Surface Dew Point and Water Vapor Aloft

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ABSTRACT

Mean monthly values of precipitable water were related to mean monthly values of surface dew point for 15 stations distributed over the continental United States. The degree of relationship was excellent, and a regression equation relating the two parameters was computed. Since surface dew point is so well related to precipitable water, this implies that the rate of decrease of moisture content through a deep layer tends toward a constant, which was approximately evaluated.

1. Introduction

It is not surprising that a relationship exists between some measure of the water vapor content of the air near the surface and the amount of moisture aloft. The processes of air-mass formation and of vertical mixing would tend to produce a similar characteristic, moist or dry, through the vertical extent of the atmosphere. Ordinarily the moisture content is greatest at the surface and decreases with height. This rate of decrease has been expressed in familiar forms as

$$1)\quad \rho_{w-z}=\rho_{w-0}\exp[-\beta z]$$

$$2)\quad r_z=r_0\exp[-z/\lambda]$$

and

$$3)\quad r_z=r_0\exp[-\delta z]$$

where

ρ_w = vapor density; g cm^{-3}

r = mixing ratio; g kg^{-1}

z = height; km

β, λ^{-1}, δ = constants for the layer from 0 to z; km^{-1}

A knowledge of the values of the constants in the above equations provides a means of estimating the vapor density distribution through a column of air. As an example of an application, Bliss (1961) has utilized one of these relationships in devising a procedure for estimating the intensity of atmospheric radiation in an engineering problem.

If the moisture content of the air at any upper level is related to the amount of moisture at the surface, it follows that the total water-vapor content of the air would also be related to a measure of surface moisture. A useful measure of total moisture is precipitable water, the depth to which liquid water would stand if all the water vapor in a column of air of unit area were condensed. One relationship between precipitable water and surface moisture has been discussed by Shands.[1] In that study, surface dew-point temperatures were related to precipitable water totals computed by assuming that the dew point decreased at the pseudo-adiabatic lapse rate. It was devised as a tool for use in hydrometeorological studies. Shands compared these empirical values to actual mean monthly values of precipitable water and, in general, found them to be underestimates in the colder months and overestimates in warmer months. Goss and Brooks (1956) mention that the local 1400 hours vapor pressure can be used as the best surface indicator of total moisture in the atmosphere. There probably exist many other local rules or procedures for estimating moisture aloft from surface indicators. This note will present a relationship between total moisture, as given by precipitable water, and a measure of surface water vapor content given by dew-point temperature, determined using mean monthly values of the two quantities; a relationship which may be found useful as a climatological tool.

2. Moisture relationships

As a measure of moisture at the surface, the dew-point temperature will be used. It was chosen as a matter of convenience and practicality since this measure is usually found as such in sources of climatological data. It is readily available and therefore easily used. Total precipitable water, usually designated by W and expressed in centimeters or inches, will be used as a measure of the total amount of moisture in the air column.

The degree of relationship between surface dew point (t_d) and total precipitable water (W) was examined using mean monthly data. Mean monthly dew points

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[1] Shands, A. L., 1949: Mean precipitable water in the United States. Tech. Paper #10, U. S. Weather Bureau, Washington, D. C., 48 pp.

TABLE 1. Values of product-moment correlation coefficients, r, and constants "a" and "b" in an equation of the form $\ln W = a + bt_d$.

Station	No. of observations	r	a	b
* 1 Columbia, Mo.	36	0.99	−0.846	0.0325
2 Grand Junction, Colo.	36	0.96	−1.304	0.0476
* 3 Great Falls, Mont.	36	0.97	−1.092	0.0396
4 Greensboro, N. C.	36	0.99	−0.975	0.0345
* 5 Lake Charles, La.	36	0.98	−0.930	0.0328
6 Medford, Oreg.	36	0.98	−1.292	0.0425
* 7 Midland, Tex.	36	0.99	−1.022	0.0354
8 Oklahoma City, Okla.	36	0.99	−0.956	0.0343
* 9 Phoenix, Ariz.	36	0.98	−1.453	0.0436
*10 Portland, Me.	36	0.98	−0.925	0.0336
11 St. Cloud, Minn.	36	0.99	−0.878	0.0321
*12 Santa Maria, Calif.	36	0.99	−1.192	0.0373
*13 Tampa, Fla.	36	0.99	−1.378	0.0396
*14 Tatoosh Island, Wash.	36	0.98	−1.466	0.0429
*15 Washington, D. C.	36	0.99	−0.948	0.0345
15 Stations	540	0.98	−0.981	0.0341

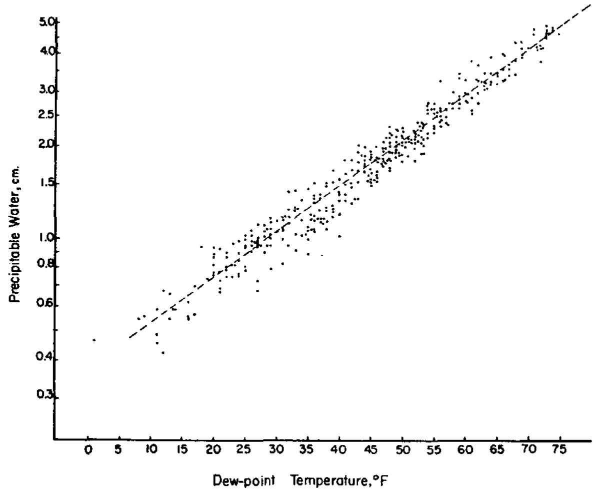

FIG. 1. Scattergram relating mean monthly dew-point temperature and precipitable water for the ten starred (*) stations in Table 1.

TABLE 2. Standard error from regression, $s_{y.x}$, and the coefficient of variation of the standard error from regression, $(s_{y.x}/\bar{y})100$, for the individual stations.

	$s_{y.x}$	$(s_{y.x}/\bar{y})100$
Columbia, Mo.	0.19 cm	10%
Grand Junction, Colo.	0.23	22
Great Falls, Mont.	0.15	14
Greensboro, N. C.	0.13	6
Lake Charles, La.	0.24	8
Medford, Oreg.	0.14	9
Midland, Tex.	0.16	9
Oklahoma City, Okla.	0.19	9
Phoenix, Ariz.	0.28	17
Portland, Me.	0.10	6
St. Cloud, Minn.	0.10	7
Santa Maria, Calif.	0.18	11
Tampa, Fla.	0.27	9
Tatoosh Island, Wash.	0.18	11
Washington, D. C.	0.19	9
All	0.18	10

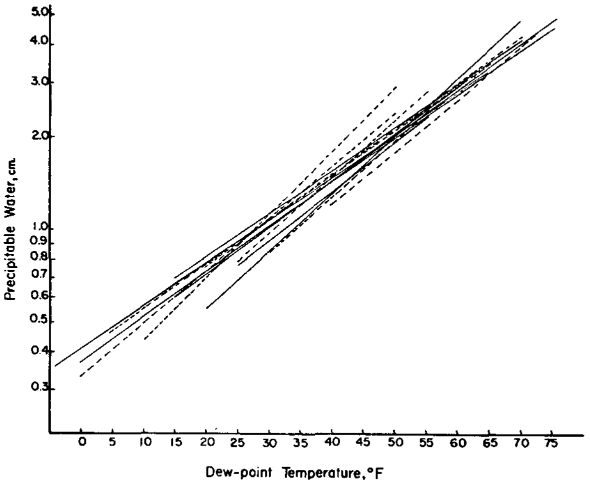

FIG. 2. Computed regression equations of the form $\ln W = a + bt_d$ for the 15 stations in Table 1.

were taken from the publication *Climatological Data—National Summary* and were based on four observations per day during the years of interest. Mean monthly values of precipitable water, in cm, were taken from Reitan (1960). Fig. 1 is a scattergram relating mean monthly surface dew point and precipitable water for ten stations. Three years of data were chosen to give convenient sample sizes, and the years used were 1954, 1955 and 1956. It can be seen that the degree of relationship is excellent and that $\ln W$ seems linearly related to the dew point. In order to have a manageable number, the points in Fig. 1 are for 10 of the 15 stations in Table 1, which are starred (*). These ten stations represent a sampling of locations from all sections of the continental United States and represent varied climatic regimes. Nevertheless, Fig. 1 suggests that they all can be represented by one relationship. Table 1 presents data on the degree of relationship for all 15 stations. Values of product-moment correlation coefficients, r, and values of "a" and "b" in a regression equation

$$\ln W(\text{cm}) = a + bt_d(\text{F})$$

are given.

The degree of relationship as given by the values of the product-moment correlation coefficients is excellent for all stations. Variations are observed in the values of "a" and "b," but the degree of difference is illustrated in Fig. 2, which presents the 15 regression lines plotted over the dew-point interval observed at the particular station during the three-year sample. Fig. 2 suggests, as does Fig. 1, that the differences which do exist are small, and, by and large, the 540 pairs of data from the 15 stations do seem to have about the same dew point-precipitable water relationship. It was pointed out in review that there seemed to be a geographical dependence on the values of "a" and "b" in the regression equations for the 15 stations. Low values of "$|a|$" and "b" were found in the central and eastern portion of the United States, while higher values were typical of those stations west of the 100th meridian. This regional pattern suggests that, although the variations noted among the regression equations for the 15 stations seem small, these variations probably indicate real meteorological differences.

A regression equation for all the data combined was determined. It is plotted in both Fig. 1 and Fig. 2, and is

$$\ln W(\mathrm{cm}) = -0.981 + 0.0341 t_d(\mathrm{F}).$$

Given a value of surface dew point, the total precipitable water can be estimated using this equation. Although better equations for individual stations can be obtained, it is suggested that this regression equation can be used in all instances as an estimator of precipitable water from surface dew point when more precise equations are not available. It should be kept in mind that the precipitable-water—dew-point relationships presented here are based on mean monthly data. It is known that the degree of relationship is less for daily values, but data are not readily available to make a meaningful estimate of the magnitude of such correlation coefficients. It would be expected that the same basic relationship would exist between daily values of the two parameters as was found for the mean monthly values, but this point has not been investigated.

It is of interest to examine the deviations of the individual stations from the composite regression line. The standard errors from regression, $s_{y \cdot x}$, were computed and are given in Table 2. Another quantity given is the standard error from regression for each station divided by the mean at that station, multiplied by 100. This value expresses the standard error in relationship to the average value of precipitable water at the station and provides a number which can be compared among stations, a type of coefficient of variation involving the deviations from regression.

These values illustrate that standard errors generally run about 10 per cent of the mean, but that there are locations which do have larger errors. Grand Junction and Great Falls, both at high elevations in the western mountain regions, and Phoenix in the arid Southwest have relative standard errors a bit higher than the majority of the stations.

As a test, the regression equation was used to estimate precipitable water for eight new stations and for two years not included in the original sample. The average error in the magnitude of precipitable water between the estimated and actual value was 0.14 cm. The standard error of the deviations from regression was found to be 0.18 cm, which was about 11 per cent of the mean value of precipitable water for the eight-station sample.

3. Vertical distribution of moisture

The fact that precipitable water can be well estimated from surface dew point indicates that moisture in the atmosphere has some sort of a uniform lapse rate, that the average rate of decrease through a deep layer tends toward some constant. If the decrease of vapor density can be described as

$$\rho_{w-z} = \rho_{w-0} \exp[-\beta z]$$

this equation can be combined with the equation for computing precipitable water,

$$W = \int_0^z \rho_w dz$$

to arrive at an expression

$$W = \rho_{w-0} \left(\frac{1 - \exp[-\beta z]}{\beta} \right).$$

If the depth of the moisture is assumed to be 9 km, and if the ratio of the dew-point temperature to the dry-bulb temperature, both in absolute degrees, is assumed to be unity, β can be evaluated since precipitable water, W, can be empirically determined from the dew-point temperature, which specifies vapor density, ρ_{w-0}, at the surface. Because dew point, vapor density and precipitable water are not identically interrelated, β would be expected to vary over the range of values of dew point. The following values were found:

t_d, deg F:	5	14	23	32	41	50	59	68	77
β, km^{-1}:	0.35	0.38	0.41	0.43	0.44	0.45	0.45	0.44	0.44

For the most part, $\beta = 0.44$ km^{-1} seems a representative value. If one uses a $\beta = 0.44$ km^{-1} to compute W, the differences between the computed and empirical value is less than 3 per cent of the empirical value for temperatures 32F and greater. At lower temperatures, the per cent error is larger but the absolute error is still less than 0.1 cm of precipitable water.

If β is 0.44 km^{-1}, it can be shown that the mixing ratio at some elevation, z, is given by

$$r_z = r_0 \exp[-\delta z] = r_0 \exp[-z/\lambda]$$

where δ is approximately equal to 0.35 km^{-1} and $\lambda \approx 2.9$ km. Lambda has the physical interpretation of the depth through which r reduces to $1/e$ of its value at the base of the layer.

The basic empirical relationship between mean monthly values of surface dew point and $\ln W$,which seems reasonably good, has been used to determine the average rate of decrease of moisture with height. Beta is the average rate of decrease through a deep layer, and is not a constant with height. Byers[2] has presented variations of λ with height that illustrate the values are not constant. Variations of δ with height have been done in the course of this study, but are not presented here. A value of β, λ, or δ constant with height is the exception rather than the rule. In fact, vertical variations in β, λ, or δ at a particular station can be thought of as a characteristic of the area, and uniformity among areas in different climatic regimes would not be expected.

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