# The Vaisala RS-80H Radiosonde Dry-Bias Correction Redux

*B. M. Lesht*
*Environmental Research Division*
*Argonne National Laboratory*
*Argonne, Illinois*

*S. J. Richardson*
*Department of Meteorology*
*Pennsylvania State University*
*University Park, Pennsylvania*

## Introduction

In previous studies (e.g., Lesht 1997, 1998, 1999; Lesht and Richardson 2001; Richardson et al. 2000) we examined the effects of dry bias in Vaisala RS-80H radiosonde humidity measurements on Atmospheric Radiation Measurement (ARM) data. Some of this analysis was done by using a preliminary version of a humidity correction algorithm that was developed by Vaisala in conjunction with their colleagues at the National Center for Atmospheric Research (NCAR). Because Vaisala insisted that the information included in the algorithm be proprietary, we were required to execute a non-disclosure agreement before we could obtain a version of the algorithm sufficiently detailed for us to test and apply. Under the terms of this agreement, we were not permitted either to describe the details of the algorithm or to distribute computer code incorporating it. Recently, however, researchers from NCAR and Vaisala have had an explanation of the correction process, and an example of its application to data from Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE), accepted for publication (Wang et al. 2002). Although the fundamental aspects of the algorithm described by Wang et al. (2002) are identical to those we previously used in correcting ARM data, there are some important differences. The purpose of this paper is to describe the current algorithm as implemented by ARM and to evaluate the effects of the differences between the current and earlier versions of the algorithm on our analysis of ARM data.

## Radiosonde Humidity Sensor and Calibration

To understand the nature of the errors affecting the Vaisala RS-80H radiosonde humidity measurement, it is necessary to understand the basic functioning of the humidity sensor and how it is calibrated. A more detailed description of the calibration process may be found in Tappila (1989) and in Paukkunen (1998).

The RS-80H humidity sensor is based on a polymer membrane that acts as the dielectric in a thin-film capacitor. Water molecules bound to the polymer change its dielectric value and hence the capacitance, which is the fundamental variable sensed. The polymer surface is intended to mimic the behavior of a water surface with respect to adsorption of ambient water vapor. Because the polymer's water vapor adsorption capacity depends on its temperature, the sensor responds to changes in relative humidity (RH) rather than to changes in absolute humidity. The basic sensor calibration process relates the sensor capacitance to ambient RH. Because both the functional form of the dependence of the sensor capacitance on RH and the dependence of the capacitance-RH relationship on temperature are assumed known, each individual sensor is calibrated by measuring its capacitance at several points in temperature-RH space. The accuracy of the calibration depends on how well the assumed functions (sometimes referred to as sensor response models) describe the relationships between capacitance, temperature, and RH, and on how well the sensor membrane equilibrates with the true value of ambient RH. The Vaisala correction algorithm is designed to compensate for known problems, both in the calibration functions and in the ability of the polymer to measure atmospheric water vapor.

## Error Sources and Magnitudes

**Calibration Model Error**. The first issue to address is the basic calibration model, or the accuracy of the function-relating capacitance to RH at a fixed temperature. By performing detailed chamber tests on 400 radiosondes Vaisala concluded that the RH-80H calibration model is inaccurate at high values of RH, tending to be moist. They proposed a correction equation in the form of a third-order polynomial,

$$\Delta Um = H_0 + H_1U + H_2U^2 + H_3U^3 \tag{1}$$

in which $\Delta Um$ is the difference between a reference sensor value of RH and the radiosonde-reported RH value, U is the radiosonde-reported RH value (adjusted to calibration temperature), and the $H_i$ are empirical coefficients (numerical values made be found in Wang et al. 2002). Figure 1 shows that the basic model error is insignificant through most of the RH range, but approaches 3% RH at the upper end of the scale. It should be noted that Wang et al. (2002), citing a procedural concern about the experiment from which Equation 1 was derived (a concern not shared by their Vaisala colleagues), do not apply this correction. We do, however, include this correction in the results shown below.

**Temperature Model Error**. Vaisala accounts for the sensitivity of the RH sensor to temperature by using another polynomial function that relates the output value of RH to the ambient temperature (t) and to the value of RH at calibration temperature (U) corresponding to the measured capacitance (Equation 1). Written as

$$RH = \frac{U + a_0 + a_1t + a_2t^2 + a_3t^3 + a_4t^4}{b_0 + b_1t + b_2t^2 + b_3t^3 + b_4t^4} \tag{2}$$

the $a_i$ and $b_i$ again are empirical coefficients. During chamber testing Vaisala determined that the original coefficient values used in Equation 2 resulted in a dry bias at ice-saturation levels. Based on these findings, the original correction algorithm included an additive term that depended on temperature, saturation RH with respect to water, the radiosonde-measured RH. The original correction formulation

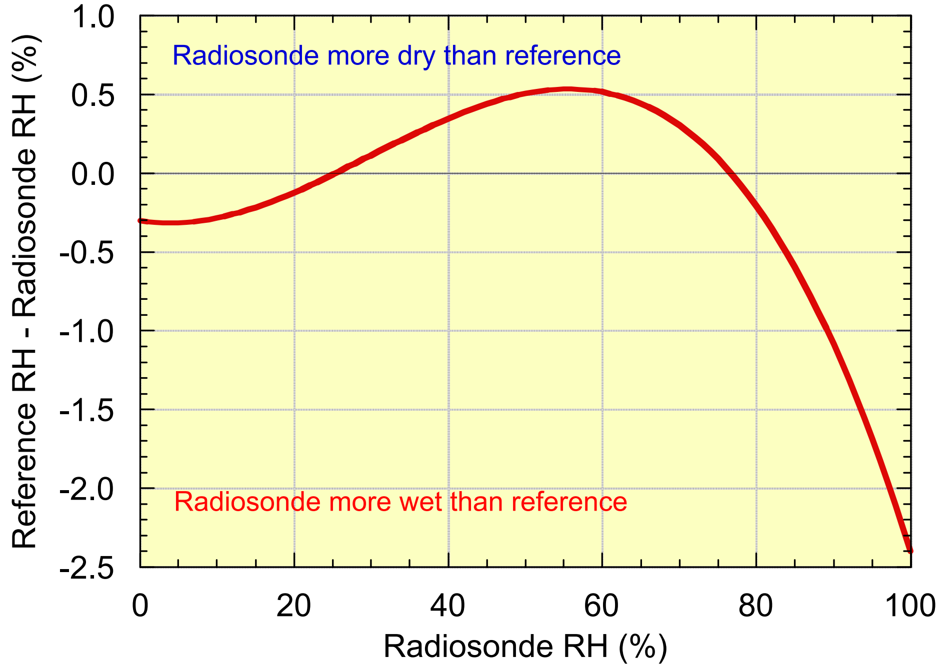


**Figure 1**. Vaisala-estimated error in RS-80H basic calibration model.

we used with the ARM data included this additive correction. In contrast to the additive correction, Wang et al. (2002) use Equation 2 with an updated set of coefficients. Figure 2 shows the differences in the two methods of calculating the temperature model error.

**Contamination Error**. The largest contribution to the dry bias that we have observed in the RS-80H radiosonde humidity measurements is that caused by contamination of the polymer sensor by organic molecules originating in the radiosonde's plastic parts. These molecules occupy binding sites on the polymer that otherwise might be available for water molecules and thus result in lower than expected humidity values. The contamination appears to be progressive with time, and the effect of the contamination is dependent on the ambient humidity. Vaisala has developed another polynomial function to describe the correction necessary to account for the contamination. Denoting $C_{ch}$ as the correction (in % RH) to the RH at calibration temperature (U), d as the age of the radiosonde in years, and $kh_i$ and $ph_i$ empirical constants, this function is written

$$C_{ch} = (kh_o + kh_1 d + kh_2 d^2 + kh_3 d^3 + kh_4 d^4) * (ph_0 + ph_1 U + ph_2 U^2 + ph_3 U^3). \quad (3)$$

Because the temperature dependence of the contamination correction is relatively weak at high temperatures, these results are almost identical to the original correction (e.g., Lesht (1999), Figure 2). However, at lower temperatures such as the -40°C shown in Figure 3, applying the new temperature dependence model increases the contamination correction by nearly 2% RH at saturation.

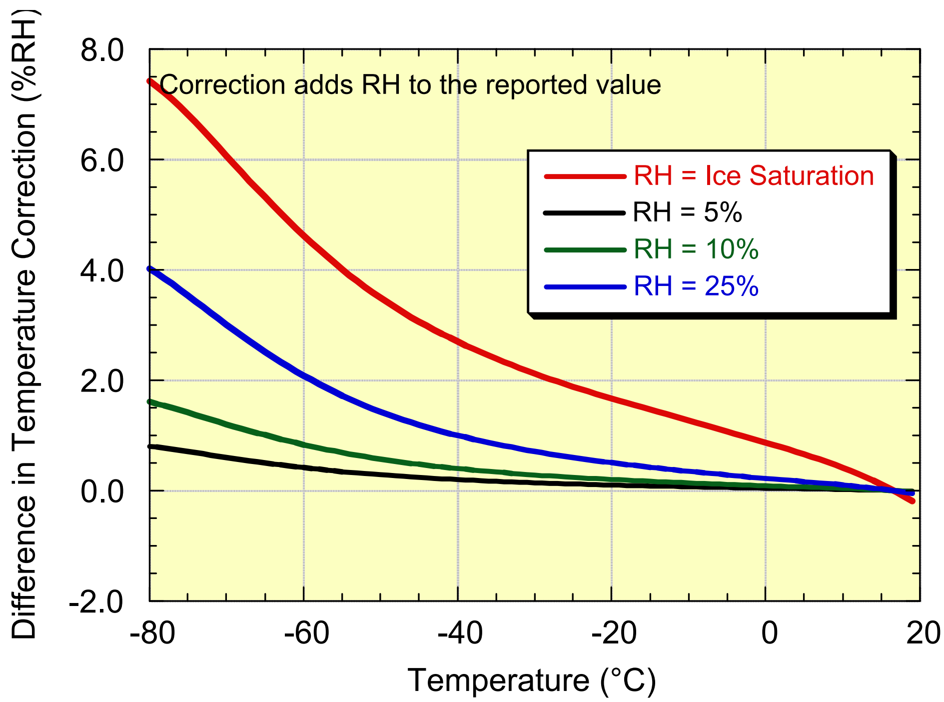


**Figure 2**. Difference in the temperature dependence model correction. The current correction increases the RH more than the previous version.

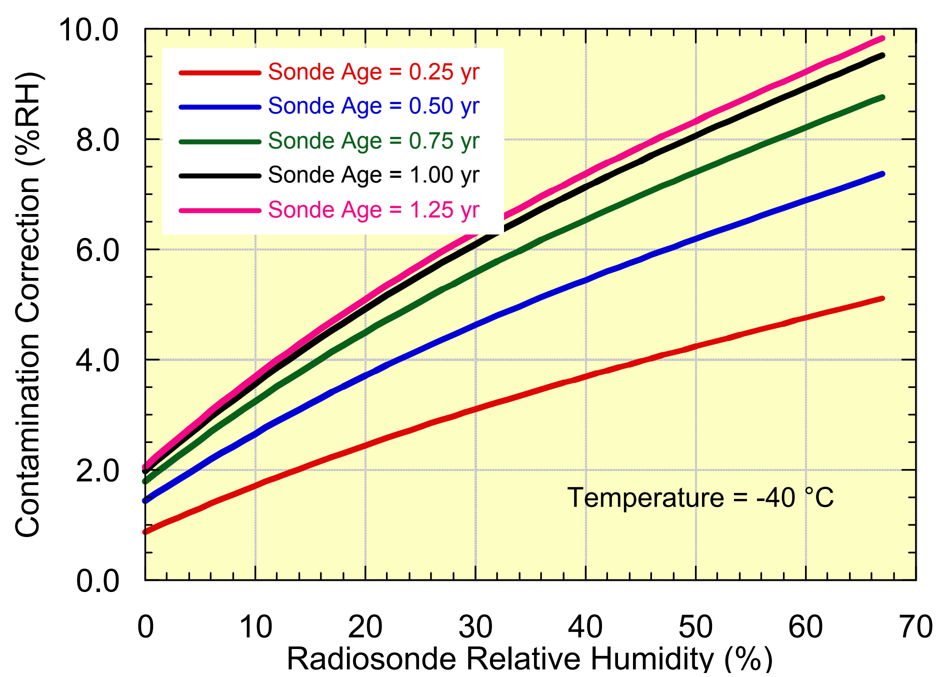


**Figure 3**. Contamination correction at -40°C as a function of reported RH for several different radiosonde ages.

**Sensor Aging Error**. Other than the age dependence incorporated in the contamination correction, our original application of the correction algorithm did not include a correction for "sensor aging." Although Tappila (1989) reports that long-term drift during storage is not a problem for the RS-80H, Wang et al. (2002) introduce a factor to compensate for a tendency of the polymer membrane to become less sensitive to water vapor as it ages. The correction factor, a second-order polynomial function of radiosonde age, is shown in Figure 4. Because this correction factor seems somewhat ad hoc to us, and contradicts other carefully controlled studies of the effects of aging on the H-humicap sensor, we have chosen not to apply it to ARM data.

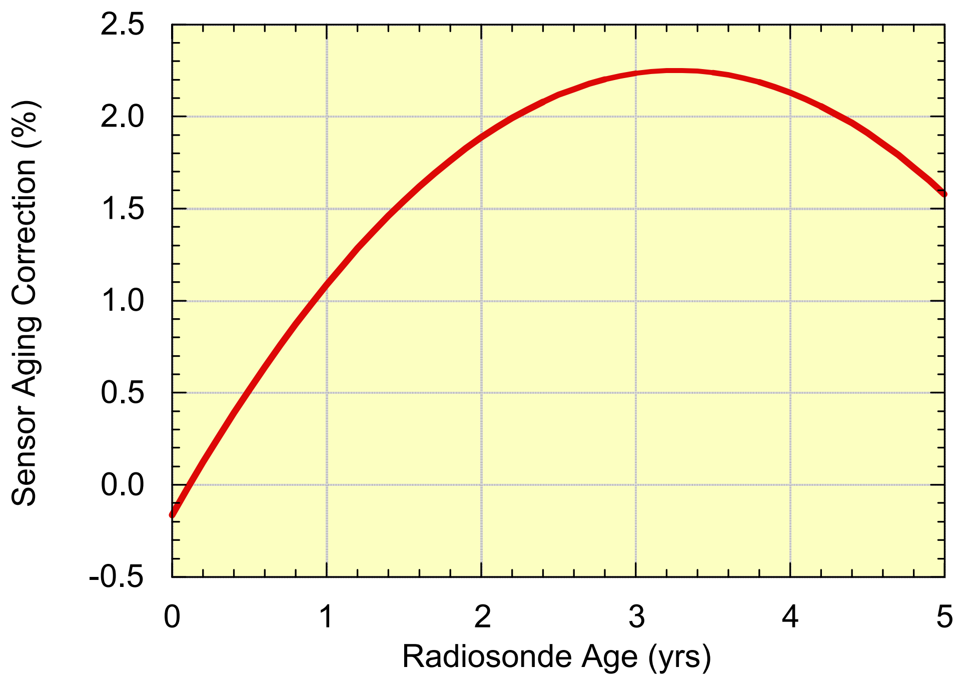


**Figure 4**. Sensor aging correction from Wang et al. (2002).

**The Bottom Line:** The changes in the Vaisala RS-80H correction algorithm as reported in Wang et al. (2002) will have an effect on analysis of ARM radiosonde data. Differences between the original and new methods of correcting for the sensor temperature dependence, in particular, may result in substantial differences (~5%) in high values (near saturation) of RH at low temperatures. Because the new corrections are not much different from the old at higher temperatures, there should be little effect on the integrated column precipitable water vapor obtained from the corrected radiosonde profiles. The uncertainty about application of the basic humidity model correction and about the sensor aging correction requires further analysis to resolve. Other efforts (see Miloshevich poster) that are directed toward correcting for time-response errors in the radiosonde RH measurements offer even greater opportunities for improving the accuracy of upper-air observations of water vapor.

## Corresponding Author

Barry M. Lesht, barry.lesht@anl.gov, (630) 252-4208

## References

Lesht, B. M., 1997: An Internal Analysis of SGP/CART Radiosonde Performance During the September 1996 Water Vapor Intensive Observation Period. In *Proceedings of the Seventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, CONF-970365, pp. 59-62. U.S. Department of Energy. Available URL: http://www.arm.gov/docs/documents/technical/conf_9703/lesht-97.pdf

Lesht, B. M., 1998: Uncertainty in Radiosonde Measurements of Temperature and Relative Humidity Estimated from Dual-Sonde Soundings Made During the September 1996 ARM Water Vapor IOP. In *Proceedings of the Tenth Symposium on Meteorological Observations and Instrumentation*, Phoenix, Arizona, American Meteorological Society, pp. 80-85.

Lesht, B. M., 1999: Reanalysis of Radiosonde Data from the 1996 and 1997 Water Vapor IOPS. In *Proceedings of the Ninth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* p. 59. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9903/lesht-99.pdf

Lesht, B. M., and S. J. Richardson, 2001: Radiosonde Intercomparison During the Fall 2000 Water Vapor IOP. In *Proceedings of the Eleventh Atmospheric Radiation Measurement (ARM) Science Team Meeting.*

Paukkunen, A., 1998: New Calibration Procedure Optimizes RS90 Radiosonde Performance. *Vaisala News*, **147**:4-6.

Richardson, S. J., M. E. Splitt, and B. M. Lesht, 2000: Enhancement of ARM Surface Meteorological Observations During the Fall 1996 Water Vapor IOP. *J. Atmos. Oceanic Tech*., **17**:312:322.

Tappila, P., 1989: Long-Term Stability of RS80 Radiosonde. *Vaisala News*, **117**:11-15.

Wang, J., H. L. Cole, D. J. Carlson, E. R. Miller, K. Beirle, A. Paukkunen, and T. K. Laine, 2002: Corrections of Humidity Measurement Errors from the Vaisala RS80 Radiosonde-Application to TOGA-COARE Data. *J. Atmos. Oceanic Tech*., in press.