Lidar-Based Retrievals of the Microphysical Properties of Mixed-Phase Arctic Stratus Clouds and Precipitation

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Introduction

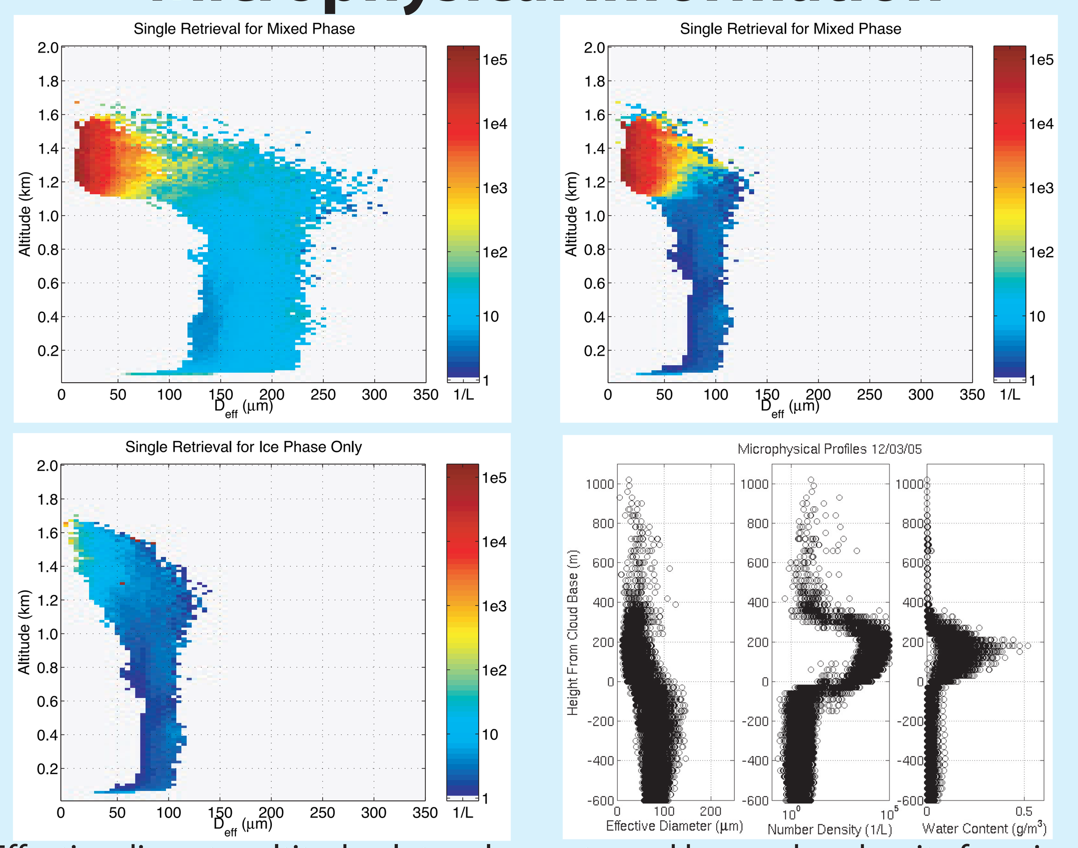
The Arctic has long presented itself as a challenging environment for scientists and instruments alike. Because of this, there exists a relative lack of understanding and observations of meteorological phenomena found in these unforgiving locations. One example of such phenomena is the mixed-phase stratus decks which last for extended periods of time over large spatial scales. The longevity of these structures defies our current state of knowledge. Traditional theory would allow the ice portion of the cloud to rapidly consume liquid present in the cloud layer until it has glaciated. The high amount of liquid present for long time periods, however, demonstrates that unknown mechanisms are involved in their development and maintenance.

In order to better understand these and other Arctic cloud structures, the University of Wisconsin Lidar Group has developed and deployed a remotely operated High Spectral Resolution Lidar (UW-AHSRL, Eloranta, 2004). This instrument has collected data sets in both Barrow Alaska (71.2 N, 156.4 W) during the Mixed Phase Arctic Clouds Experiment (M-PACE, Harrington and Verlinde, 2004) as well as in Eureka, Canada (80.0 N, 85.9 W). In addition to traditional HSRL based measurements of aerosol backscatter cross-section and depolarization ratio, we have developed and continue to improve a suite of cloud microphysical retrievals modeled after the technique implemented by Donnovan and Van Lammeren (2001). In conjunction with a NOAA ETL Millimeter Cloud Radar (MMCR), AHSRL measurements are being utilized to estimate values of effective diameter, number density and water content.

Here, we illustrate examples of these retrievals, as well as comparisons of these techniques with in-situ measurements. Long-term analysis of this data will include the development of climatology for these clouds, as well as utilization of these measurements to validate atmospheric simulations of these clouds.

The modified sea-tainer housing the AHSRL together with the NOAA MMCR in Eureka, Canada. The instruments have recorded 10 months of nearly continual data.

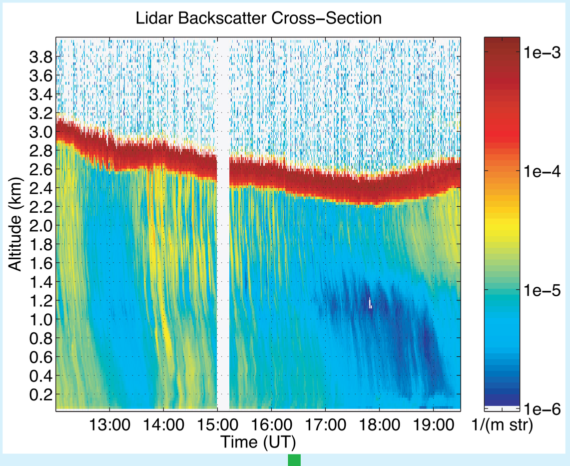
Microphysical Information

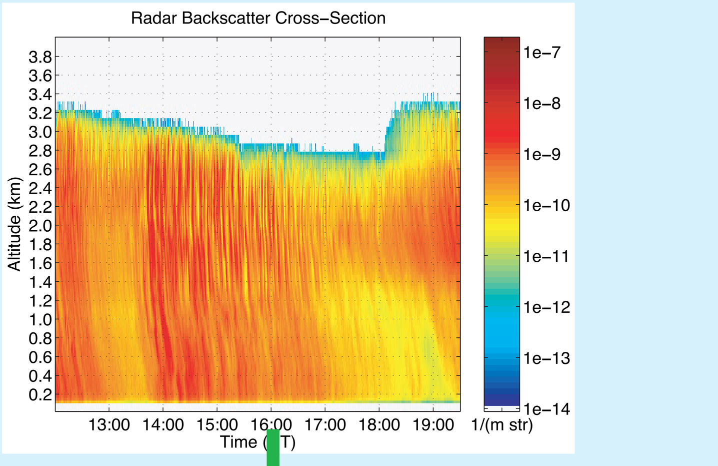


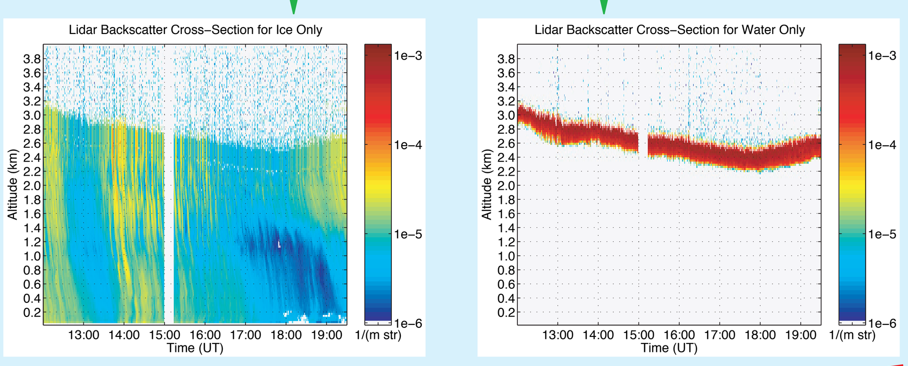
Effective diameter-altitude plots color contoured by number density for mixed phase spheres (top-left), mixed phase non-spheres (top-right) and ice phase only (bottom left). The bottom right image shows vertical profiles of effective diameter, number density and water content for non-spherical mixed phase.

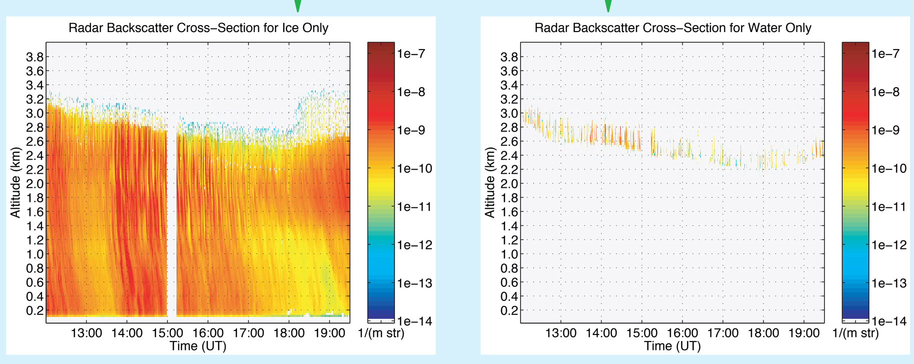
METHOD

Donovan and Van Lammeren (2001, Revised)









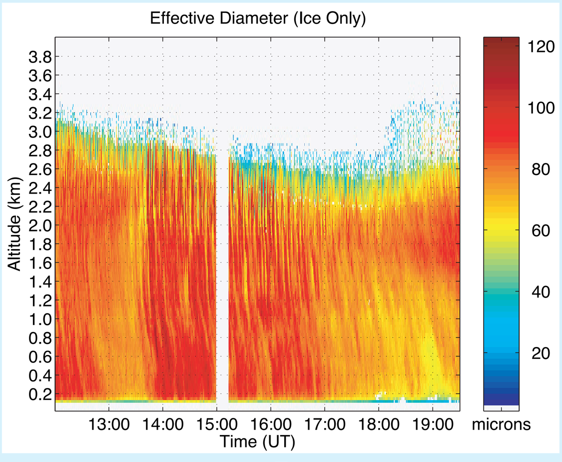
- $\beta_{rad} = \frac{24\pi^3 k^2}{\lambda^4}\langle V^2\rangle$, $\beta_{lid} = 2\langle A\rangle$
- $$\frac{\frac{P(180)}{4\pi}}{\frac{3}{8\pi}}\frac{\beta'_{rad}}{\beta'_{lid}} = \frac{12\pi^3 k^2}{\lambda^4}\frac{\langle V^2\rangle}{\langle A\rangle}$$
- $$\frac{\frac{P(180)}{4\pi}}{\frac{3}{8\pi}}\frac{\beta'_{rad}}{\beta'_{lid}} = \frac{8\pi^3 k^2}{\lambda^4}D_{eff}\frac{\langle V^2\rangle}{\langle V\rangle}$$
- $V = \sigma_V \frac{\pi}{6} D_{ref}^{3-\delta_V} D^{\delta_V}$

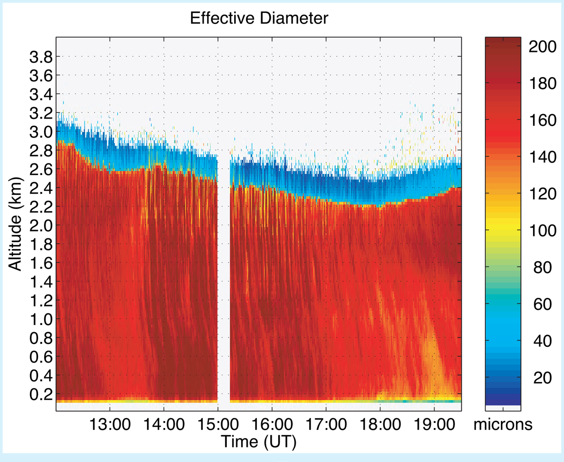
- $A = \sigma_A \frac{\pi}{4} D_{ref}^{2-\delta_A} D^{\delta_A}$
- $$N = \frac{\beta'_{lid}}{2\left(\frac{P(180)}{4\pi}\right)\langle A\rangle}$$

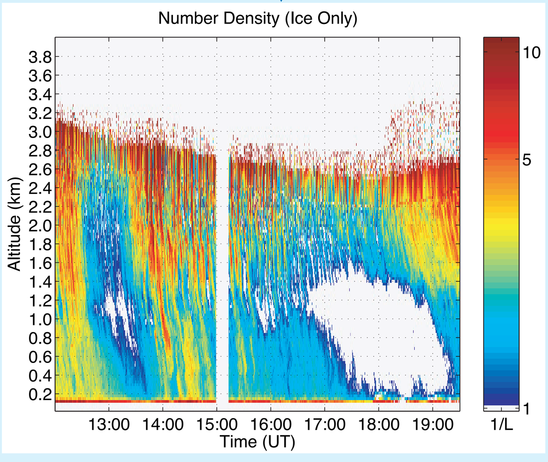
- $D_{eff} = \frac{3\langle V\rangle}{2\langle A\rangle}$
- $WC = \frac{2}{3}N\rho\langle A\rangle D_{eff}$

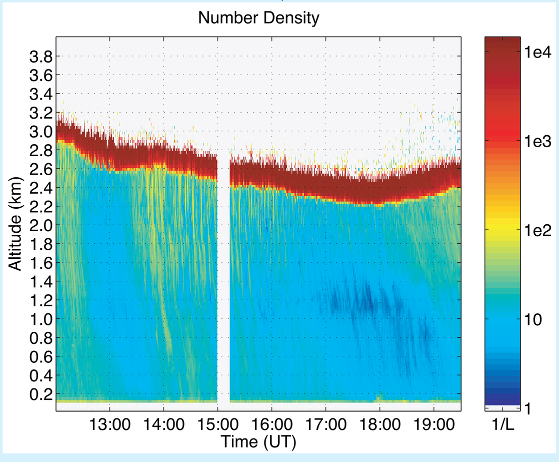
Assumptions for phase separation

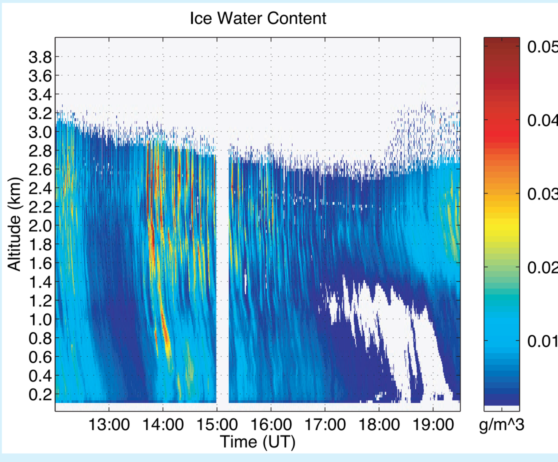
- **Even Ice Distribution vertically throughout cloud**
- **Ice amount directly below cloud is same as inside cloud layer**

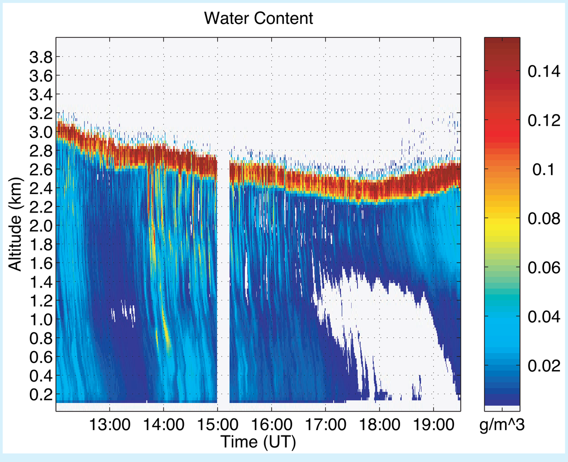












ICE ONLY

$\alpha_{liquid} = \alpha_{ice} = 2$

$\gamma_{liquid} = \gamma_{ice} = 1$

$\sigma_a = 1 \quad \delta_a = 2$

$\sigma_v = 0.2 \quad \delta_v = 2$

Here, we use a volume filling fraction, reducing the volume of ice.

MIXED PHASE

$\alpha_{liquid} = \alpha_{ice} = 2$

$\gamma_{liquid} = \gamma_{ice} = 1$

$\sigma_a = 1 \quad \delta_a = 2$

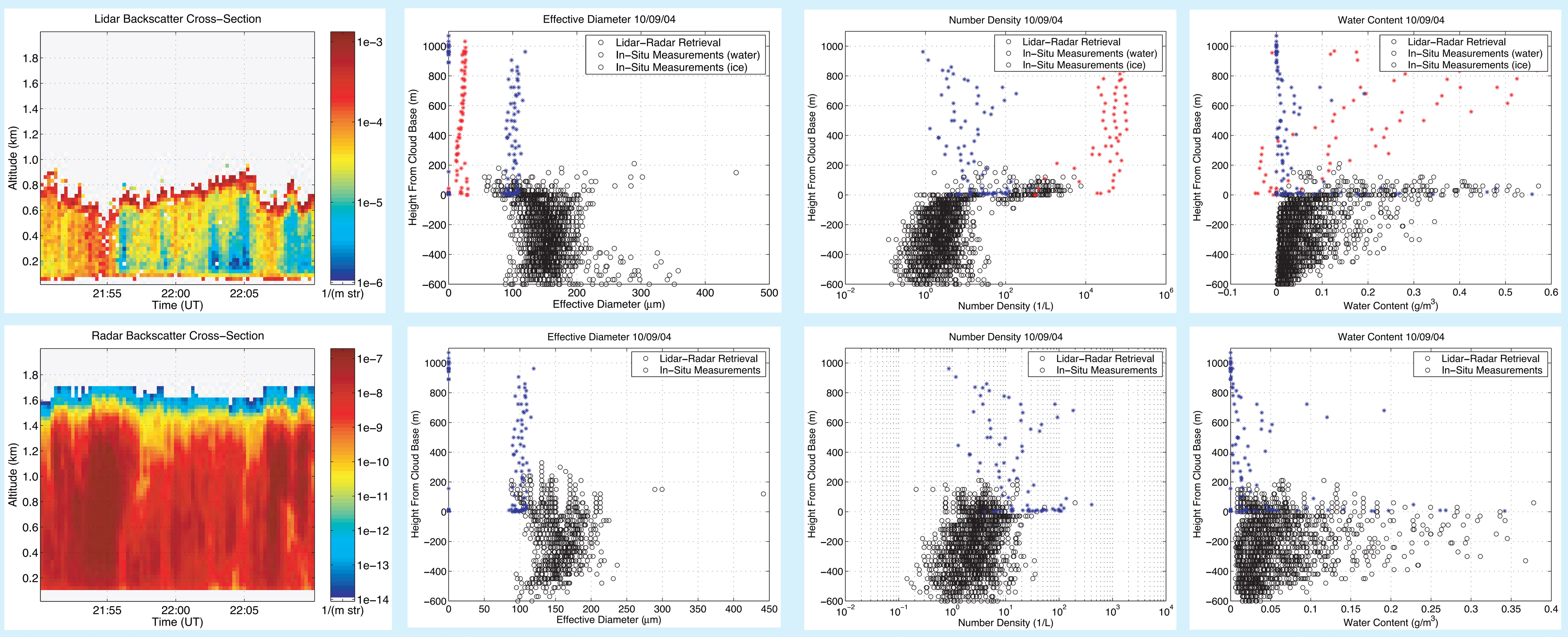
$\sigma_v = 1 \quad \delta_v = 2$

Basically, spheres...But doesn't need to be.

Assumed Size Distribution

$$n(D) = aD^{\alpha}\exp(-bD^{\gamma})$$

In-Situ Validation



Lidar and radar backscatter cross-section (left top and bottom) from October 9, 2004 from 21:50-22:10 UTC. Comparisons of lidar-radar retrieved effective diameter (2nd column), number density (3rd column) and water conent (right-most column) with in-situ measurements from the citation aircraft. Comparisons are done for combined phase (using volume filling fraction, top row) and ice only (bottom row). Aircraft data thanks to Gong Zhang and Greg McFarquhar (U. Illinois).

Remaining Challenges

- Radar cannot resolve smallest particles
- Crystal habit estimation through measurements
- Improved separation of phase
- Improved estimation/measurement of aerosol effects

Possible Additional Information Sources

- Other instrumentation/measurements
- Radar fall velocity
- Aerosol measurements from Eureka site
- Numerical simulation of cloud structures