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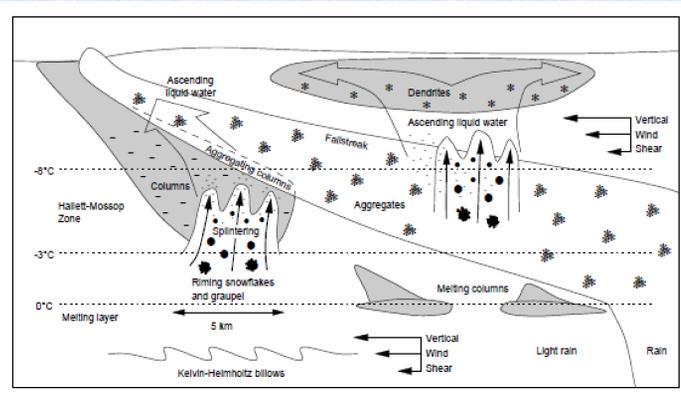
ABSTRACT

The Colorado Airborne Mixed-Phase Cloud Study (CAMPS) was an experiment conducted in winter 2010-11 that sought to increase our understanding of mixed-phase clouds and their effects on climate using airborne radar, lidar, and a variety of in-situ measurements. Studies of mixed-phase clouds have been performed previously on other cloud types, such as Arctic stratiform clouds, but little work has involved orographic clouds, those formed by uplifting due to mountains. The results of CAMPS may aid in creating more accurate climate models as well as improving predictions of icing conditions, which can threaten the safety of air travel.

This project is a study of an orographic mixed-phase cloud system, containing water in solid, liquid, and vapor phases, which occurred over Muddy Mountain in Wyoming during two days in February 2011. Using the University of Wyoming King Air research aircraft, measurements were obtained at a variety of altitudes, which provides useful information on the spatial and temporal variations within the cloud. This cloud system is an ideal case to study because it contains pockets of supercooled liquid water interspersed among pure ice clouds containing an assortment of ice crystal sizes, shapes, and concentrations. In particular, I have investigated the presence of liquid water pockets within the cloud and their relation to vertical wind speed, particle size distribution, and the physical structure of the cloud. The goal of this project is to explain the development of liquid water pockets in areas of updrafts, as well as the effects this process has on the particle size distribution, overall structure of the cloud, and ultimately, on the amount of snowfall produced beneath the cloud.

INTRODUCTION

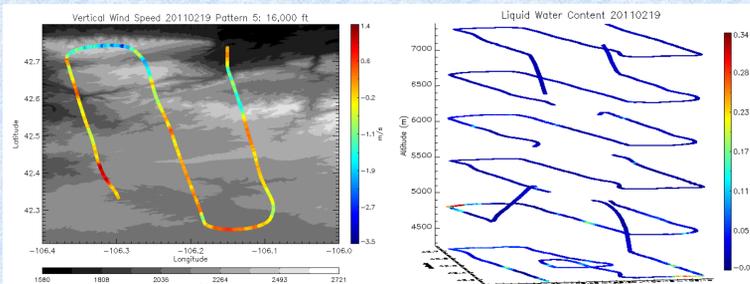
Studies of mixed-phase clouds have mainly focused on Arctic clouds, which have a great effect on the climate system, including the lifetime of sea ice. Other studies, such as the one referenced in the figure below, focus on frontal clouds at lower latitudes. While these studies are beneficial, not all of the knowledge can be directly applied to orographic clouds, which may have different temperature structures, particle formation mechanisms, and physical cloud structure. In addition, the small-scale convection within orographic clouds is greatly influenced by the topography beneath them, which is often insignificant for other cloud types.



A schematic drawing of a mixed phase cloud, including areas of particle formation, ascending liquid water, and a variety of ice crystals. Figure from Hogan et al., 2001.

EXPERIMENT

CAMPS used a host of instruments on the University of Wyoming King Air research aircraft to allow for multiple observation methods, creating a comprehensive study with a rich data set. An example flight path is depicted below. By following this same path at six different altitudes, ranging from 14,000 to 24,000 ft, the aircraft was able to effectively map the three-dimensional structure of the cloud. The chosen flight path crosses over the Muddy Mountain area, which contains multiple peaks that provide insight into the topographical effects on mixed-phase clouds.

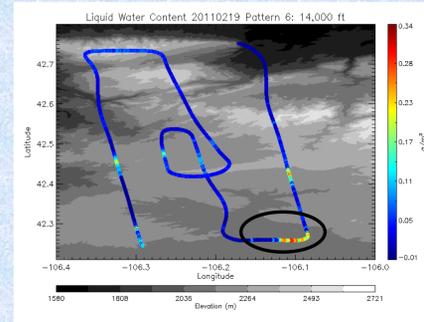


Left: Depiction of the flight pattern at one elevation, also showing the vertical wind speed variations as well as the underlying topography.

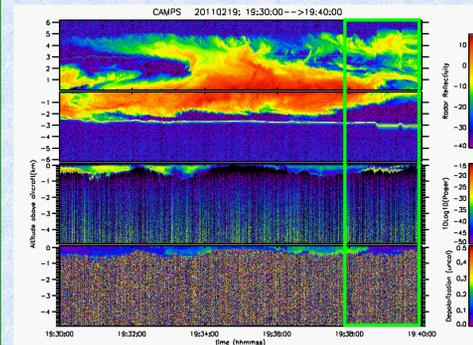
Right: 3-D depiction of the entire flight pattern for February 19th, 2011, also showing the variations in liquid water content throughout the flight.

1st Area of Interest

This 1st area of interest (circled right) features high liquid water content, a significant drop in particle size, and updrafts at both 14,000 and 16,000 ft.



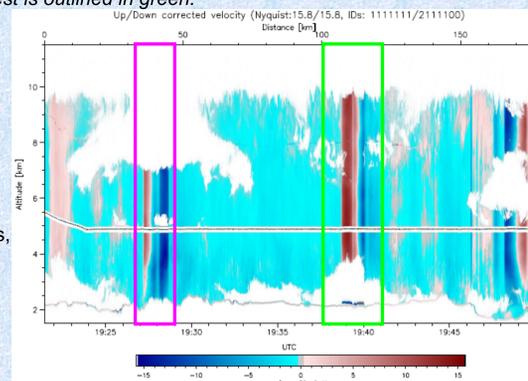
Liquid water content, with the area of interest circled.



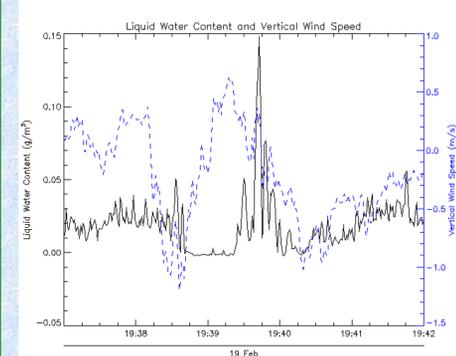
Radar above and below aircraft (top two panels), lidar reflectivity (3rd panel), and lidar depolarization (bottom panel). Area of interest is outlined in green.

The area at 16,000 ft (19:38 – 19:40 UTC) occurs during a period of low density clouds, as shown in the radar image. The lidar image reveals that pockets of liquid water are prominent below the aircraft.

The area features a band of strong upward velocity wind that is less than 10 km across. These vertical velocities are capable of carrying liquid droplets and ice crystals to higher altitudes, where changes in temperature and liquid water content can influence the formation of new particles.

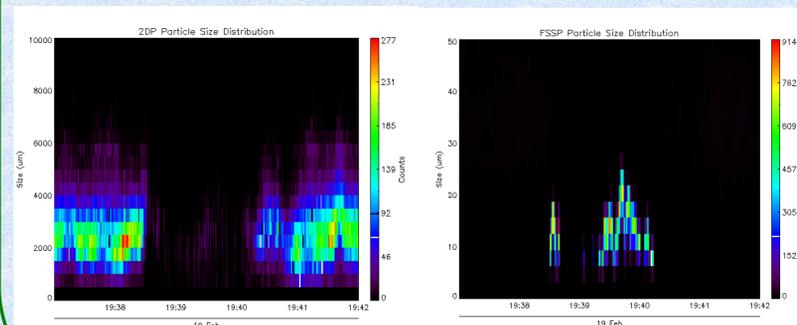


Vertical wind velocity; red corresponds to updrafts while blue corresponds to downdrafts. The 1st area of interest is outlined in green, and the 2nd in pink.



Comparison of liquid water content and vertical wind speed at 16,000 ft.

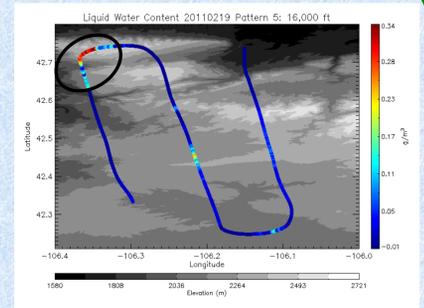
The area contains updrafts and a sudden increase in liquid water content (left). During this time the mean particle size drops almost 100X because ice crystals generally grow to much larger sizes than liquid water droplets could achieve. Note that there is a slight (< 1 second) lag between the peak velocity and the peak liquid water content.



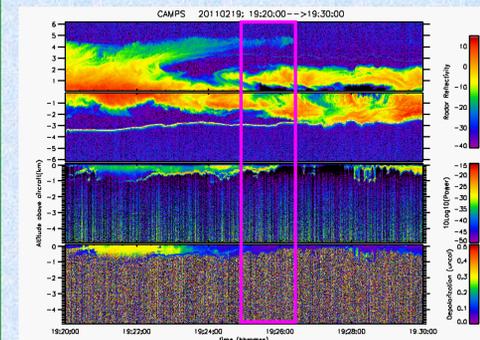
Variations in particle size distribution at 16,000 ft. Larger particles are detected by the 2D-P instrument (left) while smaller particles are detected by the FSSP instrument (right).

2nd Area of Interest

The 2nd area of interest (circled right) occurs at 16,000 ft and again features increased liquid water content, decreased particle size, and updrafts.



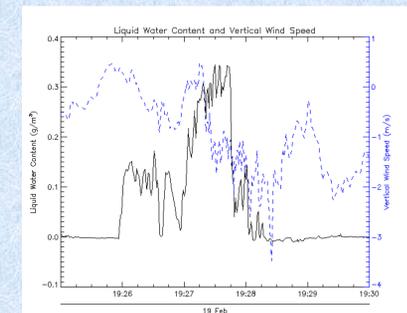
Liquid water content, with the area of interest circled.



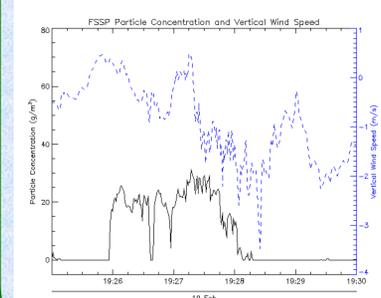
Radar above and below aircraft (top two panels), lidar reflectivity (3rd panel), and lidar depolarization (bottom panel). Area of interest is outlined in pink.

The area (19:26 – 19:28) occurs along the bottom edge of a patch of clear air (see radar). The lidar image shows a drop in ice particle density and areas of liquid water.

This area includes a narrow band of updrafts approximately 5 km wide (see left, pink outlined area). As in the previous area, an increase in liquid water content occurs during the updraft, with a slight lag (right).



Comparison of liquid water content and vertical wind speed at 16,000 ft.



Comparison of FSSP particle concentration (small particles) and vertical wind speed.

Again, the FSSP particle concentration, which measures small, liquid droplets, increases suddenly during the periods of updrafts and increased liquid water content.

CONCLUSIONS

- In mixed-phase clouds, areas of increased liquid water content are likely to occur in areas of updrafts, with a slight lag between the peak velocity and peak liquid water content.
- Sudden increases in liquid water content are accompanied by a drastic change in the particle size distribution, with a sharp decrease in the concentration of ice crystals and a simultaneous increase in small liquid droplets, indicating the formation of new particles.