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LIDAR MEASUREMETNS OF WIND, MOISTURE AND BOUNDARY LAYER EVOLOUTION IN A DRYLINE DURING IHOP2002.

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1. INTRODUCTION

Variability in the convective boundary layer moisture, wind and temperature fields and their importance in the forecasting and understanding of storms have been discussed in the literature. These variations have been reported in relation to frontal zones, stationary boundaries and during horizontal convective rolls (see Weckwerth et al. 1996 for a discussion and references). While all three vary substantially in the convective boundary layer, moisture poses a particular challenge. Moisture or water vapor concentration (expressed as a mass mixing ratio, g kg^{-1}), is conserved in all meteorological processes except condensation and evaporation. The water vapor mixing ratio often remains distinct across an air-mass boundary even when the temperature difference is indistinct. These properties make it an ideal choice in visualizing and understanding many of the atmosphere's dynamic features. However, it also presents a unique measurement challenge because water vapor content can vary by more than three orders of magnitude in the troposphere. Characterization of the 3D-distribution of water vapor is also difficult as water vapor observations can suffer from large sampling errors and substantial variability both in the vertical and horizontal.

This study presents ground-based measurements of wind, boundary layer structure and water vapor mixing ratio measurements observed by three co-located lidars. This presentation will focus on the evolution and variability of moisture and wind in the boundary layer during a dry line event that occurred on 22 May 2002. These data sets and analyses are unique in that they combine simultaneous measurements of wind, moisture and CBL structure to study the detailed thermal variability in and around clear air updrafts during a dryline event. It will quantify the variation caused by, in and around buoyant plumes and across a dryline. The data presented here were collected in the panhandle of Oklahoma as part of the International H_2O Project (IHOP_2002), a field experiment that took place over the Southern Great Plains (SGP) of the United States from 13 May to 30 June 2002. The chief goal of IHOP_2002 is to improve characterization of the four-dimensional (4-D) distribution of water vapor and its application to improving the understanding and prediction of convection

2. INSTRUMENT DESCRIPTION

Ground based lidar remote sensing of water vapor and wind has been making steady progress. At present, lidars exist that are operating year round measuring water vapor mixing ratio profiles. Reliable and continuous measurements of wind are also possible. 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.

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2.1. The Goddard Laboratory for Observing Winds (GLOW)

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 GLOW mobile lidar system has a twofold purpose: (1) to provide wind profile measurements from the surface into the stratosphere for use in scientific measurement programs and (2) as a testbed for validating the performance of new technologies and measurement techniques proposed for use in future spaceborne applications.

Figure 1 The mobile Doppler lidar system is mounted in a modified delivery van. The 45 cm clear aperture azimuth-over-elevation scanner is mounted on the roof to allow full sky access.

The system is contained in a modified van to allow deployment in field operations. The lidar system 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_2002. 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.

2.2 The Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)

Figure 2 Photograph of the HARLIE transceiver assembly and electronics rack.

HARLIE uses a 40 cm diameter transmission holographic optical element (HOE) as the collecting and focusing aperture (Figure 1). The HOE has a 45-degree diffraction angle and is rotated during operation resulting in a conical scan of the atmosphere. Figure 2 shows the electronics rack and transceiver assembly. The laser is a 2 mJ, 1064 nm Nd:YAG pulsed at 5 kHz. The output of a single Geiger-mode avalanche photodiode detector is ping-ponged between two multi-channel scalars. A profile each 0.10 second is produced by accumulating photo-counts for 500 shots. The use of the HOE in HARLIE allows for several advantages: a compact design of scanning lidar systems at the 1064 nm wavelength, the ability to withstand moderately high laser power and energy loading, sufficient optical quality for most direct detection systems, overall efficiencies rivaling conventional receivers, and the stability to last several years under typical lidar system environments.

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 of aerosol backscatter, and principal data products include aerosol backscatter profiles, cloud bottom 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.

Figure 3. – Layout of the location of HARLIE, SRL, and GLOW at Homestead, OK. HARLIE is packaged in the small trailer in the foreground.

2.3. The Scanning Raman Lidar (SRL)

The NASA/GSFC Scanning Raman Lidar is a mobile system contained in a single environmentally controlled trailer. It includes two lasers (XeF excimer and Nd:YAG), 0.76 meter telescope and large aperture scanning mirror. Using Raman scattering from atmospheric molecules, the SRL system measures high temporal and spatial resolution profiles of aerosol backscattering/extinction and water vapor mixing ratio profiles during the daytime and nighttime. 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 of the atmosphere. These data sets have proven very useful in advancing our understanding of a variety of mesoscale phenomena; including atmospheric frontal structures, gravity and bore waves, thunderstorm outflows, drylines and many other mesoscale features.

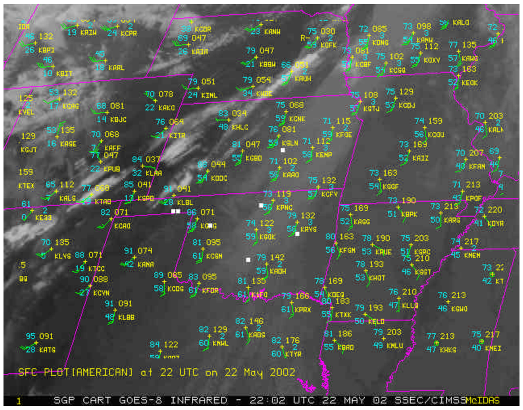

Figure 4. Satellite (enhanced) and surface observations at 2200 UTC, on 22 May 2002. The ground instrument site for IHOP_2002, Homestead, location is shown by double white squares in the OK, Panhandle. Other dots in central OK indicate DOE- ARM sounding ground stations.

3. CASE STUDY: THE 22 MAY 2002 DRYLINE

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. Dew points by 1900 UT were approximately 50F and quickly falling to the west of the dryline. The moisture pool was moving west but seemed to reverse by 1900 UT and then again move west around 2200 UTC. The boundary was oriented roughly N-S.

This dryline was sampled by a number of instrumented mobile vehicles, aircraft and S-Pol radar. Synthesis of all these data sets is ongoing and will be reported elsewhere. We will limit our discussion here to the observations made by the three NASA/GSFC lidars only.

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 direction, and moisture profile is captured (Figs. 5, 6, and 7).

4. DISCUSSION

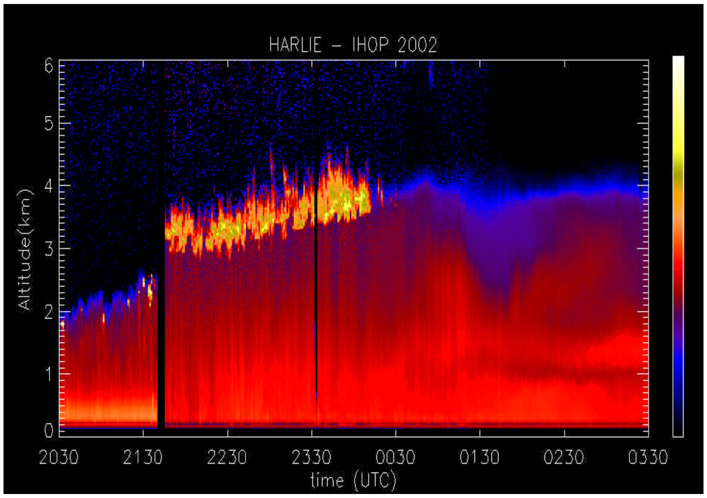

Figure 5. False color image of HARLIE backscatter profiles showing location of the cumulus clouds, growth of the BL, and the nighttime demise. HARLIE operated in profile mode till about 2130 UTC and switched to conical scanning afterwards, thus the data gap.

A more complete analysis of these results is underway but a number of points can clearly be seen from the lidar measurements shown in the figures above.

The development of the BL following sunrise and the subsequent cloud development is clearly seen. During most of the morning and afternoon, surface heating caused the lifting and mixing of the low level moist air with dry air aloft, leading to the development of cumulus clouds. This has been noted before and is the explanation given for the apparent eastward movement of the dryline. The mixing has lifted the moisture to higher and higher altitudes reaching about 3.5km (cloud base) above ground. Starting a little before sunset, (near 24 UT in the SRL images) the vertical mixing abruptly stops and a better definition of the dryline boundaries start to emerge. Thus, for this case, convection was generated near the dryline interface in the afternoon, somewhat agreeing with the conceptual picture given by Parsons et al. (2000). Note, however, that the plot from HARLIE tends to indicate a cloud deck during most of the day. This is because it takes data in a 45-degree angle cone, and the plot shown in Fig. 5. is an average of a single sweep along the surface of the cone. This leads to detection of cloud almost in every scan and thus the cloud deck appearance. In contrast, the SRL, pointing in a vertical mode, shows much lower cloud coverage (not shown here). A simultaneous interpretation of these two data sets provides better statistics of the development of the PBL in pre-dryline condition.

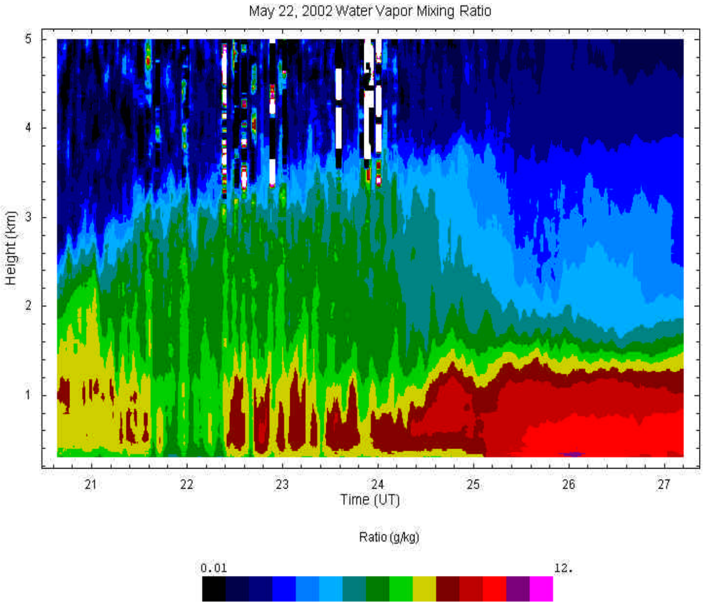

Figure 6. False color time-height plot of the SRL measured water vapor mixing ratio (g kg-1) at Homestead. OK on 22 may 2002. Note the location of the clouds shown by the base of white strips and the dryline, about 2400 UTC.

The prevailing wind during most of the time was from the south, parallel to the dryline, with interesting variations in the vertical evolution of the speed (Fig. 7). Although a complete analysis of the entire data collected by GLOW is on going, some coclusions can be made with what is shown in Fig. 7. A general shift in direction from southerly to South-south west is visible starting at about 1.5km (near the top of the moist air). Wind speed below 2km where generally less than about 25m/s. Between 2-5km, higher wind speeds are clearly visible. A complete analysis of the full GLOW record will allow us to investigate any occurrences of low level jets associated with the dryline and/or the other flows detailed in the conceptual picture of the dryline given by Parsons et al. (2000).

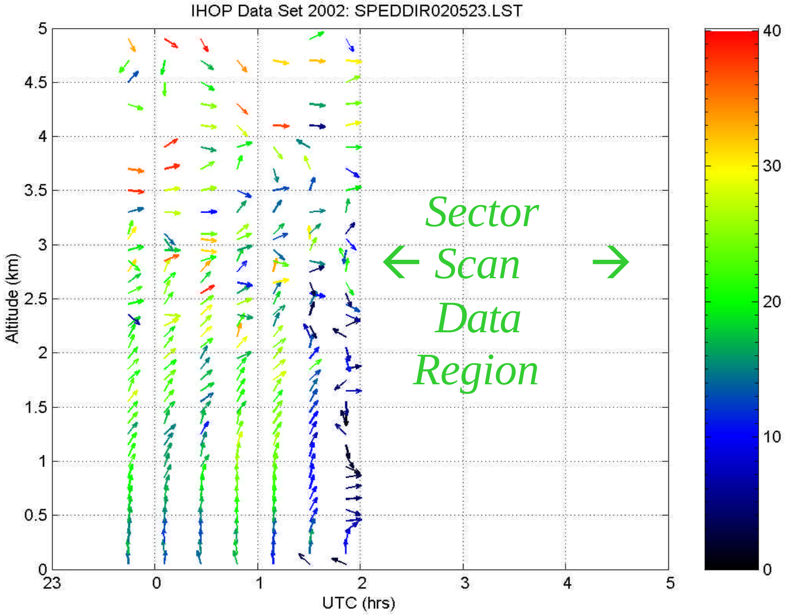

Figure 7. GLOW measurements of the wind speed and direction on 22 May 2002 at Homestead, OK, during dryline conditions. Sector scans at different elevation were made in order to detect variations in the dryline associated flows but not yet fully analyzed. They will be presented at the conference.

A more detailed comparison of our measurements with previous conceptual pictures and modeling studies of the dry line will be presented at the conference.

5. ACKNOWLEDGEMENT

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