4.3 LIDAR APPLICATIONS IN ATMOSPHERIC DYNAMICS: MEASUREMENTS OF WIND, MOISTURE AND BOUNDARY LAYER EVOLUTION.

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1. INTRODUCTION

A large array of state-of-the-art ground-based and airborne remote and in-situ sensors were deployed during the International H_2O Project (IHOP), a field experiment that took place over the Southern Great Plains (SGP) of the United States from 13 May to 30 June 2002. These instruments provided extensive measurements of water vapor mixing ratio in order to better understand the influence of its variability on convection and on the skill of quantitative precipitation prediction (Weckwerth et all, 2004). Among the instrument deployed were ground based lidars from NASA/GSFC that included the Scanning Raman Lidar (SRL), the Goddard Laboratory for Observing Winds (GLOW), and the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE). A brief description of the three lidars is given below. This study presents ground-based measurements of wind, boundary layer structure and water vapor mixing ratio measurements observed by three co-located lidars during IHOP at the IHOP ground profiling site in the Oklahoma Panhandle (hereafter referred as Homestead). This presentation will focus on the evolution and variability of moisture and wind in the boundary layer when frontal and/or convergence boundaries (e.g. bores, dry lines, thunderstorm outflows etc) were observed.

2. INSTRUMENT DESCRIPTION

We present here three, state of the art, lidars from NASA/GSFC that participated in IHOP_2002: the Scanning Raman Lidar (SRL), the Goddard Laboratory for Observing Winds (GLOW), and the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE). A brief description of the three lidars is given below. The Goddard Laboratory for Observing Winds (GLOW) is a mobile Doppler lidar system which uses direct detection Doppler lidar techniques to measure wind profiles from the surface into the lower stratosphere (Gentry 2000). The system, contained in a modified van, uses a Nd:YAG laser transmitter to measure winds using either aerosol backscatter at 1064 nm or molecular backscatter at 355 nm. The receiver telescope is a 45 cm Dall-Kirkham which is fiber coupled to separate Doppler receivers, one optimized for the aerosol backscatter wind measurement and another optimized for the molecular backscatter wind measurement. The receivers are implementations of the 'double edge' technique and use high spectral resolution Fabry-Perot etalons to measure the Doppler shift. Because of logistical reasons, only the molecular recievers were operational during IHOP. A 45 cm aperture azimuth-over-elevation scanner is mounted on the roof of the van to allow full sky access and a variety of scanning options.

The second lidar, HARLIE uses a 40 cm diameter transmission holographic optical element (HOE) as the collecting and focusing aperture. The HOE has a 45-degree diffraction angle and is rotated during operation resulting in a conical scan of the atmosphere. The laser is a 2 mJ, 1064 nm Nd:YAG pulsed at 5 kHz. A profile of aerosol backscatter is produced each 0.10 second by accumulating photo-counts

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for 500 shots. HARLIE rotates continuously in azimuth, at rates as high as 30 rpm. It can also be tipped at 45 degrees and kept pointed in a fixed direction so that conventional vertical pointing measurements can also be used. The scanning data provides a pseudo-3D visualization the data products which include aerosol backscatter profiles, cloud base and top heights, boundary layer heights and entrainment zone thickness. In addition, coherent structures in the backscatter field can be tracked as they progress across the conical scan surface, resulting in an estimation of the wind speed.

The third lidar deployed from NASA/GSFC is the Scanning Raman Lidar (SRL); a mobile system contained in a single environmentally controlled trailer. It included a Nd:YAG laser, 0.76 meter telescope and large aperture scanning mirror. The SRL measures profiles of aerosol backscattering, extinction and water vapor mixing ratio using Raman scattering from atmospheric molecules. Derived products from the system include water vapor mixing ratio, aerosol scattering ratio and extinction, cloud optical depth and cloud base height. UV transmission windows permit measurements during rainfall. A more complete description of the SRL has recently been published (Whiteman and Melfi, 1999). Extensive data sets exist now from several field campaigns and investigations.

3. BOUNDARY-1: 22 MAY 2002

On 22 May 2004, satellite and mesonet data revealed a dryline just west of the Homestead area in the Oklahoma Panhandle. GOES visible imagery, revealed a band of cumulus clouds oriented roughly NNE-SSW. A sharp drop in dew point temperature between the east and west side of the Oklahoma panhandle were recorded. The dry line oscillated over the profiling site leading to observations of both the dry and moist side of the dryline. This dryline was sampled by a number of instrumented mobile vehicles, aircraft and S-Pol radar. Synthesis of many aspects of these data sets is ongoing and will be reported elsewhere. We will limit our discussion mainly to mechanisms controlling the moisture distributions as observed by the profiling site instruments. HARLIE, GLOW and SRL collected continuous measurements of aerosol backscatter, wind and water vapor mixing ratio profiles. An interesting picture of the mesoscale variability, the boundary layer evolution, wind speed and

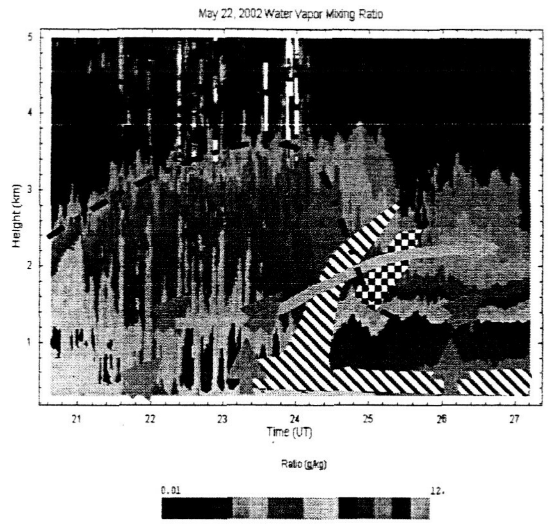

Figure 2. Time-height plot of the SRL measured water vapor mixing ratio (g kg-1) at Homestead. OK on 22 May 2002. BL evolution, airflow, and notable wind areas (jet, direction, convergence zone) are indicated. The white strips indicate laser attenuation by clouds.

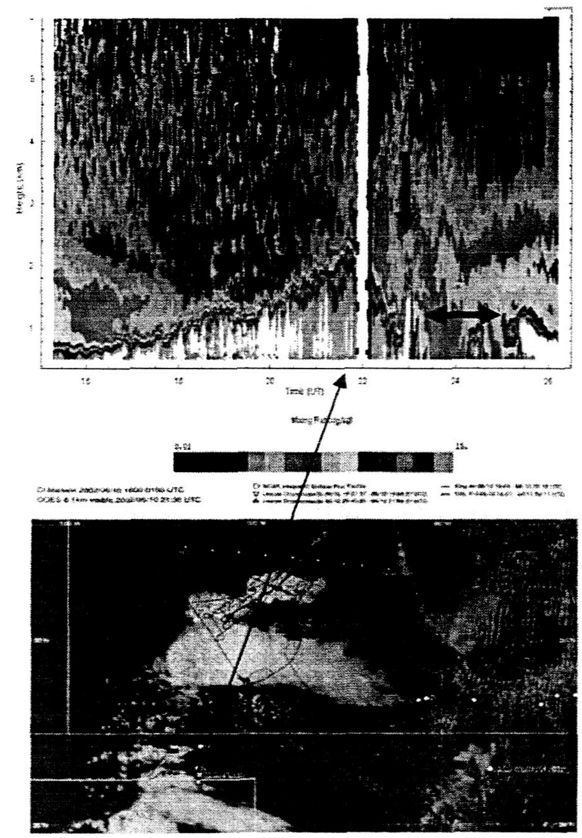

Figure 3: GOES image at 2138 UTC and time-height plot of water vapor mixing ratio (g kg^{-1}) at Homestead, OK on 10 June 2002. Note the location of the bore, the transition to drier airmass, and the CI target region on this day.

direction, and moisture profile is captured (Figs. 2) and confirms, many of the observations and speculations that formed conceptual pictures of drylines (Ziegler and Hane, 1993).

4. BOUNDARY-2: 10 JUNE 2002

10 June 2002 was also another IHOP convection initiation mission over the Homestead profiling site. CI was expected to develop in central Kansas along a week, quasi stationary, cold frontal boundary. Initial point for the CI mission was slightly north of Dodge City, KS (see figure 3) along a boundary indicated by the NRL P3 aircraft. But the boundary stretched all the way south to the Texas panhandle and was visible in radars but also in the 2000 (UTC, time first cumulus along the boundary observed) and 2138 GOES (figure 3) images shown. The SRL data sets show that the boundary was deep (~ 15 g kg^{-1}) and deep (~ 2km) on the eastern side of the boundary when cumulus and cumulonimbus clouds occurred. Both the BL moisture and depth dropped fast by 2230 UTC except for a brief increase at 2300 as a result of a fast SSW-to-NNE moving boundary, most probably a thunderstorm outflow. Preliminary analysis of radar and surface data indicate that the moisture drop was mostly associated with passage arrival and passage of the drier airmass located west of the boundary. *Unlike the 22 May dryline case, this case produced rapidly developing convection along the boundary. We note that the BL was moister and deeper than the 22 May dryline case.*

5. BOUNDARY-3: 11 JUNE 2002

The third case we present here is the 11 June 2002 IHOP CI case. The target area was set to be the Oklahoma panhandle (the Homestead profiling and the Spol location area). Which started as a fast southeast-ward moving boundary west of Spol early slowed considerably and stalled near Homestead. Around 2000, a number of additional boundaries formed to the NE and SE of the "main" boundary and it was decided to shift the measurement armada to the NW, to what was thought to be a better defined and retreating boundary, while the P3 made a NW-SE box pattern flights. The general behavior of the reflectivity fine lines on this day resembled that of the 22 May case; multiple lines first moveing to the SE and then retrograding.

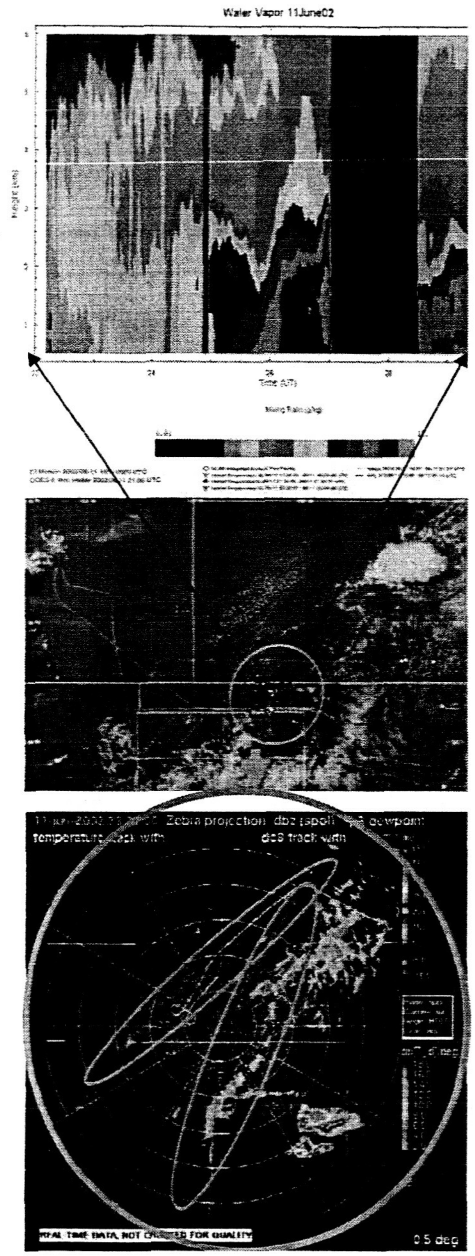

Figure 4: Time-height plot of water vapor mixing ratio (g kg^{-1}) at Homestead, GOES image at 2109 UTC and Spol reflectivity at 2330 on 11 June 2002. Note the strong gradient in moisture between the different airmasses, deep BL and high moisture to the east of the boundary and the radar fine lines and the NRL P3 dewpoint temperatures (overlaid).

The SRL data for this case started at 2200 UTC but showed little structure in the BL (shallow BL and relatively dry). But by 2400 UTC, a well defined moist boundary moved from SE to NW over Homestead revealing deep and moist BL to the east. Although understandable, it was unfortunate that 1) it was decided to sample the NW boundary lines 2) sampling was not extended longer. In addition, although clouds did form along the boundary, no deep convection developed in the area. The only vigorous convection observed was towards the NE end of the boundary line in Kansas.

7. DISCUSSION

A more complete analysis of these cases is underway but a number of points can be stated from the lidar measurements presented above.

1. All the cases presented above were designated as Convection Initiation (CI) days in IHOP. However, only one of the cases (10 June 2002) produced deep convection in the targeted area for observation. The other two cases (22 May and 11 June 2002) did not show appreciable convection in the observation target area although deep convection was observed much north in Kansas. Fair weather cumulus clouds were observed in all cases in the target areas.

2. The 10 and 11 June cases showed more deeper and moister Boundary Layer (BL) formation than the 22 May 2002 case. The BL moisture on 10 June was moister than the other cases and the moisture levels were recorded starting early at the start of the day and reaching about 2km AGL by the time CI initiated. A combination of the BL depth and the amount of moisture (both in absolute and abundance) within it are key to CI and this case had plenty of both, compared to the other two cases.

3. All these ad other bore/front cases (will be discussed during the presentation) reveal that the BL moisture and the convergence zones are highly variable in time and space. This makes it logistically hard to accurately design an observation campaign with limited knowledge of this variability. And even harder is the forecasting of and accurate initialization of models to predict CI. One proposed solution for this may be a network of moisture profiling stations that are able to capture the temporal and spatial variability not only on convective scale but also the meso-scale. We will discuss the viability of Raman lidars for such a network.

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