CHAPTER ONE HUNDRED FORTY FIVE

Quantification of Shoreline Rhythmicity

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Abstract

The study of beach morphology, for example, its changes with wave and tide conditions, is facilitated by the development of simple numerical values which characterize the morphology. Multivariate (EOF) analysis of topographic contour data is a means for determining important morphologic components which vary independently. If these components correspond to familiar shoreline features the researcher considers important, then the development of each component can be quantified by its significance, or weighting, in each sample. Alternatively, the components may be complicated and not useful in quantifying beach morphology. A study of these morphologic components, however, can provide insights into the dynamics of the beach system.

If multivariate analysis produces complicated components, an alternative approach, of subjectively identifying shoreline characteristics of interest, can be taken. The characteristics may be the same as those frequently used in past studies, such as beach slope or sand volume. It is likely, though, that EOF analysis of topographic data will suggest more sophisticated characteristics which should be used. Some of these, for example, mean shoreline position or amplitude of a rhythmic shoreline, may be easily quantified, whereas, others such as longshore position of rhythmic features or cusp width relative to embayment width, may be more difficult to quantify.

Both of these analysis approaches were applied to beach survey data obtained over a period of ten months (including the El Niño winter of 1982/83) on Siletz Spit, Oregon. The shoreline was rhythmic with an 800-850 m wavelength throughout the duration of the study. Rhythmic topography has been associated with significant past beach and dune erosion at this site. Hence, it is of interest to describe the beach morphology quantitatively, and relate three dimensional beach changes to wave and tide conditions.

Field observations and EOF analysis determined three important characteristics of shoreline morphology: overall accretion/erosion of the shoreline, amplitude of the rhythmic topography, and longshore position of the rhythmic features. EOF analysis was not able to separate these three morphologic components. They were quantified, respectively, by mean distance offshore to a specified contour, the standard deviation of a contour about that distance, and the weights of the first eigenvector calculated by EOF analysis of topographic contour data normalized to the same mean and standard deviation.

Mean shoreline position was shown to move onshore with increasing wave height, as expected. Rhythmicity amplitude varied inversely

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with the wave height, but there is evidence to believe this is not the case for all winters on Siletz Spit. Rhythmic topography formed and increased in amplitude under depositional conditions during the ten months of this field study. Due to differences between the rates of change of mean shoreline position (up to 5 m/2 wks) and of rhythmicity amplitude (up to 10 m/2 wks), rhythmic topography should be able to develop under erosional conditions as well.

In many beach systems, EOF analysis of topographic contour data should not be expected to produce simple morphologic components which correspond to familiar shoreline features. EOF analysis can be an aid in furthering one's understanding of the dynamics of a beach system and can be a useful guide in subjectively identifying important shoreline characteristics. In some instances, EOF analysis of a modified data set may allow one to quantify one or more of these characteristics.

Introduction

Simple numerical values are needed to describe beach morphology before three dimensional beach changes can quantitatively be related to wave, tide, or other 'environmental' forces. In general, two approaches can be taken to determine useful values which characterize the beach morphology. Both require data documenting beach topography in three dimensions.

One approach is a multivariate analysis of beach profile data collected at different longshore locations and/or different times (Winant et al., 1975; Aubrey et al., 1980; Wright et al., in press). This provides an objective determination of important and independent components of beach morphology. It also weights each component, depending on its importance. Ideally, the components correspond to familiar features such as a straight beach profile with an offshore bar (if beach profiles are analyzed) or perhaps a shoreline with cuspate protrusions (if topographic contours of the beach are analyzed). The weightings then provide a measure of how well developed that feature was at the time of the survey. However, depending on the field site, numbers of samples taken, and duration of the study, the components may be complicated and not represent morphologies of interest.

An alternative analysis approach is to determine, subjectively, characteristics of the topography which are of interest, such as foreshore beach slope or average surf zone beach slope, beach volume, or the horizontal or vertical amplitude of cusps. Many such characteristics are easily quantified, but others, for example, longshore positions and spacing of a rhythmic shoreline pattern, can prove to be more elusive.

The goal of the present investigation was to apply both of these approaches to examine the origin and development of large scale rhythmic shoreline forms. In particular, much attention was given to determine the applicability of multivariate analysis of topographic contour data to studies of three dimensional beach topography. To this end, a ten-month long field study was undertaken on the Oregon coast to document changes in beach topography. The field site was an 830 m long stretch of beach on Siletz Spit, 30 km north of Newport, Oregon (Fig. 1). Eleven evenly-spaced beach profiles were obtained at two-week intervals during times of low Spring tides. Other data utilized in analyses of the observed beach topography changes include direct measurements of the incident waves (obtained every six hours), continuous tidal measurements, and local weather conditions, all measured at Newport.

This study was part of a larger effort to improve our understanding of rhythmic topography. Also included in the larger study, but presented elsewhere (Garrow, 1985), were the analyses of 24 historical air photo mosaics, more extensive statistical analyses of the survey data, evaluations of the proportions of infragravity and incident wave energy on the foreshore (from time-lapse films of wave run-up), and the development of a model for the formation of rhythmic topography at this site.

Field Techniques and Observations

Eighteen beach surveys, each consisting of eleven evenly-spaced beach profiles, were carried out on a bi-weekly basis between September 1982 and June 1983. Beach profile locations were constant throughout the study with all elevations referenced to a local base line and datum. Profiles were determined using 'Emery Boards' (Emery, 1961). The absolute x,y,z, coordinate system was established using an Omni-1 Total Station. Because of the high energy winter wave conditions on the Oregon coast, beach profiles often extended only 5 to 10 m seaward of estimated MLLW.

Seven storms, with deep-water significant wave heights greater than 5 m, occurred during the study. This period of time is especially interesting due to the El Niño phenomenon and its associated anomalous environmental conditions. Sea level anomalies up to 1.1 m occurred, associated with thermal and shelf wave phenomena (Huyer et al., 1983; Enfield and Allen, 1980), and up to 0.28 m due to low barometric pressures. Normal tides on the Oregon coast range from 2 to 4 m.

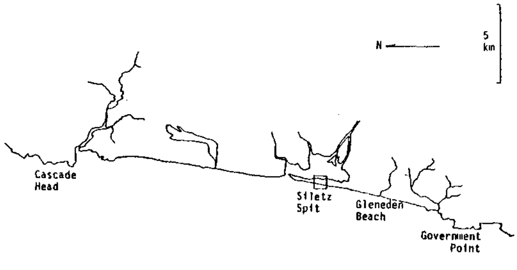

Figure 1. The field site was located on Siletz Spit, Oregon. It was approximately 2 km south of the Siletz Inlet and 8 km north of Government Point.

Contour maps from the survey data show the cycle of beach response to winter storms. Initial surveys showed a typical summer profile which rapidly eroded in early October. While there were moderate-scale fluctuations throughout the winter, significant accretion did not occur until near the end of the field program in June.

A common feature throughout the study period was a large scale rhythmicity in the shoreline. While the amplitude of the rhythmicity varied, statistical analyses showed that the wavelength was stable at 800-850 m. Additional characteristics of the rhythmic topography are: 1) localization of the rhythmicity to 3-4 km south of Siletz Inlet, and 2) variations in the longshore locations of rhythmic features, including longshore migration of a well developed rhythmic morphology (Garrow, 1985).

Important to the problem of understanding variations in beach morphology is the ability to quantify these variations in simple terms. Our visual and survey observations suggested that beach variability was composed of three components; average accretion or erosion, variations in the amplitude of rhythmicity, and variations of the longshore position or phase of the rhythmicity (as noted, the wavelength appeared stable). Empirical orthogonal eigenfunction analysis, a multivariate technique of data analysis, was applied in an attempt to separate these components of beach morphology variations.

Multivariate Analysis of Topographic Data

Empirical orthogonal eigenfunction (EOF) analysis is a mathematical technique which may simplify one's original data by reducing the number of variables which need to be considered. Explanations of the details of EOF analysis (also referred to as R-mode analysis) can be found in most texts considering mathematical analyses of multivariate data (ex. Davis, 1973). Aubrey (1979) provides brief reviews of the mathematics involved.

This technique has two main goals, both attained through simple, though voluminous, matrix algebra. First, one must realize that the variables in the original data set are not linearly independent and, hence, are redundant. That is, if one calculated the correlation between all pairs of variables, it is unlikely that all correlations would be zero. With this in mind, one goal is to determine a new set of variables (eigenfunctions or eigenvectors) which are independent. For example, if the original data set (or data matrix) had four variables, perhaps β_f (beach foreshore slope), β_s (average beach surf zone slope), $H_{1/3}$ (significant wave height), and T (incident wave period), then each of the new variables would have four elements. A new variable may look like [-2 -5 4 0.5], indicating that it is composed of 'a lot' of $H_{1/3}$, and 'a lot of the opposite (-)' of β_s, since 4 and -5 are large, relative to 2 and 0.5. This particular example indicates the typically moderate correlation between increasing wave height and decreasing average beach slope in the surf zone.

The second goal is to define the fewest new variables possible, which will completely describe the original data, such that all samples can be written as the linear sum of the new variables. Mathematically, the phrase 'completely describes,' means that the new variables must account for all of the variance in the original data set. The importance of each new variable can be considered as how necessary it is in reconstructing the original data set. It is described by the percentage of the total variance (in the original data) for which it accounts. If four new variables were determined by EOF analysis, then one may explain 80% of the variance, another 15%, another 4.99%, and the fourth, only 0.01%. In this case, it could be said that three new variables could be used to describe the original data. In fact, for many applications, only two new variables would suffice. In addition to the percentage of total variance explained by each factor, EOF analyses also evaluate the importance of each new variable to the individual samples. Thus, if one wished to reconstruct sample #6 from the new variables, they may need to 'weight' one new variable by 85%, another by 12%, and the others by 2% and 1%, respectively. However, the 'weightings' for reconstruction of sample #7 may be 70%, 25%, 5%, and 0%. These weightings can be useful in that they show the change in importance of a new variable (or synonymously of a certain relationship between the original variables) from sample to sample.

This technique can be applied to the analysis of beach profile data if one evisions a topographic data set from the study site in which each variable represents one of the 11 profile ranges. EOF analysis of this matrix will produce 11 or fewer eigenvectors, each with 11 elements, which account for all of the variance in the data. Each vector will represent an alongshore topographic pattern or morphology. The hope is that most of the variance in the data set will be accounted for by several dominant morphologies which may be associated with known or hypothesized nearshore processes.

In deciding to perform such an analysis, the question arose as to what the actual elements of the data matrix should be. A number of possibilities were tried and evaluated with the specific goal of better understanding the nature of shoreline rhythmicity at the field site. As noted in the previous paragraph, the variables in all of the matrices evaluated represented longshore position. Several different types of elements were evaluated and discarded. These included: 1) elevations at different offshore distances, 2) local beach slope at different offshore distances, and 3) local alongshore beach slope at different offshore distances. An inverse approach of using the offshore distance to particular topographic contours proved successful.

Cross-shore distances to a particular contour as a function of time, therefore, were used to study the variability of rhythmicity through the 18 separate surveys. If the changes in beach morphology through time are relatively simple, then the mean contour calculated from such a matrix should describe a reasonable longshore topography and EOF analysis of such a matrix should produce one or two meaningful eigenvectors to account for most of the variance.

One's understanding of the results of this analysis on the Siletz Spit data set is enhanced by first examining results of this analysis approach on hypothetical data matrices representative of ideal beach topographies. The first, and simplest, case is that of a straight beach extending different distances offshore at different times (accreting and eroding). The mean contour is straight, and EOF analysis determines a single dominant eigenvector. This vector is straight alongshore, and the weightings indicate the amount of accretion (positive weights), or erosion (negative weights), about the mean contour location at each time. An additional eigenvector is present in this, and all of the following cases, though it accounts for less than a few percent of the variance. This vector represents noise in the data.

A more interesting case for the study of longshore rhythmicity is that of a cuspate shoreline exhibiting sinusoidal topographic contours. One can imagine a number of changes such a shoreline might experience, including variations in amplitude and longshore phase, as well as combinations of these with general erosion and accretion.

If the sinusoidal pattern remains stable in the longshore, but varies in amplitude, the analysis produces a sinusoidal mean and a single sinusoidal eigenvector 180 degrees out of phase with the mean (Fig. 2a). The vector weightings describe 'how much' of the vector must be added to, or subtracted from, the mean to regain the original data. In this simple beach environment, the vector weights can be used directly to describe the amplitude of the rhythmicity present at the time of each survey.

Results from a rhythmic shoreline exhibiting changes in both on/offshore position and amplitude through time is just a combination of the above cases. There is a sinusoidal mean and two dominant eigenvectors (Fig. 2b), one representing variations in amplitude, the other representing erosion or accretion. The percentage variance explained by each of these vectors depends on the relative magnitudes of amplitude variation and changes in on/offshore position.

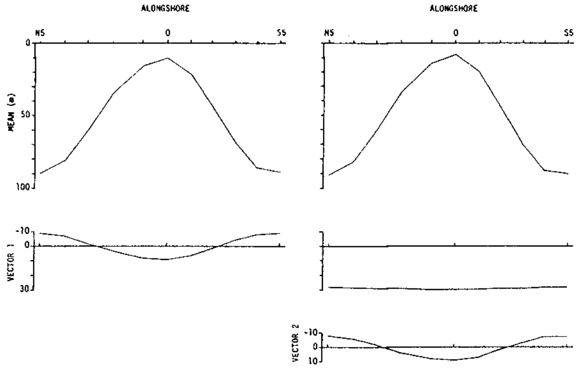

Figure 2. a) Mean contour and first eigenvector of data depicting a stable longshore rhythmic pattern with amplitude variations; b) Mean contour and first and second eigenvectors of data depicting a stable longshore pattern with amplitude variations and overall on/offshore movement.

The previously discussed characteristics of rhythmicity at the study site suggest that a still more realistic hypothetical set of circumstances would include longshore migration, or phase shifting, of the sinusoidal contours. Three cases will be explored using random phase variations within 90, 180, and 360 degree (1/4, 1/2, and full wavelength, respectively) envelopes. One-hundred synthetic contour lines were generated in each case. No on/offshore migration of the beach is included in the analyses discussed here; inclusion of this signal does not alter the basic results.

The mean contour and the first and second eigenvectors calculated by the EOF analyses for the 90 degree, 180 degree, and 360 degree phase variation cases are shown in Figures 3a, b, and c, respectively. Any apparent distortion of the mean contour from a perfect sinusoid occurs because the wavelength is not an even multiple of the spacing between variables (beach profiles). It can be noted that the amplitude of the mean decreases with increasing phase shift envelope. Eigenvectors 1 and 2 are sinusoidal and exactly 90 degrees out of phase in all instances. They are also out of phase with the mean by approximately 25 and 205 degrees. This phase offset from the mean accounts for the longshore phase shifting in the data. As phase variation in the data increase, the second vector becomes increasingly important. The 90, 180, and 360 degree phase envelope examples, respectively, have eigenvector 2 to eigenvector 1 ratios, of percents of variance accounted for, of approximately 0.07, 0.14, and 0.06. With longshore migration of a rhythmic shoreline, factor scores still indicate 'how much' of a vector must be added to the mean to regain the original data. However, they now include the longshore location of rhythmic features relative to the mean. When analyzing real data, the meaning of the vector weights must be evaluated subjectively, based on the shapes of the mean and dominant eigenvectors, and the phase relations between them.

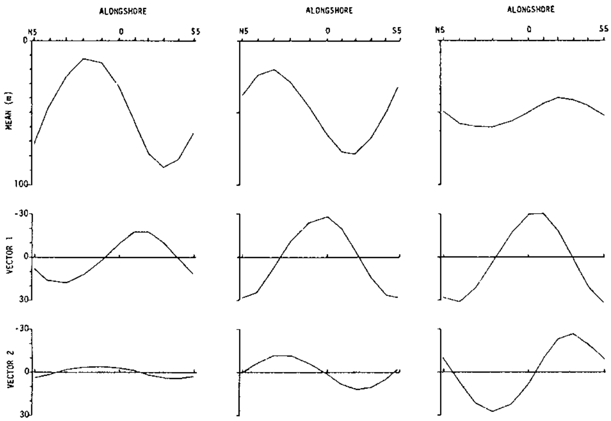

Figure 3. Mean contours and first and second eigenvectors for data depicting a longshore rhythmic pattern with amplitude variations, and a) 90° envelope phase shifting; b) 180° envelope phase shifting, c) 360° envelope phase shifting.

Finally, the influence of noise in the data was investigated. For the case of a matrix consisting solely of random noise, the mean contour is a straight line. EOF analysis produces the same number of eigenvectors as there are variables, all accounting for approximately equal amounts of variance. The vectors themselves are irregular when plotted. In an effort to determine how much noise could be present in a matrix based on a longshore rhythmic beach system and still yield interpretable results, many analyses were run on matrices similar to those just discussed, but including amplitude variations, on/offshore variations in beach position, and varying amounts of noise. It was determined that noise can hinder interpretations of the mean and eigenvectors when it is of the same order of magnitude, or larger than the amplitude of the rhythmic signal. In general, this condition can be identified by the need for more than two or three eigenvectors to account for more than 90% of the variance.

EOF Analysis of the Field Data

For analysis of the Siletz Spit topographic data, EOF analysis was run for seven different elevation contours spaced 0.5 m apart. Plots of the means and eigenvectors are shown in Figure 4. All mean contours appear rhythmic with approximately the same lengthscale of 800-850 m. For higher elevation contours, those nearest the dunes, the first eigenvectors show lower amplitude rhythmicity and account for less of the total variance in their matrices than do the first eigenvectors for contors further offshore.

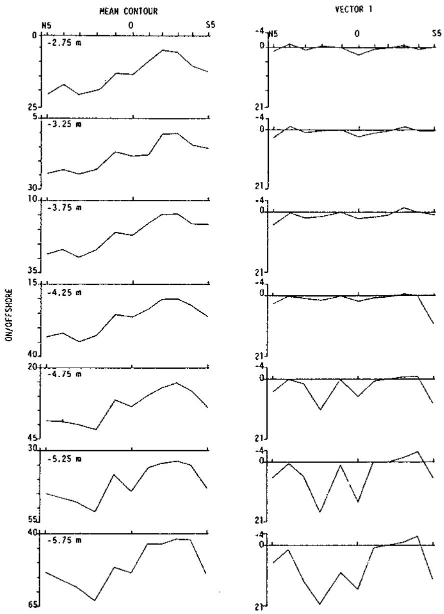

Figure 4. The mean contours and first eigenvectors for each of the seven Siletz Spit contour data sets.

The results of EOF analysis of the seaward-most data are shown more fully in Figure 5. The alongshore patterns are more irregular than those of the synthetic analyses, as would be expected in a natural system, but they definitely reflect some characteristics of the shoreline rhythmicity. The mean contour is obviously rhythmic with a longshore wavelength of 800-850 m and an amplitude of approximately 20 m. Two eigenvectors account for 83% of the variance in the data suggesting that although there is some noise in the system, it is probably much less than the amplitude of the rhythmicity signal. The shapes of the first two vectors are reassuringly similar to those determined in analyses of the hypothetical rhythmic shoreline with amplitude variations and phase shifting of the pattern. Eigenvector 1 departs from the expected phase relation with the mean for this model in the southern part of the area. The nature of the departure suggests that phase shifting at this site was possibly accompanied by small changes in the wavelength of the rhythmicity. Eigenvector 2 also departs from the expected phase relation with the mean, but it is 90 degrees out of phase with vector 1 for most of its length and this is consistent with the model. The amplitudes of the mean, first eigenvector and second eigenvector are 20 m, 25 m, and 15 m, respectively. This is very reminiscent of the synthetic data set with 180 degree phase shifting. The percentages explained by the first two vectors from the Siletz data are also similar to this hypothetical case. The ratio of percent explained by eigenvector 2 to that explained by eigenvector 1 de-emphasizes the noise in the natural system. The ratio for the hypothetical example with a 180 degree phase envelope is 0.15, and for the Siletz field site is 0.17.

Examination of eigenvector 1 shows it to have a mean of 6.4 m, implying an associated on/offshore movement of the contour. Sites labelled S1, S2, S3, and S4 have values near zero, while sites to the north have larger values indicating a greater on/offshore fluctuation in position. Figure 6 shows plots of the sum of the mean contour and

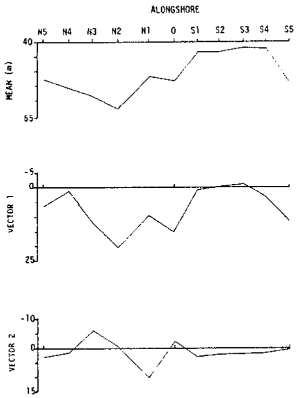

Figure 5. The mean contour and the first and second eigenvectors for the seawardmost contour of the Siletz Spit data set.

the most positively and most negatively weighted first eigenvectors in the data set. From these it is concluded that a change from large positive to large negative for vector weights would describe erosion in the north, a broadening of the embayment in the south, and migration of the cusp to the north with a concurrent decrease in amplitude. Though examination of vector 1 alone suggests that it might describe variation in the wavelength of the rhythmicity, it does not appear to do so within this data set. Eigenvector 2 has a mean near zero and shows most variation in the northern half of the study area. Figure 7 shows plots of the most positively and most negatively weighted second vector in the data set added to the mean contour. A transition from large positive to large negative second eigenvector weights represents a straightening of the beach to the south, a large increase in topographic complexity to the north, and a concurrent decrease in amplitude and northward migration of the southernmost embayment. Vector by vector reconstructions of the data, such as this, can prove extremely enlightening in understanding both the significance of the vectors and the dynamics of the beach system.

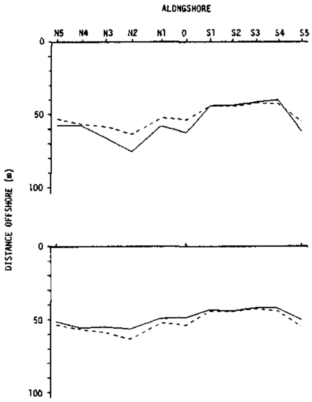

Figure 6. The sum of the mean contour and the most positively weighted (top) and most negatively weighted (bottom) first eigenvectors (solid lines). For reference, the mean contour is shown as a dotted line.

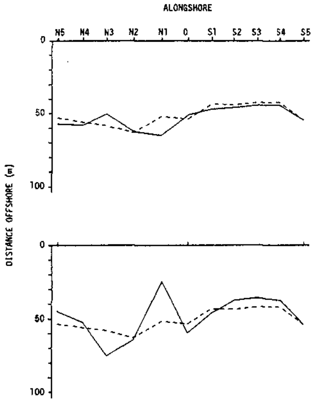

Figure 7. The sum of the mean contour and the most positively weighted (top) and most negatively weighted (bottom) second eigenvectors (solid lines). For reference, the mean contour is shown as a dotted line.

This analysis confirms the visual and survey observations that there are three primary components in the beach variability data. These are general accretion or erosion of the shoreline, amplitude of a dominant 800-850 m wavelength rhythmic pattern, and longshore location or phase of the rhythmic pattern through approximately 180 degrees (or 400 m). EOF analysis is useful in verifying the importance of these components, as demonstrated here and in the analyses of the synthetic data. Furthermore, it is capable of separating accretion/erosion and rhythmicity amplitude variations in a simple two-component system where these morphologies are independent.

Unfortunately, in an interdependent multiple component system, or a phase varying sinusoidal system (both of which apply to the Siletz data), the resulting eigenvectors fail to provide a simple separation of the three topographic parameters.

Quantification of the Components of Beach Morphology

To study the relationships between topography and wave and tide conditions, it is desirable to separate the three morphologic components and express each by a meaningful numerical parameter. On/offshore position, and amplitude of rhythmicity, can be described by the mean and standard deviation of the distance offshore to a contour at a given time (Fig. 8). For a truly sinusoidal pattern, the standard deviation of a contour produces a low estimate of rhythmic amplitude. In light of the variations found in natural systems, however, it seems to be a satisfactory descriptor. One possibility for quantification of longshore position of the signal would be longshore location of extrema. The signal produced by the real data is sufficiently noisy to preclude this approach. Recall that for any rhythmic shoreline exhibiting less than about 200 degrees of longshore phase shifting, EOF analysis produces a single eigenvctor which describes much of the topographic variation. Vector weights for each excursion are meaningful numerical descriptors of the overall topography. In this instance, if the on/offshore movements of the shoreline and amplitude variation signals can be removed from the data, then the first eigenvector calculated by EOF analysis should describe only the phase shifting, or longshore migration of the rhythmic pattern.

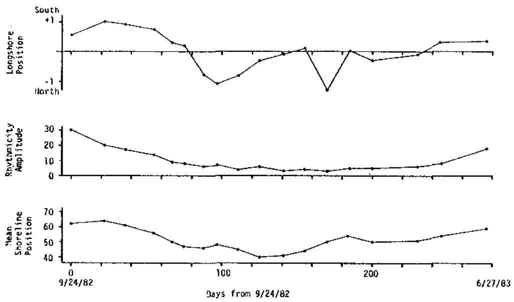

Figure 8. On/offshore position of the shoreline and amplitude of rhythmicity can be described by the mean and standard deviation of the distance offshore to a contour at a given time. The weightings of the first eigenvector of the normalized data matrix can be used as quantitative descriptors of longshore position of the rhythmic pattern.

To this end, the seaward-most contour data was normalized to the same mean and standard deviation. This normalization results in varying amounts of noise for different excursions, increasing the noise in low amplitude (mid-winter) data sets relative to higher amplitude data sets. Figure 9 shows plots of the mean contour, first, second, and third eigenvetors from EOF analysis of the normalized data. Because of the increased noise, 5 vectors are necessary to account for 90% of the variance. For the non-normalized data, the same amount of variance is explained by only 3 vectors. Longshore migration of the rhythmic pattern is described mostly by eigenvector 1. Eigenvectors 2 and 3, primarily 'fine-tune' the shape of the topographic features by narrowing cusps and broadening embayments. Comparison of the first vector weights of the normalized data (Fig. 8) to topographic maps of the beach for each excursion (Garrow, 1985), confirms that these weights can be used as quantitative descriptors of longshore position of the rhythmic pattern. Large negative weightings describe a number of the winter beaches when the embayment was located in the north central part of the site.

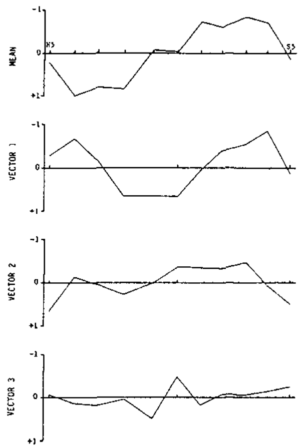

Figure 9. The mean contour and the first, second, and third eigenvectors from EOF analysis of the normalized -5.75 m contour matrix.

Careful analysis of the topographic data reveals three primary components of topographic change on Siletz Spit and suggests three independent and quantitative parameters to describe them. On/offshore position of the shoreline is best described by the mean distance offshore to a predetermined contour for each excursion. The amplitude of rhythmic topography is most simply and accurately described by the standard deviation of a contour about its mean offshore distance. The longshore position of rhythmic features is best expressed by the weights of the first eigenvector as calculated by EOF analysis of the contour data set in which each sample is normalized to the same mean and standard deviation.

Waves, Weather, and Topography

Relationships between parameters which represent important characteristics of shoreline morphology and the wave, tide, or weather conditions permit us to: 1) improve our understanding of which variables are important in producing rhythmic topography, 2) make estimates of the response times for the beach morphology components, and 3) learn something about the way in which rhythmic topography forms. Regression analysis between the available topographic and environmental variables confirms some well established trends, but also provides new insights and surprises. The values used to represent wave and weather conditions in this investigation are the means for the time periods between surveys.

Though the linear correlation between mean significant wave height and the position of the mean shoreline is not high (-0.720), the expected relationship exists (Fig. 10). As significant wave height increases, the mean shoreline position moves onshore (decreases) as a result of beach erosion. It is suggested that the correlation is as low as it is due to the rather slow response time of the mean shoreline to changes in incident wave conditions. Although the bi-weekly sampling precludes comments on very rapid responses, the mean shoreline position changed, at most, five meters between surveys.

Of interest, the amplitude of the rhythmicity also shows a negative correlation (-0.614) with mean significant wave height (Fig. 11). This is opposite to the relationship observed previously during major episodes of erosion on Siletz Spit. At those times, erosion resulted from embayments impinging on the foredune during storms with incident wave heights exceeding six or seven meters (Rea, 1975; Komar and Rea, 1976; McKinney, 1977; Komar, 1983).

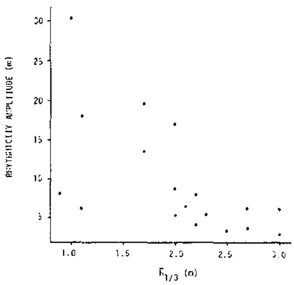

Figure 10. Mean Significant wave height versus mean shoreline position showing a negative correlation between these variables.

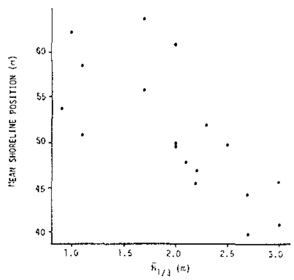

Figure 11. Mean significant wave height versus rhythmicity amplitude. The negative correlation between these variables differs from a positive correlation observed during major erosional episodes of the 1970's.

The winter of 1982/83 was characterized by anomalous weather and tide conditions due to El Niño. Consideration of three well documented periods of significant dune erosion on Siletz during the 1970's (McKinney, 1977), reveals a fundamental difference in conditions between those periods and the 1982/83 winter. First, incident wave conditions do not differ appreciably between the 'erosive' winters and the winter of 1982/83. Incident wave periods during the three major erosive storms varied from 9 to 17 sec. and significant breaking wave heights ranged from 6 to 7 m. However, barometric pressures in the winter of 1982/83 were anomalously low. Monthly mean barometric pressures for January through April were the lowest since sometime before 1971 (Huyer et al., 1983). This difference reflects that storm centers were closer to the Oregon coast in 1982/83, being located off the central California coast, than during the periods of major erosion when they were located in the North Pacific, just south of the Aleution Islands in the Gulf of Alaska (McKinney, 1977). It is speculated, then, that incident wave characteristics related to the proximity of a storm center may be important in determining the amplitude of rhythmic topography on Siletz Spit.

Of interest, the amplitude of the rhythmicity in the 1982/83 winter showed larger responses to incident wave conditions than did the mean shoreline position. Up to 10 m of change occurred during any two-week period. The relationship between mean shoreline position and rhythmicity amplitude can reveal whether the rhythmic topography is erosional or depositional in origin. The correlation between these two morphology components is +0.841, indicating that the amplitude increased as the shoreline prograded (Fig. 12). However, spectral analyses of the high water lines on air photo mosaics obtained in previous years (Garrow, 1985) suggest a possible negative correlation between these same two variables. The photographs showing significant spectral peaks were taken during August, September, October, February, and April of the several years of photo availability. The high spectral energy found on the fall and mid-winter

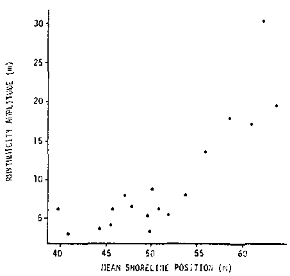

Figure 12. Mean shoreline position versus rhythmicity amplitude. The positive correlation indicates rhythmic topography was of a depositional origin during the time of this study.

photographs indicate that the rhythmic topograpy may also form, as well as show rapid growth under erosional conditions. It is probable, however, that the development of rhythmicity to very large amplitudes is most likely to occur under erosional conditions. This seems likely, given the more rapid response of rhythmicity amplitude than of mean shorline position to changes in significant wave height.

Conclusions

Emperical orthogonal eigenfunction analysis of a matrix containing offshore distances to an elevation contour provides a means for determining the important morphologies variables in an area. These may not correspond to single morphologies deemed important by the researcher if these morphology components do not behave completely independently over the period represented by the measurements. They will also not correspond if longshore migration of a sinusoidal pattern occurs during the time of study. Reconstruction or partial reconstruction of the original data by summing weighted eigenvectors or 'new variables' with the mean can provide insights into the significance of the vectors and the dynamics of the beach system.

Three important morphologic components were identified on Siletz Spit: overall accretion or erosion of the shoreline, amplitude of an 800-850 m wavelength rhythmic topography, and longshore position or phase of the rhythmic features. EOF analysis was useful in verifying the importance of these components but was not able to provide a simple separation of them.

It was determined that the mean shoreline position and rhythmicity amplitude can be quantified, respectively, by the mean distance offshore to a specified contour and the standard deviation of the contour about that distance. Longshore position or phase of the rhythmic pattern can be described by the weights of the first eigenvector, calculated by EOF analysis, of a contour data matrix in which each contour is normalized to the same mean and standard deviation. This should also apply for other, similar systems showing less than about 200 degrees of longshore migration.

This quantification permitted evaluation of the effects of various wave and weather conditions on the shoreline morphology. As expected, the mean shoreline position moved onshore as wave height increased. The amplitude of the rhythmicity was inversely correlated with wave height, though there is some question as to whether this is true for all winters on Siletz Spit. During the winter of 1982/83, rhythmic topography formed and increased in amplitude under depositonal conditions. Again, there is some question as to whether this is always the case at this site. Mean shoreline position was shown to change, at most, 5 m during a two-week period, whereas, rhythmicity amplitude changed by as much as 10 m. This difference in rates of change should make formation and development of rhythmic topography possible under erosional conditions, as well as under the depositional conditions observed during this study.

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