6.1 THE MORPHOLOGY OF TWO MIXED PHASE CLOUDS

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1. INTRODUCTION

The DOD-sponsored Center for Geosciences and Atmospheric Research (CG/AR) at CIRA-CSU recently completed the most successful of its Complex Layered Cloud Experiments (CLEX) over the Western Nebraska Panhandle region. The motivation for CLEX is to further our understanding of the processes inherent to the formation, maintenance and dissipation of mid-level, non-precipitating, mixed phase clouds. A better understanding of mid-level clouds has many applications for both military and civilian purposes. For example, during DESERT SHIELD/STORM, mid-level cloud systems often masked target areas and hampered use of electro-optic sensors and weapons systems. For civilian pilots, poorly forecast mid-level clouds often restrict flight visibility and can create icing hazards.

2. MOTIVATION

The mixed phase structure (i.e., the location, characteristics and amounts of ice and supercooled water) of mid-level clouds has received little attention in the atmospheric science community. Their ice-liquid stratification, ratios, temperatures, ice crystal habits, lifecycle and horizontal and vertical structure are still largely unknown. More observations and a better understanding of these characteristics are necessary for the proper modeling, forecasting and detection of mid-level clouds.

Because they do not produce severe weather and are typically ignored in climate change scenarios, mid-level, non-precipitating clouds are the forgotten clouds of the atmospheric science community. To fill this research void, the CG/AR is sponsoring an ongoing investigation, the Complex Layered Cloud Experiment (CLEX). The CLEX addresses a better physical understanding of the microphysical, dynamical and radiative properties of these clouds with the goal of improving their forecasting, modeling and remote detection.

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Using in-situ aircraft observations, recent CLEX campaigns (e.g., CLEX-5 during Nov-Dec 1999, CLEX-7 during March-April 2000 and CLEX-8 during May-June 2001) have documented the detailed microphysical and radiative structure of eight mid-level clouds (Fleishauer et al. 2002; Carey et al. 2001) and have addressed the question of what causes altocumulus clouds to decay (Larson et al., 2001). These results have provided insight toward better forecasting of mid-level clouds. More in-depth information about the CLEX project and recent CLEX field campaigns can be found at:

http://www.cira.colostate.edu/GeoSci/clex_home.htm

3. CLEX MEASUREMENTS

The primary observational platform utilized during this most recent effort, CLEX-9 (8 Oct - 4 Nov 2001) was the University of Wyoming King Air (UWKA) research aircraft. In addition to a comprehensive suite of microphysical and radiation probes, the UWKA carried the upward- or side-looking Wyoming Cloud Radar (WCR). The WCR (95-GHz Doppler) provided high-resolution observations of cloud structure, microphysics and kinematics. These airborne measurements were complemented by a suite of ground-based instruments (CSU surface radiation station, IR interferometer, micro-pulse LIDAR and supplementary radiosondes and the NOAA ETL and University of Massachusetts dual frequency microwave radiometers) located at the North Platte Regional Airport in North Platte, Nebraska. Utilizing 38 UWKA flight hours, CLEX sampled 9 different mid-level, mixed phase clouds on 8 different mission days. On one of those days, CLEX accomplished a successful dual-aircraft mission (SPEC Inc. Learjet and UWKA) in a multi-layered cloud system.

As observed in previous CLEX field campaigns, cloud vertical structures were predominately mixed phase with liquid water content (LWC) peaks generally occurring near cloud top and ice water contents (IWC) peaking near cloud base. Combining cloud radar and in-situ measurements provides a three-dimensional view of the previously observed vertical profiles of water and ice, revealing molar-shaped mixed phase generating cells and mostly ice fall streaks cascading from the base of the cells (e.g., Fig. 3). This study compares and contrasts preliminary in-situ and remote sensing measurements of mixed phase clouds sampled on the 14 Oct and 2 Nov operational days.

4. OVERVIEW

4.1 CASE 1: 14 OCT 2001

A large area of mid-level clouds was embedded in northwesterly flow associated with the backside of an upper-level shortwave trough that had moved through the CLEX region during the prior evening. The UWKA sampled mid-level clouds from 1210 to 1600 UTC. Figure 1 shows the horizontal extent of the cloud field as observed from a GOES-IR perspective. Here we see the extensive coverage of the cloud deck over western Nebraska. Cloud top temperatures were noted to be around –22°C. The UWKA then lifted off again for another mission from 1715 through 1900 UTC. This second mission sampled mid-level clouds under a near-nadir 1755 UTC TERRA satellite overpass.

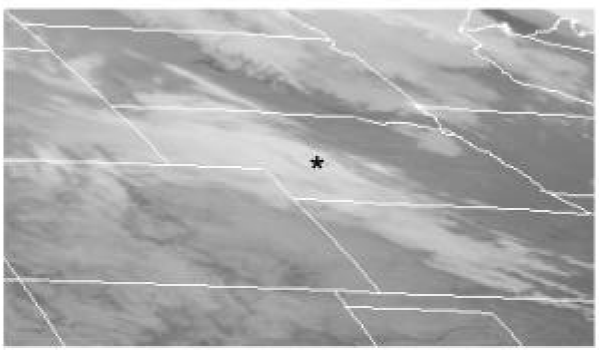

Fig. 1. GOES-10 infrared image on 14 Oct 2001 at 1245 UTC. The asterisk denotes location of CLEX instrumented ground site at North Platte, NE.

4.2 CASE 2: 2 NOV 2001

Beneath an upper-level ridge, weak positive vorticity advection combined with mid-level moisture to produce mid-level clouds over the CLEX target region. Figure 2 shows a GOES-IR view of the mid-level cloud deck. Cloud top temperatures over North Platte, NE were around –13°C. The UWKA sampled these mid-level clouds from 1220 UTC through 1620 UTC. Though not shown here, cloud breakup was observed beginning after 1600 UTC, with complete cloud dissipation occurring by 1730 UTC.

5. PRELIMINARY RESULTS

On both days, combined horizontal flight legs and spiral soundings were preformed to maximize the cloud sampling capabilities of the UWKA. Radar and in-situ measurements show that both days' mid-level cloud profiles were mixed phase, with the LWC peaks located near cloud top while the IWC peaked near the mid and lower regions of the clouds.

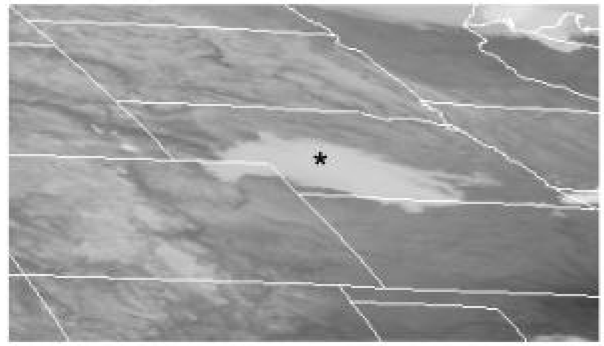

Fig. 2. Same as Fig. 1 but on 2 Nov 2001 at 1245 UTC.

The 14 Oct WCR cross-section of the cloud (Fig. 3) depicts the observed cell-like structures that become sheared in the lower regions of the cloud. Areas of higher reflectivity correspond to regions of higher ice

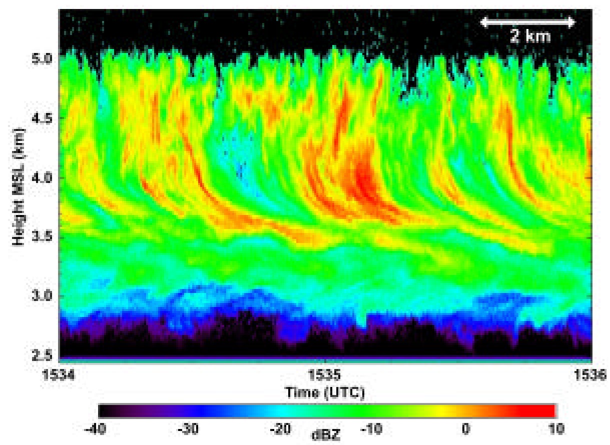

Fig. 3. A vertical cross-section of WCR reflectivity data from 14 Oct 1534-1536 UTC.

concentration. Figure 4 (a) displays WCR reflectivity data in contoured frequency by altitude diagram (CFAD) format (Yuter and Houze, 1995). Here rapid broadening of reflectivity is evident just below the 5 km altitude. The wide distribution of reflectivity at the 4 km altitude indicates a significant variability in the horizontal homogeneity of these clouds. Vertical profiles of LWC and IWC (Fig. 4b) compare well with previous CLEX-observed mid-level clouds (Fleishauer et. al. 2002), with the liquid water located in the upper region of the clouds and ice concentrations increasing below the peak in LWC.

After landing and re-fueling in North Platte, NE, another set of mixed phase mid-level clouds were sampled by the UWKA. WCR cross-sections of reflectivity data (Fig. 5) at 1720 UTC reveal a vertical extent similar to that of clouds observed earlier (Fig. 3). A CFAD of WCR reflectivity data (Fig. 6a) shows that while the upper regions of the cloud have similar

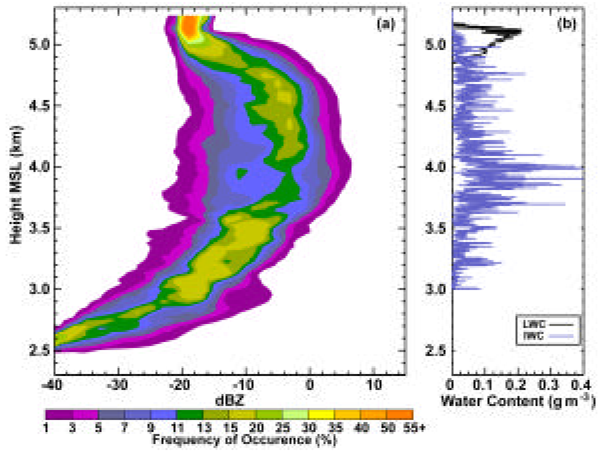

Fig. 4. (a) A Contoured Frequency by Altitude Diagram (CFAD) of reflectivity taken on 14 Oct 1533-1543 UTC. (b) Vertical profile of in-situ liquid and ice water contents taken on 14 Oct 1450-1509 UTC.

distributions of reflectivity as observed earlier (Fig. 4a), the middle region (e.g., near 4 km) shows a much narrower distribution of reflectivity. Preliminary results suggest that this narrowing of the reflectivity may be due to enhanced aggregation that may have formed within this region of the cloud. Vertical profiles (Fig. 6b) reveal a similar distribution of LWC and IWC as shown before (Fig. 4b), although the LWC is less than that observed earlier.

While the 14 Oct sampled cloud was vertically extensive in nature, the 2 Nov sampled cloud was much less extensive in its vertical depth. WCR reflectivity cross-sections (Fig. 7) show a similar cell-type structure

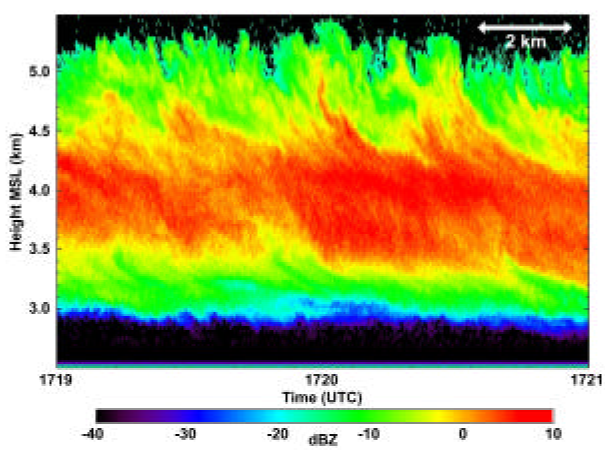

Fig. 5. A vertical cross-section of WCR reflectivity data from 14 Oct 1719-1721 UTC.

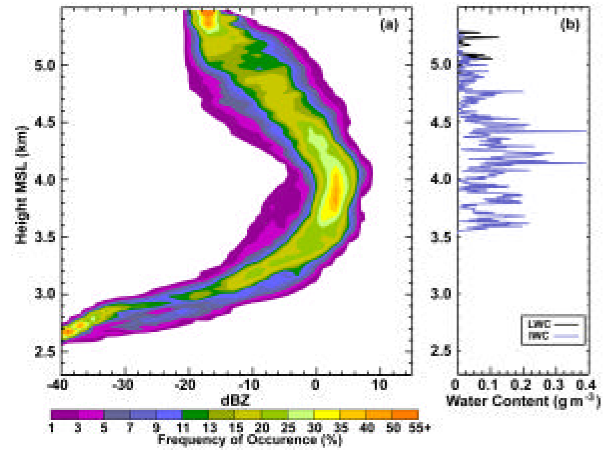

Fig. 6. (a) A Contoured Frequency by Altitude Diagram (CFAD) of reflectivity taken on 14 Oct 1718-1722 UTC. (b) Vertical profile of in-situ liquid and ice water contents taken on 14 Oct 1722-1729 UTC.

as that seen on the 14 Oct clouds. A CFAD of reflectivity data from the 2 Nov sampled cloud (Fig. 8a) shows a similar shift in reflectivity through the upper regions of the cloud (as seen in Figs 4a and 6a) that corresponds well with the location of the peak liquid

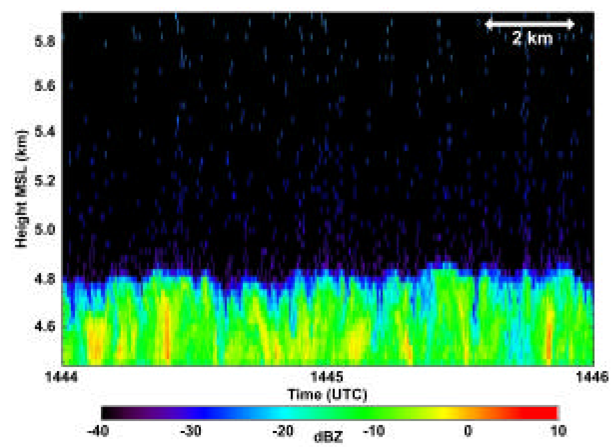

Fig. 7. A vertical cross-section of WCR reflectivity data from 2 Nov 1444-1446 UTC.

water region (Fig. 8b). Though not shown here, the LWC observed throughout this cloud's lifetime was nearly constant (between 0.2 and 0.3 g m^{-3}). Only the IWC decreased in magnitude over time. The CSU micro-pulse LIDAR (Fig. 9) confirms the thin nature of this cloud, and indicates that strong backscatter existed through the very end of the cloud's lifecycle.

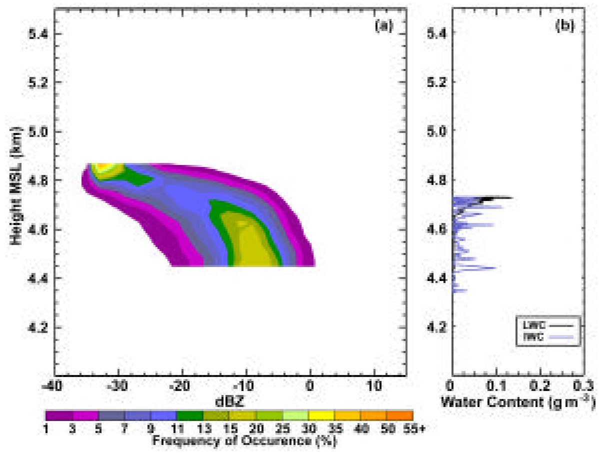

Fig. 8. (a) A Contoured Frequency by Altitude Diagram (CFAD) of reflectivity taken on 2 Nov 1441-1447 UTC. The sharp cutoff below 4.45 km is due to limited data sampling. Actual cloud base was observed to extend down to just below 4.3 km. (b) Vertical profile of in-situ liquid and ice water contents taken on 2 Nov 1434-1436 UTC.

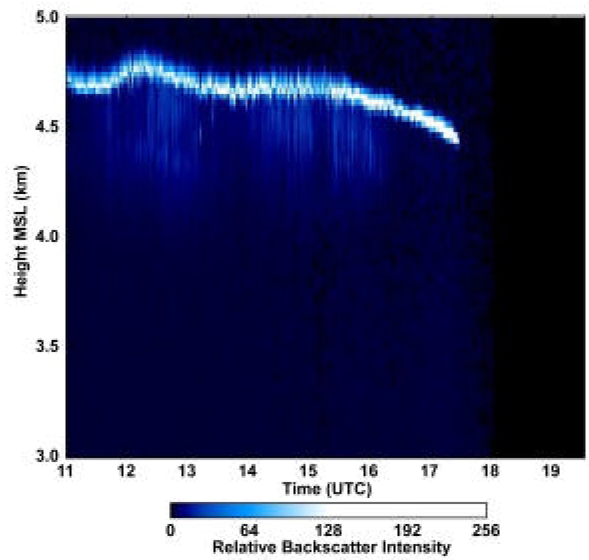

Fig. 9. A CSU micro-pulse LIDAR time/height cross-section of relative backscatter intensity on 2 Nov 2001 from North Platte, NE.

6. CONCLUSIONS AND FUTURE WORK

Through the CLEX program we have sampled a wide variety of mixed phase altostratus clouds in many different temperature and synoptic regimes. During CLEX-9, the overwhelming number of clouds sampled confirmed that LWC peaked near cloud top while the IWC peaked toward the middle and lower regions of the cloud (Fleishauer et al. 2002). The truly mixed phase region was often only a few hundred meters in depth and located near cloud top.

Once the processing of the in-situ data is complete, the next step will be to tie the in-situ measurements to satellite imagery, with emphasis on developing improved forecasting techniques and remote sensing algorithms for mixed phase systems.

Future work will center on refinement of the measurements taken thus far, such as retrieving liquid and ice particle sizes and concentrations. We plan to document both the vertical and horizontal cloud morphology and evolution from several CLEX-9 WCR case studies of mid-level clouds. Using both WCR and in-situ probe data, we will investigate the origins and evolution of ice in mixed phase mid-level clouds. Cloud dissipation mechanisms for mixed phase clouds will also be explored. Products, such as turbulent kinetic energy, potential temperature, lapse rates, and radiative heating and cooling rates will also be derived from CLEX-9 in-situ measurements. Extensive Cloud Particle Imager (CPI) data has also been collected which is being used to identify crystal habit information within the mixed phase cloud environments.

ACKNOWLEDGEMENTS

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