In Situ Moisture Measurements Using Chilled Mirror Sensors

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Abstract

Chilled mirror moisture measurement systems were installed at the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed (CART) Central Facility (CF) at the balloon borne sounding system (BBSS) launch site and at 25 m and 60 m on the CART tower from September 1997 through January 1998. This paper will present results from comparisons between the chilled mirror (CM) sensors and the standard ARM CART instrumentation. This work represents an extension of the work performed during the first Water Vapor (WV) Intensive Observation Period (IOP) in 1996 and shows that the redundant Vaisala sensors and the CMs located on the tower agree to within 2% in mixing ratio. In light of these findings, it does not appear necessary to use CM sensors for in situ moisture measurements at the CART CF.

Purpose

Three General Eastern, Inc. D2/M4 CM dewpoint hygrometers were used during the WV IOP, which occurred in conjunction with the 1997 Fall Integrated IOP. This IOP took place at the ARM Program CART CF. The CM sensors were used as a reference to check the accuracy of the CART tower (25-m and 60-m levels) and surface [surface meteorological observation system (SMOS) and BBSS] temperature (T) and relative humidity (RH) sensors. The CMs were also used to check the operation of other sensors brought to the CART CF during the IOP period.

Results indicate that the Qualimetrics sensors previously located on the 60-m tower were, as suggested by findings from the first WV IOP, not sufficiently accurate for use in the ARM Program. The Qualimetrics sensors were replaced with duplicate Vaisala sensors (two identical Vaisala, Inc. HMP 35 sensors are now located at the 25-m and 60-m tower levels to detect instrument drift or failure). Comparison of the Vaisala sensors with the CMs indicated that they were accurately calibrated and capable of moisture measurements with accuracies approaching that of the CMs. The SMOS T and RH sensor appeared to be accurately calibrated, however, the Temperature, Humidity, Winds and Pressure System (THWAPS) moisture sensor appears to be biased slightly dry.

Another reason the CM sensors were used during the second WV IOP was to determine if the CART CF required them to obtain sufficiently accurate moisture measurements. This proved not to be the case, the redundant capacitive (Vaisala) humidity sensors on the 60-m tower proved very accurate and the CMs will be used for other applications in ARM.

Discussion

CM Systems and Calibration Procedure

Three CM systems were obtained (General Eastern, Inc. D2/M4), which consisted of a sampling system (a pump with carefully controllable flow rate), an air filter to reduce mirror contamination, the CM device and accompanying electronics, a data logging system (a Campbell Scientific Inc. CR-10 datalogger and SM-716 storage module), and a battery backup system capable of saving data for several months in the event of a power failure. These systems were packaged into a standard weather-proof enclosure (Campbell ENC 16/18) making the system portable, and requiring only 110 V power to operate the CM. The storage module is capable of storing several months of data even if real-time data collection is not available.

The CM sensors were subject to very careful calibrations and field checks prior to use in the IOP to ensure confidence in the measurements. The Oklahoma Mesonet (Brock et al. 1995) calibration facilities were used in a manner similar to that described in Richardson and Splitt (1998) [for a description of the calibration chamber, see Richardson (1995)] to verify the operation of the CMs. The CMs were tested at dewpoints of –5 °C, 3 °C, 9 °C, 18 °C, and 22 °C. The manufacturer-stated inaccuracies of each of the CMs is approximately ± 0.2 °C and all the sensors agree within this uncertainty. (Strictly, two sensors each with inaccuracies of ± 0.2 °C need only agree within $\pm\sqrt{\left(0.2^2+0.2^2\right)}\approx\pm 0.28$ °C, assuming the errors are independent.)

Field Tests

Following the laboratory tests, the three CMs were mounted at the BBSS launch site at the CART CF for one week prior to the start of the 1997 WV IOP. The agreement between the three CMs showed the agreement to be generally within ± 0.3 °C. This indicated that the CMs could be used in the field to provide reasonably accurate measurements of dewpoint.

Comparison of CMs and CART Sensors

Figure 1 is a histogram comparing the CM at 60 m and the Vaisala sensor at 60 m (the data plotted here are 20-minute averages). The mean difference between the mixing ratios computed from the Vaisala and CM sensors is less than 2%, within sensor uncertainty.

Similar results were obtained at the 25-m tower level and at the SMOS site. However, the THWAPS sensor was biased approximately 6% dry relative to the CM at the BBSS launch site.

At the start of the second WV IOP, there were two RH sensors at the 25 m and 60 m levels on the tower, an RH sensor made by Qualimetrics, Inc. and a T and RH sensor manufactured by Vaisala, Inc. Approximately half way through the 1997 WV IOP (early November), a second Vaisala sensor replaced the Qualimetrics sensor because the Qualimetrics was in error. It was clear from plotting the RH and mixing ratio that the Qualimetrics sensor was in error relative to the Vaisala sensor. The Vaisala sensor was known to be accurate because it agreed well with the CM mounted at the same level.

One of the most important findings of this work was that the duplicate Vaisala sensors mounted at each tower level agreed very well with each other and with the CM. This implies that the Vaisala sensors can be used on the tower and that the CMs are not needed.

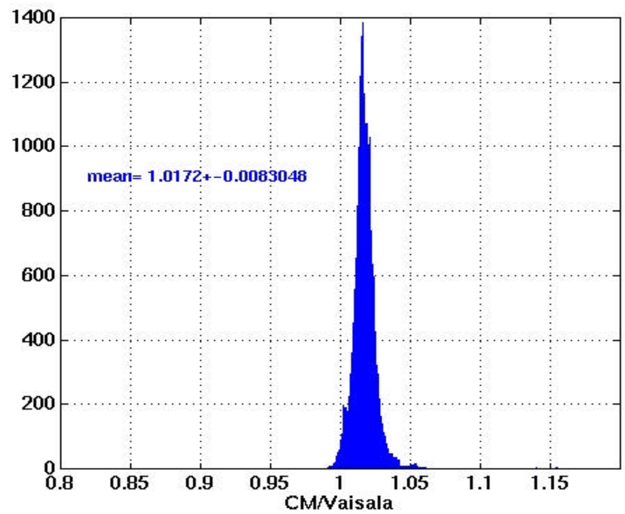

Figure 1. Histogram comparing the CM at 60 m and the Vaisala sensor at 60 m. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/richardson-98.pdf*.)

The Qualimetrics RH sensor at 25 m was also replaced during the IOP and similar results were obtained.

Temperature measurements on the tower have been very good to date with all sensors agreeing within expected uncertainties.

It was found that the CM data should be averaged for at least 5 to 10 minutes when comparing the CM to other sensors. This is because of the air filtering that is required to keep the mirror surface clean. The filter acts as an air "reservoir" and causes small time-scale fluctuations, on the order of one minute, to be smeared out.

Calculation of PWV

To compare the tower-based sensors (point measurements) to other instruments measuring total precipitable water vapor (pwv), pwv values representative of the tower measurements have been calculated in the following way. For every GSFC scanning Raman lidar (SRL) profile obtained during the 1997 WV IOP, which extends down to 60 m, the SRL profile is scaled so that its value is equal to either the 60-m Vaisala or CM mixing ratio measurement at that time. The same multiplicative factor is also applied to the entire SRL profile, independent of altitude. Then, when integrating to compute pwv, the tower values at 0 and 25 meters are added below the SRL profile and the radiosonde profile (interpolated to the SRL observation time and scaled to be continuous with the modified SRL adjusted profile) is added above the SRL profile. This procedure is followed for each SRL profile and results in "tower pwv" values representative of the 60-m Vaisala and CM sensors for each SRL profile. This can be thought of as a point calibration of the SRL for each observation. The main assumption of the validity of this approach is that the SRL profiles have the correct shape, even for the lowest altitude bins, and that the correct calibration is represented by a altitude-independent multiplicative constant (similar to what is done with pwv based calibration).

Figures 2 and 3 show the comparison of the Vaisala pwv calculations to the CART microwave radiometer (MWR) and to the SGP site GPS (Scripps processing) pwv measurements for selected clear-sky cases. The CART MWR comparison shows that the MWR and the Vaisala measurements are extremely stable with respect to one another (slope = 1.01 + 0.01 with a 3 sigma standard deviation) but that there is a pure bias of ~0.18 cm between the two. The comparison to the SGP site GPS values with Scripps processing shows a fractional difference of ~5% and only a small offset. Comparisons to the Environmental Research Laboratory (ERL) processing of the Lamont site GPS shows similar results, but with pwv values, which are only ~2% dryer than the tower values.

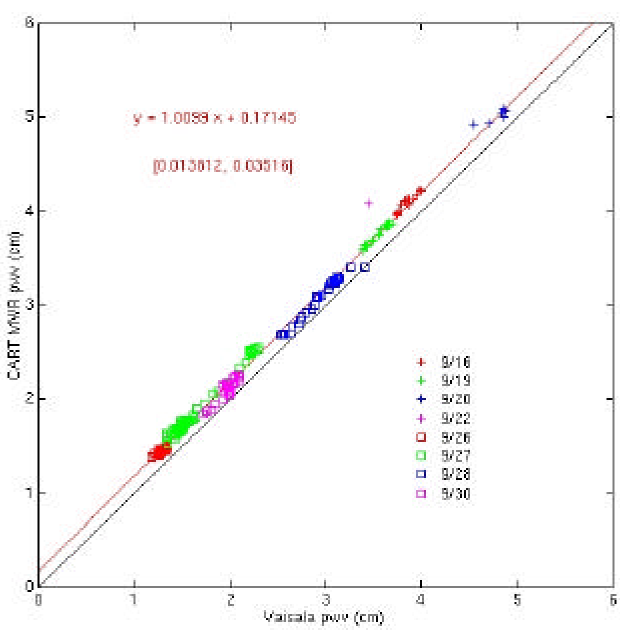

Figure 2. Comparison of PWV calculated using the Vaisala tower measurements and the CART MWR. See text for a discussion. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/richardson-98.pdf*.)

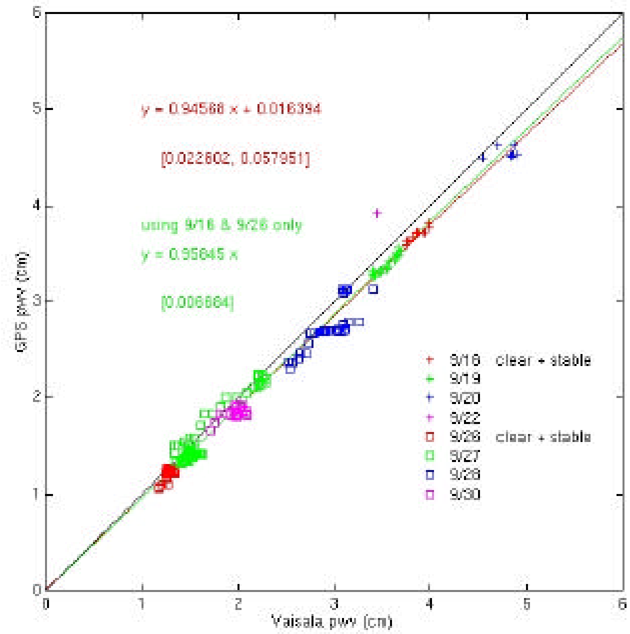

Figure 3. Comparison of PWV calculated using the Vaisala tower measurements and the SGP site GPS. See text for a discussion. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/richardson-98.pdf*.)

Conclusions

This work showed that accurate moisture measurements can be obtained at the SGP ARM CART CF using standard capacitive RH sensors; Vaisala HMP 35 temperature and relative humidity probes were used. Collocating CM sensors with Vaisala sensors showed that agreement between all three sensors was about 2% to 3%, within the uncertainty of the instrumentation. The redundant RH measurements made on the 60-m tower should make it possible to ensure accurate moisture measurements. The SMOS RH sensor appeared to be accurate when compared to the CM located at the BBSS launch site. However, the THWAPS sensor appears to be biased and may require recalibration. Although 1-minute observations of dewpoint are available from the CM systems, data should be averaged for at least 5 to 10 minutes when comparing the CM with other sensors.

Acknowledgments

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Other Publications in Progress

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