# New Surface Meteorological Measurements at SGP, and Their Use for Assessing Radiosonde Measurement Accuracy

*L.M. Miloshevich*
*National Center for Atmospheric Research*
*Boulder, Colorado*

*B.M. Lesht and M. Ritche*
*Argonne National Laboratory*
*Argonne, Illinois*

## Introduction

Several recent ARM investigations have been directed toward characterizing and improving the accuracy of ARM radiosonde water vapor measurements. Tobin et al. (2002) showed that calculating the downwelling and outgoing longwave fluxes with a target accuracy of 1 W $m^{-2}$ requires knowing the total-column precipitable water vapor (PW) with 2% absolute accuracy and knowing the upper troposphere (UT) water vapor with 10% absolute accuracy. Turner et al. (2003) used an empirical technique to correct for variability in the calibration accuracy of Vaisala RS80-H radiosonde humidity measurements, by scaling the measurements with a constant factor that matches the total-column PW from the radiosonde with that measured by a microwave radiometer (MWR). The MWR-scaling was shown to successfully address the radiosonde calibration bias, which improves the accuracy of the lower tropospheric humidity where most of the PW resides. However, this approach has little impact on the larger and more complicated radiosonde measurement errors in the UT that are caused by slow sensor response at cold temperatures ("time-lag error"). Miloshevich et al. (2004) developed a correction method for time-lag error based on laboratory measurements of the sensor time-constant as a function of temperature, which was shown to recover vertical structure in the UT humidity profile that had been highly "smoothed" by the slow sensor response. Ferrare et al. (2004) found from comparisons of various in-situ and remote water vapor measurements, using the airborne Lidar Atmospheric Sensing Experiment (LASE) instrument as a reference sensor, that the time-lag correction reduced the mean dry bias of RS80-H radiosondes in the UT from 15-20% to <5%. Work is in progress to combine the MWR-scaling and time-lag corrections into a new ARM "Best Estimate" radiosonde datastream, thereby addressing both the radiosonde-specific calibration bias ("production variability") that dominates the lower tropospheric measurement error, and the time-lag effects that dominate the measurement error in the UT.

Accurate measurements at the surface of relative humidity (RH) and temperature (T) can be used as references for characterizing the accuracy of (corrected and uncorrected) ARM radiosonde measurements under surface conditions, as well as providing accurate surface measurements for modeling and other purposes. The current surface measurement system at the SGP radiosonde launch site consists of a chilled-mirror hygrometer (CM) and a Rotronic T/RH sensor located inside a ventilated "mailbox" (Figure 1). This system is shown below to be neither accurate nor reliable enough for operational radiosonde characterization. A new surface meteorological reference station containing six T/RH sensors was designed for the SGP site, and this paper assesses its performance during its initial deployment for the recent AIRS Water-vapor EXperiment (AWEX) in November 2003. When implemented operationally at ARM, this datastream will provide a "best estimate" of surface T/RH conditions that will automatically be correlated with the radiosonde data. Detailed descriptions of the current and new surface measurement systems, and scientific justification for the change, are given at http://www.mmm.ucar.edu/science/ecr/ecr.html

**Figure 1**. Prior to launch, radiosondes are placed in this ventilated mailbox at the SGP radiosonde launch site. The mailbox contains a Rotronic T/RH sensor and the sampling inlet for a chilled-mirror hygrometer that is located in the box at left. Additional T/RH measurements outside the mailbox are made by the THWAPS sensors in the round housing.

## Current Surface Reference Measurement System

At present, radiosondes are placed in the mailbox prior to launch, where measurements are made continuously by the CM and the Rotronic T/RH sensors. The raw radiosonde data can then be correlated with the reference measurements during the prelaunch time period, thereby characterizing the radiosonde measurement accuracy under surface conditions (relative to the reference measurements), and possibly allowing for an empirical bias correction somewhat analogous to the MWR-scaling approach. Figure 2 shows comparisons between Rotronic RH measurements (red) and the corresponding radiosonde RH measurements (green), revealing a consistent but different bias in each case. Since the portion of the prelaunch time period when the radiosonde was actually in the mailbox is unknown, times near the beginning of the period when the radiosonde is removed from its package are rejected when calculating the mean bias (blue dots), as is the time just prior to launch (yellow asterisk) when the radiosonde has presumably been removed from the mailbox. The radiosonde calibration consists of polynomial fits that give the average behavior of many radiosondes as a function of RH and T, and the observed mean bias characterizes the accuracy of the radiosonde calibration for a given individual radiosonde. This bias for a given radiosonde is primarily a random error that forms a distribution referred to as "production variability."

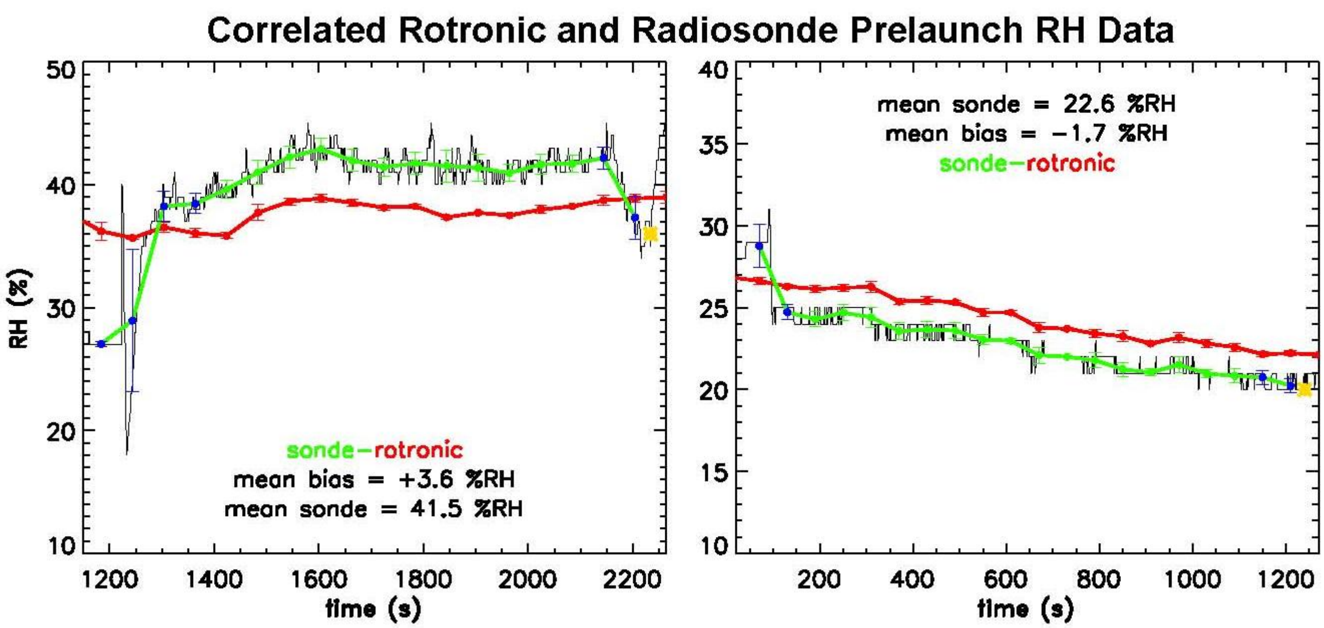


**Figure 2**. Examples of correlated RH time series from the Rotronic senor (red) and an RS80-H radiosonde (black), acquired at the surface while both instruments are being ventilated in the mailbox. Dots and bars are the mean and standard deviation of the measurements for 1 minute time periods (green for the radiosonde). Blue indicates radiosonde points that were excluded when the mean bias is calculated (e.g., before the radiosonde is placed in the mailbox, or after it is removed for launch). Yellow asterisk indicates the launch time.

The current reference measurement system is far from ideal on several counts: 1) the two reference sensors in the mailbox (CM and Rotronic) often differ substantially (Figure 3, left), usually because the CM (blue) was not designed for continuous operational use; 2) the accuracy of the calibration for the single Rotronic sensor (red) is generally unknown and changes with time, and although the THWAPS T/RH measurements (yellow) provide a consistency check, the THWAPS samples air from outside the mailbox that might be different than air inside the mailbox due to radiative effects; 3) the radiative characteristics of the mailbox are undoubtedly poor and variable, and although the RH comparison made inside the mailbox is still valid, it does not represent the ambient air with sufficient accuracy to be generally useful as surface measurements for model input or other applications; and 4) there is no indication of when a radiosonde is actually in the mailbox. In summary, the current reference measurement system cannot provide the desired ±2%RH absolute accuracy.

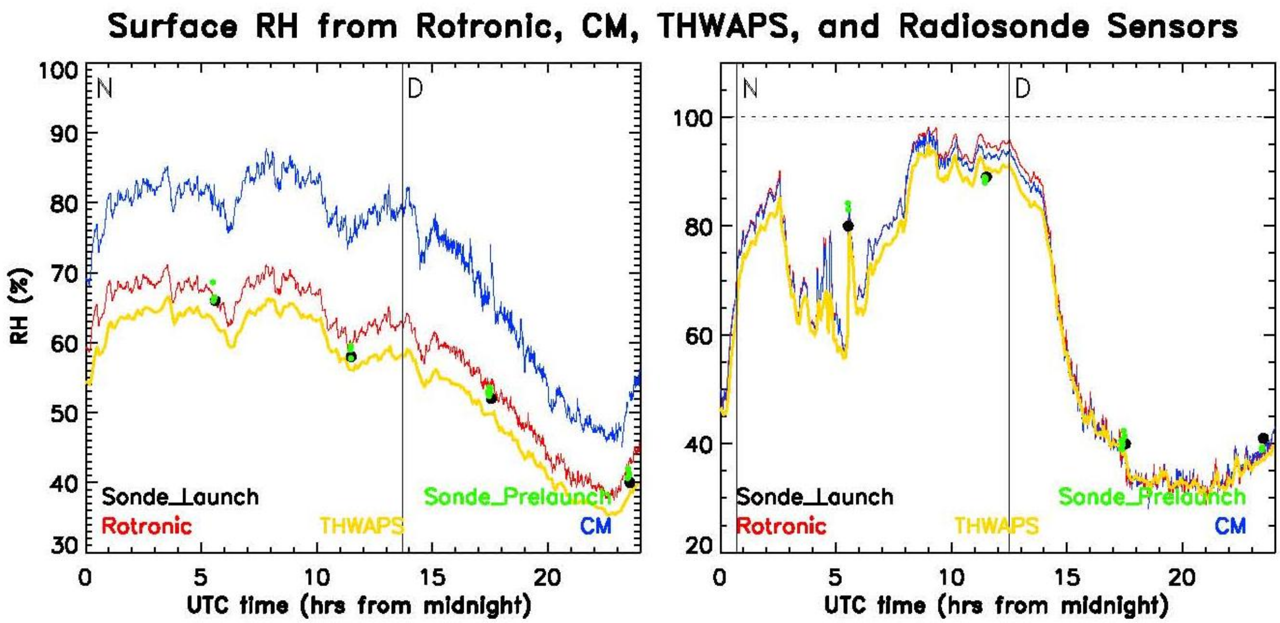


**Figure 3**. Comparison of RH measurements from the chilled-mirror hygrometer (CM, blue), the Rotronic sensor (red), the THWAPS sensor located near but outside the mailbox (yellow), the surface radiosonde measurement that is read by the operator from the THWAPS and placed in the t=0 position in the radiosonde data files (black dots), and the radiosonde 1-minute averages while it is being ventilated in the mailbox (green).

## New Surface Reference Measurement System

The new reference measurement system (Figure 4) consists of 6 T/RH sensors (3 Rotronic and 3 Vaisala) mounted in a ventilated chamber within a “Stevenson screen” that protects the interior from solar radiation while allowing substantial ventilation. The sensor redundancy allows automated detection of any sensor that is out of calibration or otherwise not performing well, and the redundancy

**Figure 4**. The new system for surface meteorological reference measurements to be installed at the SPG radiosonde launch site. The inner chamber houses 6 T/RH sensors, ventilation fans, and a switch that records when a radiosonde is placed upon it. The outer “Stevenson screen” shelters the sensors from solar heating and rain.

reduces the random calibration error through averaging. When a radiosonde is placed in the proper position, a switch is depressed that records its presence in the datastream for later use in correlating the radiosonde and reference sensor measurements. Time series of RH and T measurements from the 6 sensors are shown in Figure 5 for a 20 hour period during AWEX. The 3 sensors from a given manufacturer agree with each other within the advertised specifications (±1 %RH and ±0.2°C), where the average over the time period of the range between the highest and lowest measurement for each manufacturer is about 0.3 %RH and <0.2°C. However, the two manufacturers' calibrations differ systematically, and the average range of the measurements from all 6 sensors is 2 %RH and 0.35°C.

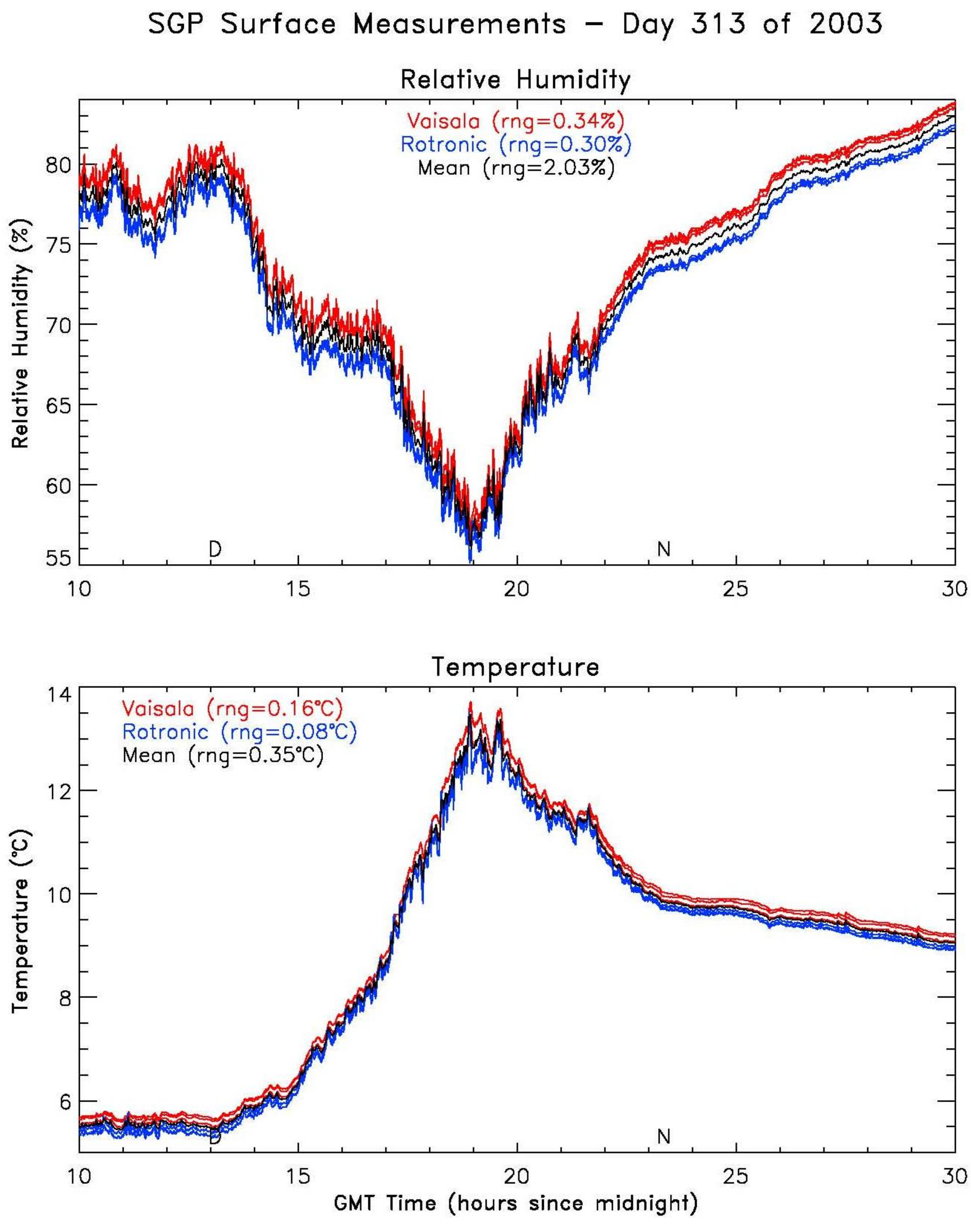


**Figure 5**. Time series of relative humidity (top) and temperature (bottom) from the three Vaisala sensors (red), three Rotronic sensors (blue), and the mean of all six sensors (black). Numbers give the average range of values (max minus min) over the time period. The beginning of daytime and nighttime are indicated by "D" and "N".

The RH calibration bias between manufacturers is seen in Figure 6 (top panel) to vary as a function of both RH and T, where the quantity plotted is the difference between the respective means of the 3 sensors from each manufacturer. The calibrations agree within 1 %RH at all humidities if the

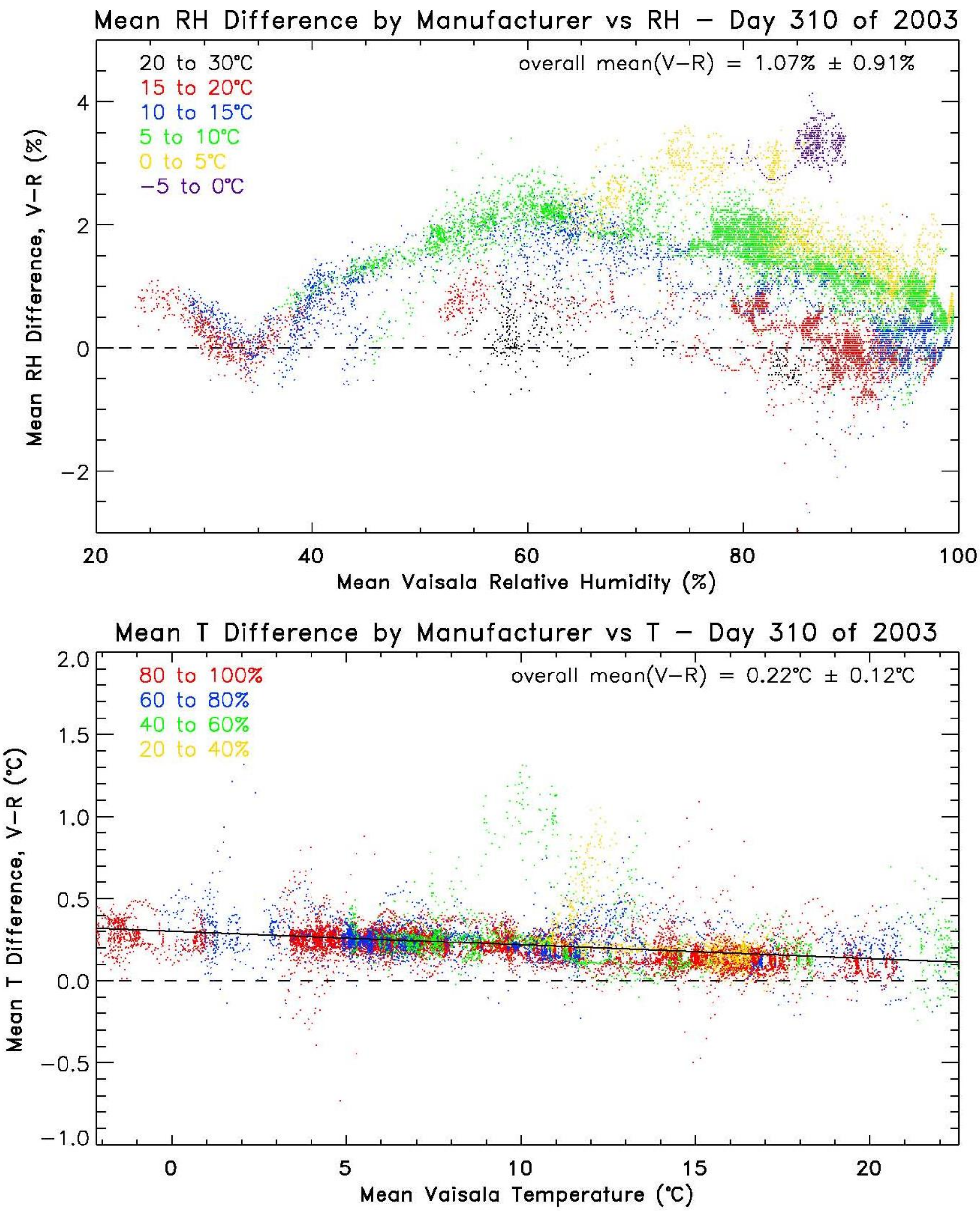


**Figure 6**. Difference between the mean of the 3 Vaisala sensors and the mean of the 3 Rotronic sensors for each 1 minute datapoint for a period of about 12 days. Top panel shows the RH-dependence of the RH difference between manufacturers, partitioned by color for 5°C temperature intervals. Bottom panel shows the T-dependence of the T difference between manufacturers, partitioned by color for 20%RH intervals.

temperature is near +20°C, but the Vaisala sensors are increasingly moist relative to the Rotronic sensors as the temperature decreases, up to 3-4%RH for moist conditions near 0°C (no dry, cold conditions occurred during AWEX). The manufacturer difference in the calibration of the temperature sensors (bottom panel) increases with decreasing temperature from about 0.1°C at 20°C to 0.3°C at 0°C, and is independent of the RH. The advertised accuracy specifications of 1%RH and 0.2°C only apply at a temperature of +25°C, and one or both manufacturers' calibration is less accurate at lower temperatures.

For purposes of radiosonde accuracy assessment it is only important that the radiosonde and reference sensors measure the same air, not that the air faithfully represent the ambient conditions. The sensor redundancy allows estimates of solar radiative effects on the measurements. Figure 7 shows measurements of RH (top 2 panels) and T (bottom 2 panels) from each of the sensors for a time period centered on midday. The quantity plotted is the difference between a given sensor and the mean of all 3 sensors from the same manufacturer (Vaisala in panels 1 and 3; Rotronic in panels 2 and 4). Before and after the feature in the center of the plot, each sensor tracks the others with a relatively constant bias of up to ±0.2 %RH or ±0.1°C relative to the appropriate mean. The feature in the center of the plot is believed to be a solar radiative effect, where the three sensors nearest the sunlit side of the shelter (V1, V3, and R2) are warmed relative to the 3 more interior sensors by up to 0.4°C (bottom panels, curves with positive deviation). The warmer air is also drier by up to 0.9 %RH (top panels, especially V1 and R2). The interpretation that this is a solar radiative effect was confirmed by rearranging the sensors and observing the same warming effect from different sensors located nearest the sunlit side of the shelter. This effect will probably be reduced by orienting the shelter with the exhaust fans facing south, rather than west as during this test. Further reduction of solar radiative effects can be achieved by shading the shelter's south side.

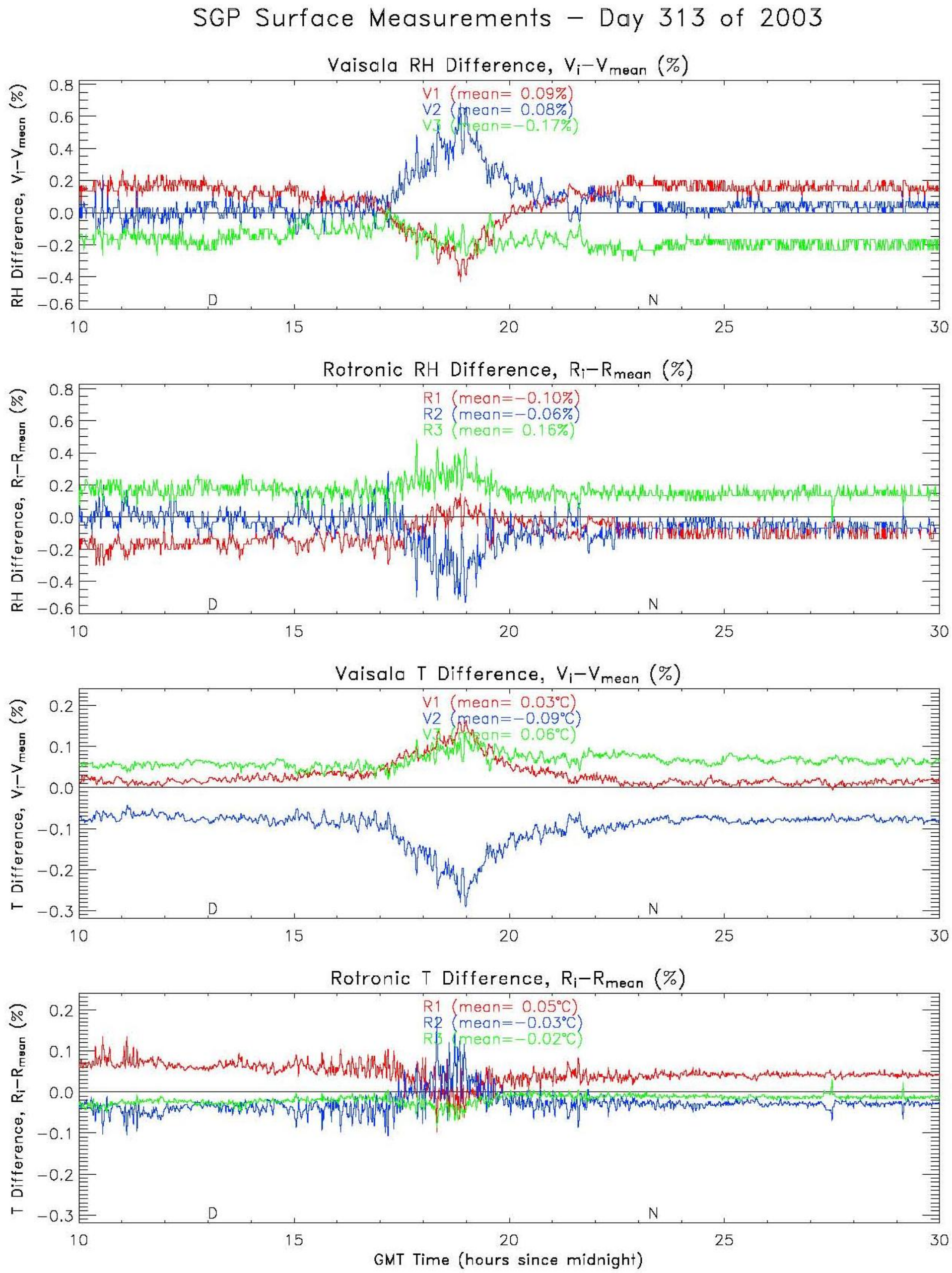


**Figure 7**. Time series of the RH difference (top 2 panels) or T difference (bottom 2 panels) between each individual sensor's measurement and the mean of the 3 sensors from the same manufacturer. The Vaisala RH and T measurements are shown in panels 2 and 4. Numbers give the average difference from the mean for each sensor over the time period. The beginning of daytime and nighttime are indicated by "D" and "N".

## Future Plans

When operational at ARM, these T/RH measurements will replace the current 'sgpcm' datastream. The new datastream will contain one-minute mean and standard deviation values from each of the 6 T/RH sensors, a 0/1 flag that indicates whether or not a radiosonde is being ventilated, and "best estimate" T/RH values determined by analyzing the performance of all sensors and averaging the "good" measurements. For example, Figure 8 suggests that the Rotronic sensors may be more susceptible to sensor wetting effects in saturated air, and such measurements will not be used when calculating a best-

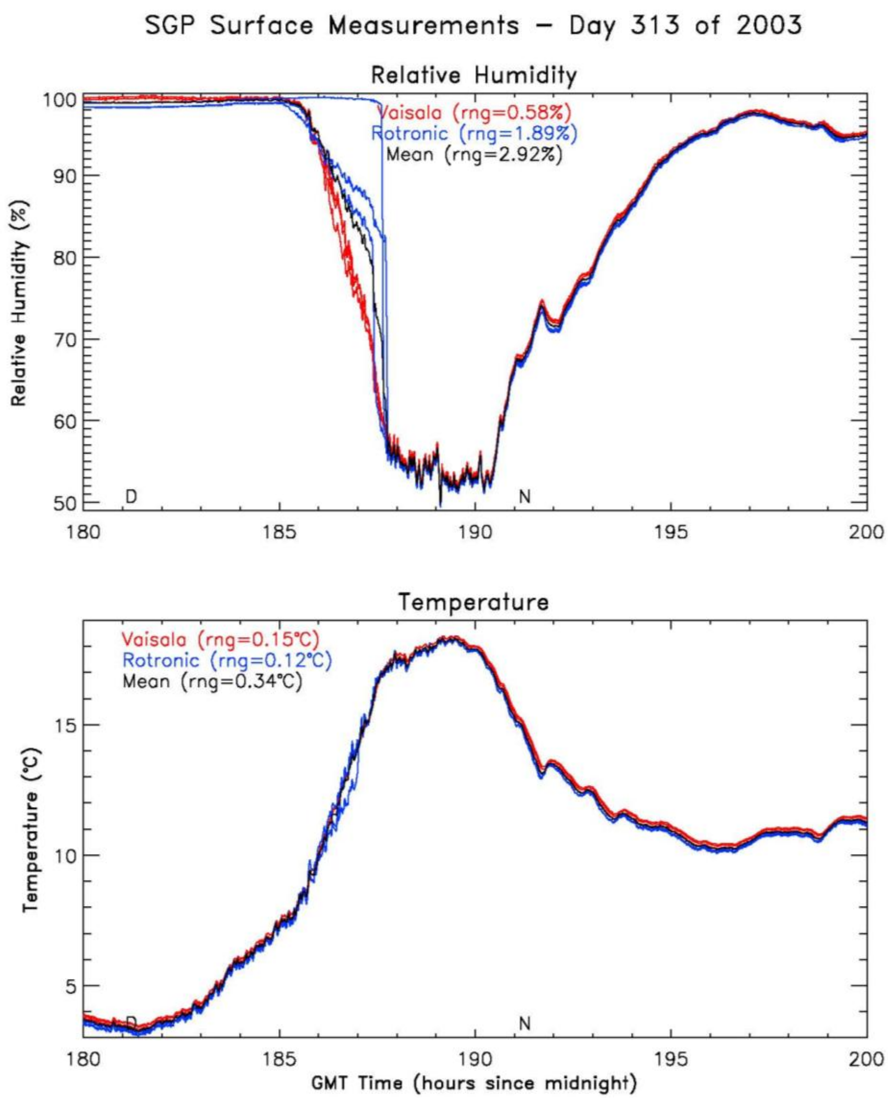


**Figure 8**. Time series of relative humidity (top) and temperature (bottom) from the three Vaisala sensors (red), three Rotronic sensors (blue), and the menu of all six sensors (black). Numbers give the average range of values (max minus min.) over the time period. The beginning of daytime and nighttime are indicated by "D" and "N".

estimate value. Further investigation into which manufacturer has the more accurate calibration at lower temperatures is warranted, as is further investigation of solar radiative effects after the shelter is installed in its permanent location and orientation.

The new datastream may be used as input to a new Value Added Product (VAP) currently being proposed to ARM. The new VAP well give a "Best Estimate" of the radiosonde humidity measurements by first applying the time-lag and other sensor-based corrections, followed by the MWR-scaling that at present is applied to the (uncorrected) radiosonde data in the 'lssonde' VAP. The proposed new VAP will also contain information that characterizes the accuracy of the radiosonde measurements, including the bias at the surface determined as in Figure 2 by correlating the raw radiosonde data with the reference sensor data during the time period when the radiosonde flag is enabled.

## Corresponding Author

Larry Miloshevich
milo@ucar.edu
(303) 497-8963.

## References

Ferrare, RA, EV Browell, S Ismail, S Kooi, LH Brasseur, VG Brackett, M Clayton, J Barrick, G Diskin, J Goldsmith, B Lesht, J Podolske, G Sachse, FJ Schmidlin, D Turner, D Whiteman, D Tobin, and L Miloshevich. 2004. "Characterization of upper troposphere water vapor measurements during AFWEX using LASE." *Journal of Atmospheric and Oceanic Technology.* Submitted.

Miloshevich, LM, A Paukkunen, H Voemel, and SJ Oltmans. 2004. "Development and validation of a time-lag correction for Vaisala radiosonde humidity measurements." *Journal of Atmospheric and Oceanic Technology.* Accepted.

Tobin, DC, HE Revercomb, and DD Turner. 2002. Overview of the ARM/FIRE water vapor experiment (AFWEX). *Proceedings of the 12th ARM Science Team Meeting*, St. Petersburg, Florida, April 8-12.

Turner, DD, BM Lesht, SA Clough, JC Liljegren, HE Revercomb, and DC Tobin. 2003. "Dry bias and variability in Vaisala RS80-H radiosondes: The ARM experience." *Journal of Atmospheric and Oceanic Technology*, 20:117-132.