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

Richard Ferrare[1], Chris Hostetler[1], John Hair[1], Anthony Cook[1], David Harper[1], Mike Obland[1,2], Ray Rogers[1,3], Mike Wusk[1], Sharon Burton[1,3], Chieko Kittaka[1,3], Lorraine Remer[4]
[1]NASA Langley Research Center, [2]Oak Ridge Associated Universities, [3]SSAI, [4]NASA Goddard Space Flight Center

Introduction

We have developed and implemented retrievals that combine airborne lidar and MODIS measurements to derive aerosol extinction profiles. We use the airborne data acquired by the new Langley High Spectral Resolution Lidar (HSRL). In addition to measuring aerosol backscatter and depolarization at 532 and 1064 nm, this lidar system is unique in that it directly measures aerosol extinction at 532 nm without additional information or assumptions about aerosol properties. These measurements are initially used to directly validate the aerosol extinction profiles derived using aerosol backscattering profiles and MODIS retrievals.

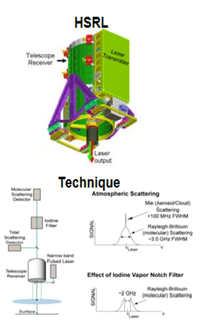
Methodology

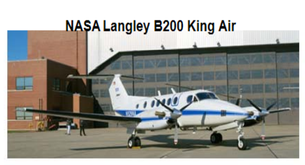
Retrievals of aerosol backscatter and extinction profiles from backscatter lidars (e.g. CALIOP) rely on linking aerosol extinction and backscatter (e.g., that the aerosol extinction-to-backscatter ratio, S_a, is reasonably spatially constant through a solution layer) and require an additional boundary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

Moderate-resolution Imaging Spectroradiometer (MODIS) measurements of aerosol optical thickness (AOT) are used to constrain the total transmission through the atmosphere and so derive a mean value of the lidar ratio (S_a) through the layer. This approach of using aerosol optical thickness as an external constraint has been successfully used to derive aerosol extinction profiles using airborne and ground based backscatter lidar data and AOT provided by ground-based Sun photometers and MODIS measurements.

Measurements

The primary data that are described here to develop, evaluate, and validate these techniques are the aerosol backscatter and extinction profiles measured by the NASA Langley airborne High Spectral Resolution Lidar (HSRL). This lidar is ideally suited for such activities, since it can directly measure both aerosol extinction and backscattering simultaneously at 532 nm, and so does not require external information or assumptions about the aerosol extinction-to-backscatter ratio. This system also measures backscatter at 1064 nm and depolarization at both wavelengths.





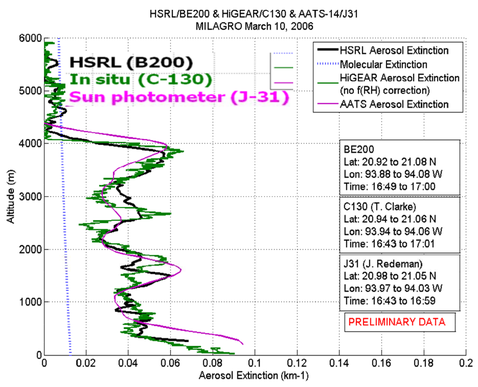
Data Products

- 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

The HSRL technique

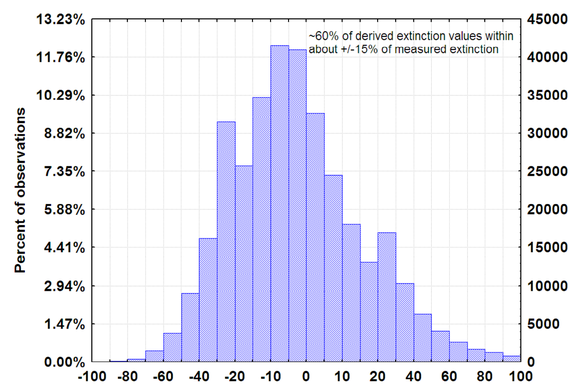
- independently measures aerosol and molecular backscatter
- can be internally calibrated
- provides intensive optical data from which to infer aerosol type
- provides more accurate aerosol layer top/base heights

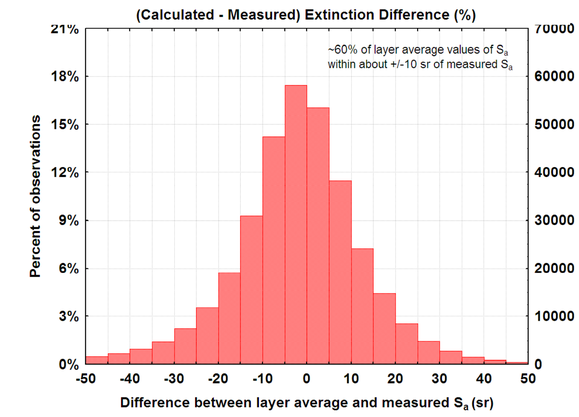


This figure shows the excellent agreement among aerosol extinction profiles derived from coincident measurements from the HSRL, NASA Ames Airborne Tracking Sun photometer (AATS-14), and Hawaii Group for Environmental Aerosol Research (HiGEAR) in situ instrumentation (scattering + absorption) (courtesy of Tony Clarke, Univ. of Hawaii). These profiles were acquired over the Gulf of Mexico between approximately 16:45-17:00 UT on March 10, 2006.

Vertical variability of extinction-to-backscatter ratio and impacts on calculated aerosol extinction profiles

Techniques for improving aerosol backscattering and extinction retrievals rely on spatial homogeneity of the aerosol extinction-to-backscatter ratio, S_a, through a layer. We examined the vertical variability of S_a using the HSRL measurements acquired during about 240 hours of operations over approximately 80 flights that occurred during four field campaigns in 2006 and 2007. Extinction profiles were derived using a standard backscatter lidar retrieval technique constrained by the AOT derived from the HSRL extinction measurement in the layer between 0-6 km. These calculated extinction profiles were then compared with the extinction profiles obtained from the HSRL direct measurement of extinction. Layer averaged extinction-to-backscatter ratios that were calculated using the backscatter lidar retrieval technique constrained by the HSRL layer AOT were also compared with the extinction-to-backscatter ratios obtained directly from the HSRL extinction and backscatter profiles. These results indicate that S_a is relatively constant about 60% of the time over the 0-6 km layer, and the aerosol extinction derived using the layer AOT constraint is within +/15% of the aerosol extinction derived directly from the HSRL molecular channel about 60% of the time.

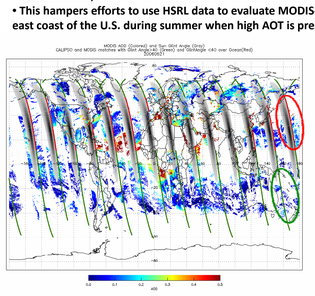




CALIPSO track and MODIS Sun Glint Mask

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.**

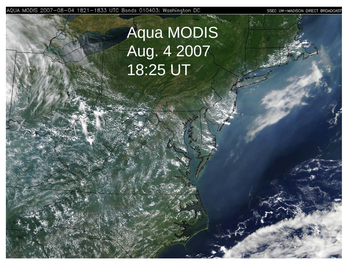


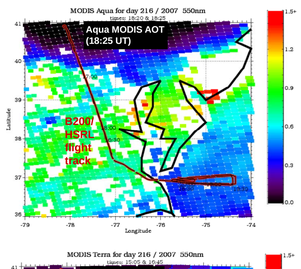
CALIPSO track within MODIS glint region

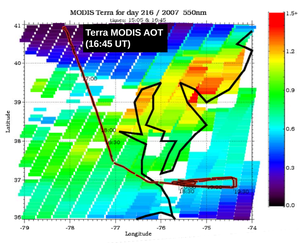
CALIPSO track out of MODIS glint region

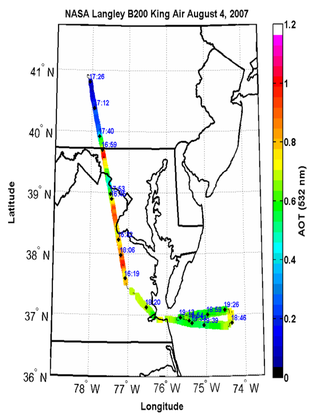
August 4, 2007 Example

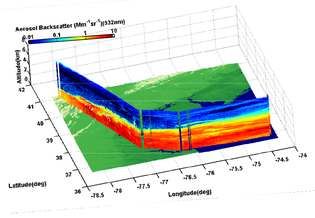
The HSRL acquired data along the CALIPSO ground track over land as well as over the water. The HSRL data are used to examine the AOT derived from both the Aqua and Terra MODIS sensors and as well as to develop and test algorithms used to derive aerosol extinction profiles. These algorithms will then be applied to the CALIOP data.



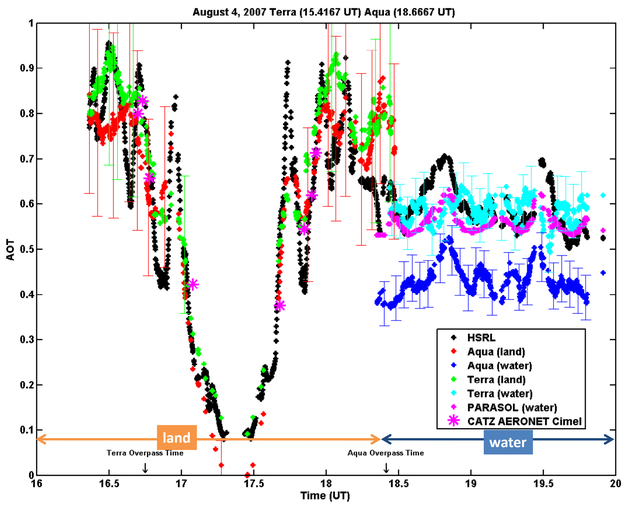








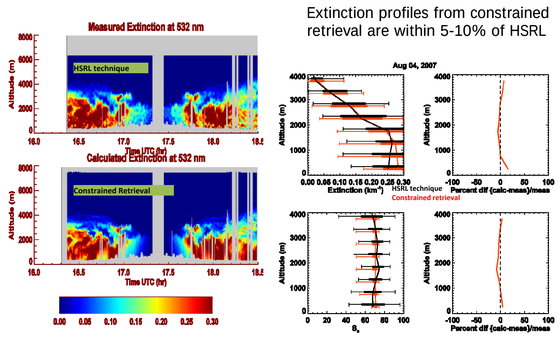
These figures show the Aqua MODIS true color image (top left), the Aqua and Terra MODIS AOT (550 nm) images (top right), the B200/HSRL flight tack color coded by AOT (532 nm) derived from the HSRL data (bottom left), and a pseudo-3d image of aerosol backscatter along the B200/HSRL track (bottom right).



This figure shows the AOT derived from: 1) HSRL molecular channel data along the flight track, 2) interpolating the Aqua and Terra MODIS measurements to the B200/HSRL track, 3) interpolating PARASOL measurements to the B200/HSRL track, and 4) AERONET Cimel Sun photometer measurements (courtesy of Brent Holben) at the surface along the B200/HSRL track. All AOT values correspond to 550 nm. There is excellent agreement among the measurements over land, however, over water, Aqua MODIS AOT measurements appear to be about 0.15-0.2 (25-30%) too low.

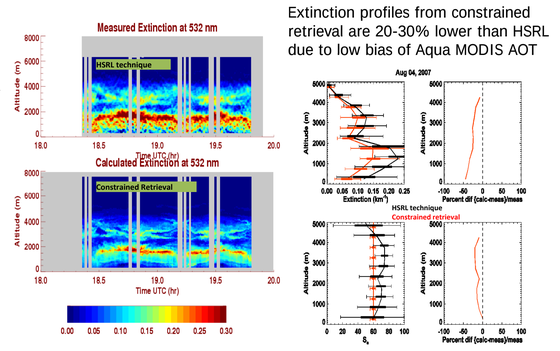
Constrained Retrieval over land (August 4 - Aqua MODIS AOT)

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



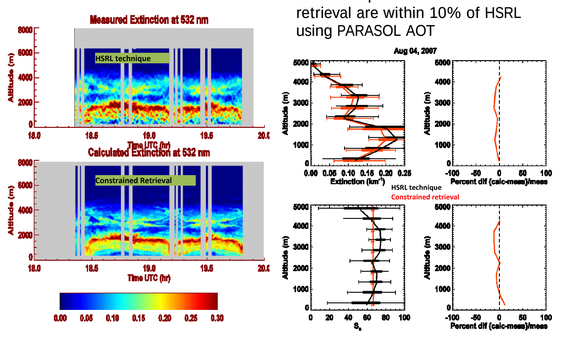
Constrained Retrieval over water (August 4 - Aqua MODIS AOT)

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

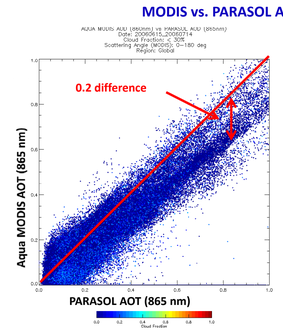


Constrained Retrieval over water (August 4 – PARASOL AOT)

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



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

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 +/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

Acknowledgements

We acknowledge the support of NASA Headquarters Science Mission Directorate (SMD) and NASA LaRC for their support of the development of the Airborne HSRL. We also acknowledge the support of NASA SMD and the NASA Langley Flight Research Services Directorate for their support of the deployment of the B-200 on these field missions. This research was supported by the NASA Science Mission Directorate, the U.S. Department of Energy's Atmospheric Science Program (Office of Science, BER, Grant No. DE-AI02-05ER63985) and the NASA CALIPSO project. We thank Phil Russell, Jens Redemann, and John Livingston for the NASA Ames Airborne Tracking Sun photometer (AATS-14) data, Antony Clarke (Univ. of Hawaii) for the HiGEAR data, and Brent Holben for the AERONET Sun photometer data.