Looking Back: Lessons Learned from CALIPSO Validation

Dave Winker,
NASA Langley Res Ctr

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Validation Objectives

- Verify instrument performance (w.r.t. Level 1 data)
  - 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

\- Validate uncertainty estimates !

Validation Resources

CALIPSO
Science Validation Plan
PC-SCI-501

Dave Winker and Chip Trepte
NASA Langley Research Center, Hampton, Virginia

Jacques Pelon and Anne Garnier
Institut Pierre Simon LaPlace, Paris, France

Tom Kovacs
Hampton University, Hampton, Virginia

Version 4.0
December 2004

- Ground-based networks
  - Aeronet
  - Earlinet, ADnet
- Satellite comparisons
  - MODIS, MLS, AIRS
  - SAGE-III
- Targeted, aircraft campaigns
  - LaRC HSRL (King Air) — Jun 2006 - 20012
  - NOAA ESRL (Cessna) — Jul-Aug 2006-2009
  - NASA ER-2 — Aug 2006, ORACLES
- 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

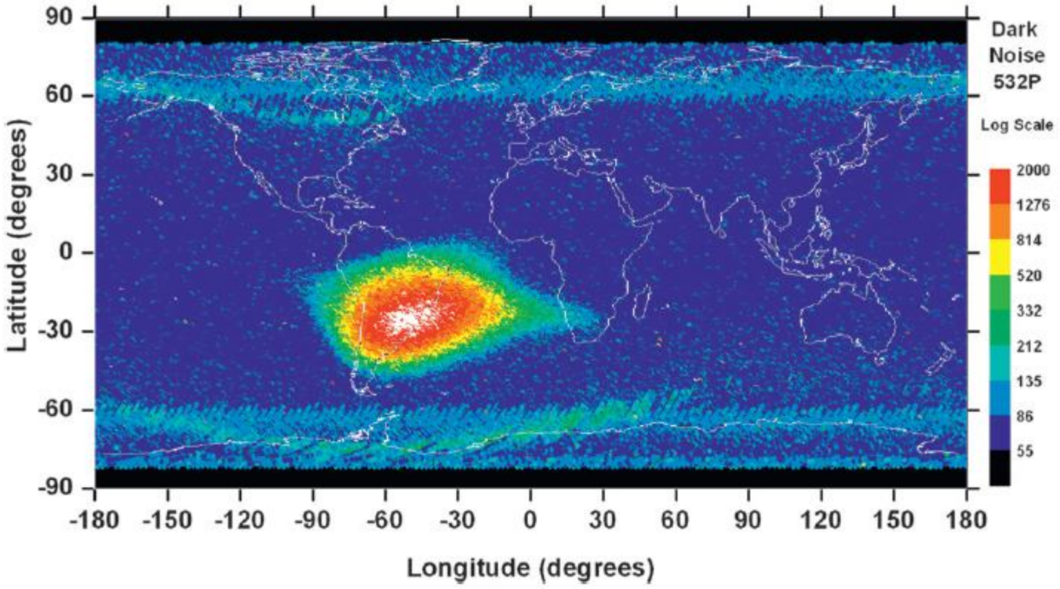





Lessons Learned from On-orbit Checkout

- **Discovered ranging error**
  - Speed of light ≠ 3.000E+8 m/s
  - Required a change to payload software (~ 1 week)
- **Discovered intra-orbit drifts in 1064 channel calibration**
  - Not fixed until 2014
- **Discovered excess PMT noise in South Atlantic Anomaly**
  - Not seen during LITE (260 km orbit altitude)
  - Required modification of 532 nm calibration algorithm

532n m dark noise



Initial Level 1 Validation

- **Early validation of Level 1 profiles was critical**
- **Dedicated 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
  - A first check on calibration

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]

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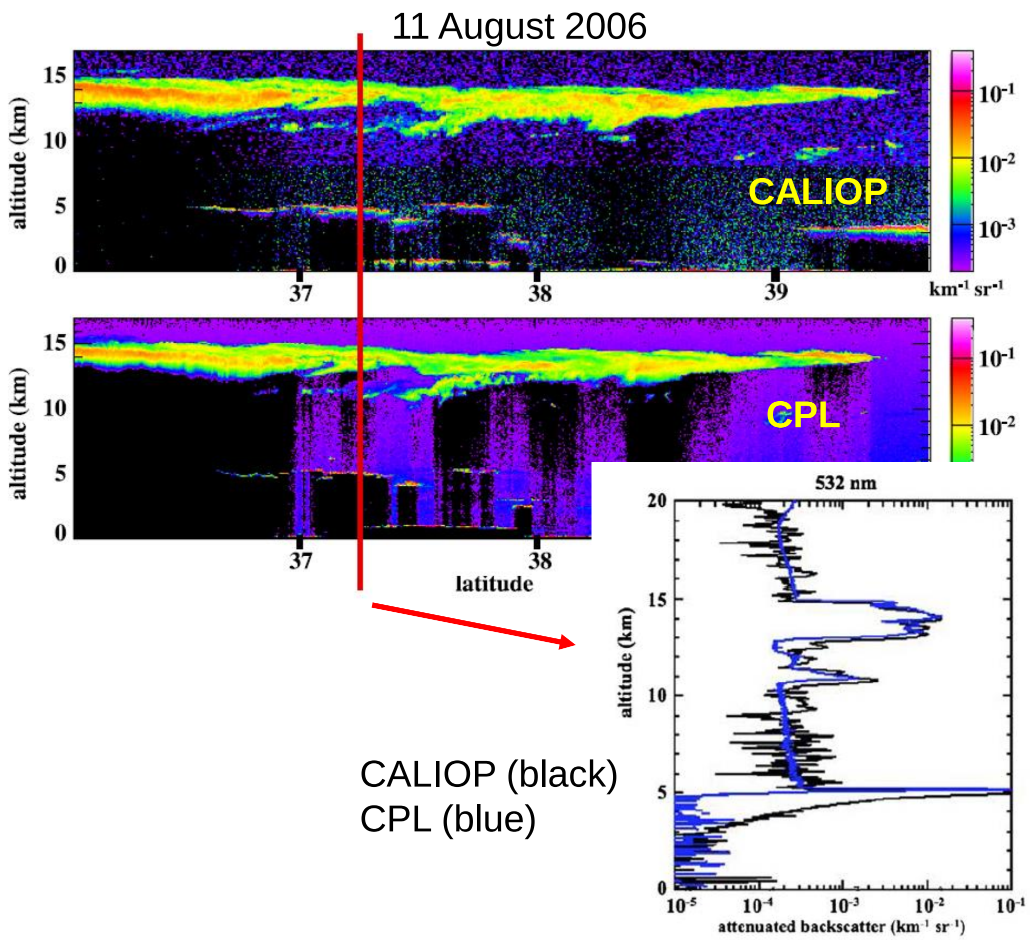
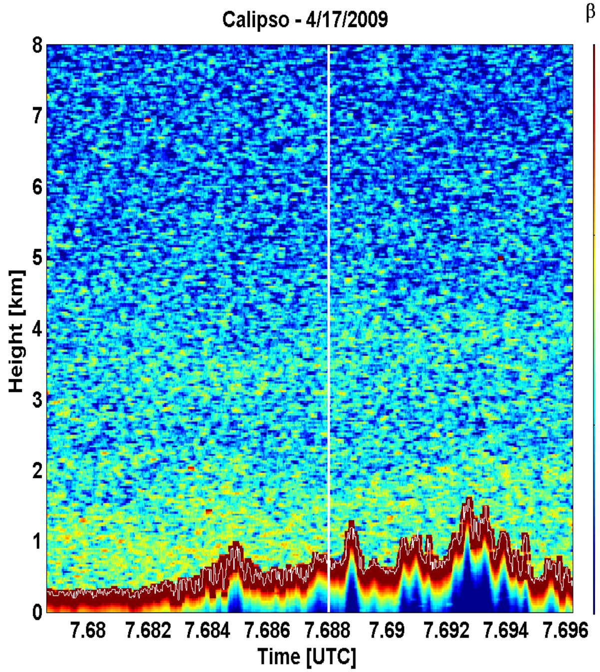
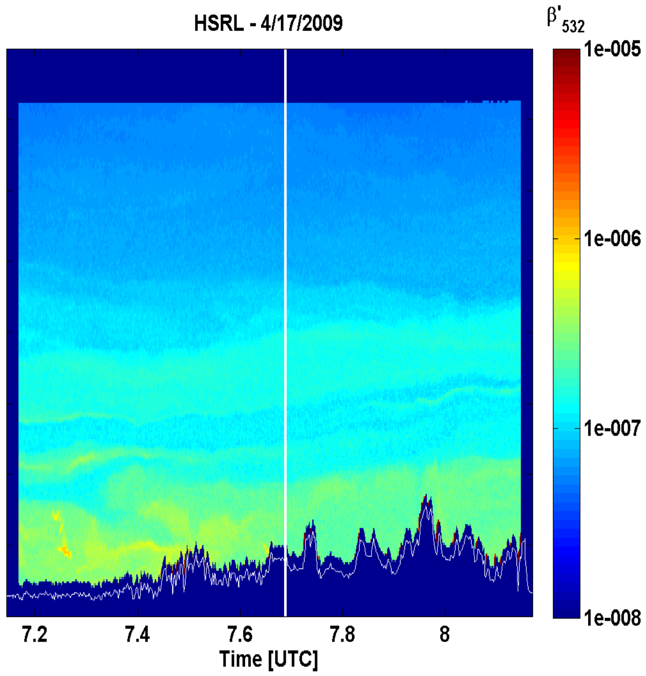


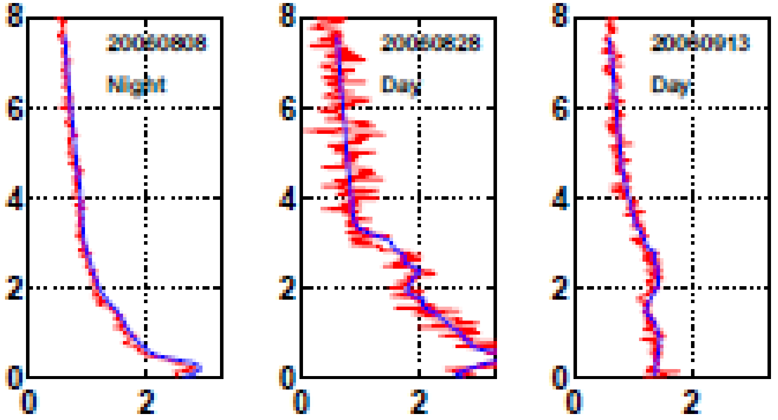
Long term HSRL campaign: Level 1, Level 2

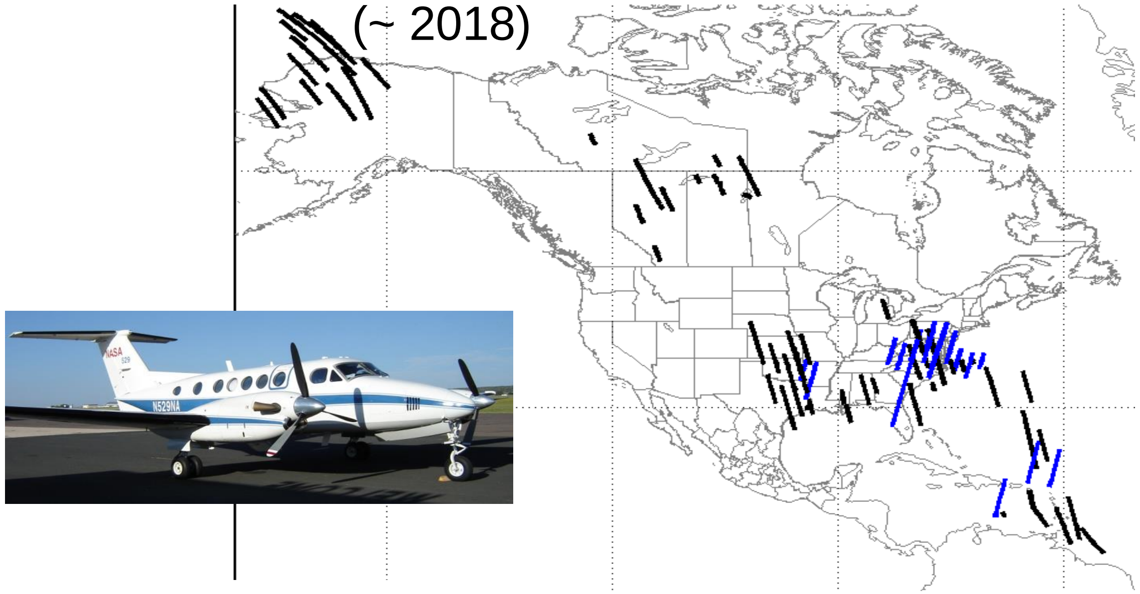
CALIPSO



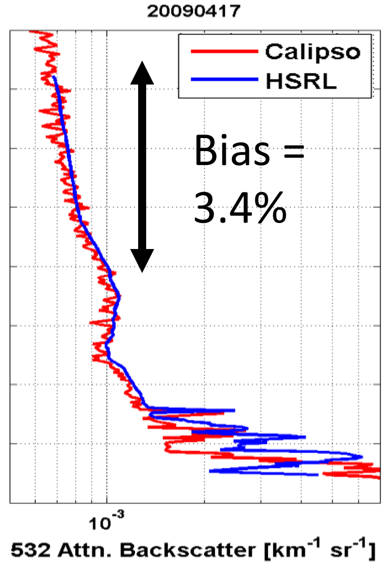
HSRL



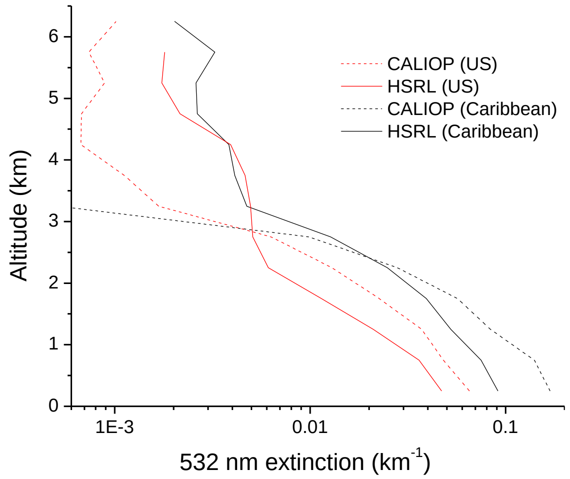




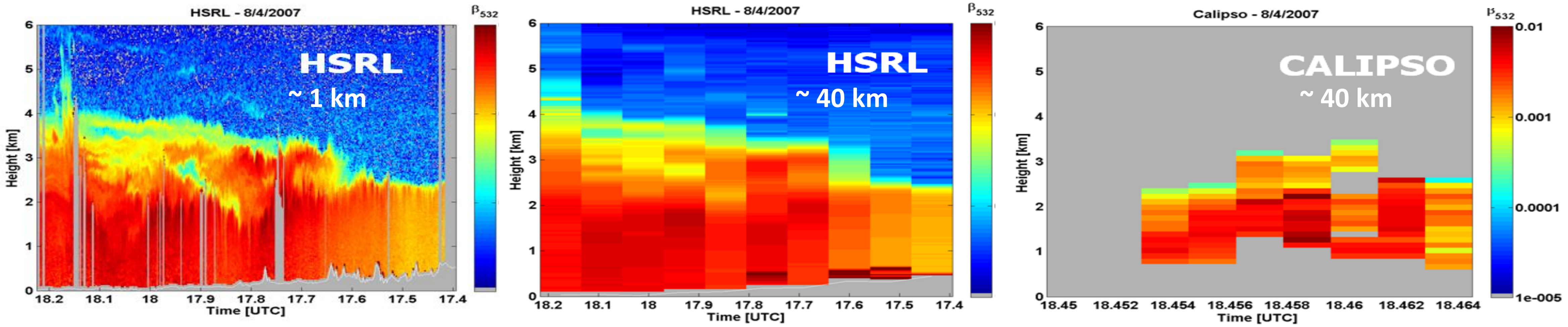
(~ 2018)



Mean extinction profiles from HSRL underflights (mostly in eastern US)



From HSRL aggregated statistics

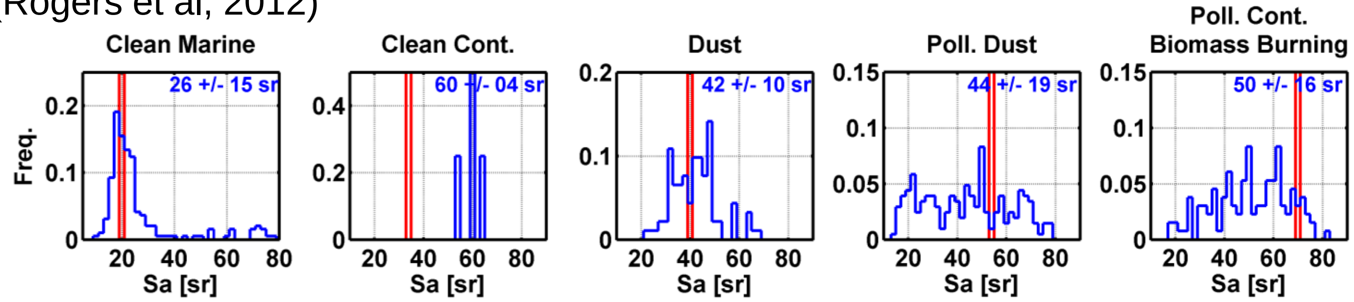


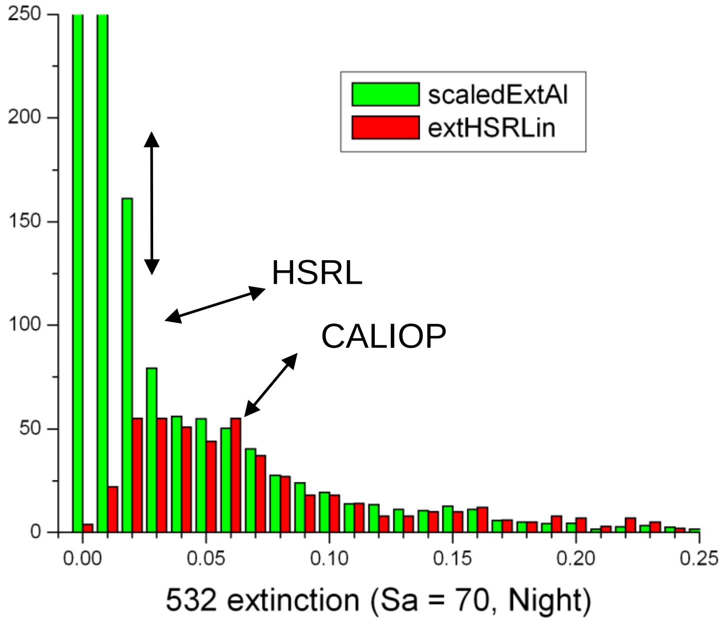
Characterization of CALIOP detection sensitivity:

- Average HSRL to CALIOP resolution
- Aggregate measurements of similar aerosol type
- Compare histogram of HSRL bins inside CALIOP layer with histogram of all HSRL bins

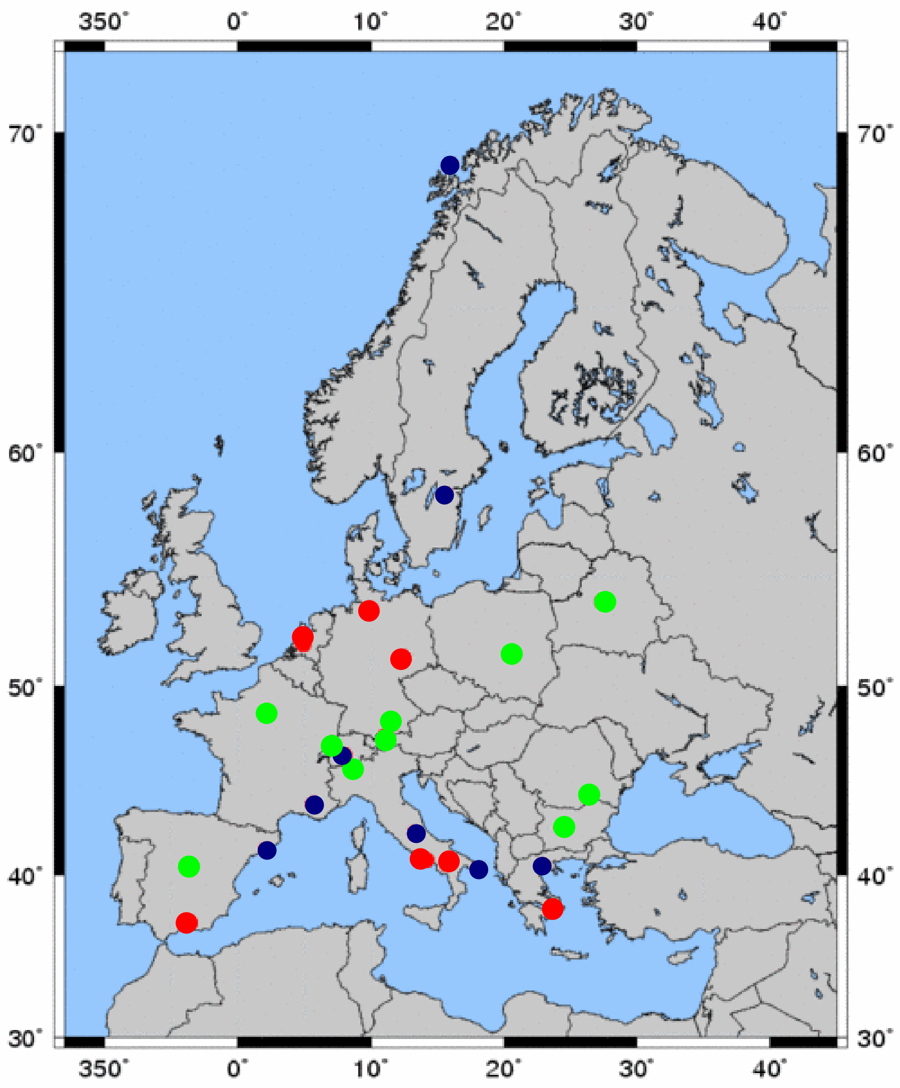
S_a: HSRL vs. CALIOP:

(Rogers et al, 2012)





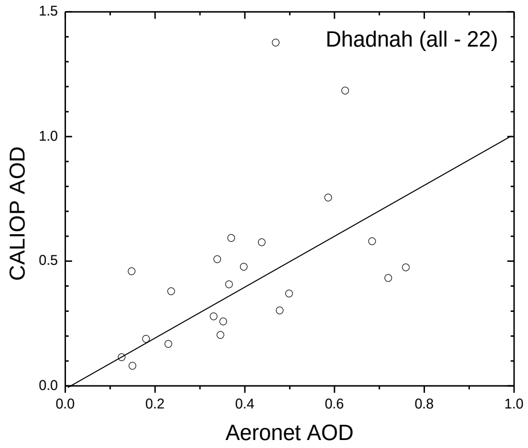
Ground Networks (example): Earlinet (circa 2011)

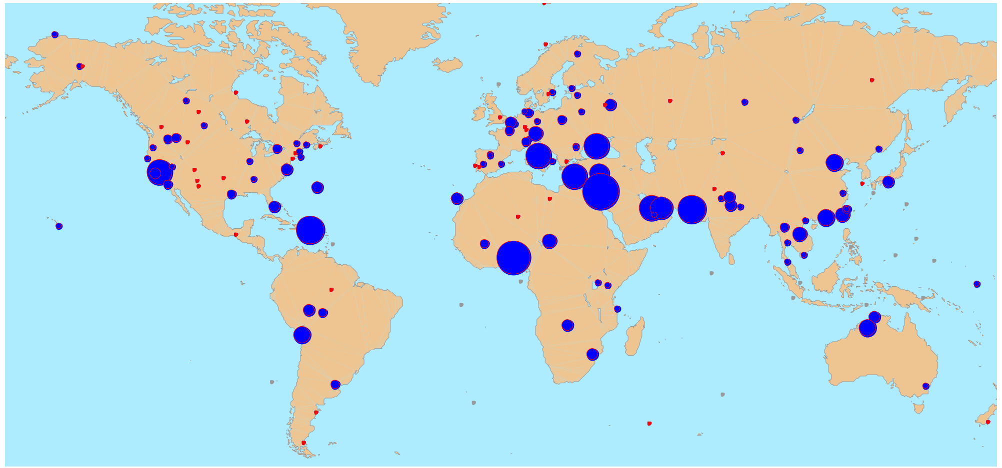


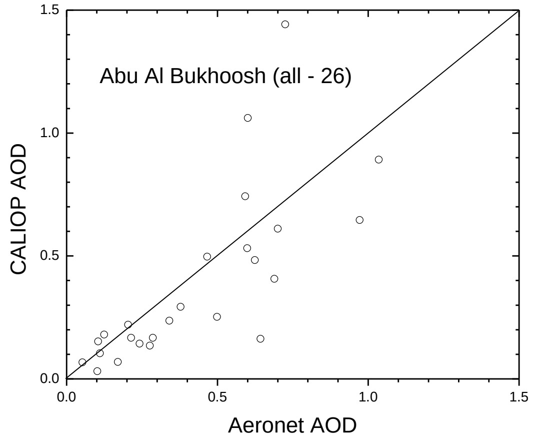
- **One of several lidar networks**
  - > 20 stations
- **Many 355 nm Raman lidars**
- **A few 532 nm Raman lidars**
- **Routine observations over many years**
- **Issues:**
  - Requires time to acquire a sufficient collection of matched observations
    - Spatial mismatches with CALIPSO
    - Blockage by clouds
  - Raman is (was?) mostly night-only
  - Comparison methodology: Perrone et al (2011)

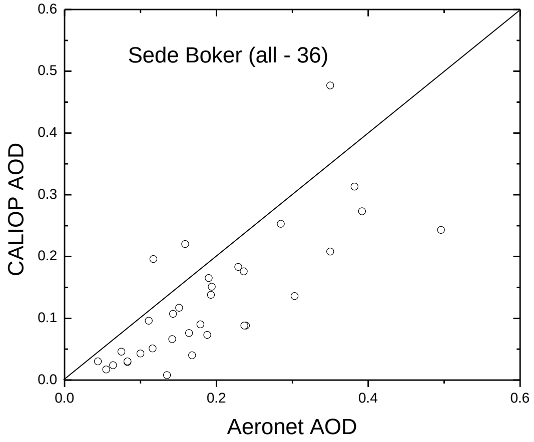
Ground Networks: Aeronet

Even with > 400 Aeronet sites, need to accumulate matched samples over several years









Omar et al, 2012: 1081 samples over 4 years (600 cloud-free)

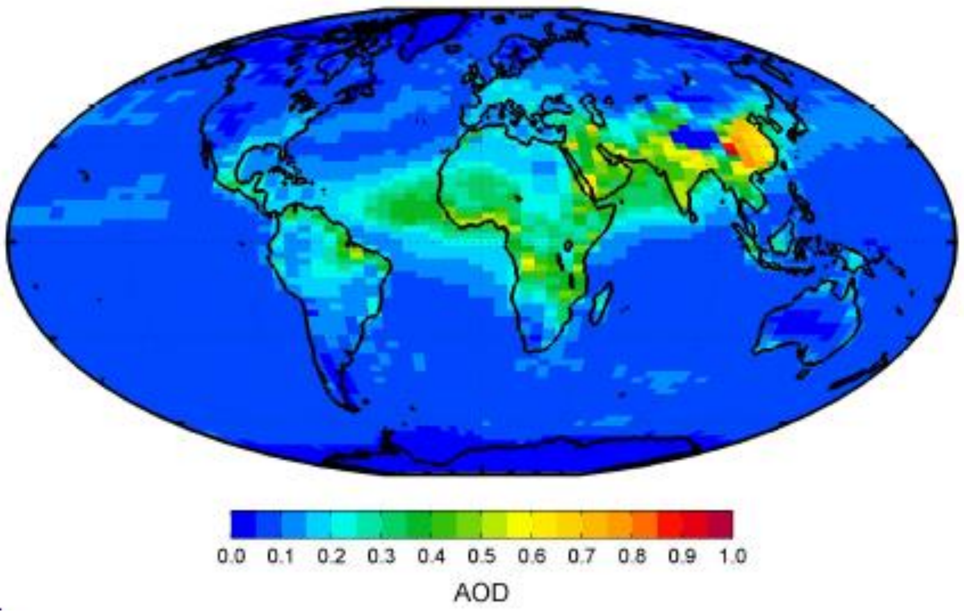
Typically, only one or two usable samples/station/year

In addition to CALIOP retrieval errors, AOD biases could be due to:

- Spatial mismatch
- Topography
  - elevation at Aeronet site higher or lower than CALIOP groundtrack
- Aeronet cloud contamination

Validation 'truth' is not always available

- The goal is 'global validation'
  - Field campaigns are expensive and rare
  - Ground networks have limited coverage
- Satellite intercomparisons
  - Depending on parameter and sensor, varies from true validation to 'sanity check'
- Consistency checks (does it 'look right')
  - Can be useful, especially in the early days

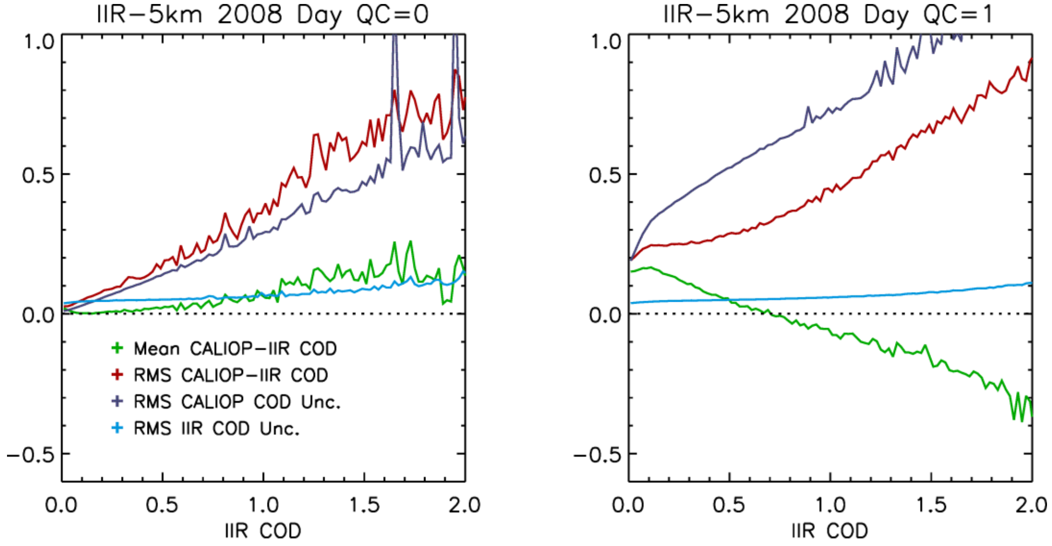


Validation using other satellite sensors: CALIOP vs IIR

- IIR has been very useful for validating CALIOP cirrus retrievals:
- Constraints on cirrus lidar-ratio LUT
- Identified biases in daytime constrained cirrus retrievals
- ‘Validated’ extinction retrieval uncertainty estimates
- Resolved MODIS-CALIOP cirrus OD discrepancy:
    - IIR visible OD more accurate than MODIS (till C6)

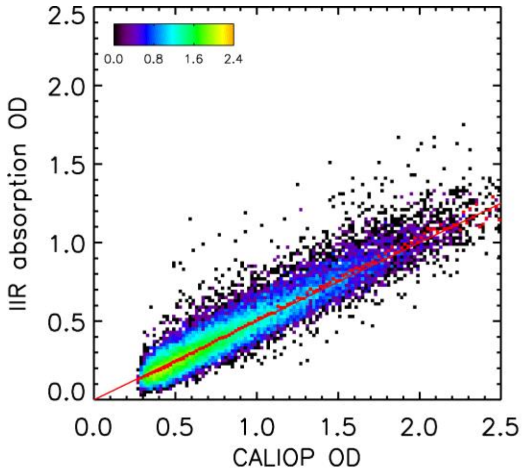
(daytime, 2008 over oceans)

unconstrained (QC=0) constrained (QC=1)



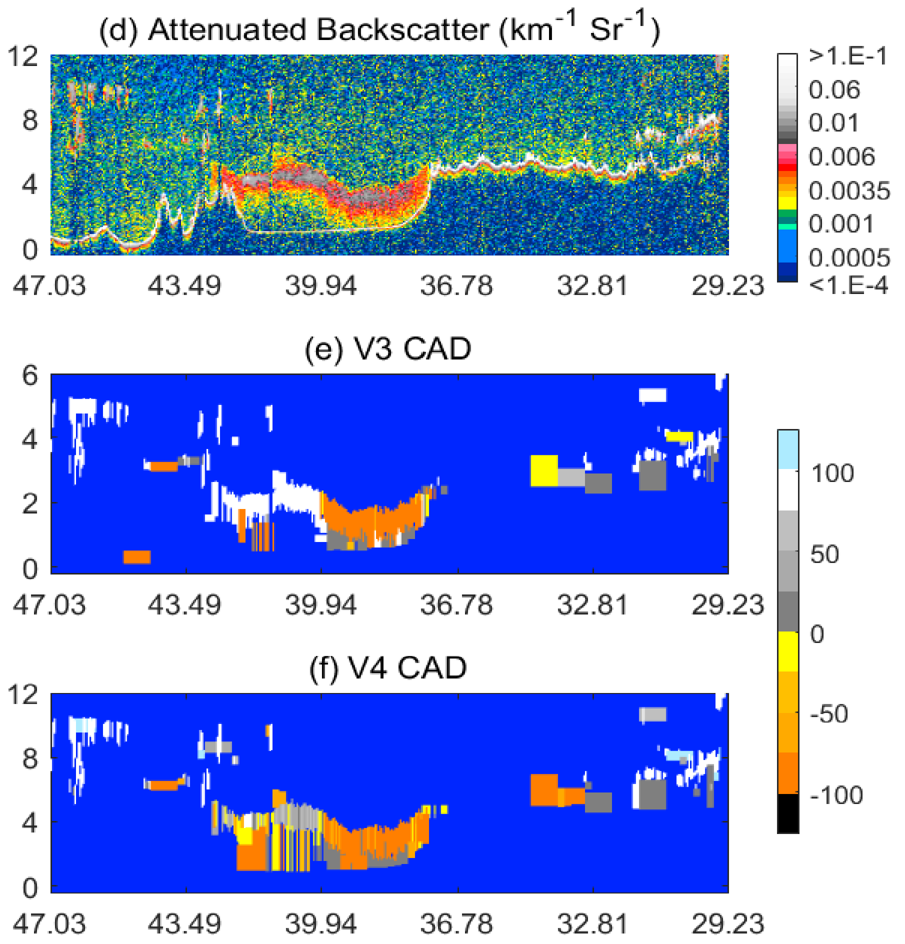
Green: Mean CALIOP-IIR COD difference
Red: RMS CALIOP-IIR COD difference
Purple: RMS CALIOP COD uncertainty estimates
Light Blue: RMS of IIR COD uncertainty

cirrus OD retrievals
IIR vs CALIOP constrained
(nighttime)

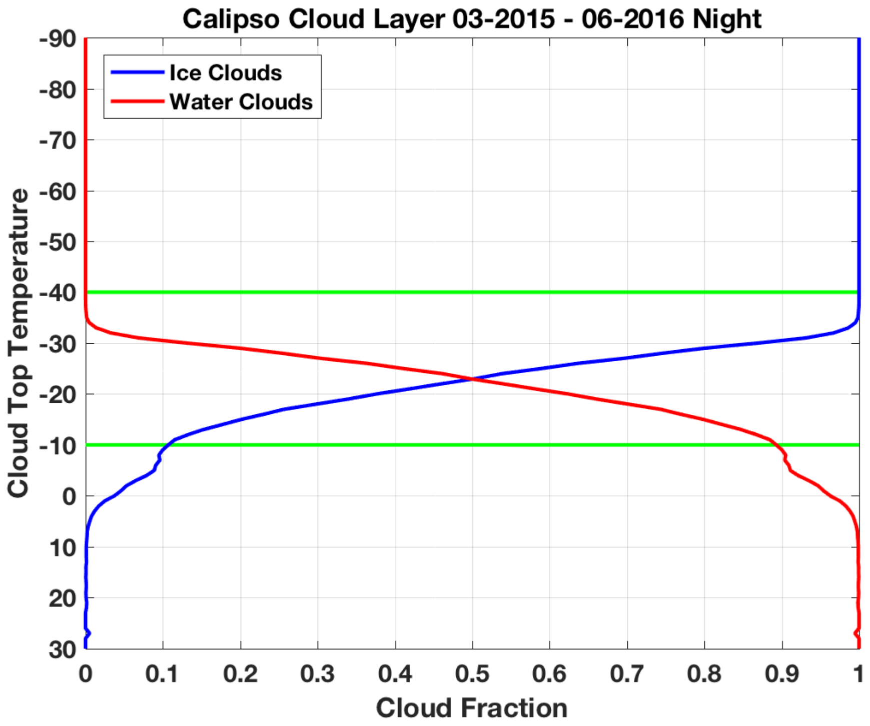


Consistency Checks: Examples

Visual inspection can identify non-physical results

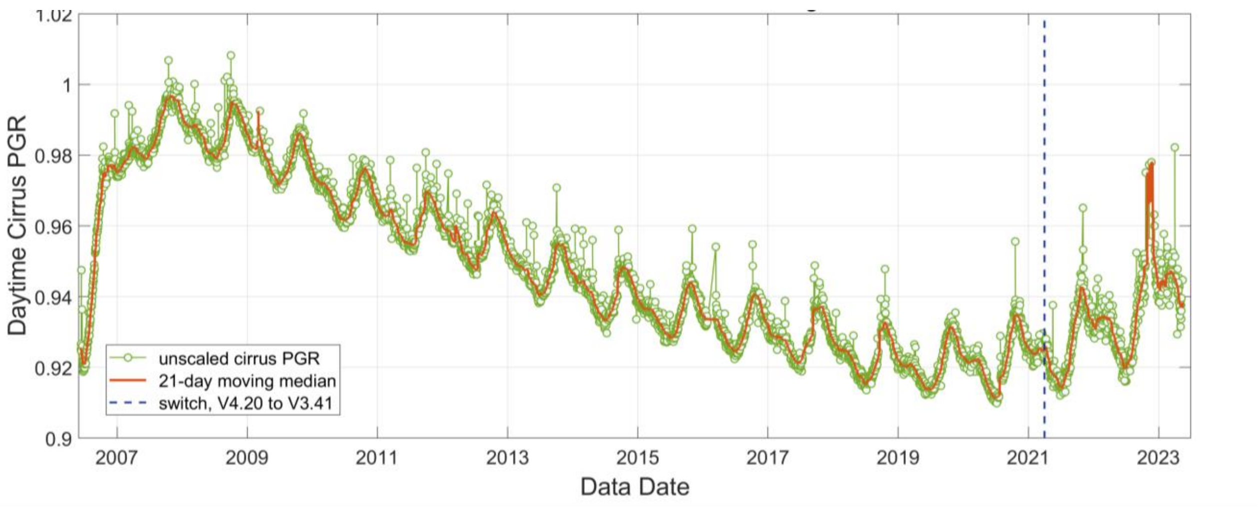


- Cloud ice-water fraction vs. temperature relations should be stable over time
- A drift in phase vs temperature relationship may indicate drifts in polarization calibration



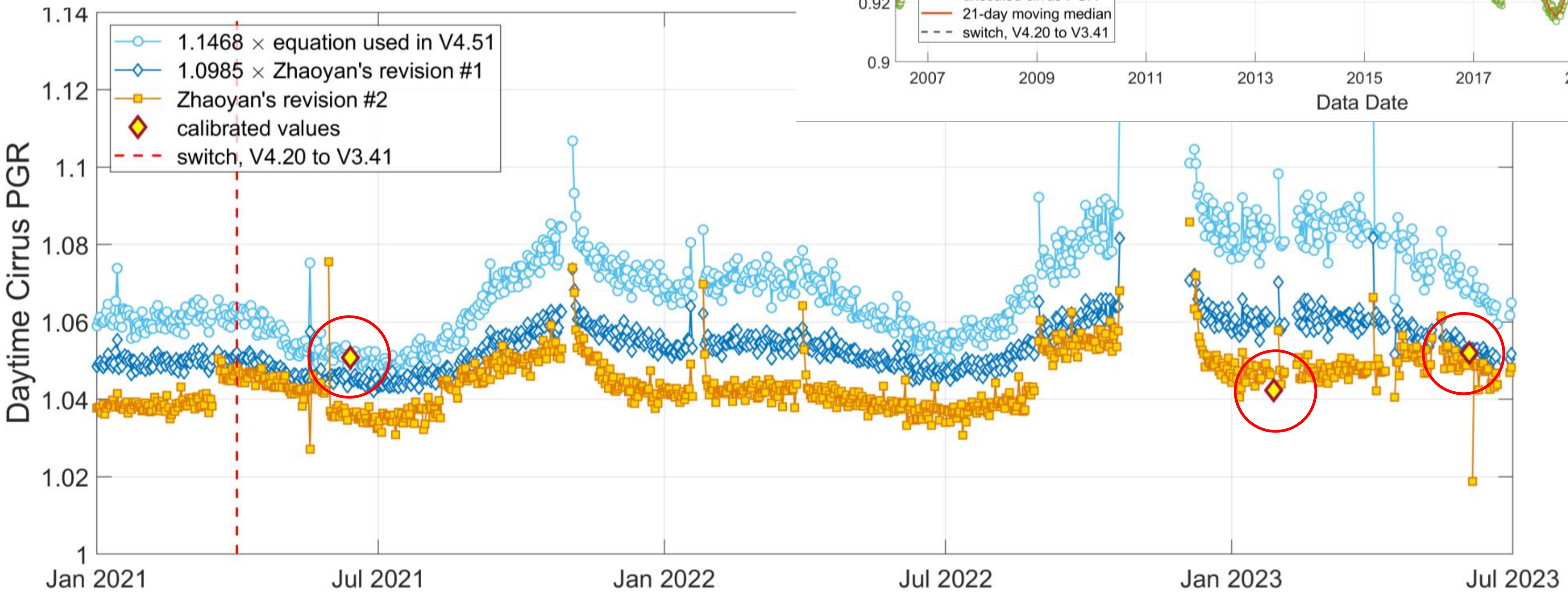
Calibration of Polarization Gain Ratio (perp/par channel)

Unscaled daytime PGR from “solar background above opaque cirrus”



Difficult validation problems:

latitudinal (intra-orbital) biases
seasonal (intra-annual) biases



Summary

- **Never as much high quality validation data as you want (need)**
  - Must be creative
- **Co-located, accurate, airborne profiles are ideal, but:**
  - Airborne campaigns are rare, and regional
  - Also need long-term measurements (ground sites, ‘dedicated’ aircraft)
- **Often no validation data available for remote regions, so must rely on:**
  - Consistency checks
  - Statistical comparisons against previous datasets (CALIOP)
  - Evaluation using models (if they are good enough)
- **Validation of uncertainty estimates is also important**
  - Value of assimilation improves with good estimates of uncertainties

Summary

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- **Validation of uncertainty estimates is also important**
  - Value of assimilation improves with good estimates of uncertainties
- **Don’t forget to intercompare results from different algorithms**
  - Single-instrument vs. Synergistic
  - European vs Japanese

We're looking forward to the launch of EarthCARE …

Good Luck!