# Overview of the ARM/FIRE Water Vapor Experiment (AFWEX)

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## Introduction

An overview of the ARM/FIRE Water Vapor Experiment (AFWEX) is given. This field experiment was conducted during November-December 2000 near the central ground-based Atmospheric Radiation Measurement (ARM) site in north central Oklahoma, and was sponsored jointly by the ARM, the National Aeronautics and Space Administration (NASA) First ISCCP Regional Experiment (FIRE), and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) programs. Its primary goal was to collect accurate measurements of upper-level (~8 to 12 km) water vapor near the ground-based ARM site. These data are being used to determine the accuracy of measurements that are made regularly from the ARM site. Relevant scientific interests include the effect of upper-level water vapor on outgoing longwave (LW) radiation, the formation of cirrus clouds, and validation of operational satellite-based products. The experiment included in situ, active, and passive sensors aboard two high altitude aircraft that flew over the heavily instrumented ground-based ARM site. This abstract describes the motivation and basic goals of the project, the experimental design, atmospheric conditions encountered during the experiment, and some preliminary findings.

## Upper-Level Water Vapor Accuracy Goals

The goal of previous ARM investigations of lower tropospheric water vapor (e.g., water vapor intensive operational periods, [WVIOPs]) has been to characterize and improve the ARM water vapor measurements, and to measure the total column water vapor amounts to ~2% absolute accuracy. This is driven by the impact of water vapor absorption on the downwelling radiance observed at the surface, and the desire to calculate the downwelling flux to an accuracy of ~1-2 W/m$^2$ under clear-sky conditions. Similarly, for upper level water vapor and outgoing LW flux, we have determined a metric for the accuracy goals of AFWEX for clear-sky conditions. For outgoing radiance at the top of atmosphere (TOA), the primary factor is the integrated amount of water vapor from the TOA to some lower altitude. Using Rapid Radiative Transfer Model (RRTM) (Mlawer 1997) to compute LW fluxes and cooling rates for a profile representative of conditions encountered during AFWEX, we have computed changes in net flux at TOA due to perturbations in the upper-level water vapor. Sample flux calculations for a +20% water vapor change above 8 km is shown in Figure 1, and the generalized accuracy goal is shown in Figure 2. To constrain the outgoing TOA LW flux to better than ~1 W/m$^2$, the uppermost 0.1 mm of water vapor must be known to ~10% or better. For AFWEX conditions, the upper most 0.1 mm is typically contained above 8 km and so comparisons of the various AFWEX

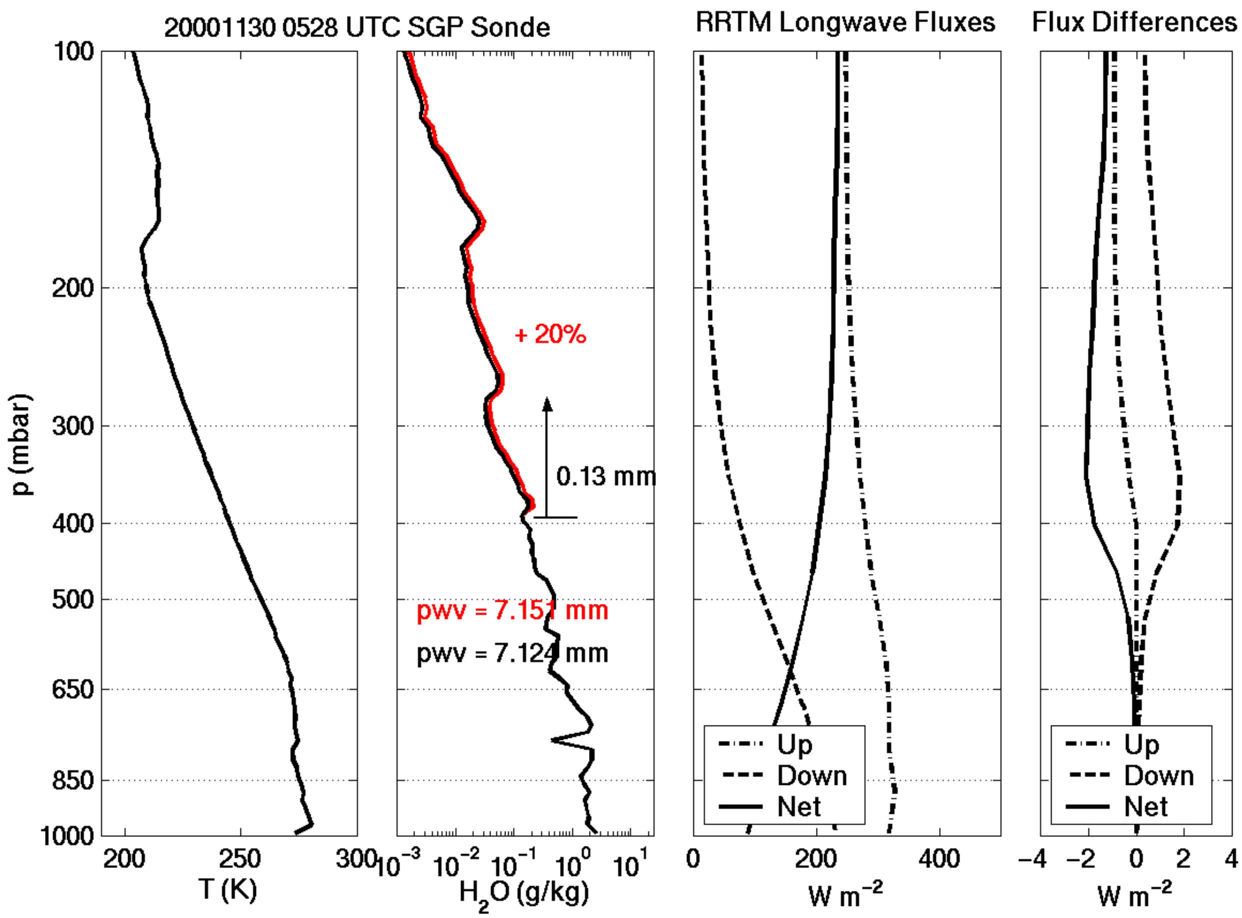


**Figure 1**. A sample calculation showing the effect of upper-level water vapor perturbations on clear-sky atmospheric flux profiles. Panels (left to right): temperature profile; unperturbed and perturbed water vapor profiles; unperturbed LW flux profiles computed with RRTM; flux profile differences due to the water vapor perturbation. In this case, water vapor above 8 km is increased by 20%, and the net flux is resulting decreased by ~1 $W/m^2$ at TOA and ~2 $W/m^2$ at 10 km.

observations have focused on the 8-12 km region. We note that this accuracy goal is valid only for clear-sky conditions, and that other applications (e.g., cloud formation) may require more strict upper level accuracy goals.

## Experimental Design and Participants

As stated above, the main goal of AFWEX is to characterize and improve the ARM upper-level water vapor measurements. The basic experimental design then was to collect ARM measurements (primarily from radiosondes and the Raman lidar) collocated along with other reference measurements, which could be used to assess the accuracy of the ARM observations. These IOP sensors included both ground and aircraft based observations. The primary upper-level reference measurements included two in situ sensors (the NASA Langley Research Center [LaRC] DLH and the NASA LaRC CRYO) and a

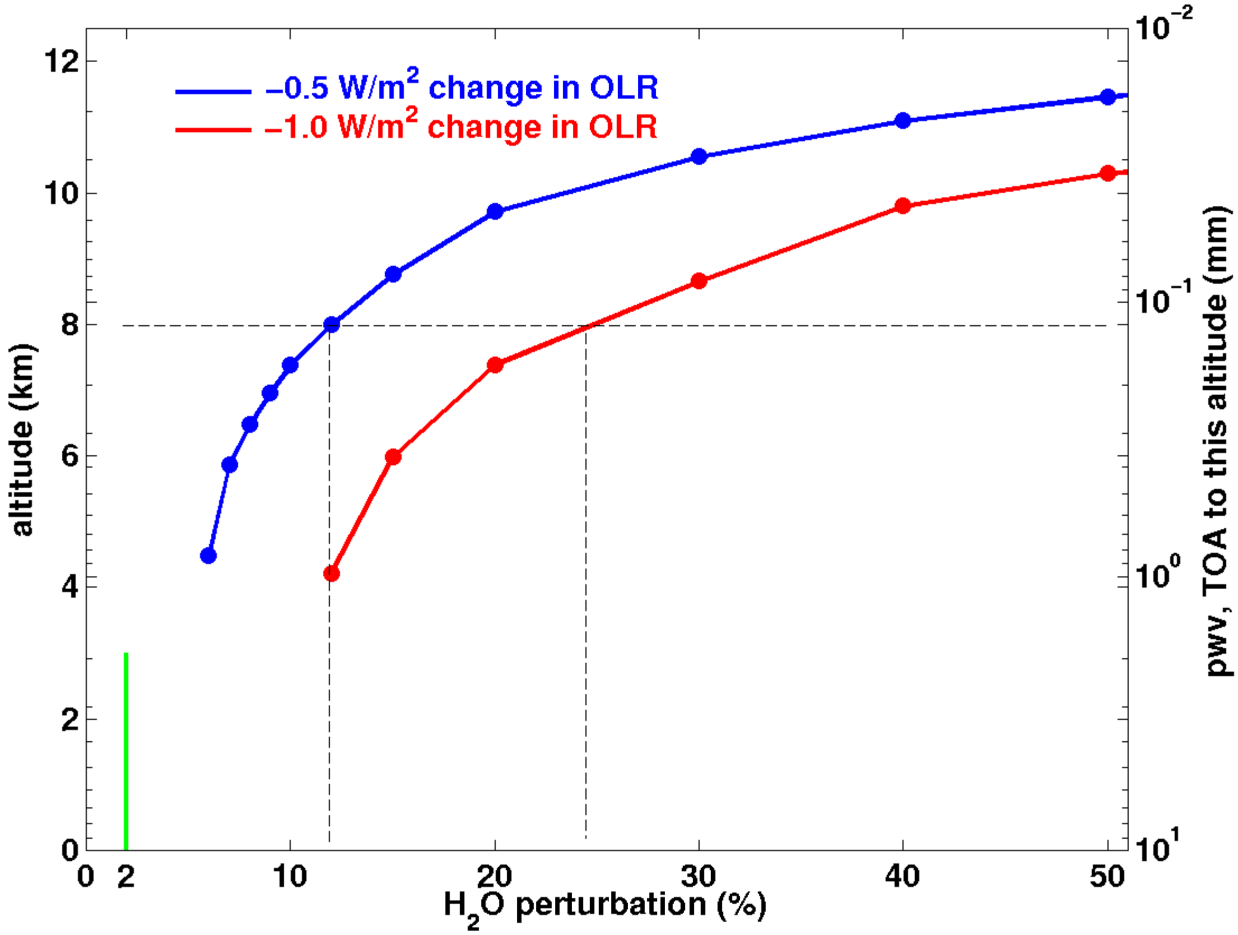


**Figure 2**. Clear-sky lower (green) and upper-level water vapor accuracy goals. The blue and red curves show the water vapor perturbations from TOA down to a given altitude (or integrated water amount from TOA to that altitude as given by the right-hand ordinate axis labels) for resulting 0.5 and 1.0 W/m$^2$ decreases in the outgoing LW flux at TOA.

differential absorption lidar (DIAL) system (the NASA LaRC Lidar Atmospheric Sensing Experiment [LASE]) flown on the NASA DC-8. Ground based reference observations included another Raman Lidar system (the NASA Goddard Space Flight Center [GSFC] scanning raman lidar [SRL]) and a DIAL system (the MPI DIAL). In addition to the routine ARM observations, other AFWEX participants included a high spectral resolution interferometer (the U. Wisconsin Scanning-High-resolution Interferometer Spectrometer) and trace gas in situ sensors (NASA LaRC COAST) flown on the NASA DC-8, chilled mirror and VIZ radiosondes (NASA WFF), microwave (NAST-M), and high spectral resolution infrared (NAST-I) and far-infrared (FIRSC) interferometers flown on the Proteus aircraft, and satellite observations (GOES). The AFWEX/WVIOP2000 science plan (ARM IOP Web page) has more information on the participants.

Operations included the collection of collocated ground and aircraft based observations over the ARM central facility (CF). Typical flights included (a) spirals ascents and descents centered on the CF with both the NASA DC-8 and Proteus, allowing the in situ sensors to obtain full profiles over the site and

(b) level leg and mapping patterns centered on the CF at 8 to 12 km for the NASA DC-8 and at ~16 km for the Proteus. Figure 3 shows the DC-8 and Proteus flight tracks overlaid on a water vapor time/altitude cross section for a typical flight. This combination of observations allowed for many hours of collocated observations to be collected. Since the Raman systems have better high altitude performance at night, most flights started at dusk and lasted 4 to 8 hours. Clear skies were targeted but some flights include observations of thin cirrus. Daily reports and sample data from the experiment are available on the Web at: http://cimss.ssec.wisc.edu/afwex/.

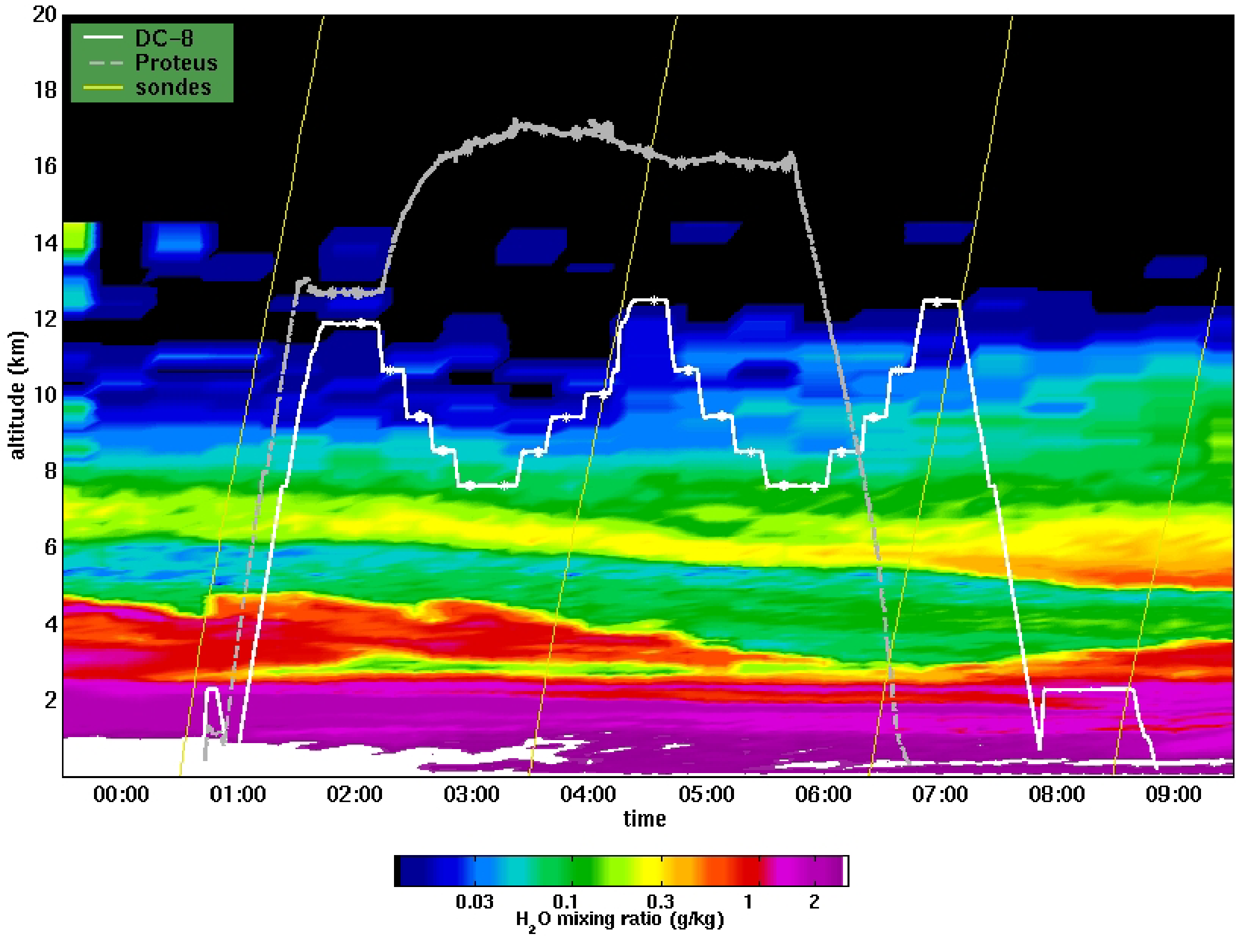


**Figure 3**. A water vapor mixing ratio cross section derived from the ARM Raman lidar along with NASA-DC-8 (white curve), Proteus (gray curve) flight tracks and radiosonde trajectories (yellow curves) for an AFWEX flight on December 5, 2000. The spiral ascents and descents of the DC-8 and Proteus at ~01:00, 06:00 and 07:00 Universal Time Coordinates (UTC) and the DC-8 level legs from ~01:30 to ~07:00 UTC are centered on the ARM CF.

# Preliminary Findings

A workshop was held in November 2001 to discuss AFWEX (and WVIOP2000) analyses. Presentations and preliminary findings from the workshop are available on the Web at: http://glacier.ssec.wisc.edu/~davet/November2001WaterVaporMtg/. Also, this ARM science team meeting contains results from several AFWEX investigations (e.g., Ismail et al. 2002, Lesht and Richardson 2002, Miloshevich and Paukkunen 2002, Soden et al. 2002, Whiteman et al. 2002).

Figure 4 shows the comparison of 8 to 12 km integrated water vapor amounts observed by the ARM Vaisala RS-80 radiosondes and the ARM Raman lidar during AFWEX. This result, which has been observed with previous ARM and other data, suggests a ~20% dry bias in the sonde observations, relative to the Raman lidar. These differences become larger at higher altitudes, and approach only a

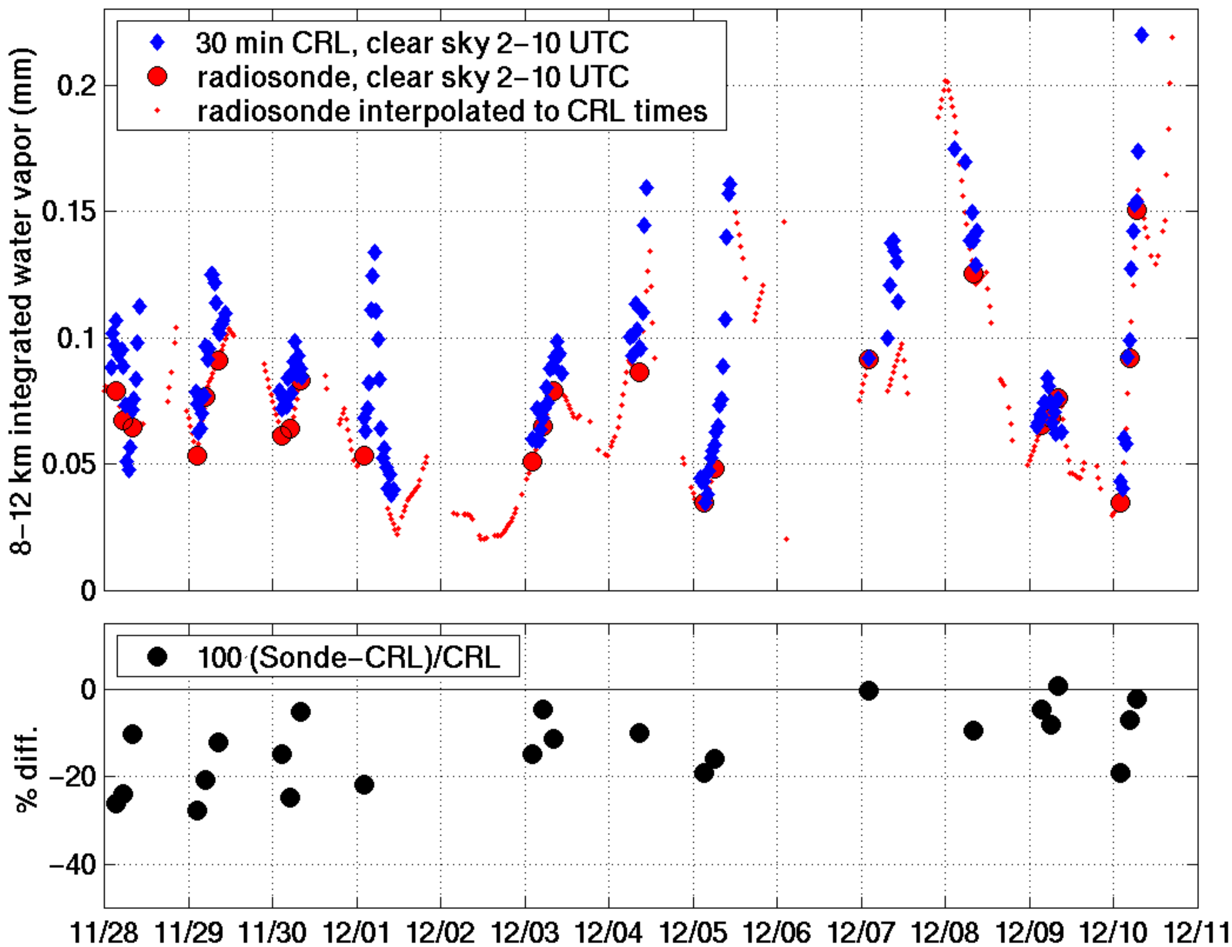


**Figure 4**. A comparison of 8-12 km integrated water vapor amounts as measured by the ARM radiosondes and Raman lidar during AFWEX. Note the large percent variability in the diurnal cycle of the upper level water vapor. Physically based corrections to both the radiosonde and Raman lidar profiles (not shown in this plot) produce good agreement between the two systems.

few percent at lower altitudes. Ongoing AFWEX investigations, however, have shown that various physically based corrections to both the radiosonde and Raman lidar data tend to moisten the sonde profiles and dry the Raman profiles and produce good agreement between the two systems on average. Furthermore, comparisons to the reference measurements on the DC-8 (Ismail et al. 2002) also show very good agreement. These comparisons show good agreement between the radiosondes, ARM and NASA Raman lidars, NASA LASE, and NASA DLH in situ sensors.

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