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A CASE STUDY OF HORIZONTAL VARIABILITY IN ARCTIC CLOUD MICROPHYSICAL PROPERTIES

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1. OVERVIEW

The importance of arctic cloud properties to the surface radiative flux budget is well known and accurate representation of these clouds is essential to proper modeling of the Arctic environment. One of the cloud properties influencing the radiative budget is particle phase (McFarquhar and Cober, 2004; Curry and Ebert, 1992). The optical depth of a cloud layer decreases significantly when changing from all liquid to all ice. A good knowledge of the spatial variability of cloud properties is necessary for accurate model parameterizations (McFarquhar and Cober, 2004).

An interesting characteristic of arctic clouds is the prevalence of mixed phase cloud layers. In these mixed phase clouds the water content tends to dominate the radiative effects, causing them to act as all liquid clouds. Measurements have shown these clouds to be highly inhomogeneous in terms of ice and liquid water content. The horizontal dimension is important to proper interpretation of remotely sensed data where properties are averaged over space and/or time. It is also of interest to the modeling community for the parameterization of sub-grid scale features. The objective of this research is to characterize the horizontal variability of the cloud microphysical properties sampled during the Mixed-Phase Arctic Cloud Experiment (M-PACE).

2. CASE STUDY

The cloud on October 9 and 10, 2004, was a single-layer mixed-phase stratus forced by cold air flowing off Arctic ice pack over open ocean water (Fig. 1). The cloud layer formed in a well-mixed boundary layer. The low level wind had a slight on-shore component and the clouds developed in rolls parallel to the flow. The cloud depth increased with distance from the ice pack, as in Harrington and Olsson (2001).

In situ measurements during M-PACE were made using the University of North Dakota Citation research aircraft. The Citation was equipped for microphysical and aerosol measurements, as given in Table 1. Back to back missions were flown through this study cloud layer late on October 9 and early October 10, UTC. The samples extended from Oliktok Point to Barrow, a distance of ~250 km (Fig. 1), and were collected through a series of ramp climbs/descents and level legs (Fig. 2).

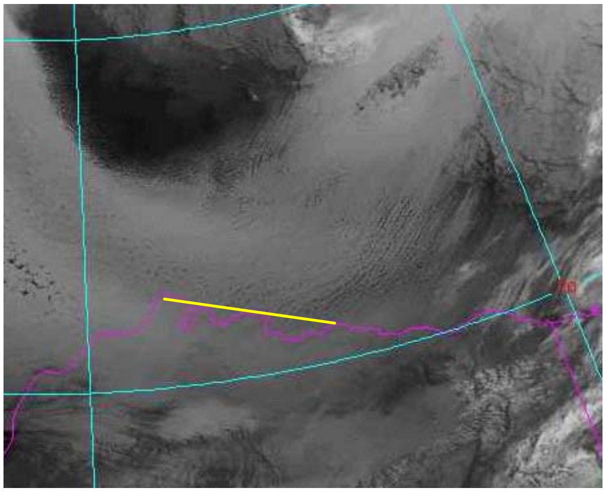

Fig. 1. AVHRR image from October 9, 2004, 2340 UTC. Yellow line is Citation track

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Table 1. Citation Instrumentation

Variable	Instrument
Temperature	Rosemount Total Temperature
Pressure	Rosemount Absolute Pressure Transducer
Dew Point	EG&G Hygrometer
Water Vapor	Maycomm TDL Hygrometer
Wind, turbulence	Pressure Transducers and Applanix POS
Cloud Droplet Spectrum	PMS FSSP
Cloud Particle Spectrum	PMS 1D-C Optical Array
Cloud Particle Images	PMS 2D-C Optical Array
Cloud Particle Images	SPEC Cloud Particle Imager
Precipitation Particle Images	SPEC HVPS
Liquid Water Content	PMS King Probe
Supercooled Liquid Water	Rosemount Ice Detector
Total Condensate	DMT Counterflow Virtual Impactor
Ice Nuclei Concentration	CSU Continuous Flow Diffusion Chamber
Condensation Nuclei	TSI Condensation Nuclei Counter
Position, Attitude, Accelerations	Applanix Position and Orientation System

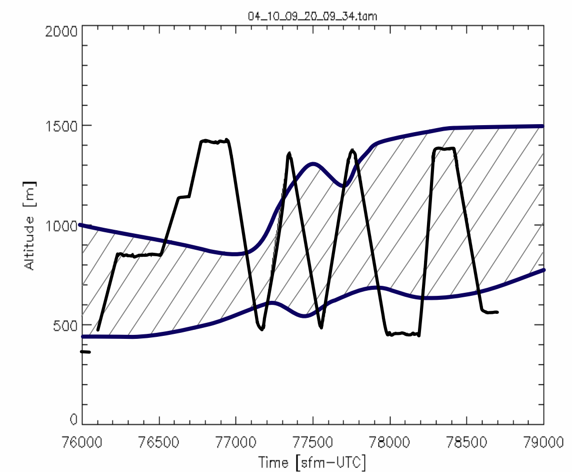

Fig. 2. Citation time-height for October 9 with estimated cloud boundary

3. HORIZONTAL VARIABILITY

The climb/descent mission profiles present a challenge to deriving horizontal variations. The liquid water content vertical profile was nearly adiabatic, making it difficult to distinguish horizontal from vertical gradients. However, the number concentration was typically independent of height and precipitation ice columns, as detected by ground-based cloud radar, extended throughout the cloud depth (Verlinde et al., 2006). These parameters could then be used to estimate horizontal variations. Therefore, the analysis approach was to use relatively short level legs for small-scale variability, continuous in-cloud flight segments for mid-scale variability and averaged values to look at larger scale variations.

3.1 *Small to Mid-Scale*

Time series of liquid water content and vertical wind are shown with probability distributions in Fig. 3. The fluctuations suggest spatial scales of 6-8 km. Images from the CPI (Fig. 4) show liquid water and ice crystals (some unrimed) in close proximity.

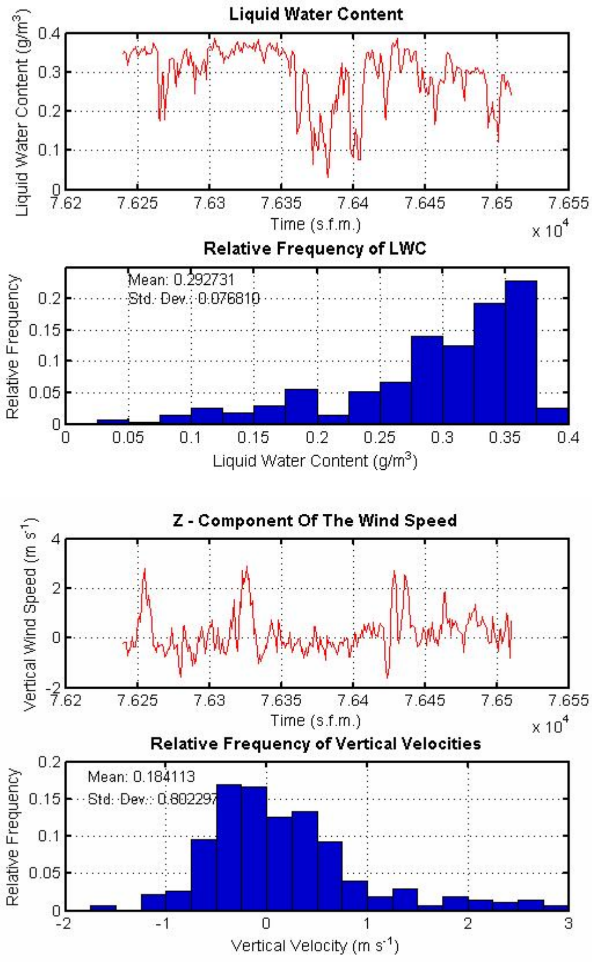

Fig. 3. Liquid water (top) and vertical wind (bottom) from level leg.

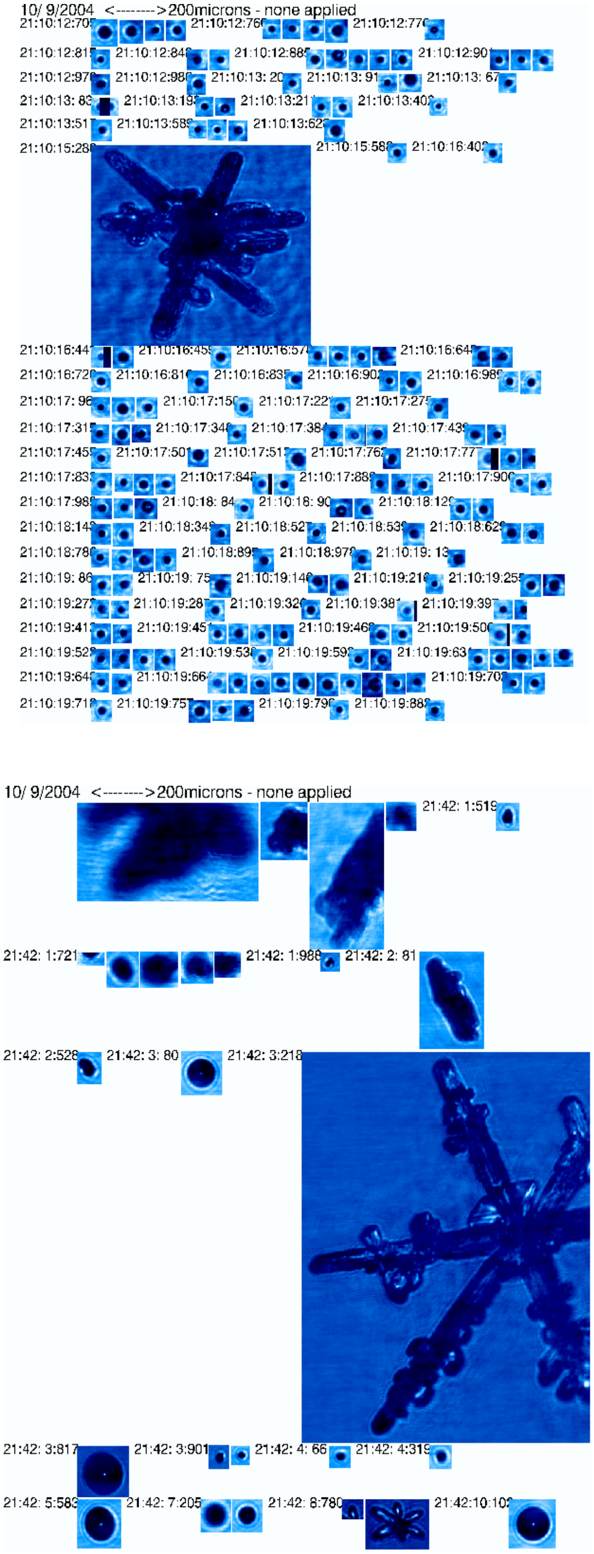

Fig. 4. CPI images in cloud (top) and below cloud bottom).

3.2 *Large Scale*

Average liquid water content, droplet concentration and droplet diameter are shown in Figs. 5-7. These values are derived from the ramp climbs and descents, with the cloud partitioned into three layers. Each degree of longitude is approximately 37 km. These plots suggest microphysical variations on a scale of 150-175 km. The larger number of samples on the first mission reveals variability on a scale about 1/3-1/2 of this value. This does not preclude the possibility that conditions were actually more variable. The second flight saw higher liquid water contents than the first in the lower and middle portions of the cloud along with lower droplet concentrations. There was also more uniformity of concentrations in the vertical in the second flight.

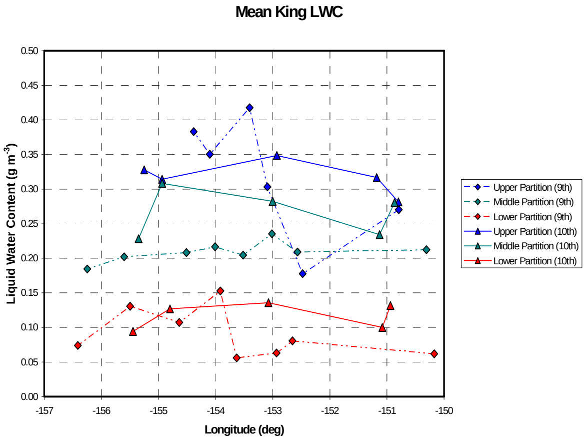

Fig. 5. Mean liquid water content (King probe)

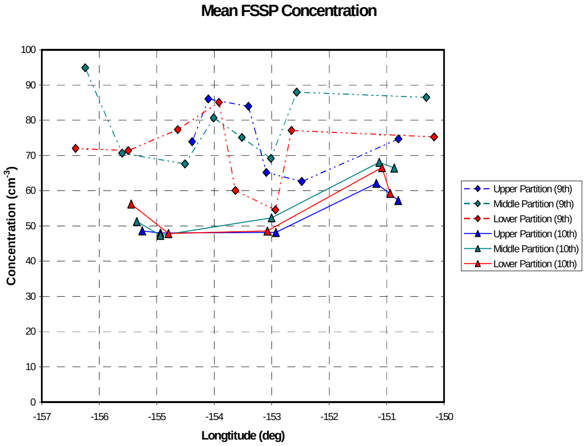

Fig. 6. Mean droplet concentration (FSSP).

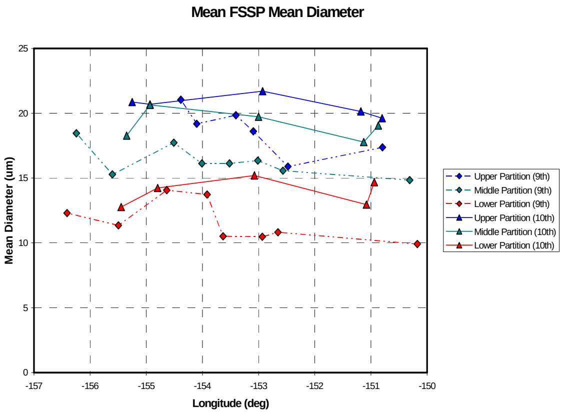

Fig. 7. Mean droplet diameter from FSSP.

A time series of 2D-C concentrations from the first mission (Fig. 8) shows an increase along the flight track. A similar trend was found for the second flight (not shown). Examination of the 2D-C and CPI images showed these particles to be primarily ice crystals. It is not yet known what the nucleation mechanism or scale for this may be.

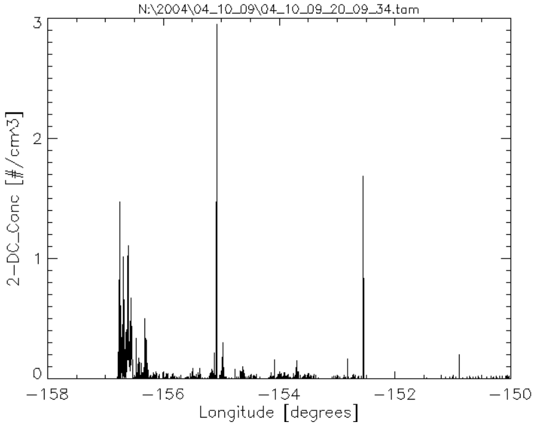

Fig. 8. 2D-C concentrations

4. PRELIMINARY OBSERVATIONS

Analysis of data from two flights in a single-layer arctic stratus cloud shows evidence for small-scale variability of microphysics and dynamic forcing on scales from tens to hundreds of meters. Larger features appeared on scales of 50 km to greater than 150 km. Some ice crystals were able to grow to large sizes in a mixed-phase environment before significant riming occurred. A spatial relationship of ice and liquid water in this mixed-phase cloud is still under investigation.

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