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Effect of averaging time on the apparent threshold for aeolian transport

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A fundamental feature of any wind-eroding surface is its threshold — the lowest wind speed (or friction velocity) at which soil movement is initiated. Many theoretical equations and numerical models of the saltation process include threshold as an important basic parameter. The question addressed here is whether or not the averaging time of a wind speed measurement affects the observed wind speed threshold. Using wind speed data taken at 1 Hz and simultaneously measuring saltation activity with a piezoelectric saltation sensor it was possible to calculate threshold. Threshold was then recalculated using the same data set averaged over periods of 2, 5, 10, 20, 30, and 60 s. The results reveal that, under typical field conditions with gusty turbulent winds, long averaging times produce an apparent threshold that is considerably lower than the true wind speed at which saltation is initiated. This result suggests that high-frequency sampling of wind speed and saltation activity is critical to the accurate determination of the true threshold of a wind-eroding surface.

Keywords: saltation; threshold; wind erosion; unsteady wind

Introduction

Wind tunnels are often used to establish the threshold of a wind-eroding surface (Bagnold, 1941; Kawamura, 1951; Zingg, 1953; Nickling, 1988; Nickling & Gillies, 1989; Pietersma *et al.*, 1996). Typically sand or soil is placed within the test section of a wind tunnel or a portable wind tunnel is hauled to a field site, the wind tunnel speed is adjusted, and the critical threshold is noted. Steady winds within a wind tunnel provide an ideal environment for a careful and systematic study of threshold.

Determination of threshold in the field under natural wind conditions is often more difficult. Gusty turbulent winds and complex surface structures often preclude controlled experiments and often thwart efforts to obtain precise measures of threshold *in situ*. Yet we need to venture to the field if we wish to obtain a true picture of aeolian processes under realistic wind and surface conditions.

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This paper examines one of the potential problems associated with determining threshold under unsteady wind conditions — the effect of averaging time on threshold. For example, past researchers have reported threshold based upon wind speed averaged over various sampling intervals. Holcombe *et al.* (1997) used mean hourly wind speed data and calculated a mean hourly threshold. Gillette *et al.* (1996) used 2-min averaged wind data to calculate a 2-min averaged threshold friction velocity. Stout & Zobeck (1996) used 1-min wind data to obtain a 1-min averaged wind speed threshold. More recently, Stout & Zobeck (1997) used 1-s wind data to calculate a wind speed threshold. One might ask whether the averaging time has any effect on the measured threshold value. Here an attempt is made to answer this question using data taken during a field experiment in the Southern High Plains of West Texas, U.S.A.

Study area

The experimental site was a bare cotton field located north of Lubbock, Texas. Lubbock lies within the Southern High Plains of North America, a region with a long history of wind erosion problems associated with agriculture. The primary crop grown in and around Lubbock is cotton, which typically is grown on vast tracts of land. Cotton provides little residue after harvest leaving an unprotected soil surface. In the late winter and spring, exposed soils, high winds, and low soil moisture combine to produce massive and frequent dust storms.

The surface soil type of the experimental site was classified as a sandy loam with 80% sand, 4% silt, and 16% clay. The organic matter content was 0·7%. The surface had been ploughed a few months before the experiment creating a series of furrows spaced about 1 m apart with their long axes running WSW–ENE. Rainfall had considerably smoothed the surface, producing a crusted layer with loose erodible soil particles perched on top of a weak crust. Most of the erodible material tended to accumulate at the bottom of the weathered furrows, providing multiple line sources of saltation-sized grains.

Experimental system

The experimental system consisted of a portable 2 m meteorological tower, a piezoelectric saltation sensor (Sensit[1]), and a data logger for recording their output. Wind velocity was measured at a frequency of 1 Hz using a lightweight, fast-responding cup anemometer mounted at a height of 2 m. Saltation was monitored by counting the number of particles that impact a piezoelectric sensing element each second (Gillette & Stockton, 1986; Stockton & Gillette, 1990). As shown in Fig. 1, the saltation sensor was mounted so that the lower edge of the piezoelectric crystal was flush with the eroding surface.

As explained in Stockton & Gillette (1990), the sensitivity of the piezoelectric crystal was purposely adjusted so that it primarily responds to the impact of saltating grains. This adjustment eliminates false readings from wind vibration and electrostatic noise. In addition, the instrument will not respond to the presence of fine dust grains.

A 1-h dataset was collected from 1724h to 1824h on 19 April 1995 during a strong wind event associated with the passage of a cold front. The 2 m wind speed and saltation activity are plotted as functions of time in Fig. 2.

[1] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

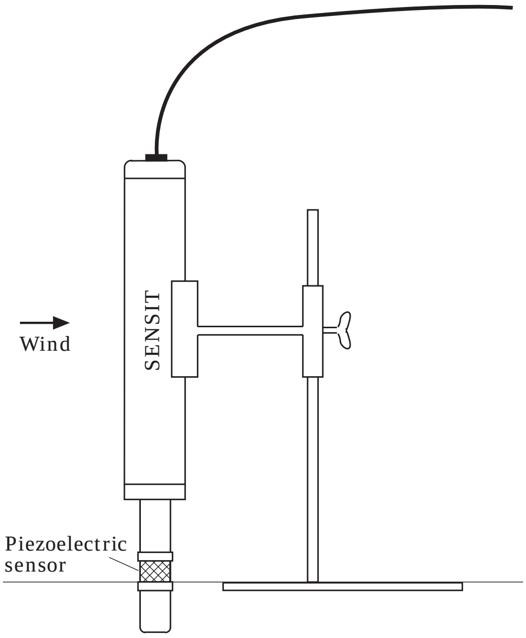

Figure 1. Schematic drawing of the piezoelectric saltation sensor (Sensit) and its mounting stand.

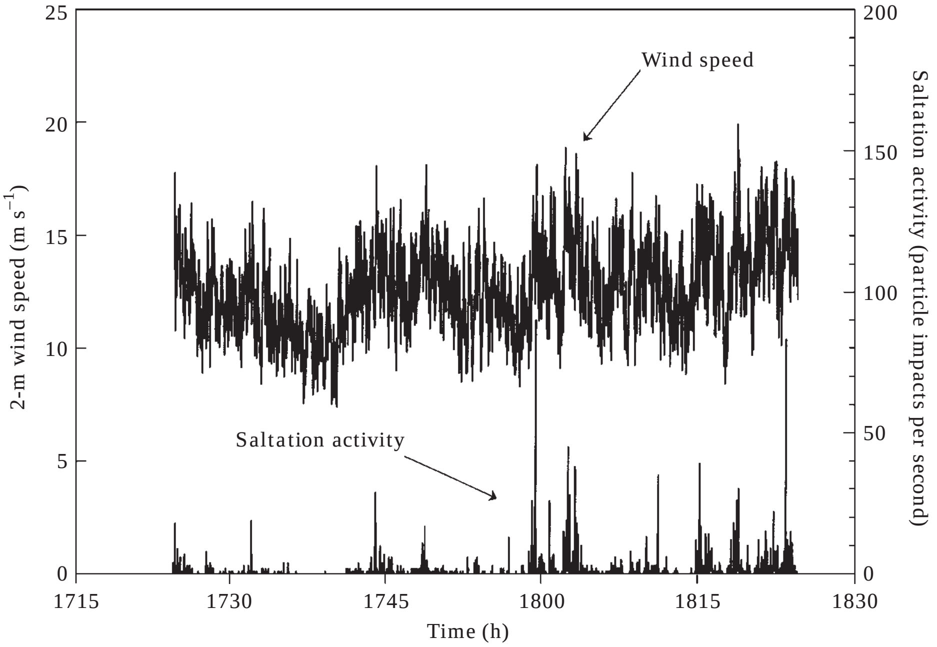

Figure 2. Plot of wind speed measured at a height of 2 m and saltation activity as measured by the piezoelectric saltation sensor during the 1-h sampling period.

Table 1. *Calculated wind speed threshold as a function of averaging time*

Averaging time, T (s)	Wind speed threshold, u_t (m s^{-1})
1	13·80
2	13·19
5	12·28
10	11·70
20	11·16
30	10·98
60	10·17

Data analysis

During a typical field experiment wind speed is measured by sampling the output from an anemometer at a given frequency; the sampled values are then averaged over a fixed averaging time before output to final storage. The length of the averaging time determines the characteristic time-scale of the wind speed measurement. For example, hourly wind speeds are averaged over a period of 1 h.

Here wind speed was sampled at a frequency of 1 Hz; then these values were averaged over periods of 2, 5, 10, 20, 30, and 60 s. Similarly, saltation activity was sampled at a frequency of 1 Hz by counting the number of particle impacts each second; these values were then summed over 2, 5, 10, 20, 30, and 60 s to match the time-scale of the wind speed measurements. In the end, six additional datasets were created each containing a time series of wind speed and saltation activity pairs averaged over longer periods than the original dataset.

Using each dataset, separate threshold values were calculated using the ‘time fraction equivalence method’ as discussed in Stout & Zobeck (1997). The guiding principle of this method is that the fraction of time that saltation activity is recorded should be equivalent to the fraction of time that winds exceed threshold. One simply has to determine by iteration the value of threshold that yields this equivalence.

For example, suppose a dataset consists of 1-min averaged wind speed data and 1-min saltation activity measurements. For the sake of argument, suppose that we detect saltation activity for 12 min out of a total of 60 min, then the fraction of time that saltation activity is detected, γ_p, is simply 0·2. Next we make an initial guess at the threshold wind speed u_t and count the number of minutes that the measured 1-min wind speed, $u(t)$, is greater than or equal to u_t and divide this number by the total time (in this case 60 min). The resulting fraction, denoted γ_u, is the fraction of time that the wind speed is greater than or equal the selected value of u_t. Next, we compare the fraction of time that saltation activity is detected γ_p to the fraction of time that the measured wind speed is above the selected threshold wind speed γ_u. If $\gamma_u > \gamma_p$ then the value of u_t is increased so that γ_u is reduced. If $\gamma_u < \gamma_p$ then the value of u_t is decreased so that γ_u is increased. This process is repeated over many iterations until $\gamma_u = \gamma_p$. The final value of u_t that satisfies this equality is considered to be threshold. This method, called the ‘time fraction equivalence method,’ provides a simple and quantitative means of calculating threshold.

Results and discussion

A threshold value was calculated from the original 1 Hz dataset and separately for each dataset created by averaging over periods of 2, 5, 10, 20, 30, and 60 s. The results are presented in Table 1.

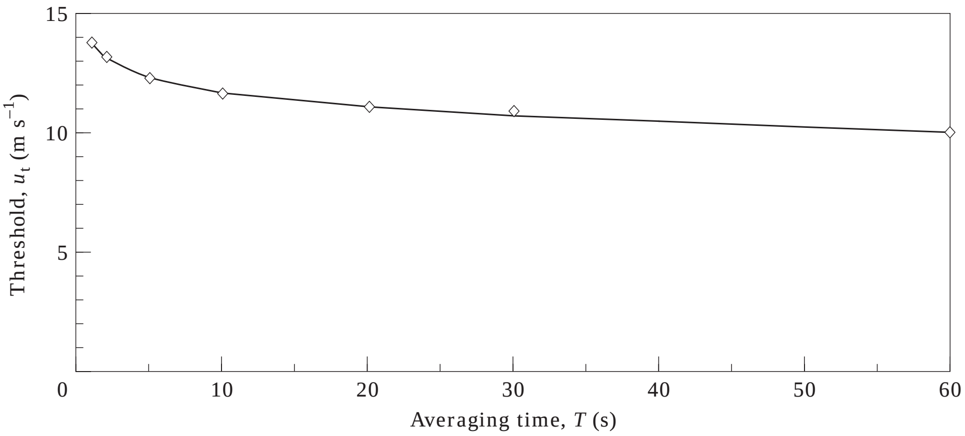

Figure 3. Plot of calculated wind speed threshold as a function of averaging time.

A plot of the calculated threshold as a function of the averaging time T is shown in Fig. 3. Note that as the averaging time approaches zero, the calculated threshold appears to asymptotically approach a value that lies between 14 and $15\,\mathrm{m\,s^{-1}}$. The value of threshold as the averaging time approaches zero most likely represents the true threshold: the actual wind speed at which saltation is initiated.

The calculated or apparent threshold u_t decreases as the averaging time T is increased. Initially, a small increase in averaging time produces a rapid reduction in the calculated threshold. The slope, $\mathrm{d}u_t/\mathrm{d}T$, defines the sensitivity of threshold to changes of averaging time. A close inspection of the data reveals that the magnitude of the sensitivity appears to be inversely proportional to averaging time or:

$$\left|\frac{\mathrm{d}u_t}{\mathrm{d}T}\right| \propto \frac{1}{T}. \qquad \text{(Eqn 1)}$$

Thus, one expects that the magnitude of the sensitivity $\mathrm{d}u_t/\mathrm{d}T$ will gradually approach zero with increasing T, indicating a lower sensitivity to changes in T with increasing T.

As shown in Fig. 4, calculated threshold values fall along a straight line when plotted using semi-log scales. This result suggests that one may linearly extrapolate from a threshold value taken at one time-scale to a value associated with a different time-scale.

For example, an attempt was made to estimate the hourly wind speed threshold by extrapolation, as shown in Fig. 4. Since only a single hour of data was taken during this experiment, it was not possible to calculate the hourly threshold directly. It is certainly risky to extrapolate over such a long distance, but such an extrapolation can provide a rough estimate of the hourly threshold value. As shown in Fig. 4, the apparent threshold for a 1-h averaging period (3600 s) appears to fall somewhere between 6 and $7\,\mathrm{m\,s^{-1}}$ which is less than half the true threshold of 14 to $15\,\mathrm{m\,s^{-1}}$ associated with $T \to 0$.

Conclusion

Field measurements of threshold in turbulent wind conditions can be a challenge. During dust storms, winds are frequently passing above and below threshold causing intermittent saltation activity. By simultaneously measuring saltation activity and a

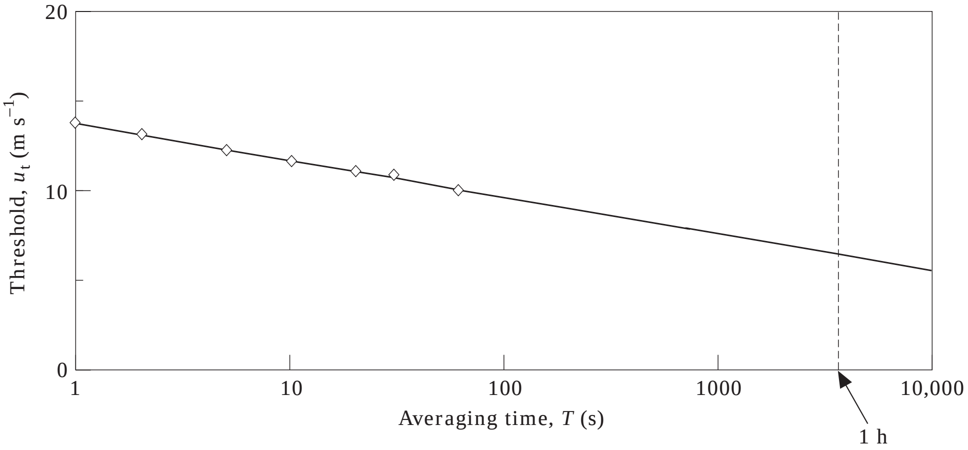

Figure 4. Calculated wind speed threshold as a function of averaging time plotted on semi-log axes.

reference wind speed, it is possible to determine the threshold wind speed which satisfies the condition that the fraction of time that winds exceed threshold is equivalent to the fraction of time that saltation activity occurs. The principle of time fraction equivalence provides an objective method for establishing the threshold condition for soil movement under natural field conditions.

Calculations of threshold based upon wind measurements averaged over periods of 2, 5, 10, 20, 30, and 60 s reveal that a large averaging time can produce an apparent threshold that is considerably lower than the true threshold. Generally, the calculated threshold decreases as the averaging time increases. As the averaging time approaches zero, the calculated threshold appears to approach the true threshold wind speed. This result suggests that high-frequency sampling of wind speed and saltation activity is critical to the accurate determination of the true threshold of a wind-eroding surface.

It has become increasingly apparent that future advances in our understanding of aeolian processes will require high frequency sampling of wind speed and saltation activity (Thorne *et al.*, 1989; Butterfield, 1991, 1993; Hardisty, 1993; Lancaster, 1997). This will require improvements in instrumentation for high frequency detection of saltating grains. The results reported here further support this conclusion.

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