A Chilled Mirror Dew Point Hygrometer for Field Use

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Introduction

Three chilled mirror (CM) dew point hygrometer systems have been developed at the University of Oklahoma to provide a method for obtaining NIST (National Institute for Standards and Testing) traceable atmospheric moisture measurements. The three CM systems have been designed for relatively unattended use requiring only minimal maintenance (about weekly). The CMs have a lab inaccuracy of ±0.2 °C and a field inaccuracy of roughly ±0.4 °C.

The CM systems have recently been upgraded and now include a temperature (T) and relative humidity (RH) sensor that acts as secondary reference to check the operation of the CM. This additional sensor is included because CMs are not ideally suited for field use and can fail in dirty environments. The CM units require 110 V AC and can store over one month of data in non-volatile on-board memory.

One CM system has been installed at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) central facility (CF) Balloon Borne Sounding System (BBSS) launch site. This CM will become a CART instrument and act as a NIST traceable moisture measurement. The other two CM systems are available for use in field projects and will be used during intensive observation periods (IOPs) to provide a high accuracy surface moisture measurement. The University of Wisconsin used one system at Andros Island during the Convection Moisture Experiment (CAMEX)-III project with good success.

This paper describes the CM systems and gives sample data from the ARM CART CF.

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CM System Design

Each CM system (Figure 1) consists of an air sampling system (a pump with carefully controllable flow rate), an air filtration system to reduce mirror contamination, the CM device (General Eastern, Inc.

Figure 1. CM system installed at the ARM CART CF BBSS.

D2/M4) 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 addition, a Rotronic HP043 combination T and RH sensor is included with each system to verify the operation of the CM system. Each CM is packaged into a standard weatherproof enclosure (Campbell ENC 16/18) making them portable (but weighing 40 lbs) and requiring only 110 V power. The on-board storage module is capable of storing several months of data in the event real-time data collection is not feasible. The data logger program and all data is stored in non-volatile memory.

The CM sensors described here can and do fail and require maintenance to maintain peak performance. This is because CMs are better suited for laboratory use than for field deployments. Large RH errors are not uncommon but generally detectable using the T&RH sensor included with the system.

Adjusting for Ice Saturation Conditions

In meteorological application, RH is defined as the ratio of ambient water vapor pressure to saturation vapor pressure

$$RH = 100 \times \frac{e}{e_s} = 100 \times \frac{e_{water}}{e_{s\ water}} = 100 \times \frac{e(T_d)_{water}}{e_s(T_{air})_{water}} \tag{1}$$

where e is the vapor pressure and e_s is the saturation vapor pressure. RH is defined using vapor pressure relative to a plane surface of water. However, when $T_d < 0$ °C, either dew or frost may exist on the mirror, which implies the CM may be measuring the dew point or the frost point. However, capacitive RH sensors (e.g., Rotronic T&RH sensors) always respond to RH relative to a plane surface of water. Therefore, when comparing a CM and an RH sensor when $T_d = T_f < 0$ °C, T_d from the CM should be treated as a frost point temperature (T_f) and RH should be calculated as:

$$RH = 100 \times \frac{e}{e_s} = 100 \times \frac{e_{ice}}{e_{s\ water}} = 100 \times \frac{e(T_f)_{ice}}{e_s(T_{air})_{water}} \text{ when } T_d = T_f < 0\,°C \tag{2}$$

Dew can exist on the mirror for temperatures well below 0 °C and using Eq. (2) for all temperatures below 0 °C can result in errors in excess of 5% RH. On the other hand, assuming liquid water is always on the mirror results in far larger errors as shown in Figure 2, which compares the CM and the RH sensor assuming both dew and frost on the mirror surface. This figure indicates that for dew points between 0 °C and -5 °C, RH error appears to be ±5% RH

CM Applications

University of Wisconsin CAMEX-III CM Deployment

A CM system was deployed in Andros Island and operated by the University of Wisconsin (UW) during the CAMEX-III field project. The moisture measurements made by the CM were used as a

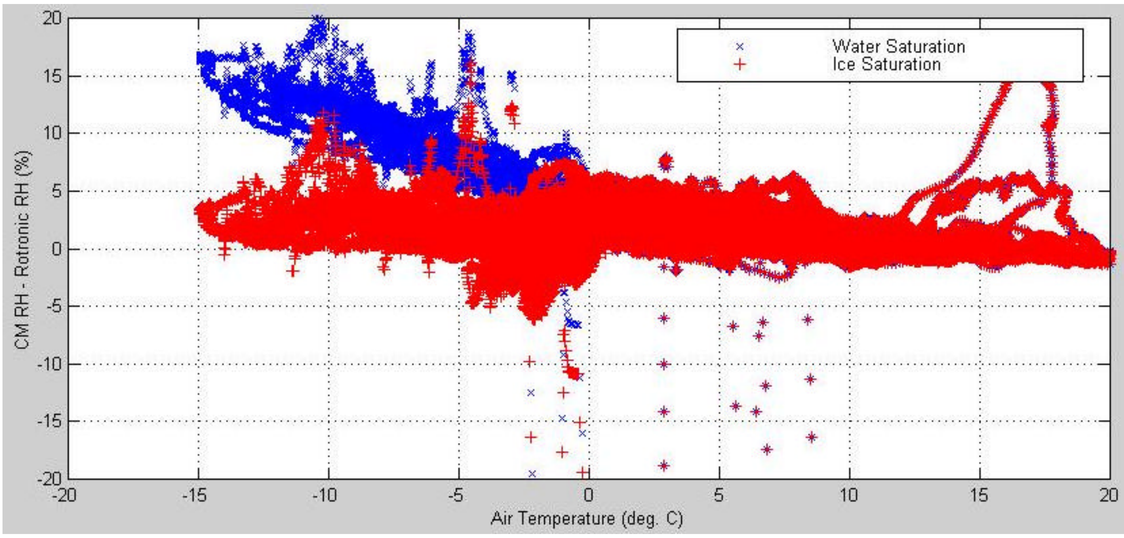

Figure 2. (CM RH - Rotronic RH) before and after applying Eq. (1) and (2) above. Data are 1-minute averages from November 20, 1998, to March 1, 1999.

reference for comparison with other ground-based temperature and humidity sensors. The CM system helped identify a T bias in the T&RH sensor used by the University of Wisconsin. In addition, the CM measurements were used as input to a T and water vapor vertical profile retrieval algorithm using data from an AERI instrument collocated with the CM. Finally, the CM data will be used for validation of the Vaisala humidity correction algorithm (resulting from packaging contamination) for Vaisala sondes launched by the UW during CAMEX-III.

THWAPS RH Sensor

The CM located at the CF BBSS was compared with the THWAPS Vaisala T&RH for a three-month period. The RH sensor at the BBSS is biased relative to CM system (including both the CM and the Rotronic moisture measurement) as shown in Figure 3. The Rotronic T&RH sensor was used to develop a correction for the THWAPS RH and the corrected THWAPS sensors will be used to examine the Vaisala radiosonde dry bias.

Conclusions

The CM systems described here are available for field deployment, requests should be sent to *scott@ou.edu* or to the address above. Each system includes a NIST traceable dew point measurement and a secondary T&RH sensor to verify the operation of the CM system. In addition, a readme accompanies the CM system making it possible for users to retrieve the data in real-time (as was done by UW during CAMEX-III) or the data can be stored for later retrieval.

The following are notes regarding the operation of the CM system.

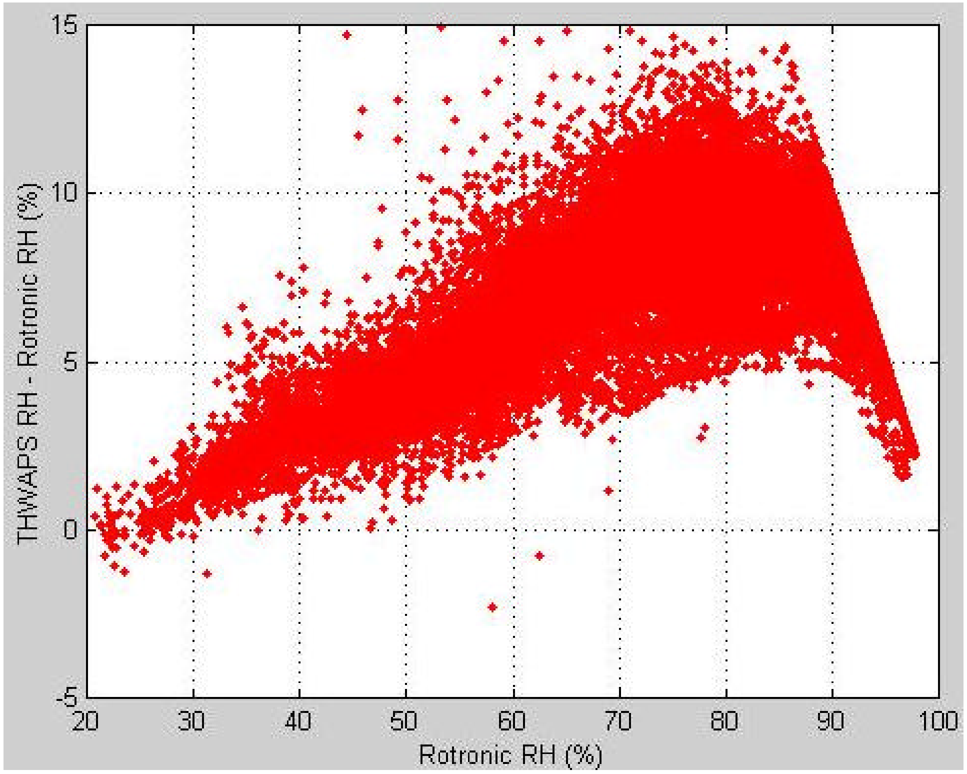

Figure 3. THWAPS RH "ERROR" relative to Rotronic RH.

- The CM or T&RH sensor data should be adjusted during ice saturation conditions as described in the section "Adjusting for Ice Saturation Conditions." Failure to do so will result in errors in excess of 20% RH for temperature below 0 °C.

- The CM and T&RH sensors agree within ±2% RH (1 σ) for the period September 20, 1998, to March 18, 1999 (this data was adjusted for ice saturation conditions).

- The CM performance is increased if mirror cleaning is performed weekly.

- The air filtration system used with the CM appears to cause errors. Use of the filter is not necessary under normal conditions if mirror maintenance is performed.