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Monitoring the Cresmina dune evolution (Portugal) using differential GPS

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ABSTRACT

The Cresmina dune is a transgressive loose sand body of approximately 300m wide by 230m long, that is moving from NNW to SSE along the Guincho-Oitavos dunefield. This dunefield, located near Cascais, in the west coast of Portugal, can be classified as an headland bypass dunefield. The sand enters the system from two beaches at north, migrates on top of a marine abrasion platform, cut into cretaceous hard rocks, returning to the sea at south.

In order to determine the trend of evolution, the advance rate and the resultant sand drift that is occurring, a four year campaign (2000-2004) for monitoring the precipitation ridge of the transgressive dune and the contiguous area, is being carried out with one detailed topography survey per year.

Topography surveys are made using a Trimble DGPS with 1.5cm and 2.5cm of horizontal and vertical accuracy respectively. ArcView GIS is used to process the data and display the results. Because subtraction of 3D surfaces relative to different years is our goal, a very large effort is made to survey all the elevations on the studied area. Detail surveys of the 43,067m^2 have been done with approximately 10m spaced measurements in flat smooth topography but 0.15m in rough topography. A 10cm grid is calculated using the measured points and the resultant Digital Elevation Models show elevations below 10cm.

The comparison between surfaces obtained from the 2000 and 2001 surveys clearly show the areas affected by deflation and accumulation. A volume of transported sand into the study area of 14,249m^3, approximately 39.7$m^3 year^{-1}$ per meter of dune section, and a variation of the precipitation ridge advance of 0.5m to 10m, depending on dune high and relative position were determined. Asymmetric evolution of the dune and influence of leeward relief in sand drift are clear.

ADDITIONALINDEX WORDS: *Geographical Information System – GIS; Headland bypass dunefield; Aeolian sand transport.*

INTRODUCTION

The Cresmina dune belongs to a more vast and complex dune system, known as the Guincho-Oitavos dunefield (Figure 1). Due to coastal morphology and orientation, and to the prevailing wind regime, the sand enters the continent, at the north, from two beaches, migrates on top of consolidated rocks and then returns to the sea again, at the south (REBÊLO, 1998). This is why this system is classified as a headland bypass dunefield (TINLEY, 1985). Because there is not enough sand to fill all of the dune corridor, parabolic dunes are generated when destabilisation of vegetated dunes occur.

The aim of this work is to quantify the advance rate and the resultant aeolian sand transport of the Cresmina dune. The characterization of the changes in the morphology will contribute towards our understanding of the dunefield evolution pattern and the parabolic dunes formation.

STUDYAREA

The Cresmina dune is a large unvegetated sand body, with approximately 300m width by 230m long, that is being pushed by the wind from NNWto SSW(Figure 2). It can be regarded as a first stage in the formation of a parabolic dune. Because the volume of sand involved is very large, vegetation can no longer sustain the dune advance. This body of sand is covering older dunes, which are fixed by vegetation. The west and the east part of the Cresmina dune shows different patterns of evolution. In the west part, the sand, advancing as a sand sheet, is covering hardrock and small hummocky dunes with a thin layer of sand. In the east part the Cresmina dune shows a well-developed precipitation ridge, in some places with more than 7m high (REBÊLO *et al*., 2000).

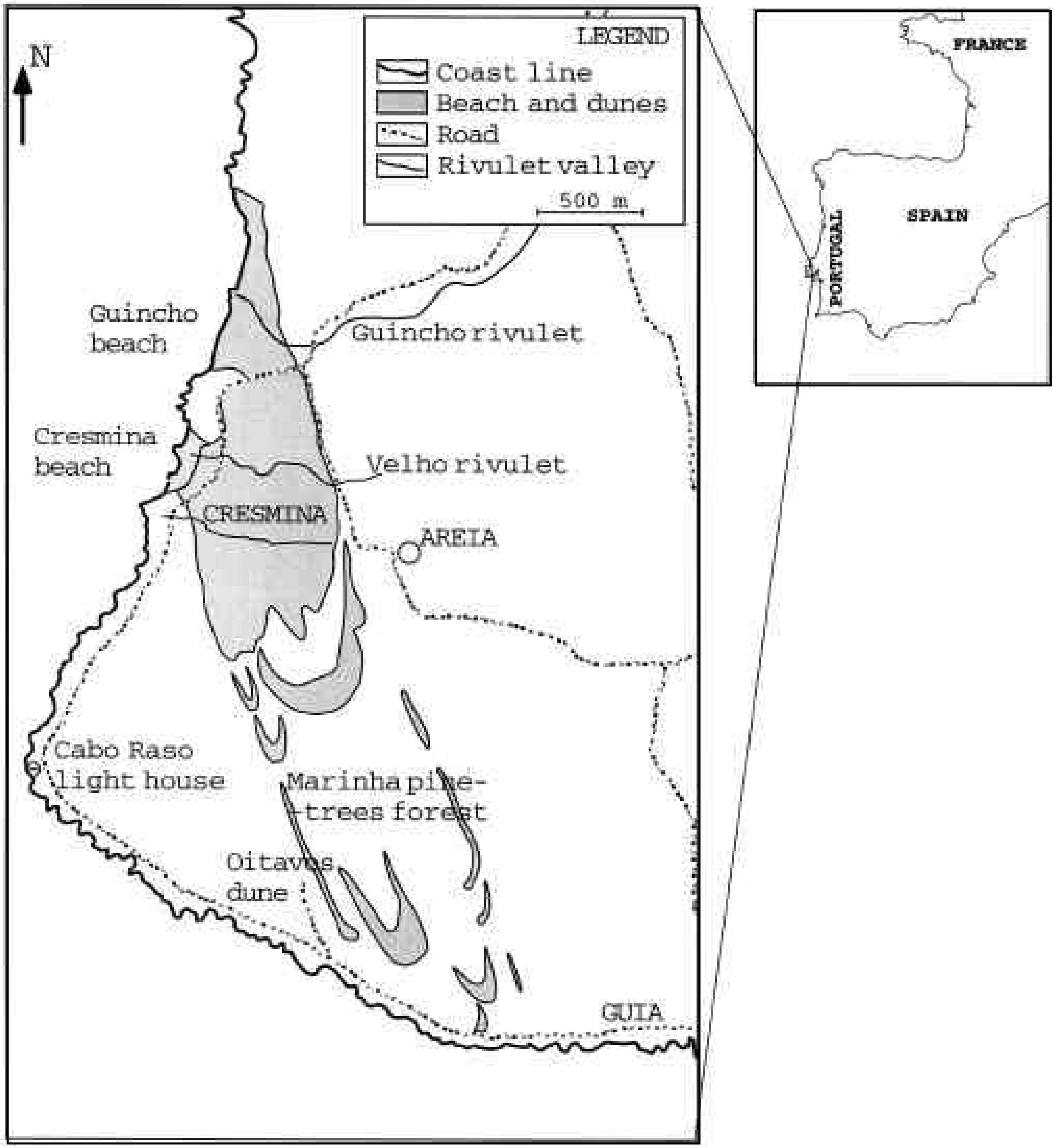

Figure 1. Guincho-Oitavos headland bypass dunefield localization and dune distribution.

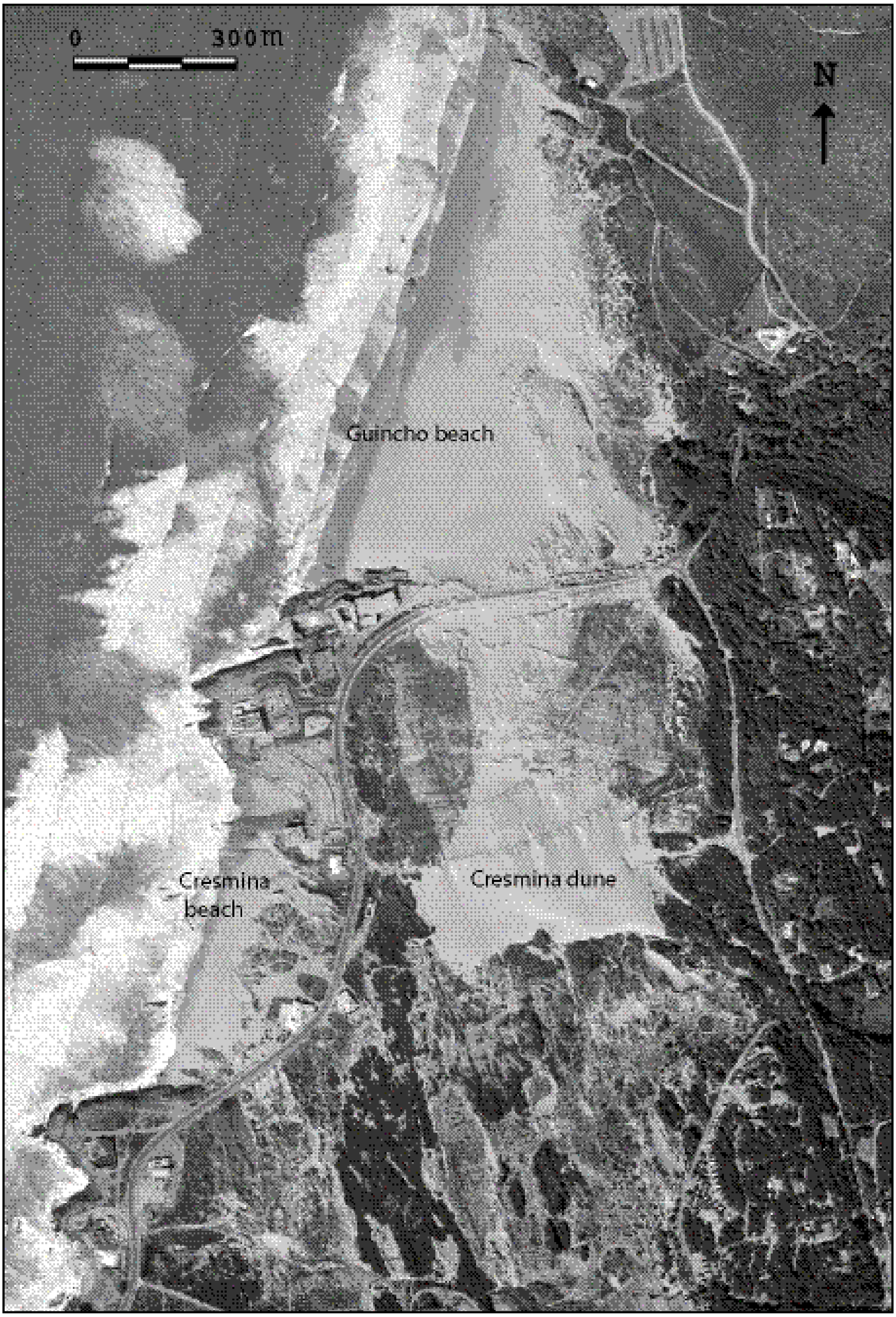

Figure 2. Aerial photo from 2000. The Cresmina dune is the light gray colored loose sand body in the center of the photo.

METHODS

If we have, for a particular area, two different surfaces relative to different times, we can compare them and analyse the occurred changes. Therefore, the advance rate and the sand transport can be achieved from the subtraction of two consecutive years' dune surfaces. This is possible due to particular characteristics of this dunefield:

i) It is a headland bypass dunefield;

ii) The contact between the transgressive dune and the vegetated dunes is, for most of the time, distinctive.

With this background, monitoring the advance front of the dune, allows us to know how much sand has entered the surveyed area and also it's resultant displacement. To accomplish this, we first have to measure the surfaces in consecutive years, create digital elevation models (DEM) and then, calculate the difference between them and the distance between the precipitation ridges.

Dune surface measurement

A Trimble 4400 Differential GPS was used to collect data points in Real Time Kinematics (RTK) mode. Each GPS measurement represents a 3D location and is described by a north, west, and height values (x,y,z) for each point. The hardware horizontal and vertical accuracy are respectively 1cm and 2cm ± 2ppm times distance between the base station and the rover. Due to the short distance between the rover and the base, 2ppm never exceeded 0.05mm, which is a negligible value for our purpose. To make the data acquisition faster, a software filter was used in order to shorten the static period. As a consequence, the accuracy was lowered to 1.5cm in (x,y), 2.5cm in (z).

To improve consistency in the measurements and fastness in the base station set up, the base antenna was mounted on a concrete pole, specially built on top of a dune, near the monitoring zone, Geodetic Survey Division (1992).

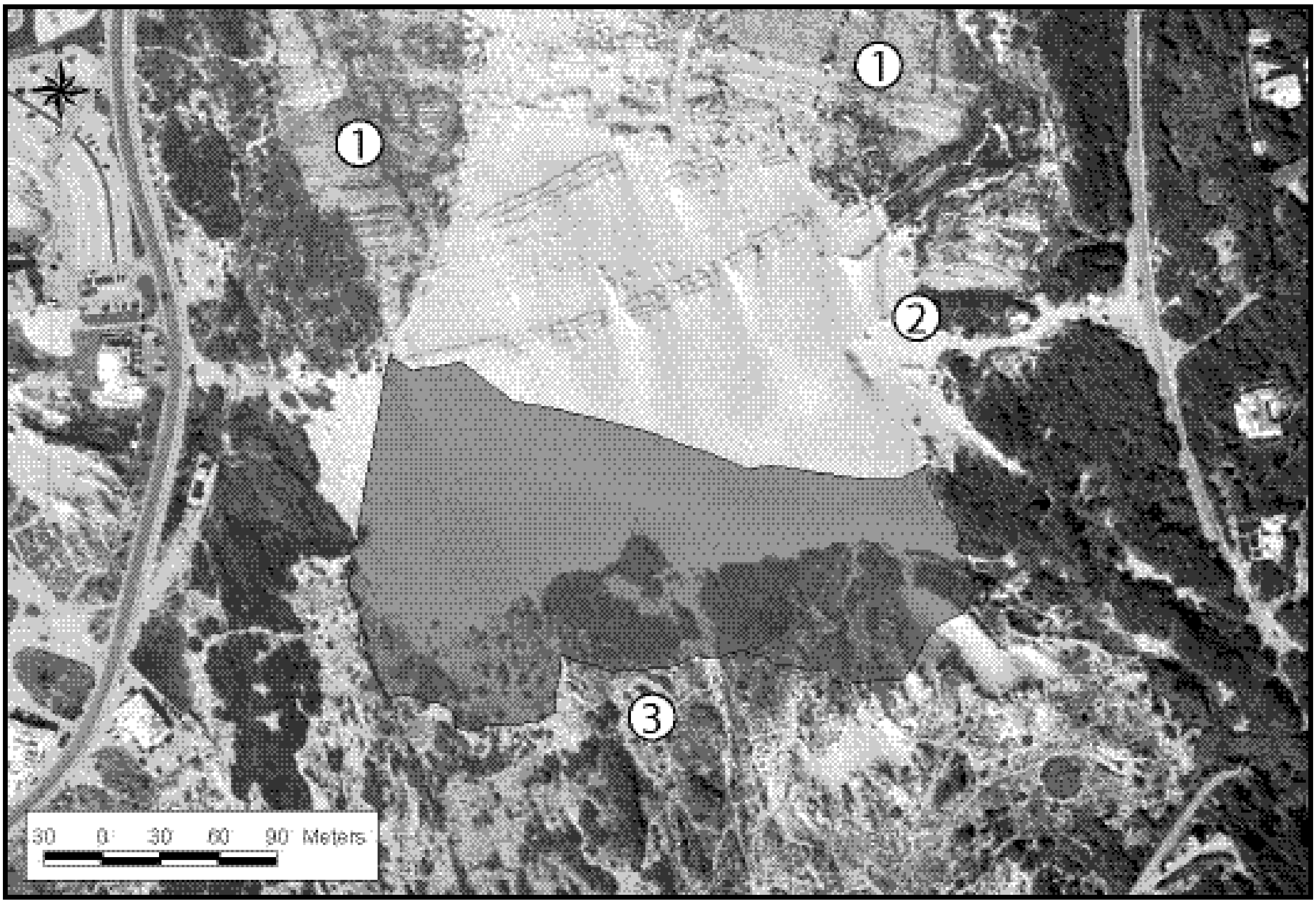

Figure 3 . Monitored area of 43067m^2 (grayish transparent layer) on top of the 2000's aerial photo. 1- Deflated area with exposed hardrock; 2 – Sand pit; 3 – Vegetated dunes.

The study area was calibrated using three geodesic points from the national geodesic network to anchor the surveys to the existent maps. Control points where installed in the field to check the accuracy of the daily surveys. Two accessories were devised to aid in using the antenna rover's pole at the study site. An articulated dish, mounted on the bottom of the pole, so it doesn't sink on sand, and a 2m extension for the regular 2m pole, so the survey could be done under small trees (acacias and pine trees). Due to the large monitoring area, we were aware that changes in morphology could take place during the monitoring period. To minimise this, the unvegetated part of the dune was monitored during winter and in the shortest time period possible.

So far, two detailed surveys, one in 2000 and other in 2001, have been carried out. The 'selective sample method' (BURROUGH, 1998) was used, where sample points were selected during the sample process. In each survey, the space between measurements is not rigid but dependent on topography. The rougher the surface is, the smaller is the space between measurements. An approximately 10m interval was used in flat smooth topography, but only 0.15m where topography was very rough. Morphology of inaccessible places, due to tall and dense trees and bramble, was measured using offsets.

Dune Digital Elevation Models (DEMs)

Arcview, a Geographical Information System (GIS), was used to import and process the (x,y,z) data. Interpolation was applied to convert data point observations to continuous fields, generating Grids (altitude matrices).

Hillshades, contour lines, profiles and 3D visualization were generated from a 0.10m grid. Spline mode interpolation with type = tension, neighborhood points = 8 and weight = 2 was used to generate all grids.

In order to calculate volume and area differences between consecutive years' surfaces, the cut and fill ArcView command was used. This command measures the volumetric difference between two surfaces, allowing to determine how much material (sand) is lost and gained in an area by comparing two DEMs: one before a change and other after.

After building the 2001 and 2000 grids, cut and fill was applied using both surfaces.

Because cut and fill gives only numeric values, to map the occurred changes, 2001 and 2000 grid subtraction was made. From the resultant grid, contour maps were drawn.

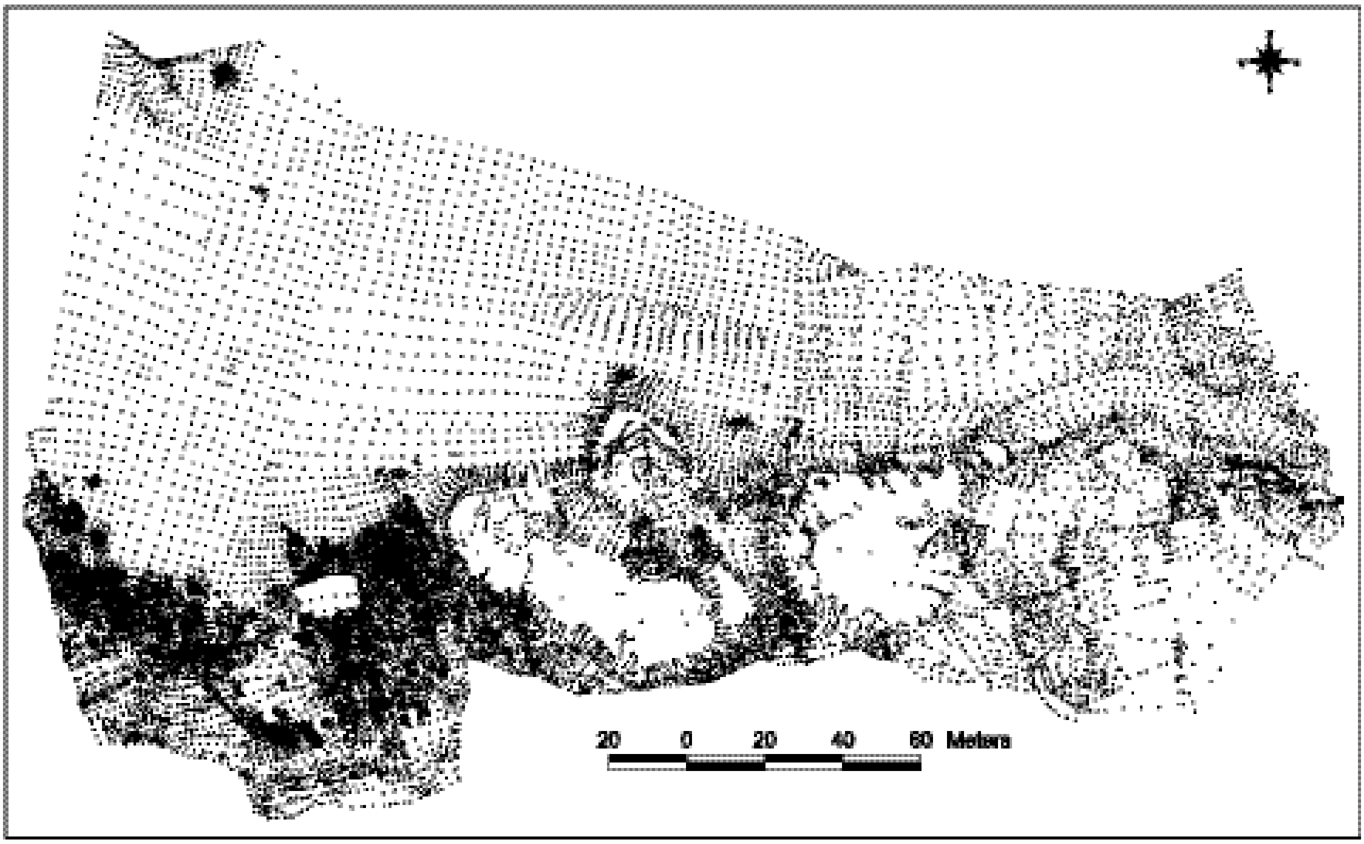

Figure 4. 2000's data points (x,y,z) set.

Monitored Area

In order to monitor the Cresmina dune evolution we measured, in the first survey, an area with vegetated dunes, at south of the precipitation ridge, and a strip of sand from the transgressive dune, in a total of 43,067m^2 (Figure 3). We covered most of the dune corridor's width to follow the resultant sand displacement. We choose to monitor a larger area at the west than at in the east because of the vegetated dunes, and downwind the contact between the loose sand/vegetated dunes, is low and sparse. As a consequence, the dune front is not well defined, the sand is blown as a sand sheet and dune advance is expected to be faster than at the east, where a 7m precipitation ridge slows down the dune progression.

The second survey was made only in the loose sand area and on a narrow strip near the contact of moving sand/vegetated dunes. Vegetated dunes, with no signs of significant aeolian transport, were not monitored again. Because we assume that the possible changes in their topography is negligible, the vegetated area points from the first survey were used in the second 2001 DEM.

RESULTS

The 2000 survey was held from 20 of January to 30 of August and was programmed with two phases. The first phase was oriented for monitoring the transgressive dune area in the shortest period possible. It took place from 20 of January to 16 of February, a 28-day period. The second phase was oriented for monitoring the vegetated area. Because we assume that changes in this area are negligible and also because it is far more difficult to survey vegetated dunes, the field work was done from 17 of February to 30 of August 2000. A total of 19,585 (x,y,z) points were measured during the 2000 survey (Figure 4) and 127 offsets were used to generate the 2000 grid's DEM (Figure 5).

The 2001 survey took place from 26 March to 18 of April, a 23-day period. In all, 11,546 (x,y,z) points were measured, 123 offsets and 5,551 points from the 2000 vegetated area, outside the 2001 survey, were used to generate the 2001 point data set (Figure 6). This data set was used to generate the 2001 grid's DEM (Figure 7).

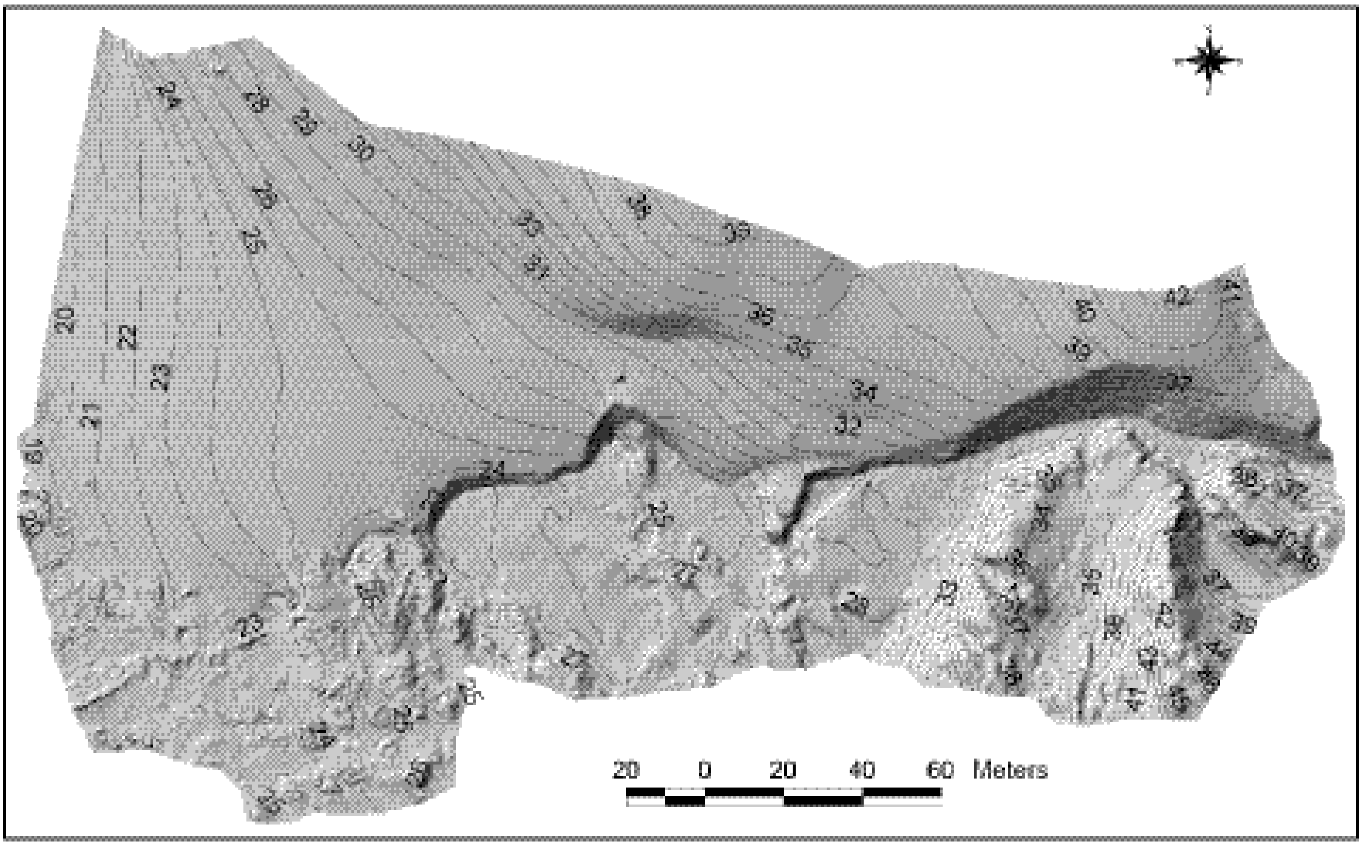

Figure 5. 2000's Digital Elevation Model. Altimetry in meters.

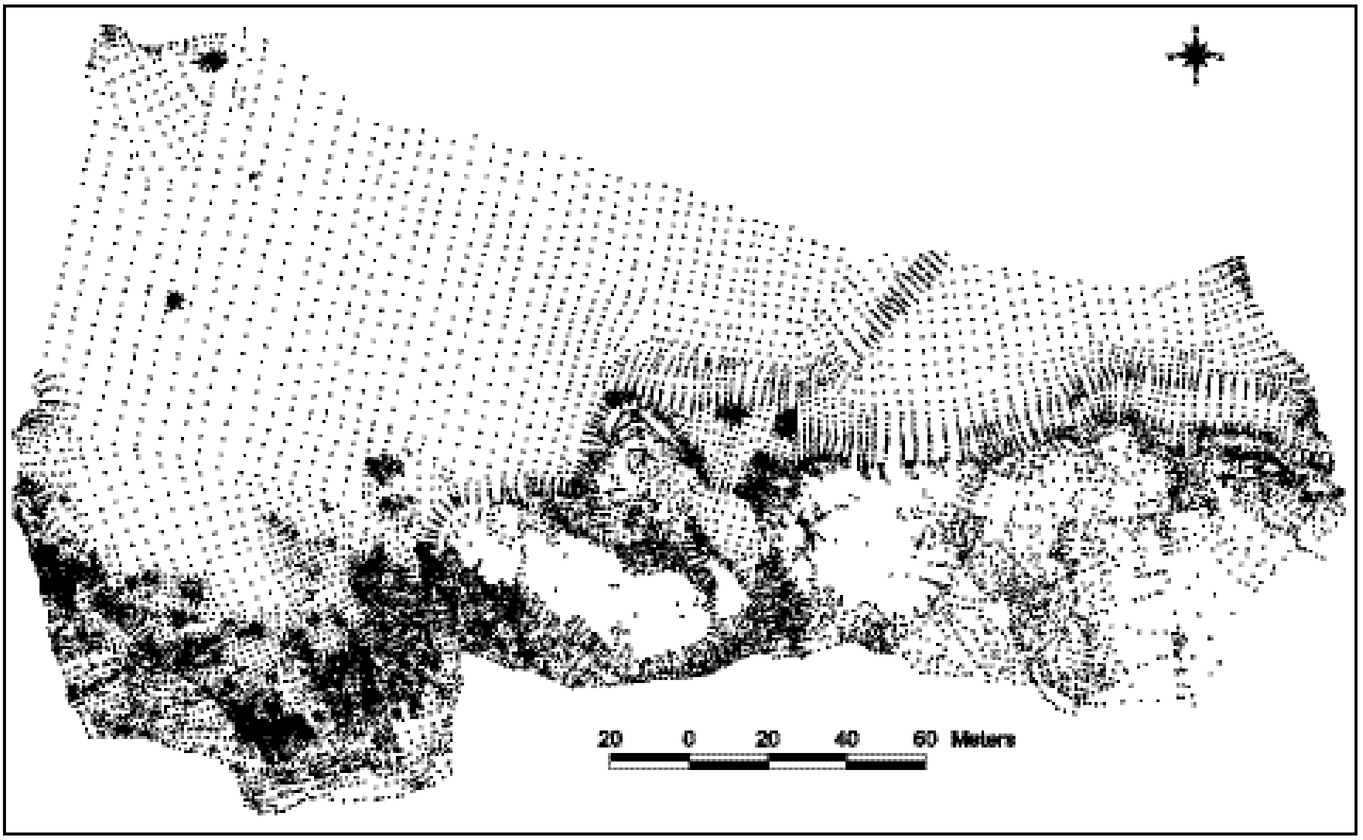

Figure 6. 2001's data points (x,y,z) set.

Table 1. Dune volume variations, per entire area and per sectors, obtained with the cut and fill command, using the 2000 and 2001 DEMs (14 months period). New sand corresponds to the positive minus negative variation values.

	Area (m^2)	**Pos. variation (m^3)**	**Neg. variation (m^3)**	**New sand (m^3)**
Entire area	29540	16476	2227	14249
West sector	14436	2614	1235	1379
Central sector	10166	9818	582	9236
Eastern sector	4938	4044	410	3634

Table 2. Dune volume variations, per entire area and per sectors, calculated for a 12 months period.

	Area (m^2)	**Pos. variation (m^3)**	**Neg. variation (m^3)**	**New sand (m^3)**
Entire area	29540	14122	1909	12213
West sector	14436	2241	1059	1182
Central sector	10166	8415	499	7917
Eastern sector	4938	3466	351	3115

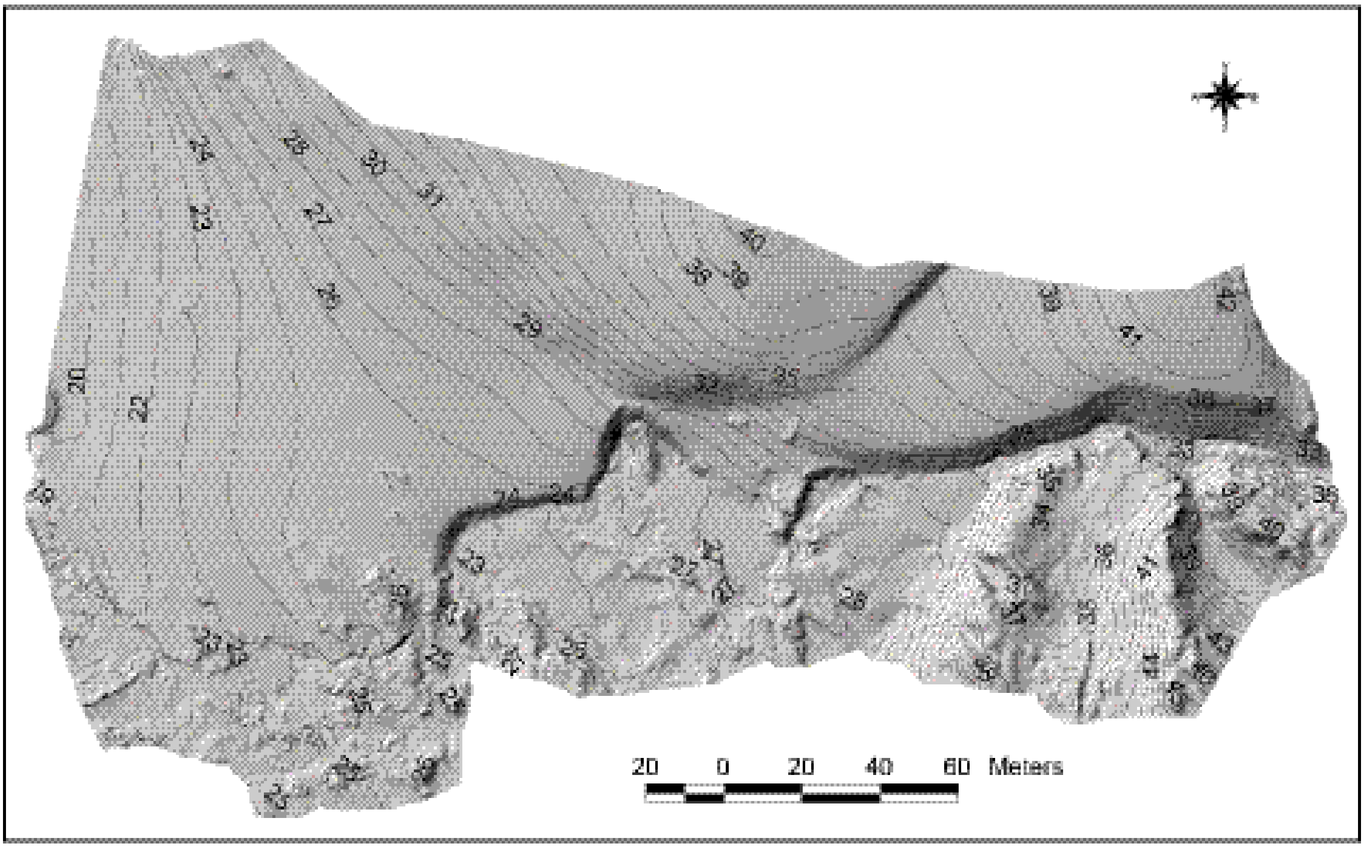

Figure 7. 2001's Digital Elevation Model. Altimetry in meters.

The analysis of the cut and fill command results, using the 2001 and 2000 grids (Table 1) shows an increment of 14,249m^3 of sand in the surveyed area (new sand). Changes in topography, represented by the accumulation (16,477m^3, the positive variation), and deflation (2,227m^3, the negative variation), occurred in 29,540m^2 of the total surveyed area.

Sand transport values are usually referred to in the timescale of an annual rate but our data corresponds to a 14 months interval. Consequently, a simple calculation was done to transform the cut and fill values to an annual basis, dividing them by the number of months between surveys, to get the monthly variation, and then multiplying by twelve (cut and fill values x 12/14) (Table 2).

Considering that:

i) Aeolian sand transport is the sum of incoming sand plus the deflated sand, being represented by the positive height variation between the two measured surfaces (C+B, in Figure 9);

ii) The sand can only get into the surveyed area from north;

iii) The north border measures approximately 308m,

we calculated the average aeolian resultant sand transport (ERST) for an annual period, per meter of dune section (Table 3), obtaining a ERST of 45.9m^{3}year^{-1} per meter of dune section.

We also calculated the annual volume of new sand that crossed the north border per year (Table 3). Knowing that the positive variation, C+B in Figure 9, represents the volume of the new incoming sand plus the deflated sand, and that the negative variation, C in Figure 9, represents the deflated volume of sand, we can easily calculate the incoming sand, B in Figure 9, by a simple equation: B=((C+B)-C), obtaining a value of 39.7m^{3}year^{-1} per meter of dune section for it.

In order to analyse the asymmetry of the dune evolution we divided the dune in three sectors, in relation to the main geomorphologic units (Figure 10), and we weigh the ERST by the north border length (Table 3). The west sector, with a north border length of 93m, comprises the flattest and more depressed area, where sand sheet deposition prevails; the central sector, with a north border length of 125m, where a new sand pulse is reaching the precipitation ridge; and the east sector, with a north border length of 90m, where the precipitation ridge is well developed.

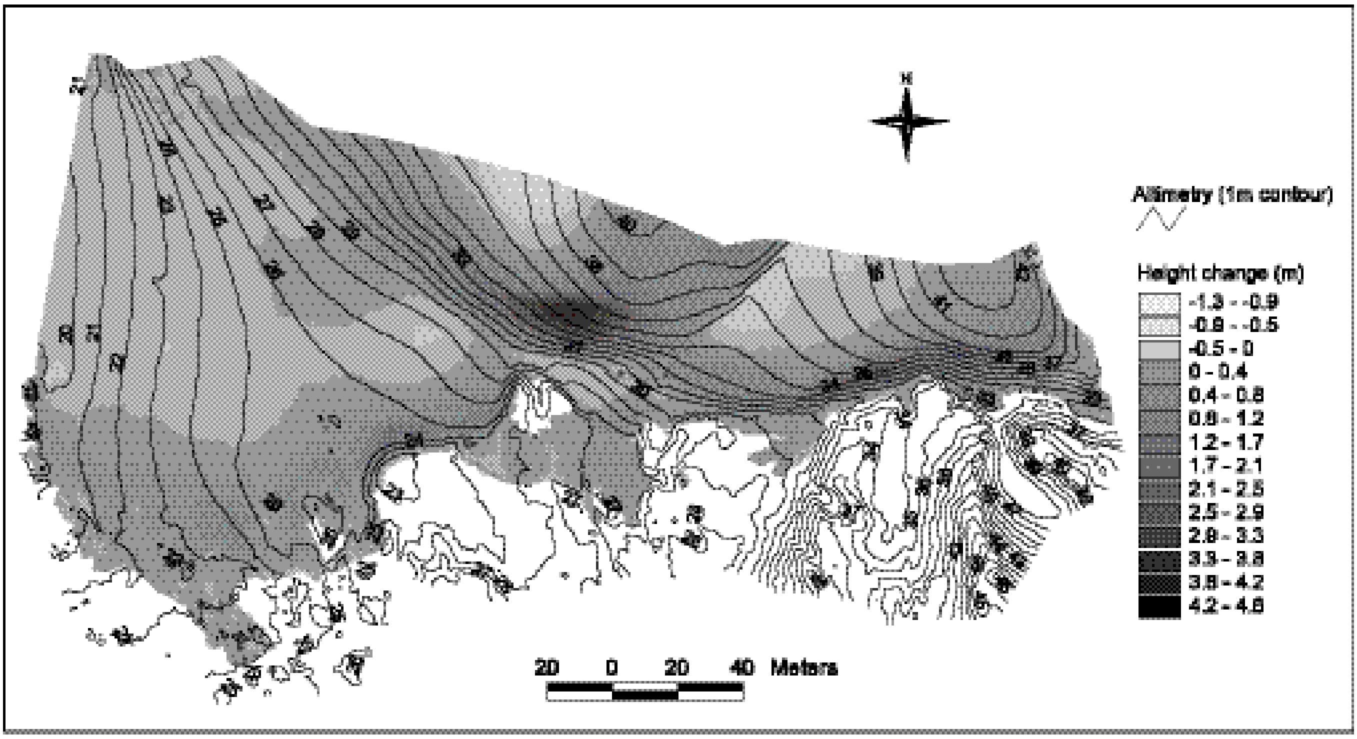

Figure 8. Altimetry differences between the 2001 and the 2000 DEMs (grayish polygons) for a 14 month period. The positive altimetry differences corresponds to accumulation and the negative differences to deflation. Black lines correspond to the 2000 altimetry.

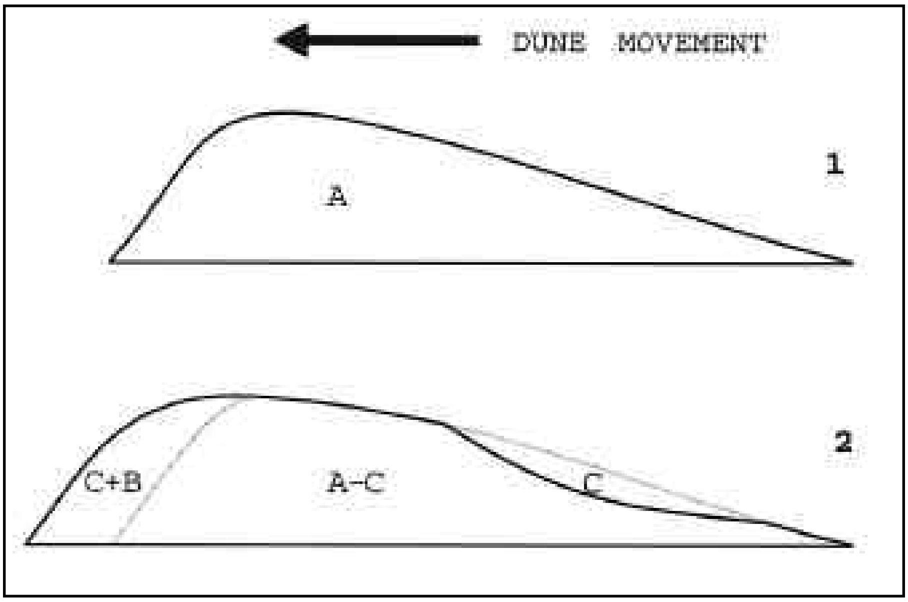

Figure 9. Schematic representation of the relation between positive and negative volume variation, deflation and accumulation, sand supply and ERST. 1 – Cross section of the initial surface (the one measured in 2000); 2- Cross section of the final surface (the one measured in 2001; gray line represents the 2000 surface position); A – Original sand volume; B+C – Positive variation of the 2001 and 2000 surfaces subtraction = sand volume accumulation = ERST; C - Negative variation of the 2001 and 2000 surfaces subtraction = volume of deflacted sand; B – Volume of new incoming sand = sand supply.

Table 3. North border length, eolian resultant sand transport (ERST), new incoming sand and asymmetry index for the entire area and for the three defined sectors.

	North border length (m)	**ERST**	**12 month period (values in m3m-1) New sand**	**Asymmetry index (New sand/ERST)**
Entire area	308	45.9	39.7	0.86
Western sector	93	24.1	12.7	0.53
Central sector	125	67.3	63.3	0.94
Eastern sector	90	38.5	34.6	0.90

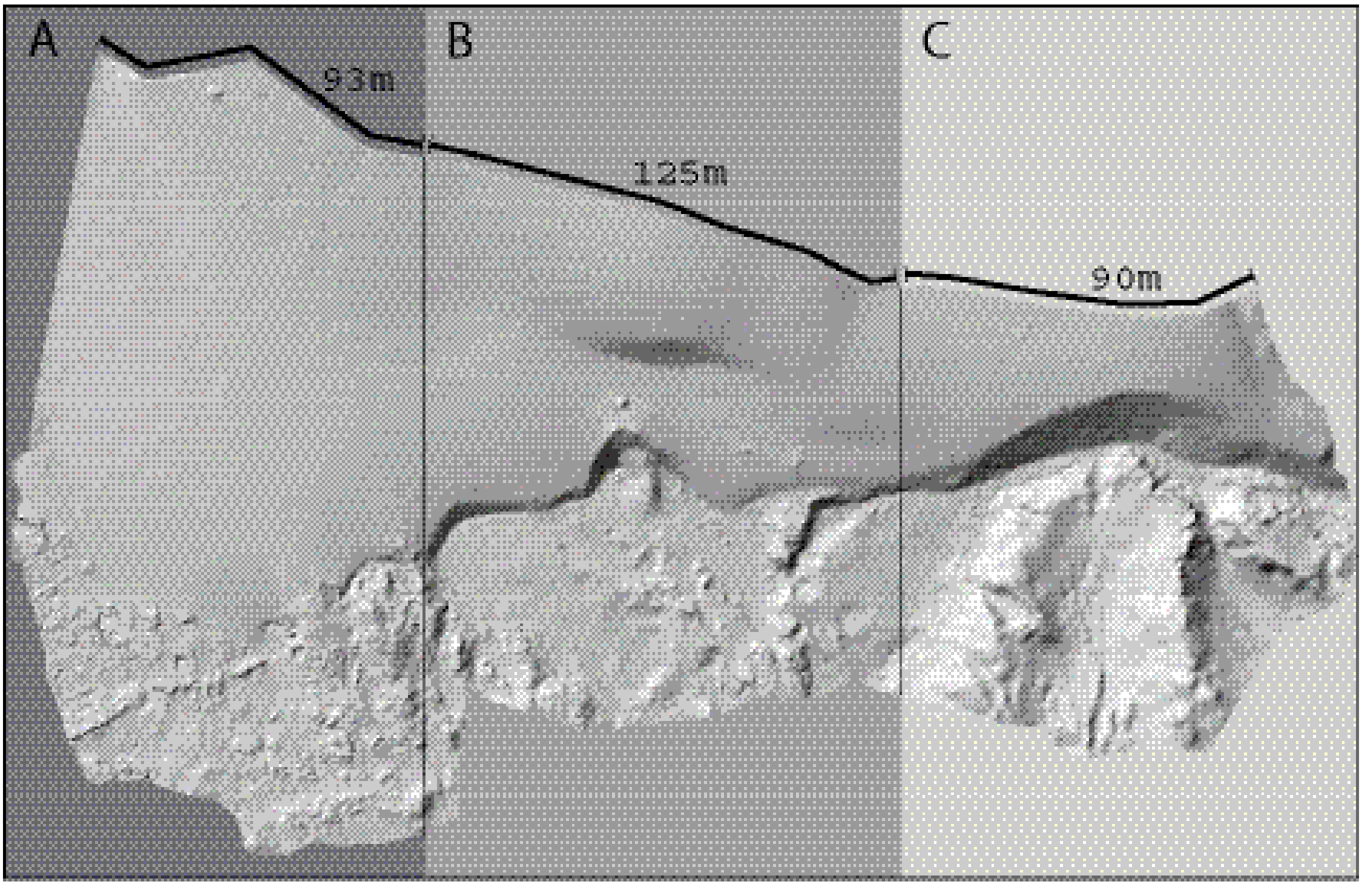

Figure 10. Study area subdivisions, associated with different relief domains. A – Flat depressed area; B – New sand pulse reaching the precipitation ridge; C – Well developed precipitation ridge.

Calculations were made and the results (Table 3) shows that the central sector has the higher ERST comparatively to the east and west sectors. The central sector has an ERST of 67.3, the west sector 24.1 and the eastern sector 38.57m^{3}year^{-1} per meter of dune section.

The asymmetry in the Cresmina Dune advance can also be observed if we compare the positions of the two consecutive years dune precipitation ridge (Figure 11). The higher the dune, the slower it advances. The east part of the dune, where the precipitation ridge is 7m high, shows an advance in the order of 0 to 4.6m, whereas in the western part, with lower precipitation ridges we can observe an advances in the order of 10m.

Deflation occurred in the west, center and east part of the dune but accumulation is larger in the central and eastern part of the dune front.

Higher precipitation ridges tends to form in the eastern and central part of the dune.

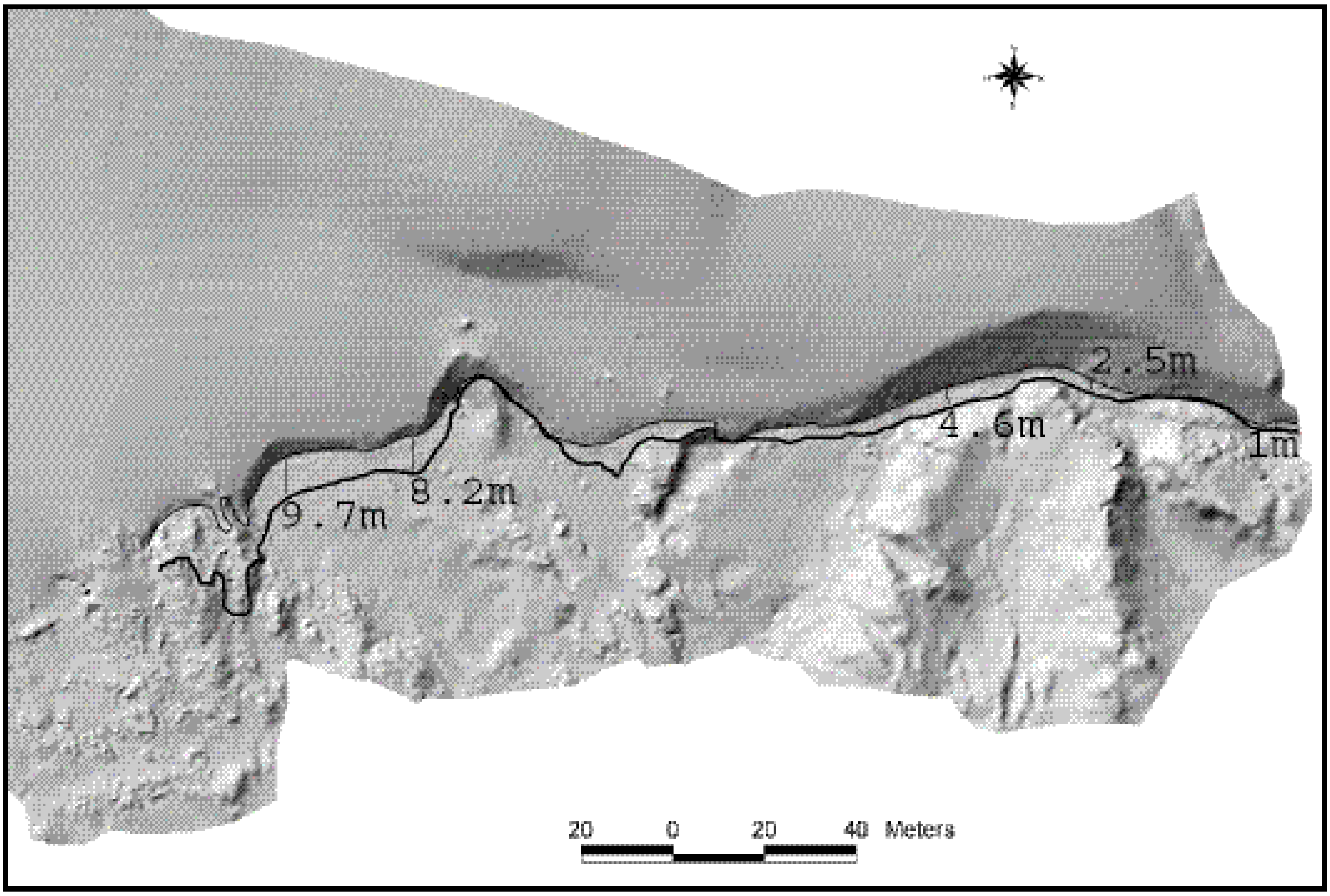

Figure 11. Cresmina's dune precipitation ridge advance from Februry 2000 to April 2001. Black lines represents the precipitation ridge position: Thick line, 2001 position and thin line the 2000. Values indicates the dune advance. 2000 DEM is shown as background.

DISCUSSION

The dune surface elevation measurement and the generation of DEMs to calculate the sand movement on the Cresmina dune is only one part of the study that is being carried out in this dunefield. Wind speed and direction is also being recorded in an autonomous station, installed in the dune. These two different approaches to wind and sand transport will allow us to compare the sand movement obtained from wind data to the one measured in the field. Dune elevation measurements also allow us to detect the influence of the pre-existent relief in the dune advance behavior and to understand the asymmetries observed in the dunefield.

Why use arbitrary GPS measurements instead of profiles?

Because dune movement is not homogeneous, the profile approach for measuring variations in a moving sand body, and hence, the sand transport, could lead to wrong results. It is difficult to establish the right place to locate the profile and the correct location today, could not be correct in the future. The space between profiles are not measured and in consequence, the occurred changes are not recorded. Profiling gives us a 2D information and several profiles give us only an approximation of the surface. Profiling follows a rigid pattern of measurements.We always have to begin in one point, follow a certain direction and end in another point.

On the other hand, the arbitrary GPS measurements provide the freedom to choose the best place to make the measurements. We are not constrained by a certain direction but by the existing morphology. We can make a detailed survey of a small hummocky dune in one year and, if for any reason it disappears before the following survey, then we just don't have to survey detail that particular area with the level of detail. Due to dune morphology complexity, particularly within vegetated dunes, the ability to measure in all directions allows us to make a correct representation of dune morphology.

As a result, 3D surfaces obtained with GPS measurements are much closer to the reality than 3D surfaces obtained from profiles.

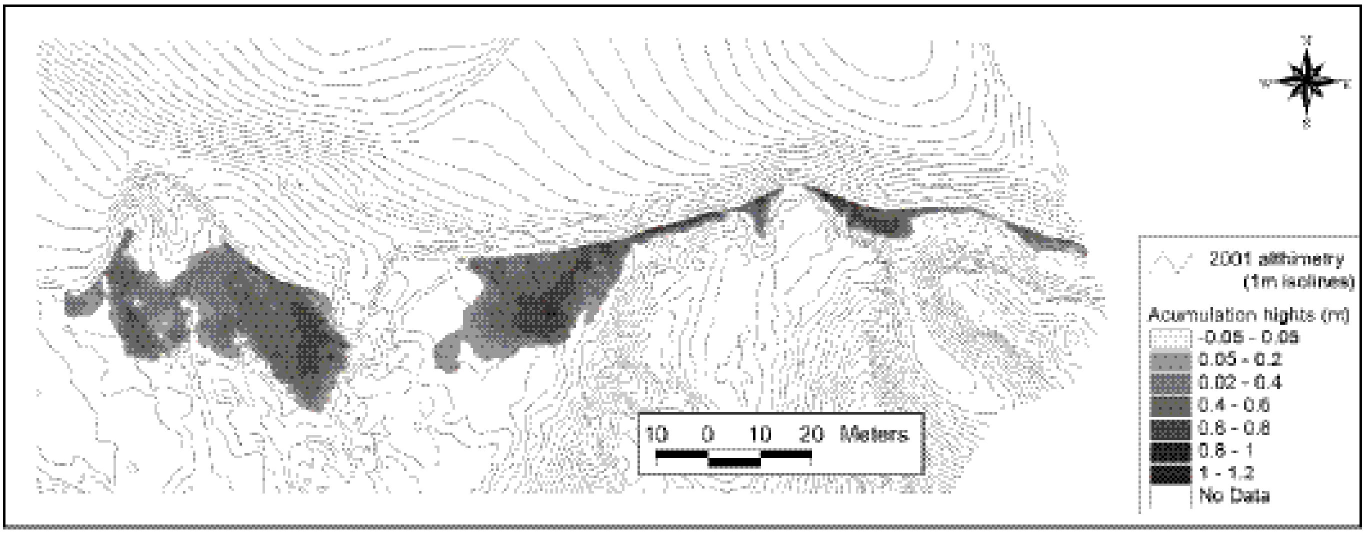

Figure 12. Sand accumulation due to rivulet activity. 2001 altimetry superimposed on the volume variation.

ArcView DEMs parameters

From the beginning we were aware that it is impossible to produce a perfect surface (close to the real one) from a sample data point set. The sample method, previously referred, and the software interpolation methods and variables were applied in a way that the derived surface should represent reality, as close as possible. Local interpolation methods were chosen because, on the contrary of global interpolation ones, local variations are taken in account.

TIN and Inverse Distance Weighted (IDW), tends to represent the surface with a very angular shape, which is not the way dune morphology occurs. Besides, IDWcommonly have a 'duck-egg' pattern around solitary data points, BURROUGH (1998). On the other hand, 'spline' works like a sheet of plastic, or a rubber sheet, that is bent around the sample points. That is why 'spline' is appropriate for gently varying surfaces like elevation, ESRI (1998).

Spline uses a two-dimensional minimum curvature interpolator ESRI (1998), which indicates that there is one continuous derivative at each knot (BURROUGH, 1998), and the surface passes exactly through the sample points.

Test data for smooth surfaces show predictions are very close to the values being interpolated, providing the errors associated with the data are small, (BURROUGH, 1998). The most critical disadvantage is that spline provides a view of reality that is unrealisticly smooth, (BURROUGH, 1998). We counteract this behavior using the 'selective sample method', diminishing the sample space interval in places where there were abrupt relief changes and generating a 0.10m grid.

In the ArcView spline mode we can choose between two options: Regularised and Tension. Regularised choose the space between samples to generate the break points, (BURROUGH, 1998). This option produces overshoots and undershoots, what is not appropriate for our case. Tension makes the break points to coincide with the data points, witch forces the curve to fit the points, ESRI (1998).

In the Tension mode we can control two variables: weight and neighbourhood points. Weight = 2 and neighborhood points = 8 were used in the tension parameter. The chosen number of neighbourhood points is intentionally not high due to the used 'selective sample method'. Because we believe that all the significant relief's and break lines were sampled in such a way that even with triangulation the relief was represented, we did not want the distant points to interfere with the local terrain model. The used settings produced acceptable DEMs and were chosen after several experiences. We use the word 'acceptable'in that the DEMs derived from the points were able to represent detailed variations in the surface, like small dunes and precipitation ridge break lines. Ground-truthing was also carried out, during the survey, to certify that altitude variations in DEMs were representative of reality.

Sand supply and resultant aeolian sand transport (ERST)

Sand supply is regarded as the sand that enters the monitored area during our study. ERST is the resultant volume of sand moved by the wind during the study.

In the Guincho-Oitavos dunefield, in which the Cresmina dune lies, the resultant sand transport, obtained by aerial photo interpretation and by wind data analysis, is from NNW-SSW(REBÊLO, 1998). Furthermore, we assume that the sand can only get into the study area by the northern border because the sand that can be blown from east is not regarded as significant, due to the existent vegetation, or from west, due to the small fetch area and the existent vegetation. From south, due to the well-developed vegetation and the existent precipitation ridge, it is very unlikely that the sand can be pushed into the dune.

Looking to the dune as a semi-closed system, where the sand can only get in and out from the north border, the sand volume differences, obtained with cut and fill from the two years surfaces (Figure 8), means that a positive or negative balance has occurred. The sand budget, that can be seen as the positive variation minus the negative variation (Figure 9), is the sand supply.

Negative volume variation represents the occurred deflation during two consecutive surveys (Figure 8). It could be seen as sand, already present in the study area, that was remobilised by the wind. This sand is going to be deposited in other places on the dune together with the new incoming sand (sand supply). This volume of sand, the remobilised plus the sand supply, is represented by the positive volume variation (Figure 8). This is how the ERST value is obtained. In terms of wind, it means that the wind was capable, at least, of transporting the sand that came into the system plus the deflacted sand.

Deflated areas can be regarded as lack of sand supply in terms of the blown wind. If there is plenty of sand supply, deflation does not occur. However, if the wind energy applied to the dune is capable of transporting more sand than the sand available to be blown, then is more likely that deflation will occur.

Asymmetry of the system

The Cresmina dune morphology and volume of sand is different from east to west.

If we look to the changes in the dune (Figure 8), from west to east, we can see that the deflated area is larger in the west than in the central and eastern part. The ratio of volume of new sand to volume of sand accumulated' can give us a comparative index for the sediment availability upwind the study area. Deflated areas means that the wind blown during that period is capable of transporting more sand than the sand that is available to be blown. Following this approach, we used the previous divisions of the dune field (Figure 10) and in each of the sectors the calculation for the new sand (positive minus negative variation) and sand accumulation (positive variation) was made (Table 2). The ratio obtained for the western sector is 0.53, for the central sector is 0.94 and to the eastern sector is 0.90 (Table 3). These results point out a lack of sediment supply in the western part of the studied dune.

To find the possible causes for these results we examined the 2000's aerial photograph (Figure 3). There, we can see that the western part of the dune is in the continuation of a deflated area, where the bed rock is already exposed. This is a good indication for lack of sand supply in our study area. Upwind of the eastern part, there is a depression caused by a small sand-pit. This depression acts like a sink hole, slightly reducing the sand flux towards the south, being probably the cause for the 0.90 index value, compared with the 0.94 of the central sector.

The downwind dunes' size and morphology also contributes to the asymmetry of the dune evolution. The higher the downwind vegetated dune is, the higher the precipitation ridge grows. This is clear in the east part of the Cresmina dune, where a 7m high precipitation ridge has been built by the wind. However, the aerodynamical effect caused by the downwind vegetated dunes does not make the dune grow higher indefinitely. There is a limit above which, the dune begins to move forward instead of getting higher. This limit seems to have already been reached because the precipitation ridge did not get higher from 2000 to 2001, but instead, it moved forward showing a wider development (Figures 3 and 5).

Effects of river discharge on dune evolution

The Cresmina dune sits on an headland bypass dunefield (Figure 1), and the wind- blown sand moves on top of an old marine abrasion platform (RAMALHO *et al*., 1980), today uplifted in relation to the mean sea level. With the geomorphologic evolution, two small rivulets cut the platform, generating two gently sloped E-W valleys. In order for the dunes to cross these valleys, in their migration to south, the rivulet water flow must have less transport capacity than the wind capacity to transport sand. Otherwise the wind blown sand would return to the sea again. Runoff doesn't occur every year. When it occurs, and the flow is small, generation of ponds and infiltration occurs. When the runoff is high, the subsurface flow, due to the infiltration, is not enough to discharge all the water and the dunes tend to halt.

During the 2000 summer the precipitation ridge had migrated to south, closing the river channel. The precipitation ridge was beginning to cover the old high dune located southward (this state was not captured in our surveys). In December 2000 and beginning of January 2001 heavy rainfall occurred. When the rivulet began to run this sand acted like a dam, slowly accumulating the incoming water and creating a pond near the precipitation ridge in the east side of the dune. When the water level reached the top of the sand dam, the discharge was intense, flushing the entire pound and taking with it a large amount of sand. The consequence of this phenomena in the dune precipitation ridge advance and in the redistribution of the sand can be seen by analysing figures 5, 7 and 11. In the 2001 survey, the channel between the precipitation ridge and the old southward dunes is narrower, than in 2000, and the precipitation ridge has a strange form, as a response of the sand flushing (figures 5 and 7). The dune advance in the eastern part has smaller values, between 0 and 1 meters, than the ones observed closer to the west, 2.5 to 4.6 meters (Figure 11). The sand removed from the precipitation ridge was deposited in the central area, southward the precipitation ridge (Figure 12), as a consequence of the diminishing transport capacity when the water is spread in more flat areas. A 592 m^3 volume of sand was transported by the rivulet, having being deposited in a 1,609m^2 area, southward of the precipitation ridge. Because the sand was not transported outside the study area, volume transport calculations can still be done without sediment loss. However, calculations for the ERST by sectors can be affected by this remobilisation.

CONCLUSIONS

The use of differential GPS and GIS to monitor the Cresmina dune advance rate and the resultant sand transport, proved to be effective. So far, two dune front detailed surveys, the first in 2000 and the second in 2001, were carried out, with a 14 months interval. Digital elevation models comparisons gives the possibility to visualise and to measure the changes in any part of the dune front. The precipitation ridge moved southward, as expected, from 0 to 9.7 m. The smaller values are related with higher precipitation ridges and rivulet erosion.

In the 43,067m^2 surveyed area, a total of 16,477m^3 of sand was transported by the wind: 14,249m^3 of new sand and 2,227m^3 from local remobilised sand. The mean aeolian resultant sand transport is 45.9$m^3 year^{-1}$ per meter of dune section, but in the central part of the dune a value of 67.3 is reached. The largest sand accumulation, occurred between 2000 and 2001, is not connected to the precipitation ridge but with a new dune that is being built up in the central part of the monitored area. Results shows a pronounced asymmetry in the dune advance, probably due to downwind morphology but also to differences in the sand supply.

Rivulet activity plays an important role in redistributing the wind blown sand.

LITERATURE CITED

BURROUGH, P.A., and MCDONNELL, R.A., 1998. *Principles of Geographical Information Systems*. Oxford University Press, 333p.

ESRI Educational Services, 1998. *Working with ArcView Spatial Analyst.* ESRI: Environmental Systems Research Institute, Inc.

GEODETIC SURVEY DIVISION, 1992. *Guidelines and Specifications for GPS Surveys*. Canada Center for Surveying; Surveys, Mapping and Remote Sensing Sector, 30p.

RAMALHO, M.M. *et al*., 1980. *Carta Geológica de Portugal, Notícia Explicativa da Folha 34C* - Cascais. Serviços Geológicos de Portugal, 87p.

REBÊLO, L.P., 1988. Dinâmica do Sistema dunar do Guincho-Oitavos. *Actas do V Congresso Nacional de Geologia, Lisboa*. Comunicações do Instituto Geológico e Mineiro, Tomo 84, Fascículo 1, C83-C84.

REBÊLO, L.P.; BRITO, P.O., AND MONTEIRO, J.H., 2000. Monitoring the Cresmina dune advance. 3° *Simpósio sobre a Margem Ibérica Atlântica (Faro, Portugal)*, 133-134.

TINLEY, K.L.,1985. Coastal Dunes of South Africa. Pretoria, South Africa. *Council for Scientific and Industrial Research, South African National Scientific Programmes Report* No. 109, 300p.