A Study of the Movement of Surface Wind

By Austin W. Zingg

MEMBER A.S.A.E.

WIND IS THE primary force common to soil blowing in the high plains area. A comprehensive understanding of the phenomena is basic to the design of measures to alleviate the problem. Particularly is it true that a program of research on soil erosion by wind cannot be conceived without taking cognizance of the natural forces involved. The purpose of this paper is to develop and present methods of approach to the analysis of records of wind movement.

When thinking of soil movement by wind, this universal question comes to mind: How, when, why, where, and how much does the surface wind blow? In striving to find answers to these questions, one is confronted almost immediately with the fact that very little analytical work on the subject has been done. It is true that many readings of wind velocity have been recorded; however, one will find that records at a given location usually do not have continuity with respect to time, environment, elevation, instrumentation, etc. Again, upon comparing records from one location with those of another, non-uniformity in the same items is to be found. This condition is a natural characteristic of development, growth, and the changing demand for the collection of weather data; consequently, it is necessary to make adjustments in the data as collected before they can be analyzed on either a qualitative of quantitative basis. This has not been done. Methods of describing and estimating the characteristics of wind, in manners analogous to those developed for the science of hydrology, do not exist.

In this treatise the author has attempted to adjust and interpret some items common to the longest record of wind velocity available in the state of Kansas. Measurements of wind movement at Dodge City have been made by the U. S. Weather Bureau since 1875.

Dodge City is a historic point on the Old Western Cattle Trail from the Southwest. It is located in the 20-in rainfall belt on the eastern edge of the Great Plains.

This paper was prepared expressly for AGRICULTURAL ENGINEERING. Authorized for publication as Contribution No. 402, Kansas Agricultural Experiment Station and Soil Conservation Service, cooperating.

AUSTIN W. ZINGG is project supervisor, wind erosion mechanics research, Soil Conservation Service (Research), U.S. Department of Agriculture. (Author's address: Agronomy Dept., Kansas State College, Manhattan)

AUTHOR'S ACKNOWLEDGMENT: Acknowledgment is made to D. A. Russ, agricultural aide (SCS), for assistance in assembling and processing the data necessary to this manuscript, and to Ralph V. Hanlon, in charge of Dodge City (Kansas) office, U. S. Weather Bureau, for his help in assembling and interpreting basic data.

Adjustment of Wind Velocities to a Common Base. Records of wind movement have been obtained in and near Dodge City with a cup-type anemometer located at eight different points during the 74-yr period of measurement. Pertinent data regarding these locations are given in the following tabulation:

Date Started	Location	Gage height above ground, ft	Gage elevation above sea level, ft
1874, Sept. 15	Dodge House, Chestnut and Railroad	54	2553
1876, June 5	Lake Building, Walnut and Second	54	2557
1883, Jan. 1	Hoover Building, Front Street	54	2557
1886, Sept. 1	Palace Drug Store, Front Street	54	2563
1909, Nov. 22	Weather Bldg., Central and Spruce	51	2573
1931, April 7	First National Bank	100	2578
1932, May 21	Post Office, Central and Spruce	86	2585
1942, July 1	Municipal Airport, 2.8 mi east of postoffice	58	2652

The first four locations of the gage, yielding the record for 1874 to 1909, are at equal height above the ground, and their sea level elevations vary but little. For adjustment purposes the records for this period have been considered by the author to be representative of those from one location. The records from the remaining four locations are considered separately.

Before adjusting the measurements to represent historic velocities at one location, the author converted to true velocities[1] the published values of wind movement for each month of the entire record. Briefly this constitutes a calibration adjustment of the data as secured directly with an anemometer. True velocities for each of the calendar months were then averaged to yield the pattern and level of wind movement for each of five locations on an annual basis for the length of record available. A plotting of the values obtained is shown in Fig. (1a).

An inspection of Fig. 1(a) reveals that the average monthly values of wind movement have varied greatly according to the location of the anemometer. It will also be noted that the differences in the levels of lines, representing records at different locations for several years' time, may be well represented by additive constants of variation. Another point of interest is that values of velocity for the winter months fit into a more regular pattern than do those of the spring and summer months. Obviously the present location of the gage yields wind velocities in the neighborhood

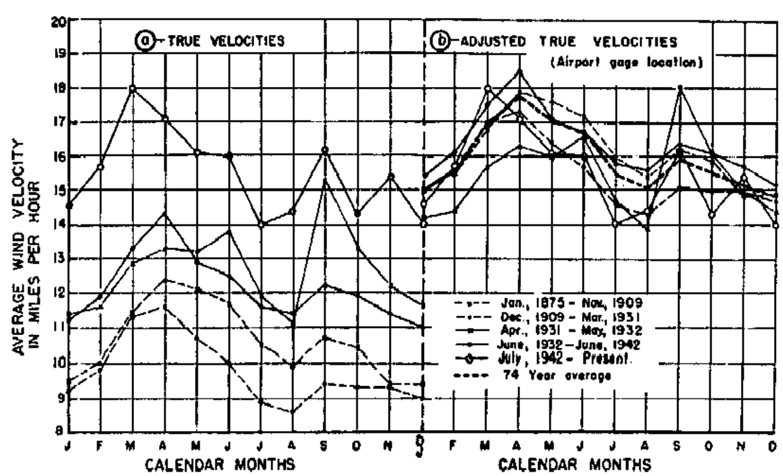

Fig. 1 (a) True velocities based on recorded wind movement at the several locations common to the gage at Dodge City. (b) Wind velocities adjusted to form a historic record for the present location of the gage at the Dodge City airport

[1]Fergusson, S. P. and Covert, R. N. New Standards of Anemometry, Monthly Weather Review, vol. 52, no. 4, p. 216-218, April, 1924.

This article is reprinted from AGRICULTURAL ENGINEERING (vol 30, no. 1, pp. 11-13, 19, January, 1949), the journal of the American Society of Agricultural Engineers, St. Joseph, Michigan

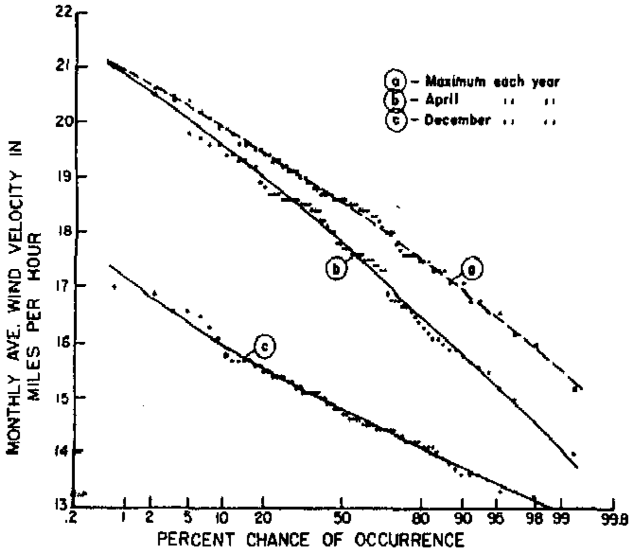

Fig. 2 Plotting of monthly averages of wind velocity as a probability series for the period 1875-1948

of 4 to 5 mph greater than records obtained prior to 1930. This is to be expected from a consideration of the present unobstructed location and elevation of the anemometer. The gage is located presently on the upland. It was formerly above the flood plain of the Arkansas River.

For future reference it would be of most value to have all velocities adjusted to the present location, the municipal airport, where records are obtained with an anemometer 58 ft above the ground surface at an assigned elevation of 2652 ft. This procedure was adopted. The results of such adjustment are shown in Fig. 1(b). An explanation of the details of adjustment is contained in the Appendix.

A heavy line representing the average wind distribution by months is also shown in Fig. 1(b). It is of interest to note that the greatest intensity of wind movement occurs in April. This is the time of year when the winter wheat crop is emerging from a more or less dormant condition. If the fall-seeded crop has made a poor growth, living vegetal cover will be meager. The month of April is normally a critical one for the movement of soil by wind.

Probability of Occurrence of Velocities of Various Magnitudes. Estimates of the frequency of occurrence of a given flood on a stream, or of intensities of rainfall for given time periods, are made commonly by probability methods. It is reasonable to expect that the magnitude of wind movement should also be amenable to estimation by similar devices.

To test this premise, the adjusted values of wind velocity were subjected to treatment by the criterion described by Hazen[2]. The formula used was $P=(2m-1)/2n$, where P designates the plotting position in per cent of time; m, the number of the observation as determined by its sequence in a descending series, and n, the total number of years in the series.

Plotting of the values for wind velocity on Hazen's probability scale, using an arithmetic ordinate, resulted in frequency curves as shown in Fig. 2. To avoid confusion only the maximum average monthly velocity for each year (a), the average velocity for the month of April for each year (b), and the average velocity for the month of December for each year (c) are plotted in the figure.

One concludes that the distribution of wind velocities of various magnitudes at a given location tends to approximate the normal law of chance; and, further, that the frequency of occurrence of a given intensity can be estimated by probability methods.

Considering values from the curves of Fig. 2, it will be noted that the range of average wind velocities for the month of April varies from approximately 21 to 14 mph at the 1 per cent and 99 per cent points, respectively. In other words, there is an equal chance of obtaining either extreme of velocity 1 per cent of the time. Upon first consideration, it may appear that this difference is not great; however, it should be remembered that the drag of wind on the land surface is proportional to the square of the velocity, $\tau \propto V^2$. Assuming that the movement of air were uniform under the two extremes, the magnitude of τ would be $(21/14)^2$, or 2.25 times as great for the 21 as for the 14-mph wind.

The fact that the data fit smoothly into probability series gives some assurance that the velocity adjustments as made by the author are reasonable. If the data shown in the probability series are accepted as a representation of fact, it is found that for the month of April the 5 years of highest wind movement rank in the order 1877, 1896, 1935, 1884, and 1879. The slope of the curve near the upper limit of plotted points is also such that wind movement greater than any which has occurred during the 74 years of record is well within the range of probability.

Deviation of Hourly Wind Movement from Monthly Average. The level of wind intensity, as an average for a month, undoubtedly bears a relationship to the soil-blowing problem. The picture is not complete, however, without a measure of the departure of velocities for short-time periods from an average monthly value.

The variation in wind movement from an average may be shown by a dimensionless plot of velocity and time. In this instance, the deviation of each hourly velocity from the average for the month was determined. After each of the 720 values for a month was placed in a decreasing series, a curve was drawn through them to represent the time a given velocity was equalled or exceeded.

Intensity-duration curves for the month of April for several years are shown in Fig. 3. The years for which curves are derived were selected arbitrarily at 6-yr intervals, starting with 1917 and ending with 1947. It is to be noted that the shape of the several curves does not vary greatly from year to year. On the average, wind velocities for the month of April exceed the mean value 50 per cent of the time. They exceed the average by 10 mph about 10 per cent of the time.

The measured true average velocities for April of the years shown are tabulated in Fig. 3. Recorded also are average velocities derived to represent historic conditions at the present location of the gage.

Characteristics of Wind Storms. High winds or "blows," as they are called in the Great Plains, appear to have the characteristics ascribed commonly to the word "storm."

Diurnal variation in wind movement is recognized generally. A clear explanation of this phenomenon is given by Brunt[3]. Typical of such variation, near the ground surface,

[3]Brunt, Davis. Physical and Dynamical Meteorology. Cambridge University Press. Second Edition. Reprinted 1944.

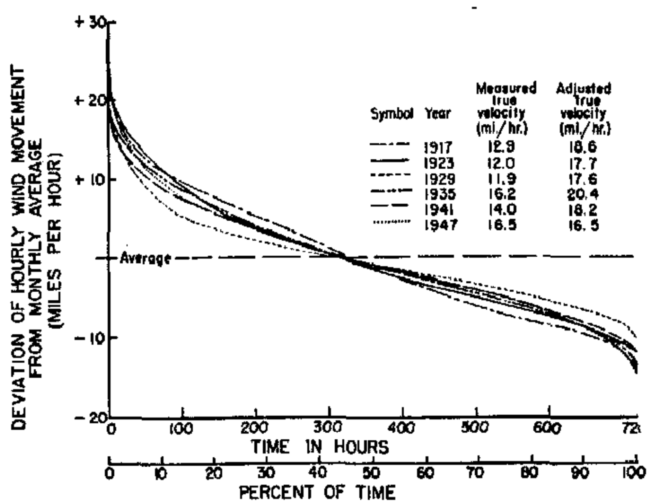

Fig. 3 Deviation of hourly wind movement from the monthly average

[2]Hazen, Allen. Flood Flows. John Wiley & Sons, 1930.

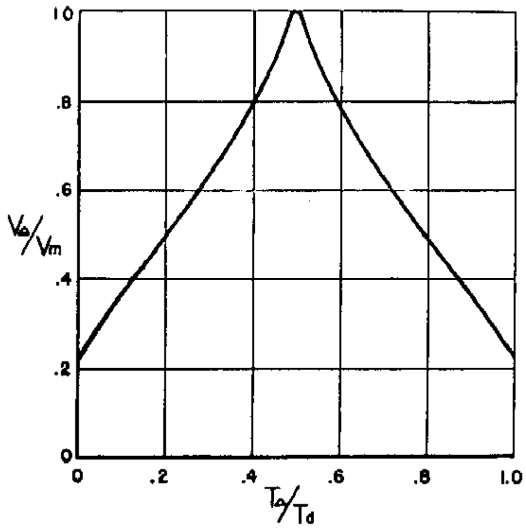

Fig. 4 Average dimensionless pattern of windstorms based on data from twelve storms occurring during April, 1935

is a slackening of the wind during the night. This normally occurs during inversions of temperature. With an adiabatic state of the atmosphere during the day, velocities near the ground surface increase. The peak of velocity associated with diurnal variation usually occurs in the afternoon. A plot of this variation for the Dodge City location is shown in a recent publication by the Kansas State Board of Agriculture[4].

A windstorm represents a marked ascension in wind velocity for possibly 36 to 72 hrs. During this time diurnal fluctuations may be superimposed upon the ascending or descending limb of the storm, but they are, in the main, of a secondary nature.

To describe a typical windstorm, twelve of them occurring in April, 1935, were averaged in dimensionless form. The result is shown in Fig. 4, wherein the ratios $V\Delta/V_{max}$ to $T\Delta/T_D$ are plotted. The symbols referring to a specific storm are defined as follows:

$V\Delta$ = hourly wind velocity at a given time

V_{max} = maximum hourly wind velocity

$T\Delta$ = time from beginning of storm

T_D = time of storm duration

A study of the dimensionless plots of the twelve storms indicated that the peak of intensity of wind movement came, on the average, at the midpoint of storm duration. This point was confirmed by the study of many additional storms. Also, on the average, the rise and fall of the wind tended to be equal and symmetrical. Again no particular hour for the beginning, ending, or peak appeared to be characteristic. The dimensionless average storm of Fig. 4 was, therefore, derived by plotting the average duration of all intensities above given levels symmetrically from the midpoint of storm duration. The form of the plot is approximately triangular, and the wind velocity before and after the storm averages about 0.2 of the maximum attained.

It should be recognized fully that the curve of Fig. 4 is an average pattern. Individual storms will differ greatly from this average; further, a specific storm may have many secondary fluctuations in intensity. The average duration of the 12 storms selected for study was 53 hrs, varying from 33 to 72 hrs. The maximum velocity of the average storm for one hour's time was 29 mph, with a variation ranging from 23 to 35 mph. These values were common to the location of the Weather Bureau anemometer in Dodge City during 1935.

Investigation possibilities latent to deriving excess curves, representing wind movement over and above a given velocity, will be apparent immediately to those acquainted with processes of hydrologic analysis.

Discussion and Interpretation of Results. It is believed that much information of practical value to the problems of agriculture remains to be derived from existing climatological data. Possibly no other type of weather data has been so little explored from the standpoint of scientific agriculture as records of wind movement. The fact that records at one station must be subjected to adjustment before analysis can be undertaken presents a difficult but not insurmountable task.

The results of this study indicate that once such adjustments are made, the data on wind movement will permit many analytical approaches similar to those employed presently in the fields of hydrology and flood control.

The analysis presented herein pertains to only one gage at one location. It is further limited to one height above the ground. One of the first steps which needs to be taken to make a record useful to an analysis of the phenomenon of soil erosion by wind is to bring the record down to earth where the problem exists. This can be accomplished with certainty only by installing a recording anemometer or anemometers near the ground surface. If such were properly located, they would provide a tool for converting the large body of data secured at greater heights to a more usable form.

A recognition of the type or pattern of the windstorm associated with soil movement is of importance. It is not inconceivable that the design of measures to control soil drifting will be based ultimately on the probability level of a windstorm, or storms, associated with a condition of drought.

SUMMARY

The purpose of this paper is to develop and present methods of approach to the analysis of records of wind movement with a view to obtaining a better understanding of the characteristics of the natural force encountered in soil erosion by wind. Records of wind movement obtained at Dodge City, Kansas, during a 74-year period were used for the purpose. Certain adjustments in these data were made in an attempt to make them representative of the present location of the gage.

Adjusted monthly averages of wind velocity were found to be amenable to study by probability methods.

Wind intensity-duration curves were developed for wind movement occurring during the month of April for selected years. The general pattern of these curves was found to be similar.

An average dimensionless pattern of windstorms was derived from storms occurring during the month of April, 1935. The peak of storm intensity was found to be at the midpoint of storm duration.

The results of the study indicate that the problem of soil erosion by wind may be approached analytically by methods similar to those employed in the fields of hydrology and flood control.

APPENDIX

As a first step in adjusting the data on wind movement to a common base, a long-time average was obtained for the period 1875-1930. This yielded a long-time pattern of wind movement by months at the average level of 10.3 mph. Since the object was to adjust all data to approximate values for the present location of the gage, the difference between the long-time average, 1875-1930, and the record at the airport location 1942-46 was secured. This difference was found to be 5.2 mph.

From a study of records at Colby and Garden City, it was found that wind movement for the period 1942-48 was approximately 0.4 mph below the level of the long-time average. This value was, therefore, added to the 5.2 difference already obtained. A long-time pattern of wind movement for the airport location was then established at the average level of 15.9 mph.

[4]Climate of Kansas. Report of the Kansas State Board of Agriculture, vol. LXVII, no. 285, p. 251, June, 1948.

All lines representing wind movement for the five groups of data itemized in the body of this report and plotted in Fig. 1(a) were then adjusted to the long-time average for 1875-1930 as transposed to the airport location. In making such adjustment, consideration was given to differences in the level of wind movement for the various periods at other locations in western Kansas, namely, Tribune, Garden City, and Colby.

The following table is a summary of the adjustments (mph) made for the several groups of data:

Period	(1)	(2)	(3)	(4)
Jan. 1875-Nov. 1909	+ 5.2	+ .4	− .1	+ 5.5
Dec. 1909-Dec. 1927	+ 5.2	+ .4	+ .1	+ 5.7
Jan. 1928-Mar. 1931	+ 5.2	+ .4	+ .1	+ 5.7
Apr. 1931-May 1932	+ 2.4	+ .4		+ 2.8
June 1932-June 1942	+ 3.4	+ .4	+ .4	+ 4.2
July 1942-present	No change			

(1) Location or environmental adjustment based on long-time averages.

(2) Adjustment to allow for below-average velocities at the airport since July, 1942

(3) Adjustment for deviation of wind movement for the period from the long-time average at that location

(4) Net adjustment.