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DUNE BUILDING ON THE PENINSULA DO ANCÃO

S.M. Arens, J.H. van Boxel, R.M.K. Haring
University of Amsterdam
Institute for Biodiversity and Ecosystem Dynamics
Physical Geography
Nieuwe Achtergracht 166
1018 WV Amsterdam
The Netherlands

Introduction

Barrier systems are dynamic features, of which the top surfaces are usually shaped under the action of overwash and aeolian processes (e.g. Otvos, 2000). Dunes are more or less developed, depending on inlet migration rates, vegetation characteristics and wind energy,

Within the framework of a large project on inlet dynamics in a barrier system in the Algarve region (O'Connor et al., 1999, Williams et al. 1999) a field study was performed on the aeolian dynamics of beach and dune on the barrier ridge. Goal of this study was to investigate the aeolian part of the sediment budget of the system and to measure the dynamics of the system through detailed field measurements. This paper reports about the aeolian dynamics of the dunes on one of the barrier ridges, the peninsula do Ancão.

Study area

The study area is situated on the peninsula do Ancão, about 200 m northwest of the new Ancão inlet (Vila et al., 1999). The peninsula do Ancão is the most westerly barrier in the barrier system of the Ria Formosa, in the Algarve, southern Portugal (Pilkey et al., 1989, Vila et al., 1999, Gomes et al., 1994).

The site is south-westerly exposed, and characterised by a steep and narrow reflective beach bordered by low, hummocky dunes that are partly vegetated (Figure 1). The beach is very dynamic in time (Balouin and Howa, in prep.). Dune height ranges between 1 and 5 m above the high tide mark. Especially the higher dunes are vegetated with Artemisia Campestris, Medicago Maritima and Crucianella Maritima. Grasses like Ammophila Arenaria and Elymus Farctus are only present in very small percentages. Vegetation cover ranges between 5 and 25 %, with clustering of plants. On beach and dunes, the sand bed is usually dry and loose, also because of disturbance by trespassers. Crusts, due to the strong evaporation rates, are rarely observed. On the beach, the sand is locally very coarse (> 1 mm). Grain-size at the upper part of the beach and in the dunes averages 350 mm. At the back of the dunes some fishermen houses are located. Due to trespassing, some minor tracks have been developing. Figures 1 and 2 gives an impression of the site.

Methods

Detailed measurements of sand transport and meteorology were performed over a 3-month period, from 12-01-1999 to 28-03-1999. Figure 2 shows the meteorological mast on the dune crest. Omnidirectional sand traps (Arens and Van der Lee, 1995) were placed in an array on the beach and the dune, to measure transport gradients. Saltiphones (Spaan and van den Abeele, 1991; Arens, 1996) were installed on the beach and near the dunefoot to measure intensity of transport. Erosion pins were placed in a grid over the dunes to measure height changes as a result of sand transport. The dune profile was measured with a total station. Wind speed and direction at the site were measured in two masts, one at the dunefoot and the other on the crest (Figures 1 and 2). Wind speeds were measured at 0.7,1.2,2.2 and 4.2 m above the surface. Temperature and relative air humidity were measured in the crest mast at a height of 1.5 m above the surface. Due to instrument failure, only remote rainfall data are available, measured by the Portuguese Meteorological Office at Faro airport, as daily totals. Also wind speeds and direction were recorded in a video mast (Morris et al., 2000) at the island of Barreta. Here, wind speeds were measured at a height of 10, 13 and 20 m, direction was measured at 10 m. At this height, the wind profile still is adapted to the open ocean. Therefore, these measurements are used to estimate the upstream wind velocity, which is not yet adapted to the changing surface. During some events wind profiles were measured on the beach, with cupanemometers at heights of 0.25, 0.50, 1.0, 2.0 and 4.0 m.

In order to estimate the total amount of sediment that was trapped in the foredunes during the measuring period, both results of erosion pins, sand traps and saltiphones are used. Ideally, the amount of sediment stored in the dunes should be measured by means of profile measurements at different time intervals. However, the actual change in height over the dune was too limited to be recorded in this way. Actual changes were a few centimetres locally, on average in the order of millimetres. These changes are in the order of measurement errors, in case of height recordings with levelling equipment.

An estimate of deposition caused by a major storm event prior to the fieldwork was based on burial of vegetation by aeolian deposition.

Results

characterisation of the aeolian system / winds

The aeolian system in the Algarve is characterised by a bi-modal wind regime, with clear westerly and easterly peaks. Figure 3 depicts several wind roses. Figure 3a shows the wind rose for long term data, between 1973 and 1993 (FCCA, 1995). Figure 3b shows the wind rose for the period July 1997 to March 2000. There are some differences between 3a and 3b. Between 1973 and 1993 the western peak is straight from the west, while between 1997 and 2000 this peak has shifted slightly to west-southwest. A wind rose of the fieldwork data is shown in Figure 3c. The wind speeds per class are different, because wind speeds at Ancão are higher than at Faro Airport (see paper “COMPARISON OF WIND MEASURED AT FARO AIRPORT AND AT PENINSULA DO ANCÃO”). During the fieldwork the percentage of south-southwesterly winds is higher than average, and the number of very strong winds is lower (Table 1). Note that at the field site westerly winds blow onshore, while easterly winds blow offshore. Strongest winds blow from westerly or southwesterly direction and are onshore.

Table 1. Number of hours with average wind speed in the period July 1997 – March 2000 and for the fieldwork period (January-March 1999).

	1997-2000		**Jan-Mar 1999**
wind speed Faro Airport (m/s)	**number of hours**	**wind speed Ancão (m/s)**	**number of hours**
0-4	13815	0-4.5	1325
4-6	4176	4.5-7.2	292
6-8	1871	7.2-10.0	123
8-10	583	10.0-12.7	29
10-12	106	12.7-15.5	0
12-15	27	15.5-19.6	0
15-20	4	19.6-26.4	0
>20	1	>26.4	0

Wind speeds above the threshold for aeolian transport (about 6 m/s: saltiphone data; see section below) are much less frequent than wind speeds below. Storms with wind speeds higher than 10 m/s are rare. Wind speeds during gusts can be high but are not frequent, even during storm periods. Storm duration during sand transport events ranged between 5 and 12 hours during daytime, apparently related to the daily wind cycle.

Prior to the fieldwork, a violent storm occurred from the southwest with wind speeds up to 23.9 m/s (hourly average at 10 m high at Faro airport, data derived from Portuguese Meteorological Office). This storm event resulted in considerable aeolian sand transport, with complete burial of vegetation and transfer of sand over the beach ridge into the lagoon. The frequency of such storms is small. This was the only major storm event in the period of June 1997 to December 1999. Storms with wind speeds higher than 20 m/s (hourly averages) occurred 5 times between 1986 and 1993 (FCCA, 1995) of which only 3 were onshore, and no reference to such wind speeds between 1973 and 1986. On average, one major storm event occurs every 2-3 year.

Wind speeds at Faro airport and at the site are moderately well correlated. The regression coefficient R^2 for all data (hourly averages) is 0.74, but there is a dependency on wind direction. Worst correlation is for winds from north to northeast (offshore, R^2=0.57), and best correlation is for winds from the east to southeast (offshore, R^2=0.91). Regression coefficients for onshore winds ranged from 0.60 to 0.91. For a detailed discussion on the correlation between local and remote wind data, we refer to the paper “COMPARISON OF WIND MEASURED AT FARO AIRPORT AND AT PENINSULA DO ANCÃO”.

Roughness length for the beach was calculated using linear regression through wind speeds measured at 0.25, 0.5 and 1.0 m height. Figure 4 shows some typical wind profiles measured on the beach. Most profiles show a kink between 1 and 2 m height. Based on the lowest wind speed measurements, the derived roughness lengths ranged from $2.1*10^{-5}$ to $2.8*10^{-3}$ for 26 half hourly wind profiles (wind speed at 1 m height > 4 m/s). This variation is partly related to stability effects. The smallest roughness lengths are for profiles measured between 13 and 15.30 hr. Arens *et al*. (1995) showed that roughness lengths measured during day time often were too low, due to stability effects.

The influence of local topography on wind speed-up is demonstrated by Figure 5. Relative wind speeds indicate speed-up as related to wind directions (Arens *et al.*, 1995). In Figure 5 wind speeds measured at a height near the dune crest are divided by wind speeds measured at the dune foot at the same height. As wind direction changes, the effect of topography on the wind profile also changes. During parallel winds, the profiles are most adapted to the surface (beach, dune), whereas during onshore or offshore winds, the profiles are disturbed by changes in topography. This is reflected in a lower wind speed at the dune crest than at the dune foot during parallel winds (relative wind speed < 1) and a higher wind speed during onshore and offshore winds (relative wind speed > 1). The topography also influences the direction of the air flow. Due to the presence of the dune the flow is deflected. Figure 6 shows the difference in wind direction measured at the dunefoot and the dune crest versus the wind direction measured at the crest. The maximum difference is about 10º with oblique offshore winds (80º). Comparison of beach wind speeds with dune crest wind speeds reveals that during onshore conditions winds close to the surface are only slightly accelerated while during oblique onshore and parallel winds, the speed on the beach is higher than the speed on the dune crest at the same height. This indicates that wind speeds are stronger influenced by surface roughness than by topography.

measurements of events / sand transport

During the field work there occurred several events during which sand transport was observed. During some of these events wind direction was onshore, and sand was transport from the beach over the dune profile. Table 2 gives some information on the aeolian events.

Table 2. Events with aeolian transport.

event	remarks	sand traps	saltiphone	maximum wind speed	maximum 10 min average wind speed	wind direction	rain at site	daily rainfall (mm) Faro
21-1-99	aeolian transport during showers	-	-	20.2	12.9	193-238	Y	17
1-2-99	few sand grains in traps	-	-	9.1	6.9	61-67	N	0
2-2-99	aeolian transport near the inlet	-	-	11.1	7.7	60-80	N	0
6-2-99	very slight saltation at the beach	-	-	10.5	8.7	250-270	N	0
9-2-99	heavy transport, first during showers, later without rain, transport over dune	B/D	B/D	14.6	11.9	257-285	Y	0
24-2-99	transport, first during parallel, later during onshore winds. In the afternoon with showers. Heavy transport during the night	B/D	D	20.0	12.0	252-310	Y	0
3-3-99	sand transport over dune during dry conditions, at the end of the afternoon also with showers	B/D	B/D	14.9	12.1	243-264	Y	0
4-3-99	very slight saltation	B/D	B/D	12.5	8.5	286-315	N	0
9-3-99	very slight saltation at the end of the afternoon		B/D	12.3	8.9	190-205	Y	0
10-3-99	slight saltation, severe showers		(B)/D	15.5	9.3	186-240	Y ++	1
11-3-99	strong wind and showers		(D)	18.9	13.4	180-250	Y ++	23
12-3-99	very heavy showers		(D)	18.5	13.3	155-200	Y ++	10
13-3-99	slight saltation, several showers	B/D	(D)	20.7	10.3	85-186	Y ++	16
23-3-99	transport during offshore winds, later during parallel winds with slight showers	B	B/D	16.4	12.1	67-130	N	0
25-3-99	transport before rain		B/D	13.0	10.4	249-276	Y	6
26-3-99	ripples on beach from W, sand deposited on coarse sand zone		B/D	12.1	9.0	290-330	N	0
27-3-99			B/D	13.3	10.7	265-310	N	0

Measurements with the saltiphone give insight in transport intensity. Figure 7 contains results for a number of days with transport. The intensity is clearly related to the wind speed, but there are important differences between days. The threshold for transport is variable. Threshold velocity on the beach ranges between 5.5 and 10 m/s (wind speed at the crest at 4.2 m height). Results for dune foot and beach are comparable. Figure 7 shows good correlation between the two measurements. Correlation is bad for 12 March, probably due to measuring problems caused by rain, and for 23 March, when during parallel winds transport near the dunefoot is much lower than on the beach.

Figure 8 illustrates the effect of wind direction on the saltiphone counts. All data are presented. It is clear that for parallel winds transport is larger than during onshore winds with the same speed. During onshore winds the fetch over the beach is limited and the saltation cloud is not fully developed. Although the number of data is limited, there is some vague evidence of correlation between air humidity and transport intensity. Figure 9 demonstrates that onshore winds are much more humid than offshore winds. For onshore winds we find the strongest effect of humidity on transport. In Figure 10 clearly the transport curve shifts to the right (higher threshold) for higher levels of air humidity. The shape of the curve remains constant. For other wind directions the relationship is not clear, or not existent. Probably the effect of fetch overrules a humidity effect.

Figure 11 illustrates the sediment curves for sand trapped at several locations on the dune profile, the 9th of February 1999. Transport rates increase from the beach to the dune toe and than sharply decrease. By integrating the sediment curves over height, the total transport at a certain point is calculated and the gradient in transport over the dune profile is derived. In Figure 12 those gradients are plotted for all days when transport was measured with sand traps. Of these days 23 March are with parallel winds, the rest is mostly with onshore winds. All measurements indicate a decline in transport to virtually nothing when the flow passes the dune crest.

Changes in height were recorded with erosion pins. The observed changes were very small: at the end of the field work the average change in row 1 was 1.2 cm, 2.4 cm for row 2 and 1.4 cm for row 3. For the rest of the rows the change was less than 1 cm. When we assume that the average change per row are representative for the whole area around a row, we can calculate the net input in that area, and by totalising the results for all rows, we can estimate the net input in the total dune area. Results are presented in Figure 13. Only results after 03-02-1999 are shown. Before that time most calculations indicated a negative input, which is hard to believe. Wind erosion during offshore winds was never observed, neither was there any indication of erosion during onshore or parallel winds. Because of the small changes, which are mostly in the range of measurement errors, there is some doubt about the results of the erosion pins. Despite this, the results are in the same order as the other transport calculations (Table 4).

By means of saltiphone and sand trap measurements we have calculated the total input of sand into the dunes for a number of days. The number of saltiphone counts can be related to mass transport, when this is compared to the trapped amount of sand during an interval of time. All saltiphone counts are integrated over the period that a trap was collecting sand. The total number of saltiphone counts divided by the total amount trapped gives the ratio to convert saltiphone counts to mass transport (equation 1). These ratios are given in Table 3. It appears that it is not constant, but changes even during a day.

$$R_{counts-to-mass} = \frac{I_{saltiphone}}{q_{sandtraps}} \tag{1}$$

with:

$I_{saltiphone}$ = number of counts for a period
$q_{sandtraps}$ = mass transport during the same period (kg/m)

Application of the ratio makes it possible to estimate total transport during an event, by dividing saltiphone counts per 10 minute period by the ratio for that period. Totalising of all 10 minute transports yields the total transport for the event:

$$\sum_{i=1}^{n} I_{saltiphone\_n} R_{counts-to-mass\_n} \tag{2}$$

with

$I_{saltiphone\_n}$ = saltiphone counts for 10 minute period n
$R_{counts-to-mass\_n}$ = ratio for 10 minute period n

Table 3. Ratio of the total number of grain counts for a certain period, divided by the total amount of sand trapped during that same period.

date	time	ratio	ratio	used for calculations
09-02-99 14:06	09-02-99 14:27	5.86	5.27	13:00-15:10
09-02-99 15:09	09-02-99 15:39	3.67	3.62	15:20-16:30
09-02-99 16:28	09-02-99 16:58	2.31	3.04	16:40-21:10
24-02-99 14:05	24-02-99 18:12	-	1.16	13:20-18:50
24-02-99 19:20	25-02-99 08:30	-	0.66	19:00-19:50
03-03-99 11:50	03-03-99 14:55	2.23	1.68	11:50-14:30
03-03-99 14:55	03-03-99 15:40	2.54	2.29	14:40-15:40
03-03-99 15:45	03-03-99 19:23	4.16	4.65	15:50-18:30
03-03-99 19:23	04-03-99 09:25	0.53	0.11	18:30-20:00
04-03-99 14:35	05-03-99 11:40	0.01	0.04	9:30-20:10
23-03-9916:10	23-03-9917:20	2.52	0.09	23-03 to 26-03

In fact this is an estimation of the total transport on the beach. By assuming that all this sand is stored in the dunes (at least for onshore or oblique onshore winds) we can calculate the sediment budget for the dunes. Every 10 minute transport must than be multiplied by the cosine of the wind direction during that period:

$$\sum_{i=1}^{n} I_{saltiphone\_n} R_{counts-to-mass\_n} \left|\cos\left[dd_n - 225\right]\right| \qquad (3)$$

with
dd_n - 225 = wind direction relative to the normal (225 is onshore).

We call this the “measured” transport to the dunes. To compare the “measured” transport with potential transport rates, we have applied the transport equation of Kawamura (Kawamura, 1951) to all 10 minute periods:

$$q = 600\ C_K \frac{\rho}{g}(U_* - U_{*_t})(U_* + U_{*_t})^2 \qquad (4)$$

with:
q = transport in kg.m^{-1}.10min^{-1}
C_K = constant in Kawamura’s equation
ρ = air density (1.22 kg/m^3)
g = gravity (9.81 m/s^2)
U_* = friction velocity (m/s)
U_{*_t} = threshold friction velocity (m/s)

Since potential transports are usually much higher than actual transport, we have fitted a Kawamura like equation with the “measured” transport totals.
The equation is:

$$q = \frac{C_{emp} * (U_{Ancao\_4.2m} - U_t) * (U_{Ancao\_4.2m} + U_t)^2}{\eta / 100 * W * 1000} \qquad (5)$$

with:
C_{emp} = constant (kg^{1}s^{3}m^{-3}10min^{-1})
$U_{ancao\_4.2m}$ = wind speed at Ancão dune crest at 4.2 m (m.s^{-1})
U_t = local threshold velocity (m.s^{-1})
η = Efficiency of sand trap (15%)
W = Effective trapping width of sand trap (0.1 m)

By assuming that total transport for an event with the empirical equation should equal the total “measured” transport, we optimised the equation by varying the values of C_{emp} and U_t. Values of respectively 0.12 and 6.8 gave the best results.

$$q = \frac{0.12 * (U_{Ancao\_4.2m} - 6.8) * (U_{Ancao\_4.2m} + 6.8)^2}{0.15 * 0.1 * 1000} \text{ in kg.m}^{-1}\text{.10min}^{-1} \qquad (6)$$

This equation can be used to make estimations of sediment transport over a longer time period, using wind data from Faro Airport. In this paper we will concentrate on the variation of 10 minute transports. For an extensive discussion on potential and actual sediment budgets, we refer to the paper “AEOLIAN SEDIMENT BUDGET OF THE DUNES OF THE PENINSULA DO ANCÃO”.

Table 4. Sediment budgets for days with aeolian events; predicted and measured.

date	Kawamura $m^3m^{-1}.day^{-1}$	Empirical $m^3m^{-1}.day^{-1}$	“measured” $m^3m^{-1}.day^{-1}$	erosion pins $m^3m^{-1}.day^{-1}$	rain (mm)
31-12-98	9.98	2.46	8.25	?	2
9-2-99	0.78	0.16	0.16	0.22	0
24-2-99	0.32	0.09	0.02	-0.14	0
3-3-99	0.68	0.16	0.12	0.34	0
4-3-99	0.28	0.01	0.01	-0.25	0
10-3-99	0.51	0.10	0.00	0.60	1
11-3-99	0.61	0.12	0.05		23
12-3-99	1.15	0.39	0.04		10
13-3-99	0.13	0.05	0+		16
23-3-99	0.00	0.00	0.00	-0.12	0
24-3-99	0.19	0.02	0.00		0.1
25-3-99	0.57	0.09	0.09	0.05	6
26-3-99	0.29	0.01	0.01		0
27-3-99	0.32	0.06	0.00	0.06	0
Total	15.52	3.66	8.75	?	-
Total 1999	5.53	1.20	0.50	0.65	-

Figure 14 displays sand trap determined transport, “measured” and empirically predicted transport (all left-axis) and potential transport (right-axis) for 6 events in February and March 1999 for all 10 minute periods. For most of the time, potential transport is 2 times higher or more than the “measured” transport, but there are a few 10 minute periods where the “measured” transport equals the potential transport (03-03 14:20, 23-03, 25-03 15:00). Often this is during parallel winds, but in some cases also during onshore winds (3-3-99). Apparently it is very rare that conditions are optimal for aeolian sand transport (see also paper “AEOLIAN SAND TRANSPORT EVENTS ON THE PENINSULA DO ANCÃO”). Although the empirical equation yields good results for the total duration of an event, it is clear from Figure 14 that is does not accurately reproduces the transport at a time scale of 10 minutes. Especially it does not predict at which periods with high wind speeds <u>no</u> transport occurs, which is the problem of all transport equations. There are too much factors that limit transport and are not quantified yet.

We have made an estimate of the duneward transport during the storm of 31-12-1998. During this storm, most of the vegetation was buried. Figure 15 shows photographs of the site before and after the storm. These photographs prove that most of the vegetation was buried by deposition. The average vegetation height is about 20 cm. By estimating the extent of the burial and the height of the deposition, we could make a rough guess of the total deposition. Assuming an extent of total burial of 55 m and a deposition depth of 0.15 m, the total deposition per m width amounts $55*0.15*1=8.25$ m^3. If we assume a variation of deposition depth of 0.10 to 0.20 m, and an extent of the deposition zone of 30 to 60 m, the total deposition should be between $30*0.1*1$ and $60*0.2*1$, or 3 and 12 m^3.

We assume that all deposition is aeolian. Wave height during the storm was not very high (O. Ferreira, personal communication) and the height of the dune is such that overwash is very unlikely at this site. Figure 16 shows that deposition occurred also on higher parts against buildings, which proves that sand was transported in a suspension cloud. Therefore we believe that the evidence of deposition in Figure 15 is of aeolian origin.

To compare the total transport during the measured events and the deposition produced by the storm of 31-12-1998, we totalised the input during all events, and calculated the relative contribution of all events to the total input. The results are presented in Figure 17. Without doubt we can state that the storm of 31-12-1998 produced almost the total aeolian input in the system. Although we measured some transport during the events in February and March 1999, their input is insignificant when compared to the input after the 31-12-1998 event.

Conclusions and discussion

Dune building during the fieldwork was limited. The estimated input in the dunes amounts 0.5 m^3m^{-1} for the period between 16-01-1999 and 28-03-1999. For 14 events the input could be calculated. Of these 14, only 4 events contributed to the dunebuilding with inputs of around 0.1 m^3m^{-1} or more. Estimates of the transport during a storm event on the 31st of December 1998, prior to the field work, indicate that dune building is driven by extreme events. During this storm, most of the vegetation was buried due to aeolian transport, with an estimated input of around 8 m^3m^{-1}. The frequency of these storms is very low, about once in 3 years. In contrast to other dune systems, like those in the Netherlands, dune building in the Algarve seems to be related to high magnitude, low frequency events.

Comparison of transport measurements and calculation of potential transport learns that only during very short time periods the actual transport equals the potential transport. For most of the time actual transport is much lower. This is partly related to the small and steep beach and therefore the limited fetch, partly to unfavourable conditions for transport and partly to the lack of sand available for aeolian transport.

Storage of aeolian sand in the dunes occurs over a large part of the profile. The present vegetation grows very slowly. Because of its limited height, it can be completely buried during strong transport events. After burial it is not able to catch more sand, and transport can continue further landwards. This results in a typical dune morphology, which is very much different from dunes that grow in marram grass.

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Figures

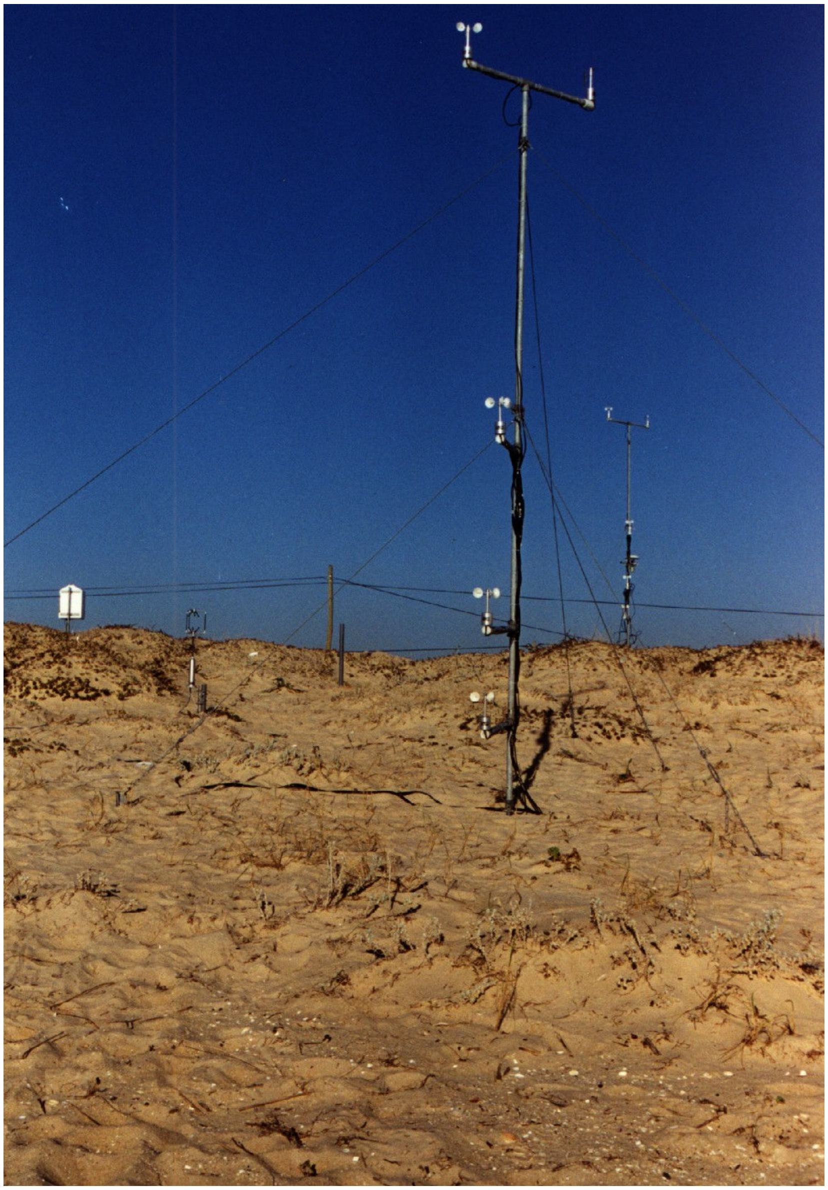


Figure 1. Impression of the aeolian field site with meteorological equipment.

Figure 2. The dune crest with typical vegetation cover and mast with cupanemometers, wind vane and psychrometer.

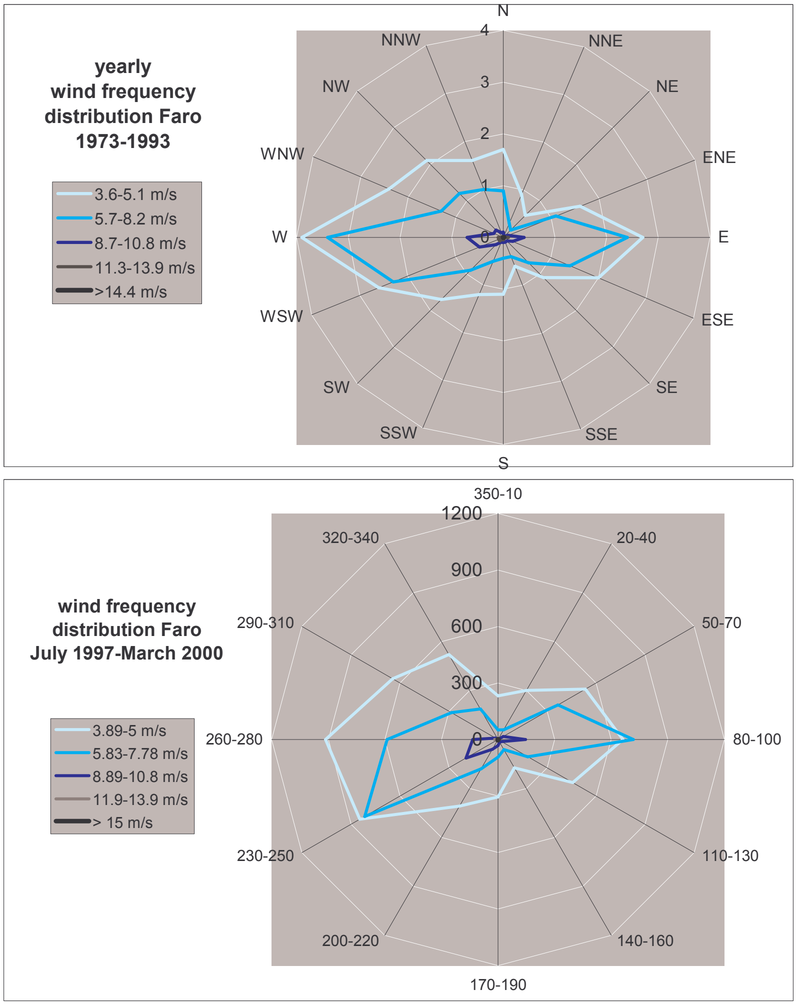


Figure 3a&b. Wind roses for Faro Airport, 1973-1993 (above, data in percent of total) and 1997-2000 (below, data in number of hours).

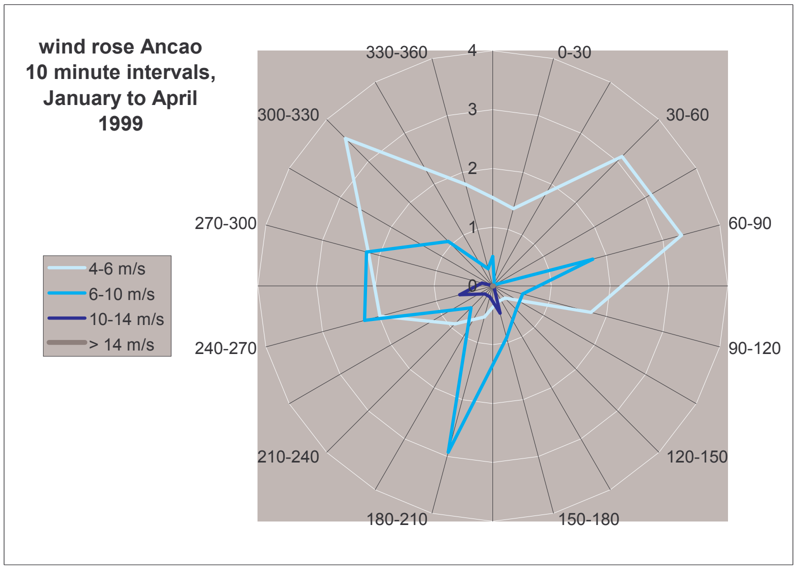


Figure 3c. Wind rose for Ancão, January-March 1999, data in percent of total.

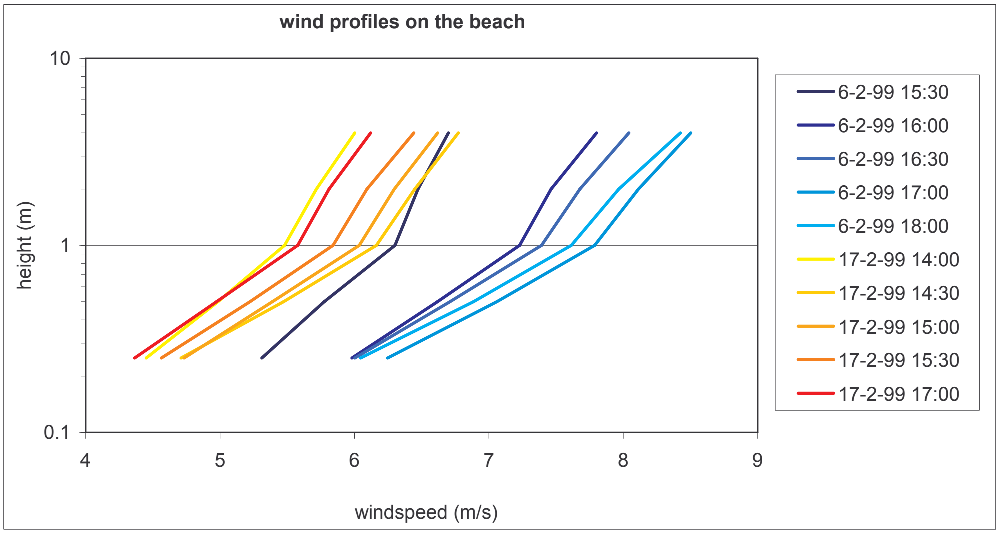


Figure 4. Some wind profiles measured on the beach.

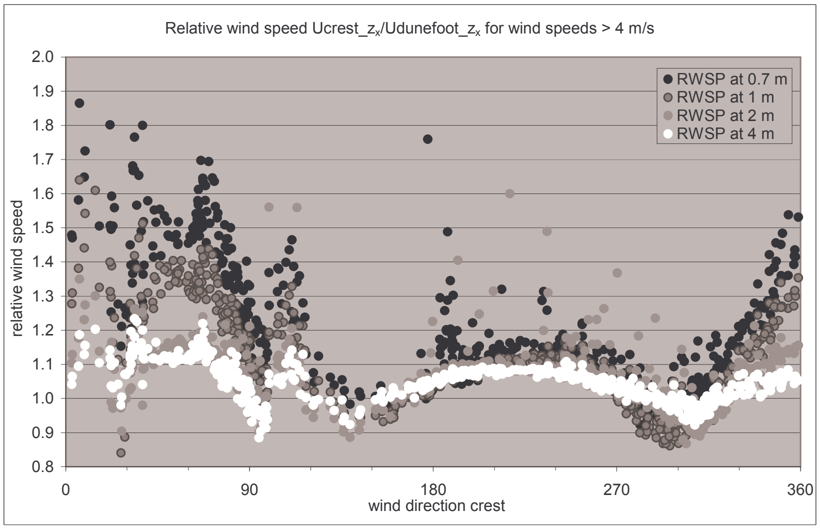


Figure 5. Relative wind speeds at Ancão: comparison of wind speeds at dune crest and dunefoot. 225 degrees is onshore, 45 degrees is offshore.

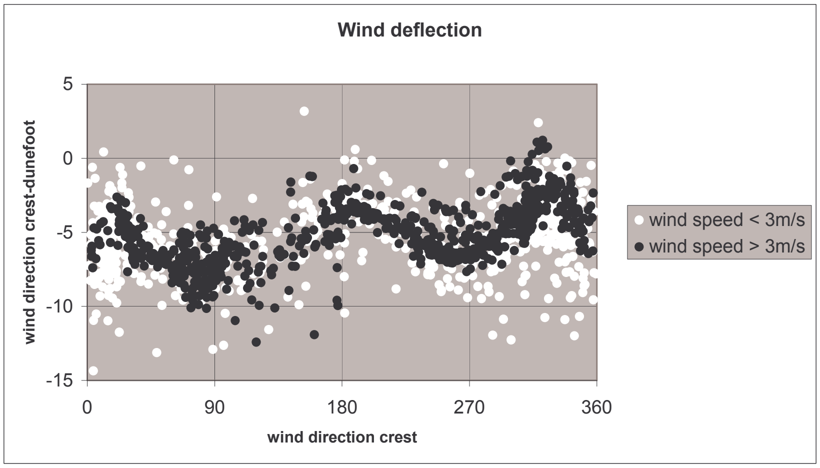


Figure 6. Difference in wind direction measured at the dunefoot and at the crest for wind speeds above and below 3 m/s.

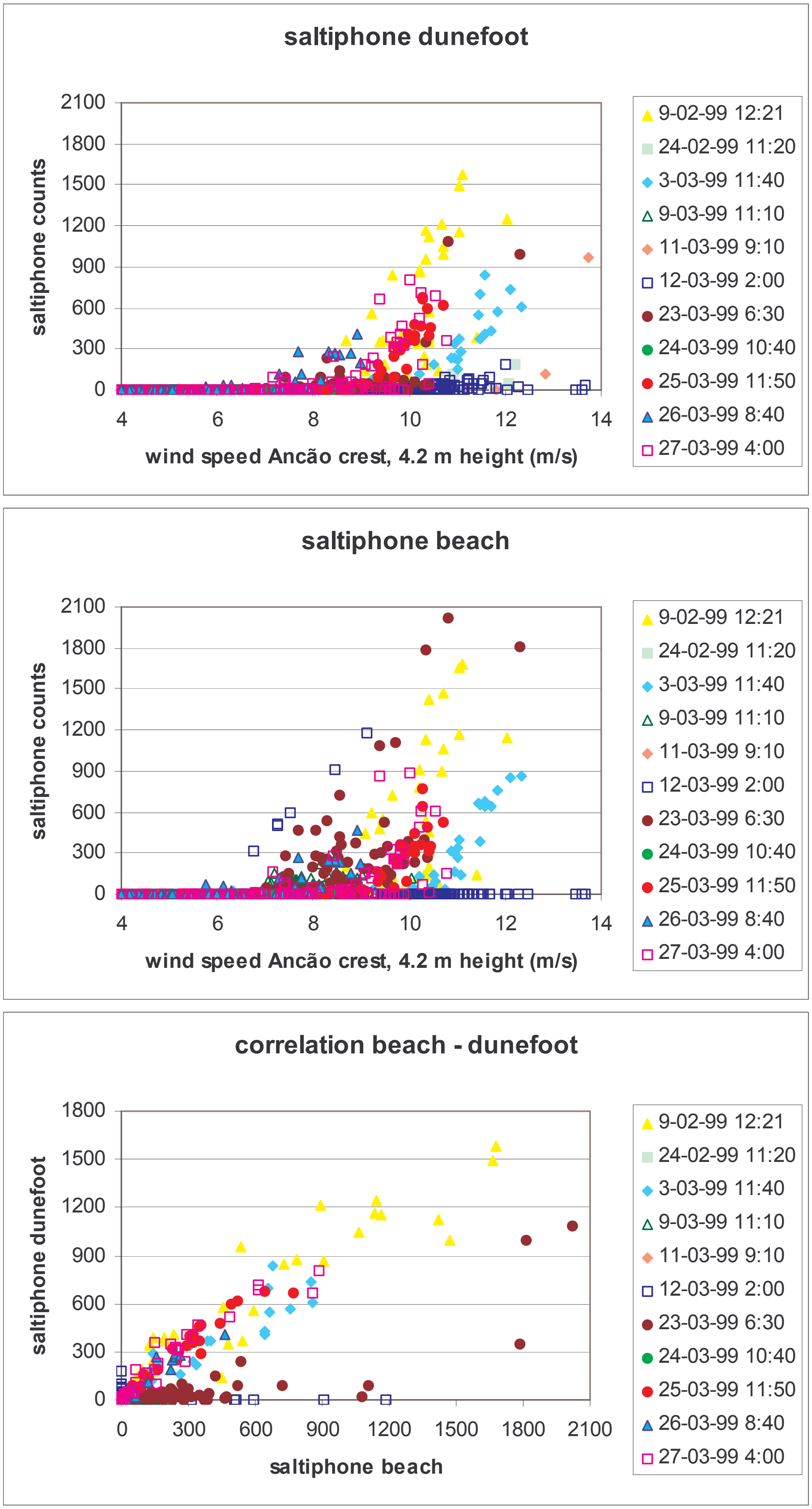


Figure 7. Saltiphone counts for several days at beach and dunefoot, and correlation between dunefoot and beach measurements (below).

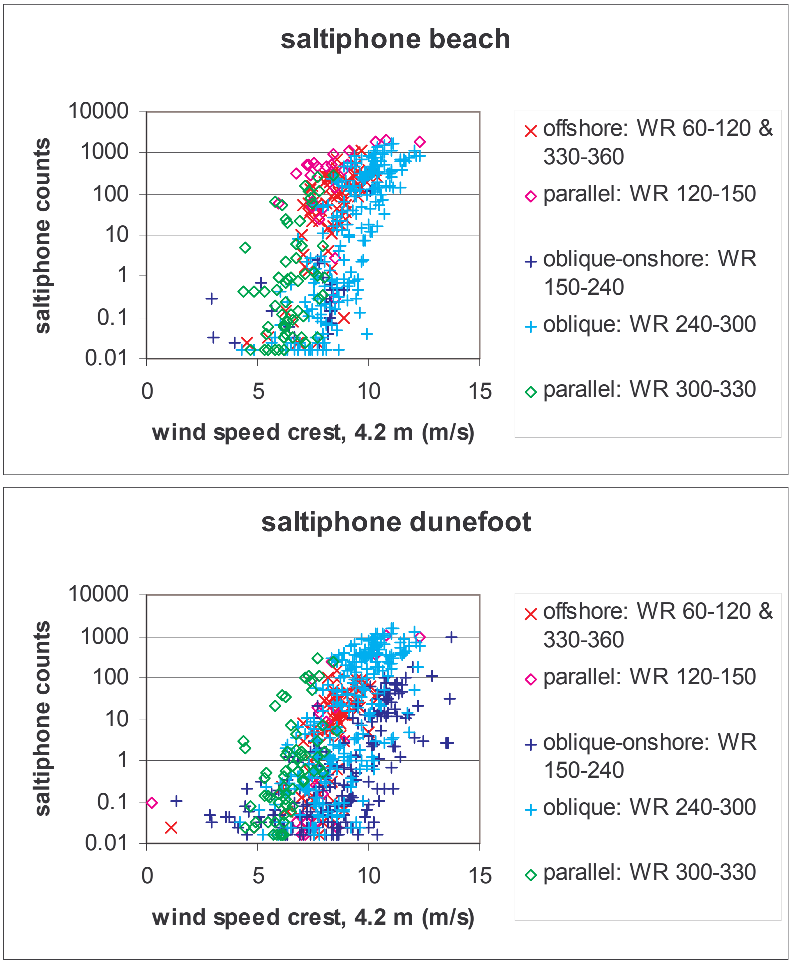


Figure 8. Effect of wind direction on saltiphone counts, for beach and dunefoot.

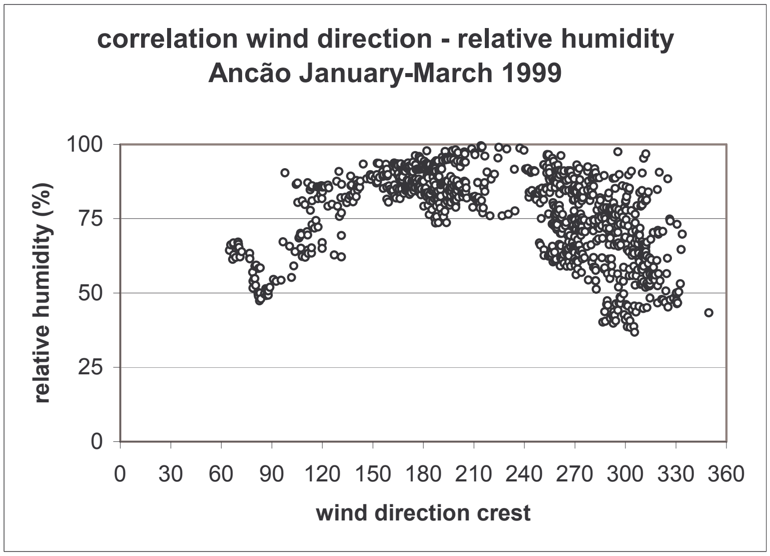


Figure 9. Relationship between wind direction and relative humidity.

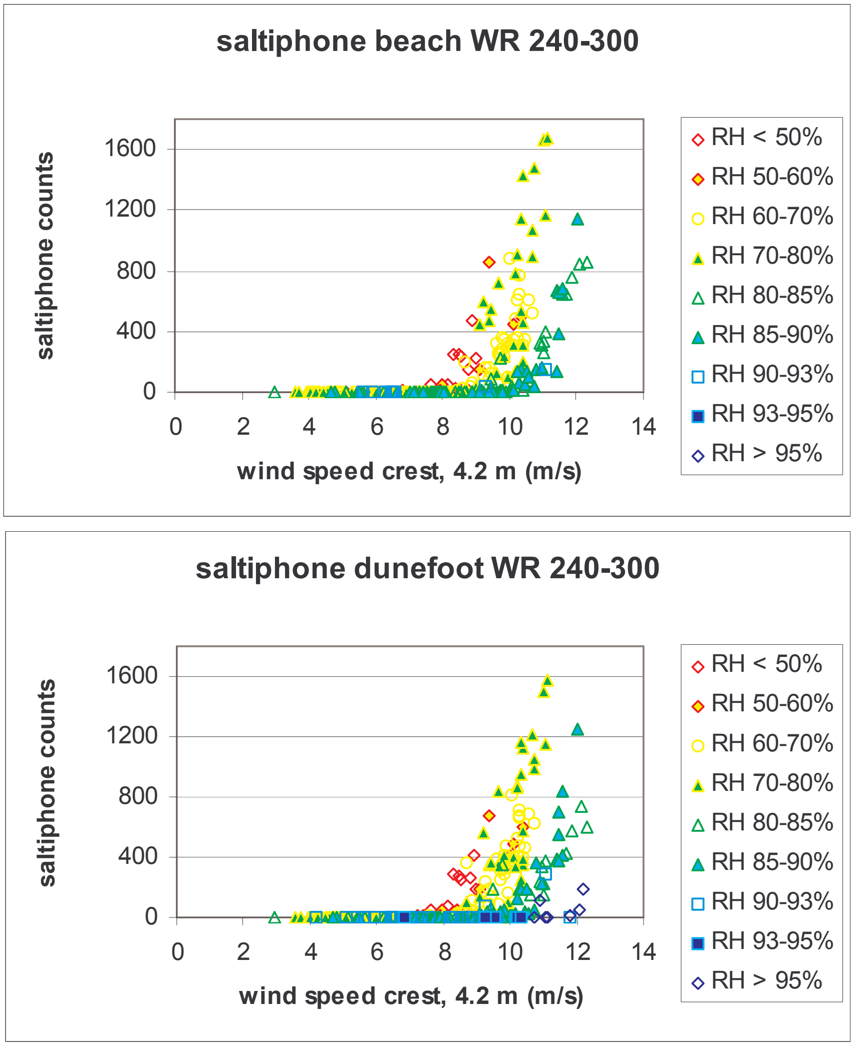


Figure 10. Effect of relative humidity on saltiphone counts for (oblique) onshore winds.

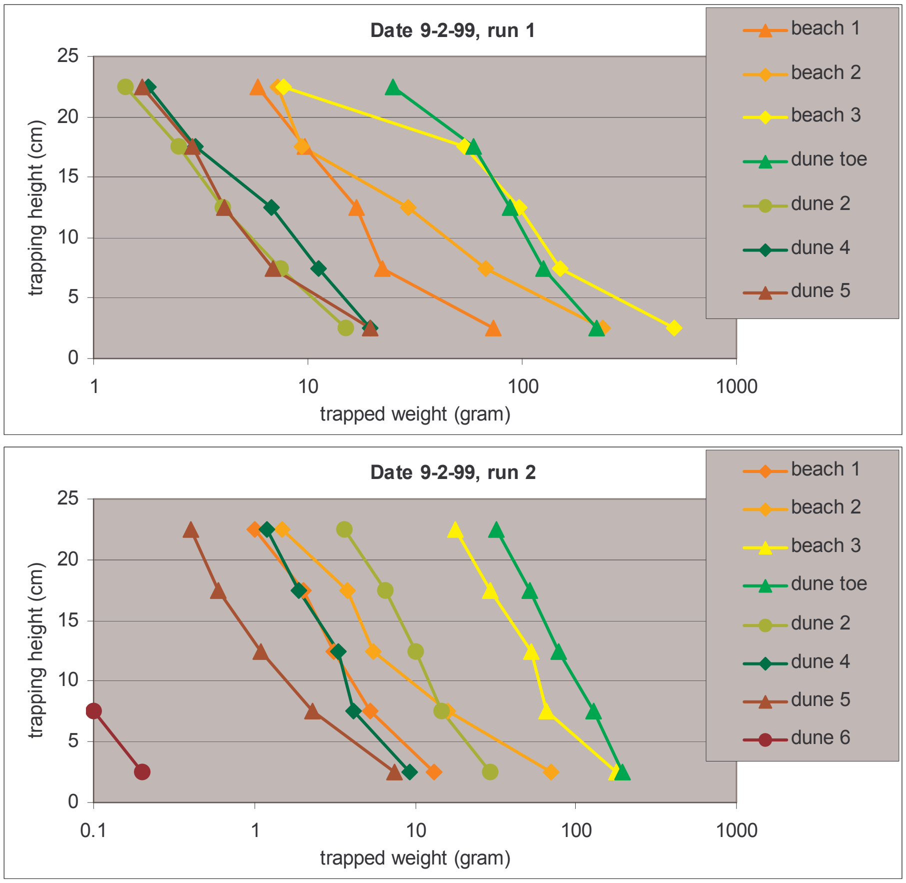


Figure 11. Results of sand trap measurements for two runs February 9th 1999.

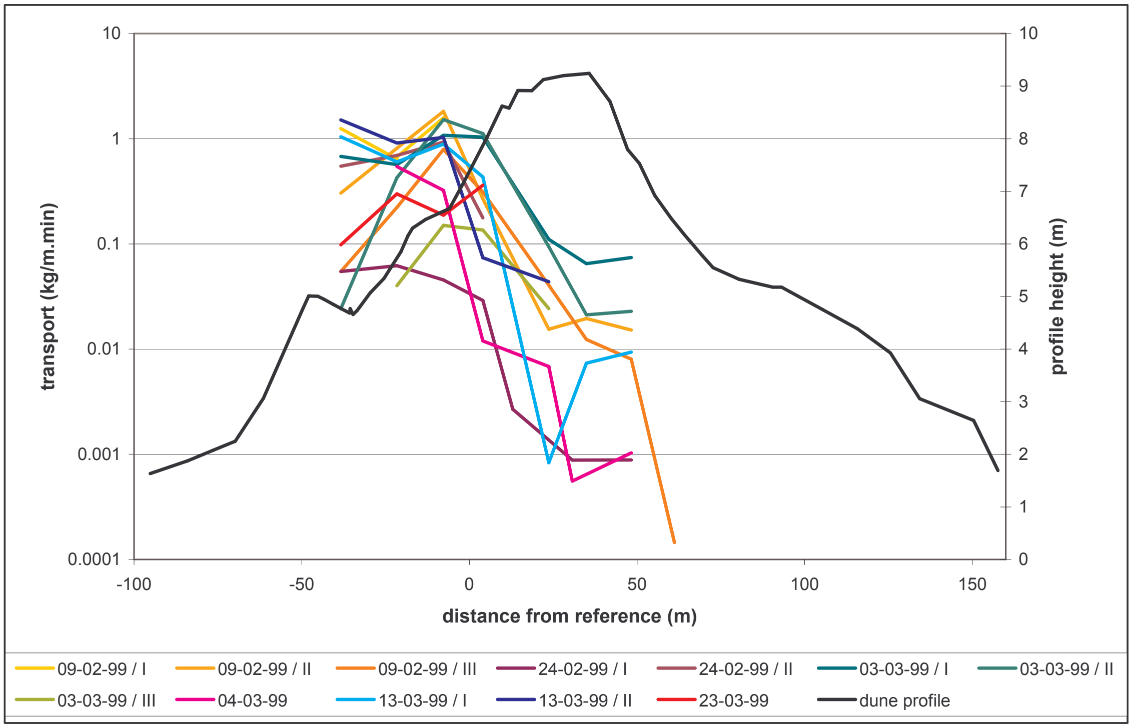


Figure 12. Sand flux over the dune profile measured with sand traps for several days in February and March 1999.

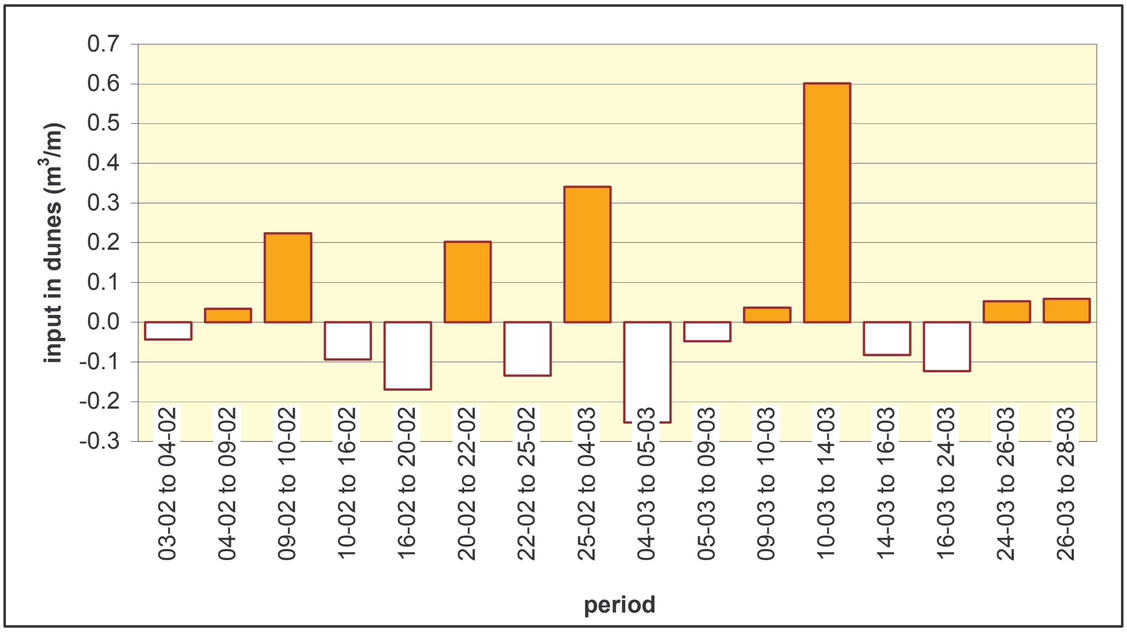


Figure 13. Net input into the dunes measured with erosion pins for a number of periods.

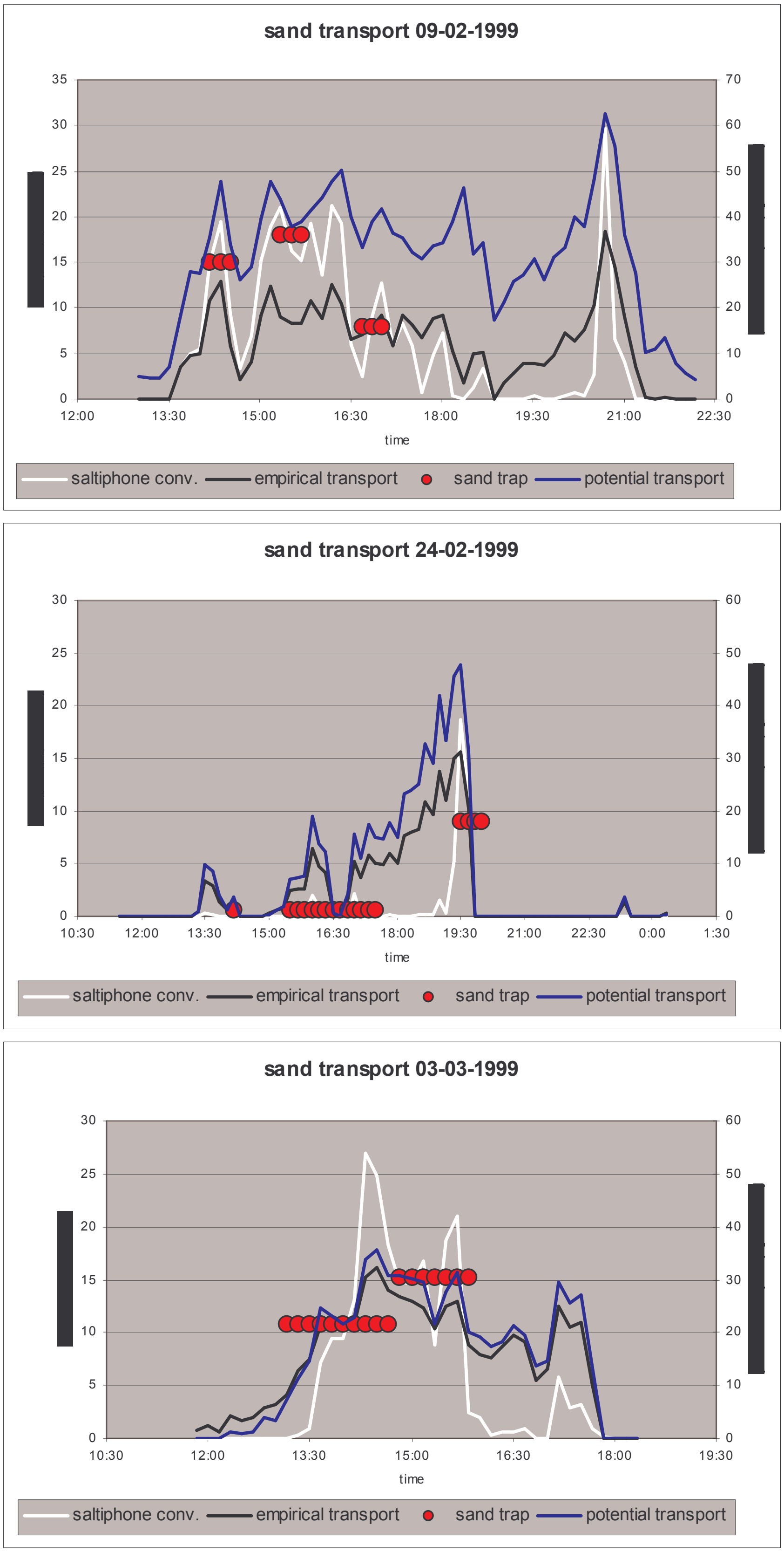
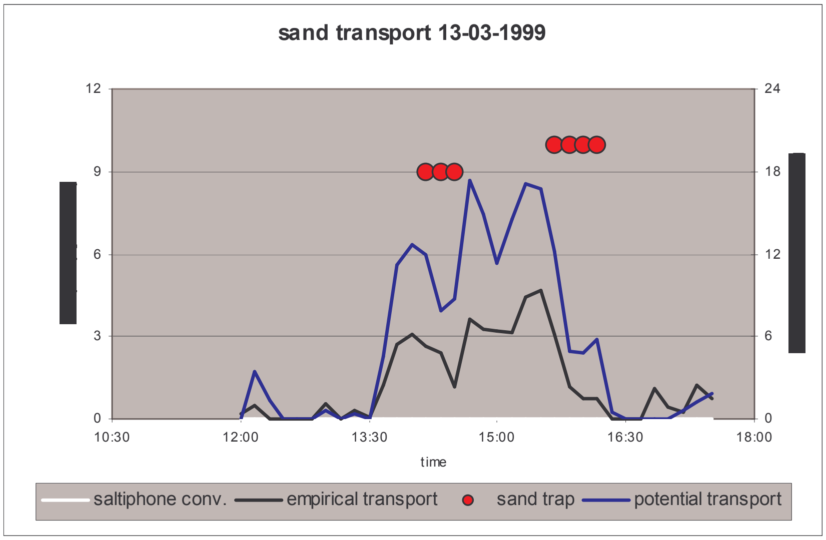
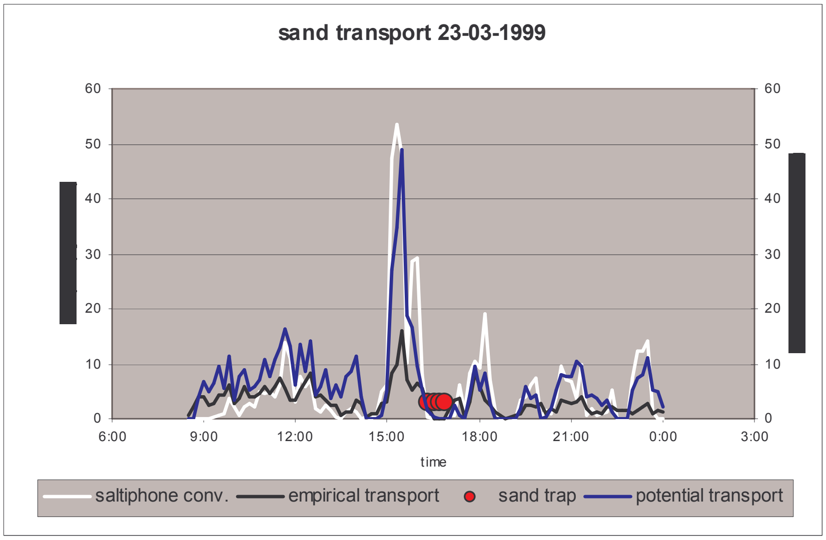


Figure 14. Measured, estimated and potential transport rates for some days with aeolian transport.





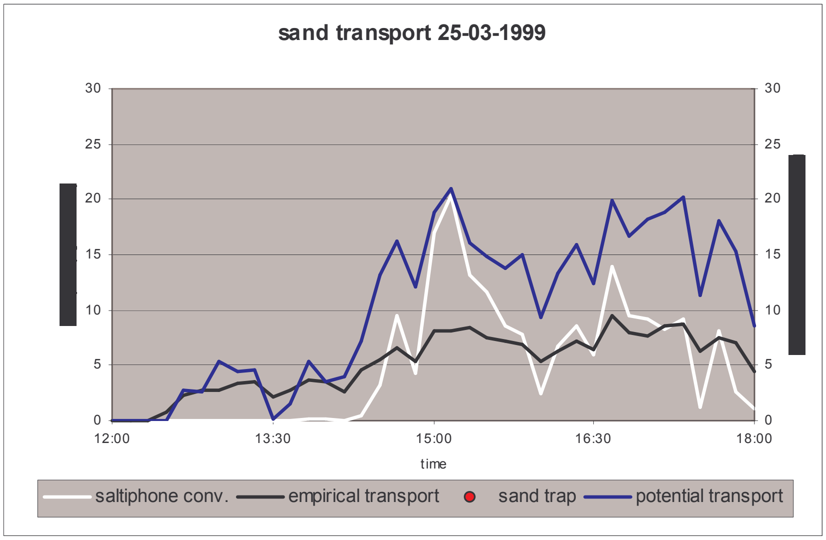


Figure 14 Continued.

Figure 15. The dune crest at Ancão before (above, November 1998) and after (below, January 1999) the storm of 31-12-1998.

Figure 16. Traces of sand moving in suspension after the storm of 31-12-1998.

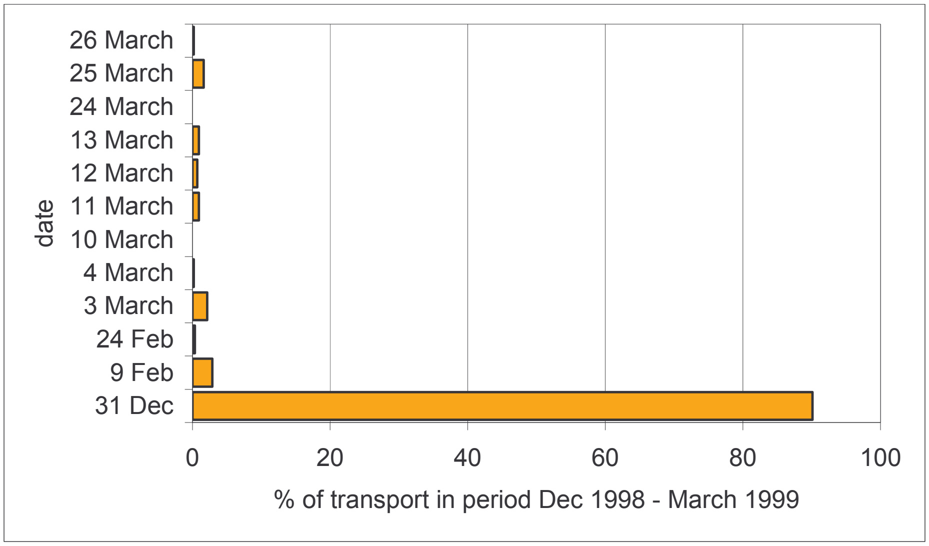


Figure 17. Contribution of different events to the sediment storage in the dune profile.