JP6J.1

The dryline on 19 June during IHOP_2002: The thin-line structure and convection initiation.

Hanne V. Murphey[1], Roger M. Wakimoto[1], Cyrille Flamant[2], and David E. Kingsmill[3]

[1]Department of Atmospheric Sciences
UCLA
Los Angeles, CA 90095-1565

[2]Institut Pierre-Simon Laplace
Service d'Aeronomie
Paris, France

[3]Cooperative Institute for Research
in Environmental Sciences
University of Colorado
Boulder, CO 80309

1. Introduction

The predictability of warm season deep moist convection has remained a challenge for forecasters, since summer time storms are often dominated by processes in the daytime convective boundary layer (CBL). Some progress has been made though, as research has shown that convection tends to form along low-level convergence boundaries such as fronts, drylines or the leading of edge of outflow from previous convection (Wilson and Schreiber 1986). However, due to large variability of the thermodynamic (water vapor in particular) and kinematic structure of the CBL, it is still difficult to predict which boundaries will eventually initiate storms and even more challenging is predicting the precise locations of the convective initiation along each line. Studies have indicated that as little as 1 g kg^{-1} change in water vapor in the CBL can mean the difference between convective initiation or a null situation (Crook 1996; Weckwerth 2000).

The International H20 Project (IHOP_2002, Weckwerth et al. 2004) was organized in an attempt to better understand the three-dimensional distribution of water vapor in the lowest part of the atmosphere. One of the components was Convective Initiation (CI) along low-level convergence boundaries. The field phase of the project took place during the late spring and early summer of 2002 over the Southern Great Plains of the United States. The project was designed to be highly mobile, such that boundaries could be followed during the CBL evolution up until the time that either storms initiated or failed to do so. A dryline, which initiated a line of thunderstorm, was intercepted on 19 June 2002 in the Northwestern corner of Kansas by multiple observing platforms including an airborne dual-Doppler Radar (ELDORA) and an airborne water vapor DIAL (Leandre II), both housed on the NRL-P3. Soundings were also launched on both sides of the boundaries in order to document the vertical structure of the atmosphere.

2. Environmental Conditions and the development of convection:

A cold front was forecast to move into the northwestern corner of Kansas by the morning of 19 June 2002. A dryline formed out ahead of the front separating a relatively hot, dry air mass from a warm moist air mass to the east. The three different air masses can be seen in surface data superimposed onto a radar reflectivity image from the Goodland WSR-88D (Fig. 1) at 2000 UTC (hereafter all times are UTC). The dryline is visible as an enhanced echo running southsouthwest to northnortheast. with southerly winds to the east, while the winds between the dryline and the cold front are approximately westerly. The cold front is not visible in

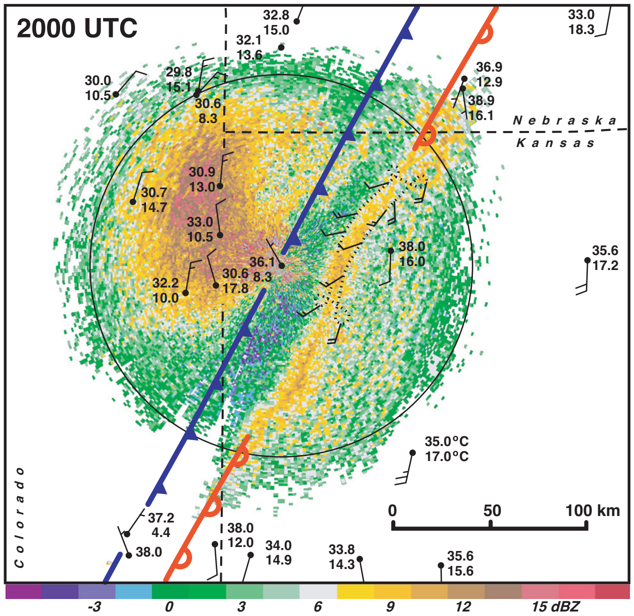

Fig 1: Radar reflectivity from the Goodland WSR-88D at 2000 UTC. Surface data and NRL-P3 flight track have been superimposed onto the image.

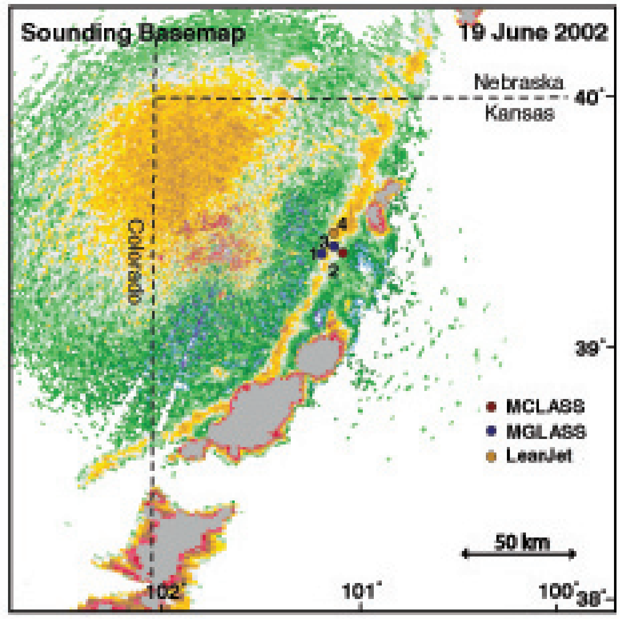

Fig 2: Sounding basemap for a time series of soundings launched east of the dryline superimposed onto radar reflectivity from the Goodland WSR-88D at 2200 UTC.

the radar data, but indicated in the surface date with colder temperature, higher dewpoints and northerly winds. The flight track for the NRL-P3 (shown in the figure as a dotted line) was an elongated box enclosed the boundary with flight legs approximately 75 km in length. By 2200 deep convection was forming all along the dryline (Fig. 2) and the mission was terminated due to safety concerns for the aircraft and crew.

The locations of a time series of soundings launched in the moist air mass east of the dryline is shown in Fig. 2. For simplicity all locations were mapped on a single radar image and since the dryline propagated slightly toward the east during the observational period, the locations appear slightly offset. Several sound-

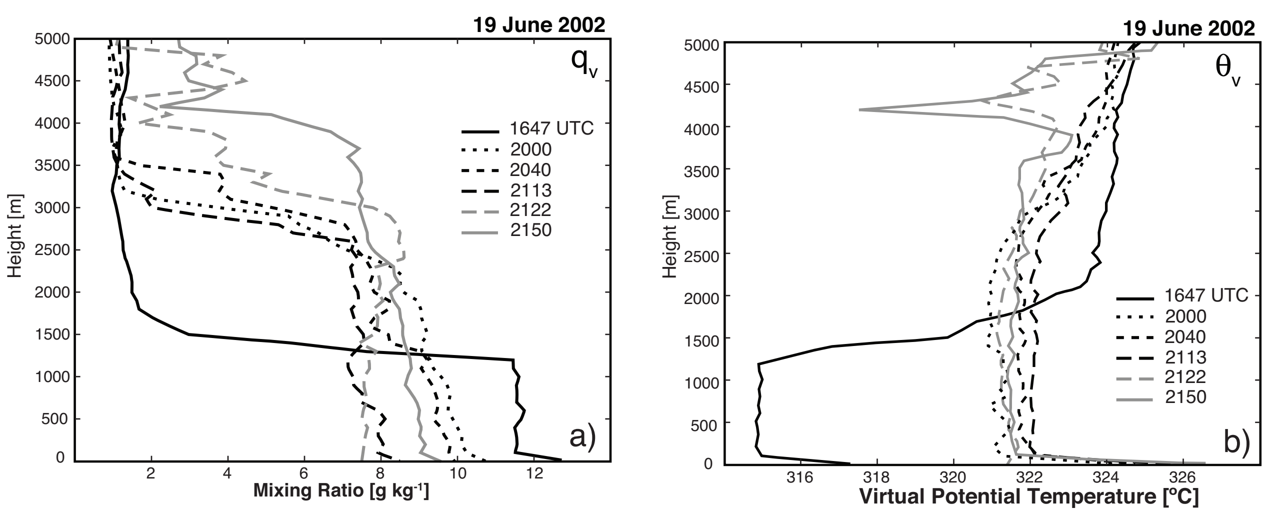

Fig. 3: Time series of the soundings launched east of the dryline: a) Water vapor mixing ratio and b) Virtual Potential Temperature.

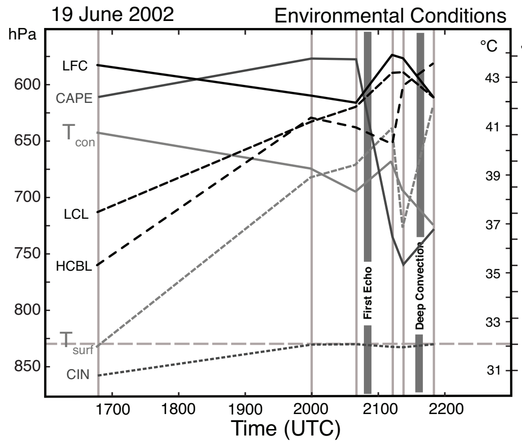

Fig. 4: A time series of CAPE, CIN, LFC, LCL, The convective temperature and the surface temperature from 1647 to 2150. Each sounding is indicated by a vertical gray solid line. The horizontal dashed line is the zero J kg^{-1} line. The time of "First echo" and "Deep convection" were determined from vertical cross sections from ELDORA.

ings were launched from the same location (1 and 3).

The evolution of the lowest 5 km of the atmosphere for mixing ratio (q_v) and virtual potential temperature (θ_v) is shown in Fig. 3. During the afternoon hours, the CBL rapidly deepens and the lowest levels dry out (Fig. 3a). A dramatic change in the low-level moisture (< 1.5 km) occurs between 2040 and 2113, where q_V decreases by nearly 2 g kg^{-1}. It is during this time that first echo is observed by ELDORA (Wakimoto et al. 2004, see their Fig. 5). Over the next hour the depth of the CBL deepened by 1 km as the storms developed along the fine line drawing up moisture from the surface.

Also as the surface warmed during the day, θ_v increases (Fig. 3b), thereby destabilizing the boundary layer. By 2040 the gradient of θ_v is less than 2°C/km. The stability indices are shown in Fig. 4. The Level of Free Convection (LFC) gradually lowers prior to the first radar echo, while the Lifted condensation level (LCL) rises due to surface heating. At 2040 the LFC and the LCL are virtually colocated, consistent with the time of first echo approximately 10 minutes later. At the same time, The Convective Available Potential Energy (CAPE) is a maximum and the Convective Inhibition (CIN) is zero. The point, at which the surface temperature is the same as the convective temperature, occurs before the LFC and LCL are collocated and the surface temperature remains warmer until the storms start precipitation, thereby cooling the ground. The apparent lag between the surface temperature reaching the convective temperature and the first echo, may be explained by the calculations used to estimate the various parameters. A mean value of the lowest 500 m was used to calculate the LFC, while the surface temperature is the value at the lowest level. A superadiabatic layer often existed just above the surface, which would be warmer than the mean value used in the other calculations. By ~2140 storms were precipitating (Wakimoto et al. 2004, Murphey et al. 2005).

3. Mean Vertical Cross sections

Mean vertical cross sections were produced by averaging at least 100 cross sections per leg for each flight leg for ELDORA. The averaging effectively removes the along-line variability. The results indicate that the cross boundary wind component (u') east of the boundary increases in magnitude during the day leading to an increase in the strength and depth of the low-level convergence and consequently the updrafts located at the boundary (Fig. 5a and b). The enhancement of the easterly wind component is believed to be caused by a hydrostatic pressure gradient produced by differential heating across the dryline which produces lower pressure in the dry hot air mass to the west (e.g. Ziegler and Hane 1993 and Jones and Bannon 2002). While the strongest updrafts are located at ~2 km, the updrafts in Fig. 5 do reach above 3 km, which is enough to lift the air to the LFC.

4. Along-Line Variability

Another important aspect of this study was to better understand the along-line variability and identify preferred locations for CI. Since the NRL-P3 was equipped with both a dual-Doppler radar and a water vapor DIAL, this allowed

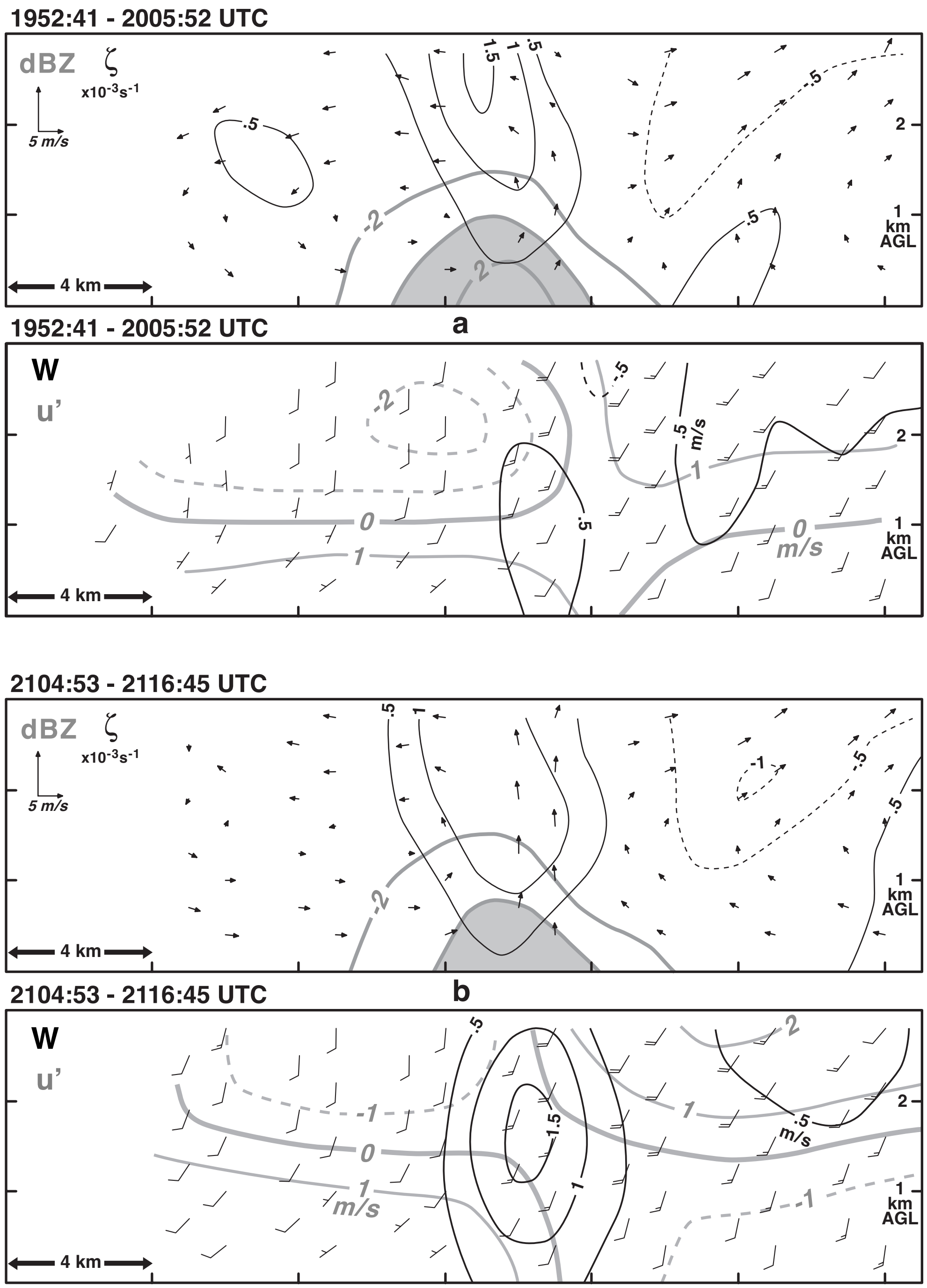

Fig. 5: Mean Vertical Cross Sections of the dryline from ELDORA at a) 1952:41-2005:52 and b) 2104:53-2116:45 UTC. Arrows indicate the winds in the cross sections, while wind barbs show the mean horizontal wind field at each level. Cross sections were rotated such that the u' component was perpendicular to the radar fine line.

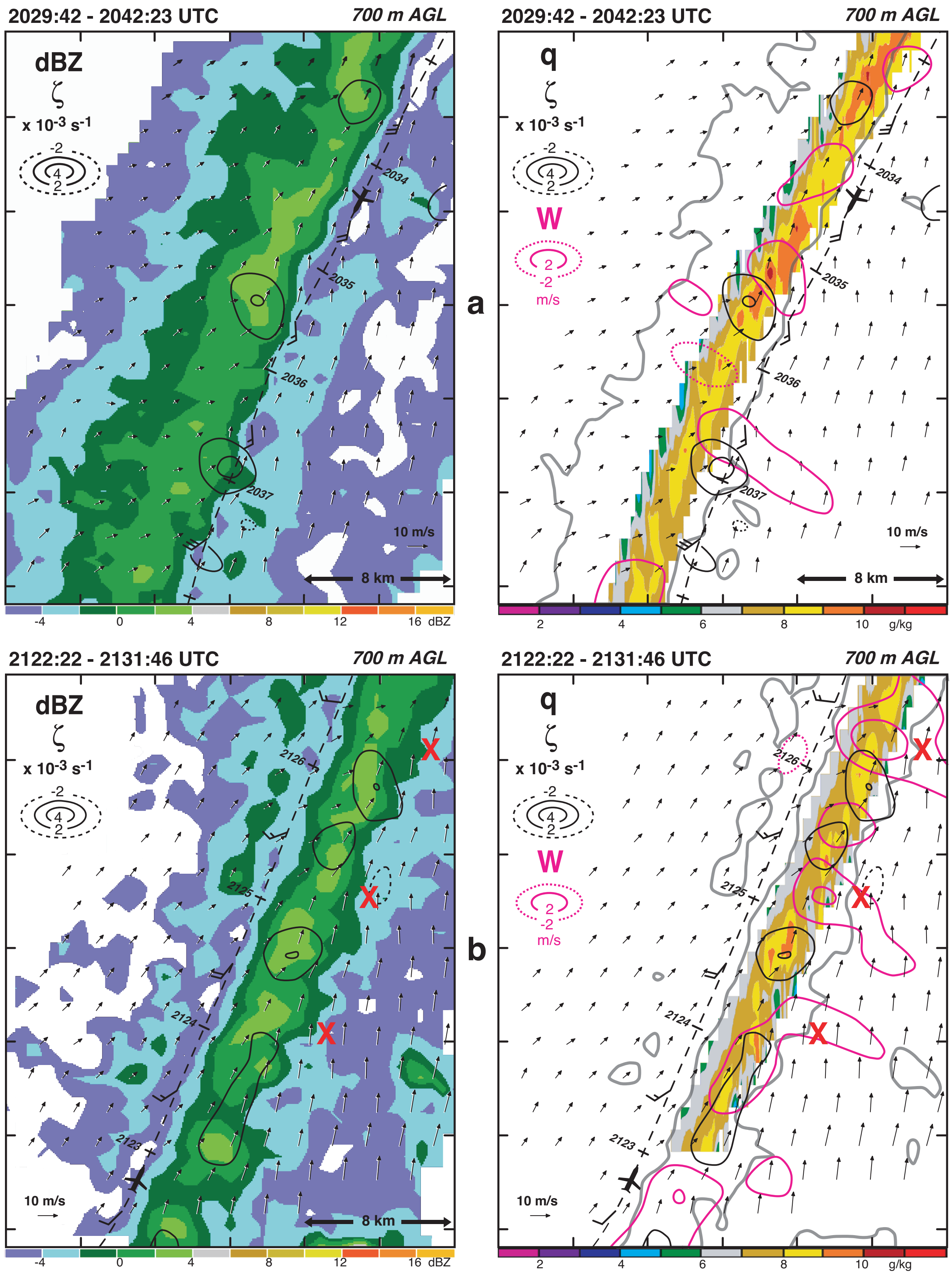

Fig. 6: Horizontal Cross sections at 700 m AGL of radar reflectivity from ELDORA (left panels) and water vapor mixing ratio from Leandre II (right panels). Superimposed is vertical vorticity and vertical velocity for a) 2029:42-2042:23 and b) 2122:22-2131:46 UTC. The gray solid line in the right panels indicate radar reflectivity above -2 dBZ. The red X's in b) show the location of the strongest updrafts in developing storms along the dryline.

for an opportunity to study the thermodynamics and the kinematics simultaneously. Leandre II was pointing horizontal during the CI mission of IHOP and through an interpolation process a horizontal cross section of q_v for a portion of the boundary was obtained. These fields were overlaid then with the kinematic fields obtained and derived from ELDORA.

On this day misocyclones (< 4km diameter) were observed all along the fine line (Murphey et al. 2005). A small portion of the line is shown in Fig. 6. The radar reflectivity shows that most of the circulations are located near the southern end of a maximum (Fig 6a) with updrafts displaced to the north. This is consistent with previous studies (Mueller and Carbone 1987). The moisture data also appears to be maximized to the north the circulation. This is believed to happen when the line is distorted by the misocyclone and the moist (dry) air to the east(west) is brought across the line to the north(south) of the circulation. The wind field is also perturbed leading to enhanced convergence. *As a result the areas immediately to the north of the circulations are hypothesized to be preferred locations for CI to form due to enhanced moisture and low-level convergence as well as strong updrafts that are capable of lifting the air to the LFC*. In order to test this theory, the locations of the developing clouds were found and these were consistently located just to the north of the vortices (Fig 6b).

As the storms developed, the low-level moisture was depleted out of the CBL except within the center of the misocylones. Here the moisture is believed to be suppressed due to a downward directed pressure gradient force produced by the low pressure within the vortex near the ground.

6. Summary and Discussion

The evolution of a dryline and the surrouinding environment on 19 June 2002 was presented. An aircraft equipped with a dual-Doppler radar and a water vapor DIAL was able to document the kinematic and thermodynamic structure of the boundary prior to convective initiation, while soundings were used to document the environment.

Analyses show that storms formed along the line when temperatures reaches the convective temperature and the updrafts at the boundary were strong enough to push the air to the LFC. Also, preferred locations for CI were indentified to the north of circulations located along the line. The misocyclones were able to distort the radar fine line and perturb not only the wind fields, but also the moisture fields by advecting moist air across the line to the north and drier air to the south. This additional moisture along with enhanced low-level convergence produced preferred locations for lifted air to reach the LFC. Locations of updrafts observed by ELDORA were consistent with this hypothesis.

Acknowledgements: Research results presented in this study were supported by the National Science Foundation under Grant ATM-021048 (though RMW) and Grants ATM-9901688 and ATM-0432951 (through DEK).

References:

Crook, N.A., 1996: Sensitivity of moist cov ection forced by boundary layer processes to low-level thermodynamic fields. *Mon. Wea. Rev.*, **124,** 1767-1785.

Jones, P.A. and P.R. Bannon, 2002: A mixed-layer model of the diurnal dryline. *J. Atmos. Sci.,* **59,** 2582-2593

Mueller, C.K. and R. Carbone, 1987: Dynam ics of a thunderstorm outflow. *J. Atmos. Sci.*, **44**, 1879-1998.

Murphey, H.M., R.M. Wakimoto, C. Flamant, and D.E. Kingsmill, 2005: Dryline on19 June 2002 during IHOP. Part I: Airborne Doppler and LEANDRE II analyses of the thin line structure and convection initia tion, *Mon. Wea. Rev.*, Accepted for publication.

Wakimoto, R.M., H.V. Murphey, and R.G. Fovell, 2004: Mantle echoes associated with deep convec tion: Observations and numerical simulations. *Mon. Wea. Rev.*, **132**, 1701-1720

Weckwerth, T.M, 2000: The effect of small scale moisture variability on thunderstorm initiation. *Mon. Wea. Rev.*, 128, 4017-4030.

--------------, D.B. Parsons, S.E. Koch, J.A. Moore, M.A. LeMone, B.B. Demoz, C. Flamant, B. Geerts, J. Wang, and W.F. Feltz, 2004: An overview of the International H20 Project (IHOP_2002) and some preliminary highlights. *Bull. Amer. Meteor. Soc.,* **85**, 253-277

Wilson, J.W. and W.E. Schreiber, 1986: Initia tion of convective storms by radar-ob served boundary layer convergent lines. *Mon. Wea. Rev.*, **114,** 2516-2536

Ziegler, C.L. and C.E. Hane, 1993: An obser vational study of the dryline. *Mon. Wea. Rev.,* **121**, 1134-1151