CHAPTER 94

WIND AND SEDIMENT MOVEMENT IN COASTAL DUNE AREAS

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JOHN R. HAILS
Director, Centre for Environmental Studies, University of Adelaide, Adelaide, South Australia

and

JOHN BENNETT
Flinders Institute of Atmospheric and Marine Sciences, The Flinders University of South Australia, Bedford Park, South Australia.

INTRODUCTION:

Little is known about how air-sediment interaction processes control the differential rates and direction of dune migration along the coast of South Australia. Information is needed on sand transport and dune formation in order to establish better guidelines for conservation and agricultural management programmes in areas that are undergoing erosion.

The writers, with financial support from the Coast Protection Board, Department for the Environment, South Australia, have commenced a pilot research project to examine dunes in the lower Coorong and adjacent areas in the southeast of the State (Figure 1). The aims of the project are -

To determine:

(a) instantaneous surface stress values on the windward slopes of active transgressive dunes;

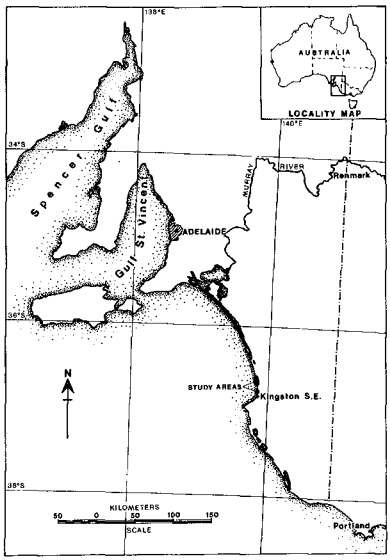
(b) sand movement over the crestline as a function of surface stress on the windward slope in order to establish the life expectancy of stability of individual dunes;

(c) the extent to which the local topography affects the wind regime in the dunal areas.

To obtain:

(a) air trajectories over and around transgressive dunes;

(b) information on dune geometry (slope inclinations, crest heights, base lengths, etc.).



To measure thermal energy budgets so that time histories of the change in surface cohesion can be found - cohesion depending to a degree on moisture content, evaporation rate and surface temperature.

Monitoring stations have been established within an amphitheatre and along the crest of an active transgressive dune complex at the southern end of the Coorong in order to make a comparative study of the wind flow within, over and around different morphological features in dune fields (Figures 2 and 3) So far, field work has been conducted in the summer months with visits to the experimental areas in December and February.

← *FIG. 1: Locality map to show study area.*

↓ *FIG. 2: Surveyed transects across the amphitheatre (top) and active transgressive dune complex (bottom).*

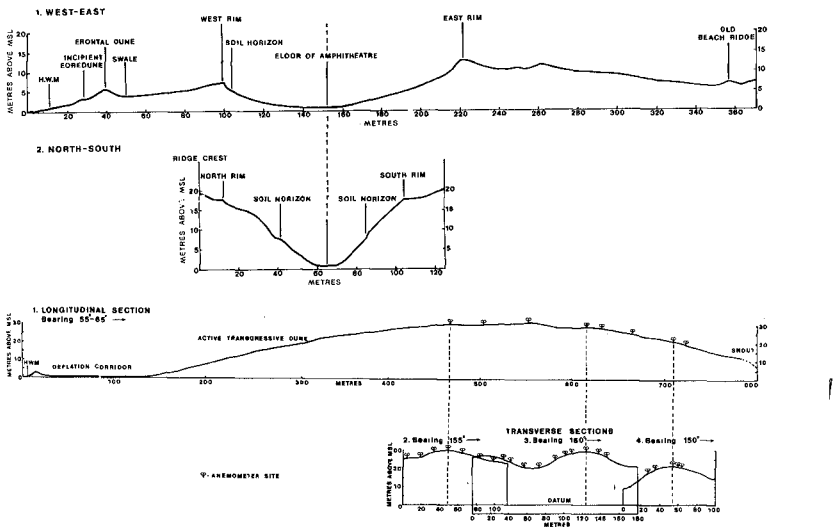


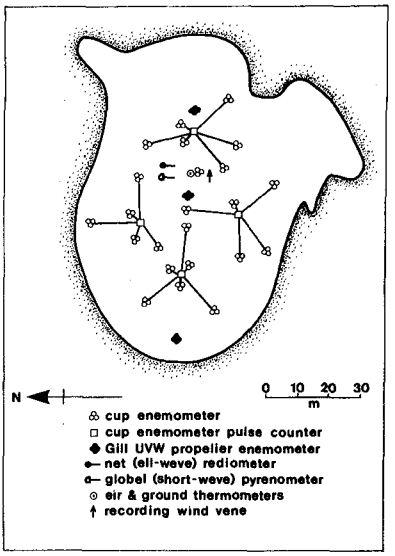
FIG. 3: Seaward and landward margins of active transgressive dune complex

FIELD TECHNIQUES:

Miniature cup and Gill UVW propellor anemometers are used to determine the surface shear stress from profile measurements and eddy correlation techniques respectively. It is intended to relate the shear stress to the initiation, rate, and direction of sand transport at the monitoring stations. The complexity of the flow at sites where air is accelerated or decelerated by the topography makes the interpretation of data from shear stress measurements difficult. Results will be reported when further work has been completed.

The meteorological factors that control the cohesion of surface sand grains through the thermal energy and water budgets of the sand surface require the measurement of net radiant energy to it, the sensible (convective) and latent heat (water vapour) losses from it, and the conducted heat into the sand. The radiant energy is measured with a net all-wavelength pyranometer and the sensible heat flux is found from observation of the vertical profiles of air temperature and windspeed above the surface. Heat conducted into the dunes is estimated from records of temperature at two depths (2.5 and 13 cm) in the sand. The latent heat flux is to be determined from eddy correlation techniques combined with measurements of the sand moisture content.

The variations in wind speed through the active dune fields are measured with arrays of cup anemometers. In the amphitheatre, a total of twenty-four instruments were placed at regular intervals over the floor and sloping sides (Figures 4 and 5), while at the active transgressive dune, they were placed along and across the crest at three places (Figure 2, bottom). Because of the size of the dune, it was difficult to arrange the anemometers so that a detailed wind pattern could be observed at one time. Since the direction and speed of the wind on the approach slopes were practically constant over several hours, more detail was obtained by moving part of the array to new sites on different occasions.



The cup anemometers are mounted 60-70 cm above and perpendicular to the sand surface, in order to measure the component of the wind parallel to the ground. The anemometers, manufactured after the design by Bradley (1969), have starting speeds of around 20 cm s^{-1}, and produce electrical pulses that are counted some distance away from the sensors.

← *FIG. 4: Schematic diagram to show instrument layout within amphitheatre, February 13, 1980.*

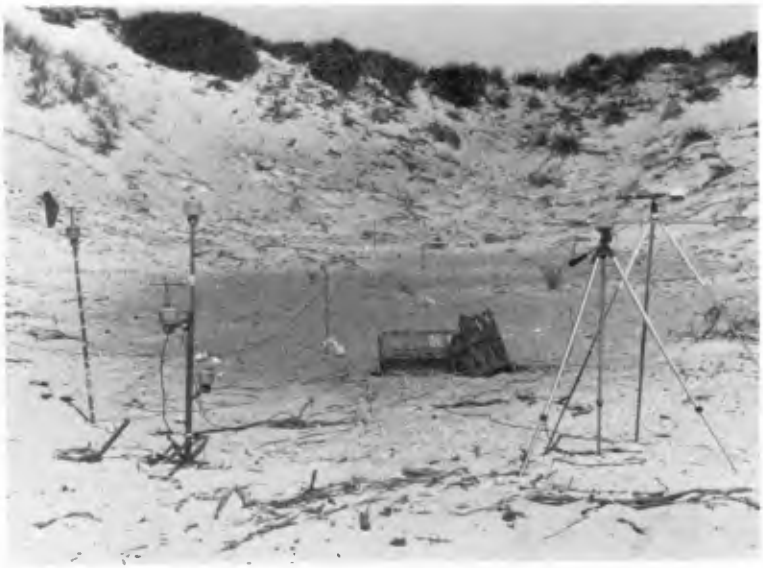


FIG. 5: Floor and west rim of amphitheatre

The mean wind speed is calculated from the counter readings by using the individual calibrations of the anemometers. For all the anemometers, the counting period began at almost the same time and had the same duration, so the mean speeds apply to effectively the same instant for one set of observations.

The wind direction is monitored with a portable, damped wind vane and magnetic compass.

The steadiness of the wind direction at both sites during the observation periods (generally to better than $\pm 10^{\circ}$) means that wind vectors, showing the speed and direction of airflow, can be constructed for each anemometer site. In addition, it is possible to construct isotach maps (showing lines of constant speed over an area) from the twenty-four average windspeeds centred at a particular time and measured at points across each site. This is done here from linear interpolations of the speed between adjacent anemometer stations.

Sand movement is measured with the aid of a 6-bin horizontal sand trap, with an effective downwind length of 1.5 metres. The mass of sand per unit time and per unit across-wind distance, in saltation and as surface creep, is calculated from the amount caught in the trap.

The textural (size distribution, shape, etc.) properties of the sand are determined by sieving and other standard sedimentological techniques.

RESULTS:

(a) Amphitheatre

The "surface" wind maps, showing the mean isotachs and wind vectors generally indicate that the velocities are higher near the floor of the amphitheatre and they progressively decrease towards the rim. The wind direction inside the depression depends strongly upon the direction of the undisturbed flow some distance from it. Two examples are illustrated in Figure 6.

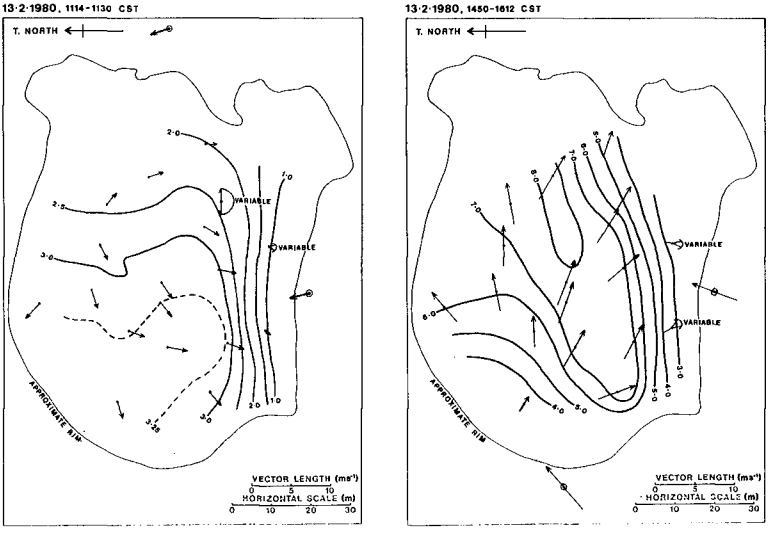


FIG. 6: Mean isotachs (ms^{-1}) and wind vectors in amphitheatre, 1114 to 1130 (left) and 1450 to 1612 (right), February 13, 1980.

The one on the left shows the isotachs for mid-morning, February 13, 1980, when the wind direction measured at the eastern rim was about 150°. At the time, the wind strength was insufficient to transport dry sand within the amphitheatre. On the same day, the wind veered to the southwest and freshened partly because of a change in the synoptic situation which reinforced a local sea-breeze. The one on the right applies to the later afternoon, by which time the wind speed was high enough to move sand on the north and south walls of

the amphitheatre. The isotachs show that the maximum speed was still confined to the floor, which was damp because of a shallow water table. No sand was moved from this relatively cohesive area.

Operation of a Gill UVW anemometer set erected on the east rim, when a strong and steady wind was blowing from the west in the amphitheatre, showed that the flow there was also quite steady. In addition, there was practically no evidence for any updraught from the amphitheatre.

It was observed that unobstructed airflow off the sea, as measured on the beach, had a more southerly component than at the western rim of the amphitheatre. Flow inside the depression had a decidedly westerly component, but the speeds on the beach and at the west rim were nearly identical.

The sand in the amphitheatre is predominantly medium to fine-grained, with mean values within the range 1.75ϕ to 2.10ϕ (phi = $-\log_2$ diameter in mm). Standard deviation (sorting) values, in the range 0.35ϕ to 0.55ϕ, show that the sand is well to moderately-well sorted. The values for skewness, or the third moment measure, vary from -.32 to +.52. Coarser sand grains occur at the western (seaward) and eastern flanks of the amphitheatre, while poorer sorting has been identified along its west-east axis. The sign of skewness varies from site to site, and there is no clearly-defined trend with height above the floor of the depression. The skewness vs sorting is shown in Figure 7.

(b) Active Transgressive Dune

So far, observations indicate that the wind flow over one of a number of parallel, elongated active transgressive dunes and originating in an extensive deflation hollow, appears to be quite smooth and regular. Both the wind direction and strength were almost constant over an averaging period, although there was a freshening in the afternoons from the same cause as reported for the amphitheatre. When wind directions were around 190° (off the sea and at roughly 50° to the dune ridge) the isotachs were parallel and uniformly spaced down the windward and leeward sides of the ridge. The pattern was slightly displaced to windward of the crest. The highest speeds occurred along the crest rather than on the exposed upwind slopes with their long fetch across the relatively flat deflation hollow. The wind always slackened towards the snout of the dune while on the lee side, the lowest speeds occurred on the floor of the valley between neighbouring dunes. The speed there was 42-47% below the value on the crest.

The wind direction veered slightly from the windward side to the crest and backed a similar amount to the lee. An example of the wind distribution is given in Figure 8.

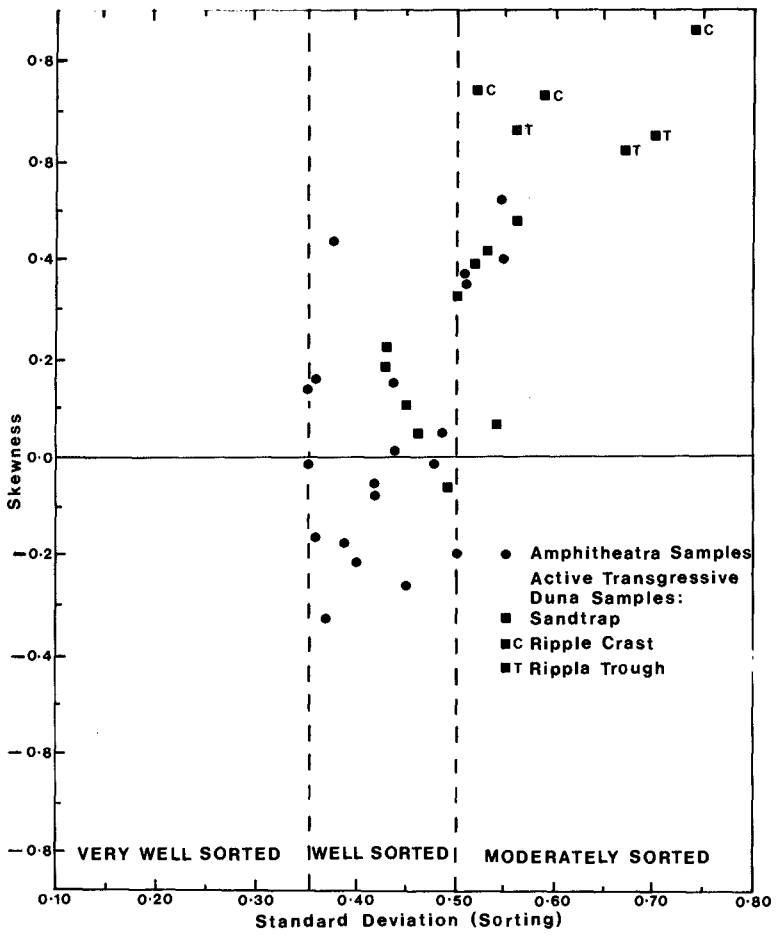


FIG. 7: Plot of the skewness versus standard deviation (sorting) for sand samples collected from the amphitheatre and active transgressive dune complex.

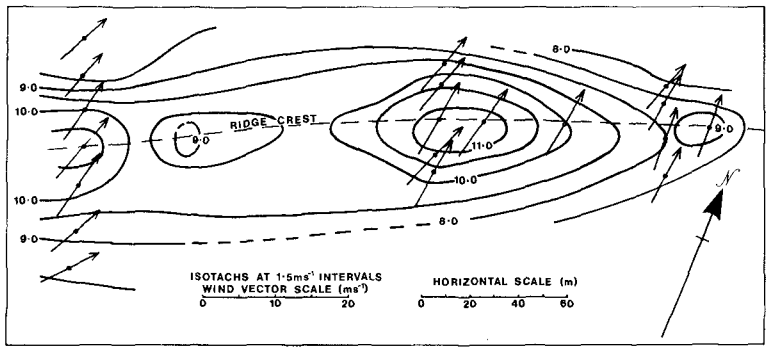


FIG. 8: Isotachs and wind vectors for active transgressive dune, February 15, 1980.

The windspeeds were sufficiently high to move a considerable volume of dry sand across the crest of the dune, and to carry fine dust high into the air. The amount of dry sand removed from some areas was sufficiently large to expose a moist, stable surface.

Analysis of the active transgressive dune sand shows that it is mainly medium-grained, with mean values between 1.65ϕ and 2.27ϕ. Overall, the dune sands are not so well sorted as those in the amphitheatre, with values in the range 0.43ϕ to 0.74ϕ. Except for one sample, the skewness values are positive and fall within the range +.05 to +.86 (see Figure 7). Such positive values are indicative of sands deposited under uni-directional flow conditions.

DISCUSSION:

The wind maps for each site show that, for the particular wind conditions recorded, the flow within the amphitheatre is much more complex than across the active transgressive dune. The wind vectors are the more informative parameters. At the amphitheatre, Figure 6 (left) shows that when the wind blows from 150° (as indicated by the two vectors at the eastern and southern sides outside the rim) there is pronounced reversal in the flow direction across the entire floor of the depression. This strongly suggests that a rotor forms in the lee of the southern rim for that particular wind direction. The nature of the circulation in both horizontal and vertical sections as deduced from Figure 6 (left) is sketched in Figure 9.

When the wind veered 50° from a direction along the crest of the main dune within which is the amphitheatre, the dominant contrary flow contracted to a small region high up on the southern wall, and was

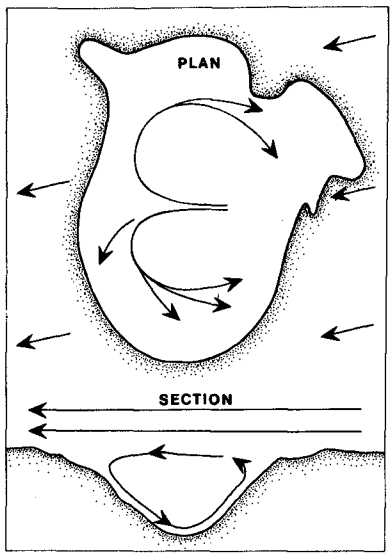


FIG. 9: Schematic diagram of wind circulation in amphitheatre (inferred from Figure 6, left)

replaced by a strongly-channelled flow through the amphitheatre from the west (Figure 6, right). The diminution in reversed flow is partly explained by the relatively low entrance to the amphitheatre from the west compared with the south (see sections in Figure 2, top). However, the main flow direction still differs appreciably from that of the unobstructed wind off the sea. Hence it is apparent that the foredune and main dune steer the flow to some degree, with the break in the main dune formed by the west rim, acting as a point of convergence for that flow. At the east rim, the flow was still from the west rather than the south-southwest, so the horizontal scale of any modification to the wind was of the same order as the length of the amphitheatre at least.

The wind observations in the amphitheatre suggest that the history of sand movement might be quite complicated in depressions. The sand could be moved from an area that is apparently sheltered from the unobstructed wind (but is actually exposed to a reversed flow) to a new location that becomes exposed subsequently to winds from other directions. The observations also suggest that sand should be preferentially removed from the bottom and transported outside, or deposited on the walls of the depression. Here, however, because the floor was continually damp, even during the height of a hot and dry summer, it is unlikely that significant amounts will be transported from this part of the amphitheatre. The observations to date suggest that the driest sand on the walls moves first. There is active deposition on the east and south walls, while some sand moves through a small col on the northeast rim to add to a small dune behind it. The source of the mobile sand appears to be within the amphitheatre itself because a fresh supply of beach sand must cross a barrier of about 50 metres of thick vegetation before it reaches the depression. Old soil horizons are exposed on those parts of the north and west walls which are depleted of sand.

The distribution of windspeed across the amphitheatre might be expected to produce a corresponding variation in such statistical parameters as the first moment (mean), standard deviation (sorting), the third moment (skewness) and the fourth moment (kurtosis). Although the samples collected at different sites within the amphitheatre are generally well sorted, there is no marked trend in the degree of sorting from site to site, apart from poorer grain sorting along the west-east axis of the depression.

Figure 7 shows that 50% of the sand samples from the amphitheatre are negatively skewed, thus indicating a coarse-grained tail in the distribution. It is possible that the skewness values partly reflect the history of the sands, as well as the subtleties of air-sediment interaction, if the material in the amphitheatre has been reworked repeatedly over geologic time and can be described as both *polygenetic* and *polycyclic*. However, higher moments are extremely sensitive to small changes and/or inaccuracies in the grain size distribution data, and therefore the values of these moments must be treated with caution (Hails, 1972). Obviously more analyses are needed to see if a relationship exists between environment-sensitive parameters and airflow within the amphitheatre.

Surprisingly, the airflow over the transgressive dune was comparatively simple. There was no reversal and only very slight steering of the wind by the dune itself. The absence of any lee eddy when the wind was blowing diagonally across the crest is presumably related to the smooth profile presented by that dune. The approximatley 45% decrease in speed from the crest to the valley floor between adjacent dunes means that sand in transport on the crest would be dumped in the lee if the critical velocity for sand transport was higher than the actual velocity there. This feature would cause the dune crest to move downwind over an extended period of time, rather like a barchan dune.

In contrast to the amphitheatre sands, those comprising the active transgressive dune complex are positively skewed, except for one sample. This trend is characteristic of both modern and fossil dune sands and, in this instance, reflects the relatively simple uni-directional airflow over the dune system.

Figure 7 shows that, overall, the dune sands are less well sorted than those in the amphitheatre. The elongated shell fragments and sand comprising ripple crests are coarser than those in the troughs.

REFERENCES

Bradley, 1969 A small sensitive anemometer system for agricultural meteorology. *Agr. Met. 6: 185-193.*

Hails, J.R. 1972 The significance and limitations of statistical parameters for recognising sedimentary environments. *Soc. Analyt. Chem. Proc. 9: 115-118.*