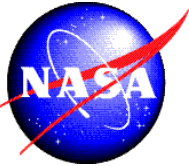


The role of airborne campaigns for calibration and validation of space-borne lidars

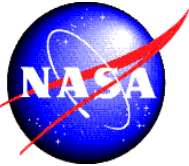
Dave Winker and Jason Tackett
NASA LaRC





CALIPSO Status

New orbit: see charts from Chip
Latest laser stats



Payload

CALIPSO:

Launched April 2006

Equator crossing, 1:30 a.m./p.m.

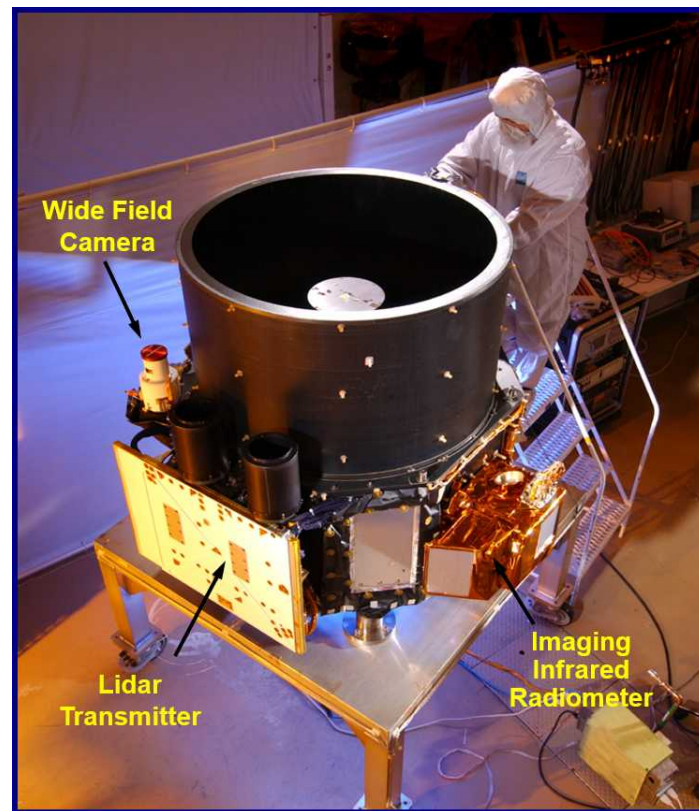
Sun-synchronous polar orbit at 705 km

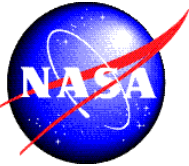
Three co-aligned instruments:

CALIOP (lidar)

- 532 nm, 1064 nm
- Depolarization at 532 nm

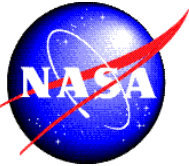
Passive visible and IR imagers



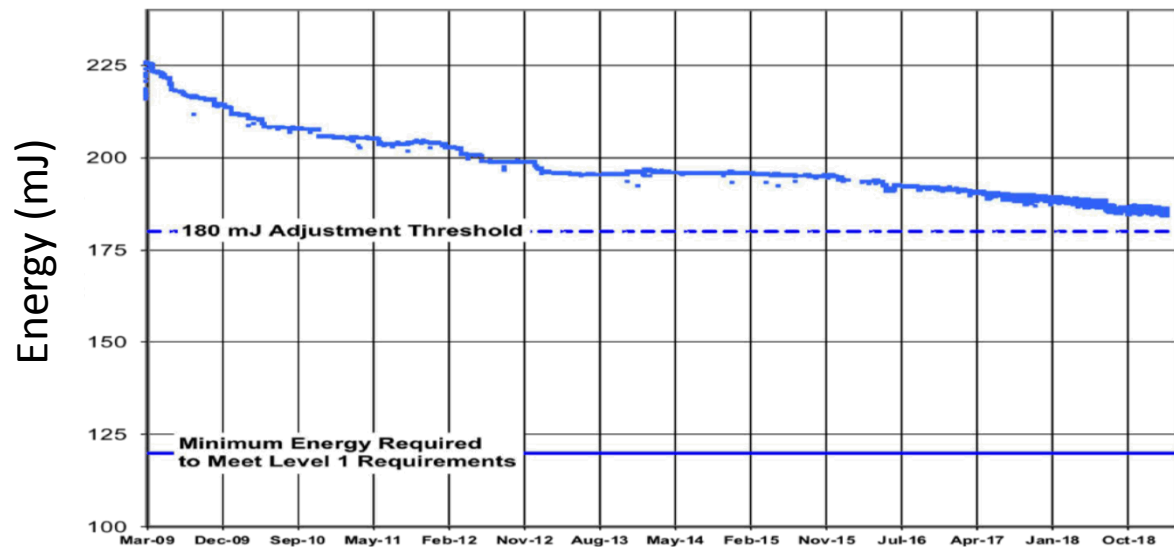


Mission Status

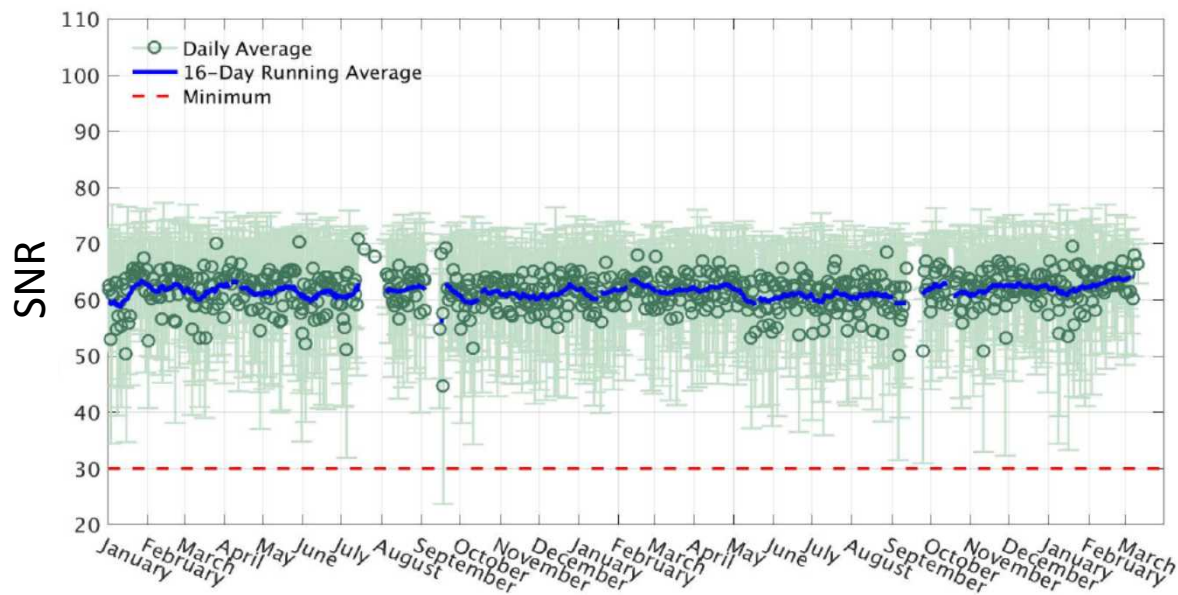
- **All Spacecraft and payload subsystems are currently healthy**
- **Operational Achievements:**
 - Will complete 13 years on orbit next month
 - Operating on backup laser since March 2009, still healthy
 - After 12 years in formation in A-train, lowered orbit in fall 2018 to fly with CloudSat
- **Projected mission life**
 - Payload and platform still fully functional and healthy
 - Essentially out of fuel
 - Small reserve left for collision avoidance
 - No further orbit inclination adjustments or drag make-up
- **NASA Senior Review in early 2020 to approve operations into 2023**



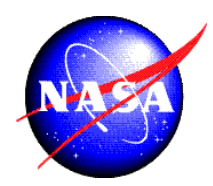
Laser Energy and SNR Trends



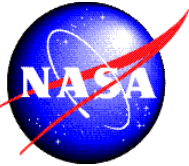
Total Laser Energy
(1064 nm + 532 nm)
Mar. 2009 – Nov. 2018



Nighttime SNR 532 nm
24-30 km, 45° S/N
Jan. 2017 – Feb. 2019



Validation



Validation Activities

CALIOP validation has taken advantage of:

- **Ground-based networks**

- Aeronet
- Earlinet, ADnet

- **Satellite comparisons**

- MODIS, MLS, AIRS
- CALIOP vs. IIR

- **Targeted aircraft campaigns**

- LaRC HSRL (King Air)
- NOAA ESRL (Cessna)

- **International field campaigns**

- NASA AMMA (Cape Verde)
- SAMUM
- CIRCLE-2
- NASA TC⁴ (Costa Rica)
- ASTAR/PAM-ARCMIP
- ARCTAS/PolarCat
- SEAC4RS

Jun 2006 - 20012

Jul-Aug 2006-2009

Aug 2006

2006, 2008

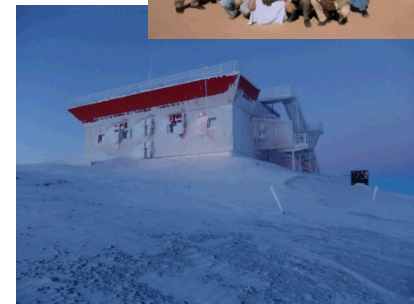
May 2007

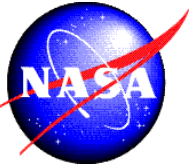
Jul-Aug 2007

April 2007/09/11/12

April, July 2008

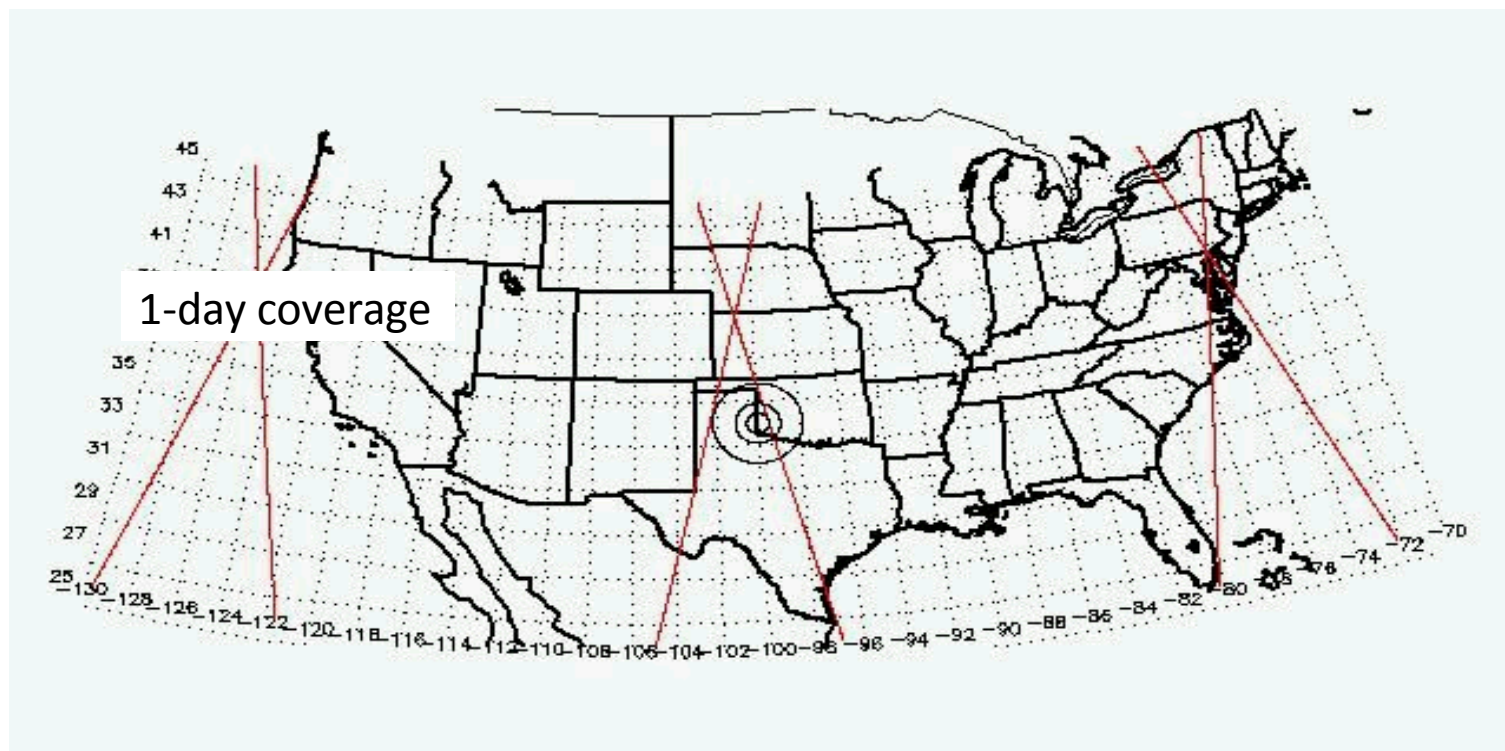
Aug-Sep 2012

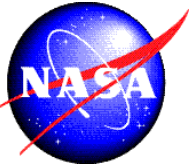




Validation Obstacles

- 70 meter 'swath' – spatial matching to ground sites is difficult
- We need to validate *profile* measurements – few validation datasets
- Nighttime aerosol measurements – few validation datasets
- Aerosol above cloud – no validation datasets except airborne lidar
- Global data products means global validation

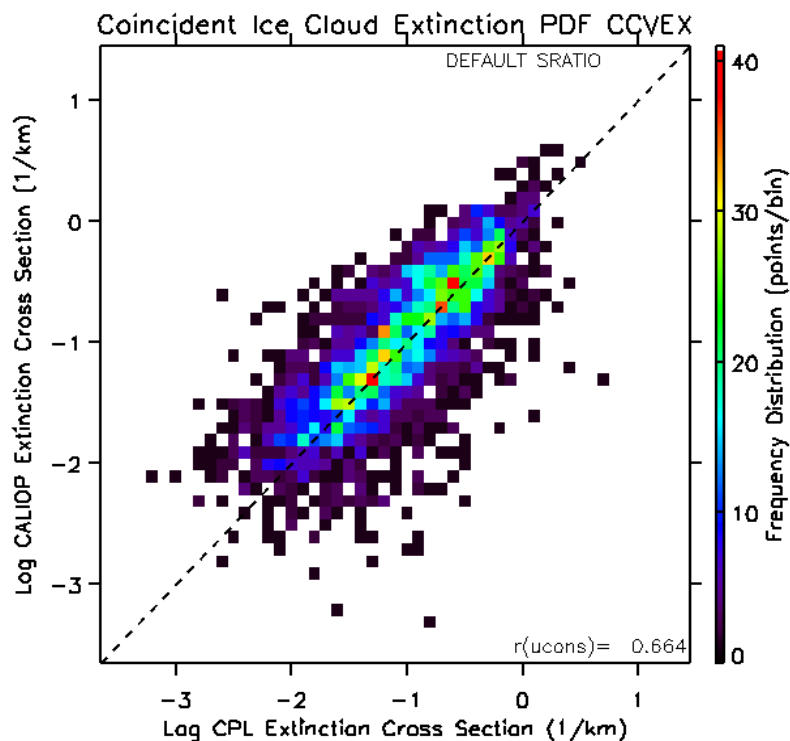




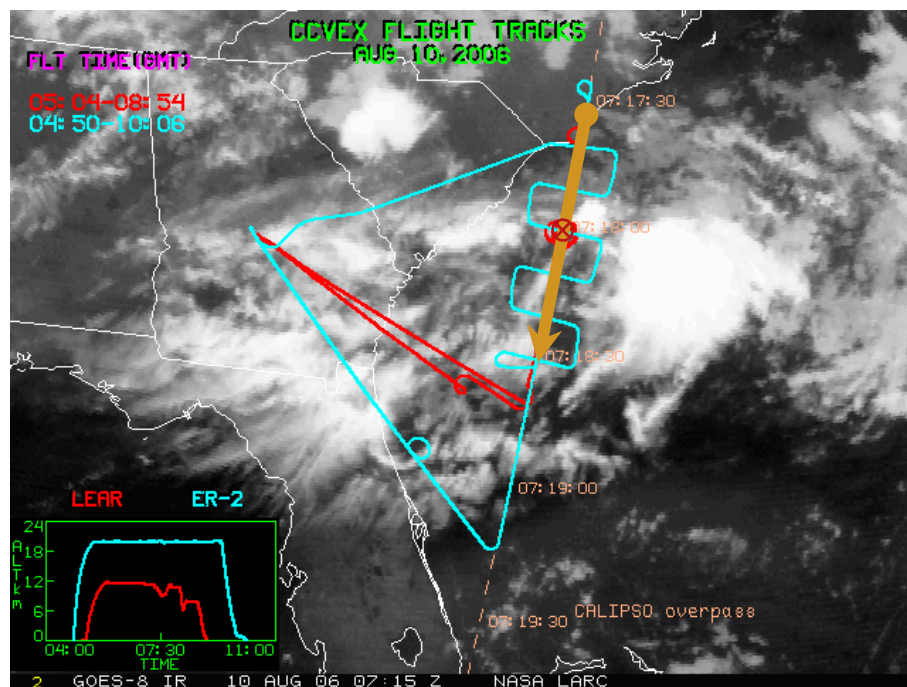
B-200 vs. ER-2 (CPL)

ER-2 – flies ‘above atmosphere’, mimics CALIOP viewing geometry, provides cirrus validation
But:

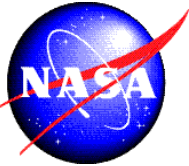
- more expensive,
- heavily subscribed
- logistics are complex (limited # airports)



10 Aug 2006 (night)
170 m offset at coincidence



CC-VEX Campaign



Initial Validation using ER-2/CPL

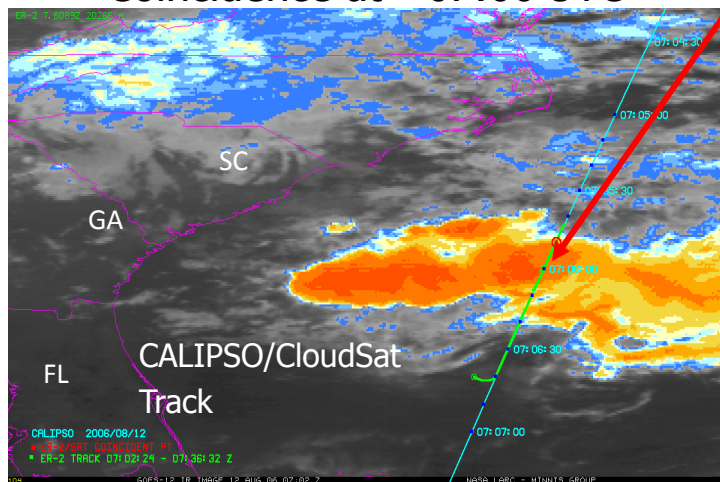
12 August 2006

Flight Objectives

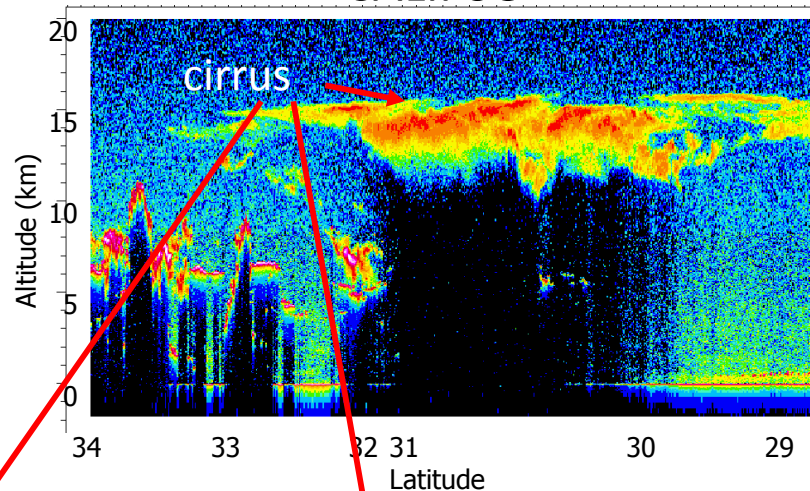
- verify lidar calibration over thick cirrus layer at night
- verify 1064 and 532 sensitivities with complex cloud & aerosol scenes

GOES Image

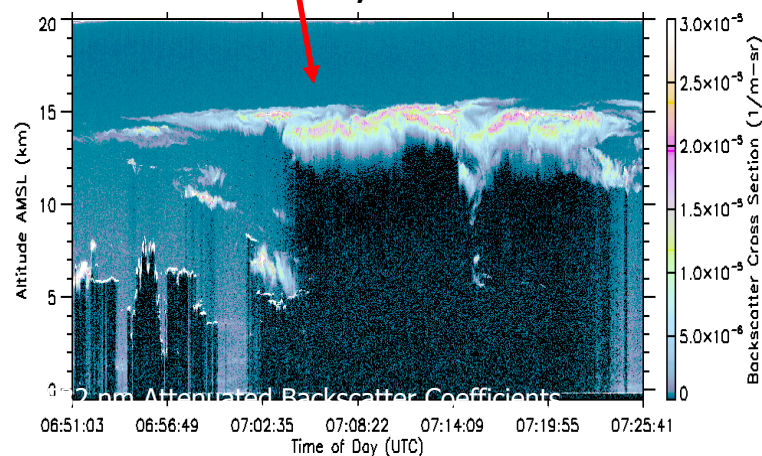
Coincidence at ~07:06 UTC



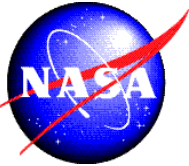
CALIPSO



ER2 Cloud Physics Lidar



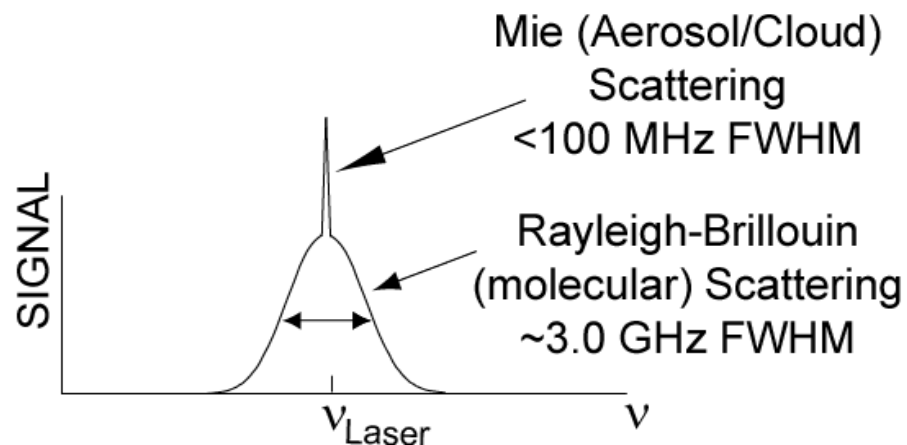
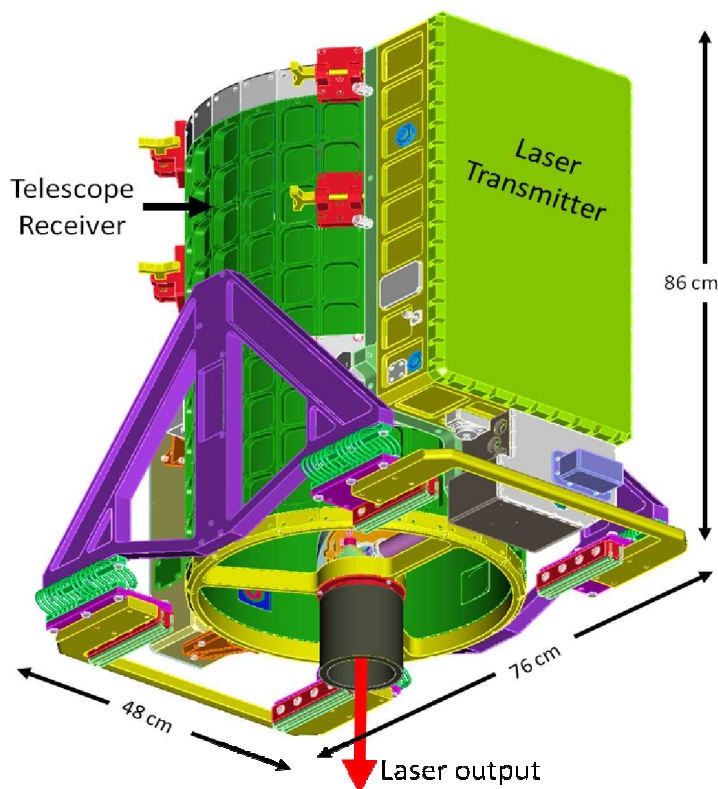
532 nm Attenuated Backscatter Coefficients

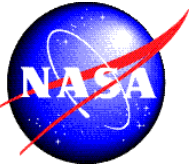


HSRL on NASA B-200

A key resource for CALIOP validation:

- Aerosol backscatter and depolarization at 532 nm and 1064 nm
- Aerosol extinction via HSRL technique at 532 nm
- Dec 2005: first test flight NASA King Air (B-200)
- 2006-2011: > 100 CALIPSO underflights





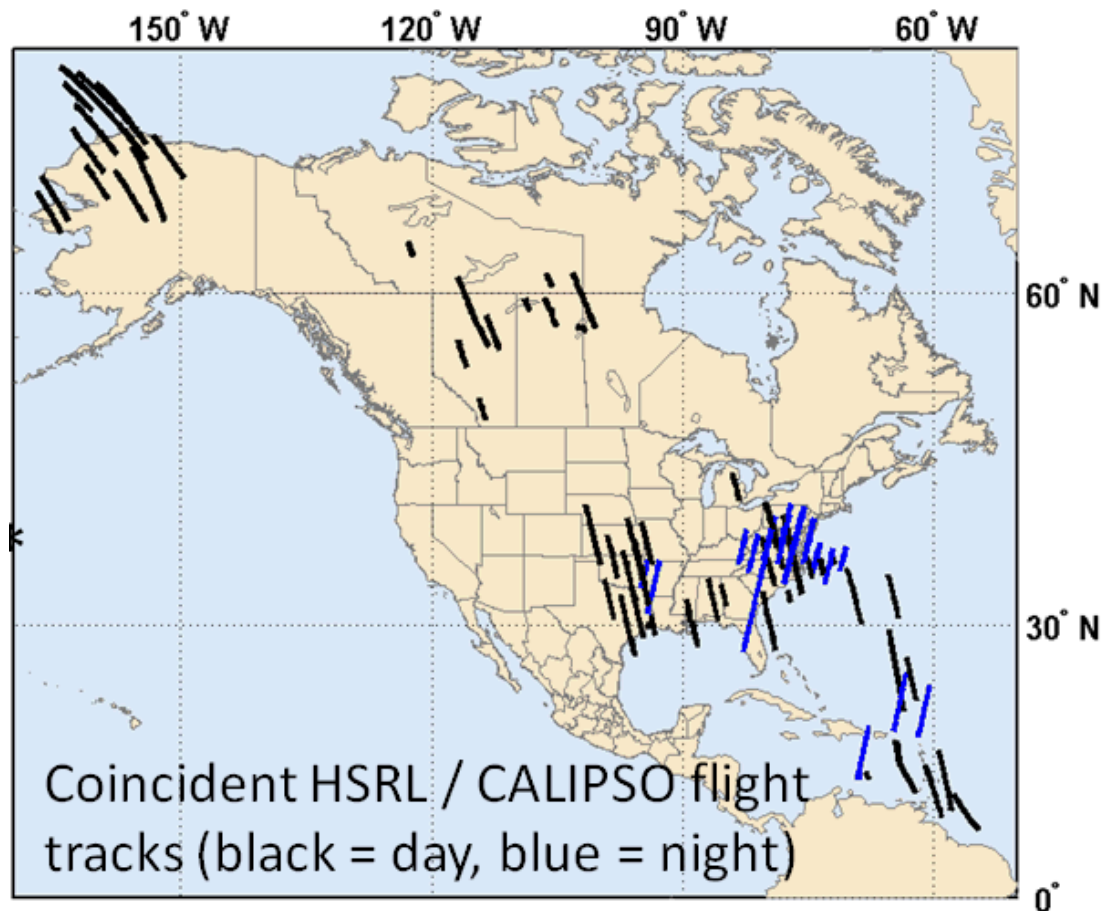
Approach used for HSRL validation of CALIOP

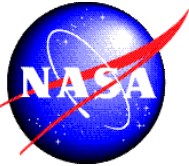
- **>100 underflights of CALIPSO satellite**
- **HSRL-1 instrument used to validate CALIOP**

- Calibration
- 532 nm backscatter
- 532 nm extinction
- Lidar ratio
- Aerosol type

■ See

- Rogers, R. R., et al. (2011), Assessment of the CALIPSO Lidar 532 nm attenuated backscatter calibration using the NASA LaRC airborne High Spectral Resolution Lidar, *Atmos. Chem. Phys.*, 11(3), 1295-1311, doi:10.5194/acp-11-1295-2011.
- Rogers, R. R., et al. (2014), Looking Through the Haze: Evaluating the CALIPSO Level 2 Aerosol Layer Optical Depth using Airborne High Spectral Resolution Lidar Data, *Atmos. Meas. Tech.*, 7, 4317-4340, doi:10.5194/amt-7-4317-2014.



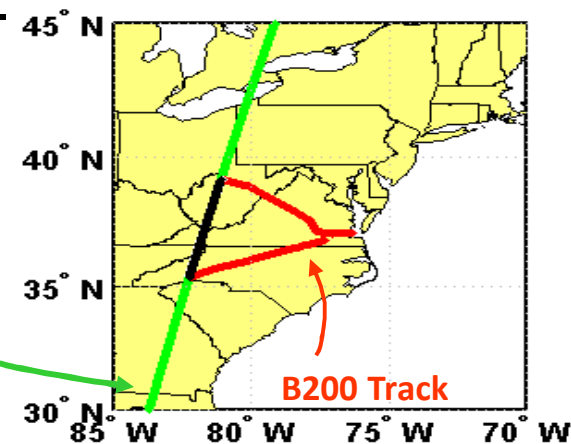


532 nm Calibration Assessment

4/17/2009

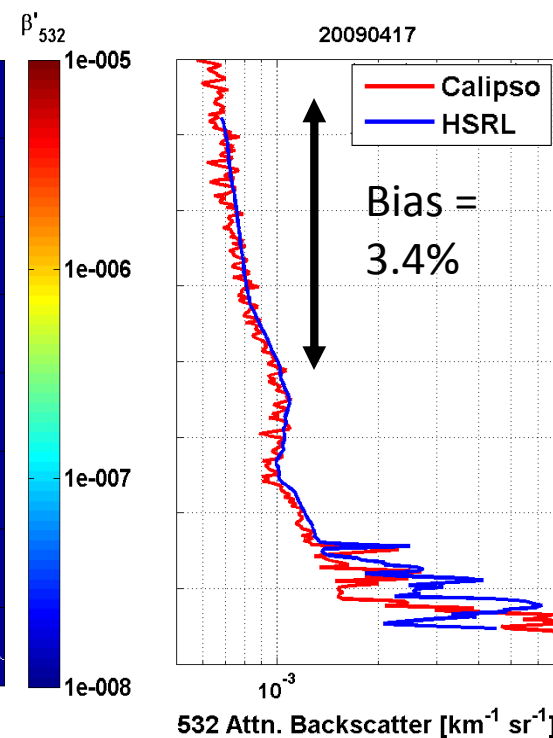
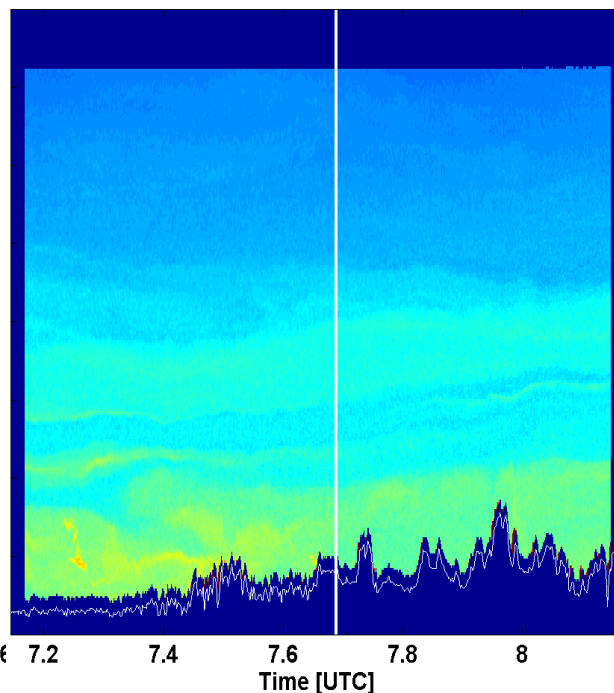
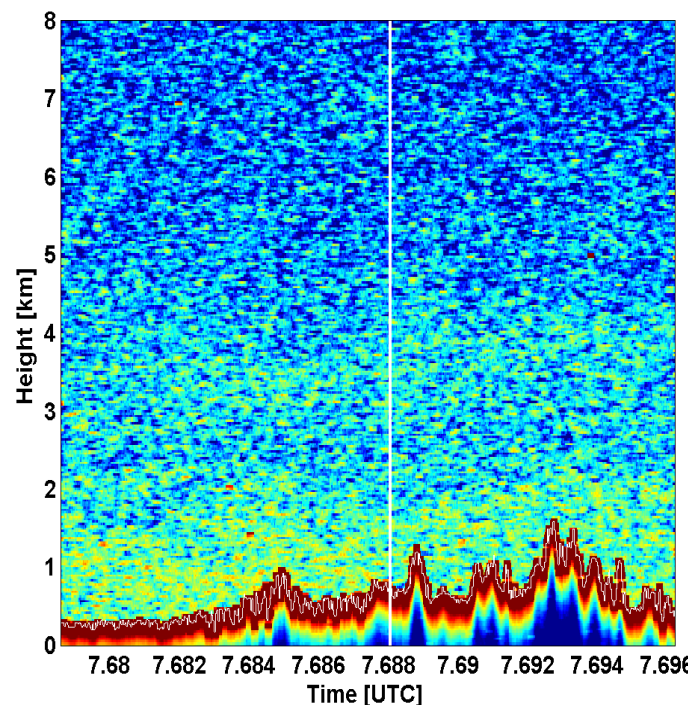
- Below: CALIOP and HSRL 532 nm attenuated backscatter data on 4/17/2009.
- CALIOP-HSRL bias calculated from backscatter signals in the free troposphere.

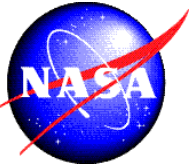
CALIPSO Track



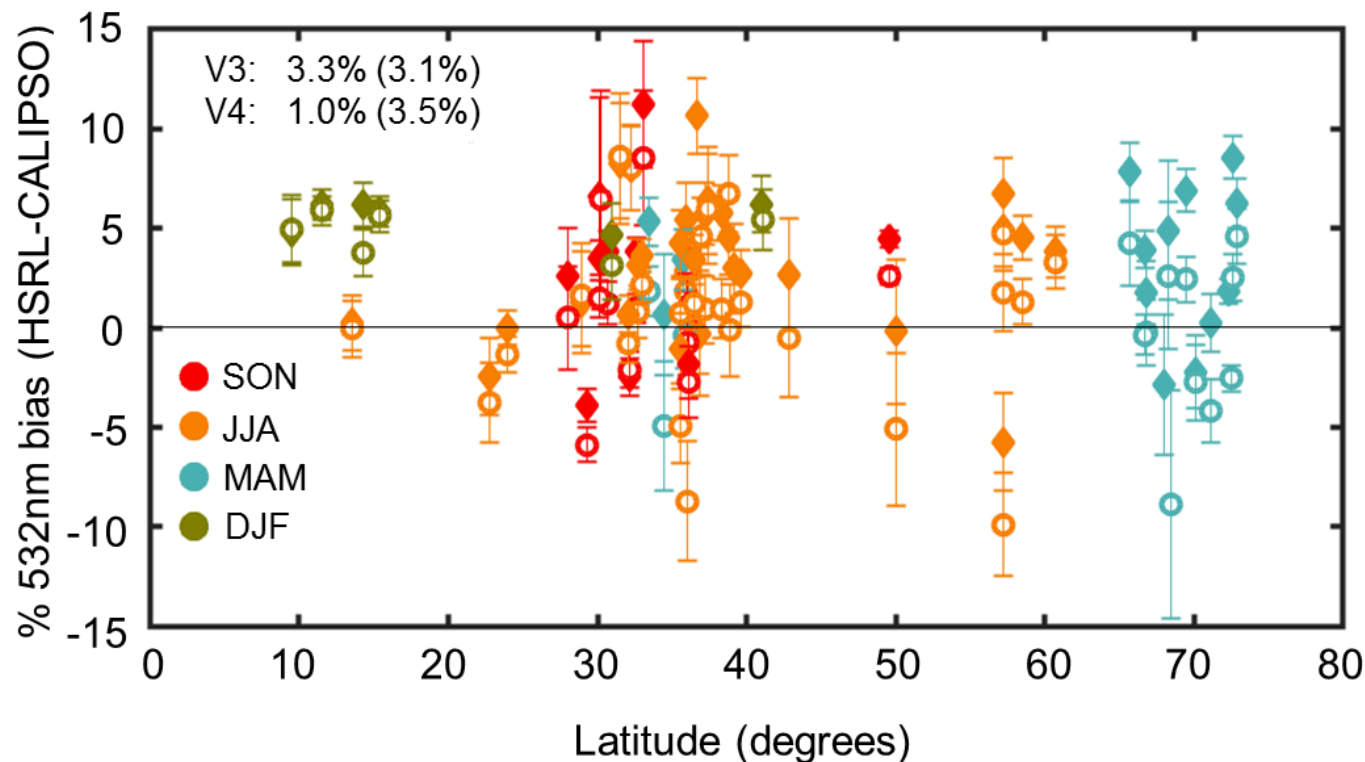
CALIPSO

HSRL

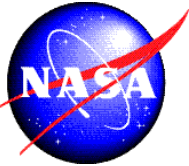




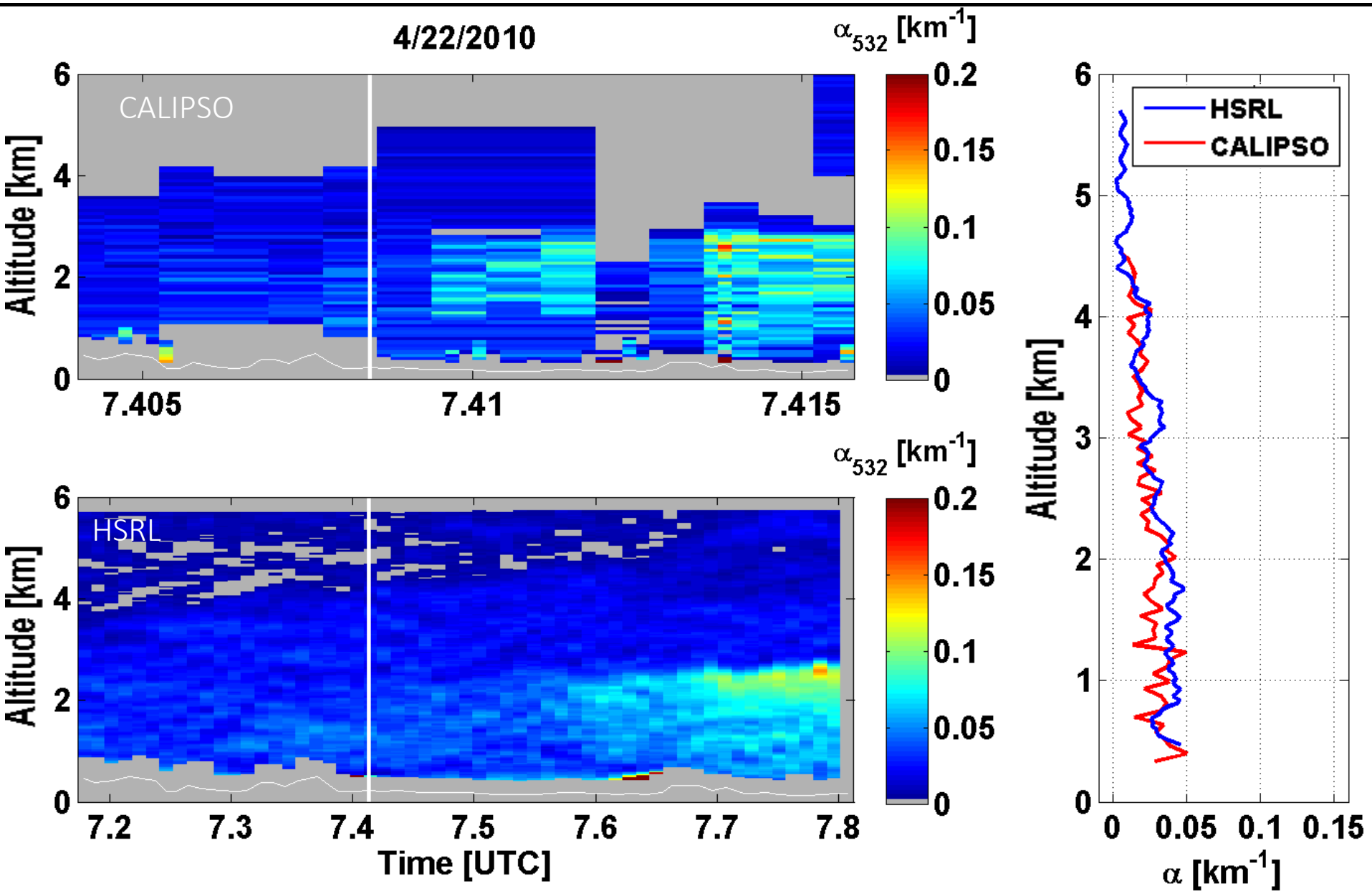
Level 1 Validation

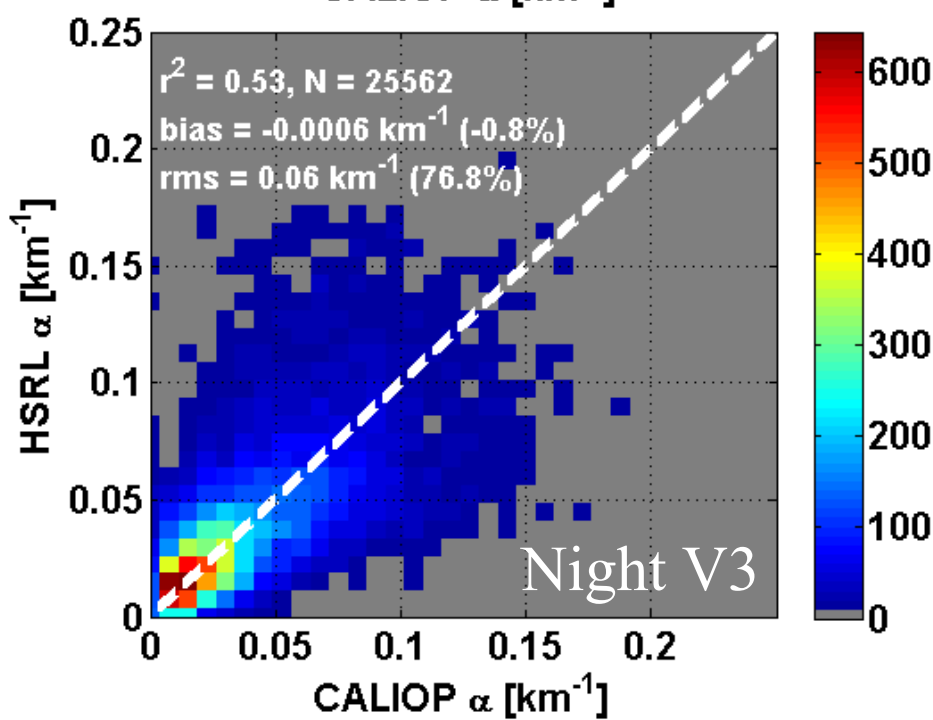
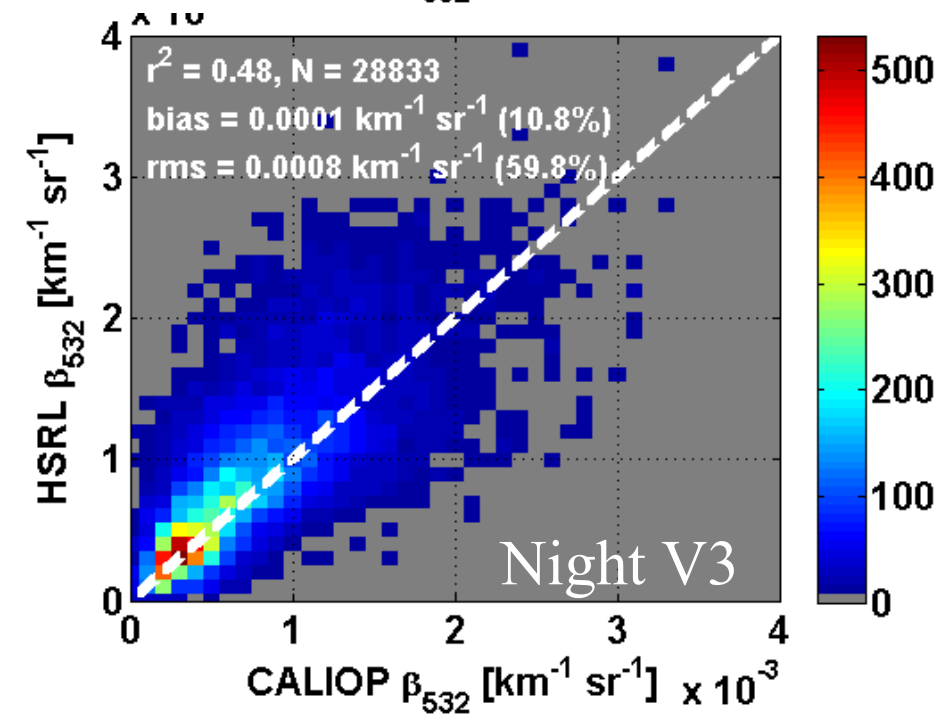
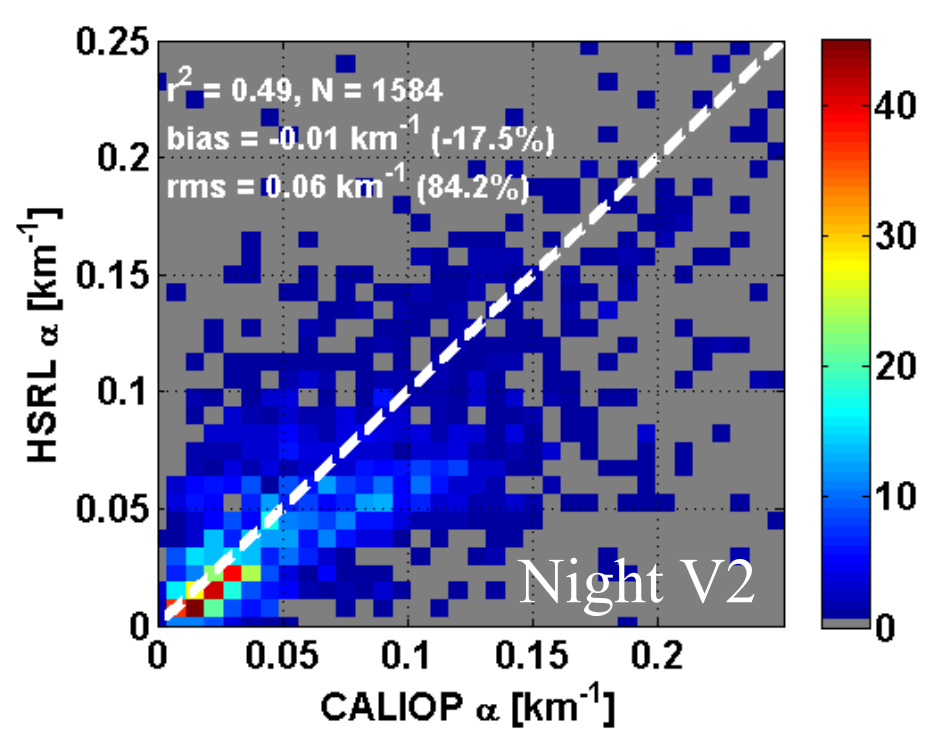
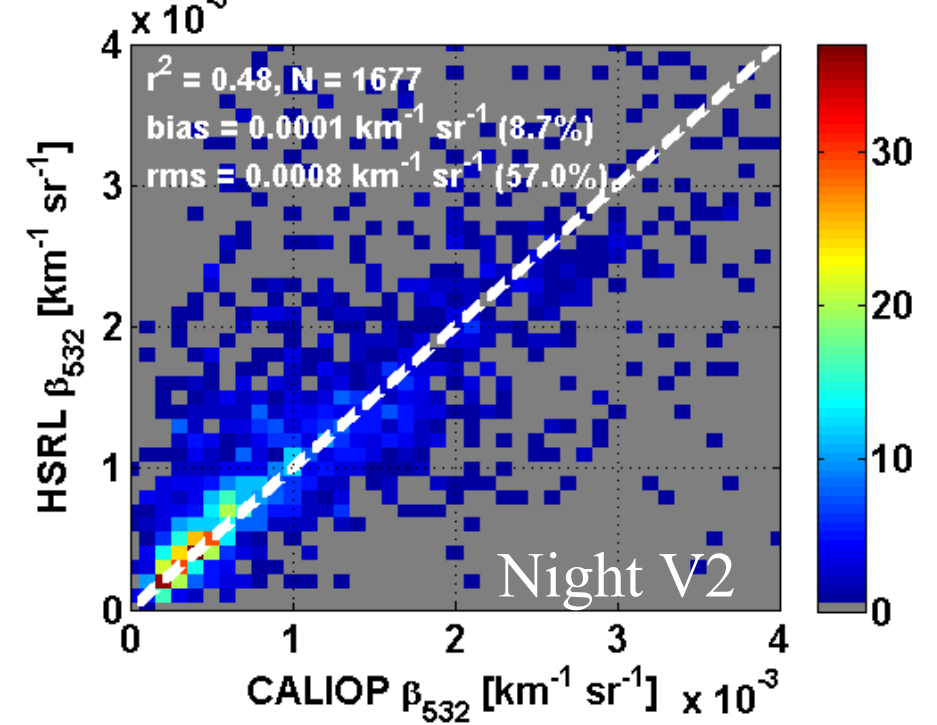


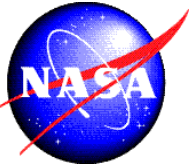
Bias of the daytime 532 nm attenuated backscatter measured between HSRL and CALIPSO for several over-flight campaigns between 2006 and 2014 broken by season and latitudes. The comparisons used both V3 (solid diamonds) and V4 (open circles) L1 data. Each point represents the mean and uncertainty of the HSRL-CALIPSO difference for each of the 62 flights conducted.



Level 2 Aerosol Profile (v3.01)

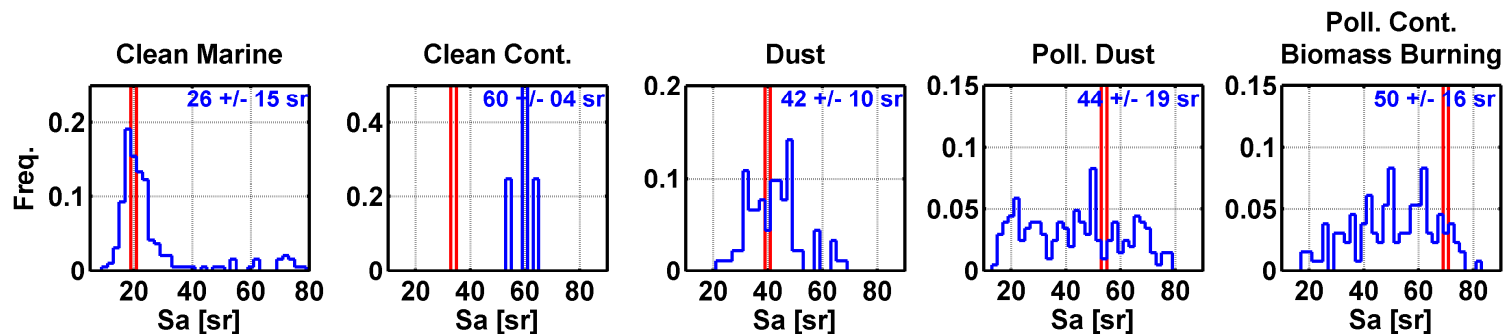




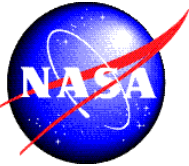


Validation of Level 2 aerosol from HSRL

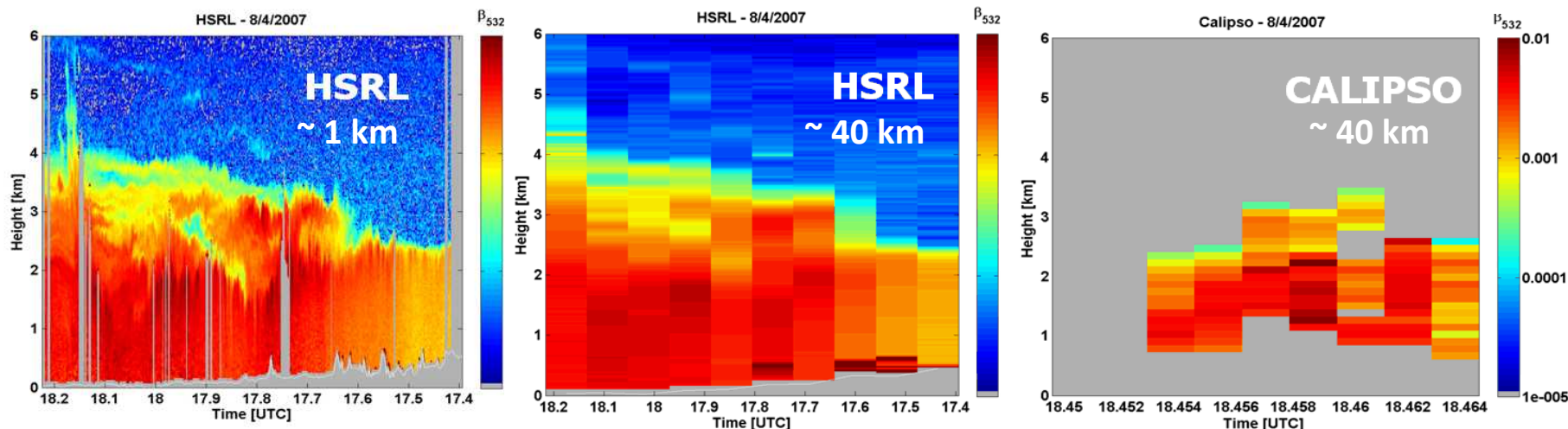
HSRL measured lidar ratio vs. CALIOP aerosol type (daytime)



(Rogers et al, 2012)

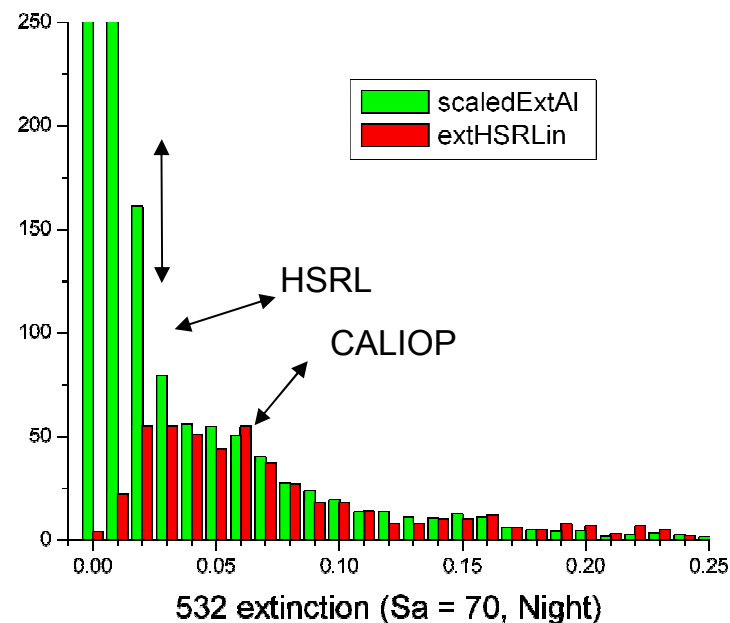


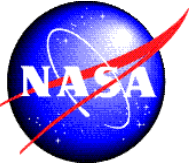
CALIOP Aerosol Detection Sensitivity



Method:

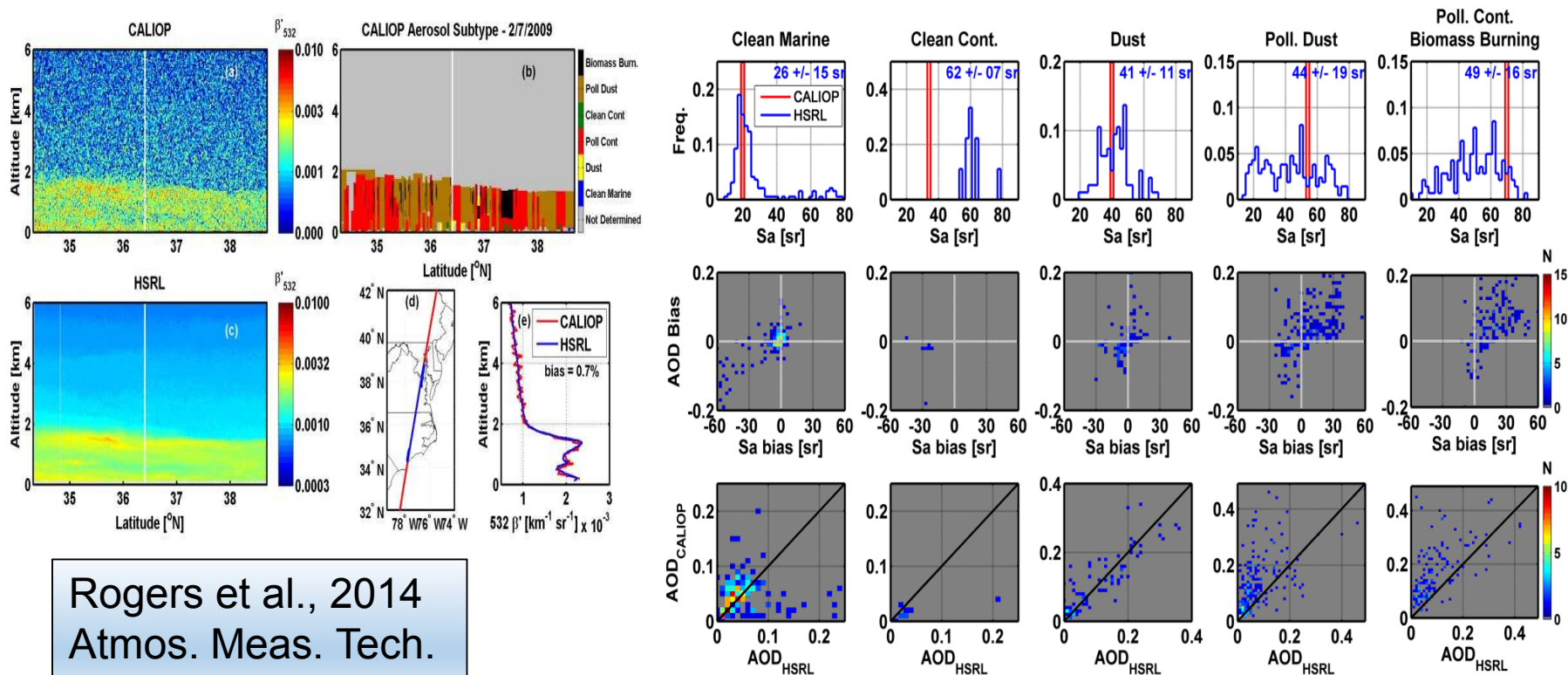
- Average HSRL to CALIOP resolution
- Aggregate measurements of similar aerosol type
- Compare histogram of HSRL bins inside CALIOP layer to histogram of all HSRL bins
- Requires many flights to have sufficient statistics



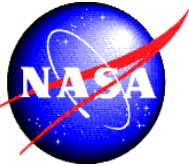


HSRL data used for Validating CALIOP Level 2 Data Products

- More than 100 HSRL underflights of CALIOP since 2006
- HSRL data:
 - Confirm CALIOP level 1 calibration uncertainty
 - Quantify CALIOP AOD uncertainties
 - Assess aerosol lidar ratios used in CALIOP algorithms

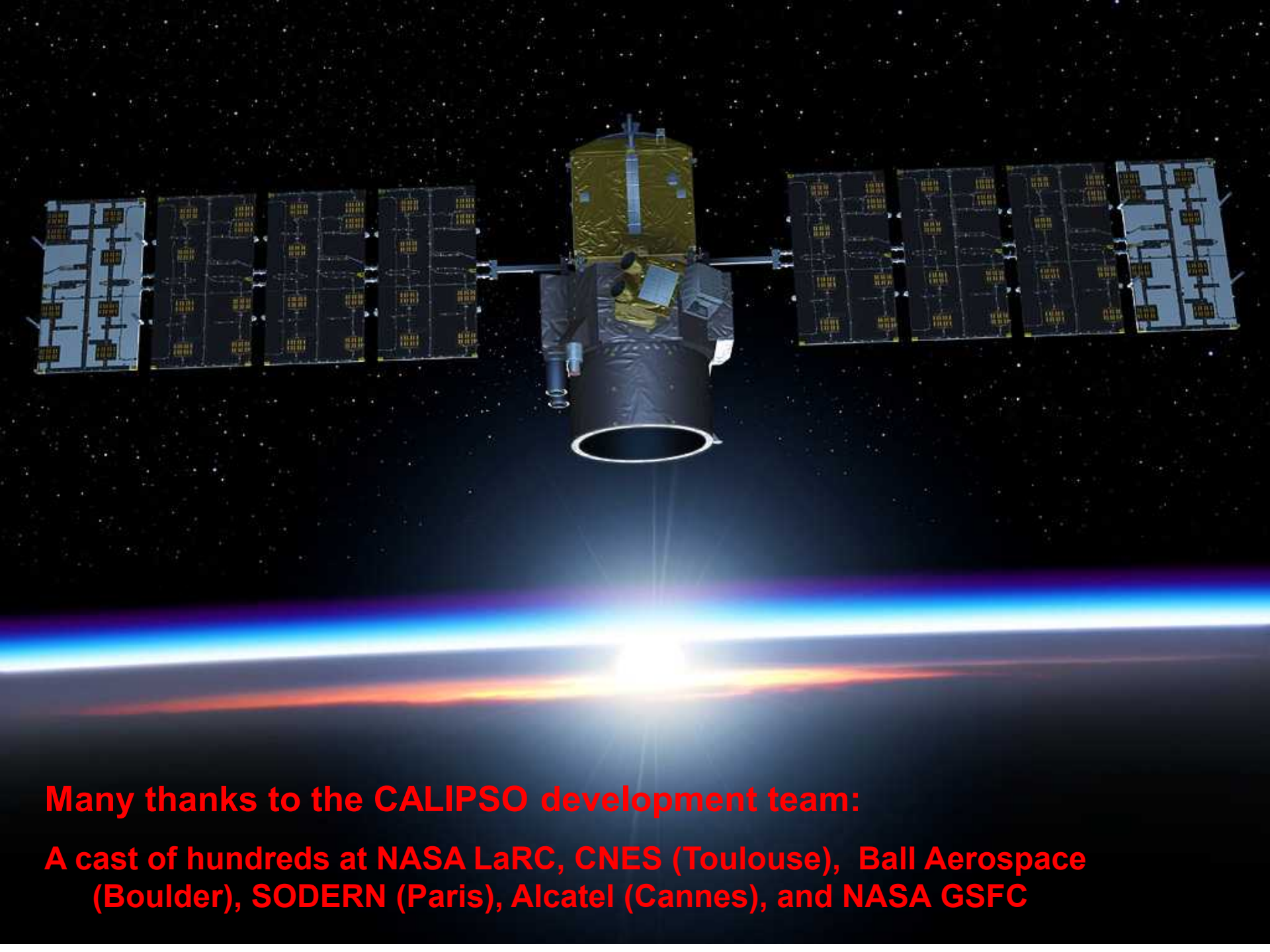


Rogers et al., 2014
Atmos. Meas. Tech.



Lessons Learned on Validation

- **Airborne instruments better suited than ground sites for validation of nadir-only measurements**
- **But traditional “large” campaigns provide datasets with few samples, making assessments of data product uncertainties difficult**
- **HSRL on B-200 aircraft has been an important validation tool:**
 - Monitor 532 nm calibration
 - Evaluate detection sensitivity
 - Validate aerosol extinction retrievals
 - Evaluate selection of aerosol lidar ratios
 - Flights in different regions to sample different aerosol types
- **NASA B-200 provides a flexible, inexpensive platform**
 - Based at LaRC, flexible scheduling
 - Some flights funded by larger field campaigns
 - Many flights funded by CALIPSO



Many thanks to the CALIPSO development team:

A cast of hundreds at NASA LaRC, CNES (Toulouse), Ball Aerospace (Boulder), SODERN (Paris), Alcatel (Cannes), and NASA GSFC