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TECHNIQUES FOR THE EVALUATION OF SURFACE WIND DATA IN TERMS OF EOLIAN SAND DRIFT

by

Steven G. Fryberger

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

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INTRODUCTION

The purpose of this report is to summarize briefly techniques presently in use by the U.S. Geological Survey (Denver) to analyze surface wind data in terms of eolian sand drift. These techniques were developed for regional analysis of surface wind directional and energy characteristics in connection with Chapter F "Dune Forms and Wind Regime" in U.S.G.S. Professional Paper 1052, "A study of Global Sand Seas", (Fryberger, 1978). These techniques essentially aim at quantifying and standardizing methodology used to analyze different types of wind data. The methods also allow easy interpretation of energy and directional properties of wind regimes with particular reference to sand blown about deserts, both as dunes and as streamers.

The approach adopted was suggested by Bagnold, (1954, p. 184). Winds were evaluated and defined in terms of potential sand-moving effectiveness through the use of a suitable weighting equation applied to a standardized set of data. In general, this approach proved excellent for analyzing the seasonal and directional properties of energy release for most of the arid regions studied in the professional paper. Our techniques stop short, however, of prediction of actual rates of sand drift in terms for example of m^3/m width-yr . This decision was made because it was felt that so little is known about the process of sand drift in deserts that such estimates might be incorrect, and tend to obscure the fact that much remains to be learned about the subject. Thus, the numbers referred to later as "drift potentials", "resultant drift potentials" and so forth, are relative only. However, these numbers do serve to illustrate well the various types of wind regimes in deserts - as studied with reference to potential sand-moving effectiveness. The magnitudes of numbers such as drift potentials, while exactly proportional to potential sand drift, have been adjusted in the computational process so that most values fall in a convenient size range, usually zero to 2,000 units. It seems practical to retain the terminology described later in this report for predictions of specific amounts of potential sand drift; but with a substitution of units. Thus, the "drift potential" at a place might be referred to as 450 "vector units"; or as 35 m^3/m width-yr, or 175 kg/m width-yr; depending on the approach desired by the investigator, and his confidence in his mathematical predictions. However, the use of the term "vector unit" described later, should be restricted to computations done exactly in the manner described in this report, since the final values are dependent upon the equation used, and an arbitrary division by 100 as a scaling factor. The use of "vector unit" terminology as described in this report will allow comparison of a wind system at any given place with the data available from the regional analyses performed on hundreds of wind summaries for the professional paper "A Study of Global Sand Seas".

SUITABLE TYPES OF WIND DATA

Sand drift refers to the process of sand movement as a result of surface winds. Most estimates of sand drift given in the report were made from surface wind tabulations known as "N-summaries". These were prepared by the Environmental Technical Applications Center of the U.S. Air Force. They are stored at the National Climatic Center, Asheville, North Carolina, U.S.A., and are available by station name or by World Meteorological Organization (W.M.O.) number. Each W.M.O. station summary normally contains both monthly and annual data. Wind speed is recorded in knots to the nearest 10^{o} of direction at 3- to 6-hour intervals. The period of record for stations used in this report averages 10 years.

Two N-summary formats are available (fig. 1). The first format (fig. 1A) is more useful because wind velocities are divided into 9 or 11 categories, whereas the second format (fig. 1B) has only 5 velocity categories. About 100 summaries using the first format were analyzed (both monthly and annual data). The linear-regression technique was used to estimate relative sand drift from 34 summaries in the second format.

Detailed wind data, other than the N-summaries, can also be obtained from some government offices, desert research organizations, corporations, and libraries. These data can then be reduced to a form similar to that shown in figure 1A, and evaluated by the same methods.

23194 YUMA ARIZONA IAP 48-71 ALL
STATION / STATION NAME / YEARS / MONTH

ALL WEATHER ALL
CLASS / HOURS (L.S.T.)

CONDITION

(A)

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥ 56	%	MEAN WIND SPEED
N	1.[illegible]	3.4	3.1	1.[illegible]	.4	.1	.0					5.7	8.0
NNE	1.[illegible]	3.8	2.5	.7	.1	.0	.0					7.7	6.6
NE	.8	2.1	1.1	.2	.0	.	.0					4.3	5.6
ENE	.5	1.1	.4	.1	.0	.0						2.2	5.7
E	.7	1.0	.3	.1	.0	.0	.0					2.2	5.7
ESE	.4	.9	.4	.1	.0	.0						1.7	5.8
SE	.5	2.6	1.9	1.5	.3	.0	.0					5.8	8.9
SSE	.5	1.9	3.0	2.2	.4	.0	.0					8.5	9.5
S	.5	2.6	3.2	1.6	.1	.0						8.4	7.9
SSW	.6	1.7	1.8	.7	.0	.0	.0					4.9	7.1
SW	.4	2.6	1.9	.3	.0	.0						5.6	6.2
WSW	.5	2.6	2.1	.4	.0	.0						5.7	6.5
W	.7	3.0	2.5	.5	.2	.1	.0					7.3	7.5
WNW	.5	2.3	2.2	1.5	.3	.1	.0	.0	.0			6.9	8.2
NW	.6	1.8	1.3	.5	.1	.0	.0					4.3	6.9
NNW	.6	1.7	1.8	.9	.1	.0	.0					5.1	7.8
VARBL													
CALM												9.6	
	10.0	33.8	29.6	13.6	2.1	.3	.0	.0	.0			100.0	6.7

TOTAL NUMBER OF OBSERVATIONS 160705

(B)

AIR WEATHER SERVICE . PERCENTAGE FREQUENCY OF SURFACE WINDS N SUMMARY #1

CLIMATIC CENTER 62271 KUFRA LIBYA

DATA PROCESSING DIVISION 24 13 N 023 20 E 1254 FT JAN

YEARS 49,51,52,53,54,56,57,58,59,60,61,62,63

DIRECTION	WIND SPEED GROUPS IN KNOTS 01-06	07-16	17-27	28-40	GTR 40	TOTAL %	TOTAL OBS	MEAN WIND SPEED/KTS
N	7.1	6.5	.3			13.9	268	7.4
NNE	3.4	2.1	.1			5.5	107	6.9
NE	2.6	2.7	.1			5.3	103	7.2
ENE	3.9	1.9				5.9	113	5.5
E	7.6	1.9				9.5	184	5.0
ESE	1.6	.3				1.9	36	4.4
SE	.9					.9	18	3.6
SSE	1.9	.8	.1			2.7	52	6.2
S	2.8	1.6	.1			4.5	86	6.1
SSW	2.6	1.2	.1			3.9	75	5.6
SW	.6	.2				.8	15	4.8
WSW	1.4	.6				2.0	39	5.1
W	2.6	.9				3.5	68	5.1
WNW	1.9	.8				2.7	52	5.5
NW	1.2	1.8	.2	.1		3.2	62	8.9
NNW	1.9	3.7	.5			6.1	117	9.4
VARIABLE CALM						27.8	536	
TOTALS	44.2	26.9	1.2	.1		100.0	1931	4.6

MAXIMUM WIND NW 30 KTS

Figure 1.-- Two types of N-summaries containing surface wind data from which estimates of relative sand drift can be made. (A) 11 velocity categories, (B) 5 velocity categories.

LIMITATIONS OF TYPICAL SUMMARIZED WIND DATA

N-summaries and other W.M.O. data are generally of good quality. However, methods of gathering data and summarization processes may introduce some systematic inaccuracies.

Inaccuracies introduced during data gathering occur primarily in two ways. The first, known as observer bias (Ratner, 1950, p. 185), is the tendency for weather observers to record wind occurrences from the prime directions rather than from intermediate directions of the compass. For example, when an observer is uncertain, he commonly records wind as coming from the northeast rather than the east-northeast.

A second type of inaccuracy occurs during data gathering because of deviations from standard observing conditons as specified in the W.M.O. "Guide to Meteorological Practices." One common occurrence is the mounting of an anemometer at a height other than the standard 10 m specified by the World Meteorological Organization. For example, the anemometer height at El Golea, Algeria, was 4 m during 1949-56, 22 m during 1956-60, and 7 m from 1960-73. Additionally, a station may be sheltered from the wind by nearby trees, buildings, or high ground.

The mounting of anemometers at nonstandard heights may slightly affect some calculations of drift potential, because threshold drag velocity assumed in calculations is based on wind velocity at a 10-m height. If anemometers are mounted lower than the standard 10 m, calculated drift potential will be slightly less than the true drift potential which would result from calculations based on a 10 m height. This is because wind velocities are lower near the ground; thus, the theoretical threshold velocity will be exceeded less often.

Inaccuracy also arises during summarization of data, usually in two principal ways. First, inaccuracy enters a summary when data is condensed from 36 to 16 compass directions. This is known as procedure error (Wallington, 1968, p. 293). The result is to create an apparent increase in observations from the prime compass directions at the expense of the intermediate directions. Second, summarizing of observations results in a coarsening of the resolution in terms of velocity, direction, and percent occurrence. Most percentages on N-summaries are expressed to the nearest 0.1 percent (fig. 1A). Depending on the number of observations, however, single occurrences may be represented in a summary as more than 0.1 percent. For example, an easterly maximum wind of 17 knots was recorded during October at T' ieh-kan-li-k'o, China, for which period only 137 observations are available. This single observation is represented as 0.7 percent of all observations. It is questionable whether this occurrence represents a group of winds which blew 0.7 percent of the time, or 5.2 hours of the 744 hours in October.

Corrections can usually not be made for the limitations just described because in large data sets it can not be known when and where they occur. Furthermore, techniques available for correcting observer bias and procedure error (Wallington, 1968, p. 296; Ratner, 1950, p. 186) can not be applied uniformly to the different types of wind summaries used in some studies. Detailed work involving the collection and summarization of surface-wind data would be improved by taking the factors previously discussed into account. However, these factors probably will not affect most data enough to detract from the general conclusions of a study.

EVALUATION OF WIND DATA

Selection of a Weighting Equation

A number of equations are available to compute rates of sand drift if the shear velocities are known. The most useful formulas, including those of Bagnold (1954), Kawamura (1951), and Zingg (1953) were tested by Belly (1964, p. 3-5) with data from his wind tunnel studies. All formulas were found by Belly to describe the data well when suitably evaluated. A formula suggested by K. and H. Lettau (written commun., 1975) produces a theoretical curve that agrees very well with Belly's work for 0.44-mm-diameter sand (fig. 2). For this reason, the Lettau equation for the rate of sand drift was used in this report as the basis for the weighting equation for sand movement, although other formulas probably would have given similar results. Lettau's equation is as follows:

$$\frac{qg}{C''p} = V^{*2}(V^{*} - V^{*}_{t}) \qquad (1)$$

where q = rate of sand drift

g = gravitational constant

C''= empirical constant based on grain diameter

p = (rho) density of air

V^* = shear velocity

V^*_t = impact threshold shear velocity, or the minimum shear velocity required to keep sand in saltation.

Additionally, $C'' = C'(d/d^*)^n$

where C' = universal constant for sand (approx. 6.7)

d = mean diameter of sand moved

d^* = 0.25 mm (standard size), and

n = empirical constant approximately equal to 0.5.

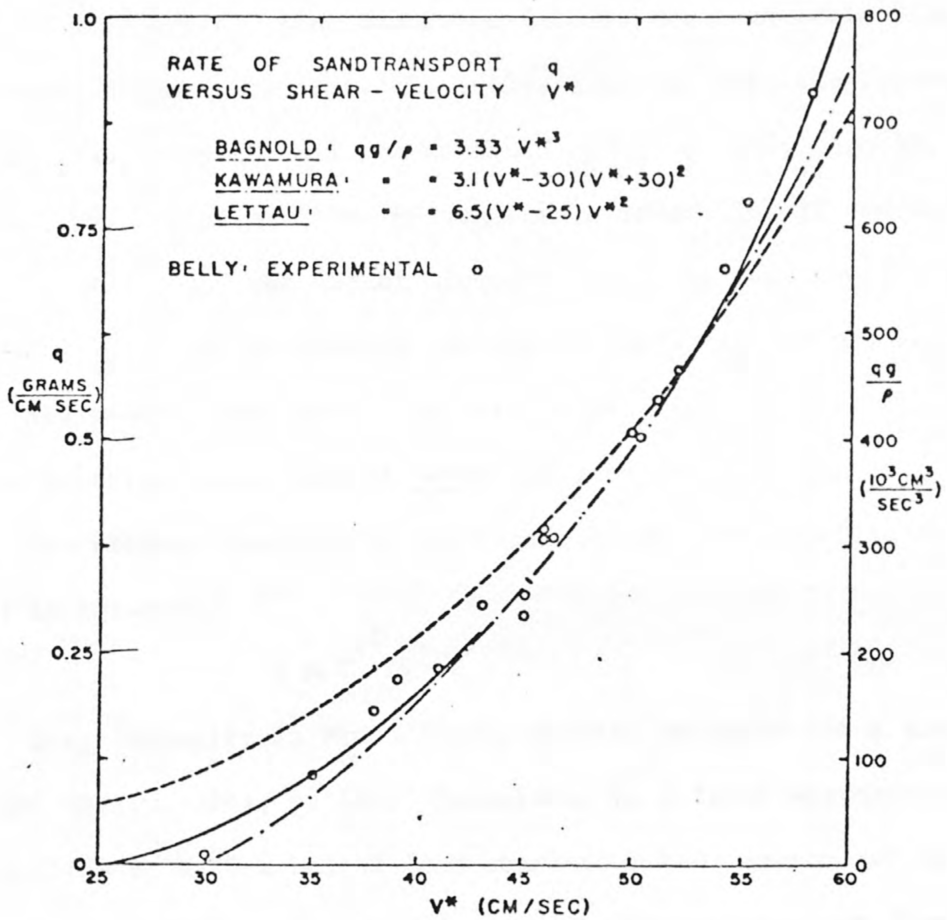

Figure 2.-- Rate of sand drift (grams moving per second across a crosswind distance of 1 cm, q, versus shear velocity, V^*, of air motion, according to theoretical curves by Bagnold, (1941), Kawamura (1951), and Heinz Lettau (1975, unpublished data) in comparison with wind tunnel measurements (circles) by Belly (1964 p. 17). Reproduced by permission of K. and H. Lettau, Meteorology Department, University of Wisconsin, Madison, Wisconsin, U.S.A.

all units are c.g.s.

Surface conditions, in addition to shear velocity, control the rate of sand drift. Four important factors are mean grain diameter of the sand (Bagnold, 1954, p. 67; Belly, 1964, p. 13), the degree of surface roughness (Chepil and Woodruff, 1963, p. 240; Bagnold, 1954, p. 71), the amount and kind of vegetative cover (Chepil and Woodruff, 1963, p. 221), and the amount of moisture in the sand (Belly, 1964, p. III 21). These parameters can not be evaluated for may localities. For this reason, wind energy at various places should be compared initially using relative quantities of potential sand drift.

The Lettau equation for the rate of sand transport can be generalized as follows:

$$q \propto V^{*2} (V^* - V^*_t). \qquad (2)$$

Drag velocity is proportional to wind velocity for a given height (Belly, 1964, p. 18). Therefore, as a first approximation, wind velocities at a 10-m height (the standard W.M.O. anemometer height) can be substituted for drag velocities. The Lettau equation then becomes:

$$q \propto V^2 (V - V_t), \qquad (3)$$

where V = wind velocity at 10-m height, and

V_t = impact threshold wind velocity at 10-m height (minimum velocity at 10-m height to keep sand in saltation.

This relationship (equation 3) can be used to produce a number which expresses the relative amount of sand potentially moved by the wind during the time it is presumed to blow. When the factor of time is added to equation 3 (threby creating equation 5, discussed later), the resulting number is referred to as the drift potential (DP) and is a measure of the relative amount of potential sand drift at a station for a stated period of time. For convenience, the units of drift potential are here called vector units (VU) because wind velocities are treated as vectors. The detailed method of computation of drift potentials is described next.

Calculation of Drift Potentials

Assumptions required to Apply the Weighting Equation. In order to use a weighting equation to determine the effect of surface winds, the condition of the surface over which the wind blows must be assumed. For most purposes, this surface can be assumed to consist of loose quartz sand grains with an average diameter of 0.25 to 0.30 mm. The surface must further be assumed to be without bedforms larger than ripples, to be dry, and to be without vegetation since generally these parameters can not be known exactly over a wide area. Similar surfaces have been used for most wind tunnel studies of sand drift, and 0.25 to 0.30 mm is the average diameter of many desert dune sands (Ahlbrandt, 1978, fig. 21). The assumed surface might not serve to predict actual rates of sand drift in areas with very large dunes, but it is useful when comparing one area to another in terms of available wind energy.

A threshold wind velocity must be determined in order to use a weighting formula. For a sand surface of 0.30-mm average diameter quartz sand, the surface roughness factor (Z') as determined by Belly (1964, p. 11-12) during sand driving was 0.3048 cm. The threshold wind velocity at height Z', (V_t') was 274 cm/s and V_t^* was 16 cm/s. V_t' can be extrapolated to a 10-m height (the height at which most wind data are collected) using the equation (Bagnold, 1954, p. 104):

$$V_{t(10\ m)} = 5.75\ V_t^* \log \frac{Z}{Z'} + V_t'. \qquad (4)$$

When this is done, a value of 11.6 knots is obtained for V_t (impact threshold wind velocity at 10 m height).

This value indicates that for the conditions described, threshold wind velocity as measured at a 10-m height should be within the 11-16 knot velocity category on N-summaries such as that shown in figure 1A. For this report a value of 12 knots was chosen for $V_{t(10\ m)}$.

The assumption must also be made in most instances that a wind speed and direction component occurs in nature for an amount of time proportional to its percentage in a summary. With a few exceptions, such as that previously discussed for T'ieh-kan-li-k'o, China, this assumption seems reasonable, because periods of record are often long, observations are taken at different times of day and night, and each annual N-summary usually averages more than 1000 observations.

Derivation of weighting factors Weighting factors as used here are numbers which represent the relative rates at which winds of differing average velocities can move sand. These numbers are derived by substitution of values for wind velocity (average wind speed of a velocity category) into the weighting equation of Lettau (equation 3) as shown in table 1.

The weighting factors represent rates of sand transport, and the percentages of wind occurrence in the summaries represent the length of time during which the winds blew. Therefore,

$$Q \propto V^2(V - V_t)t, \qquad (5)$$

or, $Q \propto$ (weighting factor) x (time as percent)

where t = time wind blew, expressed as a percentage on N-summary; and

Q = annual rate of sand drift.

Table 1.-- Derivation of weighting factors for relative rate of sand transport by substitution of average wind velocities into the generalized Lettau equation (equation 3 in text). (The value of $V^2(V - V_t)$ is divided by 100 to reduce weighting factors to smaller sizes for convenience in plotting sand roses, as described in text. Velocities exceeding 40 knots are rare in data used in this report and are not computed.

N-summary velocity category (knots)	Mean velocity of winds in category (V,kts.)	V^2	$(V-V_t)$	weighting factor $V^2(V-V_t)/100$
11-16	13.5	182.3	1.5	2.7
17-21	19.0	361.0	7.0	25.3
22-27	24.5	600.3	12.5	75.0
28-33	30.5	930.3	18.5	172.1
34-40	37.0	1,369.0	25.0	342.3

To evaluate the relative amount of sand drift which potentially occurs at a station, the weighting factor derived from equation 3 for each velocity category is multiplied by the percentage occurrence of wind in that category for all 16 directions (or more) of the summary, and the results are totaled. This computation is shown for a single direction in table 2.

Table 2.-- Computation, from N-summary, of vector unit total from the west-northwest, Yuma, Arizona, U.S.A.

(The drift potential at the station is the sum of the vector unit totals computed in the same manner from each of the 16 compass directions. Total vector units from west-northwest equals 18.6. Drift potentials are usually rounded to nearest whole unit. Wind data shown in figure 1A.

	velocity category (knots)				
	11-16	17-21	22-27	28-33	34-40
Weighting factor	2.7	25.3	75.0	172.0	342.3
Percent occurrence	1.3	.3	.1	0	0
Vector units	3.5	7.6	7.5	0	0

Calculations of this sort are tedious, therefore, a programmable calculator was used for much of the work of this report. The most convenient expression of the results is the "sand rose" diagram, construction of which is described later.

Calculation and Plotting of Sand Roses

A sand rose is a circular histogram which represents potential sand drift from the 16 directions of the compass (fig. 3). The arms of a sand rose are proportional in length to the potential sand drift from a given direction as computed in vector units. Thus, a sand rose expresses graphically both the amount of potential sand drift (drift potential) and its directional variability.

These diagrams differ from paleocurrent roses constructed from crossbedding dip directions, because the arms point toward the direction from which sediment moved, that is, "into the wind". Sand Roses are based on surface wind only and thus reflect only potential sand drift. The pattern indicated by a sand rose may be considerably modified by local conditions.

Sand roses can be plotted with a Hewlett-Packard 9810 A calculator and 9862 A plotter [1/] or similar programmable calculator-plotter system. When the vector unit total for any direction exceeds 50, all arms of that sand rose are divided by two until the longest arm of the sand rose plots at less than 50 mm in length. The number by which the arms are divided is known as the reduction factor and is shown in the center circle of the sand rose when desired (fig. 3).

Vector unit totals from the different directions can be resolved to a single resultant. The direction of this computed resultant is referred to as the resultant drift direction (RDD), as shown on figure 3. The RDD expresses the direction which sand would tend to drift under the combined influence of winds from the different directions. The

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1/ Use of a specific brand name does not necessarily constitute endorsement of the product by the U.S. Geological Survey.

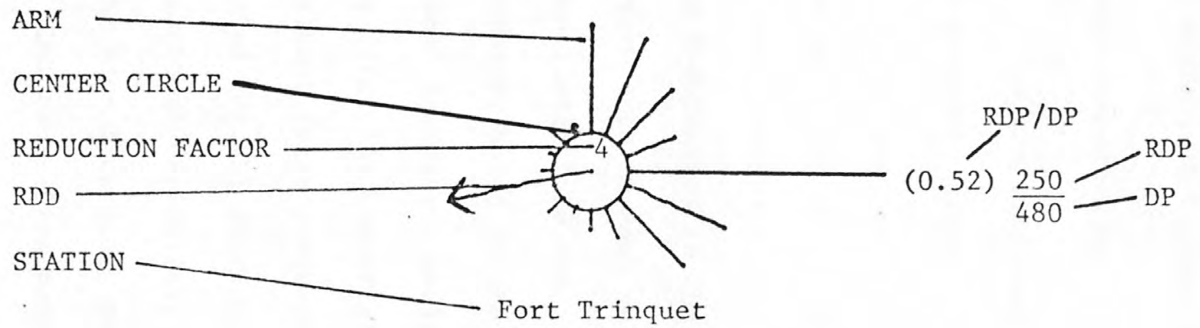

Figure 3.-- A Sand Rose. Components are as follows: Arm (vector unit totals, plotted in mm), proportional in length to potential amount of sand drift from a given direction toward center circle. Reduction factor, number by which vector-unit total of each sand rose arm was divided so the longest arm would plot at less than 50 mm. DP (drift potential) is in vector units, measure of relative sand moving capability of wind; derived from reduction of surface-wind data through a weighting equation (equation 3 in text). RDD (resultant drift direction),net trend of sand drift. Station, name of meteorological station at which wind data was recorded. RDP (resultant drift potential) net sand moving capability of all winds at a station, in vector units.

magnitude of the resultant drift direction may be found from the same data, using the Pythagorean theorem, and is referred to as the resultant drift potential (RDP). The RDP expresses, in vector units, the net sand transport potential when winds from various directions interact.

Additional Computations

"estimated" drift potentials Surface wind data summarized in formats coarser than that of the type N-summary shown in figure 1A were considered to require so many approximations to analyze for drift potentials that the results must be thought of as estimates. Thus, drift potentials were estimated in this report for a number of stations in India, Libya, and China for which only those N-summaries in the less detailed format (fig. 1B) were available. Percentages in each velocity category of the figure 1B summary were apportioned into two smaller velocity categories of the figure 1A summary, based on the ratios of adjacent percentages established by linear regression analysis, using data from 36 randomly selected, detailed (fig. 1A) summaries for each computation.

RDP/DP The ratio of the resultant drift potential to the drift potential --the RDP/DP (ratio) was computed for all stations in the study. The RDP/DP is an index of the directional variability of the wind. Where the wind usually comes from the same direction, the RDP/DP approaches unity. In contrast, where the wind comes from many directions, the RDP/DP approaches zero because the resultant drift potential is very low.

Absolute rates of sand drift Although this study uses only qualitative estimates of rate of sand drift, quantitative rates can be predicated using equation (1). The relationship of drift potential to annual rate of sand drift predicted by this equation for two presumed threshold drag velocities is shown in figure 4.

CLASSIFICATION OF WIND ENVIRONMENTS

Direction of Surface Winds

Most sets of surface wind observations, such as those used in this report, exhibit groupings, or distributions, in terms of both direction and speed (for example, figs. 1A,1B). Some sets of surface-wind-direction distributions may be described as elliptical, or may be complicated because of mixed land and sea breezes, through mixtures of seasonal flows, or for other reasons (Crutcher and Baer, 1962, p.522). For example, the 360-point directional wind rose for Juraid Island, Arabia, (fig. 5) indicates four groups of wind; a group from the west, northwest, northeast, and southeast. However, most directional observations at Juraid Island are encompassed within groups of winds from the west and northeast which make an obtuse angle with each other. Sand roses plotted from surface wind data reflect such directional groupings. Although surface wind distributions, such as that for Juraid Island, can be very complex in detail, experience indicates that, as a first approximation, five relationships of directional distributions occur frequently. These relationships form the basis for the classification of directional characteristics of effective winds in terms of sand roses shown in figure 6. The five commonly occurring wind regimes (fig. 6) are:

Narrow unimodal.-- 90 percent or more of the drift potential at a station falls within two adjacent directional categories (16 point data) or a 45° arc of the compass.

Wide unimodal.-- any other directional distribution with a

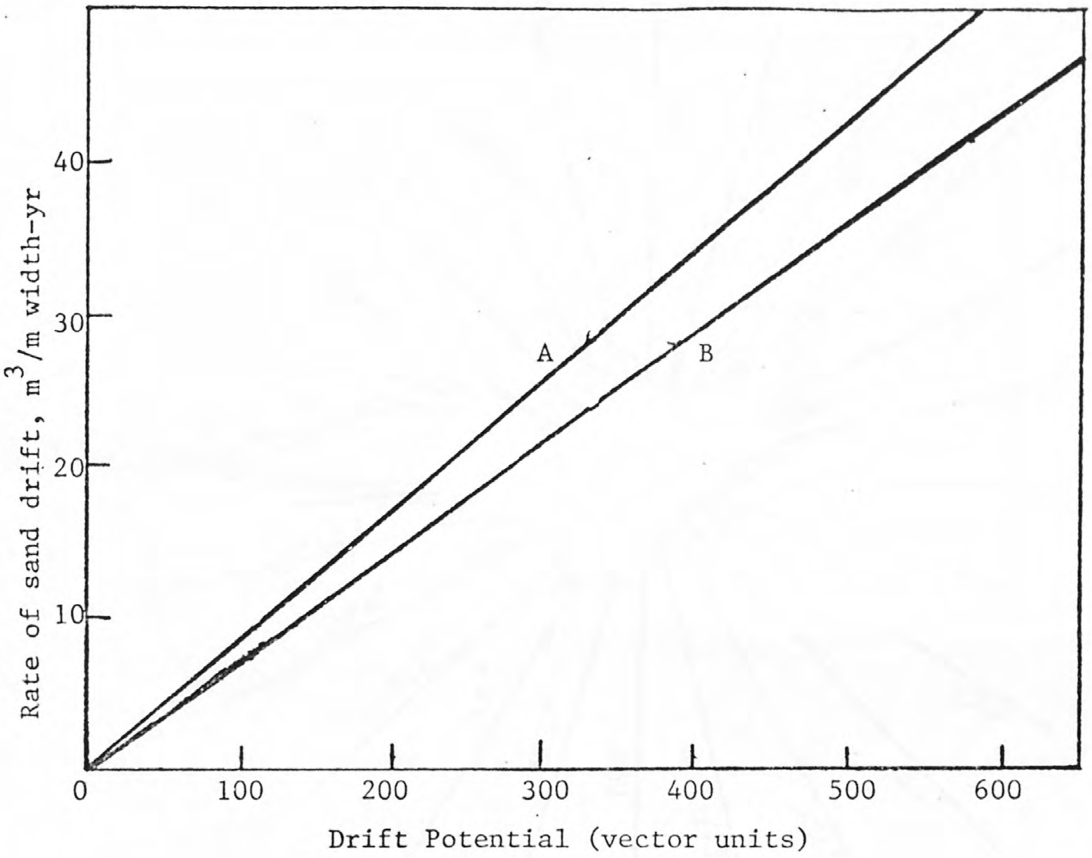

Figure 4.-- Drift potential (annual) versus annual rate of sand drift across a 1-metre section normal to the drift direction for two threshold drag velocites, according to the Lettau equation (equation 1 in text). Line A, V_t^* = 16 cm/s (Belly, 1964, p. 11); line B, V_t^* = 19 cm/s (Bagnold, 1954, p. 60). Bulk density of 1.34 g/cm^3 assumed for loosely packed quartz sand grains.

POLAR COORDINATE HISTOGRAM PLOT
OF DIRECTION

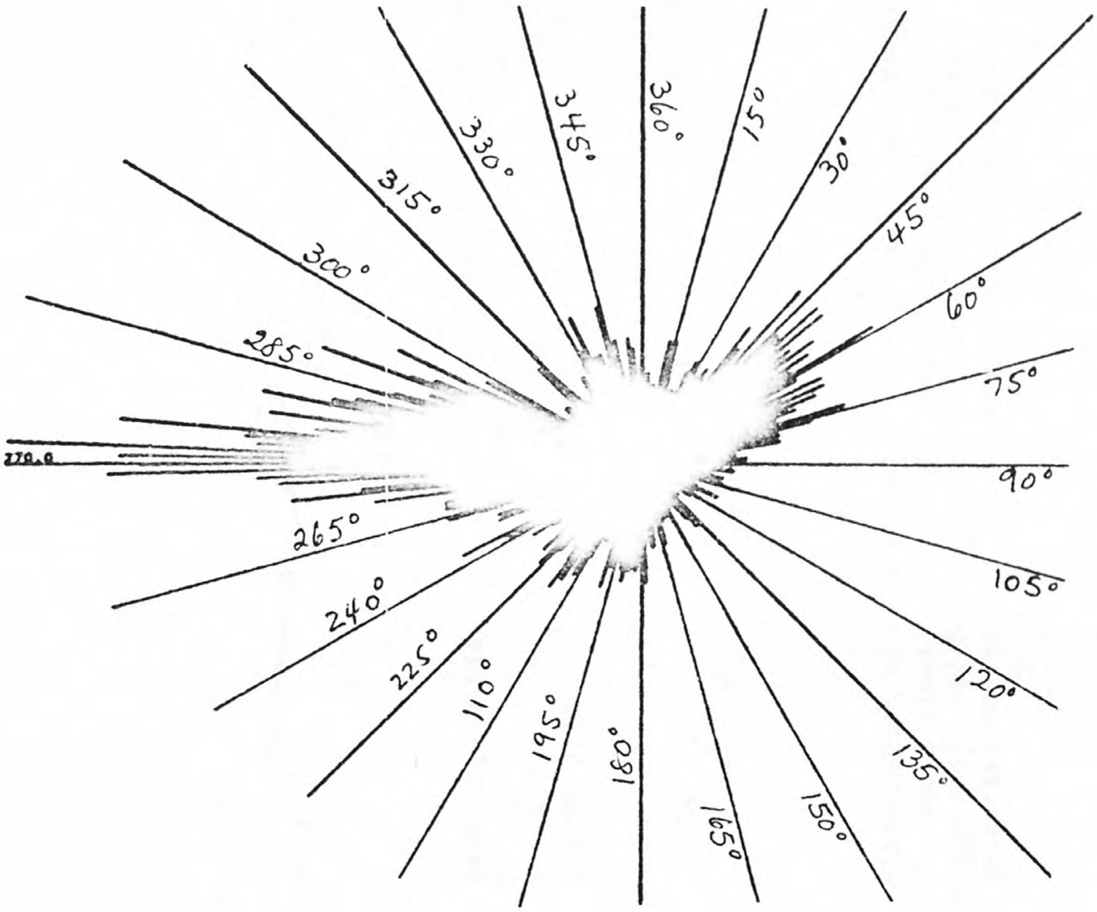

Figure 5.-- Wind rose for Juraid Island, Arabia (lat 27° 12'03" N., long 49°57'23" E.) showing relative numbers of wind observations for 360° of the compass. Lengths of arms of the rose are proportional to the number of times the wind came from a given direction. Winds from the west and northeast constitute the dominant groups. Based on wind records during March 10-April 10, 1971, observations at 15 minute intervals. (Data from Arabian American Oil Co.).

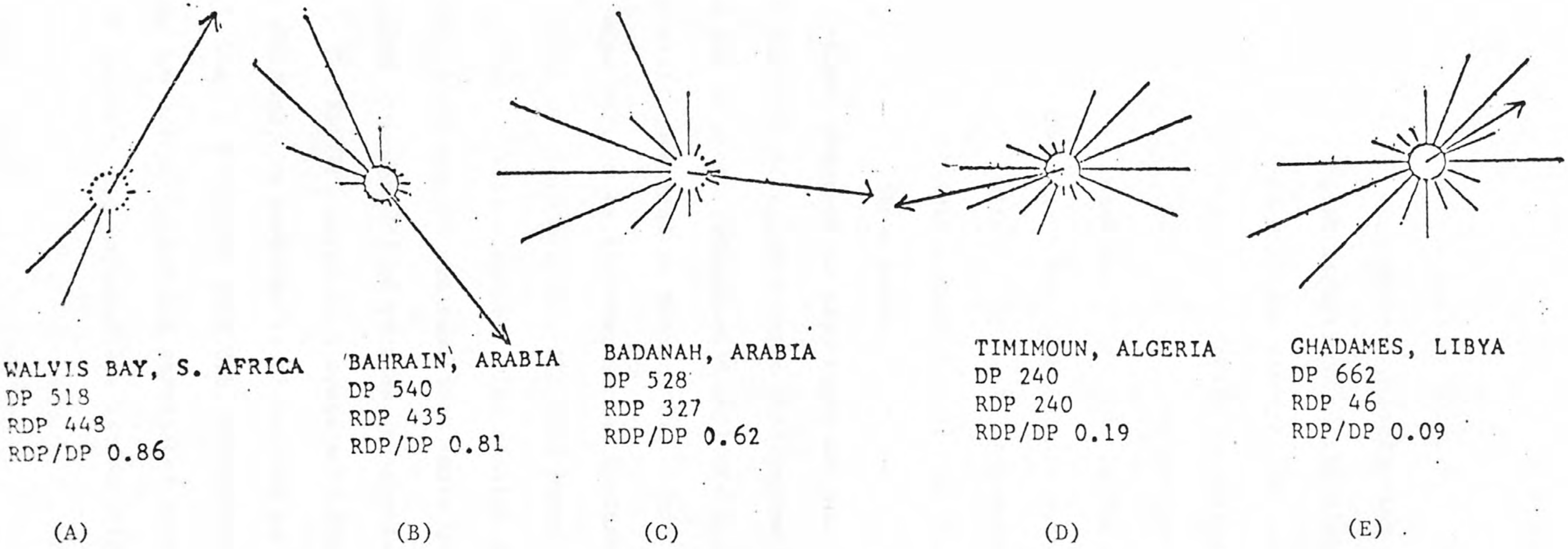

Figure 6.-- Five commonly occurring relationships of directional distributions on sand roses. A, Narrow unimodal; B, wide unimodal; C, acute bimodal; D, obtuse bimodal, (a special instance in which the modes are almost exactly opposed); and E, complex. DP is drift potential in vector units, RDP is resultant drift potential in vector units. Arrows indicate resultant drift direction (RDD).

single peak or mode.

Acute bimodal.-- a distribution with two modes, in which the peak directions of the distributions (longest arms on the sand rose) of the two modes form an acute angle (here arbitrarily including also the right angle, 90^{o}).

Obtuse bimodal.--a distribution with two modes, in which the peak directions of the two modes form an obtuse angle.

Complex.-- any distribution with more than two modes, or with poorly defineable modes. The 16 point directional data commonly available will not clearly show more than three modes.

Modes observed on sand roses are not considered to be significant for purposes of classifying a wind regime if the modal direction and the two adjacent categories constitute less than about 15 percent of the drift potential at the station. This simplifies the classification of wind regimes by focusing on the dominant modes that are usually controlled by large pressure systems. All sand roses tend to reflect procedure and observer bias. Extreme bias results in a "sawtooth" pattern of arms. This pattern can sometimes make unimodal or bimodal wind regimes seem bimodal or complex, respectively.

The RDP/DP, which is a measure of the directional variability of the wind, is arbitrarily classified as follows; 0.0 to less than 0.3, low; 0.3 to less than 0.8, intermediate; 0.8 or greater, high. Many low RDP/DP ratios are associated with complex or obtuse bimodal wind regimes, the intermediate ratios with obtuse bimodal or acute bimodal wind regimes, and the high ratios with wide and narrow unimodal wind regimes.

Energy of Surface Winds

Drift potentials, which are measures of the energy of surface winds in terms of sand movement, are classified according to rough groupings of average annual drift potential for the desert regions shown in table 3. The deserts in China (127 VU; 81 VU) and India (82 VU) constitute a low energy group. The northern Saudi Arabian (489 VU) and northwest Libyan (431 VU) deserts are a high-energy group. All other deserts studied are in the intermediate-energy group. On the basis of this breakdown, low-energy wind environments have drift potentials less than 200 VU; intermediate-energy wind environments have drift potentials of 200-399 VU; and high-energy wind environnents have drift potentials of 400 VU or greater. This grouping of regions by wind energy in terms of potential sand movement applies only to the generally arid regions surveyed during this study. Other regions probably have different average drift potentials (perhaps very much higher than desert regions, many of which are known to be relatively calm). However, within the regions studied, the differences in relative sand-moving wind energy are related to specific weather patterns.

Further, the relative wind energies (in terms of sand movement) shown in table 3 are rough approximations. In fact, most desert regions are strongly zoned in terms of wind energy.

Table 3. --Average monthly and annual drift potentials for 13 desert regions, based on data from selected stations

*, drift potentials estimated; (---), no data

Desert region	Number of Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual drift potential
High-energy wind environments														
Saudi Arabia and Kuwait (An Nafūd Desert, north)	10	35	39	52	54	51	66	49	33	20	18	16	25	489
Libya (Northwest Desert)	7	40	42	48	64	51	41	20	18	24	24	22	37	431
Intermediate-energy wind environments														
Australia (Simpson Desert, south)	1	43	40	27	17	13	10	18	26	52	56	46	43	391
Mauritania (Western Desert)	10	45	49	45	38	33	40	26	19	20	20	19	30	384
U.S.S.R. (Peski Karakumy, Peski Kyzylkum Deserts)	15	39	41	43	43	33	25	22	21	23	23	24	29	366
Algeria (Erg Oriental and Occidental)	21	21	27	37	48	32	27	18	13	15	16	16	23	293
South-West Africa (Namib Desert)	5	8	2	6	17	13	50	19	22	27	44	17	12	237
Saudi Arabia (Rubʿ al Khali Desert, north)	1	23	28	53	32	20	30	---	---	---	1	7	7	201
Low-energy wind environments														
South-West Africa (Kalahari Desert)	7	14	11	8	10	9	11	18	24	26	26	17	18	191
Mali (Sahelian Climatic Zone, Niger River)	8	9	12	14	12	19	22	15	9	10	5	5	7	139
China (Gobi Desert)*	5	9	11	16	23	20	11	7	5	5	5	7	8	127
India (Thar Desert)*	7	2	2	5	5	10	21	19	9	5	2	1	1	82
China (Takla Makan Desert)*	11	3	2	9	16	16	9	9	5	4	5	2	1	81

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