VOL. 20, NO. 1 JOURNAL OF APPLIED METEOROLOGY JANUARY 1981

# The Relationship between Total Precipitable Water and Surface Dew Point

Y. VISWANADHAM

*Instituto de Pesquisas Espaciais, Conselho Nacional de Desenvolvimento Científico e Tecnológico,*
*São José dos Campos, São Paulo, Brazil*

(Manuscript received 5 November 1979, in final form 18 July 1980)

## ABSTRACT

Mean monthly and annual values of total precipitable water are compared with mean monthly and annual values of surface dew point for each 5° latitude circle from the equator to 85°S. The correlation coefficients are lower for latitudes 0–20°S than for latitudes 25–85°S. The degree of relationship between mean monthly values of total precipitable water and mean monthly values of surface dew point is good in winter for all latitudes but much weaker in warmer months for latitudes 0–20°S. The computed regression equations give excellent estimates of monthly mean zonally averaged precipitable water from surface dew point for middle and higher latitudes in cooler seasons. Zonally averaged values of the moisture profile power index $\lambda$ for the Southern Hemisphere are presented. This power index is highly variable ($-0.26$ to $+4.57$) even for mean monthly moisture profiles. These results are useful for the zonally averaged climatic models.

## 1. Introduction

The water vapor content of the atmosphere is highly variable in relation to both space and time. Knowledge of total moisture present in the atmosphere is necessary for many purposes. Because of the growing need and current interest, more detailed information regarding the distribution of water vapor present at any moment in different air layers of the atmosphere is of fundamental importance in meteorological, hydrometeorological and electromagnetic wave propagation studies (Reber and Swope, 1972). Younkin *et al.* (1956) and Lowry (1972) pointed out the importance of vertically integrated moisture in the objective prediction of clouds and precipitation. Thus, moisture has a large effect on atmospheric temperature conditions. The water vapor content may be temporarily increased by evaporation from the underlying earth or decreased by precipitation falling to the earth. It may also be increased or decreased by a net inflow or outflow of moist air into a region.

Because its source is the earth's surface, atmospheric water vapor is strongly concentrated in the lower layers and normally about half of its total is found below the level of 2 km (~800 mb). This is facilitated by the dependence of saturation vapor pressure on temperature. The amount of water vapor, in a vertical column of air, is given by the total precipitable water ($W$), defined as the depth of water which would accumulate if all the water vapor in that column was condensed. The amount of moisture at the surface is measured by such parameters as relative humidity, vapor pressure, absolute humidity and dew point.

Reitan (1963), Smith (1966), Benwell (1965),[1] Bolsegna (1965), Lowry and Glahn (1969) and Karalis (1974) have established a relationship between the logarithm of $W$ and surface dew-point temperature ($t_d$). They found that the correlation coefficient between the logarithm of $W$ and $t_d$ ranges from 0.33 to 0.99. The correlation coefficient between mean monthly $W$ and $t_d$, at the surface, is greater than that resulting from mean daily and hourly values (Bolsegna, 1965). According to Smith (1966), the relationship between $W$ and $t_d$ depends on the variability of the moisture profile, with the expectation, that the correlation coefficient will increase with increasing time intervals. The existence of such an empirical (or a statistical) expression between surface moisture parameter and the water content aloft, in the absence of an atmospheric sounding, is hoped to be of value not only in future studies of large-scale atmospheric processes, but also in the preparation of climatic normals for the water vapor content in the Southern Hemisphere. The value of this paper is that it provides, probably for the first time, a method for estimating the large-scale distribution of Southern Hemisphere atmospheric water vapor that is comparable to one which has been the subject of many publications using Northern Hemisphere data. Since the present paper is largely confined to monthly zonal

---

[1] Benwell, G. R. R., 1965: Estimation and variability of precipitable water. U.S. Dept. Commerce, Wea. Bur. Tech. Pap. No. 10, 48 pp.

0021-8952/81/010003-06$05.50

averaged values, however, it really only represents a starting point for work of this type.

## 2. Moisture relationships and data

If the moisture content of air, at all upper levels, is related to the amount of moisture at the surface, it follows that the total vapor content of the entire column would also be related to a measure of surface moisture. 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. Shands (1949)[2] has discussed a relationship between total precipitable water ($W$) and surface dew-point temperature ($t_d$). Results of many investigators (Reitan, 1963; Bolsegna, 1965; Lowry and Glahn, 1969; Glahn, 1973) show the relationship between $W$ (cm) and $t_d$ (°C) as

$$\ln W = C + Mt_d, \tag{1}$$

where $C$ is the intercept constant and $M$ the slope constant. In the present work Eq. (1) is used to conduct regression analysis.

Ordinarily the moisture content is greatest at the earth's surface and decreases to a value of zero at the top of the atmosphere. Regardless of the exact moisture profile, with the proper choice of a power $\lambda$ for a given atmospheric situation, the average decrease of moisture through the entire atmospheric column may be described by the power law

$$r = r_0\left(\frac{P}{P_0}\right)^{\lambda}, \tag{2}$$

where $r$ is the mixing ratio at any pressure level $P$, and $r_0$ is the mixing ratio at the earth's surface or at a reference level $P_0$. Eq. (2) seems to have been first introduced by Smith (1966). The power index $\lambda$ is a variable and depends on latitude, season and atmospheric situation. Mean values of this variable are claimed to give good estimates of the water vapor profile for mean latitudinal and seasonal conditions.

The precipitable water content ($W$) above a point on the earth's surface is given by

$$W = g^{-1}\int_{P_z=0}^{P_0} q dp, \tag{3}$$

if the column extends from pressure $P_0$ to $P_z$ (=0). Further it has been considered that, for pratical purposes, $q$ is equal to the mixing ratio ($r$) and the acceleration of gravity ($g$) is equal to 10 ms $^{-2}$. The value of $W$ present from the surface to 500 mb level may be considered as equal to the total precipitable water, since the amount above that elevation is very small. The mean total precipitable water content for each grid point data is expressed by

$$W = g^{-1}\int_{500}^{P_0} \bar{r} dp, \tag{4}$$

where $\bar{r}$ is the average mixing ratio of the layer under consideration and $W$ will be given in g cm$^{-2}$ or as the depth (cm) of precipitable water. The total precipitable water is obtained from Eq. (4).

For most practical purposes, the relation between vapor pressure ($e$) and dew point may be given by the empirical formula of Tetens (1930). An empirical moisture relationship also is derived from Tetens' (1930) equation with the aid of Eqs. (2) and (4) as

$$\ln W = [0.1133 - \ln(\lambda + 1)] + 0.0393t_d, \tag{5}$$

where $W$ is in centimeters and $t_d$ in degrees Farenheit. Eq. (5) has the same form as Eq. (1), with the exception that the parameter $C$ in Eq. (1) is not a constant, but a variable which is clearly dependent on the actual moisture profile. The power index $\lambda$ is calculated from Eq. (5).

The present study is based on the hemispheric data given in Taljaard *et al.* (1969). The grid-point data of mean ambient and dew-point temperatures from surface to 500 mb level for every 5° longitude around each 5° latitude circle between the equator and 90°S are utilized. The charts of Taljaard *et al.* (1969) contain a space-time specification of atmospheric conditions in the hemisphere, the details of which can be exposed best by a large number of derived charts and diagrams. The charts are intended to show the long-term mean monthly distributions of the elements (dry-bulb temperature, dew-point temperature and heights at selected pressure levels and sea level pressure). Considerable care was taken to clean the data and to ensure consistency from month to month and from level to level. The upper-air observations used consisted mainly of the data published in *Monthly Climatic Data of the World* (U.S. Weather Bureau, 1948–66). The published values are as assumed to be 24 h means, but in cases where the means were based on only two or three observations per day they probably deviate somewhat from 24 h means due to the diurnal variation of the elements. Furthermore, the location and height of many stations changed from time to time and the corrections applied are not known in all cases. Therefore, it was taken for granted that the compilers of *World Weather Reports* ensured uniformity to a higher degree than could be done by anybody else, so that the data were used unchanged except in a few cases where obvious discontinuities occur in the series.

Although mean temperatures were computed for stations on oceanic islands, these values were used

---

[2] Shands, A. L., 1949: Mean precipitable water in the United States. U.S. Dept. Commerce, Wea. Bur. Tech. Pap. No. 10, 48 pp.

only as a rough guide to draw the isotherms, because it is known that even on small islands the temperature is highly dependent on local exposure and topography. More weight was attached to the mean temperatures from ships' observations over the sea, as contained in the marine climatic atlases. Comparison of surface air temperatures read at corresponding points on different marine climatic atlases for the southern oceans reveals appreciable differences. The hydrostatic checking program was able normally to identify temperature errors over 2–4°C.

The lapse rate method was used for obtaining the 850, 700 and 500 mb level temperatures. However, for 850 and 200 mb the calculated temperatures often deviated appreciably from the station mean temperatures and therefore the calculated temperatures could be used only as a rough guide. It is evident that lapse rate complexities near the surface and round the troposphere are responsible for the decreasing quality of the calculated temperatures on either side of 500 mb.

The analysis of the dew-point charts was more problematical than that of the pressure, height and temperature charts because indirect information often had to be employed in the analysis and the station averages in themselves leave much to be desired. Cloud and precipitation types and frequencies, as given in marine climate atlases were consulted to get an impression of the probable distribution of the dew points at 850, 700 and 500 mb. Also, the monthly mean rainfall, as given, for example, in *World Weather Records*, is to a certain extent an indicator of the average humidity at the levels of precipitating cloud types. Over the vast expanses of the oceans where subsidence plays a major role in producing low dew points, such as off the western coasts of continents in subtropical latitudes, the analysis may be appreciably in error. In these regions the analysts were guided by the indirect information from climatic atlases, and from investigations such as the kite soundings of the Atlantic Meteor Expedition, as discussed by Riehl (1954). The location of the intertropical convergence zone also was taken into account. Of all the charts in Taljaard *et al.* (1969) the dew-point charts are viewed with the least confidence, but in terms of information available this is probably the best summary that can be produced at present.

TABLE 1. Latitudinal variations of intercepts $C$, slopes $M$, correlation coefficients $R$, standard error of estimates $S_{Y,X}$ and $F$ values of regression lines for January. Subscript $Y,X$ represents the product of $\ln W$ and $t_d$.

| Latitude (°S) | Number of pairs | $C$ | $M$ | $R$ | $S_{Y,X}$ (cm) | $F$ |
|---|---|---|---|---|---|---|
| 00 | 72 | 0.667 | 0.03458 | 0.59 | 0.08 | 37.00 |
| 05 | 72 | 0.392 | 0.04552 | 0.54 | 0.12 | 28.81 |
| 10 | 72 | 0.461 | 0.04324 | 0.59 | 0.13 | 37.93 |
| 15 | 72 | 0.441 | 0.04239 | 0.57 | 0.15 | 34.24 |
| 20 | 72 | 0.776 | 0.01610 | 0.21 | 0.22 | 3.23* |
| 25 | 72 | 0.580 | 0.02769 | 0.61 | 0.15 | 40.43 |
| 30 | 72 | 0.293 | 0.03911 | 0.76 | 0.10 | 93.92 |
| 35 | 72 | −0.028 | 0.05477 | 0.82 | 0.06 | 139.58 |
| 40 | 72 | 0.071 | 0.04593 | 0.78 | 0.05 | 106.61 |
| 45 | 72 | 0.083 | 0.04353 | 0.77 | 0.06 | 99.00 |
| 50 | 72 | 0.018 | 0.05015 | 0.95 | 0.04 | 616.44 |
| 55 | 72 | −0.009 | 0.05152 | 0.94 | 0.05 | 549.94 |
| 60 | 72 | −0.049 | 0.05319 | 0.91 | 0.06 | 351.29 |
| 65 | 72 | −0.102 | 0.05575 | 0.86 | 0.08 | 205.63 |
| 70 | 50 | −0.120 | 0.05591 | 0.73 | 0.14 | 53.35 |
| 75 | 38 | −0.503 | 0.01206 | 0.78 | 0.06 | 55.80 |
| 80 | 39 | −0.661 | 0.01367 | 0.78 | 0.06 | 58.80 |
| 85 | 39 | −0.935 | 0.00850 | 0.63 | 0.03 | 23.78 |

TABLE 2. As in Table 1 except for April.

| Latitude (°S) | Number of pairs | $C$ | $M$ | $R$ | $S_{Y,X}$ (cm) | $F$ |
|---|---|---|---|---|---|---|
| 00 | 72 | 1.220 | 0.01316 | 0.33 | 0.07 | 8.57 |
| 05 | 72 | 0.819 | 0.02924 | 0.38 | 0.10 | 12.18 |
| 10 | 72 | 0.715 | 0.03104 | 0.46 | 0.12 | 18.91 |
| 15 | 72 | 0.757 | 0.02493 | 0.51 | 0.13 | 24.46 |
| 20 | 72 | 0.752 | 0.01286 | 0.26 | 0.19 | 5.10 |
| 25 | 72 | 0.435 | 0.03060 | 0.75 | 0.12 | 90.79 |
| 30 | 72 | 0.252 | 0.03605 | 0.78 | 0.09 | 108.24 |
| 35 | 72 | 0.011 | 0.04765 | 0.73 | 0.07 | 80.17 |
| 40 | 71 | 0.102 | 0.03655 | 0.67 | 0.06 | 56.66 |
| 45 | 72 | 0.017 | 0.04262 | 0.92 | 0.03 | 362.36 |
| 50 | 72 | −0.017 | 0.04386 | 0.95 | 0.03 | 680.55 |
| 55 | 72 | −0.066 | 0.04889 | 0.98 | 0.02 | 1897.71 |
| 60 | 72 | −0.110 | 0.05705 | 0.98 | 0.03 | 1363.16 |
| 65 | 72 | −0.148 | 0.05944 | 0.87 | 0.10 | 221.11 |
| 70 | 50 | −0.314 | 0.04000 | 0.82 | 0.15 | 100.66 |
| 75 | 39 | −0.786 | 0.01861 | 0.60 | 0.15 | 20.81 |
| 80 | 39 | −1.011 | 0.01867 | 0.73 | 0.14 | 41.68 |
| 85 | 39 | −1.189 | 0.02103 | 0.76 | 0.11 | 49.22 |

TABLE 3. As in Table 1 except for July.

| Latitude (°S) | Number of pairs | $C$ | $M$ | $R$ | $S_{Y,X}$ (cm) | $F$ |
|---|---|---|---|---|---|---|
| 00 | 72 | 0.052 | 0.06076 | 0.75 | 0.08 | 92.28 |
| 05 | 72 | 0.321 | 0.04646 | 0.70 | 0.11 | 68.46 |
| 10 | 72 | 0.516 | 0.03281 | 0.70 | 0.12 | 66.94 |
| 15 | 72 | 0.389 | 0.03471 | 0.78 | 0.13 | 109.21 |
| 20 | 72 | 0.321 | 0.02700 | 0.69 | 0.15 | 64.27 |
| 25 | 72 | 0.148 | 0.03897 | 0.89 | 0.11 | 255.90 |
| 30 | 72 | 0.032 | 0.04405 | 0.77 | 0.13 | 99.07 |
| 35 | 72 | 0.003 | 0.03901 | 0.75 | 0.06 | 92.54 |
| 40 | 72 | 0.059 | 0.02301 | 0.68 | 0.04 | 60.37 |
| 45 | 72 | −0.077 | 0.03220 | 0.77 | 0.04 | 101.88 |
| 50 | 72 | −0.149 | 0.04338 | 0.94 | 0.03 | 575.57 |
| 55 | 72 | −0.213 | 0.04554 | 0.98 | 0.03 | 1441.06 |
| 60 | 72 | −0.285 | 0.04831 | 0.94 | 0.06 | 509.92 |
| 65 | 72 | −0.282 | 0.05502 | 0.90 | 0.09 | 303.01 |
| 70 | 50 | −0.409 | 0.04563 | 0.89 | 0.11 | 181.09 |
| 75 | 39 | −1.247 | 0.01617 | 0.71 | 0.11 | 37.78 |
| 80 | 39 | −1.434 | 0.01629 | 0.64 | 0.13 | 25.67 |
| 85 | 39 | −1.546 | 0.02107 | 0.61 | 0.10 | 21.76 |

TABLE 4. As in Table 1 except for October.

| Latitude (°S) | Number of pairs | $C$ | $M$ | $R$ | $S_{Y,X}$ (cm) | $F$ |
|---|---|---|---|---|---|---|
| 00 | 72 | 0.951 | 0.02086 | 0.42 | 0.11 | 15.12 |
| 05 | 72 | 0.541 | 0.03666 | 0.58 | 0.12 | 35.54 |
| 10 | 72 | 0.691 | 0.02648 | 0.49 | 0.14 | 22.56 |
| 15 | 72 | 0.741 | 0.01907 | 0.41 | 0.15 | 13.86 |
| 20 | 72 | 0.583 | 0.01569 | 0.34 | 0.17 | 9.34 |
| 25 | 72 | 0.296 | 0.03310 | 0.75 | 0.14 | 88.33 |
| 30 | 72 | 0.107 | 0.04122 | 0.63 | 0.16 | 46.95 |
| 35 | 72 | −0.064 | 0.04988 | 0.73 | 0.06 | 82.03 |
| 40 | 72 | 0.011 | 0.03839 | 0.70 | 0.05 | 67.62 |
| 45 | 72 | −0.136 | 0.05842 | 0.85 | 0.06 | 178.11 |
| 50 | 72 | −0.118 | 0.05621 | 0.97 | 0.03 | 1291.76 |
| 55 | 72 | −0.128 | 0.06005 | 0.99 | 0.02 | 3686.42 |
| 60 | 72 | −0.074 | 0.07313 | 0.97 | 0.04 | 1108.30 |
| 65 | 72 | 0.143 | 0.08700 | 0.92 | 0.10 | 404.99 |
| 70 | 50 | 0.200 | 0.07086 | 0.93 | 0.11 | 324.43 |
| 75 | 39 | −0.833 | 0.01954 | 0.65 | 0.15 | 27.07 |
| 80 | 39 | −1.285 | 0.01361 | 0.63 | 0.14 | 24.35 |
| 85 | 39 | −1.512 | 0.01773 | 0.62 | 0.11 | 23.61 |

## 3. Results

Monthly values of total precipitable water ($W$) for the four mid-season months were calculated using the Southern Hemisphere grid-point data and Eq. (4). A regression analysis was conducted between $\ln W$ and $t_d$ (°C) for each 5° latitude circle using the form of Eq. (1). The results for the four mid-season months and annual (mean values of $W$ and $t_d$ for the four months) are presented in Tables 1–5. The product-moment correlation coefficient ($R$) permits conclusions as to the existence of a linear relationship between two variables $\ln W$ and $t_d$, but does not indicate which variable causes the variation of the other. In fact, a relation between two variables $\ln W$ and $t_d$ may exist because the variation of both these variables is influenced by the variation of a third variable.

The correlation coefficients obtained range from 0.21 (January) to 0.99 (October). Thus, the value of $R$ is always positive, but widely variable. The magnitude of $R$ indicates that the same basic relationship [Eq. (1)] is valid in each case. However, the degree of relationship is less for the latitude circles 0–20°S in January, April and October ($R \leq 0.59$). The values of $R$ show that the differences in $W$ are related to differences in $t_d$ for monthly and annual values. Generally, higher $t_d$ values are observed at equatorial regions in summer (January), autumn (April) and spring (October) as compared with winter (July). It is noteworthy that, largely because of the stability of the air and despite the prevailing winds from the sea, great coastal deserts exist in the low-latitude portions of these areas. The poor (zonally averaged) results obtained for the tropics may be the product of the pronounced spatial variations of sea surface temperature that occur in these latitudes (e.g., the Gulf Stream surface temperatures, the Canaries, Benguela, California, Peru and West Australian currents) and the strong influence this has on the spatial variability of surface dew point—an influence which may not extend that far up into the troposphere. Thus, in the latitudes 0–20°S, large variability of the moisture profile [Eq. (2)] makes it more difficult to obtain high values of $R$ and accurate regression line coefficients. Therefore, dew-point temperature becomes a poor predictor of the zonal average of $W$ in the warm season, particularly at low latitudes.

It is obvious from the results that the relationship between $\ln W$ and $t_d$ is best during winter ($R \geq 0.61$). The seasonal and annual values of R are >0.59 for latitude circles 25–85°S. In the more southerly latitudes (Southern Hemisphere) and in the cooler season, the greater frequency of low-pressure systems contributes to vertical transport of low-level moisture plus advection of higher level moisture, both of which ordinarily contribute to higher correlations. In addition, a larger range with equal scatter in surface dew points also contributes to higher correlations. Therefore, dew-point temperature is a good predictor of the zonal average of $W$ in the cooler season, particularly at middle and higher latitudes.

The goodness of fit of the regression line can be tested by means of the analysis of variance. As a test, the $F$ values and the standard error of estimate $S_{Y,X}$ ($Y = \ln W$ and $X = t_d$) are calculated and given in the last two columns of Tables 1–5. The $F$ values indicate that the regression constants obtained are highly significant above a 99% significance level. But, the regression constants in Tables 1 and 5 marked by an asterisk, are only significant at the 95% significance level. The values of $S_{Y,X}$ are found to be

TABLE 5. As in Table 1 except for annual values using mean values of $W$ and $t_d$ for the four months.

| Latitude (°S) | Number of pairs | $C$ | $M$ | $R$ | $S_{Y,X}$ (cm) | $F$ |
|---|---|---|---|---|---|---|
| 00 | 72 | 0.224 | 0.05373 | 0.62 | 0.07 | 43.99 |
| 05 | 72 | 0.227 | 0.05283 | 0.65 | 0.09 | 51.50 |
| 10 | 72 | 0.237 | 0.05001 | 0.66 | 0.11 | 53.12 |
| 15 | 72 | 0.035 | 0.05716 | 0.69 | 0.11 | 63.98 |
| 20 | 72 | 0.721 | 0.01265 | 0.23 | 0.20 | 4.00* |
| 25 | 72 | 0.167 | 0.04440 | 0.75 | 0.12 | 90.74 |
| 30 | 72 | −0.220 | 0.06746 | 0.83 | 0.09 | 154.31 |
| 35 | 72 | −0.455 | 0.08455 | 0.78 | 0.06 | 106.50 |
| 40 | 72 | −0.161 | 0.06138 | 0.72 | 0.06 | 75.35 |
| 45 | 72 | −0.036 | 0.04805 | 0.90 | 0.03 | 307.95 |
| 50 | 72 | −0.131 | 0.06412 | 0.96 | 0.03 | 886.74 |
| 55 | 72 | −0.086 | 0.05000 | 0.96 | 0.04 | 843.58 |
| 60 | 72 | −0.113 | 0.05645 | 0.94 | 0.05 | 559.70 |
| 65 | 72 | −0.063 | 0.06485 | 0.91 | 0.08 | 337.67 |
| 70 | 50 | −0.159 | 0.04756 | 0.76 | 0.15 | 66.00 |
| 75 | 39 | −0.545 | 0.02559 | 0.73 | 0.14 | 42.47 |
| 80 | 40 | −1.063 | 0.01330 | 0.62 | 0.17 | 23.73 |
| 85 | 39 | −1.272 | 0.01449 | 0.66 | 0.07 | 29.04 |

in the range 0.02–0.22 cm. Since $S_{Y,X}$ values are small, it follows that the water vapor values calculated from mean monthly and annual regression equations, may be reliable.

A unique relationship between $W$ and $t_d$ depends on the variability of the moisture profile [Eq. (2)] and time-interval (hourly, daily and monthly mean). For practical purposes, the values of $\lambda$ are calculated for the four mid-season months using Eq. (5) and the zonally averaged values are presented in Table 6. Smith's (1966) values of $\lambda$ for the Northern Hemisphere (NH) are given in Table 7. These results illustrate the dependence of $\lambda$ on latitude and season in the Northern and Southern Hemispheres. It may be true, as stated by Smith (1966), that, "the scatter about the statistically determined regression lines merely results from variations in $\lambda$." Even from mean monthly values of $W$ and $t_d$, large variations in $\lambda$ are evident with a range of $-0.26$ to $+4.57$ (Tables 6 and 7). The variation of $\lambda$ depends on the geographical position of the station, season and time interval. Thus, the $\lambda$ values derived from seasonal and latitudinal mean moisture profiles are inadequate during various months of the year. More accurate $\lambda$ values can be derived for individual stations. It is apparent from Schwarz's (1968) results that $\lambda$, in many cases, should be allowed to vary with respect to time and the synoptic situation.

As an example, the $\lambda$ values are computed from five individual radiosonde ascents of São José dos Campos (23°13′S, 45°51′W), Brazil and they are given in Table 8. The $\lambda$ values for 20 July, 17 September and 18 January compare very well with the values obtained from monthly grid-point data (Table 6). But, the values for 5 October and 5 April do not agree as well with Table 6 as others. The station, São José dos Campos was overcast with altocumulus and altostratus clouds and it had also a drizzle type of precipitation during the time of radiosonde ascent on these two days (5 October and 5 April). Thus, the obtained $W$ values are high and the computed $\lambda$ values are lower than the values in Table 6. Tables 6 and 7, also show, very distinctly, the characteristic variation of $\lambda$ in both hemispheres. However, the Southern Hemisphere (SH) results show slightly higher values than the NH. This may be due to lower $W$ values in the SH compared to the NH. Bannon and Steele (1960)[3] have analyzed, for the four mid-season months, the mean moisture content for the whole atmosphere (and the portions above certain pressure surfaces). These show that the moisture content generally is greater in the NH than in the SH. Sutcliffe (1956) also shows that the NH, as a whole, is richer in water vapor than the SH, largely owing to the higher values in summer.

TABLE 7. Seasonal and latitudinal mean values of $\lambda$ for the Northern Hemisphere (after Smith, 1966).

| Latitudinal zone (°N) | Season<br>Winter | <br>Spring | <br>Summer | <br>Fall | Annual average |
|---|---|---|---|---|---|
| 00–10 | 3.37 | 2.85 | 2.80 | 2.64 | 2.91 |
| 10–20 | 2.99 | 3.02 | 2.70 | 2.93 | 2.91 |
| 20–30 | 3.60 | 3.00 | 2.98 | 2.93 | 3.12 |
| 30–40 | 3.04 | 3.11 | 2.92 | 2.94 | 3.00 |
| 40–50 | 2.70 | 2.95 | 2.77 | 2.71 | 2.78 |
| 50–60 | 2.52 | 3.07 | 2.67 | 2.93 | 2.79 |
| 60–70 | 1.76 | 2.69 | 2.61 | 2.61 | 2.41 |
| 70–80 | 1.60 | 1.67 | 2.24 | 2.63 | 2.03 |
| 80–90 | 1.11 | 1.44 | 1.94 | 2.02 | 1.63 |
| Northern Hemisphere average | 2.52 | 2.64 | 2.62 | 2.70 | 2.61 |

TABLE 6. Seasonal and latitudinal mean values of $\lambda$ for the Southern Hemisphere (present study).

| Latitude (°S) | January (summer) | April (autumn) | July (winter) | October (spring) | Annual average |
|---|---|---|---|---|---|
| 00 | 3.62 | 3.44 | 3.61 | 3.56 | 3.56 |
| 05 | 3.59 | 3.52 | 3.79 | 3.79 | 3.67 |
| 10 | 3.59 | 3.72 | 4.02 | 3.94 | 3.82 |
| 15 | 3.67 | 3.82 | 4.03 | 3.97 | 3.87 |
| 20 | 4.52 | 4.57 | 4.47 | 4.50 | 4.51 |
| 25 | 3.83 | 3.94 | 4.03 | 3.95 | 3.94 |
| 30 | 3.98 | 4.13 | 4.10 | 4.12 | 4.08 |
| 35 | 4.14 | 4.21 | 4.29 | 4.28 | 4.23 |
| 40 | 3.99 | 4.15 | 4.16 | 4.05 | 4.09 |
| 45 | 3.63 | 3.74 | 3.80 | 3.74 | 3.72 |
| 50 | 3.33 | 3.46 | 3.66 | 3.54 | 3.49 |
| 55 | 3.18 | 3.32 | 3.60 | 3.43 | 3.38 |
| 60 | 3.14 | 3.27 | 3.49 | 2.29 | 3.05 |
| 65 | 3.20 | 3.22 | 3.20 | 3.09 | 3.18 |
| 70 | 2.99 | 2.29 | 2.33 | 2.25 | 2.46 |
| 75 | 2.17 | 0.93 | 1.25 | 1.20 | 1.39 |
| 80 | 1.88 | 0.71 | 0.67 | 0.98 | 1.06 |
| 85 | 1.15 | 0.18 | 0.50 | 0.86 | 0.67 |
| 90 | 0.44 | −0.26 | 0.04 | 0.30 | 0.13 |
| Southern Hemisphere average | 3.16 | 2.96 | 3.11 | 3.04 | 3.06 |

## 4. Summary and conclusions

The correlation coefficients between mean monthly precipitable water and mean monthly surface dew

TABLE 8. Values of $\lambda$ from individual radiosonde ascents for the Southern Hemisphere station São José dos Campos (23°13′S, 45°51′W), Brazil.

| Date | Time (GMT) | $t_d$ (°C) | $W$ (cm) | $\lambda$ |
|---|---|---|---|---|
| 20 Jul 1971 | 1155 | 13.8 | 2.19 | 3.77 |
| 17 Sep 1971 | 1200 | 12.8 | 2.00 | 3.86 |
| 5 Oct 1971 | 1208 | 17.0 | 3.20 | 3.10 |
| 18 Jan 1972 | 1210 | 19.0 | 3.41 | 3.43 |
| 5 Apr 1972 | 1235 | 16.0 | 3.00 | 3.07 |

---

[3] Bannon, J. K., and L. P. Steele, 1960: Average water vapor content of the air. Geophys. Memo. No. 13, London, Meteor. Office, 38 pp.

point are always positive but widely variable (0.21–0.99). The relationship between $\ln W$ and $t_d$ is excellent in winter but much weaker in warmer months. The power-index parameter $\lambda$ is highly variable ($-0.26$ to $+4.57$) even for mean monthly moisture profiles. The variation of $\lambda$ depends on the geographical position of the station, season, time, time interval and synoptic situation. The zonally averaged values of $\lambda$ are useful for the zonally averaged climatic models.

The results of the present study demonstrate that the estimates of precipitable water from mean monthly surface dew-point temperature are not sufficiently reliable to justify making surface measurements to infer existing precipitable water. Even with a judiciously chosen estimate of mean vertical distribution of moisture, one should expect, for some areas and seasons at least, some large error in trying to estimate total precipitable water from surface dew points. And, for those stations and conditions, where a significant correlation does not exist between surface dew point and total precipitable water, the predicting equation has no value. When an accurate assessment of the precipitable water is required, there is no satisfactory substitute for direct measurements. This study provides a general idea of the degree of correlation between mean monthly dew point and water vapor. Much additional work is needed in a similar manner for individual stations in the Southern Hemisphere.

*Acknowledgments.* The author is thankful to Dr. Nelson de Jesus Parada, Director, and Dr. Luiz Gylvan Meira Filho, Coordinator of the Departmente of Meteorology, Institute de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil, for their encouragement. He would like to acknowledge the assistance of Mr. J. C. Conforte, Mr. N. Jagan Mohana Rao and Mr. G. S. S. Nunes in the data computation. Thanks are due to Miss Sueli Aparecida Freire Valentim for typing the manuscript. Finally, the author is grateful to the anonymous reviewers for their useful comments. This work was partially supported by the Finaciadora Estudos e Projetos (FINEP) under Contract B-28-79-001.

## REFERENCES

Bolsegna, S. J., 1965: The relationship between total atmospheric water vapor and surface dew-point on a mean daily and hourly basis. *J. Appl. Meteor.*, **4**, 430–432.

Glahn, H. R., 1973: Comments "On the correlation of the total precipitable water in a vertical column and absolute humidity at the surface." *J. Appl. Meteor.*, **12**, 1411–1414.

Karalis, J. D., 1974: Precipitable water and its relationship to surface dew-point and vapor pressure in Athens. *J. Appl. Meteor.*, **13**, 760–766.

Lowry, D. A., 1972: Climatological relationships among precipitable water, thickness and precipitation. *J. Appl. Meteor.*, **11**, 1326–1333.

——, and H. R. Glahn, 1969: Relationship between integrated atmospheric moisture and surface weather. *J. Appl. Meteor.*, **8**, 762–768.

Reber, E. E., and J. R. Swope, 1972: On the correlation of the total precipitable water in a vertical column and absolute humidity at the surface. *J. Appl. Meteor.*, **11**, 1322–1325.

Reitan, G. H., 1963: Surface dew-point and water vapor aloft. *J. Appl. Meteor.*, **2**, 776–779.

Riehl, H., 1954: *Tropical Meteorology*. McGraw-Hill, 53–71.

Schwarz, F. K., 1968: Comments on "Note on the relationship between total precipitable water and surface dew-point." *J. Appl. Meteor.*, **7**, 509–510.

Smith, W. L., 1966: Note on the relationship between total precipitable water and surface dew point. *J. Appl. Meteor.*, **5**, 726–727.

Sutcliffe, R. C., 1956: Water balance and the general circulation of the atmosphere. *Quart. J. Roy. Meteor. Soc.*, **82**, 385–395.

Taljaard, J. J., H. van Loon, H. L. Crutcher and R. L. Jenne, 1969: Temperature, Dew-Point and Heights at Selected Pressure Levels. *Climate of the Upper Air, Part I—Southern Hemisphere*, Vol. I, A joint production of NCAR, ESSA-NWRC and DOD, 140 pp. [NAVAIR 50-1C-55.]

Tetens, O., 1930: Über einige meteorologische Begriffe. *Z. Geophys.*, **6**, 297–309.

U.S. Department of Commerce, Weather Bureau, 1948–66: *Monthly Climatic Data of the World*.

Younkin, R. J., J. A. LaRue and F. Sanders, 1965: The objective prediction of cloud and precipitation using vertically integrated moisture and adiabatic vertical motions. *J. Appl. Meteor.*, **4**, 3–17.