

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



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AOT-Constrained Lidar Retrievals



Background

- Retrievals of aerosol backscatter and extinction profiles from backscatter lidars (e.g. CALIOP) rely on linking aerosol extinction and backscatter and require an additional boundary value or parameter specification information (e.g., a known layer optical depth or specification of a value for the lidar ratio). Uncertainties in the lidar ratio can be the largest source of error and hence the limiting factor in these retrievals.

Objectives

- Improve retrievals of aerosol backscattering and extinction using satellite (e.g. MODIS, PARASOL) measurements of aerosol optical thickness (AOT) to constrain the atmospheric transmission and so derive a mean value of the lidar ratio (S_a) through the layer (constrained retrieval)

Requirements for AOT-constrained Retrieval

- Extinction-to-backscatter ratio (" S_a " or "lidar ratio") constant with altitude
- Accurate aerosol optical thickness (AOT) measurement from passive radiometer



Methodology

Use data from NASA Langley airborne High Spectral Resolution Lidar (HSRL) to:

- Examine vertical variability of lidar ratio
- Evaluate satellite retrievals of AOT
- Provide high S/N, well calibrated backscatter data to test constrained retrievals
- Provide direct measurements of aerosol extinction to evaluate constrained retrieval results

Airborne HSRL System and Data



HSRL Technique:

- Relies on spectral separation of aerosol and molecular backscatter in lidar receiver
- Independently measures aerosol backscatter, extinction, and optical thickness
- Requires no assumptions or additional data to relate backscatter and extinction
- Can be internally calibrated
- Provides **intensive** aerosol parameter to help determine aerosol type

Data Products

- Aerosol scattering ratio (aerosol/molecular backscatter) (532 nm) ($\Delta x \sim 1$ km, $\Delta z \sim 60$ m)
- Aerosol backscatter coefficient at 532 nm ($\Delta x \sim 1$ km, $\Delta z \sim 60$ m)
- Aerosol extinction coefficient at 532 nm ($\Delta x \sim 6$ km, $\Delta z \sim 300$ m)
- **Aerosol wavelength dependence (532/1064) (i.e. Angstrom exponent for aerosol backscatter) (similar to backscatter color ratio)**
- **Aerosol extinction/backscatter ratio ("lidar ratio") (532 nm) ($\Delta x \sim 6$ km, $\Delta z \sim 300$ m)**
- **Aerosol depolarization (532 and 1064 nm) ($\Delta x \sim 1$ km, $\Delta z \sim 60$ m)**

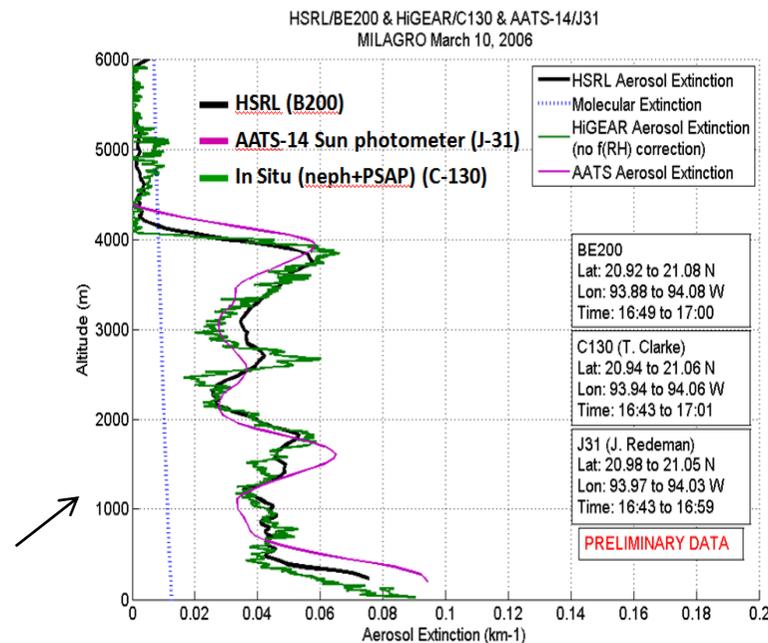
Extensive – depend on aerosol amount and type

Intensive – depend on aerosol type

Validation – aerosol extinction



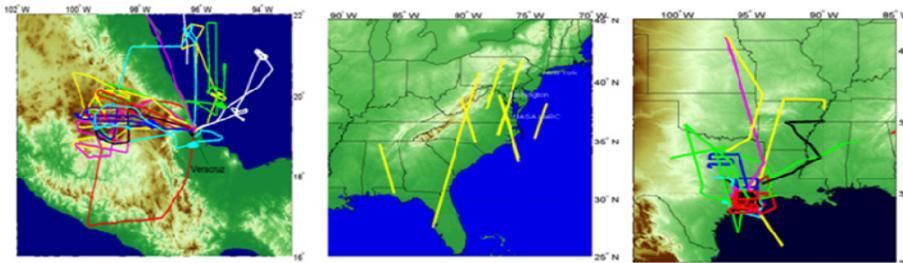
AATS-14 data (Jens Redemann, Phil Russell)
HIGEAR in situ data (Antony Clarke)



NASA Langley airborne High Spectral Resolution Lidar (HSRL)



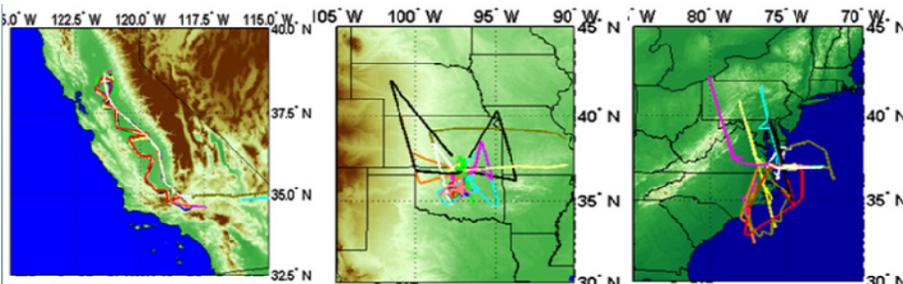
Past and Future Campaigns:



MAXMex/MILAGRO/INTEX-B
Mexico City
March 1-30, 2006

CALIPSO Validation
Eastern U.S.A.
June 14 – Aug 10, 2006

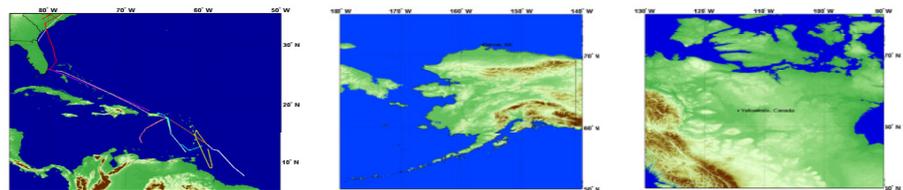
TexAQS II/GoMACCS
Houston
Aug 27 – Sep 29, 2006



San Joaquin Valley
California
February 8-21, 2007

CHAPS
Oklahoma
June 3-29, 2007

CALIPSO/MODIS/CATZ
Eastern U.S.
January 17– Aug 11, 2007



CALIPSO Validation
Eastern Caribbean
Jan 22 - Feb 3, 2008

ARCTAS-I
Arctic - Alaska
April, 2008

ARCTAS-II
Arctic - Canada
July, 2008

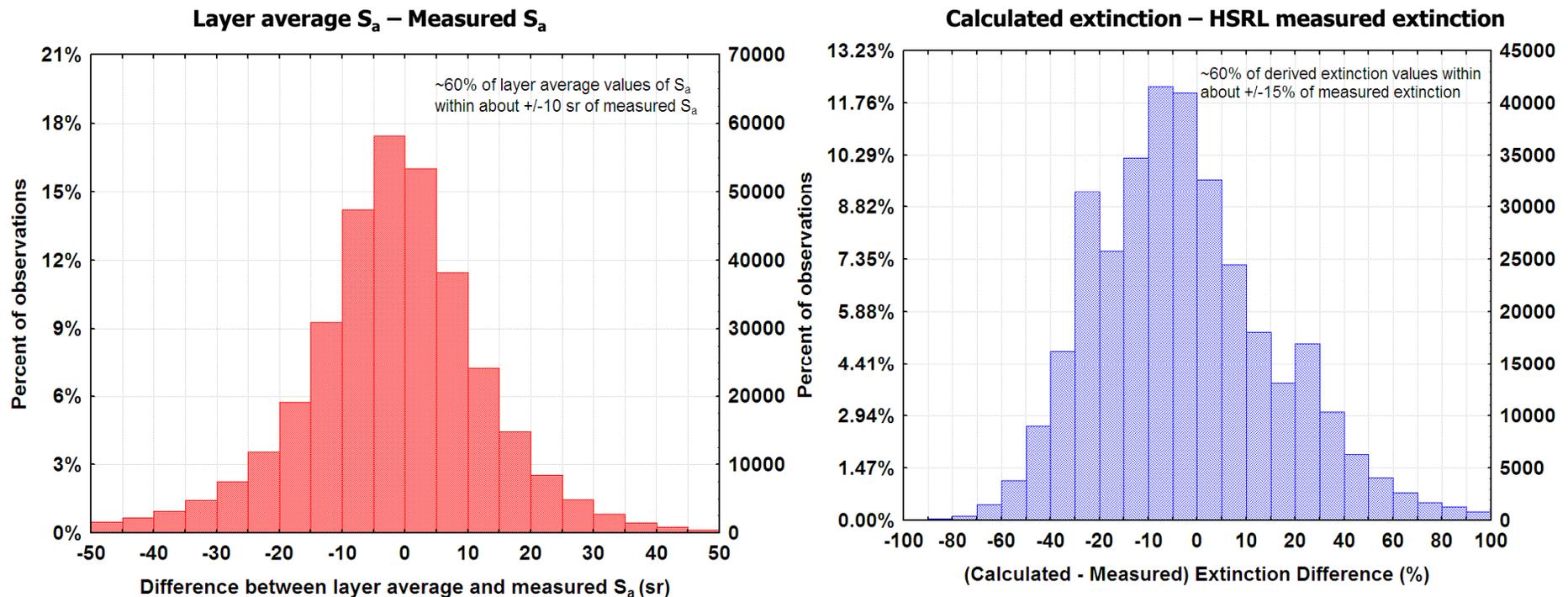
History

- 2000-2004: instrument development and integration
- Dec 2004: first test flight on Lear Jet
- Dec 2005: first test flight NASA Langley King Air
- 2006: flew on 3 major campaigns: MILAGRO (55 hours), TexAQS/GoMACCS (90 hours) CALIPSO Val (51 hours)
- 2007: flew on 3 campaigns: San Joaquin (EPA) (43 hours), CHAPS/CLASIC (70 hours), NASA CALIPSO/CATZ (50 hours)
- 2008: two campaigns (so far): CALIPSO Caribbean (~35 hours), ARCTAS (Spring) (~95 hours)
- More than 520 hours of data and 140 science flights over two years!
- 57 CALIPSO underflights so far



Vertical Variability of Lidar Ratio

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



- S_a is relatively constant about 60% of the time over the 0-6 km layer
- Aerosol extinction derived using HSRL backscatter and the layer AOT constraint is within +/-15% of the aerosol extinction derived directly using the HSRL technique about 60% of the time

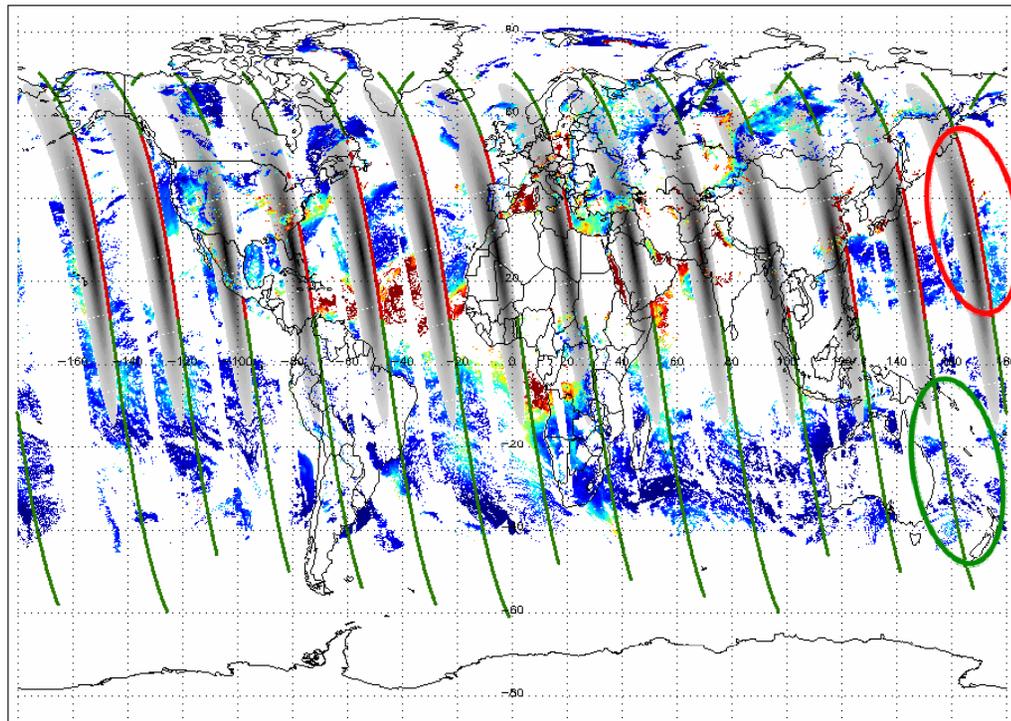
CALIPSO track and MODIS Sun Glint Mask



CALIPSO track is within MODIS operational sun glint mask region over Northern Hemisphere during summer

- In these cases, MODIS AOT not available to constrain retrievals over water.
- This hampers efforts to use HSRL data to evaluate MODIS-CALIPSO constrained retrievals off the east coast of the U.S. during summer when high AOT is present.

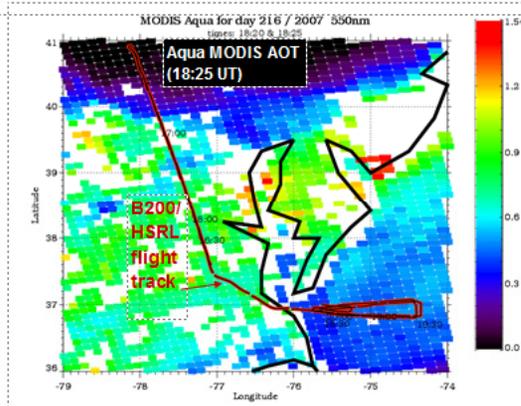
MODIS AOD (Colored) and Sun Glint Angle (Gray)
CALIPSO and MODIS matches with Glint Angle > 40 (Green) and Glint Angle < 40 over Ocean (Red)
20060621



**CALIPSO track within
MODIS glint region**

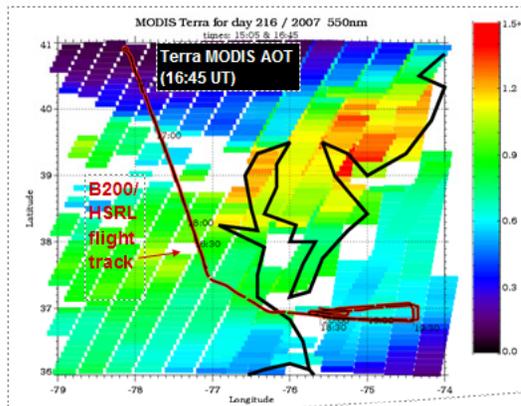
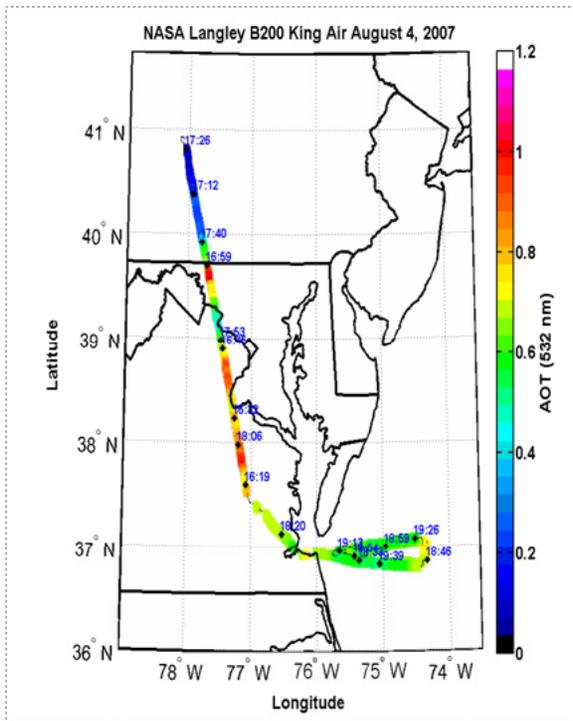
**CALIPSO track out of
MODIS glint region**

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

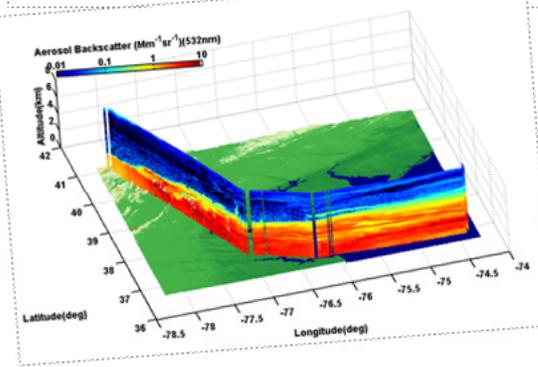


August 4, 2007

Aqua MODIS 18:25 UT

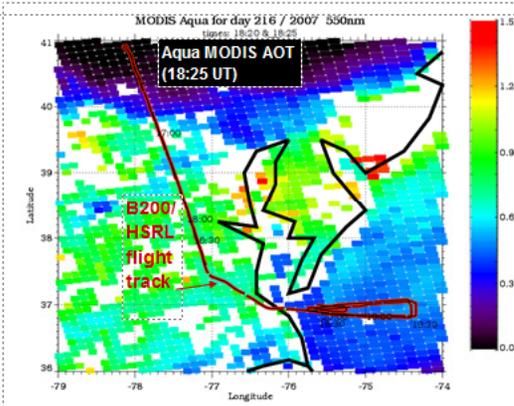


Terra MODIS 16:45 UT



HSRL profiles along B200 flight track

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

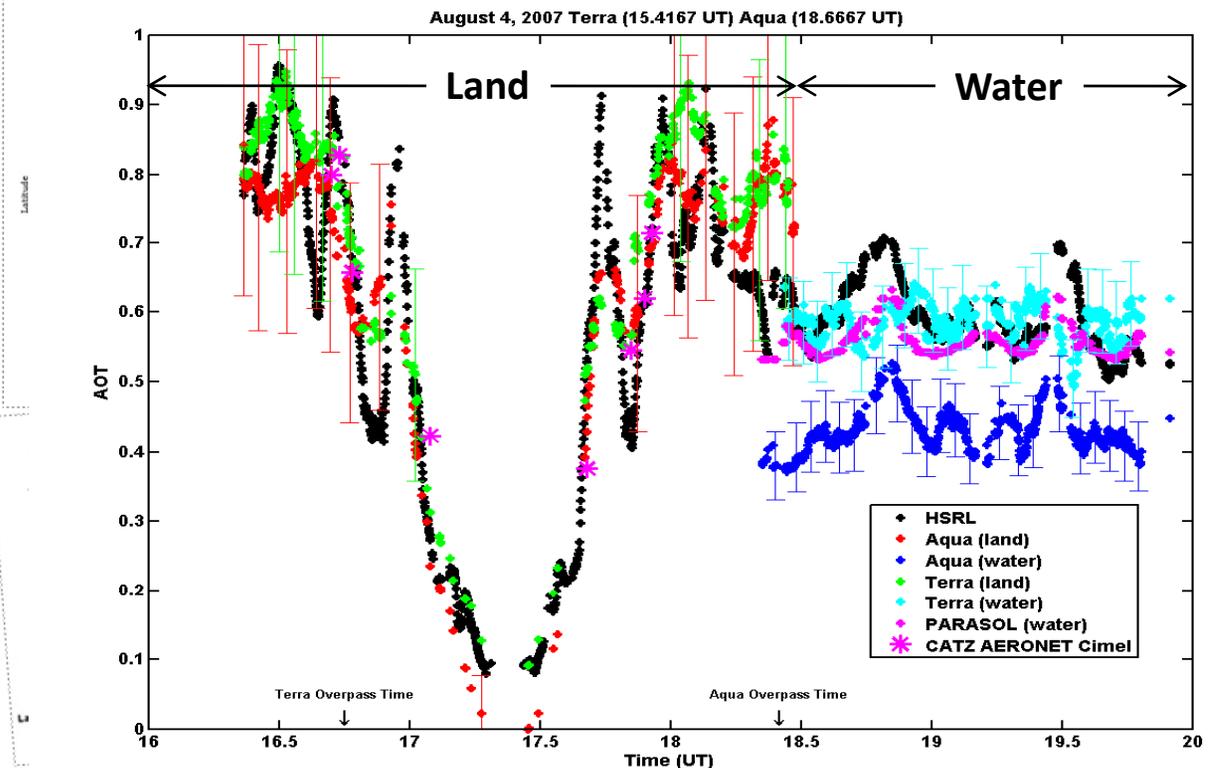
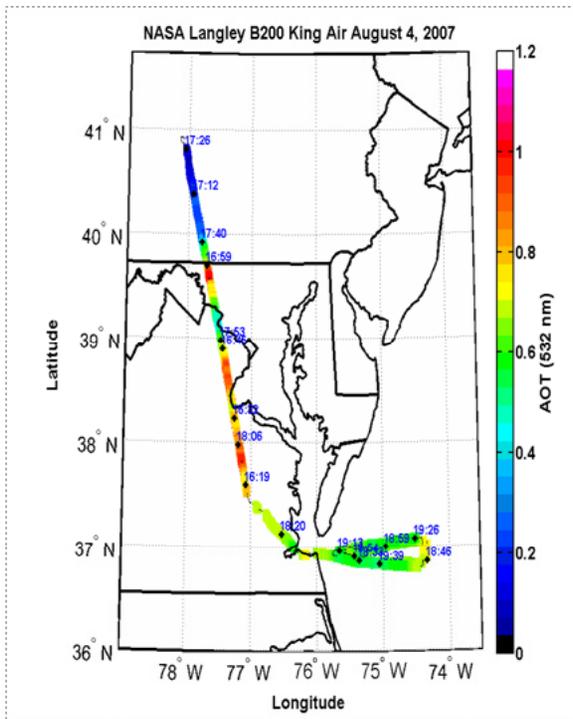


AOT Over land:

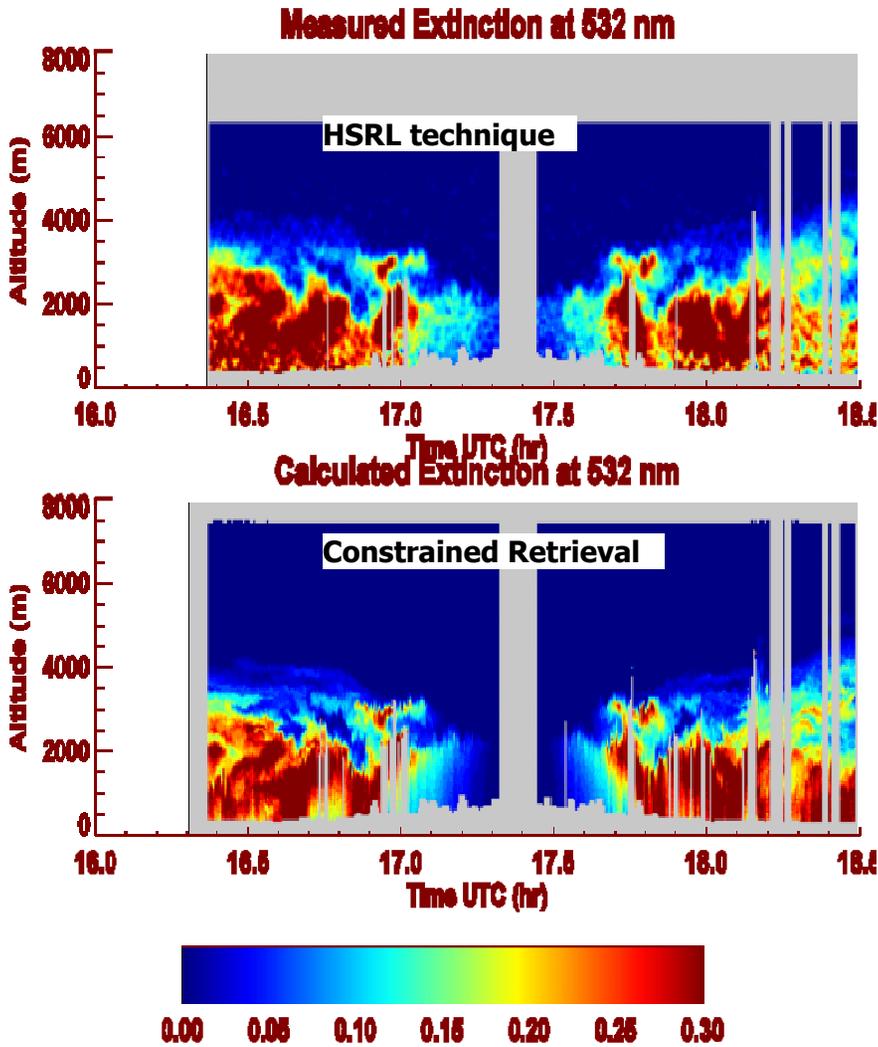
- Terra and Aqua MODIS, HSRL, and AERONET agree

AOT over water:

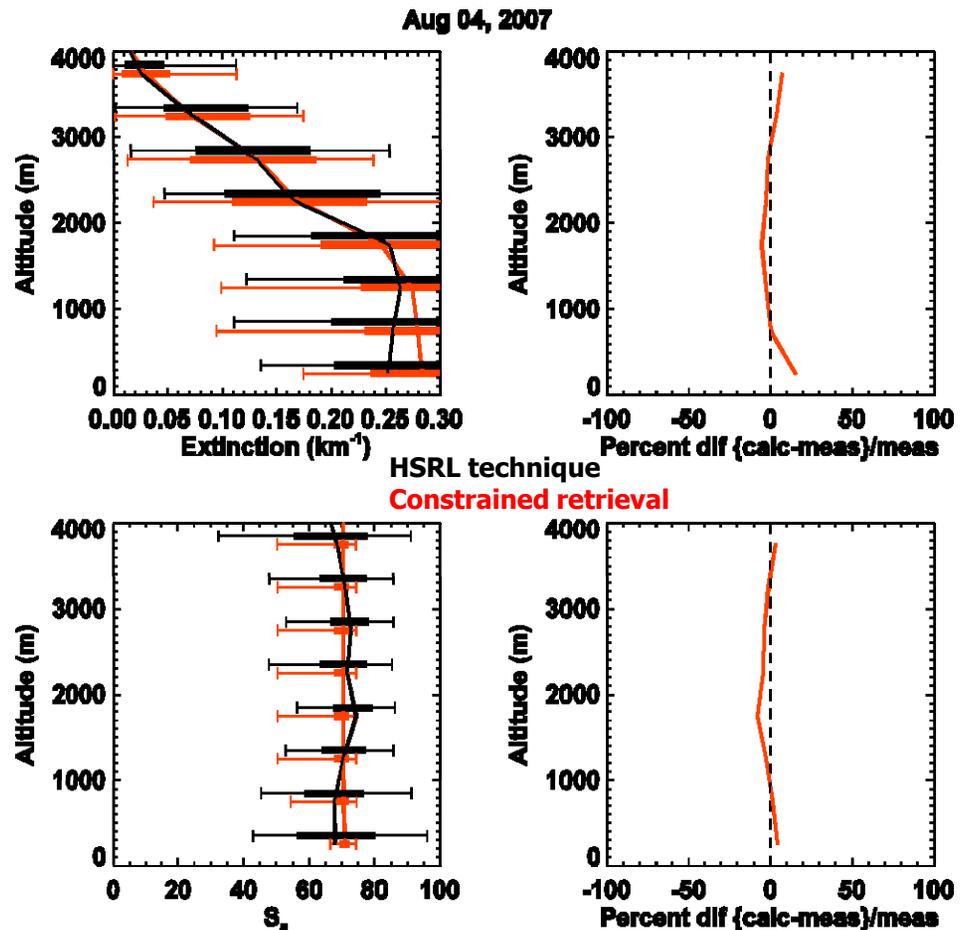
- Terra MODIS , PARASOL, and HSRL in general agreement
- Aqua MODIS AOT about 0.2 (33%) low



Constrained Retrieval over land (August 4 - Aqua MODIS AOT)



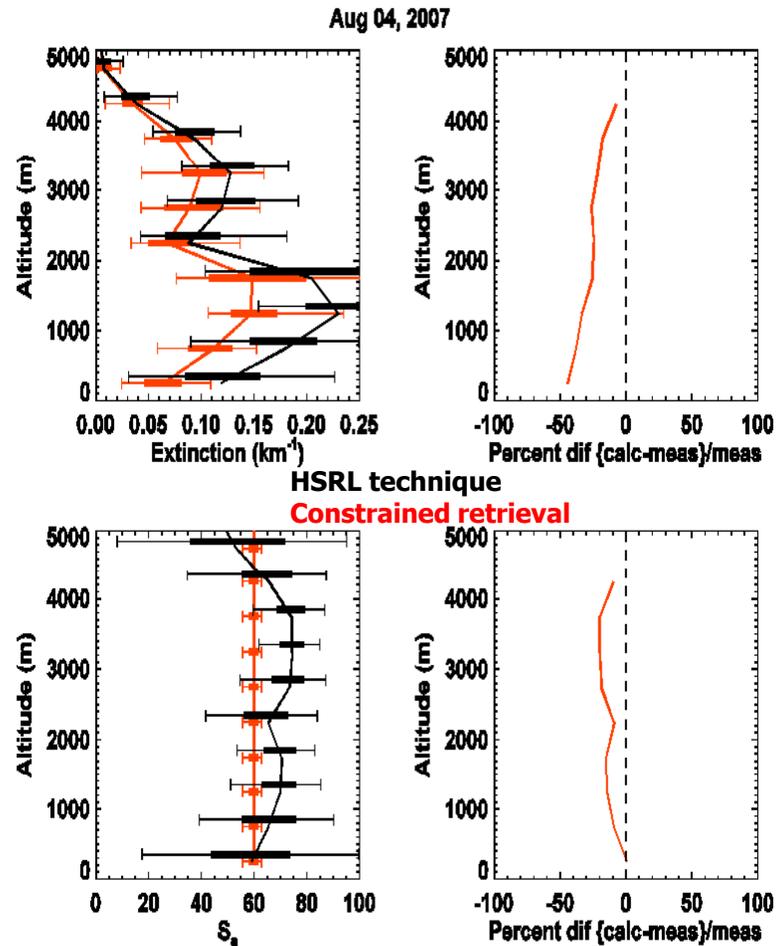
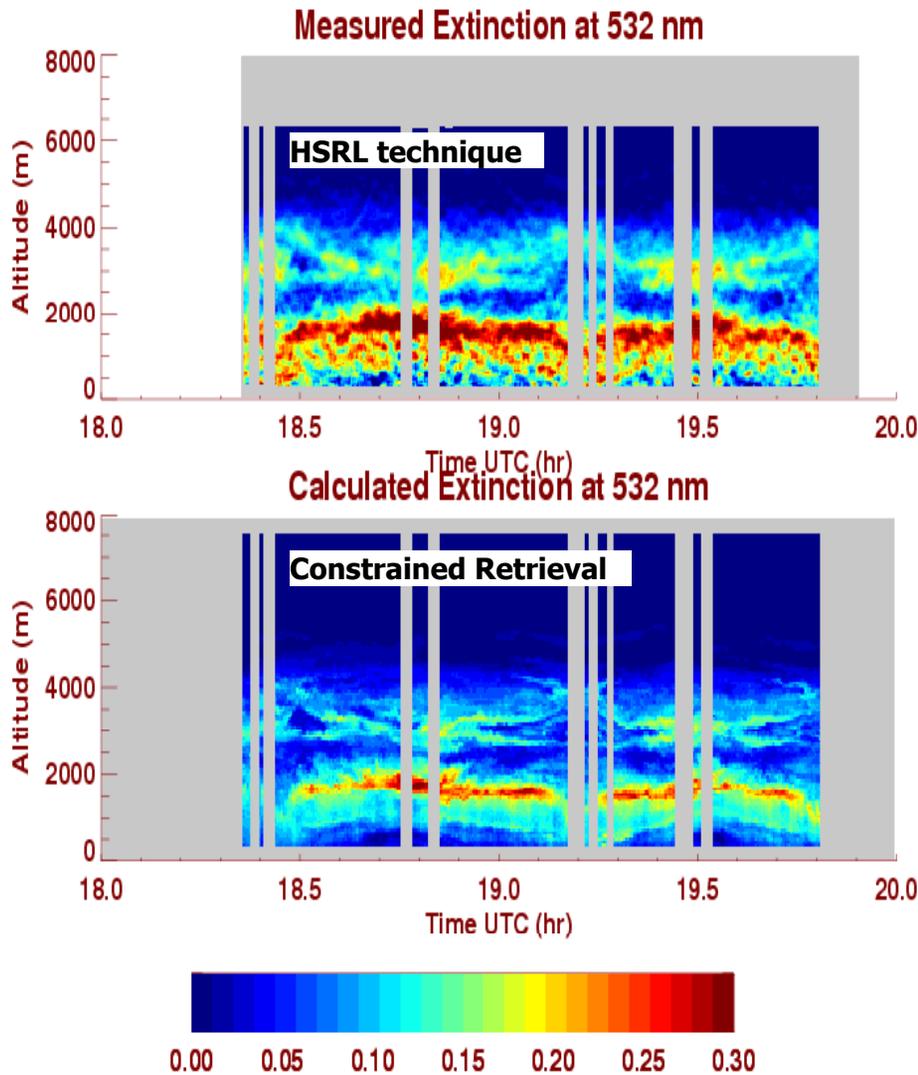
Extinction profiles from constrained retrieval are within 5-10% of HSRL



Constrained Retrieval over water (August 4 - Aqua MODIS AOT)



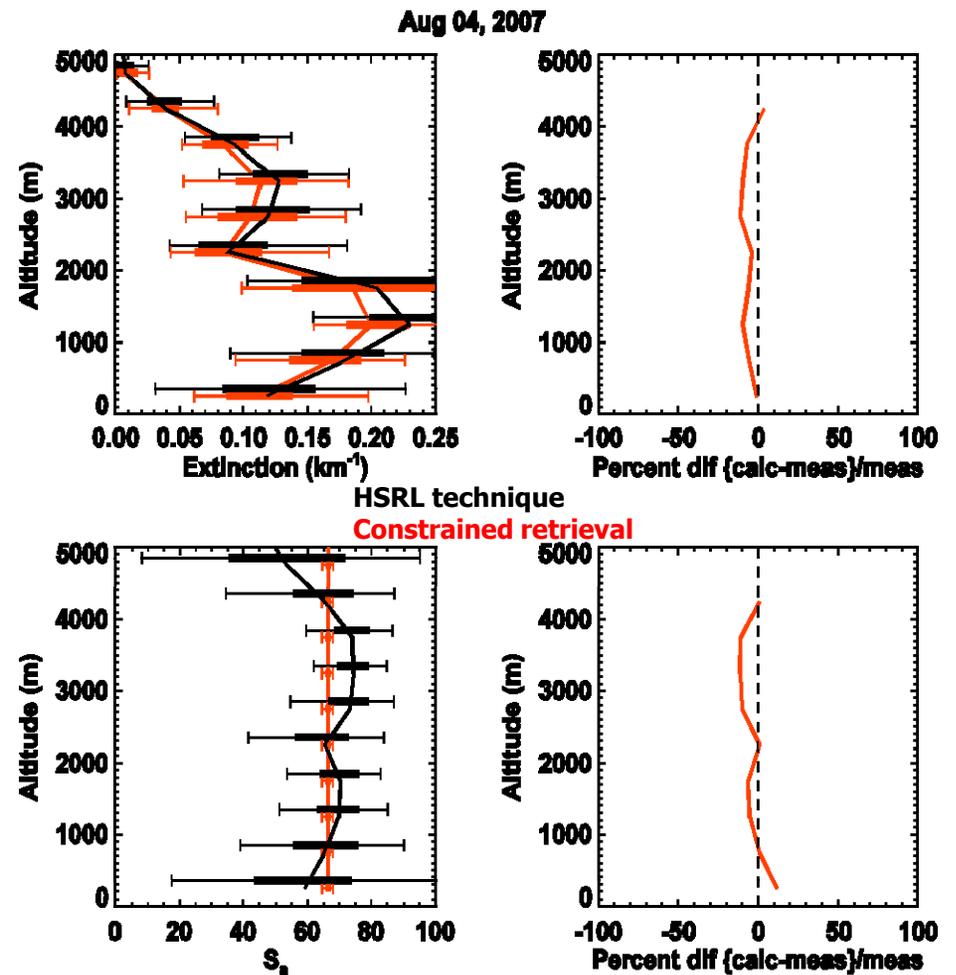
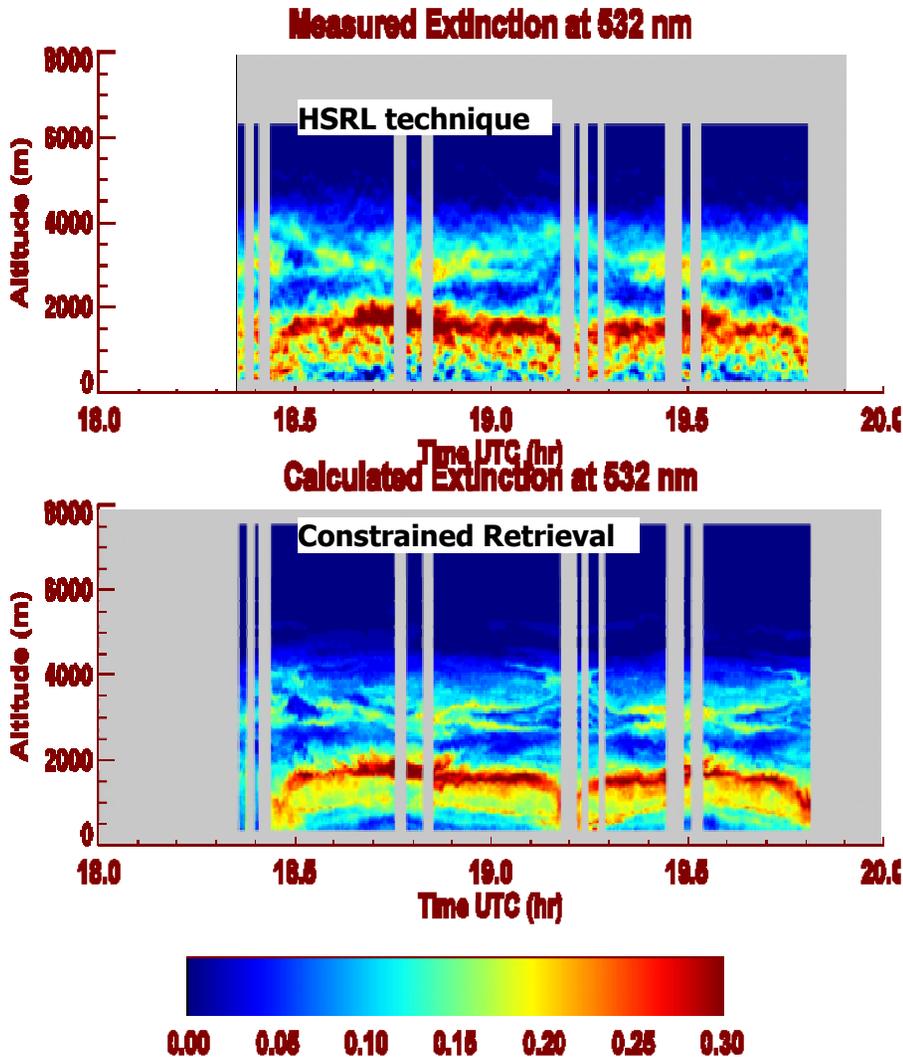
Extinction profiles from constrained retrieval are 20-30% lower than HSRL due to low bias of Aqua MODIS AOT



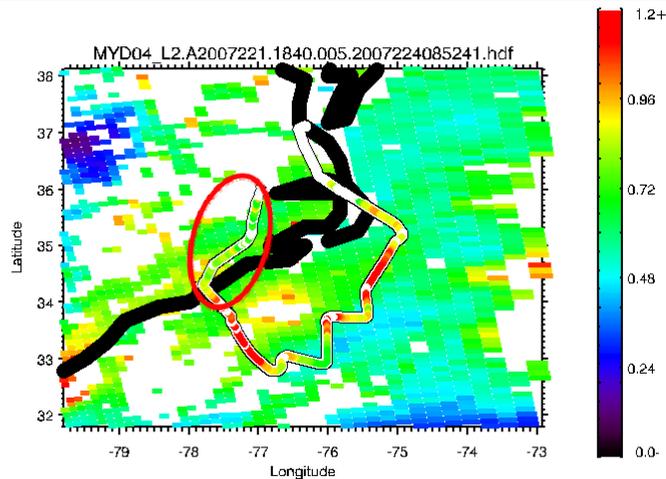
Constrained Retrieval over water (August 4 – PARASOL AOT)



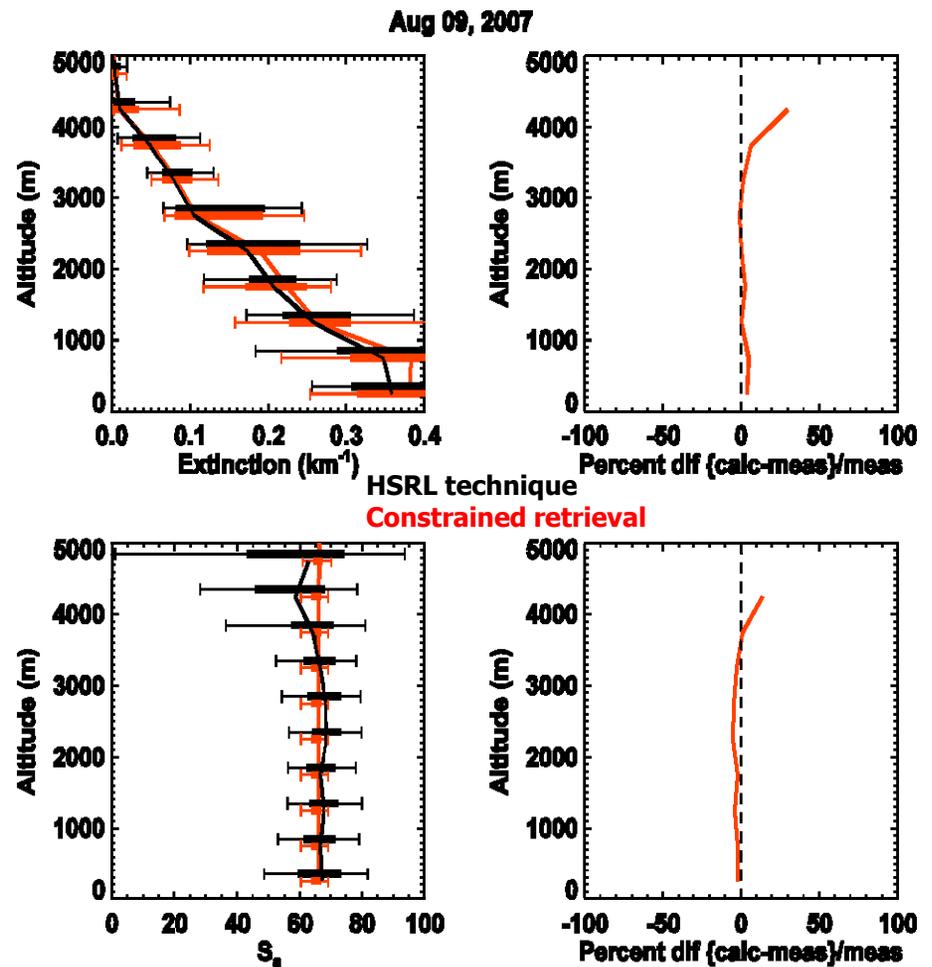
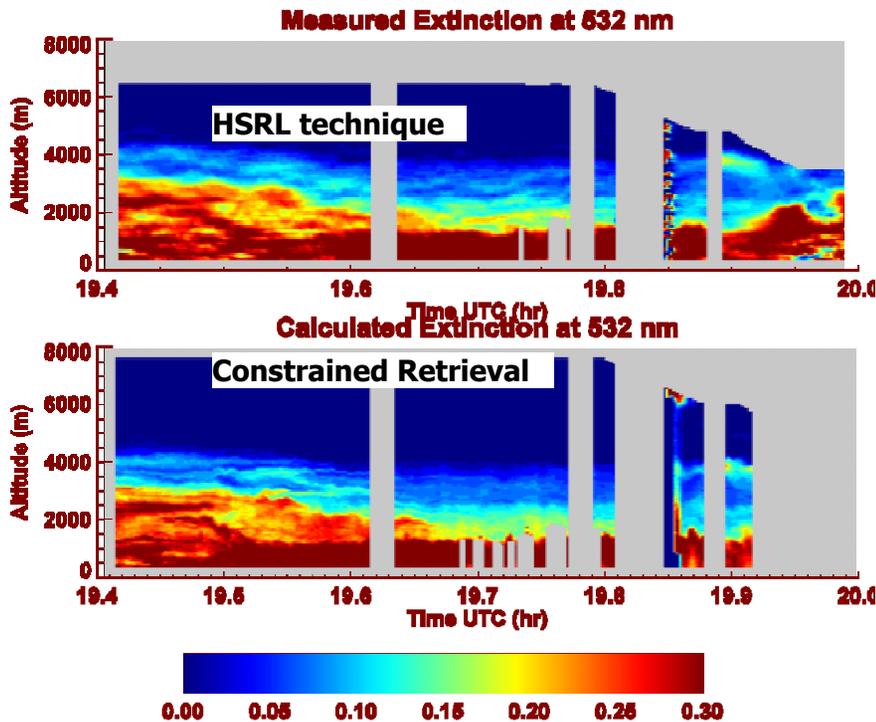
Extinction profiles from constrained retrieval are within 10% of HSRL using PARASOL AOT



Constrained Retrieval over land (August 9, 2007 - Aqua MODIS AOT)



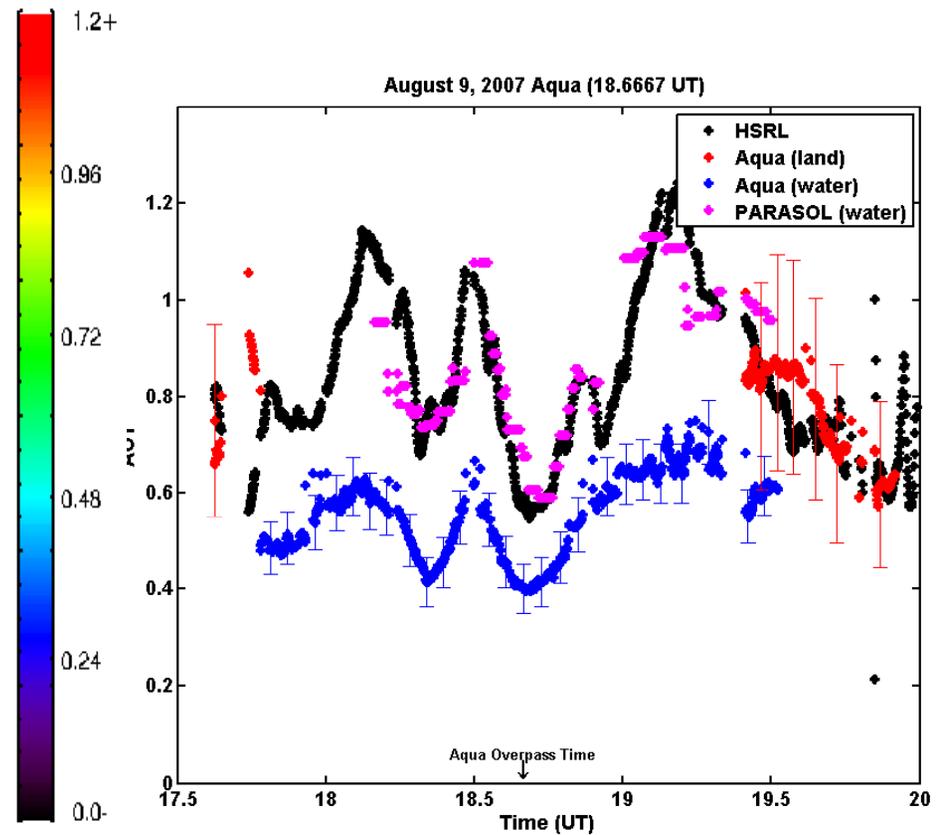
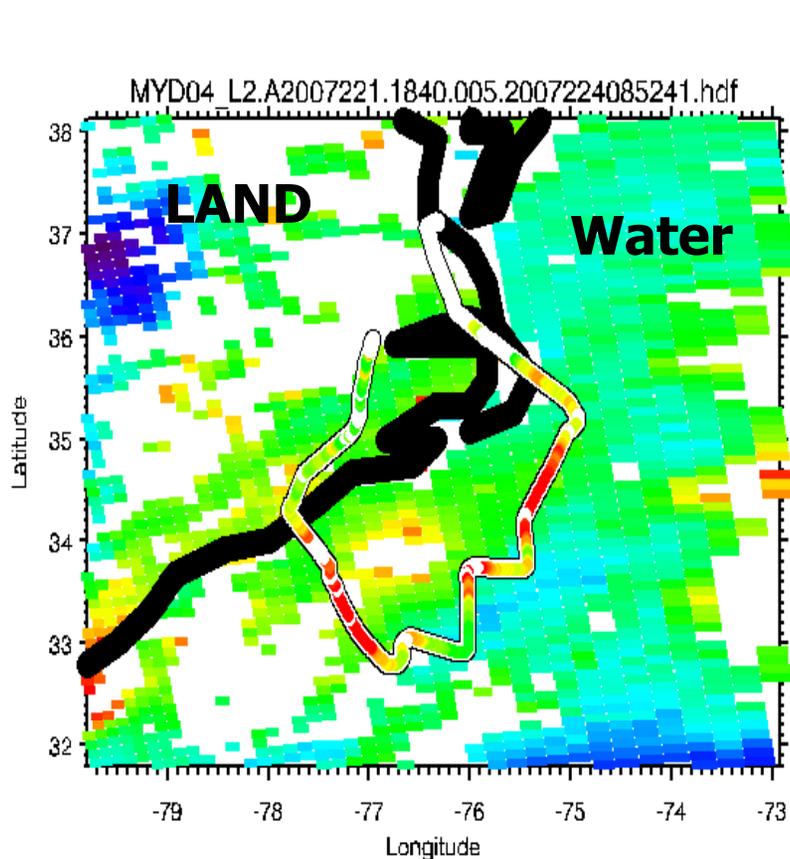
Extinction profiles from constrained retrieval using Aqua MODIS AOT over land are within 5% of HSRL



August 9, 2007 – Aqua MODIS AOT low bias over water



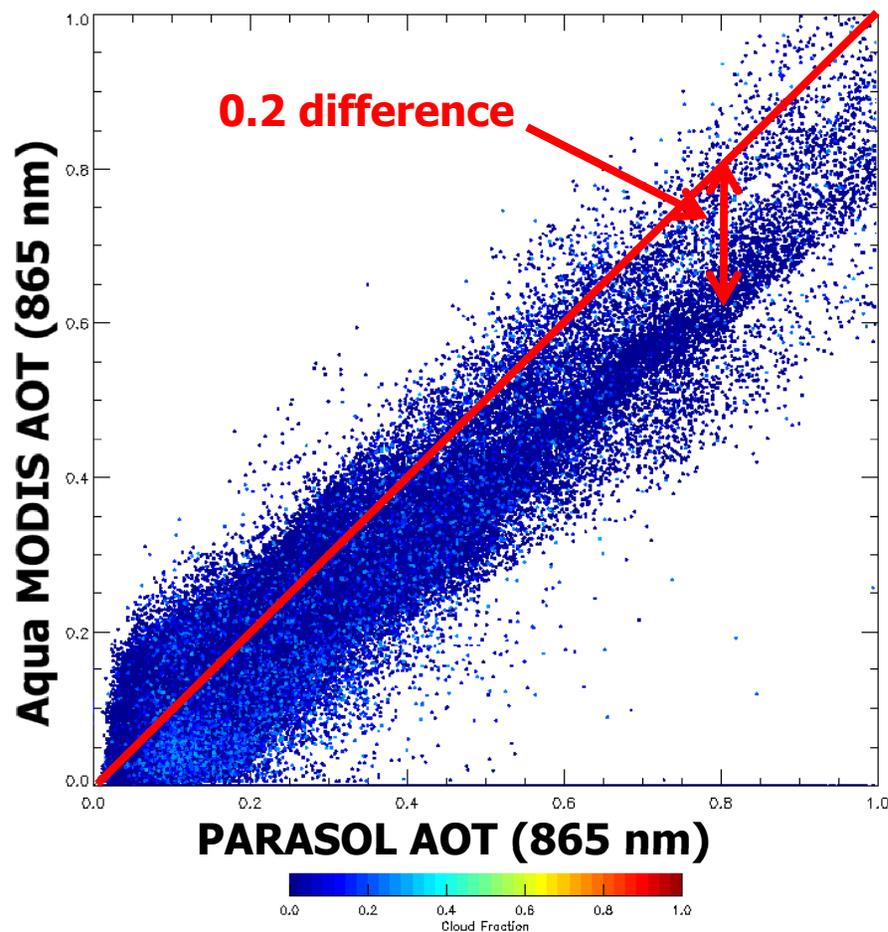
- Aqua MODIS AOT over water is again (0.2-0.3, 20-30%) lower than PARASOL and HSRL
- Aqua MODIS AOT over land in agreement with HSRL AOT





MODIS vs. PARASOL AOT

AQUA MODIS AOT (860nm) vs PARASOL AOT (865nm)
Date: 20060615_20060714
Cloud Fraction: < 30%
Scattering Angle (MODIS): 0-180 deg
Region: Global

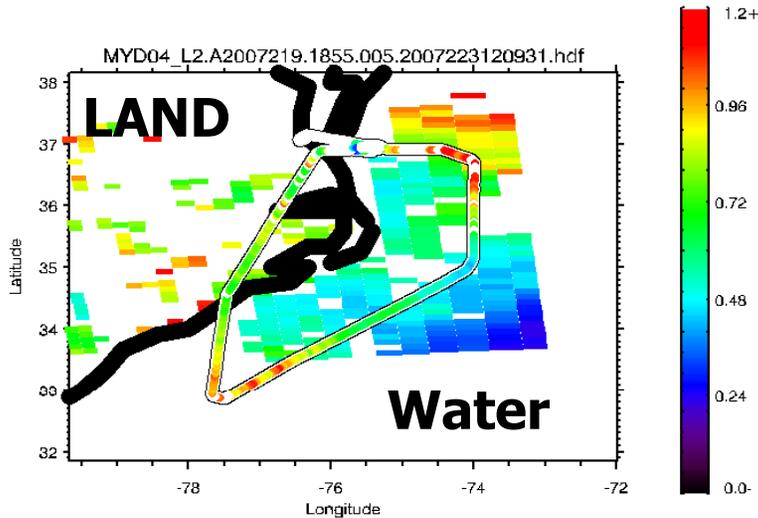


Comparison of MODIS AOT (860 nm) vs. PARASOL AOT (865 nm)

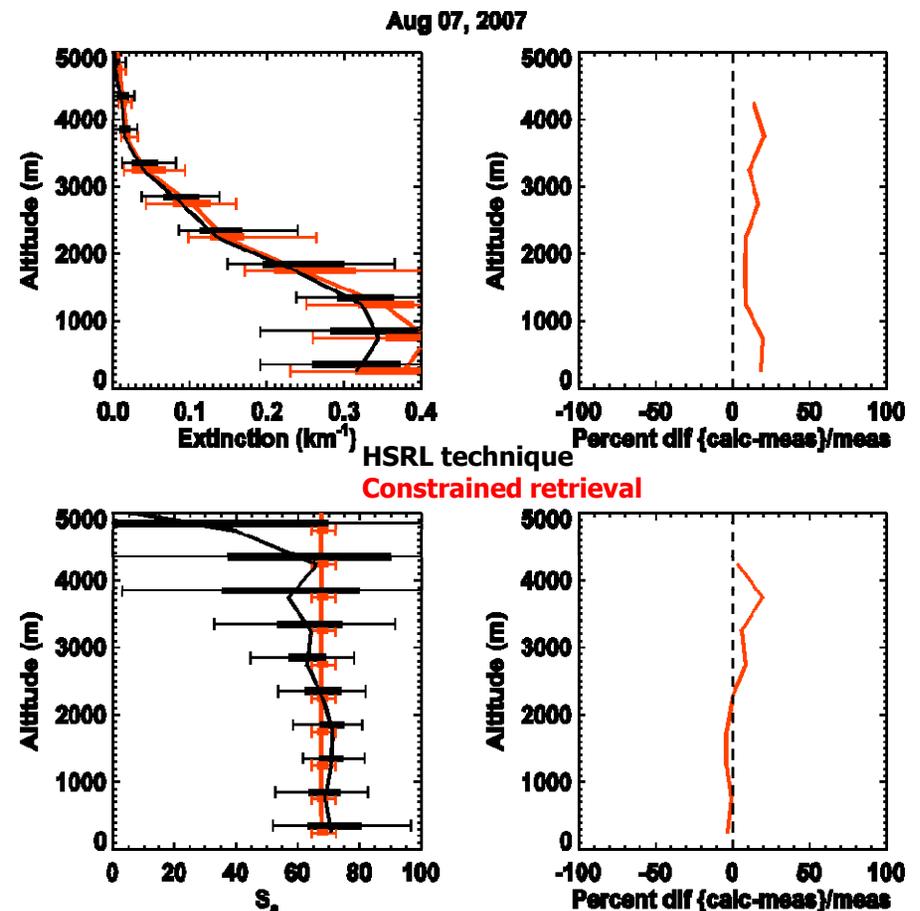
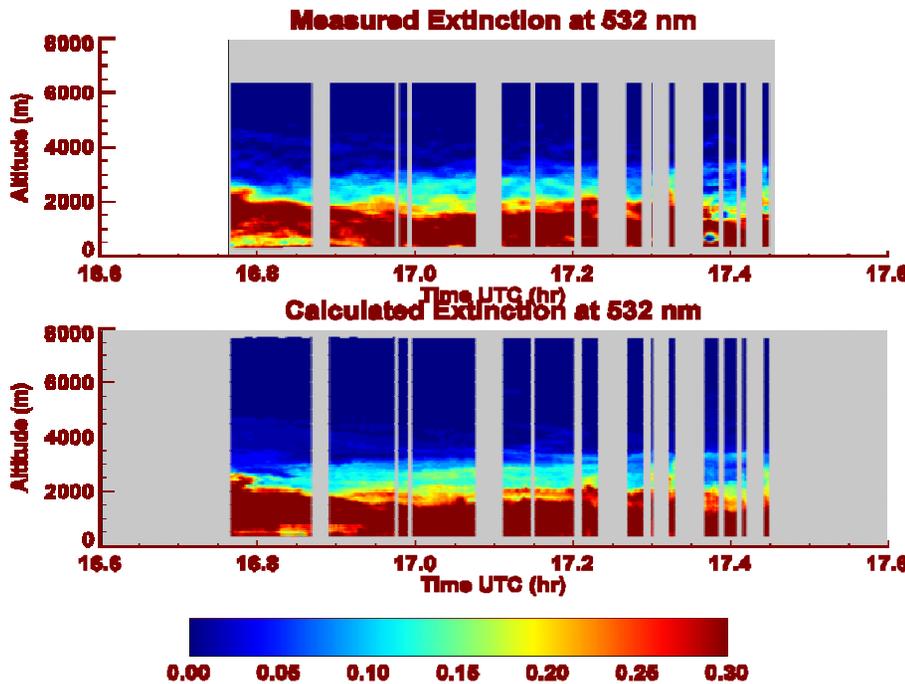
- Global data
- June 15, 2006 – July 14, 2006
- Cloud fraction < 30%

Aqua MODIS AOT is often considerably lower than PARASOL AOT

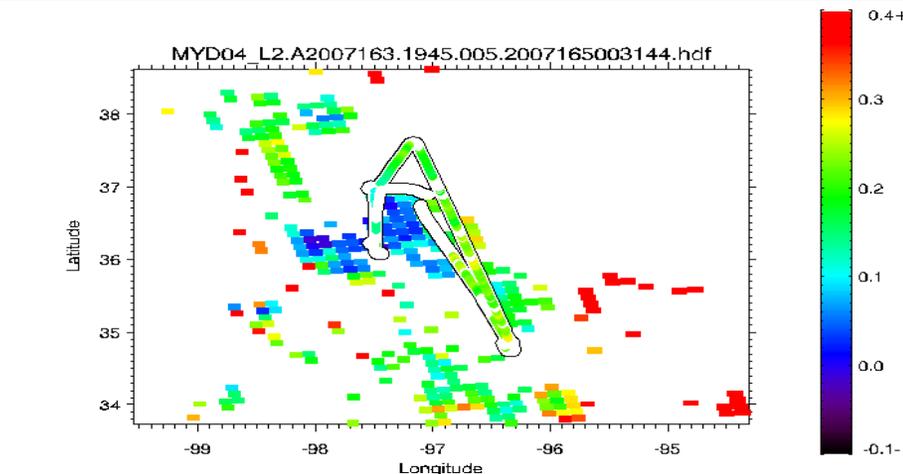
Constrained Retrieval over land (August 7, 2007 - Aqua MODIS AOT)



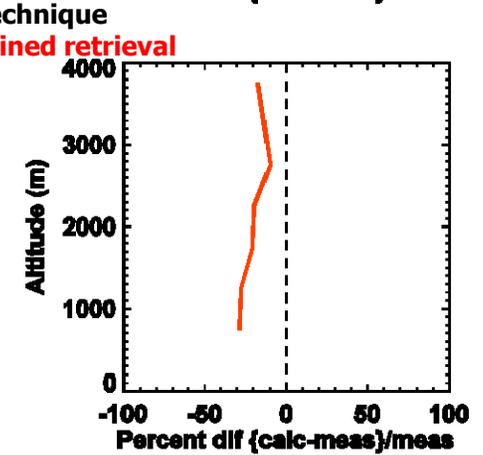
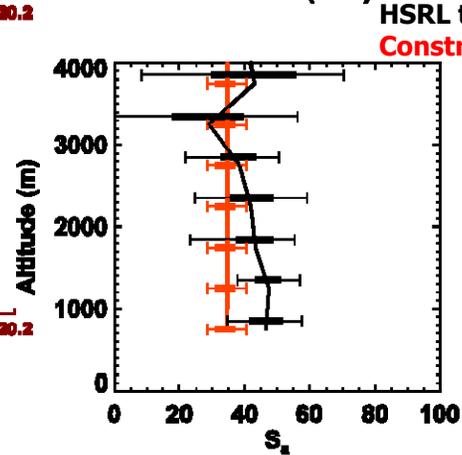
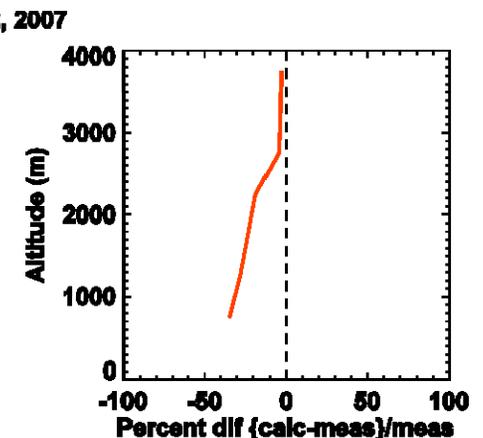
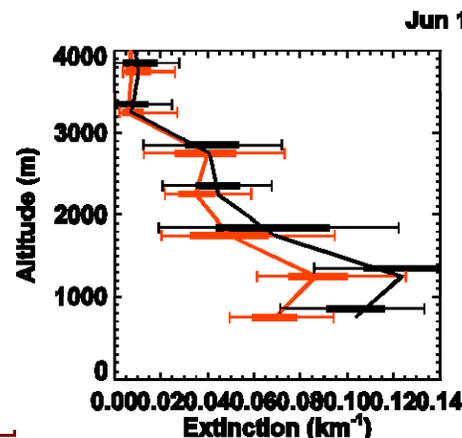
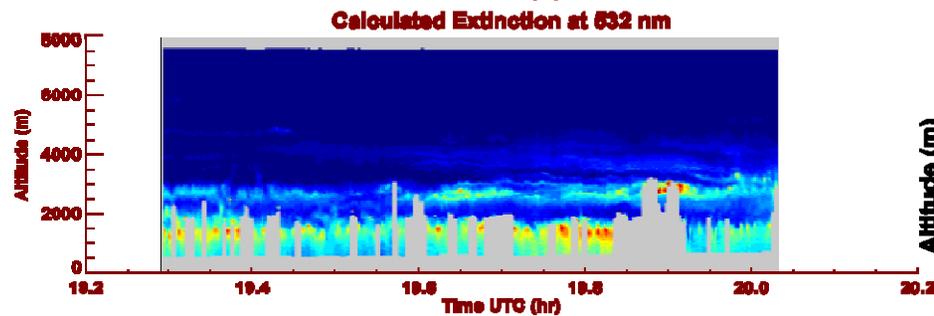
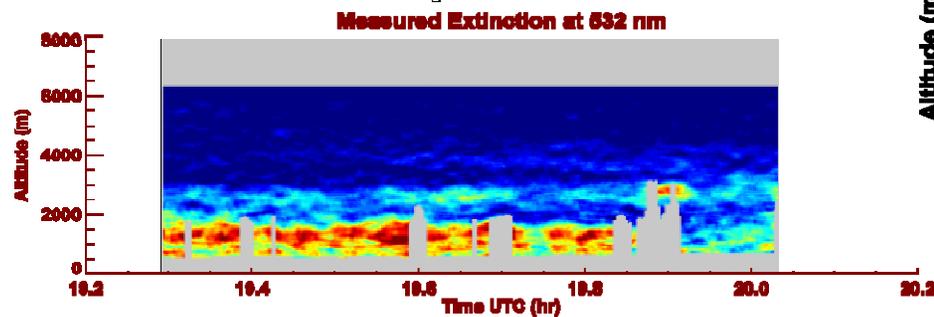
- Extinction profiles from constrained retrieval are 10-20% higher than HSRL
- Aqua MODIS AOT again biased low over water



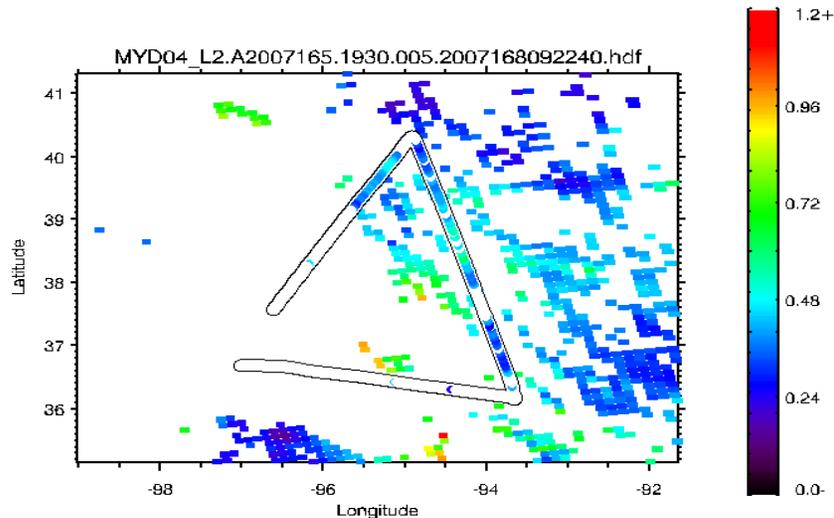
Constrained Retrieval over land (June 12, 2007- CHAPS/CLASIC, Oklahoma - Aqua MODIS AOT)



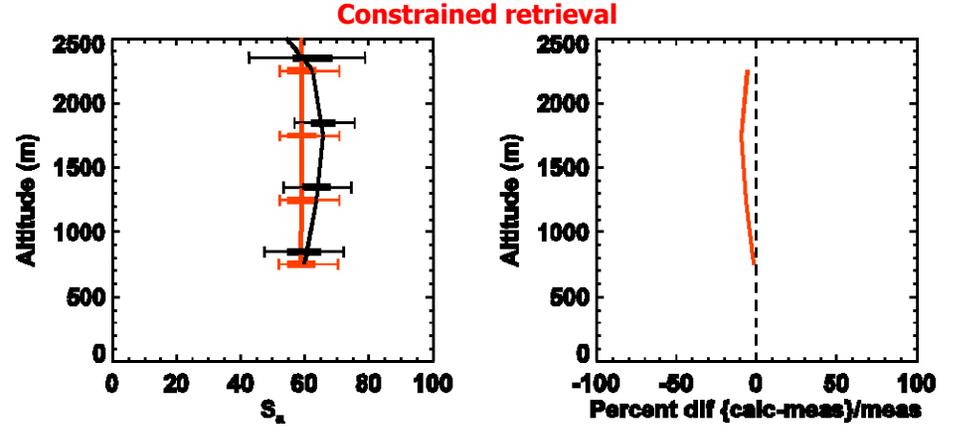
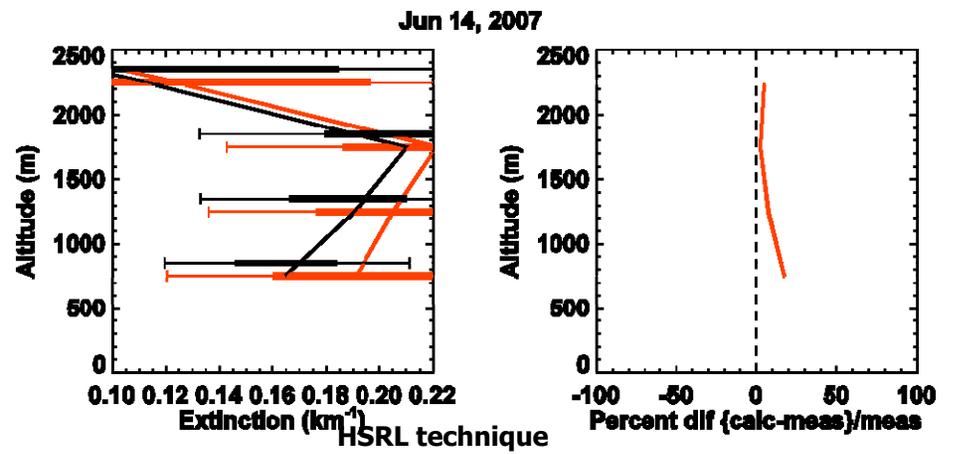
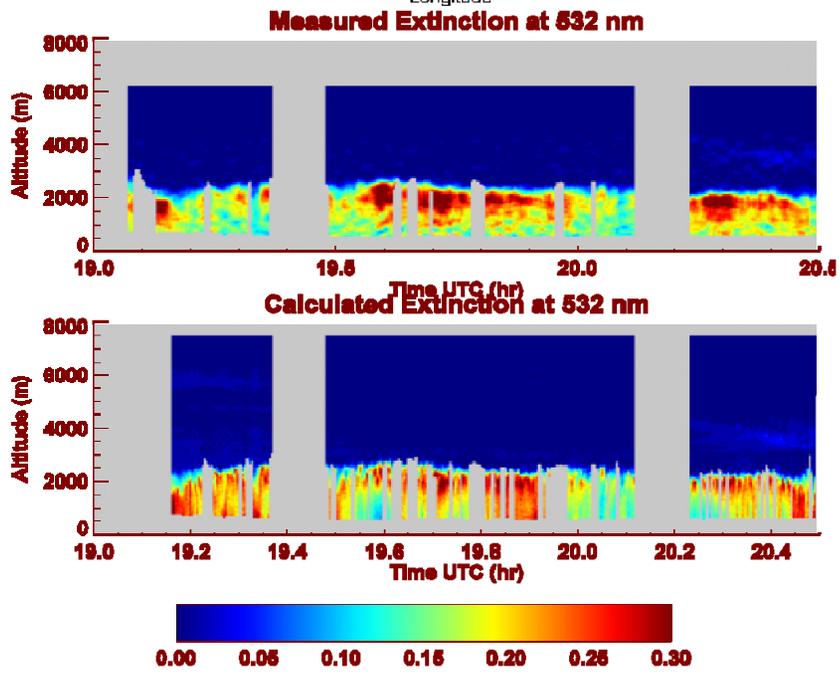
- Extinction profiles from constrained retrieval are 20-30% lower than HSRL
- MODIS AOT lower than HSRL
- HSRL measurements show vertical variability of S_a



Constrained Retrieval over land (June 14, 2007- CHAPS/CLASIC, Oklahoma - Aqua MODIS AOT)



Extinction profiles from constrained retrieval are within 10% of HSRL



Summary



- HSRL measurements show:
 - Lidar ratio (S_a) is relatively constant about 60% of the time over the 0-6 km layer
 - Aerosol extinction derived using HSRL backscatter and the layer AOT constraint is within $\pm 15\%$ of the aerosol extinction derived directly using the HSRL technique about 60% of the time
 - Suggest using aerosol backscatter wavelength dependence and depolarization to infer when lidar ratio varies with altitude
- Constrained retrieval over water:
 - Aqua MODIS AOT biased (~ 0.2 , 20-30%) lower than HSRL and PARASOL AOT - this low bias leads to similar low bias in derived aerosol extinction profiles
 - PARASOL and HSRL AOT in general agreement – using PARASOL AOT over water in constrained retrievals led to derived aerosol extinction profiles in better agreement with HSRL
- Constrained retrieval over land:
 - Aqua MODIS AOT in much better agreement with HSRL – consequently, derived extinction profiles are in better agreement with HSRL
- Ongoing work using HSRL data – systematically examine:
 - MODIS and PARASOL AOT
 - CALIOP extinction retrievals constrained by MODIS and PARASOL AOT