P1.25 A COMMON MICROPHYSICAL STRUCTURE FOR MIDLEVEL MIXED-PHASE CLOUD IN THE MID-LATITUDES: RESULTS FROM THE CLOUD LAYER EXPERIMENT (CLEX-9)

Jianguo Niu, Lawrence D. Carey, and Ping Yang
Department of Atmospheric Sciences, Texas A&M University

J. Adam Kankiewicz and Thomas H. Vonder Haar
DoD Center for Geosciences/Atmospheric Research, Colorado State University

1. INTRODUCTION

Significant effort on cirrus ice cloud and water cloud research has been reported in the literature. The thorough investigations on ice cloud parameterizations and their application to the satellite remote sensing have been conducted by Baum (2000), Key (2001), and Yang (2001, 2003), among others.

For temperatures between 0°C and -40°C at mid-tropospheric levels, water and ice particles may co-exist in a single cloud layer. Although studies have indicated that the parameterization of so-called mixed-phase clouds is critical for understanding the radiative impact of clouds in climate models and satellite remote sensing algorithms, relatively little is known about their microphysical characteristics even though roughly 22% of the globe is covered by mid-level clouds.

The vertical distribution of liquid and ice water content is of primary importance for modeling radiative transfer within mixed-phase clouds. Recent in situ measurements (e.g., Korolev et al. 2003) demonstrate that the distribution of liquid and ice water content with temperature in mixed-phase clouds is complicated. Nonetheless, past observations may suggest a common vertical profile of liquid and ice water for single-layer mixed-phase clouds at mid-levels. In two cases of single-layered cloud, Fleishauer et al. (2002) observed an increase of liquid water content with altitude, whereas the ice water content maximized in the middle to lower parts of the cloud.

This paper presents *in-situ* vertical profiles of ice and liquid water content, size distributions, and particle habit fractions within a midlevel, mixed-phase cloud in the mid-latitude region, as part of an ongoing modeling study of the radiative properties of mixed-phase clouds.

Corresponding Author Address: Dr. Jianguo Niu, Department of Atmospheric Sciences, Texas A&M University, College Station, TX, 77843-3150; e-mail: niu@ariel.met.tamu.edu

2. CLEX-9 CAMPAIGN

The Cloud Layer Experiment (CLEX), which started in 1996, is aimed at a better understanding of mixed-phase non-precipitating clouds in the middle troposphere. CLEX-9 is the ninth in the series and was conducted over North Platte Nebraska from October 8 to November 4, 2001. CLEX-9 employed the University of Wyoming King Air Research aircraft (UWKA). The UWKA was equipped with a variety of observational instruments and probes, including the 95-GHz Wyoming Cloud Radar (WCR), which provided highly resolved radar reflectivity, Particle Measuring System (PMS) 2-DC and 2-DP probes, which provided measurements of the ice particle size distribution, a Forward Scattering Spectrometer Probe (FSSP), a Droplet Measurement Technology (DMT) model LWC-100, a Rosemount 871FA icing detector and a Gerber PVM-100A, which all provided simultaneous observations of liquid water content and droplet size distribution. Other probes provided the necessary thermodynamic parameters and aircraft geo-location information.

To obtain the vertical microphysical structure of clouds, different types of flight tracks were employed in the campaign. The direct ascending or descending was the simplest track to penetrate the cloud, which is a slant leg from cloud bottom to top or vice versa. Some times we also employed a ladder like route leg that included repeated slant up (down) and horizontal level tracks. The descending (ascending) Lagrangian spiral was the most widely accepted route for cloud microphysical study, in which the aircraft flew down (up) spirally from cloud top to base (or vice versa) while drifting with the horizontal winds. Some times, when the cloud layers were very thin, we employed a sinusoidal flight pattern between cloud top and bottom, which we called the "porpoise" track. After excluding purely horizontal and incomplete vertical flight legs, thirty (30) effective cloud profiles were collected.

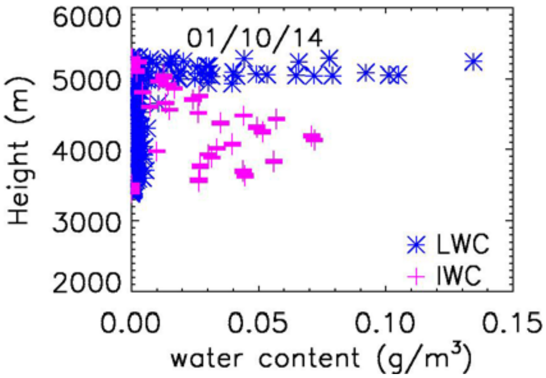

Figure 1. Vertical profile of ice (IWC) and liquid (LWC) water content associated with a common mixed-phase microphysical structure consisting of a super-cooled liquid droplet layer located at the cloud top and ice particles located below. The profile was obtained by the UWKA aircraft beginning at 17:21 UTC on October 14, 2001, just prior to a TERRA/MODIS satellite overpass.

3. COMMON MICROPHYSICAL STRUCTURE FOR MIXED-PHASE ALTOCUMULUS

During CLEX-9, the UWKA aircraft completed ten separate flight missions in eight different days (12, 13, 14, 19, and 31 in October, and 1, 2 in November, 2001). More than 16 hours of cloud observational data were obtained during the missions. After eliminating horizontal flights legs and incomplete vertical cloud penetrations from the in-cloud observational data set, we determined that 2/3 of the 30 effective cloud profiles exhibit a common structure of liquid layer on top and ice particles below as also found by Fleishauer et al. (2002).

Figure 1 illustrates an example of this common mixed-phase cloud structure, which was obtained starting at about 17:21 UTC on October 14, 2001 just prior to a TERRA/MODIS overpass. In this case, a 300 meter thick super-cooled liquid layer was present at the top of the cloud and a roughly 2000 meter thick ice particle layer was distributed in the lower part of cloud. A narrow zone in between the two layers was actually mixed-phase (i.e., contained both ice and liquid water particles). The temperature varied from –10°C at the cloud bottom to –22°C at cloud top. The temperature at the peak of the liquid layer was –22°C, and the peak of ice layer was –13°C.

The remaining 1/3 of the 30 cloud profiles were ice particle dominated clouds. Figure 2 is one example profile obtained on October 19, 2001. In this case the ice water content (IWC) was 10 times larger than the liquid water content (LWC). However more liquid droplets were still distributed at upper part of the cloud than the lower part.

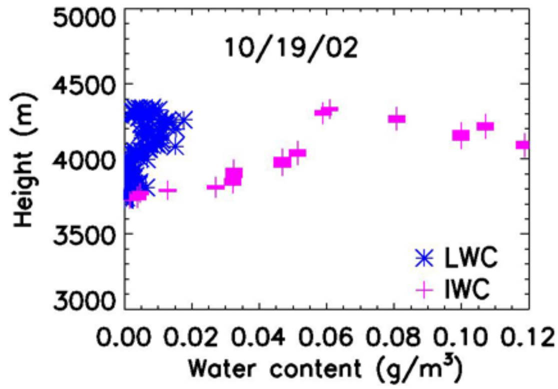

Figure 2. Same as Figure 1 except for an ice particle dominated cloud obtained after 12:30 UTC on October 19, 2001. In this observation, the LWC is much smaller than that of IWC.

3.1 Particle Size and Habit Distribution

To understand the radiative transfer properties of this liquid topped mixed-phase altocumulus, and its contribution to the satellite remote sensing, we proposed a radiative transfer study of this commonly occurring cloud. We sliced up the above mentioned cloud into 100-meter thick layers. The UWKA aircraft penetrated each layer and measured ice and water particle size distributions and cloud particle habit fractions in each specific layer. The ice particle size distributions have been obtained by PMS OAP2D-C with 20 bins. Water droplet size distributions have been measured by PMS FSSP-100 with 16 bins. Ice particle habits in the mixed-phase cloud have been measured from the 2-D imagery of particles by the PMS-2DC cloud probe. The liquid particle fraction was obtained from the FSSP-100 observations. Figure 3 illustrates the droplet size distributions in the upper four layers. Since the amount of liquid particles decreased rapidly below 4.9 km, the size distributions for liquid at lower layers are all close to zero. In a contrast, ice particles were distributed everywhere in the cloud. Figure 4 shows the ice particle size distributions in every other layer.

For simplicity in the radiative transfer calculations, the cloud habit fractions at each layer were divided into three habit categories, including water droplets, sector plates, and dendrites or aggregates. (Note: dendrites and aggregates were grouped together since their single particle scattering properties are likely similar.) The total ice and water droplet fractions were determined from the 2-DC and FSSP-100 observations. The two ice crystal habit fractions are determined by the 2-DC observed two-dimensional crystal images. Figure 5 illustrates these three particle habit fraction profiles. The sector plate crystals were normally small crystals and were most likely located at higher and colder portions of the cloud. The dendrites and aggregates were usually larger particles and were most likely located in the lower and warmer portions of the cloud, consistent with microphysical laboratory studies. The water droplet habit appears as a sharp peak at cloud top, which is the same as the liquid water content profile as shown in Figure 1.

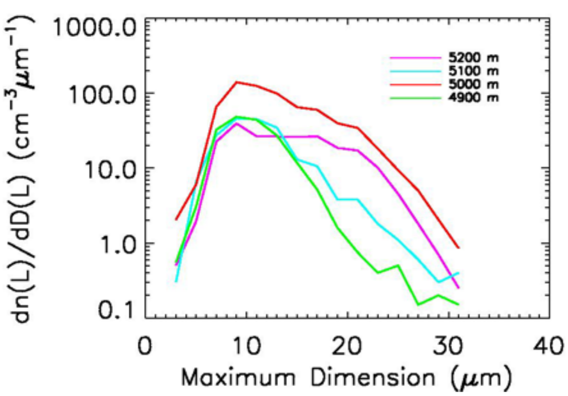

Figure 3. Liquid droplet particle size distributions at upper four layers of the sampled cloud.

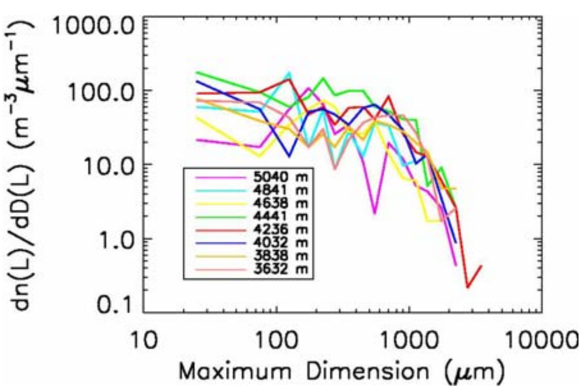

Figure 4. Ice particle size distributions are plotted at every other 100-meter thick layers.

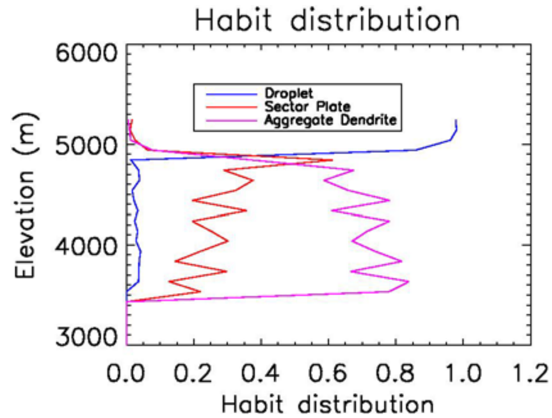

Figure 5. Particle fraction profiles for water droplet (blue), sector plates (red), and dendrites/aggregates (magenta).

4. SUMMARY

Comprehensive measurements of midlevel mixed-phase clouds in the mid-latitude region were conducted during the CLEX-9 campaign in North Platte (41.13N, 100.68W) Nebraska from October to November 2001. The experiment was accomplished by employing the University of Wyoming King Air (UWKA) aircraft equipped with typical *in-situ* cloud microphysical instruments. The campaign flew ten flight missions in eight different days, accumulated more than 16 hours of in-cloud observational data. Approximately 2/3 of the thirty (30) total measured effective cloud profiles show a common feature that super-cooled liquid droplets were topped or near the top of the clouds with ice particles falling as virga beneath. We refer to this common structure as liquid topped mixed-phase cloud. This discovery confirms an earlier speculation that the midlevel mixed-phase clouds in the mid-latitude region possesses a microphysical structure similar to that recently reported for mixed-phase Arctic stratus. Another interesting phenomena is that the remaining 1/3 of the total measured effective cloud profiles are ice dominated cloud with little liquid water content.

To understand the radiative transfer properties of this liquid topped mixed-phase altocumulus cloud and its contribution to the satellite remote sensing, a cloud profile with a nearly simultaneous TERRA/MODIS satellite overpass has been thoroughly sampled and is being parameterized for the purpose of the radiative transfer study.

The cloud has been sliced into thin layers of 100 meter thickness. The droplet and ice crystal size distributions at each layer have been derived. The cloud habits have been simply divided into three categories of liquid droplet, sector plate, and aggregate/dendrite. The three habit fractions as a function of height have been determined. A very large fraction of water appeared at the cloud top and sharply decreased to a very small value. The small sector plate crystals were distributed in all cloud layers, but peaked immediately beneath the thin water layer. The large aggregates/dendrites were also distributed everywhere in the cloud, but had maximum habit fractions at the cloud bottom.

The following summarizes additional ongoing and future research associated with the radiative transfer study of midlevel, mixed-phase clouds: The optical properties of individual particle have been computed. A new mixture scheme for modeling the mixed-phase cloud is being developed. The bulk cloud particle optical properties at each sliced layer will be computed and tabulated into a library. Combining this pre-computed cloud library, *in-situ* atmospheric profiles, and surface parameters, the upwelling radiance to the satellite sensor will be accurately estimated. Finally, a study on the sensitivity of satellite sensor channels to variability in the specific cloud profile presented herein and TERRA/MODIS validation will be documented in future papers.

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