THOUGHTS ON LARGE SCALE COASTAL BEHAVIOUR

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ABSTRACT: Large scale coastal behaviour (LSCB) deals with the development of coastal profiles and sediment budgets of a large coastal stretch (order tens of km's) over a considerable period of time (order decades). The knowledge of coastal behaviour at these scales is still very limited. Approaches to arrive at this knowledge are (in order of increasing complexity) the geostatistical, the phenomenological and the modelling approach. The main problems related to these approaches are: to give a proper description of the integrated temporal and areal developments of the coast; to determine the driving forces that govern LSCB, to schematize or parameterize the forces and relate them to these developments and finally to develop physically based models which describe adequately these developments. Possible solutions are suggested and limitations are discussed.

INTRODUCTION

Sedimentary coastlines normally show variable changes in time and space. Policy decisions concerning coastal management may cover different areal and temporal scales. For convenience sake we may distinguish small, meso and large scales. The boundaries between them are arbitrary. The small scale reflects coastal variations over a short time (up to a year) and limited area (up to a kilometer). The large scale considers variations over decades and tenth of kilometers. The meso scale ranges in between. Many problems of coastal management refer to the large scale coastal development. There are numerous studies recording coastal morphological changes by means of repeated levelling of coastal stretches. There is also an extensive literature, attempting to explain these morphological changes focussing on processes and sometimes resulting in quantitative modelling.

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However, we may question whether the observations and the results of process studies are representative or applicable for large scale coastal developments, and whether the temporal and areal resolutions of these studies are appropriate for these developments.
Therefore, large scale coastal behaviour poses two major questions related to this scale:

- How can we describe coastal variations and developments at this scale?
- How can we define appropriate process systems relevant for this behaviour?

This paper addresses especially the first question from a more or less philosophical point of view.

THE PROBLEM OF SCALES

Coastal morphodynamics deals with variations in profiles and sediment budgets in relation to energetic processes. Crucial in the distinction between small, meso and large scales is the recognition of a hierarchy in hydrodynamic processes and morphological changes as illustrated in figure 1.

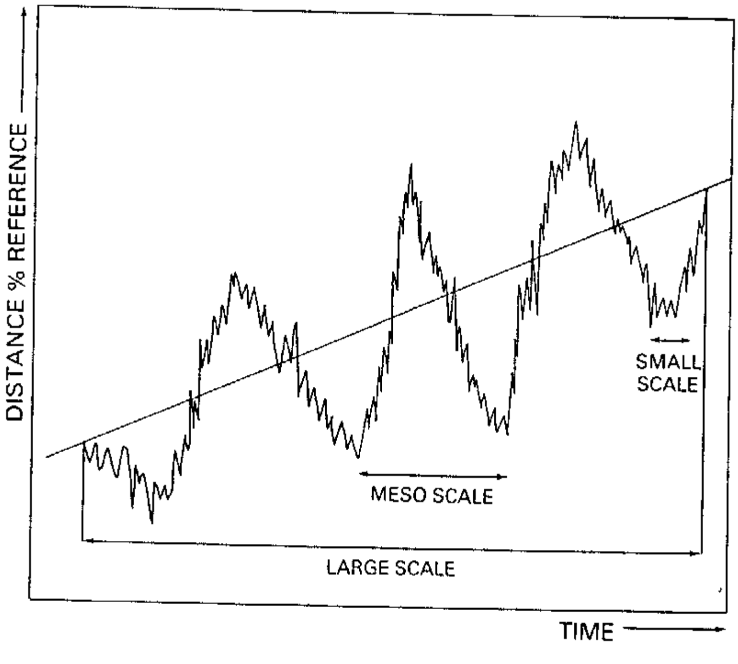

Figure 1. Schematic representation of the distance of a contour line to a certain reference in time, showing different scales of coastal variation.

On a small scale the processes and the responses of profiles and budgets are rather variable: the most energetic processes predominate, producing quick adaptations in the morphology. On a larger scale the more energetic processes are smoothed out and the less energetic but systematic processes come to the fore. At the larger scale the variations produced by the small scale processes are noise to a large extent and they contribute to the larger scale behaviour only in a net averaged way. In essence this means that the small scale processes reflect the gross sediment fluxes and budgets, and the large scale processes the net effects.

A major question is whether the large scale coastal behaviour is "just" the net average result of the small scale processes (Di Silvio, 1986; 1989; Di Silvio and Gambolati, 1990) without changes in the boundary conditions over time and area, or that over this time lap there may operate autonomous processes that causes systematic changes in the boundary conditions. One may think of changes in wave and current climate or in the sediment sources or sinks.

Another problem is: how can we determine the relevant scales. In this respect we may formulate the following hypothesis: an area in which the coastal profiles show a similar development in time is governed by a specific process system. Thus, if we have bounded areas showing a similar behaviour we have also bounded a specific operating process system in space. An illustrative example is presented in figure 2 (Wiersma, 1987) showing the position of the foot of the dunes along the central part of the Dutch coast, over 115 years. There are large areas which are almost stable (e.g. km 60-105) and some small areas exhibiting a definite trend (e.g. km 30-40; km 7-15). It should be noted that engineering construc-

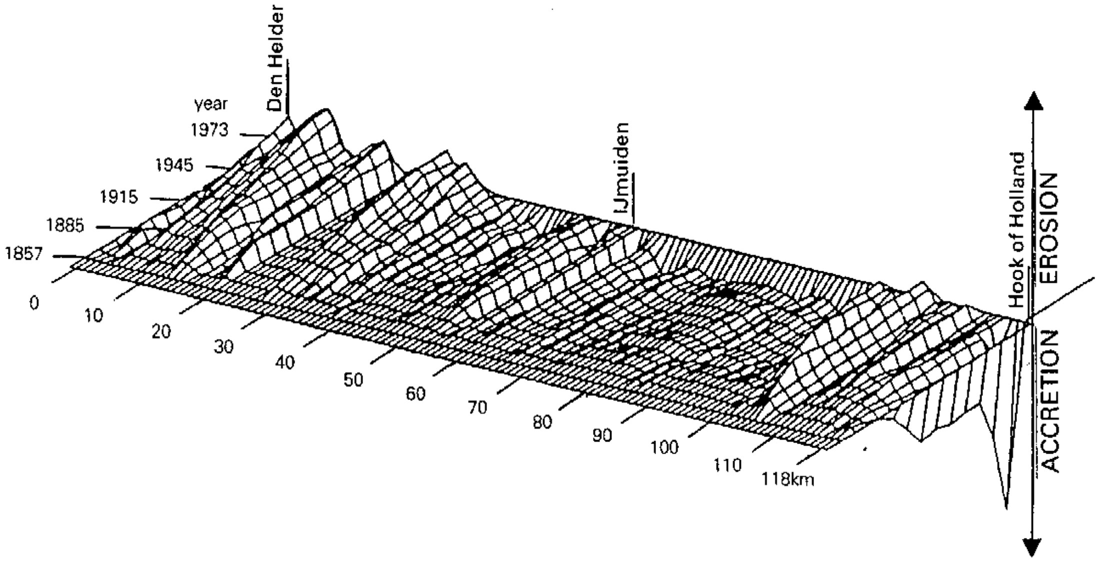

Figure 2. Time-distance diagram of the position of the foot of the dunes along the central part of the Dutch coast. (Ten years filtered mean; 1857 as reference). After Wiersma (1987).

tions may have a disturbing influence on the beach development. For instance the development around km 55-62 is related to the building of the harbour moles of IJmuiden. We are dealing here with only one contour line on the beach. Of course we have to include the whole coastal profile in our analysis. But the main point is that we may set boundaries on the process systems on the basis of the morphological behaviour.

APPROACHES TO LARGE SCALE COASTAL BEHAVIOUR

Continuing the discussion on the hypothesis presented in the previous paragraph, we are facing two major problems viz. an adequate discription of the morphological developments in time and space, and a correlation of these developments with process parameters or process formulations.
In this respect Terwindt and Battjes (1991) distinguished three approaches with increasing complexity and necessary level of knowledge, viz. the geostatistical, the phenomenological and the modelling approach.

The geostatistical approach. The geostatistical approach is merely descriptive. It deals with the analysis of data sets of coastal profiles and sediment budgets for trends in time and/or space.

The phenomenological approach. The phenomenological approach tries to correlate the results of the statistical analysis to parameters which are considered relevant for the processes of interest. Emperical relations are derived without formulating or using a model for the basic physical processes.

The modelling approach. In the third approach the basic driving forces are structured into a comprehensive framework or model. Such models aim at the quantifications of the sediment movement and the related morphological adaptations.

THE GEOSTATISTICAL ANALYSIS OF COASTAL PROFILE DATA

Geostatistics deal with properties of regionalized variables (Davis, 1986). Repeated measurements of coastal profiles over a certain area provide a data matrix D_{xyt}, where D is a depth reading in an x,y co-ordinate system at time t. Several manipulations may be excercised on this data matrix.
We may generate plots of the position of e.g. a depth contour alongshore at a certain fixed time or the variation in time of a position of a depth contour at a certain fixed location or a combination of both (fig. 2). Another example is to examine the differences of the values of D in the x-y grid over a certain time interval Δt. These differences may be recalculated into net erosion and sedimentation volumes in time and space. Regression analyses may be applied to discover trends in the generated data.
More complicated statistical techniques have to be used if we want to compare the properties of the profiles with their neighbours and if we want to accomplish this comparison in time. For the purpose of the analysis of large scale coastal behaviour we want to know:

- a mean profile over a certain distance and time;
- time trends of the development of the mean profile;
- a good representation of the breaker bars in the profile;
- the representation of the movement and adaptation of these bars in time.

In fact we are dealing with two aspects viz. a static (spatial variation of the profile and breaker bars therein) and an evolutionary (developments of profile and bars in time).

The huge amount of profile data involved in the description of large scale coastal behaviour, has to be compressed into a few new variables that describe most of the variability in the data set. Statistical techniques suitable for this purpose are time series analysis (each profile being a time series) and multivariate analysis (depth readings cross-shore being variables). The main criterion for selecting a certain technique is the power to describe the characteristics of coastal behaviour.

In time series analysis we may distinguish parametric models, such as ARMA and ARIMA models, and non-parametric models, such as autocovariance functions and power spectra.

Parametric models are widely used for prediction of future values of a series (Jenkins and Watts, 1968). Non-parametric models aim at describing the nature of a time series, for example to compare signals and develop transfer functions. Since we are interested in describing the nature of the profile, the non-parametric models seem to be more appropriate for our purpose than the parametric models.

From the non-parametric time series analysis methods, spectral analysis has an advantage over the other methods because in spectral analysis the signal is decomposed into uncorrelated frequency components. Since the components are not correlated, it is possible to reveal the existence of different time and length scales in the variability of the distinct characteristics of the profile.

A multivariate technique operating in a more or less comparable way, is principal component analysis (PCA). This technique decomposes the data set into several uncorrelated components that are linear combinations of the original variables. Spectral analysis, however, seems to be more appropriate than PCA to describe the profile characteristics, because spectral analysis is based on Fourier analysis, which is designed to describe periodic, wave-like phenomena (in time or space), such as bars. Therefore, the physical meaning of the resulting components is à priori known. PCA, contrarily, is not designed to take account of spatial relationships, therefore, a physical meaning of the components, in the sense of spatial characteristics, has to be assigned afterwards by trial and error. PCA may show that certain relationships exist, but it does not offer any clue on the physical nature of those relationships.

Spectral analysis as a tool to describe bathymetric data was applied by Dolan et al. (1979) to reveal the orientation and wave length of offshore shoals along the North Carolina coast. The significance of peaks in the power spectra was not tested statistically (no general accepted test exists), but was determined by an arbitrary rule-of-thumb. This brings us to the major problem in applying spectral analysis on profile data.

Treated as time series the profiles represent a very short sample.

Therefore, the reliability of the power spectrum will be low. The profiles in most data sets usually contain only one to three bars with different wave lengths and amplitudes. In order to get reliable phase estimations, the major wave length has to occur at least several times in the signal, which is hardly the case. Therefore, the reliability of the phase spectra will be low too. Hence, the description of bar migration rates, which is an essential feature of coastal behaviour, is not possible. The lack of phase information also inhibits the reconstruction of an 'average' profile later on. Another adverse effect of the differing wavelengths and amplitudes of the bars, together with assymetrical features within the bar-trough topography, is that dominant frequencies can not be related to the observed bar-trough dimensions. From a preliminary analysis of profile data of the Dutch coast it appeared (Helsloot, 1990) that the wave length corresponding with the dominant frequency in the spectrum, is in some cases related to the position of a large bar but in other cases to a deep trough. Whether we are dealing with a bar or a trough can not be deduced from the spectrum. In addition, the dominant frequency is sometimes associated with an outer bar-trough topography and in other cases to a more landward located bar-trough system. Therefore, it may be concluded that the translation of dominant frequencies to profile characteristics is not satisfying.

Since spectral analysis requires a stationary time series, the profile must be detrended before analysis. Therefore, the mean profile and its behaviour have to be described by other means than spectral analysis. This fact will increase the number of variables required for accurate profile description.

Principal component analysis, or empirical eigenfunction analysis, has been (relatively) widely used to describe profiles (table 1). Since principal components are orthogonal they are uncorrelated and therefore offer the same possibilities as spectral analysis to reveal different time and length scales in variability of distinct profile characteristics. This statement is illustrated by Weishar and Wood (1983), who show that the behaviour of the inner bar is noise on a time scale of years while the behaviour of the outer bar definitly shows trends and periodicities on that time scale.

One of the advantages of PCA compared to spectral analysis is that PCA includes the behaviour of the mean profile. Further, no functional form is imposed on the components as in spectral analysis (in which the components are sinusoids). However, this advantage also poses the major problem of applying PCA in profile description: the morphodynamic interpretation of the components. Several researchers, however, have shown that the first 2 to 4 principal components may be interpreted in the sense of mean profile and position of bars. These results are promising with respect to the possibilities of this method to describe essential features of the profiles in our data set.

Whether principal components are also suited to describe profile behaviour, such as bar migration rate and rate of change of the mean profile, is not yet established. In previous studies conclusions on temporal developments have been limited to rather qualitative statements, such as (cyclic) redistribution patterns of the sediment

(Winant et al., 1975; Aubrey, 1979; Lins, 1985; Aubrey and Ross, 1985), or rough time scales of bar migration (Weishar and Wood, 1983).

Table 1. Overview of profile data sets described with PCA

Authors	Geographical location of the data set	Spatial resolution	Temporal resolution	
		Total alongshore length/ Number of profile locations/ Profile spacing/ Profile length	Levelling interval	Total period
Winant et al. (1975)	Torrey Pines Beach (California)	1.2 km / 3 / 0.4 km + 0.8 km / 400 m	monthly	2 year
Vincent et al. (1976)	Atlantic and Gulf coast	± 3000 km / 530 / 4 km / 5.7 km	-	-
Resio et al. (1977)	Atlantic and Gulf coast	± 3000 km / 296 / 16 km / 14 km	-	-
Dolan et al. (1977)	Atlantic and Gulf coast	± 3000 km / 504 / 5-500 km / 365 m	-	-
Aubrey (1979)	Torrey Pines Beach (California)	1.2 km / 3 / 0.4 km + 0.8 km / 400 m	monthly	5 year
Aubrey et al. (1980)	Torrey Pines Beach (California)	1 km / 6 / 50-350 m / 150 m	daily	1 month
		1 km / 2 / 1 km / 150 m	± weekly	1.5 year
Weishar and Wood (1983)	Lake Michigan	0.9 km / 3 / 0.3 km + 0.6 km / 300 m	monthly	4 year
		- / 1 / - / 300 m	yearly	13 year
Fisher et al. (1984)	Outer Banks (North Carolina)	71 km / 222 / 65 m / 305 m	39 year	2 yearly data sets
Aubrey and Ross (1985)	Torrey Pines Beach (California)	1.2 km / 3 / 0.4 km + 0.8 km / 130 m	weekly	1 year
		0.4 km / 2 / 0.4 km / 560 m	monthly	5 year
Lins (1985)	Outer Banks (North Carolina)	- / 1 / - / 235 m	daily	3 months
Zarillo and Liu (1988)	Long Island	134 km / 72 / 2.5 km / 700 m	-	-

According to the Eckart-Young theorem (Davis, 1986) it should be possible to reconstruct profiles from the first n principal components. Aubrey and Ross (1985), for example, reconstructed profiles from the first two principal components. The advantage of being able to reconstruct profiles is that one can visualize the essentials of large scale coastal behaviour, and that in an additional phenomenological and/or modelling stage one can use well founded representative profiles.

When using statistical techniques one has to deal with several requirements on the statistical properties of the data set. This aspect is left underexposed in all the articles on profile description by PCA. PCA extracts eigenvalues and eigenvectors from a matrix containing measures of association between variables. When using the covariance or the correlation coefficient as a measure of association, the variables are assumed to be normally distributed, otherwise the covariance or correlation coefficient are not good measures of association between variables (PCA itself does not require the data set to be normally distributed). Even small departures from normality appear to have pronounced effects upon component structure and scores (Clark, 1973). Several transformations are possible to avoid non-normality. However, when different variables need different transformations, the physical meaning of the principal components will be obscured even more.

Statistical tests available for testing the significance of the principal components (Daultrey, 1976) only apply when the data are multivariate normally distributed and strictly speaking only when the eigenvalues are derived from a variance-covariance matrix.

With respect to the interpretation of the principal components one has to realize that PCA based on the correlation or covariance matrix, assumes linear relationships between the variables. When relationships between variables are non-linear this implies that, although the principal components are orthogonal and consequently uncorrelated, interpretations of the various components may still be related (Norris, 1971). In other words, when relationships between variables are linear it is impossible that more than one component refers to, for example, the outer bar, while with non-linear relationships it is not.

Having outlined the general merits of PCA and spectral analysis in profile analysis, we may conclude that PCA is the better tool for describing profiles. Evaluating the conclusions derived from profile description by PCA with respect to coastal behaviour, we may conclude that none of the studies cited considered both large length and time scales. Studies incorporating both temporal and spatial variation were all applied to smaller scales. These studies considered daily to monthly profiles, measured during periods of one month to several years at a few locations (2 to 6) with spacings ranging from 150 m to 800 m.

The studies of Weishar and Wood (1983) and Zarillo and Liu (1988), outline the power of PCA to describe profile variability on respectively a large time scale and a large length scale. Based on their results we expect that description of the Dutch data set (Rijkswaterstaat, JARKUS data set) by PCA will reveal characteristics of large scale coastal behaviour, as it contains 21 years of yearly profiles over a 120 km stretch of coast with an alongshore profile spacing of on average 250 m.

An additional advantage of using PCA for description is the attractive possibility it offers to explore relationships between processes and morphological changes, as outlined by Aubrey et al. (1980). This will be amplified in the next paragraph.

THE PHENOMENOLOGICAL APPROACH

This approach tries to correlate the results of a (statistical) analysis of coastal profiles to parameters which are considered relevant for the processes that have generated these profiles. Not the processes themselves but representative descriptive parameters are used and empirical relations are derived without formulating or using a model for the basic physical processes. Several parametrisations have been proposed in relation to beach profile changes. These include the Dean and surf-scaling parameters (Dean, 1973; Guza and Inman, 1975; Battjes, 1974) comprising wave characteristics, slope and sediment size, related to beach configurations (reflective or dissipative) (Wright et al., 1979; Zarillo and Liu, 1988; Short, 1991). Another example is the correlation of beach profile changes to several wave characteristics, such as the onshore component of the radiation stress, the wave energy, the wave energy flux and the wave steepness (Aubrey et al., 1980). Weishar and Wood (1983) related changes in beach and offshore topographies to water level variations in the Great Lakes. A final example is the relation between the geometry of tidal channels and shoal systems and the tidal prism or mean tidal velocities (Eysink, 1991; Gerritsen et al., 1991, O'Connor et al., 1991).

Two general problems come up with this approach. The first is how can we specify "relevant parameters" and the second, how can we determine the systematic changes of the parameters in time and space. The parameter chosen must reflect the properties of the water and sediment movement, thus the wave and current effects on sediment movement.

A possible approach was presented by Aubrey et al. (1980). The considered wave characteristics were averaged over the period between the successive levellings of coastal profiles on three locations. For every location a PCA was applied and empirical eigenfunctions of the wave characteristies were associated with the eigenfunctions of the profile data. The total period of observations in the data set was 1½ year. Although this time lap is rather short for large scale behaviour and no spatial variation was included, the basic ideas of this approach certainly merits further exploration for the large scale case.

Considering long-term alongshore variations in characteristics of the water movement, one may think of longshore changes in wave climate (height, direction), tidal current strength due to slight variations in the tidal constituents, longshore energy fluxes due to bends in the coastline, the presence and number of bars in relation to the wave energy dissipation, etc.

In conclusion, the phenomenological approach for describing large scale coastal behaviour is still in its infancy.

THE PROCESS-MODELLING APPROACH

The objective is to formulate and model process-systems, which determine large scale coastal behaviour, starting from the driving forces. Two ways may be followed to accomplish this objective viz. the scaling up of small scale processes or the formulation of new specific large scale models.

Scaling up means integration of the processes or outcomes of small scale models to a larger time scale. The reliability of the results of the upscaling depends on the accuracy of the small scale models. It is possible to formulate state-of-the-art models comprising the present knowledge on wave propagation and decay across the surf zone and the associated velocity field, on refraction, on sediment transport under the combined effect of currents and waves etc. In essence this approach was used by Roelvink and Stive (1989; 1991) and Stive et al. (1991). However, the reliability of such models is questionable (Terwindt and Battjes, 1991).

The main problem is the inadequacy of the present knowledge of the water movement in the surf zone and the related sediment transport. Another point is the amplification of errors when integrating the non-linear mathematical system to a larger scale. Thus the scaling up approach, although valuable in the process of extension of our knowledge is still not advanced enough to describe the large scale behaviour.

The development of new formulations to describe the processes which determine large scale coastal behaviour on the appropriate scale has hardly started at this moment.

CONCLUSIONS

For many coastal problems, for instance effects of engineering works, we are not only interested in the rather quick small scale responses, but even more in the long-term effects which manifest itself on larger areal and temporal scales. It is necessary to determine these scales. Coherent studies on large scale coastal behaviour are scarce.

The major difficulties associated with the large scale aproach are

- the description of the integrated areal and temporal developments of coastal profiles and sediment budgets;
- the determination of the driving forces which govern these developments;
- the formulation of the interaction between these forces and these developments.

It seems that principal component analysis is a valuable tool for the morphological description of large scale coastal behaviour. Still there are important aspects left which deserve further attention. This regards the boundary conditions for the statistical elaborations and the morphodynamic interpretation of the outcomes of the statistical analysis.

The determination of the controlling forces operating on this scale is still a matter of trial and error. Process parameters may be tested for their relevance to coastal behaviour by means of statistical techniques (as PCA). This is a phenomenological approach.

The modelling of physical processes and process effects to arrive at a determination of large scale coastal behaviour are still in its infancy.

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