

EVALUATION OF HUMIDITY AS A SCREEN FOR URBAN HEAT ISLAND STUDIES

Vincent J. Biancomano and Mark D. Shulman

Department of Meteorology and Physical Oceanography
Cook College—New Jersey Agricultural Experiment Station
Rutgers—The State University of New Jersey
New Brunswick, NJ 08903

Abstract

A previous study using temperature data to determine the magnitude of the New York City—Northern New Jersey urban heat island in summer set a screening parameter for relative humidity. Specifying such a screening condition to isolate nights of strong radiational cooling, however, is not necessary for any season. Furthermore, neither the relative nor absolute humidity at ground level is a useful predictor of the differences in minimum temperature between any two given locales in the lower troposphere.

1. Introduction

A study by Kirkpatrick and Shulman (1987) using temperature data to characterize the New York City—Northern New Jersey urban heat island in summer specified a screening parameter for relative humidity. The screen, i.e., a given set of synoptic conditions within the heat island favorable to the observation of strong radiational cooling, included a specification for light winds, clear skies, no precipitation, and a condition in which the relative humidity at 0700 Local Standard Time (LST) at Newark is less than 68 percent. The rationale for developing a humidity specification is clear. During the summer, the nominally accepted screening criteria for wind and sky condition may not be sufficient to ensure that the heat island under study will exhibit maximum radiational cooling, as determined by a maximized difference in minimum nighttime temperatures between urban and rural regions. In summer, water vapor content (i.e., absolute humidity) values may be at their highest, as may relative humidity values on average. In short, large amounts of water vapor in summer are assumed to be inconsistent with good radiational cooling. An investigation of the aforementioned hypothesis, as part of a recent study by Biancomano (1989) to characterize the New York City heat island over a period of approximately 50 years, has been performed and proves this assumption invalid.

2. Method

The relationship between relative humidity and absolute humidity, not readily available, is derived in the Appendix. With this equation, we may easily calculate absolute humidity from relative humidity and vice versa, in order to plot each versus differences in minimum temperature between two locales. The relationship between absolute humidity, relative humidity and temperature has been determined from two moisture-variable equations, one for mixing ratio and the other for relative humidity; and the Clausius-Clapeyron equation from Hess (1959), which relates the saturation vapor pressure to temperature.

Now consider figures 1a–1d, in which differences in minimum temperature between Newark and a rural station, Newton, have been plotted versus both the 0700 LST absolute humidity and relative humidity at Newark for 76 days in 1981–83, pre-screened according to the following criteria similar to those set by Kirkpatrick and Shulman (1987), and O'Reilly et al. (1988): winds less than 5 knots at Newark at 0700 LST; cloud cover less than 0.2 at 0700 LST; no precipitation observed at Newark from 1900 LST of the previous evening. The minimum temperature is a function of the integrated effect of radiative cooling throughout the night, and nights in which the 0700 LST screening parameters have been met are likely to be those in which maximum cooling is observed.

3. Results

The linear correlation coefficient as computed by the Short Formula of Panofsky and Brier (1968) for the relative humidity plots (Figs. 1a–1b) yields values of 0.09, 0.11, 0.09 and –0.03 for the summer, fall, winter and spring seasons, respectively (Table 1). The number of summer cases was 31; there were 12 cases for autumn, 14 for winter, and 19 for spring. Given the number of cases in each season, the coefficient values required for significance at the 1% level are 0.48, 0.82, 0.75 and 0.63, respectively, assuming a normally

Table 1: Linear correlation coefficients as a function of season for 0700 LST absolute and relative humidity at Newark, with respect to the difference of daily minimum temperature between Newark and Newton, for 76 pre-screened days, 1981–83.

Hum Class	Season	# Days	Coefficient Value	Coefficient 1% Significance
R	Summer	31	0.09	0.48
E	Fall	12	0.11	0.82
L	Winter	14	0.09	0.75
A	Spring	19	–0.03	0.63
T	Summer	31	0.27	0.48
I	Fall	12	0.09	0.82
V	Winter	14	0.42	0.75
E	Spring	19	0.07	0.63

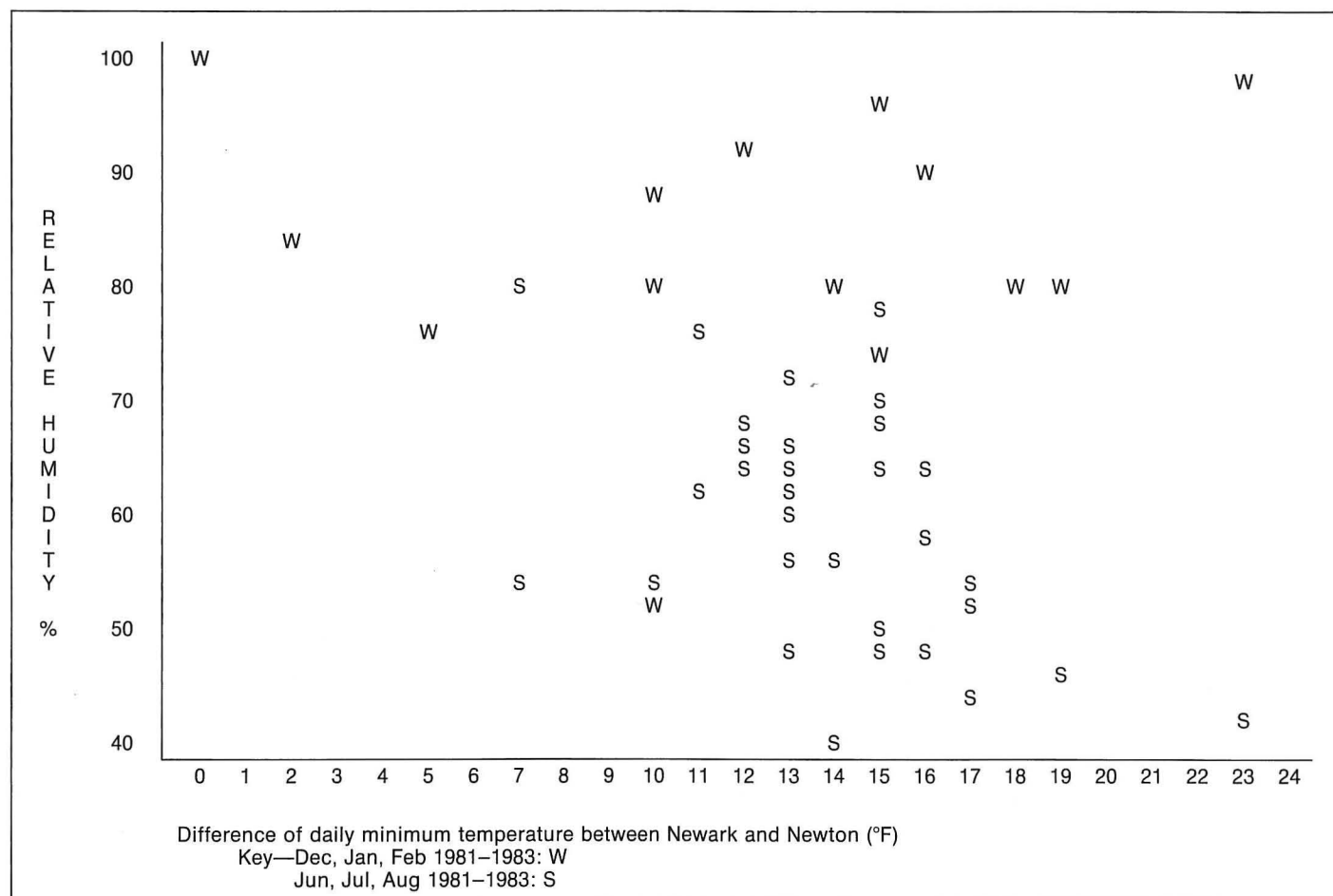


Fig. 1a. Relative Humidity at Newark at 0700 LST, versus difference in minimum temperature between Newark (higher temperature) and Newton for nights of strong radiational cooling 1981–1983.

distributed data set. The existing data sets are not normally distributed, owing to the limited number of cases. Statistical significance at the 1% level, however, requires a relatively high coefficient value when the number of data points is small. It is thus extremely unlikely that the relatively small values of 0.09, 0.11, 0.09 and -0.03 are significant for any distribution.

The correlation between absolute humidity and temperature differences, on the other hand, is greater, but again is not significant from a statistical standpoint even at the 10% level. The Short Formula computation as applied to the data illustrated in Figs. 1c–d, for example, yields values of 0.27 for summer, and 0.42 for winter. The values are below 0.10 for fall and spring. The values required for significance at the 1% level for summer and winter are 0.48 and 0.75, respectively. The corresponding values required for significance at the 10% level are 0.29 and 0.46.

4. Conclusion

The lack of a significant relation between the magnitude of the heat island to season (and therefore indirectly, to absolute

humidity) appears to be well explained on physical grounds. In short, the boundary layer represents only a small fraction of the total volume of atmosphere through which radiation emitted from the ground must travel. Therefore, the humidity as measured at ground level is apparently not a useful predictor of the magnitude of temperature changes between two locales in the lower troposphere.

In summary, the use of relative or absolute humidity as a qualifying screen is not necessary in order to isolate the urban heat island in any season.

Acknowledgments

The authors wish to thank Dr. Nathan M. Reiss of the Department of Meteorology and Physical Oceanography, Cook College, Rutgers University, for his assistance with this research. This is a paper of the Journal Series, New Jersey Agricultural Experiment Station, Cook College, Rutgers University, New Brunswick, NJ. This work was performed as part of NJAES Project No. D-13001-3-90, supported in part by the New Jersey Agricultural Experiment Station.

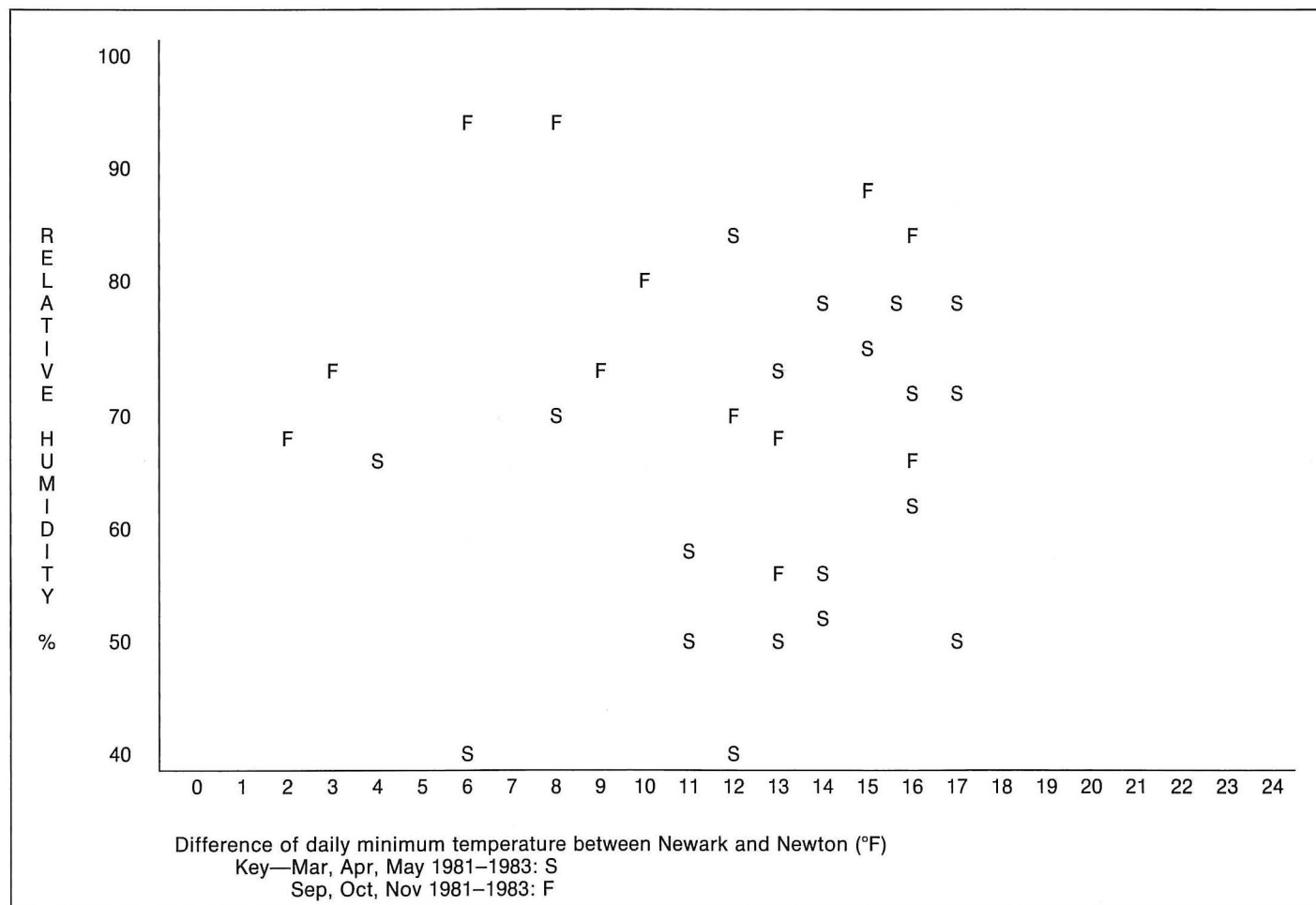


Fig. 1b. Relative Humidity at Newark at 0700 LST, versus difference in minimum temperature between Newark (higher temperature) and Newton for nights of strong radiational cooling 1981–1983.

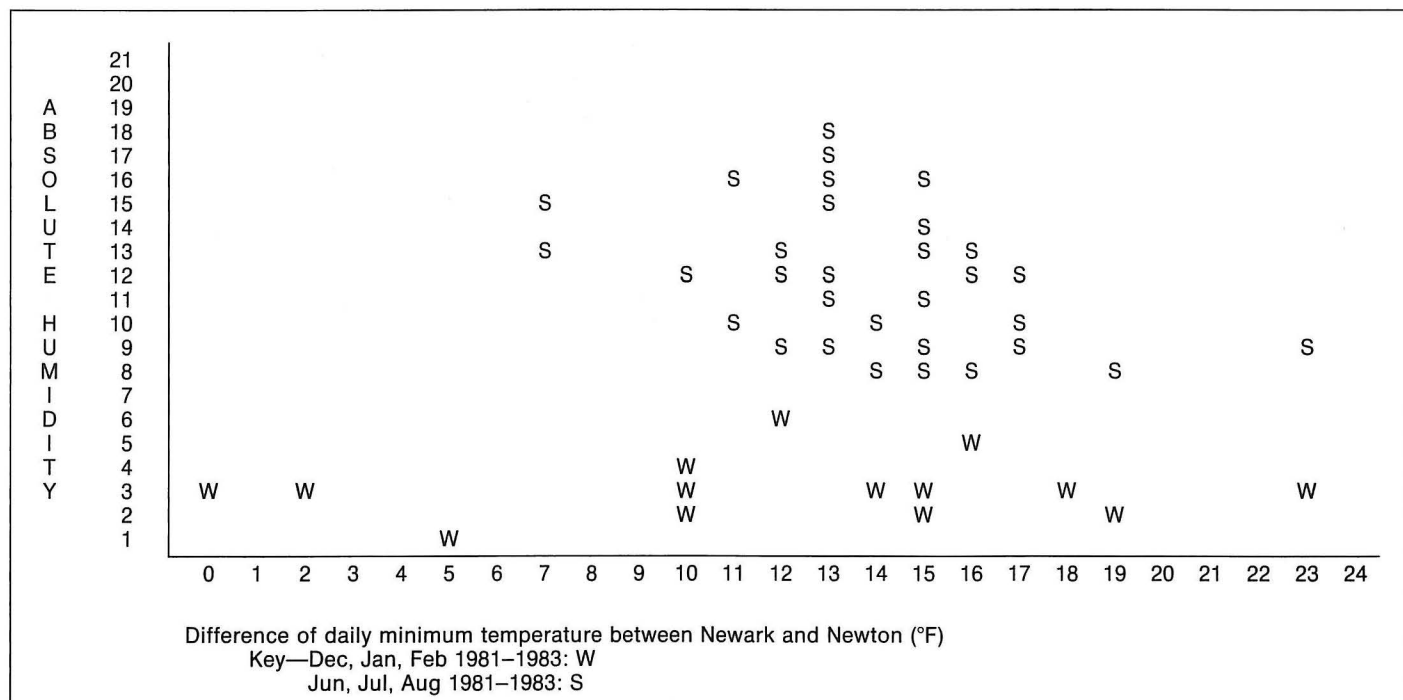


Fig. 1c. Absolute Humidity in grams per cubic meter, at Newark at 0700 LST, versus difference in minimum temperature between Newark (higher temperature) and Newton for nights of strong radiational cooling 1981–1983.

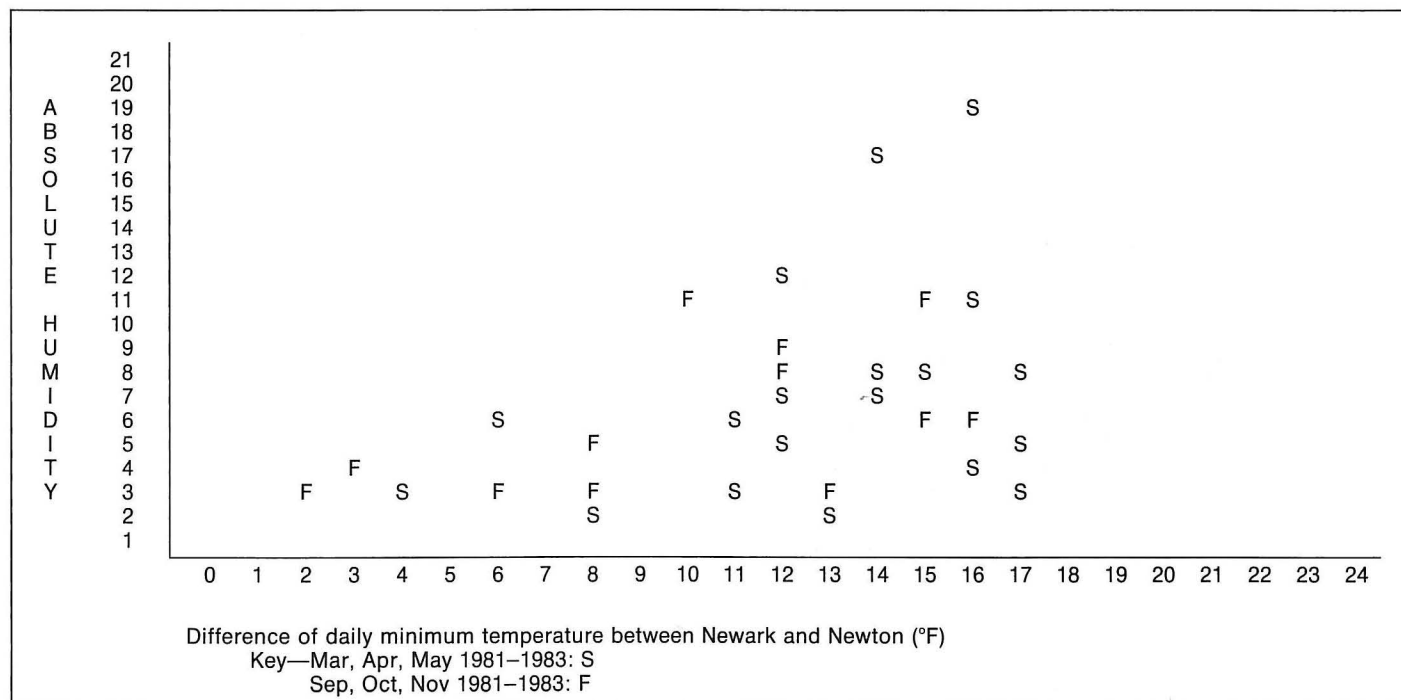


Fig. 1d. Absolute Humidity, in grams per cubic meter, at Newark at 0700 LST, versus difference in minimum temperature between Newark (higher temperature) and Newton for nights of strong radiational cooling 1981–1983.

Authors

Mr. Biancomano received the B.S. in Electrical Engineering from Fairleigh Dickinson University and the M.S. in Meteorology from The Graduate School, Rutgers University. He is currently a Managing Editor for the Magazines Division of the Institute of Electrical and Electronics Engineers, Inc.

Dr. Shulman, a past President of the National Weather Association, and President of the American Association of State Climatologists, received the B.S. in Meteorology from City College of New York, and the M.S. and Ph.D. from the University of Wisconsin. He has served as Dean of Academic and Student Affairs and is now Professor and Chairman of the Department of Meteorology at Cook College, Rutgers University. He has more than 80 publications, mostly in the area of applied climatology.

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APPENDIX

Derivation of the equation for absolute humidity in terms of relative humidity

Absolute humidity may be expressed as a function of relative humidity and temperature using three equations: one for mixing ratio; an equation for relative humidity expressed in terms of mixing ratio; and the Clausius-Clapeyron equation, which relates the saturation vapor pressure to temperature.

The equation for mixing ratio (Hess, 1959) is:

$$w = \rho_v/\rho_d = \epsilon e_v/(p - e_v) \approx \epsilon e_v/p \quad (1)$$

Similarly, the expression for the saturation mixing ratio is:

$$w_s = \epsilon e_s/p \quad (2)$$

where w is the mixing ratio, ρ_v is the density of the water vapor in a sample of moist air, also known as the absolute humidity, ρ_d is the density of the dry air contained in the same sample, ϵ is equal to the ratio of molecular weights of water vapor and dry air, e_v is the vapor pressure, and e_s is the saturation vapor pressure.

The relative humidity is defined as:

$$r = w/w_s = \rho_v/\rho_d w_s \quad (3)$$

Rearranging the variables to solve in terms of absolute humidity, we obtain:

$$\rho_v = r \rho_d w_s = r(m_{\text{air}} p / R^* T)(\epsilon e_s / p) \quad (4)$$

where ρ_d is expressed in terms of the variables of the Equation of State, and m_{air} is the molecular weight of the sample of dry air at pressure P and temperature T . R^* is the universal gas constant.

The Clausius-Clapeyron equation (Hess, 1959), suitably re-arranged, is:

$$e_s(\text{mb}) = 6.11 \exp[(m_v L / R^*)(1/273 - 1/T)] \quad (5)$$

where m_v is the molecular weight of water vapor, and L is the latent heat of evaporation for water. Substituting for e_s in Eq. 4 with Eq. 5, we get:

$$\rho_v = r(m_{\text{air}} / R^* T) \epsilon 6.11 \exp\{[m_v L / R^*](1/273 - 1/T)\} \quad (6)$$

Replacing each term with its numerical value where known:

$$\rho_v = \frac{r}{T} \frac{28.96 \frac{\text{g}}{\text{mol}} 0.622 6.11 \text{ mb } 10^3 \frac{\text{dy}}{\text{cm}^2 \text{ mb}}}{8.3144 (10^7) \frac{\text{erg}}{\text{mol K}} \frac{\text{dy cm}}{\text{erg}}} \exp \left[\frac{18.016 \frac{\text{g}}{\text{mol}} 597.3 \frac{\text{cal}}{\text{g}} 4.186 (10^7) \frac{\text{erg}}{\text{cal}} \left(\frac{1}{273} - \frac{1}{T} \right)}{8.3144 (10^7) \frac{\text{erg}}{\text{mol K}}} \right]$$

or $\rho_v = 1.324(10^{-3})(r/T) e^{5417.75 (1/273 - 1/T)} \text{ g/cm}^3$
where T is expressed in degrees Kelvin, and the range of r is 0 to 1.

Finally,

$$\rho_v = 1.324(10^3)(r/T) e^{5417.75 (1/273 - 1/T)} \text{ g/m}^3 \quad (7)$$

with the value of the exponential constant equal to 5417.75 for temperatures greater than 273 K. The value of the constant is 6139.81 for temperatures less than 273 K, because L in equation 6 becomes the latent heat of sublimation for water, equal to 677 cal/g.