MORPHOLOGIC BEHAVIOUR OF BALNEÁRIO CAMBORIÚ BEACH, SANTA-CATARINA - BRAZIL: PRELIMINARY RESULTS

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ABSTRACT

The beach of Balneário Camboriú (Southern Brazil) has begun to attract large numbers of national and international tourists since 1960. Due to the intense urbanisation, two environmental problems were recognised: pollution of the water and changes in morphologic behaviour of the beach dueto the removei of the coastal dunes. In the management of the coastal zone, it is important to understand this morphological behaviour. Therefore, a monitoring study of the Balneário Camboriú beach was carried out between January 1994 and February 1996, with the objective of analysing the morphologic behaviour of the beach and identifying the controlling variables. The method of analysis consisted of computation of morphological variables, such as beach volume, width, slope and form, and correlating these variables with the wind-direction and -speed. The method has been applied on a data set of 200 profiles. The data set consisted of 8 profiles per survey along portions of about 5 km length. The interval between successive surveys fluctuated between two weeks and one month. Application of the method on the data set revealed that the subaerial volume changes do show a temporal cyclic behaviour on a time-scale of months, with periods of erosion and deposition. These periods can be correlated to the 'periods of storm' and 'periods of fair weather'. Due to the parabolic form of the bay, a longshore variation in beach dynamics can be observed, with higher dynamics in the Northern part of the bay and lower dynamics in the Southern part. No clear long-term trends of subaerial volume have been observed.

Key word: Coastal behaviour - Balneário Camboriú-SC, Parabolic form, Beach profiles

COMPORTAMENTO MORFOLÓGICO DA PRAIA DE BALNEÁRIO CAMBORIÚ, SANTA CATARINA - BRASIL: RESULTADOS PRELIMINARES

RESUMO

A praia de Balneário Camboriú (Sul do Brasil) tem atraído grande número de turistas nacionais e internacionais desde 1960. Devido à intensa urbanização, dois problemas ambientais foram reconhecidos: poluição da água e mudanças no compartamento morfológico da praia devido à remoção de dunas costeiras. No gerenciamento costeiro da área é importante entender o compartamento morfológico da praia. Portanto, um estudo de monitoramento da praia de Balneário Camboriú foi desenvolvido entre Janeiro de 1994 e Fevereiro de 1996, objetivando analisar o comportamento morfológico da praia e identificar as variáveis controladoras. O método de análise consistiu no cômputo das variáveis morfológicas como volume, largura, declividade e forma da praia, e da correlação destas variáveis com a direção e velocidade do vento. O método foi aplicado em 200 perfis. O grupo de dados inclui 8 perfis por levantamento ao longo de um trecho de praia de 5 km de extensão. O intervalo entre levantamentos sucessivos flutuou entre duas semanas a um mês. A aplicação do método nos dados revelou que as variações no volume subaéreo apresentam comportamento cíclico, dentro de uma escala temporal de meses, com períodos de erosão e deposição. Estes períodos podem ser correlacionados a períodos de tempestade e a períodos de calmarias. Devido à forma parabólica da baía, uma variação pode ser observada na dinâmica da praia ao longo de sua extensão, com elevada dinâmica na parte Norte da Baía e baixa diâmica na parte Sul. Nenhuma tendência em termos de longo prazo foi observada no volume subaéreo da praia.

Palavras-chaves: Costa - modificações - Balneário Camboriú-SC, Praia parabólica, Praia - perfil

INTRODUCTION

Balneário Camboriú is located along the Southern Brazilian coast, in the Santa Catarina State (Figure 1). The first house in Balneário Camboriú was constructed in 1926. Since 1960, the beach of. Balneário Camboriú has begun to attract a large number of national and international tourists and the growing urbanisation has not always been established at a safe distance from the shoreline.

As a result of the urbanisation of the area, two mains environmental problems were recognised:

- Due to the replacement of the coastal dunes by a road, the dynamic equilibrium of the beach was disturbed. This could cause an increased erosion during storms, leading to a reduction of the beach width;
- Pollution of the coastal waters, especially in the summer, due to the increased population.

In 1994, a research project was started by the Faculdade Ciências do Mar (FACIMAR) of the Universidade do Vale do Itajaí (UNIVALI) in association with the City Hall of the Balneário Camboriú. The aim of the project was to obtain an integrated understanding of the morphodynamic behaviour of the beach and the water quality, in order to facilitate the management of the coastal zone. This report will present the results of the study of the morphodynamic behaviour of the beach.

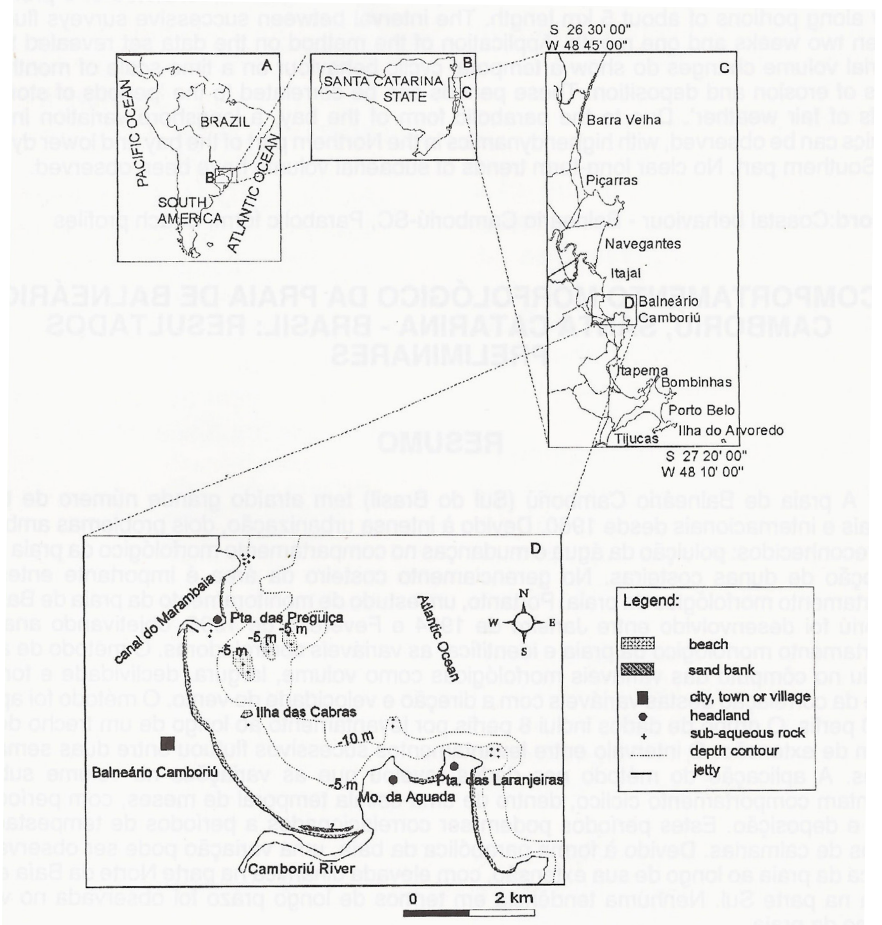

Figure 1 - Map of the study area.

The general objective of the research was to analyse the morphologic changes of the Balneário Camboriú beach on a time scale of years. To reach the general objective, the following research questions were formulated:

1. What are the temporal volume changes?
2. Is there a longshore variation in volume changes?
3. Can the volume changes be correlated to storms?

STUDY AREA

Geology and geomorphology

In geologic terms, the study area is composed of a pre-Cambrian crystalline complex, involving igneous and metamorphic rocks. Due to regression phase in the Holocene, the coastal plain consists of Quaternary beach ridges (Martin et al., 1988). The morphology of the Balneário Camboriú beach is controlled by two geologic headlands: Ponta da Preguiça in the North and Ponta das Laranjeiras in the South. In the study area, two rivers can be found: Canal do Marambaia in the north and Camboriú River in the south. The Canal do Marambaia is mainly used as a waste water disposal. The Camboriú River has an ebb-tidal flat at it's outlet. The mean discharge of the Camboriú River is 6 m^3/s (Schettini et al., 1996). The beaches in Camboriú are composed of wellsorted sandy. Values for d_{50} range from 0.1 mm to 0.2 mm (very fine to fine sand). There are no measurements available of the fluvial input of sediment to the coastal zone of Balneário Camboriú. Between these two rivers, the beach describes a parabolic form. Parabolic beaches are found on many of the world's swell-dominated coasts (Silvester & Hsu, 1993). It is is hypothesed that the parabolic shape of these beaches is an static equilibrium form, which is dependent on the incident wave approach, result of distance between the headlands and sediment flux (Carter, 1988). The small island in the middle of the bay (Ilha das Cabras) is composed of crystalline rocks. The parabolic form of Ihe beach is distorted in the area behind the Ilha das Cabras due to lee cusp deposits.

Climate, tides and waves

The climate of the coastal regions of Santa Catarina is under Ihe control of the high-pressure centre of the Atlantic anticyclone. The presence of the anticyclone causes a dominance of NE winds (about 5m/s) throughout the year (Nobre et al., 1986). During a cold-front passage the SWwinds dominate, with velocities of about 8 m/s. These winds are more common in winter than in summer.

The tide regime of Itajaí is microtidal and mixed, mainly semi-diurnal. Mean tidal renge is 0,8 m and maximum 1,2 m (Schettini et al., 1996). The meteorological influence over the mean sea levei is very important to the coastal dynannics, since it can increase up to 1 meter the sea-level (Schettini et al.,1996).

Dueto the semi-protected character of the Balneário Camboriú beach, the swell waves of the Atlantic Ocean are largely dissipated before they reach the coastline. From visual observations wave heights, ranging between 0.2 and 2.0 m are estimated in the surf zone. The predominant wave direction is from the north-east (Hogben & Lumb, 1967; Hogben 1967; Figure 2). Normally, Ihe wave energy decreases southwards within of the bay. The Northern part is more exposed to energic swell waves than the Southern sections. In the coast classification proposed by Hayes (1979: *apud* Davis & Hayes, 1984), based on Ihe parameters mean tidal range and mean wave height, Ihe beach of Balneário Camboriú is wave-dominated in the northern pari, and the mixed-energy, in the southern part.

Anthropogenic influences

Four anthropogenic influences can be identified: (1) In Ihe north of Ihe bay, a jetty

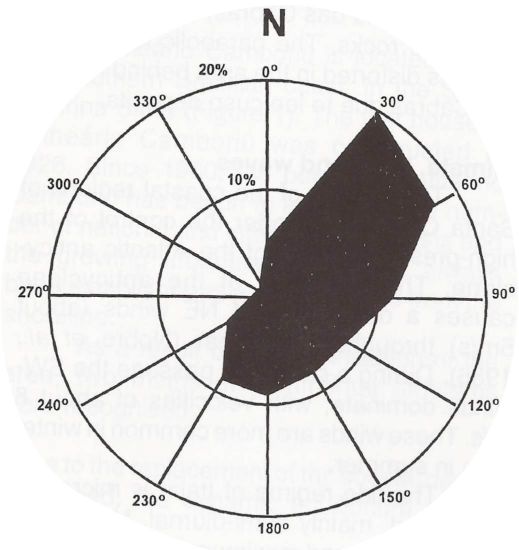

Figure 2 - Frequency distribution of wave directions for latitudes between 20°S and 30°S, based on 40 years of visual observations from ships. Data is published in Hogben and Lumb (1967) and Hogben (1967).

has been build. The purpose of this jetty is to facilitete lhe transport offshore. (2) During the summer (December to February), the beach of Camboriú is flattened by machines, usually after rains. The purpose of this action is to provide a nice, flat beach for the tourists. These procedures erode the tida! berms. (3) With exception of the extreme southern end of the beach, a road separated of to the beach by a seawall has fixed the location of the coastline. The road was built in the fifties. (4) Several storm outlets have been constructed along the beach in order to transport rain-water quickly from the city to the bay. These canais can cause a considerable offshore sediment transport.

METHODS

Measurements and data processing

The methods to reach the objectives, are presented in Figure 3. From the measured beach profiles, morphologic variables are calculated. Using morphologic variables, such as sand volume, length, slope and form of the beach, each profile were characterized into few parameters. When the nnorphologic variables are plotted as function of time, changes in the volume, length, slope and form of profiles can be detected. From the plot of the beach volume versus time, periods of erosion and sedimentation can be identified.

Since wave heights and directions were not measured, volume changes were correlated to the available meteorologic data. From the measurements of wind velocity and direction, the storms were identified. By correlating the periods of erosion and sedimentation with the occurences of onshore-directed storms, it was tested whether these control coastal behaviour.

Morphologic data

In the period between January 1994 and Februarv 1996, a beach-profile measu-

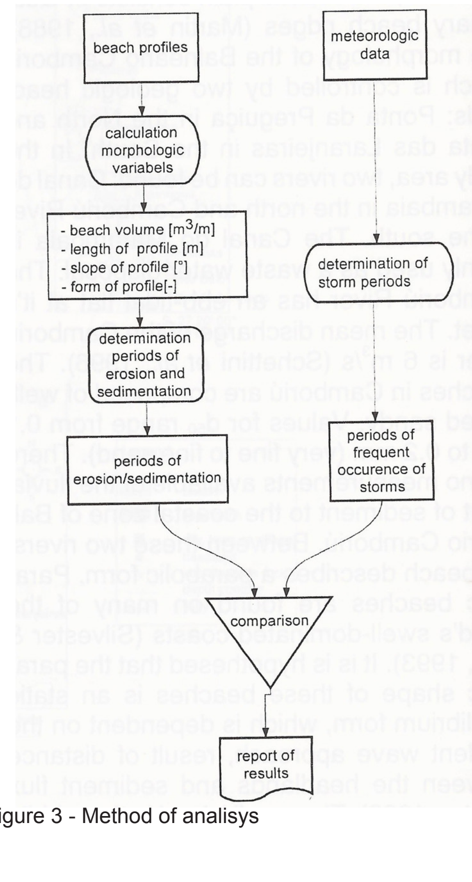

Figure 3 - Method of analisys

rement program was conducted in Balneário Camboriú. In total, 18 beach profiles were monitored with a levelling instrument, as proposed by Birkemeier (1981). The a long-shore distance between profiles is about 300 m (see Figure 4). In the first year (1994) the interval between successive surveys was about 2 weeks. In the next year, the surveys were conducted monthly. From January 1994 to February 1995, nearly ali profiles were measured during each survey. From February 1995 to February 1996, uneven profiles (e.g. profile 1,3,5 etc.) were measured more frequently than even profiles.

The beach profiles were evolucted by the Interactive Survey Reduction Program ISRP (Birkemeier, 1986). In order to reduce the period of data processing , only the profiles of the cross-shore sections 1, 3, 5, 7, 9, 11, 13 and 15 were imported into the program. These profiles were selected because they were measured most frequently. The profiles containing errors were removed from further analysis. In total, 200 profiles were stored. Ali profiles were made equidistant by linear interpolation between the data points, using the LOD_EQUI program (Bresters & Reijngoud, 1996). The distance between successive points is 1 m as recommended by Bresters & Reijngoud (*op.cit.*). Two tools have been written to speed up the data processing:

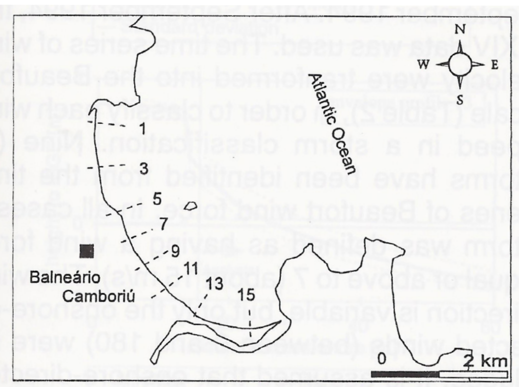

Figure 4 - Location of the profiles.

ISRP2TXT and EQU2MAT. By using these programs in combination with LOD_EQUI, the output file of ISRP was transformed into a format that could be used in any spreadsheet.

From the profiles, the following mor-phologic variables were calculated (Figure 5):

- beach volume (Q) [m^3/M];
- beach width (S) [m];
- beach steepness (tan) [-];
- beach shape [-].

The x-axis extends seawards, whereas the y-axis extends vertically upwards. The origin of the coordinates is located at mean sea levei (also IBGE, Instituto Brasileiro Geografia e Estatistica) at a fixed reference point. The morphological variables are computed using the landward boundary (x1) and the seaward boundary (x2). The landward boundary (x1) is constant per profile. The locations of these points are determined using the profile envelopes (see Figure 6). The profile-envelope is defined by the maximum and minimum height at each cross-shore distance. From the profile envelopes, part of the profile, where the morphological changes are essentially zero, due to the road, can be identified. The location of x1 is chosen so that this part of the profile is not included in the analysis. The cross-shore locations of boundary x1 are given in table 1. As seaward boundary, the location of the mean sea levei (x2) is used in ali cases. In consequence, only the subaerial part of the profiles are analysed. The beach volume (Q) is defined as the cross-sectional area within the boundaries x1 and x2, so that:

$$Q=\int_{x1}^{x2} y.dx$$

This parameter is proportional to the volume of sediment contained in a subaerial profile seaward of the origin, per unit length of the shoreline (Sonu & van BeeK, 1971).

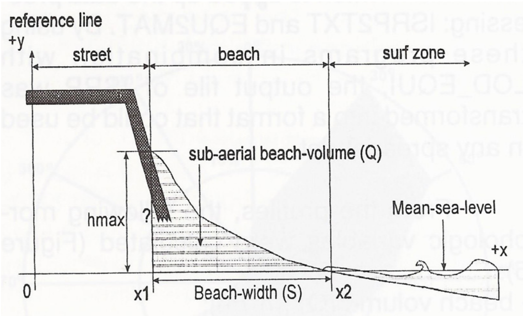

Figure 5 - Coordinate system employed for representation of beach profiles.

Table 1 - Cross-shore location of the landward boundary.

prolife	landward boundary x1 [m]
1	0
3	6
5	10
7	3
9	6
11	15
13	15
15	18

The width of the beach (S) is defined as the distance between the boundaries x1 and x2. The beach slope is defined as the slope between the boundaries x1 and x2, h_{max}/S, where h_{max} is the maximum height of the profile. The shape of Ihe beach is defined as $Q/S.h_{max,}$. This parameter describes the form of the profile. High values (about 0.7) can be related to a convex profile and low values (about 0.3) are related to a concave form. A linear beach profile is represented by a value of 0.5 (Fucella & Dolan, 1996).

Meteorological data

There are two sources of meteorological data:

- Station at Arvoredo Island: Arvoredo Island is located about 50 km south of Balneário Camboriú (see Figure 1). The meteorological data include wind speed, wind direction and atmospheric, pressure. The visual observations were conducted 3 times a day. Only Ihe information of the period from January 1994 to January 1995 is available.

- Station PXIV: PXIV is an ou I platform located about 180 km offshore. Hourly measurements (70m above sea levei) of wind speed and direction are available covering the period from August 1994 to March 1996.

The fact that there is an overlapping period between the available meteorological data from Arvoredo and the PXIV stationsmakes it possible to correlate of the data. In Figure 7, the wind velocities from the two meteorological stations are compared. From the PXIV timeseries, five storms (1 to 5) where selected with a wind velocity above 20 m/s. These stornns were identified in the Arvoredo time-series. Two of the five stornns (3 and 5) do show a good agreement, with wind speed above 20 m/s in the Arvoredo data. The other storms (1,2 and 4) could not be identified at Arvoredo. The differences in the measured time-series were possibly explained by the location of the meteorological stations: The measurements at Arvoredo Island were disturbed by the influence of the island. Therefore, it was decided to use in the analysis only the part of the Arvoredo data that is not present in the PXIV data. This means that the Arvoredo data is used before September 1994. After September 1994, the PXIV data was used. The time series of wind velocity were tranformed into Ihe Beaufortscale (Table 2), in order to classify each wind speed in a storm classification. Nine (9) storms have been identified from the time series of Beaufort wind force. In ali cases a storm was defined as having a wind force equal or above to 7 (about 15 m/s). The wind direction is variable, but only the onshore-directed winds (between O and 180) were included. It is assumed that onshore-directed winds can be better correlated with the morphologic changes, because they do generate higher waves and wind set up.

The following selections of occurences of storms are made (storms with a wind direc-

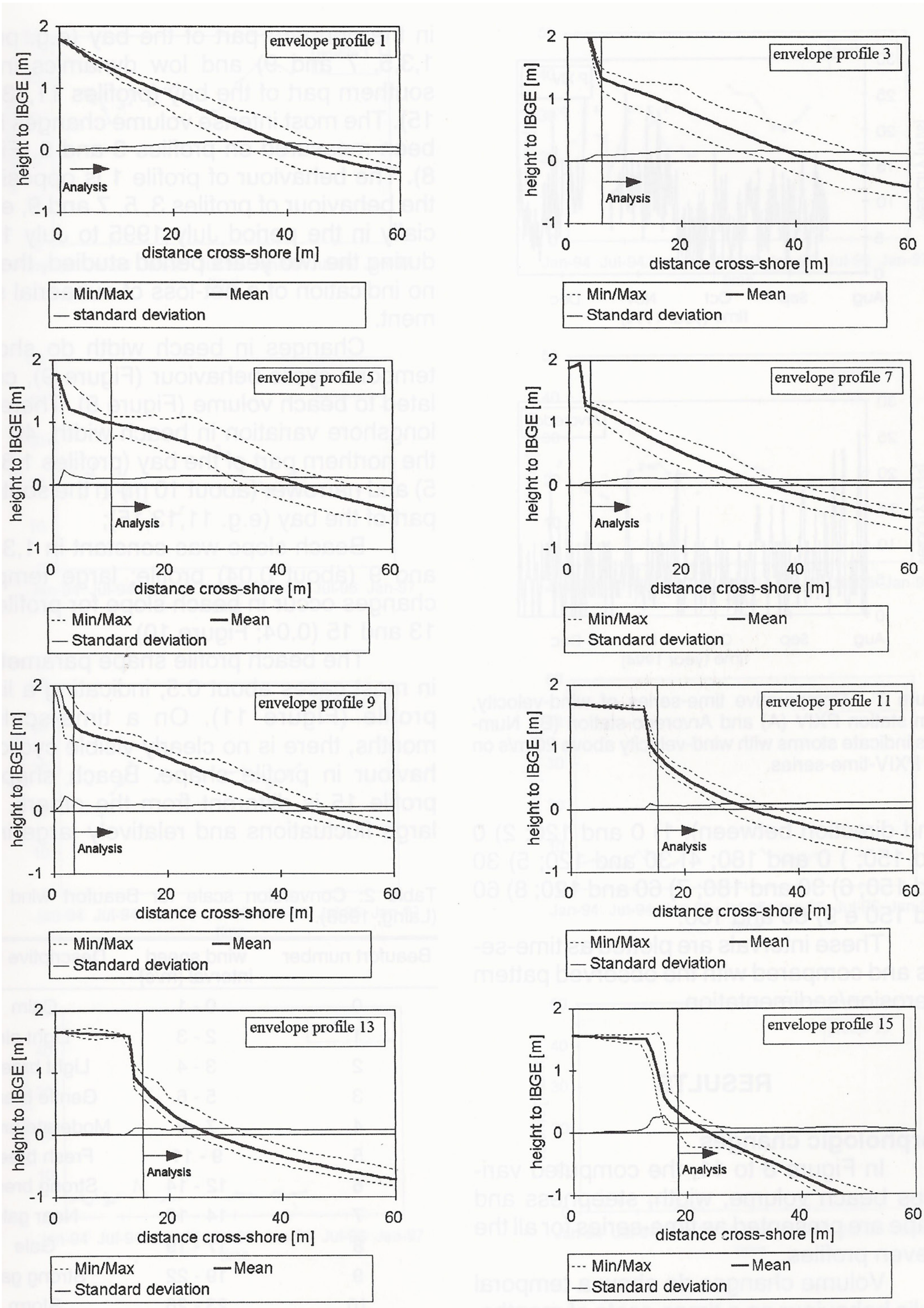

Figure 6 - Beach-profile envelopes. Arrow indicates starting point of beach-profile analysis.

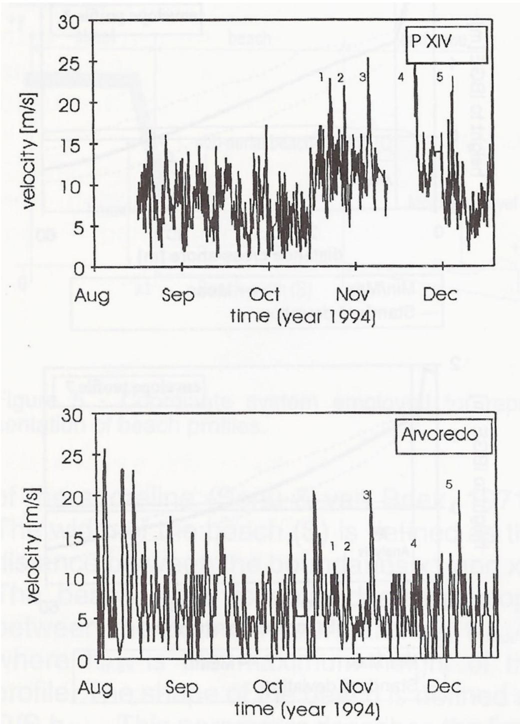

Figure 7 - Comparative time-series of wind-velocity, from station PXIV (A) and Arvoredo-station (B). Numbers indicate storms with wind-velocity above 20 m/s on the PXIV-time-series.

tion between): 1) O and 120; 2) O and 150;) O and 180; 4) 30 and 120; 5) 30 and 150; 6) 30 and 180; 7) 60 and 120; 8) 60 and 150 e 9) 60 and 180.

These intervals are plotted as time-series and compared with the observed pattern of erosion/sedimentation.

RESULTS

Morphologic changes

In Figure 8 to 11, the computed variables beach volume, width, steepness and shape are presented as time-series for ali the uneven profiles.

Volume changes do show a temporal cyclic behaviour on a times-scale of months, with clearly visible periods of erosion and deposition (Figure 8). There is a longshore variation in beach dynamics, high dynamics in the northern part of the bay (e.g. profile 1,3,5, 7 and 9) and low dynamics in the southern part of the bay (profiles 11,13 and 15). The nnost intense volume changes have been measured on profiles 3 and 5 (Figure 8). The behaviour of profile 1 is opposite to the behaviour of profiles 3, 5, 7 and 9, especially in the period July 1995 to July 1996; during the two years period studied, there is no indication of a net-loss of subaerial sediment.

Changes in beach width do show a temporal cyclic behaviour (Figure 9), correlated to beach volume (Figure 8). There is a longshore variation in beach width, 40 m in the northern part of the bay (profiles 1,3 and 5) and narrower (about 10 m) in the southern part of the bay (e.g. 11,13,15);

Beach slope was constant in 1,3,5, 7 and 9 (about 0.04) profile; large temporal changes occur in beach slope for profile 11, 13 and 15 (0.04; Figure 10).

The beach profile shape parameter is in most cases about 0.5, indicating a linear profile (Figure 11). On a time-scale of months, there is no clearly visible cyclic behaviour in profile shape. Beach shape at profile 15 is different from the others, with large fluctuations

Table 2 - Conversion scale for Beaufort wind force (Laing, 1988).

Beaufort number	wind speed interval [m/s]	Descriptive term
0	0 - 1	Calm
1	2 - 3	Light air
2	3 - 4	Light breeze
3	5 - 6	Gentle breeze
4	7 - 9	Moderate breeze
5	9 - 11	Fresh breeze
6	12 - 14	Strong breeze
7	14 - 16	Near gale
8	17 - 19	Gale
9	19 - 22	Strong gale
10	23 - 26	Storm
11	26 - 30	Violent storm
12	> 31	Hurricane

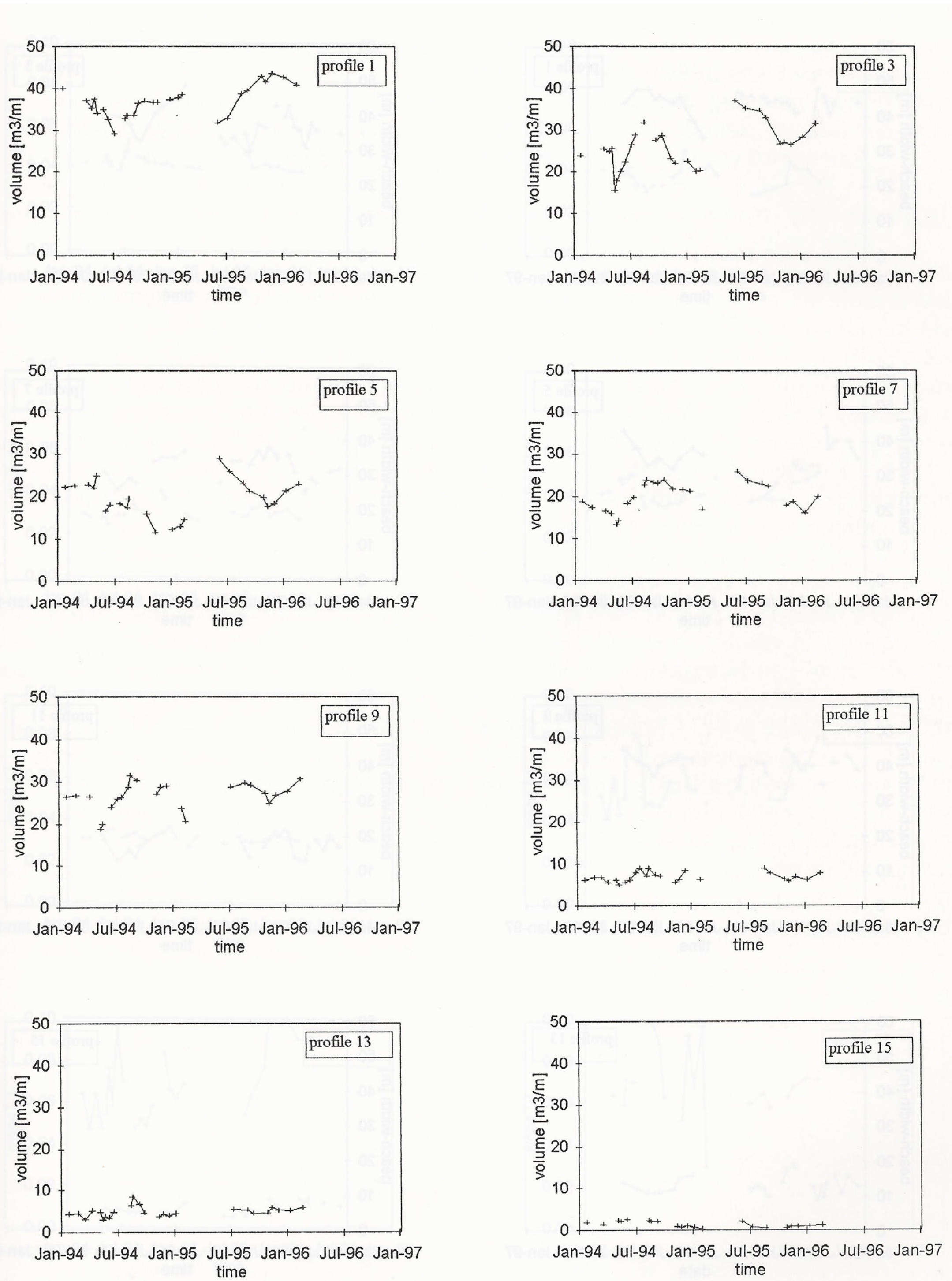

Figure 8 - Time-series of subaerial volume for ali beach profile.

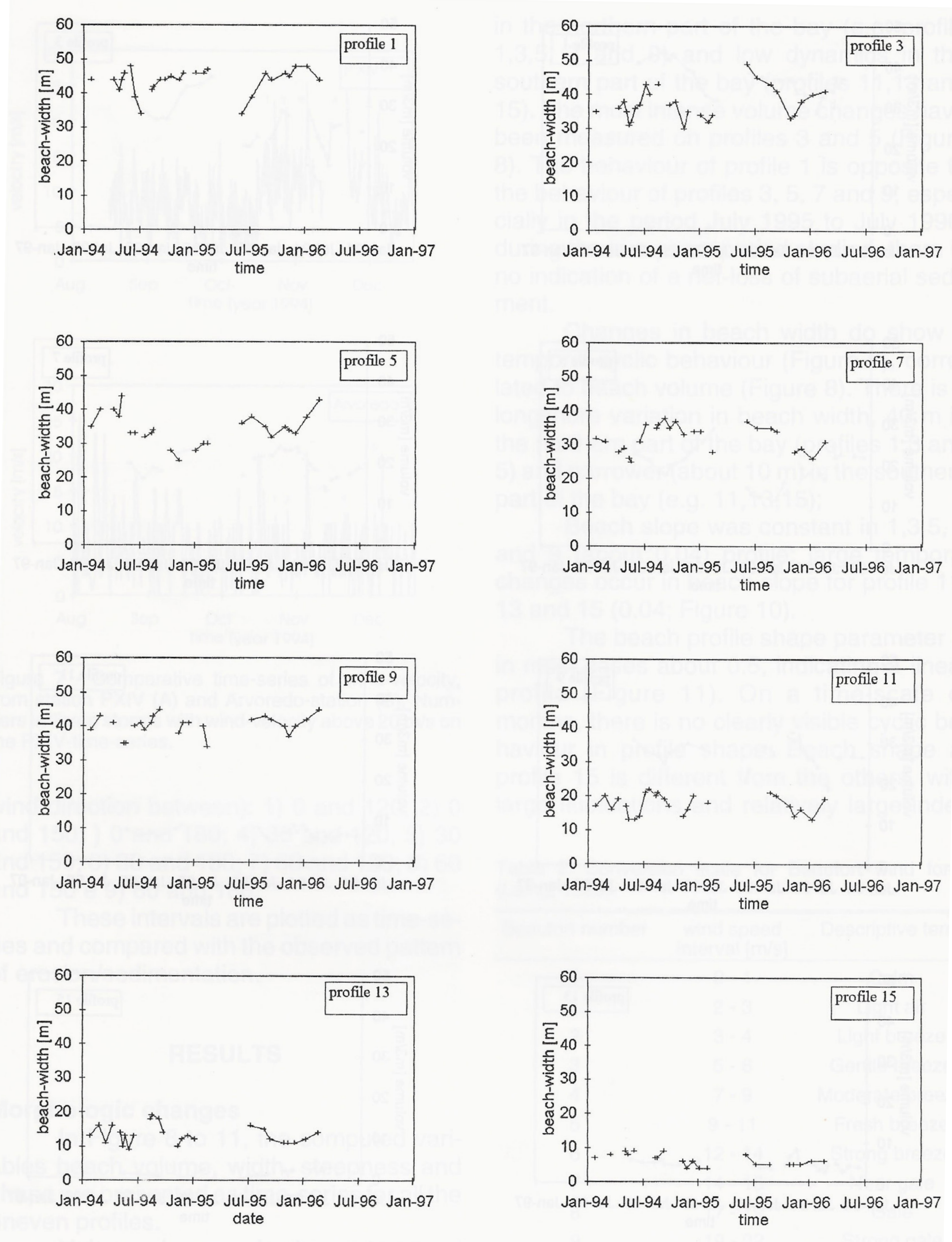

Figure 9 - Time-series of subaerial beach width changes for ali beach profiles.

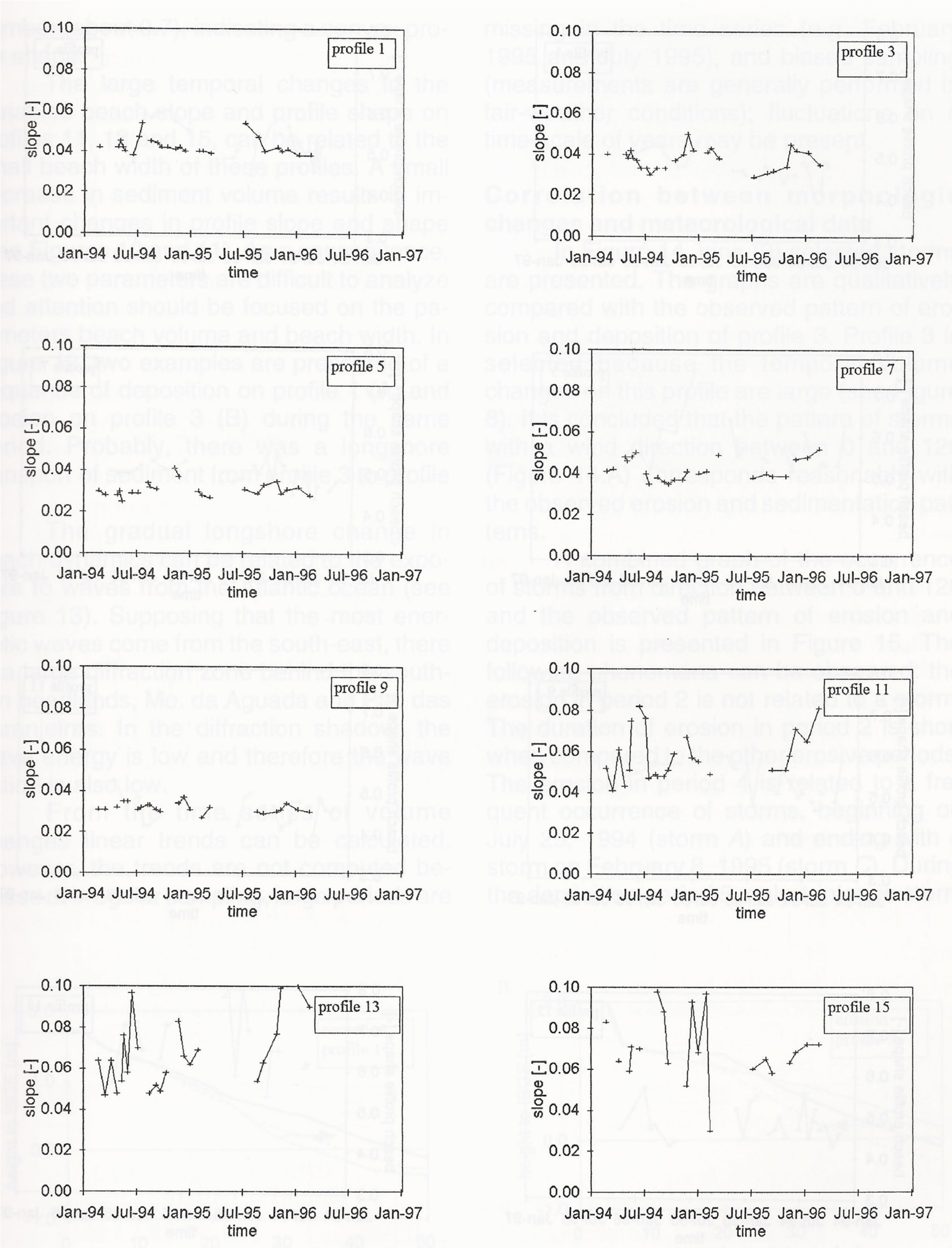

Figure 10 - Time-series of subaerial beach slope for ali beach profiles.

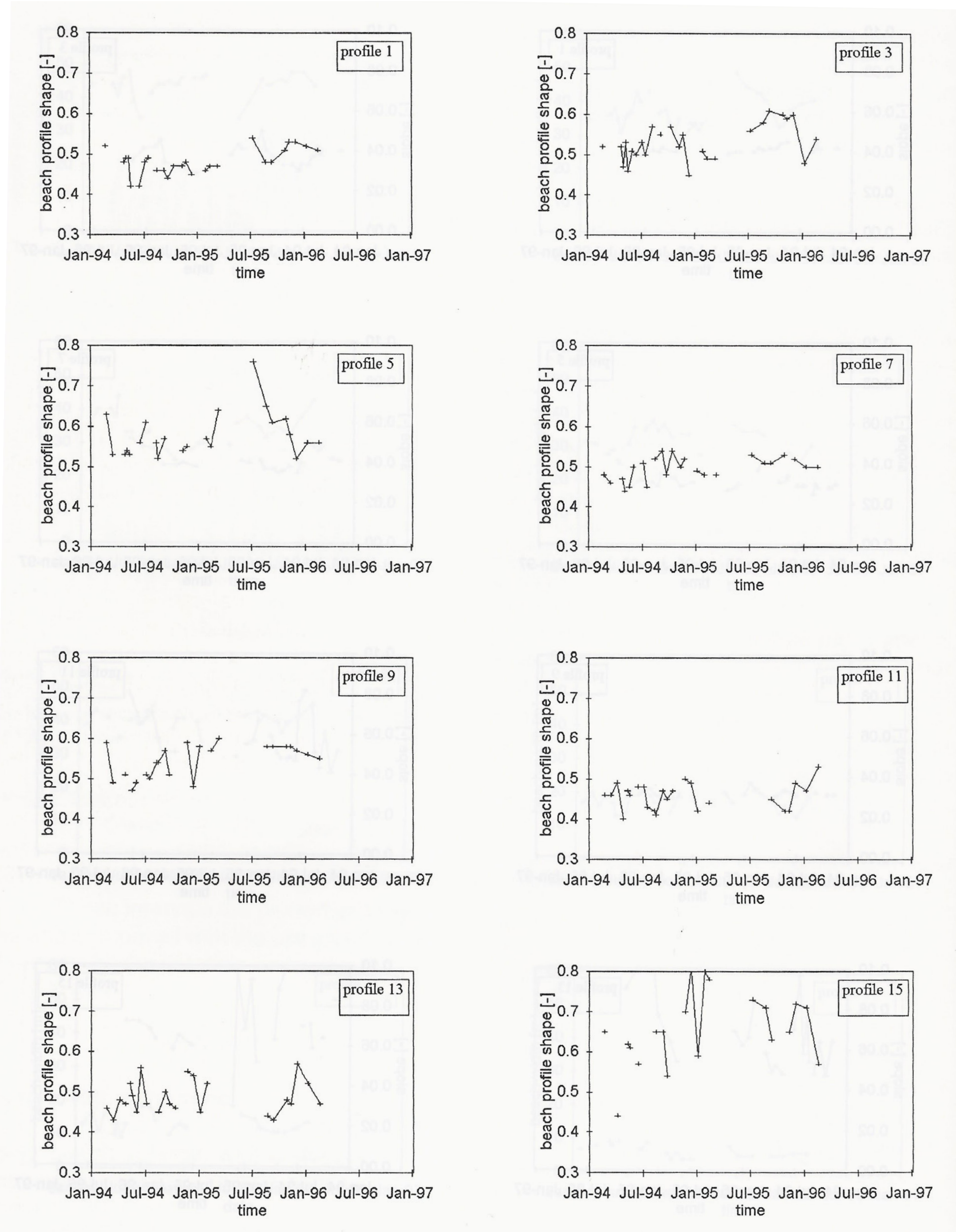

Figure 11 - Time-series of subaerial beach shape for ali beach profiles.

and relatively large index number (about 0.7), indicating a convex profile shape.

The large temporal changes in the variables beach slope and profile shape on profiles 11, 13 and 15, can be related to the small beach width of these profiles. A small decrease in sediment volume results in important changes in profile slope and shape (see Figures 10 and 11). As a consequence, these two parameters are difficult to analyze and attention should be focused on the parameters beach volume and beach width. In Figure 12, two examples are presented of a sequence of deposition on profile 1 (A) and erosion on profile 3 (B) during the same period. Probably, there was a longshore transport of sediment from profile 3 to profile 1.

The gradual longshore change in beach dynamics can be related to the exposure to waves from the Atlantic ocean (see Figure 13). Supposing that the most energetic waves come from the south-east, there is a large diffraction zone behind the southem headlands, Mo. da Aguada and Pta. das Laranjeiras. In the diffraction shadow, the wave energy is low and therefore the wave action is also low.

From the time series of volume changes linear trends can be calculated. However, the trends are not computed because of irregular sampling, large periods are missing in the time series (e.g. February 1995 and July 1995), and biased sampling (measurements are generally performed in fair-weather conditions); fluctuations on a time-scale of years may be present.

Correlation between morphologic changes and meteorological data

In Figure 14, nine (9) selected storms are presented. The graphs are qualitatively compared with the observed pattern of erosion and deposition of profile 3. Profile 3 is selected because the temporal volume changes on this profile are large (see Figure 8). R is concluded that the pattern of storms with a wind direction between O and 120 (Figure 14.A) corresponds reasonably with the observed erosion and sedimentation patterns.

A combined graph of the occurrence of storms from direction between O and 120 and the observed pattern of erosion and deposition is presented in Figure 15. The following phenomena can be observed: the erosion in period 2 is not related to a storm. The duration of erosion in period 2 is short when compared to the other erosive periods. The erosion in period 4 is related to a frequent occurrence of storms, beginning on July 25, 1994 (storm A) and ending with a storm on February 8, 1995 (storm C). During the deposition period 5, only 1 intense storm occurred in the begin of Abril

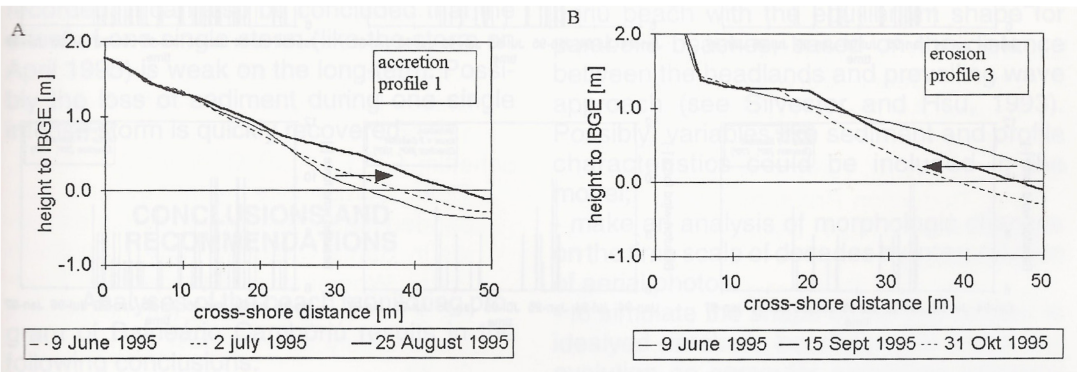

Figura 12 - Example's of accretionary sequence on profile 1 (A) and erosional sequence on profile 3 (B).

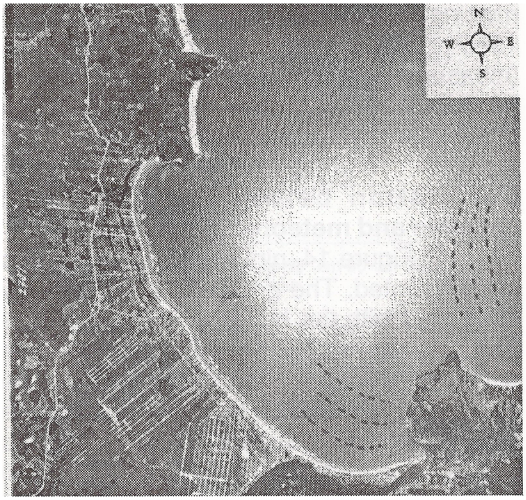

Figure 13 - Aerial photo of Balneário Camboriú from 1957, showing wave-diffraction in the southern part of the bay.

1995 (storm D). During this storm no morphologic data is available. The erosion in period 6 can be related to a frequent occurrence of storms in the period between February 15, 1995 (storm E) and June 1996 (storm F).

Possible explanations for the low correlation between storm occurrence and erosion during period 2 are: 1) no measurements from the PXIV platform are available. The doubtful Arvoredo data have been used; 2) the erosion in period 2 is forced by the occurrence of swell waves. Swell waves have travelled out of the wind field, and therefore could not be correlated to the wind field. The low correlation cannot be explained by the occurrence of storms from the southern direction because no storms from this direction were observed during this period 2; 3) antropogenic influences (beach flattening).

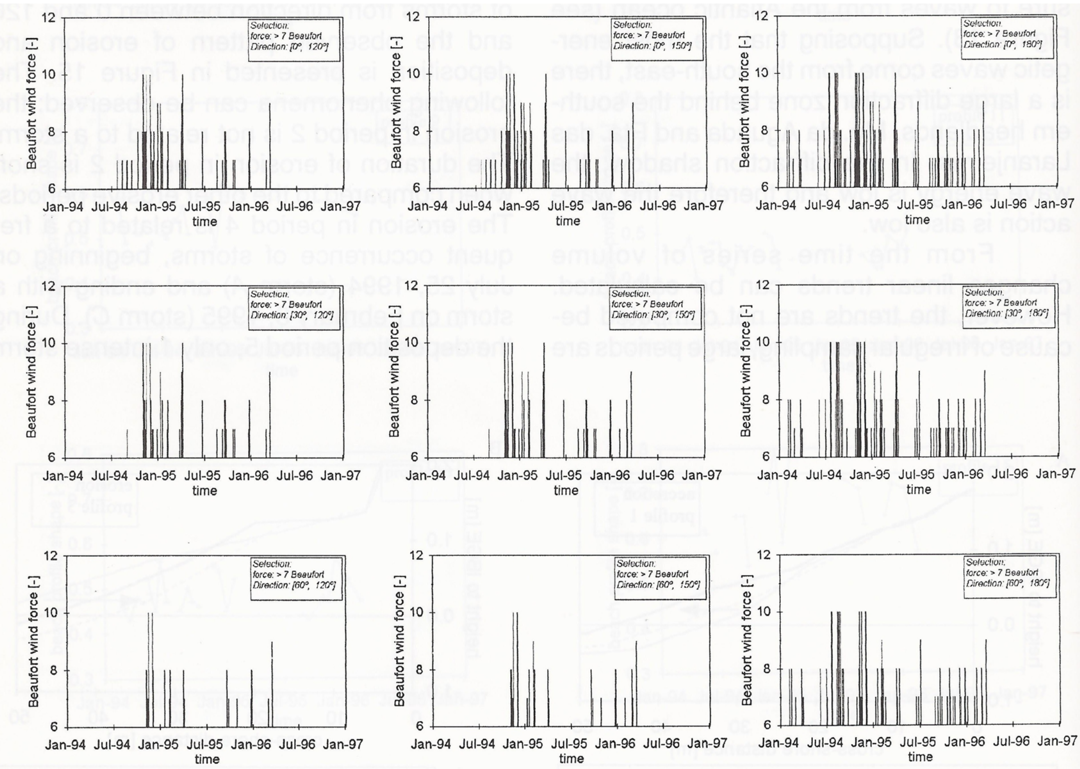

Figure 14 - Selection of storms with a force 7 Beaufort from different directions.

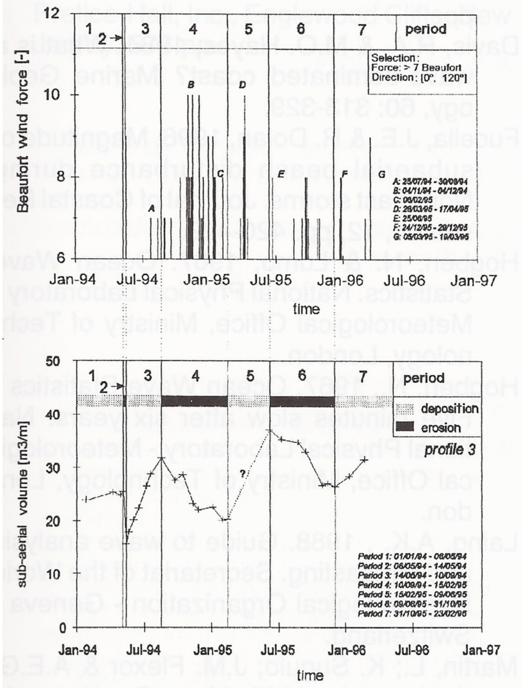

Figure 15 - Time-series of storm-ocurrence (A) and subaerial volume changes (B).

Based on these observations it can be concluded that periods of erosion can be correlated to 'stormy periods'. Duringin periods of a low storm frequency, deposition is recorded. R can also be concluded that the effect of one single storm (like the storm on April 1995) is weak on the long-term. Possibly the loss of sediment during one single intense storm is quickly recovered.

CONCLUSIONS AND RECOMMENDATIONS

Analyses of the beach monitoring program of Balneário Camboriú results in the following conclusions:

- Subaerial beach volume changes do show a temporal cyclic behaviour on a time scale of months. The cyclic behaviour can be correlated to 'periods of storm' and 'periods of fair-weather';
- Beach dynamics does show a longshore change, with higher dynamics in the northern part of the bay and lower dynamics in the southern part. This gradual change can be related to the exposure to waves from the Atlantic ocean;
- There is no indication of a long-term net sediment loss.

At this moment it is not possible to make any reliable conclusions about trends in the volume changes because of the short measuring period, rnissing values and biased sampling. Therefore, it is necessary to obtain a longer record of profiles and continue with the measurements.

The recommendations should be split up in two parts: those concerning the measurements and those concerning the analysis of the data set. It is recommended to:

- make detailed and systematic observations of morphological features (like berms and cusps) during the measurements;
- continue the measurements, especially in the northern part of the bay (e.g. profile 3 and 5).
- analyse the remaining profiles 2, 4, 6, 8, 10, 12, 14, 16 and 18;
- compare the form of the Balneário Camboriú beach with the equilibrium shape for parabolic beaches, based on lhe distance between the headlands and prevailing wave approach (see Silvester and Hsu, 1993). Possibly, variables like sediment and profile characteristics could be included in the model;
- make an analysis of morphologic changes on the time scale of decades by interpretation of aerial photos.
- to simulate the shape of lhe bay related to idealyed parabolic beaches of to forecost it evolution on computer simulation prograns (GENESIS).

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