Initial Results from the Cloud, Aerosol Polarization And Backscatter Lidar at Summit, Greenland

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Why did we put this lidar at Summit?

- **I**ntegrated **C**haracterization of **E**nergy, **C**louds, **A**tmospheric state, and **P**recipitation at **S**ummit (ICECAPS)
- Clouds affect the **Mass** and **Energy** Budget of the Greenland Ice Sheet

- How do clouds impact the Greenland Ice Sheet?
  - Source: Precipitation => Mass Budget
  - Sink: Radiation => Energy Budget
- Significant sea level rise is predicted from a melting Greenland Ice Sheet

What are we observing?
Cloud and precipitation phase

$$\delta = \frac{N_\perp}{N_\parallel}$$

Thanks to Ed Stockard for all the photos.

How Do We Determine Orientation of Scatterers in CAPABL Polarization Measurements?

- CAPABL is polarization lidar described by the stokes vector lidar equation:

$$\vec{N} = \mathbf{O}\mathbf{M_{RX}}\left[\left(G(R)\frac{A}{R^2}\Delta R\right)\mathbf{T}_{atm}(\vec{k}_s, R)\mathbf{F}(\vec{k}_i, \vec{k}_s, R)\mathbf{T}_{atm}(\vec{k}_i, R)\mathbf{M_{TX}}\vec{S}_{TX} + \vec{S}_B\right]$$

- When scatters may be assumed to be randomly oriented the depolarization ratio is derived as:

$$\delta = \frac{f_{11} - f_{22}}{f_{11} + f_{22}} = \frac{N_\perp}{N_\parallel}$$ where $$\mathbf{F}(\pi) = \begin{bmatrix} f_{11} & 0 & 0 & 0 \\ 0 & f_{22} & 0 & 0 \\ 0 & 0 & -f_{22} & 0 \\ 0 & 0 & 0 & f_{11} - 2f_{22} \end{bmatrix}$$ is the **randomly oriented** backscatter matrix.

- When scatters are not randomly oriented the depolarization ratio is derived as:

$$\delta = \frac{\mathcal{F}_{11} + \mathcal{F}_{33}}{\mathcal{F}_{11} - \mathcal{F}_{33}} = \frac{N_\perp}{N_\parallel}$$ where $$\mathbf{F}(\vec{k}_i, -\vec{k}_i) = \begin{bmatrix} \mathcal{F}_{11} & \mathcal{F}_{12} & 0 & 0 \\ \mathcal{F}_{12} & \mathcal{F}_{22} & 0 & 0 \\ 0 & 0 & \mathcal{F}_{33} & \mathcal{F}_{34} \\ 0 & 0 & -\mathcal{F}_{34} & \mathcal{F}_{44} \end{bmatrix}$$ is the **oriented** backscatter matrix.

We measure 3 planes of polarization to improve cloud property retrievals.

- By measuring N_{45}, we qualitatively determine if the scatters exhibit orientation through a quantity known as **diattenuation**:

$$\vec{N} = \begin{bmatrix} N_{\|} \\ N_{45} \\ N_{\perp} \end{bmatrix}$$

$$\mathbf{F}(\vec{k}_i, -\vec{k}_i) = \begin{bmatrix} \mathcal{F}_{11} & \mathcal{F}_{12} & 0 & 0 \\ \mathcal{F}_{12} & \mathcal{F}_{22} & 0 & 0 \\ 0 & 0 & \mathcal{F}_{33} & \mathcal{F}_{34} \\ 0 & 0 & -\mathcal{F}_{34} & \mathcal{F}_{44} \end{bmatrix}$$

  - Diattenuation allows us to unambiguously infer the form of the scattering matrix.

$$D_q = \frac{\mathcal{F}_{12}}{\mathcal{F}_{11}} = \frac{2N_{45}}{N_{\|} + N_{\perp}} - 1$$

$$D_q \begin{cases} = 0; & \delta = \dfrac{f_{11} - f_{22}}{f_{11} + f_{22}} \\ \neq 0; & \delta = \dfrac{\mathcal{F}_{11} + \mathcal{F}_{33}}{\mathcal{F}_{11} - \mathcal{F}_{33}} \end{cases}$$

L

- **Triple linear polarization** measurement

- **30m** spatial and **5s** temporal resolution

- **24/7** automated operation with remote access.

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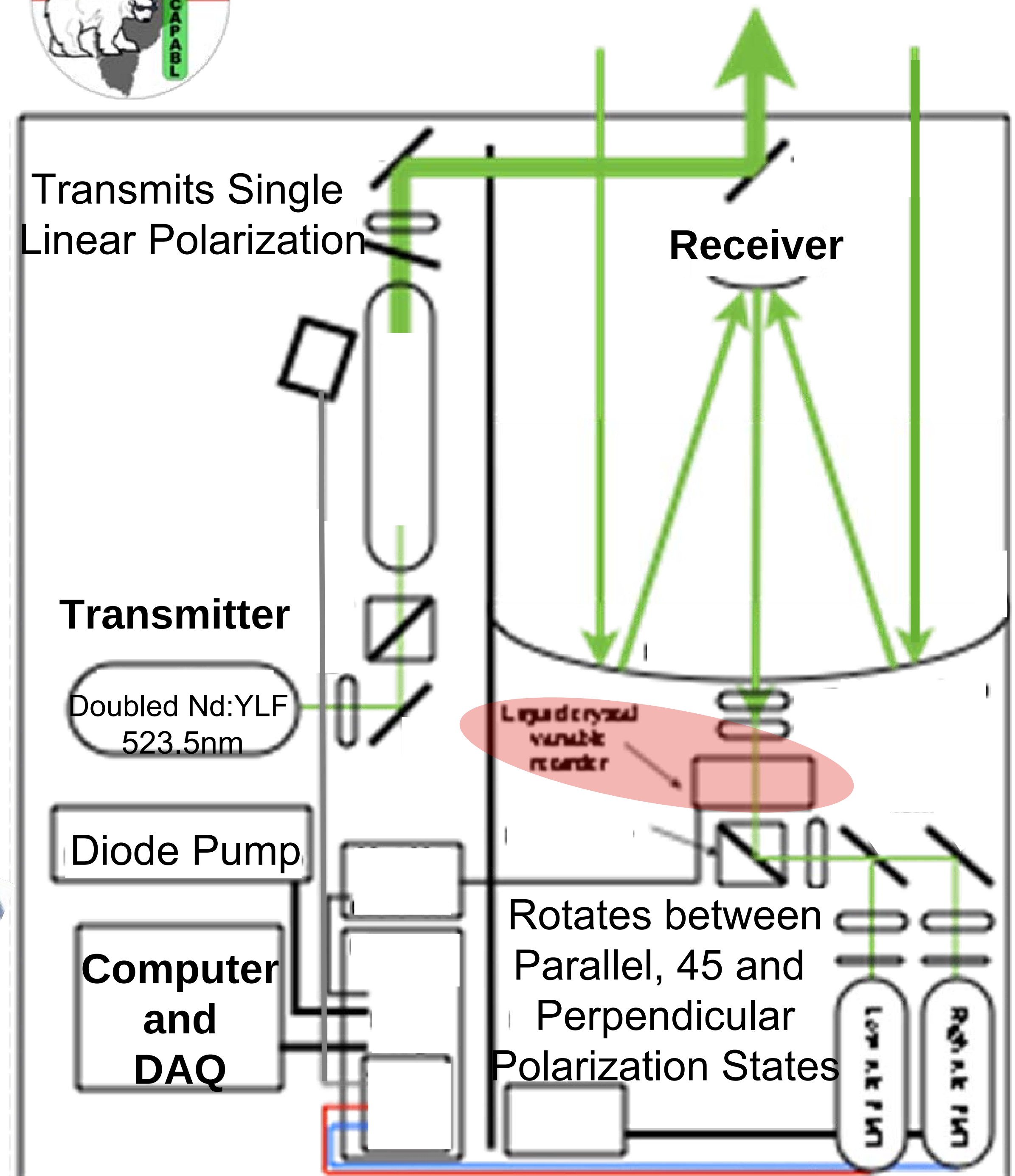
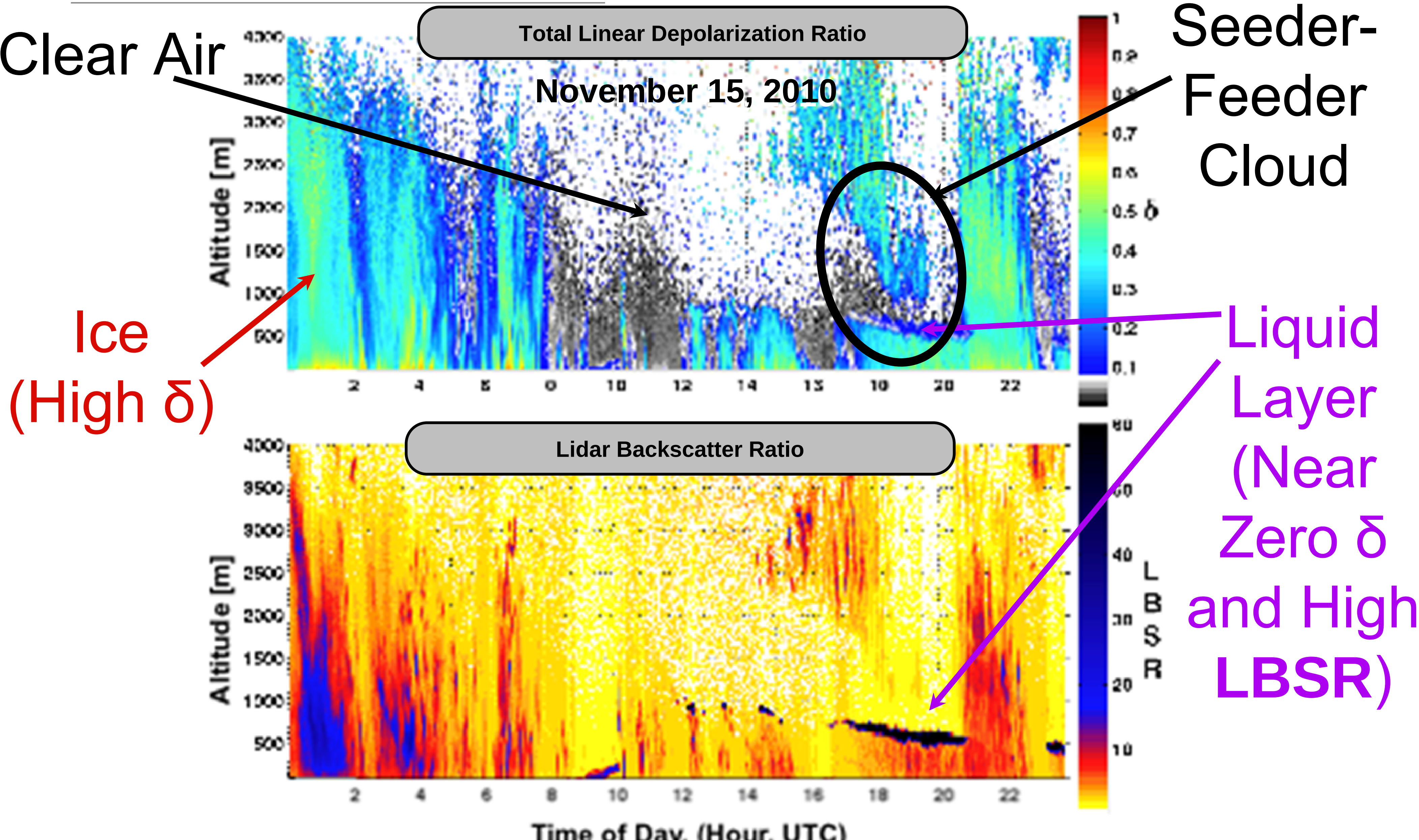
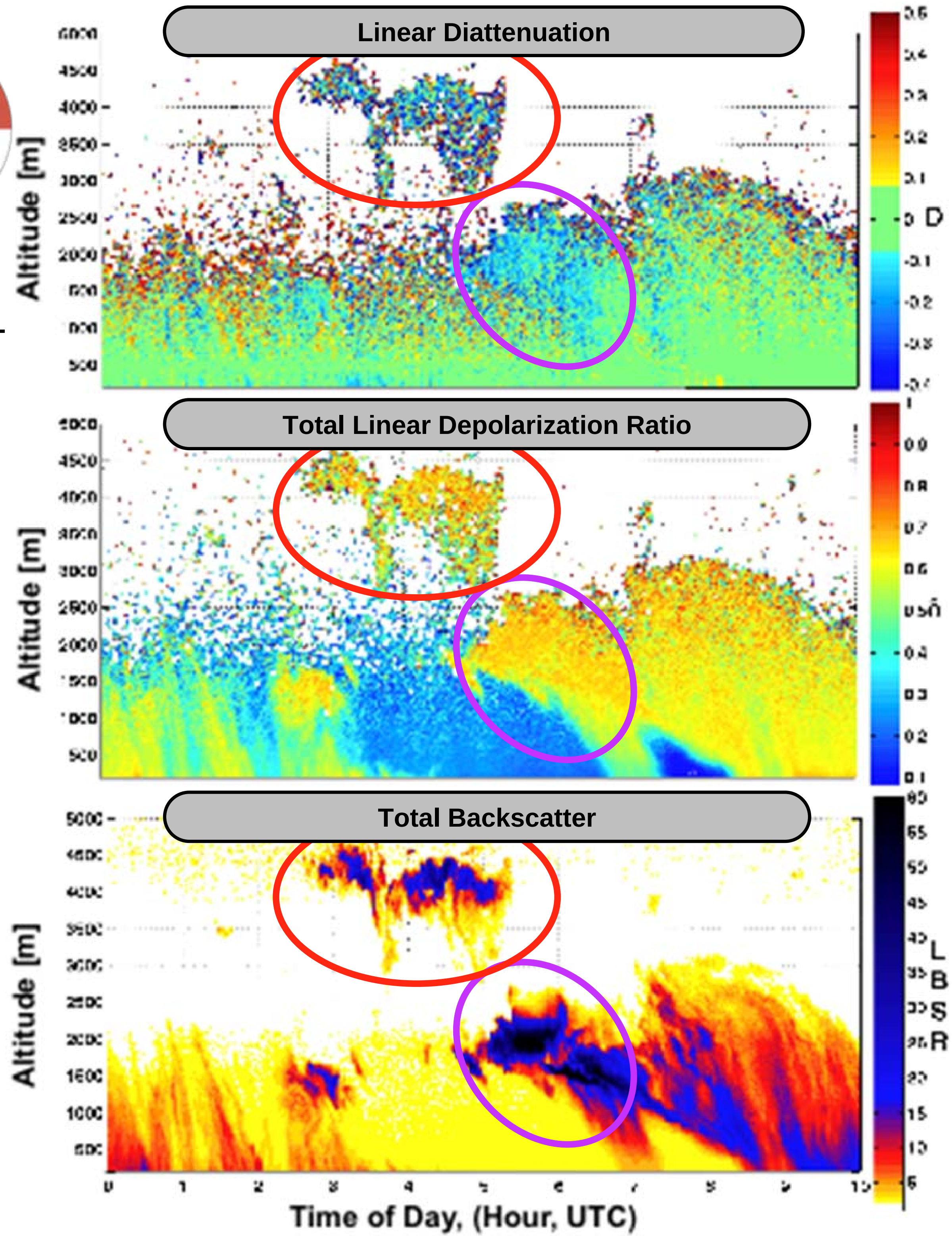


Example Observation



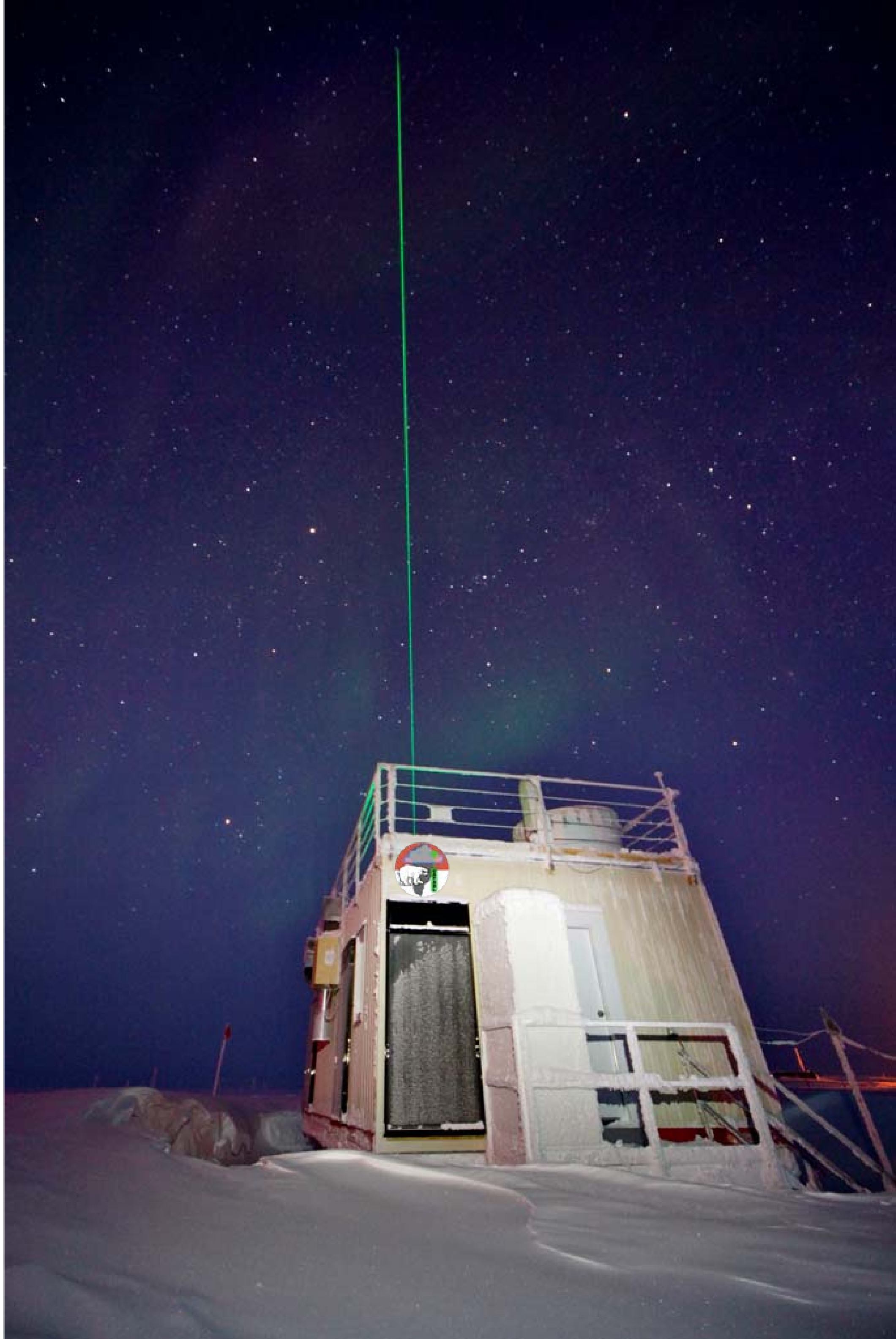
Observation of Diattenuation

- On 18 February 2012, CAPABL observed two diattenuation signatures (Light blue in top panel).
- Cirrus cloud
  - Expected regime for oriented crystals as shown by observations from CALIPSO
- Cumulus
  - Unexpected particle orientation due to turbulence from strong precipitation
  - Enhancement of linear depolarization in area of strong diattenuation



Conclusions

- CAPABL can simultaneously determine:
    - Cloud phase (linear depolarization ratio) of randomly oriented scatterers
    - Variations in the diattenuation of the scatterers, which may be used to interpret the presence of HOIC.
- Diattenuation measurements improve the overall quality of cloud phase measurements (less than 2% error in linear depolarization ratios) by reducing uncertainty about the orientation of scatterers.
- Current observation provides a first demonstration of operationally detecting HOIC by direct polarization determination.



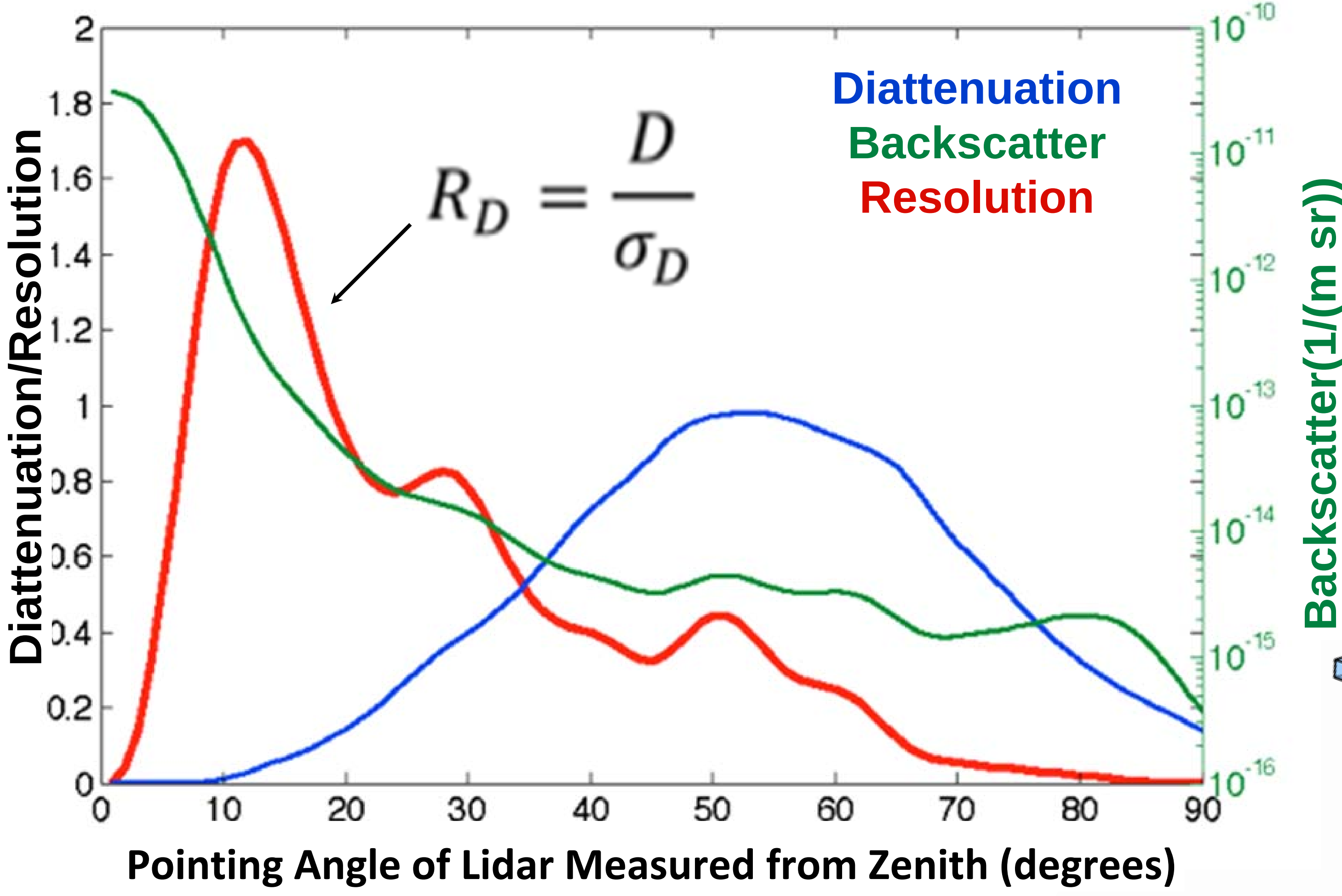
Thank You

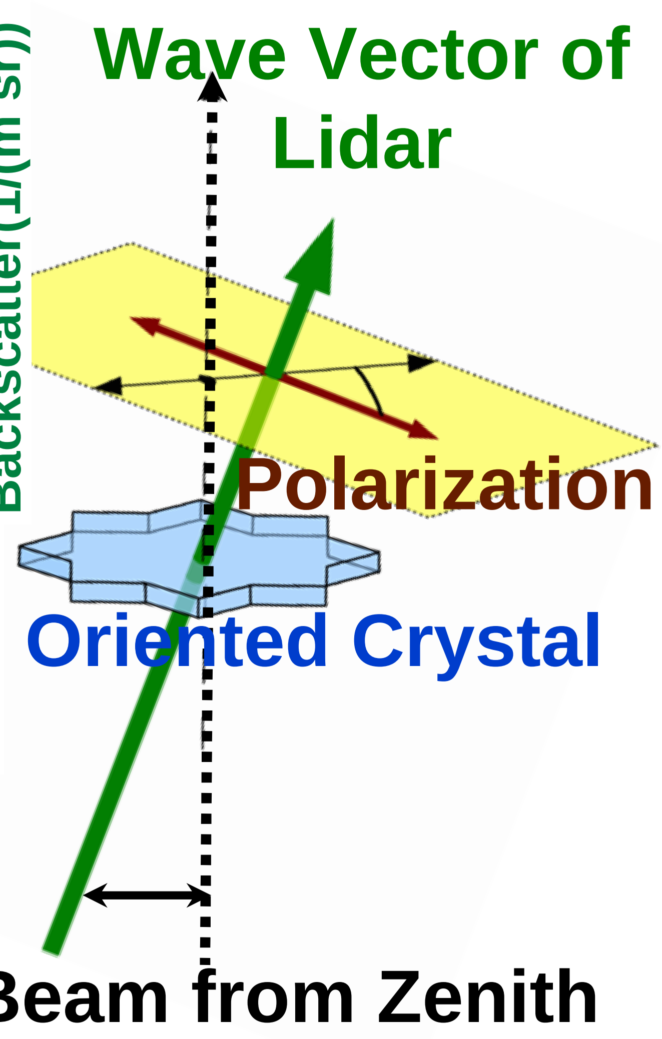
Where did we put it?

- Summit Station
  - Peak of the Greenland Ice Cap (3.2km a.s.l)
  - 400km from coast
  - 72°34'44.10"N 38°27'34.56"W

NSF's Mobile Science Facility

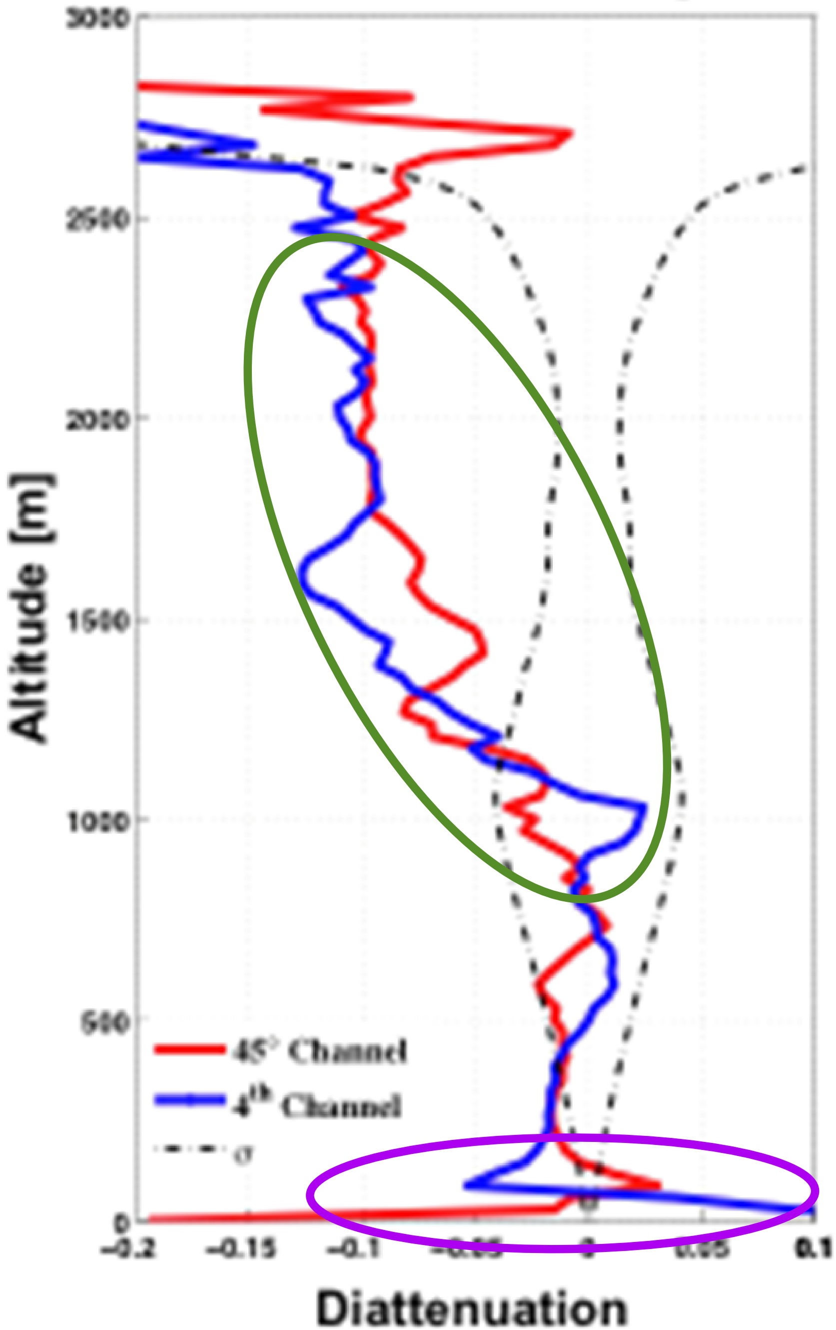
Ability to measure oriented ice crystals is dependent on pointing angle of lidar.



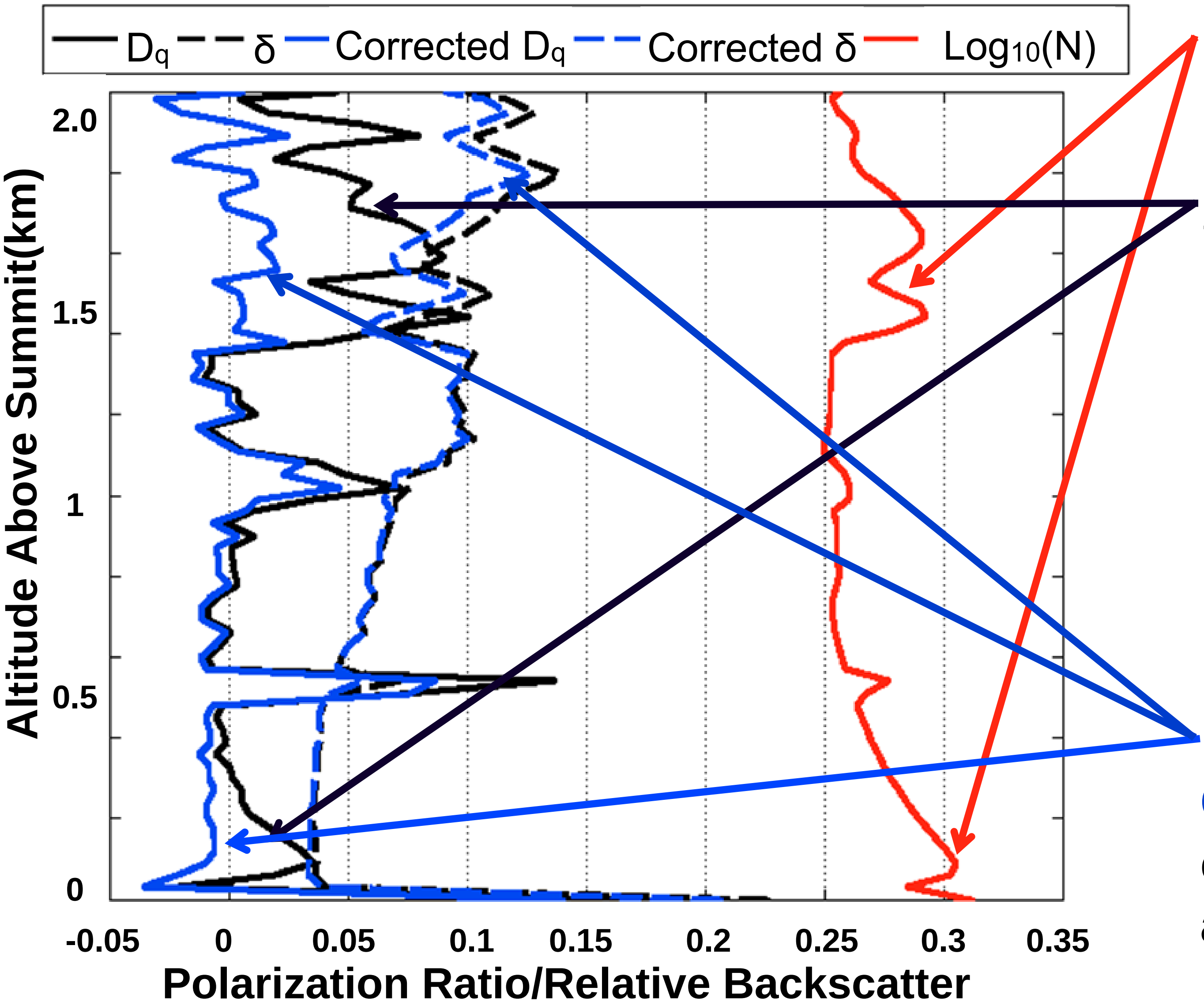


Self Validation of Diattenuation Measurement Against Instrumental Effects

- **Integrated profile** from 5:30 to 6:00 UTC on February 18, 2012 (a section from the whole day shown in **pervious slide**).
- Using the liquid crystal rotator we can make a **second** measure of diattenuation using another set of off diagonal elements form the scattering matrix.
- This allows for the **two measures of diattenuation** to be **influenced differently by detector saturation.**
- Regions **where both diattenuation profiles track together,** above the error limits**, contain positive detection of diattenuatting scatterers.**
- Regions where the two diattenuation profiles **behave oppositely,** as is seen in the bottom of the profile, **is due to detector saturation.**



Diattenuation help lidar observations to be more accurate in other ways.



Strong Backscatter introduces **error** to data products due to nonlinear detector gain (pulse pile up).

Nonlinearity may be solved for because diattenuation detected in zenith direction is defined as zero.

Corrected backscatter counts produce **more accurate** data products.

Dynamic range of backscatter detection is increased by an order of magnitude.