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ANALYSIS OF THE TROPOSPHERIC WATER DISTRIBUTION DURING FIRE-II

Douglas L. Westphal

NASA Ames Research Center, Moffett Field, California

1. INTRODUCTION

We have been using the Penn State/NCAR mesoscale model, as adapted for use at ARC, as a testbed for the development and validation of cloud models for use in GCMs. This modeling approach also allows us to intercompare the predictions of the various cloud schemes within the same dynamical framework. The use of the PSU/NCAR mesoscale model also allows us to compare our results with FIRE-II observations, instead of climate statistics.

Though a promising approach, our work to date has revealed several difficulties. First, the model by design is limited in spatial coverage and is only run for 12 to 48 hours at a time. Hence the quality of the simulation will depend heavily on the initial conditions. The poor quality of upper-tropospheric measurements of water vapor is well known and the situation is particularly bad for mid-latitude winter since the coupling with the surface is less direct than in summer so that relying on the model to spin-up a reasonable moisture field is not always successful. Though one of the most common atmospheric constituents, water vapor is relatively difficult to measure accurately, especially operationally over large areas. The standard NWS sondes have little sensitivity at the low temperatures where cirrus form and the data from the GOES 6.7 μm channel is difficult to quantify. For this reason, the goals of FIRE Cirrus II included characterizing the three-dimensional distribution of water vapor and clouds.

In studying the data from FIRE Cirrus II we find that no single special observation technique provides accurate regional distributions of water vapor. The Raman lidar provides accurate measurements, but only at the Hub, for levels up to 10 km, and during nighttime hours. The CLASS sondes are more sensitive to moisture at low temperatures than are the NWS sondes, but the four stations only cover an area of two hundred kilometers on a side. The aircraft give the most accurate measurements of water vapor, but are limited in spatial and temporal coverage.

This problem is partly alleviated by the use of the MAPS analyses, a four-dimensional data assimilation system that combines the previous 3-hour forecast with the available observations, but its upper-level moisture analyses are sometimes deficient because of the vapor measurement problem.

In our work we are attempting to create a consistent four-dimensional description of the water vapor distribution during the second IFO by subjectively combining data from a variety of sources, including MAPS analyses, CLASS sondes, SPECTRE sondes, NWS sondes, GOES satellite analyses, radars, lidars, and microwave radiometers.

2. WATER VAPOR MEASUREMENTS

The primary technique for determining the regional vapor distribution is the rawinsonde. But the AIR (CSU) and VIZ (NWS, SPECTRE) sondes seldom report relative humidities below 25% and become temperature sensors in the upper troposphere. The Vaisala sonde (NCAR CLASS) appears to be more accurate. Three intercomparisons are shown in Figure 1. In the first, the CLASS sonde agrees with the GSFC Raman Lidar data while the SPECTRE sonde indicates values that are too high between 300 and 650 mb. In the second example, the SPECTRE sonde is again unable to detect the dryness of some layers in the troposphere and, more importantly, parallels the temperature curve above about 400 mb showing no sensitivity to moisture. In Figure 1c, we show another example of the good agreement between the CLASS and Raman data, although comparison above 400 mb is difficult because the Raman signal becomes weak. Apparently, the VIZ sondes (NWS, SPECTRE) will always indicate too much upper-tropospheric water vapor, except when high values actually occur. This has a significant impact when using them for validating satellite retrievals, interpreting ground-based radiative measurements, and initializing or validating a numerical model.

3. MOISTURE ANALYSIS

After many frustrating days of clear skies, rain, or dissipating cirrus at the FIRE Cirrus II Hub, a cirrus cloud field developed as it moved eastward across Kansas on November 26, 1991. Analyses by Mace et al. associates the clouds with a jet streak that propagated across Kansas on that day. The model simulation for the period is in agreement with Mace et al. revealing the jet streak, the passage of a shortwave, a divergence/convergence couplet, and vertical velocities of 8 cm/s.

As an example of the difficulties encountered in water vapor analyses, we present in Figures 2a and 2b the N-S cross-sections of relative humidity with respect to ice for 2000 UTC on 26 November which is near the time of maximum cloudiness at the Hub site (37.1N, 95.6W). The radiosonde data are used in 2a and the MAPS analysis (only available at 2100 UTC) is shown in 2b. We see similarities in both analyses, but the MAPS analysis is missing the thin layer of high humidity at 370 mb that covers the Hub. The absence of this layer would no doubt impact the interpretation of FIRE observations at the Hub. Above 300 mb at OMA, TOP, and GGG we see the high humidities typical of the NWS sondes and cannot say whether the MAPS analyses are in error for not having high humidities above 300 mb. In Figure 2c we present the 2000 UTC cross-section predicted by the PSU/NCAR mesoscale model initialized with the 1200 UTC MAPS analyses. The model more accurately resolves the 370 mb layer of moisture over the Hub than does the MAPS analyses but misses the layer at 680 mb. Initializing the model from earlier MAPS analyses yields significantly different results (not shown). We are investigating these differences now and will determine whether the errors are due to initial conditions, model physics, or model dynamics.

4. CONCLUSIONS

We conclude that much subjective analysis will be required to understand the water vapor fields during the case study days and the rest of FIRE Cirrus II. Automated processing of all the FIRE dynamical data is unlikely to yield fields of practical use to the instrumentalists.

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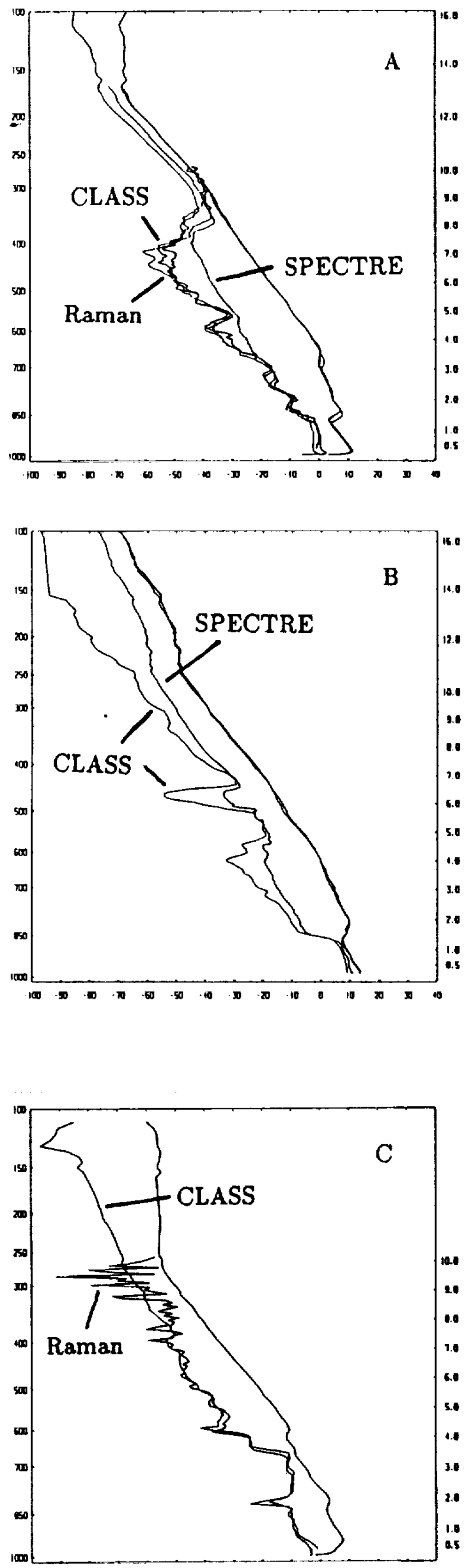

Figure 1. Vertical profiles of temperature and dewpoint temperature at the Hub (Coffeyville, KS). Data sources include NCAR CLASS sondes (Vaisala), SPECTRE sondes (VIZ), and GSFC Raman lidar. The temperature profile from the nearest (in time) CLASS sonde was used to complete the Raman lidar profiles.
a: Comparison of CLASS, SPECTRE, and Raman lidar for times within one half hour of 0100 UTC 6 December, 1991. The two Raman dewpoint profiles and the CLASS sonde are in good agreement, while the SPECTRE sonde is too moist between 300 and 650 mb. The atmosphere is probably saturated above 300 mb.
b: CLASS and SPECTRE sondes launched within 13 minutes of each other at 2300 UTC 6 December. The SPECTRE sonde indicates a moister atmosphere at almost all levels and becomes a temperature sensor above about 400 mb.
c: CLASS and Raman profiles for 0537 UTC 26 November, 1991. The Raman measurement is a ten minute average, while the CLASS sonde takes over an hour to complete. Nevertheless, note the good comparison at nearly all levels up to 400 mb, above which the Raman lidar signal becomes weak.

Figure 2. Meridional cross-section of relative humidity with respect to ice running from Omaha NB (OMA),through the Hub, to Midland TX (GGG).
a: Analyis of NWS and CLASS sondes for 2000 UTC, 26 November, 1991;
b: MAPS analyses for 2100 UTC, 26 November;
c: 20-hour model prediction, valid at 2000 UTC.