Wind Velocities Associated with Dust Deflation Events in the Western Sahara

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(Manuscript received 5 March 1986, in final form 9 January 1987)

ABSTRACT

Data from eight meteorological stations in the western Sahara for the period 1 July–15 August 1974 indicate that the mean wind velocity associated with dust-raising events is about 10.5 m s\(^{-1}\). The mean deflation velocity at individual stations ranged from 6.5 to 13.0 m s\(^{-1}\). At most stations the wind velocity associated with the onset of a dust-raising event (the threshold velocity) appears to be a reproducible characteristic of the environment. Threshold velocity variations appear to be attributable in part to differences in soil and terrain characteristics at the stations.

1. Introduction

The threshold velocity is the minimum wind speed required to initiate deflation of surface sediments. At this velocity the aerodynamic drag on the surface is sufficient to dislodge particles from the surface, setting them in motion and lifting them into the atmospheric boundary layer. The threshold velocity depends on a number of soil and sediment characteristics such as particle sizes and shapes, soil composition and moisture content, and the aerodynamic properties of the surface (Gillette et al., 1981). Because soil properties can be quite variable, the threshold wind velocity could vary widely from place to place and even with time at the same place. Dust generation is also affected by many larger scale characteristics of soils and terrains (Bagnold, 1941; Gillette et al., 1981; McCauley et al., 1981; Greeley and Iverson, 1985).

We are interested in factors that effect large-scale dust storms in North Africa. Previous studies (Carlson and Prospero, 1972; Prospero, 1981; Prospero and Nees, 1977, 1986; Jaenicke and Schutz, 1978) have shown that large numbers of dust storms emerge from the west coast of North Africa during much of the year. Dust from these events is frequently transported across the Atlantic by the trade winds. Long-term studies of mineral aerosol at Barbados, West Indies, (Prospero and Nees, 1977, 1986) show a very large annual cycle with the maximum concentrations occurring in the summer months. High concentrations of Saharan dust are also found during the summer as far north as Miami (Carder et al., 1986; Prospero, et al., 1986) and Bermuda (Chen and Duce, 1983).

In this work we study the relationship between the occurrence of dust events and the anemometer wind speed as reported by meteorological stations in the Sahara. In particular, we wished to see if there were a characteristic wind speed at which dust was mobilized in the locality of the reporting station and if this characteristic wind speed differed from station to station. We refer to this characteristic wind speed as the threshold velocity. The use of the term “threshold velocity” in this context is somewhat different from that in micrometeorological studies of soil deflation where the threshold velocity is usually reported in terms of the surface friction velocity (Greeley and Iverson, 1985). While the threshold velocities reported here cannot be accurately converted to an equivalent friction velocity, they can provide some insights on the macroscopic factors controlling soil deflation.

2. Data and method of analysis

This study covers the period 1 July–15 August 1974, which coincided with the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE). GATE provided us with a larger meteorological data set and improved coverage of North Africa via the SMS-1 geostationary satellite. Ancillary studies of dust events during 1974 (Prospero, 1981) revealed that many of the largest dust outbreaks observed off the west coast of Africa could be traced to immense dust storms over the western Sahara. These storms were clearly visible in infrared imagery (Prospero, 1981).

For our study we used data from the major reporting stations in the western Sahara: Beni Abbes, Timimoun, Ain Salah, In Amenas, Ghadames, Fderik, Nouadhibou and Akjoujt (Fig. 1). These stations are all located in a region where synoptic-scale dust storms were most frequently observed on satellite imagery (Prospero, 1981; Prospero and Carlson, 1981). All stations are located in hyperarid regions.

Data on surface wind speed and dust-related phenomena were obtained from the 1200 UTC surface meteorological observations from the eight stations. We

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used only the 1200 UTC data because the analysis of IR satellite imagery showed that major duststorms generally began in the late morning and the early afternoon (Prospero, 1981). The standard meteorological reporting SYNOP codes (WMO, 1974) permit the identification of four different classes of dust-related conditions: 1) dust being raised from the ground at the time of observation (08); 2) dust storms of various degrees of intensity (29, 30, 31, 32, 33, 34, 35); 3) dust suspended in the air but not being raised from the ground at the time of observation (06; presumably, remnants of an earlier deflation event); and 4) haze (05; presumably caused by dust). All the surface wind speed observations and the associated dust phenomena (when reported) were tabulated and then plotted in the form of frequency diagrams for each station. The tabulations and diagrams allow us to determine the lowest wind speed capable of raising dust from the ground (the threshold wind velocity) at each station. They also allow us to determine the highest wind speed that occurred in the absence of rising dust, a value that can be used to confirm the threshold wind velocity. Our procedure is similar to that used by Morales (1979) in a study of deflation winds in the vicinity of a single station in the Sudan.

3. Results

Dust-raising events were associated with a range of wind speeds. The frequency of occurrence of dust events at all stations as a function of wind speed is shown in Fig. 2. Of the 41 events, 32 (78%) were associated with winds between 6.5–13.5 m s\(^{-1}\).

Table 1 presents a summary of the wind speed characteristics at each station for dust-raising events and for cases where dust was not raised. The mean wind speed for all dust-raising events was 10.5 m s\(^{-1}\); however, the means for the individual stations extended over a considerable range, from 6.5 m s\(^{-1}\) (Ain Salah, six events) to 13 m s\(^{-1}\) (Timimoun, nine events). Some stations experienced relatively few dust events, three of them having only two or three deflation episodes; consequently, the data from these stations might be statistically unreliable.

Also shown in Table 1 is the lowest wind speed observed in association with a dust-raising event at each station. These values can be regarded as an approximation of the threshold velocity for the vicinity of each station. The mean of the lowest deflation wind speed at each station was 8.2 m s\(^{-1}\); the range is rather broad: 5 to 12.5 m s\(^{-1}\).

The mean wind speed for all meteorological observations where no deflation was observed was 4.5 m s\(^{-1}\). Included in this category are 1) reports of haze; 2) cases of dust suspended in the air but not being raised from the ground at the time of the observation; and 3) meteorological reports that do not cite any dust-related phenomena. The highest wind speed observed in the absence of deflation at each station is also shown in Table 1; the average of these maximum dustless winds is 9 m s\(^{-1}\), and the range is 6 to 11 m s\(^{-1}\), values that are quite close to those observed for the lowest wind speeds observed during deflation events.

Although the range of values is relatively large for all stations, the data for individual stations are internally consistent. This can be seen more clearly in Fig. 3a–h, which presents frequency diagrams for deflating and nondeflating winds at each station. Note that at most stations there is a relatively clear demarcation between the wind speed range that characterizes dust generation and wind speeds where deflation does not occur. The one notable exception is Ain Salah where a considerable overlap exists. In a few cases, the highest wind speed observed without dust is greater than the lowest wind speed deflation event. The difference could be due to a number of factors such as errors in the
Table 1. Wind speeds associated with cases where dust was raised and where dust was not raised.

<table>
<thead>
<tr>
<th>Cases where dust was raised</th>
<th>Cases where dust was not raised</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
<td>Mean wind speed (m s(^{-1}))</td>
</tr>
<tr>
<td>Ain Salah</td>
<td>6</td>
</tr>
<tr>
<td>Akjoujt</td>
<td>5</td>
</tr>
<tr>
<td>Beni Abbes</td>
<td>3</td>
</tr>
<tr>
<td>Fderik</td>
<td>2</td>
</tr>
<tr>
<td>Ghadames</td>
<td>2</td>
</tr>
<tr>
<td>In Amenas</td>
<td>5</td>
</tr>
<tr>
<td>Nouadhibou</td>
<td>9</td>
</tr>
<tr>
<td>Timimoun</td>
<td>9</td>
</tr>
</tbody>
</table>

Reporting of wind speeds, differences in wind direction and gustiness and changes in soil conditions such as moisture or land use.

In general, at any one station there is at most about 2 m s\(^{-1}\) difference between the lowest threshold wind speed accompanying deflation and the highest wind speed.
speed observed without deflation. This is strong evidence that the threshold wind speed is probably in this approximate range. The fact that the threshold values differ from one station to another suggests that the local environmental parameters controlling deflation are also important and that they are a fairly well defined characteristic of the area.

4. Discussion

The range of threshold velocities observed by us are generally consistent with values reported in the literature. Morales (1979) found a threshold velocity of about 6 m s\(^{-1}\) using data from Dongola, Sudan, during April 1973. Shikula (1981) indicates that about 30% of the dust storms cases in Ukraine (U.S.S.R.) occurred during winds in the 6 to 10 m s\(^{-1}\) range with a very small percentage at the 5 m s\(^{-1}\) value. Most events (64%) occurred at wind speeds greater than 11 m s\(^{-1}\). Studies at several sites in the United States indicate threshold velocity values of 7.5 m s\(^{-1}\) or less. McCauley et al. (1981) report that a 6.5 m s\(^{-1}\) wind is capable of starting motion of fine-grained sand at a location near Clovis, New Mexico. Warn and Cox (1951) indicate that loose clay and silt particles are mobilized and transported close to the ground by 6.5 m s\(^{-1}\) wind speed in the Lubbock, Texas area. Based on threshold friction velocities (about 20 cm sec\(^{-1}\)) and roughness heights (from about 0.1 to 0.001 cm) given by Gillette et al. (1981) for various disturbed soil types in the Mohave Desert, we calculate (by assuming a logarithmic wind profile) that the threshold wind speed at 10 m above the site was in the range of 5 to 7 m s\(^{-1}\).

It is noteworthy that in this study two stations accounted for almost half of the deflation events: Nouadhibou and Timimoun (nine events each). The wind deflation statistics for these two stations are quite similar. The mean wind speeds for deflation were 12.5 and 13 m s\(^{-1}\), respectively, and the mean speeds in the absence of deflation were 7 and 7.5 m s\(^{-1}\). The lowest speed deflation winds (10 and 8.5 m s\(^{-1}\)) and also the highest speed winds without deflation (11 and 10.5 m s\(^{-1}\)) are quite similar. The two stations are located about 2000 km apart (Fig. 1) and the terrains in the region of these two stations are quite different. Nouadhibou is located on the coast of Mauritania in a region of extensive sand dune fields; the high threshold velocity is reasonable since it is known that dune sands are relatively difficult to mobilize and dunes are relatively poor sources of fine dust.

On the other hand, stations that are located in the same region can have quite different characteristics. For example, Timimoun and Ain Salah are located in terrains that are geologically similar, yet the deflation wind characteristics appear to be quite different. This difference could be attributable to the fact that the meteorological station at Timimoun is located at an airport on the edge of a dune field on a sandy tableland east and above the town; thus the threshold speed at the airport could be considerably higher than in the valley below. On the whole, our data suggest that the threshold velocity characteristics of stations are determined by meteorological, geological and surficial features that might be relatively localized.

We summarize in Fig. 4 the frequency of occurrence of dust events at all stations as a function of wind speed; percentages are based on the total number of meteorological reports for the indicated wind speed interval. Note that there is a significant increase of dust-raising cases from the 5 to the 7.5 m s\(^{-1}\) categories. The increase reflects the fact that the average threshold wind velocity for the eight stations (8.2 m s\(^{-1}\)) is in the 7.5 m s\(^{-1}\) wind category. Deflation is observed at all times at wind speeds in the range of 11.5 to 13.5 m s\(^{-1}\) and above. (Note, however, that the data for winds above 10 m s\(^{-1}\) is dominated by Nouadhibou and Timimoun). Also displayed in Fig. 4 are the percentages of haze cases and of cases of dust suspended in the air (but not being raised from the ground). In contrast with the dust-raising cases, the percentages of haze cases and of cases of dust suspended in the air (but not being raised from the ground) start to decrease at the 7.5 m s\(^{-1}\) wind category.

5. Conclusion

Based upon an investigation of data from eight meteorological stations in the western Sahara during 1 July–15 August 1974, we obtained an average threshold wind velocity of 8.2 m s\(^{-1}\) for dust deflation occurrences. However, the threshold speed varies considerably from station to station with a maximum of 12.5 m s\(^{-1}\) and a minimum of 5 m s\(^{-1}\). The data at each of the stations appear to be internally consistent and,
consequently, they appear to reflect environmental characteristics of the locality. Variations are most likely attributable to different terrain conditions at the stations and possibly in some cases to land use practices. Although the range of threshold values was relatively large, the mean threshold value for the eight stations does not differ greatly from values previously mentioned in the literature for arid regions in other parts of the world.

We emphasize that our findings are based on selected data sites for only a period of one and a half months in summer. Therefore, they might not be generally applicable to arid North Africa in all seasons and years. Nonetheless, the range of environmental settings of these meteorological stations was rather broad; consequently, in the absence of better data, these results are probably useful as a general predictor for threshold velocities in this region. However, meteorological records at individual stations would serve as a more reliable predictor for more localized areas.

Finally, it should be noted that dust event statistics for the year 1974 might not be representative of normal meteorological conditions in North Africa because of widespread drought which had begun in 1968 (Lamb, 1982). The drought was especially severe in the early 1970s and again in the early 1980s. Large-scale deflation increased sharply as a consequence of the drought and associated meteorological conditions (Middleton, 1985). Dust concentrations in the western Atlantic increased by a factor of 3 over values measured before the drought (Prospero and Nees, 1977, 1986).

Although the data presented here may not be representative of normal conditions, they do demonstrate that soil deflation in the western Sahara appears to be consistent with the general behavior of soils from regions of less extreme weather and climate.

Acknowledgments. We acknowledge helpful discussions with D. Martin. This work was supported by Army Research Office Contract DAAG29-83-K0082.

REFERENCES