P1.71 **Characteristics of water vapor structure of two cold front systems over the central U.S.: High-resolution numerical simulations**

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1. Introduction

It has been recognized that the details of water vapor mixing ratio profiles in the mixed layer and lower troposphere are crucial for generating and/or maintaining mesoscale convective system. However, due to lack of high temporal and spatial resolution water vapor measurement, understanding of the characteristics of water vapor structures for mesoscale severe weather systems remains a challenging problem.

This presentation illustrates the characteristics of water vapor structures of two cold front systems over central U.S. through 1) the observations obtained by the NASA/GSFC Scanning Raman Lidar (SRL) and the Department of Energy Atmospheric Radiation Measurement's (DOE/ARM) Raman lidar (known as CARL) instrument in very high temporal and vertical resolutions; and 2) the numerical simulations from the PSU/NCAR mesoscale model version 5 (MM5) in high-resolution (~1.3km horizontally). The observed and model simulated water vapor profile data and associated structures of two cold front systems are compared.

2. Brief description of the Raman lidar

A Raman Lidar is an active remote sensing system that uses a laser to excite Raman scattering in the atmosphere and a telescope and wavelength sensitive optics to distinguish the Raman scattering from various atmospheric molecules such as water vapor and nitrogen. By measuring the Raman scattering signals from water vapor and nitrogen molecules, the water vapor mixing ratio can be calculated with high temporal (seconds to minutes) and spatial resolution(from tens of meters to about a ~100m vertically). The signal from a Raman lidar can be averaged to extend its vertical range and reduce the associated errors. Raman lidars have been used as to provide excellent measurements of upper troposphere water vapor during the nighttime.

The SRL was deployed at the ARM Southern Great Plains (SGP) Climate and Radiation Test bed (CART) near Lamont, Oklahoma, for several Intensive Operations Periods (IOPs) during 1994~2000, the 2002 International H_2O Project (IHOP 2002) field campaign and several other projects. The SRL has demonstrated the ability to quantify water vapor mixing ratio with less than 10% random error throughout the daytime boundary layer with 2-minute temporal resolution and between 60 and 200-meter spatial resolution. This is sufficient resolution to permit convective plumes to be observed in the boundary layer. A similar lidar, the CARL, has also been operating continuously since 1996 at CART.

Two Raman lidar observed cold fronts are discussed below: one was observed during the ARM RCS IOP on 14-15 April 1994 (Demoz et al. 2005) and the other was observed on the 28th of September 1997 (Demoz et al. 2000) at SGP CART. The MM5 numerical simulations are conducted to simulate these two cases.

3. The design of numerical simulations

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The nonhydrostatic version of PSU/NCAR MM5 model is used in this study to conduct numerical simulations of two front systems. Physics options used for this study include the Kain-Fritsh cumulus parameterization, the simple ice cloud microphysics scheme, the Blackadar high-resolution planetary boundary layer parameterization scheme, and the cloud atmospheric radiation scheme. For a more detailed description of MM5, the reader is referred to Dudhia (1993) and Grell et al. (1995).

A two-way interactive, four-level nested grid technique is employed to achieve the multi-scale simulation. Figure 1 shows the four model domains used. The outer domains 1 (36 km horizontal grid spacing) is designed to simulate the synoptic-scale and mesoscale environment in which the system evolves. The finer domains 2, 3 and 4 (12 km, 4 km and 1.3 km grid spacings) are used to simulate the detailed structure of the front systems over the central U.S. The finest domain D is started at 9 h into the simulation for both cases. The model vertical structure is comprised of 35 σ levels with the top of the model set at a pressure of 50 hPa. The σ levels are placed in high-density at the low-level (below 500hPa) of troposphere and relatively coarser in the high levels (over 500hPa). For the simulations, the model physics are the same for each domain except that no cumulus parameterization scheme is included for the 4-km and 1.3-km domains.

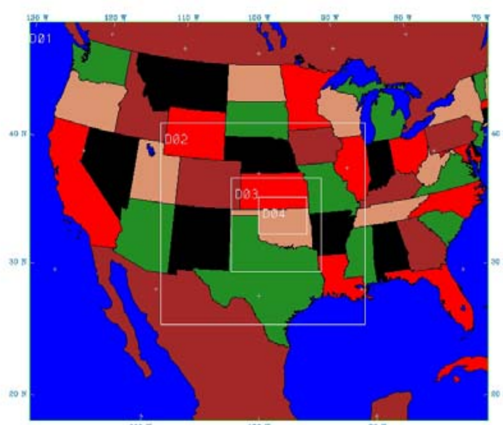

Figure 1 The map of model domains.

For the experiments, the initial conditions for domains 1 and 2 are derived from NCEP global analyses for the front case in 1994 and from the NCEP Eta mesoscale analysis for the case in 1997, respectively. The domain 3 is initialized by interpolation (see Grell et al. 1995) of all prognostic variables from the domain 2 using a monotonic interpolation scheme based upon Smolarkiewicz and Grell (Grell et al. 1995). Domain 4 is started at 9 h into the forecast and is initialized by interpolation of all variables from the domain 3.

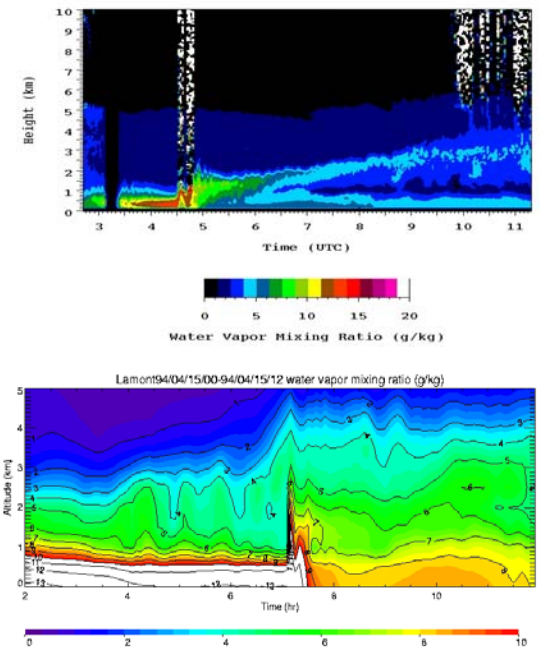

Figure 2. Color-coded image of the water vapor mixing ratio (g kg^{-1}) profiles. The top panel was measured by the Scanning Raman Lidar and on the night of 14-15 April 1994 over the CART station. Note the data gap around 0310 UTC in the top image; and the vertical striping around 0430 UTC and near the end, which indicate laser beam attenuation by clouds. The bottom panel was the MM5 simulated water vapor mixing ratio (g kg^{-1}) profiles (made from every five-minute outputs from domain 4) on the night of 14-15 April 1994 over the CART station.

4. Characteristics of water vapor structure from observations and numerical simulations

4.1 The 15 April 1994 cold front-dryline cases

During the night of 14-15 April 1994, moist air moving northward from the Gulf of Mexico converged with a cold frontal airmass from the northwest over north central Oklahoma in the presence of a well-mixed mid-tropospheric layer. Figure 1 show the water vapor mixing ratio profiles measured by the Scanning Raman Lidar during the period and Figure 2 illustrated corresponding MM5 simulations.

Figure 2 indicates that the MM5 high-resolution simulation produced high-spatial and temporal resolution water vapor simulations that show similar structure as the Raman lidar measurements, although the simulated 8.5 g/kg contour (which indicates the bore-front merger) had about a 2 hr delay compared with the observed feature.

4.2 The 28 September 1997 cold front: A symmetric convergence case

Surface and satellite charts for 27 September showed rapid development and organization of a cold frontal system over the Northwest US. Through much of 27-28 September, a persistent and standing wave/tough (dashed-line) was also located over the Oklahoman-Panhandle. Locations east of the trough and much of Oklahoma were under a southerly flow of moist air. By 0900 UTC on 28 September, the low pressure system has moved over Nebraska and the associated cold front was affecting the northern Oklahoma region. A confluence of the northward-moving moist air and the post-frontal cold/dry air-mass led to a wide-scale cloud development over the CART site.

A dramatic picture of the dynamics of the interaction between two different air masses is revealed by the CART Raman Lidar measured water vapor mixing ratio profiles (Figure 3). The sharp transition between the air-masses at 0900-1000 UTC, the lifting of the pre-frontal moisture up to about 3 km in height, the subsequent moisture spread and cloud formation, and the contrast between the cold air and warm moist air are all visible in great detail.

Fortunately, MM5 model successfully re-produced (simulated) this lidar-measured water vapor structures (Figure 4). The simulated wind field illustrated this strong convergence lifting. In addition, the simulated surface conditions over the CART station also show good agreement with the surface observations (Figure 5 and 6).

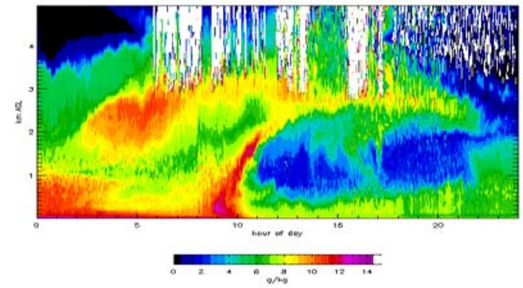

Figure 3. The water vapor mixing ratio (g kg^{-1}) profiles measured by the Raman Lidar and on the 28 September 1997 over the CART station. It shows the details of location of clouds (cloud bases correspond to bases of the white attenuation spikes between 0530 and 1700 UTC) and moisture structure of a symmetric convergence flow.

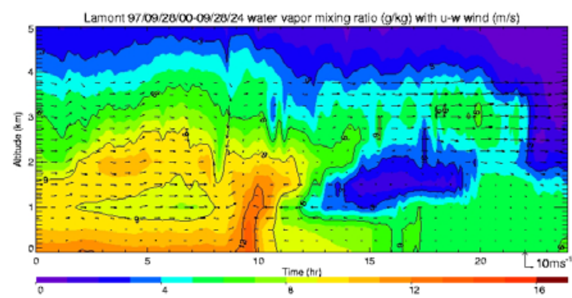

Figure 4. MM5 simulated water vapor mixing ratio (g kg^{-1}) and u-w vector wind profiles (made from every five-minute outputs from domain 4) on the 28 September 1997 over the CART station. Note the unit of wind is m/s for horizontal component u but 0.1m/s for vertical component w.

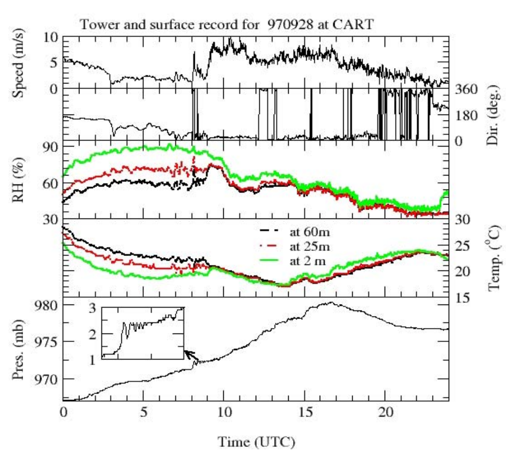

Figure 5. Surface and tower temporal records of temp. (^{0}C), humidity (%), wind direction (deg.), wind speed (m s^{-1}) and surface pressure (mb) on 28 September 1997 at CART, OK. Tower (dotted - 25 m, dash - 60 m) data are also plotted.

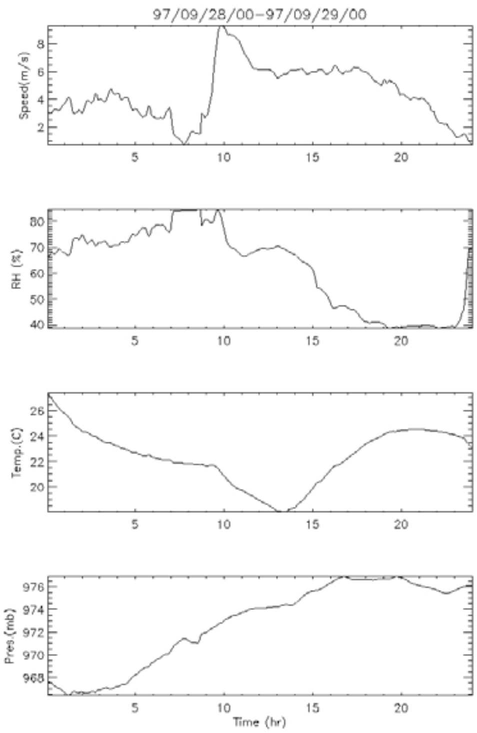

Figure 6. MM5 simulated surface temporal series of temperature (^{0}C; 2-m level), humidity (%), wind speed (m s^{-1}) and surface pressure (mb) on 28 September 1997 at CART, OK.

5. Summary

The MM5 numerical simulations are able to reproduce Raman Lidar observed water vapor features for the cold front systems in lower troposphere. Simulated results show good agreement with the observations. As the numerical simulations produce the three-dimensional structure of thermodynamic field variables associated with water vapor fields, the mechanism of water vapor variations during the cold front systems are going to be investigated. Detailed results will be presented in the conference.

6. Acknowledgement

This research was supported by the National Science Foundation Grant # ATM-0129605. The SRL was supported during its early years by NASA's Atmospheric Dynamics Program under Dr. Ramesh Kakar and the DOE-ARM program. CARL is operated by DOE ARM.

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