On-Orbit Validation of Space Lidar Depolarization profiles

Dave Winker & Mark Vaughan
NASA Langley Research Center

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Outline

- The Polarization Gain Ratio (PGR) is the depolarization calibration coefficient

$$PGR = \frac{\overline{X_{\perp}(r)}}{\overline{X_{\parallel}(r)}} = \frac{C_{\perp}}{C_{\parallel}}$$

- CALIOP PGR is calibrated by inserting a depolarizer into the receive-optics so both 532 nm channels see the same signal
  - Briefly interrupts routine data acquisition
  - Used every once every few months, nighttime only due to SNR considerations
- Daytime PGR calibration is performed using the cirrus background method (Liu et al 2004)
  - But, there is a 10-15% bias between daytime and nighttime PGR calibrations
  - So daytime calibrations are scaled to nighttime
- To provide more insight into daytime PGR calibrations, we have recently developed an alternate depol calibration method
- The method can also be used to check ATLID on-orbit depol calibration

PGR Calibration Errors Propagate into Level 1 Profiles

Impact of PGR change

Reducing the PGR will increase the

- Perpendicular attenuated backscatter
- Total attenuated backscatter
- Volume depolarization ratio

$$\beta'_{\perp}(z) = \frac{X_{\perp}(z)}{PGR \cdot C_{\parallel}}$$

$$\beta'(z) = \frac{X_{\parallel}(z)}{C_{\parallel}} + \frac{X_{\perp}(z)}{PGR \cdot C_{\parallel}}$$

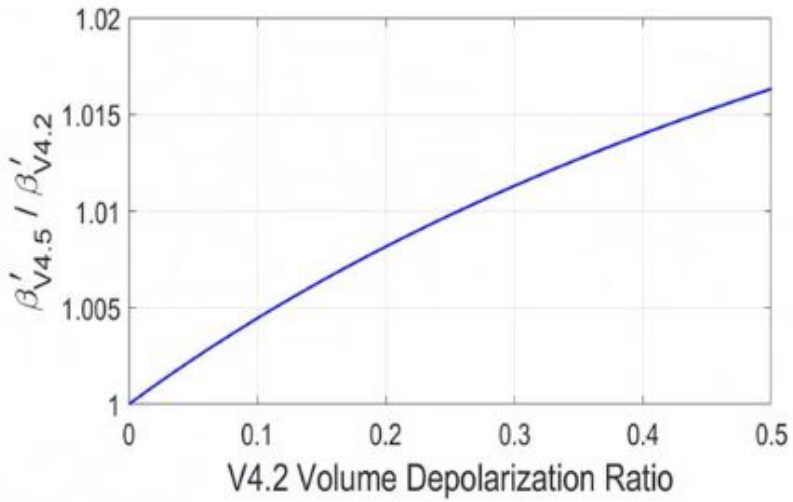
$$\delta_{v}(z) = \frac{X_{\perp}(z)}{PGR \cdot X_{\parallel}(z)}$$

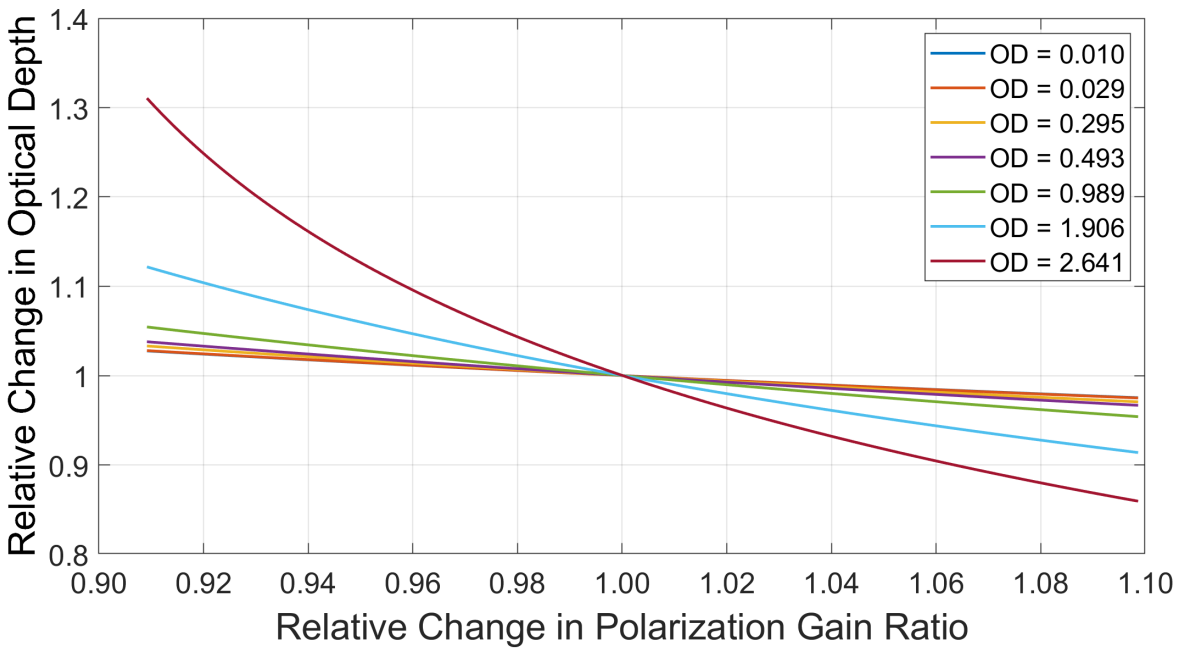
How much will they increase?

Mark used some algebraic hocus-pocus with these equations to show the predicted change for a 4.9% decrease in PGR:

$$\frac{\beta'_{V4.5}(z)}{\beta'_{V4.1}(z)} = \left(\frac{1+\delta_{V4.5}}{1+\delta_{V4.1}}\right) \approx \left(\frac{1.049 \cdot \delta_{V4.1} + 1}{\delta_{V4.1} + 1}\right)$$

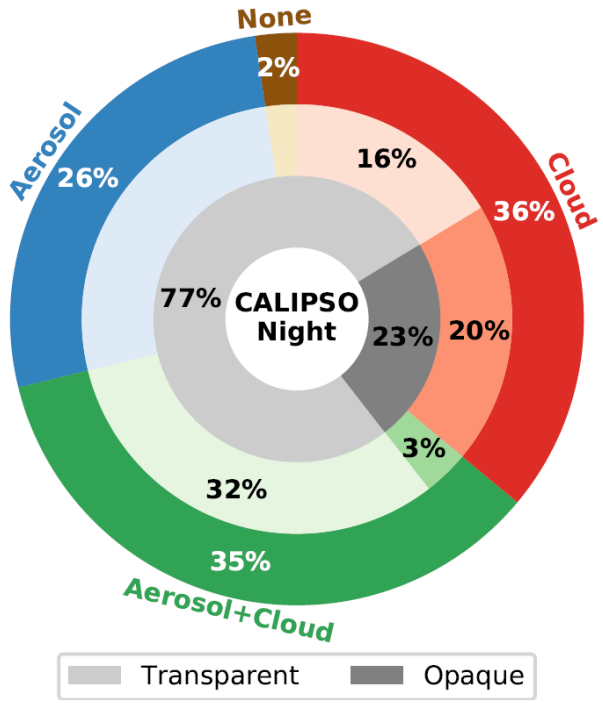
The amount that the total attenuated backscatter increases depends on the depolarization of the scatterer.





Relative change in cirrus cloud optical depths as a function of relative error in PGR

For CALIOP, where clouds lie above aerosols the optical depth errors seen in the left panel will propagate nonlinearly into the extinction retrievals in the underlying aerosol layers.



PGR Calibration Using Cirrus Background

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 1, NO. 3, JULY 2004

Validating Lidar Depolarization Calibration Using Solar Radiation Scattered by Ice Clouds

Zhaoyan Liu, Matthew McGill, Yongxiang Hu, Chris Hostetler, Mark Vaughan, and David Winker

- From single-scatter theory:
  - Above optically thick cirrus, the reflected solar radiance is *almost* completely polarized
  - Insensitive to scattering angle and solar elevation
  - Caveat: must correct for molecular scattering above the cloud

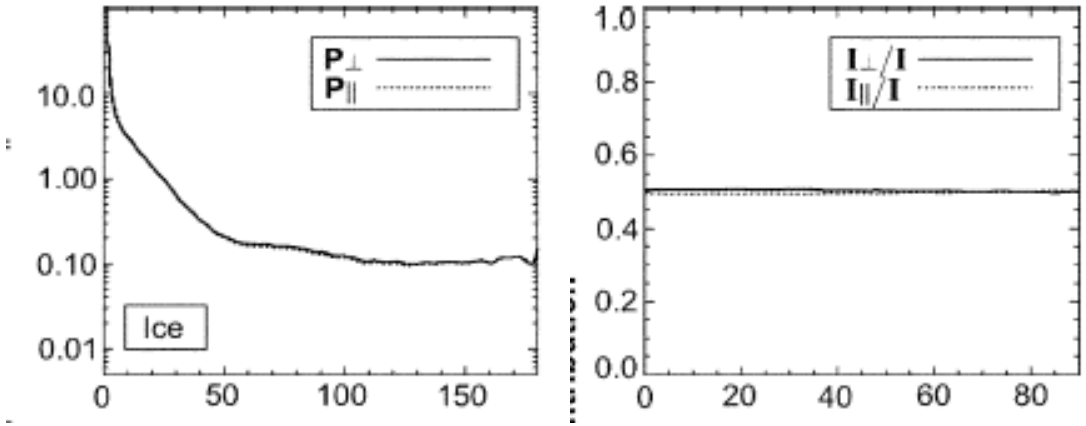
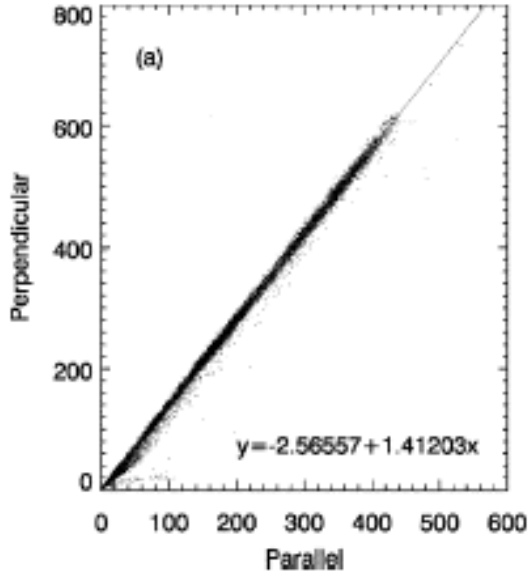
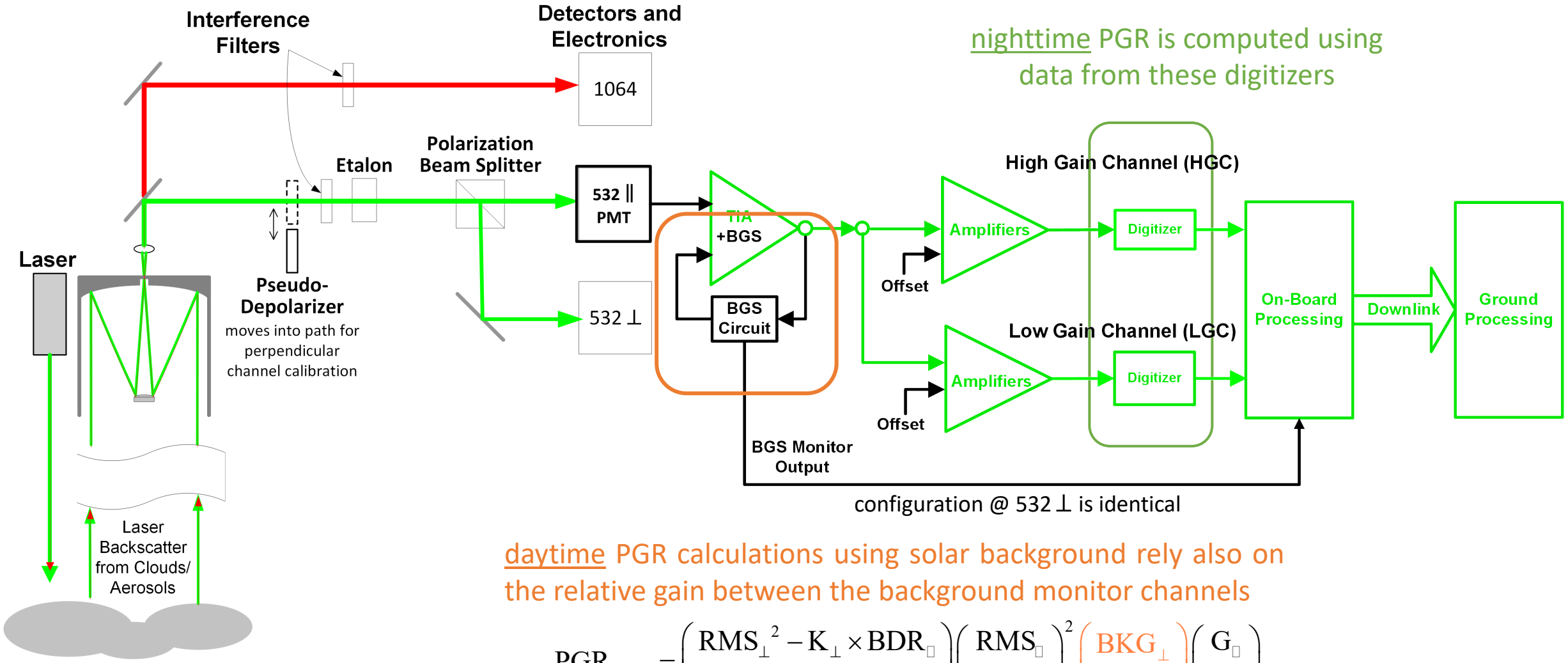


Fig. 1. Polarization components for ice

Results from CPL observations



CALIOP Polarization Measurements

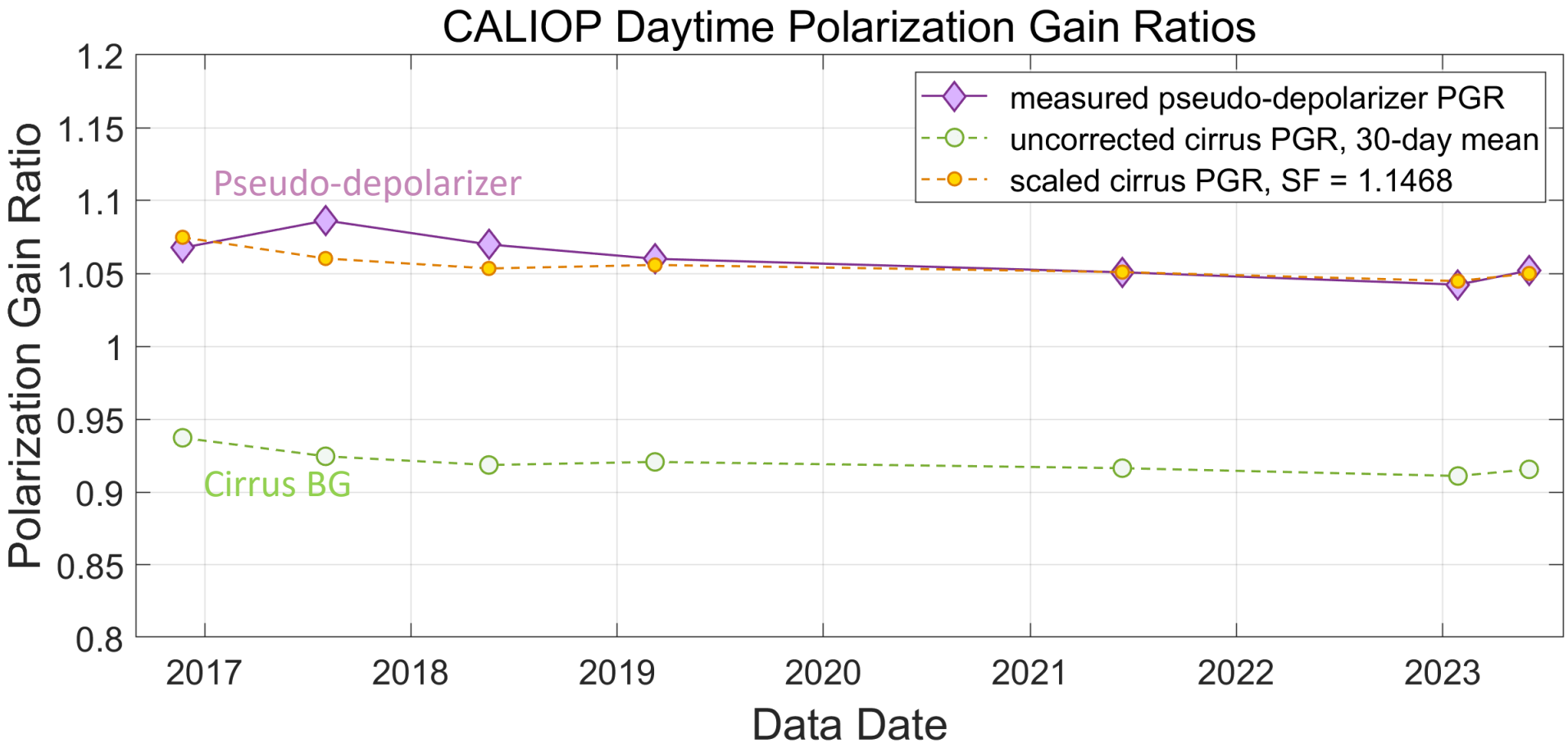


nighttime PGR is computed using data from these digitizers

daytime PGR calculations using solar background rely also on the relative gain between the background monitor channels

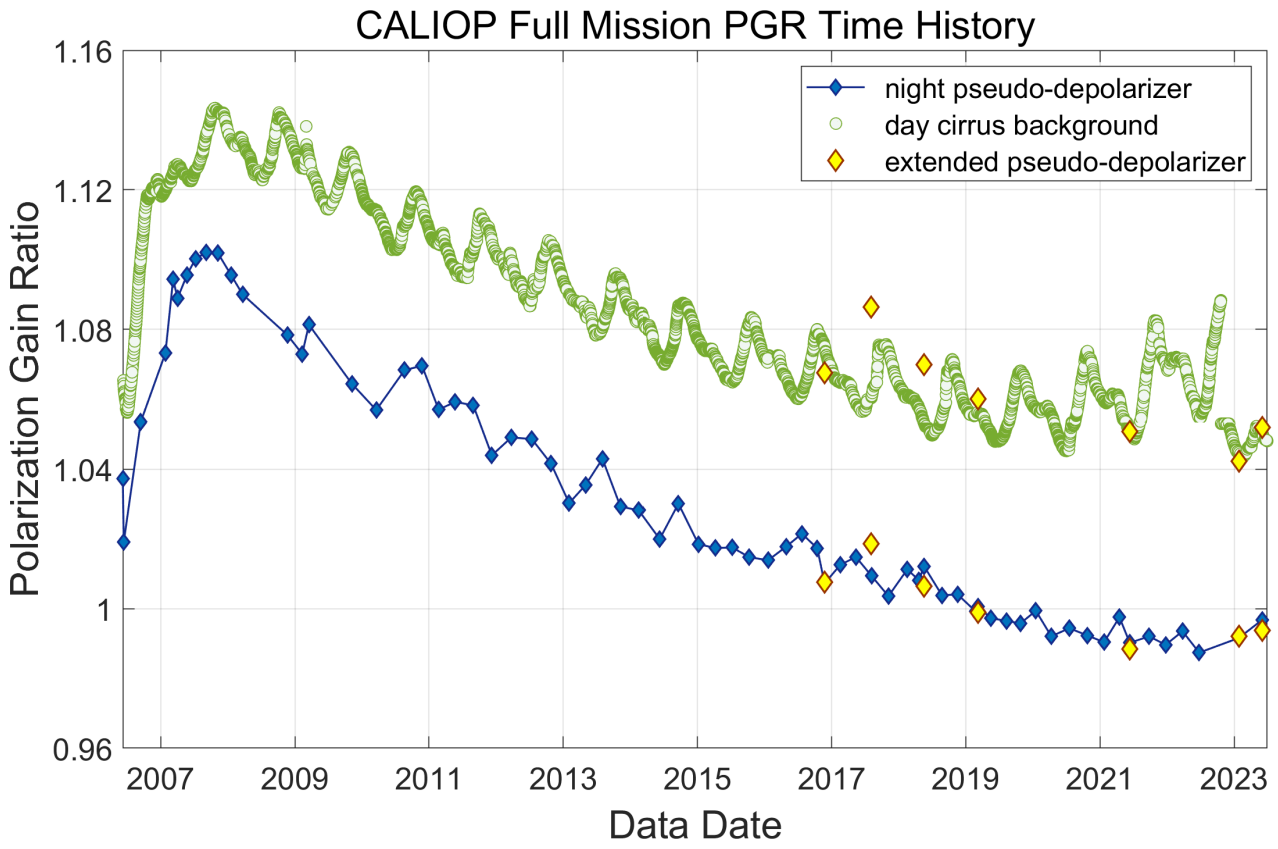
$$PGR_{cirrus} = \left(\frac{RMS_{\perp}^{2} - K_{\perp} \times BDR_{\parallel}}{RMS_{\parallel}^{2} - K_{\parallel} \times BDR_{\perp}}\right)\left(\frac{RMS_{\parallel}}{RMS_{\perp}}\right)^{2}\left(\frac{BKG_{\perp}}{BKG_{\parallel}}\right)\left(\frac{G_{\parallel}}{G_{\perp}}\right)$$

Figure 2.2 Functional block diagram of CALIOP

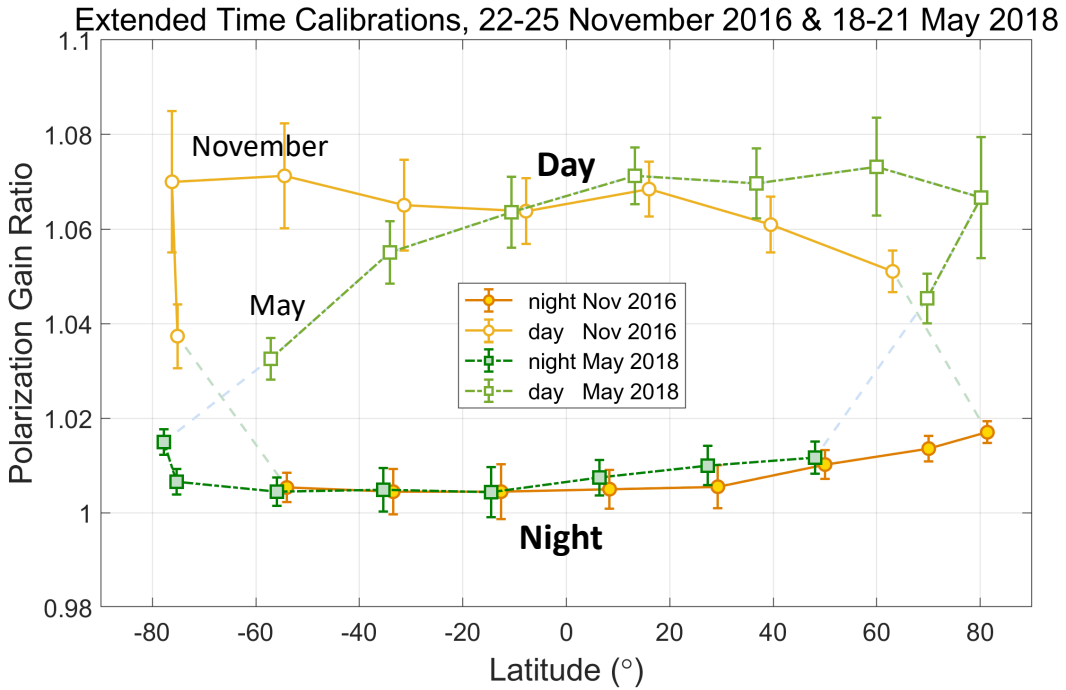

CALIOP Daytime Polarization Gain Ratios
Polarization Gain Ratio
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
2017
2018
2019
2020
2021
2022
2023
Data Date
measured pseudo-depolarizer PGR
uncorrected cirrus PGR, 30-day mean
scaled cirrus PGR, SF = 1.1468
Pseudo-depolarizer
Cirrus BG

On-Orbit PGR Calibration Results

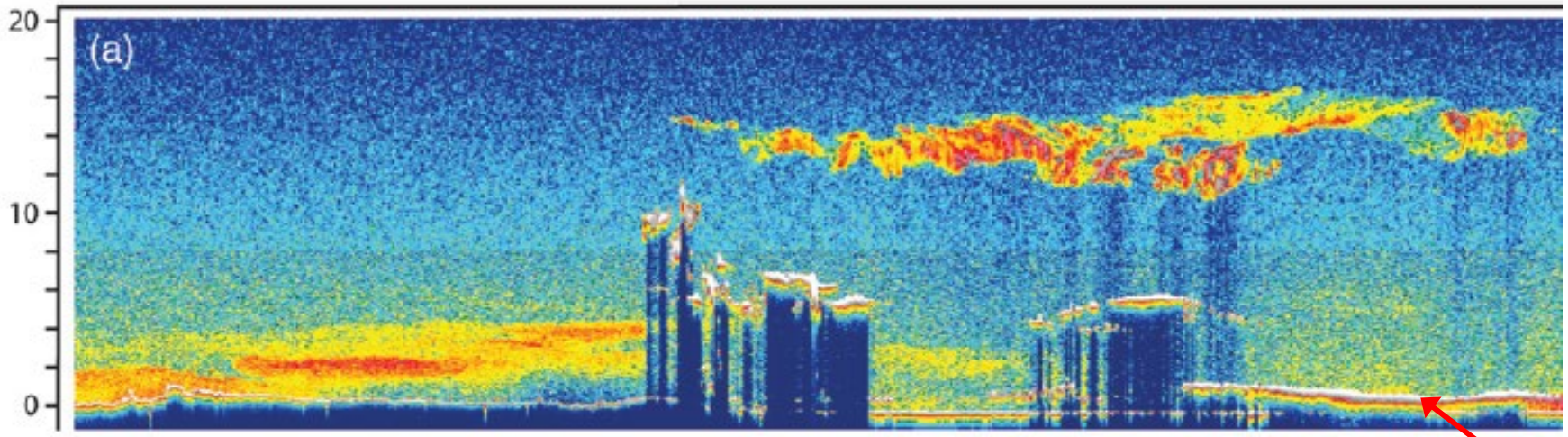
Long-term drift, intra-annual variation



Variations with latitude change with season



Opaque Water Cloud (OWC) Method



τ_{above}

opaque stratus: γ_c', S_c, η_c

IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 4, NO. 4, OCTOBER 2007

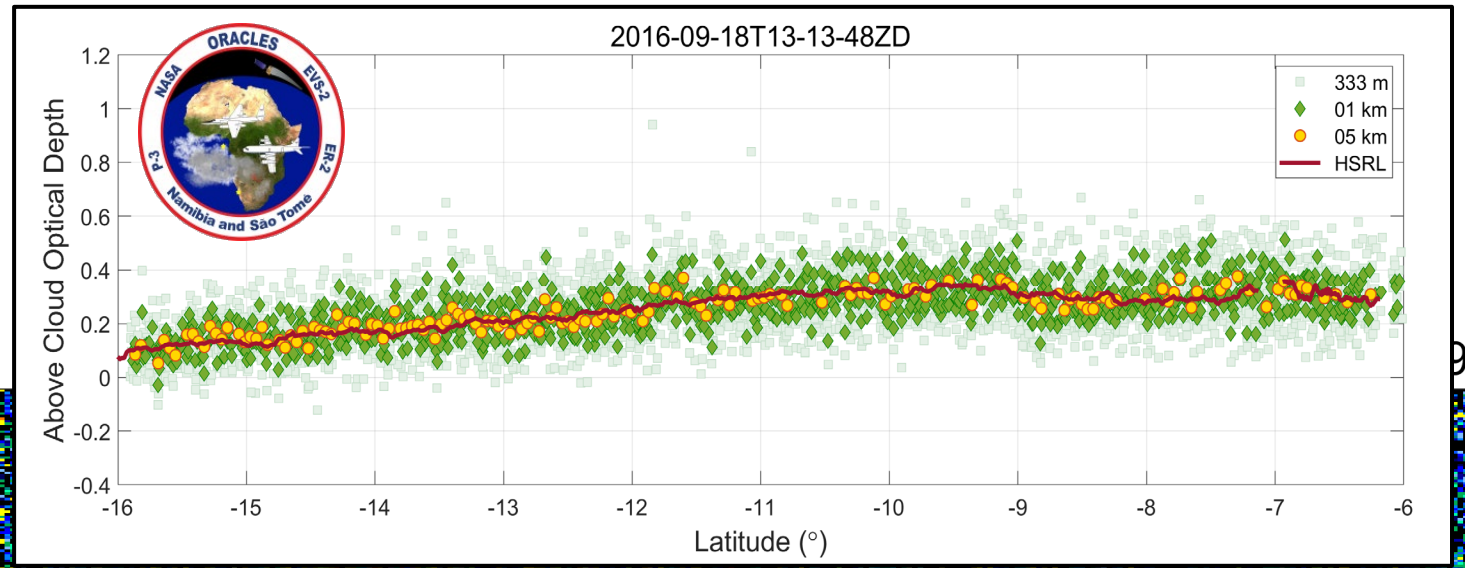
Retrieving Optical Depths and Lidar Ratios for Transparent Layers Above Opaque Water Clouds From CALIPSO Lidar Measurements

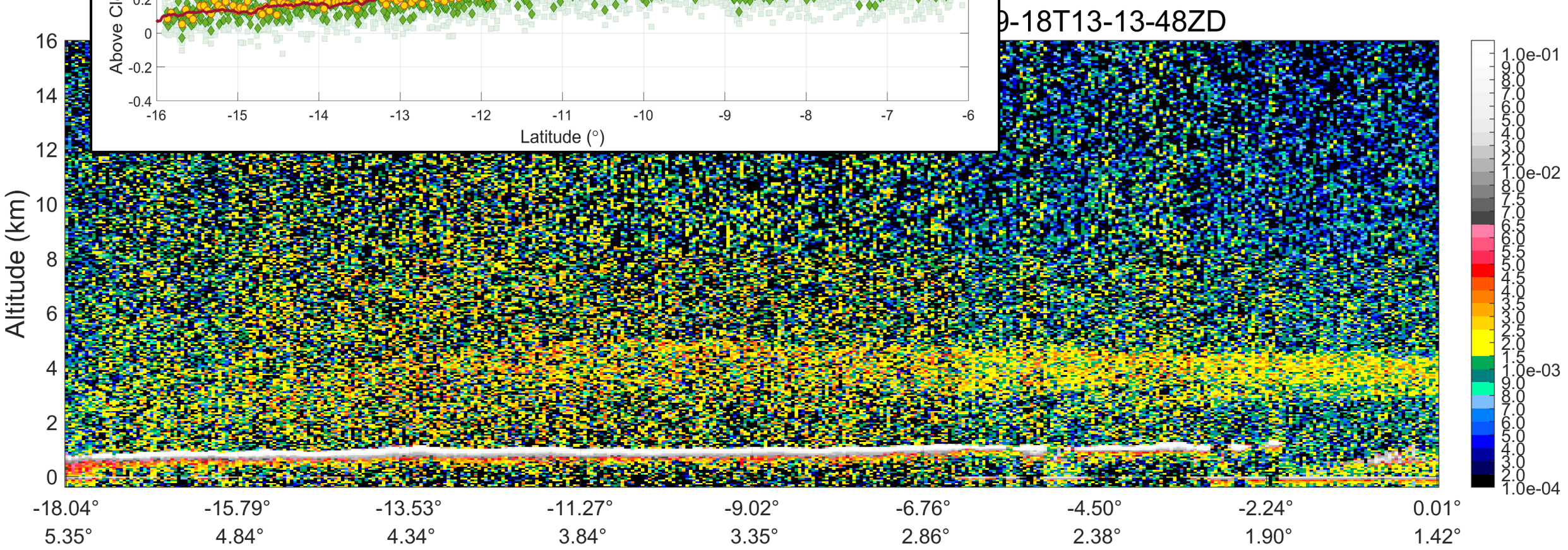
Yongxiang Hu, Mark Vaughan, Zhaoyan Liu, Kathleen Powell, and Sharon Rodier

$$\tau_{above} = -\frac{1}{2}\ln(2\gamma_c' S_c \eta_c)$$

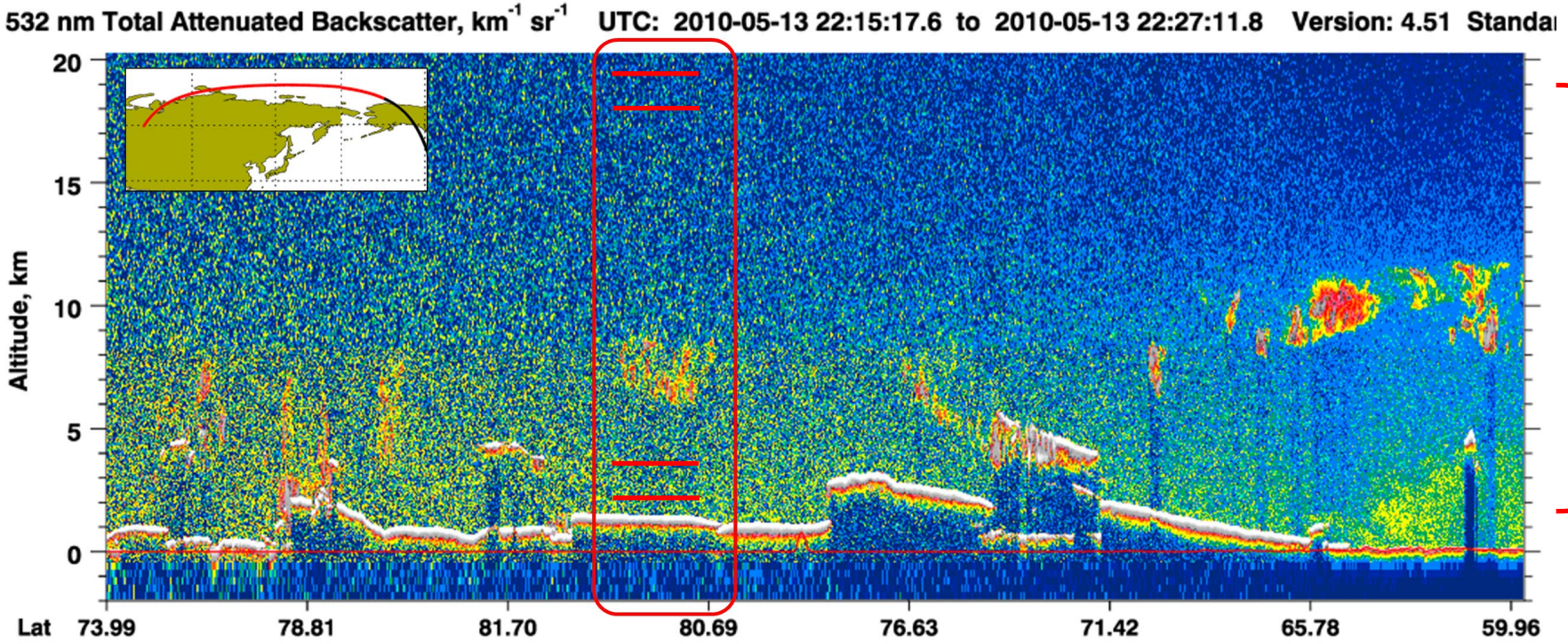
are all measurable, can use a priori value for S_c or retrieve in clear skies

Validation: LaRC HSRL vs. OWC Retrieval





Estimating PGR from OWC Retrievals



Compute τ_{above} using 2-way transmittance from clear-air regions

T^2_{above}

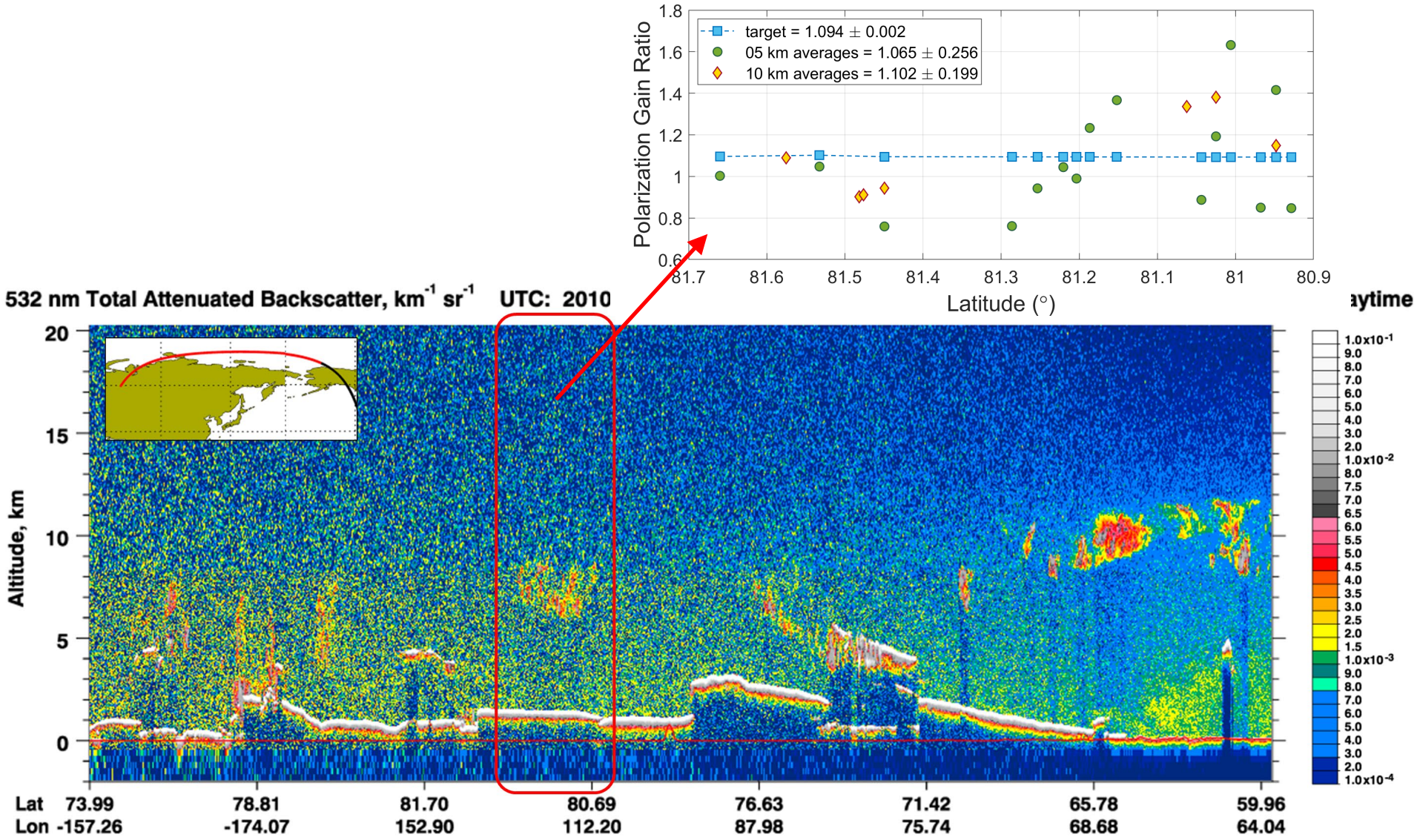
Expressing η_c in terms of volume depolarization, δ_V:

$$\tau_{\text{above}} = -\frac{1}{2}\ln\left(2\,\gamma'_c\,S_c\eta_c\right) = -\frac{1}{2}\ln\left(2\,\gamma'_c(\text{PGR})\,S_c(\text{PGR})\left(\frac{1-\delta_v(\text{PGR})}{1+\delta_v(\text{PGR})}\right)^2\right)$$

integrated volume depolarization ratio

- Compare τ_{above} from OWC method with τ_{above} from 2-way transmittance method
- Adjust PGR until they agree
- Repeat along-track and take the average

Preliminary Results (night)



Conclusions

- Daytime bias in CALIOP PGR calibration likely due to poorly characterized background monitor gain ratio and/or method used to merge high- and low-gain channels
  - CATS PGR also shows a bias, possibly due to uncharacterized polarization cross-talk
- The OWC method provides an independent means of checking CALIOP PGR daytime calibration over the mission life
  - In a preliminary test, PGR from OWC method is within 1% of pseudo-depolarizer PGR
- The OWC method can be used by ATLID to verify depolarization calibration
  - Method can be applied both day and night
- The OWC method should be more accurate for ATLID as the overlying atmospheric optical depth can be measured directly from the Rayleigh channel
- A proposal to fund application of the OWC method to ATLID for calibration of depolarization has been submitted to NASA ROSES