Chapter 5

FACTORS GOVERNING OVERWASH SEDIMENTATION AND ITS ROLE IN BARRIER ISLAND DYNAMICS

5.1. INTRODUCTION

Overwash related studies are often associated with storm events, and particularly to hurricanes. Equally, the occurrence of washover deposits in the sedimentary record has been interpreted as an evidence of a storm. However, non-storm overwash can also result from other situations that can occur alone or combined: low-lying supra-tidal area, sediment starvation and equinoctial tides. Non-storm overwash events have been less studied probably due to their dependence on restricted geomorphologic conditions and to their relatively transitional character. Also, non-storm overwash does not have the media effects that hurricane overwash does because is a process with a higher frequency. The main goals of this chapter are: (1) to evaluate the relative role of overwash in barrier island dynamics; and (2) to determine the factors governing overwash sedimentation.

In medium-term studies, both storm and non-storm overwash are likely to occur, and therefore different combinations of geomorphologic and oceanographic conditions may be measured. The most common fieldwork technique in medium-term monitoring studies was topographic surveying with theodolites, total stations or benchmark heights (e.g. Leatherman, 1976; Kochel and Wampfler, 1989; Dingler and Reiss, 1990; Guillén *et al.*, 1994; Cloutier and Héquette, 1998; Stone *et al.*, 2004). Other complementary techniques were also used such as aerial and ground photographs (e.g. Davidson-Arnott and Fisher, 1992; Sexton, 1995; Cleary *et al.*, 2001), excavations, trenches or cores (e.g. Leatherman, 1976; Orford and Carter, 1982; Courtemanche *et al.*, 1999), and painted sand plugs (e.g. Kochel and Dolan, 1986; Leatherman and Zaremba, 1987; Kochel and Wampfler, 1989).

The current study area is Barreta Island which was chosen due to its relatively high frequency of overwash processes (every winter overwash events are observed). The collection of fieldwork data on extremely dynamic washover plains, such as in the study area, is difficult due to the lack of local permanent references that could be used as benchmarks for traditional surveying techniques. Further to this some coastal processes that rework the washovers may induce relatively small elevation variations. To cover a wide study area while assuring the precise repetition of defined profiles (including origin and orientation) without benchmarks, and to obtain a high density of data points for each profile, a real time kinematic differential GPS (RTK-DGPS) was used. A study covering a 3-year monitoring period of an active washover plain, including contrasting periods, with such detailed surface measurements, complemented with oceanographic data is not commonly found in the literature. The measured profiles underwent quality control and were subject of exhaustive analysis to determine the type of processes and amount of morphologic changes during overwash and post-overwash periods.

5.2. METHODS

5.2.1. OCEANOGRAPHIC DATA

Tidal and wave data from the period between June 2001 and June 2004 were used for this study. Due to the absence of available measured tidal data, predicted tidal data (daily time and level of high and low tide) from the Instituto Hidrográfico de Portugal, were used to compute daily tidal ranges. Offshore wave data were recorded by the Instituto Hidrográfico de Portugal using a directional wave-rider buoy offshore of Cape Santa Maria (Figure 3.1) at a location (36°54.3’ N, 7°53.9’ W) in a depth of 93 m (Costa, 1994). Records were obtained for 20 min every 3 h, except during storm periods when data were recorded every half hour. All wave data was reduced to daily records of mean significant wave height (H_s), mean peak period (Tp) and mean wave direction (θ). Linear wave theory was applied to the wave data in order to provide an estimation of the deep-water incident wave power (P),

$$P = E\,C_g \tag{5.1}$$

$$E = \frac{1}{8}\rho g H_s^2 \tag{5.2}$$

$$C_g = \frac{1}{4\pi} g Tp \tag{5.3}$$

Were E is the wave energy, C_g is the group velocity, ρ is the marine water density (1.026 kg/m^3) and g is the acceleration due to gravity (9.8 m/s^2). The P calculated was then partitioned according to the orientation of the waves, which due to the orientation of the south coast of Portugal are always between 90^o and 270^o: W-SW for those with $180^o<\theta<270^o$ and E-SE (“Levante”) for $90^o< \theta<180^o$.

5.2.2. FIELDWORK DATA COLLECTION

The selected study area for analysing the evolution of a washover plain was the western part of Barreta Island (location and background information in chapter 3.3.2). A monitoring programme was established consisting of periodic field surveys performed at spring low tide. Thirteen profiles were selected (P1-at NW to P13-at SE; Figure 5.1) with a variable distance between consecutive profiles (23 m to 67 m), leading to a total survey longshore length of about 530 m. Each cross-shore profile started at the low tide level of the oceanic beach face, and ended at the washover terminus, at the low tide lagoon water level (Figure 5.1). Surveys were performed monthly during winter (October to March) and bi-monthly during summer (April to September), from June 2001 to June 2004, totalling 26 surveys (Table 5.1).

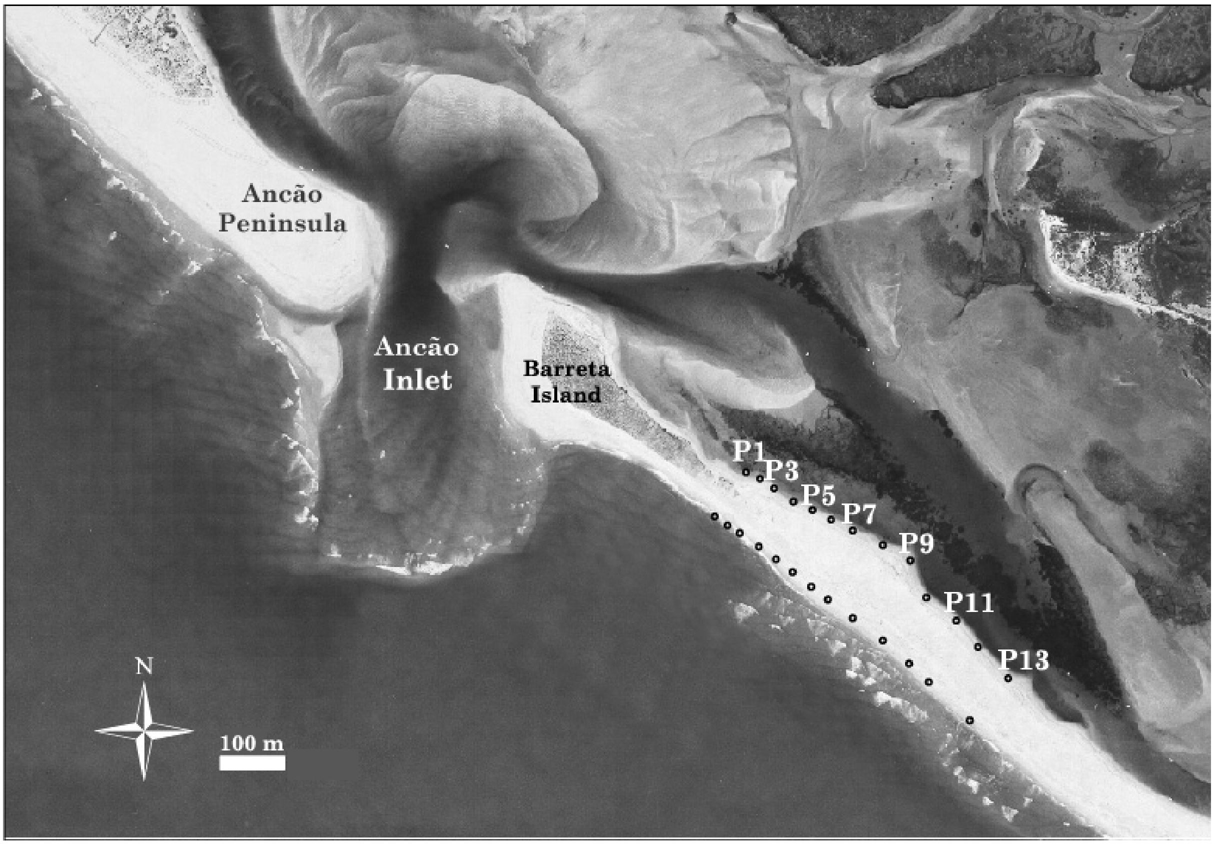


Figure 5.1. Location of the cross-shore profiles, represented by the start and end points. Aerial photograph from 2001.

All measurements were made using an RTK-DGPS, sampling data at 1 Hz. Field observations and photos were used to complement the measurements and to define the type of processes acting on the washover plain morphologies.

Due to problems with the precise location of the profiles during fieldwork #2 (July 2001), this survey was considered unreliable for calculations (Table 5.1). The 19th September 2001 fieldwork (#4) was performed during an overwash event, therefore the profiles were not completed, i.e. did not reach the lagoon and ocean mean sea level. Therefore, this survey can only be used for qualitative analysis.

Table 5.1. Survey dates, reliable surveys and corresponding season.

Fieldwork	Date	Reliable surveys	Season
#1	25-06-2001	✓	Summer 2001
#2	19-07-2001		
#3	13-09-2001	✓	
#4	19-09-2001		
#5	23-09-2001	✓	
#6	20-10-2001	✓	Winter 2001/2002
#7	19-11-2001	✓	
#8	16-01-2002	✓	
#9	20-02-2002	✓	
#10	18-03-2002	✓	
#11	16-04-2002	✓	Summer 2002
#12	14-05-2002	✓	
#13	26-07-2002	✓	
#14	10-09-2002	✓	
#15	24-10-2002	✓	Winter 2002/2003
#16	22-11-2002	✓	
#17	24-01-2003	✓	
#18	06-03-2003	✓	
#19	16-04-2003	✓	Summer 2003
#20	02-06-2003	✓	
#21	31-07-2003	✓	
#22	10-10-2003	✓	Winter 2003/2004
#23	11-11-2003	✓	
#24	22-01-2004	✓	
#25	08-04-2004	✓	Summer 2004
#26	03-06-2004	✓	

5.2.3. MORPHOLOGIC DATA PROCESSING AND ANALYSIS

Data was referenced to the Portuguese Melriça Grid, a recti-linear UTM co-ordinate system, and MSL. The RTK-DGPS has an accuracy of 5 mm as quoted by the manufacturer (DSNP). However, this is under optimal conditions and in the field the accuracy is dependent on several factors, including satellite configuration and dilution of the precision of the position solution (DOP). Using the standard deviation of the positions given by the RTK-DGPS, which is included in the collected data, as an estimate of the accuracy shows that the errors in horizontal and vertical are respectively 2 cm and 4 cm or better (Morris *et al.*, 2004). Higher errors are expected during fieldwork operation of the equipment that includes the inclination of the telescopic pole (maximum expected of 2 cm, assuming 10^{o} inclination) and its variable height above ground when the operator is moving (maximum expected 3 cm). Each profile was converted into distances to a reference line located landward of the lagoon side washover terminus. Data were smoothed by a 3-point to 5-point average resulting in an average point-to-point distance of about 2 m. Therefore, the error of fieldwork data is expected to be less then 10 cm.

Data obtained from the barrier profiling were used to determine the barrier width, the washover terrace width, the barrier volume, the beach volume, the washover and beach slopes, shoreline and washover crest positions, and identify the morphological changes. The barrier width corresponded to the horizontal distance between the positions of MSL on both oceanic and lagoon sides of the barrier. The washover terrace width was measured by the horizontal distance between the position of the washover crest and washover terminus. Volume computations per linear meter of coastline were made for all profiles, using the MSL as base line. Field observations and photos allowed the definition of the dominant processes occurring in between surveys: Swash, Overwash, Aeolian and Lagoon. Volumetric changes due to each of these processes were also quantified. Swash processes were considered to be the main process responsible for oceanic beach volume variation that was calculated between the washover crest and MSL (Figure 5.2).

The volume variation attributed to overwash processes was calculated between the washover crest and the determined overwash intrusion. Therefore, in case of complete overwash, the barrier volume variations were all due to swash and overwash processes (Figure 5.2a). If no overwash occurred between surveys, the washover terrace volume variation was attributed to aeolian processes.

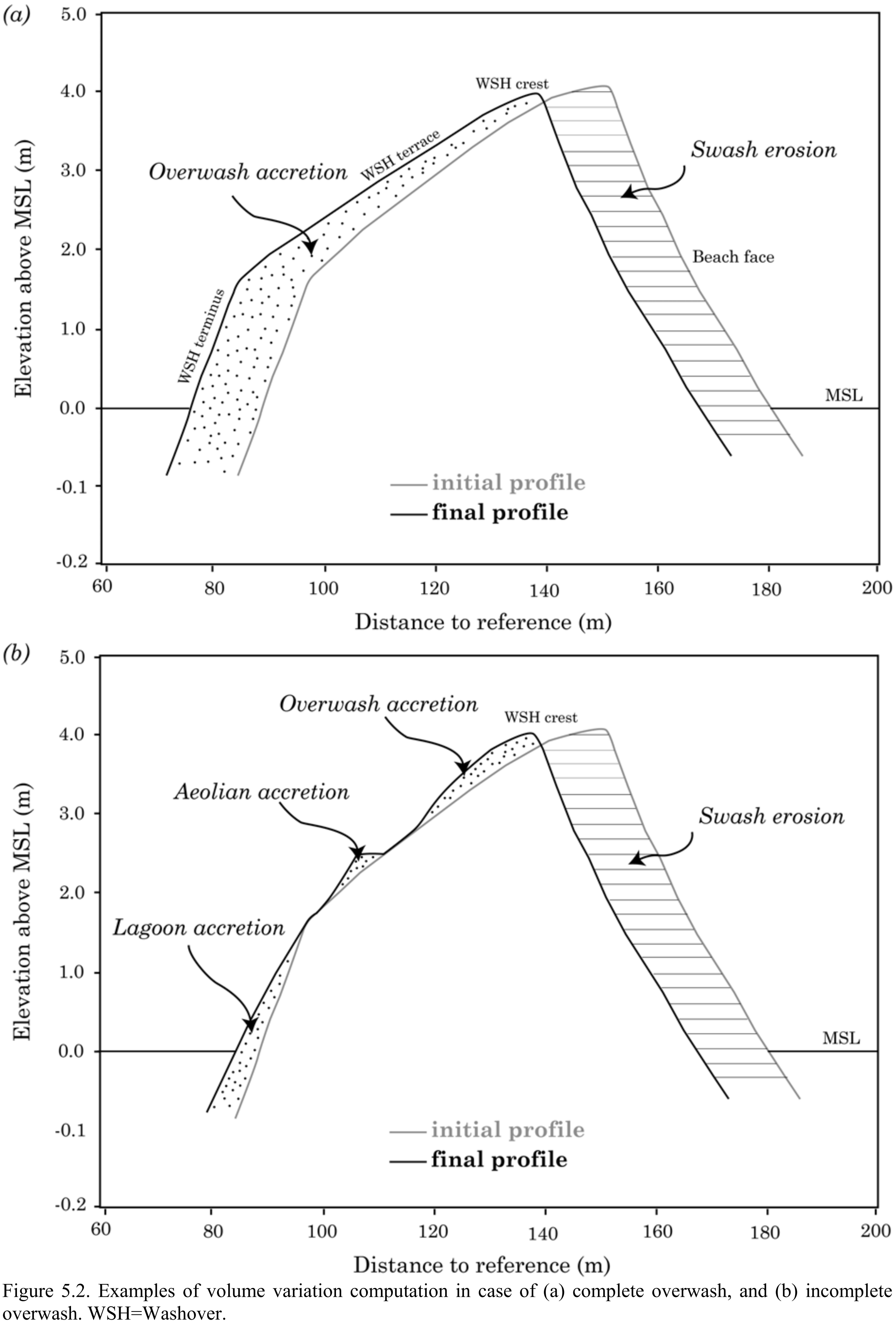


Figure 5.2. Examples of volume variation computation in case of (a) complete overwash, and (b) incomplete overwash. WSH=Washover.

If incomplete overwash occurred, the volume variations of the seaward washover terrace were attributed to overwash and the landward parts of the washover to aeolian processes (Figure 5.2b). Except when complete overwash occurred (Figure 5.2a), the washover terminus variations were attributed to lagoon processes (Figure 5.2b).

Taking into account the estimates of accuracy of the RTK-DGPS and the errors introduced by the operation of the equipment, topographic variations smaller than 10 cm may be attributable to errors in measurements. Therefore, considering the width of beach and washover terrace (generally smaller than 50 m), the volume variations computations may have a maximum error of ± 5 m^3/m.

5.3. RESULTS

5.3.1. HYDRODYNAMICS

The offshore wave data used for this study had in average 2% missing days per month; with a maximum of 7 days missing in February 2003. Offshore wave data and tidal ranges are shown in Figure 5.3. Propagation of the waves from deep water to the breaker zone using a model could not be performed due to the lack of a detailed bathymetric map covering all the area from the study site to the wave-rider buoy off Cape Santa Maria (for location see Figure 3.1). Additionally, because the study area is immediately downdrift of a migrating inlet, the bathymetry was neither regular nor constant through the study period.

During most of the study period, H_s was less than 2 m (94%; Figure 5.3a), and Tp was less than 12 s (85%, Figure 5.3b). There is significant seasonality in the wave climate with average winter H_s of 1.2 m and average summer H_s of 0.8 m. As can be seen in Figure 3.5c, the wave climate for the study area can be considered as bimodal in terms of wave direction. Predominantly, 76% of the time, the offshore direction of the waves was W-SW ($\theta > 180^o$) and "Levante" episodes ($\theta < 180^o$) were only recorded during 24% of the study period. The W-SW waves had average H_s of 0.90 m and Tp of 9 s, while the E-SE waves had an average H_s of 1.2 m and Tp of 6 s. Figure 5.3d shows the predicted tidal ranges for the study area. The average maximum daily tidal range for the studied period was 2.2 m, ranging between 3.5 m and 0.7 m.

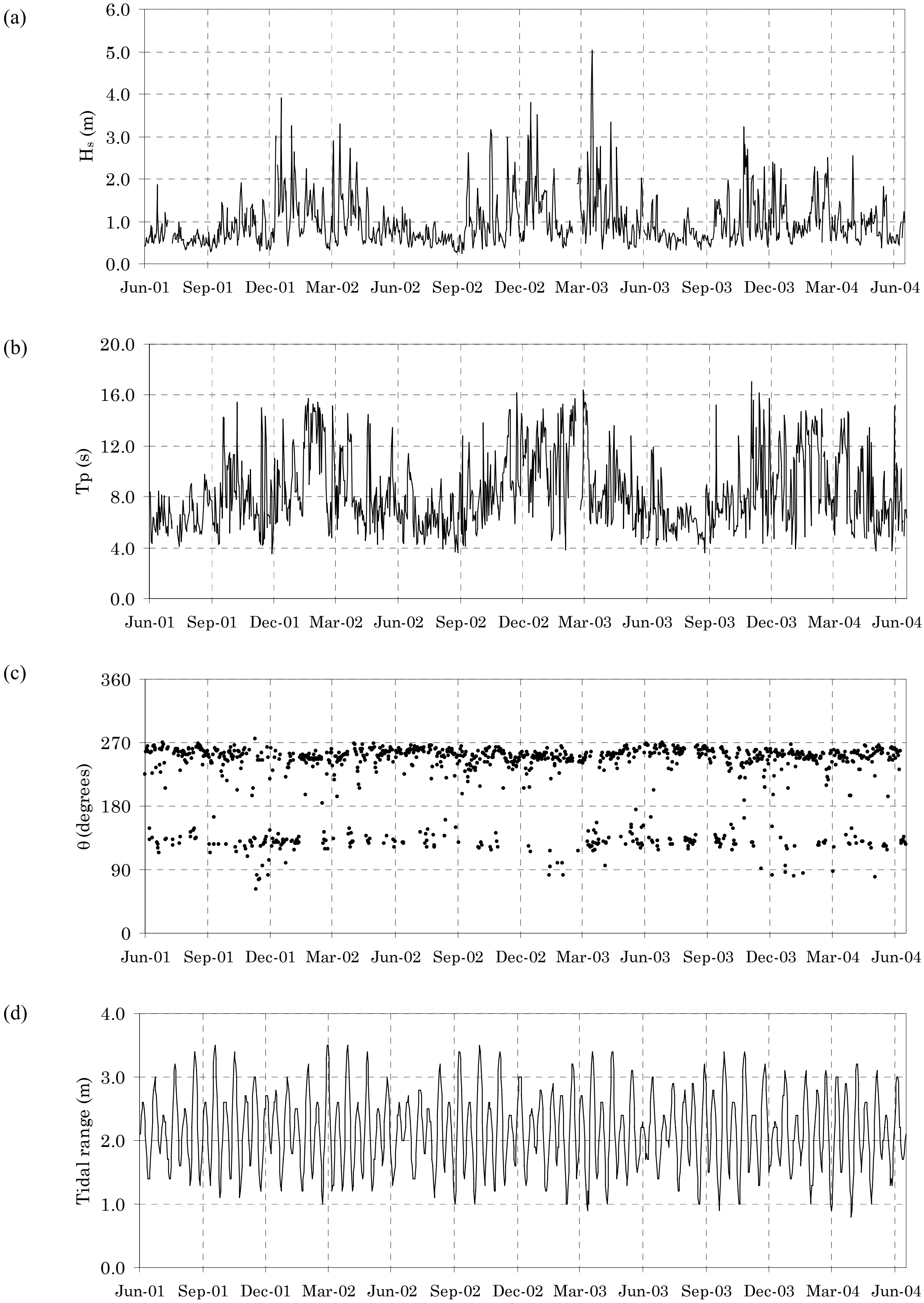
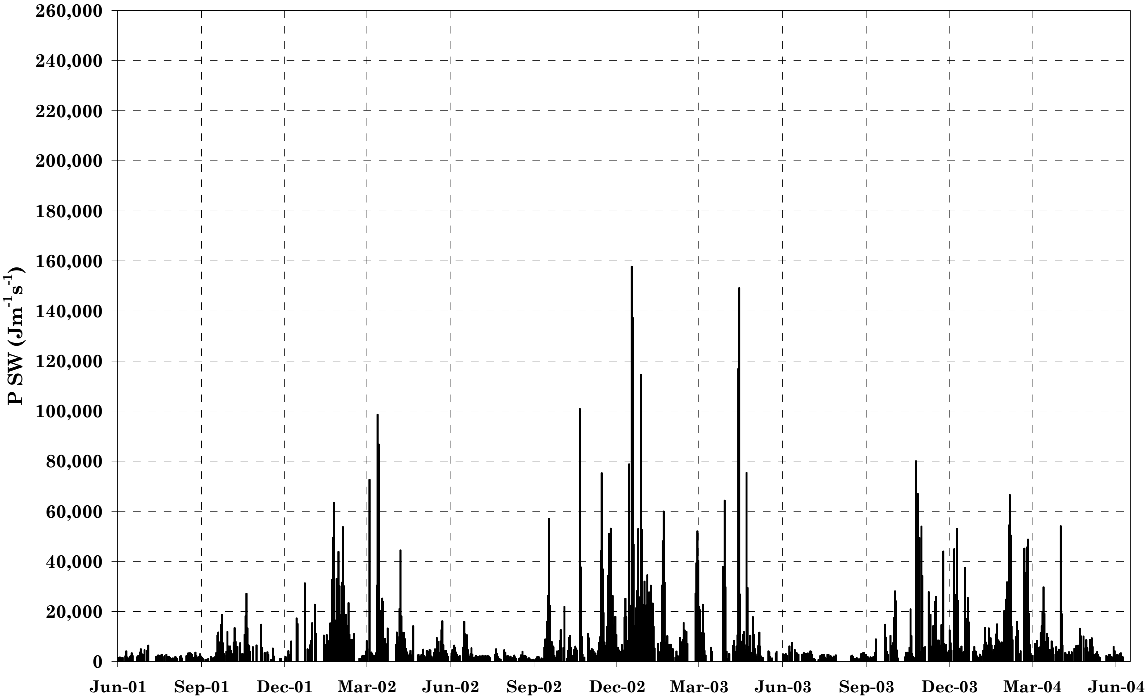


Figure 5.3. Wave and tidal conditions for the study period: (a) significant wave height; (b) peak period; (c) wave direction at peak period; and (d) tidal range.

The wave power for the two main directions (W-SW and E-SE) is shown in Figure 5.4.

(a)



(b)

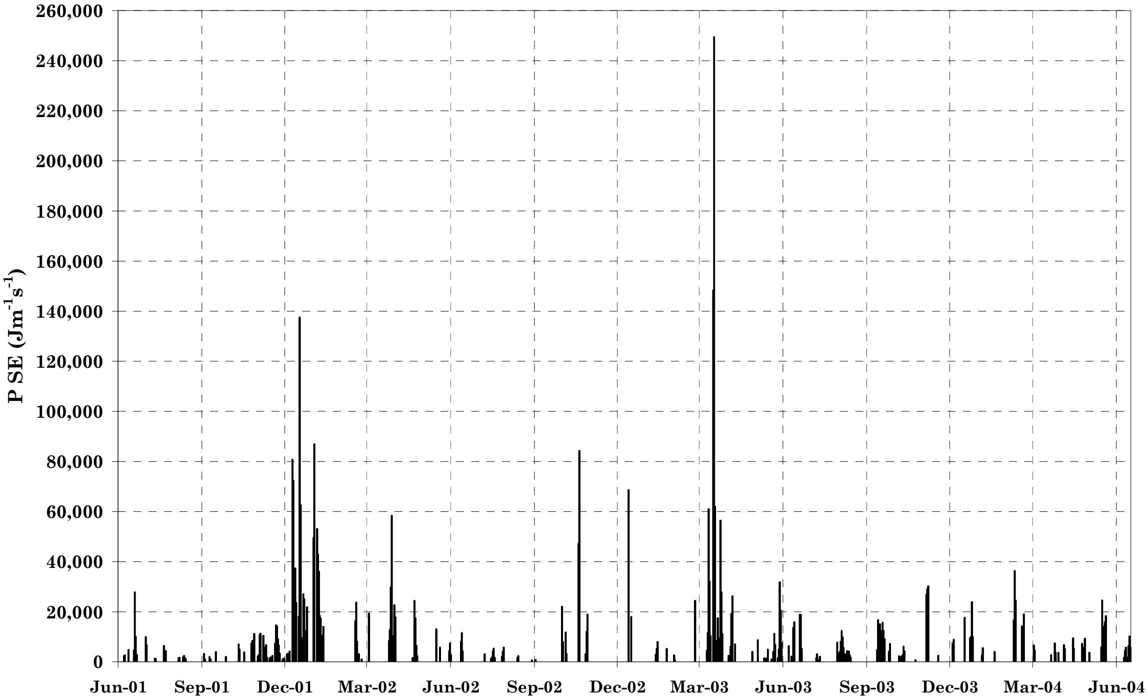


Figure 5.4. Wave power (P) for: (a) W-SW direction, and (b) E-SE direction.

The comparison between Figure 5.4a and 5.4b shows that most of the offshore wave power was from the W-SW. The maximum wave power occurred in March 2003, during a “Levante” event, when H_s reached 5.03 m (corresponding to P values in excess of 240,000 $Jm^{-1}s^{-1}$). According to Pires (1998) this magnitude of storm has a return period greater than 100 years. However, the “Levante” waves are intensely refracted, and therefore the breaking waves at the study area had a much smaller wave power. The maximum wave power for W-SW waves that are less refracted and have higher impacts on the study area was recorded in December 2002, where more than 150,000 $Jm^{-1}s^{-1}$ was reached (Figure 5.4a). The winter of 2002-2003 was the most severe (average H_s of 1.3 m) and the summer of 2002 had the mildest wave conditions (average H_s of 0.8 m).

There were 28 storm events (defined as H_s>3m by Pessanha and Pires, 1981) during the three year study period. Some details of the storm events are summarised in Table 5.2. The second year of the study period (June 2002-June 2003) was the most severe, with 13 storms (Table 5.2) that had a total duration of about 9 days and 13 hours (with $H_s \geq 3$ m). The first year had 8 storms (total duration of 3 days and 16 hours) and the third year had 7 storms (total duration of 2 days and 14 hours). About 66% of the recorded storms were W-SW events. The remaining 34% of storms were characterised by waves arriving from E-SE associated with the strong “Levante” wind. The three years of the study period had different distributions of storm directions, with “Levante” storms dominant in the first year (5 of 8 storms), minor in the second year, and in the third year all storms arrived from W-SW.

Table 5.2. Some characteristics of the storms that occurred during the study period. Storms from W-SW with number in bold and from E-SE with number in italic. The duration corresponds to the consecutive time in the record with $H_s \geq 3$ m.

1st year: Jun2001-Jun2002			2nd year: Jun2002-Jun2003			3rd year: Jun2003-Jun2004		
Storm (date)	Duration hour.min	H_s (m) θ (deg)	Storm (date)	Duration hour:min	H_s (m) θ (deg)	Storm (date)	Duration hour:min	H_s (m) θ (deg)
St1 *(09/12/2001)*	12.54	3.4; 128	**St9** **(17/09/2002)**	03.08	3.3; 235	**St22** **(25/10/2003)**	15.13	4.0; 189
St2 *(17-12-2001)*	18.39	4.9; 124	*St10* *(19/10/2002)*	42.00	3.8; 121	**St23** **(27/10/2003)**	39.45	3.4; 249
St3 *(01/01/2002)*	16.21	4.1; 130	**St11** **(13/11/2002)**	20.14	3.8; 239	**St24** **(31/10/2003)**	02.19	3.4; 256
St4 *(05/01/2002)*	09.21	3.1; 124	*St12* *(13/12/2002)*	27.24	3.7; 152	**St25** **(06/12/2003)**	01.28	3.1; 199
St5 **(04/03/2002)**	04.21	3.8; 213	**St13** **(17/12/2002)**	34.44	4.8; 236	**St26** **(09/12/2003)**	03.00	3.3; 258
St6 **(13/03/2002)**	18.00	4.0; 244	**St14** **(27/12/2002)**	16.58	4.0; 246	**St27** **(25/02/2004)**	00.29	3.0; 237
St7 *(28/03/2002)*	07.42	3.3; 123	**St15** **(20/01/2003)**	01.03	3.2; 236	**St28** **(01/04/2004)**	00.29	3.0; 230
St8 **(07/04/2002)**	00.52	3.0; 225	*St16* *(11/03/2003)*	00.29	3.0; 123			
			St17 *(16/03/2003)*	25.53	5.7; 122			
			St18 *(24/03/2003)*	01.13	3.4; 129			
			St19 **(29/03/2003)**	05.38	4.1; 246			
			St20 **(13/04/2003)**	22.26	4.2; 245			
			St21 **(22/04/2003)**	03.51	3.6; 230			

5.3.2. WASHOVER MORPHOLOGY

5.3.2.1. Spatial variability of the morphologic parameters

The study area had an average cross-shore width of about 100 m. The widest part of the barrier, on average, was at profile P9 (127 m) and the narrowest was profile P1 (85 m; Figure 5.5). The washover terrace had an average width of 54 m, and constituted 45% to 57% of the total barrier width (Figure 5.5). The oceanic beach was fairly homogeneous along the profiles, ranging from 30 m to 40 m average width, and 7.4^o to 8.2^o average beach face slope.

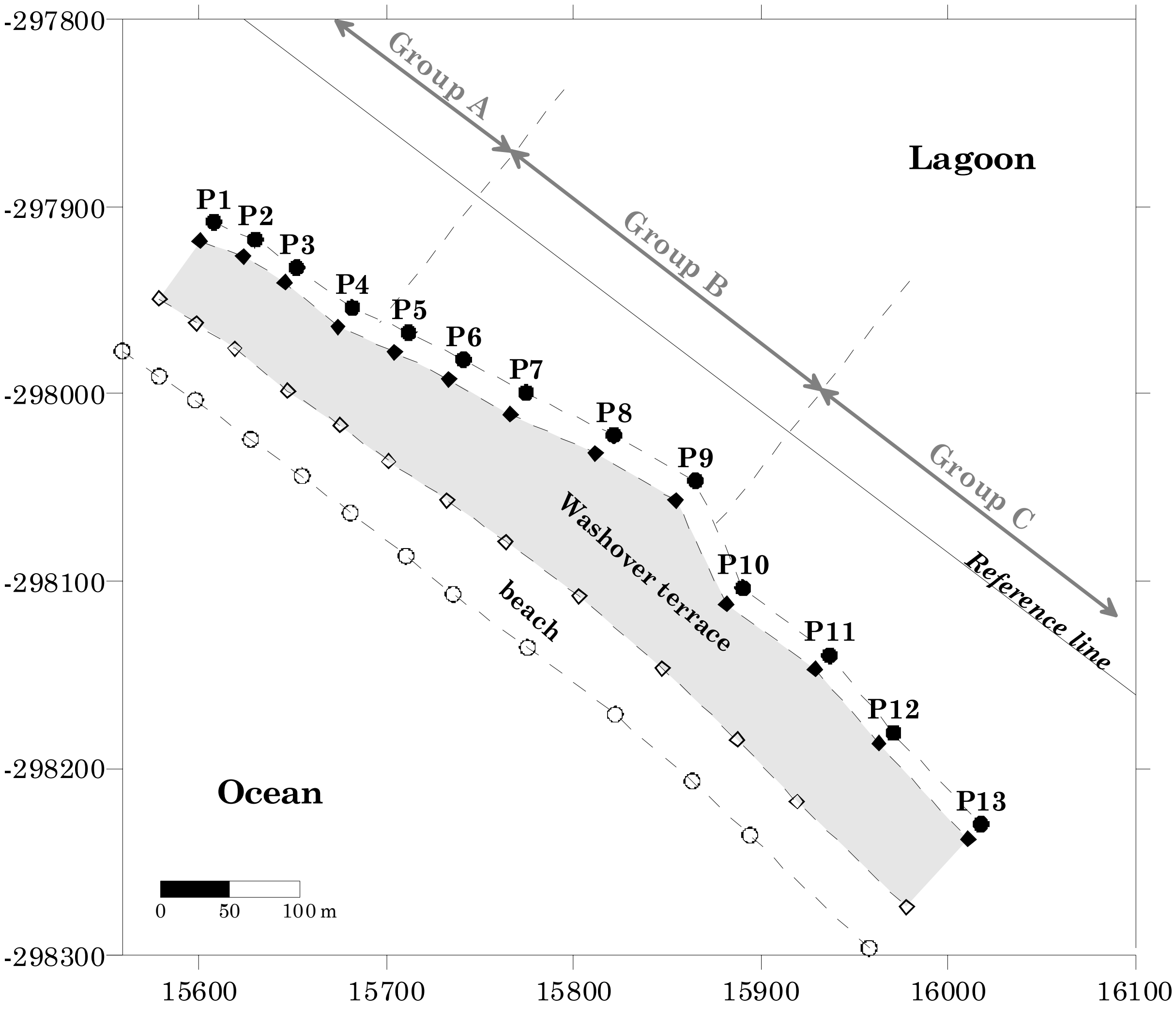


Figure 5.5. Average positions of ocean MSL (white circle), lagoon MSL (black circle), washover crest (white square), and washover terminus (black square), for the 13 profiles. The reference line used to determine the relative exposures of each profile is also represented.

The position of the washover crest, which represents the transition between the washover terrace and the beach (Figure 5.5), varied spatially along the different profiles and also over time. The average most exposed washover crest (i.e. most seaward located) corresponded to P13 and the least exposed to P9. The most exposed position for all profiles was attained either in January or February 2002. The most landward position (i.e. the most eroded) was attained in some profiles in November 2001 (P11, P12, P13), in April 2003 (P4, P6, P7, P8, P9, P10), or in October 2003 (P1, P2, P3, P5). The washover crest maximum displacement (i.e. between the most landward and seaward positions) varied between 23 m (P13) and 48 m (P2), with an average of 37 m. The washover terminus position had smaller displacements, with an average of 17 m, a maximum at P13 of 32 m and a minimum of 9 m at P5.

Profile grouping was made to reduce inter-profile variability and allow a broader analysis of the evolution of the study area. Morphologic criteria were selected to allow the best inter-group differences and intra-group similarities, taking into account that the groups had to be composed of geographically consecutive profiles. Three profile groups were defined (Figure 5.5) based on five quantitative (Figure 5.6) and one qualitative morphologic criteria (Figure 5.7): (1) beach berm width, (2) washover crest exposure, (3) washover terrace width, (4) washover terminus slope, (5) lagoon MSL position; and (6) presence of vegetation on washover plain.

The westernmost (i.e. closest to Ancão Inlet) profiles (P1 to P4) were included in Group A that was the group that showed the widest beach berms (Figure 5.6). Group A had a washover terrace that was always narrower than 45 m. Group A initially had some dune vegetation that was eroded and some vegetation colonization occurred occasionally during spring season (Figure 5.7a). Group B (P5 to P9) had the widest washover terrace (maximum around 70 m), the most landward lagoon MSL position, the more gentle terminus slope

(Figure 5.6) and had vegetation colonization on the landward parts of the washover terrace (Figure 5.7b). Group C (P10 to P13) had the most exposed washover crest, narrow washover terrace (maximum of about 55 m) and the narrowest beach berms (Figure 5.6). In Group C no vegetation colonization was noticed during the entire monitoring period (Figure 5.7c). The washover terrace and the washover terminus were generally steeper on the narrower profiles, where overwash processes were more frequent (Groups A and C).

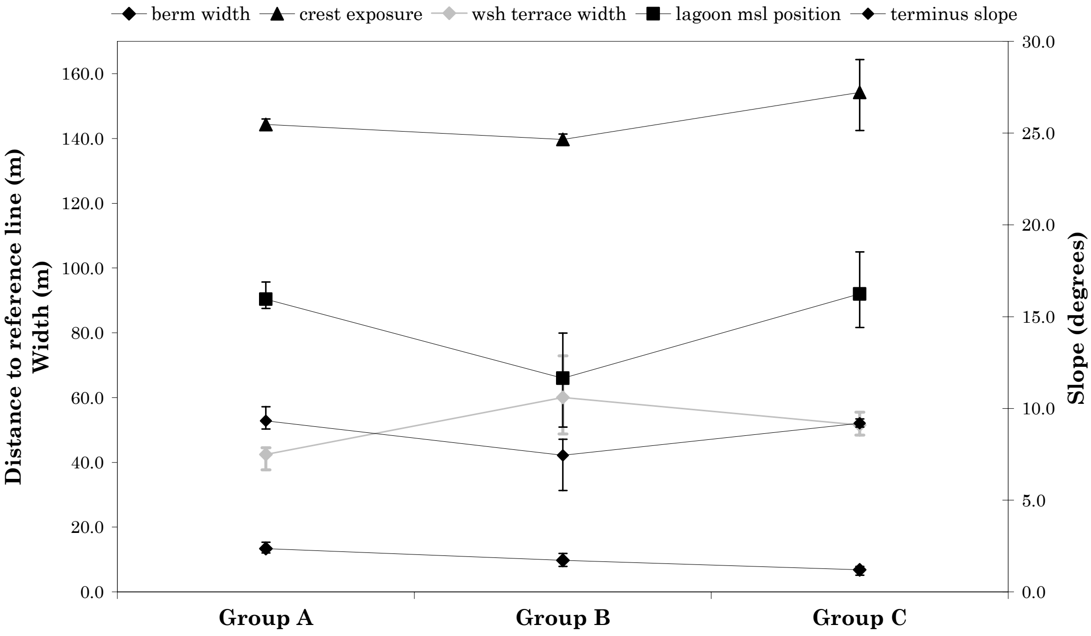


Figure 5.6. Quantitative morphologic criteria used for profile grouping. The average, maximum, and minimum values were represented for each of the criteria.

There were also significant variations in cross-shore morphology including horizontal displacements and elevation changes (Figure 5.8a to 5.8c). The beach face moved both seaward and landward, in response to swash processes (about 40 m), but maintained a steep slope for most of the study period (Figure 5.8a to 5.8c, as examples). The beach was classified as reflective according to the surf scalling parameter (ε, Guza and Inman, 1975) and also following the classification of Masselink and Short (1993) that relates the Ω (adimentional settling velocity, Gourlay, 1968) with the RTR (relative tidal range, Masselink and Short, 1993). The values of the parameters were $\varepsilon=1.4$ (reflective domain: $\varepsilon<2.5$, according to

Wright *et al.*, 1979), and $\Omega=1.65$ and $RTR=1.9$ (reflective domain: $\Omega<2$ and $RTR<3$, according to Masselink and Short, 1993).

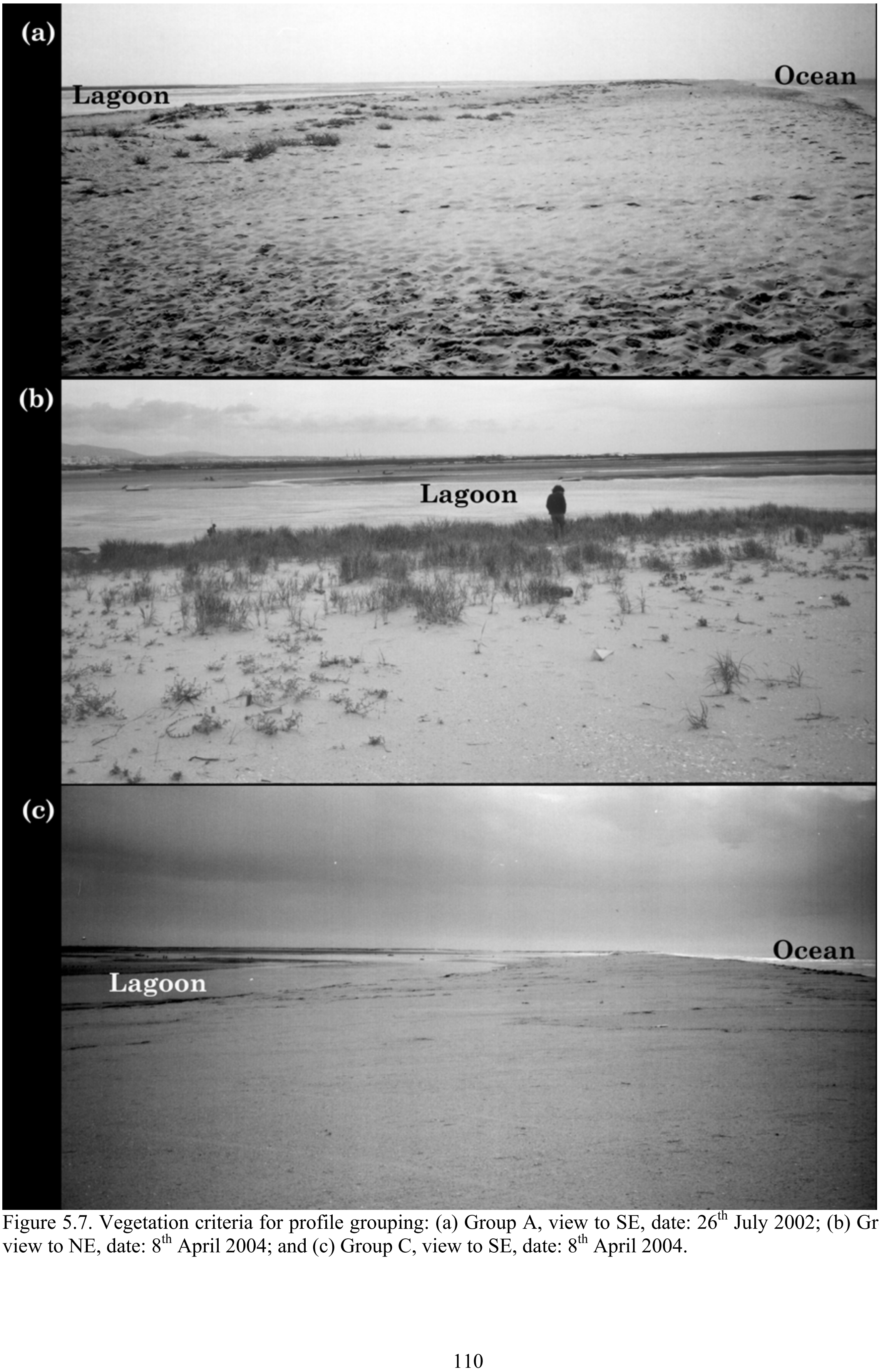


Figure 5.7. Vegetation criteria for profile grouping: (a) Group A, view to SE, date: 26th July 2002; (b) Group B, view to NE, date: 8th April 2004; and (c) Group C, view to SE, date: 8th April 2004.

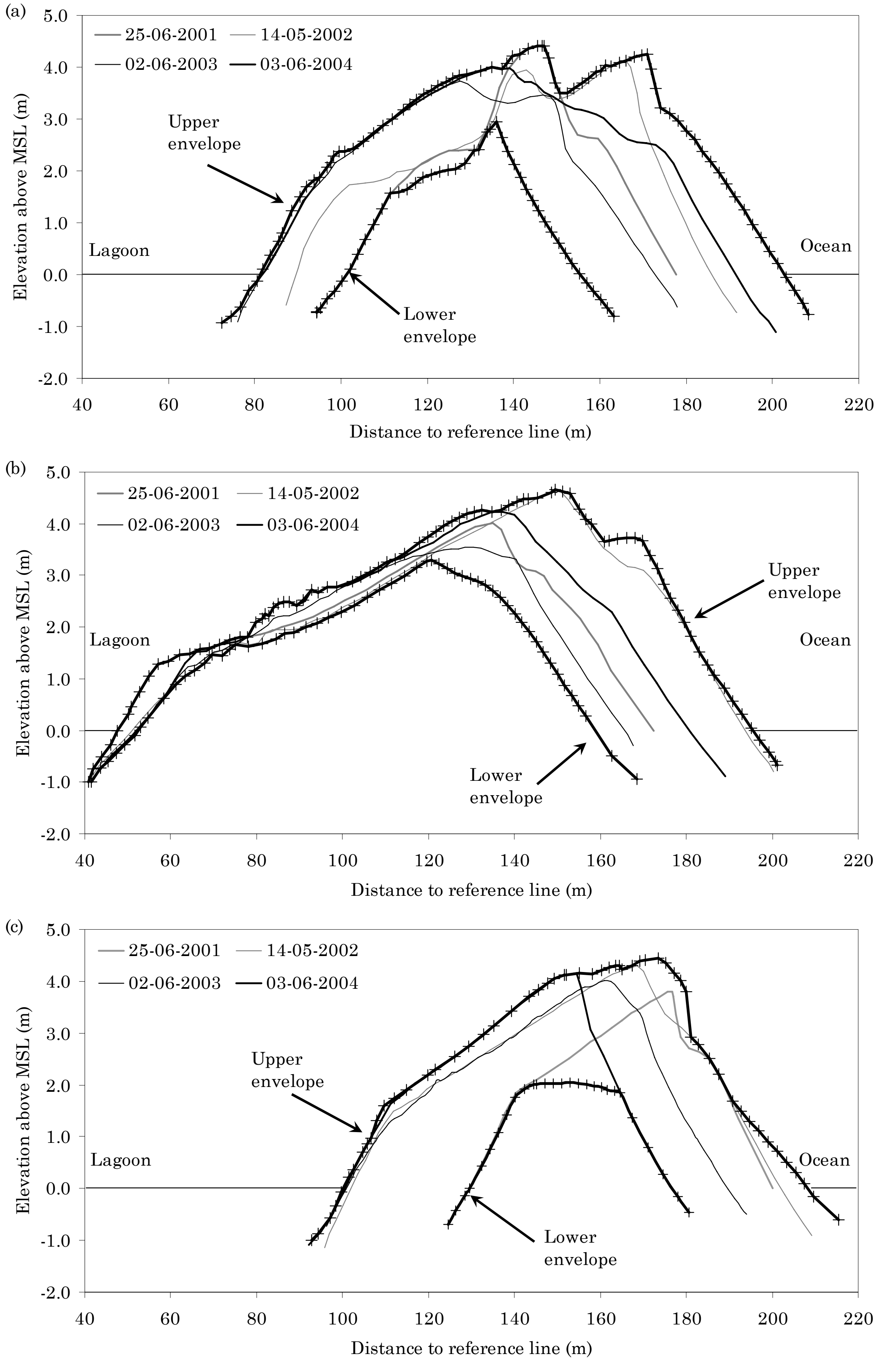


Figure 5.8. Examples of barrier cross-shore profiles and envelopes for the study period: (a) profile P3, of Group A; (b) profile P9, of Group B; and (c) profile P13, of Group C.

The upper and lower profile envelopes (i.e. the lines of maximum and minimum elevation for each location along the profile) for the seaward parts (including the beach and the washover crest) were considerably spread both vertically and horizontally (Figure 5.8a to 5.8c). For the landward parts of the washover plain, Group B had upper and lower envelopes more similar (e.g. Figure 5.8b), than Groups A and C (e.g. Figure 5.8a and 5.8c).

5.3.2.2. Volumetric evolution of the barrier

The barrier volume variation, above MSL, was +25,140 m^3 for the entire study period (Figure 5.9), which corresponded to about +47 m^3/m. There was no marked seasonality in the volumetric evolution of the barrier; both accretion (winter 2001-2002 and 2003-2004) and erosion (winter 2002-2003) were measured for winter periods. However, there was a marked seasonality in the magnitude of the volumetric variations (Figure 5.9) being higher in winter (15,000 m^3 to 43,800 m^3) than in summer (4,500 m^3 to 7,500 m^3).

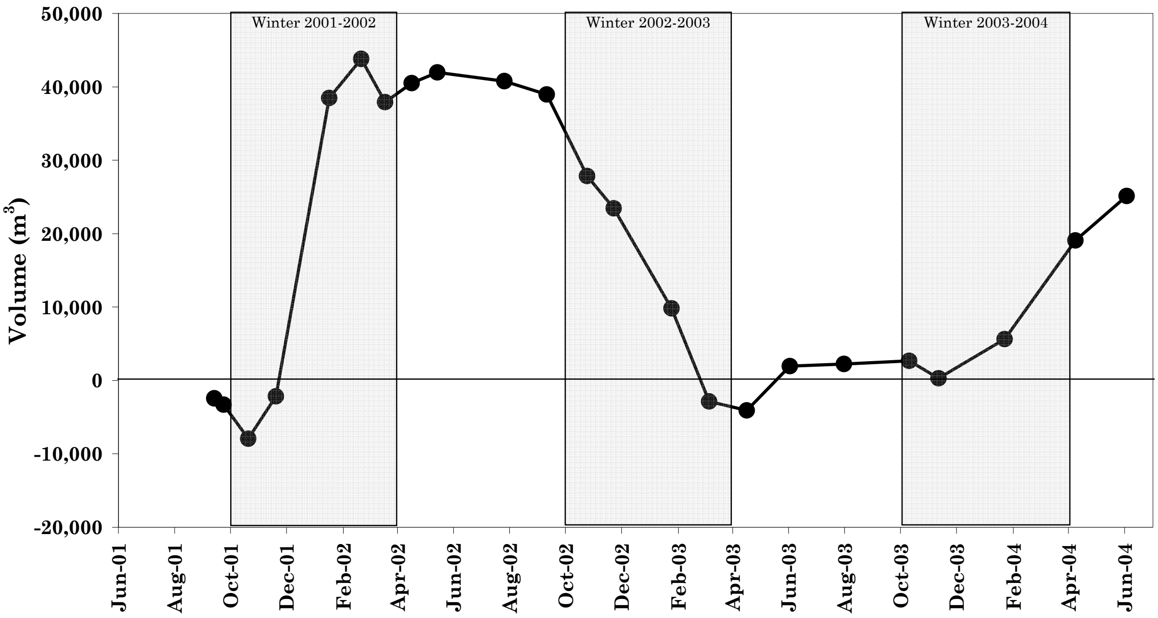


Figure 5.9. Cumulative barrier volume variation during the monitoring period.

The volumetric evolution due to the four determined processes (swash, overwash, aeolian and lagoon) for the three defined profile groups is shown Figure 5.10a to 5.10d. Due to errors in measurements, volume variations smaller than 5 m^3/m were not considered significant.

Swash processes were responsible for a major accretion event in the winter 2001-2002, for all groups (Figure 5.10a). This strong accumulation was also observed in the barrier volume variation (Figure 5.9) and occurred almost simultaneously for Groups A, B and C. Subsequently, during summer 2002, there was swash induced erosion on the Group A area, but small accretion on the other two groups. During the winter of 2002-2003, all groups underwent erosion due to swash (Figure 5.10a). During the summer of 2003 and the beginning of the following winter volume variations were relatively small for the entire study area. Accretion was registered in the middle of the winter 2003-2004 for all groups. After that, Groups A and B continued to accrete until the end of the monitoring period, with a global positive balance of +47 m^3/m and +16 m^3/m, respectively. Conversely, Group C underwent erosion until the end of the monitoring period with a global volumetric balance of -23 m^3/m.

Overwash processes promoted volumetric changes during winter, with the exception being the late summer of 2001 for Groups A and C (Figure 5.10b). During the winter of 2001-2002, Group C had significant overwash induced accretion, while Groups A and B had higher accretion volumes in the winter of 2002-2003. During the winter of 2003-2004, the overwash induced insignificant volume variations (< 4 m^3/m). Overwash processes (Figure 5.10b) induced higher accretion volumes on Groups A and C (+66 m^3/m and +57 m^3/m, respectively) than on Group B (+17 m^3/m).

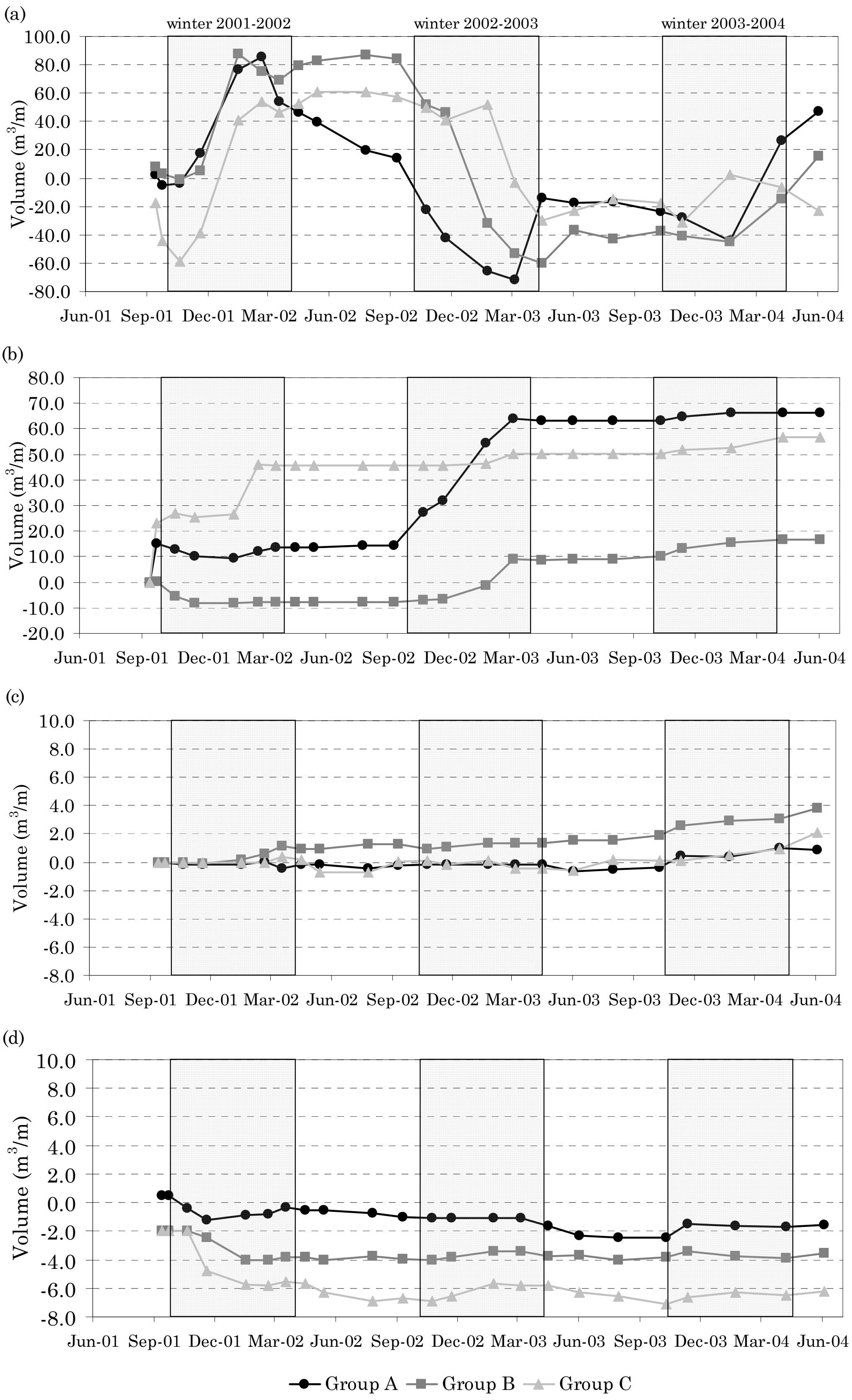


Figure 5.10. Cumulative volume variation for Groups A, B and C, due to (a) swash processes; (b) overwash processes; (c) aeolian processes; and (d) lagoon processes. Note that (a) and (b) have different volume scales than (c) and (d).

The barrier volume variation induced by overwash processes (Figure 5.10b) was attributable to variable amounts of overwash sedimentation along the study area. In certain cases very small amounts of overwash sedimentation were observed, whereas others promoted very significant accretion. The overwash accretion on the washover plain had a maximum of 64.7 m^3/m, recorded on P13, between September and October 2001. There was no period between consecutive surveys where all profiles had overwash sedimentation (Table 5.3), and only 4 surveys (#5, #9, #17, #18) recorded significant overwash sedimentation in 4 profiles or more (30%).

Table 5.3. Cross-shore profiles where insignificant and significant overwash sedimentation was registered between consecutive surveys.

Survey	Date	Insignificant overwash sedimentation $+1\ m^3/m < \Delta Vo^* < +5\ m^3/m$	Significant overwash sedimentation $\Delta Vo^* > +5\ m^3/m$
#1	25-06-2001		
#2	19-07-2001		
#3	13-09-2001		
#5	**23-09-2001**	P5, P6, P7, P9,	P1, P2, P3, P4, P10, P11, P12, P13
#6	20-10-2001	P1, P11,	P12, P13
#7	19-11-2001	P1	
#8	16-01-2002	P2, P4, P12	P1, P13
#9	**20-02-2002**	P2, P3	P10, P11, P12, P13
#10	18-03-2002	P1, P2, P3, P4	
#11	16-04-2002		
#12	14-05-2002		
#13	26-07-2002	P1, P2	
#14	10-09-2002		
#15	24-10-2002	P4, P5, P6	P1, P2, P3,
#16	22-11-2002	P4, P5, P13	P1, P2, P3
#17	**24-01-2003**	P7, P8, P9, P10, P13	P1, P2, P3, P4, P5, P6
#18	**06-03-2003**	P11	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10,
#19	16-04-2003	P2, P8, P9, P10, P11, P12,	
#20	02-06-2003		
#21	31-07-2003		
#22	10-10-2003	P6, P8, P13	
#23	11-11-2003	P4, P5, P6, P7, P8, P9, P11, P12, P13	
#24	22-01-2004	P1, P3, P4, P5, P6, P7, P8, P9,	P13
#25	08-04-2004	P7, P8, P10, P11, P12	P13
#26	03-06-2004		

*ΔVo – volume of accretion between consecutive surveys due to overwash processes.

<u>Aeolian processes</u> induced smaller volumetric variations than the preceding processes (Figure 5.10c). There was no marked seasonality observed in the volume variations. Group B was the only group where aeolian processes induced higher accretion volumes, particularly in

late winter 2001-2002, and winter 2003-2004. The net global variations were not significant: +3.8m^3/m and +2.1 m^3/m, for Groups A and B, respectively, and <1m^3/m for Group C.

Lagoon processes contributed mostly to barrier erosion with similar magnitudes as the aeolian processes (Figure 5.10d). Volumetric changes were small, but erosion occurred for all groups during the winter 2001-2002. Lagoon processes induced significant volume variation for Group C (-6.3 m^3/m) and insignificant variations for Groups A and B (-1.6 m^3/m and -3.5 m^3/m, respectively).

5.4. DISCUSSION

5.4.1. RELATIVE ROLE OF PROCESSES IN BARRIER DYNAMICS

The studied part of the Barreta Island was extremely dynamic during the monitoring period. The processes responsible for such dynamics were swash, overwash, aeolian, and lagoon processes. A maximum volume variation of +6.4 m^3/m/day was induced by overwash processes and -3 m^3/m/day occurred due to swash processes. Some processes coexisted, but were geographically separated, like swash and aeolian, while others were geographically coincident but not contemporaneous, like overwash and aeolian. The most ubiquitous process for the seaward part of the barrier was the swash processes. The landward part was mostly reworked by lagoon processes, and only occasionally by complete overwash. On the washover terrace, aeolian processes and overwash alternate according to the oceanographic, meteorological and morphologic conditions. The swash processes may also influence the washover plain either by the incorporation of a high berm, or by the erosion of the beach face and subsequent retreat of the washover crest. Each of the defined processes resulted from the combination of several factors, which were not analysed separately, but may be summarised by a combination of forcing mechanisms and barrier conditions. Swash processes were dominant during the monitoring period (Figure 5.11), they were responsible for about 83% of the barrier volume variation. Overwash was the second most dominant process, inducing 14% of barrier volume variation. The aeolian and lagoon processes were relatively less important, with only 1% and 2% respectively. Due to the seasonal character of overwash processes, their importance increased in winter and decreased in summer (almost negligible); the maximum overwash contribution was 80% and it was recorded during the period January-February 2002 (Figure 5.11).

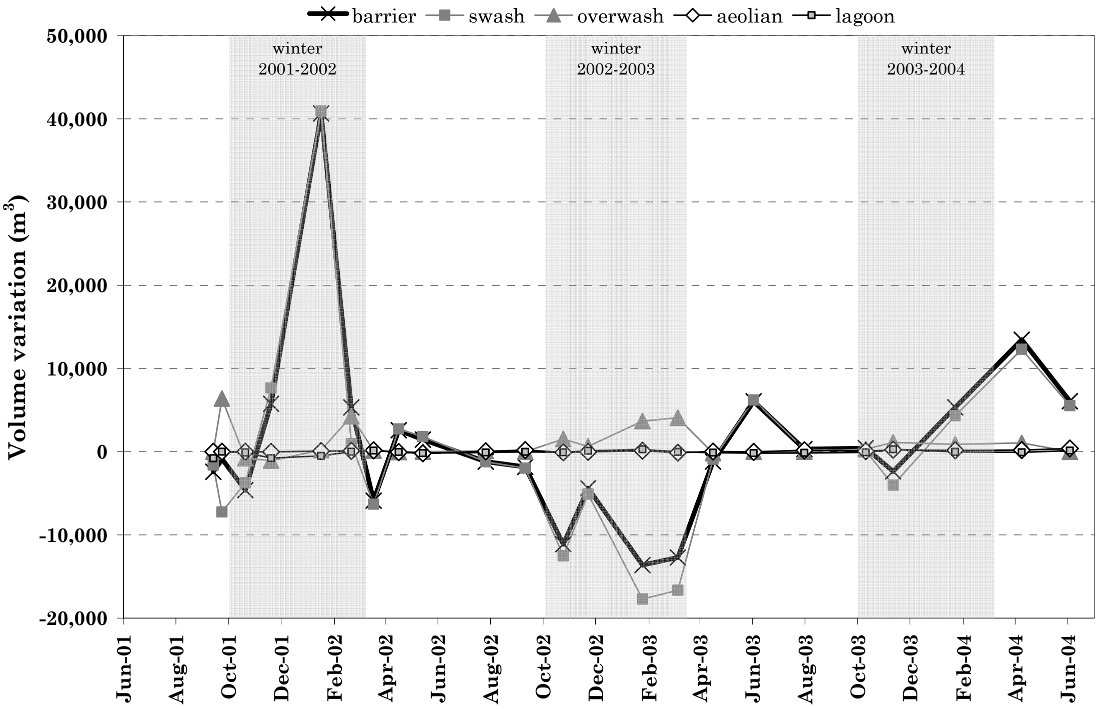


Figure 5.11. Volume variation of the barrier and component of volume variation due to swash, overwash, aeolian and lagoon processes.

Swash processes were relatively more dominant during summer because overwash was absent. The dominance of processes, in the study case, had no direct relation with the duration and frequency of the exposure of the barrier to the processes but rather with the capacity of the process for sedimentary transport and deposition. Lagoon processes reworked the landward part of the barrier continuously, but the amount of barrier changes induced by the lagoon currents was not significant (Figure 5.11). The total duration of the overwash events over the washover plain was less than the amount of time during which the washover plain surface was dry (without overwash flow or rainfall) and available for aeolian transport. However, the amount of sand transported during the overwash events was a magnitude higher than the sand deposited or deflated by the wind, during the monitoring period.

Swash processes induced greater changes during winters (Figure 5.10 and 5.11), but the type of changes was different for different winters. The increase in wave power that generally occurred during the winters (Figure 5.4) was either associated with accretion or with erosion. This is related to the location of the study area on the downdrift margin of Ancão Inlet (Figure 5.12). Vila-Concejo *et al.* (*in press a*) analysed the relationship between sediment bypassing Ancão Inlet and the volumetric evolution of the western part of Barreta Island. Vila-Concejo *et al.* (*in press a*) identified the sediment bypassing at Ancão Inlet as "Outer Channel Shifting" according to the classification given by FitzGerald *et al.* (2001). This process occurs when the seaward end of the ebb channel has been deflected downdrift due to the preferential accumulation of sand on the seaward, updrift side of the swash platform. When the seaward part of the ebb channel shifts to an updrift position, the bypassed sands moves onshore as a large swash bar. This process was particularly important for the accretion noticed in January-February 2002 (Figure 5.9 and 5.10a), that was related with the arrival and welding of swash bars (Figure 5.12) that were released from the inlet area in April and July 2001, and that had a total volume of $+63.7\times10^3 m^3$ (Vila-Concejo *et al.*, *in press a*). Swash bars were also observed in December 2002 (Vila-Concejo *et al.*, *in press a*), but their arrival and welding was only noticeable for those profiles closest to the inlet (Group A, Figure 5.10a). The relation between barrier volumes and inlet dynamics highlights the importance of complementing the analyses of oceanographic conditions with a correct identification of processes that determine the sediment budget in a given coastal area.

The cumulative variation of barrier volume during the study period was +25,100 m^3 (+47 m^3/m), with a maximum of +43,800 m^3 in February 2002 and a minimum of -4,000 m^3 in April 2003 (Figure 5.9). About +22,000 m^3 of the cumulative volumetric evolution of the barrier (88%) accreted by overwash processes. This implies that although swash processes caused more changes during the analysed period, there was a dynamic equilibrium between the accretion and erosion. On the contrary, overwash processes were essentially accretional. Additionally the later surveys (June 2004) show that the latest washover plain was coincident with the upper envelope of the profiles (Figure 5.8a, 5.8b, and 5.8c). The accretion and landward displacement of the washover plain was mainly due to overwash processes, and there was not an inverse process of sediment removal to counteract these processes. Conversely, swash induced accretion was followed by swash induced erosion. This seems to indicate that barrier island retreat was achieved by a combination of overwash accretion and swash erosion, with the overwash sedimentation being responsible for the construction of the bulk of the island.

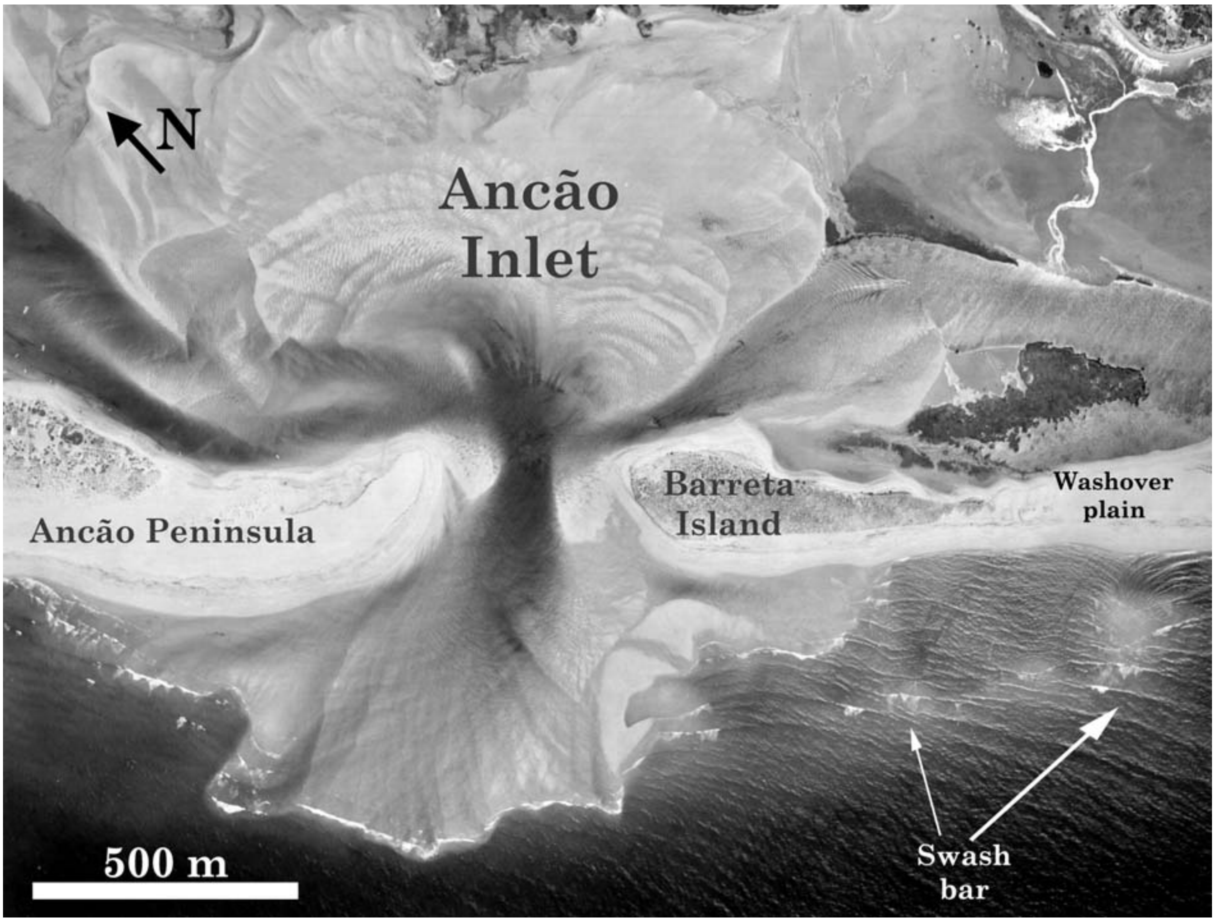


Figure 5.12. Aerial photograph of Ancão Inlet, from 2001, where swash bars related with the Ancão Inlet are visible. The swash bar is almost welding to the beach seawards of the studied washover plain.

The extrapolation of the balance of coastal processes observed in this case, to other periods or barrier island evolution, even for the same study area, is not possible. In 1947, about 32% of the barriers frontal longshore extension was composed of washovers (based in data from Garcia *et al.*, *in preparation*). This is possibly related with a major storm that according to Weinholtz (1964) and Esaguy (1985, 1986b, 1986c) occurred in 1941 and was responsible for the opening of Lacém Inlet (Esaguy, 1986b) and possibly for the opening of Ancão and Fuzeta Inlets (Vila-Concejo, 2003). About 93% of the barrier islands of the Ria Formosa, in 2001, were composed of dunes and only 7% of washover plains or washover lobes (based on data from Garcia *et al.*, *in preparation*). Most washovers from 1947 that did not disappeared due to inlet dynamics, developed dunes (Chapter 7, section 7.3.2.2) and overwash ceased to occur. Therefore, there seems to be a point where aeolian processes dominate the supra-tidal parts of the barrier islands and dunes develop at the top of the washover terrace. In the parts of the study area where overwash was less frequent and less intense (e.g. P9) the relative role of aeolian processes was higher (aeolian net variation ≈9 m^3/m; overwash net variation ≈15 m^3/m) than on the other parts (e.g. P12) where overwash was more frequent (aeolian net variation ≈2 m^3/m; overwash net variation ≈69 m^3/m). Overwash deposits and beach berms had an elevation of about 4.5 m MSL (e.g. Figures 5.8a to 5.8c). This contrasts with the average dune elevation for the study area (5.0-5.5 m MSL, Andrade, 1990). Therefore, it seems possible that the later stages of vertical accretion are caused by aeolian processes. Aerial photographs of the area taken 10 months before the start of the monitoring (August 2000), showed relatively narrow vegetated dunes in the locations of almost all profiles (except some profiles from Group C, P11 to P13). This means that between 2000 and 2001 complete overwash occurred and was responsible for the total erosion of the dune field and generation a wide washover plain. The evolution of the barrier seems to be composed of sequences of destruction (2000-2001) and construction (monitoring period) of the barrier. The destructive periods are characterised by intense overwash and washover plain creation, and the resulting barrier is wide and low. During the constructive periods the overwash processes dominate the early stages and afterwards aeolian processes promote dune development and a rise in island elevation.

The interactive nature of aeolian and overwash processes has been extensively described in the literature (e.g. Godfrey *et al.*, 1979; Rosen, 1979; Leatherman and Zaremba, 1987; Inman and Dolan, 1989). Overwash processes provided the source material for building the sub-aerial portion of the barrier system, and aeolian processes were significant for redistributing this sediment to induce vertical island growth. In low-lying barrier islands, during catastrophic storms the barrier mass may be conserved by overwash processes (Stone *et al.*, 2004). In spite of the fact that the beach recovery after overwash may be fast (1 year, Sexton, 1995), and the vegetation can grow in a matter of months (Hosier and Cleary, 1977), the full accumulation of sand through dune development in post-storm situation may be relatively slow (6 years, Stone *et al.*, 2004) or even incomplete following major hurricanes (Stone *et al.*, 1997). Fisher and Stauble (1977) recognised that in cases where the overwash intrusion is relatively small, the ultimate fate of the sediment may be to be blown back on the seaward side rather than the bay side of the island. The volume of the overwash deposition as compared with the aeolian deposition may have site specific differences or time-dependent fluctuations. Inman and Dolan (1989) presented windblown transport rates and overwash transport rates, for the Outer Banks (North Carolina, U.S.A.), where the overwash transport rates were generally higher than the wind transport. Héquette and Ruz (1991) and Cloutier and Héquette (1998), found for the southeastern Beaufort Sea (Canada) barrier islands, a proportion of 62% and 38% for overwash and aeolian transport, respectively. Davidson-Arnott and Fisher (1992) concluded that for the Long Spit of Lake Erie (Ontario, Canada) the volumes of aeolian sediment transport were of the same order of magnitude as those involved in overwash sedimentation. Leatherman (1976) found that on Assateague Island the aeolian processes were slightly more dominant than overwash. The relative dominance of aeolian and overwash processes may be attributable to different causes. Kochel and Wampfler (1989) observed variations in the dominance of processes for the Assateague Island (Maryland, U.S.A.), that the authors related with fluctuations of climatic factors. McCluskey (1987) demonstrated for Fire Island (New York, U.S.A.) that the aeolian processes were the dominant mechanism for the landward transport of sediment when the sediment budget in the littoral zone was positive, and the overwash processes were dominant when the sediment budget was negative.

In the current study area, overwash was the dominant process in barrier island accretion, due to the lack of a complementary process of sediment removal from the island. The aeolian deposition was one order of magnitude smaller in places where overwash processes were active. If a mostly depositional aeolian rework for the study area is assumed, then long aeolian events could provide sediment accumulation of similar magnitude as overwash processes. It should be mentioned that significant aeolian deposition only occurred in the seldom overwashed distal parts of the washover terrace where pioneer vegetation was also observed (Group B, Figure 5.7b). The relatively low short- to medium-term importance of aeolian processes in western Barreta Island may be different from its long-term importance because: (a) such a small aeolian role was not commonly described in the literature for other barriers; b) the long-term washover evolution showed a general tendency towards dune development (Chapter 7, section 7.3.2.2); c) lack of sand grains of sizes adequate for aeolian transport; and d) overwash is still active on parts of Barreta Island corresponding to the early stages of the constructive periods, and thus the relative role of aeolian processes will probably increase in the future. The high importance of overwash processes seems to be related to impulses of barrier displacement, while aeolian dominance may result from periods of more stable barrier positions.

The events in barrier evolution may therefore be resumed as a sequence composed of three stages: (1) during Stage 1 the geomorphologic changes of the barrier are rapid and dominated by complete overwash that leads to dune destruction and to the formation of a wide and low washover plain; (2) during Stage 2 the washover dynamics is dominated by frequent overwash, including non-storm overwash; and (3) at Stage 3 morphologic changes are slow, overwash is not common, and aeolian processes dominate the washover dynamics promoting dune development and vertical barrier accretion.

5.4.2. OVERWASH SEDIMENTATION: GOVERNING FACTORS AND THRESHOLDS

The data collected during the monitoring period recorded overwash sedimentation under different conditions. The washover plain accretion resulted from overwash flows generated both by storm and non-storm wave conditions. Because no direct measurements were made of the overwash flows for all the overwash events during the monitoring period, the intensity of the events cannot be analysed. However, it can be assumed that the intensity of the overwash is reflected in the amount of sediment transported and deposited by the overwash flows. The volume of overwash sedimentation, which is related to the overwash flow capacity, can therefore constitute a proxy of the overwash magnitude. Assuming the estimated maximum error for the volumetric determinations, the significant overwash sedimentation (OSs) corresponded to volume accretions in between surveys higher than 5 m^3/m.

From the 24 surveys where reliable data was obtained, only 8 surveys were undertaken after OSs occurred on at least one of the profiles. Because of the orientation of Barreta Island (NW-SE) the analysis of the waves that determined the occurrence of OSs was made considering only the W-SW directions. Other authors have also related the intensity and frequency of overwash to oceanographic conditions (e.g. Fisher *et al.*, 1974), including the relative orientation of the coast to the storm path (e.g. Fletcher *et al.*, 1995). Variable oceanographic conditions determined the occurrence of OSs, for the 8 considered surveys (Figure 5.13). There is no certainty about the dates when overwash occurred between surveys, but it was assumed that the peak in wave power was coincident with the peak in OSs (including relatively small peaks which were coincident with higher tidal ranges).

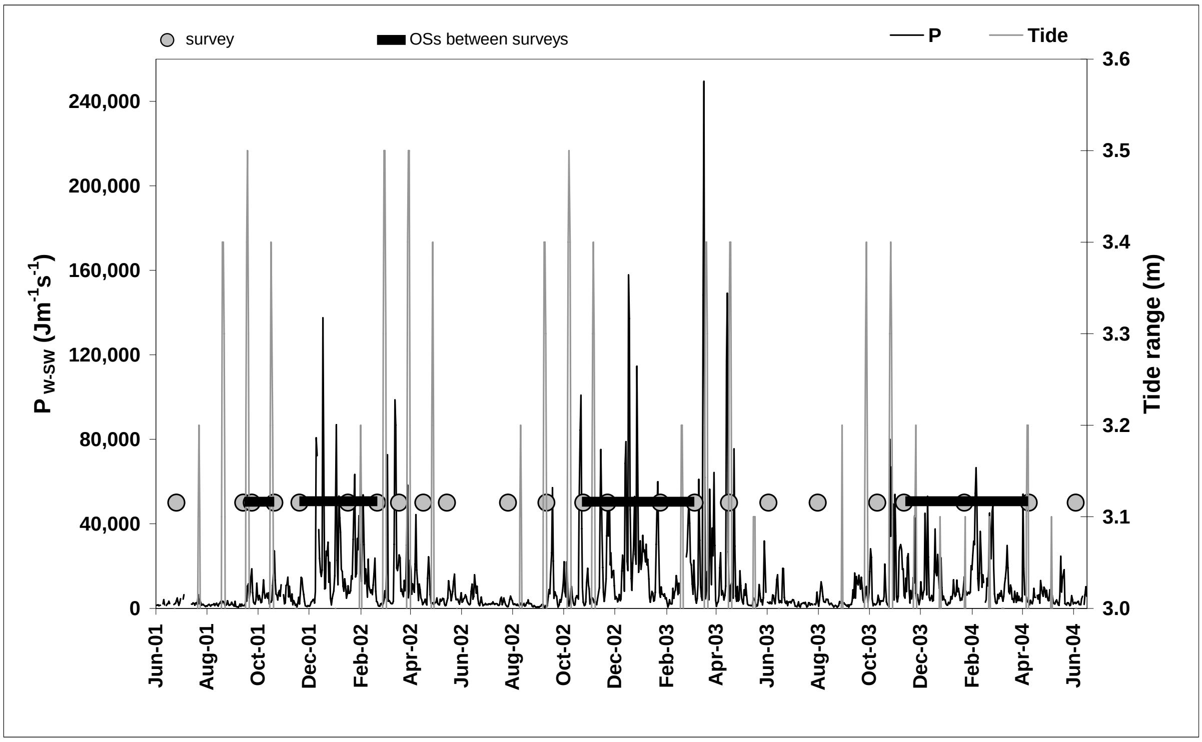


Figure 5.13. Wave power for the waves from W-SW, tidal range, survey dates, and periods with OSs, during the study period. Note that only the spring tides (tidal range>3.0m) were represented.

Surveys that recorded OSs were mostly undertaken during the winter months with the exception of September 2001 (Figure 5.13 and Table 5.3). This implies that for OSs to occur, a certain level of wave power has to be reached, however the opposite consideration is not valid, i.e. the occurrence of that level of wave power by itself does not determine the occurrence of OSs. The OSs associated with the smallest wave power occurred in September 2001 with only 11,700 $Jm^{-1}s^{-1}$, which corresponds to H_s of 1 m and a Tp of 12s. However, the visual estimation of the waves (breaking waves of about 2 m to 2.5 m, Figure 5.14) did not agree with the wave height recorded by the buoy, and scientific equipment deployed on a nearby beach (2,500 m NW of the study area) during that day was destroyed by the waves. Buoy malfunction must therefore be assumed for September 2001 and these data will not be used in this discussion. Not considering September 2001, the smallest wave power for the W-SW waves that induced OSs was recorded prior to October 2001 (18,7000 $Jm^{-1}s^{-1}$). The intensive fieldwork campaigns GO.1 and GO.3 analysed in Chapter 4, where OSs was measured and corresponded to non-storm overwash, had associated wave power of 18,200 $Jm^{-1}s^{-1}$ and 20,700 $Jm^{-1}s^{-1}$ respectively. Therefore, an estimated threshold of W-SW wave power of about 20,000 $Jm^{-1}s^{-1}$, for the occurrence of OSs may be considered, for the study area. This threshold might be associated to waves of H_s of 1.2 m and Tp of 14s or to H_s of 1.6 m and Tp of 8s. However, this threshold is only applicable to equinoctial spring tides (tidal range>3.2 m). During the monitoring period, OSs also occurred during regular spring tides or at neap tides, and for those occasions the wave power was at least 53,000 $Jm^{-1}s^{-1}$ (December 2003, H_s=2.3 m and Tp=10s). Therefore, the minimum oceanographic conditions for OSs for the study area were waves from W-SW and power higher than 50,000 $Jm^{-1}s^{-1}$ during neap tides or regular spring tides or higher than 20,000 $Jm^{-1}s^{-1}$ during equinoctial spring tides. In terms of probability of exceedence, the threshold for the W-SW wave power ($P_{P[W\text{-}SW]}$), for equinoctial spring tides, was $P_{P[W\text{-}SW]}$=14% and for regular spring tides or neap tides was $P_{P[W\text{-}SW]}$=4%.

Figure 5.14. Plunging breaker waves with about 2 m height, at Ancão Peninsula (2,500 m NW of the study area), at September 18th 2001.

During the monitoring period, there were occasions when the oceanographic threshold was exceeded but no OSs occurred, for example in March 2002 and April 2003 (Figure 5.13).

Moreover, there were surveys where only some of the profiles had OSs. Other authors have described the morphologic characteristics that controlled the intensity of overwash: beach topography (e.g. Leatherman, 1976), backbeach elevations (e.g. Morton and Sallenger, 2003), and nearshore bathymetry (e.g. Ritchie and Penland, 1988).

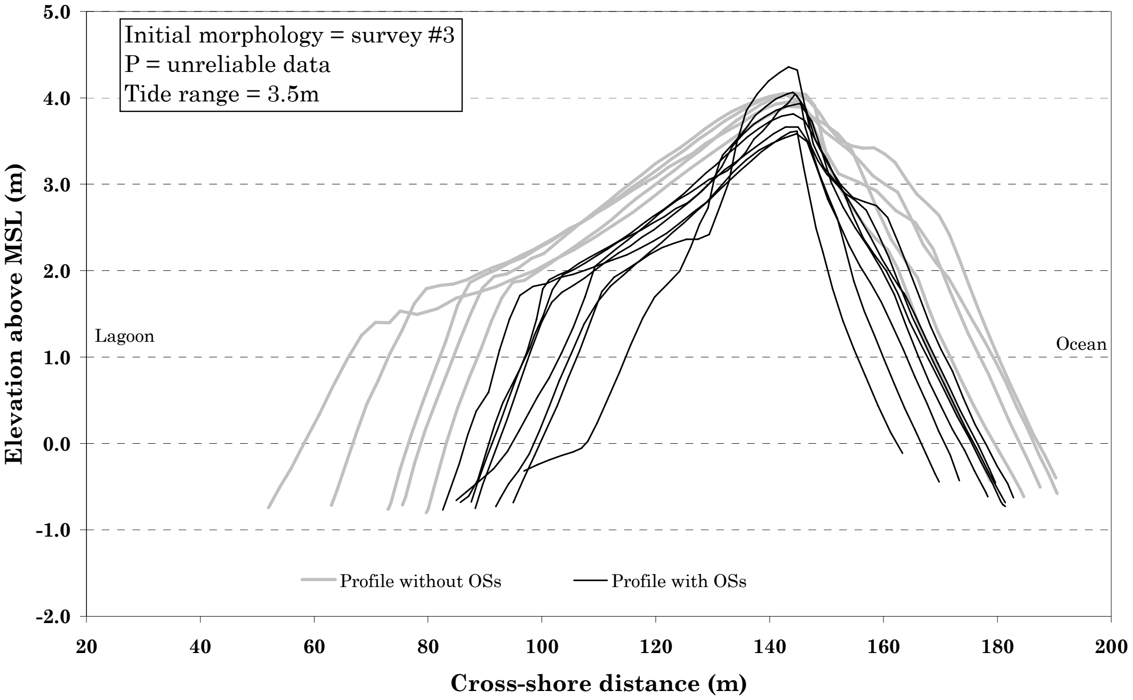
The limiting condition for overwash occurrence that was found in Chapter 4 was Z_{crest}<high tide+2.1m. This limit corresponded to a level that had to be reached for the beginning of the overwash flows over the washover crest. However, this limit is specific of the oceanographic and geomorphologic conditions that occurred during the fieldworks GO.1 and GO.3, i.e. moderate wave energy, equinoctial spring tides, steep and featureless beach face, and washover crest between 2.8 m and 3.3 m (Table 4.2). Other conditions promoted OSs during the three-year monitoring period and therefore the limit found in Chapter 4 is not applicable.

The threshold condition for overwash regime as defined by Sallenger *et al.* (1999) and explained in section 2.2, is that the wave run-up (R_{HIGH} = 2% exceedence runup elevation + sea level) exceeds the elevation of the foredune (D_{HIGH}, equation 2.2). The $R_{2\%}$, was defined by Holman (1986), as a function of the offshore wave height and the Iribarren number (incorporating beach slope, offshore wave height and wave length). For the period between surveys, the profiles were exposed to the same offshore wave heights and wave lengths; however the beach slope and the washover crest height were slightly different (Figure 5.15). R_{HIGH} and D_{HIGH} were determined for the surveys performed after OSs. The profiles that according to Sallenger *et al.* (1999), were in the overwash regime did not agree with the ones exhibiting OSs. For example, for initial conditions of survey #16 and the wave conditions that occurred between surveys #16 and #17 (when OSs occurred), all profiles except P10 were in the overwash regime, according to the Sallenger *et al.* (1999) classification. However, OSs occurred only on Profiles P1 to P6. Another example is survey #17 (overwash occurred between surveys #17 and #18), where only profiles P1, P2 and P3, were close to the overwash regime, but OSs occurred on profiles P1 to P10 (black lines of Figure 5.15b). These results show that overwash sedimentation cannot be directly derived from the threshold determined by Sallenger *et al.* (1999). However, it must be stressed that Sallenger *et al*. (1999) did not develop the relation for the purpose of distinguishing the cases in which overwash promotes significant sedimentation (OSs), but to estimate a threshold for overwash occurrence. Leatherman (1976) found that numerous and small overwash flows carried an insignificant amount of material; their role appeared to be primarily confined to the *in situ* sorting process. Therefore, the definition of the threshold for the start of overwash regime may not be indicative of the beginning of overwash sedimentation.

Only surveys with OSs on at least four profiles (#5, #9, #17 and #18, Table 5.3) were selected to determine the main morphologic parameters that change between profiles in the study area. The OSs measured in a certain survey (#n) resulted from the combination of geomorphologic conditions measured in the initial conditions (survey #n-1) with the waves and tides that occurred between surveys (period between survey #n-1 and #n). To evaluate the initial morphology of the profiles in relation with OSs occurrence the initial profiles (survey #4, #8, #16 and #17) were displaced so they had the washover crest in the same location (e.g. survey #17 in Figure 5.15b).

To determine which morphologic parameters allowed a separation between the profiles where Overwash Sedimentation (OS) occurred from the others, an analysis was made of: beach volume, beach slope, washover crest height, and washover terrace width (Figure 5.16). The comparison of the OS with the beach slope and the washover plain width showed that there was no direct relation between these variables (Figure 5.16).

(a)



(b)

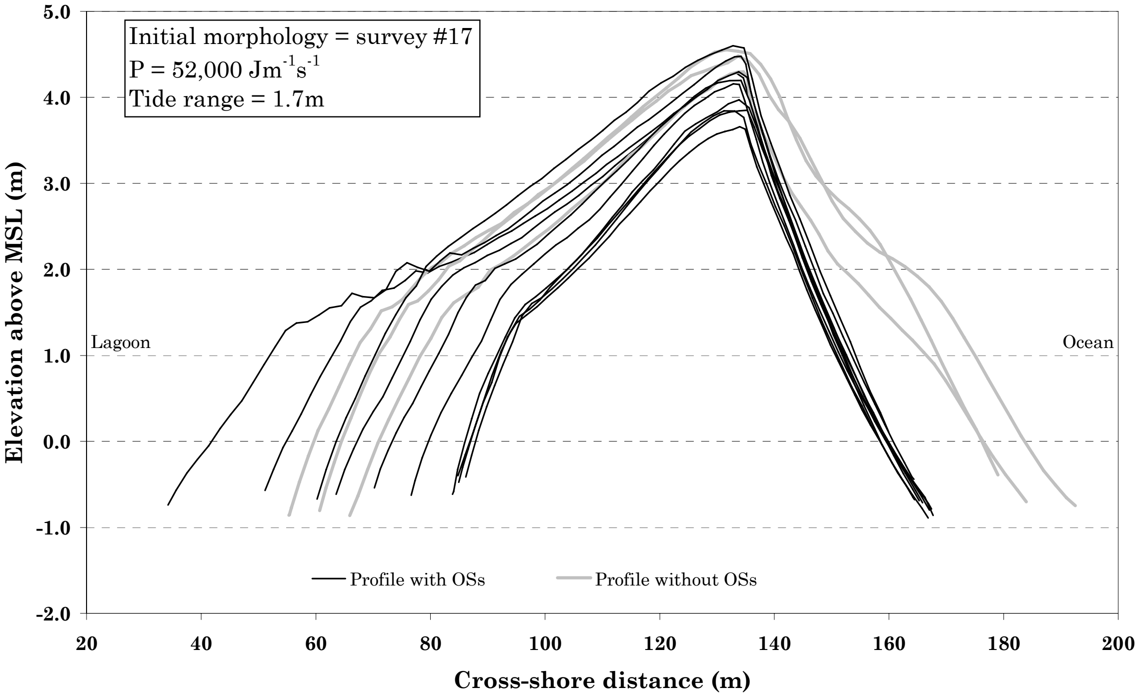


Figure 5.15. Examples of the 13 barrier profiles corresponding to the initial morphological conditions, with the distinction between the ones where (a) OSs occurred between survey #3 and #5 (September 2001); and (b) OSs occurred between survey #17 and #18 (February 2003).

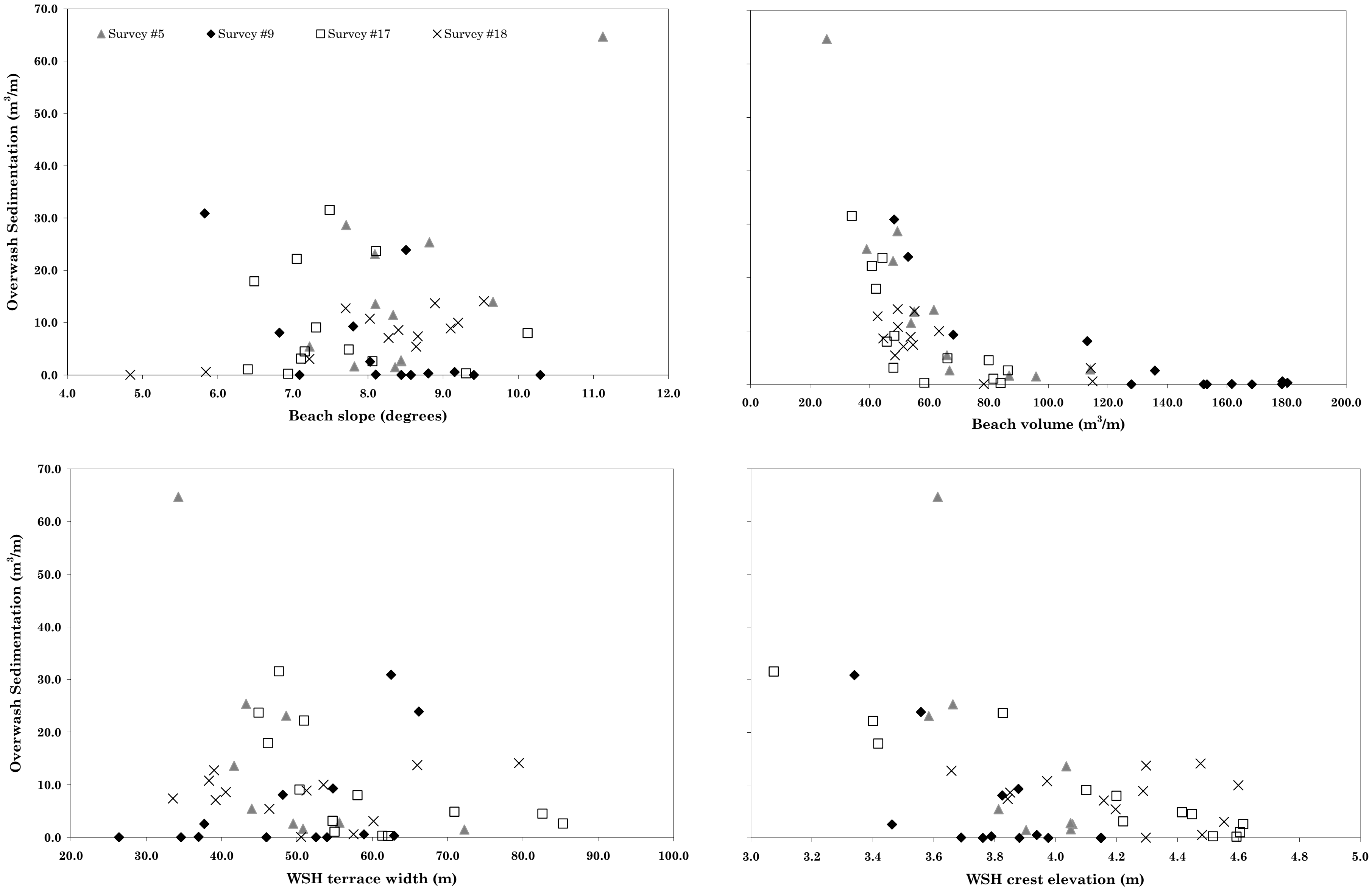


Figure 5.16. Overwash sedimentation *versus* beach slope, beach volume, washover terrace width, and washover elevation. WSH = Washover

The beach face of the study area was generally reflective, and therefore to evaluate the importance of beach slope in overwash sedimentation, it would be necessary to have data on contrasting beaches under similar oceanographic conditions and washover morphologies. The higher OS were generally associated with lower washover crest elevations. In some cases there was a linear relation between the crest elevation and OS (survey #17, Figure 5.16), but this was not always observed (survey #18). In the case of survey #5 the maximum variation in crest elevation was 50 cm, and contrasting OS were observed. Probably the obtained data set is not adequate for the analysis of the importance of the crest elevation, because the range of elevations was relatively small (between 3.1 m and 4.6 m) and did not included foredunes that have higher elevations. The factor that seemed to induce OS was small beach volumes. An exponential tendency can be observed from the relation between the OS and the beach volume (Figure 5.16). However, since the oceanographic conditions for each of the surveys were different, a unique trend line cannot be applied to all data. The variations between these values of beach volumes were related to the differences in the wave power, tide amplitude, and morphologic conditions. For similar oceanographic conditions, the profiles with smaller beach volumes had higher OS. For similar beach volumes, if oceanographic forcing increased, then larger OS would occur. The exponential relation between the volume of the beach and the volume of overwash sedimentation means that there is a certain resilience of the system to overwash sedimentation. Small sedimentation volumes occur until a critical beach volume is achieved, and after that a small decrease in beach volume allows a large amount of overwash sedimentation. OSs is considered as volumes higher than 5 m^3/m, and in the case of survey #9, OSs occurred for beach volumes smaller than +120 m^3/m (Figure 5.16). However, for survey #5, OSs only occurred for beach profiles with less than +70m^3/m. Considering all data the maximum beach volume that allowed OSs was +120 m^3/m.

From the above, the factors that mostly governed the overwash sedimentation at the washover plain under unconfined overwash flow may be summarized by:

$$\mathrm{OSs} = f(\mathrm{P}_{\mathrm{W-SW}}, \eta_{\mathrm{dtr}}, \mathrm{V}_{\mathrm{b}}) \tag{5.6}$$

where $P_{W\text{-}SW}$ is the wave power of the W-SW waves, η_{dtr} is the daily tidal range and V_b is the beach volume. For the study area, during the monitoring period, the threshold was:

$$\begin{cases} P > P_{P[W\text{-}SW]=4\%} \text{ if } \eta_{dtr} < 3.2 \text{ m} \\ P > P_{P[W\text{-}SW]=14\%} \text{ if } \eta_{dtr} > 3.2 \text{ m} \end{cases}$$

and

$$V_b < +120 \mathrm{m}^3/\mathrm{m}$$

The two wave power thresholds that were determined according to the tidal range are part of a continuum that could only be defined with more data. Comprehensive algorithms for simulating the sediment transport during overwash have been developed, amongst others, by Kraus and Wise (1993), Kobayashi *et al.* (1996), and Larson *et al.* (2004). This study brings more emphasis to the importance of overwash under non-storm conditions associated with equinoctial tides for washover plain morphologies. Also, the importance of the beach volume was quantified for the amount of overwash sedimentation in cases of relatively similar crest elevation and beach slopes. The beach volume was frequently related with the development of a beach berm, and in some cases the variations in OSs were solely related with the volume of sediments accumulated in the berm.

5.5. CONCLUSIONS

An analysis was made of three years (2001-2004) of cross-shore profiling of a low-lying barrier downdrift of a migrating tidal inlet. Offshore wave data and tidal data were also analysed. The two main objectives of this work were: (1) understand the relative role of the principal processes conditioning the barrier dynamics, and (2) determine the main factors governing overwash sedimentation.

The barrier profiles were partitioned into 3 groups (A, B, and C): Group A was the closest to the tidal inlet and exhibited the widest berms; Group B had the widest washover terraces, the least number of overwash and the most vegetated; and Group C had the more exposed washover crest, the narrower berms and no vegetation. The beach slope was generally reflective and did not have significant variations within the study area.

The studied part of Barreta Island was extremely dynamic during the monitoring period. The morphologic variations resulted from the combination of the swash, overwash, aeolian and lagoon processes. Swash was the dominant process during the monitoring period, inducing 83% of the barrier volume variation. Overwash was the second most dominant, inducing 14% of the barrier volume variation. Aeolian and lagoon processes were relatively less important with 1% and 2% respectively.

There was no marked seasonality in the signal of volume variations induced by swash, but there was seasonality in the magnitude of volume variations (larger in winter than in summer). The arrival and welding of swash bars released from the updrift Ancão Inlet were determinant in explaining the barrier volume variation. This was particularly important to development of the wider berms of Group A (nearest the inlet).

Globally, swash processes induced an almost balanced proportion of accretion and erosion, while overwash was mostly an accretional process. From the total barrier volume accretion of +47 m^3/m, about 88% was due to overwash processes. The landward displacement of washover plain in Groups A and C was mainly due to overwash processes.

The very small importance of aeolian processes observed in this study may not be representative for other barrier islands or other periods. Aeolian processes were identified as very important in the medium- to long-term recovery of washovers, both in other parts of the Ria Formosa and in other barrier systems. Probably, in barriers where overwash is frequent, aeolian processes have a reduced role in barrier dynamics. The events in barrier evolution may therefore be resumed as a sequence composed of three stages: (1) during Stage 1 the geomorphologic changes of the barrier are rapid and dominated by complete overwash that leads to dune destruction and to the formation of a wide and low washover plain; (2) during Stage 2 the washover dynamics is dominated by frequent overwash, including non-storm overwash; and (3) at Stage 3 morphologic changes are slow, overwash is not common, and aeolian processes dominate the washover dynamics promoting dune development and vertical barrier accretion.

To determine the main factors governing overwash sedimentation, the concept of significant overwash sedimentation (OSs=accumulation>5 m^3/m) was introduced to avoid data errors and noise that may bias the analyses. From the 24 surveys that were made for this study, OSs was registered in 8 of them. Except for one case (late summer 2001), OSs occurred during winter periods. When OSs was enhanced by equinoctial tides, the W-SW wave power threshold was about 20,000 $Jm^{-1}s^{-1}$, however during neap tides or regular spring tides, the threshold increased to 50,000 $Jm^{-1}s^{-1}$. Based on the study period, the probability of exceedence of the wave power thresholds was 14% and 4%, respectively for 20,000 $Jm^{-1}s^{-1}$ and 50,000 $Jm^{-1}s^{-1}$.

To determine the main morphologic parameters that controlled OSs, surveys where the oceanographic thresholds were exceeded but not all profiles experienced OSs were selected. To determine which morphologic parameters allowed the correct separation, an analysis was made of: beach volume, beach slope, washover crest height, and washover terrace width. Beach volume (V_b) was the parameter that best explained the occurrence and intensity of OSs. The OSs seems to increase exponentially as the beach volume diminishes. The threshold for the study area, during the monitoring period was V_b<+120 m^3/m. The relations and thresholds found in this study provide information that describes situations not commonly found in the literature. Particularly the study highlights some governing factors like: (1) equinoctial tides lower the wave power threshold for overwash in low-lying barriers; (2) berm development related with tidal inlets swash bars may be a crucial limiting morphologic factor; and (3) the exponential augment in overwash sedimentation with the decrease in beach volume was evidence of the systems resilience to overwash.