Dewpoint Temperature Inversions[1]

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ABSTRACT

A study was made of the diurnal and seasonal variations of the vertical dewpoint gradient based on measurements taken at 1.2, 9.4 and 131 ft above ground at the Argonne National Laboratory during the period 1 December 1960 through 30 November 1965. The results of this study are used to assess the effects of the dewpoint temperature inversion on vegetative growth, dew formation and corrosion.

Case studies employing time series presentations are used to relate the magnitude and direction of the dewpoint gradient with other meteorological variables such as air and soil temperature, pressure, solar radiation, net radiation flux, wind speed and direction, relative humidity and stability. These analyses illustrate the processes operating to influence the magnitude and direction of moisture flux in the lower atmospheric layers.

Joint frequency distributions are presented relating the vertical dewpoint temperature gradient with each of the variables—air temperature between 144 and 5.5 feet, relative humidity, net radiation flux and wind speed. Also, a multivariate study is presented showing the relations among the occurrence frequency of dewpoint inversion, wind speed, relative humidity and net radiation flux. From this study, it is possible to determine the relation between the occurrence frequency of the dewpoint inversion and any one of the above variables with the other two held constant. A similar study is presented with the air temperature difference between 144 and 5.5 ft replacing net radiation flux as one of the variables.

1. Introduction

Water vapor is a variable constituent of the atmosphere. The amount present at any one time depends upon the type of air mass, the nature of the terrain over which the air mass has traveled, radiation conditions, turbulence structure and other factors. Ordinarily, especially during clear daytime conditions, the moisture content decreases with height. During nighttime conditions with clear skies when the air is relatively moist and the winds are light, a reversal in the moisture gradient often occurs; that is, the moisture increases with height in the first several hundred feet above ground.

A number of investigators have obtained data on the variation of moisture with height in the lower atmospheric layers. Robinson (1965), for example, conducted such measurements in Greenland to study the meteorological conditions related to fog formation. Best *et al.* (1952) carried out an extensive set of temperature and humidity measurements at four levels up to a height of 106.7 m over a 3-yr period. These data were obtained for use in atmospheric refractive index determinations necessary for work involving the propagation of radio and radar signals. Many measurements of the variation of moisture with height have been made in connection with agricultural work.

Absolute humidity, specific humidity, mixing ratio, wet-bulb temperature, relative humidity, vapor pressure or dewpoint may be used to describe atmospheric moisture content. Authors have used those measures most appropriate to their studies. Since the dewpoint was measured directly, it is the primary measure of moisture used in this work.

The flux of water vapor in the atmosphere is given by

$$F=-K_S\rho(dq/dz), \tag{1}$$

where

F = the flux of water vapor (gm cm^{-2} sec^{-1}),
K_S = the eddy diffusion coefficient for moisture (cm^2 sec^{-1}),
ρ = the air density (gm cm^{-3}),
q = the specific humidity in grams of water vapor per gram of moist air, and
z = the height (cm).

Any other consistent system of units may be used.

When the moisture content decreases with height, the flux of moisture is directed upward and is considered positive. Similarly, when moisture increases with height, the vapor flux is directed downward.

The vapor pressure e is related to the specific humidity q as shown by

$$q=0.622[e/(p-0.378e)], \tag{2}$$

where e is the vapor pressure (mb), and p the atmospheric pressure (mb).

The dewpoint temperature T_d and the vapor pressure e have a one-to-one correspondence and are related by

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Table 1. Periods with dewpoint temperature difference inversions for the 131−1.2 ft layer, December 1960 to November 1965.

Month	Average number of hours per day Highest monthly average	 5-year average	 Lowest monthly average	Number of days per month Highest	 5-year average	 Lowest
December	16	10	4	31	25	12
January	18	11	5	31	26	19
February	18	9	4	29	24	17
March	15	9	4	31	25	17
April	16	7	2	30	21	12
May	12	6	1	30	21	7
June	11	6	3	29	23	16
July	7	6	4	28	23	18
August	6	5	3	25	23	19
September	6	5	1	26	21	5
October	7	4	2	22	18	10
November	14	7	3	30	21	14

the Clapeyron-Clausius equation which may be expressed as

$$de/dT_d = Le/(RT_d^2), \qquad (3)$$

where T_d is the dewpoint temperature (°K), L the heat of vaporization (cal gm^{-1}) and assumed constant for temperature above 0C, and R the gas constant for water vapor [cal gm^{-1} (°K)$^{-1}$]. Upon integration, one obtains the relation between the vapor pressure over water and dewpoint temperature, i.e.,

$$\ln e = 1.81 + 19.9\left(\frac{t_d}{t_d+273}\right), \qquad (4)$$

where t_d is the dewpoint temperature (°C).

If an unsaturated parcel of air is lifted adiabatically, its dewpoint temperature will fall even though the moisture content (grams of water vapor per gram of moist air) remains constant. The fall will be at a rate of about 0.17 times the dry adiabatic lapse rate of 10C km^{-1}. The dewpoint will thus fall at the rate of about 1.7C km^{-1}. Making use of this information and that contained in Eqs. (1)–(4), one can determine the vertical gradient of moisture content from measurements of dewpoint temperatures at two or more levels. It is of interest to point out that zero dewpoint gradients correspond to a reversal in the normal gradient of moisture concentration and to a water vapor flux directed downward.

2. Instrumentation and available data

Objectives of this study are to present data on the climatography of vertical dewpoint profile as determined by dewpoint temperature differences for the 1.2- and 9.4-ft levels and the 1.2- and 131-ft levels, and to investigate the relations between the variation of dewpoint with height and the associated meteorological conditions. Five years of hourly observations, from 1 December 1960 through 30 November 1965, made at the Argonne National Laboratory have been used. Data on solar radiation and net radiation flux, air and dewpoint temperatures, relative humidity, soil temperatures, wind speed and direction, and pressure have been examined to establish the influence of meteorological variables on the variation of dewpoint temperature with height.

At the Argonne National Laboratory meteorological installation, approximately 40 meteorological variables are measured each hour (Moses and Kulhanek, 1962). The data are recorded not only on pen and ink charts, but also on paper punch tape and on a teletype printout. The paper punch tape is converted into IBM cards and magnetic tape for computer processing. The Control Data Corporation (CDC) 3600 computer compiled the tables used in this paper.

Dewpoint measurements used in the present study were obtained by Foxboro Dewcels (Conover, 1950) at 1.2, 9.4 and 131 ft on the Argonne meteorological tower. These instruments have an absolute accuracy of about 3F and a greater relative accuracy. Dewpoints at each level were recorded for 2 min each, five times per hour, and punched on tape once an hour.

Vertical temperature gradient measurements were obtained by copper constantan thermocouples measuring the difference between temperatures at 5.5 and 144 ft. The temperature differences for this layer were integrated with a contact-closure type ball and disc integrator over a 2-min period, each hour. Hourly relative humidity values were computed from the 5.5-ft ambient air temperatures and the 4.7-ft dewpoint values. Net radiation flux measurements were obtained with a Beckman and Whitely radiometer located 6 ft above the ground. The hourly values represent the integrated value of net radiation flux ending on the hour indicated. Belfort Corporation three-cup anemometers were used for measuring wind speed on a pole 19 ft high located 200 ft east of the meteorology tower. The meteorology tower itself is unsuitable for measuring wind speed at this height because of the wind shadow effect (Moses and Daubek, 1961). The wind speed readings represent

TABLE 2. Percentage frequency distribution of the dewpoint differences, December 1960 to November 1965.

T_d(131 ft−1.2 ft) (°F)	Winter	Spring	Season Summer	Fall	Annual
<−10.0	0.2	0.8	0.7	0.6	0.6
−9.9 to −8.0	0.2	1.4	1.6	1.3	1.1
−7.9 to −6.0	0.7	3.9	5.8	4.3	3.7
−5.9 to −4.0	2.7	9.0	13.6	10.5	9.0
−3.9 to −2.0	10.6	17.8	23.0	20.0	17.9
−1.9 to −0.0	44.1	38.9	32.1	41.6	39.2
0.1 to 2.0	29.2	22.4	15.7	14.2	20.4
2.1 to 4.0	7.6	4.0	4.6	3.7	4.9
4.1 to 6.0	2.5	0.9	1.2	1.6	1.5
6.1 to 8.0	0.8	0.3	0.2	0.8	0.5
8.1 to 10.0	0.3	0.1	—	0.3	0.2
>10.0	0.3	—	—	0.1	0.1
Missing	0.8	0.6	1.6	1.0	1.0
Per cent lapse	58.5	71.8	76.8	78.3	71.5
Per cent inversion	40.7	27.7	21.7	20.7	27.6

10-min averages for each hour. The instrumentation for meteorological measurements used in this report which receive only secondary emphasis are described by Moses and Kulhanek (1962).

3. Climatological features of dewpoint inversions

a. Frequency of dewpoint inversions. Dewpoint inversions are a fairly common occurrence. In winter as many as 41% of the hourly readings showed a dewpoint inversion between the 131- and 1.2-ft levels. In summer and fall 22 and 21% of the observations, respectively, showed inversion conditions. Further, the average number of days per month during which inversions occur ranges from a minimum of 18 in October to a maximum of 26 in January (see Table 1). This table shows also that the dewpoint inversion occurs in a substantial number of hours. Table 2 presents the frequency distribution of the dewpoint temperature differences between the 131- and 1.2-ft levels for each season and for the entire year. Winter was taken as December, January and February, spring as March, April, May, etc.

A 20F range, i.e., from −10F to 10F brackets over 98% of the values (1% were missing due to malfunction at one or both levels). In winter 73%, but in summer 48%, of the dewpoint temperature differences fell within ±2F. In each season more than one-half of the observations showed hydrolapse conditions (dewpoint decreasing with height) in the 0 to −3.9F range.

Fig. 1 shows the percentage frequency distribution of the dewpoint temperature differences per 100 ft based on data for the layer from 1.2 to 9.4 ft, as well as that from 1.2 to 131 ft. The curves are reasonably symmetrical but it is evident that most of the change in dewpoint temperature takes place in the 1.2–9.4 ft layer.

b. Diurnal variation of dewpoint temperatures. In general, the dewpoint temperature rises during the daytime and falls at night. The hourly values shown in the upper part of Fig. 2 provide a picture of the diurnal variation. It is evident that when vegetation is present the amplitude of the diurnal wave is appreciably greater than during the winter months. The double maximum described by Geiger (1965) may be seen for the months of October and November.

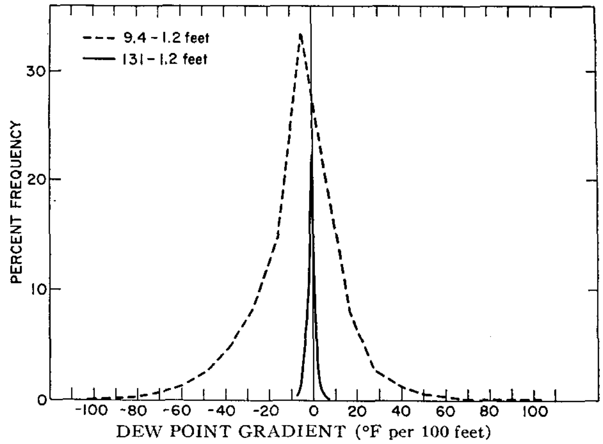

FIG. 1. Per cent frequency distribution of the dewpoint gradient.

The lower portion of Fig. 2 shows the diurnal variation of the dewpoint temperature difference for the 9.4–1.2 ft and 131–1.2 ft layers. The large differences observed during the daylight hours for months when vegetation is present, i.e., May through October, are noteworthy. During these months the largest positive as well as negative gradients are observed. Note that the curves do not cross over during these months. In strong hydrolapse conditions the average humidity decreases monotonically, but during dewpoint inversion conditions, the increases with height are not monotonic, since the dewpoint difference between the 9.4- and 1.2-ft levels is greater than the difference between the 131- and 1.2-ft levels. Thus, the average dewpoint inversion profile indicates that a maximum exists between the 1.2- and 131-ft levels. The recurrence of this pattern in other years as well, confirms its validity.

The average hourly dewpoint temperature differences between the 131- and 1.2-ft levels, for each month of each year, for the period 1 December 1960 to 30 November 1965 are presented in Fig. 3. The strong daytime hydrolapse pattern during the growing season is clearly shown. Inversion conditions appear as hatched areas. This figure shows again that dewpoint inversions are nighttime phenomena.

Since dewpoint inversions occur more frequently at night, one would expect their onset to be around sunset with disappearance shortly after sunrise. Fig. 4 shows this to be so. This figure shows the annual average frequency of onset and disappearance of the dewpoint inversion for each hour of the day. It is evident that the maximum frequency of onset occurs in the late hours of the afternoon or early evening, and the most frequent hour for ending occurs at about sunrise. The maxima are broadened because all of the data for the year were

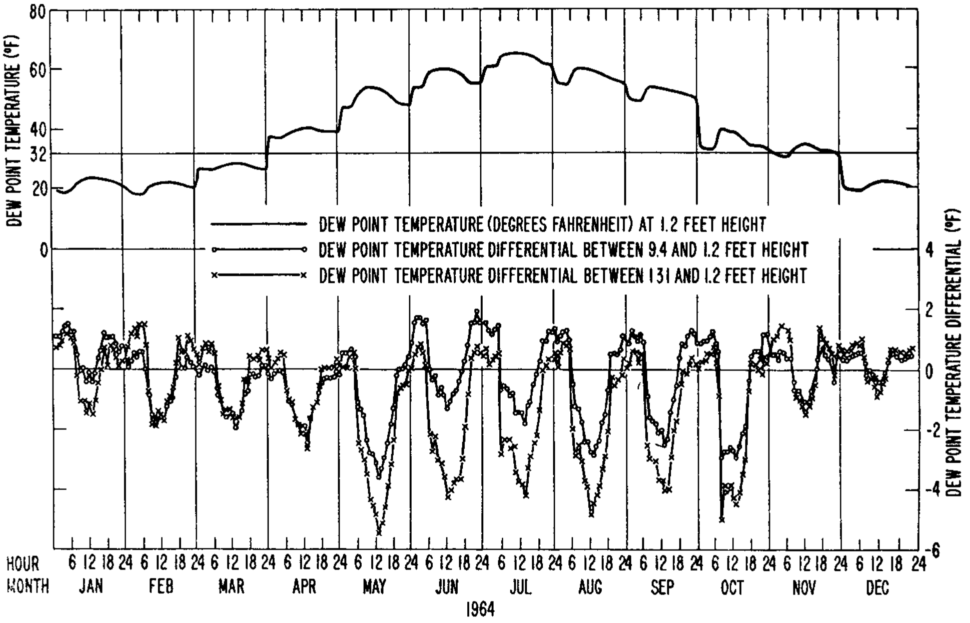

Fig. 2. Average hourly dewpoint temperature at 1.2 ft and average hourly dewpoint temperature difference between 131 and 1.2 ft, and 9.4 and 1.2 ft, for each month of 1964.

used. In similar charts, drawn for each season, the relation between disappearance and appearance with sunrise and sunset are more distinct. Charts drawn for the 9.4–1.2 ft layer show more clearly the beginning and end of the dewpoint inversion with dusk and dawn.

4. Relation between the vertical dewpoint profile and associated meteorological variables

The observed variation of dewpoint temperature with height is markedly affected by conditions which lead to condensation on or evaporation from the ground surface. It is also possible for advective processes to contribute to the changes of dewpoint temperature with height, but for this study advection is not taken into account although in some cases it may be important.

A dewpoint inversion will develop if the ground acts as a sink to remove water vapor. The ground does act as a sink whenever it cools to a point where condensation will take place or if it is hygroscopic. Condensation may be expected during clear nighttime conditions when the ground radiates strongly to outer space and cools to below the dewpoint temperature. One should expect appreciable condensation to take place during times when the relative humidity is high and when the net radiation flux is directed outward, which, in turn, leads to a strong surface inversion. During windy conditions the lower layers of the atmosphere are well mixed, thus preventing strong cooling in the lower layers because warmer air is continually brought down from above. Thus, dewpoint inversions would be expected to form

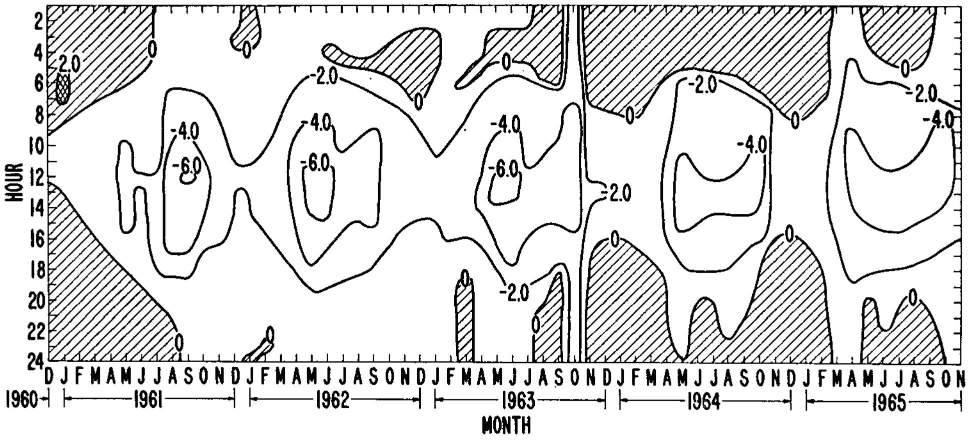

Fig. 3. Isopleths of average hourly dewpoint temperature difference for month vs hourly charts for December 1960 to November 1965.

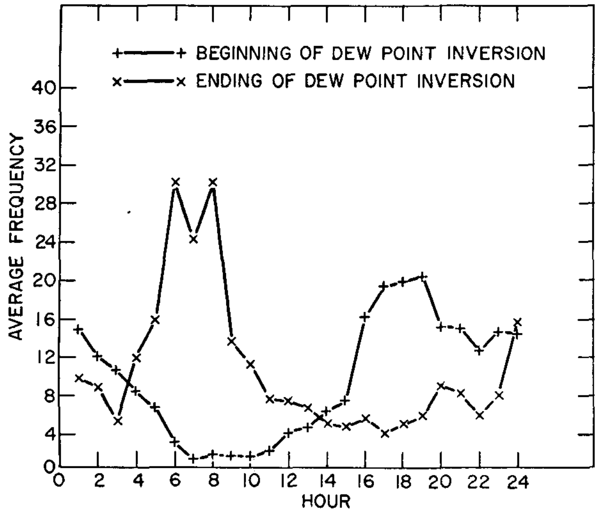

FIG. 4. Annual average frequency of the beginning and ending of dewpoint inversion (persistence ≥ 2 hr) by hour for the period December 1960 to November 1961.

more frequently under light wind conditions, all other factors being equal.

a. Dewpoint case studies. The relation between the 131- and 1.2-ft dewpoint temperature difference and the aforementioned and other meteorological variables are presented in the two case studies of Figs. 5 and 6. Fig. 5 is based on measurements for the 120-hr period beginning at 0100, 7 August 1963 and ending at 2400, 11 August 1963, all times local standard. Fig. 6 shows the data for the 72-hr period beginning at 0100, 9 July and ending at 2400, 11 July 1963. In the August case, dewpoint inversions occurred for a substantial period during each of the five nights. In the July study, dewpoint inversions occurred in only two isolated nighttime hours.

A study of these meteorological variables and their relationships throws light on the processes involved in producing downward fluxes of water vapor. The curves for net radiation flux, ambient air and dewpoint temperature, and wind speed are similar in that a maximum occurs during the daytime and a minimum during the night. Approximately 180° out of phase with these curves are those for dewpoint temperature difference, air temperature difference and relative humidity. The soil temperature changes are similar to those of air temperature.

The August period is characterized by marked dewpoint inversions. The amplitude of the day-night dewpoint temperature changes at 1.2 ft is markedly greater than at 131 feet during this period. The following factors contributed to a decrease in dewpoint temperature at 1.2 feet and the development of a dewpoint inversion:

1. Outgoing radiation for approximately 12 hr each night, with maximum values of 4–8 ly hr^{-1}.
2. Temperature inversions for 12 or more hours which reached maximum values of 4–10F. The stability of the lower atmosphere during inversion periods suppressed vertical mixing. As a result the air near the earth's surface was not replaced with warmer air from above, and the lowermost layers continued to cool to the dewpoint temperature. This, of course, allowed condensation at the ground.
3. Low wind speeds, under 5 mph, at night. It is likely that an optimum range of wind speed exists for the development of dewpoint inversions. If the winds are too strong, mixing prevents the lower layers from cooling, with the result that condensation is impeded. If the winds are too light so that the flow is nearly laminar, the vertical water vapor flux becomes markedly reduced. Thus, there must be a range of wind speeds for each combination of relative humidity, net radiation flux and stability,

TABLE 3. Joint percentage frequency distribution of the dewpoint difference and net radiation flux, December 1960 to November 1965.

T_d (131 ft−1.2 ft) (°F)	Net radiation (10^{-1} ly hr^{-1}) ≤ -50	−49 to −25	−24 to 0	1 to 99	100 to 799	Missing	Total
<−10.0	—	—	—	0.1	0.4	—	0.6
−9.9 to −8.0	—	—	0.1	0.1	0.8	—	1.1
−7.9 to −6.0	0.1	0.1	0.2	0.3	2.9	0.2	3.7
−5.9 to −4.0	0.2	0.4	0.5	0.9	6.6	0.4	9.0
−3.9 to −2.0	1.2	1.4	2.2	3.6	8.2	1.3	17.9
−1.9 to −0.0	7.1	6.5	9.6	5.9	4.4	5.7	39.2
0.1 to 2.0	6.6	4.5	3.9	1.6	0.7	3.1	20.4
2.1 to 4.0	2.2	1.7	0.4	0.1	0.2	0.3	4.9
4.1 to 6.0	0.6	0.7	0.1	—	—	0.1	1.5
6.1 to 8.0	0.2	0.3	—	—	—	—	0.5
8.1 to 10.0	0.1	0.1	—	—	—	—	0.2
>10.0	—	0.1	—	—	—	—	0.1
Missing	0.1	0.2	0.1	0.1	0.2	0.2	1.0
Total	18.4	16.0	17.1	12.7	24.4	11.4	100.0
Cumulative total	18.4	34.4	51.5	64.2	88.6	100.0	100.0
Per cent lapse	8.6	8.4	12.6	10.9	23.3	7.6	71.5
Per cent inversion	9.7	7.4	4.4	1.7	0.9	3.5	27.6

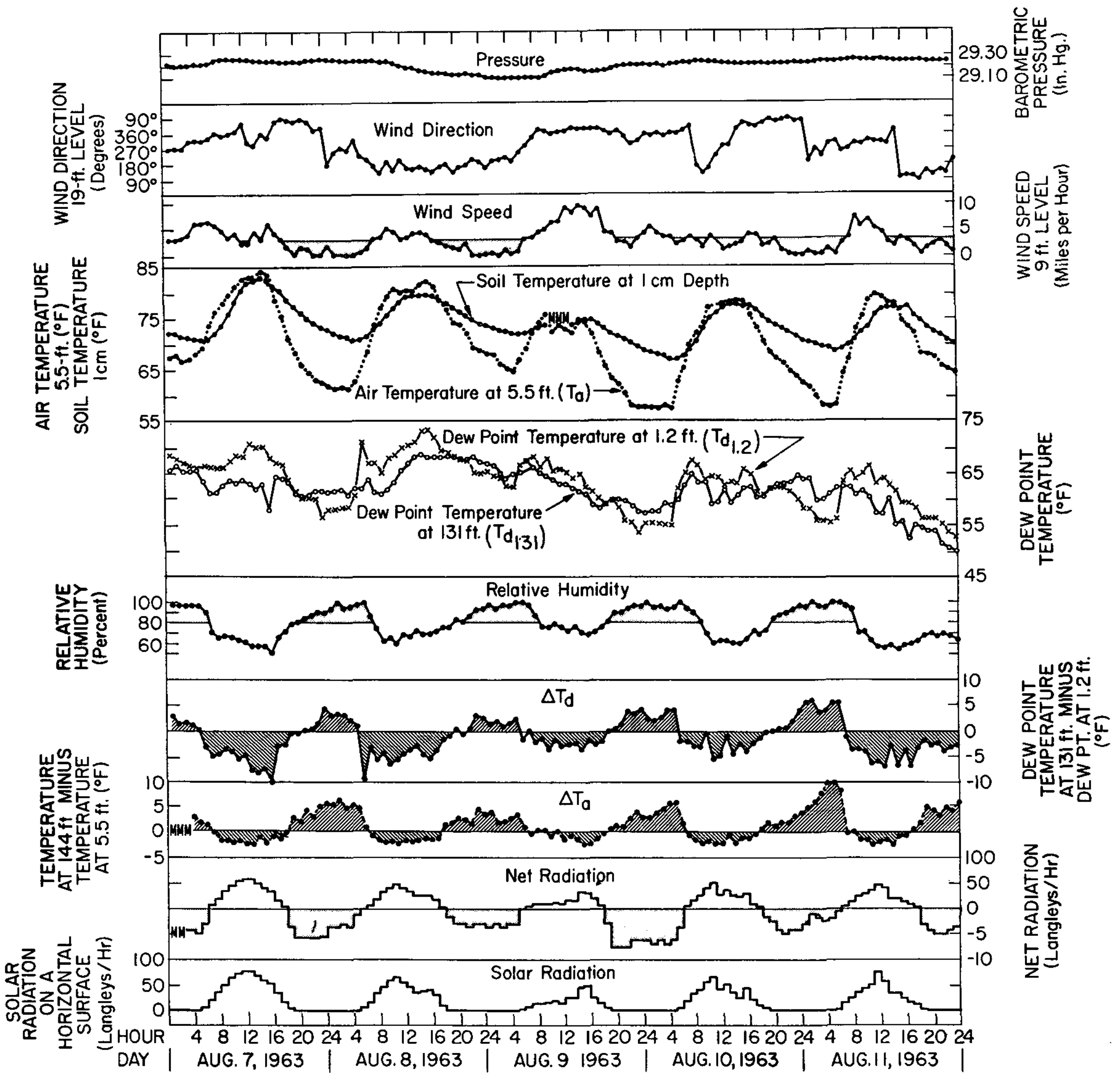

Fig. 5. Time series of hourly dewpoint temperature differences between 131 and 1.2 ft and related meteorological variables for the period 7–11 August 1963.

which are effective in bringing about dewpoint inversions.

During the July period, wind speed, net radiation flux and the air temperature difference were favorable for the development of a dewpoint inversion, but the relative humidity was too low. An inversion was recorded in only two isolated observations. The following features characterize the July case:

1. Nighttime periods of outgoing radiation were somewhat shorter and the magnitude was somewhat less than in August. During one night (9–10 July), however, greater values were observed than on two of the nights in the August period. Dewpoint inversions were not observed on that night.
2. Greater temperature inversions in July than in August. On the night of 9–10 July a difference of over 15F was observed. The relative dryness of the air no doubt contributed to this large temperature gradient.
3. Relative humidity values of less than 75%. Air temperature remained more than 9F higher than dewpoint temperature throughout the period.
4. Nighttime wind speeds under 5 mph. On the night of 10–11 July the winds were less than 2 mph or calm.

b. Joint frequency distributions of dewpoint temperature and associated meteorological variables. Joint frequency distributions are presented in Tables 3–6 for differences in dewpoint temperature between the 131- and 1.2-ft levels and each of the variables, net radiation flux, air temperature difference, relative humidity and the 19-ft wind speed.

The relation between the net radiation flux and the dewpoint temperature difference is shown in Table 3. Inversions as large as 6.0F were found only with outgoing radiation. Steep hydrolapse conditions were found with incoming radiation. With incoming radiation $\geqslant 10$ ly hr^{-1}, the hydrolapse frequency is overwhelmingly greater than the inversion frequency. Inversion frequencies exceeded hydrolapse frequencies whenever the outgoing radiation $\geqslant 5$ ly hr^{-1}.

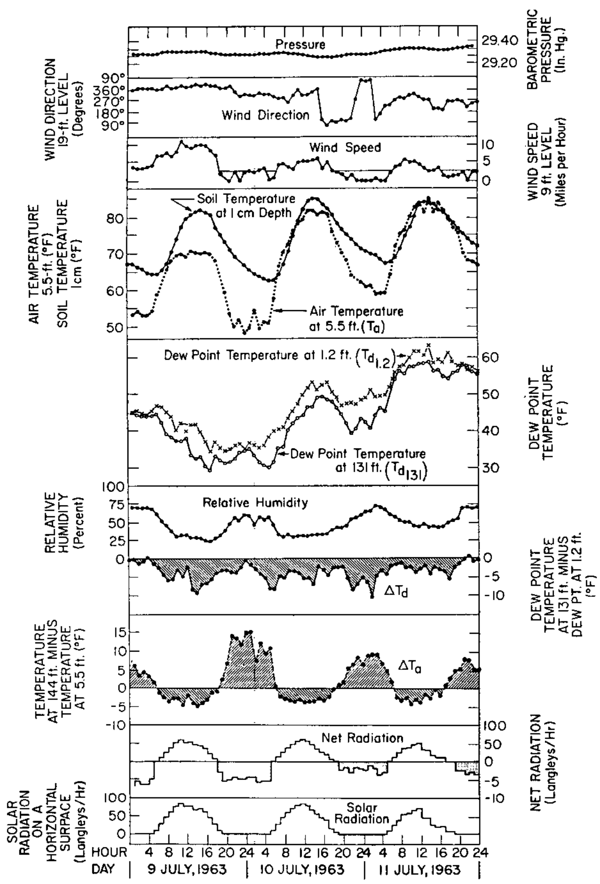

FIG. 6. Time series of hourly dewpoint temperature differences between 131 and 1.2 ft and related meteorological variables for the period 9–11 July 1963.

The relation between dewpoint inversions and temperature inversions is given in Table 4. Under temperature lapse conditions no dewpoint inversion gradients greater than 4F are found. The relatively few observations of dewpoint inversion with temperature lapse conditions may be due to transitional observations, i.e., from night to day or possible instrumental inadequacy. Large air temperature and dewpoint temperature inversions are associated, as are lapse and hydrolapse conditions.

A clear and marked relationship between relative humidity and dewpoint gradient was observed (Table 5). Only hydrolapse conditions occurred at humidities below 30%. With increasing relative humidity the ratio of the frequency of occurrence of hydrolapse to inversion cases diminishes. For the highest humidity class, 91–100%, large values of inversion were more frequent than large values of lapse conditions.

The relation between wind speed and dewpoint temperature differences is shown in Table 6. Increasing wind speed decreases the temperature differences observed. The proportion of hydrolapse to inversion increases with increasing wind speed. Dewpoint inversions, however, are found even in the highest wind speed groupings shown in the table.

c. Frequency of conditions contributing to dewpoint inversions. The frequency of occurrence of those conditions which contribute to the development of dewpoint inversions are shown in Table 7 for each season. Strong outgoing net radiation, temperature inversions, rela-

TABLE 4. Joint percentage frequency distribution of the dewpoint and air temperature differences, December 1960 to November 1965.

T_d (131 ft−1.2 ft) (°F)	T_a (144 ft−5.5 ft) (°F) $\leqslant -3.0$	−2.9 to −2.0	−1.9 to −1.0	−0.9 to −0.0	0.1 to 1.0	1.1 to 3.0	$\geqslant 3.1$	Missing	Total
<−10.0	0.1	0.2	0.1	—	—	—	0.1	0.1	0.6
−9.9 to −8.0	0.2	0.4	0.2	0.1	—	—	0.1	0.1	1.1
−7.9 to −6.0	0.8	1.4	0.6	0.4	0.1	0.1	0.2	0.3	3.7
−5.9 to −4.0	1.7	3.1	1.6	1.0	0.2	0.3	0.5	0.6	9.0
−3.9 to −2.0	1.7	3.7	3.7	3.6	1.0	1.1	1.3	1.8	17.9
−1.9 to −0.0	0.5	2.2	4.0	13.0	5.1	5.0	3.6	5.7	39.2
0.1 to 2.0	0.1	0.4	1.1	5.1	3.3	4.3	3.4	2.6	20.4
2.1 to 4.0	0.1	0.1	0.1	0.3	0.4	1.3	2.5	0.3	4.9
4.1 to 6.0	—	—	—	—	—	0.2	1.2	0.1	1.5
6.1 to 8.0	—	—	—	—	—	—	0.4	—	0.5
8.1 to 10.0	—	—	—	—	—	—	0.2	—	0.2
>10.0	—	—	—	—	—	—	0.1	—	0.1
Missing	—	0.1	0.1	0.1	0.1	0.2	0.2	0.2	1.0
Total	5.1	11.6	11.4	23.7	10.2	12.6	13.6	11.7	100.0
Cumulative total	5.1	16.7	28.1	51.8	62.0	74.6	88.2	99.9	100.0
Per cent lapse	5.0	11.0	10.2	18.1	6.4	6.5	5.8	8.6	71.5
Per cent inversion	0.2	0.5	1.2	5.4	3.7	5.8	7.8	3.0	27.6

Table 5. Joint percentage frequency distribution of the dewpoint difference and relative humidity, December 1960 to November 1965.

T_d (131 ft−1.2 ft) (°F)	Relative humidity (%) 21 to 30*	31 to 40	41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100	Missing	Total
<−10.0	—	0.2	0.1	0.1	—	—	—	—	—	0.6
−9.9 to −8.0	0.1	0.2	0.3	0.2	0.1	0.1	—	0.1	—	1.1
−7.9 to −6.0	0.2	0.6	1.1	0.8	0.5	0.2	0.1	0.1	—	3.7
−5.9 to −4.0	0.2	1.0	1.8	2.3	1.7	1.0	0.5	0.4	—	9.0
−3.9 to −2.0	0.2	0.8	2.1	3.3	4.1	3.6	2.4	1.3	0.1	17.9
−1.9 to −0.0	0.1	0.6	1.8	3.4	5.8	8.2	8.6	10.4	0.3	39.2
0.1 to 2.0	—	0.2	0.5	1.2	2.0	3.4	5.2	7.7	0.1	20.4
2.1 to 4.0	—	—	0.1	0.2	0.3	0.6	1.2	2.4	0.1	4.9
4.1 to 6.0	—	—	—	—	—	0.1	0.3	1.0	—	1.5
6.1 to 8.0	—	—	—	—	—	—	0.1	0.4	—	0.5
8.1 to 10.0	—	—	—	—	—	—	—	0.2	—	0.2
>10.0	—	—	—	—	—	—	—	0.1	—	0.1
Missing	—	—	0.1	0.1	0.1	0.1	0.1	0.1	0.4	1.0
Total	0.8	3.6	7.9	11.6	14.6	17.3	18.5	24.2	1.0	100.0
Cumulative total	0.8	4.4	12.3	23.9	38.5	55.8	74.3	98.5	99.5	100.0
Per cent lapse	0.8	3.4	7.2	10.1	12.2	13.1	11.6	12.3	0.4	71.5
Per cent inversion	—	0.2	0.6	1.4	2.3	4.1	6.8	11.8	0.2	27.6

* Zero values prevailed for 1–10 and 11–20% relative humidity.

tive humidity exceeding 80% and light winds all contribute. The frequency of air temperature inversions increases from winter to spring, summer and fall. Just the opposite is true for dewpoint temperature inversions. Each of the other variables have different frequency distribution patterns.

d. Multivariate charts relating dewpoint inversions with other meteorological variables. The relation between the variables, net radiation flux, relative humidity and 19-ft wind speed, and the occurrence of dewpoint inversion are shown in Figs. 7a–e. This presentation makes it possible to examine the frequency of simultaneous occurrence of any one of these variables and dewpoint inversion with the other two held constant. For example, in Fig. 7a the relative humidity is in the range of 91–100%. Separate curves are drawn relating the relative percentage frequency of dewpoint inversion and wind speed holding the net radiation flux within a specified interval. Thus, along any of these curves the net radiation flux is constant. Since the relative humidity is also constant, within limits, one may observe how the relative frequency of dewpoint inversion changes with wind speed under these conditions.

The relative percentage frequency refers to the percentage of the total number of observations in a particular category (i.e., having a particular combination of wind speed, relative humidity and net radiation flux) which appears as dewpoint inversion reading. For example, point P shows a value of 84%. There were actually 1025 cases of relative humidity between 91 and

Table 6. Joint percentage frequency distribution of the dewpoint difference and 19-ft wind speed. December 1960 to November 1965.

T_d (131 ft−1.2 ft) (°F)	Wind speed (mph) Calm	1 to 3	4 to 7	8 to 12	13 to 18	≥19	Missing	Total
<−10.0	0.1	0.1	0.2	0.1	—	—	—	0.6
−9.9 to −8.0	0.1	0.2	0.4	0.3	0.1	—	—	1.1
−7.9 to −6.0	0.1	0.5	1.4	1.2	0.4	0.1	—	3.7
−5.9 to −4.0	0.2	1.1	3.1	3.1	1.2	0.2	—	9.0
−3.9 to −2.0	0.4	2.4	6.4	5.7	2.5	0.5	—	17.9
−1.9 to −0.0	0.8	5.0	14.5	12.4	5.3	0.9	0.2	39.2
0.1 to 2.0	0.7	3.7	8.4	5.4	1.8	0.2	0.1	20.4
2.1 to 4.0	0.5	1.8	2.0	0.5	0.1	—	—	4.9
4.1 to 6.0	0.3	0.6	0.5	0.1	—	—	—	1.5
6.1 to 8.0	0.1	0.2	0.1	—	—	—	—	0.5
8.1 to 10.0	—	0.1	—	—	—	—	—	0.2
>10.0	—	0.1	—	—	—	—	—	0.1
Missing	—	0.1	0.4	0.3	0.1	—	—	1.0
Total	3.4	15.8	37.7	29.2	11.6	2.0	0.3	100.0
Cumulative total	3.4	19.2	56.9	86.1	97.7	99.7	100.0	100.0
Per cent lapse	1.7	9.3	26.0	22.8	9.5	1.7	0.2	71.5
Per cent inversion	1.6	6.5	11.0	6.0	1.9	0.2	0.1	27.6

TABLE 7. Percentage frequency of occurrence of outgoing net radiation flux, temperature inversion, dewpoint temperature inversion, and relative humidity related to season, December 1960 to November 1965.

Season	Outgoing radiation*	Temperature inversion* (144 ft−5.5 ft)	Dewpoint inversion** (131 ft−1.2 ft)	Relative humidity ⩾81%	Wind speed at 19 ft < 4 mph
Winter	62	29	41	55	13
Spring	45	31	28	38	12
Summer	44	42	22	39	28
Fall	56	44	21	40	23
Annual	52	36	28	43	19

* Approximately 10% of the frequency distribution values are missing due to instrument malfunction during periods of rain.
** Approximately 1% of the frequency distribution values are missing due to instrumentation malfunction.

100%, of wind speed between 3.5 and 7.4 mph, and of net radiation flux $\leqslant -5.0$ ly hr^{-1}. Of the 1025 cases in this category, 865, or 84%, were dewpoint inversions.

These graphs show clearly the high probability of dewpoint inversion existing under conditions of high relative humidity, strong outgoing radiation and relatively light winds. Of interest are the 30–40% inversion frequency values for low relative humidities with strong outgoing radiation. This must mean that the surfaces have cooled to very low levels and pronounced temperature as well as dewpoint temperature gradients exist. It is to be noted that the relative humidities measured are at 5 ft above ground. At short distances above the surface, i.e., measured in millimeters, the relative humidity values are undoubtedly appreciably higher.

Figs. 8a–d shows the relation between the occurrence frequency of dewpoint inversions and the three variables, wind speed at 19 ft., relative humidity, and stability as determined by the temperature difference between the 144- and 5.5-ft levels. In constructing the charts, the data were first divided into four wind speed groups 0–3.4, 3.5–7.4, 7.5–12.4 and >12.4 m hr^{-1}. For each wind speed category, the data were subdivided by group intervals of relative humidity. The individual charts representing the data for a given wind speed class, e.g., Fig. 8a contain curves relating relative percentage frequency of dewpoint inversion and atmospheric stability for each relative humidity grouping. The relative percentage frequency of dewpoint inversion is defined above in the discussion of Figs. 7a–e.

The uppermost curve representing conditions of 91–100% relative humidity and, to a lesser extent, the second curve from the top representing 81–90% are affected by precipitation and by ground fog, especially the patchy variety. When rainfall occurs, the copper-constantan thermocouples used for measuring stability become wet and often indicate readings of greater than actual atmospheric instability. Although a serious attempt was made to eliminate this error, the effect is probably still present. Evidence for this is shown in Fig. 8a where the relative percentage frequency of 34% is shown for a stability value of < -1.0F but falls to 25% for the stability value of 0 to 0.9F. This effect also appears on the other charts. The same effect may be due to patches of ground fog moving over one of the thermal or dewpoint elements and not the other.

The tendency for the relative percentage frequency of dewpoint inversion to fall during intense air temperature inversions, when the relative humidity is above 80%, appears to be real (see Figs. 8a, b and c). In Fig. 8a, the 81–90% curve also shows a downward slope for intense inversions when the stability categories are divided into finer class intervals. The processes giving rise to this phenomenon warrant further investigation.

In Figs. 8c and d it was necessary to combine data in the extreme categories because of the small number of cases in these intervals. With strong winds and pronounced vertical mixing the lapse rate tends toward the adiabatic, thus accounting for the few cases of strong inversion or superadiabatic lapse rates.

Figs. 8a–d bring out clearly the relation between the occurrence frequency of dewpoint inversions and the other relevant variables, wind speed, relative humidity and stability. The relatively small overlap of the relative humidity curves is marked but not unexpected; however, the change in slope of these curves with increase in stability is noteworthy.

e. Implications of dewpoint inversion. Evapotranspiration is a major component of the hydrologic cycle. Favorable conditions for evaporation and transpiration are present when the atmosphere serves as a moisture sink and an upward flux of water exists. During periods of inverted water vapor flux, an atmospheric restriction exists for evaporation and for plant water loss. Transpirational stresses are thereby relieved.

The implications of fluxes of downward flowing water vapor to agricultural problems have been discussed by Ramdas (1946), Thornthwaite (1950), and Monteith (1957). Best *et al.* (1952), Möller (1937), and Robinson (1965) have considered this process from a general meteorological standpoint. A valuable discussion of the distribution of atmospheric moisture as a function of time and space is presented by Geiger (1965).

If the flux of downward-flowing water vapor is sufficiently great, dew, frost or fog may form. Monteith (1957) has discussed the formation of dew with a reversal in vertical dewpoint temperature differences. He points out that distillation-evaporation together with condensation, which may take place simultaneously on adjacent surfaces because of differences in vapor pressure, may give the appearance of dew during a period when transpiration is still possible. For ex-

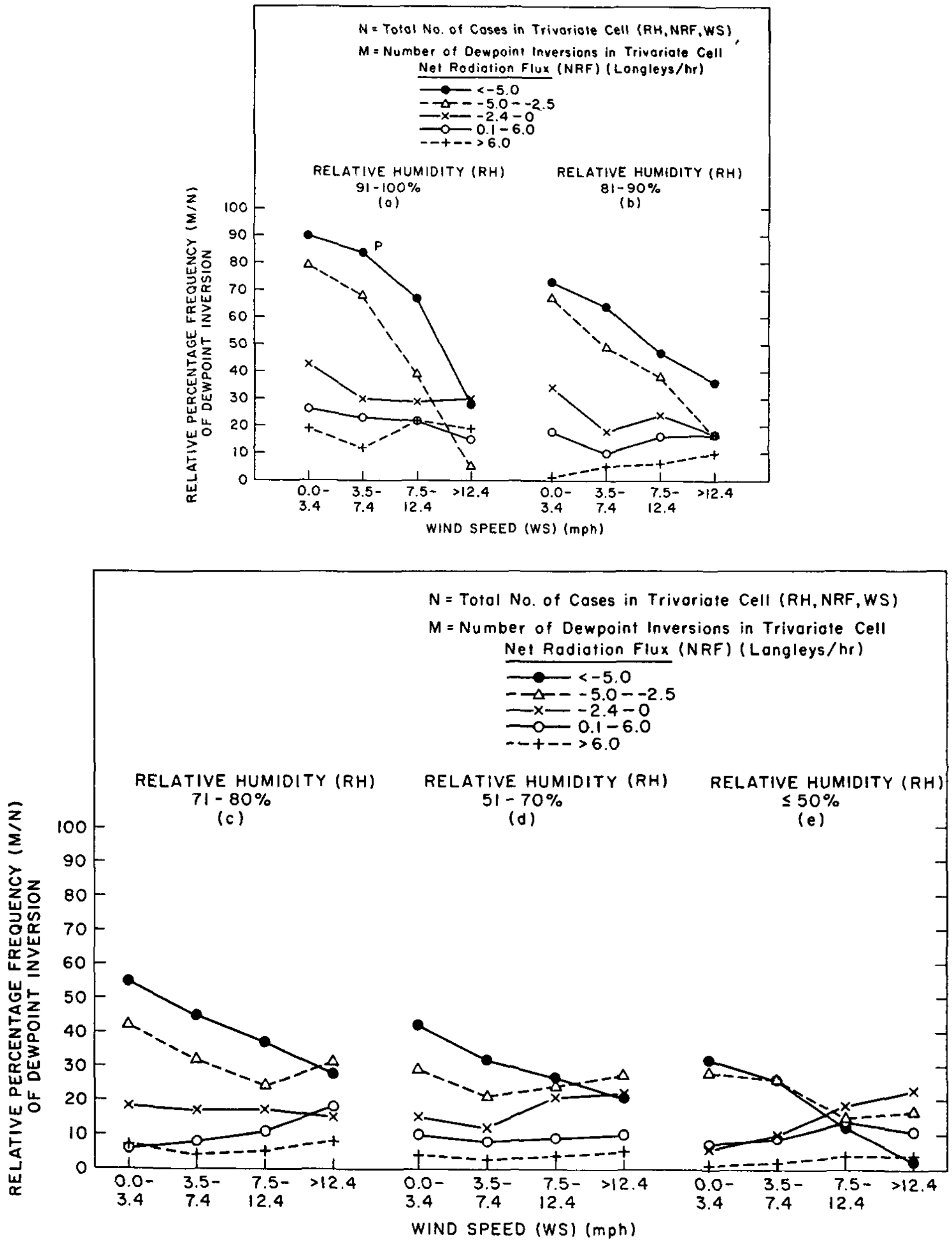

FIG. 7. Relative percentage frequency of dewpoint temperature inversion as a function of net radiation flux, relative humidity and wind speed.

ample, upper- vs-lower leaf, water, and ground surfaces may have unlike radiation characteristics, different temperatures, and appropriately varied water vapor pressures.

Knowledge of the timing and persistence of downward-directed fluxes may be of great importance in estimating evapotranspiration and in assessing climates for plant production or introduction into a new locale. As shown in the present paper, prediction of atmospheric restrictions on evaporation and plant water loss and of dew formation can be related to net radiation flux, air temperature differences at two heights, relative humidity and wind speed. Of these, relative humidity and wind speed data are widely available. Temperature inversion measurements are being obtained more frequently, primarily in connection with air pollution problems, and the existence of outgoing net radiation flux leading to cooling of ground surfaces and of the immediately overlying atmosphere can be estimated from prevailing meteorological conditions, especially solar radiation and sky cover.

Additional restrictions to plant water loss may be present. The escape of water molecules and consequent vapor pressure over a leaf surface is determined by the

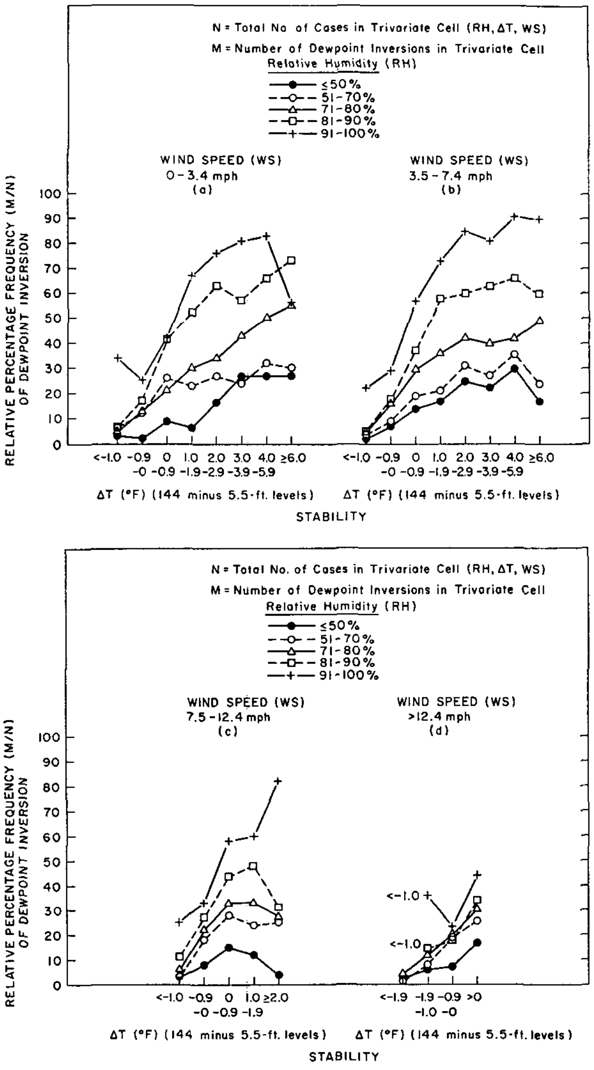

FIG. 8. Relative percentage frequency of dewpoint temperature inversions as a function of stability, relative humidity and wind speed.

leaf temperature, by the concentration of solutes in the leaf sap, by the curvature of the evaporating surfaces (convex surfaces having a higher vapor pressure than a plane surface) and by the degree of stomatal opening. Stomatal closure reduces greatly the contribution of a leaf to enrichment of the adjacent air with moisture by reducing vapor movement. It does not alter equilibrium states. The major variable influencing the vapor pressure over leaf fluids is leaf temperatures. Leaf and air temperatures both vary day to night, creating continuously altering vapor pressure gradients.

The foliage cycle in northern Illinois is that of leafing in late April and shedding of leaves in October. During this 6-month period large transpiration surfaces are present. Dewpoint inversions occur primarily at night during this period. These recurring atmospheric restrictions on evapotranspiration may be of crucial importance in enabling the restoration of a favorable plant water balance, and of cell turgor which is a component of plant growth processes. The greater prevalance of dewpoint inversions during the dormant season for most plant species is of lesser importance for their growth and survival. It may be of hydrological significance in recharge of soil moisture, and of importance to evergreen species, which are, however, of very limited occurrence in northern Illinois.

Assessment of atmospheric restrictions on water loss for a locality in which dewpoint inversion data are not available may be based on the four meteorological variables here discussed. Unlikely times are those in which wind speeds are greater than 8 mph, in which lapse air temperatures (profiles which are related to net radiation and wind conditions) are observed, and when relative humidities are below 80%. An appreciation of these relations will contribute greatly to hydrological and ecological understanding of climatic regimes.

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