Initial Results from the High Spectral Resolution Lidar (HSRL) Observations from CHAPS

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SSAI/NASA Langley Research Center

ARM Science Team Meeting
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NASA HQ Science
Mission Directorate
Radiation Sciences Program

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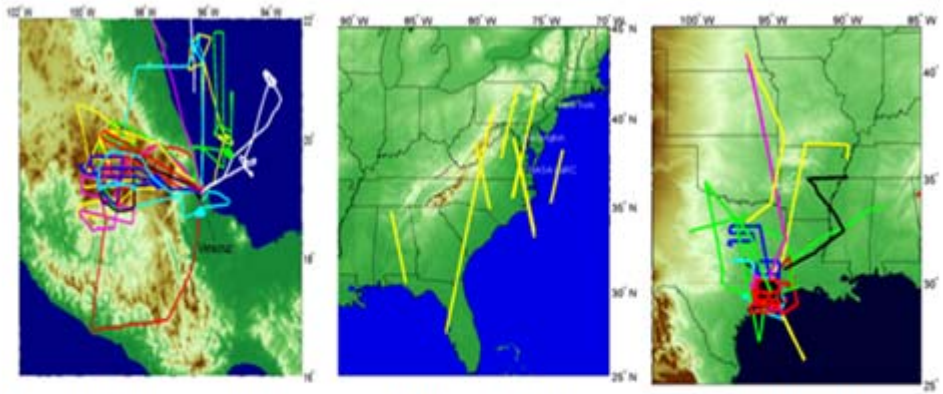
Department of Energy
Atmospheric Radiation Measurement Program
Atmospheric Science Program

NASA Langley Airborne High Spectral Resolution Lidar (HSRL)

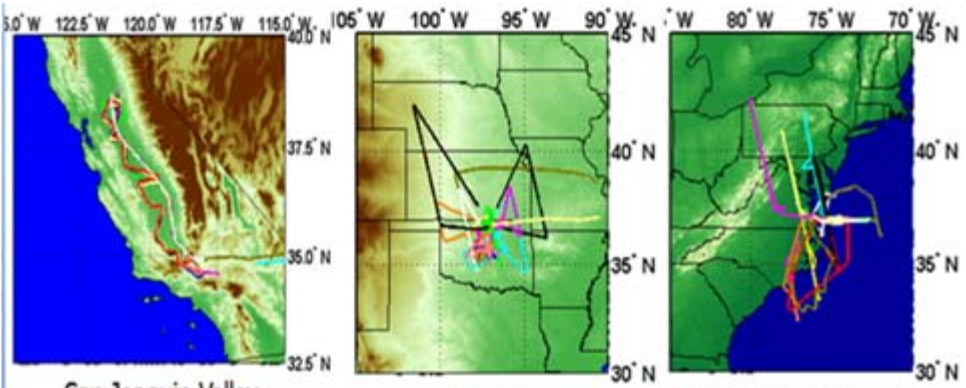
Past Campaigns:



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

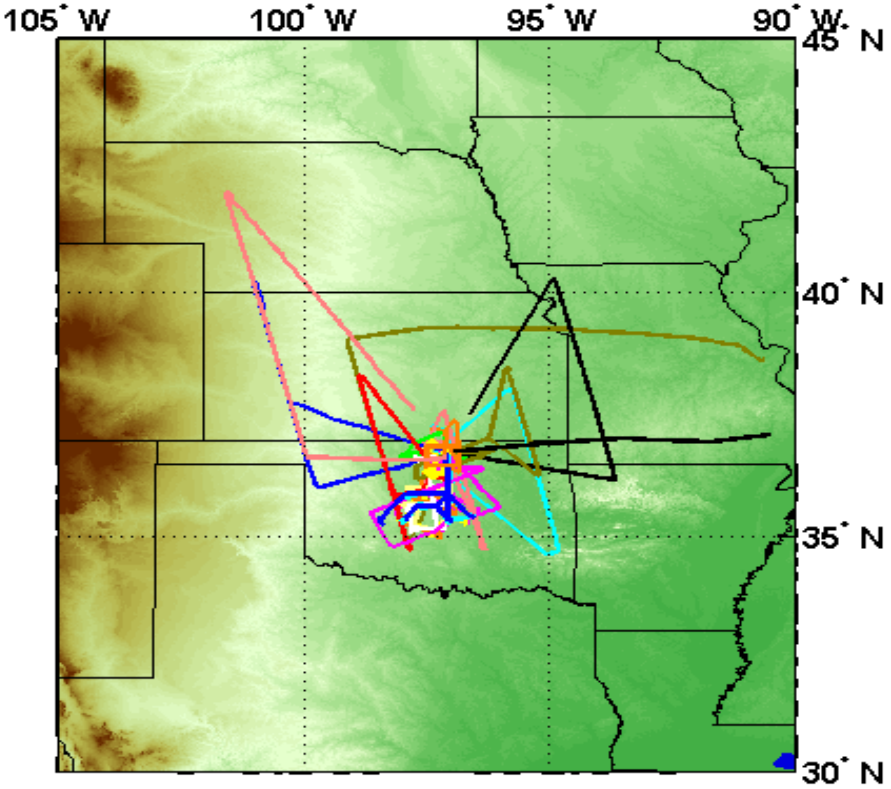
CALIPSO/MODIS/CATZ
Eastern U.S.
January 17– Aug 11, 2007

- Capabilities
  - HSRL at 532 nm: *independently* measures aerosol backscatter and extinction at 532 nm
  - Backscatter lidar at 1064 nm
  - Depolarization at both 532, 1064 nm
- History
  - 2000-2004: instrument development
  - Dec 2004: first test flight on Lear 25-C
  - Dec 2005: first test flight NASA 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 **450** hours of data and **120** science flights over two years!

CHAPS Objectives and Flights

Objectives

- Provide vertical profiles of aerosol between and above cloud
  - Provide vertical context for DOE 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)
- Locate horizontal/veritical extent of OK City plume
- Provide cloud top and PBL heights
- 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



HSRL/King Air Flights and Coordination with other Platforms

	Aircraft and HSRL flew all or partially coordinated flights
	Aircraft believed to have flown; possibly coordinated
	Aircraft and HSRL flew UNCOORDINATED flights
	Aircraft operations unknown
	Aircraft did not fly CHAPS science flight

Date	G1[2,3]	CTO[2,4]	CALIPSO underflight included?	SGP site overflight included?[2]
06/03/07			Yes	
06/04/07				Yes
06/05/07			Yes	Yes
06/06/07				
06/07/07				Yes
06/08/07				
06/09/07				
06/10/07			Yes	Yes, but cloudy
06/11/07				Yes
06/12/07				
			Yes	Yes
06/13/07				
06/14/07			Yes	
06/15/07				
06/16/07				Yes
06/17/07				Yes
06/18/07				
06/19/07		[6]	Yes	Yes, but cloudy
06/20/07				Yes, but cloudy
06/21/07			Yes	Yes
06/22/07				Yes
06/23/07				
				Yes
06/24/07				
				Yes
06/25/07				
06/26/07			Yes	Yes, but cloudy
06/27/07				
06/28/07				
06/29/07				

Total Number of Coordinated Flights with NASA HSRL:

8-10	9-10	8	15

20 science flights, **66** flight hours

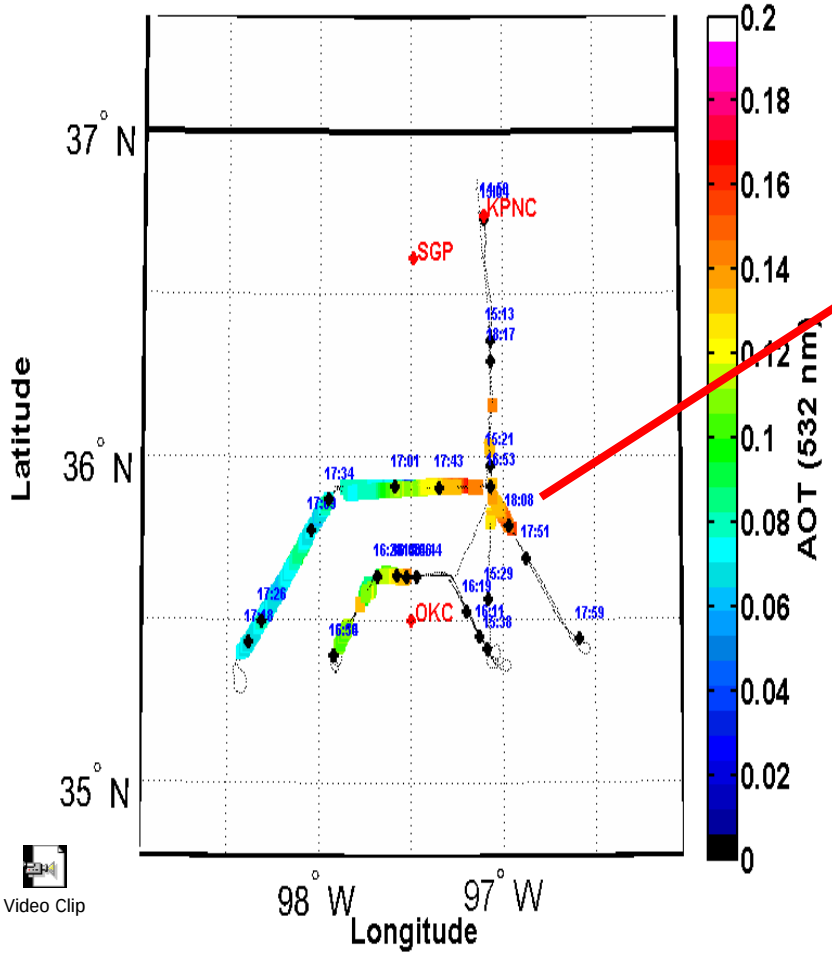
- 15 flights over ARM SGP
- 8 flights included CALIPSO validation
- 9 flights coordinated with DOE G-1
- 9 flights coordinated with CIRPAS TO
- 10 flights with MODIS/MISR

Examples:
1. June 7th
2. June 19th
3. June 24th

Example of CHAPS B200/G1 Coordinated Flight – June 24

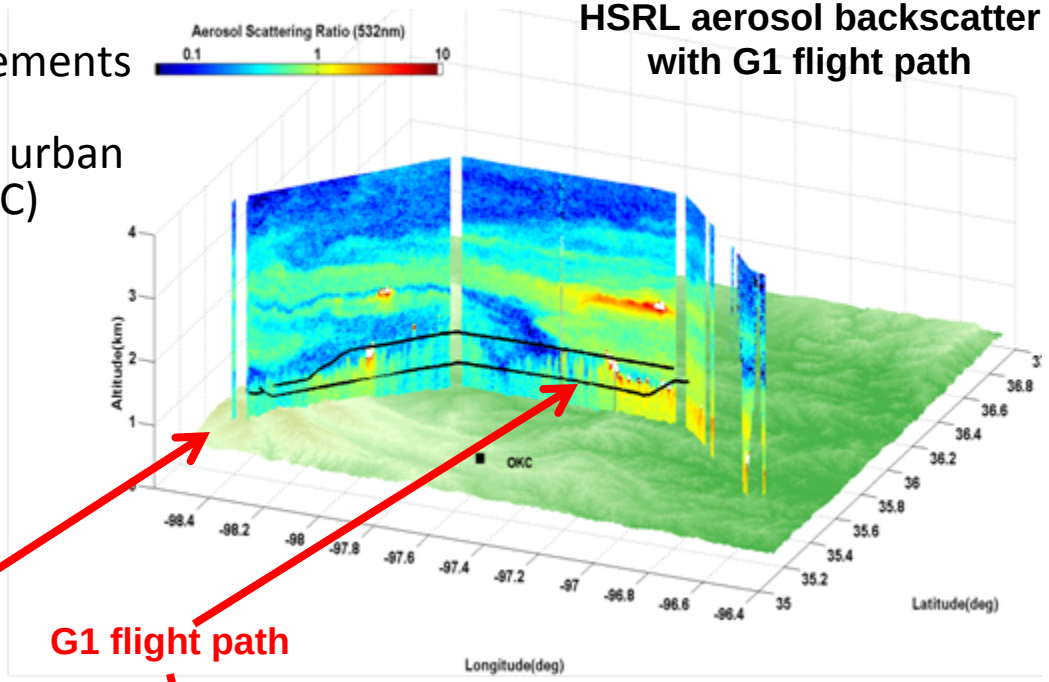
HSRL measurements :

- Provide vertical context for G1 measurements
- Investigate changes in aerosol optical properties as a function of proximity to urban center (ex. upwind vs. downwind of OKC)

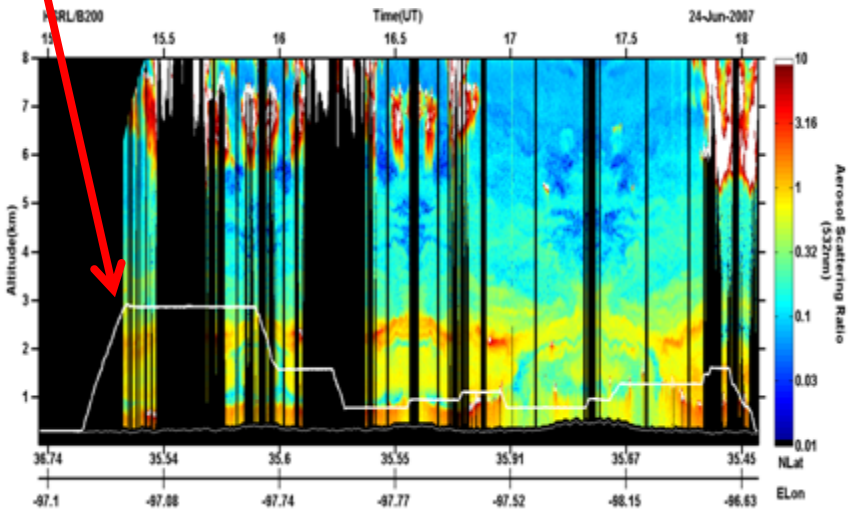


Video Clip

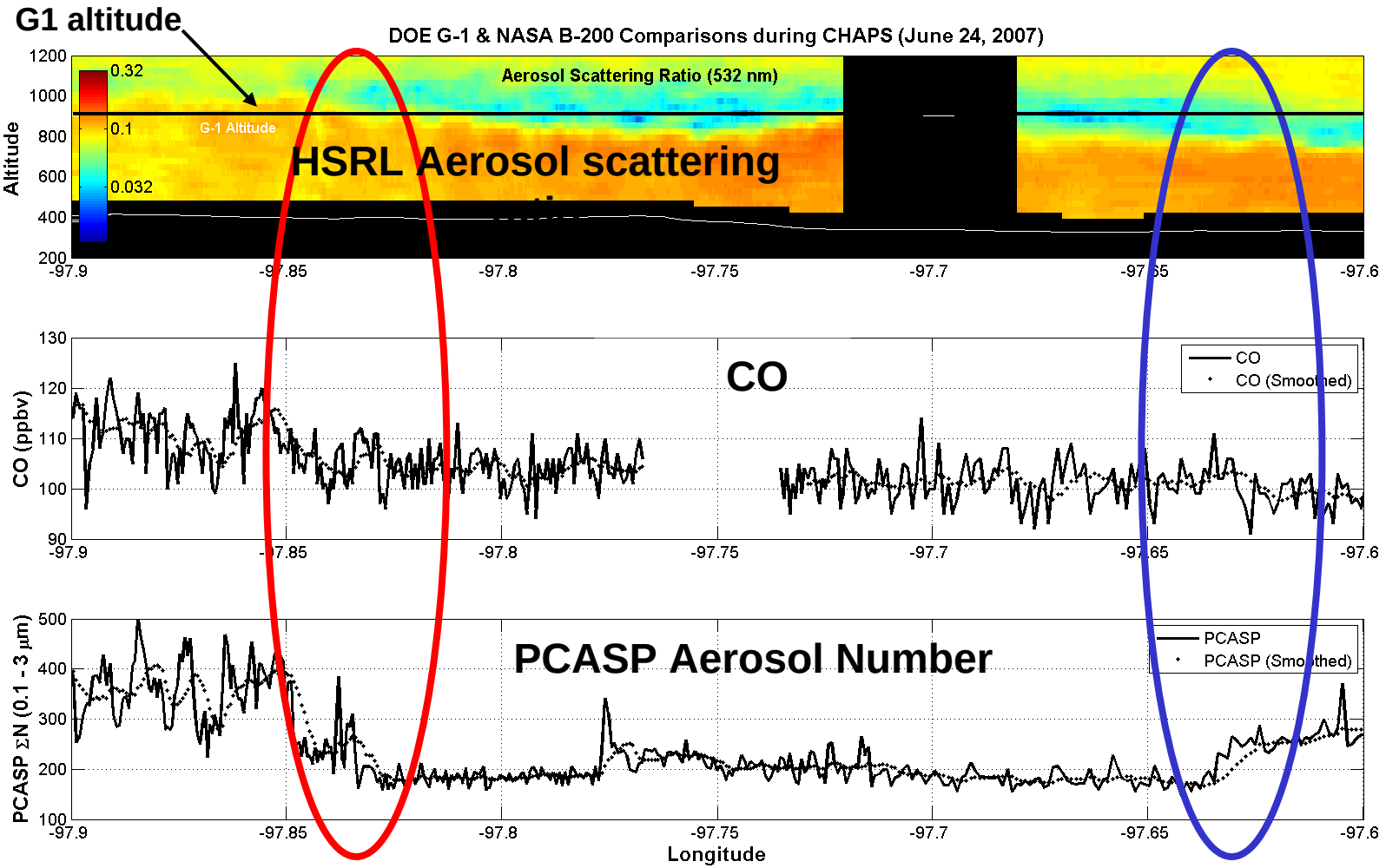
HSRL aerosol backscatter with G1 flight path



G1 flight path



Example of CHAPS B200/G1 Coordinated Flight – June 24

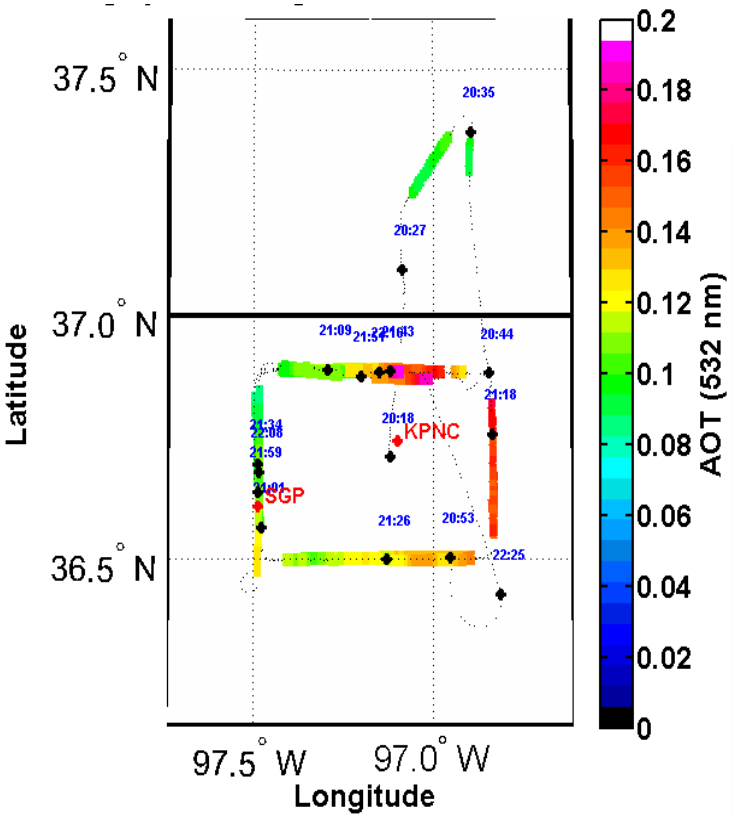


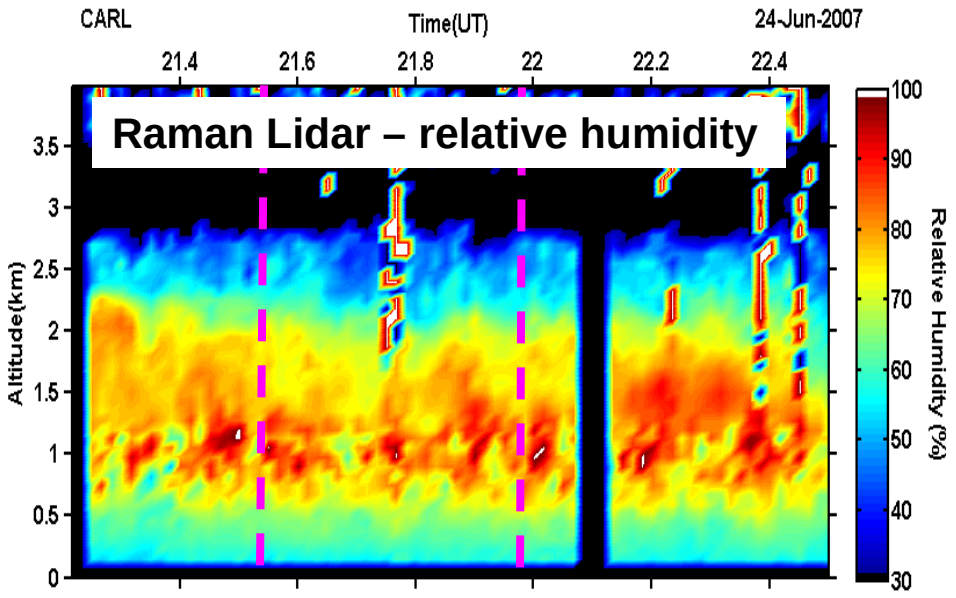
G-1 exiting aerosol layer: Decreasing HSRL Aerosol Scattering Ratio corresponds to decreasing CO and small particle concentration.

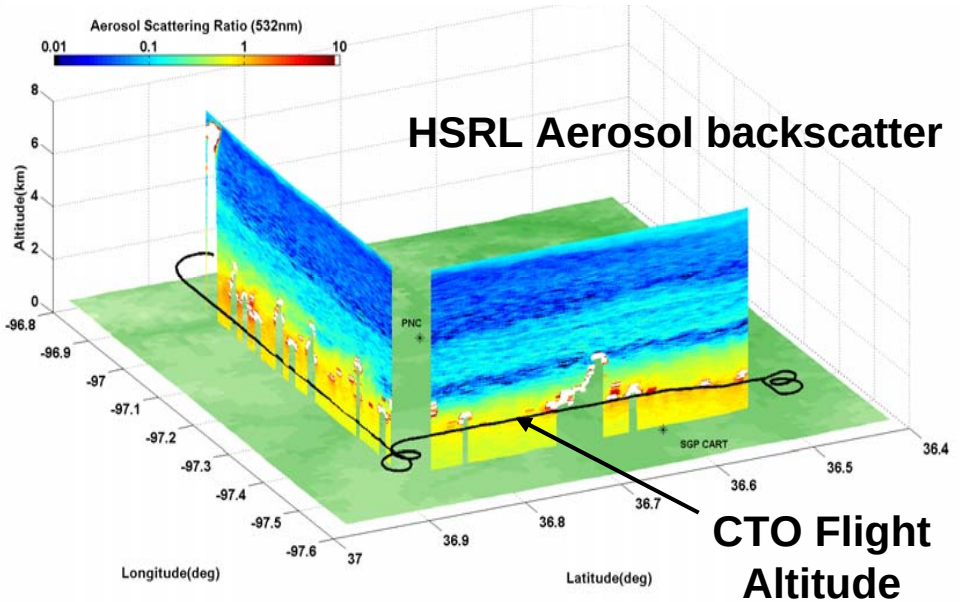
G-1 entering *different* aerosol layer: Increasing HSRL Aerosol Scattering Ratio corresponds to increase in small particle concentration with no change in CO.

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

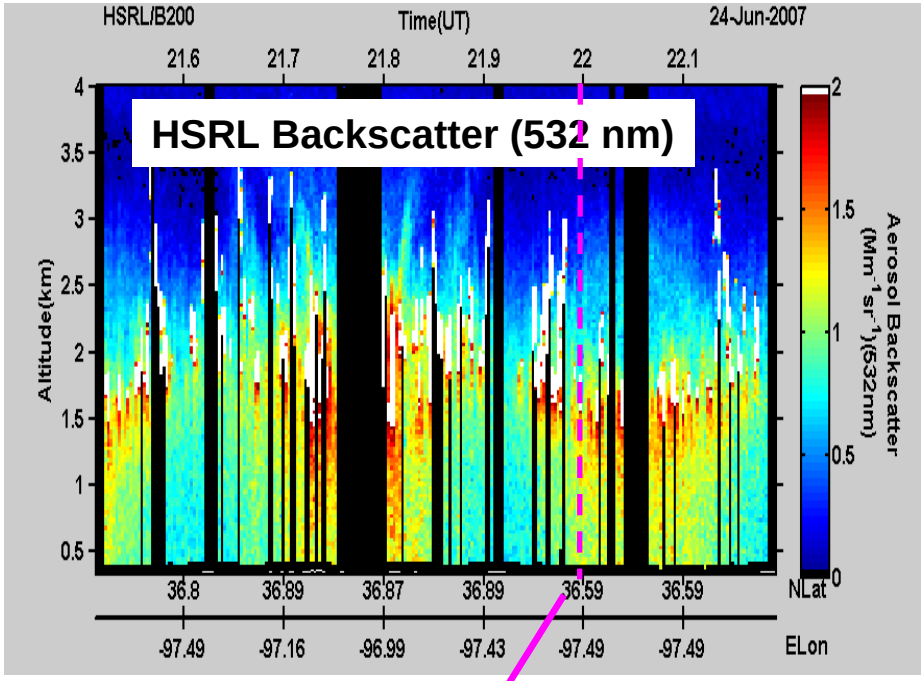
Observations from the King Air, CIRPAS Twin Otter, and DOE ARM SGP Raman lidar will be used to investigate changes in aerosol optical properties as a function of
- RH
- Distance from clouds



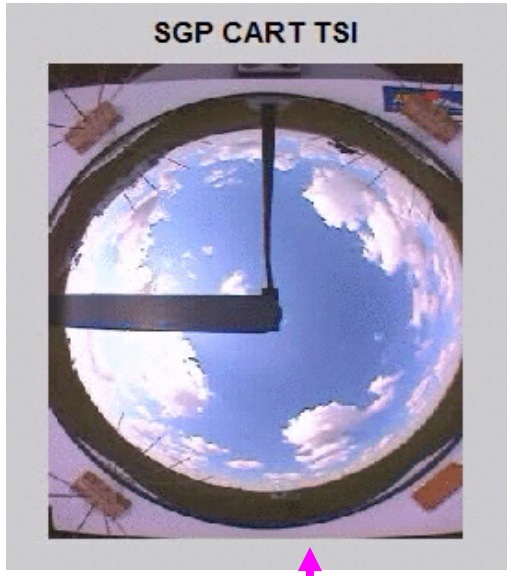


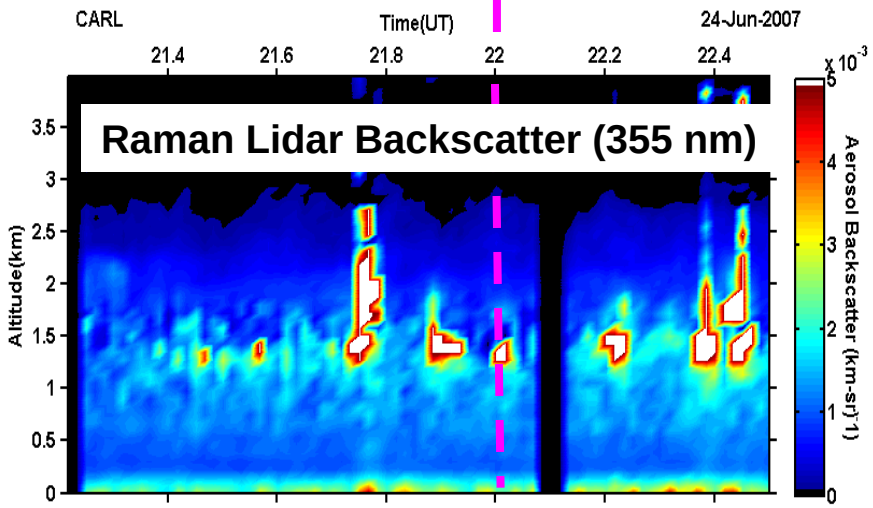


Example of measurements over SGP Raman Lidar - June 24



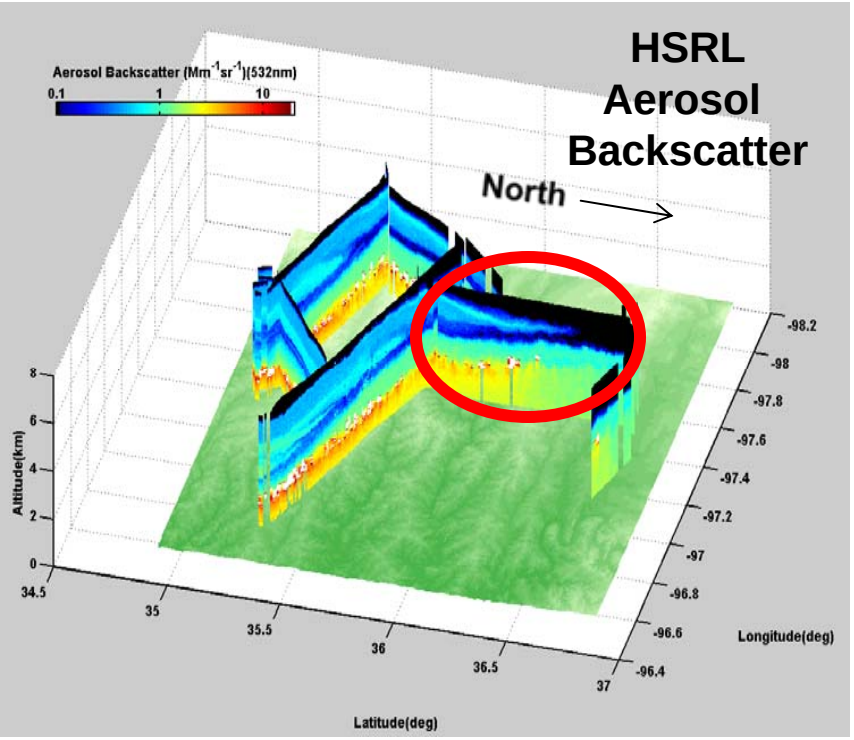
Investigate changes in aerosol optical properties as a function of distance from clouds





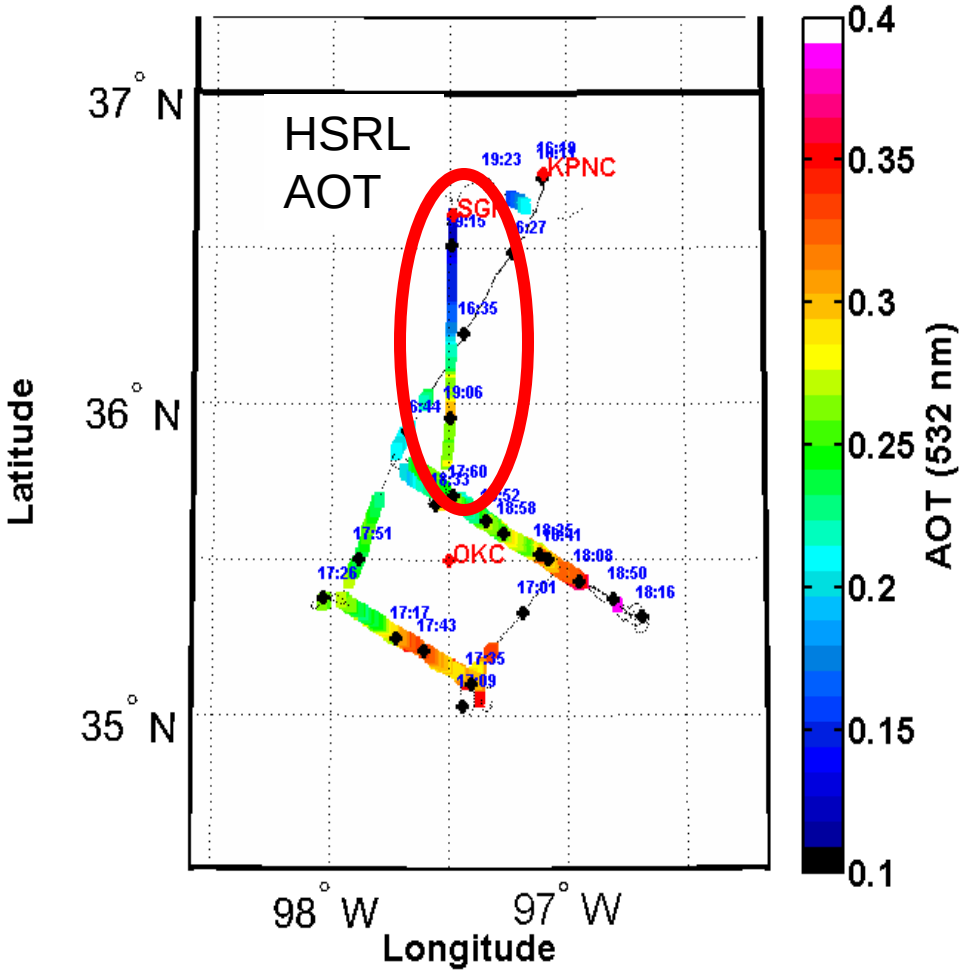
Video Clip

Water vapor and Aerosol Measurements of June 7 Dry Line

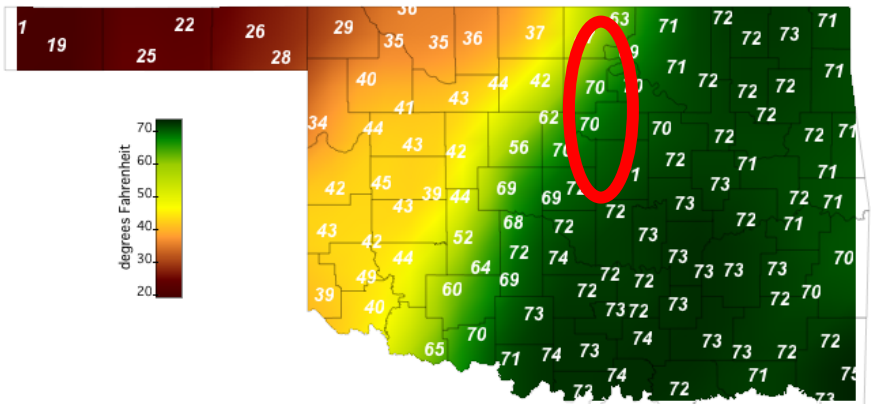


HSRL measurements show:

- High AOT ahead (SE) of dry line in OKC region
- Large decrease in AOT behind (NW) of dry line



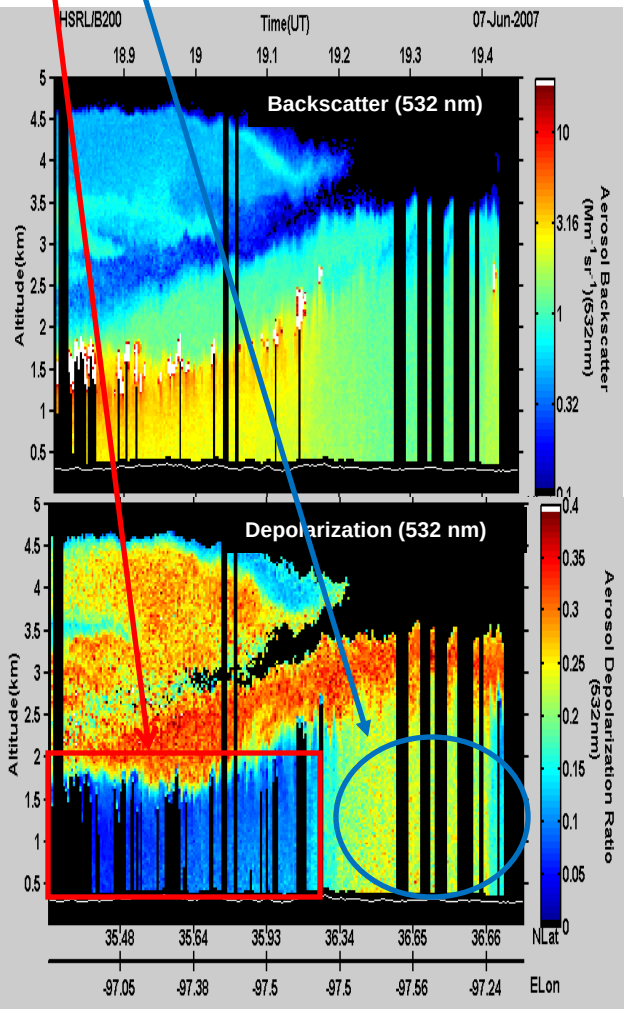
OK Mesonet; Surface Dew Point 20:00 UT

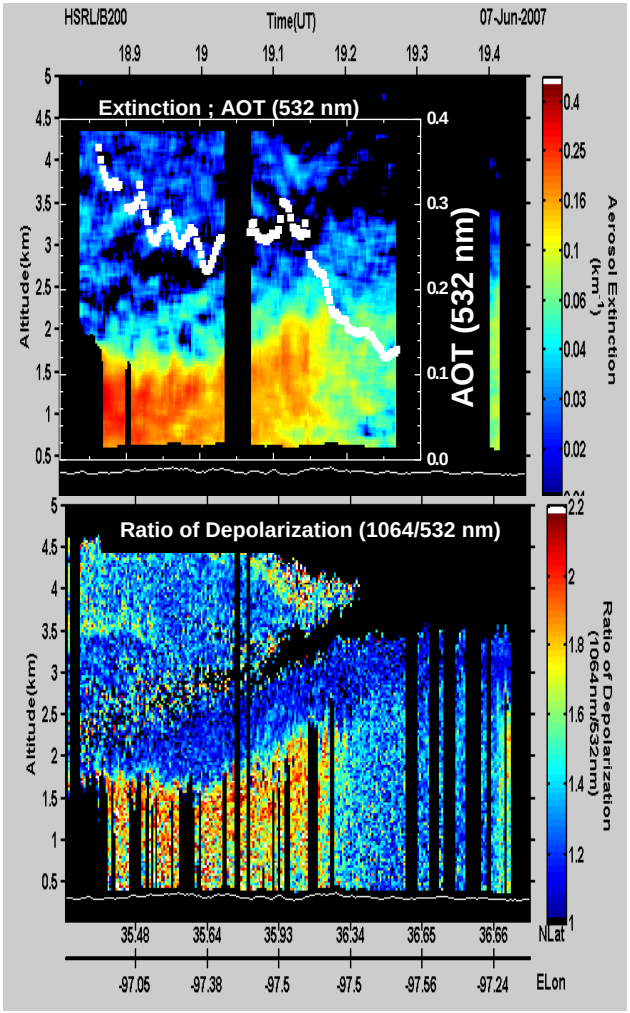


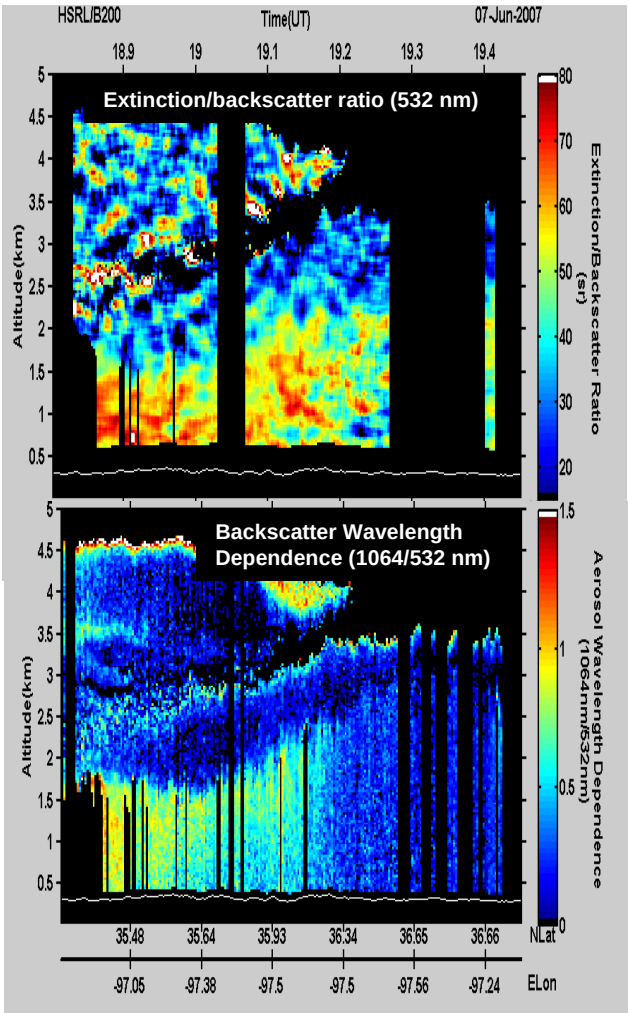
Characterizing the spatial distribution of aerosol type with HSRL measurements

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







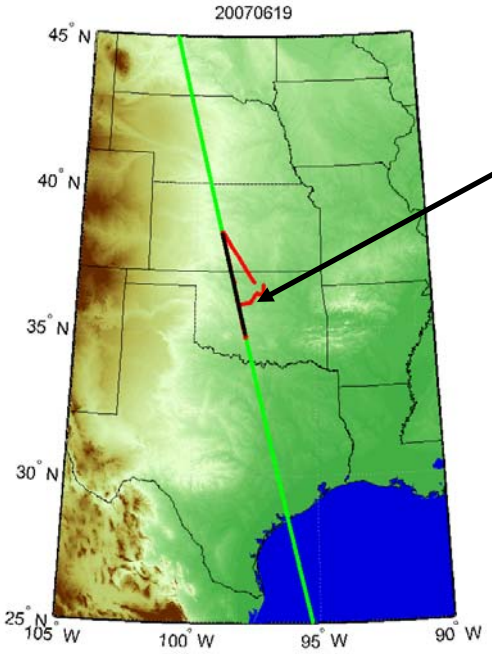
CALIPSO Validation – June 19

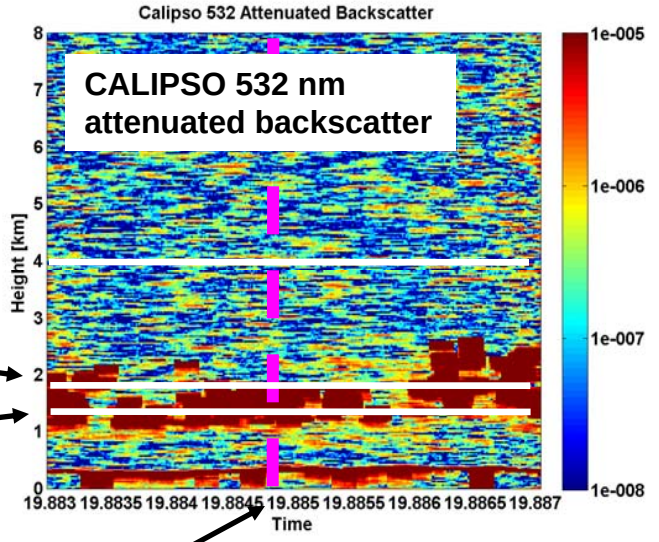
Multi-aircraft coordinated flight along CALIPSO track:

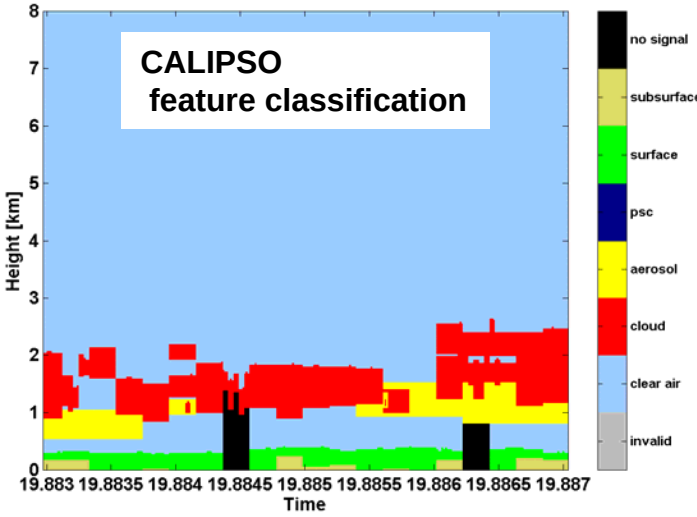
CIRPAS Twin Otter

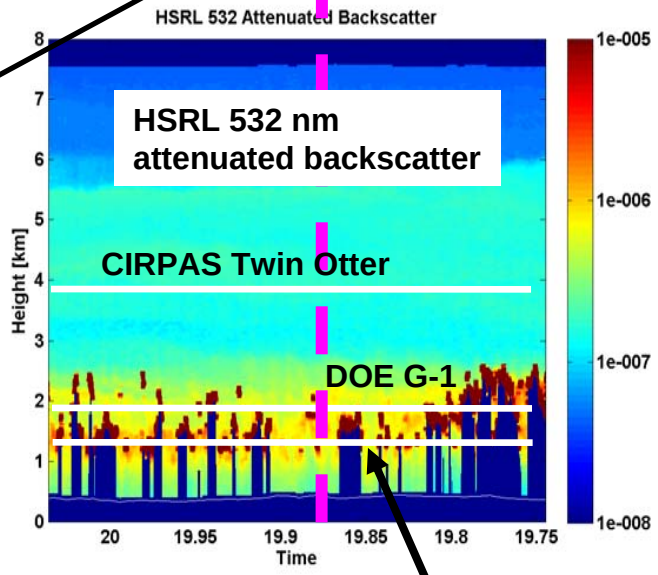
DOE G-1

DOE IAP Cessna

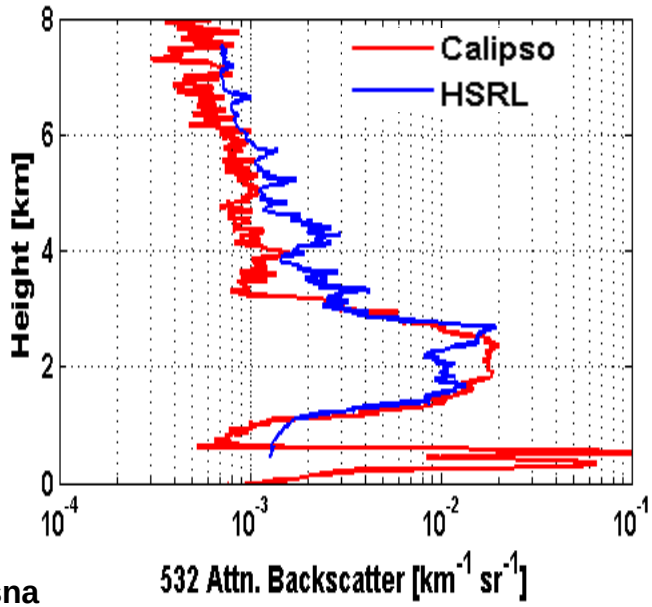








DOE IAP Cessna

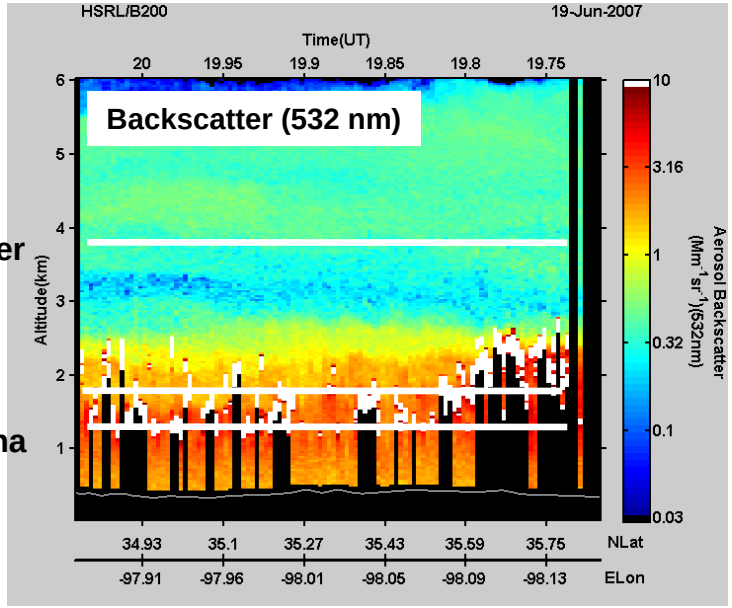


Aerosol Extinction Comparison, CALIPSO Validation – June 19

CIRPAS Twin Otter

DOE G-1

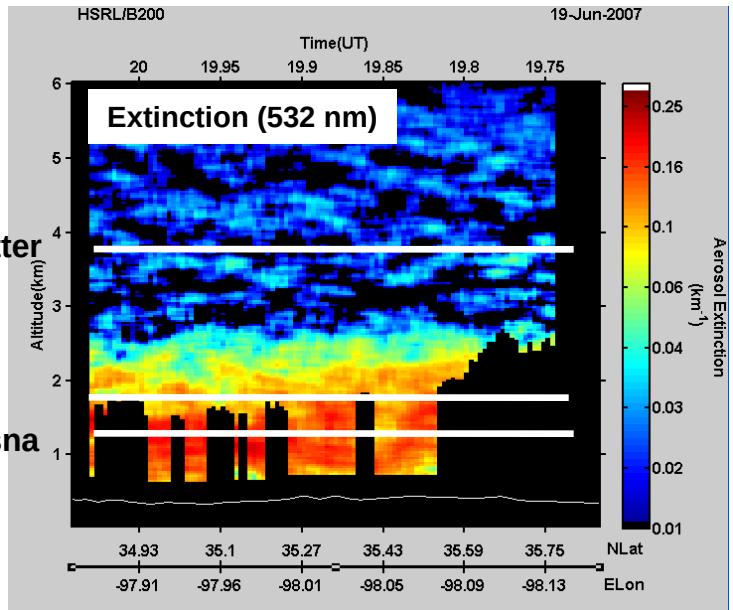
DOE IAP Cessna

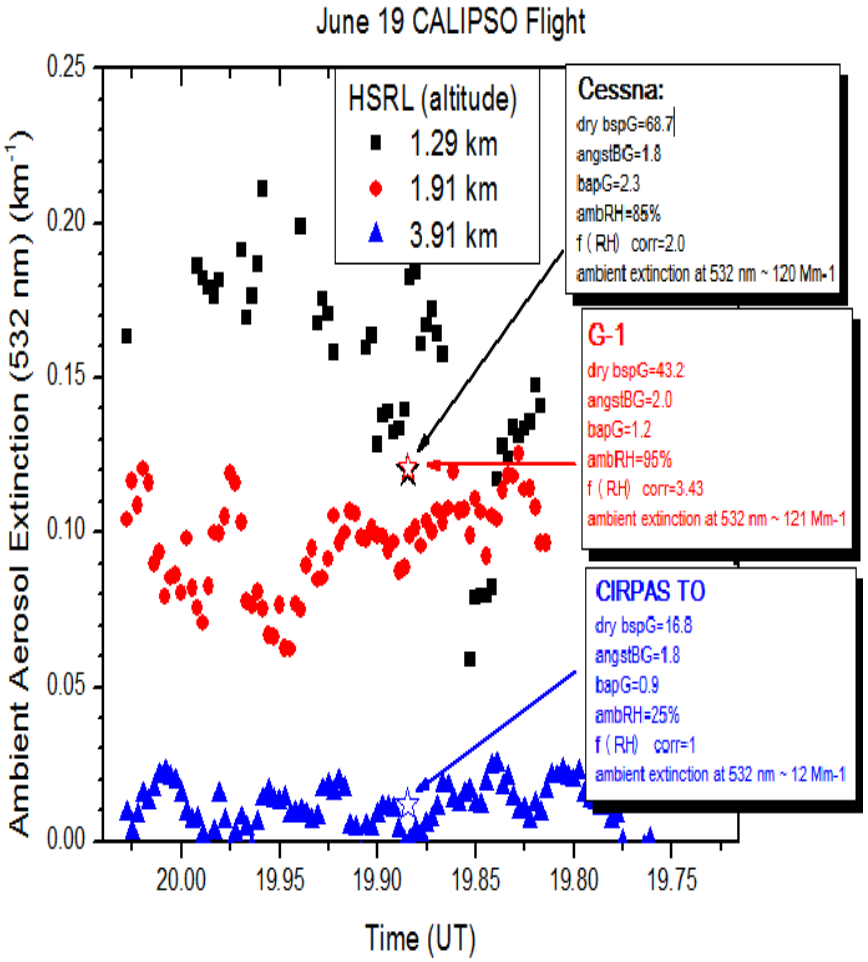


CIRPAS Twin Otter

DOE G-1

DOE IAP Cessna





Humidity-corrected in situ data courtesy of Betsy Andrews and John Ogren

Summary and Plans for Use of HSRL Data from CHAPS

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)
- Locate horizontal extent of OKC plume
- Provide vertical context for interpretation of G-1 and CTO observations
- Provide cloud top and PBL heights and AOT within PBL
- 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

HSRL data and images are available via CHAPS archive as well as from NASA LaRC FTP site

Acknowledgements

The authors would like to thank Mike Wusk, Rick Yasky, Les Kagey, Howard Lewis, Scott Sims, and Dale Bowser for support of the B200 flights during this campaign. We also thank the Department of Energy (DOE) Atmospheric Science Program, the NASA HQ Science Mission Directorate Radiation Sciences Program, and the NASA CALIPSO project for funding this HSRL-related research. Analyses of data from the DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility (CRF) Raman lidar was supported by the Office of Biological and Environmental Research of the U.S. Department of Energy (Interagency Agreement DE-AI02-02ER63328) as part of the Atmospheric Radiation Measurement Program.

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See also:

http://science.larc.nasa.gov/hsrl

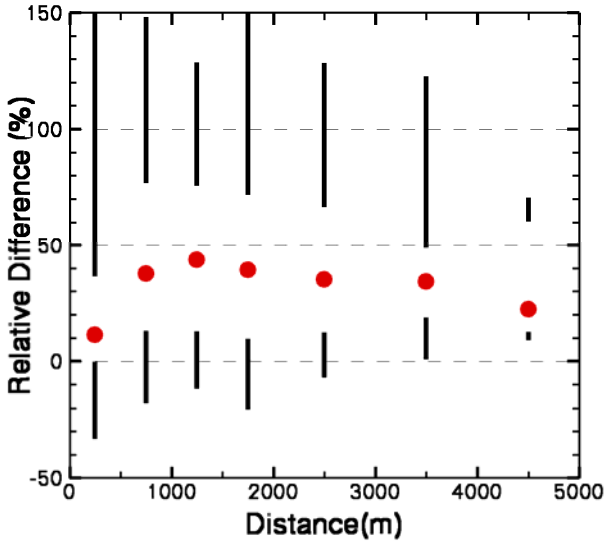
Hair, J., C. Hostetler, R. Ferrare, A. Cook, D. Harper, "The NASA Langley High Spectral Resolution Lidar for Measurements of Aerosols and Clouds", in: *Reviewed and Revised Papers Presented at the 23rd International Laser Radar Conference*, C. Nagasawa and N. Sugimoto, Eds., 411-414, 2006.

R. Ferrare, C.A. Hostetler, J.W. Hair, A.L. Cook, D.B. Harper, S. Burton, A. Clarke, P.B. Russell, J. Redemann, "Airborne High Spectral Resolution Lidar aerosol measurements during MILAGRO and TexAQS/GoMACCS", Ninth Conference on Atmospheric Chemistry, American Meteorological Society Annual Meeting, San Antonio, TX, January, 2007.

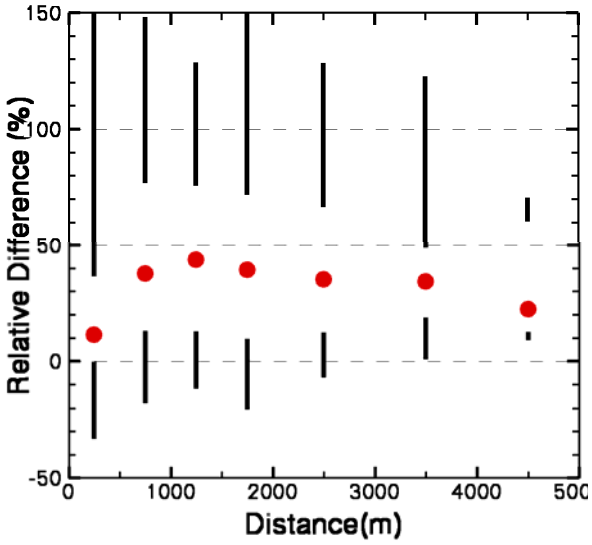
Backup Slides

Relative Difference in Lidar Observables as Function of Distance from Cloud Edge

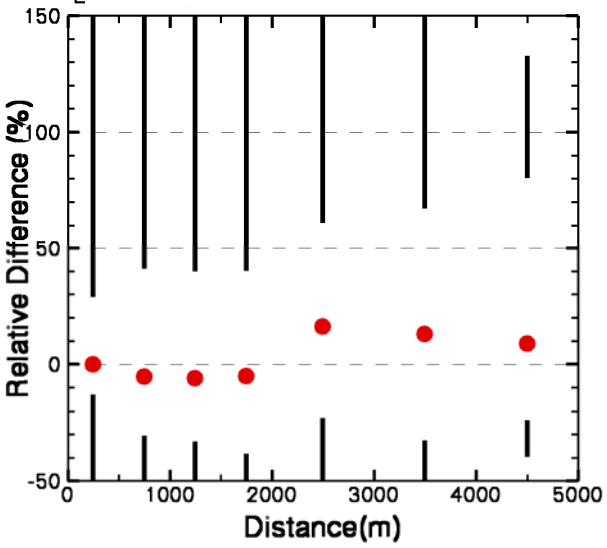
Backscatter, 532 nm



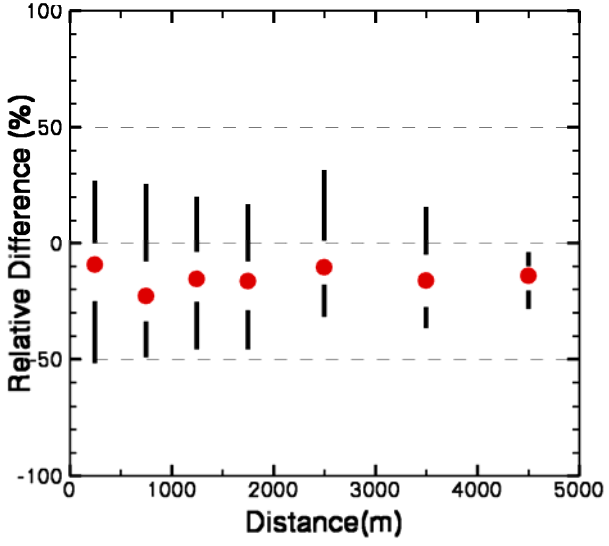
Backscatter,1064 nm



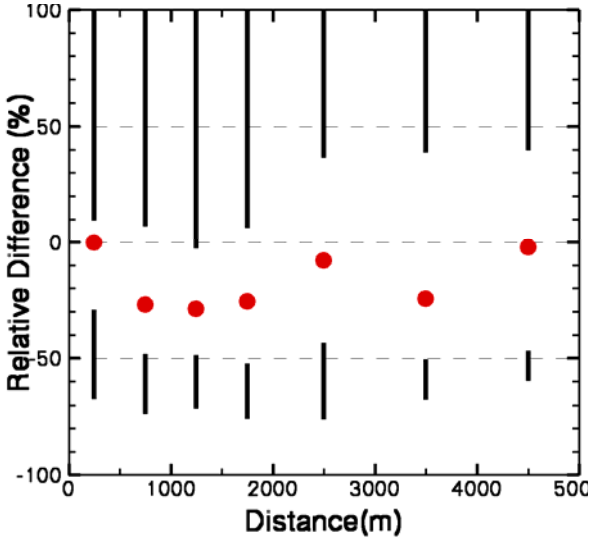
Extinction, 532 nm



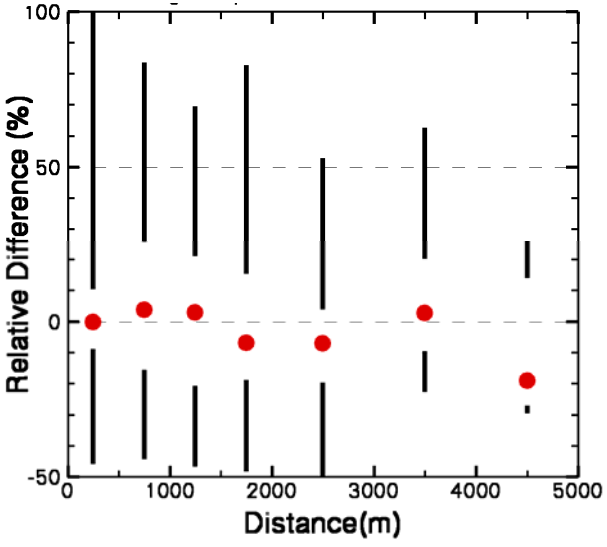
Depolarization, 532 nm



Extinction/Backscatter,532 nm

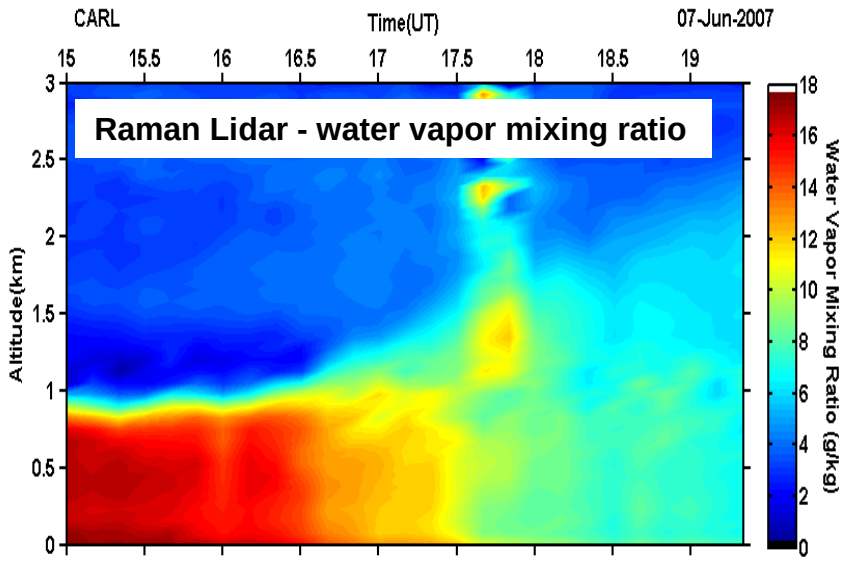


Wavelength Dependence

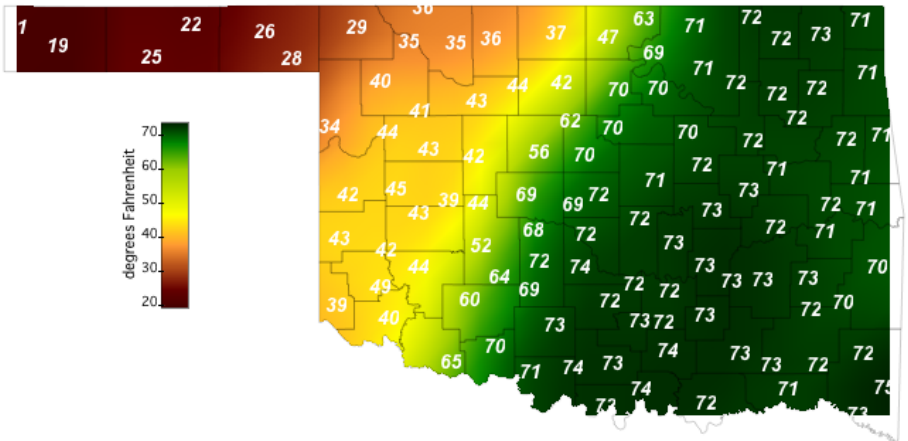


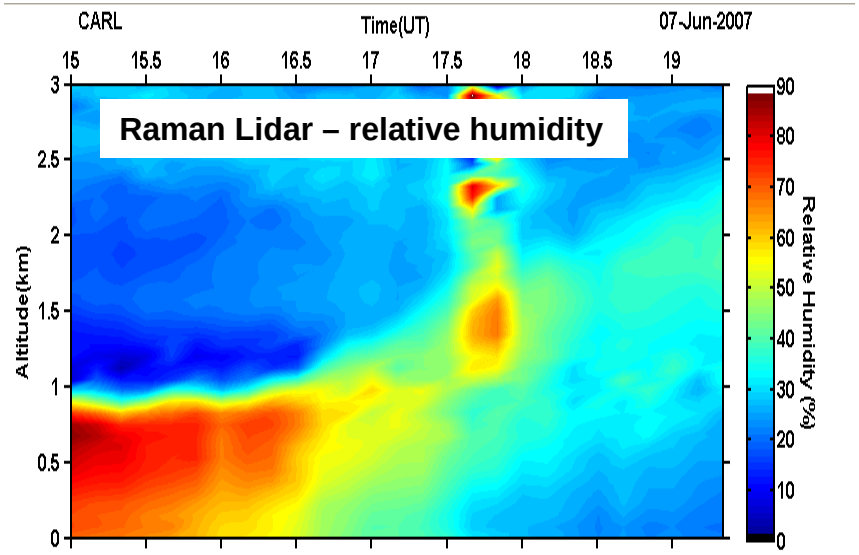
Water vapor and Aerosol Measurements for June 7 "Dry Line"

- 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





Coordinated B200 / HSRL - Airborne in situ Measurements

- Increases in total aerosol number measured by PCASP instrument on G-1 suggests penetration of plume from Oklahoma City
- However, coincident HSRL aerosol backscatter measurements show these aerosol number variations are due to G-1 flying in and out of PBL rather than Oklahoma City plume

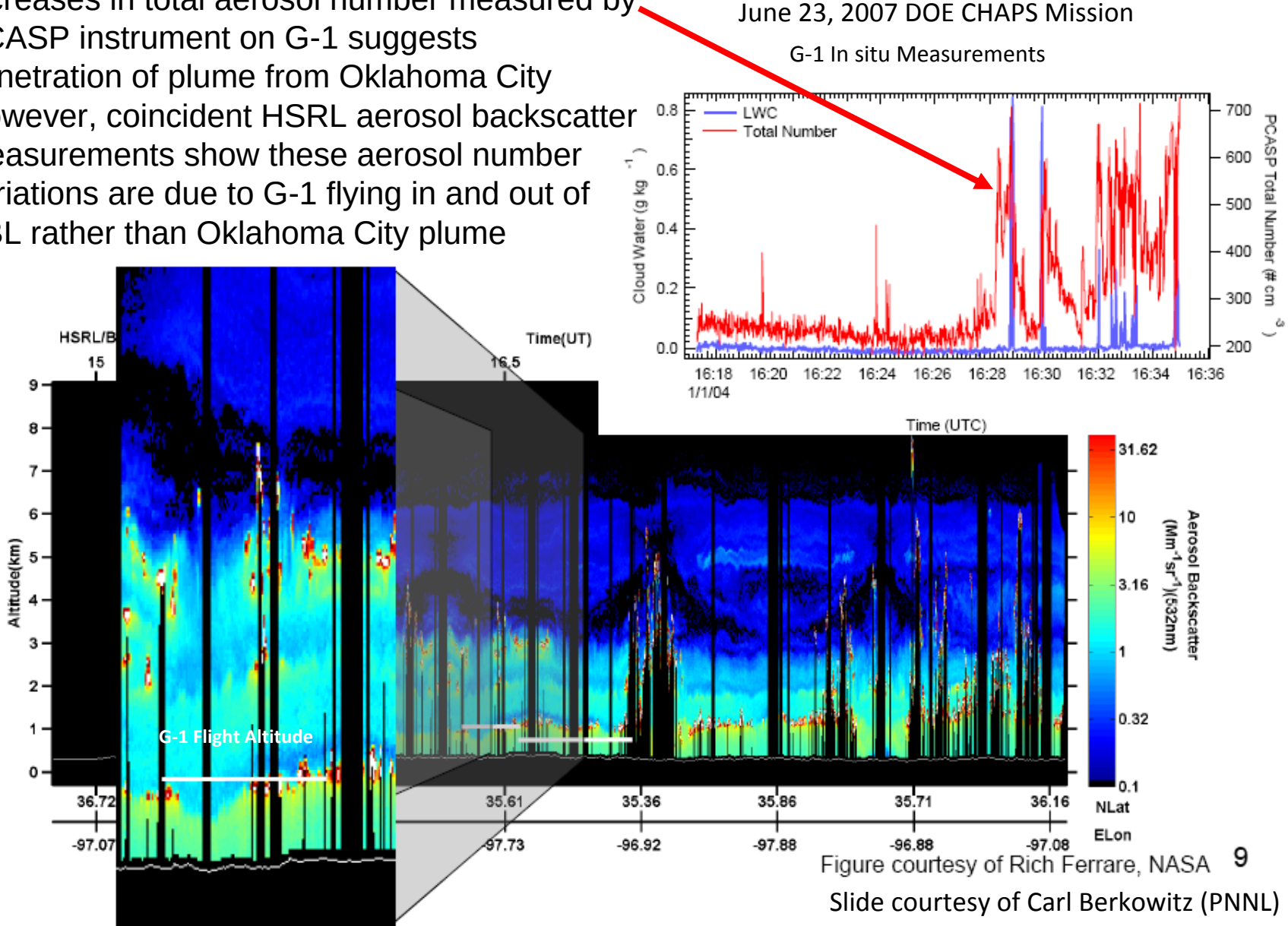
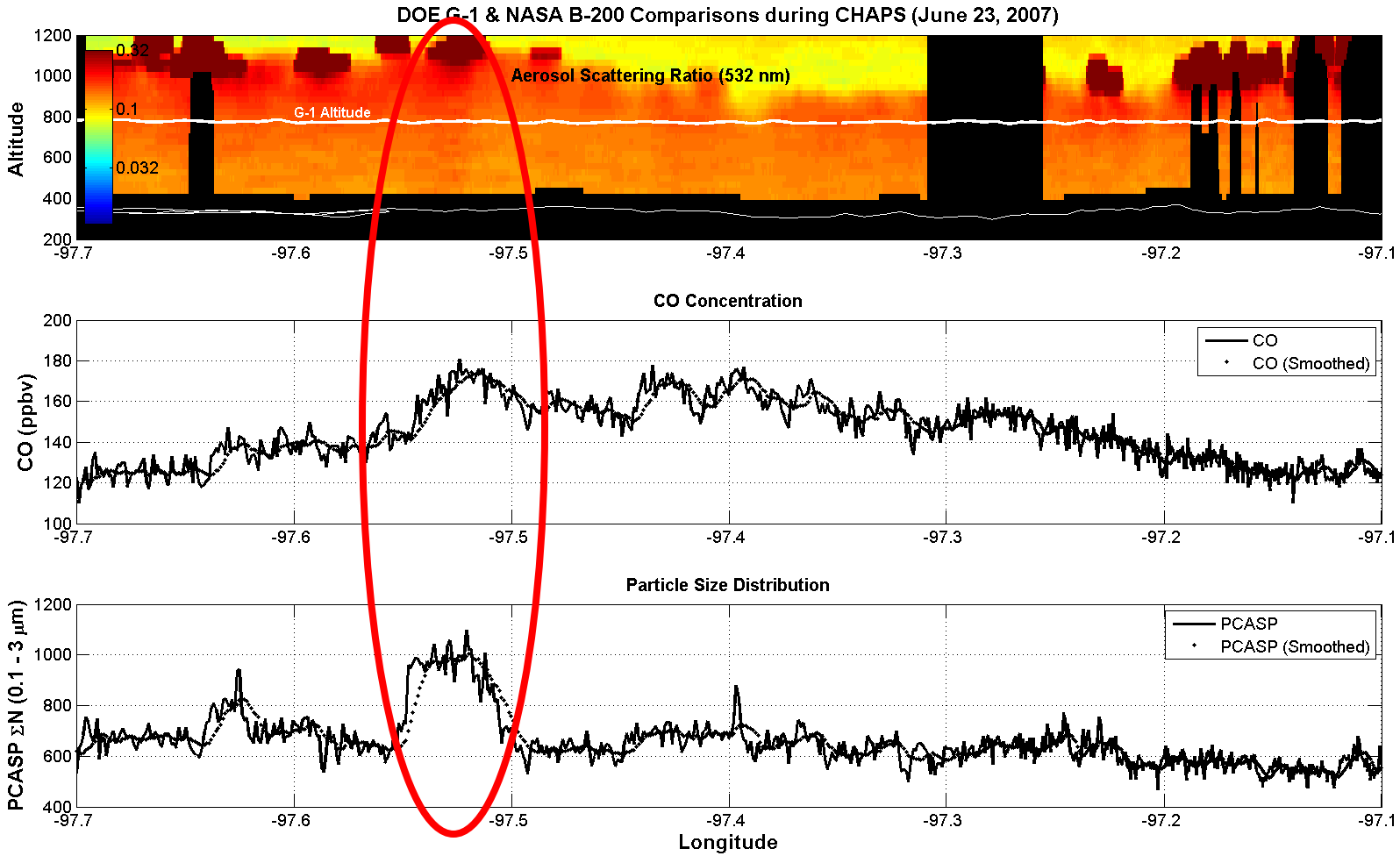


Figure courtesy of Rich Ferrare, NASA

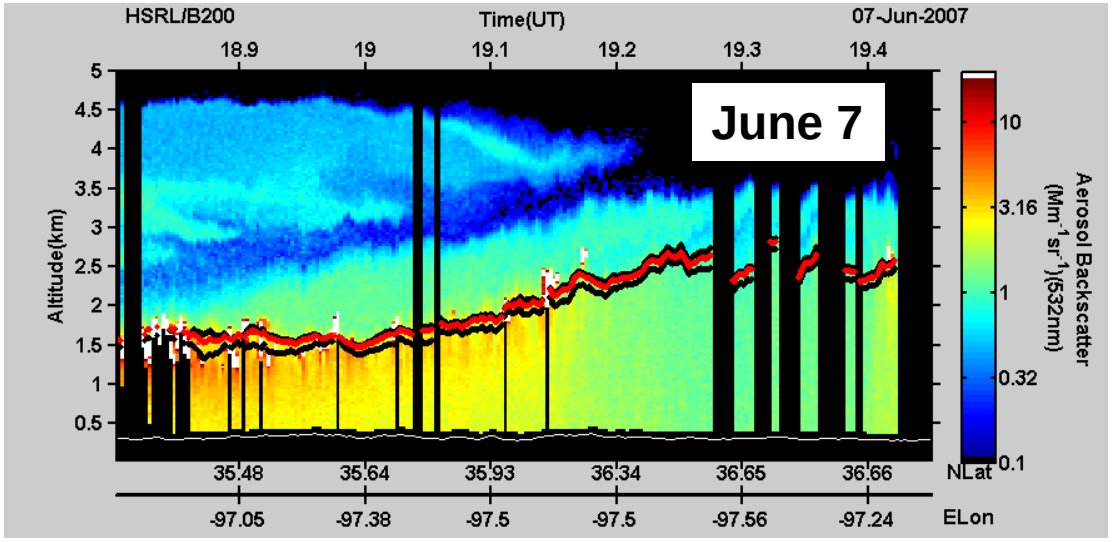
Slide courtesy of Carl Berkowitz (PNNL)

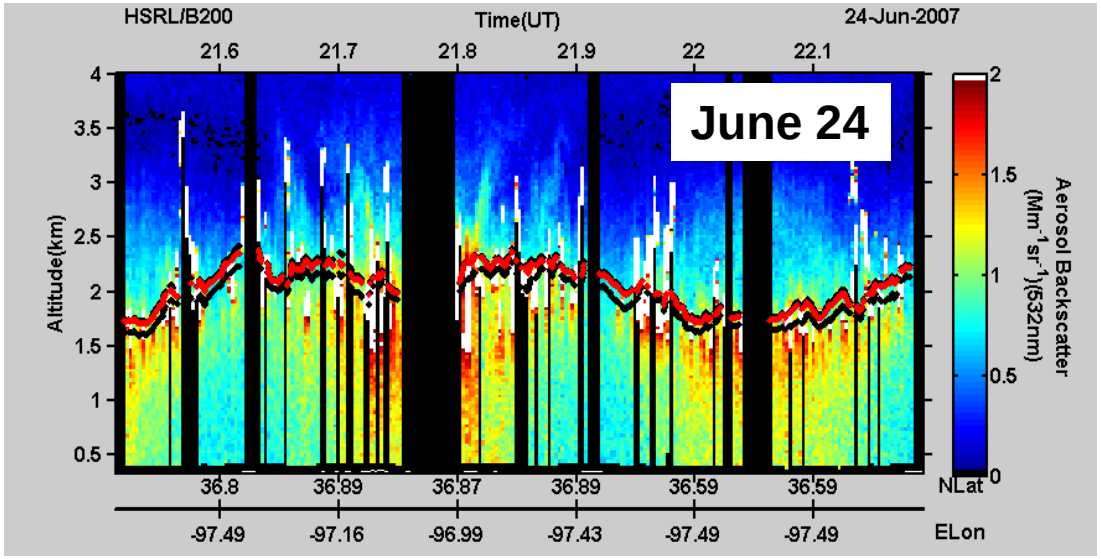
Example of CHAPS B200/G1 Coordinated Flight – June 23



OKC Plume? Increased small particle concentration and CO detected under cloud with no corresponding change in HSRL BSR. RH effect?

HSRL PBL height retrievals





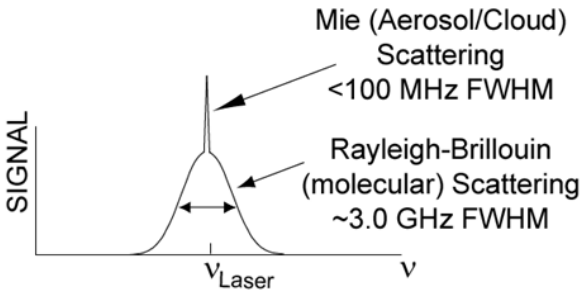
An automated technique that uses a Haar wavelet covariance transform with multiple wavelet dilations (Brooks, 2003) was used to determine:

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

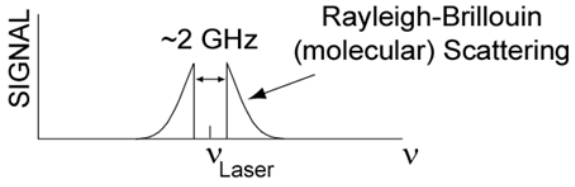
NASA Langley airborne High Spectral Resolution Lidar (HSRL)

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

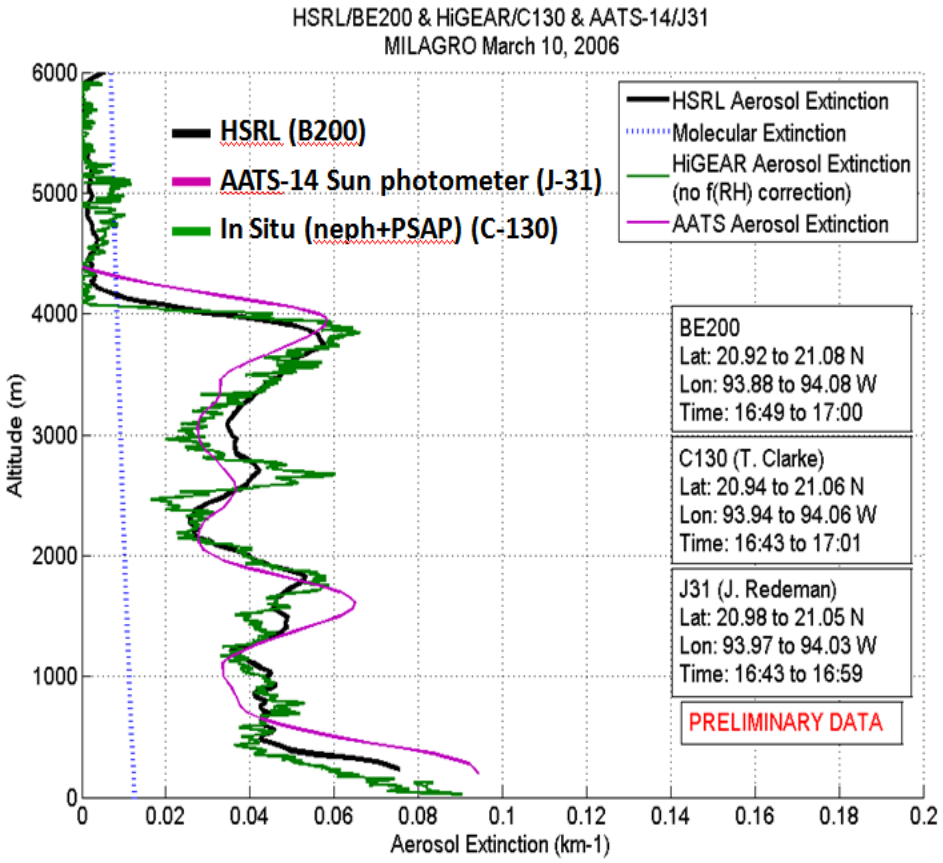
Atmospheric Scattering



Effect of Iodine Vapor Notch Filter



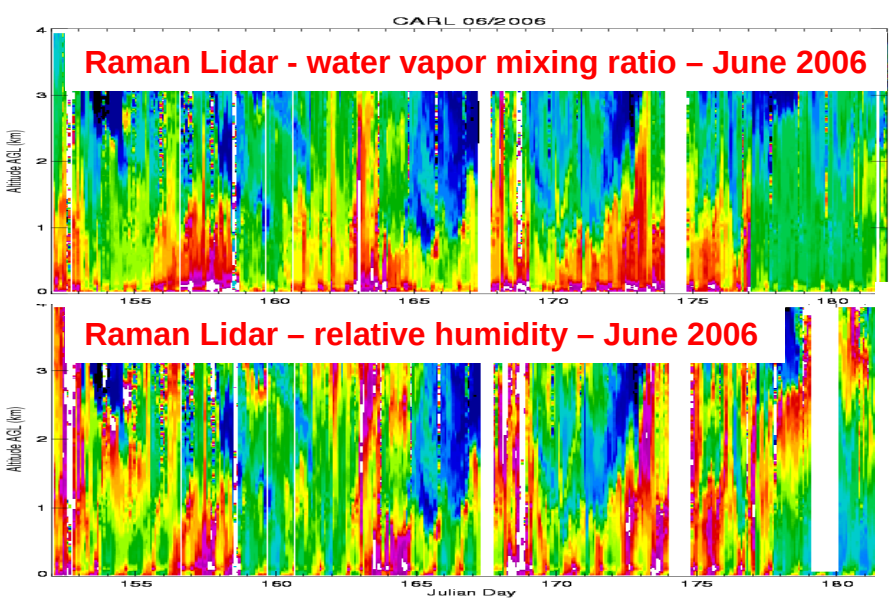
Aerosol Extinction

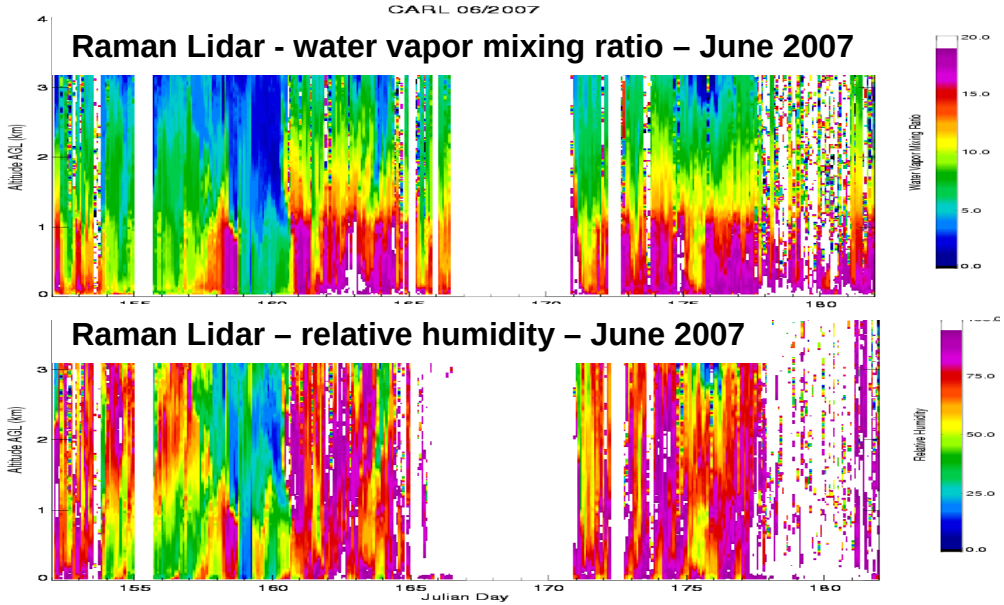


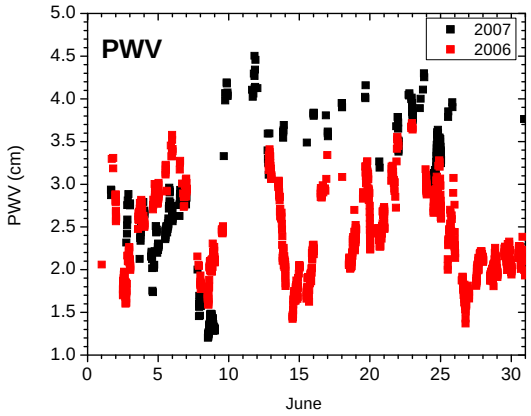
- HSRL independently measures aerosol and molecular backscatter
  - Can be internally calibrated
  - No correction for extinction required to derive backscatter profiles
  - More accurate aerosol layer top/base heights
  - Provide *intensive* optical data from which to infer aerosol type

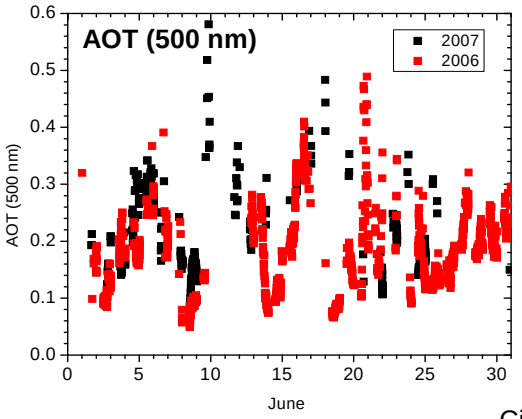
June at SGP: 2006 vs. 2007

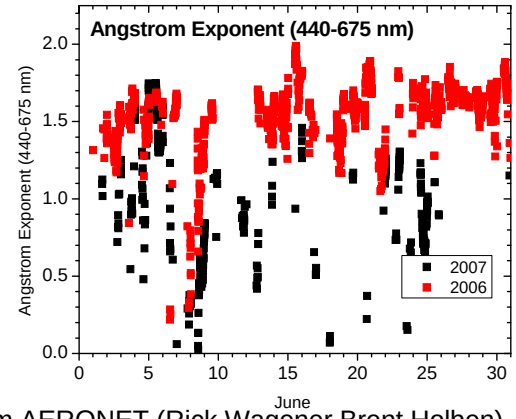
- Significantly higher water vapor and RH during latter 3 weeks of June 2007
- AOT similar but Angstrom exponent generally lower during 2007 – more large particles present during June 2006 than during June 2006



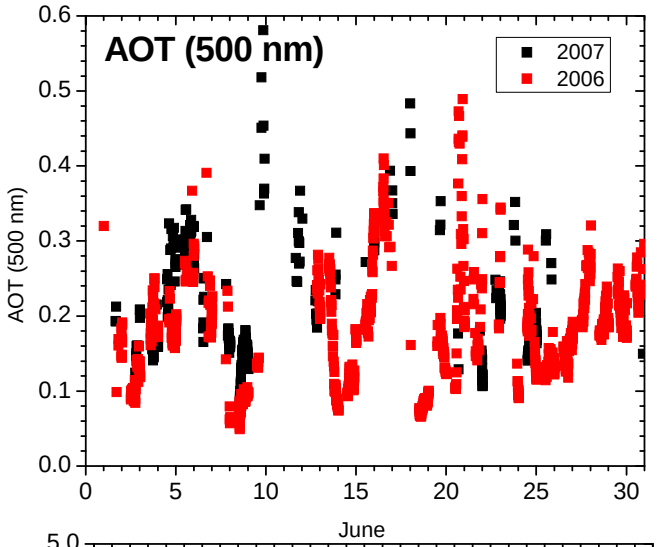


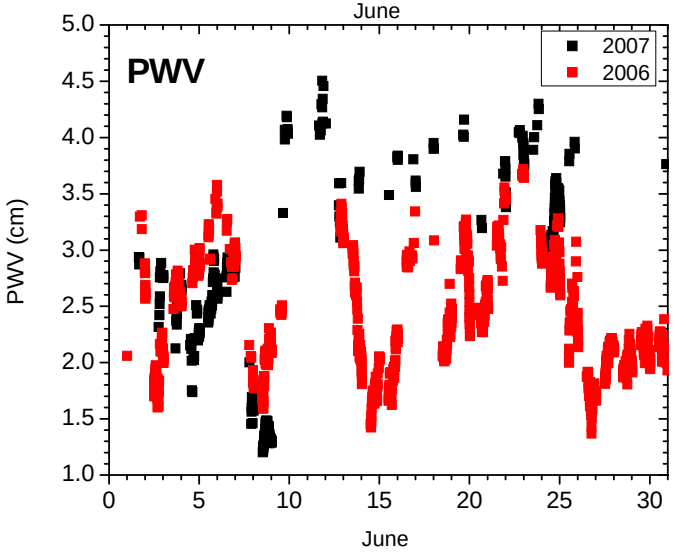




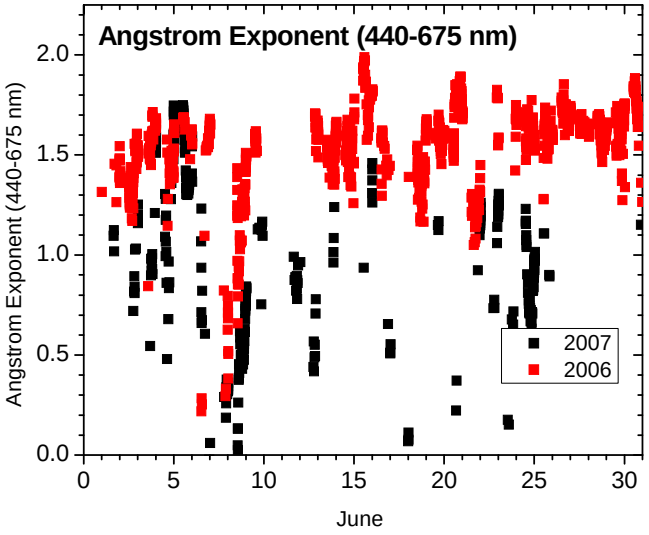


Cimel data from AERONET (Rick Wagener,Brent Holben)





- 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)