Effects of Conversion Algorithms on Reported Upper-Air Dewpoint Depressions

William P. Elliott
and Dian J. Gaffen
NOAA Environmental
Research Laboratories,
Air Resources Laboratory,
Silver Spring, Maryland

Abstract

Different nations use different algorithms or other techniques to convert temperatures and relative humidities from radiosonde observations to dewpoint depressions. Thus, it is possible for identical measured values to result in different reported dewpoints. On the basis of a sample of conversion methods, we calculate the possible differences among the national practices. In general, the discrepancies are not large and would often be lost in the usual round-off procedures associated with transmission over the Global Telecommunications System, but in cold, dry conditions dewpoints different by more than 1°C could be reported for identical conditions. Some of the methods have been changed over time, so there is also the possibility of inhomogeneities in climate records.

Increasing focus on climatological time series has prompted examination of instrument characteristics and data handling practices. Because weather data are not collected primarily for maintaining long-term homogeneous records, students of climate need to be aware of inhomogeneities in records, in both space and time. Recent articles in this journal have addressed problems with the homogeneity of radiosonde data: Finger and Schmidlin (1991) discuss comparisons of different radiosondes, Schwartz and Doswell (1991) discuss problems with North American radiosonde records, Elliott and Gaffen (1991) focus on U.S. radiosonde humidity records, and Garand et al. (1992) discuss effects of differences in humidity-reporting practices, particularly between the United States and Canada.

Garand et al. (1992) mention differences in methods of converting relative humidity, *U*, to dewpoint depression, *D*, but they do not discuss the quantitative effects of such differences, and they focus on the extremes of the relative humidity distribution. In this note, we compare quantitatively some of the different methods for calculating *D* in use around the world and assess the effects of these differences.

Radiosonde humidity elements produce signals proportional to relative humidity that are converted to *D* at the receiving station for transmission over the Global Telecommunications System (GTS). There is no agreed-upon procedure for this conversion, and different nations use different methods and algorithms. Thus, identical values of temperature, *T*, and *U* can result in different reported *D*. These potential discrepancies are separate from any differences in radiosondes themselves and from different national coding practices, including cutoff temperatures and humidities.

To investigate this potential inhomogeneity, a question on methods of converting relative humidity and temperature to dewpoint was included in a survey of the history of radiosonde instruments and practices conducted for the World Meteorological Organization (Gaffen 1993). A subset of 16 of the 48 nations that responded to the questionnaire provided information on their conversion methods. These nations were Belgium, Bulgaria, Canada, China, Cuba, (former) Czechoslovakia, Denmark, Finland, Germany, India, New Zealand, Poland, the (former) Soviet Union, Switzerland, the United Kingdom, and the United States. This sample is a small fraction of the nations taking radiosonde observations, but it represents a substantial fraction of the Northern Hemisphere land area. All told, 26 past and current techniques were reported, 16 of which were computational algorithms. The others were graphs, nomograms, and special slide rules for manually calculating *D* from *U* and *T*.

The various algorithms, slide rules, etc., were used to calculate *D* at different temperatures and relative humidities. The algorithms and other methods will be described and their differences discussed more fully in the WMO report (Gaffen 1993). Here we summarize these comparisons to call attention to this source of inhomogeneity.

Any conversion of *U* and *T* to *D* must be based on a relation between saturation vapor pressure and temperature. Because the relation is complicated, a number of approximations have been developed, based in part on experimental data. The most widely used approximation is the Magnus form,

---

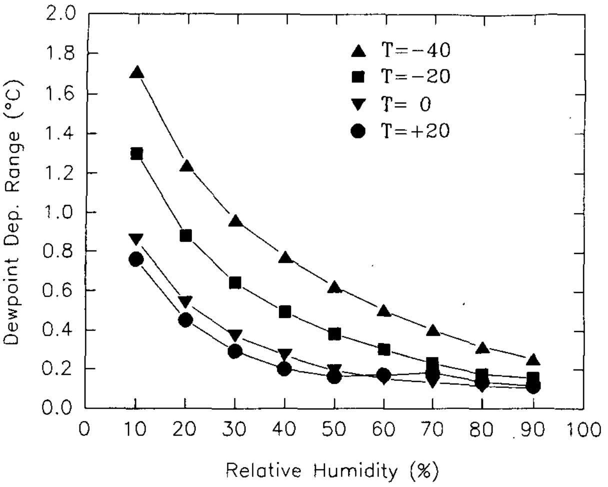

FIG. 1. The range (maximum minus minimum) of dewpoint depression values obtained from the algorithms, as a function of relative humidity, at four temperatures, –40°, –20°, 0°, and +20°C.

$$\log_{10}(e_s/e_{s0}) = aT/(b + T) \qquad (1)$$

where e_s is the saturation vapor pressure at temperature T (in °C), e_{s0} is the saturation vapor pressure at 0°C, and a and b are empirically determined constants. The most frequently reported values of these constants, $a = 7.5$, $b = 237.3$, $e_{s0} = 6.11$, were those given by Tetens (1930), although $a = 7.45$, $b = 235$, $e_{s0} = 6.107$ were also reported. Other suggested values can be found in Buck (1981). Very few replies identified the source of their algorithms, but inspection and some algebraic manipulation often revealed the underlying form (and allowed correction of some typographical errors). Many were of the Magnus form, using Tetens's or closely related values of the constants. Other relations were numerical fits to more elaborate equations (e.g., Hooper 1986). The sources of a few were not so apparent, particularly the graphs, nomograms, etc.

Figure 1 shows the differences between the largest and smallest values of D calculated with the algorithms, plotted against U, for several values of T. These could be interpreted as spatial differences found on a given day due solely to differences in algorithms. The maximum differences are not large except in cold, dry conditions, where they can exceed 1°C. In general, the range of values of D decreases with increasing T and with increasing U. Because D is transmitted over the GTS only to the nearest 1°C when D exceeds 5°C, many of these discrepancies would be lost in the round-off process, although it is possible that a small discrepancy could be magnified to a 1°C discrepancy in the transmitted value. Nevertheless, they will exist in the station records, which usually show precisions of 0.1°C.

The slide rules, graphs, and other manual methods also were used to find D, but their values were not used in Fig. 1. Some manual methods permitted only whole-number values of dewpoint depression for $D > 5$°C, and the poor precision with which others could be read, particularly at low temperatures, makes comparisons with algorithms misleading. The discrepancies among these methods is consistent with Fig. 1—that is, largest discrepancies in cold, dry conditions.

The distribution of D values for one point in Fig. 1, that at $T = 0$°C and $U = 20$%, is shown in Fig. 2. While the range of values approaches 0.6°C, two-thirds of the values do not differ by more than 0.2°C. A new formulation for the dependence of saturation vapor pressure on temperature (Sonntag 1990) leads to a value of $D = 20.31$°C. Eleven of the 16 algorithms give values within 0.1°C of this number. The difference between $D = 20$°C and $D = 21$°C at $T = 0$°C corresponds to a difference in relative humidity of almost 2%.

The implied spatial differences due to these algorithms are generally not large and are within the presumed accuracy of the basic measurement. Nevertheless, at upper levels, where air is often cold and dry, false horizontal gradients are possible.

Furthermore, those examining moisture time series need to be aware that countries have changed their algorithms at times. For one of the two countries that indicated a change in algorithm, the change could be misinterpreted as a moisture increase of about 2%–3% at 500 mb. Thus, changes in conversion algorithms are another potential source of inhomogeneity in humidity time series.

Finally, although we have focused on conversions from U to D for upper-air data, analogous problems exist in surface data. This usually involves converting wet-bulb depressions and temperatures to other humidity variables, and there are a number of different formulas employed for this purpose (Sonntag 1989).

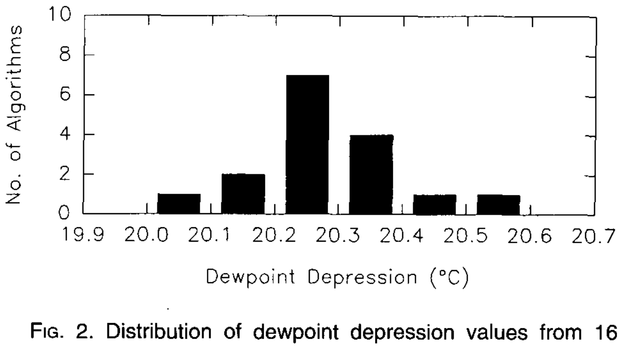

FIG. 2. Distribution of dewpoint depression values from 16 algorithms at 0°C and 20% relative humidity. Each bar represents the number of algorithms yielding dewpoint depressions between the abscissa values.

In summary, there are differences in algorithms used to calculate dewpoint depressions from upper-air measurements of temperature and relative humidity. These differences can produce small but nonnegligible inhomogeneities in upper-air humidity data, particularly in cold, dry conditions. It is important to keep in mind that we have only a small sample of national practices (albeit ones that cover a substantial number of stations). There may well be algorithms in use that produce larger discrepancies than shown here. Additionally, there very likely were changes in algorithms over time unreported to us. These would have been particularly likely when computers replaced hand calculations. Further changes are probable as nations change radiosonde systems and computers are upgraded. Adoption by all of a single conversion algorithm would relieve the problem in the future, but inhomogeneities in the record will remain. Analysts will have to consider this possibility when examining long-term records.

Acknowledgments. We are grateful to all those representatives of the various weather services who provided information on their conversion methods. Partial support for this work was provided by the NOAA National Climatic Data Center, Comprehensive Aerological Research Data Set program.

References

Buck, A. L., 1981: New equations for computing vapor pressure and enhancement factor. *J. Appl. Meteor.*, **20**, 1527–1532.

Elliott, W. P., and D. J. Gaffen, 1991: On the utility of radiosonde humidity archives for climate studies. *Bull. Amer. Meteor. Soc.*, **72**, 1507–1520.

Finger, F., and F. Schmidlin, 1991: Upper-air measurements and instrumentation workshop. *Bull. Amer. Meteor. Soc.*, **72**, 50–55.

Gaffen, D. J., 1993: Historical changes in radiosonde instruments and practices. Instruments and Observing Methods Rep. No. 50, WMO/TD-No. 541, World Meteorological Organization, 123 pp.

Garand, L., C. Grassotti, J. Hallé, and G. L. Klein, 1992: On differences in radiosonde humidity-reporting practices and their implications for numerical weather prediction and remote sensing. *Bull. Amer. Meteor. Soc.*, **73**, 1417–1423.

Hooper, A. H., 1986: Algorithms for automatic aerological soundings. Instruments and Observing Methods Rep. No. 21, WMO/TD-No. 175, World Meteorological Organization, 50 pp.

Schwartz, B. E., and C. A. Doswell III, 1991: North American rawinsonde observations: Problems, concerns, and a call to action. *Bull. Amer. Meteor. Soc.*, **72**, 1885–1896.

Sonntag, D., 1989: WMO Assmann aspiration psychrometer intercomparison. Instruments and Observing Methods Rep. No. 34, WMO/TD-No. 289, World Meteorological Organization, 177 pp.

——, 1990: Important new values of the physical constants of 1986, vapor pressure formulations based on the ITS-90, and psychrometric formulae. *Z. Meteorol.*, **70**, 340–344.

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