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Climate Databases for Wind Erosion Prediction Models

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Summary

The presently used wind erosion equation (WEQ), a revised wind erosion equation (RWEQ), and the Wind Erosion Prediction System (WEPS) now under development all require climatic data. The objective of this research was to develop the climate databases needed to support an improved climatic factor in RWEQ and in WEPS. Data from the Wind Energy Resource Information System were used to calculate for each month of the year the following: Weibull scale and shape parameters for all wind directions combined, prevailing wind erosion direction, preponderance of wind erosion forces in the prevailing wind erosion direction, the positive parallel wind erosion forces, and air density. Monthly mean maximum/minimum air temperatures, dew point temperature, solar radiation, and precipitation amount were obtained from the CLIGEN database. Other data obtained include: probability of snow greater than 1 inch, average number of days during month that had precipitation, and monthly rainfall erosivity: These data form a climate database for use with RWEQ which uses half-month time steps in simulation. Because WEPS uses a daily simulation, its climate database is slightly different. Weibull scale and shape parameters were calculated for each of the 16 cardinal directions. Prevailing wind erosion direction, preponderance of wind erosion forces in the prevailing wind erosion direction, positive parallel ratio, average number of days during the month that had precipitation, and rainfall erosivity were replaced by distribution parameters and/or functions for weather simulations in WEPS. Precipitation in the form of snow was determined as a function of daily mean temperature and annual mean temperature at a specified probability. Data were summarized for about 700 locations for both databases.

Introduction

Wind erosion is a major factor in land degradation in the USA and the world. Where it occurs, it reduces mans' ability to produce needed food and fiber. It also can result in serious environmental and health problems far from the wind erosion source. Climate variables are the driving forces that determines a land's susceptibility to erosion by wind. The climate directly influences the amount of vegetation and residue that occur on the soil surface. Extremes in temperature and/or precipitation also contribute to the amount and stability of soil aggregates..

The wind is the main driving force causing wind erosion. Wind erosion occurs when the shear stress exerted on the surface by the wind exceeds the ability of the surface materials to resist detachment and transport. Strong winds erode, and dryness increases the susceptibility of the surface to erosion. Many other climatic factors also affect soil loss by wind to some degree.

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Chepil et al. (1962) proposed a climatic factor as one of the main variables of the wind erosion equation (Woodruff and Siddoway 1965) to estimate the average annual soil loss by wind for a range of climatic conditions. The climate factor is a function of estimated soil moisture and average wind speed. FAO (1979) and Skidmore (1986, 1987) recognized serious flaws in the Chepil et al. index and proposed modifications.

Our objective was to develop procedures for and databases needed to support an improved climatic factor (Skidmore 1986) in a revised wind erosion equation, RWEQ (Fryrear et al. 1994) and the Wind Erosion Prediction System, WEPS (Hagen 1991; Skidmore and Tatarko 1990; Tatarko et al. 1995).

Methods

Extrapolation of Wind Speed to 10 Meter Height

The classical logarithmic wind profile in neutral air is given by:

$$u = \frac{u_*}{k} \ln\left[\frac{(z-d)}{z_o}\right] \tag{1}$$

where u is wind speed at height z; u_* is friction velocity; k is the von Karman constant (0.4); d is displacement height; and z_o is roughness length. Note that $u = 0.0$ when $z = d + z_o$.

Commonly, wind speed is known only at one height and required at another. Most wind speed observations are from a single anemometer (not a profile), which often is placed at a height different than the standardized reference height of 10 m (WMO 1981). If the parameters of Equation [1] are known, then the wind speed can be calculated at any height, z, within the logarithmic boundary layer.

If the parameters of Equation 1 are not known, it is possible to estimate d and z_o and eliminate u_* by division, then use Equation 2 to estimate wind speed at heights different from the measured height (Panofsky and Dutton 1984).

$$\frac{u_2}{u_1} = \frac{\ln[(z_2-d)/z_o]}{\ln[(z_1-d)/z_o} \tag{2}$$

Panofsky and Dutton (1984) proposed estimating d as 80% of the height of the roughness elements and z_o from terrain and vegetation features. Abtew et al. (1989) reviewed some of the methods for estimating roughness length and displacement height and proposed a procedure to estimate those parameters from the geometry and fraction of cover of ridged surface roughness elements.

Another alternative and common practice in engineering is to describe the wind profile with the power law instead of the logarithmic law. Hellmann cited by Sellers (1965) suggested the empirical relationship:

$$\frac{u_2}{u_1} = \left(\frac{z_2}{z_1}\right)^a \tag{3}$$

where u_1 is wind speed at anemometer height z_1, and u_2 is wind speed at height z_1 (we used 10 m); "a" is a variable depending on the stability of the air layer. Further, it can be seen by comparing Equations 2 and 3 that "a" depends on roughness and displacement height. When d is very small compared to z:

$$a = \frac{1}{\ln(z/z_o)} \tag{4}$$

Reed (1975) and Elliot (1979) analyzed long-time wind records from meteorological towers and confirmed that the rule-of-thumb law that wind speed is proportional to the one-seventh power of height above ground is a reasonable "ball-park" estimate. When z is 10 m and z_o is 1 cm, "a" is about one-seventh.

Panofsky and Dutton (1984) cautioned that if z_o and d are known, it is better to bypass the power law and estimate other speed levels directly from Equation 2. Even when d is negligible, this procedure is still theoretically preferable to the use of the power law. Nevertheless, the uncertainties of z_o and d are so great that the power law often is used in practice (Elliot 1979). We used Equation 3 with $a = 1/7$ to adjust wind speed at the height of the anemometer to the 10 m reference height.

Weibull Wind Speed Distribution Parameters

We used data from the Wind Energy Resource Information System (WERIS), Table 12 parts a through l (TD9793, National Climatic Data Center, Asheville, NC). WERIS is described briefly by Elliot et al. (1986). Table 12 presents the joint frequency of occurrence of wind speed and direction. The 26 speed classes in m/s are calm, 1, 2, ... 20, 21-25, 26-30, 31-35, 36-40, and greater than 41. Seventeen direction classes are given - one for each cardinal direction (22.5 degree increments) plus a calm class. Frequency of occurrence for each speed/direction class is given to the nearest 0.1 percent. WERIS Table 12a is for January, Table 12b is for February, etc. Table 1 in this paper is an example of WERIS Table 12c.

The wind speed classes were adjusted to the 10 m reference height as described above, then the scale and shape parameters of the Weibull wind speed distribution were calculated by a method of least squares applied to the cumulative distribution as described by Skidmore and Tatarko (1990). The scale and shape parameters were calculated for all directions combined for the period-based RWEQ (Table 2), but for the daily time step model, WEPS, the wind speed parameters were calculated for each of the 16 cardinal directions (Table 3).

Prevailing Wind Erosion Direction and Preponderance

Wind barriers and row direction are most effective for controlling wind erosion when they are oriented perpendicular to the prevailing wind erosion direction. Preponderance of wind erosion forces in the prevailing wind erosion direction gives the relative merit of specific orientation.

WERIS Table 12 (parts a through l) was modified for input to the calculation procedure by including only the wind speed classes for wind speeds greater than 6 m/s. Wind speeds less than 6 m/s are considered non-erosive. Therefore, they are not included in the computations.

Wind erosion forces for each cardinal direction were calculated, similar to the procedure described by Skidmore (1965):

$$r_j = \sum_{i=u_t}^{n} (u_i - u_t)^3 \, f_i \tag{5}$$

where r_j is the wind erosion force vector for the j^{th} direction, u_i is the mean wind speed within the i^{th} speed class, u_t is the threshold wind speed, n is the number of speed classes, and f_i is the fraction of time when the wind was in the i^{th} speed class of the j^{th} direction. The j's are numbered 1 through 16 for the cardinal directions. Number 1 is for north, number 2 is for north-north-east, ..., and number 16 is for north-north-west.

Wind erosion forces were calculated parallel and perpendicular to an imaginary line intersecting at the origin of a polar coordinate system (see Figure 1). The wind energy exceeding the threshold wind speed parallel to line p was calculated by:

$$F_{\parallel} = \sum_{j=1}^{16} r_j \left| \cos((j-1) * 22.5 - \theta)) \right| \tag{6}$$

where θ is orientation of line p.

The wind energy exceeding threshold perpendicular to line p was calculated by:

$$F_{\perp} = \sum_{j=1}^{16} r_j \left| \sin((j-1) * 22.5 - \theta)) \right| \tag{7}$$

Line p was rotated from 1 through 360 degrees in 1-degree increments and θ for maximum value of the ratio was found:

$$R = \frac{F_{\parallel}}{F_{\perp}} = \max \left(\frac{F_k(\parallel)}{F_k(\perp)} \bigg|_{k=1-360} \right) \tag{8}$$

θ for the maximum value of Equation 8 becomes the prevailing wind erosion direction, and the maximum value of the ratio expressed by Equation 8 gives the preponderance of wind erosion forces in the prevailing wind erosion direction.

Positive Parallel Ratio

One can visualize that the sum of erosion forces parallel to the prevailing wind erosion direction may also be in the opposite direction. Therefore, for more complete accounting of wind force vectors, it is necessary to evaluate those in the positive direction and those in opposition or in the negative direction.

When the prevailing wind erosion direction is substituted for θ in Equation 6, then $F_{\parallel}$ gives total wind erosion forces parallel to the prevailing wind erosion direction . When the absolute value restriction is removed and the calculation is repeated then the negative and positive forces can be summed separately. The positive and negative forces divided by the total gives the fraction in the prevailing wind erosion direction and the fraction of wind erosive force at 180° of the prevailing wind erosion direction. This is pertinent information when planning farming systems. Knowing the positive parallel ratio, prevailing wind erosion direction, and preponderance of wind erosion forces, one can calculate erosive wind energy in the direction relative to barrier orientation, etc.

Air Density

Air density was calculated from barometric pressure and air temperature using the relationship from the CRC Handbook of Chemistry and Physics (Weast, 1986, p F-8):

$$\rho = 348.0\,(P/T) \tag{9}$$

where ρ is air density (kg/m^3), T is absolute temperature (°K), and P is barometric pressure (bars). Barometric pressure was estimated as a function of elevation from a regression of handbook data (Weast, 1986, F-142):

$$P = 1.013 - 0.1183 * EL + 0.0048 * EL^2 \tag{10}$$

where EL is site elevation in kilometers.

Climate Variables Obtained from the CLIGEN Database

Monthly mean maximum/minimum air temperatures, dew point temperature, solar radiation, and precipitation amount were obtained from the CLIGEN database (Nicks and Lane, 1989). The average number of days during a month that had precipitation was calculated from CLIGEN data by dividing the monthly mean precipitation by the mean precipitation for each precipitation event. Because the mean precipitation in CLIGEN database is per event, we calculated total for the month:

$$\bar{P}_m = \bar{P}_e * DM * P(W|D) \;/\; [1 - P(W|W) + P(W|D)] \tag{11}$$

where:

$\bar{P}_m$ is total monthly precipitation,

$\bar{P}_e$ is the mean precipitation for each precipitation event,

DM is number of days in month,

$P(W|D)$ is probability of a wet day following a dry day, and

$P(W|W)$ is probability of a wet day following a wet day.

Probability of Snow

Probability of snow cover equal to or greater than 25.4 mm (1 inch) for each month for each database site was obtained by interpolation of maps of snow cover (Dickson and Posey 1967). These maps consisted of isoline depictions of constant snow cover for each month. Isoline maps were interpolated using a computer by digitizing them to gridded values (SURFER Version 4, Golden Software, Inc., Golden, CO), then interpolating between grid points for each site in the database.

Probability of snow was handled differently in WEPS than in RWEQ. A procedure was developed to determine when the precipitation predicted by the weather generator is snow and not rain (Skidmore et al. 1994). "Summary of the day" data (from EarthInfo Inc., Boulder, CO) were analyzed to determine the probability of precipitation being in the form of snow as a function of daily minimum temperature, daily maximum temperature, and daily mean temperature. The probability of snow vs. temperature data were fit to a sigmoid equation (see Equation 12 and Figure 2):

$$y = a + \frac{b}{1 + \exp\left[-\left(\frac{x-c}{d}\right)\right]} \tag{12}$$

where:

- y is the probability of precipitation being snow at temperature x,
- a is a constant that gives the value of y when x is very large,
- b is transition height (when x is very large and d is < 0.0, then $y = a + b$),
- c is center (when $x = c$ then $y = a + b/2$), and
- d is a width term.

Rainfall Erosivity

Rainfall erosivity (EI), which is an energy times intensity term, has been found to be a good indicator of erosion potential. It is useful to know because it degrades random and oriented roughness. Therefore, we determined EI from isoerodent and EI distribution numbers in Agricultural Handbook No. 703 (Renard et al. 1996) and added to the RWEQ climate database.

Computation of Half-Month Climate Variables

Calculation of time-varying wind erosion for periods of less than one month requires values for climate variables for periods shorter than one month. Three methods were used to calculate half-month variables from three different kinds of monthly variables.

Half-month climate variables with intensive properties, like air temperature and density, that do not change with mole number were calculated by linear or cubic spline interpolation of monthly values. For linear interpolation, let

$$P1 = M_{-} + 0.75*(M - M_{-}) \tag{13}$$

$$P2 = M + 0.25*(M_{+} - M) \tag{14}$$

Where $P1$ and $P2$ are calculated values of the variable for the first and second half-month periods, respectively, M is the monthly value for the month in which the period occurs, (M_{+}) is the monthly value for the subsequent month, and (M_{-}) is the monthly value for the month previous to the one in which the period occurs.

For the cubic spline, we fit monthly values assigned to the day-of-the year for the middle of each corresponding month. We actually fit a spline from December to January (14 months), so that the spline had continuous derivatives across the December-January boundary. This more elegant interpolation procedure allows not only an estimation of half-month values but also an estimation of a mean value for the climate variable for any day of the year.

Half-month climate variables with extensive properties, like precipitation and solar insolation that are additive and vary in direct ratio to mole number were converted first to rate variables in amount per day by dividing the total monthly value as stored in the monthly climate database by the number of days in the month. Then 24 half-month, daily, rate variables were calculated as above.

A third group of variables includes those that do not lend themselves to subdividing into shorter time periods (e.g., prevailing wind erosion direction and preponderance of wind erosion forces in the prevailing wind erosion direction). For these, we simply used the monthly value for both halves of the month.

The half-month climate variables actually do not appear in the database but are calculated according to the above procedure as the program is executed.

Results and Discussion

Climate data (e.g.,Table 2) are useful for calculating several input factors that are needed to predict wind erosion with period-based models like WEQ and RWEQ. Wind speed distribution parameters, percent calm, and air density are used to calculate wind energy exceeding the threshold wind speed - the wind erosion driving force. Wind speed distribution, dew point temperature, solar radiation, and air temperature are used to calculate potential evaporation. Potential evaporation and precipitation are used to estimate dryness of the near soil surface. Air temperature and frequency of precipitation are used to estimate rate of residue decomposition. Prevailing wind erosion direction, preponderance of wind erosion forces in the prevailing wind erosion direction, and positive parallel ratio are used to estimate relative merits of position and direction of wind breaks and row direction. Rainfall erosivity is used to estimate change in random and oriented surface roughness since tillage.

Because WEPS is a continuous simulation model with a daily time step, the climate database differs from that required for period-based methods. Climate variables, except wind speed and wind direction, are obtained from the CLIGEN (Nicks and Lane 1989) weather generator. Daily wind direction and subhourly wind speed are obtained by the procedure of Skidmore and Tatarko (1990). A sample data entry to support wind simulations is given in Table 3. In this case, the wind speed Weibull distribution parameters are given for each of the 16 cardinal directions.

Conclusion

RWEQ and WEPS now under development require climatic data to predict wind erosion. Data from the Wind Energy Resource Information System were used to calculate by month, the following: Weibull scale and shape parameters for all wind directions combined, prevailing wind erosion direction, preponderance of wind erosion forces in the prevailing wind erosion direction, the positive parallel wind erosion forces, and air density. Monthly mean maximum/minimum air temperatures, dew point temperature, solar radiation, and precipitation amount were obtained from the CLIGEN database. Other data obtained include: probability of snow greater than 1 inch, average number of days during month that had precipitation, and monthly rainfall erosivity. These data form a climate database for use with RWEQ which uses half-month time steps in simulation. Because WEPS uses a daily simulation, its climate database is slightly different. Weibull scale and shape parameters were calculated for each of the 16 cardinal directions. Prevailing wind erosion direction, preponderance of wind erosion forces in the prevailing wind erosion direction, positive parallel ratio, average number of days during the month that had precipitation, and rainfall erosivity were replaced by distribution parameters and/or functions for weather simulations in WEPS. Precipitation being snow is determined as a function of daily mean temperature and annual mean temperature at a specified probability.

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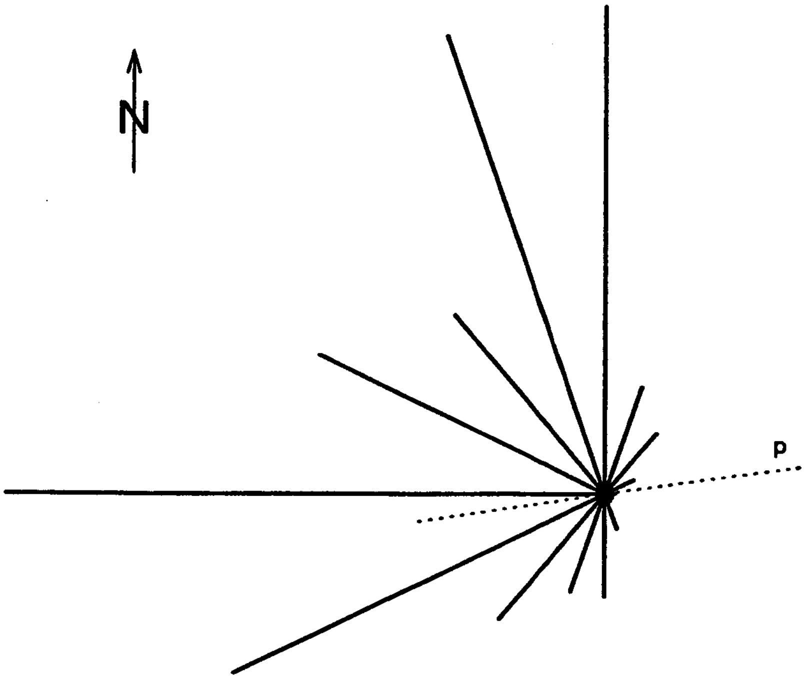

Figure 1. Wind erosion rose for March, Lubbock, TX. The length of each wind erosion vector is proportional to the wind energy exceeding threshold.

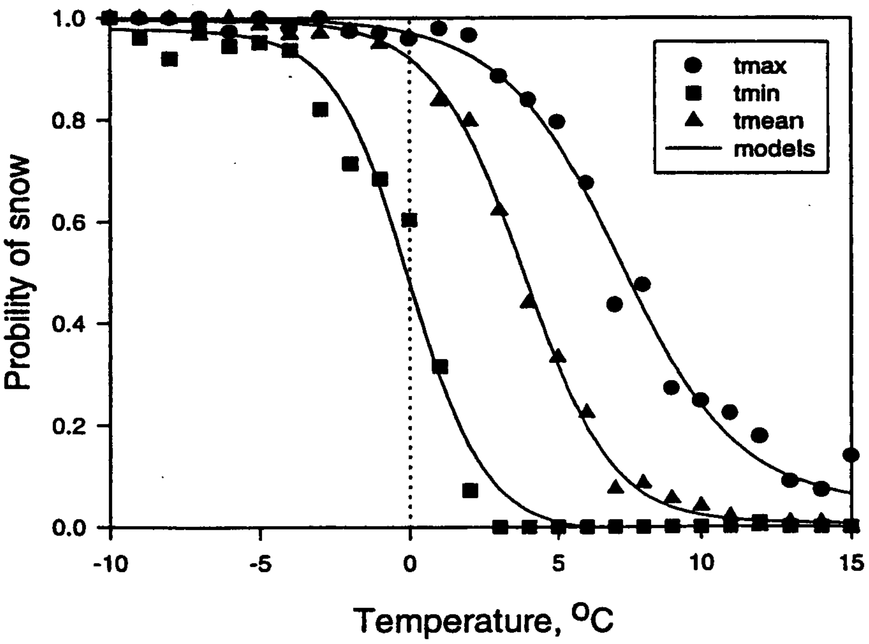

Figure 2. Probability of precipitation being snow as a function of temperature for Billings, MT.

Table 1. Joint wind speed/direction frequency for March, Lubbock, TX (Table 12c of WERIS) (Skidmore and Tatarko 1990).

								WIND DIRECTION										
SPEED (M/SEC)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM	TOTAL
CALM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.7	1.7
1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2	.3	.1	.1	.0	.1	.1	.2	.1	.3	.1	.5	.5	.6	.4	.5	.2	.0	4.1
3	.7	.3	.5	.4	.9	.4	.6	.5	.9	.4	1.1	1.1	1.5	.8	.7	.3	.0	11.1
4	1.0	.6	.8	.4	1.1	.9	1.0	.8	1.9	.6	.8	1.2	1.6	1.2	.7	.5	.0	15.1
5	.9	.6	.8	.5	.9	.9	1.0	1.3	2.1	.9	1.2	1.2	1.6	.5	.4	.5	.0	15.4
6	.7	.7	.6	.4	.6	.5	.9	.6	1.6	1.0	1.1	1.2	.7	.6	.3	.5	.0	12.2
7	1.0	.6	.6	.4	.2	.5	.4	.5	1.6	1.0	1.4	.8	.7	.5	.3	.2	.0	10.0
8	1.0	.6	.8	.2	.5	.3	.6	.3	1.4	1.2	1.0	.6	.7	.4	.4	.2	.0	10.1
9	.8	.4	.6	.2	.3	.1	.2	.4	1.0	.8	.7	.6	.6	.4	.2	.3	.0	7.6
10	.3	.4	.2	.2	.1	.0	.1	.2	.8	.4	.2	.3	.4	.3	.1	.1	.0	4.3
11	.3	.4	.1	.1	.0	.0	.1	.1	.5	.2	.3	.3	.5	.1	.1	.1	.0	3.1
12	.2	.1	.0	.0	.0	.0	.0	.1	.0	.1	.1	.2	.4	.1	.1	.0	.0	1.6
13	.2	.1	.0	.0	.0	.0	.0	.0	.0	.8	.2	.1	.3	.2	.1	.1	.0	1.3
14	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.2	.1	.1	.0	.0	.7
15	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.0	.0	.0	.0	.0	.5
16	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.0	.0	.0	.0	.2
17	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.1
18	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
19	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
21-25	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
26-30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
31-35	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
36-40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
41-up	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL	7.8	4.8	5.1	2.9	4.9	3.8	5.1	4.9	12.2	6.8	8.9	8.5	9.9	5.7	4.0	3.0	1.7	100.0
AVG SPEED	6.9	7.0	6.1	6.0	5.1	5.2	5.5	5.9	6.2	6.7	6.4	6.2	6.4	6.2	5.6	6.3	.0	6.1

Table 2. A sample entry in the RWEQ climate database. Columns of data are for months January through December.

```
1          23042 USA TX LUBBOCK
2         33 39 N 101 50 W 990 19500628 19641231 ARW   90 91

3     6.26   7.15   7.62   7.52   7.28   7.01   5.88   5.14   5.57   5.77   6.15   6.32
4     2.62   2.66   2.60   2.73   2.84   3.04   2.90   3.15   2.96   2.84   2.68   2.53
5     1.14   1.13   1.11   1.09   1.07   1.05   1.05   1.05   1.07   1.09   1.12   1.14
6       23    225    292    225    202    180    180    180    202     23     23    225
7      1.3    1.3    1.1    1.5    1.4    1.8    2.2    1.7    2.5    2.0    1.5    1.4
8     0.55   0.59   0.93   0.66   0.75   0.83   0.79   0.86   0.56   0.54   0.53   0.59
9      3.1    2.9    2.2    1.9    1.9    2.2    3.6    4.5    3.8    3.3    2.7    0.0
10    11.9   14.8   19.0   24.0   28.0   32.6   33.6   32.8   29.0   23.9   17.3   12.7
11    -3.9   -1.9    1.7    7.2   12.4   17.3   19.2   18.4   14.6    8.5    1.6   -2.6
12    -3.9   -3.3   -2.8    2.8    9.4   13.9   16.1   15.6   12.8    7.2   -0.6   -4.4
13     369    436    614    715    815    858    843    760    672    520    414    354
14      13     15     22     32     70     65     54     54     62     58     15     15
15     3.4    3.8    3.8    4.6    7.5    6.7    6.0    6.6    5.9    5.8    3.3    3.8
16     8.4    1.2    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    9.6
17       0      0     15     15    214    352    214    214    214    214     61     15

18        33 39 N 101 49 W 1.5 TX LUBBOCK WB AP
```

Row	**Meaning**
1	A unique (WBAN) number and site location.
2	Latitude, longitude, elevation, period of wind record, and anemometer information.
3	Weibull wind speed distribution scale parameter, c (m/s).
4	Weibull wind speed distribution shape parameter, k.
5	Air density (kg/m^3).
6	Prevailing wind erosion direction (degrees).
7	Preponderance of wind erosion forces in the prevailing wind erosion direction.
8	Positive parallel ratio.
9	Percent of time calm (no measurable wind).
10	Average maximum temperature (°C).
11	Average minimum temperature (°C).
12	Dew point temperature (°C).
13	Solar radiation (MJ/m^2).
14	Precipitation (mm).
15	Average number of days during the month that had precipitation.
16	Probability (%) of snow depth equal to or greater than 25.4 mm.
17	Rainfall erosivity, EI (MJ mm/(ha hr)).
18	Latitude and longitude of CLIGEN database site and distance (km) from the RWEQ site to the CLIGEN database site.

Table 3. A sample entry in the WEPS climate database. The 12 columns of data in rows 3-53 are for the months January through December.

```
1     # 23065 USA KS GOODLAND
2     39 22 N 101 42 W 1112 19500609 19640322 ARW
3       2.4  2.8  2.6  2.2  2.5  2.4  3.7  3.5  3.3  2.9  3.1  3.1
4       7.7  8.2 10.1  9.4  6.8  5.6  4.7  4.5  6.3  7.2  7.0  6.2
5       4.6  4.0  5.7  5.6  5.8  5.1  4.9  4.6  6.2  4.9  3.8  2.8
6       2.3  2.9  3.5  4.0  5.8  5.9  5.1  4.5  3.8  3.7  2.2  1.7
7       1.3  1.6  2.5  3.2  4.4  4.3  3.4  3.4  3.6  1.6  1.1  1.1
8       1.1  1.1  1.9  2.6  3.2  3.4  3.5  2.8  2.9  1.5  1.0  0.8
9       1.8  2.4  3.7  5.2  6.2  5.9  6.7  5.1  4.4  3.3  1.8  1.5
10      2.5  3.9  6.0  6.3  8.2  9.0 11.2  9.7  6.0  5.4  3.3  2.6
11      5.8  7.2  8.2 10.5 12.9 14.0 16.8 17.2 14.0 11.2  5.1  4.6
12      6.0  6.9  7.2  9.4 11.0 13.4 13.6 13.4 14.8 10.4  7.2  5.2
13      4.7  4.5  4.7  6.2  5.7  8.3  7.6  8.3  8.2  6.3  6.0  4.4
14      8.2  7.2  5.5  5.0  4.3  5.0  5.3  6.2  5.9  6.9  8.3  8.7
15     16.3 11.8  7.9  5.9  5.6  4.0  3.4  4.0  5.0  8.9 13.8 15.4
16      6.6  5.5  3.6  2.5  1.9  1.5  1.4  2.2  2.4  4.0  5.5  7.3
17      8.7  7.7  5.7  4.2  3.8  2.8  2.3  2.9  3.0  5.8  9.3 11.2
18     10.6 10.8  8.7  7.7  5.8  4.2  2.9  3.6  4.7  7.2  9.0 12.1
19      9.4 11.5 12.3 10.2  6.2  5.2  3.5  4.1  5.7  8.9 12.4 11.4
20      7.89   8.11   8.61   8.15   7.03   6.53   5.89   5.88   6.50   6.72   7.77   7.16
21      6.99   7.07   7.26   6.83   6.49   6.60   6.21   5.64   6.48   5.78   6.82   6.01
22      5.08   5.36   6.08   5.90   6.26   6.16   5.91   5.44   5.13   5.35   5.23   4.85
23      4.86   4.36   5.89   6.16   6.70   6.32   6.01   5.20   5.80   4.62   4.50   4.39
24      4.40   4.30   5.59   5.56   5.51   5.88   5.21   4.86   5.47   4.50   4.34   4.50
25      4.58   5.26   5.67   6.19   6.64   6.59   5.74   5.58   5.31   4.45   4.21   4.50
26      5.01   5.73   6.85   6.85   7.14   6.65   6.22   6.00   5.47   5.80   5.60   5.82
27      5.99   6.41   7.42   8.13   7.82   7.80   6.80   6.91   7.17   6.94   6.39   6.19
28      6.26   6.63   7.65   8.12   7.76   7.83   6.98   6.83   7.47   7.24   6.72   6.37
29      6.14   6.64   7.31   7.50   7.25   8.03   6.75   6.48   6.94   6.81   6.88   6.77
30      5.62   5.23   6.28   5.95   5.81   5.93   5.37   5.20   5.28   5.25   5.78   5.89
31      5.18   5.18   5.42   5.22   5.22   5.07   4.31   4.28   4.35   4.82   5.02   5.13
32      4.71   4.49   4.89   4.62   4.06   3.55   3.16   3.28   3.97   4.09   4.43   4.70
33      5.27   5.39   6.09   6.00   5.37   5.34   4.19   4.52   4.19   4.72   5.67   5.66
34      6.77   6.93   7.86   7.93   7.27   5.70   4.41   4.56   5.29   6.08   6.70   6.65
35      8.05   8.71   9.67   9.10   7.41   6.81   5.84   5.85   6.85   7.52   8.27   8.51
36      2.32   2.41   2.29   2.70   2.43   2.41   2.37   2.43   2.47   2.69   2.64   2.48
37      2.82   2.51   2.59   2.54   2.83   2.55   2.43   2.67   2.48   2.77   2.47   2.97
38      3.07   2.87   2.56   2.88   2.61   2.57   2.40   2.37   2.82   2.82   2.79   2.69
39      3.60   4.00   3.27   2.36   2.45   2.67   2.84   2.68   3.03   3.50   2.95   2.84
40      4.04   2.58   2.91   3.06   2.56   2.65   2.47   2.76   2.83   3.67   2.65   3.77
41      3.36   3.02   2.86   2.52   2.56   2.56   2.50   2.64   2.75   3.08   3.60   3.67
42      2.53   2.74   2.79   2.60   2.61   2.74   2.70   2.68   2.85   2.86   2.27   2.52
43      3.14   3.02   2.91   2.93   2.97   2.81   3.15   3.06   3.15   2.97   2.99   2.88
44      3.20   2.74   2.71   2.85   2.62   3.01   3.23   3.08   3.14   3.00   2.99   3.27
45      3.48   2.78   2.67   3.02   2.67   3.10   3.16   2.84   3.32   2.80   2.96   2.66
46      3.26   3.23   2.78   2.90   2.69   2.84   2.74   2.99   3.11   3.43   3.06   3.35
47      3.84   3.42   3.36   3.24   3.37   2.62   3.34   2.97   3.67   4.03   4.12   3.94
48      3.36   3.37   2.67   3.16   3.09   3.08   2.96   4.30   2.95   3.17   3.63   3.63
49      3.17   3.18   2.29   2.62   2.67   2.59   2.39   2.64   2.94   2.94   2.96   3.01
50      2.42   2.32   2.20   2.16   2.07   2.32   2.60   2.53   2.12   2.24   2.16   2.35
51      2.45   2.50   2.42   2.39   2.58   2.40   2.25   2.34   2.37   2.56   2.49   2.50
52       1.4   1.4   1.3   1.4   1.4   1.4   1.6   1.6   1.3   1.4   1.4   1.4
53        12    12    11    14    15    15    17    17    15    13    12    13
```

Row	Meaning
1	A unique (WBAN) number and site location.
2	Latitude, longitude, elevation, period of wind record, and anemometer information.
3-18	Wind direction distribution by direction for North (row 3) through North-north-west (row 18).
19	Percent calm. The sum of rows 3 - 19 is 100.0
20-35	Weibull scale parameter by direction, c (m/s).
36-51	Weibull shape parameter by direction, k.
52	Ratio of maximum to minimum hourly wind speed.
53	Average hour of maximum wind speed.

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