CALIPSO Validation Lessons Learned

Dave Winker,
Mark Vaughan
and the CALIPSO team

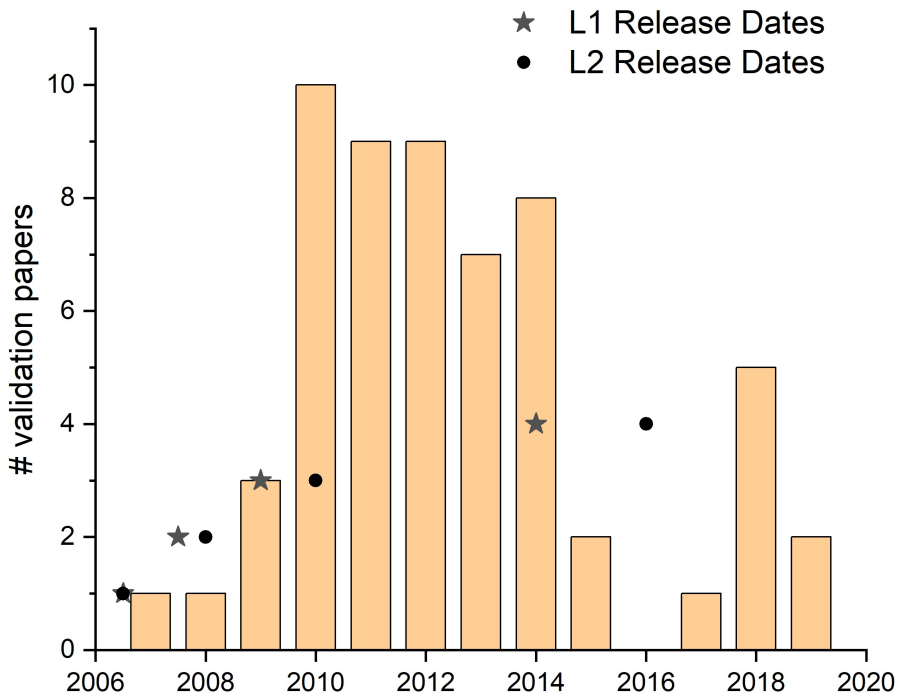
2nd EarthCARE Validation Workshop, 25-28 May 2021

Validation Objectives

- Verify instrument performance
  - calibration, SNR, linearity, transient recovery
- Verify geolocation
  - pointing, altitude registration
- Quantify the accuracy and precision of Level 2 science data products
  - identify sources of random errors and biases
- Examine underlying assumptions in retrieval algorithms
  - S_a, S_c, spectral independence of cirrus backscatter
- Supports quality assurance, algorithm improvement activities

From yesterday: "… calibration is a never-ending process … regular reprocessing campaigns … improvements of the Level 1 dataset"

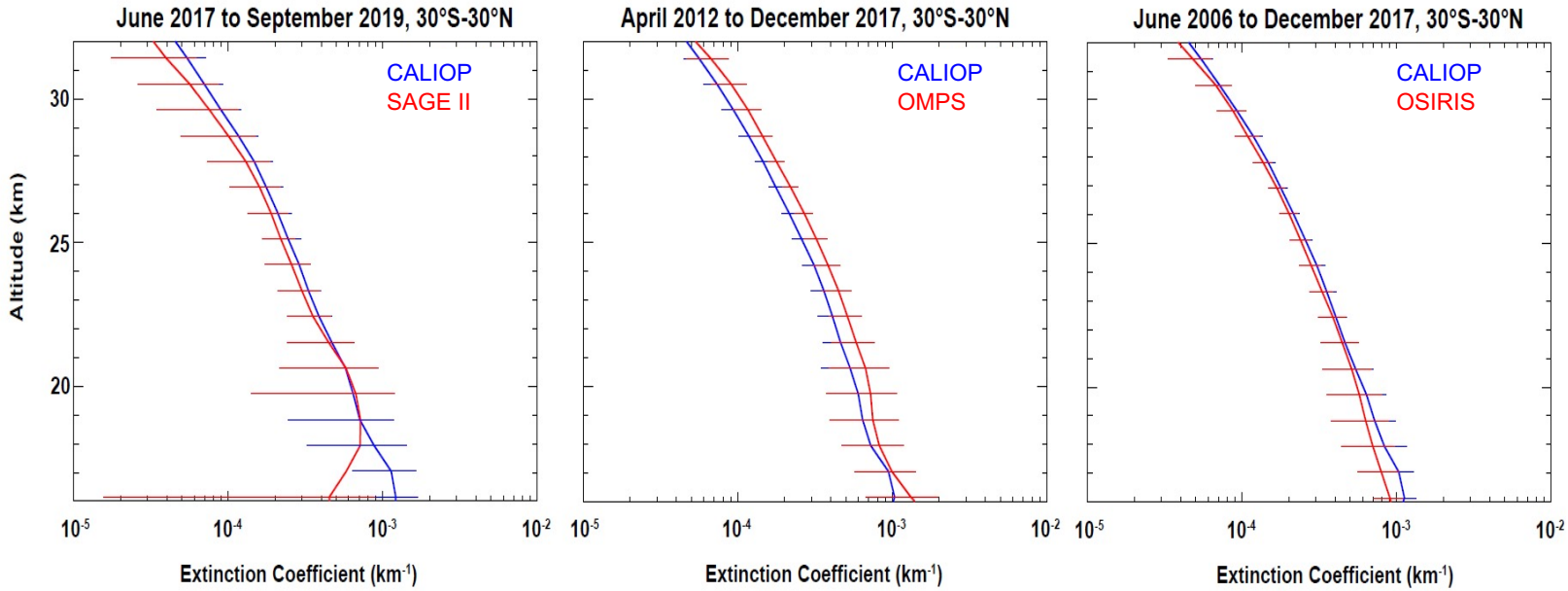
Each data release involves a new round of validation:



Example: Stratospheric Aerosol Product

- Improved calibration in Version 4 (2014) allowed aerosol retrievals to 30 km
- First stratospheric aerosol product released in 2018

Validation against solar occultation and limb scattering sensors



Zonally averaged CALIOP extinction coefficient profiles for data acquired between 30°N and 30°S compared to data from SAGE III-ISS, OMPS, and OSIRIS (Kar et al. 2019)

Initial Level 1 Validation

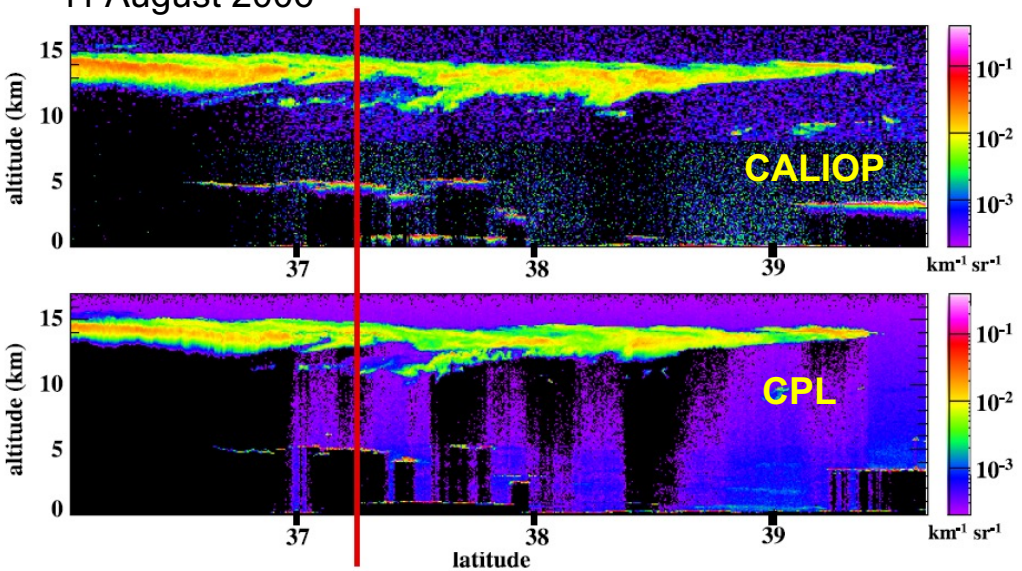
- Early validation of Level 1 profiles was critical
- Targeted airborne campaign in Aug 2006 (CC-VEX)
- Payload on NASA ER-2:
  - Goddard Cloud Profiling Lidar (CPL)
  - JPL W-band radar (CRS)
  - MODIS Airborne Simulator (MAS)
- Initial CALIOP Level 1 validation objectives:
  - Sanity check on Level 1 lidar profiles
    - Do they 'look right'? Unexpected artifacts?
  - Verify predicted detection sensitivity
  - Radiometric calibration
  - *Relative calibration of perpendicular channel (PGR)*
    - *Performed using on-board pseudo-depolarizer*

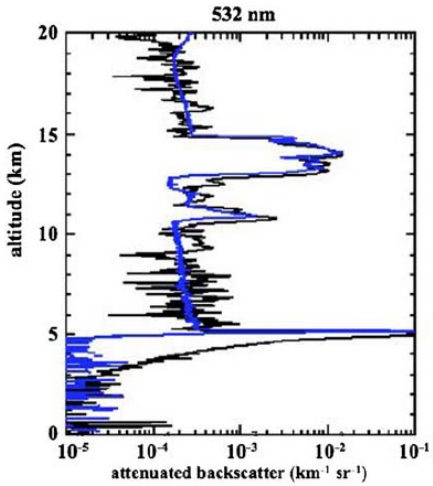
Airborne validation of spatial properties measured by the CALIPSO lidar

Matthew J. McGill,[1] Mark A. Vaughan,[2] Charles R. Trepte,[3] William D. Hart,[4] Dennis L. Hlavka,[4] David M. Winker,[3] and Ralph Kuehn[2]

Received 9 April 2007; revised 24 June 2007; accepted 16 July 2007; published 17 October 2007.

11 August 2006

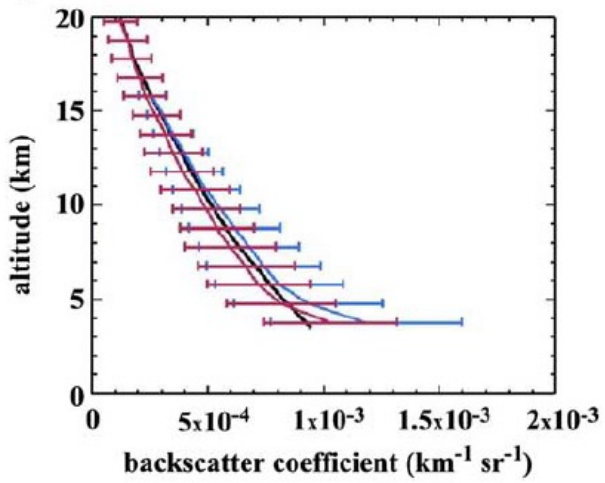




CALIOP (black)
CPL (blue)

Rayleigh backscatter profiles:

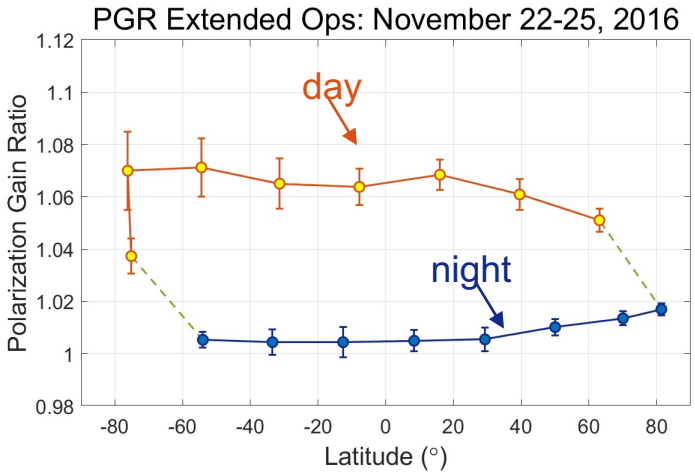
CALIOP – red
CPL – blue
rawinsonde - black

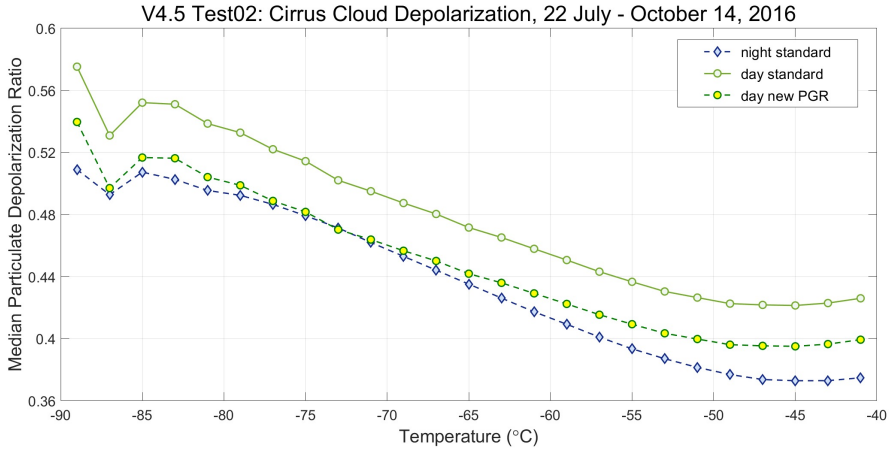


Recent Improvements in Polarization Calibration

Polarization Gain Ratio Trend (using on-board calibration hardware)

Recently identified a long-suspected day/night depolarization bias (~ 3%) using special operations:





Will improve daytime polarization calibration in next data release

Level 2 Validation

Uncertainty in Particulate Backscatter Coefficients at Altitude *n*

$$\frac{\sigma^2(\beta_{p,n})}{\beta_{p,n}^{\ 2}} = A_n^{\ 2}\left(\left(\frac{\sigma^2(\mathcal{X}_n)}{\mathcal{X}_n^{\ 2}}\right)+\left(\frac{1}{R_n}\right)^2\left(\frac{\sigma^2(\beta_{m,n})}{\beta_{m,n}^{\ 2}}\right)+(2\eta\tau_{p,n})^2\left(\frac{\sigma^2(S)}{S^2}+\frac{\sigma^2(\eta)}{\eta^2}\right)+\left(\frac{\sigma^2(T^2_{p,n-1})}{(T^2_{p,n-1})^2}+B_n^{\ 2}\left(\frac{\sigma^2(\beta_{p,n-1})}{\beta_{p,n-1}^{\ 2}}\right)\right)\right)$$

Measurement Uncertainty

Molecular Number Density Uncertainty

Lidar Ratio Uncertainty

Multiple Scattering Uncertainty

Accumulated Aerosol Attenuation Uncertainty

Includes errors due to

- ⇨ Calibration
- ⇨ **SNR**
- ⇨ molecular density (again)
- ⇨ offset calculations
- ⇨ polarization gain ratio
- ⇨ polarization cross-talk
- ⇨ ranging

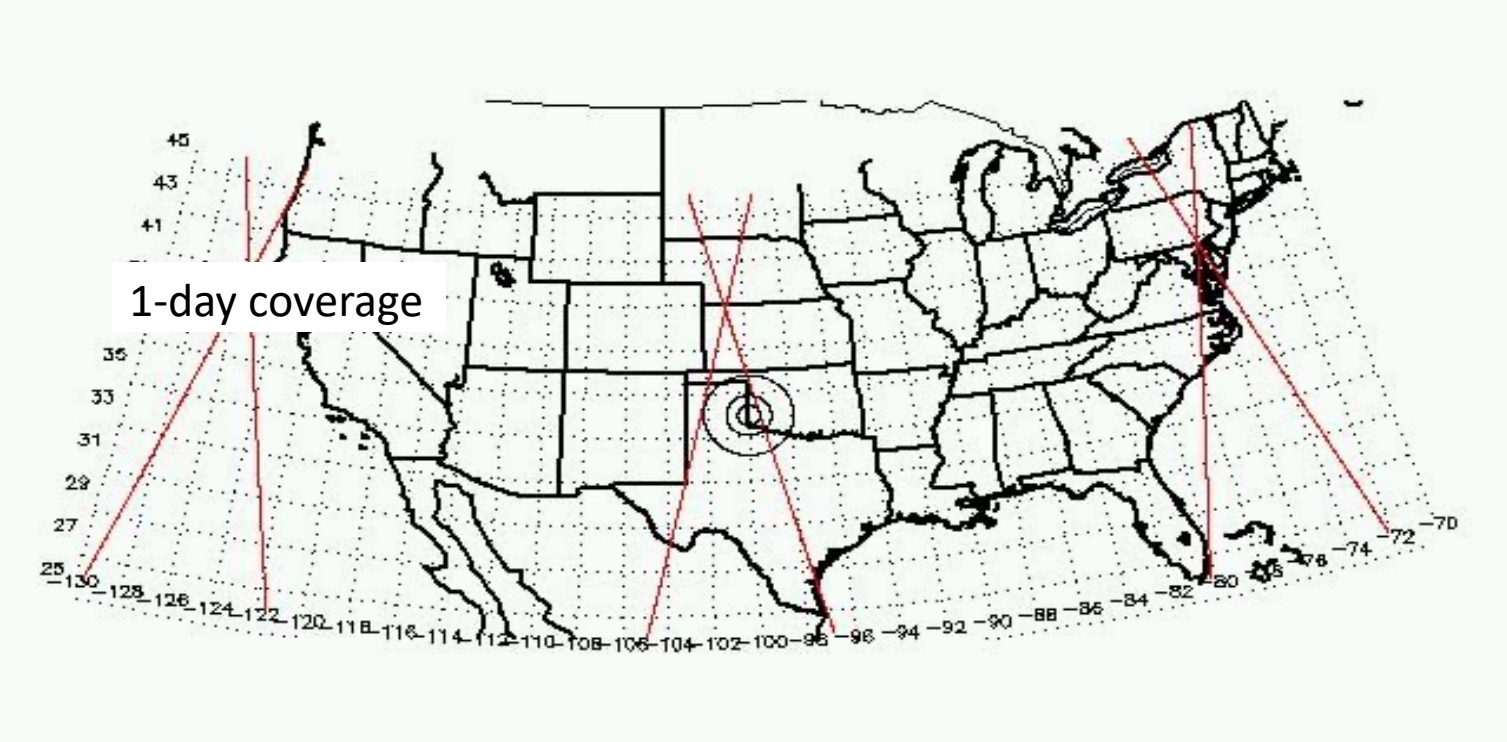
LEGEND

S = lidar ratio β = backscatter coefficient
R = scattering ratio $\sigma^2(x)$ = variance of x
T = transmittance τ = optical depth
m = molecular p = particulate (e.g., aerosol)
P = measured data C = calibration constant
η = multiple scattering factor

$$\mathcal{X}_n = \mathcal{X}(r_n) = \frac{r_n^{\ 2}\cdot P(r_n)}{C\cdot T_m^2(r_n)} \qquad A_n = \left(\frac{R_n}{R_n - 1}\right)\cdot\left(\frac{1}{1 - R_n\cdot\beta_{m,n}\cdot S\cdot\eta\cdot\Delta r_n}\right) \qquad B_n = S\cdot\eta\cdot\Delta r_n\cdot\beta_{p,n-1}$$

Unique Challenges for Active Profiling

- 70 meter 'swath' – spatial matching to ground sites is rare
- Few validation datasets available to validate
  - profile measurements
  - nighttime aerosol retrievals
  - aerosol retrievals above (low SNR) or below (attenuation correction) clouds
- Global data products means global validation



Validation Resources

- **Ground-based networks**
  - Aeronet
  - Earlinet, ADnet
- **Satellite comparisons**
  - MODIS, MLS, AIRS
  - CALIOP vs. IIR
- **Targeted, continuing aircraft campaigns**

• LaRC HSRL (King Air)	Jun 2006 - 20012
• NOAA ESRL (Cessna)	Jul-Aug 2006-2009

- **Large field campaigns**

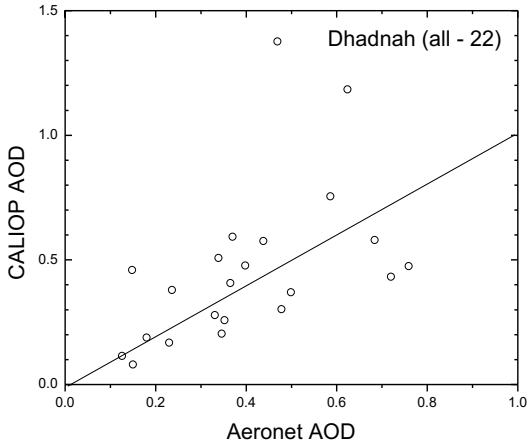
• NASA AMMA (Cape Verde)	Aug 2006
• SAMUM	2006, 2008
• CIRCLE-2	May 2007
• NASA TC^4 (Costa Rica)	Jul-Aug 2007
• ASTAR/PAM-ARCMIP	April 2007/09/11/12
• ARCTAS/PolarCat	April, July 2008
• SEAC4RS	Aug-Sep 2012
• etc	

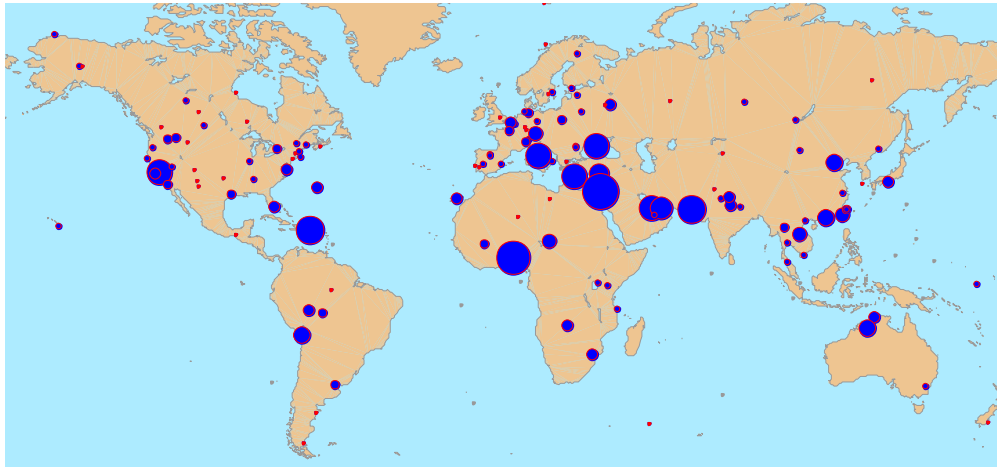


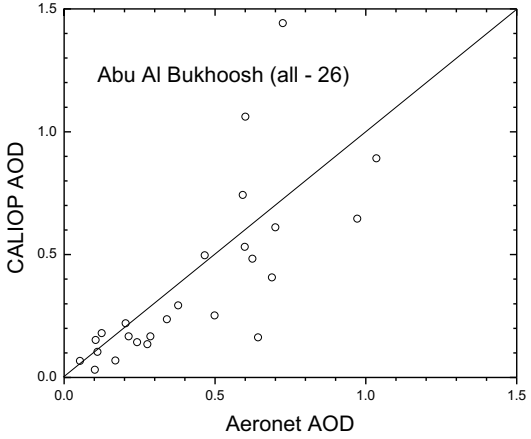


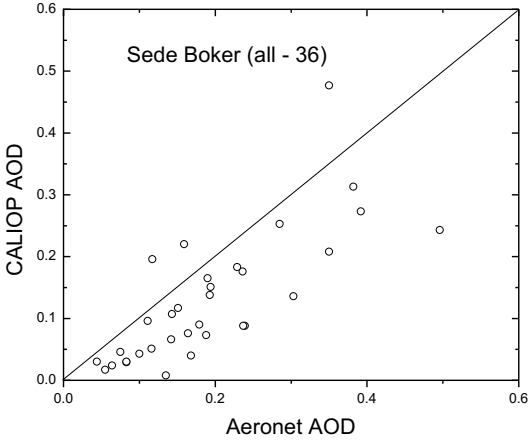

Comparisons with Aeronet

- **Useful, but need to accumulate samples over several years**
  - **Typically find one or two usable samples/station/year**
  - **Only provide column properties**







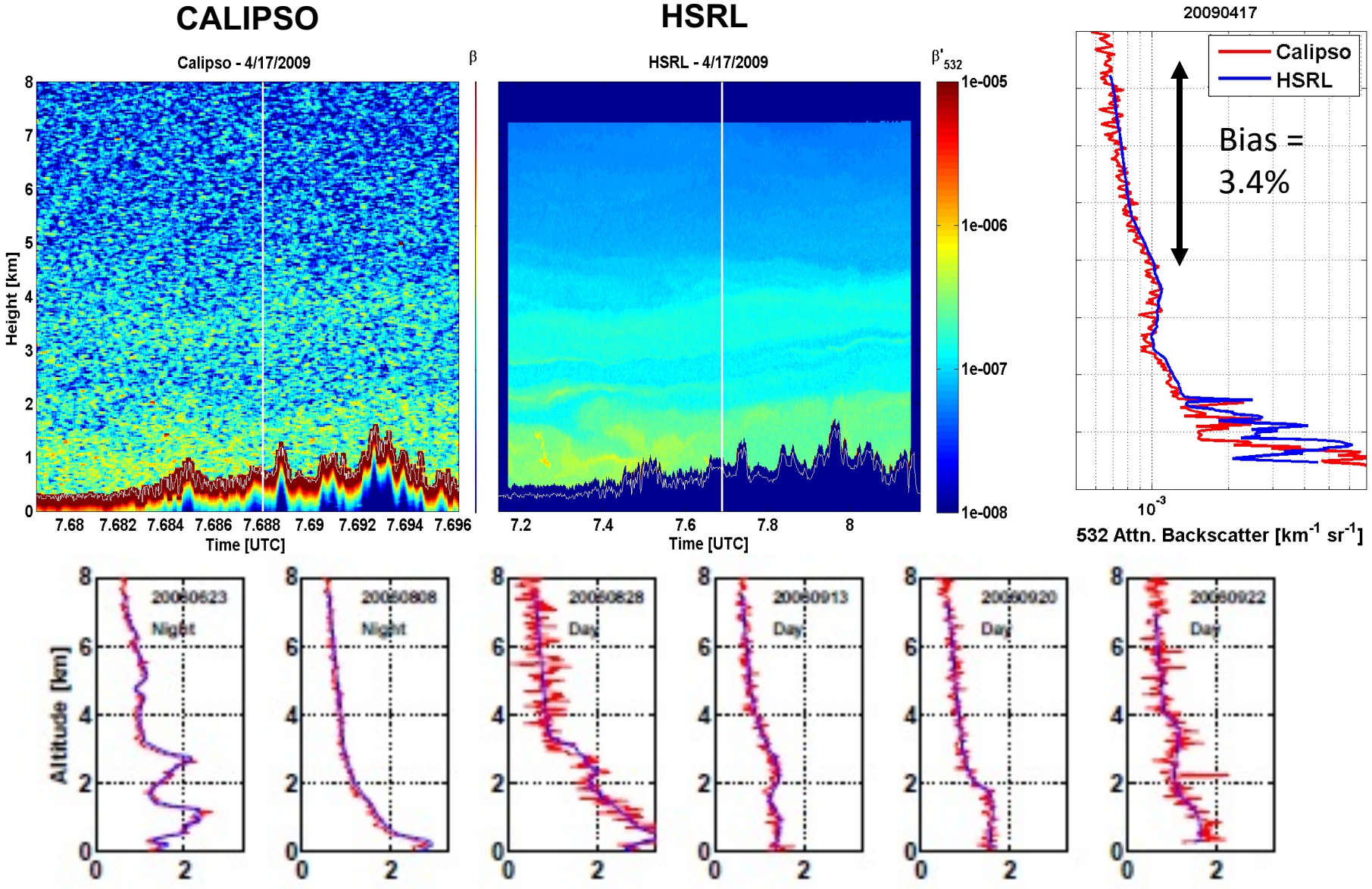


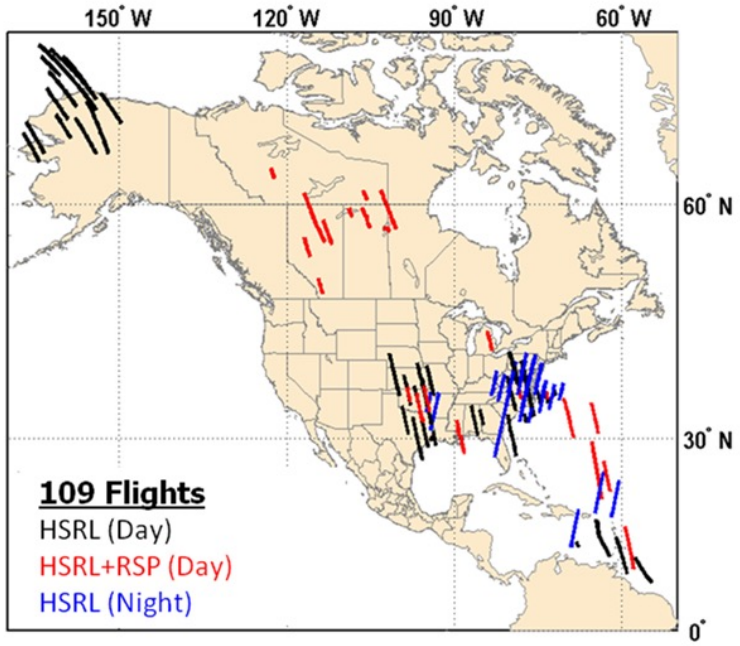
Omar et al, 2012: 1081 samples over 4 years (600 cloud-free)
Identified problems due to:
- **Spatial mismatch**
- **Topography**
- **Aeronet cloud contamination**

in addition to CALIOP retrieval errors

532 nm Calibration Assessment

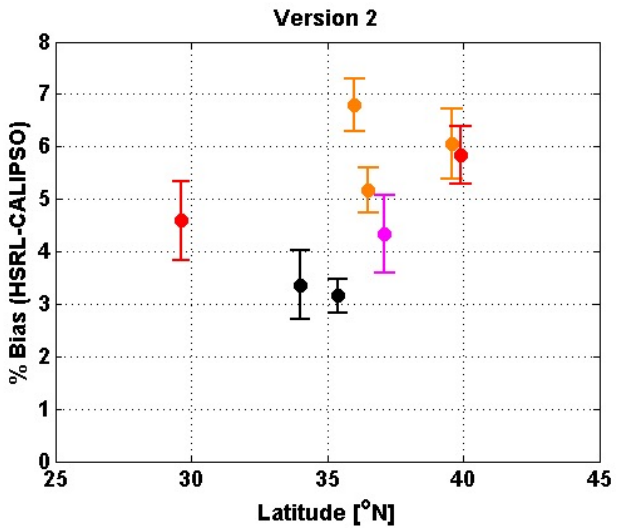
4/17/2009

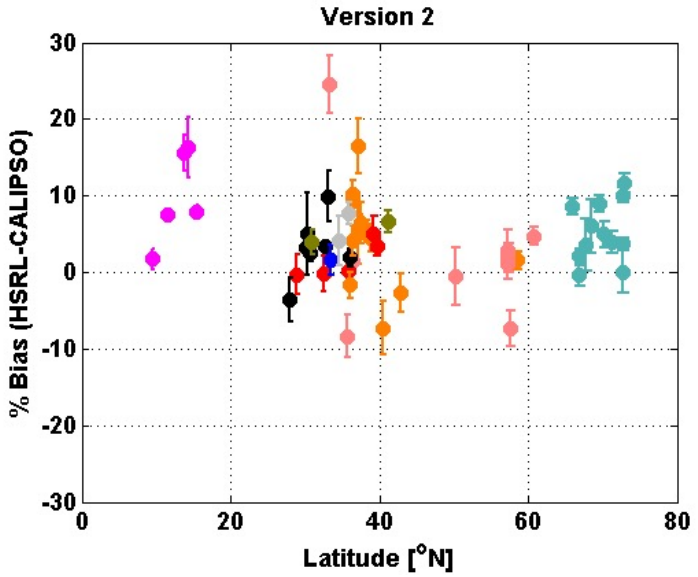




HSRL used as independent check on CALIOP calibration

Over 120 underflights since 2006:
during various campaigns
and dedicated flights



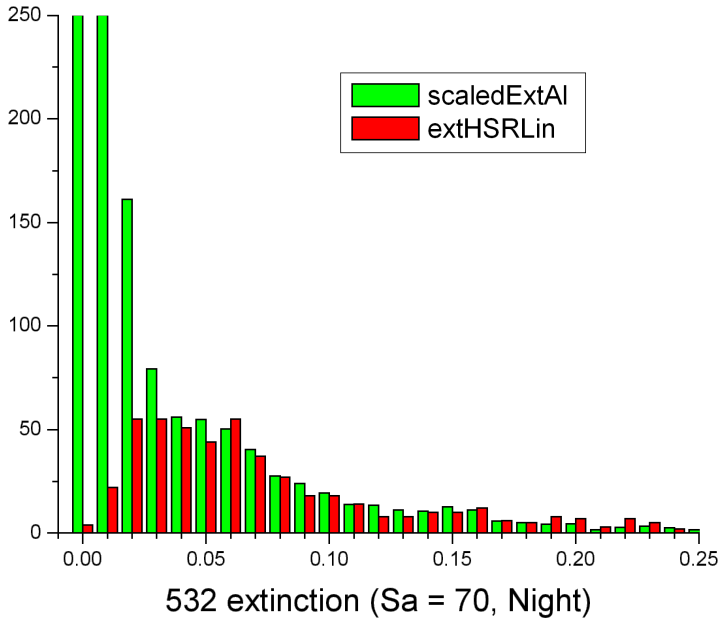


Biases and uncertainties in method estimated at 4.5%±3.2%
(Rogers et al, ACP, 2011)

Validation of Level 2 aerosol from HSRL

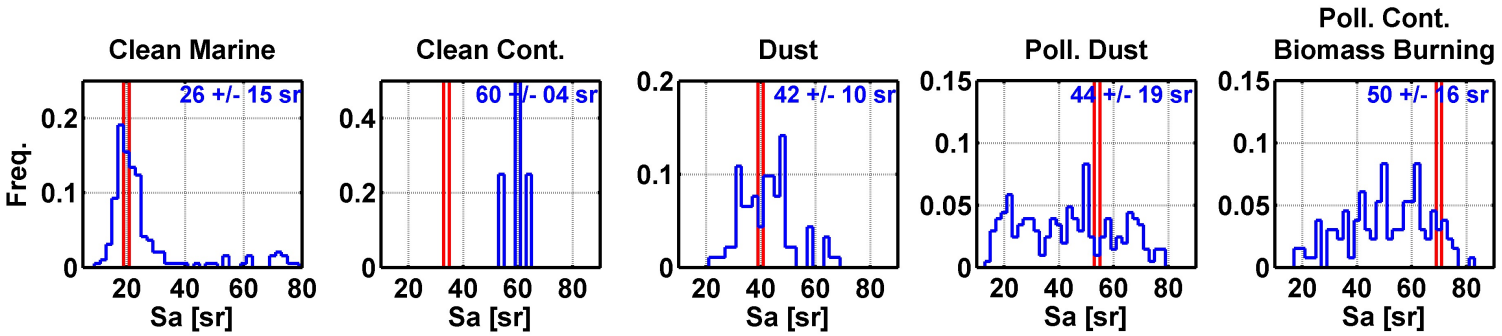
Direct characterization of extinction sensitivity:

- **histogram of HSRL aerosol inside layers detected by CALIOP vs. histogram of all HSRL aerosol**



Validation of CALIOP aerosol typing:

HSRL measured lidar ratio vs. CALIOP aerosol type (daytime)



(Rogers et al, 2012)

Final Thoughts

- “Truth” is elusive
- Validation is never finished
  - It is only approached asymptotically
- Validation of products globally is challenging
- Large field campaigns useful, but:
  - Validation tends to be one objective of many
- Not exactly “validation” but critically important
  - Consistency checks (does it 'look right’)
  - Intercomparison of multiple retrieval algorithms based on independent assumptions
- Satellite sensors may have limited accuracy, but are global
  - Depending on parameter and sensor, comparisons can vary from ‘sanity check’ to true validation