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Reprinted from SOIL SCIENCE SOCIETY OF AMERICA PROCEEDINGS
Vol. 27, No. 4, July-August 1963, pages 449-452
677 South Segoe Road, Madison 11, Wisconsin

Climatic Index of Wind Erosion Conditions in the Great Plains[1]

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ABSTRACT

A climatic index based on effective precipitation and wind velocity for a 3-year period ending May 31 can be used to predict with considerable certainty the severity of wind erosion conditions during the succeeding calendar year. On the basis of predicted severity of wind erosion conditions, farmers can be advised whether or not they should initiate special methods to control impending wind erosion.

History reveals that periods of drought, wind erosion, and dust storms have occurred simultaneously in the semiarid region of the Great Plains (7). In Kansas, the most notable droughts and associated dust storms (wind erosion) of definite record occurred in 1854-1860, 1864-1865, 1874, 1880, 1890-1894, 1901, 1910-1914, 1917, 1919, 1922-1923, 1934-1939, and 1954-1957. Periods of high wind also appear to have contributed greatly to the number and severity of dust storms.

This paper analyzes combinations of climatic conditions in relation to wind erosion and dust storms and attempts to determine, on the basis of current and recent climatic conditions, if the severity of wind erosion conditions may be predicted with some certainty 6 months to a year before they occur. Data used are from weather records at Dodge City and Garden City, Kansas. These locations are situated in one of the most serious wind-eroded areas of the Great Plains.

Low precipitation and high temperature and wind velocity long have been recognized as the main causes of wind erosion and dust storms in the Great Plains (3, 7, 11). Dry years are usually accompanied by increased temperature and wind velocity, whereas wet years often are accompanied by decreased temperature and wind velocity. Moreover, both wet and dry years tend to occur in irregular cycles. In dry periods, wind erosion and dust storms become more serious with time, as vegetative cover and soil aggregation of cultivated land become progressively poorer each successive dry year. Climatic conditions during a given year and at least 3 years preceding are especially important in predicting the number of dust storms.

In the Great Plains, wind erosion and dust storms tend to be most numerous and severe in the spring. About 80% of the dust storms occur from January through May (4). The farther south, the earlier within that period they tend to occur.

METHOD OF ANALYSIS

The intensity of wind erosion varies as the cube of wind velocity (1, 11) and inversely as the square of moisture at the soil surface (2), or inversely as the square of effective precipitation (5). The effective precipitation is influenced by the actual precipitation and by temperature (9, 10). Hence, a wind erosion climatic index C_1 for each year at a given location may be expressed as

$$C_1 = 100 \frac{v^3}{(P\text{-}E)^2}/2.9 \qquad [1]$$

in which v is the average wind velocity for that year and P-E is the effective precipitation index of Thornthwaite (9) for the year. The average annual value of $C = v^3/(P\text{-}E)^2$ for Garden City, Kansas, is equal to 2.9, hence C_1 for any location and any year is expressed as a percentage of the average annual wind erosion climatic index C for Garden City, Kansas.

The value of C_1 was computed on an annual basis for June 1 to May 31 because the number and severity of dust storms (about 80% of which occur between January 1 and May 31) are considerably influenced by the weather conditions prevailing during the initial portion (June 1 to December 31) of this period. The corresponding number of dust storms, i.e., the number of days in which dust was reported, was determined for calendar years. Virtually no wind erosion and dust storms occurred during June through September and only a few from October through December.

Since the number of dust storms during any year is largely influenced by conditions of at least three previous years, a 3-year running average of C_1, designated as C_3, was plotted against the number of dust storms occurring during the current year. Thus, the average value of C_1 for each of the three 12-month periods ending May 31 of 1959, 1960, and 1961 was plotted against the number of dust storms during the calendar year of 1961, as shown in figures 1 and 2.

To predict the number of potential dust storms, a linear equation showing the relation between the annual number of dust storms and C_3 for three previous years was determined on the basis of all available data. This prediction equation, computed by the method of linear regression (8) and shown by a curve of figure 3, was of the form

$$N = a + bC_3 \qquad [2]$$

in which N is the total number of dust storms occurring during the year and a and b are constants equal to -4.1 and 0.24, respectively. There was no significant curvilinearity in the regression as determined by the method of Snedecor (8). The simple correlation coefficients between the total number of dust storms and C_1 of the first, second, and third year preceding the prediction year were 0.55, 0.59, and 0.48, respectively. All coefficients were significant to a 1% level. The number of dust storms was correlated with C_1 of the third year slightly less than with C_1 of the other 2 years, but the difference in correlation was considered too small to warrant special recognition.

The prediction equation [2] is based on climatic and dust storm conditions involving 4 consecutive years. Thus, the average value of C_1 for each of the three 12-month periods ending May 31 of 1959, 1960, and 1961 served as an index of the potential number of dust storms during the calendar year of 1962.

An attempt was made to relate the severity of dust storms (as indicated by degree of restricted visibility) with the climatic index C_3. However, results showed no better relationship than between the total annual number of dust storms and the climatic index. It was evident from the weather records that, as a general rule, the greater the total annual number of dust storms, the more severe they were.

RESULTS

The number of dust storms and the climatic index C_3 for each calendar year for the period of record are shown in figures 1 and 2 for Dodge City and for Garden City. Both figures show that the high incidence of dust storms during the 1930's and the 1950's was associated with the high climatic indices, whereas the low incidence of dust

[1]Contribution from the Soil and Water Conservation Research Division, ARS, USDA, in cooperation with the Kansas Agr. Exp. Sta., Department of Agronomy Contribution No. 793. Presented before Div. VI, Soil Science Society of America, Aug. 20, 1962, at Ithaca, N. Y. Received Aug. 21, 1962. Approved Nov. 1, 1962.

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storms during the 1920's and the 1940's was associated with generally low climatic indices. A distinct discrepancy between the number of dust storms and the magnitude of the climatic index occurred for 1954 through 1957. The climatic index for that period was the highest recorded since the 1930's but the number of dust storms, though about double those of the 1940's and earily 1950's was significantly lower than during the severe dust storm period of the 1930's. The reason for relatively low incidence of dust storms during the 1954-1957 period may be that farmers had learned more about how to control wind erosion and were in a much better economic position to control it.

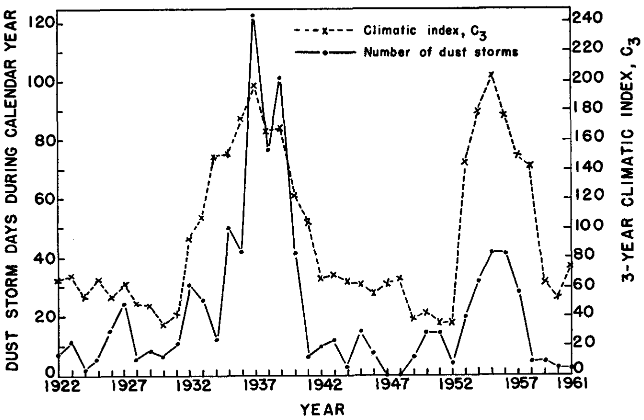

Figure 1—Number of dust storms and climatic index C_3 for each year of record for Dodge City, Kans.

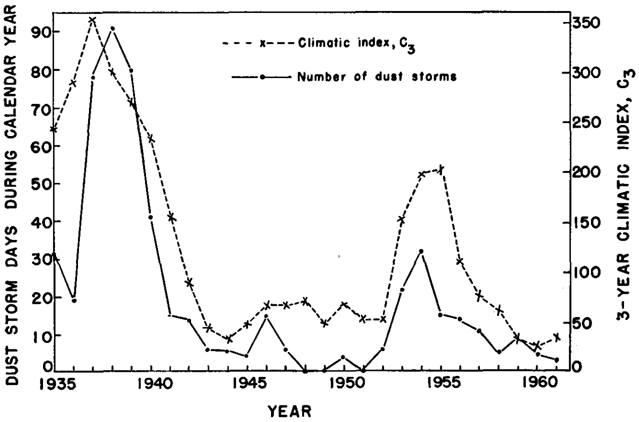

Figure 2—Number of dust storms and climatic index C_3 for each year of record for Garden City, Kans.

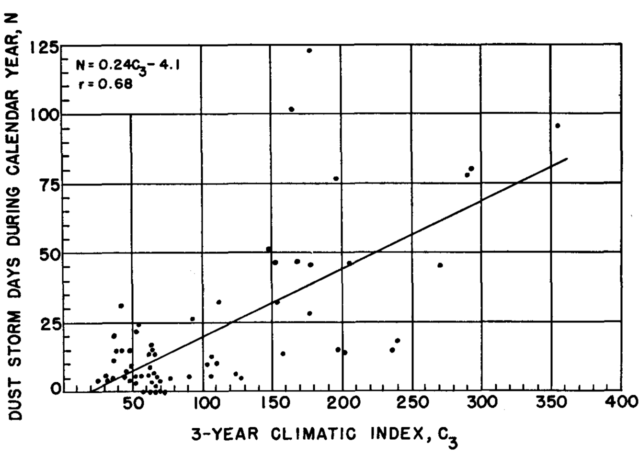

Figure 3—Regression of annual number of dust storms, N, beginning January 1, on the 3-year climatic index, C_3, ending May 31 of the preceding year.

The annual number of dust storms plotted against the climatic index C_3 for three previous years is shown in figure 3 based on all available data. The plotted curve of figure 3 fits the prediction equation (2). The correlation coefficient, r, between the number of dust storms and the climatic index is 0.68 and is significant at the 1% level.

The predicted number of dust storms and the number that actually occurred during each year of record are shown for Dodge City in table 1 and for Garden City in table 2. The predicted number of dust storms follows the same general pattern as the actual. Thus, predictions would have indicated the most severe dust storm period in the 1930's, somewhat less severe in the 1950's, and relatively few dust storms in the 1920's, 1940's, and 1960's. Although the actual number of dust storms followed this general pattern, some accountable discrepancies occurred. The discrepancies are particulary noticeable between the high dust storm periods of the 1930's and the 1950's. The predictions for the 1930's tended to underestimate and for the 1950's to overestimate the number of dust storms, again supporting the conclusion made earlier in this paper that farmers controlled dust storms in the 1950's better than they did in the 1930's.

Instead of computing the potential number of dust storms from C_3 by using equation [2], the number could be read at sight by using the prediction curve of figure 3.

DISCUSSION AND CONCLUSIONS

It appears that a prediction of the potential number of dust storms could be made within rather wide limits of

Table 1—Predicted and actual number of dust storms for Dodge City, Kans.

Year	Number of dust storms		Year	Number of dust storms	
	Predicted	Actual		Predicted	Actual
1924	11	2	1943	10	13
1925	10	6	1944	13	3
1926	12	17	1945	12	15
1927	11	24	1946	9	8
1928	11	6	1947	10	0
1929	8	9	1948	12	0
1930	6	7	1949	10	7
1931	5	11	1950	5	15
1932	6*	31	1951	6	15
1933	19*	26	1952	5	4
1934	23	13	1953	4	20
1935	30	51	1954	24*	32
1936	34	42	1955	43	41
1937	38	123	1956	43	41
1938	42	77	1957	36	28
1939	39	102	1958	27†	5
1940	33	42	1959	18	6
1941	26†	7	1960	10	3
1942	19	10	1961	9	3

* Underestimate. † Overestimate.

Table 2—Predicted and actual number of dust storms for Garden City, Kans.

Year	Number of dust storms		Year	Number of dust storms	
	Predicted	Actual		Predicted	Actual
1936	55*	19	1949	12	0
1937	71	78	1950	8	4
1938	76	91	1951	12	0
1939	66	80	1952	8	6
1940	59	41	1953	7	22
1941	50*	15	1954	35	32
1942	32*	14	1955	48*	15
1943	14	6	1956	35*	14
1944	6	6	1957	21	11
1945	5	4	1958	14	5
1946	7	15	1959	9	9
1947	13	6	1960	3	5
1948	12	0	1961	2	4

* Overestimate.

error at least 6 months ahead of their occurrence. All that is necessary to make a prediction for areas such as Garden City and Dodge City, Kansas, is to compute the wind erosion climatic index C_3 (based on precipitation, temperature, and wind velocity for three consecutive annual periods, June 1 to May 31). The prediction would be made in June for dust storms likely to occur during the next calendar year.

Periods noted for severe wind erosion conditions at Garden City and Dodge City, Kansas, generally had the wind erosion climatic index C_3 greater than 125%, which corresponds to more than 25 predicted dust storms per annum. Therefore, if a prediction should indicate a potential number of dust storms exceeding 25, extremely serious wind erosion likely would occur unless farmers took special precautions to control it. Conversely, if the prediction should indicate 25 or less potential dust storms, no special precautions would be recommended.

However, it should be emphasized that 25 potential dust storms are serious and that adequate regular methods are necessary to control them. If these regular methods had been used to the fullest, the number of dust storms associated with the wind erosion climatic index of 125% could have been drastically reduced or eliminated.

On the basis of the two categories of intensity of potential wind erosion, tables 1 and 2 indicate that 7 out of 64 (11%) predictions would have overestimated the category of wind erosion conditions and 3 out of 64 (5%) would have underestimated it. On this basis, the predictions may be considered as 84% accurate.

No serious harm would have developed from the overestimates. In practice, it would be hoped that farmers would heed the predictions of impending wind erosion conditions and take special precautions to control wind erosion so it would never occur. Thus, the predicted number of dust storms is to be viewed as a predictive index of wind erosion conditions and not as a prediction of actual number of dust storms.

A prediction resulting in a substantial underestimate of impending wind erosion conditions would be serious. However, on the basis of tables 1 and 2, such a prediction for severely wind-eroded regions as exists around Garden City and Dodge City, Kansas, will seldom be made. Only one of the three underestimates that would have been made for Dodge City, Kansas, may be considered serious. It would have been made in 1932.

A prediction of more than 25 potential dust storms for the vicinity of Garden City and Dodge City, Kansas, should give ample opportunity for farmers to establish special tillage and cropping practices that would be effective in controlling them. A prediction of fewer than 25 potential dust storms, on the other hand, would indicate that no special practices would be required; however, it is important to emphasize that such a prediction does not mean that farmers should discontinue regular wind erosion control practices.

A certain value of the wind erosion climatic index, C_3, is expected to have different degrees of significance at different geographic locations. For example, at Garden City, Kansas, $C_3 > 125\%$ occurs on the average during 3 out of every 7 years. Farmers at that location presumably have adopted regular (permanent) wind erosion control practices that are effective in controlling wind erosion under conditions in which C_3 does not exceed 125%. The C_3 value $>125\%$, according to computations by the method of Gumbel (6), occurs at Fargo, North Dakota, for example, on the average only during 1 out of every 8 years. Farmers generally are unprepared for the severity of wind erosion conditions recurring as infrequently as this. Therefore, it seems that a prediction of the wind erosion conditions for any local area should take cognizance of the wind erosion climatic factor C at that location. Since C and C_3 vary almost proportionately with the potential number of dust storms (figure 3 shows this in part), then the crucial wind erosion climatic index C_c for a given location may be expressed by

$$C_c = 125 \frac{C}{100} \qquad [3]$$

The crucial wind erosion climatic index C_c for Garden City, Kansas, is 125%. The wind erosion climatic factor, C, for that location is 100%. Very approximate values of C for different geographic locations in the United States and southern Canada are given in another publication (5).

It is indicated in figure 3 that if C_3 is 20% or less, no dust storms would likely occur. Therefore, if C_3 exceeds 20% and exceeds C_c, special measures should be established to control the impending wind erosion. If, on the other hand, C_3 does not exceed 20% or does not exceed C_c, no special (emergency) measures would be necessary. Thus, the prediction will merely indicate the maximal wind erosion climatic intensity that occurs on the average only in 3 out of 7 years. The prediction is applicable only to those fields or portions of fields where wind erosion is a problem.

The inclusion of only two locations in computing a prediction equation is admittedly fewer than would be desired in extending the use of the equations to an area as extensive and diverse as the Great Plains. No other quantitative wind erosion data were available, however. Combining the data from the two locations does include locational variation and theoretically, at least, is more applicable for predictive purposes to outside areas than the data from only one location. Even though the equation is obviously not sufficiently accurate to predict the potential intensity of wind erosion for a given year and location with a high degree of confidence, it does suggest the possibility of relatively severe wind erosion conditions early enough for the farmer to apply necessary emergency control practices. A C_3 value greater than that which occurs on the average during 4 out of every 7 years in any area that has a history of wind erosion is certainly climatically critical and gives some advance warning of the wind erosion potential.

To recapitulate, all that is necessary to determine if emergency measures to control wind erosion at a given location where wind erosion is a problem are to be recommended or not is to compute C_3 and then check it against C_c for that location. C_3 is based on the average value of C_1 for each of the three 12-month periods ending May 31 and serves as an index of potential severity of wind erosion during the succeeding calendar year. C_c is determined from C by using equation [3]. C_c is constant for each location. If C_3 is $> 20\%$ and exceeds C_c, emergency measures should be established to control potential wind erosion. If C_3 does not exceed 20% or does not exceed C_c, no special measures would be recommended.

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