CHAPTER ONE HUNDRED TWO

TIME SCALES OF NEARSHORE PROFILE CHANGES

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Abstract: Time scales of nearshore profile change are examined using a unique set of highly accurate surveys collected over a 3½ year period at CERC's Field Research Facility. The data are analyzed in terms of the formation and movement of the nearshore bars and with empirical eigenfunctions. The largest and most rapid changes in the profiles occurred during storms. The inner bar (depth of -0.6 to 1.5 m, 1.6 to 4.5 ft) moved offshore during even minor storms and recovered relatively quickly. The outer bar (depth of 3 to 4 m, 9 to 13 ft) formed during the largest storms and recovery was considerably slower, requiring six months or longer. The eigenvector analysis confirmed the importance of storms but identified a seasonal shift of material from the beach and inner bar to the offshore.

Introduction

Though it is well known that beach and nearshore changes occur rapidly during storms, and that post-storm recovery occurs more slowly, there is a general lack of field data, particularly from the nearshore zone, to quantify these processes. The objective of this paper is to examine the magnitude and temporal scales of profile change using over three years of highly accurate repetitive nearshore surveys (out to a depth of 8 m, 26 ft, MSL) collected at the Field Research Facility (FRF) of the U. S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center (CERC). The FRF is located on the Atlantic Ocean in Duck, North Carolina (Figure 1) and is described in detail by Birkemeier, et al (4).

Field Data

The survey data were collected using the Coastal Research Amphibious Buggy (CRAB), a motorized, 3-wheeled tripod capable of operating to depths of 9 m (30 ft) and in waves up to 2 m (6.4 ft). During the first six months of surveys, which began in January 1981, the position and elevation of the CRAB were determined using a level to read a 12.3 m (40 ft) high stadia board. All surveys subsequent to June 1981 were conducted using a Zeiss Elta-2s Electronic Total Station. The combined CRAB-Zeiss system (5) is unique because it permits highly accurate surveying of the zone of greatest profile activity. The data set includes over 105 surveys each of profile lines 62 and 188, which are located approximately 500 m (1650 ft) on either side of the FRF

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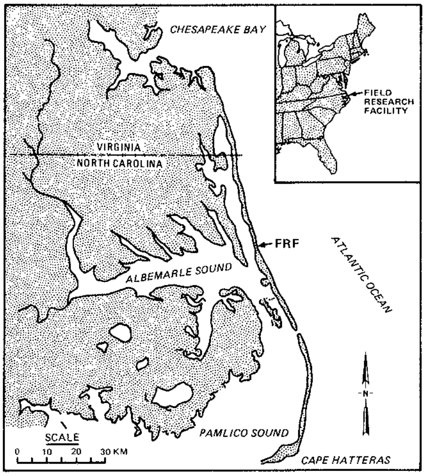

Figure 1. Location of the Field Research Facility

research pier (Figure 2). Based on monthly surveys of the bathymetry around the pier, these lines are located in a region of shore parallel offshore contours and are sufficiently removed from known pier effects (8). Surveys were generally conducted biweekly and after storms, with actual survey intervals varying from 1 to 44 days. The data provide a detailed record of profile evolution including periods of erosion, recovery and stability. The profile lines are characterized by a beach of poorly sorted, coarse-to-medium size sand and a nearshore zone composed of better sorted medium-to-fine sand. Table 1 summarizes general profile characteristics.

TABLE 1.-Profile Characteristics

Dune Height -	6 to 7 m (20 to 22 ft)
Beach Width -	20 to 45 m (65 to 148 ft)
Foreshore Slope -	1:12.5
Offshore Slope (based on 7.5 to 8 m contours) -	1:164
Maximum Shoreline Variation -	25 m (80 ft)
Maximum Volume Variation -	235 m^3/m (93.7 yd^3/ft) of beach

For the purposes of this report, the shoreline is defined as the distance to the mean sea level (MSL) intercept and profile volume changes are computed as cross-sectional changes multiplied by a unit width (1 m or 1 ft) of beach. The volume change given in Table 1 is the cumulative net volume change computed between successive surveys over the entire profile length (900 m, 3000 ft). All of the surveys of

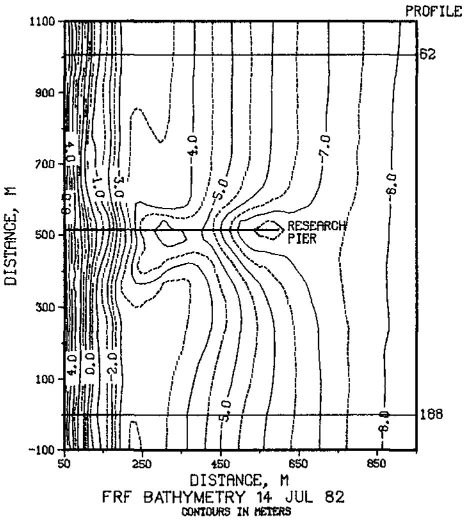

Figure 2. Location of study profile lines

line 188 are overplotted in Figure 3. As can be seen by the plot of maximum vertical change shown in the upper half of Figure 3, most profile activity is restricted to depths less than 7 m (23 ft) with little measurable vertical variation at deeper depths (only 15 cm, .5 ft, maximum variation at 8 m, 26 ft, depth). Because of this tendency for the surveys to "close out" near their offshore terminus, most of the overall volume variation given in Table 1 is attributed to longshore movement of material onto and off of the profiles.

Field Observations

Although changes occurred in both cross-shore and longshore directions, this study concentrates only on cross-shore changes resulting from the movement of material between the beach and nearshore; and the formation, movement, and disappearance of bar/trough features. The lack of detailed longshore data is important since rhythmic bar/trough and beach features frequently occur in the study area and undoubtedly affect the profile data and their interpretation. Mason, et al (7) address the formation and rapid movement of a rhythmic inner bar monitored during a detailed nearshore experiment, DUCK82, conducted around profile line 62.

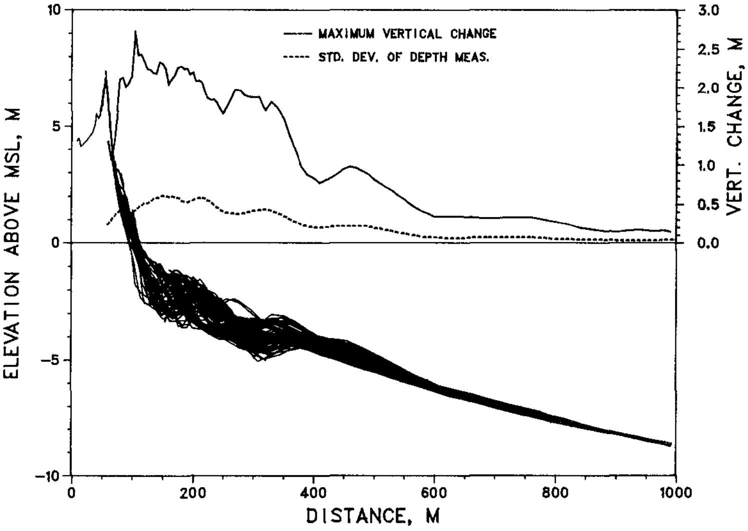

Figure 3. Envelope of 155 surveys of profile line 188 collected between January 20, 1981 and July 27, 1984

Profile changes at the study site occur at time scales ranging from swash periods (6) to annual cycles and longer. Time scales resolvable with the present data vary between a few days and one to two years. Though the profiles have varied in configuration from nearly unbarred to triple barred, they typically exhibit a double bar configuration with a narrow inner bar and a wide outer bar. Figure 4 illustrates five configurations. Most significantly, after 3.5 years the profile configurations have begun to repeat themselves. Though the reoccurrence of nearly similar profile shapes, such as those shown in Figure 5 taken nearly three years apart, is rare, the fact that they reoccur at all is most intriguing.

One of the best indicators of profile configuration and activity is the location and horizontal movement of the bar crest. Large changes to the profile, in terms of volume movements, always resulted in significant bar movement. Bar crest depth, though important, was less useful as an indicator of activity, since large bar movements occurred with little or no change in crest depth.

Figure 6 traces the time history of the shoreline and bar crest positions for both profile lines. This figure shows three major features of the data including: the relative stability of the shoreline, the formation and frequent oscillations of the inner bar, and the long period oscillations of the outer bar. Though the outer bar position has an apparent offshore trend superimposed on a seasonal-like oscillation, it is believed that this is actually the result of storm erosion/recovery sequences at varying time periods of one to two years. The

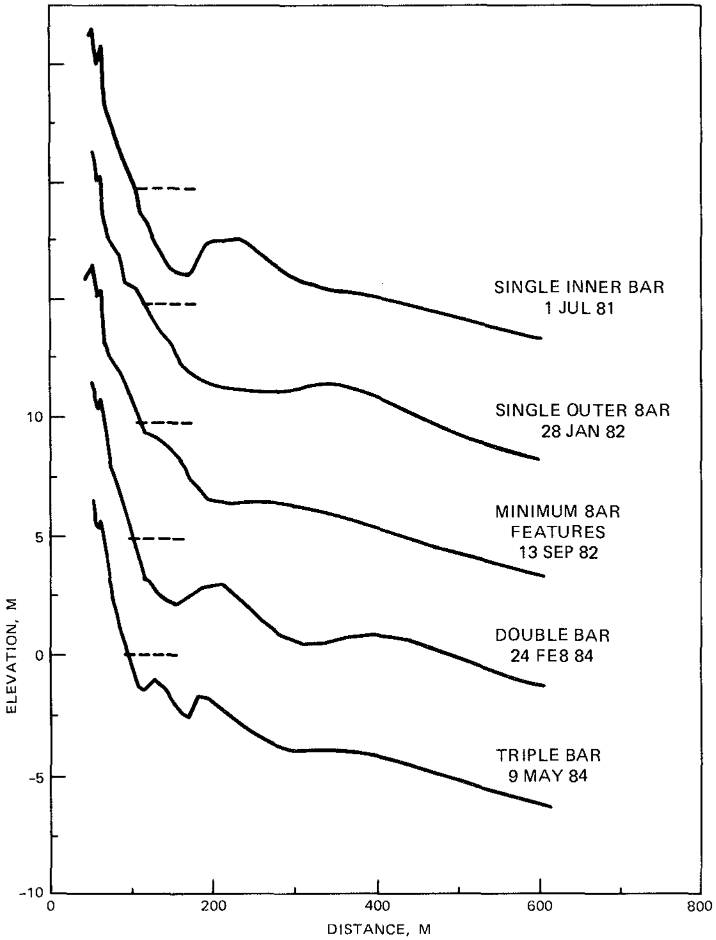

Figure 4. Typical profile configurations for profile line 62

development and slow movement of the outer bar can be better visualized with Figure 7 which is a perspective view of the data shown in Figure 3.

Minor storms affected the inner bar causing it to move offshore, while larger storms produced major changes in configuration, moving both bars offshore, and depositing sand in deeper water. Storm changes were rapid, occurring over periods of one to five days. Onshore bar movement which occurred during periods of low waves was also found to be post-storm related. The speed and amount of recovery which occurred

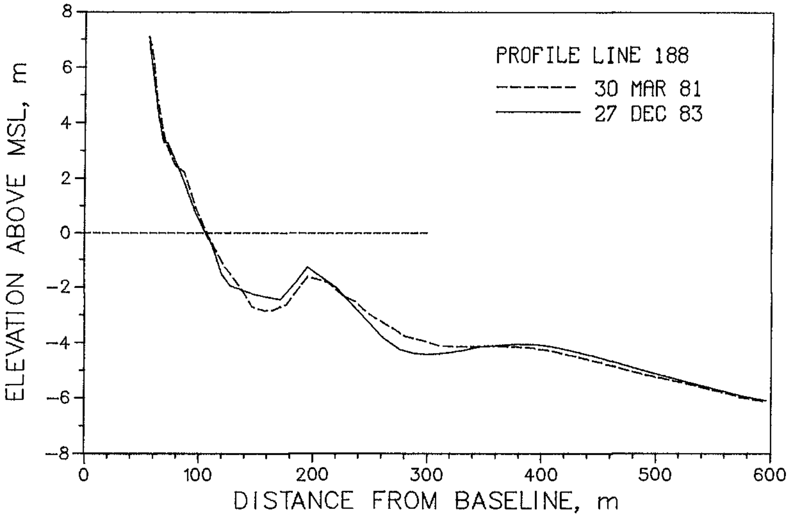

Figure 5. Similar profile shapes for surveys nearly three years apart at profile line 188

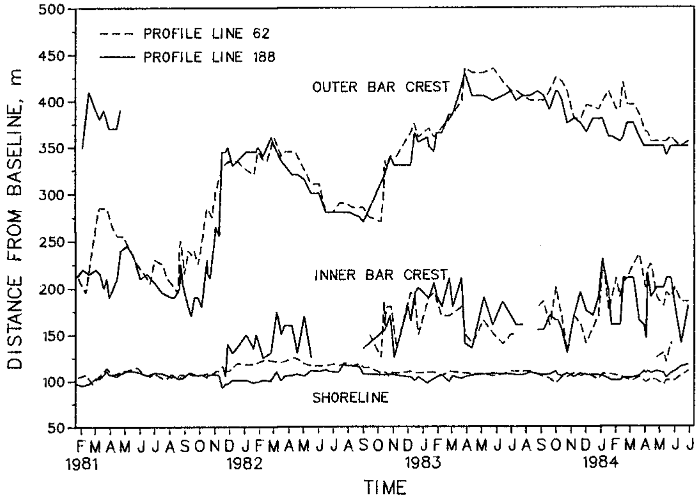

Figure 6. Variation in shoreline and bar crest positions

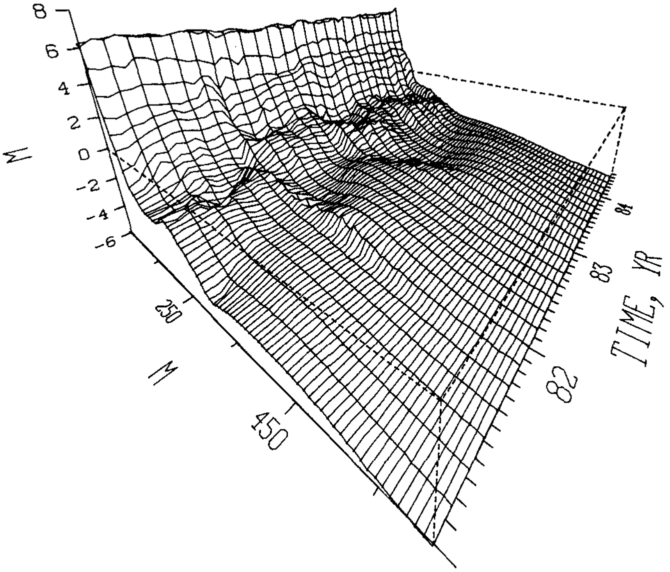

Figure 7. Perspective view of profile line 188 through time

were affected by the wave conditions and by the post-storm configuration of the profiles. All bar features tended to disappear during extended periods of low wave conditions (six months or longer).

An example of the rapid modifications caused by storms is shown in Figure 8. The surveys bracket a series of three storms with the final and most severe storm occurring November 13-15, 1981. This sequence of storms shifted the bar crest 165 m (540 ft) offshore and ultimately caused the profile to change from single to double barred. The November 13-15 storm, which produced 3.5 m (11.5 ft) waves and the highest water level of the study (1.6 m above MSL), also caused the greatest profile changes of the study, resulting in a major rearrangement of the nearshore zone. During this three-day event, the bar shifted 90 m (295 ft) offshore, at a rate that probably exceeded 30 m/da (100 ft/da), with 150 m^3/m (60 yd^3/ft) of material moving offshore. Interestingly, the two profile lines never returned to the same single bar configuration that existed prior to the November storm.

In contrast, the slow recovery from the changes caused by the Fall 1981 storms occurred during six months of relatively calm conditions from February to August, 1982 (Figure 9). During this period, the outer bar migrated onshore a distance of 85 m (280 ft) at an average rate of 0.47 m/da (1.5 ft/da). Depth over the bar remained nearly constant at -3.3 m (-10.8 ft) with a total shift of material of approximately 100 m^3/m (40 yd^3/ft). The configuration of the profile at the

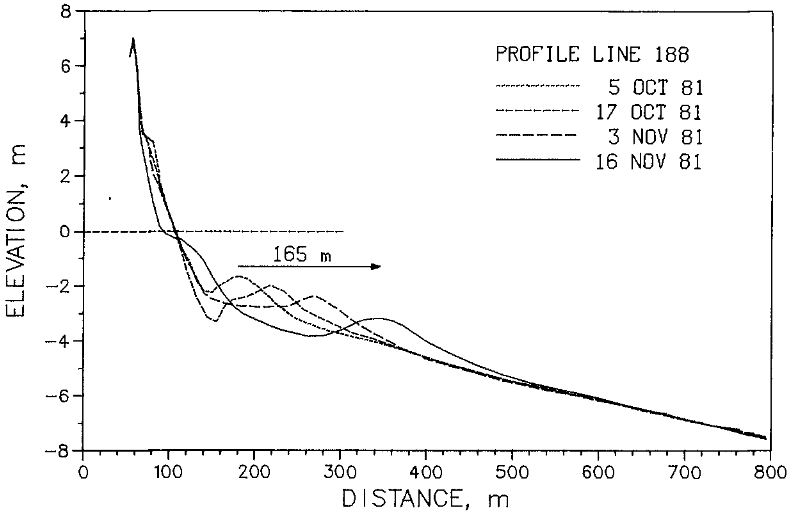

Figure 8. Rapid offshore movement of sediment resulting from three Fall 1981 storms

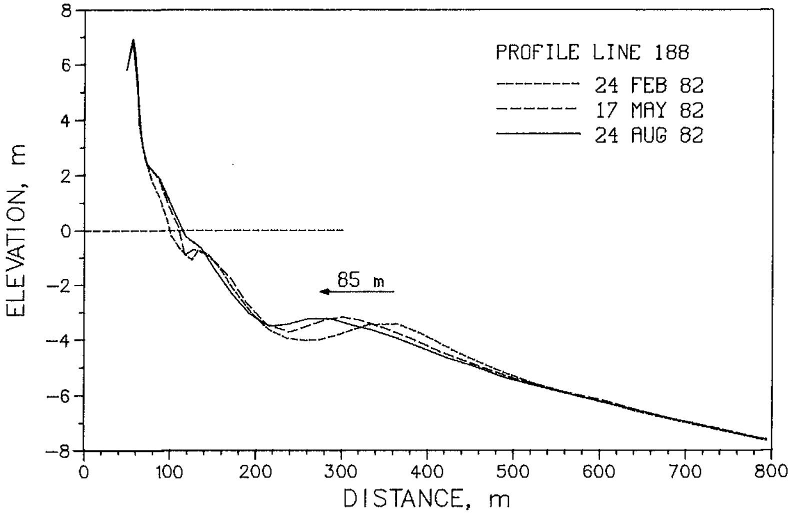

Figure 9. Slow onshore migration of the outer bar during a six month period of low wave conditions

end of the period was reflective, as defined by Wright, et al (12), with no inner bar and only a minor outer bar.

A different cross-shore sequence occurred in 1983. As shown in Figure 6, offshore movement during the fall reoccurred in 1982, but, from October 1982 to March 1983, the outer bar moved farther offshore into deeper water (-4.2 m, -13.8 ft). Though no single storm during this period exceeded the intensity of the November, 1981 storm, there were over 11 minor storms, 5 with significant wave heights in excess of 3 m (10 ft). Onshore movement of the outer bar from this deeper depth did not occur until late fall of 1983 and continued through the end of the study period in July 1984 when the outer bar nearly disappeared.

It is important to note that the observed patterns of bar formation and offshore movement always occur well within the surf zone. For example, the surf zone during the November, 1981 storm extended more than 250 m (820 ft) seaward of the post-storm outer bar position (approximately 600 m, 1970 ft,from the survey baseline, Figure 9). Based on results from DUCK82 (9) and work by Short (10), and others, bar position at these distances from the shoreline is not a function of incident wave periods but of long period, infragravity waves (0.5 to 5 min) with bars forming at either the nodes or antinodes of the infragravity wave.

Onshore movement of the outer bar, in the study area, occurred only when the bar was seaward of the surf zone. This rule does not necessarily hold for the shallow inner bar, as onshore movement of 1.2 m/hr (3.9 ft/hr) has been recorded near line 62 in October 1982 during a storm when the bar was well within the surf zone and waves were 2 m (6.4 ft) high with a 14 sec period.

Eigenvector Analysis

One technique which has found recent popularity in analyzing variation in profile shape is that of empirical eigenfunctions. In simplified terms, this statistical procedure separates the variation in a rectangular matrix of data into two sets of orthogonal functions. For the present data, one function (the set of eigenvectors) is spatially dependent, while the other (the eigenvector weightings) is dependent only on time. By requiring each successively higher eigenvector to explain, in a least squares sense, the variance remaining in the data set, only a few eigenvectors are required to explain a high percentage of the variation. Random noise in the data which is uncorrelated with the data set as a whole is filtered out to higher order eigenvectors. Since only a few vectors are usually required to reconstruct the original data, the results of the analysis provides a compact representation of the original data. The procedure is similar, and often compared, to fourier analysis where data are separated into linear combinations of sines and cosines. However, the eigenvector analysis does not assume, apriori, any functional shape.

Detailed discussions of the eigenvector analysis procedure are given by Aubrey (1,3), and by Vincent and Resio (11). Aubrey used the technique to parameterize beach and nearshore profile data and different wave-based variables. Vincent and Resio used a slightly different procedure to parameterize wave spectra. This study uses the procedure of Vincent and Resio where the eigenvectors are derived from a covariance matrix which is based on departures from the mean.

Though the eigenvector technique has been used by many different investigators to analyze nearshore profile data, it does have a number of significant limitations. First, since it is a statistical technique, the different vectors (modes of variation) do not necessarily have any physical significance,though it may be possible to attribute significance to them. For instance, Aubrey (2) found that his second eigenvector was related to seasonal sediment exchange between the nearshore bar and the beach berm. Secondly, the analysis assumes that every survey is equally spaced in time and that all cases are equally weighted, an assumption that is not usually the case with field data, including the present data set. Finally, when analyzing data from a single profile line, the eigenfunction analysis does not separate cross-shore effects from longshore effects.

Even with these limitations, an eigenvector analysis can be a powerful aid in identifying and parameterizing the major spatial and time dependent variations in a particular data set. The rectangular matrix in our case is an M by N matrix of depths, at 37 specific distances (N) along profile line 188 and for each of 115 surveys (M). The actual survey data were digitized at 17 m (55.77 ft) intervals from a distance of 70 m (229.7 ft) on the profile out to 682 m (2237.5 ft). This offshore limit was chosen because it contains most of the variation (see Figure 4) and because most of the surveys extend at least this far. Surveys which did not reach this limit were either deleted or extended using averaged data from the prior and following surveys. Data extensions were usually less than 100 m (300 ft).

Table 2 summarizes the variance explained by the first five eigenvectors which together account for 91.4 per cent of the variance in the data set. Eigenvectors 1 and 2 explain nearly equal amounts of variance suggesting that there are two basic profile configurations in the data set (in fact, these two eigenvectors are reversed on profile line 62).

TABLE 2.-Variance explained by first 5 eigenvectors

Vector	Variance Explained (per cent)	Cumulative Variance (per cent)
1	37.6	37.6
2	27.2	64.8
3	13.3	78.1
4	10.0	88.1
5	3.3	91.4

The results of the analysis are shown in Figures 10 and 11, which plot the eigenvectors and temporal weightings, respectively. These figures are most easily interpreted by first determining the effect of positive and negative weightings on the different eigenvectors when

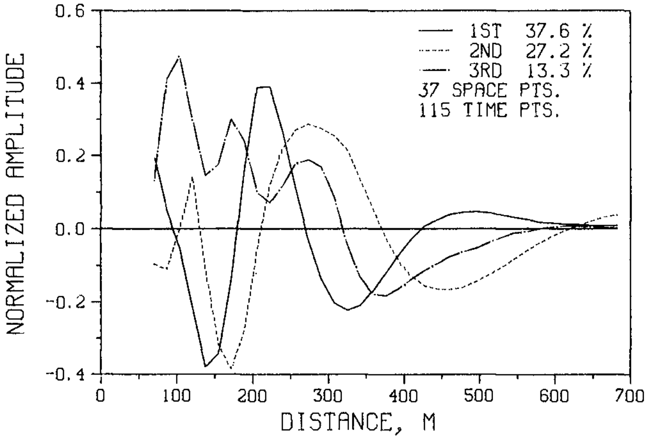

Figure 10. First 3 eigenvectors for profile line 188

combined with the mean profile, and then examining the temporal weightings for any significant trends. To determine the effect of a particular vector, multiply the amplitude of the vector at a particular distance on the profile by the weighting on that vector for a particular survey and add the result (which is in meters) to the mean depth at that distance. This has been graphically done for the first three eigenvectors in Figure 12, which shows the mean profile shape and the effect of positive and negative weightings.

From Figures 10 and 12, it can be seen that eigenvector 1 describes the change of the profile from a single bar configuration (when positively weighted) to a double bar shape (when negatively weighted) with a well-defined outer bar and an inner bar just seaward of the shoreline. By examining the weightings on the first eigenvector (Figure 11), vector 1 is of greatest importance (highest and most consistent weightings) during early 1981 and following the November, 1981 storm. This vector then accounts for the shift in profile configuration shown in Figure 8 and describes the relative stability of the profile following the Fall 1981 storms.

When negatively weighted, eigenvector 2 also describes a double bar configuration but the resulting shape is different than that described by vector 1. Both the inner and outer bars are farther offshore (Figure 12). From Figure 11, it can be seen that the weightings on the second vector are positive in early 1981 and negative in 1983. In fact, the second vector has a very low weighting during 1982 when the weighting on the first vector is high. Eigenvector 2 is of greatest importance from October, 1982 to March, 1983, the period corresponding to

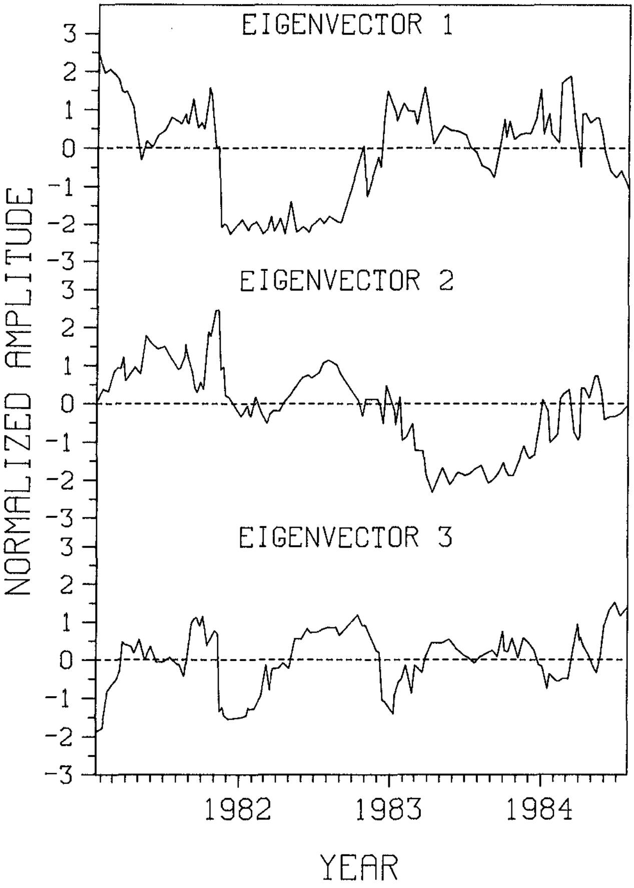

Figure 11. Temporal weightings on the first 3 eigenvectors for profile line 188

the second sequence of offshore movement of the outer bar described earlier.

Together, eigenvectors 1 and 2 describe the major cross-shore movements on the profile. Rather than being seasonally controlled, they appear to result from two unique sequences of storm/recovery activity.

Though the third eigenvector explains only 1/2 of the variance explained by vector 2, its weightings have the most well-defined annual cycle, having a negative peak every year around January and February. From Figure 12, the third eigenvector describes a shift of sediment

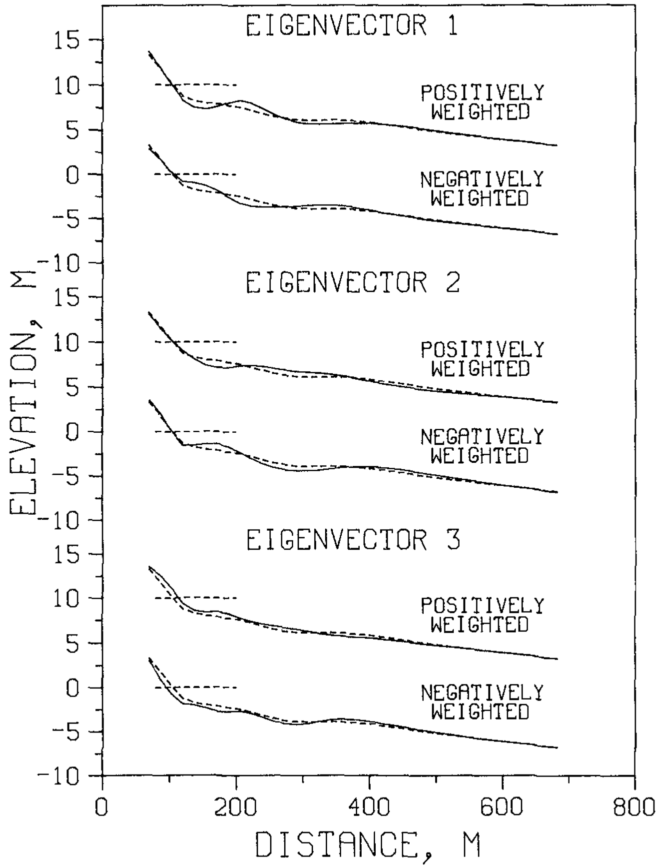

Figure 12. Effect of the first 3 eigenvectors on the mean profile using a unit weighting

from the beach and nearshore to the offshore (feeding the outer bar) when the weightings change from positive (summer) to negative (winter). The material shifts around a point 308 m (1010 ft) from the baseline at a mean depth of 3.9 m (12.8 ft). While this is a node for the third vector, both eigenvectors 1 and 2 have antinodes near this distance.

Summary

This paper uses a unique set of field data to examine the cross-shore movement of sediment. Rapid and major changes to profile shape occurred during significant storms and generally stormy periods. Minor storms caused changes only to the inner bar. The post storm recovery of the outer bar required in excess of six months of relatively low wave conditions. An eigenvector analysis of the data confirmed these findings. The first two eigenvectors, which combined account for 64.8 per cent of the variance, were attributed primarily to two different double bar configurations which resulted from storm sequences in 1981 and 1982-1983. The third vector accounted for a well-defined annual cross-shore shift of material.

The rate and quantity of material moved has implications for: the frequency and coverage of nearshore surveys, the siting of instruments, and the design of shore perpendicular structures including cable crossings and ocean outfalls. In addition, study results indicate that in order to nourish a beach, fill material must be placed in water depths less than 2 to 3 m (6 to 10 ft), the region of the inner bar, and that the timing of the placement is critical. Placement of material prior to a period of storms will result in offshore movement.

Acknowledgments

The data used for this study resulted from the combined efforts of the small but dedicated staff of the Field Research Facility and their tireless hours spent, under usually less than ideal conditions, collecting and processing the data. Results presented herein, unless otherwise noted, are based on research conducted at the Coastal Engineering Research Center, Waterways Experiment Station, under the Shore Protection and Restoration Program, Coastal Engineering Functional Area, Civil Works Research and Development, U. S. Army Corps of Engineers. Permission to publish this information was granted by the Chief of Engineers.

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