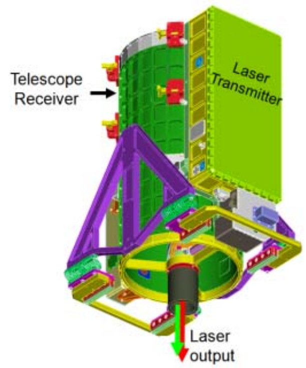
Preliminary Raman lidar and HSRL measurements of aerosols during CLASIC/CHAPS



Richard Ferrare, Chris Hostetler, John Hair, Anthony Cook, David Harper, Mike Obland, Mike Wusk
NASA Langley Research Center

Marian Clayton, Ray Rogers, Sharon Burton, (SSAI/NASA Langley)
Dave Turner (UW-Madison)

DOE ARM Aerosol/Radiative Properties Working Group Meeting
September 17-19, 2007

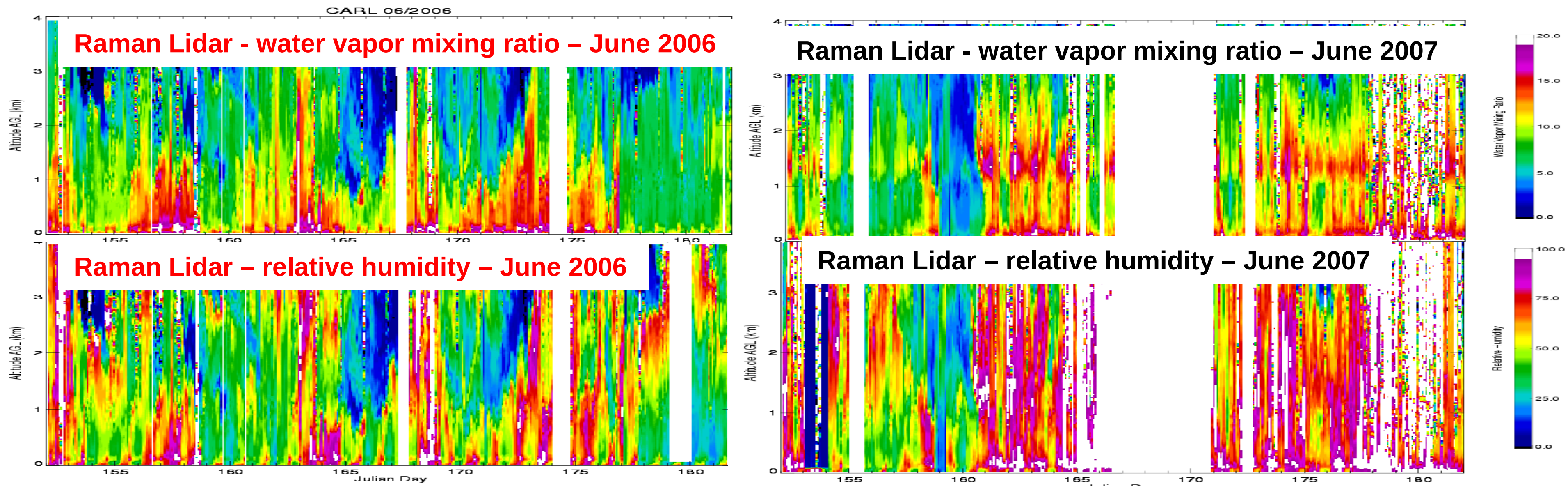
Funded by
NASA HQ Science
Mission Directorate
Radiation Sciences Program

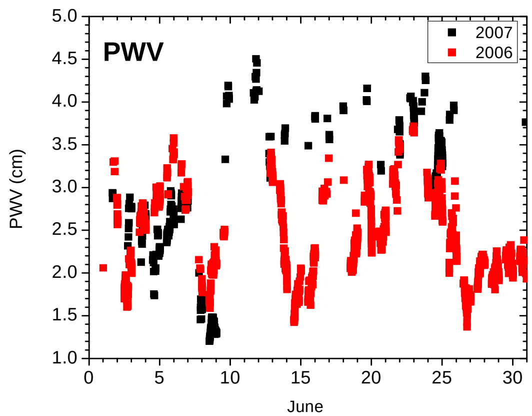
Atmospheric Science Program (ASP)

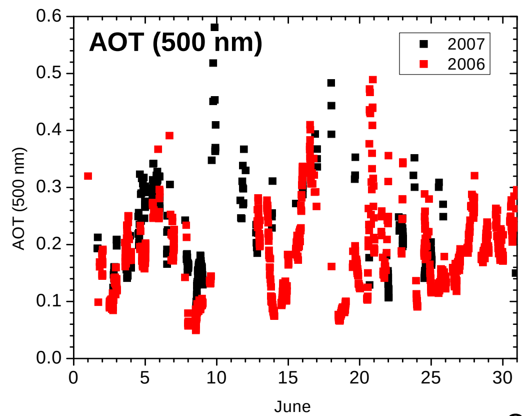
Funded by
Department of Energy
Atmospheric Radiation Measurement Program
Atmospheric Science Program

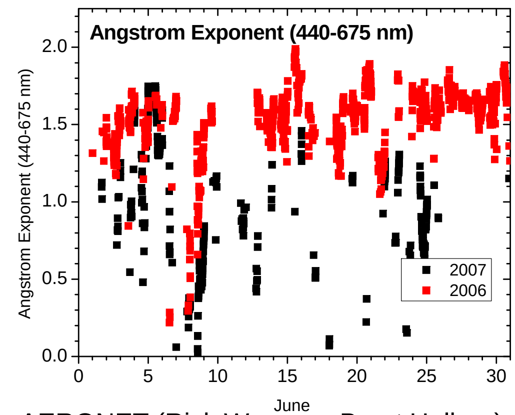
June at SGP: 2006 vs. 2007

- Significantly higher water vapor and RH during latter 3 weeks of June 2007
- AOT similar but Angstrom exponent generally lower during 2007 – more large particles present during June 2007 than during June 2006



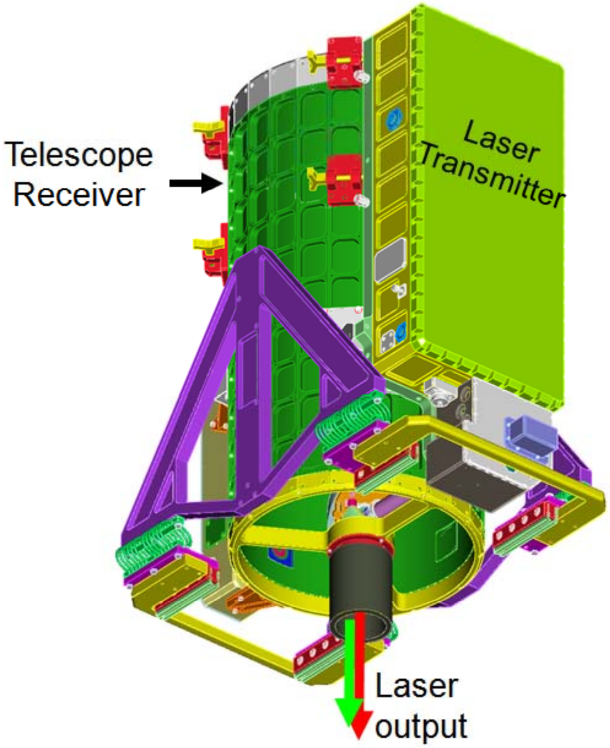






Cimel data from AERONET (Rick Wagener, Brent Holben)

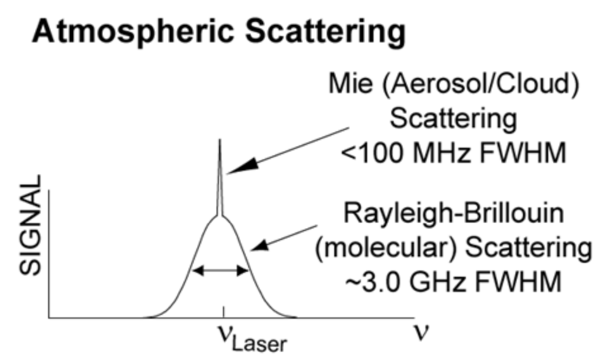
NASA Langley airborne High Spectral Resolution Lidar (HSRL)

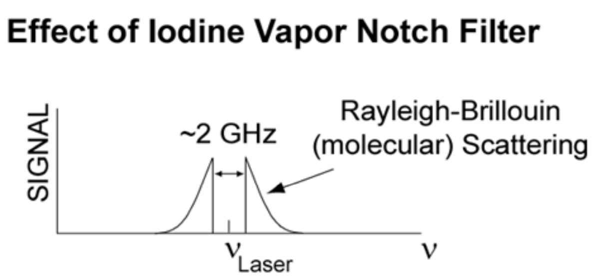


- **Capabilities**
  - **HSRL at 532 nm (iodine technique)**
    - **Aerosol backscatter and extinction (532 nm)**
  - **Backscatter lidar at 1064 nm**
  - **Depolarization at both 532, 1064 nm**
- **History**
  - **2000-2004: instrument development and integration**
  - **Dec 2004: first test flight on Lear 25-C**
  - **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)**
  - **More than 350 hours of data over two years!**

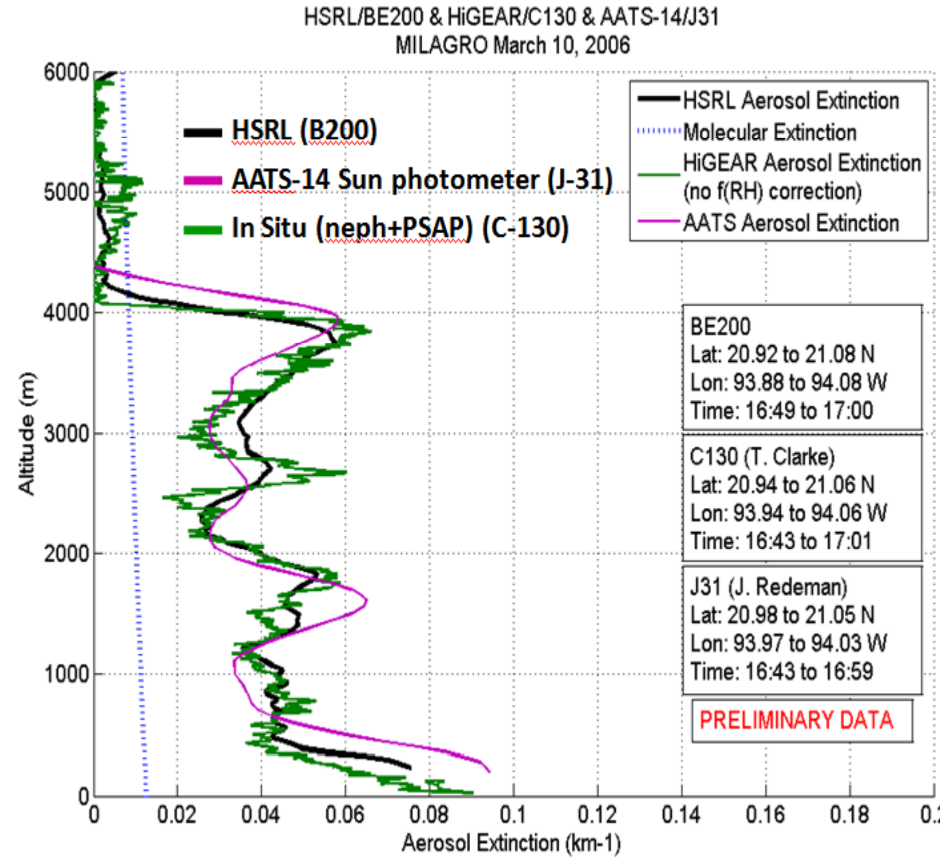
NASA Langley airborne High Spectral Resolution Lidar (HSRL)

HSRL relies on spectral separation of aerosol and molecular backscatter in lidar receiver





Aerosol Extinction

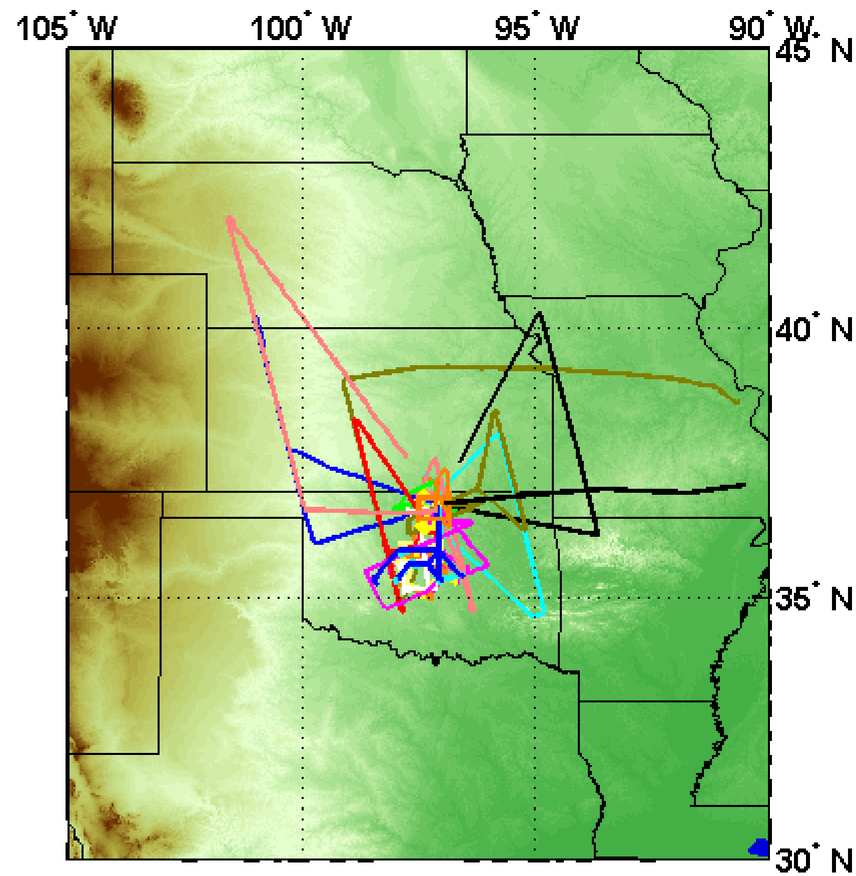


- HSRL independently measures aerosol and molecular backscatter
  - Can be internally calibrated
  - No correction for extinction required to derive backscatter profiles
  - More accurate aerosol layer top/base heights
  - Provide *intensive* optical data from which to infer aerosol type

CLASIC/CHAPS Objectives and Flights

Objectives

- Provide vertical profiles of aerosol between and above cloud
  - Provide vertical context for G-1 measurements
  - Investigate changes in aerosol optical properties as a function of:
    - Distance from clouds
    - Proximity to urban center (ex. upwind vs. downwind of OKC)
- Provide cloud top and PBL heights
- Locate horizontal extent of OKC plume
- Use HSRL measurements of aerosol intensive parameters to infer aerosol types
- Validate CALIOP lidar on the CALIPSO satellite
- Assess aerosol measurements of existing passive satellite sensors
  - MODIS, MISR, PARASOL
- Acquire data over DOE ARM SGP Raman lidar to investigate advanced, multi-wavelength lidar retrievals



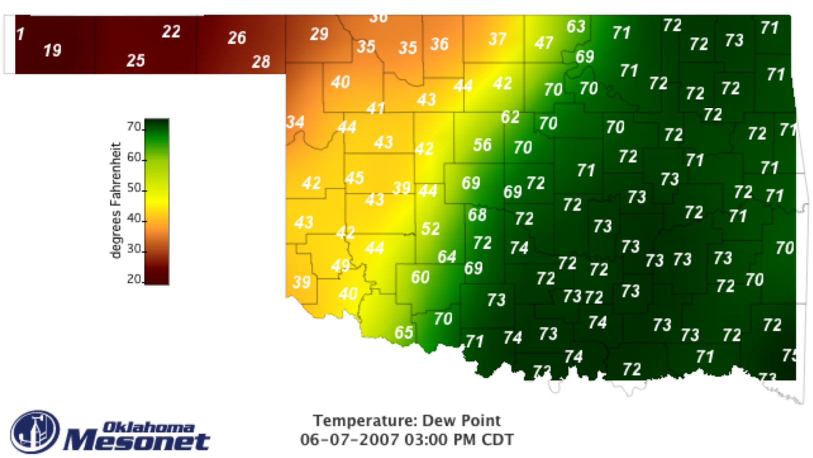
20 science flights, 66 flight hours

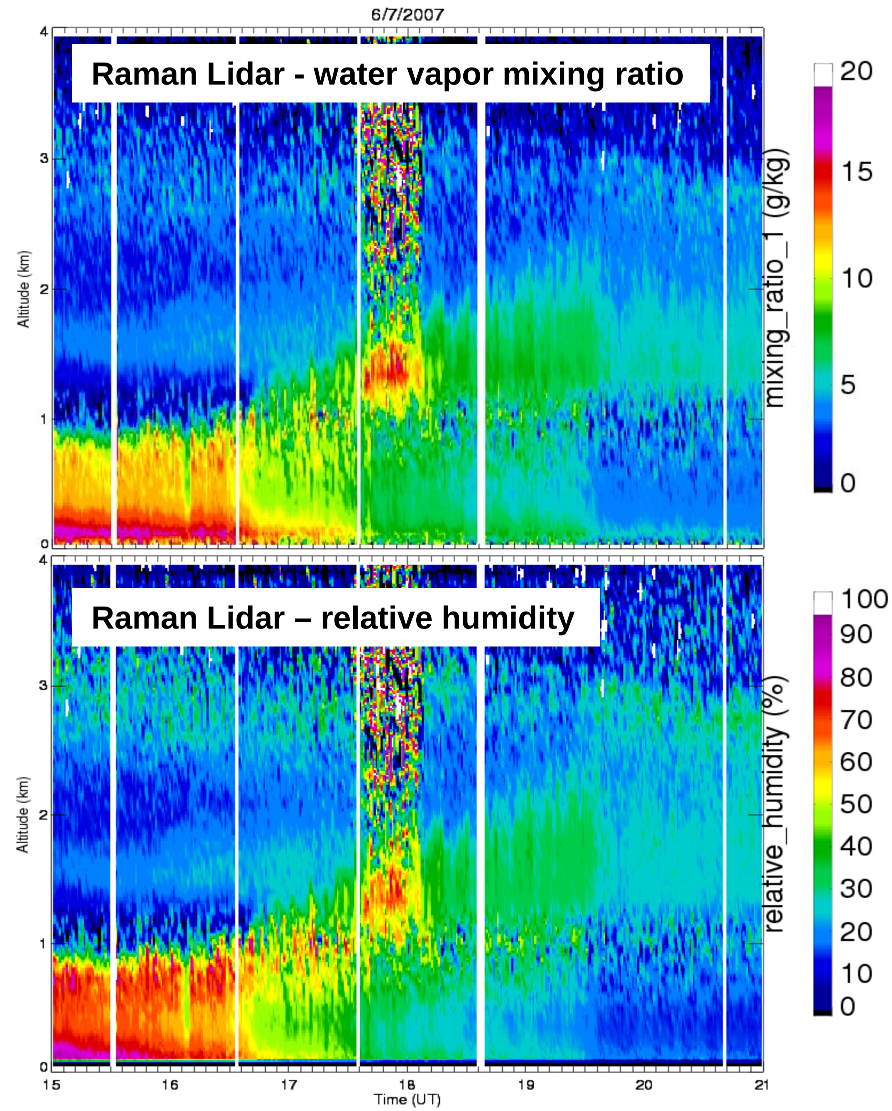
- 12 flights over ARM SGP
- 8 flights included CALIPSO validation
- ~8 flights coordinated with DOE G-1
- ~4 flights coordinated with CIRPAS TO
- ~10-12 flights with MODIS/MISR

Water vapor and Aerosol Measurements of June 7 Dry Line

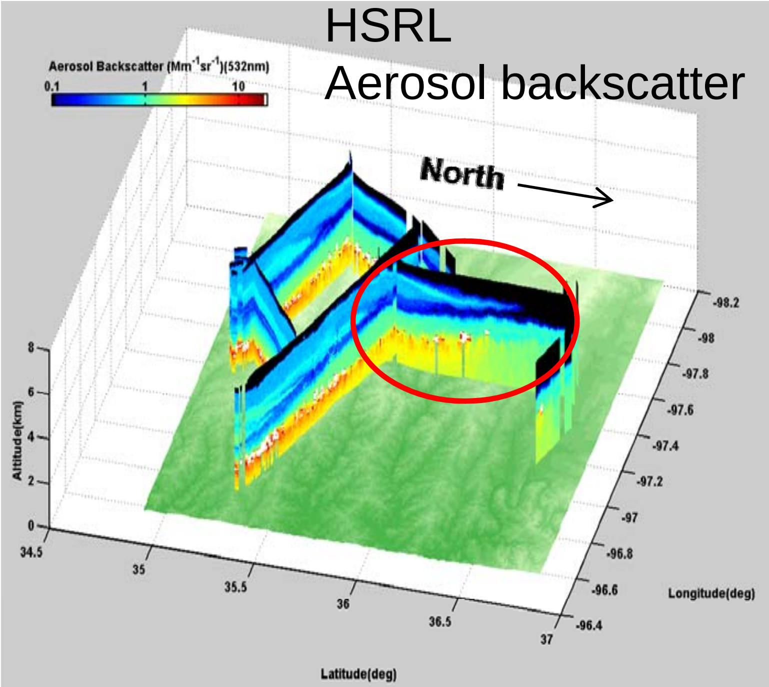
- Dry line passed from NW to SE over SGP site and crossed the region between the SGP and OKC
- Raman Lidar measurements show large decrease in water vapor after passage of dry line

OK Mesonet; Surface Dew Point 20:00 UT



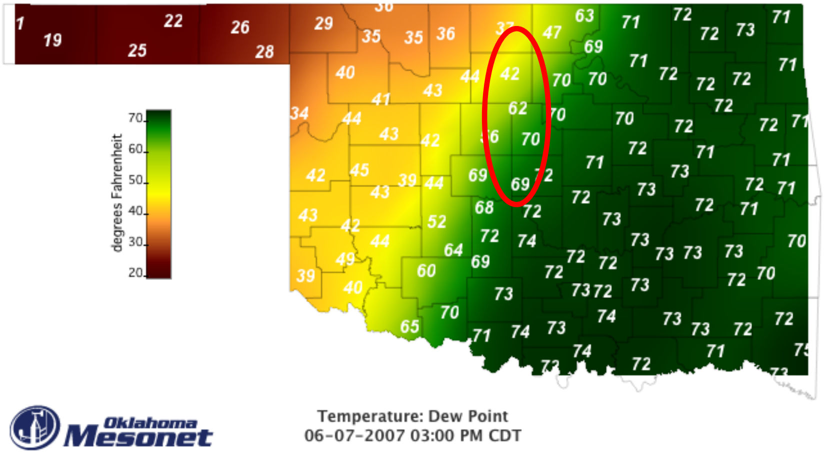


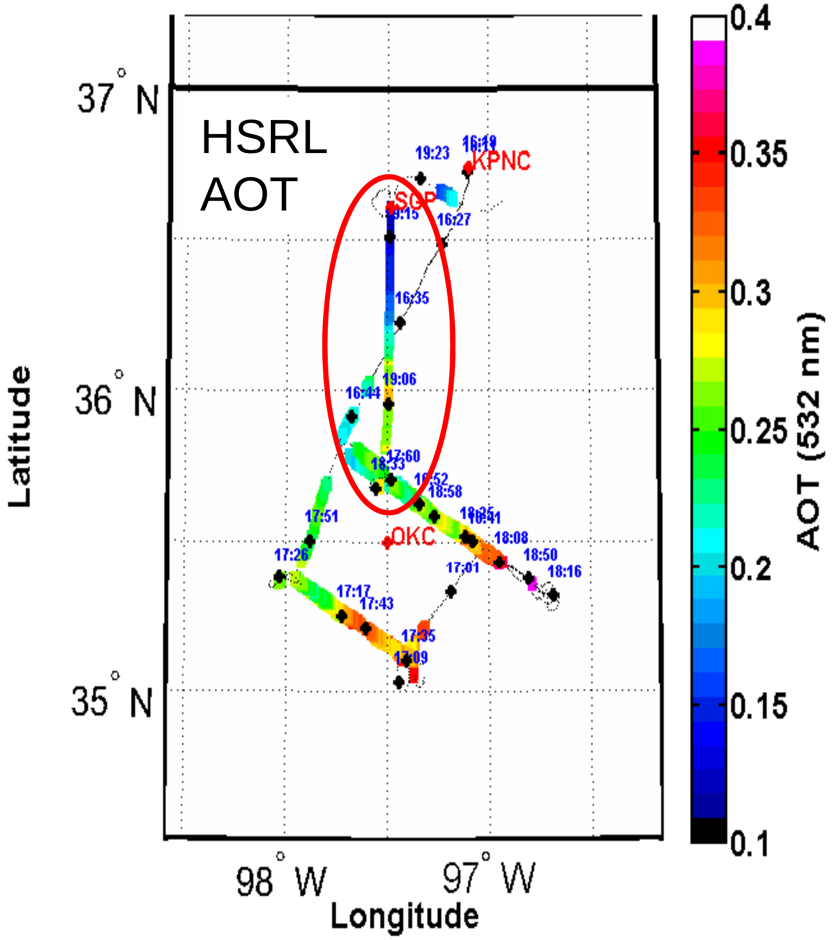
Water vapor and Aerosol Measurements of June 7 Dry Line



HSRL measurements show:

- high AOT ahead (SE) of dry line in OKC region
- large decrease in AOT behind (NW) of dry line

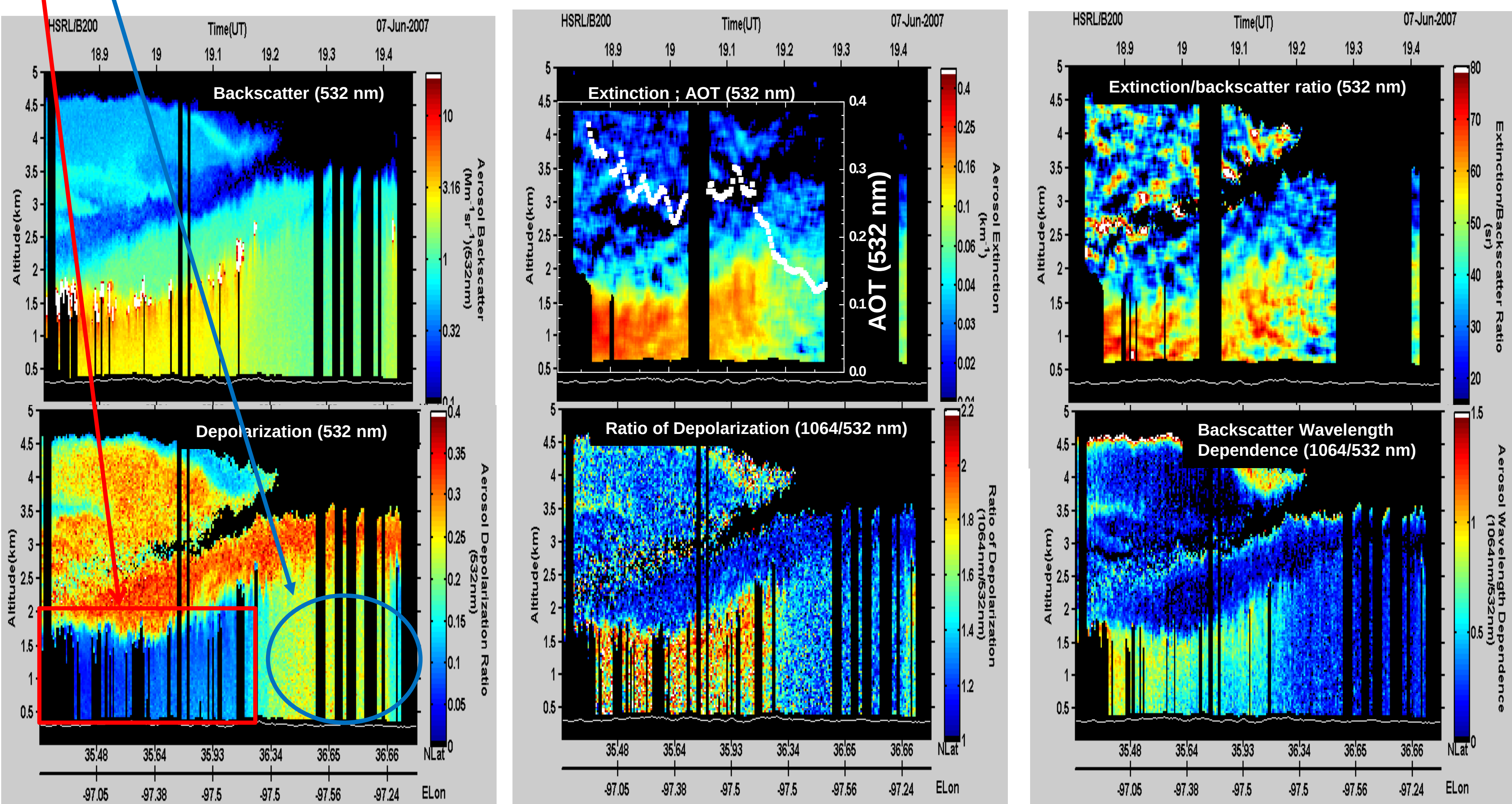




Characterizing the spatial distribution of aerosol type with HSRL measurements

LaRC Airborne HSRL Measurements over between OKC and SGP over dry line, June 7, 2007

- South, OKC, humid - high S_a, high WVD, low depolarization – urban, small, spherical
- North, SGP, dry - low S_a, low WVD, high depolarization – dustlike, large, nonspherical



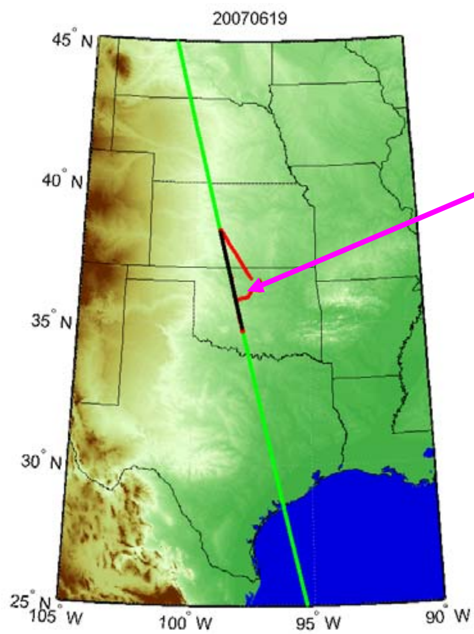
CALIPSO Validation – June 19

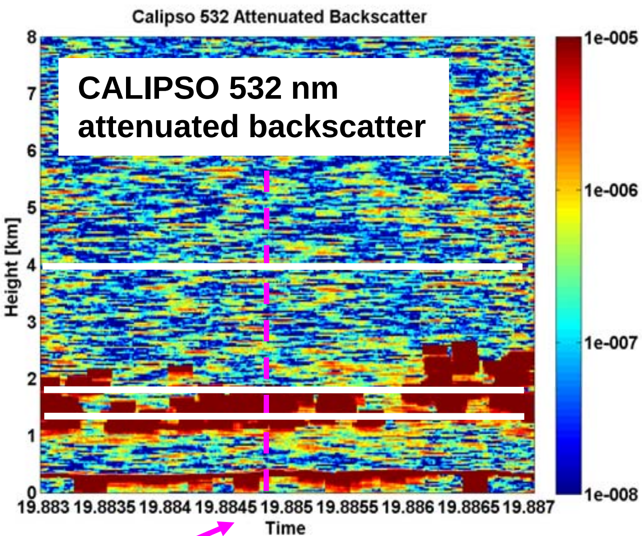
June 19 Multi-aircraft coordinated flight along CALIPSO track

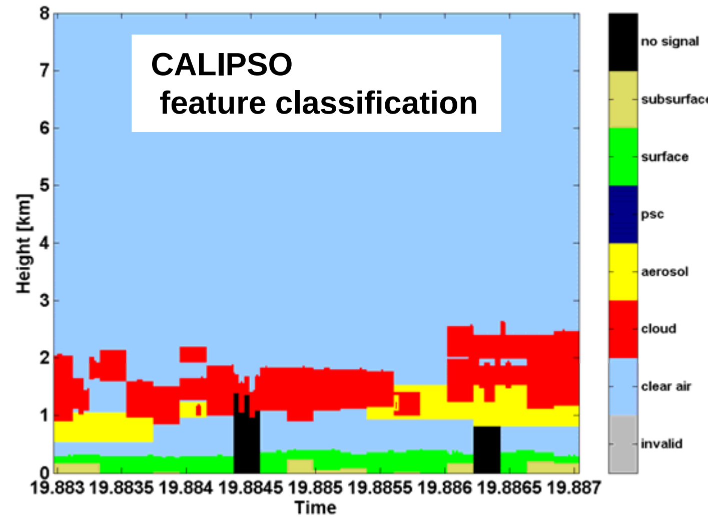
CIRPAS Twin Otter

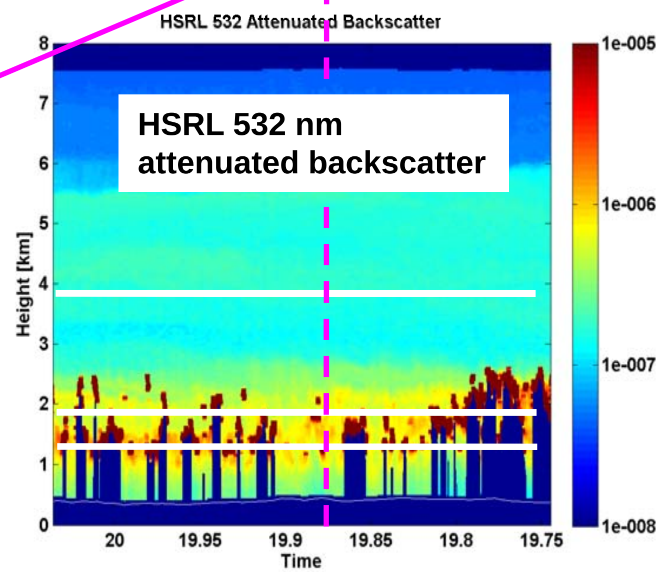
DOE G-1

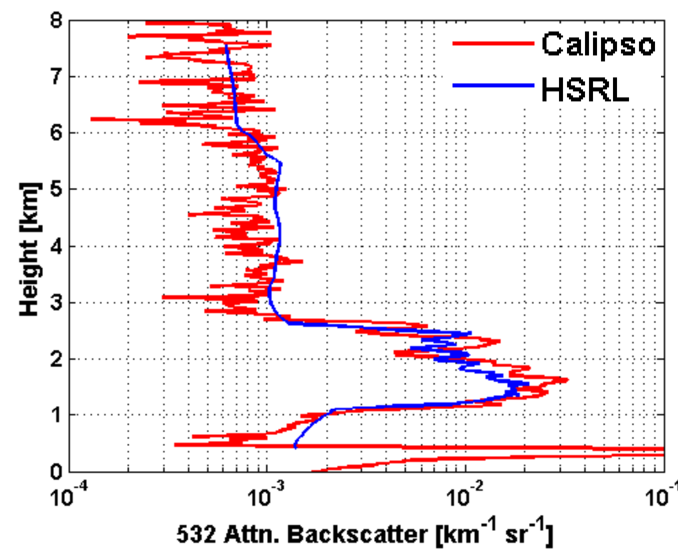
DOE IAP Cessna











CALIPSO Validation – June 19

- HSRL measurements indicate elevated layer of larger, nonspherical aerosols above smaller, spherical aerosols in PBL
- In situ measurements on DOE aircraft provide detailed measurements to assess CALIPSO and HSRL measurements

CIRPAS Twin Otter

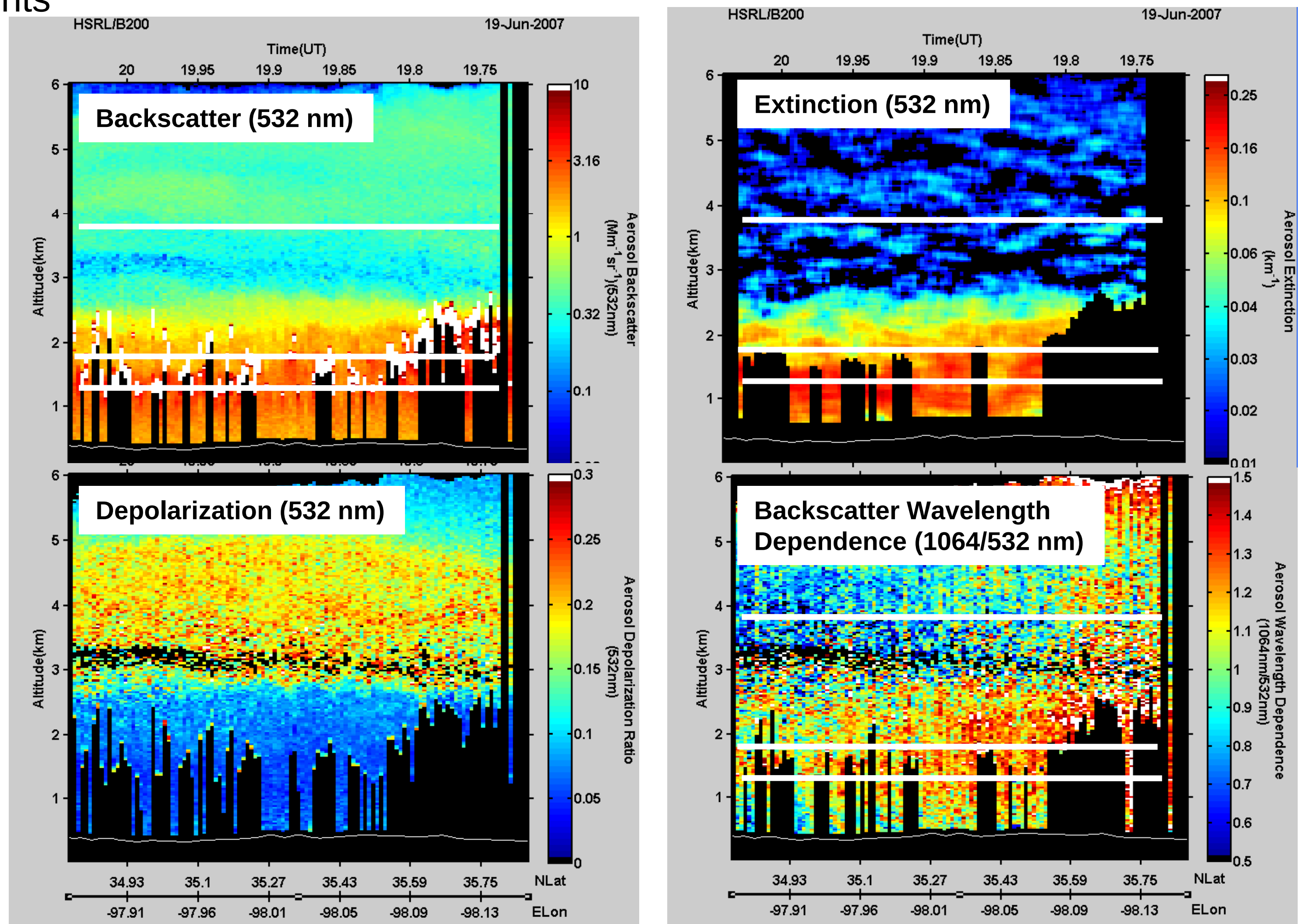
DOE G-1

DOE IAP Cessna

CIRPAS Twin Otter

DOE G-1

DOE IAP Cessna

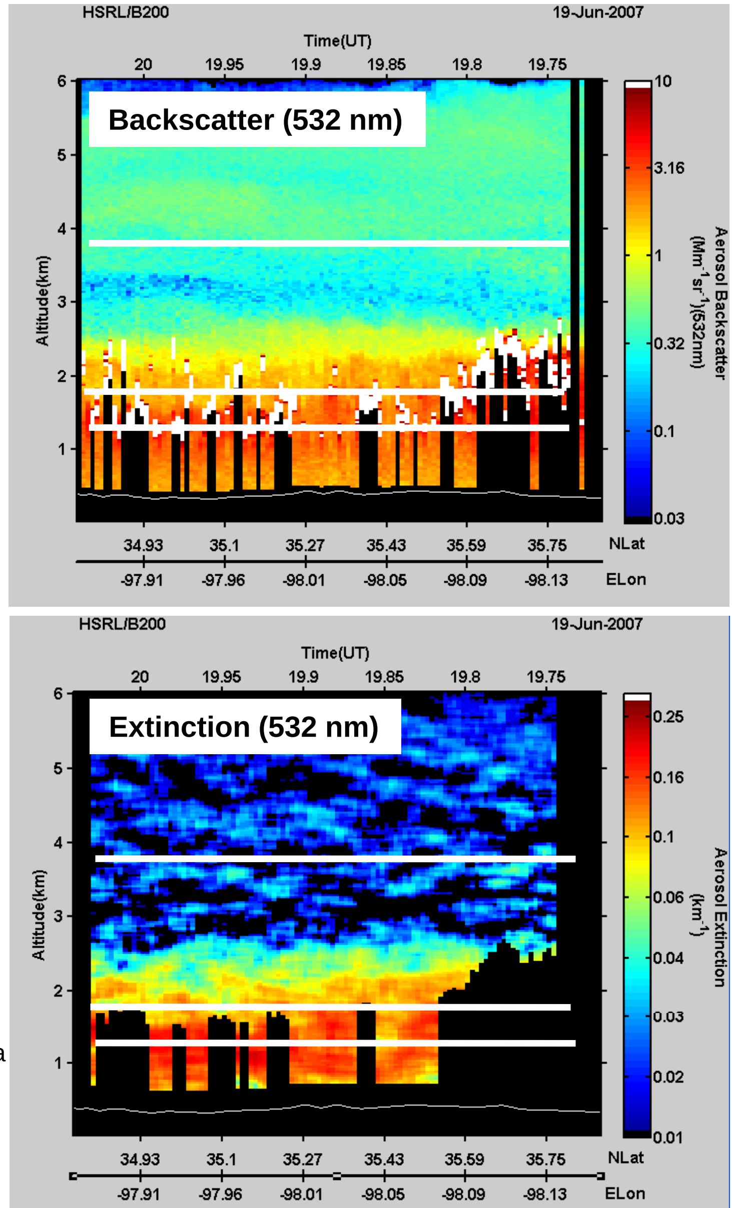


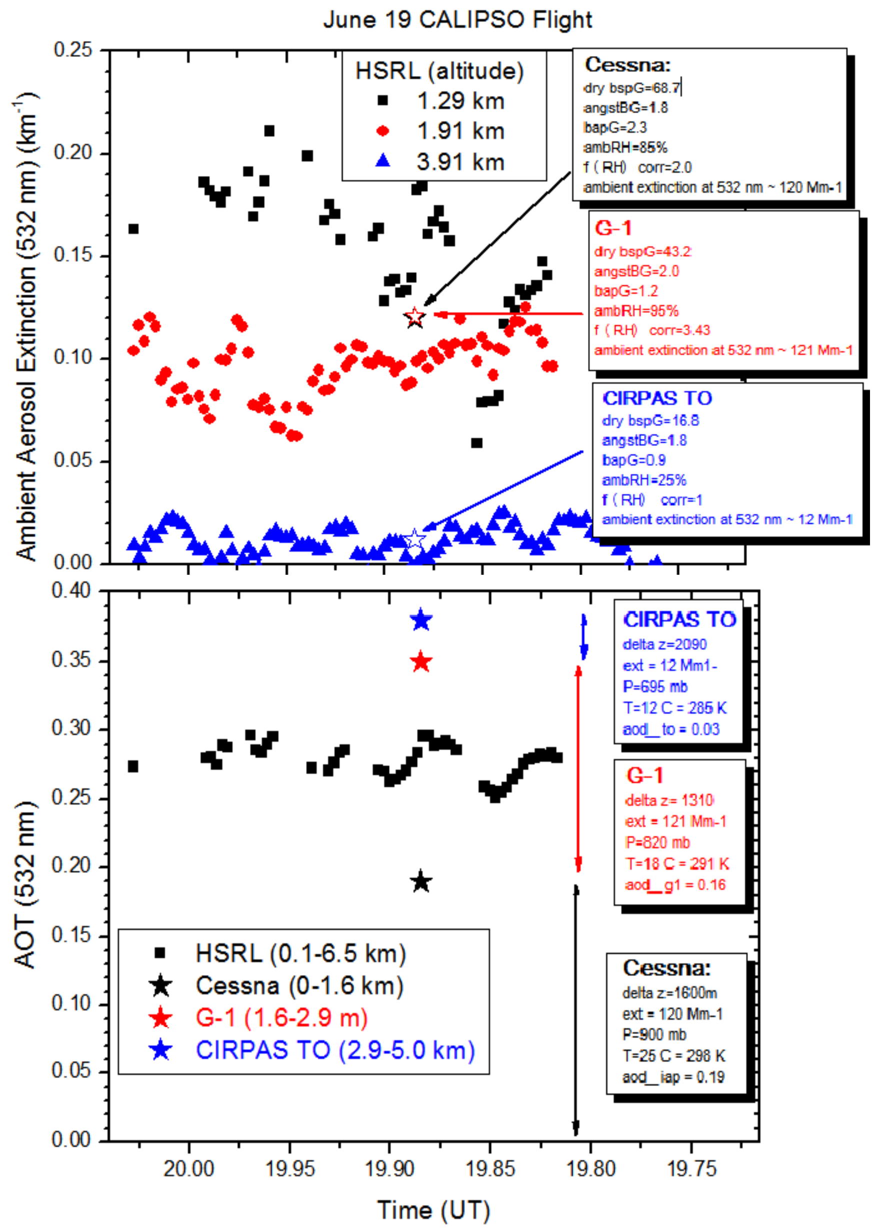
CALIPSO Validation – June 19

CIRPAS Twin Otter

DOE G-1

DOE IAP Cessna

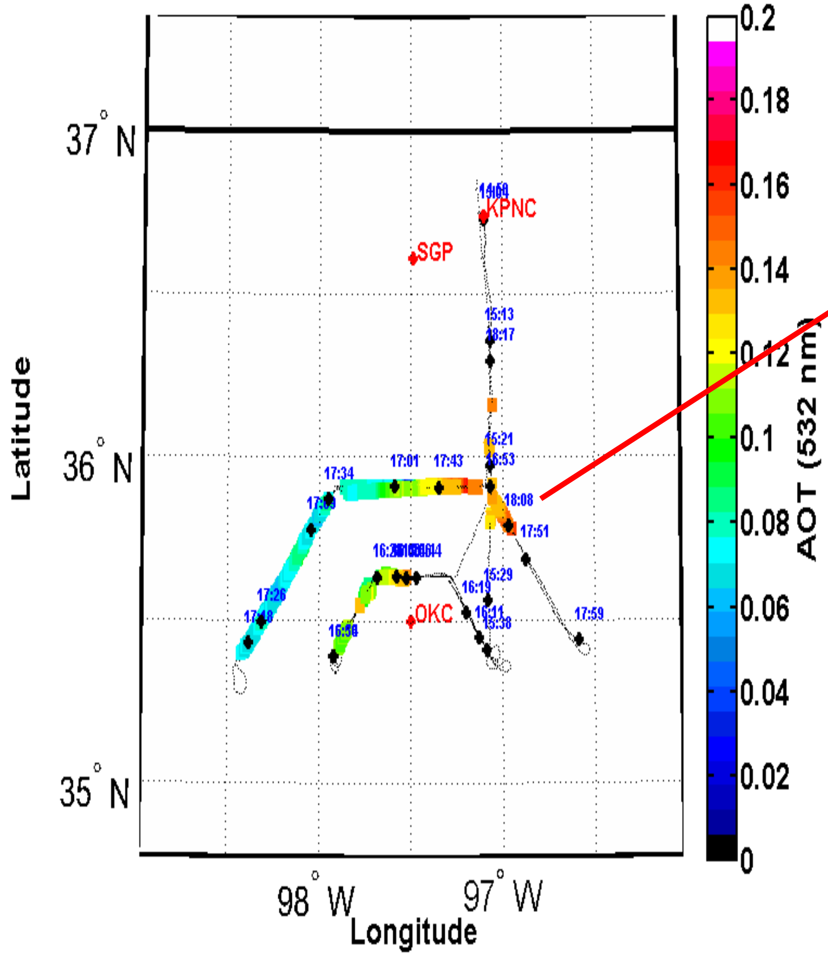




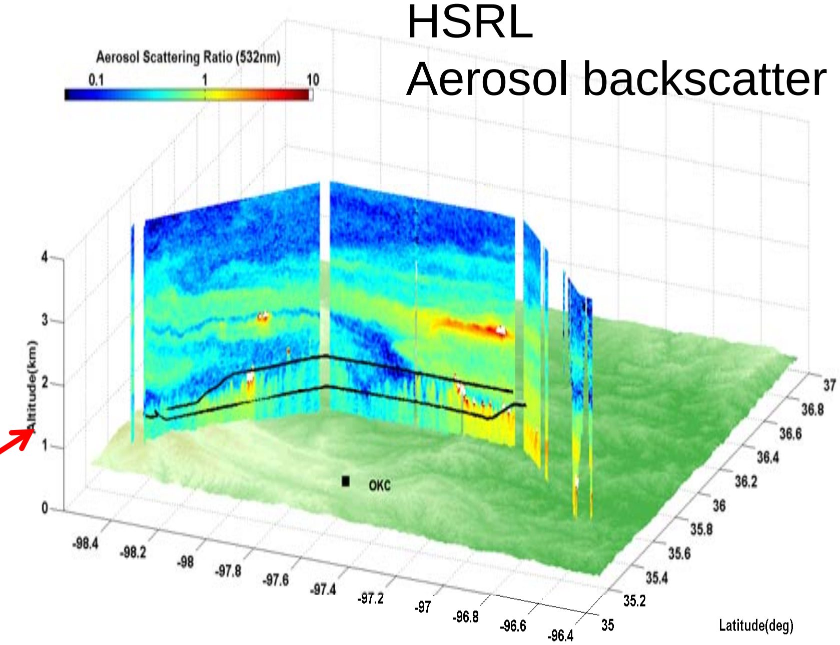
Example of CHAPS B200/G1 Coordinated Flight – June 24

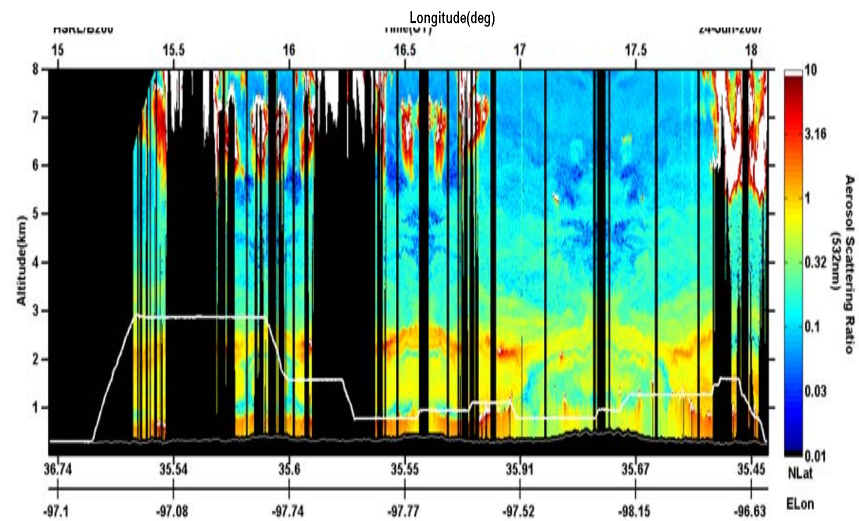
HSRL measurements :

- Provide vertical context for G-1 measurements
- Investigate changes in aerosol optical properties as a function of proximity to urban center (ex. upwind vs. downwind of OKC)



HSRL
Aerosol backscatter

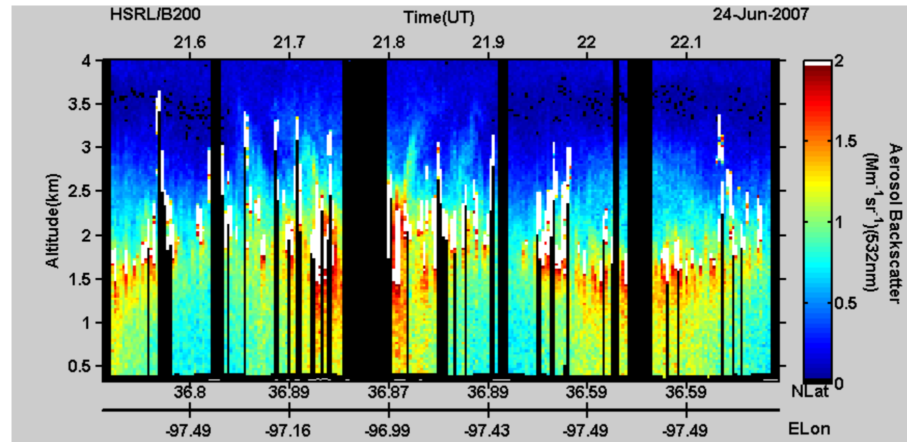


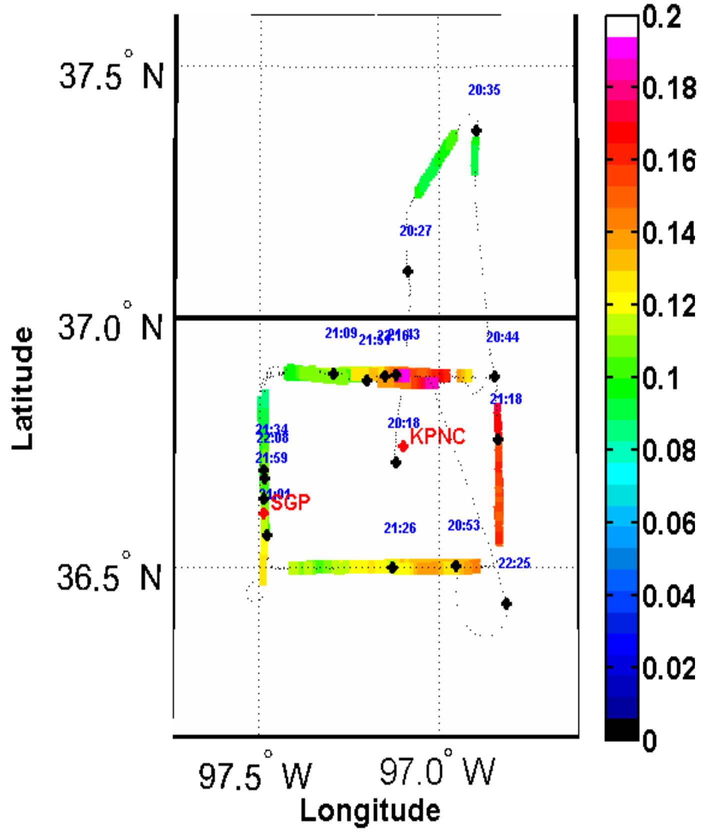


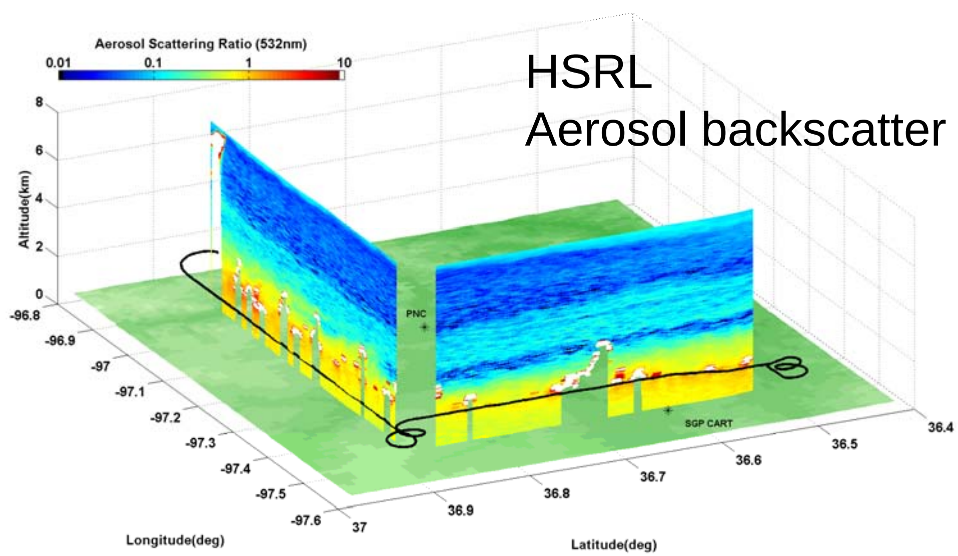
Example of CLASIC B200/CIRPAS Twin Otter Coordinated Flight – June 24

HSRL measurements :

- Provide vertical profiles of aerosol between and above cloud
- Provide vertical context for Twin Otter measurements
- Investigate changes in aerosol optical properties as a function of distance from clouds





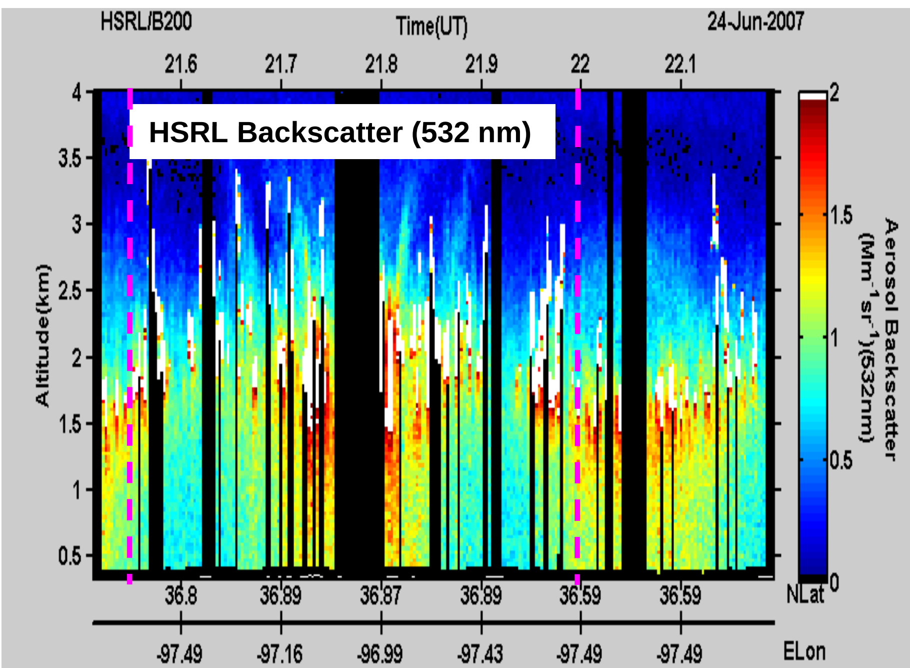


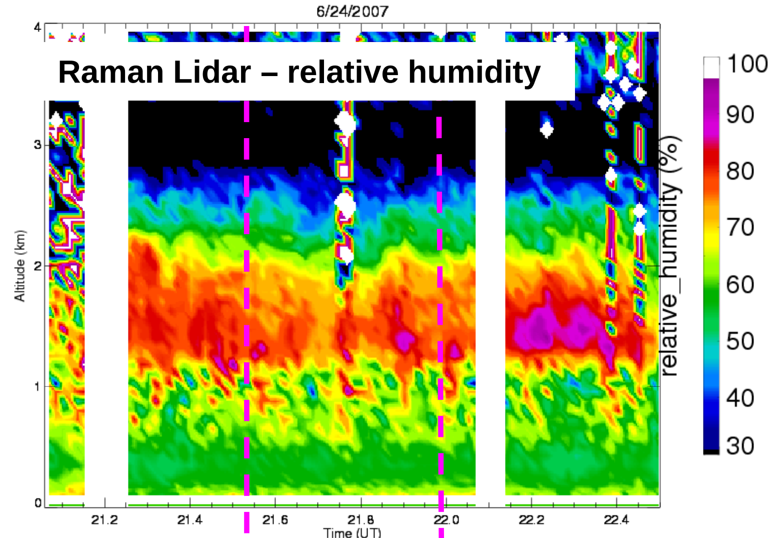
HSRL
Aerosol backscatter

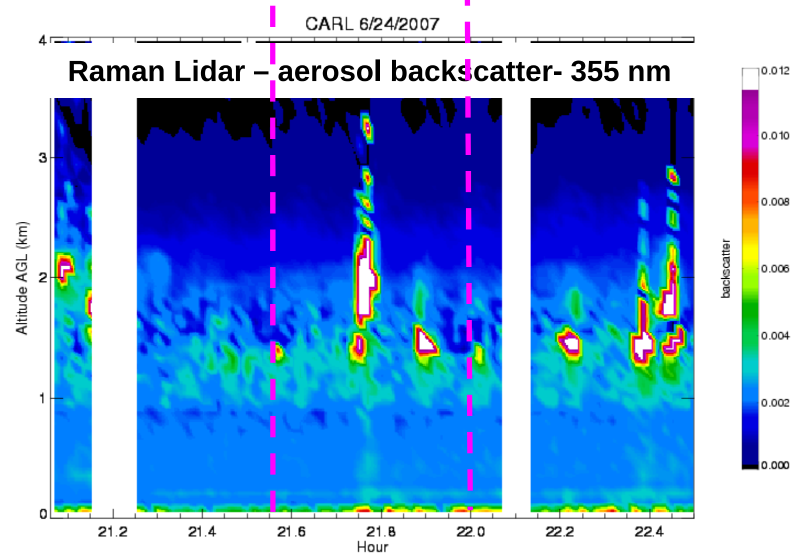
Example of measurements over SGP Raman Lidar - June 24

HSRL measurements acquired over DOE ARM SGP Raman lidar to investigate:

- Advanced, multi-wavelength lidar retrievals
- Investigate changes in aerosol optical properties as a function of
  - RH
  - Distance from clouds

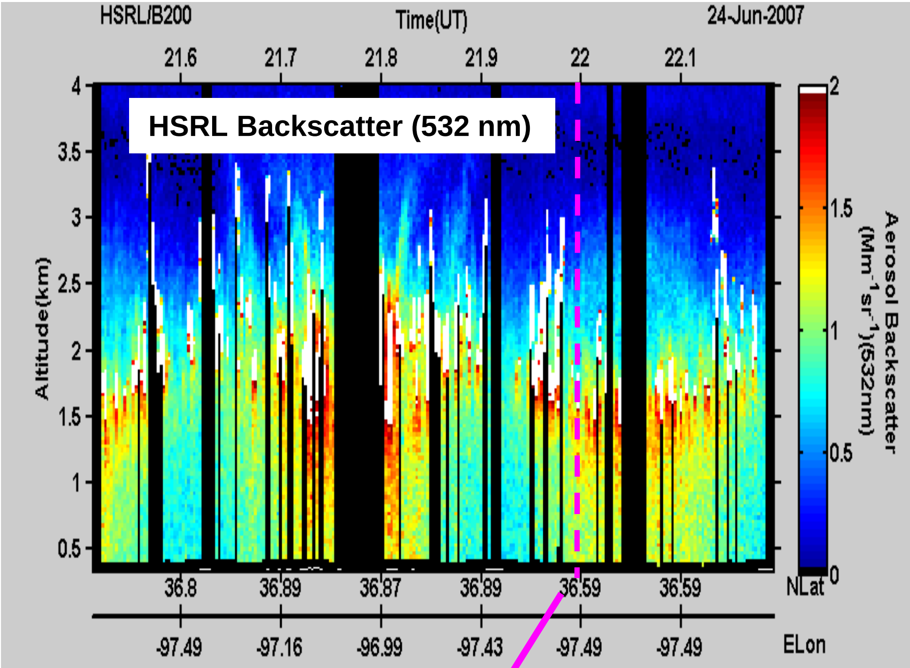


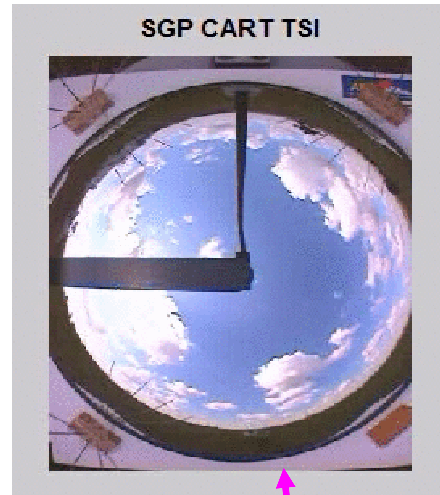




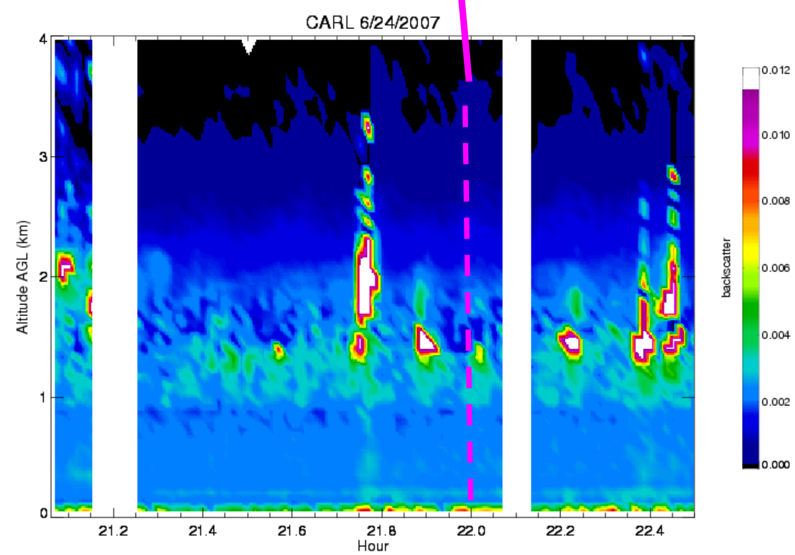
Example of measurements over SGP HSRL / Raman Lidar - June 24

Investigate changes in aerosol optical properties as a function of distance from clouds

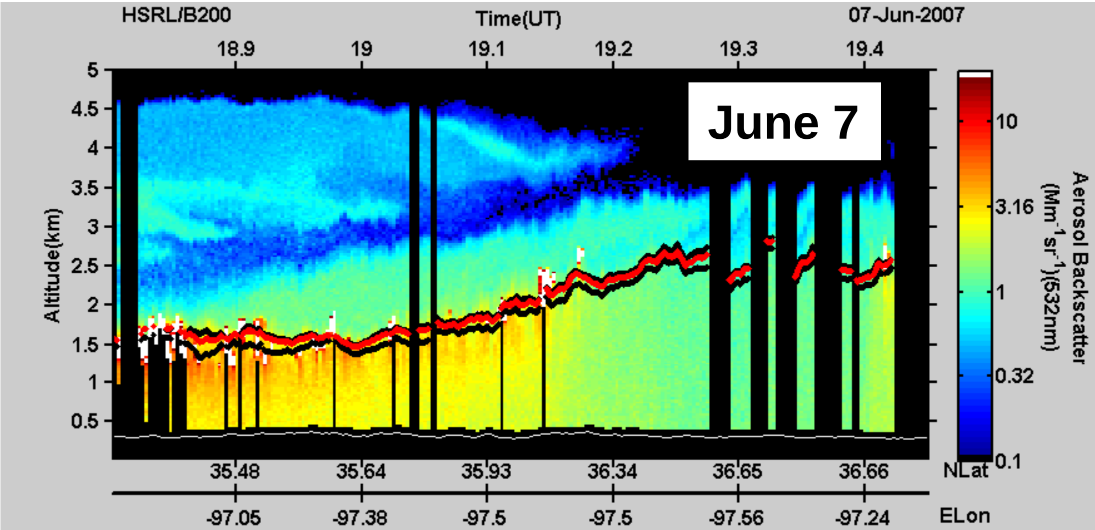


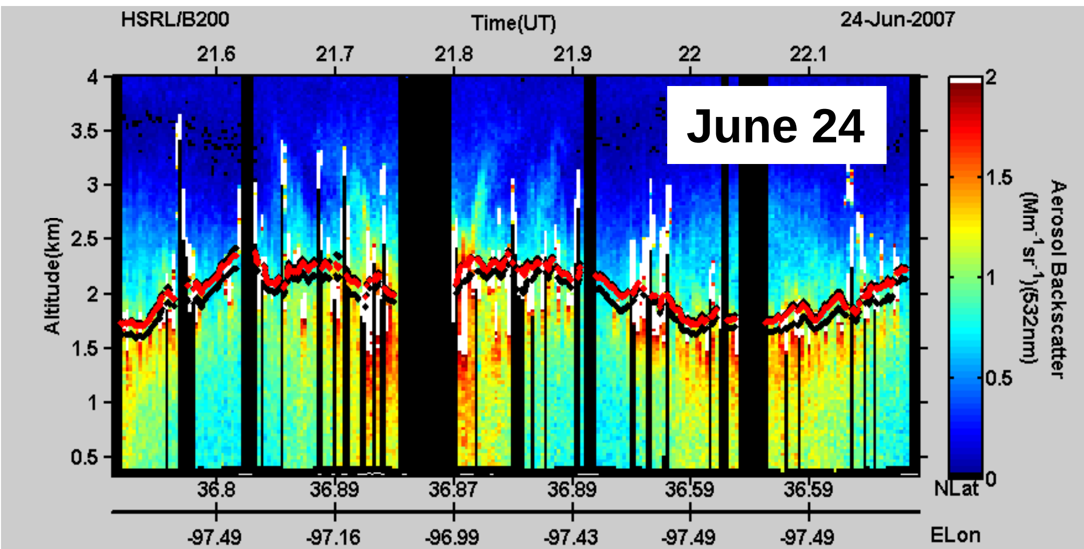


Raman Lidar – aerosol backscatter- 355 nm



HSRL PBL height retrievals





An automated technique that uses a Haar wavelet covariance transform with multiple wavelet dilations (Brooks, 2003) was used to determine:

- PBL height
- Upper and lower limits of the backscatter transition (i.e. entrainment) zone

Summary and Plans for CHAPS/CLASIC

SGP Raman Lidar

- Algorithms are being modified to process updated data
- Investigations underway to examine variability of aerosols near clouds in "Twilight Zone"

NASA Langley airborne HSRL

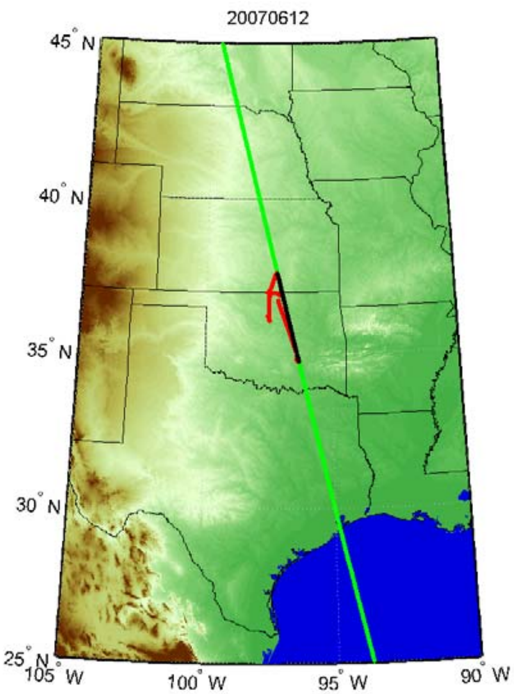
- Investigations planned or underway to
  - Study changes in aerosol optical properties as a function of:
    - Distance from clouds
    - Proximity to urban center (ex. upwind vs. downwind of OKC)
- Provide cloud top and PBL heights and AOT within PBL
- Locate horizontal extent of OKC plume
- Infer aerosol types and attribute AOT to aerosol types
- Validate CALIOP lidar on the CALIPSO satellite
- Assess aerosol measurements of existing passive satellite sensors
  - MODIS, MISR, PARASOL
- Examine feasibility of advanced, multi-wavelength lidar retrievals

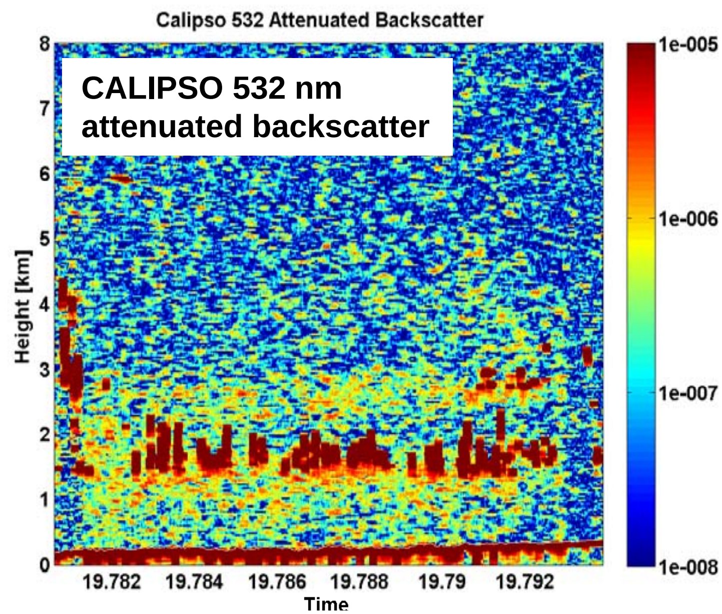
Preliminary HSRL data and images are now available to CLASIC/CHAPS investigators via ftp to ARM IOP archive

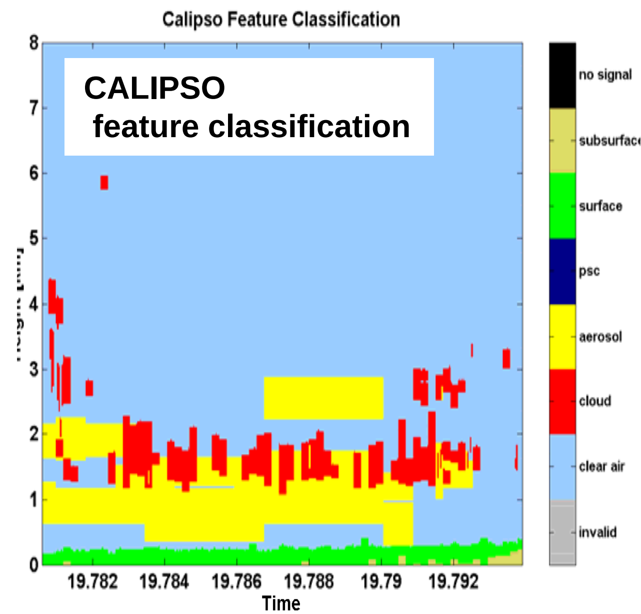
Backup Slides

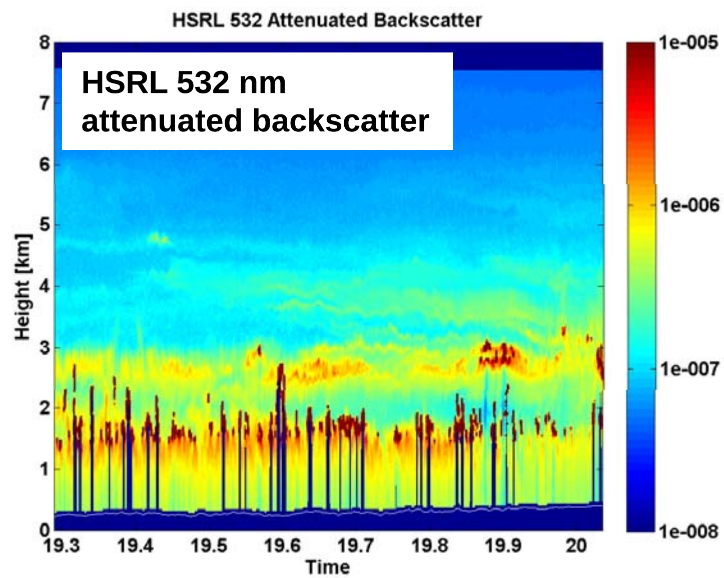
CALIPSO Validation – June 12

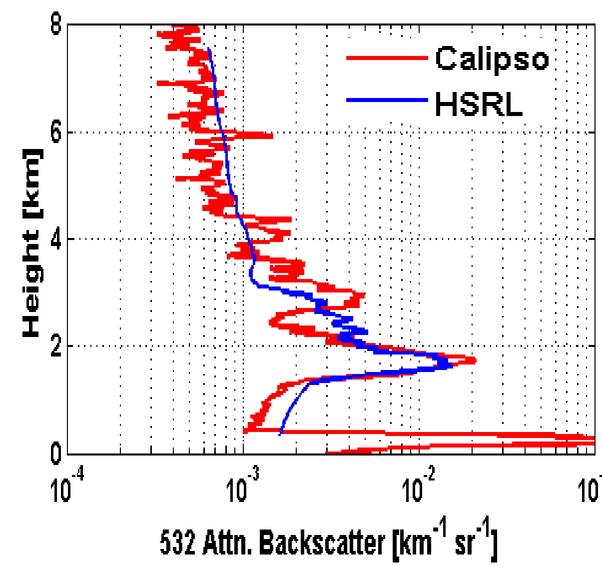
June 12 Multi-aircraft coordinated flight along CALIPSO track

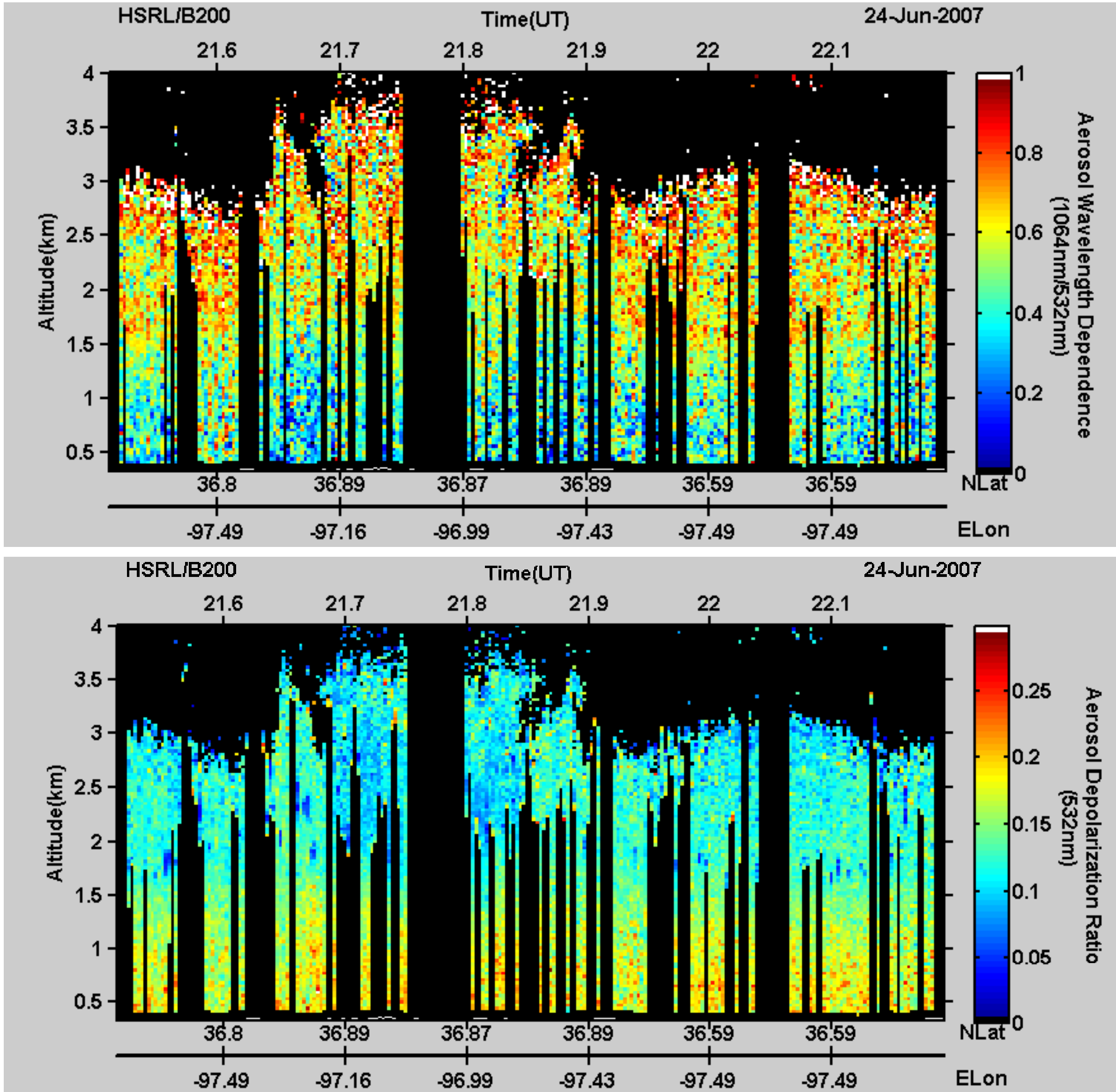




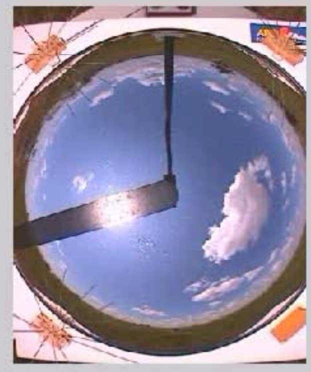







HSRL/B200
Time(UT)
24-Jun-2007
21.6
21.7
21.8
21.9
22
22.1
Altitude(km)
Aerosol Wavelength Dependence (1064nm/532nm)
36.8
36.89
36.87
36.89
36.59
36.59
NLat
-97.49
-97.16
-96.99
-97.43
-97.49
-97.49
ELon
HSRL/B200
Time(UT)
24-Jun-2007
Altitude(km)
Aerosol Depolarization Ratio (532nm)
NLat
ELon

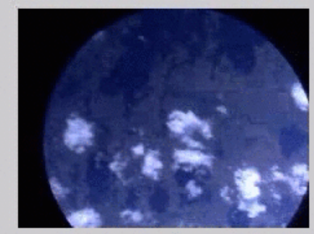
SGP CART TSI



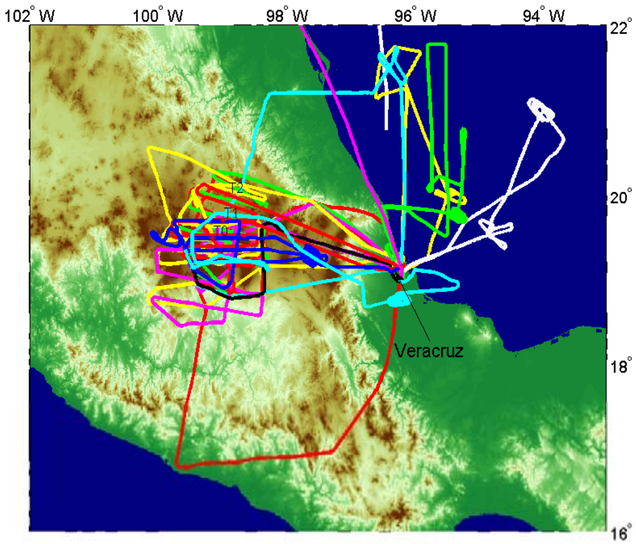
HSRL UTC

SGP CART TSI

HSRL 20070624 220000 UTC

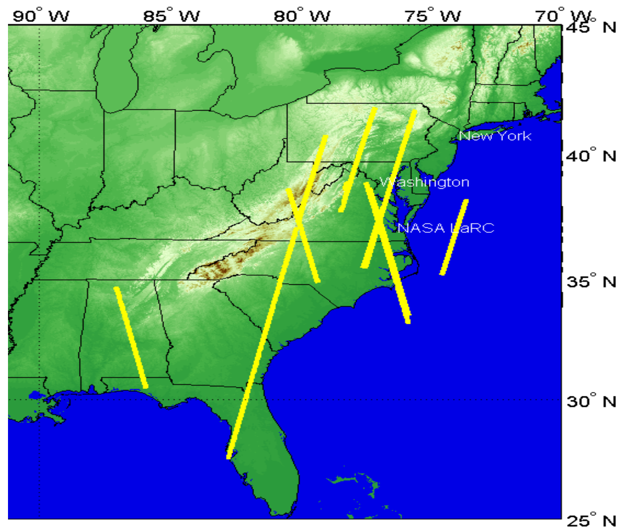


Field Missions in 2006



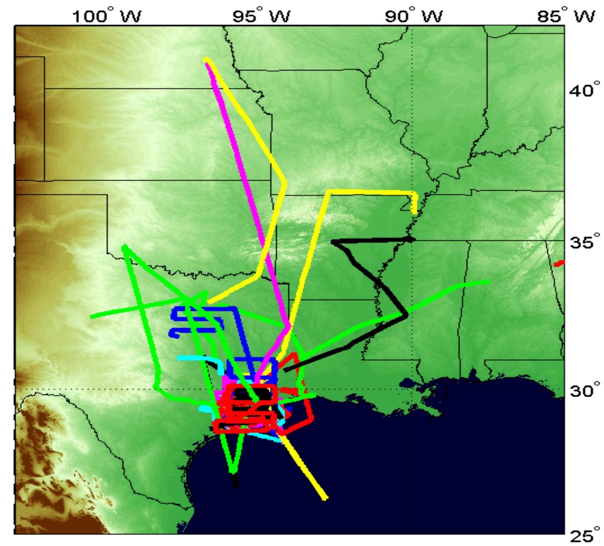
MAXMex/MILAGRO/INTEX-B
DOE-NSF-NASA-Mexico
March 1-30

15 science flights, 55 flight hr
- 5 flights with J-31
- 6 flights with G-1
- 4 flights with C-130
- 5 MISR coincidences
- 10 MODIS coincidences



CALIPSO Validation
June 14 – Aug 10

10 CALIPSO validation flights
- 6 flights in “Early Phase” starting immediately after CALIPSO configured for science ops (14-30 June)
- 4 flights as part of CCVEX (July-Aug)



TexAQS II/GoMACCS
NOAA-DOE-NASA
Aug 27 – Sep 29

22 science flights, 90 flight hr
- 7 flights with NOAA WP-3
- 6 flights with NOAA Twin Otter
- 7 flights with CIRPAS Twin Otter
- 2 flights over the RHB
- 4 MISR LM coincidences
- 14 MODIS coincidences

Algorithm Modifications

Computation of "final" CARL aerosol extinction and water vapor profiles for ALIVE required extensive modifications to CARL algorithms and software to account for several changes/upgrades that were made to the CARL hardware.

- **Addition of new Licel detection electronics requires:**
  - **combining analog-to-digital mode (A/D) and photon counting (PC) mode data via "glue coefficients". Algorithms to determine glue coefficients were developed to:**
    - **determine appropriate range of PC data rate**
    - **remove cloud contamination much earlier in processing**
    - **remove long term trends**
    - **account for diurnal variation**
  - **determining appropriate PC count threshold values**

Several other changes were made to aerosol and water vapor algorithms…

- **water vapor calibration**
- **aerosol and water vapor overlap functions for low altitude measurements**
- **cloud screening**

Since accurate and repeatable CARL measurements rely on resolution of these issues, we devoted considerable time to developing these CARL algorithm modifications and testing via comparisons with previous results and other datasets.

Objectives for CHAPS

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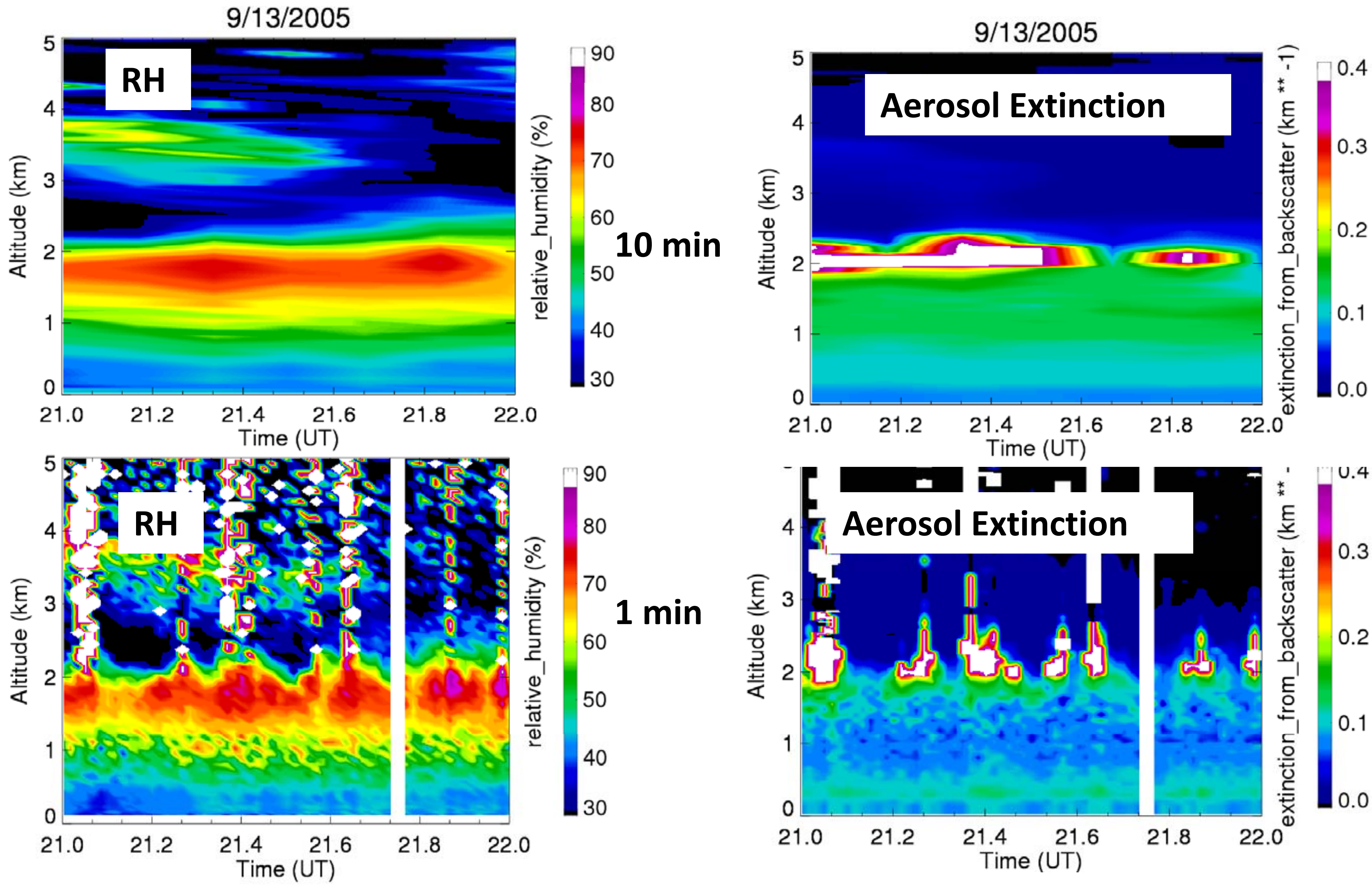
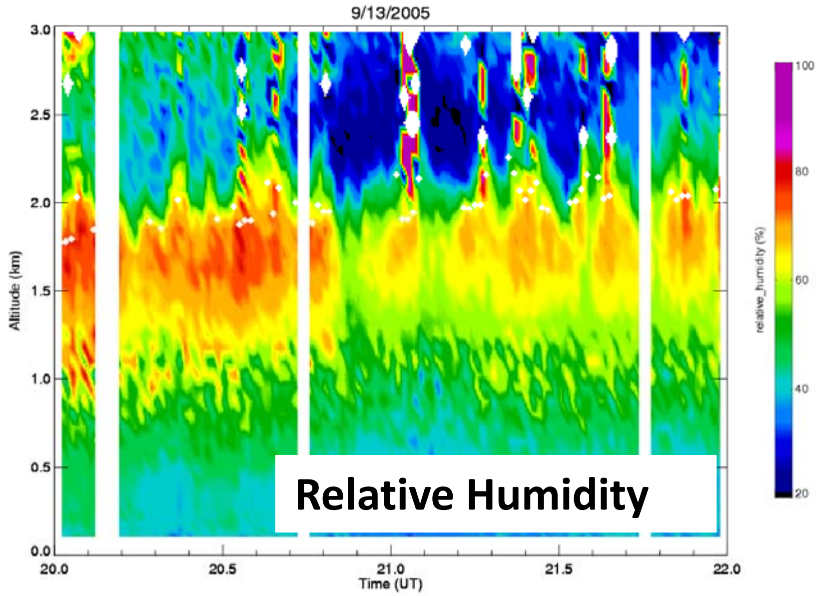
- Acquire data over DOE ARM SGP Raman lidar to investigate advanced, multi-wavelength lidar retrievals

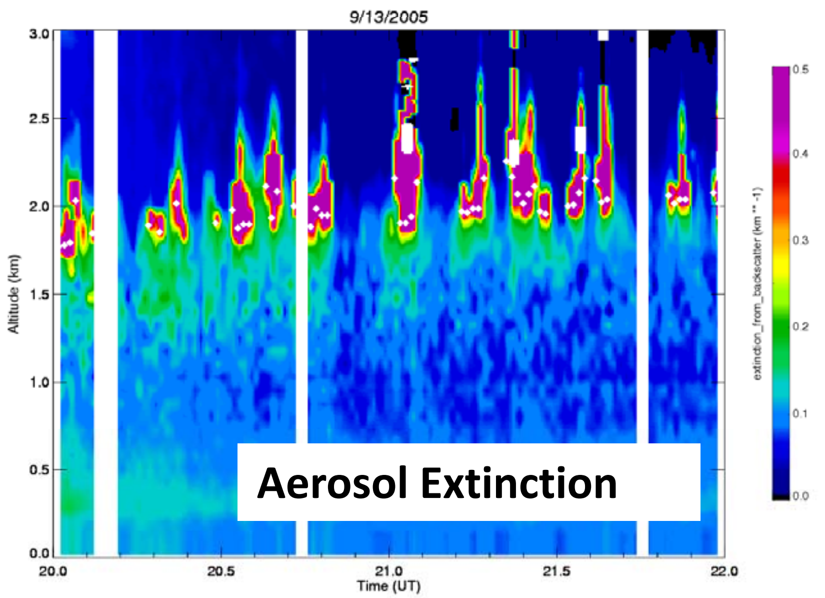
CARL High Temporal Resolution Data

Increased temporal resolution should permit more detailed analyses near clouds



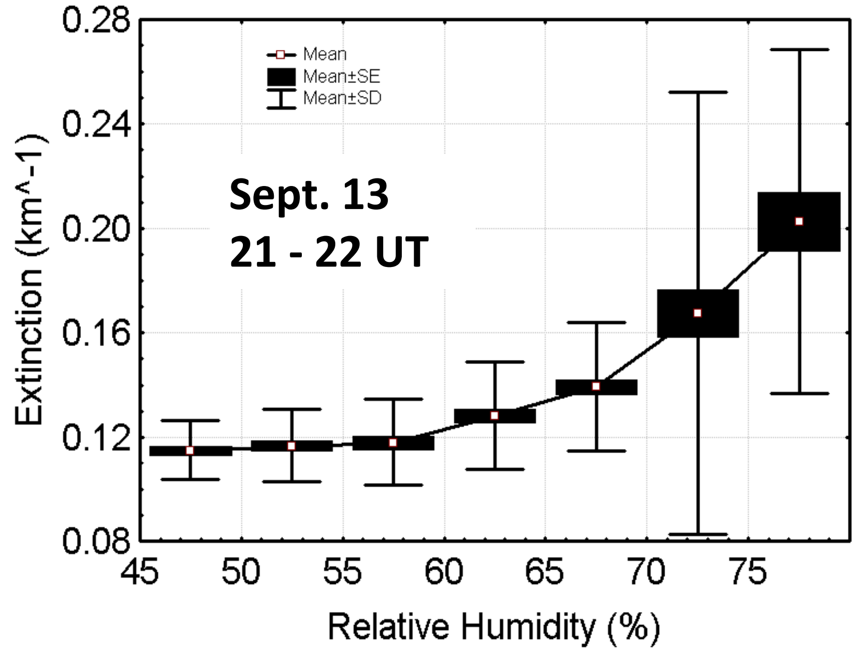
CARL observations of aerosol hygroscopicity





Increased temporal resolution permit more detailed studies of aerosol hygroscopicity

Aerosol Humidification Factor (f(RH))



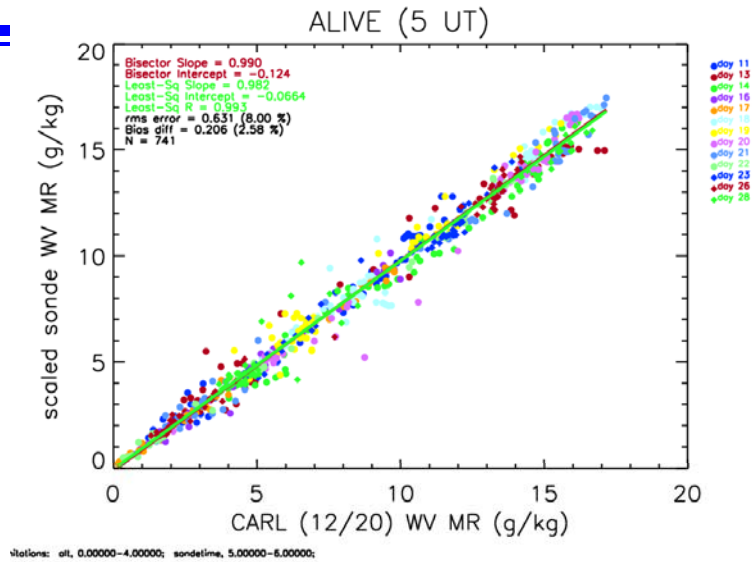
f(RH) derived from CARL measurements between 21-22 UT on Sept. 13, 2005

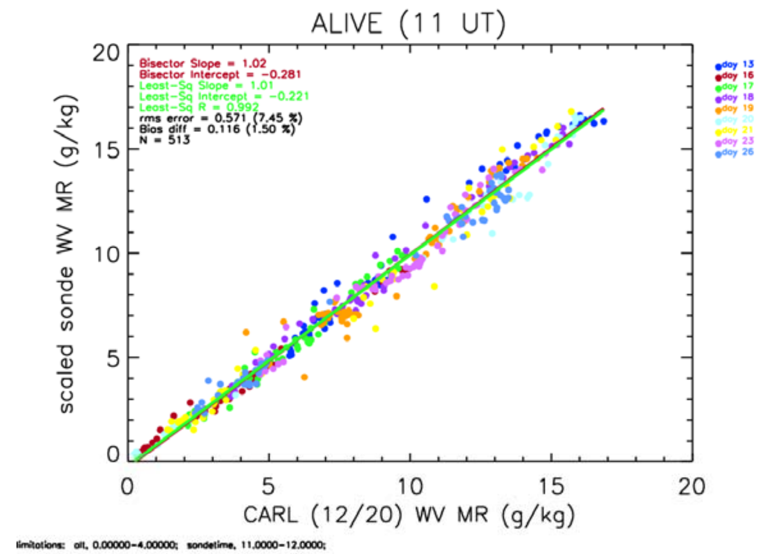
CARL vs. MWR-scaled sonde (diurnal)

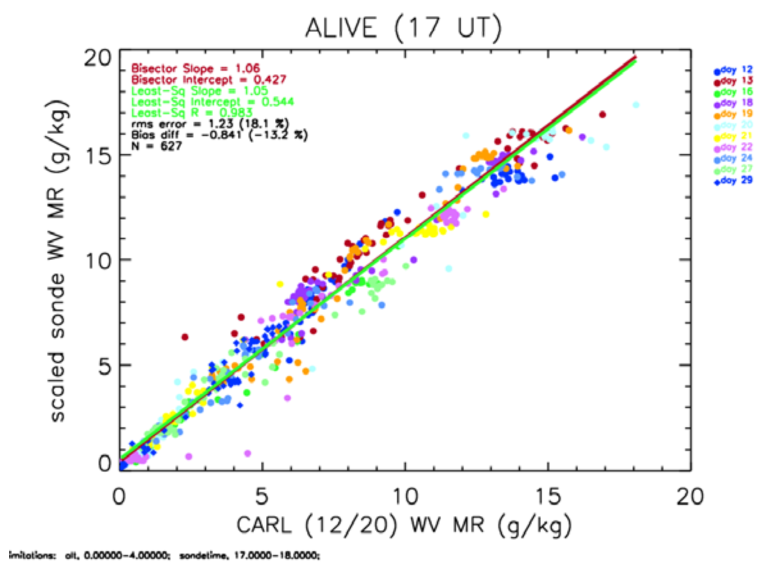
Comparison depends on time of day

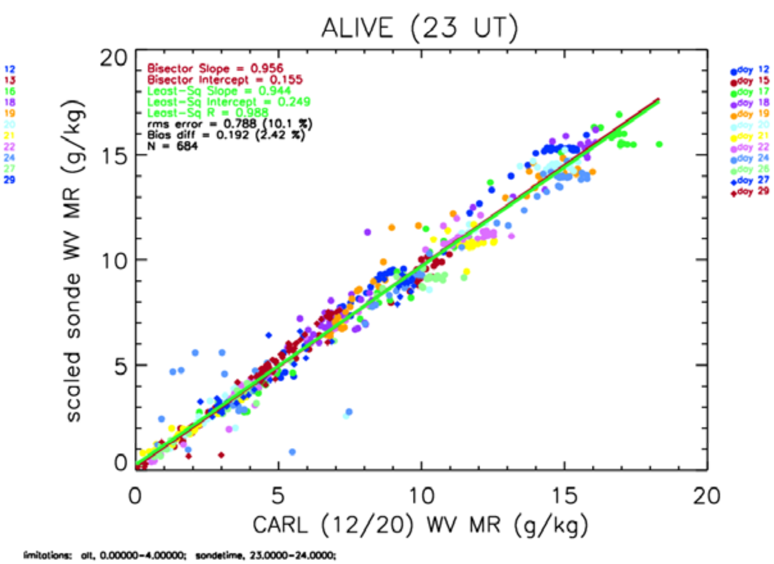
Bias differences (CARL-sonde)

5 UT	**3 %**
11 UT	**2 %**
17 UT	**-13 %**
23 UT	**2 %**



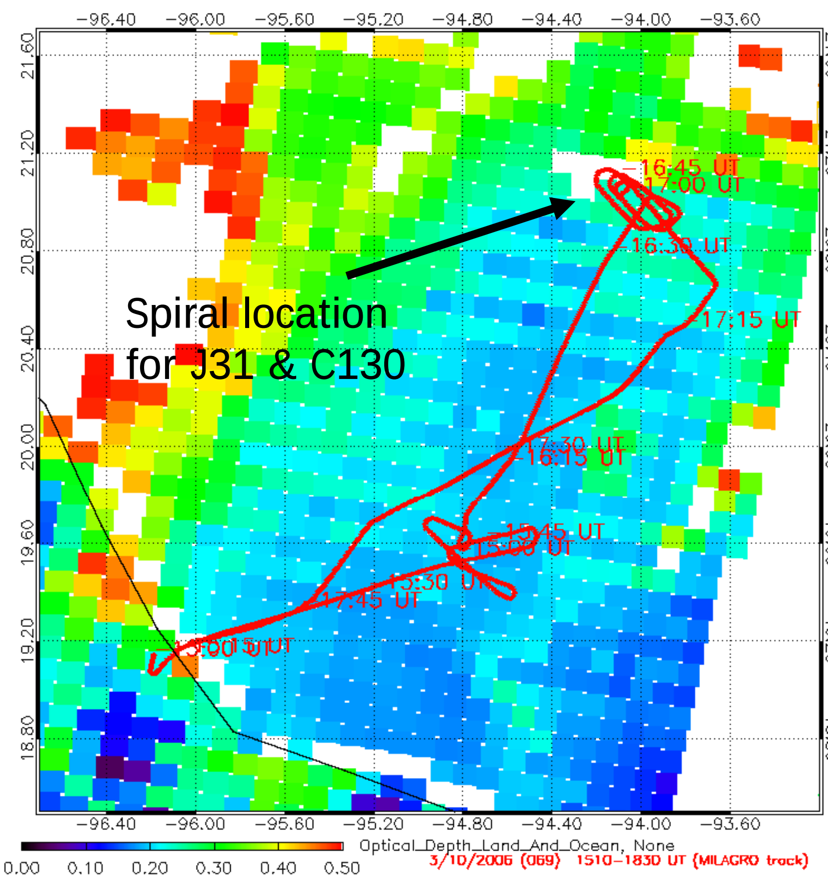




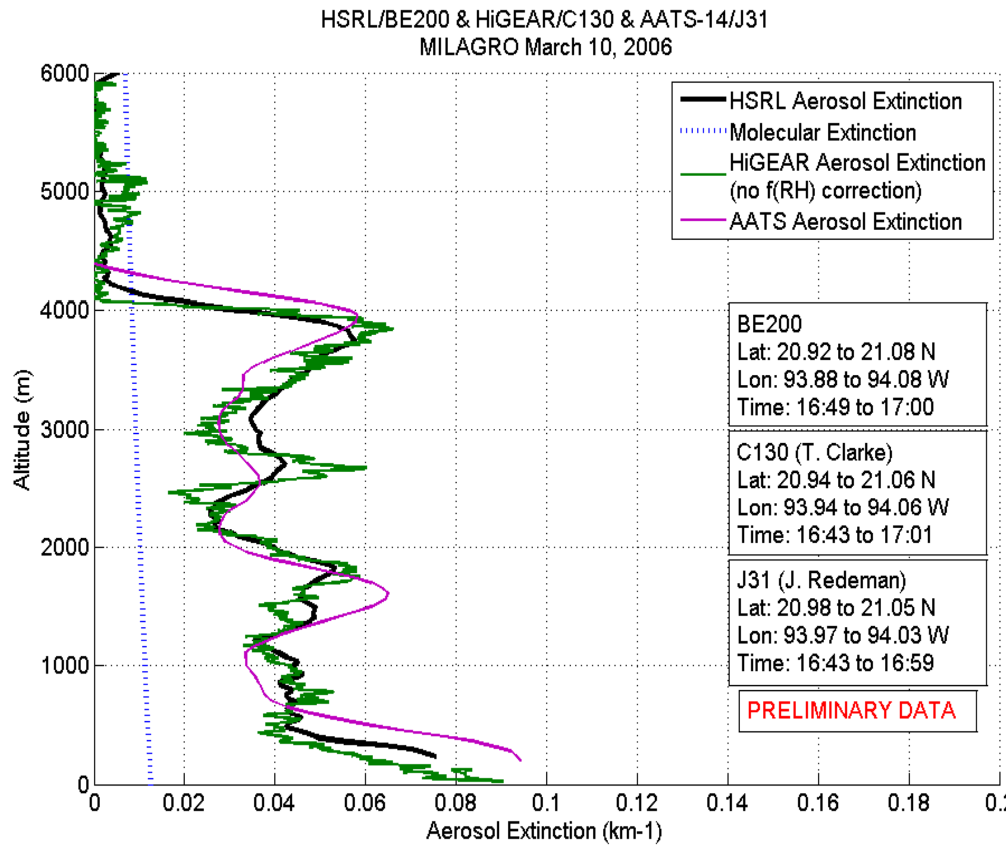


Extinction Profile Comparison from MILAGRO: HSRL, AATS14, and HIGEAR

MODIS Optical Depth



Aerosol Extinction



- Several flights coincident with MODIS (10) and MISR (5) for retrieval studies
- Coordinated flights with J-31 and C-130 for comparison of data products (aerosol extinction) and retrieval studies (e.g., combined HSRL and RSP photo-polarimeter)

Disadvantage of backscatter lidar: 1 equation, 2 unknowns

Measured Signal — Range from Instrument — Calibration Constant — Molecular Backscatter Coefficient — Molecular Extinction Coefficient ← Known

Determined from measured signals and meteorological data

$$P(r) = \frac{C}{r^2}\left[\beta_m(r) + \beta_p(r)\right]\exp\left\{-2\int_0^r\left[\sigma_m(r') + \sigma_p(r')\right]dr'\right\}$$

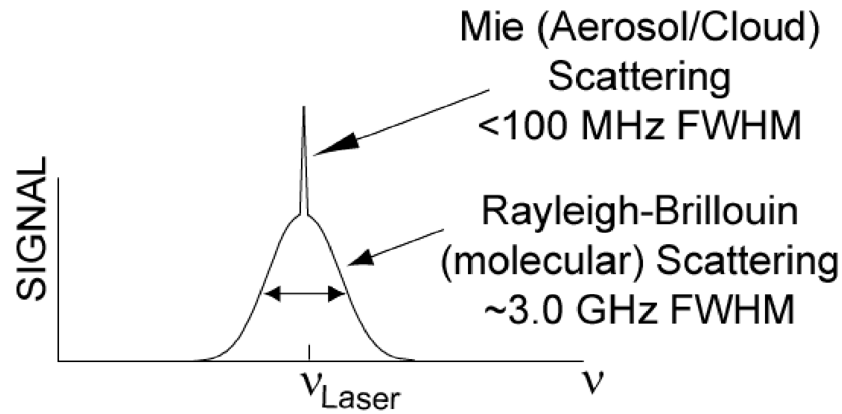
Particulate Backscatter Coefficient — Particulate Extinction Coefficient ← Retrieved Parameters

$$\frac{\sigma_p(r)}{\beta_p(r)} = S_p$$

← Assumption of value for extinction-to-backscatter (S_p) ratio required for backscatter lidar retrieval

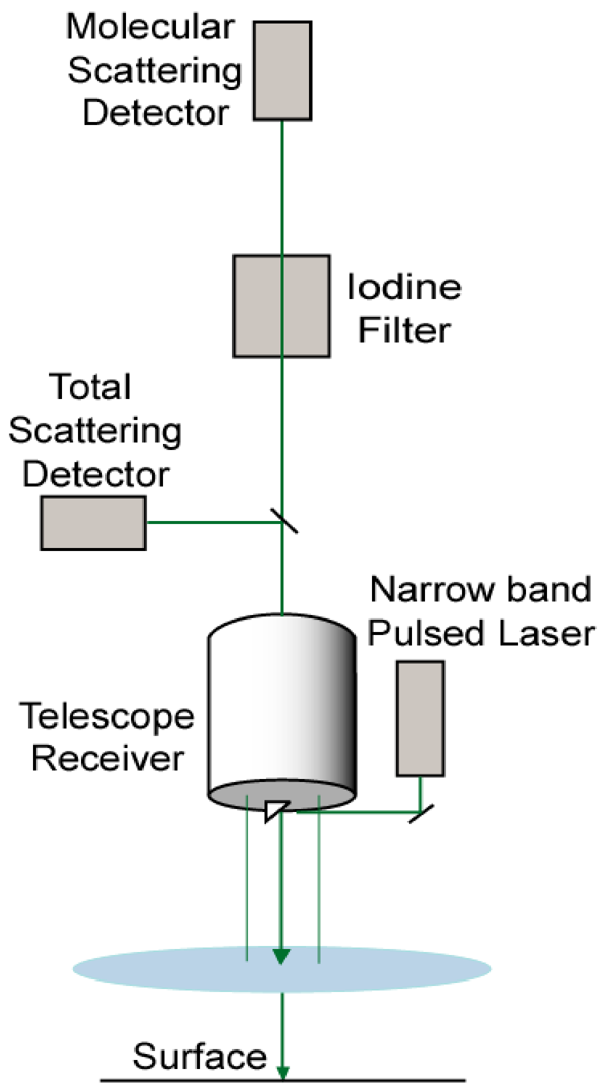
High Spectral Resolution Lidar (HSRL)

HSRL relies on spectral separation of aerosol and molecular backscatter in lidar receiver.

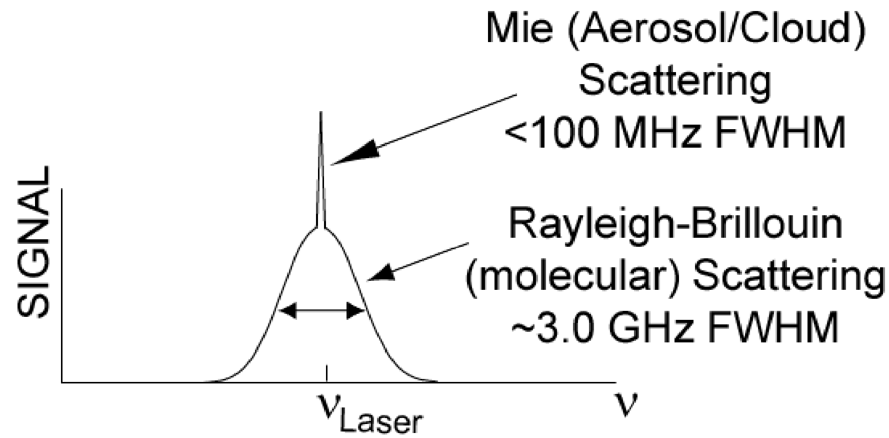


- HSRL independently measures aerosol and molecular backscatter
  - Can be internally calibrated
  - No correction for extinction required to derive backscatter profiles
  - More accurate aerosol layer top/base heights
- HSRL enables independent estimates of aerosol backscatter and extinction
  - Extinction and backscatter estimates require no S_a assumptions
  - Provide *intensive* optical data from which to infer aerosol type
  - Measurements of extinction at 2 wavelengths and backscatter at 3 wavelengths enables retrieval of aerosol microphysical parameters and concentration

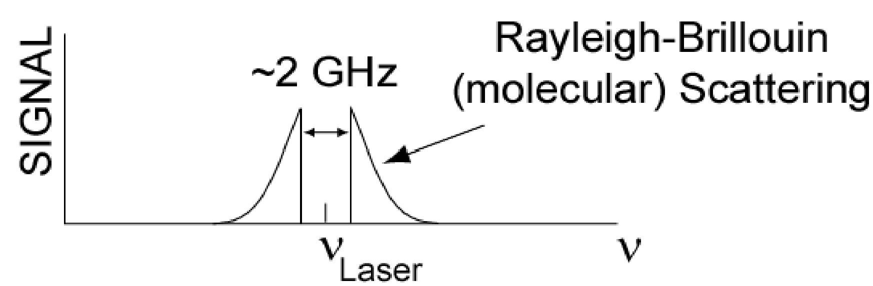
HSRL measurement concept



Atmospheric Scattering



Effect of Iodine Vapor Notch Filter



HSRL: 2 equations, 2 unknowns

Measured Signal on Molecular Scatter (MS) Channel:

$$P_{MS}(r) = \frac{C_{MS}}{r^2} F(r)\, \beta_m(r) \exp\left\{-2\int_0^r \left[\sigma_m(r') + \underline{\sigma_p(r')}\right] dr'\right\}$$

Particulate Extinction

Measured Signal on Total Scatter (TS) Channel:

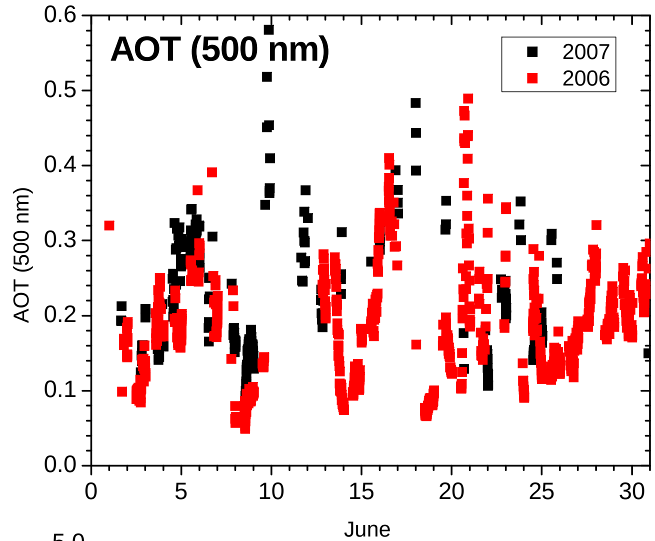
$$P_{TS}(r) = \frac{C_{TS}}{r^2}\left[\beta_m(r) + \underline{\beta_p(r)}\right] \exp\left\{-2\int_0^r \left[\sigma_m(r') + \sigma_p(r')\right] dr'\right\}$$

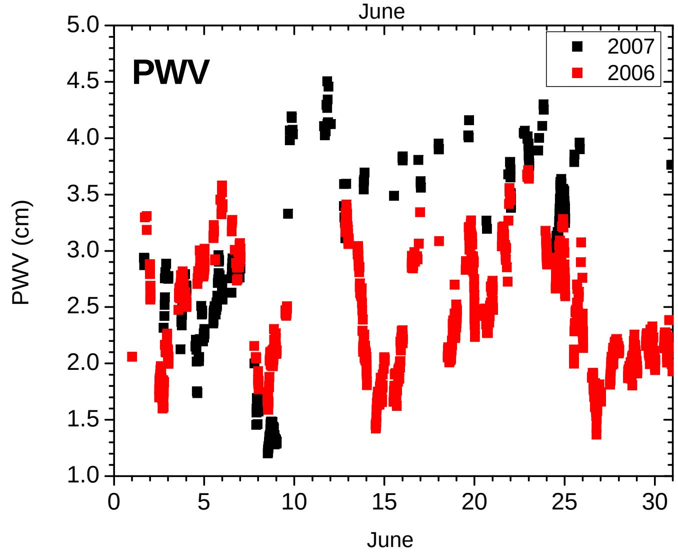
$$\frac{\sigma_p(r)}{\beta_p(r)} = \underline{S_p}$$

Particulate Backscatter

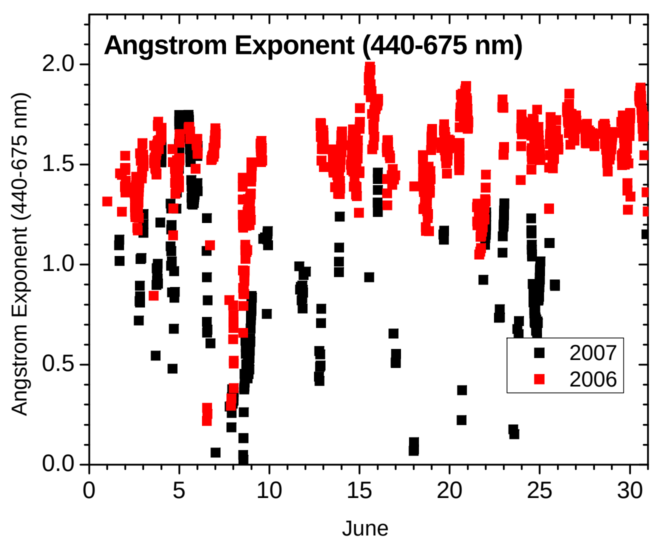
Retrieved Parameters

Ext/Backscatter

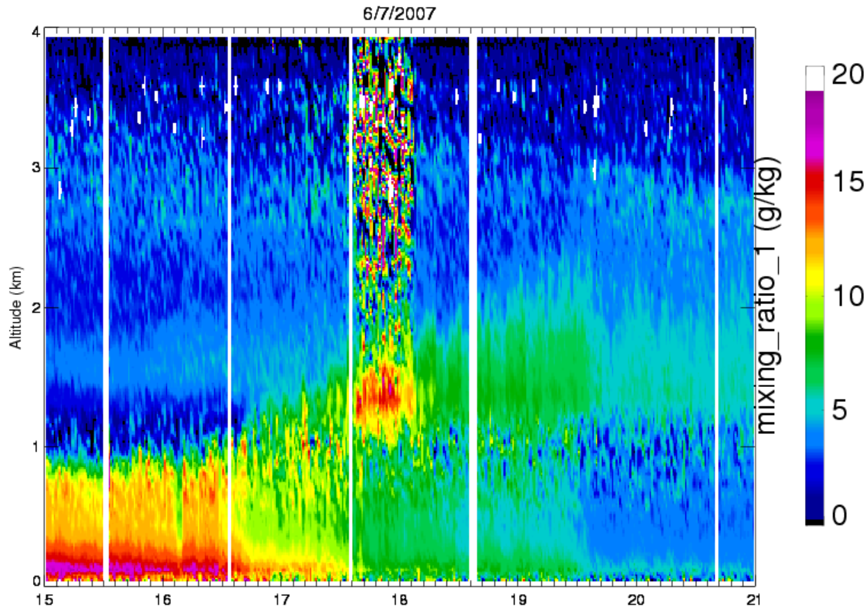


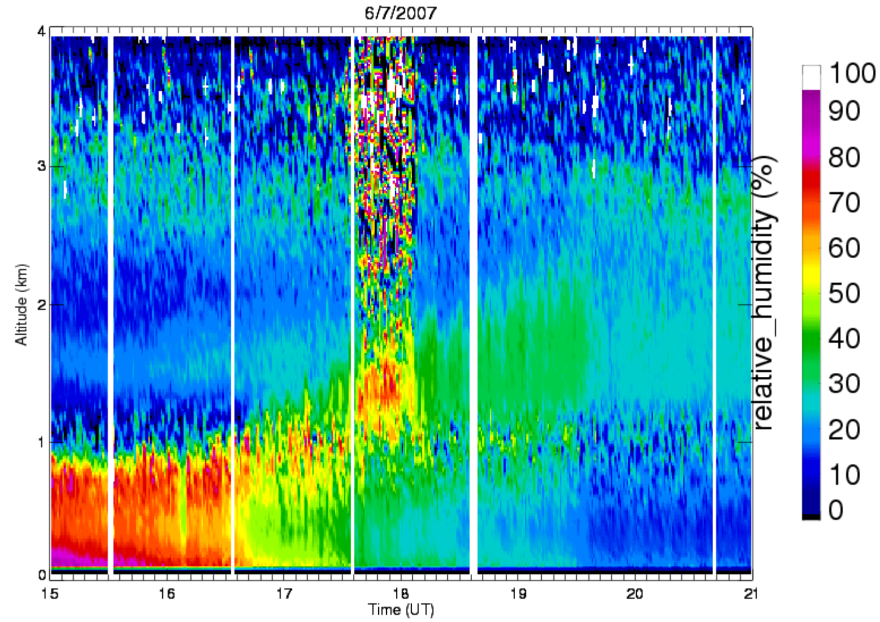


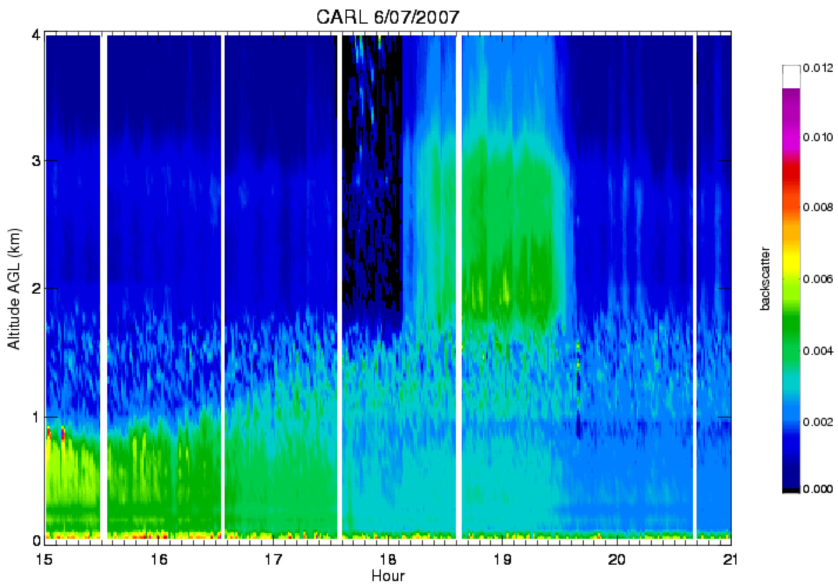
- AOT is generally similar between 2006 and 2007
- PWV is generally 1-2 cm higher during latter 3 weeks of June 2007 than during same period in June 2006
- Angstrom exponent generally lower during 2007 – more large particles during June 2007 than June 2006



AERONET Cimel Sun photometer data from Brent Holben (NASA/GSFC)


6/7/2007
Altitude (km)
mixing_ratio_1 (g/kg)


6/7/2007
Altitude (km)
Time (UT)
relative_humidity (%)


CARL 6/07/2007
Altitude AGL (km)
Hour
backscatter