Improved Water Vapor Measurements from ARM Radiosondes

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Introduction

Accurate radiosonde measurements of water vapor in the mid and upper troposphere are important for such applications as evaluating remote-sensor water vapor retrievals, initializing numerical models, and improving parameterizations of radiative and cloud processes. Measurements of relative humidity (RH) from Vaisala radiosondes are subject to several measurement errors, most of which increase in magnitude with decreasing temperature (Miloshevich et al. 2000). Several of these measurement errors have already been corrected in part of the Atmospheric Radiation Measurement (ARM) Program dataset by Barry Lesht and others. This research program addresses two remaining measurement errors that can be substantial in the mid and especially upper troposphere (UT).

The time-constant (63% response time) of Vaisala RS80-H humidity sensors increases exponentially with decreasing temperature, leading to instantaneous time-lag errors that can be as large as ±20% RH at -40°C and ±40% RH at -70°C if the gradient in ambient RH is steep. In addition, radiosonde RH sensors cannot measure ice-supersaturation because the sensor acts as a nucleation site that causes condensation of excess vapor above ice-saturation, such that the air in contact with the sensor is at ice-saturation. The two goals of this research program are to develop a correction algorithm for time-lag error in the ARM radiosonde RH data, and to characterize the structure of ice-supersaturated layers in the vertical using a dataset of water vapor measurements from the reference-quality balloon-borne cryogenic frostpoint hygrometer operated by the National Oceanic and Atmospheric Administration (NOAA). This is new research that has not yet begun in earnest. The purpose of this presentation is to inform the ARM community of limitations in the current radiosonde humidity dataset, and to facilitate introductions to ARM researchers who use the radiosonde humidity data.

Correction for Time-lag Error

The impact of time-lag error on a Vaisala RS80-H sounding is illustrated in Figure 1. The sounding penetrated a cirrus cloud, whose boundaries as measured by the Cloud and Radiation Testbed (CART) 8-mm cloud radar (MMCR) are shown. Ice crystal characteristics were measured simultaneously by a

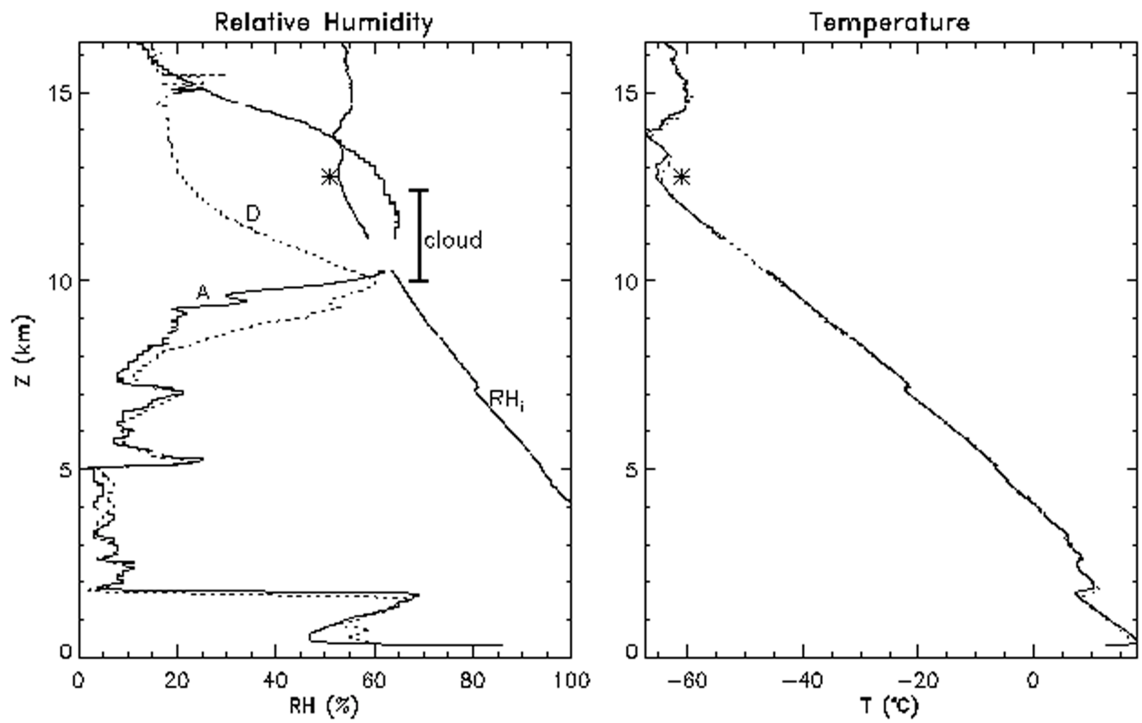

Figure 1. Relative humidity (left) and temperature (right) measured by an RS80-H radiosonde launched at the CART site on May 1, 1999. The boundaries of a cirrus cloud as measured by the MMCR are indicated. Measurements were made on both the ascent ("A") and descent ("D"). Asterisks indicate the tropopause. An ice-saturation curve is shown ("RH_i"). (Gaps in the ascent data are due to intentional signal losses.)

balloon-borne Formvar replicator (Miloshevich and Heymsfield 1997), which is a cloud sampling instrument that preserves ice crystals as plastic replicas. The ice crystals through most of the cloud depth were pristine and had sharp edges, indicating active crystal growth in an environment that is at least ice-saturated. Several RS80-H sensor characteristics can be seen by comparing the measurements acquired during the ascent versus descent portions of this sounding.

- The ambient RH above the tropopause probably decreases quickly to low RH values typical of the stratosphere, but the measured RH during the ascent decreases very slowly over a vertical distance of at least 2 km, indicating the slow sensor response. The measured RH during the descent increases very slowly below the tropopause, and does not approach ice-saturation until the radiosonde has descended through nearly the entire cloud layer.

- The upper-level winds were very light and the balloon traveled only 14 km during the entire flight; therefore, the ascent and descent profiles are nearly collocated and should be very similar (as they are at lower levels). However, the two profiles differ markedly in the UT, where time-lag error causes smoothing of the RH profile by an amount that depends on temperature and on the gradient in ambient RH. Steep humidity gradients are seen at altitudes of 2 km, 5 km, 9 km, and 13 km. The time-lag error is negligible at altitudes of 2 km and 5 km (temperatures are above -10°C), but time-lag error is evident at 9 km (-40°C), and is extreme at 13 km (-65°C).

The time-constant (63% response time) of the RS80-H sensor depends on temperature and to a lesser extent on whether the RH is increasing or decreasing. The average temperature-dependence of the time-constant as measured by Vaisala was used to simulate the time-response of an RS80-H sensor for specified ambient RH and temperature profiles (Figure 2). The ambient RH profile (bold curve in left panels) simulates a cloud layer of thickness 2 km that is ice-saturated and is between dry layers at 10%

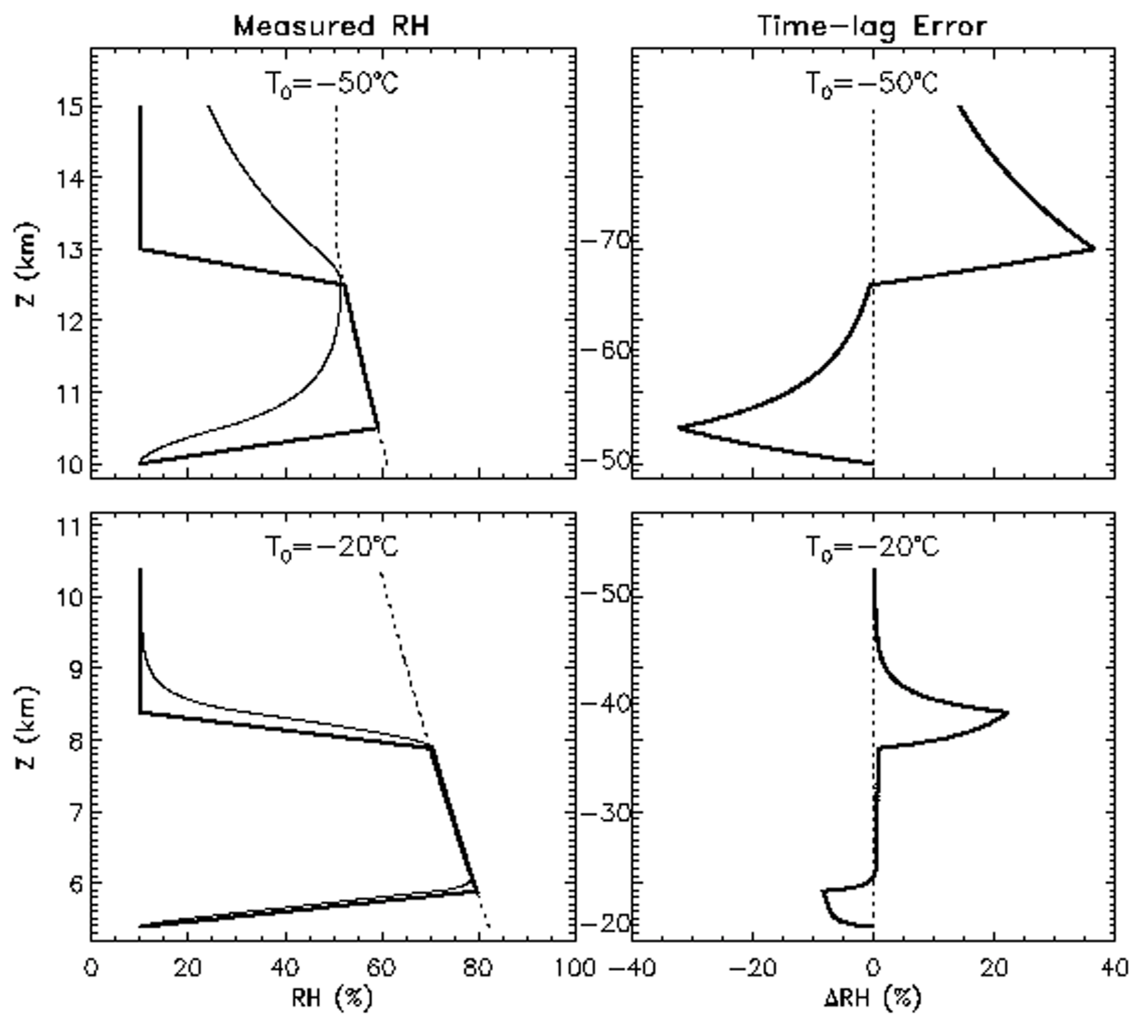

Figure 2. The left panels are simulations of RS80-H time response (light curves) for a specified ambient RH profile (bold curves), and for specified initial temperatures at the base of the simulations (T_0). The altitude scale is given by a temperature of 15°C at Z = 0 and a lapse rate of -6.5°C km^{-1}, where the temperature is held constant at –70°C above Z = 13 km to simulate the tropopause. The dashed curves are ice-saturation. The right panels show the corresponding RS80-H time-lag error, equal to the difference between the simulated RH measurements and the specified ambient RH. Temperatures (°C) are indicated between the panels.

RH, where the transition between the layers occurs linearly over a vertical distance of 0.5 km. The time-lag error (right panels) is the difference between the specified ambient RH and the simulated RS80-H measurements shown in the left panels. Maximum time-lag errors for this realistic though somewhat steep humidity gradient are about ±10% RH at –20°C, ±20% RH at –40°C, ±30% RH at –50°C, and ±40% RH at –70°C. The minimum vertical scale of structures that can be resolved in the humidity profile increases with decreasing temperature. One goal of this research program is to use both existing and forthcoming measurements of the RS80-H time-constant to develop a correction algorithm for time-lag error in the ARM dataset.

Treatment of Ice-Supersaturation

A second goal of this research program is to study the vertical distribution of ice-supersaturation within supersaturated layers, by analyzing a dataset of 95 water vapor soundings (Figure 3) from the NOAA cryogenic hygrometer (Vömel et al. 1995). Statistical analysis of the ice-supersaturated layers in the individual soundings will hopefully lead to a probability distribution for the ice-supersaturation at a given fractional height within a supersaturated layer, possibly as a function of temperature and layer thickness. We will also devise an algorithm that identifies ice-saturated layers in the time-lag-corrected radiosonde data, where the probability distribution can then be used to estimate the profile of super-saturation within the layer. The probability distribution may also be useful as a parameterization for numerical models.

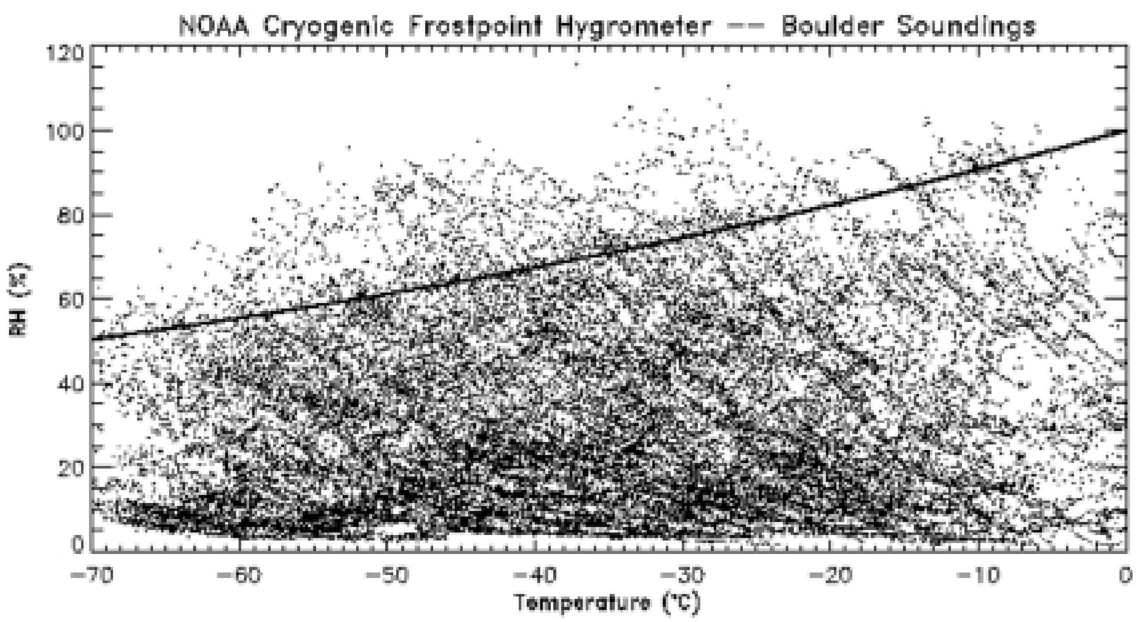

Figure 3. Dataset of RH measurements from the NOAA hygrometer. Curve is ice-saturation.

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