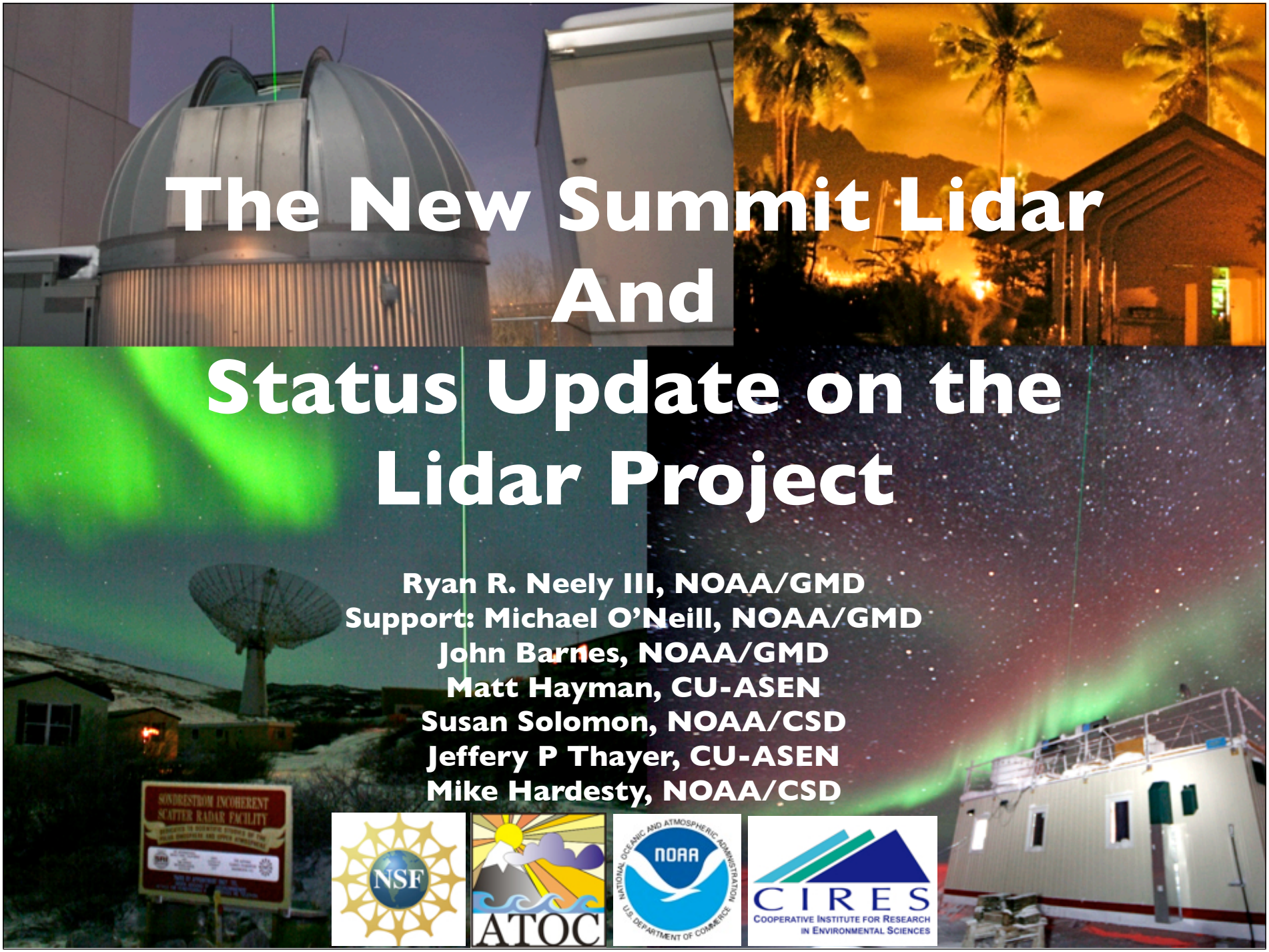
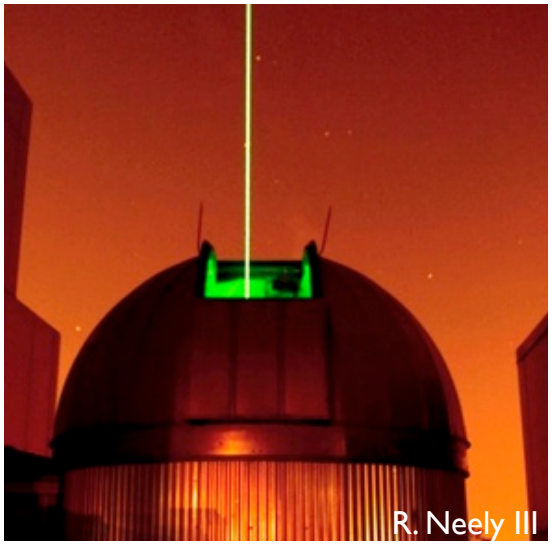


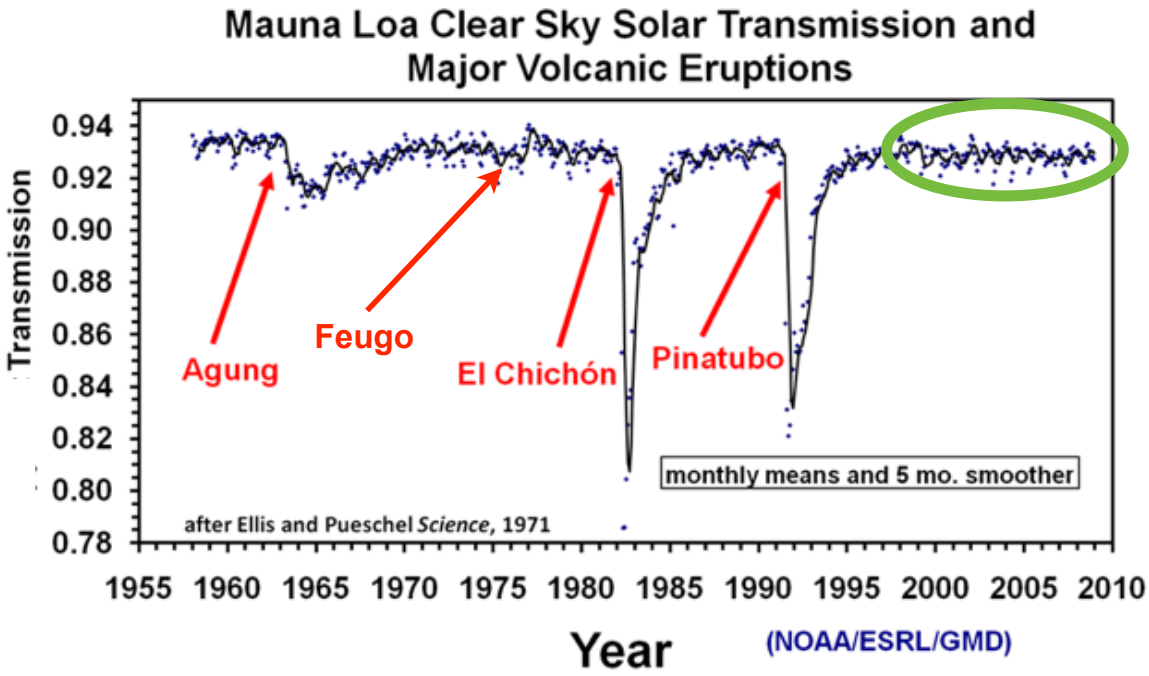
The New Summit Lidar And Status Update on the Lidar Project

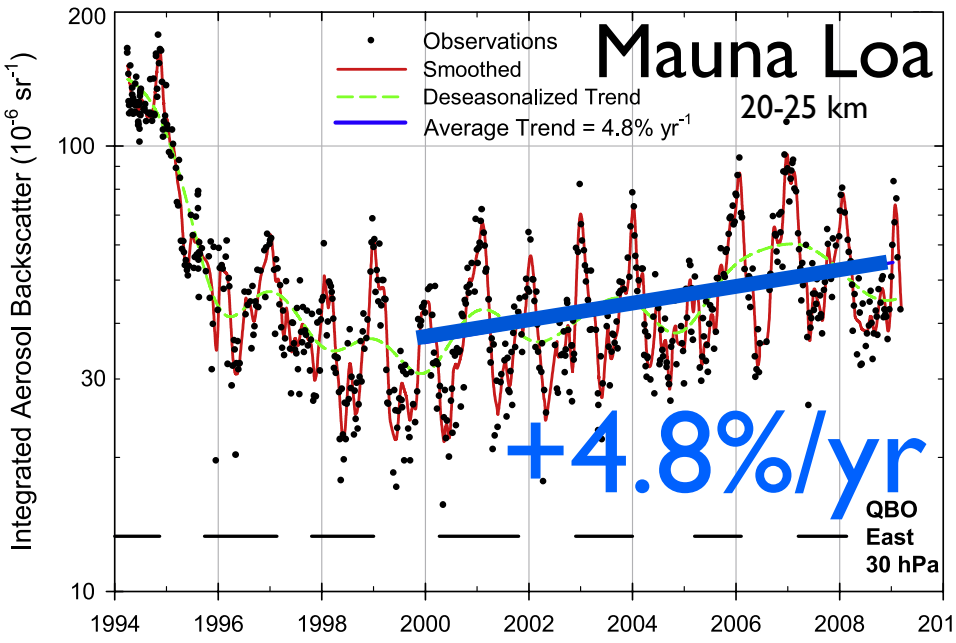
Ryan R. Neely III, NOAA/GMD
Support: Michael O'Neill, NOAA/GMD
John Barnes, NOAA/GMD
Matt Hayman, CU-ASEN
Susan Solomon, NOAA/CSD
Jeffery P Thayer, CU-ASEN
Mike Hardesty, NOAA/CSD

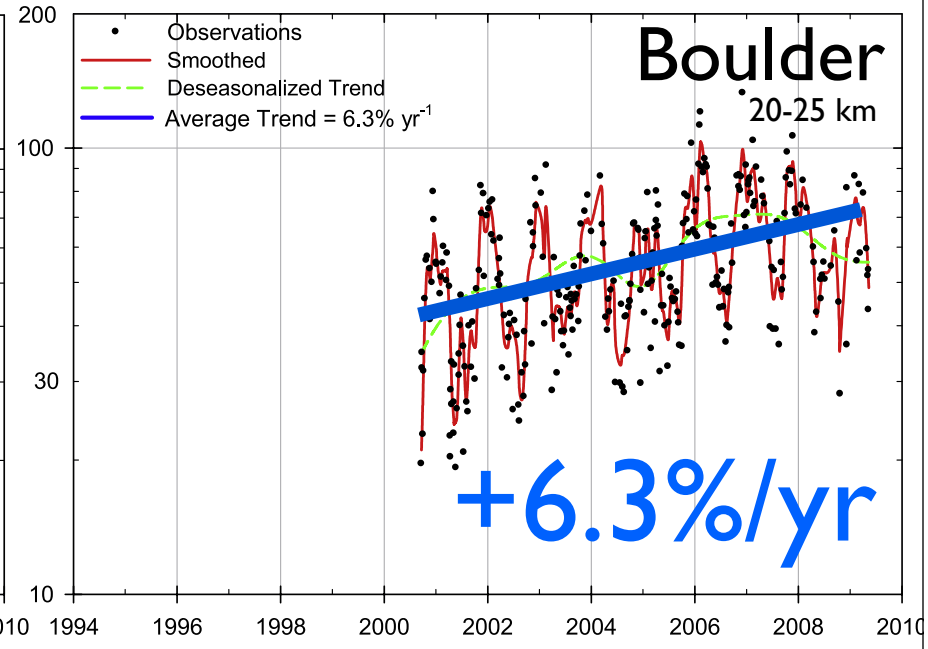
NSF ATOC NOAA CIRES Cooperative Institute for Research in Environmental Sciences

Why?









Adapted from Hofmann at al. (2009)

Research Questions

Stratospheric Aerosols:

Seasonal cycles? Sources Long-term trends?

Effects on Climate?

Clouds over the Greenland Icecap:

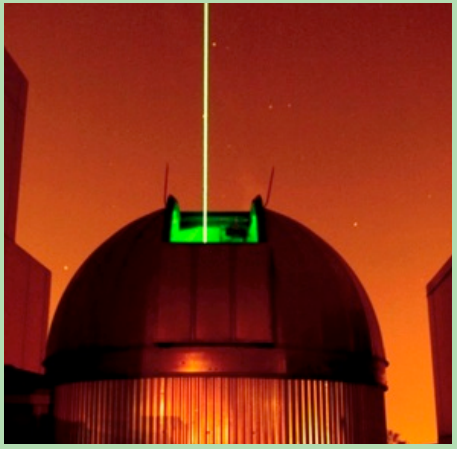
Effects of Crystal Orientation on Radiation Budget?

Arctic Cloud Microphysics

How Will I Answer These?

Observations

Lidar



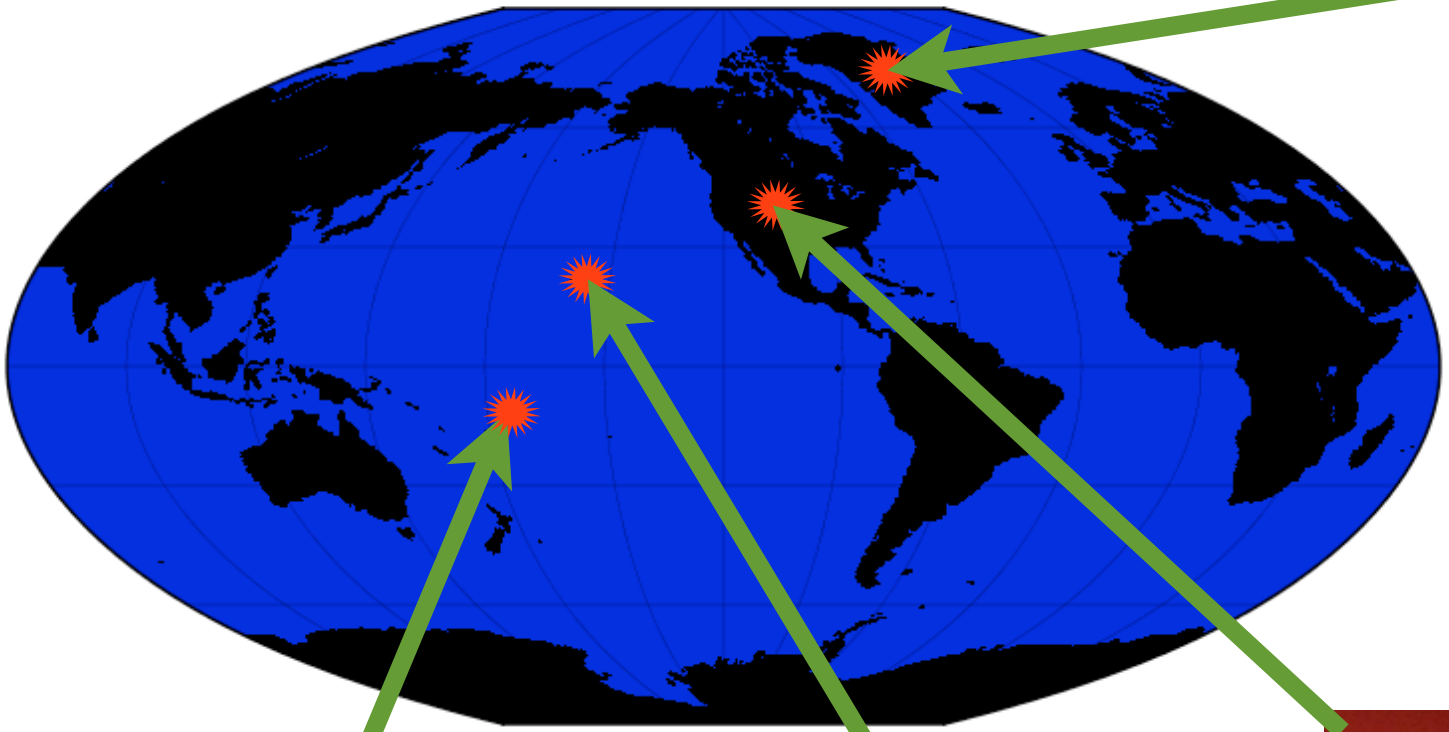
Boulder Lidar (R. Neely III)

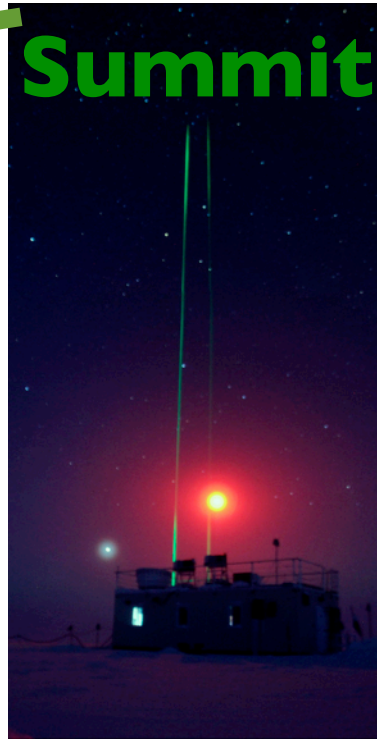
Modeling

WACCM/CARMA

Pleiades Supercomputer
(NASA AMES)

Current GMD Lidars





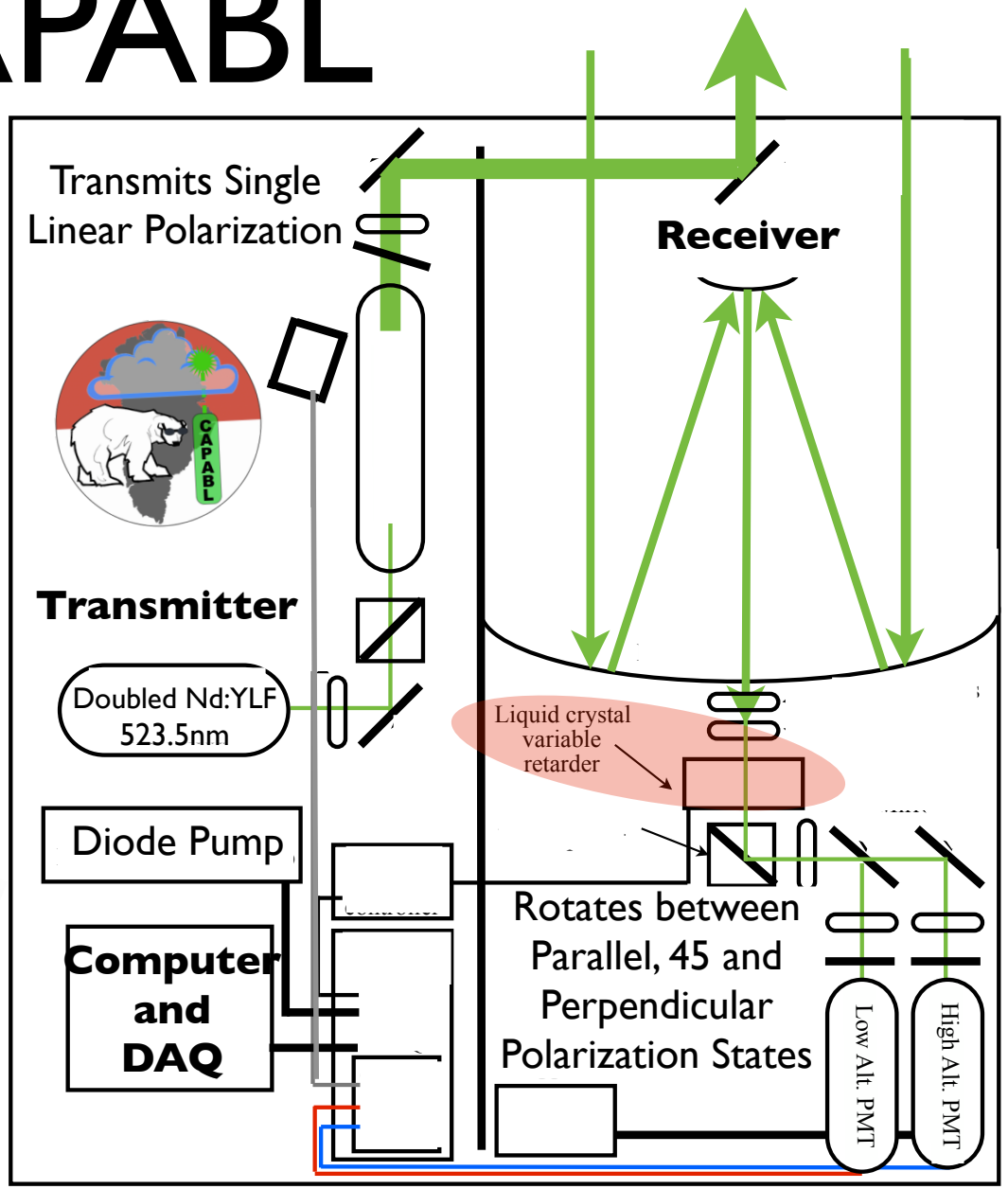
The Cloud, Aerosol Polarization And Backscatter Lidar

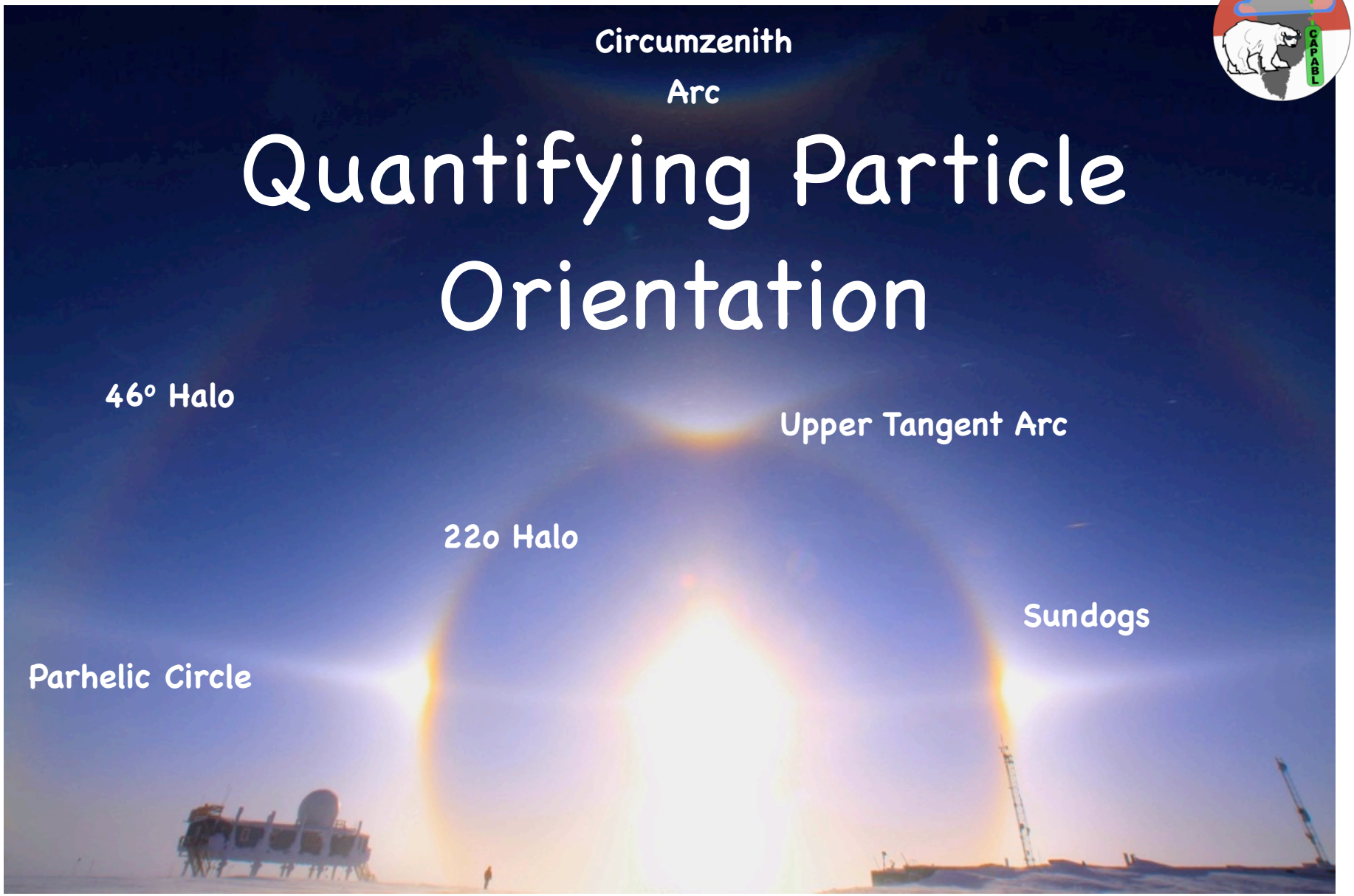
Why did we put this lidar at Summit?

- **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

CAPABL

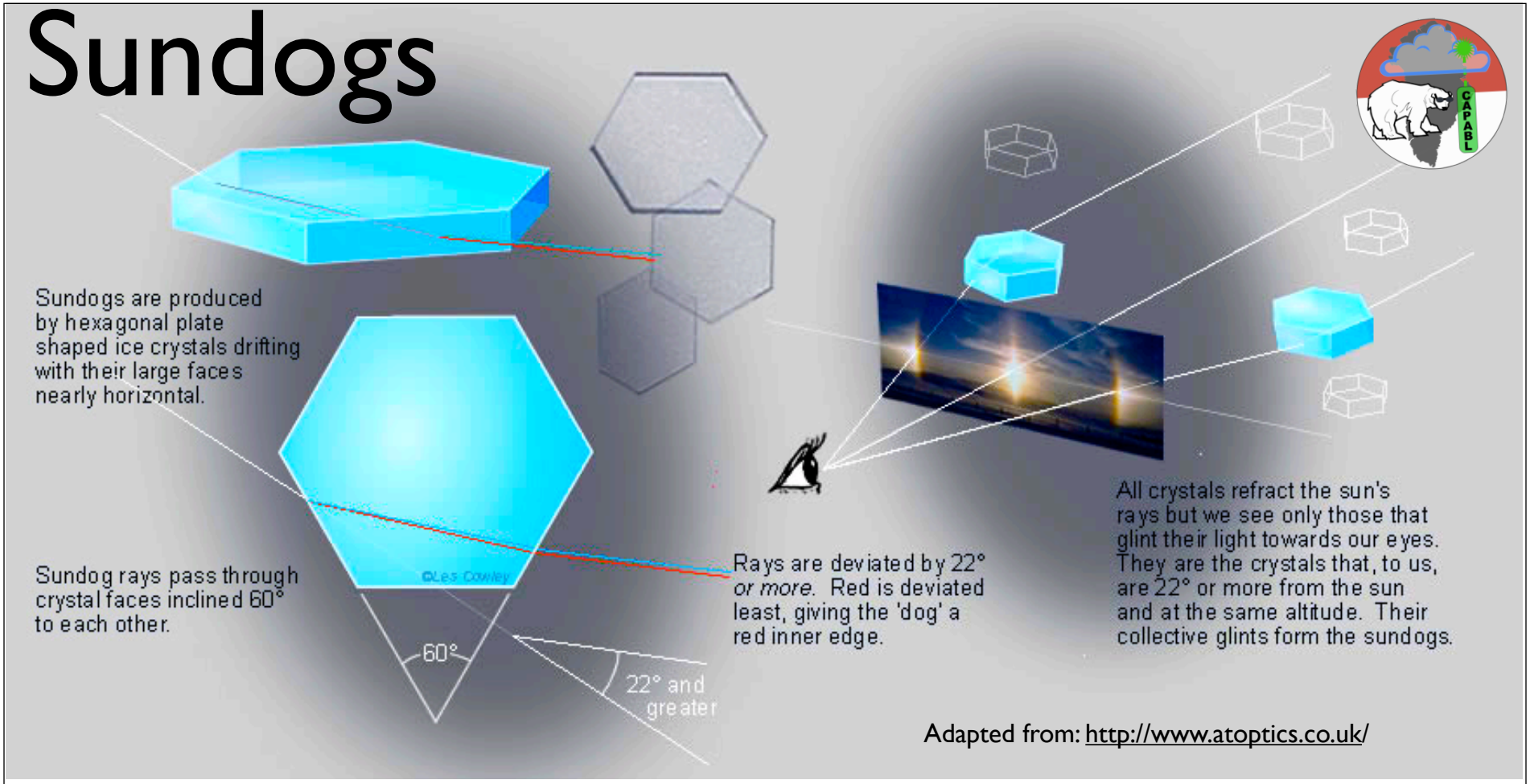
- **Triple linear polarization** measurement(Parallel, Perpendicular, 45° Polarizations)
- **30m** spatial and **5s** temporal resolution
- **24/7** automated operations with remote access.
- Controllable via iPhone (Come find me if you want to see th
- Installed at Summit Camp during May 2010



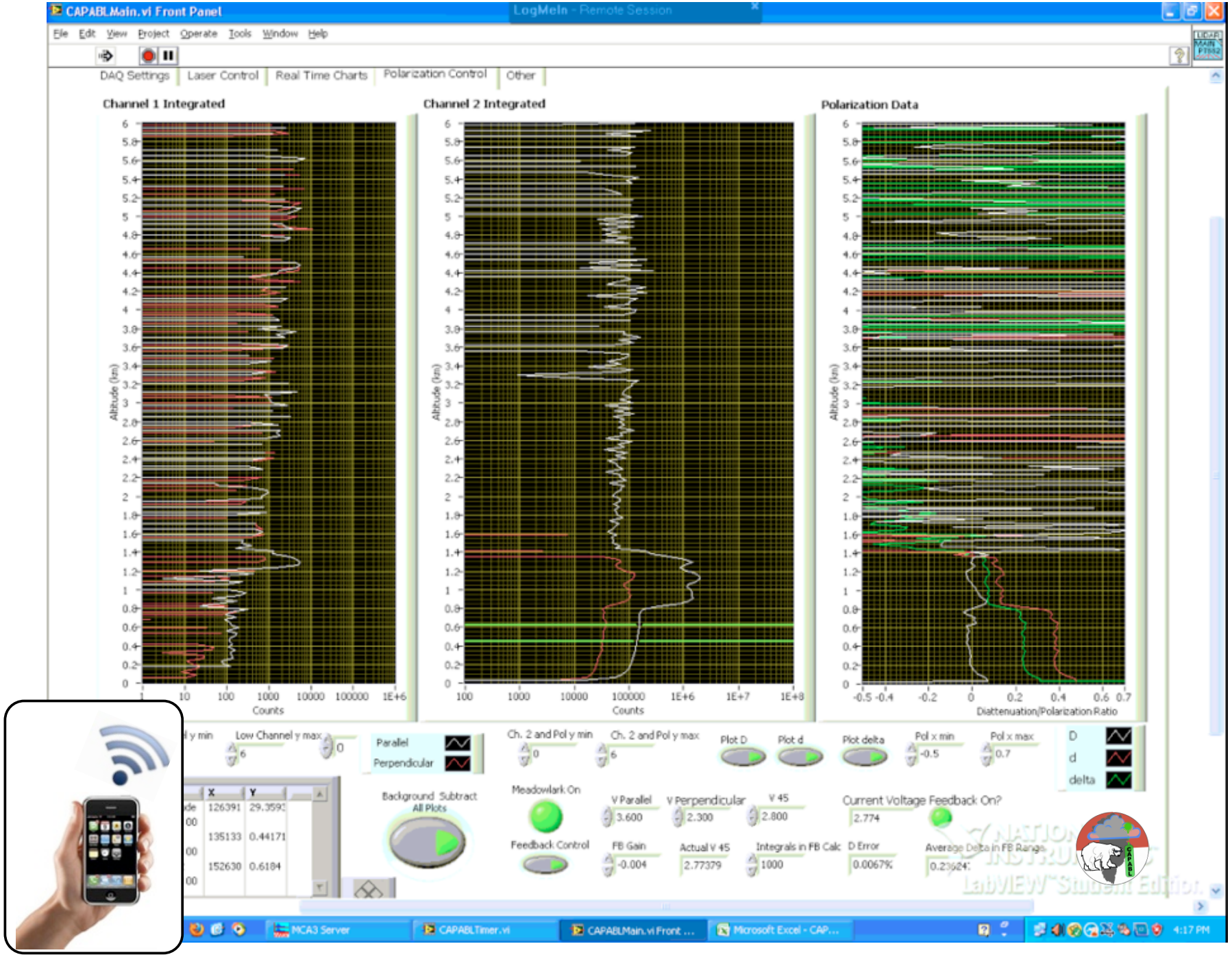


Courtesy of Chris Cox

Sundogs



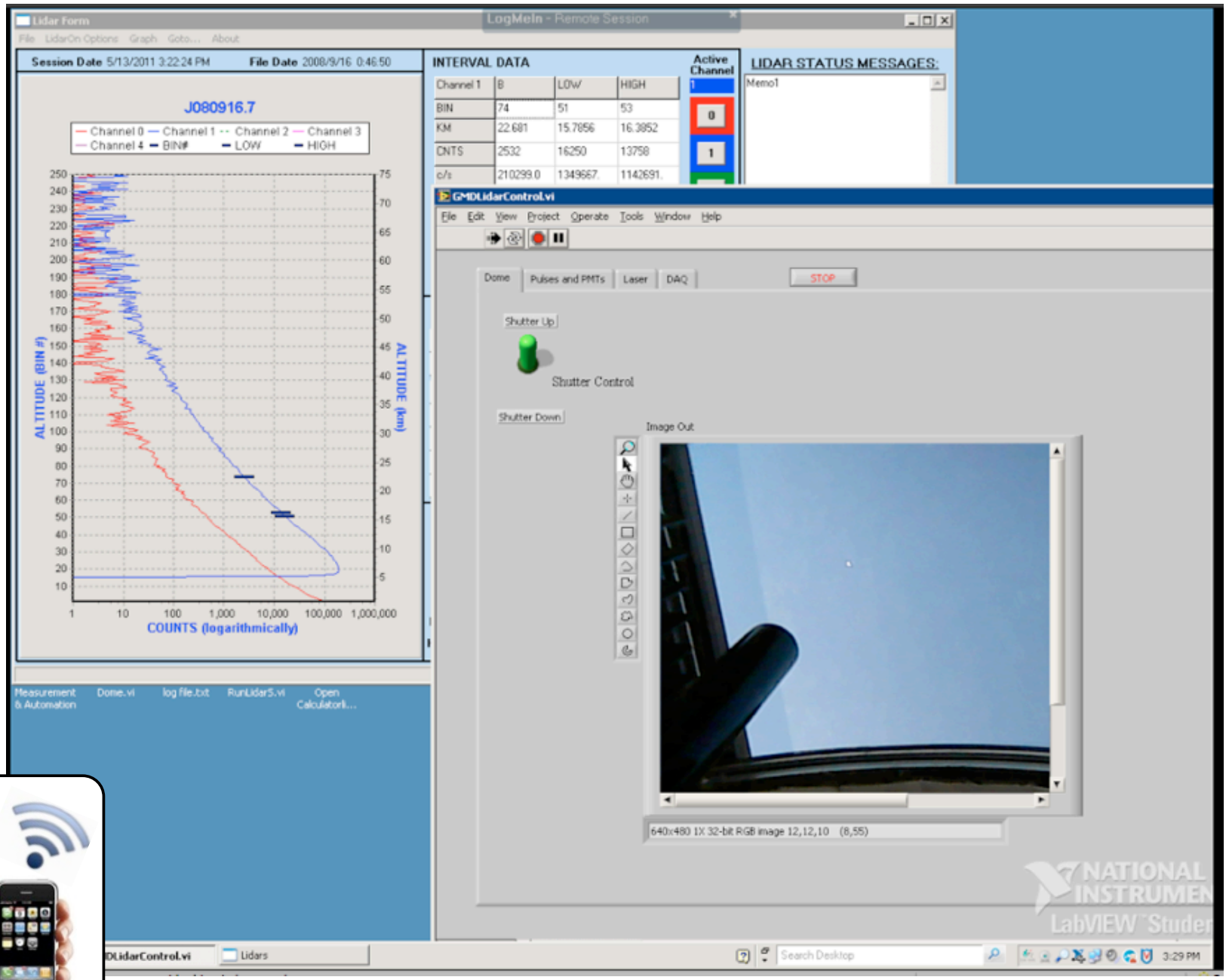
$\updownarrow + \longleftrightarrow \neq$ 2 x 45° Polarization


CAPABLMain.vi Front Panel
LogMeIn - Remote Session
File Edit View Project Operate Tools Window Help
DAQ Settings
Laser Control
Real Time Charts
Polarization Control
Other
Channel 1 Integrated
Channel 2 Integrated
Polarization Data
Altitude (km)
Counts
Counts
Diattenuation/Polarization Ratio
Low Channel y max
Parallel
Perpendicular
Ch. 2 and Pol y min
Ch. 2 and Pol y max
Plot D
Plot d
Plot delta
Pol x min
Pol x max
D
d
delta
Background Subtract
All Plots
Meadowlark On
V Parallel
V Perpendicular
V 45
Current Voltage Feedback On?
Feedback Control
FB Gain
Actual V 45
Integrals in FB Calc
D Error
Average Delta in FB Range
LabVIEW Student Edition
MCA3 Server
CAPABLTimer.vi
CAPABLMain.vi Front ...
Microsoft Excel - CAP...
4:17 PM

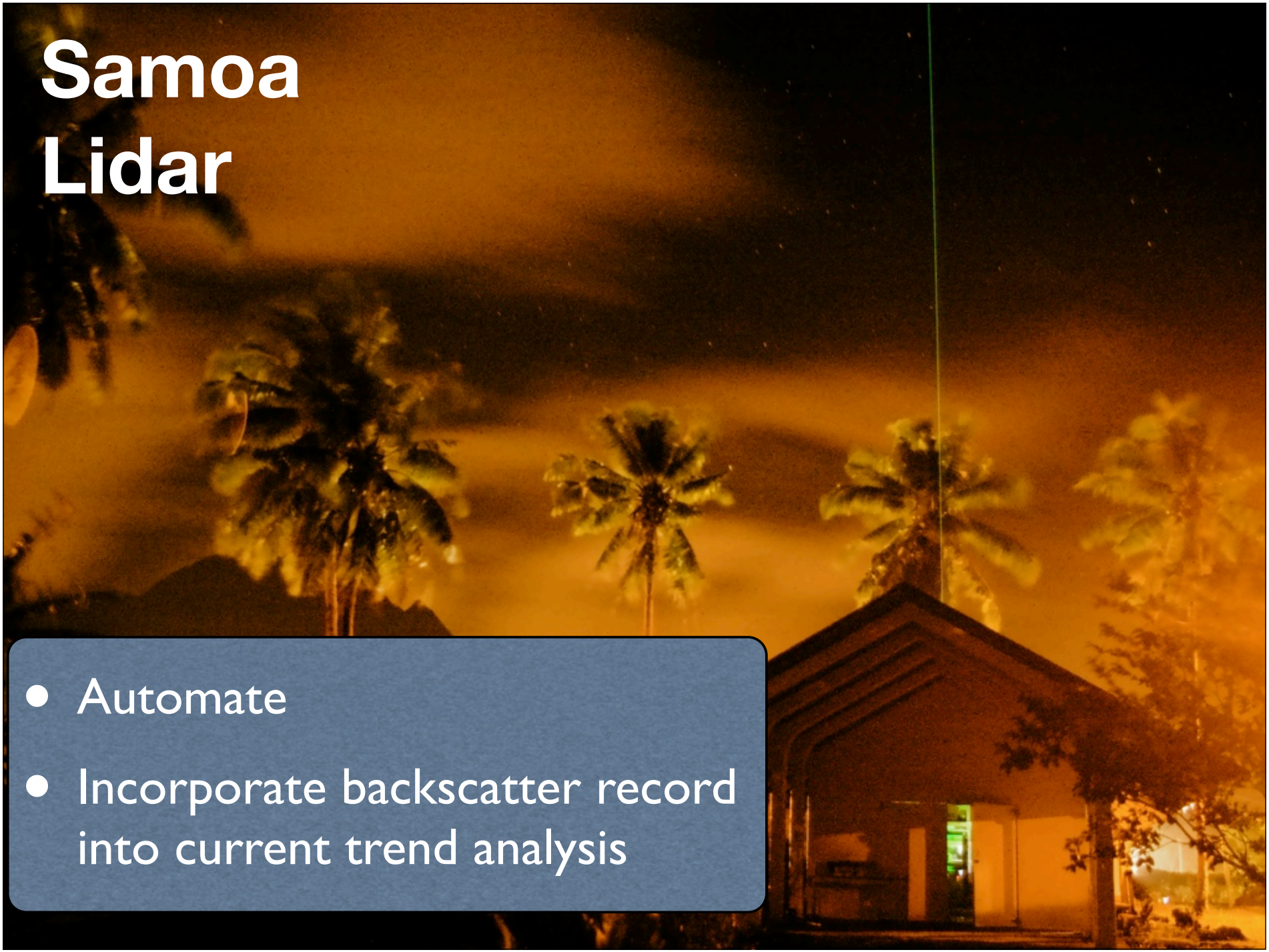
- **CAPABL produces:**
  - Total Linear Polarization Ratio
    - Better cloud phase measurement by not assuming random orientation (less than 2% error)
  - Particle Orientation
  - Backscatter
    - Extends GMD's Stratospheric Lidar Network.
- **98% Data Collection Time Over the last 11 months**

Boulder Lidar

- Finish Automation
- Improve Backscatter Retrieval



Currently Controllable via iPhone

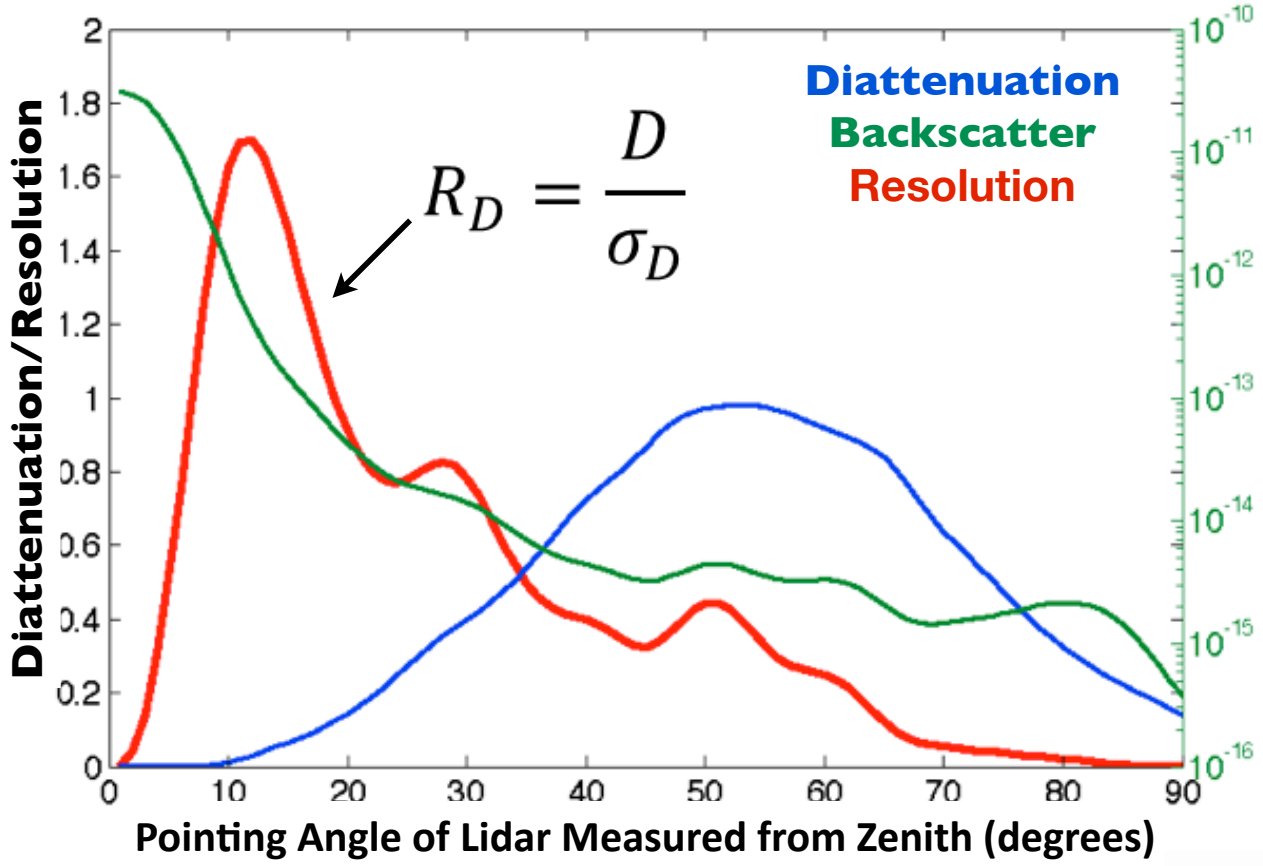

Samoa
Lidar
• Automate
• Incorporate backscatter record into current trend analysis

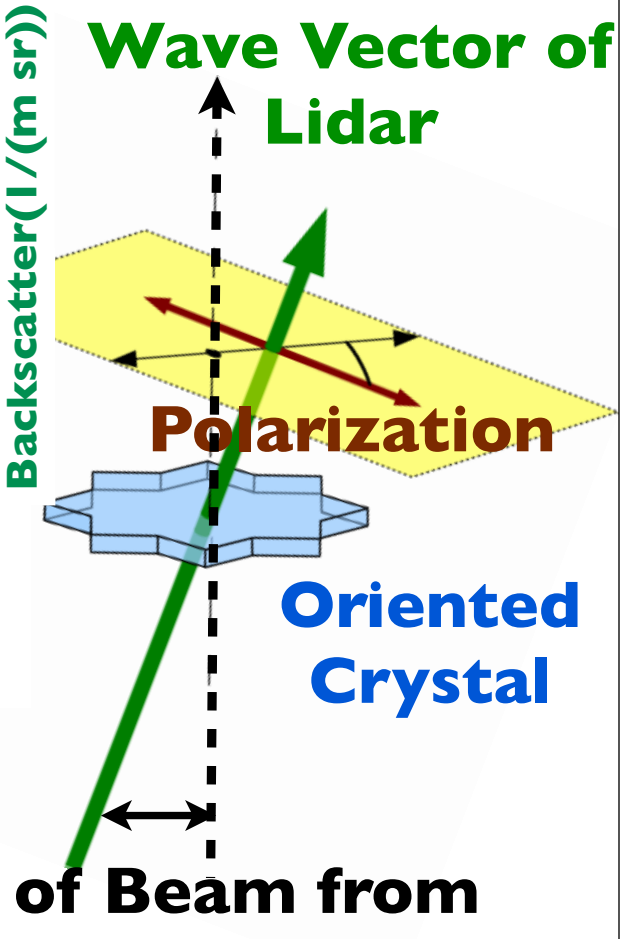
Summary

- **2011 Research Goals**
  - **Summit**
    - **Publish instrument Paper on new techniques**
  - **Boulder**
    - **Finish Automation**
  - **Samoa**
    - **Automate**
    - **Increase Data collection to at least twice weekly profiles**
  - **Updated Lidar Database**
    - **Accessible to Public**
    - **NetCDF format**
  - **Updated Backscatter Retrieval Algorithm**
  - **Finish and Publish Trend Analysis**

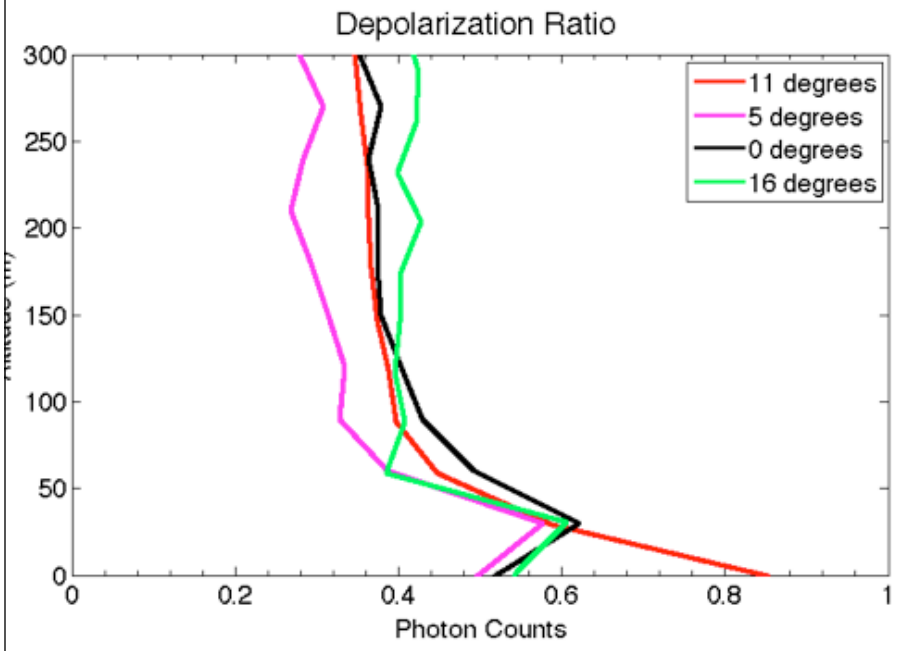

Thank You All
For Your
Help and Support
Ed Stockard

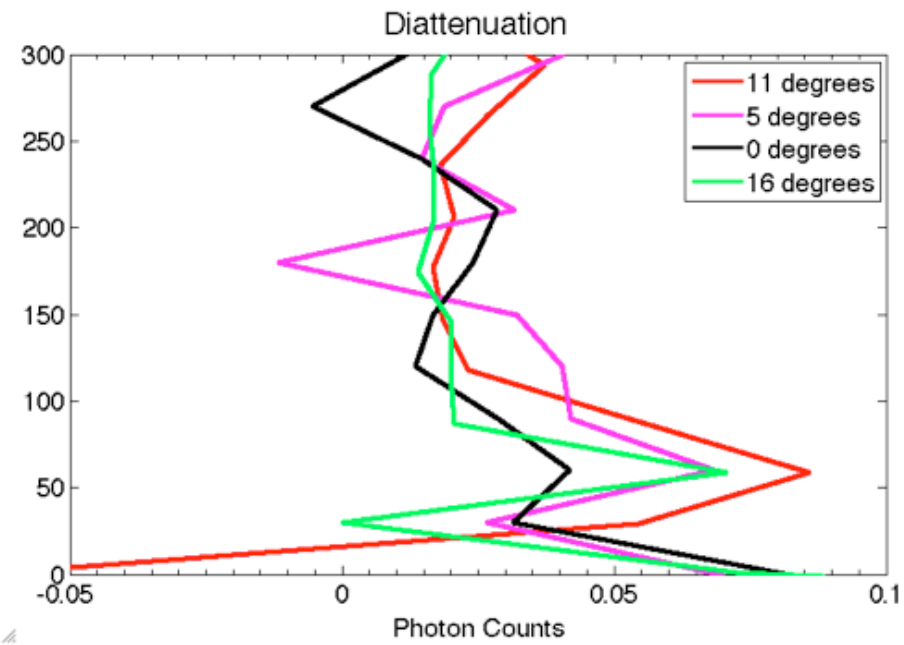
Ability to measure oriented ice crystals is dependent on pointing angle of lidar.





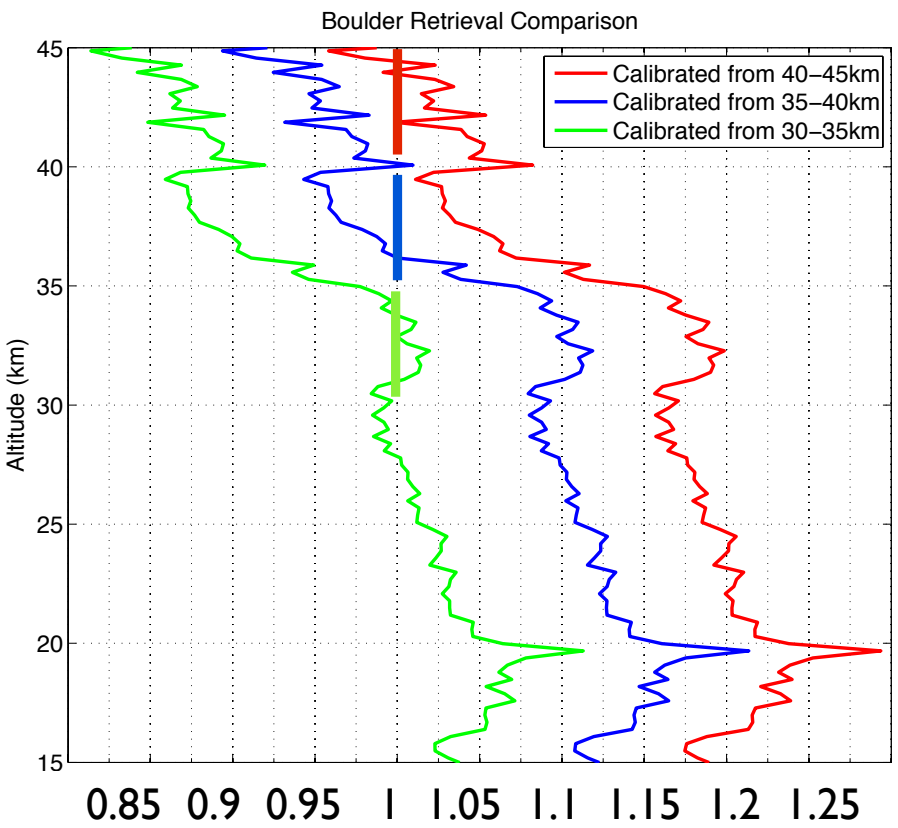
Preliminary Results: April 23, 2011





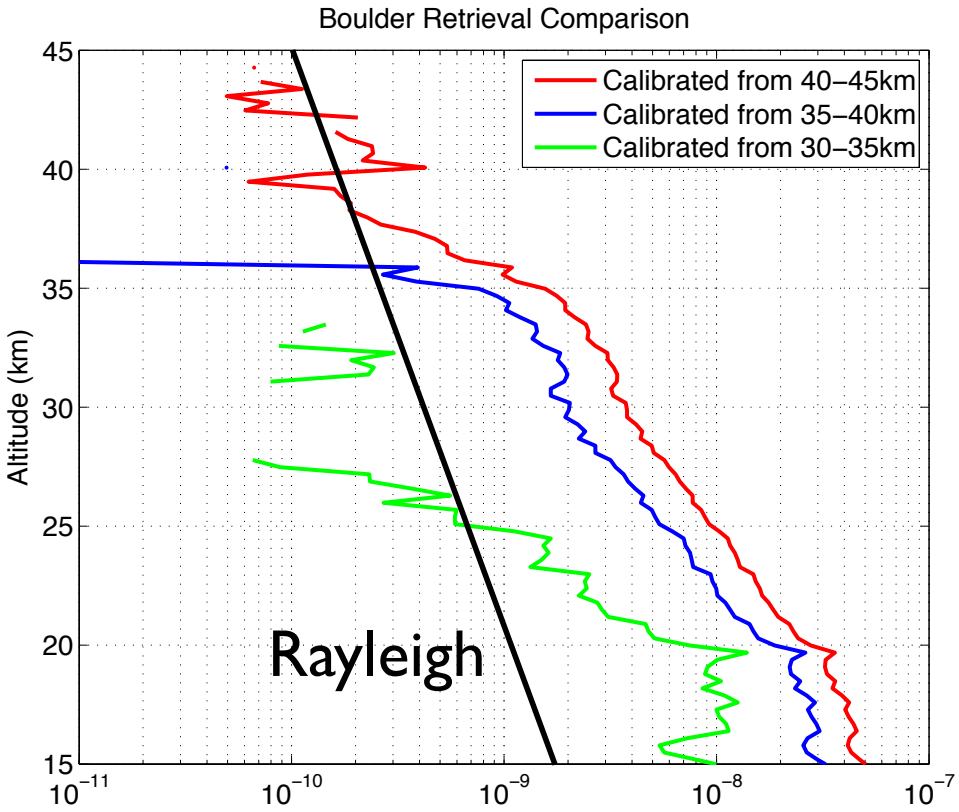
Lidar Retrieval Error

Derivable



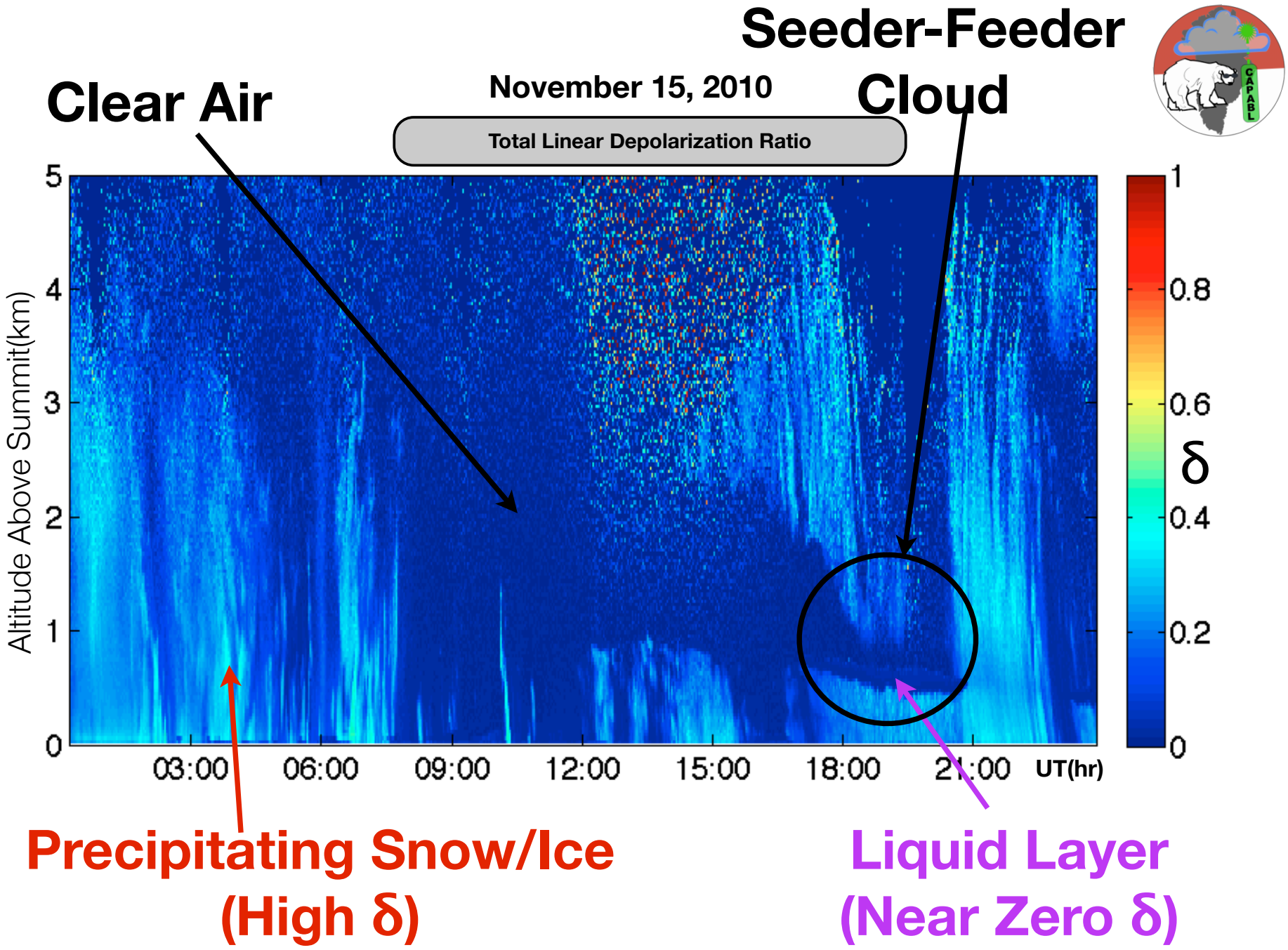
Backscatter Ratio [(A+M)/M]

Backscatter



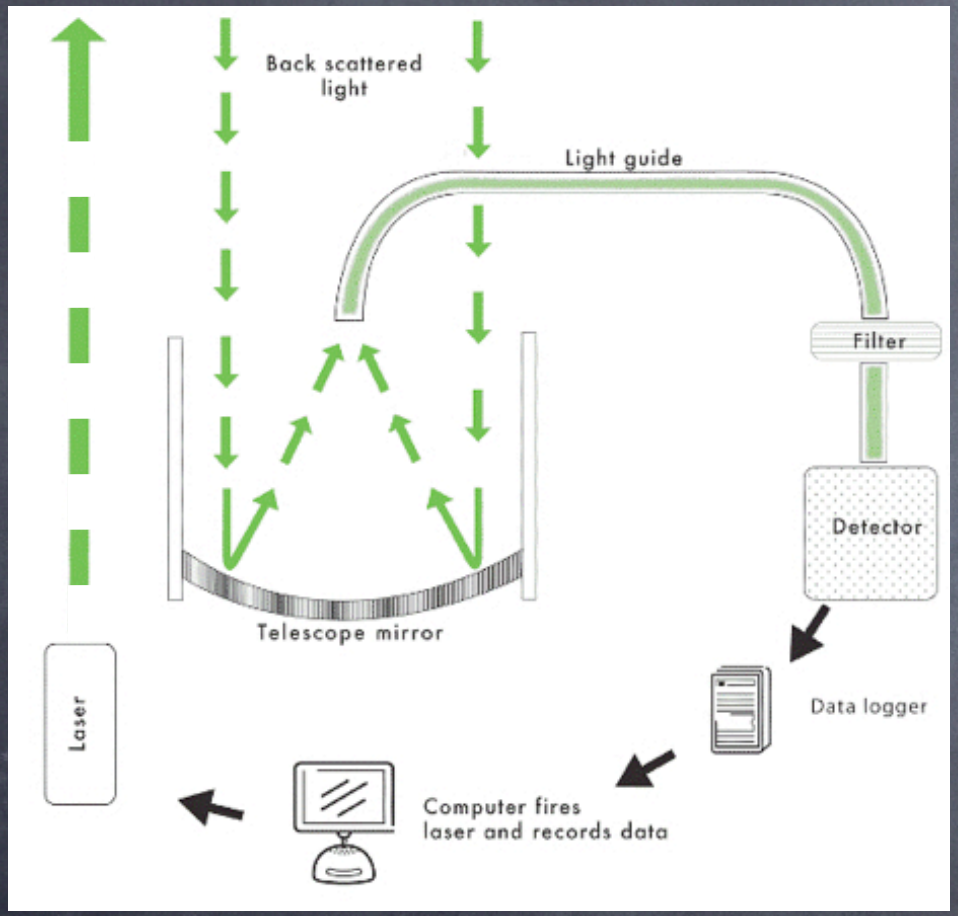
Backscatter(1/km 1/sr)

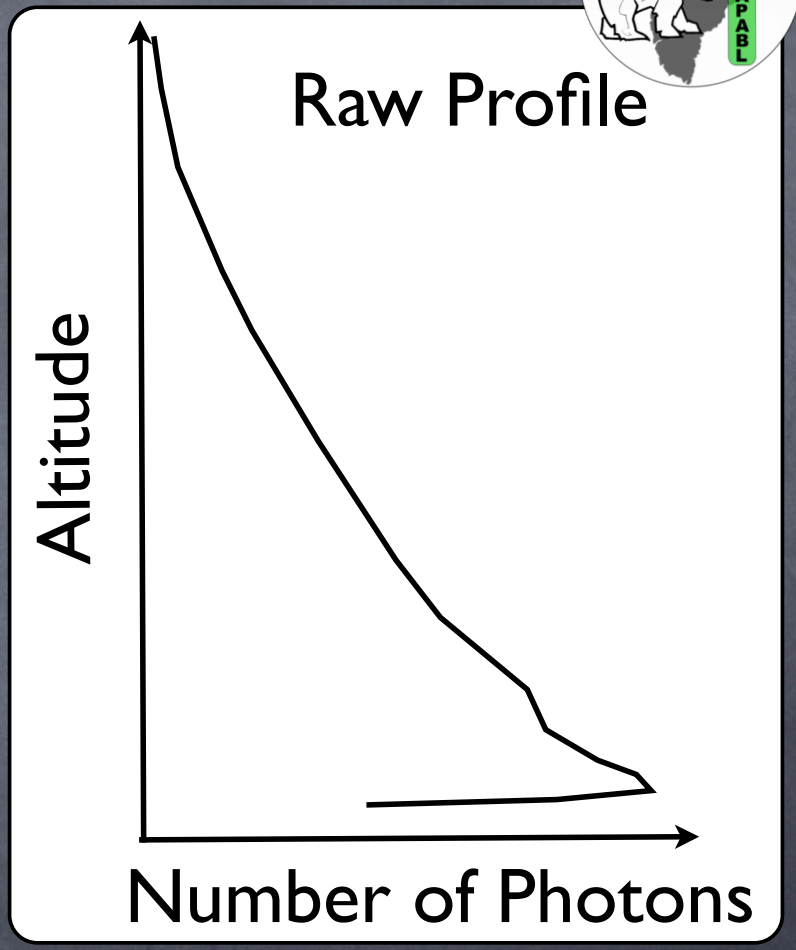
More about this tomorrow


Seeder-Feeder Cloud
Clear Air
November 15, 2010
Total Linear Depolarization Ratio
Altitude Above Summit(km)
0
1
2
3
4
5
03:00
06:00
09:00
12:00
15:00
18:00
21:00
UT(hr)
δ
0
0.2
0.4
0.6
0.8
1
Precipitating Snow/Ice
(High δ)
Liquid Layer
(Near Zero δ)

How Do I Measure That?

Answer: Polarization LIDAR



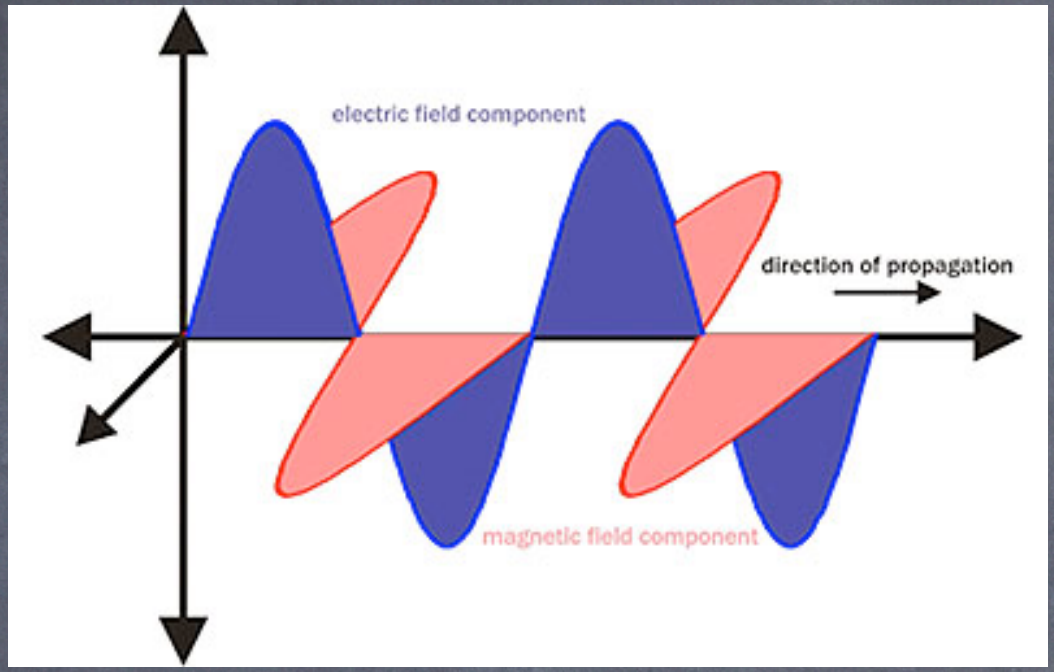


$$N(\lambda, z) = N_L(\lambda)[\beta(\lambda, z)\Delta R]\frac{A}{z^2}exp[-2\int_0^z \alpha(\lambda, z')\,dz'][\eta(\lambda)G(\lambda, z)] + N_B(\lambda, z)$$

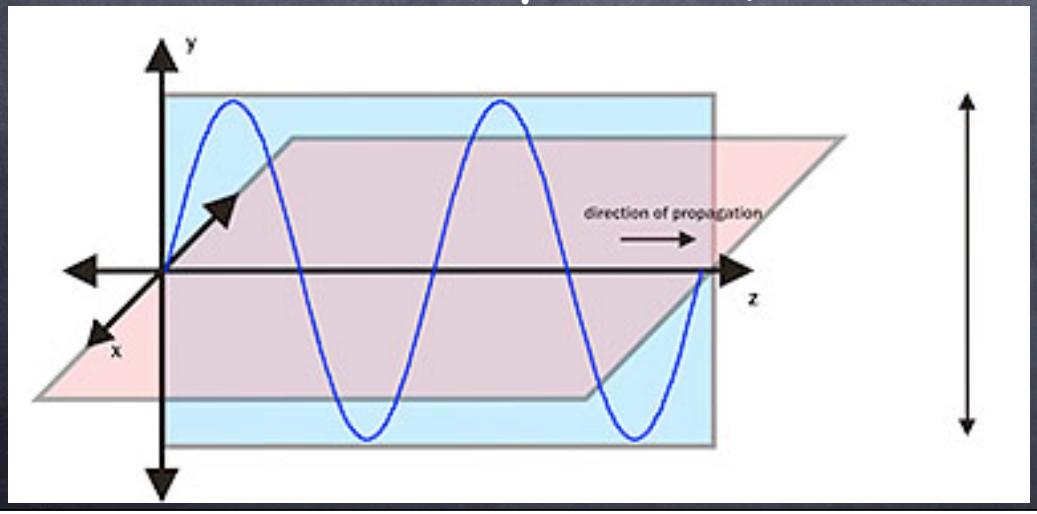
Lidar Equation

What is Polarization?

Light Wave

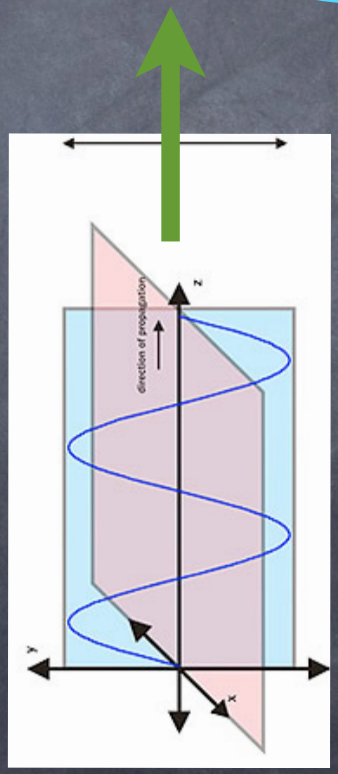


This is the basic quantity that I measure



How do we measure polarization with this lidar?

Particles



1 Transmit Highly Polarized Light From LIDAR

2 Light Scatters back to LIDAR off of Particles

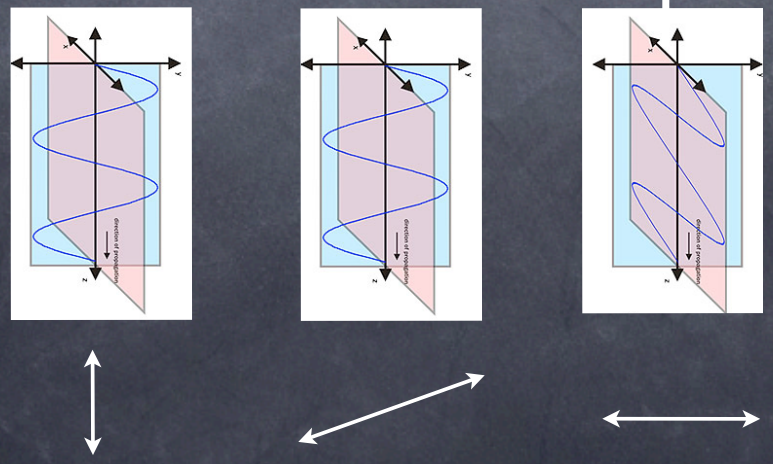
3 What is the light's polarization now?

Rotating Polarizing Optics

Parallel

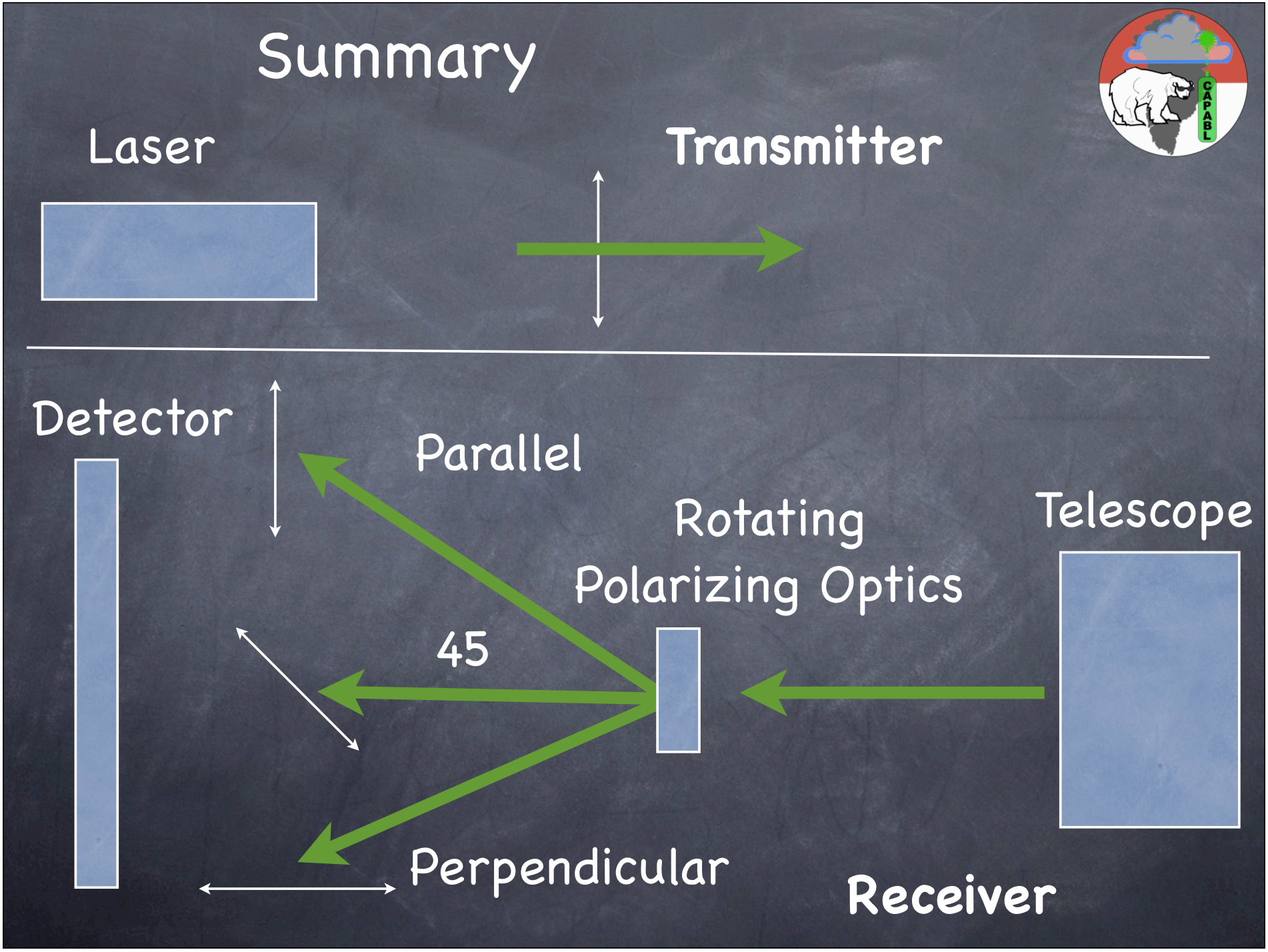
45

Perpendicular



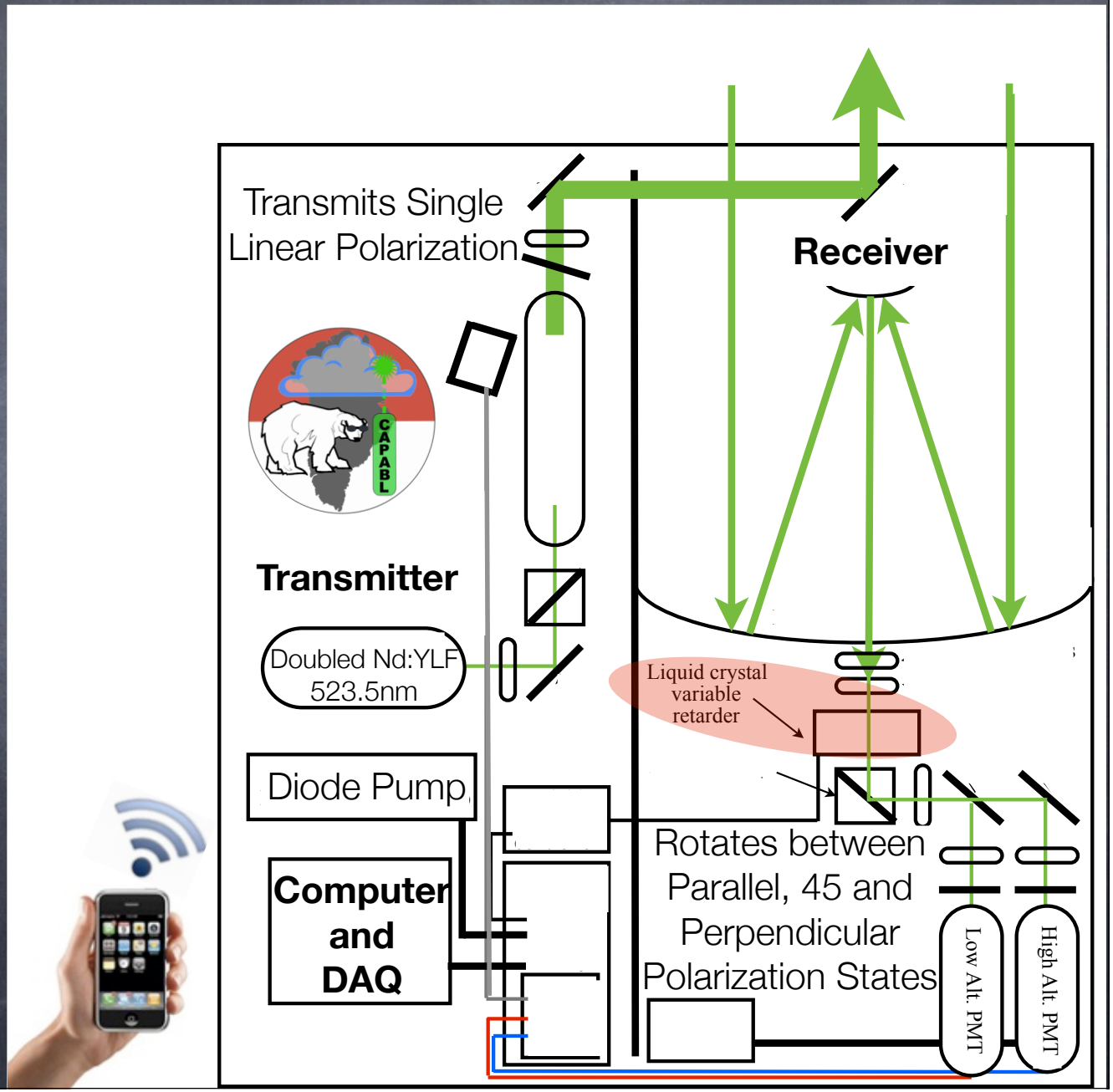
4

Summary


Laser
Transmitter
Detector
Parallel
Rotating
Polarizing Optics
Telescope
45
Perpendicular
Receiver

How does CAPABL work?

- Triple linear polarization measurement
- 30m spatial and 5s temporal resolution
- 24/7 automated operations with remote access.
- Controllable via iPhone



Why Polarization?

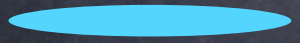
Depolarization =

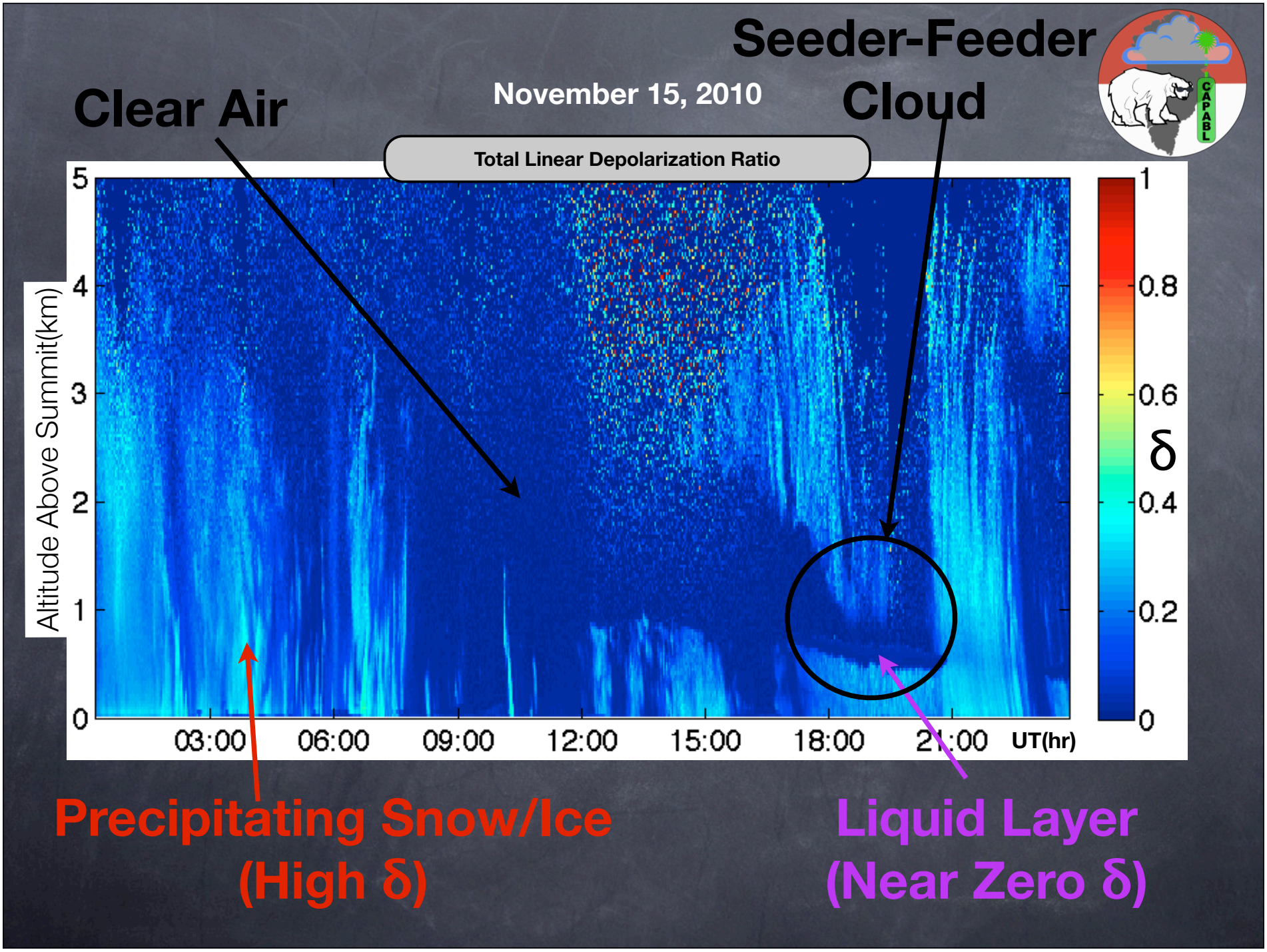
How much has my transmitted polarized light been screwed up?

$$\text{Depolarization} = \frac{\text{Perpendicular}}{\text{Parallel}}$$

Depolarization ranges from 0 to 1

Liquid  $\frac{\text{Perpendicular}}{\text{Parallel}}$ = Small

Ice  $\frac{\text{Perpendicular}}{\text{Parallel}}$ = Large(>.08)


Seeder-Feeder Cloud
November 15, 2010
Clear Air
Total Linear Depolarization Ratio
Altitude Above Summit(km)
0
1
2
3
4
5
03:00
06:00
09:00
12:00
15:00
18:00
21:00
UT(hr)
δ
0
0.2
0.4
0.6
0.8
1
Precipitating Snow/Ice
(High δ)
Liquid Layer
(Near Zero δ)

Why Measure 3 Polarizations?

Diattenuation =
Do the particles prefer
one polarization over the other?

$$\text{Diattenuation} = \frac{2 \times \mathbf{45}}{\mathbf{Perpendicular} + \mathbf{Parallel}} - 1$$

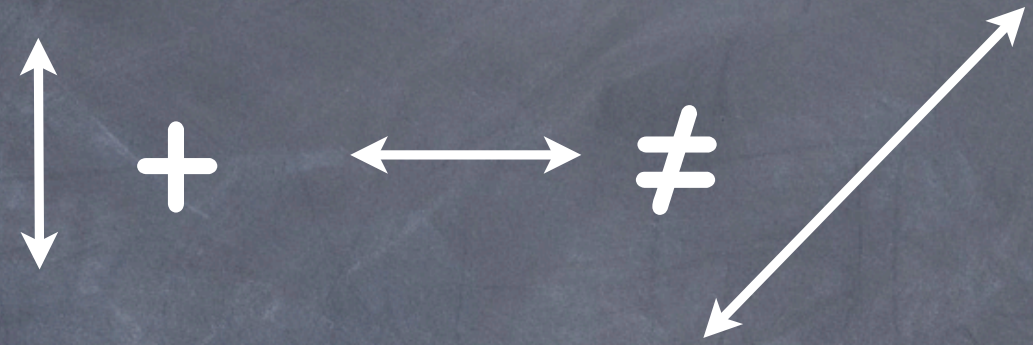
Does **Perpendicular** + **Parallel** = 2 x **45**?

Diattenuation and Oriented Particles

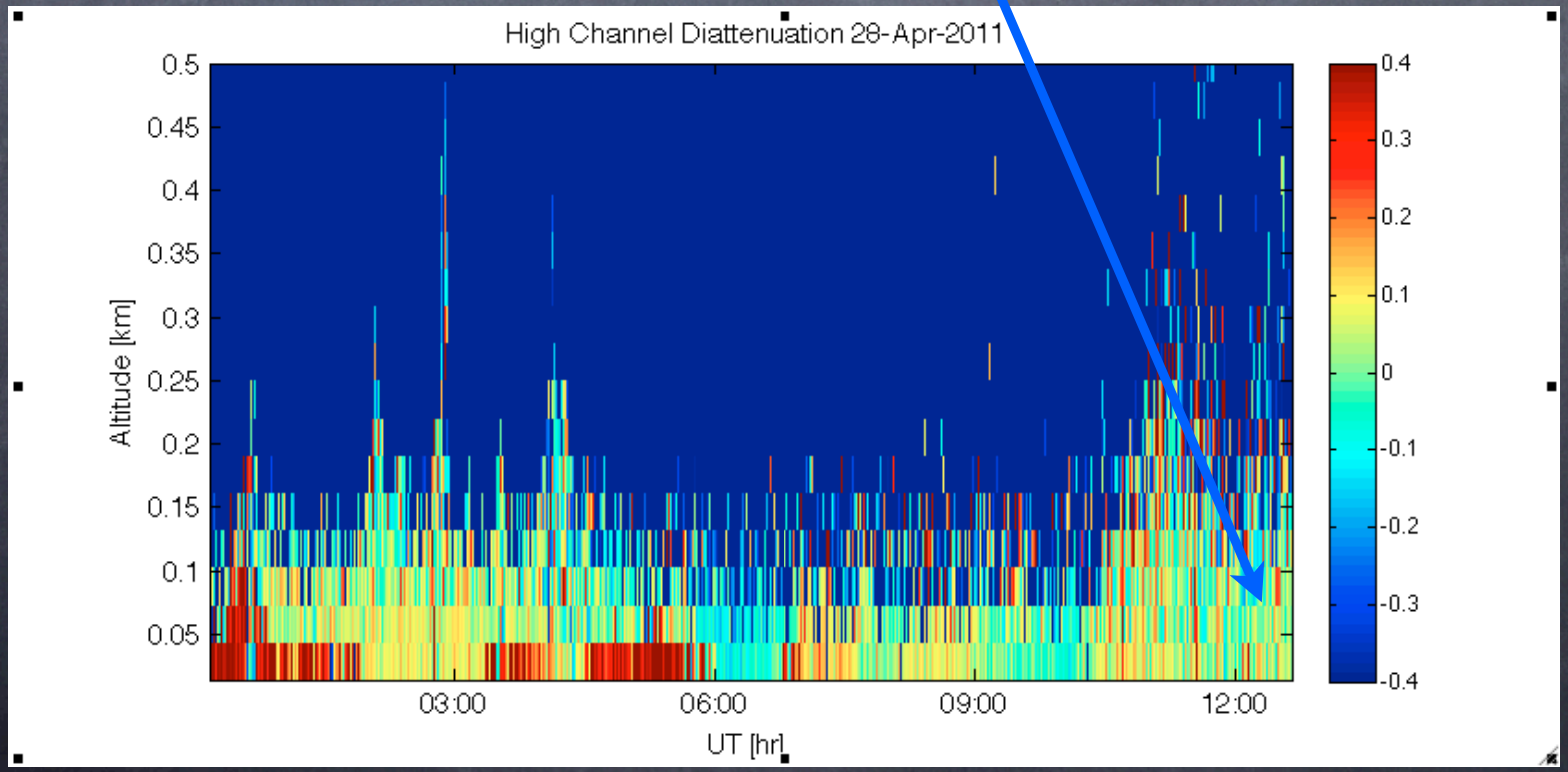
The 45 Polarization should be a linear combination of the parallel and perpendicular polarizations.

If this is not true something funny is going on

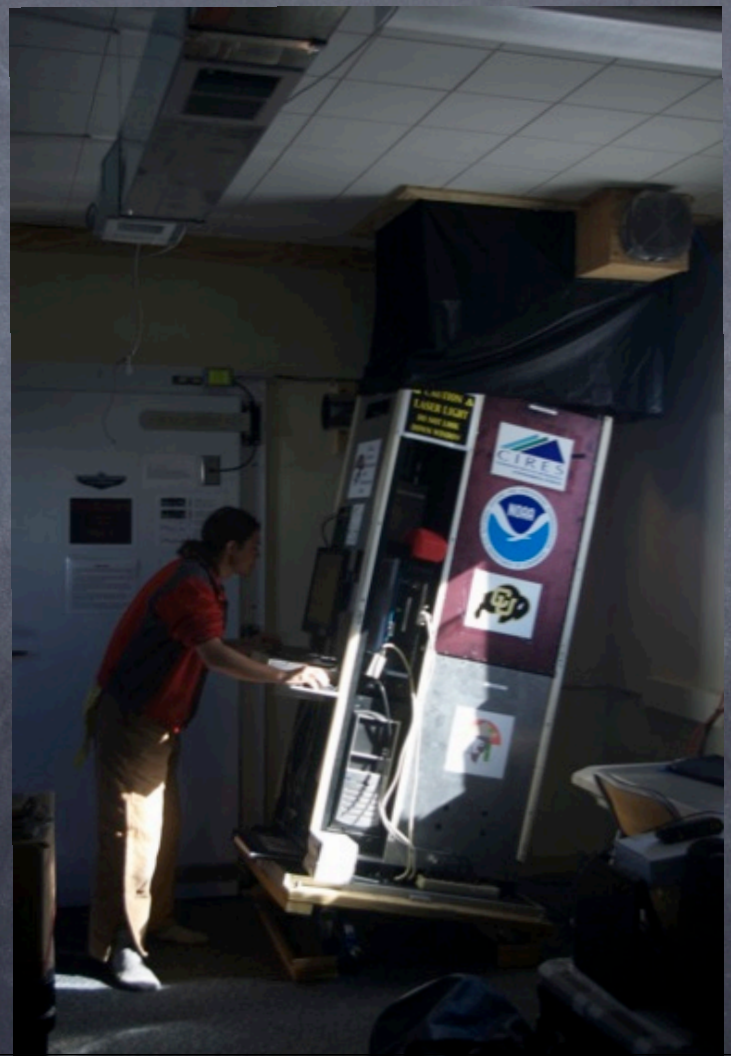
Oriented Particles



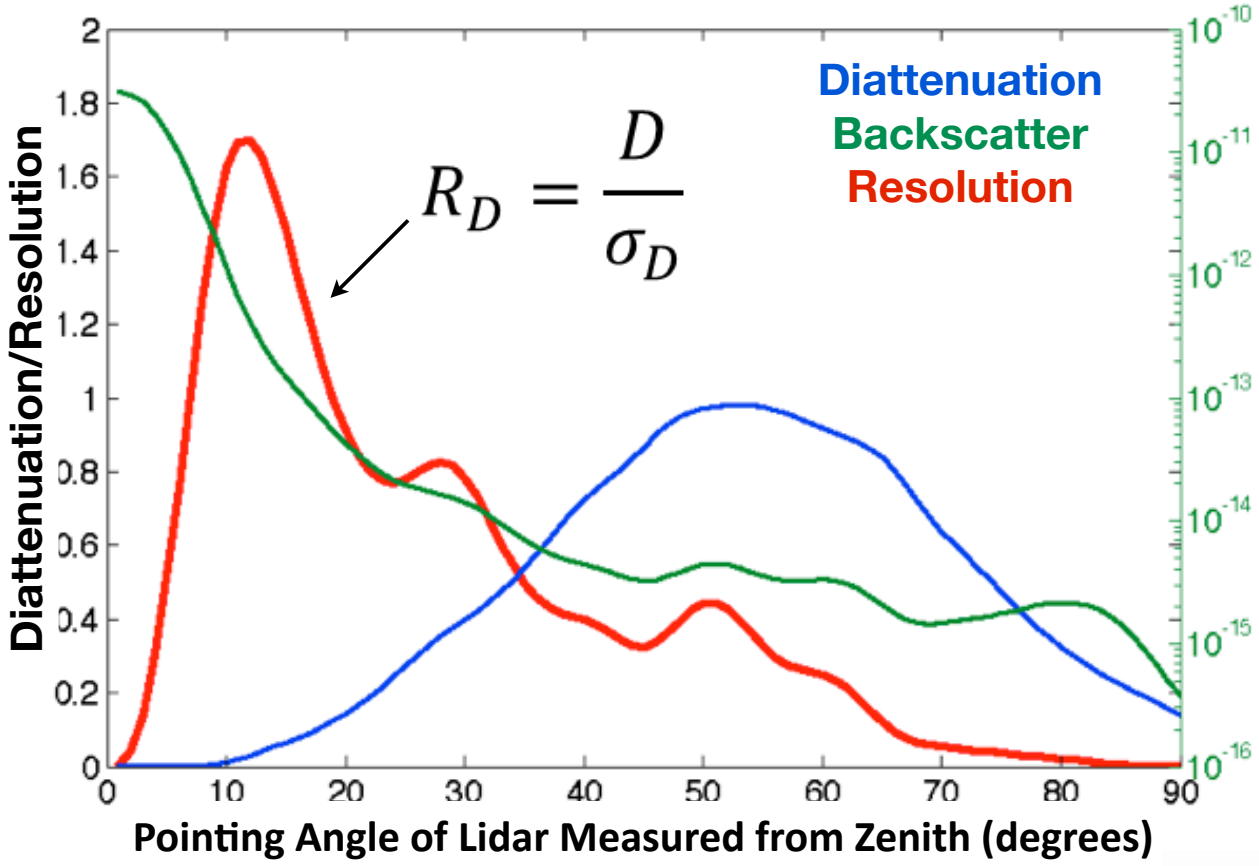
Data form Last Week

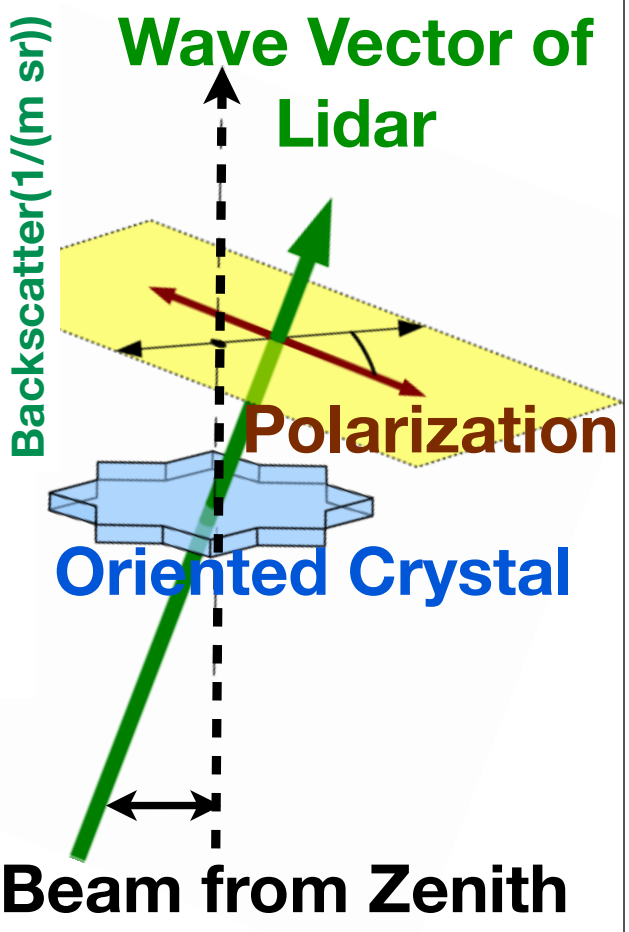


Why Have I Been Tilting CAPABL?

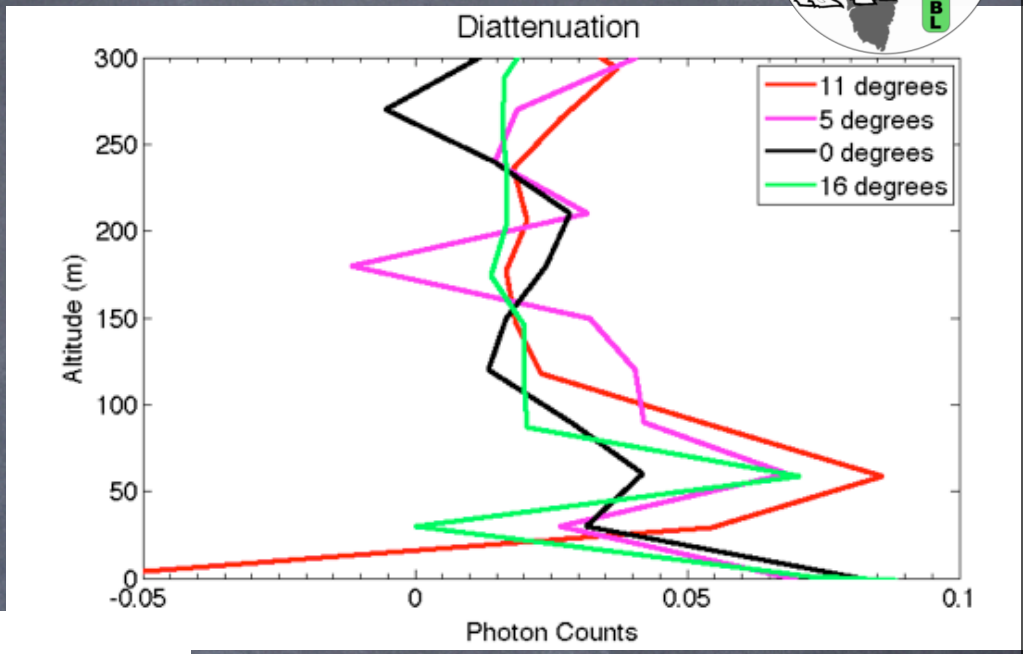


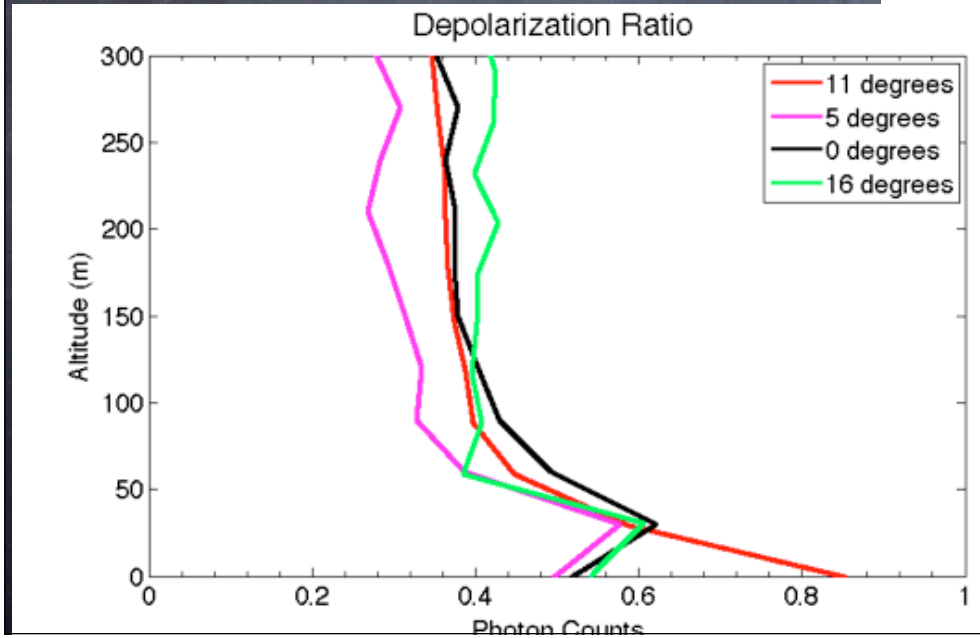
Ability to measure oriented ice crystals is dependent on pointing angle of lidar.



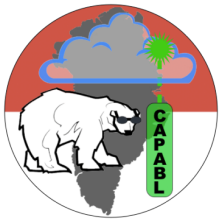


Results: April 23, 2011





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



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

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

Where $\vec{N} = \begin{bmatrix} N_{||} \\ N_{45} \\ N_{\perp} \end{bmatrix}$ are our observables and $\delta = \frac{N_{\perp}}{N_{||}}$ is the total linear depolarization ratio

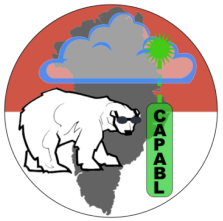
- When scatters may be assumed to be randomly oriented the depolarization ratio is derive as:

$$\delta = \frac{x_1 - x_2}{x_1 + x_2} \quad \text{where } \mathbf{F}(\pi) = \beta \begin{bmatrix} x_1 & 0 & 0 & 0 \\ 0 & x_2 & 0 & 0 \\ 0 & 0 & x_3 & 0 \\ 0 & 0 & 0 & x_4 \end{bmatrix}$$ is the **randomly oriented** backscatter matrix.

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

$$\delta = \frac{x_1 - x_2}{x_1 + x_2 + 2y_1} \quad \text{where } \mathbf{F}(\pi) = \beta \begin{bmatrix} x_1 & y_1 & 0 & 0 \\ y_1 & x_2 & 0 & 0 \\ 0 & 0 & x_3 & y_2 \\ 0 & 0 & -y_2 & x_4 \end{bmatrix}$$ is the **oriented** backscatter matrix.

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



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

$$D_q = \frac{2N_{45}}{N_{||} + N_{\perp}} - 1 = \frac{y_1}{x_1}$$

From the oriented backscatter matrix:

$$\mathbf{F}(\pi) = \beta \begin{bmatrix} x_1 & y_1 & 0 & 0 \\ y_1 & x_2 & 0 & 0 \\ 0 & 0 & x_3 & y_2 \\ 0 & 0 & -y_2 & x_4 \end{bmatrix}$$

When particles are not oriented: $y_1 = 0 \text{ and } x_2 = -x_3$

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

$$D_q \begin{cases} = 0; \ \delta = \dfrac{N_{\perp}}{N_{||}} = \dfrac{x_1 - x_2}{x_1 + x_2} \\ \neq 0; \ \delta = \dfrac{N_{\perp}}{N_{||}} = \dfrac{x_1 - x_2}{x_1 + x_2 + 2y_1} \end{cases}$$