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Relative Humidity Sensor Bias and Associated Transformations: A Field Comparison Study

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1. INTRODUCTION

Water vapor is one of the most important variables in the atmosphere. Only accurate air humidity climate records will reveal the role of water vapor in long-term climate monitoring trends. During the relative humidity (RH) measurements in various surface climate networks, the sensors are known to be temperature-compensated by manufacturers. However, previous studies and our recent field study show that the RH observations from different solid-state RH sensors had measurable temperature and humidity dependencies (Anderson, 1995 and Fleming, 1998). Anderson (1995) and Fleming (1998) developed RH correction models for specific RH sensors. It should be noted that both Anderson and Fleming focused on specific RH sensors but current RH sensors used in the current climate networks are relatively new and were not included in previous studies.

In this study, our intend is to investigate the RH measurement bias associated with ambient air temperature and ambient RH. We collected several RH sensors in this study including HMP45C, MP101, HMP233, and HMP243 sensors. Furthermore, transformation functions among them were derived from the statistical analysis of simultaneous RH measurements from HMP45C, MP101, and HMP243. In addition, monthly RH measurement bias was summarized for over year long observations.

2. DATA AND METHODS

The field observations were taken during 2002 and 2003 in Lincoln, NE. An array of capacitive RH sensors were included in this study. There are two HMP45C (Vaisala, Finland) inside the aspirated shields, two HMP45C inside the non aspirated Gill shields, two HMP233 (Vaisala, Inc. Finland), and two MP101A (Rotronic Instrument Co., USA) sensors inside the aspirated shields, which was used in the U. S. Climate Reference Networks (USCRN). All RH sensors, and three USCRN temperature sensors as well as air pressure, solar radiation, wind speed, and ground surface temperature were measured by a CR7 data logger (Campbell Scientific. Inc.) for analog output sensors and a PC for digital output sensors at the height of 1.5 meters. The 1.5 meter height refers to air intake height for aspirated sensors. All aspirated RH sensors were installed in the USCRN shields and all RH sensors were newly calibrated before observations. During the experiments, we re-calibrated all RH sensors in April, 2003 and implemented a polynomial calibration equation for each of RH sensor. The calibration was conducted using a two-pressure humidity generator (Model 2500 Humidity Generator, NIST traceable, Thunder Scientific. Corp) under different testing temperatures.

All measurement sampling rates were 5 seconds but hourly average data was used in following analysis. The available data were taken from June 1st, 2002 to October 30, 2003 except for time period of April of 2003. The latest HMP233 sensor inside the USCRN shields was taken as a reference system (average of two HMP233) because the manufacturer's stated accuracy of HMP233 is the best among all RH sensors. The RH bias is defined as the RH difference between RH sensor and the reference sensor.

The data collected from field observations provided a wide range of ambient air temperature and relative humidity. Therefore, the RH transformation/correction function was derived in terms of ambient temperature and ambient RH dependencies of RH bias. The data for deriving the transformation functions were taken from June 2002 to March 2003 (manufacturer's calibration data) because larger volume and wider ranges of data was required during simulations. We restricted the transformation functions as polynomial functions of ambient temperature and ambient RH with less than 5 coefficients. Therefore, three transformation functions for HMP45C, MP101, and HMP243 are as follows,

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$$RH\ Bias_{HMP45} = a + bT + cRH + dRH^2 + eRH^3$$

$$RH\ Bias_{MP101} = a + bT + cT^2 + dT^3 + eRH^{-1}$$

$$RH\ Bias_{HMP243} = a + bT + cRH + dRH^2 + eRH^3$$

Where T and RH represent ambient temperature (°C) and ambient RH (%). The a, b, c, d, and e represent the polynomial coefficients

3. PRELIMINARY RESULTS AND DISCUSSION

a. Normalized Frequency of Average RH Bias: Figure 1 shows the normalized frequencies of RH bias over year long observations. Note that the HMP45 RH1 and HMP45 RH2 refer to the HMP45 sensors located inside the USCRN shields while HMP45 RH3 and HMP45 RH4 were located inside the Gill shields (non aspirated). On average, RH bias during observations by manufacturers had a wet bias for each of type RH sensor (Fig.1a). However, the RH bias was improved after our own re-calibrations (Fig. 1b). It should be noted that peak of normalized frequencies was less than 15%. This result suggests that RH measurements hardly have a very high precision in field observations although they could maintain a certain level of accuracy. The monthly average of RH bias was summarized in Tables 1 and 2. From the RH bias ranges under a 95% confidence level (Tables 1 and 2), the accuracy of monthly average RH measurements ranged from ± 4% to ± 6% RH.

b. An Example of RH Bias Variations with Changes of Ambient Temperature and RH: Figure 2 illustrates that the ambient temperature and RH

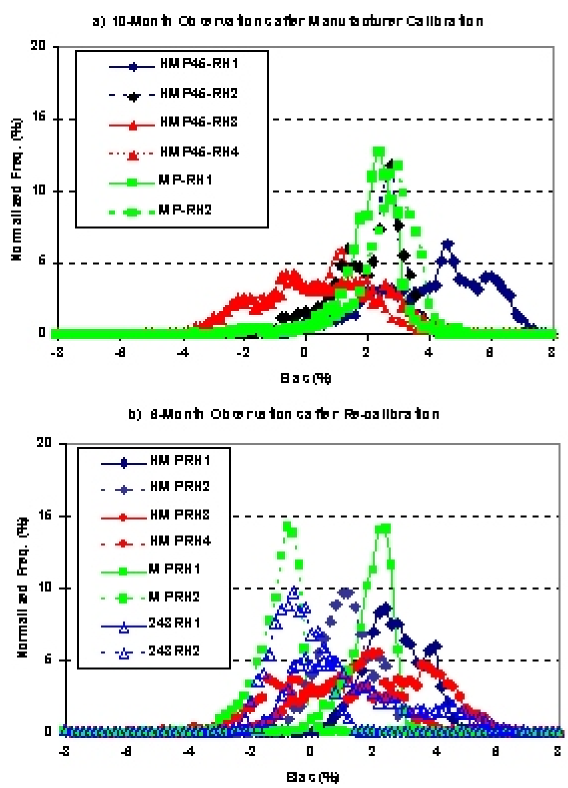

Fig.1. Normalized frequency distributions of RH bias: a) observations after manufacturer's calibrations from June 2002 to March 2003; b) observations after our own calibrations from May to October 2003.

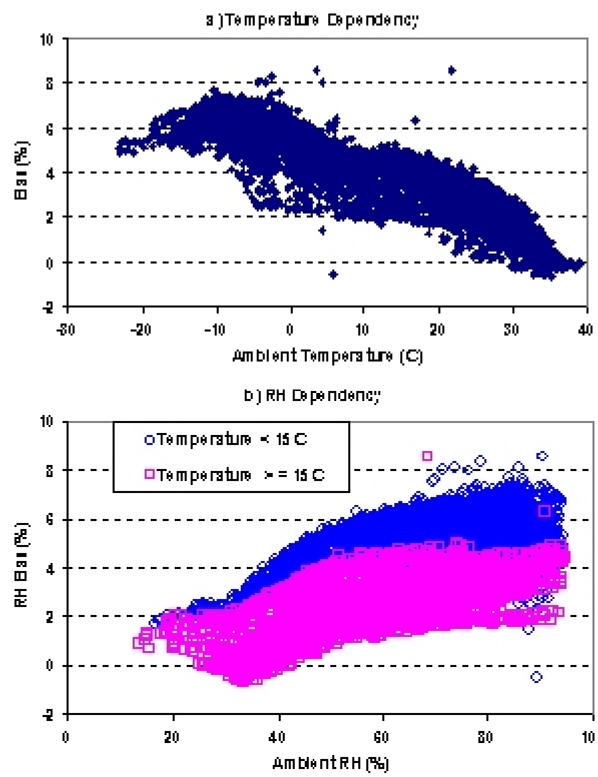

Fig. 2. Ambient temperature and RH dependencies of HMP45 RH bias. Data from June 2002 to March 2003.

dependencies of RH bias in the aspirated HMP45 sensors. The HMP45 RH bias is a non linear function of ambient temperature (Fig. 2a). In addition, the HMP45 RH bias had two obvious clusters of observations in Figure 2b. One was for higher ambient temperature and the other for lower ambient temperature. We found the similar results for the HMP243 and MP101 sensor inside the USCRN shields (not shown in this paper). However, each RH sensor performed differently in its magnitude and its variation rate.

c. Transformation function of RH Bias: The simulation results shown in Figure 3 illustrated the response surface for the RH bias in the HMP45C, MP101, and HMP243 sensors in the USCRN shields. Note that for the HMP243 sensor there was a nearly linear relationship between the ambient temperature and the RH bias (Fig.3). The simulation coefficients (a, b, c, d, and e) and the coefficients of determination (R2) are listed in Table 3.

Table3. Transformation coefficients and R^2.

Sensor	Transformation Function Coefficients					R^2
	a	b	c	d	e	
HMP45C	6.27E-01	-7.94E-02	-8.48E-04	1.20E-01	-7.12E-04	0.88
MP101	2.19E+00	1.23E-01	-6.07E-03	7.71E+00	-1.48E+01	0.71
HMP243	-3.48E+00	4.32E-02	1.01E-01	-2.54E-03	1.29E-05	0.79

It should be noted that all transformation functions might be varied due to the re-calibrations and changes of calibration methods. However, we re-calibrated all RH sensors including reference system of HMP233 sensors and we found that both ambient temperature and RH dependencies of RH bias still strongly exist. The study presented in this paper is preliminary, and deserves more extensive work including possible laboratory study on possible lower temperature conditions which may not be achieved at our experimental sites.

4. REFERENCES

Anderson, P.S., 1995: Mechanism for behavior of hydroactive materials used in humidity sensors. J. Atmos. Oceanic Technol., 12:662-667.

Fleming, R.J. 1998: A note on temperature and relative humidity corrections for humidity sensors. J. Atmos. Oceanic Tech.15(6):1511-1515.

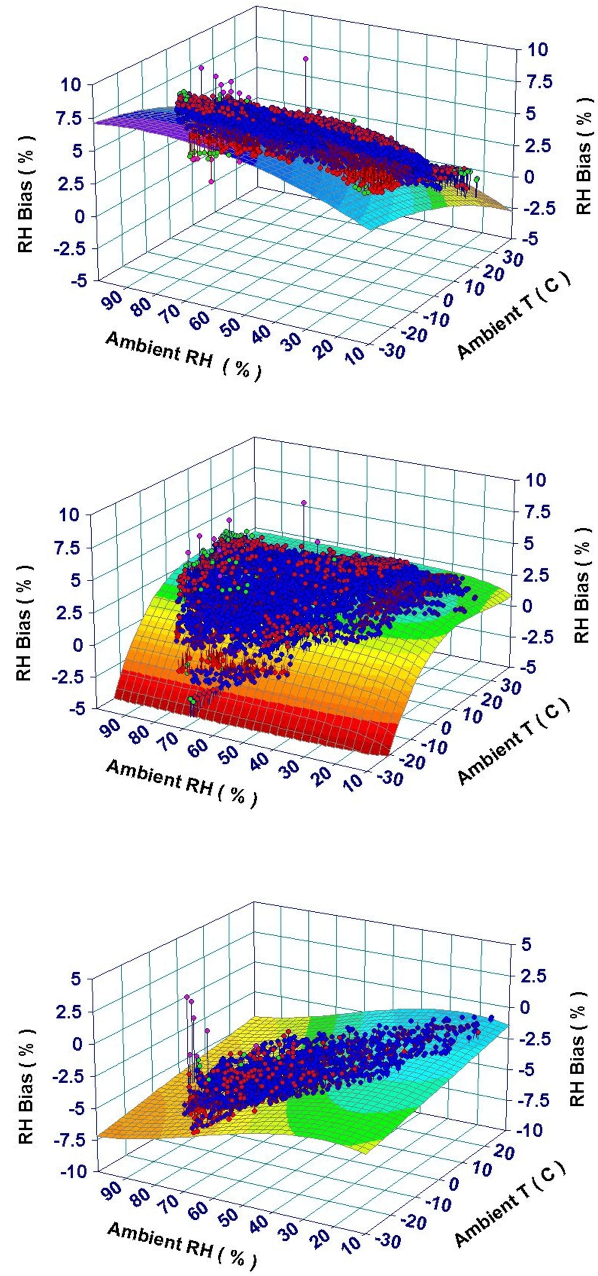

Fig.3. The distribution of RH bias, as a function of the ambient temperature and ambient RH, measured by the HMP45C (top graph), MP101 (middle graph); and HMP243 (bottom graph) inside the USCRN shields.

Table 1. Summaries of RH bias ranges under 95% confidence level. Data taken from June 2002 to March 2003.

	Hourly Obs.	HMP45-RH1	HMP45-RH2	HMP45-RH3	HMP45-RH4	MP-RH1	MP-RH2
Jun-02	719	[3.4 to -0.2]	[2.3 to -0.9]	[0.8 to -3.9]	[0.4 to -3.9]	[2.4 to 1.1]	[3.2 to 1.8]
Jul-02	624	[4.4 to -0.3]	[2.6 to -1.1]	[1.2 to -3.9]	[0.9 to -3.8]	[3.3 to 1.2]	[4.1 to 1.8]
Aug-02	693	[5.7 to 0.4]	[3.7 to 1.1]	[2.6 to -3.9]	[2.5 to -3.9]	[4.5 to 1.0]	[5.4 to 1.6]
Sep-02	638	[5.9 to 1.4]	[3.9 to 0.0]	[2.8 to -3.0]	[2.7 to -3.0]	[3.6 to 1.8]	[4.4 to 2.3]
Oct-02	578	[6.5 to 2.7]	[3.7 to 0.9]	[4.9 to -3.1]	[5.4 to -3.1]	[3.8 to 0.7]	[4.5 to 1.4]
Nov-02	669	[6.9 to 2.7]	[3.6 to 1.4]	[3.9 to -2.2]	[4.6 to -1.9]	[3.3 to 0.8]	[3.8 to 1.4]
Dec-02	611	[7.6 to 2.7]	[4.0 to 1.2]	[4.4 to -2.4]	[5.1 to -1.8]	[3.4 to 0.3]	[3.8 to 0.9]
Jan-03	744	[7.7 to 2.9]	[4.0 to 1.3]	[4.6 to -2.4]	[5.4 to -1.8]	[3.8 to -1.5]	[4.2 to -0.9]
Feb-03	547	[7.4 to 4.0]	[3.8 to 1.9]	[6.2 to -3.7]	[7.6 to -3.5]	[4.1 to -2.0]	[4.6 to -1.3]
Mar-03	715	[7.4 to 1.6]	[4.0 to 0.8]	[3.2 to -1.9]	[4.1 to -1.8]	[4.4 to -0.1]	[4.8 to 0.4]
Monthly AVE		[6.3 to 1.8]	[3.6 to 0.5]	[3.5 to -3.1]	[3.9 to -2.8]	[3.7 to 0.3]	[4.3 to 0.9]

Table 2: Summaries of RH bias range under 95 % confidence level. Data taken from May to October 2003.

	Hourly Obs	HMP45-RH1	HMP45-RH2	HMP45-RH3	HMP45-RH4	MP-RH1	MP-RH2	HMP243-RH1	HMP243-RH2
May-03	561	[3.0 to 0.7]	[2.1 to -0.3]	[6.0 to -1.0]	[4.0 to -2.3]	[2.7 to -0.3]	[-0.2 to -3.2]	[8.3 to -4]	[7.2 to -8.2]
Jun-03	464	[3.3 to 1.1]	[1.5 to -0.6]	[6.1 to -2.1]	[4.0 to -3.3]	[2.8 to 0.1]	[-0.2 to -3.0]	[5.2 to -3.0]	[0.1 to -2.5]
Jul-03	590	[8.0 to -3.7]	[6.2 to -5.4]	[8.1 to -6.5]	[6.3 to -6.9]	[7.7 to -4.0]	[4.7 to -7.0]	[3.9 to -3.0]	[0.3 to -2.5]
Aug-03	586	[4.2 to 0.8]	[2.1 to -0.7]	[5.5 to -2.5]	[3.2 to -3.4]	[3.2 to 1.2]	[0.2 to -1.8]	[4.1 to -3.1]	[0.0 to -2.1]
Sep-03	678	[4.9 to 1.5]	[3.0 to -0.1]	[6.1 to -1.0]	[4.3 to -2.6]	[3.5 to 0.5]	[0.5 to -2.5]	[5.4 to -2.4]	[1.2 to -1.8]
Oct-03	607	[7.1 to -0.3]	[5.2 to -1.9]	[7.4 to -2.0]	[5.6 to -3.5]	[5.4 to 1.6]	[2.3 to -4.7]	[5.7 to -2.0]	[1.6 to -1.5]
Monthly AVE		[5.1 to 0.0]	[3.4 to -1.5]	[6.5 to -2.3]	[4.6 to -3.7]	[4.2 to -0.7]	[1.2 to -3.7]	[5.4 to -3.0]	[1.7 to -3.1]