CHAPTER 173

TEMPORAL AND SPATIAL CROSS-SHORE DISTRIBUTIONS OF SEDIMENT AT "EL PUNTAL" SPIT, SANTANDER, SPAIN

by

M.A. Losada*
R. Medina*
C. Vidal*
I.J. Losada*

ABSTRACT

Sediment samples and beach profile evolution data, collected along one profile line at "El Puntal" Spit, Santander, Spain, are studied by means of Principal Component Analysis (PCA). This analysis technique is used to separate the temporal, spatial and grain size distribution variability of the data. The results show that there is a seasonality in the grain size distribution affecting the fine sand as well as the coarse sand. The variations of the coarse sand percentage, which occur mostly within the bar-berm area, consist of an increase, in the bar zone in winter and in the berm zone in summer. The fine sand presents a different behaviour, changing all along the profile, increasing its percentage offshore the bar in winter, and in the foreshore in summer. Thus, the sediment just relocates in the cross-shore direction.

Further, a "master" grain size distribution, which is constructed by adding all the grain samples, taken from all over the profile, is shown to be

* Ocean & Coastal Research Group. Departamento de Ciencias y Técnicas del Agua y del Medio Ambiente. University of Cantabria. 39005 Santander, Spain.

constant in time. It is suggested that the "master" grain distribution should be used in coastal engineering formulation.

INTRODUCTION

Investigators have long recognized that there is a relationship between beach profile and sediment size (see Dean, 1977, for a general reference). Though, in almost all relationships proposed, the grain size distribution and grain size related parameters are usually assumed uniform in the cross-shore direction. It is also well known that the sediment characteristics of a beach profile vary both spatial and temporally. A great number of studies have investigated the changes in sediment grain size and the onshore-offshore grain size sorting across the beach profile. Most of the studies involve using statistical granulometric parameter as sample mean, mode and skewness, determined from native sand samples (see recent work by Moutzouris, 1991). Some studies use field data from sand tracers, usually natural sand tagged with fluorescent color or with artificially induced radioactivity (Murray, 1987) and other studies present results from laboratory experiments (Kamphuis and Moir, 1977). However, there is not always agreement on the results described by the different researchers, especially on the trends followed by the degree of sorting across the beach profile.

Attempts have been made to explain and quantify the processes involved in the sorting of grain size across the profile. Two major hypotheses have been proposed in the past: the hypothesis of asymetrical thresholds under waves (see recent work by Horn, 1991) and the hypothesis of the null-point (e.g. Cornaglia, 1889). Despite the efforts undertaken to understand the processes responsible for the grain size distribution across the profile, the problem remains open and further studies are needed.

Statistical methods, such as Principal Component Analysis (PCA) or Factor Analysis (FA), provide a useful tool to objectively separate the spatial and temporal variability of beach profile data (e.g. Winant et al., 1975; Medina et al., 1991) or of sediment data (Liu and Zarillo, 1989). In all of these works, only two dimensions are considered among offshore-distance, time and grain distribution, resulting in a partial view of the problem. In the present study, sediment data is analyzed by means of the three-way PCA method in which offshore distance, time and grain distribution are used to describe the spatial and temporal structure of the grain size distribution variability.

ANALYSIS METHOD

Historically, PCA has been carried out for data which depend on two dimensions. If more dimensions were involved, data aggregation or other techniques were used to reduce the problem to a two-dimensional problem. Solutions for three-way data were first proposed by Tucker (1966) and extended by Kroonenberg and De Leeuw (1980).

A detailed discussion of the method can be found in the paper by Kroonenberg and De Leeuw (1980). In brief, one seeks a factorization of a three-way data matrix Z, such that:

$$Z_{ijk} = \sum_{p=1}^{s} \sum_{q=1}^{t} \sum_{r=1}^{u} [g_{ip} h_{jq} e_{kr} c_{pqr}]$$

where the coefficients g_{ip}, h_{jq} and e_{kr} are the elements of the columnwise orthonormal matrices G, H, E, respectively, and c_{pqr} are elements of the so-called three-mode core matrix, C. G, H and E have similar interpretations as the two-mode eigenvectors and are determined so that the difference between the data and the value obtained from the factorization is minimal according to the mean squared error. In practical applications one is just interested in the first few (two or three) principal components which account for most of the data's variance. The core matrix, C, however, is no longer a diagonal matrix of eigenvalues. One could conceive of the core matrix as describing the basic relations that exist between the various collection of variables. The solution of the problem is based on the observation that the optimal C matrix can be expressed uniquely and explicitly in terms of the data modes. The latter components' matrices are optimized by an alternating least squares algorithm.

STUDY AREA AND FIELD DATA

The study site is located on the Cantabrian Coast of Spain, Gulf of Biscay (Fig. 1). The northern coast of Spain consists of a series of pocket beaches and small inlets separated by pronounced rocky headlands. Santander Bay is one of the largest inlets on the Cantabrian Coast and is located about 200 km West of the French border. The Bay is bounded northward by "El Puntal" Spit, a sandy spit which protrudes well inside the

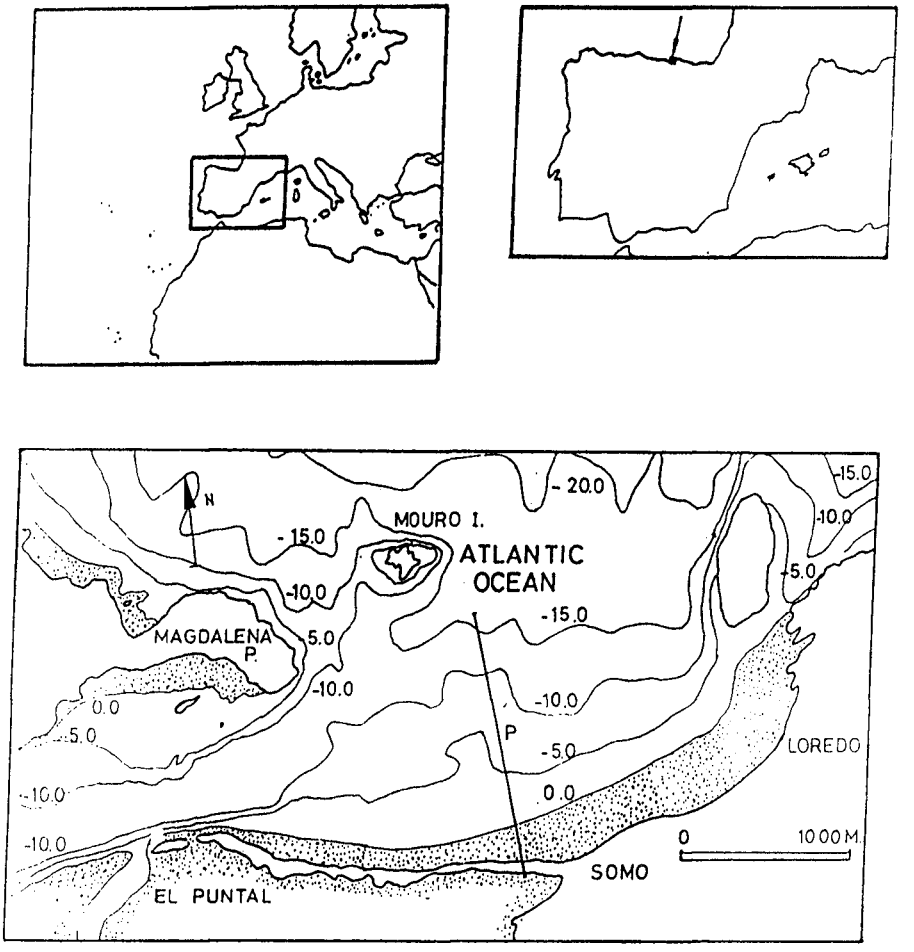


Fig. 1.- Location Map.

bay (see Fig. 1). The predominant wave approach direction is from the N/NW sector and has an annual average significant wave height of H_s = 4 m. Tides along the Cantabrian Coast are semidiurnal. The mean tidal range in Santander Bay is 3 meters and the Spring tidal range is 5 meters.

A monitoring project is being carried out to evaluate the evolution of "El Puntal" Spit. The field program includes wave and current measurements, beach profile and sand samples. A detailed description of the monitoring program can be found in the paper by Losada et al. (1991). We will concentrate our work on the beach profile data and sediment sample data.

Surface sediment grab samples were collected along one profile line at the spit (Fig. 1), over a twenty-month period from May 1990 to January 1992. Profile surveys were taken about once a month, with sediment samples collected during each monthly survey. The beach profile data were collected from permanent monuments landward of the dune seaward to a depth of -15 m, which extended up to 1500 meters. Sediment samples were collected from fifteen positions (see Fig. 2) including the berm and intertidal area, the inner bar and trough area and the nearshore zone. The sediment sampling scheme attempted to locate the sample at the same distance seaward of the base line during each sampling period. Each sample was analyzed in the laboratory and grain sizes were computed by sieving according to ASTM standards using ASTM mesh Nº 30 (0.59 mm) to Nº 200 (0.074 mm).

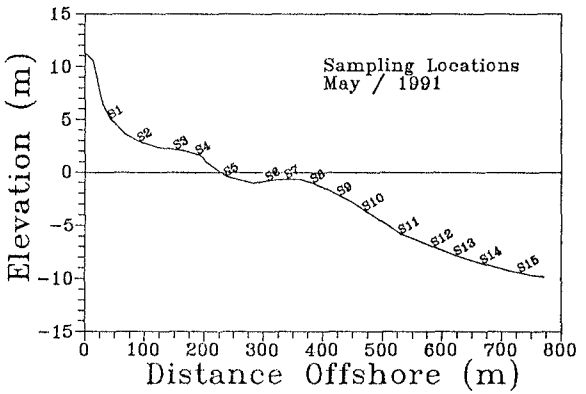


Fig. 2.- Sampling Location.

RESULTS OF ANALYSIS

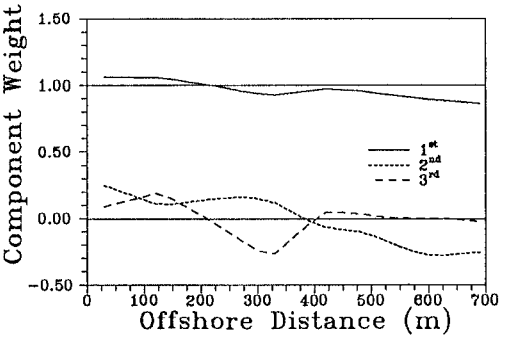
Sediment Data

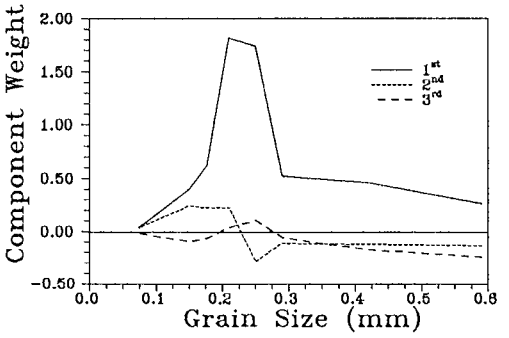
Since many of the grain size distributions obtained from the samples were not even close to a log-normal distribution, the entire grain size distribution is used instead of the usual statistics such as mean grain size standard deviation, skewness or kurtosis.

Sediment data can be arranged in the form of a matrix Z (x,t,d), where x is offshore distance, t is time (survey) and d is grain size distribution. Thus, for each survey and each location we have the complete grain size distribution of the sample. When the three-way PCA method is applied to these data, the internal structure of the data variability is separated into temporal, spatial and grain size distribution variability (eigenvectors G, H and E) and the importance of the different modes of variability is given by the core matrix, C. As previously stated, the method obtains matrices G, H and E which are columnwise orthonormal, in other words, they have length one. Bartussek (1973) suggested scaling the orthonormal eigenvectors of a three-way PCA analogously to the procedure often encountered in standard PCA. One advantage of this scaling is that the so-determined scales eigenvectors are comparable within a mode and over modes. When scaling the eigenvectors, the core matrix must also be scaled to leave the model invariant.

The corresponding Bartussek core matrix values and the percentage of variation explained by each element of the matrix are given in Table 1. The total variance explained with the first two temporal eigenvectors is, from Table 1, 97.5% with most of the variance explained with the first eigenvectors (g_{11}, h_{11}, e_{11}). This result is not surprising since we are dealing with raw uncentered data and, consequently, the centroid, defined as some mean of the data, can explain most of the data and is the best candidate for the first eigenvector.

In Fig. 3, the first three offshore distance (g_{1i}) and grain size distribution (h_{1i}) eigenvectors, and the first two temporal (e_{1i}) eigenvectors are shown. In order to interpret the results of the 3-way PCA, let us concentrate on the first temporal eigenvector (e_1) and the associated offshore distance and grain size distribution eigenvectors.





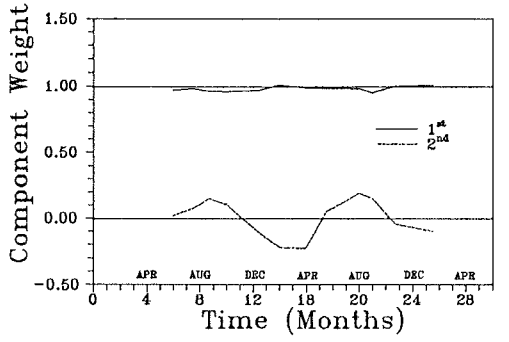


Fig. 3.- Eigenvectors.

Table 1

Frontal Planes of Core Matrix

Frontal Plane Time = 1 Down: Offshore Across: Grain size

Explained Variation			Bartussek Scaled		
.9240	.0000	.0000	1.060	-.027	-.049
.0000	.0260	.0003	-.027	-4.957	.782
.0000	.0010	.0068	.028	-1.442	5.595

Frontal Plane Time = 2 Down: Offshore Across: Grain size

Explained Variation			Bartussek Scaled		
0.002	.0016	.0003	.125	1.745	1.171
.0013	.0036	.0025	1.556	13.875	17.072
.0020	.0006	.0049	-2.874	-8.073	-35.762

The first temporal eigenvector shows an almost constant value in time, thus accounting for the mean (temporal) situation. The first offshore distance eigenvector is also characterized by an almost constant value. Consequently, if we use the first three modes eigenvectors that account for 92.40% of the variance, we obtain a mean grain size distribution in time and space. A better representation of the data can be obtained if we add the combination g_2, h_{12}, which corresponds to the second offshore distance eigenvector and the second grain size distribution eigenvector, that explains 2.66% of the variance. The second grain size distribution eigenvector accounts primarily for the fine sand and the second offshore distance eigenvectors shows a decreasing trend with a positive value at the beginning of the profile and a negative value at the end of the profile. When multiplying those eigenvectors with the corresponding Bartussek-scaled core-matrix value we get a decrease of fine sand at the beginning of the profile and an increase of

fine sand in the offshore part of the profile. Analogously, more variability of the data can be described using the combination g_{13}, h_{13}. That combination adds 0.68% of explained variance and give information of the coarse sand (g_{13}), which has negligible variability in the offshore part of the profile and maximum variability in the berm-bar zone of the profile (h_{13}). With these eigenvectors, we add coarse sand at the bar location. The final representation of the mean (temporal) situation is composed of an along-profile constant grain size distribution with finer sand in the offshore part of the profile, some coarse sand at the bar location and a well-sorted material at the beach face area (we substract fine and coarse sand). See Table 2 for an overall explanation of the sign of each term in the expansion and the action it takes over the first eigenmode.

Table 2

Grain size /Distance	Eigen-mode (1,2,2)				Action over the Eigenmode (1,1,1)
	Time T	Offshore distance X	Grain size G	Core Matrix CM	
>0.30 mm >400 m	+	-	-	-	- Substracts >0.30 mm
>0.30 mm <400 m	+	+	-	-	+ Adds >0.30 mm
<0.22 mm >400 m	+	-	+	-	+ Adds <0.22 mm
<0.22 mm <400 m	+	+	+	-	- Substracts <0.22 mm

The second temporal eigenvector (Fig. 3) shows a seasonal dependency with a maximum in the summer season and a minimum in the winter season. The eigenvectors associated with this second temporal eigenvector explain 1.70% of the variance. Among the nine possible combinations of grain size distribution eigenvectors and offshore distance eigenvectors, again the pairs g_{23} h_{23} and g_{22} h_{22} are the most important in terms of explained

variance. Notice that the second temporal eigenvector has a different sign depending on the season, thus the effect of the pairs g_{23}, h_{23} and g_{22} h_{22} changes seasonally. In this way, the pair g_{22}, h_{22} describes a seasonal variation of the fine sand along the profile. If we want to have a better representation of the summer data, we must add fine sand in the landward part of the profile and substract it in the offshore area. Inversely, in winter, fine sand must be added in the offshore zone and substracted in the landward part.

The seasonal variability of the coarse sand is controlled by the pair g_3, h_3 and bounded in the berm-bar area (see Fig. 3). In winter, more coarse sand is encountered at the bar location while the percentage of coarse sand decreases at the berm position. In summer, however, the bar suffers a decrease of coarse sand that is now located at the berm position.

WORKING HYPOTHESIS FOR THE CROSS-SHORE GRAIN SIZE DISTRIBUTION

Besides the information about the grain size distribution and the degree of sorting in the cros-shore direction, the eigenvector expansion suggests new ideas on the sediment transport that occurs in the cros-shore direction. The situation described by the spatial eigenvectors associated with the first temporal eigenvector is a "static" or "no-mobility" situation since it does not change in time. Actually, some sediment transport might exist, but it is balanced so that no temporal variations occur. On the other hand, the situation depicted by the eigenvectors associated with the second temporal eigenvector shows that some sediment transport is taking place since, for example, the percentage of coarse sand is decreasing at the bar location during the summer period. Further, the eigenvector expansion indicates that the coarse sand movement takes place mainly within a zone between the berm and the bar while the fine sand moves all along the profile.

Notice that the second temporal eigenvector shows a seasonal dependency with no net trend. Thus, the sediment transport in the crosshore direction is just a "sediment or grain size relocation": the coarse sand is seasonally redistributed between the bar and the berm and the fine sand between the offshore zone and the landward part of the profile.

For each of the twenty surveys, a "master" grain size sample constructed by adding all the grain samples taken over the profile is obtained. Figure 8 shows the "master distribution" for the winter and summer surveys. Except for minor deviations associated to a discrete sampling technique (only

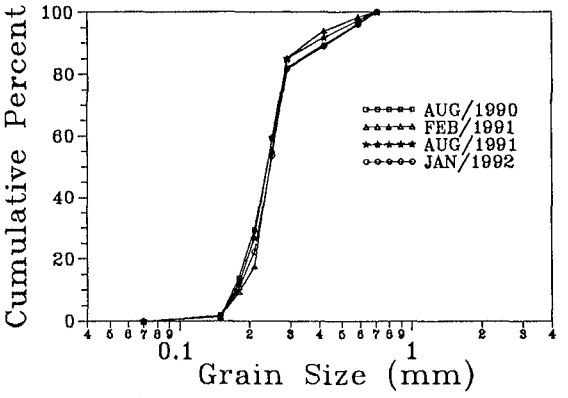


Fig. 4.- "Master sample" grain size distribution.

fifteen samples were taken along the profile for each survey), it can be accepted that a "master grain distribution", which is constant in time, exists. Thus, the following working hypothesis may be anticipated:

> *"For a beach profile within a physiographic unit, the "master grain size distribution" obtained by adding all samples taken over the active profile, doesn't depend on time".*

The application of this hypothesis should be useful to select a grain size, representative of the overall behaviour of the sand in the profile. As an example, it is suggested that parameters like "A" of the equilibrium beach profile and "K" of the longshore sediment transport formula should depend on the D_{50} of the "master" grain size distribution.

Finally, three more remarks: First, the hypothesis simplifies the field work. To know the grain size distribution in a profile, the sample may be collected anytime, since it is invariant. The unique requirement is that the samples have to be taken all over the active profile.

Second, in order to reconstruct a beach profile, the borrowed grain distribution should be as close as possible to the "master" grain distribution of the native sand.

Last, the hypothesis may be extended to 3D cases, extending the idea of "master grain size distribution" to a physiographic unit (like a pocket beach). To check this case, the development of a four-way Principal Component Analysis would be necessary.

CONCLUSIONS

* The Three-way PCA of sediment grain size data is used to separate the temporal, spatial and grain size distribution variability.

* For the case of study, it is found that the coarse sand mobility is bounded within the bar-berm area, while the changes in percentage of the fine material take place all along the profile.

* A "master" grain size sample is obtained for each of the surveys. This "master" sample is constructed by adding all the grain samples taken along the profile. Comparison between the twenty master samples points out that they are almost equal. Therefore, it can be concluded that there is a "master" grain size distribution for the profile which is constant in time.

* Adopting the previous conclusion as a working hypothesis, it is suggested that the "master" grain distribution should be used in coastal engineering formulations to determine the required single grain size value, such as "A" in the equilibrium beach profile or "K" in the longshore sediment transport formula.

* One of the main advantages of this conclusion is the remarkable reduction of the field work as one field campaign at any time is enough to obtain the "master" grain size distribution.

* Finally, it has to be pointed out that by applying a four-way PCA, a "master" grain size distribution of a physiographic unit may be determined.

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