Using Airborne High Spectral Resolution Lidar Data to Evaluate Combined Active/Passive Retrievals of Aerosol Extinction Profiles

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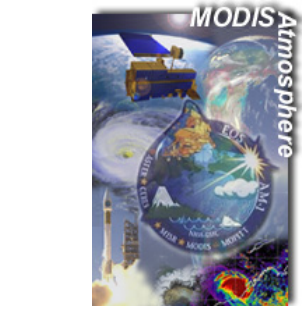
See Burton et al. (2009) submitted to JGR



Background and Motivation

Aerosol Backscatter and Extinction Retrievals

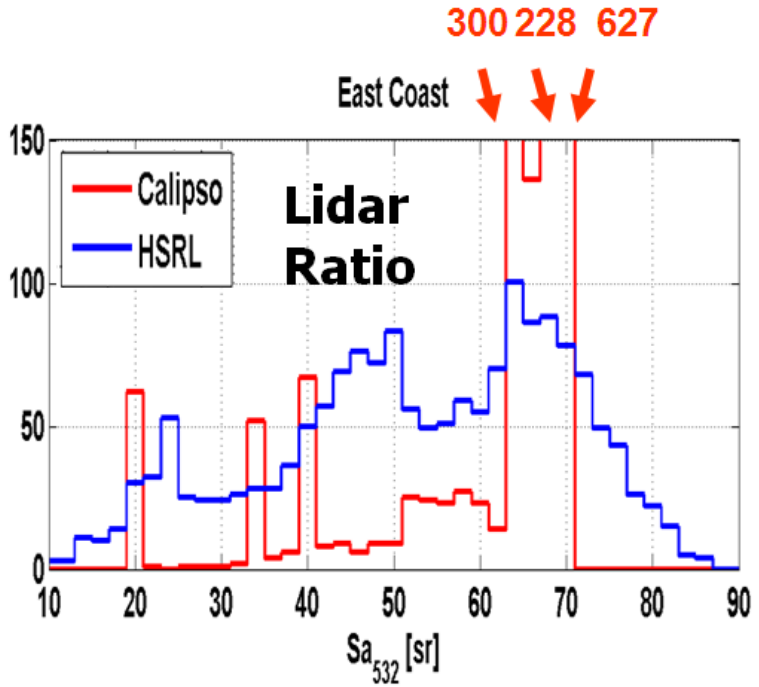
- CALIOP retrievals of aerosol backscatter and extinction profiles rely on accurately specifying the extinction/backscatter ("lidar") ratio
- CALIOP algorithms use location, altitude, integrated backscatter, depolarization to infer a specific aerosol type which is assigned a specific lidar ratio

Problems

- Inferred aerosol type may be incorrect
- Lidar ratios assigned to aerosol types may be incorrect
- Aerosols are often mixtures of aerosol types so that real distribution of lidar ratio is continuous, not discrete

Result

- -20% bias, 43% rms differences between CALIOP and HSRL lidar ratios
- 6% (backscatter) and -17% (extinction) bias differences between CALIOP and HSRL
- Bias errors are systematic and remain after averaging



See Ray Rogers et al. poster

Objective and Methodology

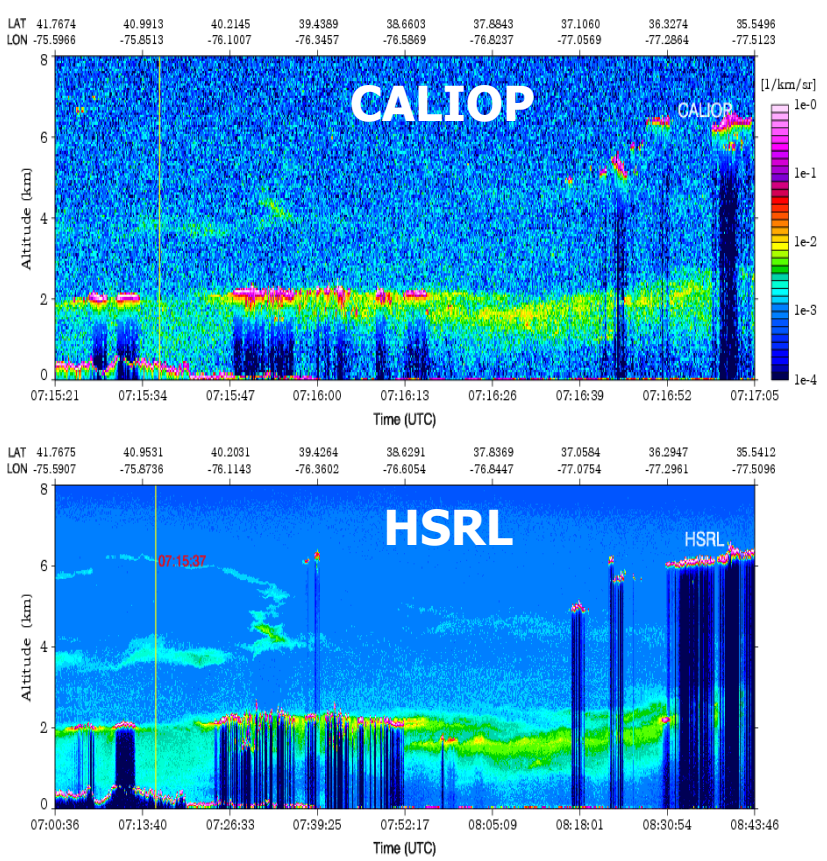
Objective

- Improve CALIPSO retrievals of aerosol backscattering and extinction using satellite (e.g. Aqua MODIS) measurements of aerosol optical thickness (AOT) as a constraint

Methodology

- Develop and test algorithm using attenuated backscatter data from NASA airborne High Spectral Resolution Lidar (HSRL) as a proxy for CALIOP data. HSRL data:
  - Provide high S/N, well calibrated backscatter data to test constrained retrievals
  - Examine vertical variability of lidar ratio
  - Evaluate satellite retrievals of AOT
  - Provide direct measurements of aerosol extinction to evaluate retrieval results
- Apply algorithms to combined CALIOP+Aqua MODIS data
- Evaluate resulting CALIOP+MODIS aerosol extinction profiles using HSRL as "truth"

532 nm attenuated backscatter

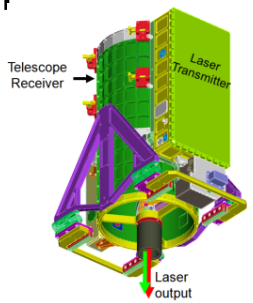


NASA Langley Airborne High Spectral Resolution Lidar (HSRL)

NASA Langley Airborne High Spectral Resolution Lidar (HSRL)

HSRL Technique:

- Relies on spectral separation of aerosol and molecular backscatter in lidar receiver
- Independently measures aerosol backscatter, extinction, and optical thickness
- Internally calibrated
- Provides intensive aerosol parameter to help determine aerosol type

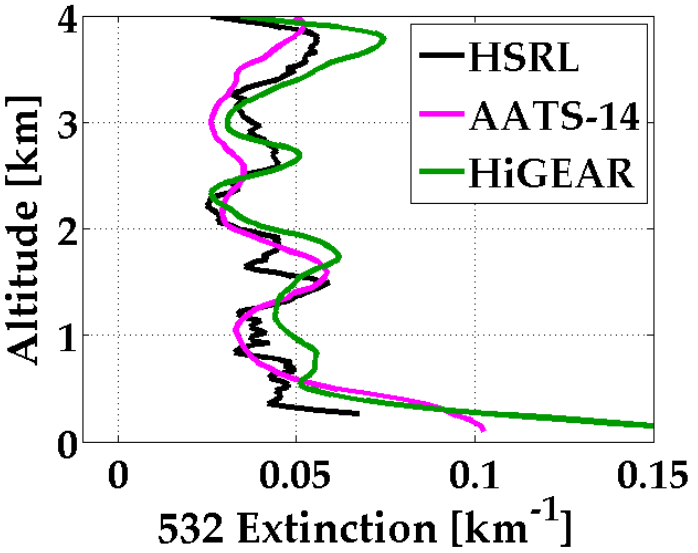


For a description of system and technique, see Hair et al., Appl. Optics, 2008

HSRL Aerosol Data Products:

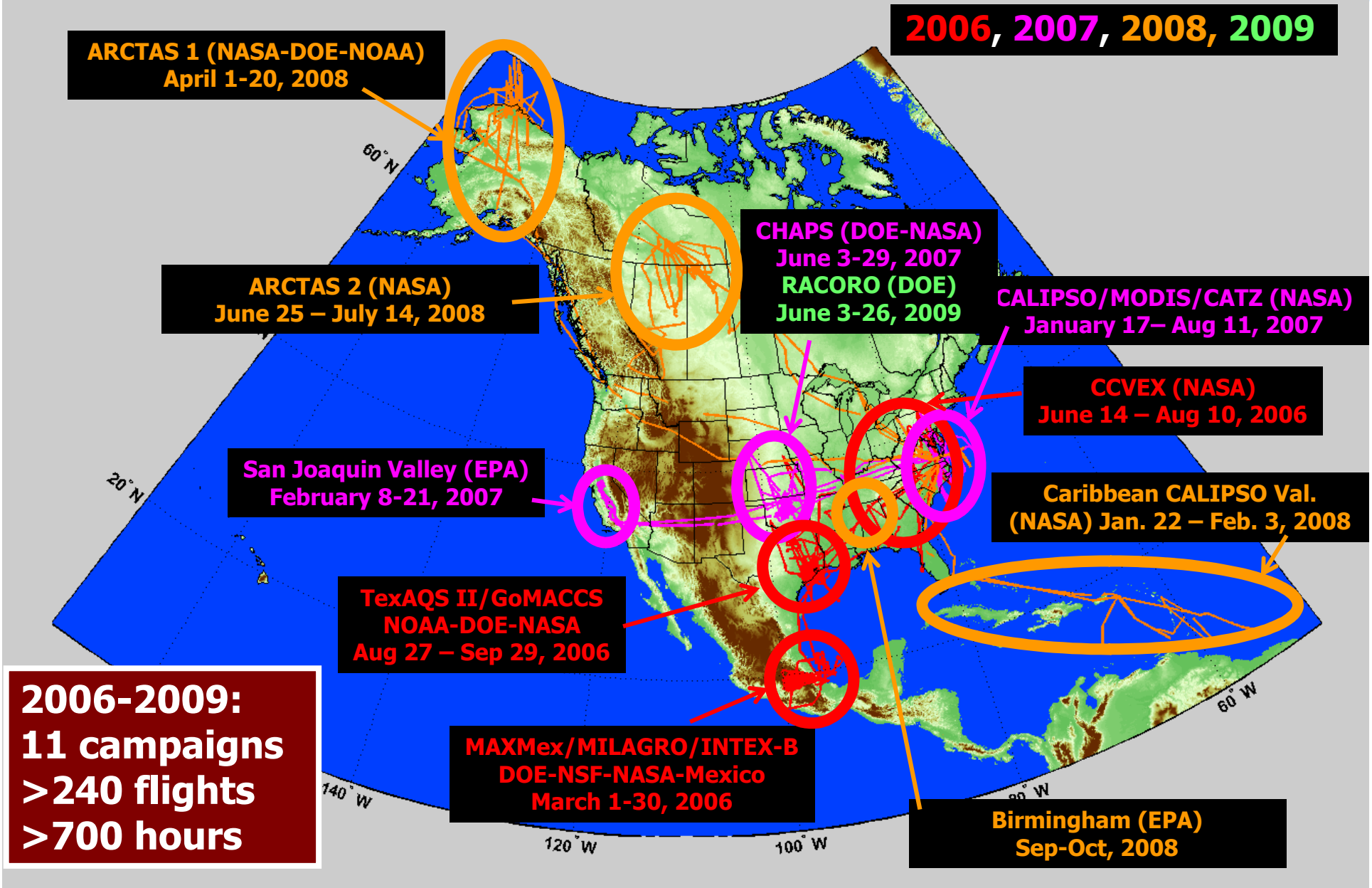
- Scattering ratio (532 nm)
- Backscatter coefficient (532, 1064 nm)
- Extinction Coefficient (532 nm)
- Backscatter Wavelength Dependence (532/1064 nm)
- Lidar ratio (532 nm)
- Depolarization (532, 1064 nm)

Validation – aerosol extinction



AATS14 data from Jens Redemann
HiGEAR data from Tony Clarke

NASA Langley airborne High Spectral Resolution Lidar (HSRL) Field Campaigns



2006-2009:
11 campaigns
>240 flights
>700 hours

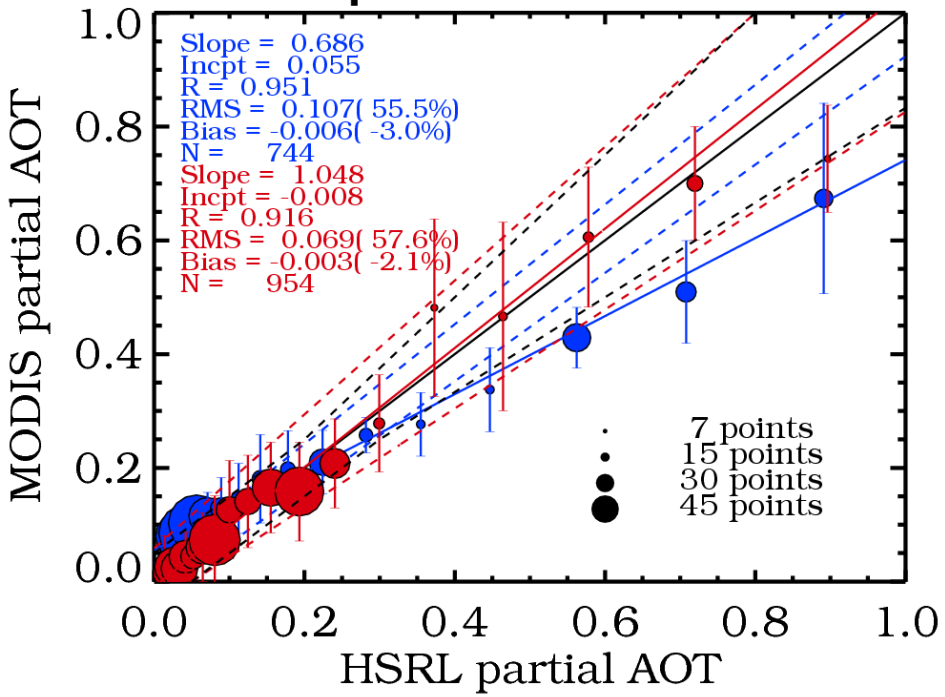
Are satellite AOT retrievals sufficiently accurate to use as a constraint?

Assessment of satellite AOT using HSRL AOT

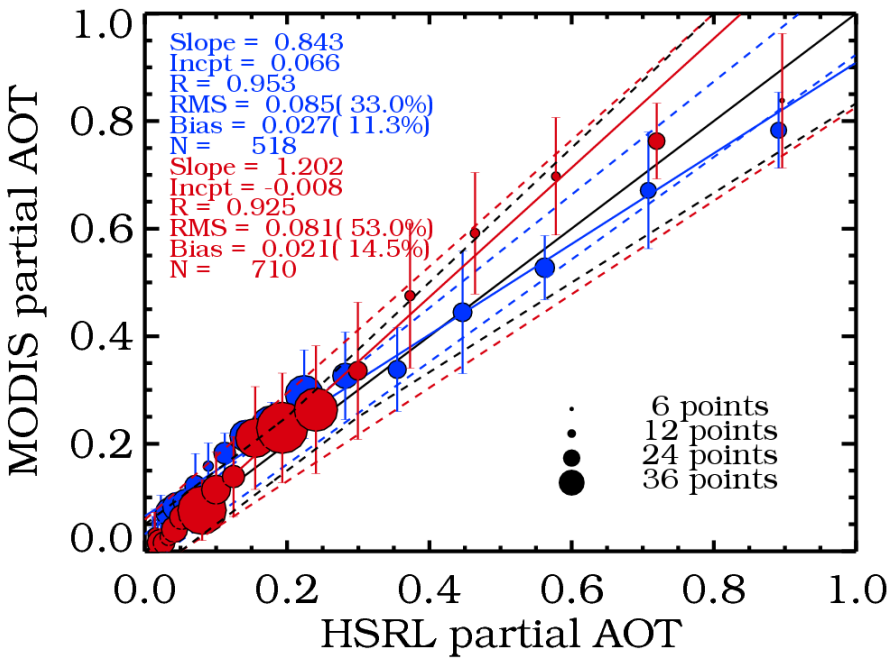
- **Methodology – use HSRL AOT to evaluate satellite AOT**
  - **Mar 2006 – Feb 2008 cases**
  - **# HSRL flights: 64 Aqua MODIS, 64 Terra MODIS, 20 MISR**
- **Results**
  - **Land – at least 60% of cases had differences within ±0.05±0.15AOT**
  - **Water - at least 50% of cases had differences within the larger of 0.05 or 20%**

➢ **Most satellite AOT values agree with HSRL AOT values within uncertainty estimates**

Aqua MODIS vs. HSRL



Terra MODIS vs. HSRL



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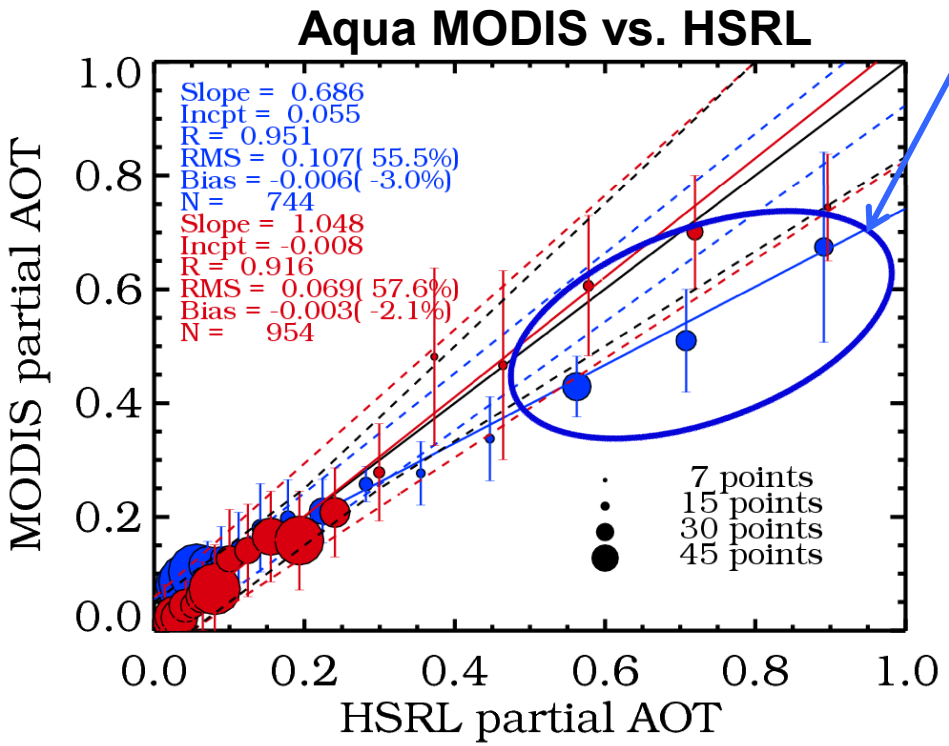
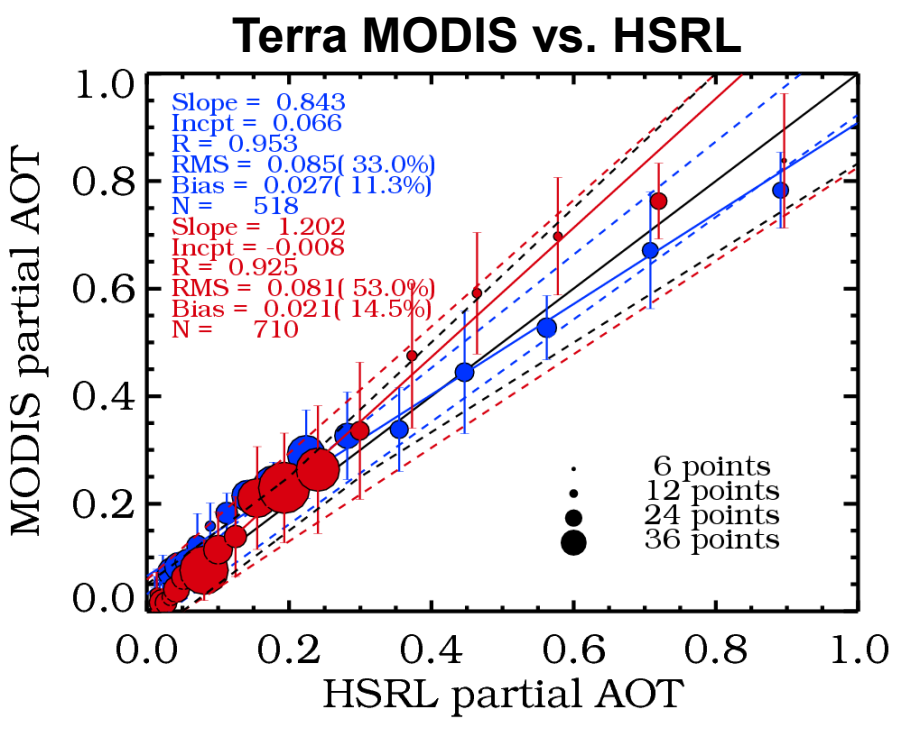
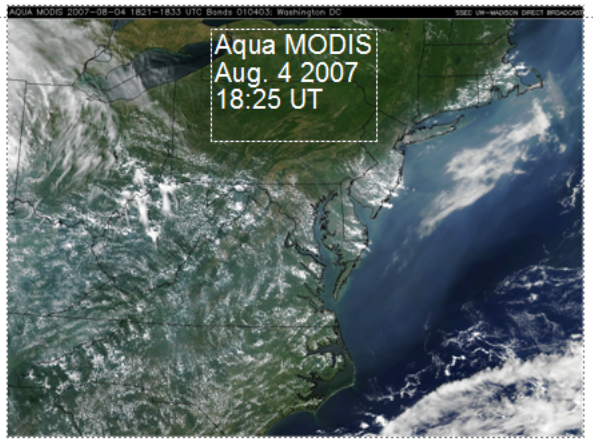
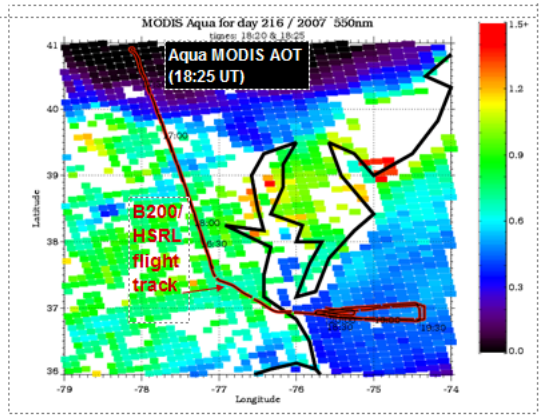
  - **Water - at least 50% of cases had differences within the larger of 0.05 or 20%**
- **Over water- Aqua MODIS sometimes has large low bias**





HSRL Measurements used to evaluate satellite retrievals of aerosol optical depth – August 4, 2007



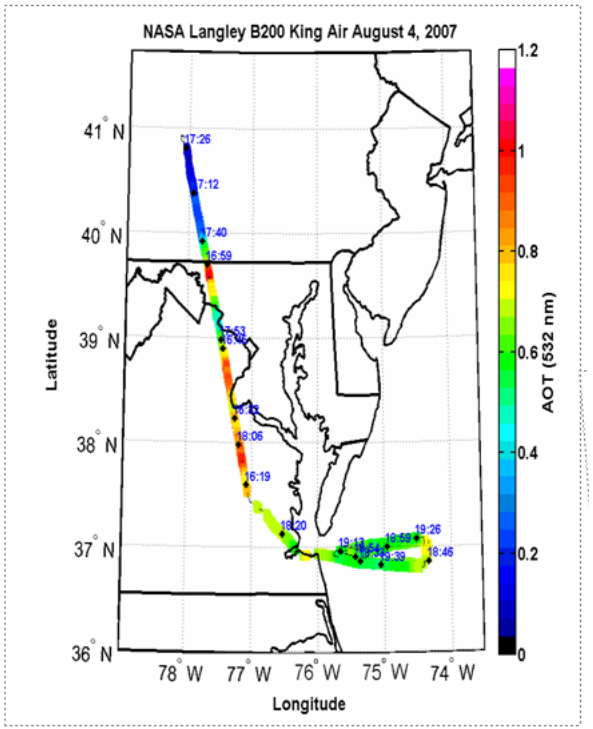


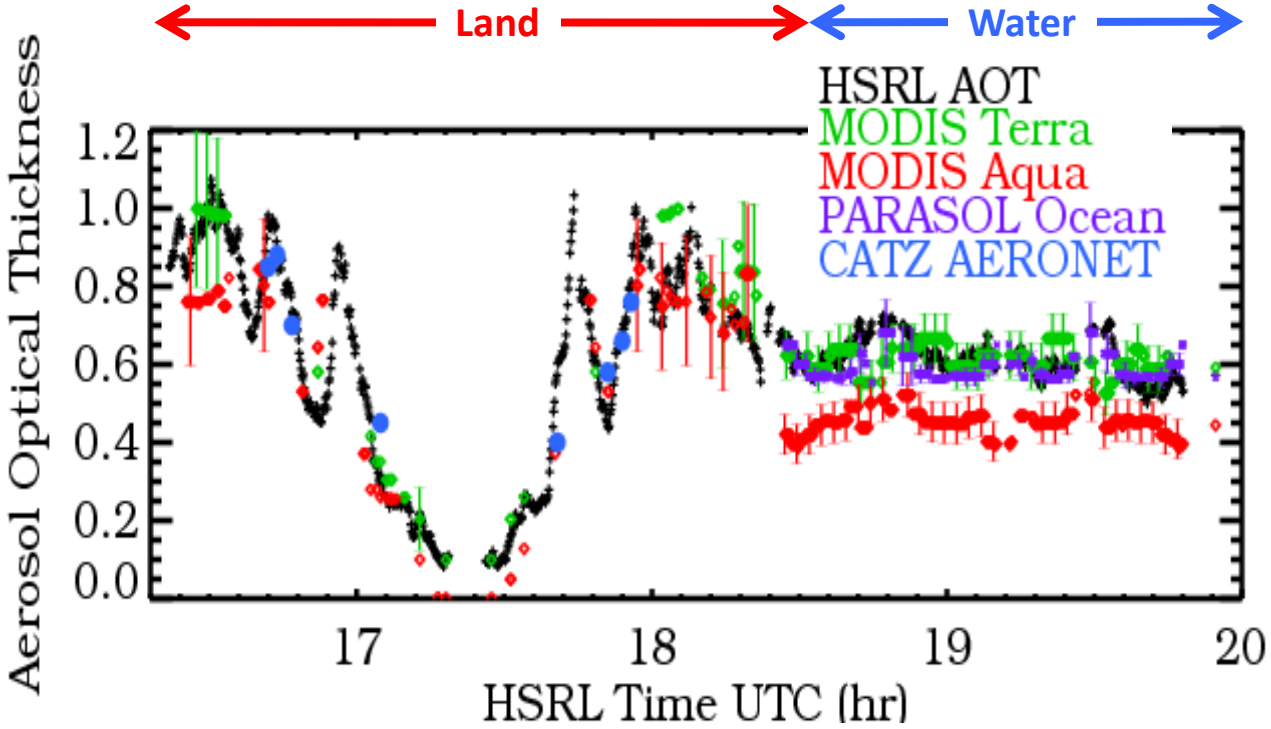
AOT Over land:

- **Terra and Aqua MODIS, HSRL, and AERONET agree**

AOT over water:

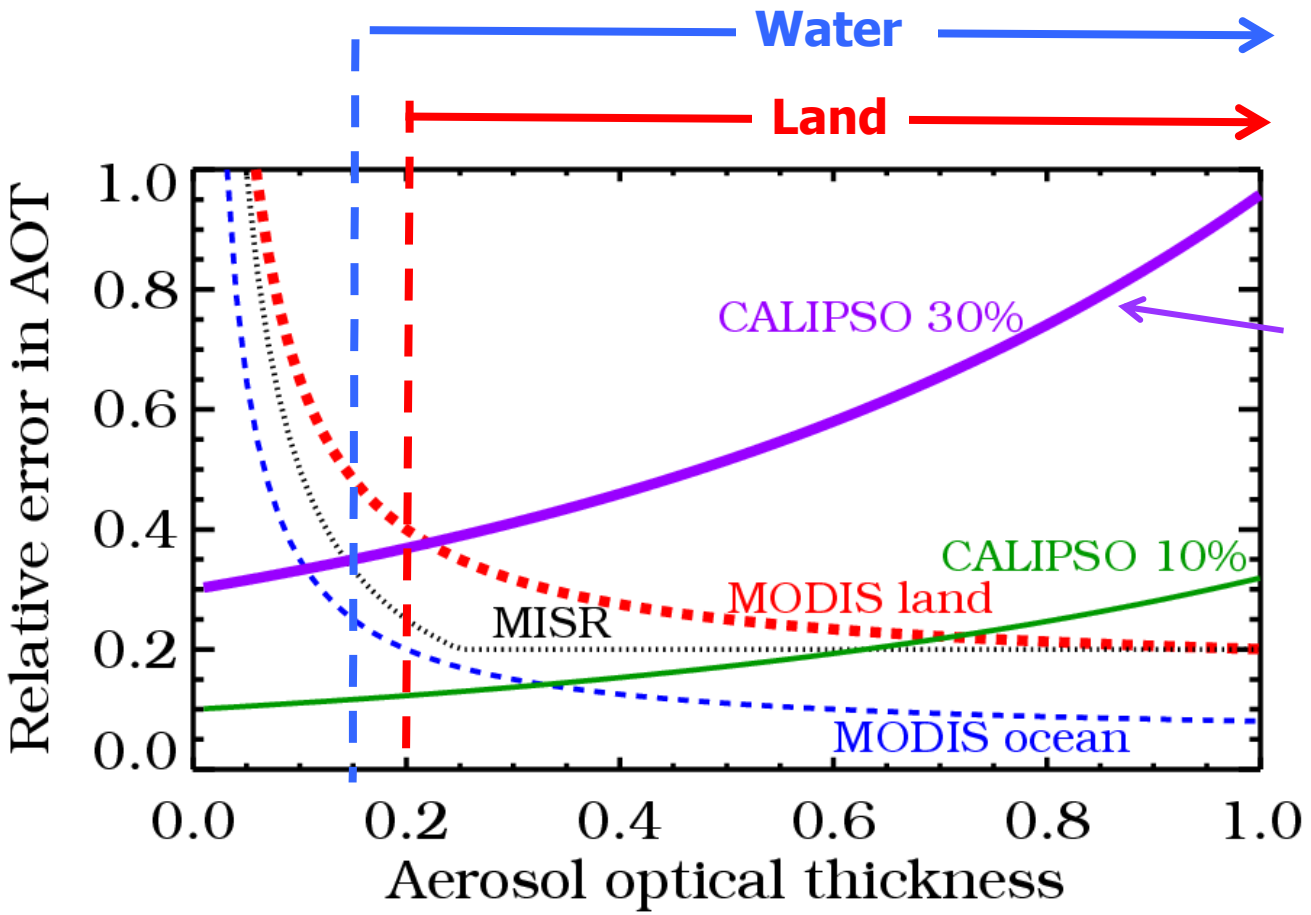
- **Terra MODIS , PARASOL, and HSRL agree**
- **Aqua MODIS AOT about 0.2 (33%) low**





Satellite AOT requirements for constrained retrievals

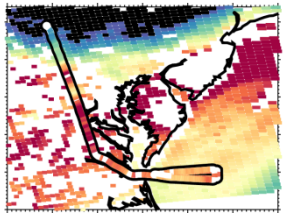
- At low AOT values, satellite retrievals of AOT have large relative uncertainties
  MODIS AOT uncertainty = (±0.05 ± 0.15 AOT) (Land)
  (±0.03 ± 0.05 AOT) (Water) (Remer et al.,2005)
- Therefore, retrievals using satellite AOT as constraint are limited to higher AOT cases:
  AOT > 0.2 (land), AOT > 0.15 (water)



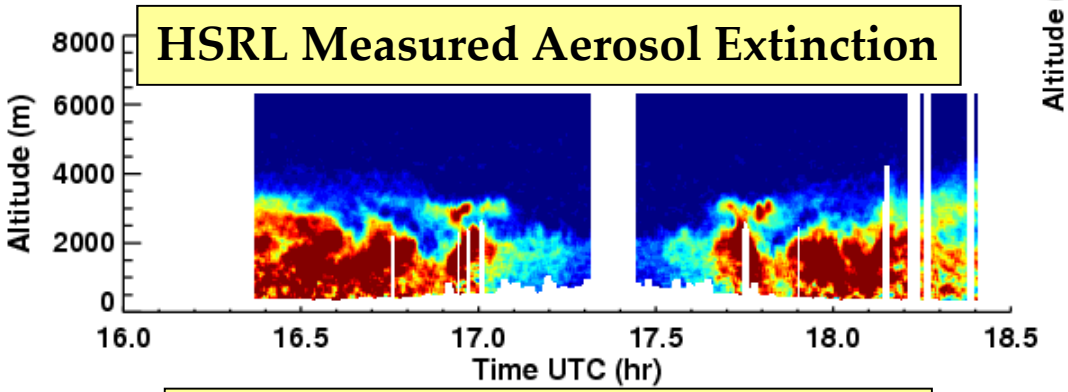
CALIOP error due to uncertainty in lidar ratio (Winker et al., 2009)

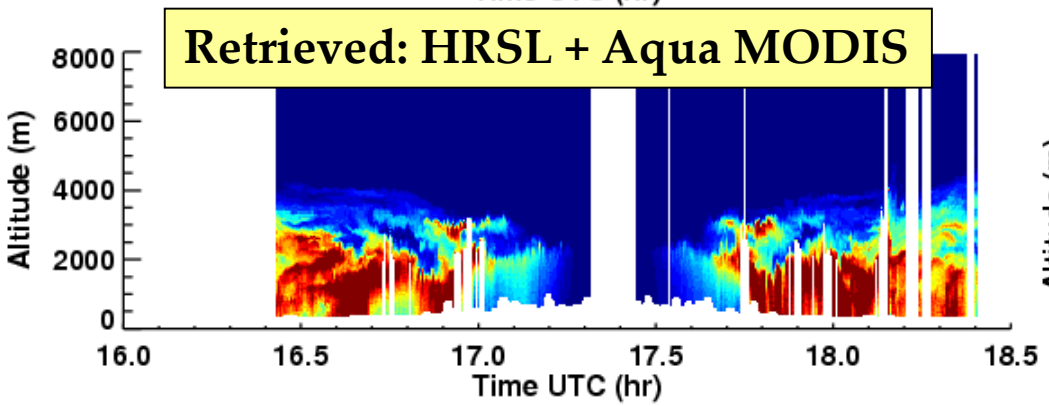
Retrievals of aerosol extinction profiles using HSRL attenuated backscatter profiles constrained by satellite AOT

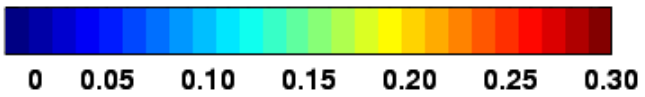
Aerosol Extinction Retrieval Example



August 4, 2007, Land

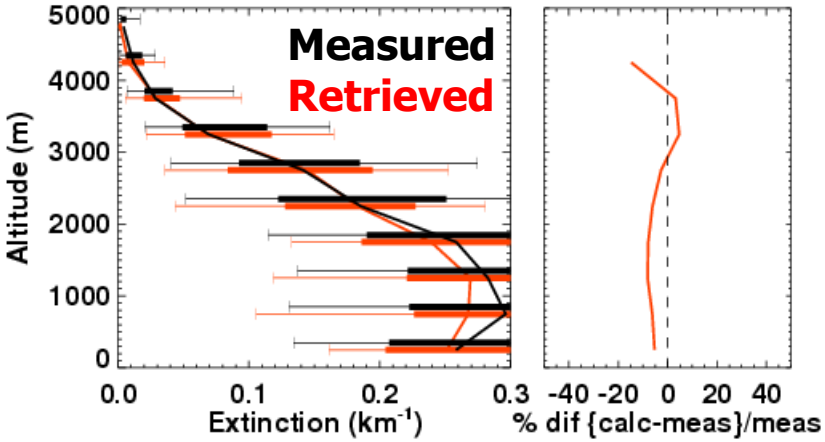




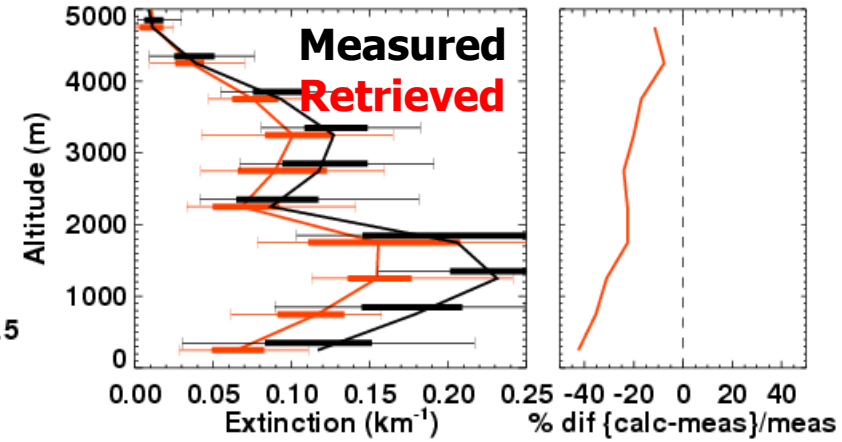


Extinction (km^{-1})

Median profile, Land



Median profile, Water



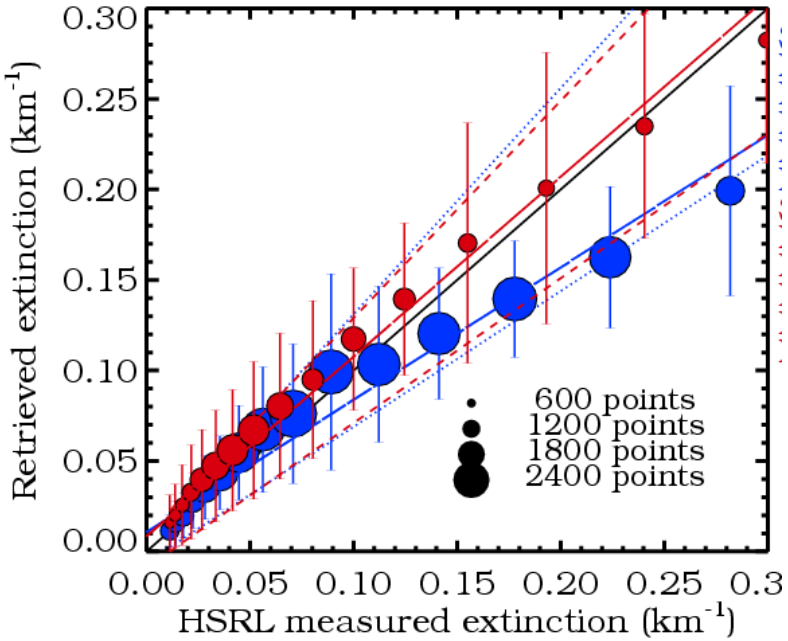
Constrained Retrieval using HSRL Backscatter – Results

When compared to HSRL, two-thirds of retrievals are within ~ ±0.01±20%

Aqua MODIS

±0.0061 km^{-1} ±25%(water)

±0.009 km^{-1} ± 20%(land)

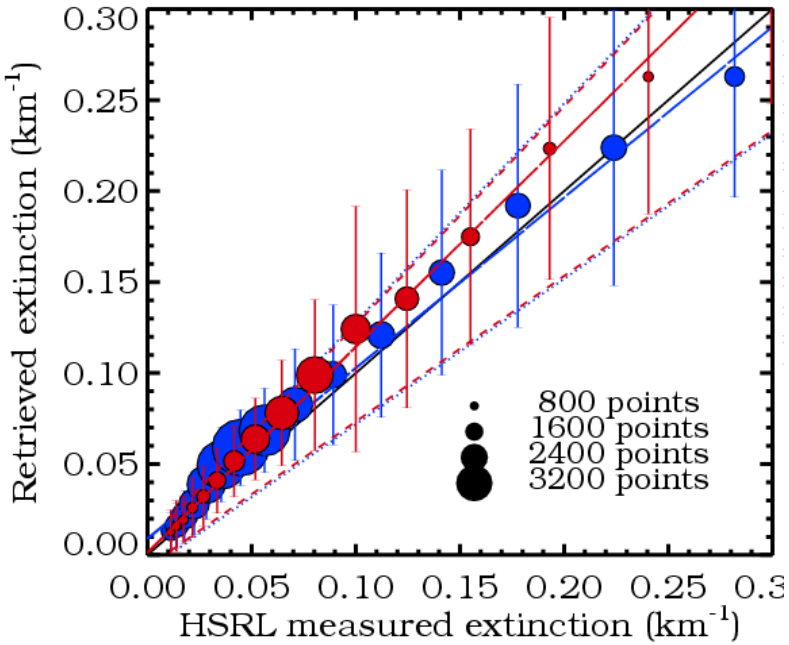


530 profiles from 44 flights

Terra MODIS

±0.0082 km^{-1} ±20%(water)

±0.0066 km^{-1} ± 20%(land)



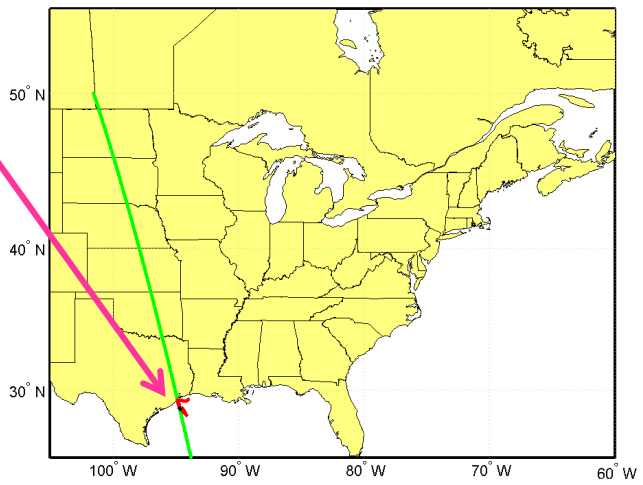
613 profiles from 39 flights

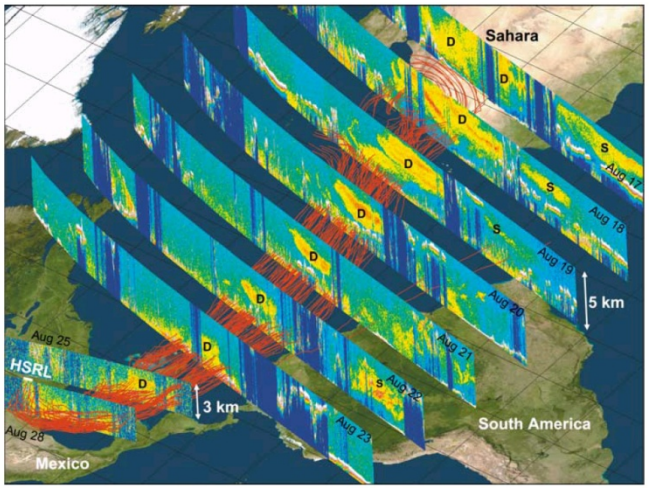
Results averaged to MODIS footprint

Retrievals of aerosol extinction profiles using CALIOP attenuated backscatter profiles constrained by satellite AOT

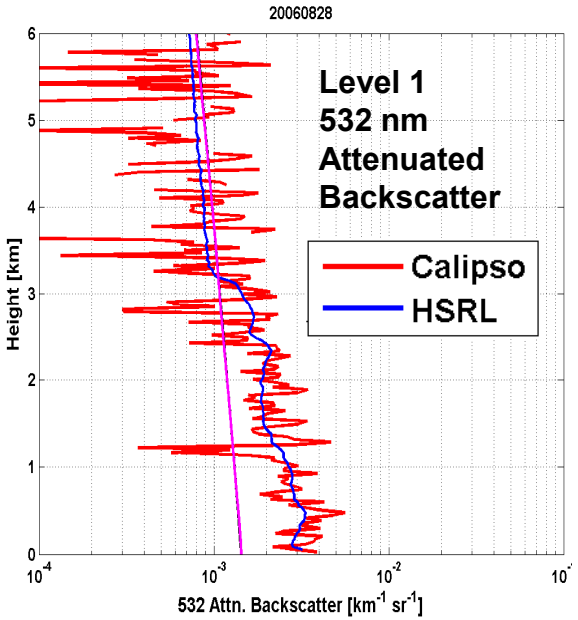
Constrained Retrieval using CALIOP Backscatter Example – August 28, 2006

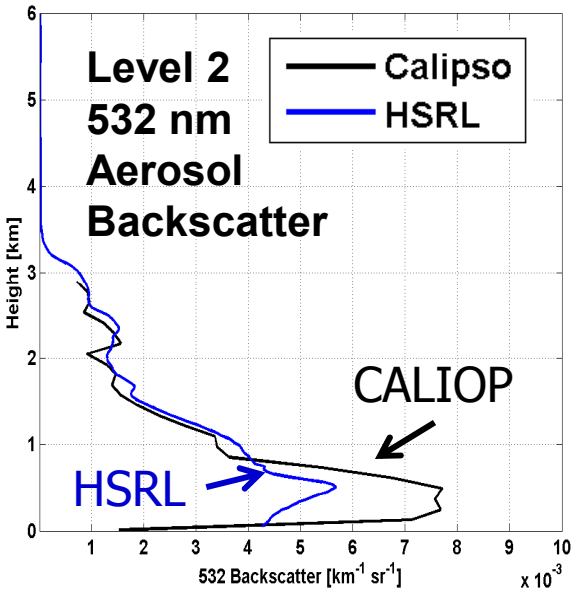
- HSRL flight near Houston observed Saharan dust (Liu et al., JGR, 2007)
- HSRL and CALIOP profiles
  - CALIOP Level 1 attenuated backscatter profile in good agreement with HSRL
  - CALIOP Level 2 backscatter and extinction profiles significantly larger than profiles measured by HSRL

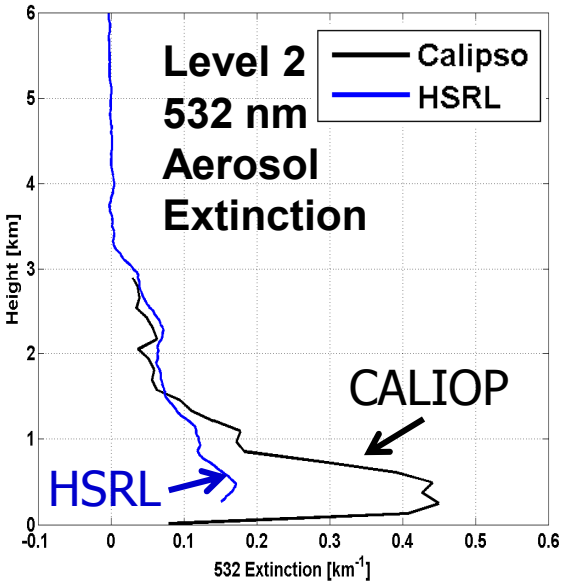




Liu et al. JGR, 2007

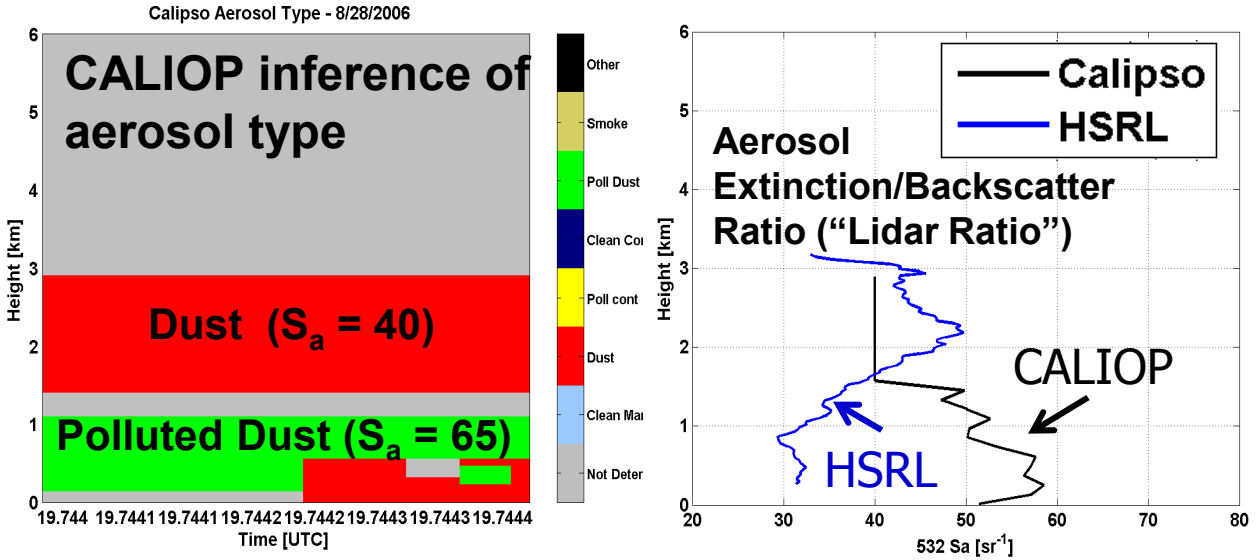




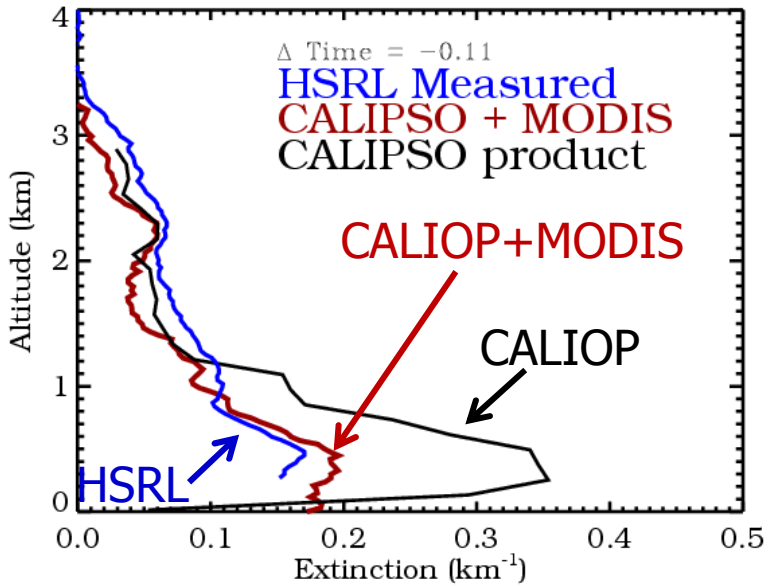


Constrained Retrieval using CALIOP Backscatter Example – August 28, 2006

– CALIOP overestimates aerosol backscatter and extinction in the lowest layer due to incorrect assignment of aerosol extinction/backscatter ("lidar") ratio
  - CALIOP chooses "polluted dust" (S_a = 65)
  - HSRL data indicate mixture of dust and maritime (S_a ~30-40)



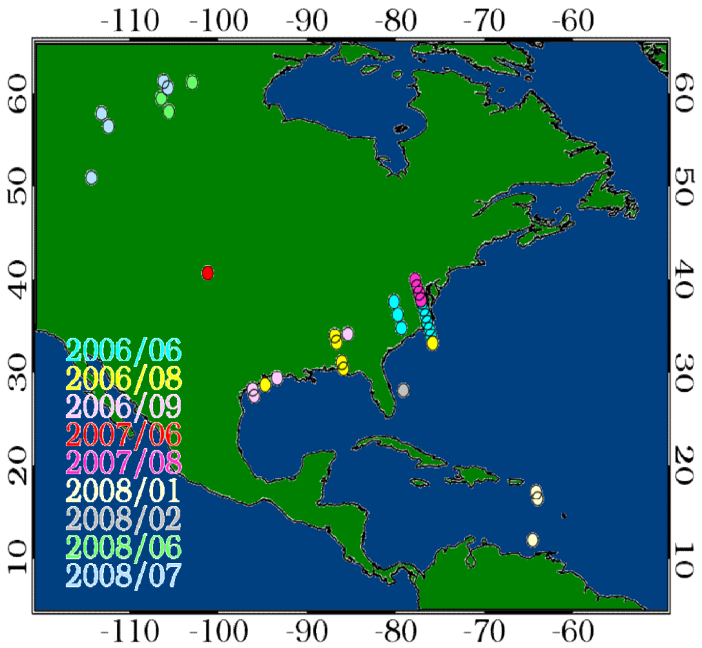
CALIOP+MODIS retrieval produced aerosol extinction profile in much better agreement with HSRL

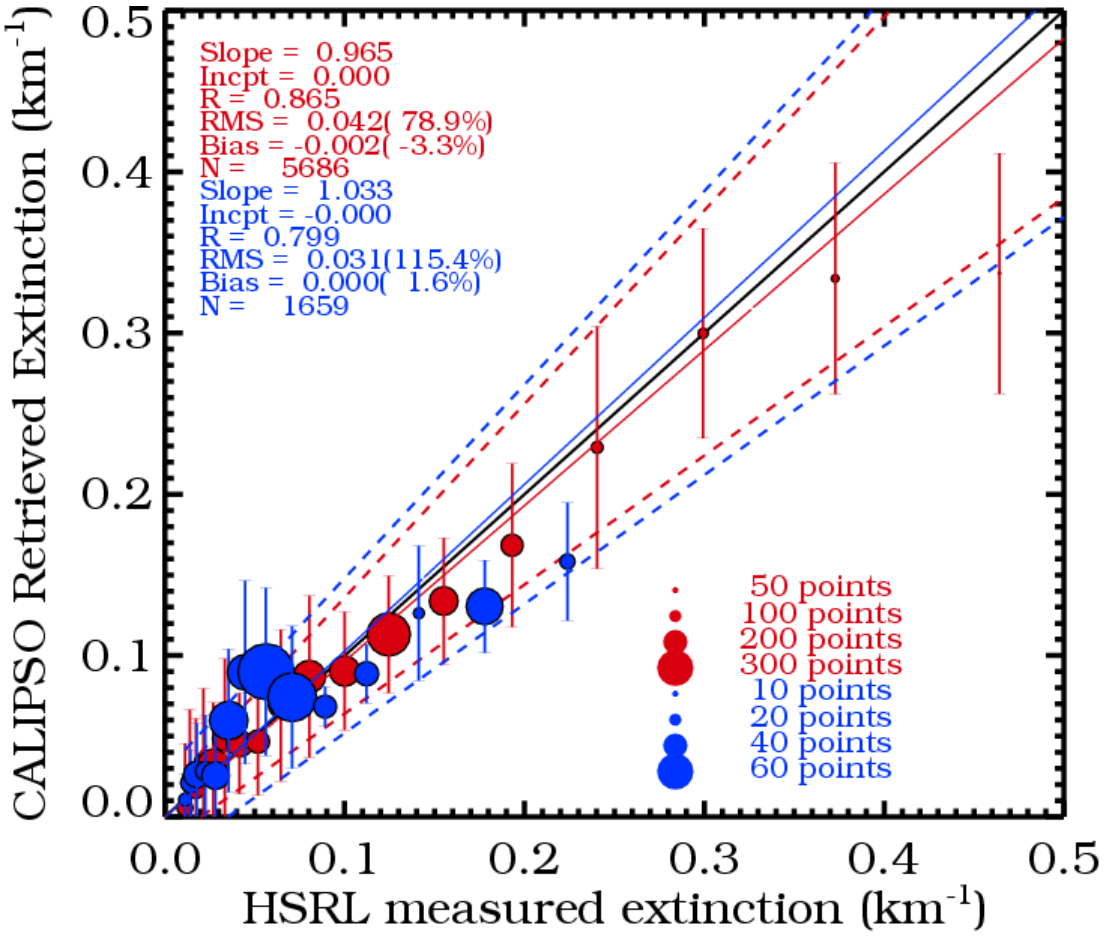


CALIPSO + MODIS Retrieval

- **Extinction retrieved via CALIOP+MODIS evaluated using HSRL**
- **18 flight dates, 28 profiles over land, 9 profiles over water**
- **80 km resolution**
- **Agreement with HSRL for two-thirds of points:**

±0.016 km^{-1} ± 20% (land)
±0.028 km^{-1} ± 20% (water)



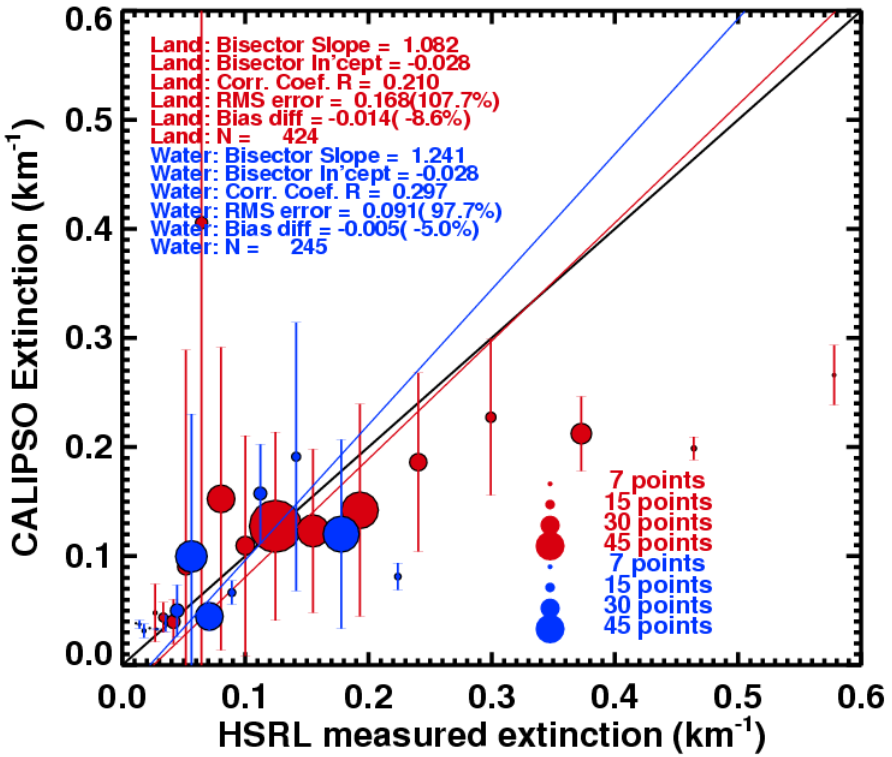


How does the CALIOP+MODIS technique compare with CALIOP provisional (Version 2) retrievals?

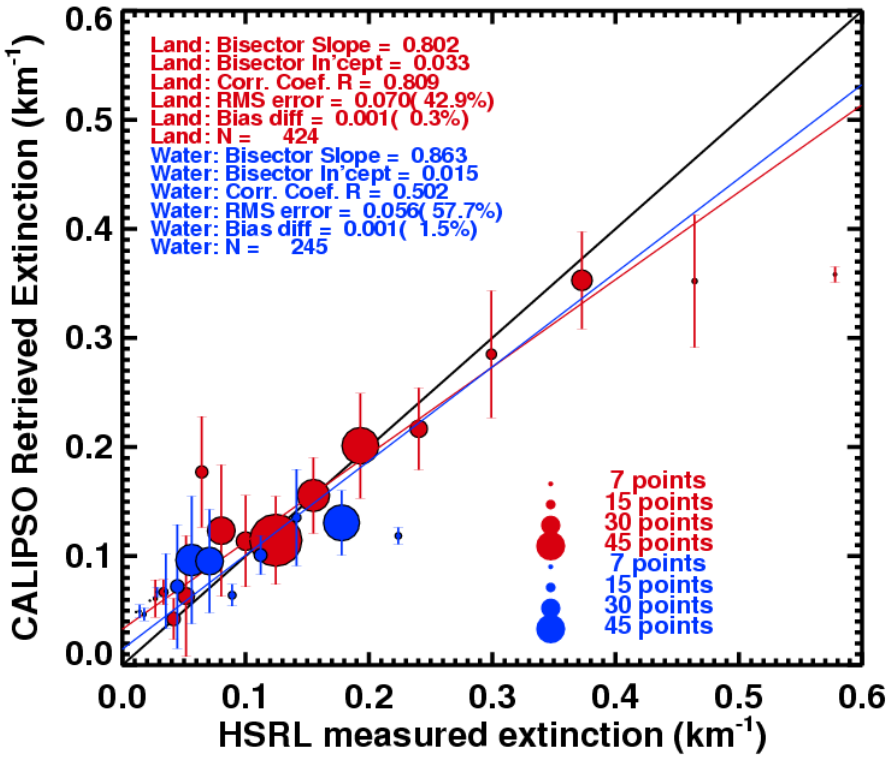
CALIPSO + MODIS Retrieval

- 12 flights, 13 profiles over land, 5 over water, 80 km resolution
- When compared to corresponding CALIOP provisional level two extinction profiles using HSRL measured extinction as truth, constrained (CALIOP+MODIS) retrievals produced
  - rms differences 60% smaller over land (0.07 vs. 0.17 km^{-1})
  - smaller bias differences
  - higher correlation coefficients (r increased from 0.21 to 0.81 over land)

CALIOP V2 Provisional Product



CALIOP+MODIS AOT



What's next?

Ongoing and Future Retrieval Studies

- Evaluate CALIOP+MODIS retrievals using CALIOP version 3 products (Ferrare, Burton et al.)
- Continue work on advanced CALIOP retrievals
  - CALIOP+MODIS+PARASOL over land (Ferrare, Burton et al.)
    - extinction, lidar ratio, fine mode fraction
  - CALIOP+MODIS over water (Remer, Borda, Martins et al.)
    - extinction, lidar ratio, fine mode fraction
  - CRAM, E-CRAM (Hostetler,Ferrare,Reagan,McPherson et al.)
    - extinction profiles without reliance on additional satellite data
  - CALIOP+APS (Glory) (Hostetler, Ferrare, Cairns et al.)
    - extinction profiles using more accurate AOT and additional column constraints

Thank You !

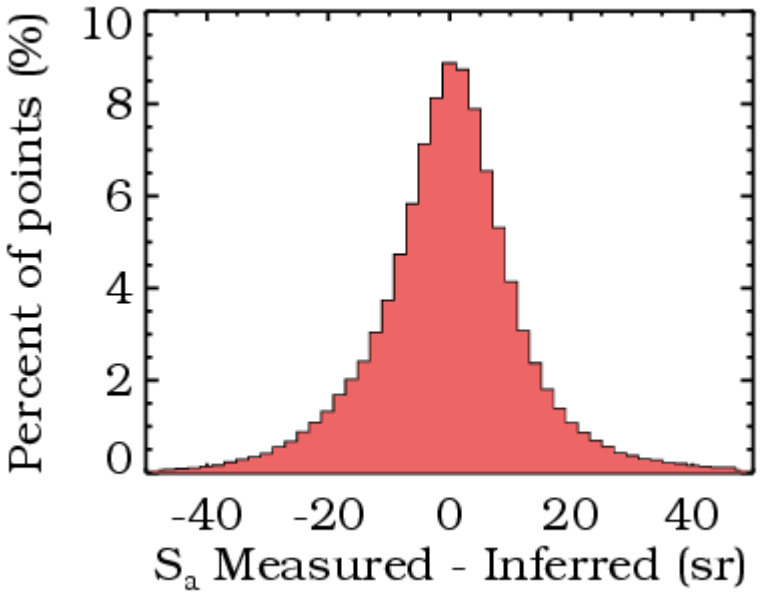
Questions ?

How much does the lidar ratio vary with altitude?

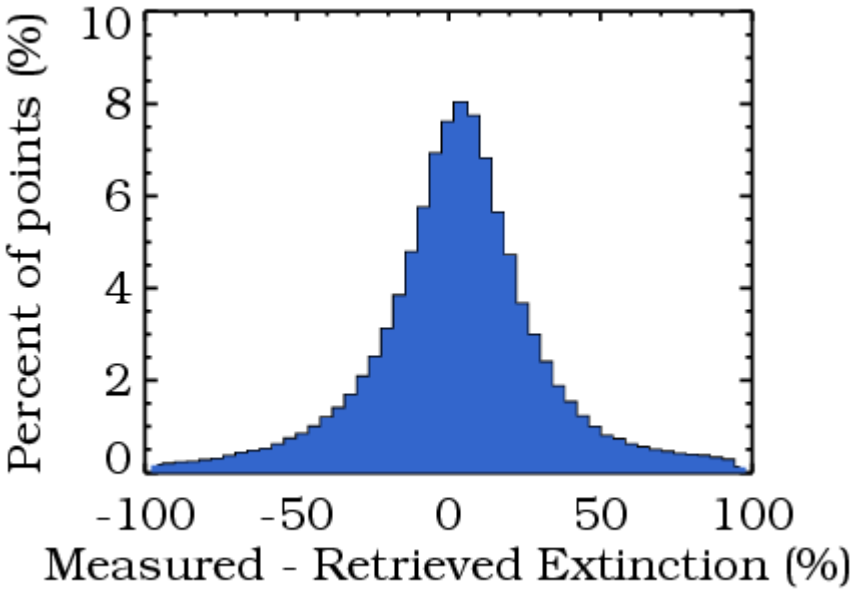
Vertical Variability of Lidar Ratio

Vertical variability of the lidar ratio (S_a) is examined using HSRL data acquired during field campaigns from 2006 and 2007

Lidar Ratio

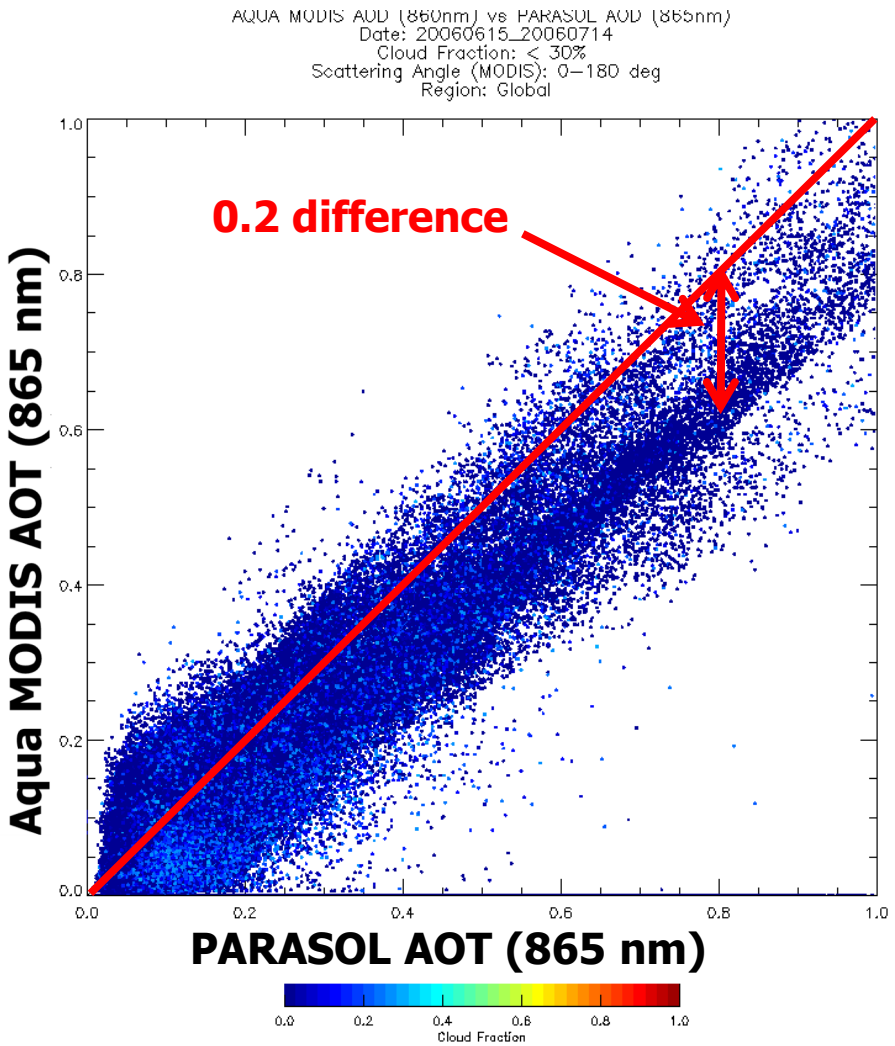


Aerosol Extinction



- Assumed-constant lidar ratio compares well with altitude dependent HSRL measurements: 65% of data points are within 10 sr
- Retrieved extinction using inferred lidar ratio: 60% of points within 20%

MODIS vs. PARASOL AOT

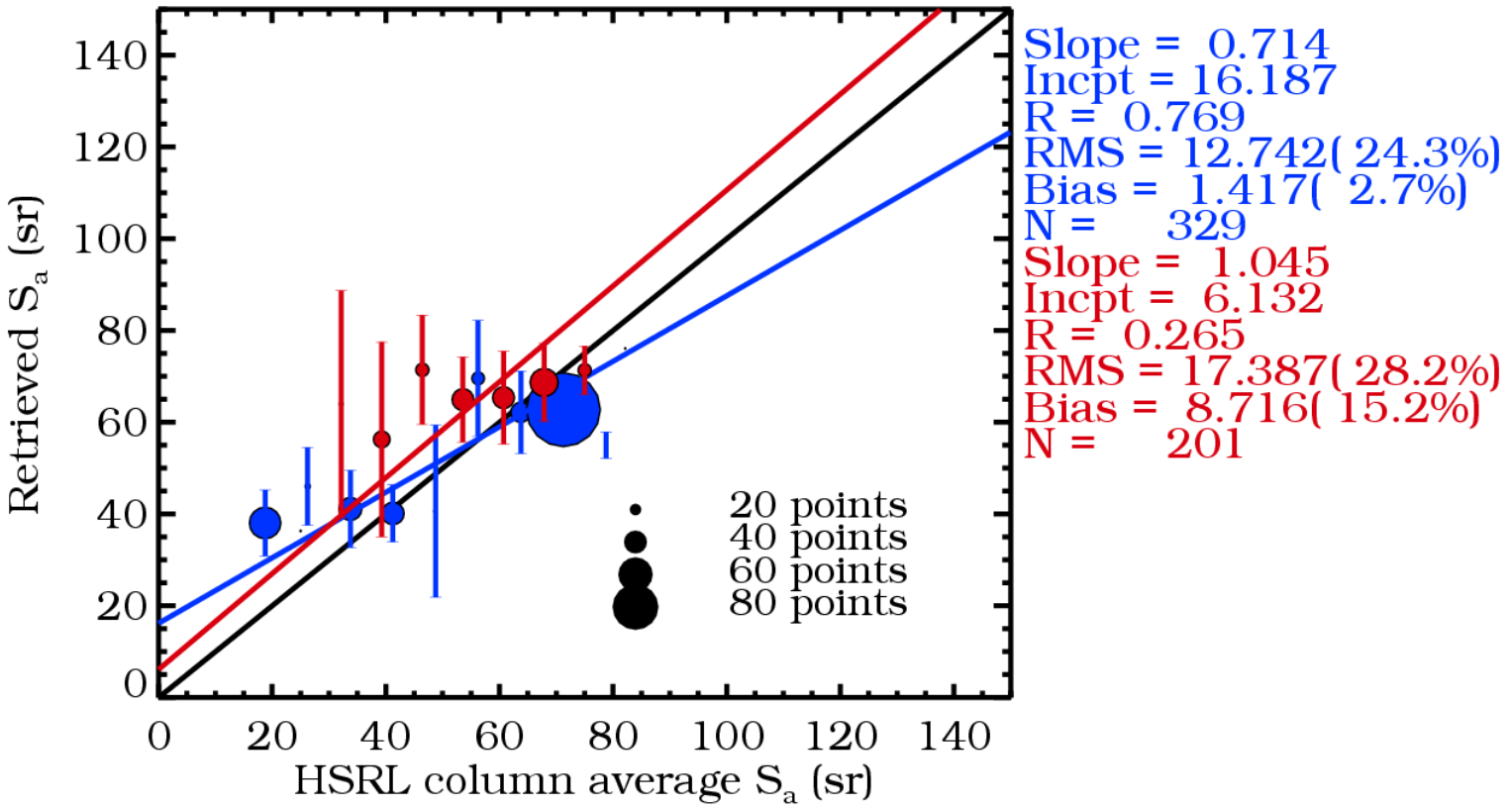


Comparison of MODIS AOT (860 nm) vs. PARASOL AOT (865 nm)

- **Global data**
- **June 15, 2006 – July 14, 2006**
- **Cloud fraction < 30%**

Aqua MODIS AOT is often considerably lower than PARASOL AOT

Retrieved Lidar Ratio



- **Abscissa is the equivalent constant-altitude lidar ratio calculated from measured extinction and backscatter column totals**
- **Lidar ratio from retrieval shows less variability than measurement**
- **Overall, agreement is reasonable, slope is 0.714 for water and 1.045 for land**