ENVIRONMENTAL CHARACTERIZATION OF SANDY BEACHES IN SOUTHERN BRAZIL

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INTRODUCTION

The short-term variability of beach environments is related to the complex interactive forces causing beach changes. This variability has been the principal obstacle to the understanding of the physical processes on beaches (King, 1972). Description of the principal transforming agents and their interaction were provided by King (1972), Komar (1976) and Swart (1983).

The southern Brazilian beaches have been the subject of different studies focusing on their physiography (Delaney, 1965), sediments (Martins, 1967) and waves (Motta, 1969). However, these studies have not considered the interactions between the different factors that control sandy beaches.

Based on these descriptive studies, the first qualitative approach to the beach environment processes was done by Gianuca (1985), who presented a general classification of Southern Brazil beaches which he characterized as exposed sandy beaches, using the exposure index proposed by McLachlan (1980). Although eliminating the subjectivity in beach classification, this index is a static characterization of the environment and does not reflect its highly dynamic nature.

Borzone (1988) in a study of the shallow infralittoral and surf-zone macrofauna, adopted a beach classification proposed by Wright *et al.* (1982), based on the dynamic characteristics of the beach environments (Short & Wright, 1983). Using wave data and sedimentological characteristics he suggested that southern Brazil sandy beaches near the outlet of Patos lagoon could, during a large part of the year, be classified as dissipative, approaching the intermediate bar-trough stage under lower-energy wave conditions.

The objective of this work is to characterize the climatic, morphodynamical and sedimentary variability, identifying their principal interactions, at four different sites along the southern Brazil sandy beaches.

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MATERIAL AND METHODS

Four transects A, B, C and D were located at 2, 8, 26 and 76 km, respectively, south of the outlet of Patos lagoon (Fig. 1). At each transect seven stations (I to VII) were fixed at 10 m intervals and surveyed weekly at transect B and monthly at the other transects between 02-05-88 and 15-07-89. During this period, data were obtained on the midlittoral profile, sea water salinity, water, air and sediment temperature, and wind direction. Tides are usually very small, rarely exceeding a range greater than 0.5 m (Motta, 1969), and were thus not considered in this work. Samples of sediment were collected at every station at 3 monthly intervals.

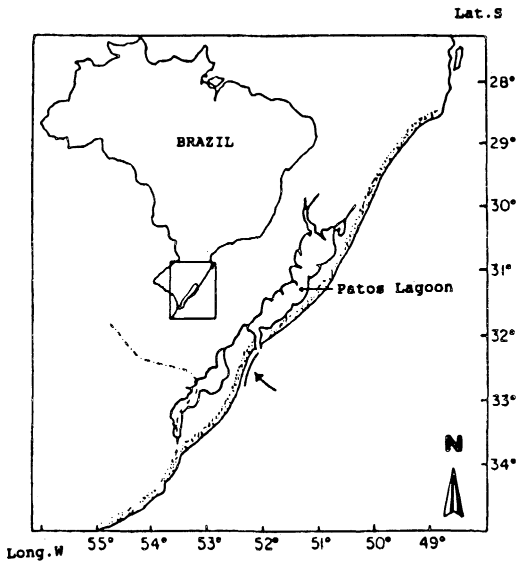

Fig. 1
Map showing the location of the study area (shown by arrow) in southern Brazil.

Published data were used for wave climate (Motta, 1969). The Meteorological Laboratory of Universidade do Rio Grande kindly provided the precipitation data for the study period.

Wave data were used both to calculate wave energy, using the formulae **E = (w.Ls.Hs^2)/8.Ts** (modified from King, 1972) (where w = 141 kg; Ls is significative wave length; Hs is significative wave height, and; Ts is significative wave period), and to estimate values of an erosion index, developed in this work, corresponding to the wave steepness (Hs/Ls) multiplied by the frequency of a particular wave length class.

Surface sediment samples (0 - 5 cm depth) were collected at the five stations for each transect. These stations followed the seasonal variation of the sea and sediment level in order to maintain the same relative position on the midlittoral. For each transect the following stations were surveyed:

Transects	A	B	C	D
Dates		Stations		
winter (07-88)	III to VII	III to VII	III to VII I	II to VII
spring (10-88)	I to V	I to V	II to VI	III to VII
summer (02-89)	I to V	I to V	II to VI	II to VI
autumn (05-89)	II to VI	II to VI	III to VII	III to VII

These samples were processed using the sieving method described in Buchanan (1984) and the formula of Folk & Ward (1957) were used in order to estimate the grain-size statistical parameters, mean, median, standard deviation, skewness and kurtosis of the samples.

In order to discriminate general patterns in the beach sediments, a cluster analysis using as attributes the percentage of sediment retained by each sieve was used, grouping the stations of all transects for each period. Bray-Curtis index was used as a measure of dissimilarity and arithmetic average (UPGMA) was used for clustering.

RESULTS

a. Salinity and Temperature

During the study period the sea water salinity varied between 17 and 35°/oo, being highest in February 1989 and lowest in June 1988. For the same period, lower salinity occurred generally at transects A and D. The temporal variation of the salinity values for transect B is presented in Fig. 2.

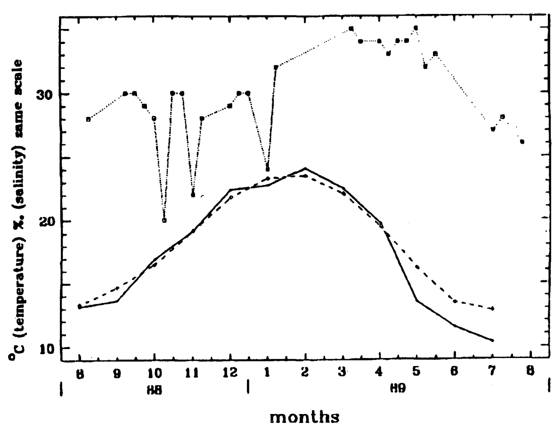

Fig. 2

Air (solid line) and sea water (broken line) mean monthly temperatures (°C) and punctual sea water salinity (°/oo) (dotted line) for transect B.

Air temperature varied between 2.5 °C (06-07-89) and 28.5 °C (04-03-89) with a typical seasonal pattern (Fig. 2). Fig. 3 shows the existence of a high correlation between air and water temperatures on different time scales. Sediment temperatures followed the air and water temperatures but showed higher variation (Table 1).

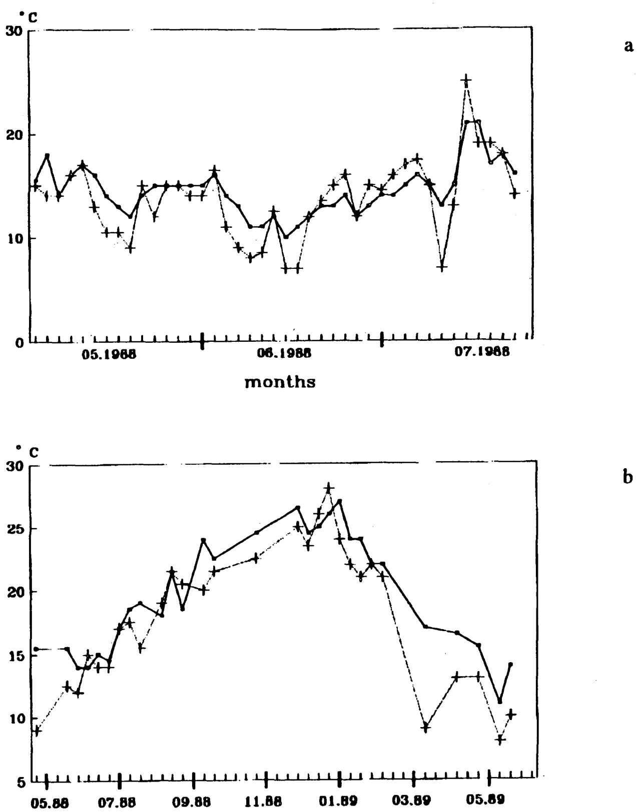

Fig. 3

Air (dotted line) and sea water (solid line) temperature at transect B for different time scales: a- two days interval; b- weekly variation.

b. Winds and Wave Energy

Northeast winds were most frequent during the study period, occurring on 36% of the days, with southwest winds occurring on 21% and south winds on 12% of the days.

Fig. 4 shows the monthly frequency of occurrence of winds from south to west (180 to 290 degrees) which are generally associated with cold fronts (Vieira, 1983). During the data recording period these winds maintained a frequency greater than the mean for a 30 years period (Vieira, 1983). Between April and July 1989 values of exceptional high frequency (50%) were observed.

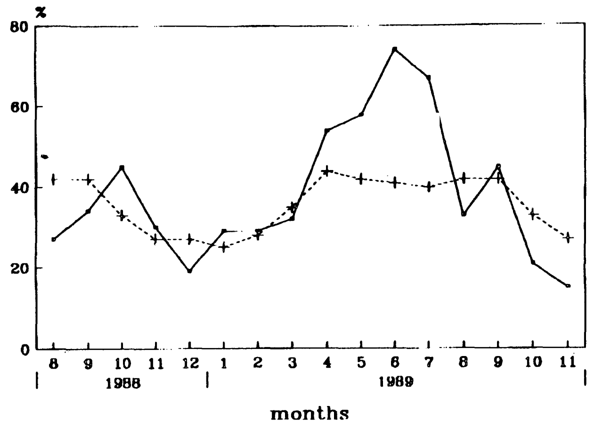

Fig. 4

Monthly frequency of occurrence of winds from south to west (180 to 290 degress) during the recorded period (·) and mean values for a 30 years period (+).

Wave energy (Table 2) shows a maximum of intensity during early autumn. The lower values of energy were found during spring, early summer and specially during the winter season.

40% of annual wave energy came from waves of Hs 2 m though these occurred only during 18% of the time. Most of these waves (59%) came from SE-S (angle 107.5°), though only 41% of the total registered waves procceeded from this sector. Therefore the difference between waves of Hs 2 m and 2 m can be characterized by their energy contribution and principal direction. The mean steepness values for the two groups of waves show significant differences (Table 3) with greater values for waves equal or greater than 2 m which implies a greater erosion capacity for the latter.

Taking these facts into account, the erosive power of waves was calculated only for waves equal or greater than 2 m. The period of maximum erosion was early autumn (Table 2).

c. Beach Profiles

The beach profiles were surveyed 13 times at approximately monthly intervals. Two general patterns of beach profile morphology could be distinguished (see Fig. 5). The first one was characterized by a system of ridge and runnel, and a concave profile with a steeper seaward (2.0 to 5.0 degrees) than landward (0.5 to 1.5 degrees) slope (15-03-89, Fig. 5). The second pattern is characterized by a uniform convex slope across the profile (0.5 to 2.0 degrees) (09-06-89, Fig. 5).

Although during a large part of the year a similar kind of profile occurred at all transects, two groups of transects could be distinguished. Transects A and B were dominated by a convex profile while transects C and D possessed greater temporal variability in the morphological pattern of their profiles.

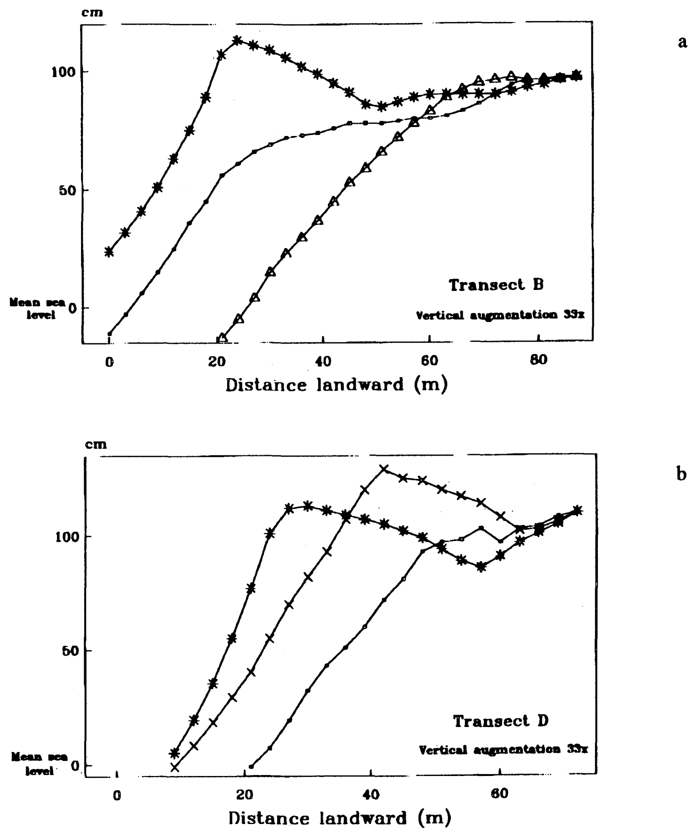

Fig. 5

Temporal variation of beach profile: a- transect B; b- transect D. 18-11-88 (), 15-03-89 (*), 02-06-89 (x) and 09-06-89 ().

Between May-88 and February-89 transects A and B possessed a regular and convex profile with little modifications. This profile assumed a ridge and runnel morphology only in March-89 and maintained this configuration up to May-89. In July-89 the regular profile returned but with a ridge and runnel developing at the lower stations.

The C and D transects, initially (May-88) had a well marked ridge and runnel that began to disappear on June-88. A regular and convex profile became evident on July-88, staying up to November-88 when the ridge and runnel profile returned. On December-88 the ridge and runnel were completely developed, staying up to May-89.

Fig. 5 makes possible the determination of the processes that caused the temporal modifications in the beach profiles at transects B and D. It can be noticed that the formation of the ridge and runnel profile is associated with depositional processes whereas the regular profile is formed by erosive processes.

d. Sediment

Most of the samples were well or very well sorted and were composed of fine sand (2 to 3 phi). Skewness varied from positive to negative with almost 50% of the samples presenting symmetric distribution. The values for kurtosis presented a larger variability, being well distributed amongst the plati-, meso- and leptokurtic classes.

A first characteristic presented by all dendrograms was a good discrimination between stations of transects A and B, and those of transects C and D which were always located in different groups. Thus, the description of the observed temporal pattern will be done separately for the two groups of transects. Fig. 6 presents schematically the temporal variation of the formed associations.

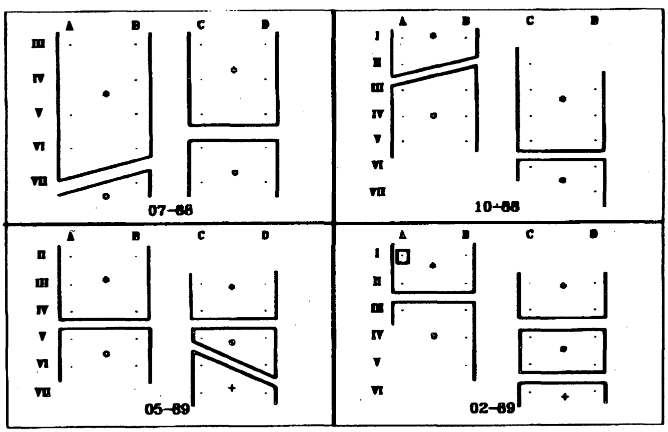

Fig. 6

Schematic representation of the cluster analysis results for the different sampled stations and dates. (*) lower midlittoral zone, (o) upper midlittoral zone, (+) runnel system. Isolated station of transect A on 02/89 was sampled at the swash zone.

Initially, (07-88) two levels could be distinguished in the midlittoral zone for the group formed by A and B transects. Most of the stations formed a lower level with only station VII of B transect separated on an upper level. The standard deviation of the lower level was at its maximum value (Table 4), characterizing the period of greatest variation of environmental energy (Riedl & McMahan, 1974). Later, (10-88 and 02-89) a reduction of the standard deviation occurred and the upper level of the midlittoral region increased along a great part of the sampled area (station III and higher). The statistical parameters of the upper level showed great stability without presenting significant temporal variations due to the inclusion of new stations. The lower level, representing stations I and II, presented two distinct phases during this period. First

(10-88), the mean grain size coarsened and the skewness became positive. Later (02-89), a drastic reduction of the grain size occured and the distribution became symmetric and mesokurtic.

With the increasing level of the environmental energy variation (05-89), as expressed by the standard deviation, new changes occurred at the sub-systems of the midlittoral zone. Once more stations III and IV formed part of the lower level, decreasing the mean grain size of this system and increasing the kurtosis compared with the 02-89 values.

The group formed by transects C and D presented initially a midlittoral zone well differentiated into two levels, with the lower level (stations III, IV and V) presenting a coarser sand (2.25 phi) of symmetric distribution while the upper level presented negative skewness with a mean grain size of 2.46 phi (Table 4).

The reduction of the environmental energy (the mean grain size becomes smaller on 10-88) changed the statistical parameters, mean and median, at all stations. The decreased standard deviation indicated a greater stability in the energy level. On 02-89 the lower level is reduced in the sampled area, resulting in an increase in the mean grain size (Table 4). Associated with the increase of the upper level along the midlittoral region, a runnel developed at station VI while the grain size of this station decreased.

On 05-89 all stations presented a decreased sand grain size, but without modification of the general appearance of the system. Again station IV formed part of the lower level.

In terms of the mean values of the statistical parameters, the upper midlittoral zone can be distinguished from the lower by its better sorted and smaller sand grain size at the two transect groups (Table 5).

DISCUSSION

The air temperature followed a typical seasonal pattern with monthly means similar to the means registered for a period of 30 years (Vieira, 1983). The sea water temperature was strongly influenced by the air temperature. The sediment temperature values showed, only by its greater coefficient of variation, the effects of both the insulation and the wind, following generally the values found for air or water temperatures.

Gianuca (1985) associated the seasonal pattern of the sea water salinity with the local variations of evaporation and precipitation throughout the year. The years 1988 and 1989 were extremely dry with precipitation values irregularly spaced and less than 50% of the 30 year mean (Fig. 7). Nevertheless, the seasonal pattern was maintained with salinity values lower than those recorded by Gianuca (1985). These results support Magliocca *et al.*'s (1982) suggestion that the seasonality results from the differential influence of the principal water masses on the coastal water. The local precipitation showed only a brief impact being the main factor responsible for the reduced salinity observed on 28-09 and 19-10-88 (Fig. 2). This impact was probably due to the low

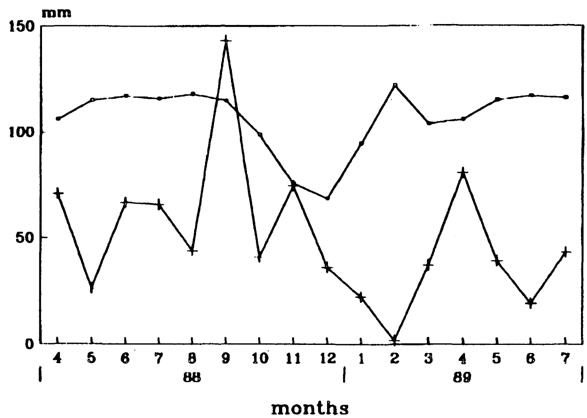

Fig. 7
Monthly precipitation values (mm) for the registered period (+) and mean values for a 30 years period (·).

turnover rate of the sea water inside the breaker zone of dissipative beaches (Swart, 1983).

Castello & Moller (1977) recognized at the Brazilian Southern continental shelf two distinct areas as a function of the salinity pattern, with lower values situated south of the Sarita phare. This observation explains the lower values of salinity found at transect D (located south of the Sarita phare) and indicated the strong influence of continental shelf over nearshore water. The proximity of transect A to the Patos Lagoon jetties explains the lower mean values of sea water salinity at transect A.

The wave data used in this study present several limitations once they were recorded on a site with distinct continental shelf bathymetry and for a period of only one year. Even if Motta (1969) concluded that the wave data are representative for the coast of Rio Grande do Sul, these data will be used only in association with well established patterns for other parameters.

The formation of a ridge and runnel system at the midlittoral of southern Brazil sandy beaches was attributed by Gianuca (1985) to the prevailing northeast winds that, eroding the dunes, transport sediments to the midlittoral zone. The orientation of the coast do not support a generalization of this view. Although at transects A and B this wind could aid the formation of the ridge and runnel system, this could not happen at transects C and D where this wind blows into the dune field (Fig. 1).

This type of profile, generally called summer profile (King, 1972), is generally associated with a wave climate pattern with low erosive power (low Hs/Ls or steepness). As was also observed by Gianuca (1985), there is a major tendency for the presence of the undulation profile during spring and summer. This period, characterized by moderate wave energy and mean values of the erosion index (Table 2), is also the period of highest frequency of the northeast and north winds (Fig. 4).

As stated by King (1972), winds blowing opposite to the approximation direction of the waves can reduce their height, and so, their steepness. In this way, the northeast wind can act independently of the coastal orientation, reducing the height of waves coming from southeast-south (with greater energy and destructive power) and thus diminishing their erosive effect. This action explains the formation of a profile with great declivity in all transects, not by direct action of the wind but by its interaction with the waves. The coincidence between the principal accretion period for all stations and the higher frequency of northeast winds between 11-88 and 03-89 (Fig. 4) supports this view. During autumn (when the erosion maxima were registered) both the erosion index and the energetic level of the waves increased, and associated with the greater frequency of winds from the southwest and south (Fig. 4 and Table 2) determined the moment of greatest destructive power during the year, with drastic erosion of the beach that assumes a winter or swell profile. Bernardi *et al.* (1987) found during autumn-1985 a mean beach erosion of 48 cm as result of a single event.

Borzone (1988), applying punctual measures of wave height and period at the breaker zone and the settling velocity for the median grain size to the omega index (Wright *et al.*, 1982), classified a beach near transect C as dissipative (characterized by the presence of a bar-trough system at the breaker zone and low declivity of the midlittoral), probably passing to an intermediate stage under conditions of low wave energy (this stage characterized by migration of part of the bar sediment to the midlittoral zone (Short & Wright, 1983)). Using the wave data together with grain size parameters of transects C and D, omega values were obtained (Table 2) which are all indicative of dissipative conditions (values greater than 6) and suggest that the scale of the omega index as proposed by Wright *et al.* (1982) is inadequate for the studied southern Brazil sandy beaches. It should be said however that the variation of the index values through time was coherent with the morphological variations of the beach observed in the midlittoral zone. The index omega can, in this way, be useful to reduce the information of the midlittoral morphology to a single number for a restricted region (probably dependent on the sediment origin).

The observed profile differences between transects for a given period were probably related to the sedimentological differences of these transects. The settling velocity of the sand is inversely proportional to the omega index, thus a greater grain size implies a lower value of this index. The mean difference of the grain size between the transect group A + B and the group C + D (Table 5) determines a particle settling velocity 80% greater for the latter group, from which we can derive (considering the same wave climate) values of the omega index 80% higher for transects A and B, delineating their greater dissipative tendency.

The lower dissipative tendency of transects C and D implies a morphological profile characterized by a ridge and runnel system during a longer period. Short & Hesp (1982) showed that abrupt profile changes (as those of the ridge and runnel system) can reduce the velocity gradient of the wind and thus diminish the volume of eolian transported sand. As a direct consequence, this profile reduced the volume and the rate of transport of sand into the dune field. The lower volume of sand in the dune fields in the area of transects C and D observed by C. S. B. Costa (personal communication) could be associated with the sedimentological characteristics and support in this way the lower dissipative tendency of transects C and D.

The variation of the sedimentological characteristics along the transects was in accordance with the results of Martins (1967), with lower midlittoral sediment being coarser and better sorted than at the higher level (Table 4 and 5). The results of the cluster analysis showed however the presence of well delineated boundaries that determine distinct levels on the midlittoral zone. These boundaries presented different positions for the different transects and specially a distinct temporally changing pattern. The differences related to the grouped stations can be attributed to the greater energy impacting the midlittoral zone at transects C and D (which are less dissipative), resulting in greater declivity and thus greater run-up.

The temporal pattern (Fig. 6) is related to the seasonal variation of the sea level that presents its maximum (+8 cm) between February and April and its minimum (-10 cm) between August and October (Patullo, 1966). The lower sea level resulted in a growing beach line by stimulating the transport of the infralittoral sand deposits into the midlittoral zone (BIRD, 1983). The differences in the temporal pattern between transects reflected the slower deposition processes at transects C and D due to their larger grain size.

The temporal evolution of the statistical parameters of the sediment (Table 4) was well related to the erosive or depositional processes, decreasing the grain size and increasing selection during deposition moments and decreasing selection and increasing its size during erosion periods.

The strongly seasonal pattern of the different factors studied emerge as the general feature of the surveyed southern Brazil beaches where different dynamics are a primary function of sediment parameters and geographic orientation.

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ABSTRACT

The year round changes in morphology of four southern Brazil sandy beaches was quantitatively studied. The sea water inside the breaker zone, although presenting a low turnover rate characteristic of dissipative beaches, shows in its salinity the strong influence of continental shelf water on nearshore water. Two types of beach profiles (undulation and swell profiles) were described which were distinctly associated with the interaction between wave climate and local winds. Different beach profiles along the coastline were registered during the same period, as a reflection of different sand grain parameters. The principal feature of the southern Brazil high energy sandy beaches was the strongly seasonal pattern of climate, morphology of beach profile and sediment parameters.

Key-words: Sandy beaches; seasonal cycles; beach morphodynamics; grain-size parameters; wave energy; temperature; salinity; Southern Brazil.

RESUMO

A variação da morfologia de praia, parâmetros sedimentares, ventos, salinidade e temperatura foi acompanhada durante um ano em quatro perfis estabelecidos ao longo das praias do Rio Grande do Sul. Dados bibliográficos de ondas foram utilizados para auxiliar na interpretação dos resultados. Os valores relativos à salinidade da água da zona de arrebentação indicam que apesar da taxa de renovação ser fraca, característica das praias dissipativas, seus valores são fortemente influenciados pela água da plataforma continental. Dois tipos de perfil de praia foram descritos (perfis de ondulação e de vagas) estando claramente relacionados a interação entre o clima de ondas e os ventos locais. Ao longo do litoral foram observados num mesmo momento perfis com diferentes morfologias expressando desta forma suas diferenças granulométricas. A característica principal das praias arenosas de grande energia do Rio Grande do Sul foi a forte sazonalidade observada nos padrões climáticos, morfologia do perfil de praia e parâmetros granulométricos.

Palavras-chave: Praias arenosas; variações sazonais; morfodinâmica de praia; parâmetros granulométricos; energia de onda; temperatura; salinidade; Rio Grande do Sul; Brasil.

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Table 1 - Mean ($\bar{x}$) and variance (s^2) of the sea water, air and sediment temperature (°C) for the different transects.

Transects	A		B		C		D	
Stations	X	s^2	X	s^2	X	s^2	X	s2
Seawater	17.93	21.50	18.50	23.90	18.40	22.80	18.20	24.80
II	18.32	27.10	19.10	33.90	...	...	...	...
III	19.25	23.50	21.00	38.20	19.10	30.10	18.80	29.10
IV	19.58	32.50	21.20	39.60	20.30	32.10	18.80	25.10
V	19.69	36.00	21.20	34.60	21.80	44.10	19.20	27.90
VI	...	...	...	...	21.30	49.80	19.00	31.80
Air	19.92	21.20	20.90	27.00	20.10	37.50	20.00	24.00

Table 2 - Monthly values for wave energy ($kg.m^3.1,000$),erosion (%) and omega index (wave data from Motta, 1969).

Months	1	2	3	4	5	6	7	8	9	10	11	12
Wave energy	...	7.1	6.6	8.3	3.2	...	...	5.8	5.4	...	...	6.4
Erosion index	...	0.3	0.6	0.6	0	...	...	0.4	0.4	...	...	0.4
Omega index	...	9.4	9.0	9.4	8.3	...	...	8.2	8.6	...	...	9.0

Table 3 - Monthly steepness values for waves equal or greater than 2 m and for waves smaller than 2 m (wave data extracted from Motta, 1969).

Months	1	2	3	4	5	6	8	9	11	12
W < 2m	0.016	0.021	0.016	0.013	0.016	0.011	0.015	0.015	0.016	0.016
A										
V										
E > 2m	...	0.023	0.024	0.021	...	...	0.024	0.020	0.024	0.022
S										

(t-statistic = -6.45 ; p<0.01)

Table 4 - Sedimentological statistical parameters for the different midlittoral textural groups over time (values in phi).

		Lower midlittoral		Upper midlittoral		Runnel
Transects		A & B	C & D	A & B	C & D	C & D
	Mean	2.70	2.25	2.85	2.46	...
07	Median	2.72	2.25	2.80	2.54	...
/	St. Dev.	0.41	0.49	0.32	0.46	...
88	Skewness	-0.11	0.03	0.19	-0.26	...
	Kurtosis	1.31	0.77	1.07	0.99	...
	Mean	2.49	2.33	2.85	2.55	...
10	Median	2.48	2.35	2.83	2.60	...
/	St. Dev.	0.35	0.50	0.35	0.39	...
88	Skewness	0.10	-0.04	0.09	-0.27	...
	Kurtosis	1.30	0.80	1.19	1.11	...
	Mean	2.92	2.23	2.87	2.41	2.29
02	Median	2.90	2.21	2.83	2.49	2.30
/	St. Dev.	0.36	0.51	0.34	0.45	0.47
89	Skewness	0.02	0.11	0.11	-0.24	-0.02
	Kurtosis	0.90	0.92	1.02	1.01	0.76
	Mean	2.83	2.40	2.87	2.52	2.37
05	Median	2.81	2.46	2.81	2.60	2.42
/	St. Dev.	0.38	0.53	0.32	0.44	0.48
89	Skewness	0.02	-0.11	0.20	-0.24	-0.13
	Kurtosis	1.25	0.87	1.00	1.18	0.83

Table 5 - Mean for the sediment statistical parameters of the different midlittoral textural groups (values in phi).

	Lower midlittoral		Upper midlittoral	
Transects	A & B	C & D	A & B	C & D
Mean	2.74	2.30	2.86	2.48
Median	2.74	2.32	2.82	2.55
St. Dev.	0.38	0.50	0.34	0.44
Skewness	-0.01	-0.01	0.13	-0.26
Kurtosis	1.22	0.83	1.08	1.05