ± 5 cm, and about five hours were required to measure the three-dimensional morphology. CRAB operations were suspended when wave heights exceeded 2 m (6½ ft), and strong longshore currents occasionally prevented the CRAB from crossing the triangular tow line of the sea sled to obtain data near the sled profile line.

To define micro-scale processes of foreshore deposition and erosion, a tightly-spaced grid of steel pins was emplaced for high-frequency sampling of bed elevations within a small portion of the main survey area (6).

Storm Characteristics

Figure 5 shows the time history of waves and winds prevailing at the FRF site during October. Fortuitiously for the experimental plans, two northeasters provided typical storm conditions in mid and late

Figure 4. Coastal Research Amphibious Buggy (CRAB)

October, 1982. The first of these storms began to affect the study area early on the morning of 10 October. Northeast winds reached a maximum sustained speed of 13 m/s (30 mph), and wave heights rapidly increased to over 2 m (6½ ft) by 1000 on the 10th. As the storm moved offshore, winds slowly abated, and within 24 hours had decreased to only about 7 m/s (16 mph). However since the storm center moved almost due east (Figure 6), it continued to generate large waves, and significant wave heights in excess of 2 m (6½ ft) were measured by the Waverider^R buoy until 0200 on the 13th. The maximum height of 2.6 m (8½ ft) occurred at 1200 on the 12th.

Peak wave periods during the early part of the storm averaged about seven seconds (Figure 5), reflecting the locally-generated nature of the waves. As the storm moved offshore, a gradual shift in the peak period to higher values occurred. On the evening of the 11th, the peak period was 13 seconds, and by noon on the 12th it had reached 17 seconds. Wave spectral plots (Figure 7) clearly show the shift in peak period that occurred between the 10th and 11th, as well as the concurrent change from a multi-modal to a uni-modal spectra.

Longshore currents measured along the sled line were southward during the storm, reaching a maximum of about 1 m/sec (3 ft/sec) on the 10th. As the storm moved eastward, the wave approach angle changed from northeast to southeast, producing a change in the longshore current direction such that by the 12th, currents were directed northward.

The second storm of the season, between 23 and 25 October, was considerably more severe than the first. Winds from the northeast increased gradually to a maximum sustained speed of 23 m/sec (51 mph) on the evening of the 24th (Figure 5), with a concurrent increase in significant wave height to a maximum of over 4 m (13 ft) shortly thereafter. Peak periods remained between 6 and 9 seconds (Figure 7), with

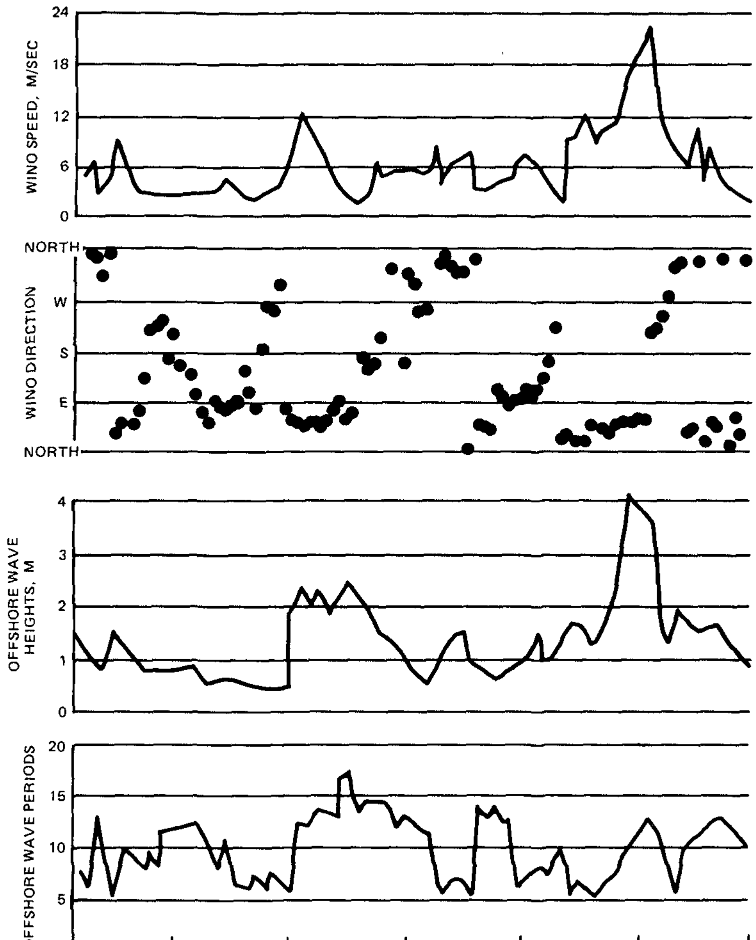


Figure 5. Wind and wave conditions, Oct 82, Duck, NC

only slight indications of energy at longer periods.

Longshore currents were directed southward at about 0.5 m/sec (1½ ft/sec) during most of the storm, but reversed direction at about 2200 on the 24th, reaching a maximum northward speed of 0.7 m/sec (2 ft/sec) at 0500 on the 25th. Radar images obtained during the storm clearly show that the direction of wave approach changed gradually from a northeast angle on the 24th to a southeast angle by 0730 on the 25th,

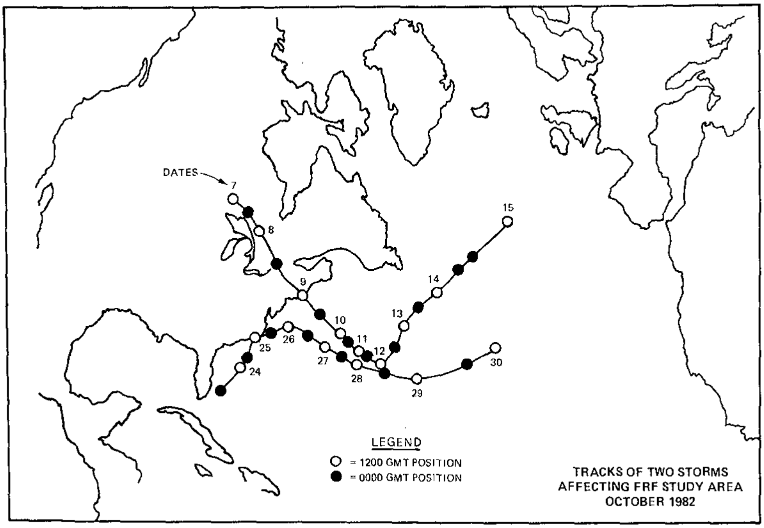


Figure 6. Storm tracks, Oct 82 (after NWS)

and wind data indicate a similar shift in direction (Figure 5) as the storm center moved northward past the site (Figure 6).

Morphological Response

This section describes the two and three-dimensional response of the nearshore study area to the storm of 10-15 October 1982, and the two-dimensional response to the storm of 23-25 October.

The first three-dimensional survey was completed on 7 October prior to the first storm. The next was completed on 13 October, when wave conditions had subsided sufficiently to allow deployment of the CRAB. Full surveys were also completed on the 15th and 19th. Profile data from the single sled profile line were obtained twice daily throughout the first storm and the subsequent recovery period, but a severely abraided tow line precluded sled operations during the second storm. Therefore, CRAB profiles were used for interpreting late-October nearshore profile changes.

Inner Bar Changes

Prior to the first storm, nearshore morphology was characterized by a well-developed berm and relatively small nearshore bar (Figure 8a). The bar crest was about 0.3 m (1 ft) above the trough level, and was positioned only 13 m (42 ft) offshore. The bar was relatively linear and shore-parallel, although some irregularities were apparent at the northern end of the survey area (Figure 9a).

During the storm, the bar crest at the sled line migrated offshore 57 m (185 ft), Figure 8a. Thirteen meters (42 ft) of this migration

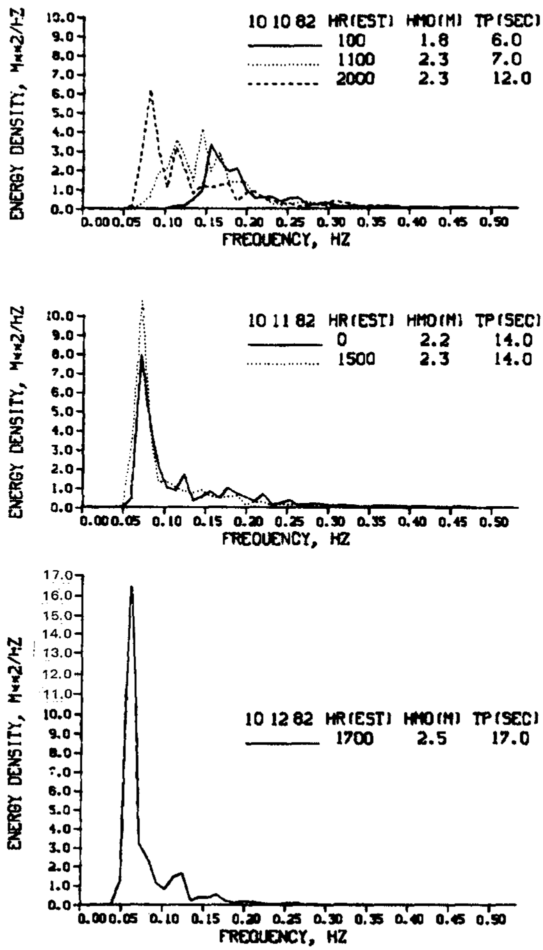
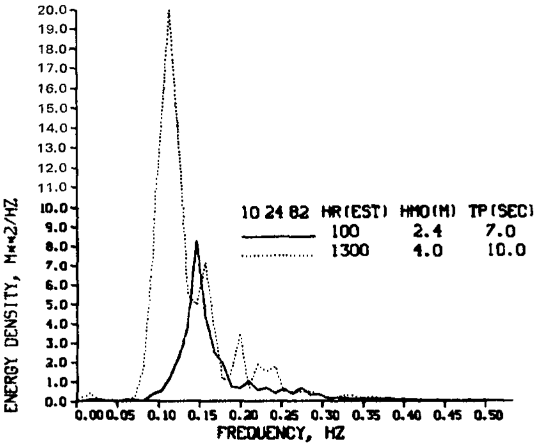


Figure 7. Wave spectra, FRF offshore Waverider[R], October 1982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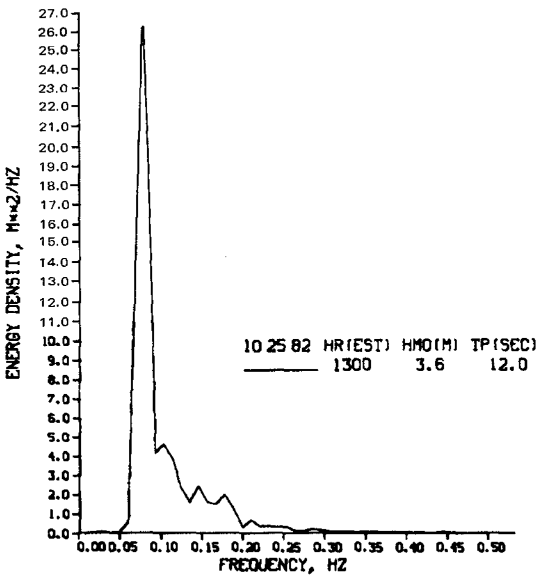
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occurred over a six hour period on the 10th, yielding a very rapid migration rate of 2.2 m/hr (7 ft/hr). Between the 10th and 11th, the bar was stable, while between the 11th and 12th, it again migrated offshore, at a rate of 1.4 m/hr (4½ ft/hr). Since the CRAB could not operate due to high waves, the three-dimensional characteristics of the inner bar during the storm could not be determined, although seaward movement of the entire bar crest is hypothesized.

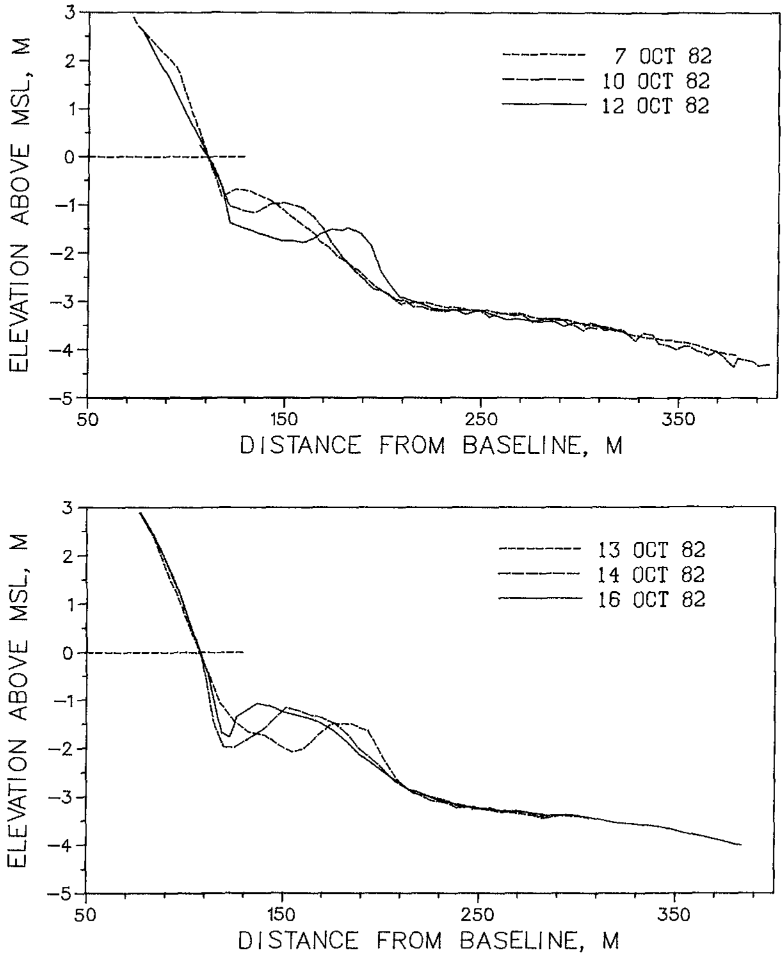

Figure 8. Sea sled profiles, 7-16 October 1982

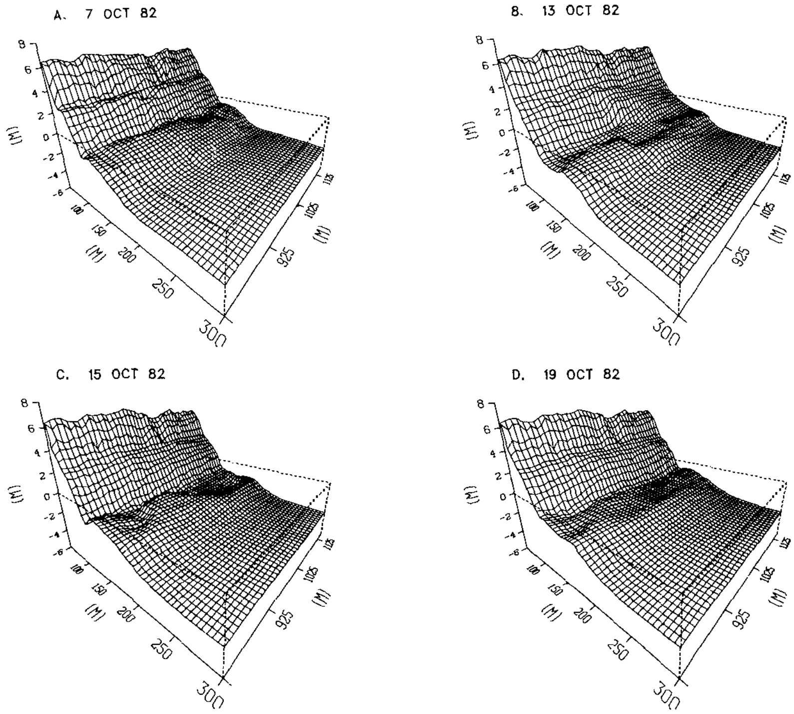

Figure 9. Three-dimensional plots of nearshore bathymetry

On the 13th, the day after the period of peak incident energy, the nearshore bar appeared to be roughly crescentic (Figure 9b). Between the 13th and 15th, the crescentic shape became better developed and by the 15th had reached a classic crescentic configuration. The longshore wave length was approximately 205 m (666 ft) and the cross-shore distance to the crescentic bar crest was about 70 m (227 ft).

In addition to becoming better developed, the bar system also appeared to have migrated northward about 40 m (130 ft), Figures 9b and 9c. This migration and the developing crescentic form caused nearshore profiles to change very differently depending upon longshore location. For example, between the 13th and 15th, the bar at the sled line showed an apparent landward migration of 36 m (117 ft), whereas during the same period only 69 m (224 ft) northward the bar migrated offshore 18 m (58 ft). These changes were occurring very rapidly even though wave energy was decreasing. For example, over a 24 hour period on the 13th and 14th, the bar crest on the sled line migrated onshore at the rate of 1.2 m/hr (5 ft/hr). Between the 14th and 16th, this rate decreased to 0.5 m/hr (1½ ft/hr), Figure 8b.

Between 15 and 19 October, the inner bar migrated landward, and by the 19th had disappeared, leaving a platform similar to that of 7 October.

Outer Bar Changes

Prior to the first storm, there was no indication of an outer bar on the profile. However, during that storm a small amount of deposition occurred about 350 m (1137 ft) seaward of the baseline (Figure 10). During the second storm, the trough deepened and widened, and the bar crest rose and migrated farther offshore. The net result of both storms was the formation of an outer bar about 360 m (1170 ft) from the baseline. The bar remained stable between storms, and did not acquire a crescentic configuration during storms.

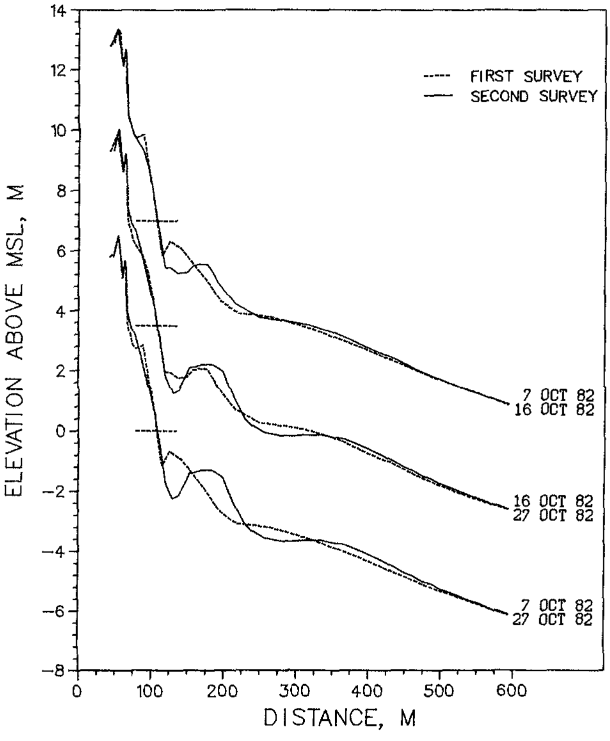

Figure 10. CRAB profile 62 - 7-27 October 1982

Discussion

Figure 11 shows the significant breaker locations and bar crest distances throughout the storm. The surf zone width reaches 900 m (2925 ft), whereas the bar migrated no farther than 70 m (227 ft) from the shoreline. It is important that during the storm, waves were breaking continually across the surf zone, and were not reforming and breaking on the bar crest. Therefore, it is clear that the inner bar could not have formed according to a plunging breaker hypothesis, where a bar is formed at the breaker position by scouring of a trough by the breaker. The inner bar (located within the landward 10 percent of the surf zone) became better developed and migrated offshore in the presence of spilling breakers. The outer bar was also well inside the surf zone during the storm.

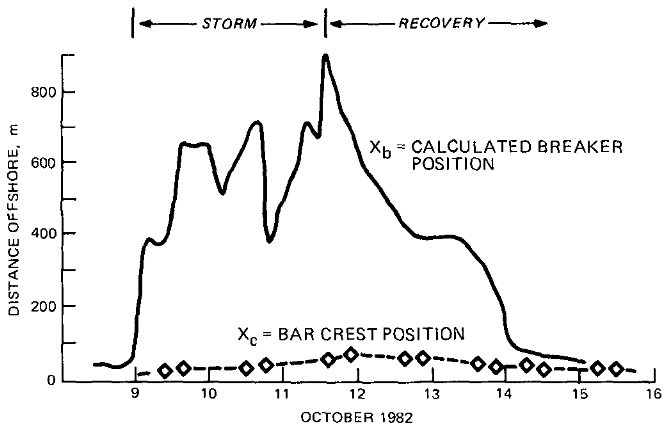

Figure 11. Time history of bar crest and breaker positions and depths

Sallenger, et al (11) indicate that the inner bar movement could have been caused by a standing infragravity wave with a period between 55 and 75 seconds. The inner bar would have formed at either the first node or antinode of the standing wave pattern as described by Bowen (4). Sallenger, et al (11) also hypothesized that crescentic development of the inner bar may have been forced by standing infragravity edge waves as the storm waned. Sallenger and Holman (10) provide evidence that infragravity waves were indeed very important during the storm. However, additional analysis of the wave and current data is required before the relationship between infragravity waves and bar response can be confirmed.

Related Results

Since the DUCK82 experiment consisted of several related areas of investigation, the ICCE-84 proceedings contain papers summarizing results to date, which are introduced below. Two of these papers concern wave characteristics measured during the storms, while the three remaining papers discuss cross-shore and/or beach face sediment transport processes.

As mentioned previously, Sallenger and Holman (10) confirmed the existence of significant currents associated with infragravity waves during the first storm. RMS cross-shore flows due to waves with periods greater than 20 sec exceeded 0.5 m/sec (1½ ft/sec) over the bar crest. Holman and Sallenger (5) also investigated infragravity wave activity during the second storm, when surface water level setup and significant swash heights exceeded 1.5 and 2.5 m (5 and 8 ft) respectively. Although offshore wave periods were less than 10 seconds, runup data collected on the shoreface indicated that dominant oscillations were of much longer periods, with approximately 75 percent of the variance in the infragravity band.

Using data collected from the sled-mounted current meters and optical suspended sediment meter, Jaffe, et al (7) concluded that suspended sediment transport played a major role in the cross-shore profile changes. A strong coupling was found to exist between material suspended high in the water column and the onshore phase of wave-induced flows such that a net onshore flux of particles occurred even though the mean flow was offshore. Richmond and Sallenger (8) found that during the first storm, different sediment sizes could be transported in opposite cross-shore directions under the same incident wave field. The field data corroborated sediment transport patterns predicted by Bowen's (4) equations as derived from Bagnold's theory on sediment transport. Finally, Howd and Holman's (6) high frequency sampling of swash zone bed elevations showed coherent perturbations to the foreshore slope with RMS heights of nearly 5 cm which were progressive upslope, with periods of 8 to 10 minutes.

Summary and Conclusions

A comprehensive nearshore processes experiment was conducted which, for the first time, documents detailed temporal and spatial storm-related processes and morphological response. Two-dimensional profile response measurements indicate that large and rapid changes occurred. As wave heights increased, the inner bar became better developed and migrated offshore at very rapid rates (>2 m/hr, >6 ft/hr). Development of the outer bar also showed a dependence upon wave heights, with minor changes when offshore waves were less than 2.5 m (8 ft), and significant changes when heights exceeded 3.5 m (11 ft). During the waning stages of the first storm, the inner bar rapidly developed a crescentic morphology, with parts of the bar migrating onshore at rates of over 1 m/hr (3 ft/hr). Neither the inner nor outer bars appeared to be related to breaking wave processes, since both bars were well within the storm surf zone. Rather, based on frequent quantitative measurements of wave and current conditions, the inner bar formation seems to be better explained by the effect of infragravity waves, which appear to play the leading role in controlling the response of nearshore sedimentary features to storms.

The rapid response of bar morphology to changing wave conditions indicates the need for more rapid sampling of surf zone morphology. It appears that previously held concepts of a slowly responding system may be erroneous. Only with a much-improved spatial and temporal sampling scheme can this be verified, since even with the frequent sampling conducted during this experiment, there is no guarantee that the dominant time scale of bar response was captured. The problem is further complicated by the apparent ease with which natural bar systems become three-dimensional. The development of instrumentation to measure three-dimensional morphology during storm conditions should be given high priority in the future.

Acknowledgment

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