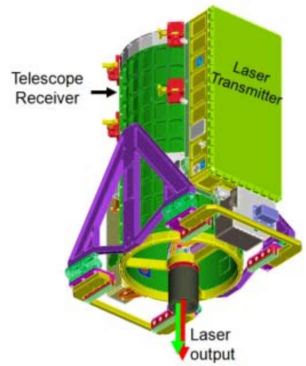
Airborne and Ground-based Lidar Measurements of Aerosols and Clouds During CLASIC/CHAPS



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DOE ARM Science Team Meeting
March 11, 2008

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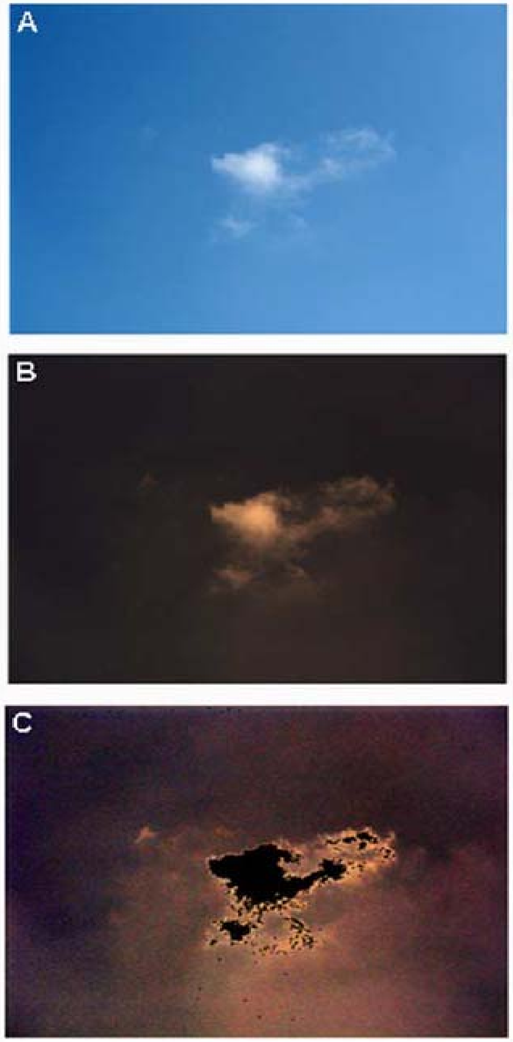
NASA HQ Science
Mission Directorate
Radiation Sciences Program

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

Aerosol Properties Near Clouds

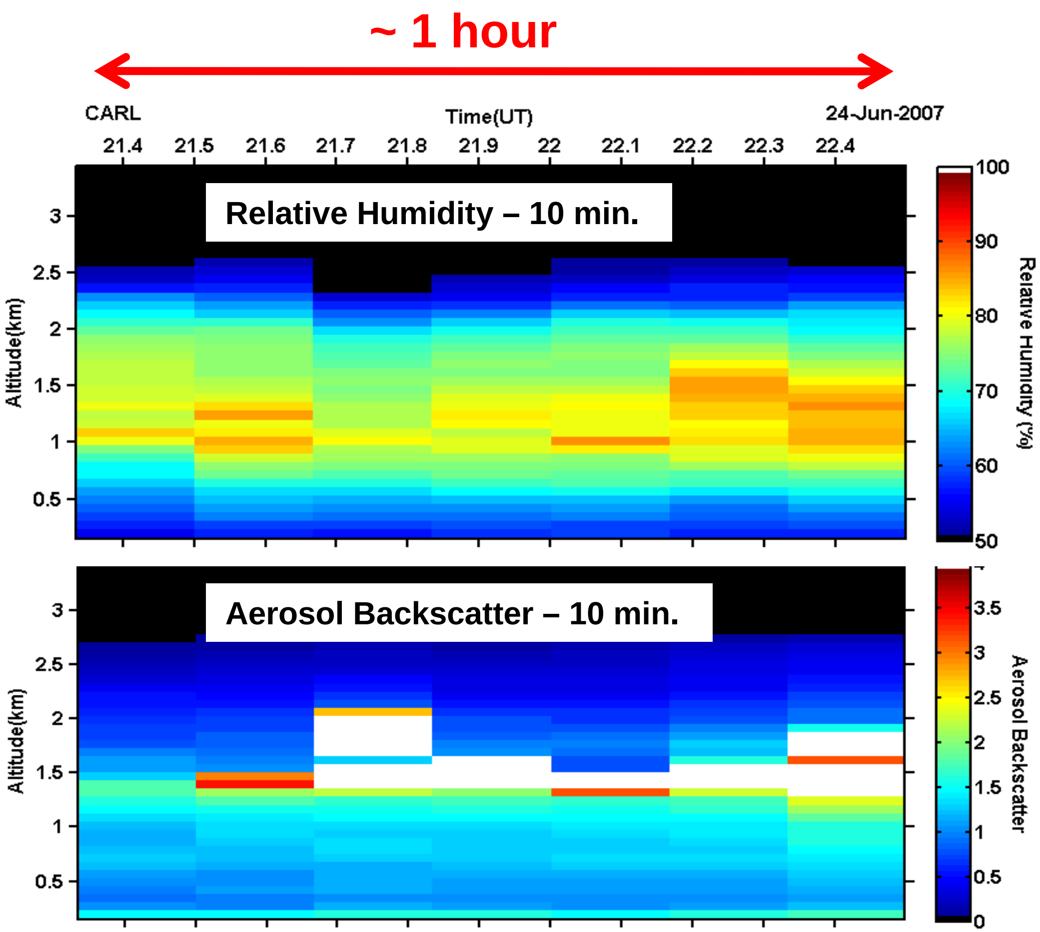
- Satellite, airborne, and surface sensors have noted significant changes in aerosol properties in transition zones near clouds (“Twilight Zone”, Koren et al., 2007)
  - Area of forming/evaporating cloud fragments and hydrated aerosols
- Increase in aerosol optical thickness (5-25%) has been observed in such zones
- Other studies have pointed out existence of continuum in optical depths and cloud albedos rather than distinct separation of aerosol and cloud values (Charlson et al., 2007)
- Questions:
  - How do the sizes of such zones vary ?
  - How are these effects related to hygroscopic growth, increased particle production, in cloud processing?
  - How do we interpret satellite observations of such zones given 3-D cloud radiative effects, sample bias, etc. ?
- We use combination of advanced ground (SGP Raman Lidar) and airborne (NASA/LaRC HSRL) lidars to address these questions



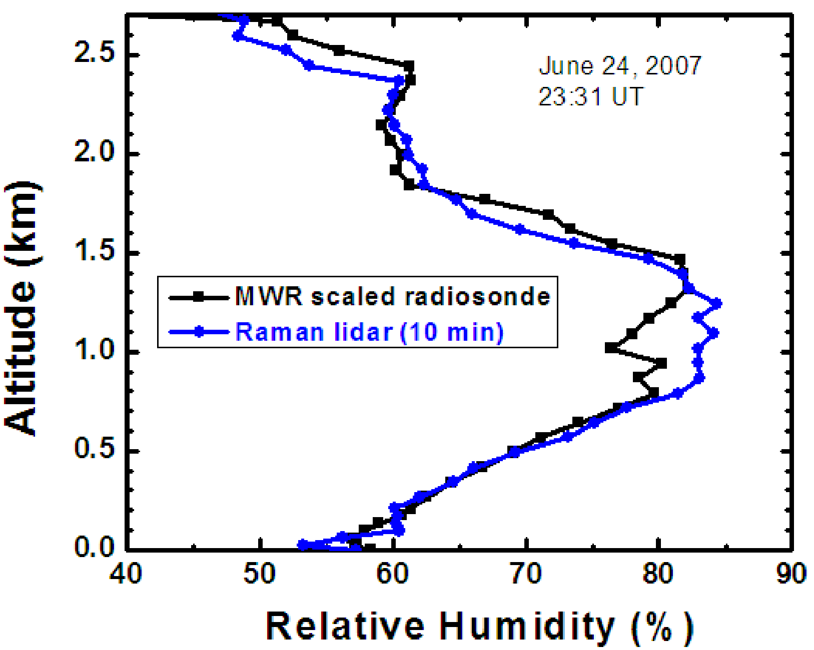
Koren et al., 2007

SGP CART Raman Lidar (CARL)

- Water vapor, aerosol, depolarization profiles
- Precipitable water vapor and aerosol optical thickness (355 nm)
- Designed for continuous, autonomous (24/7) operation
- Operational retrievals since 1998

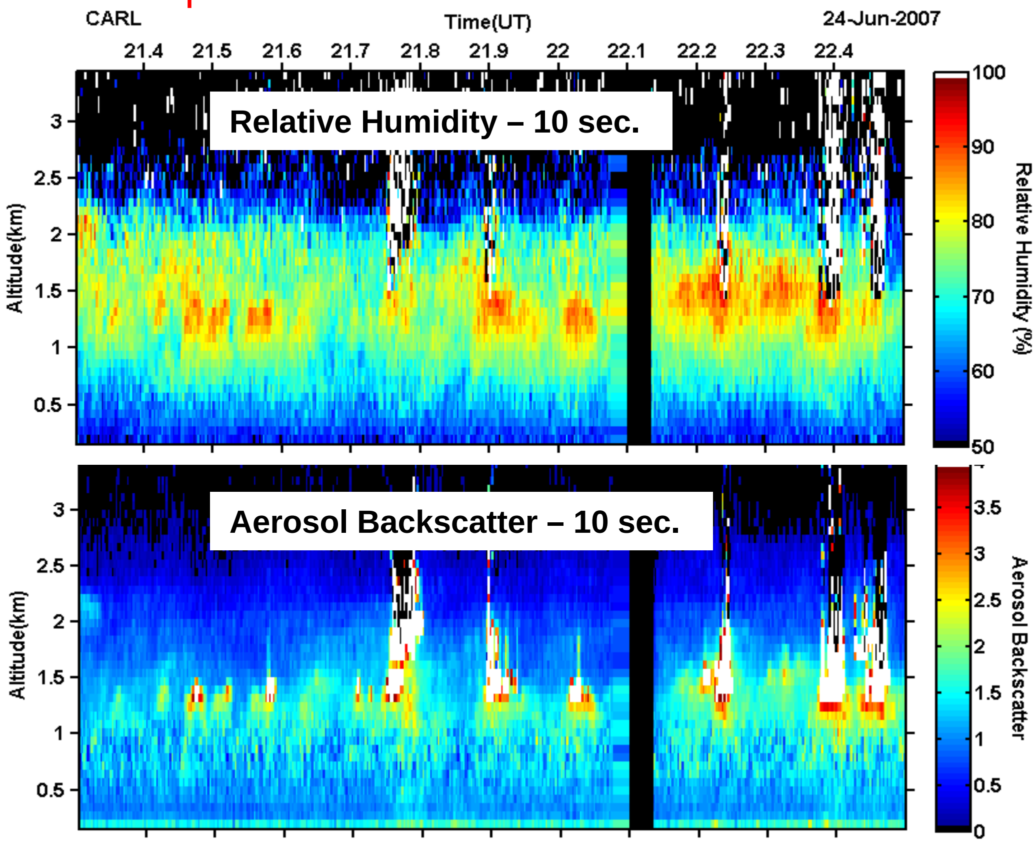


(Turner et al., JAOT, 2002)

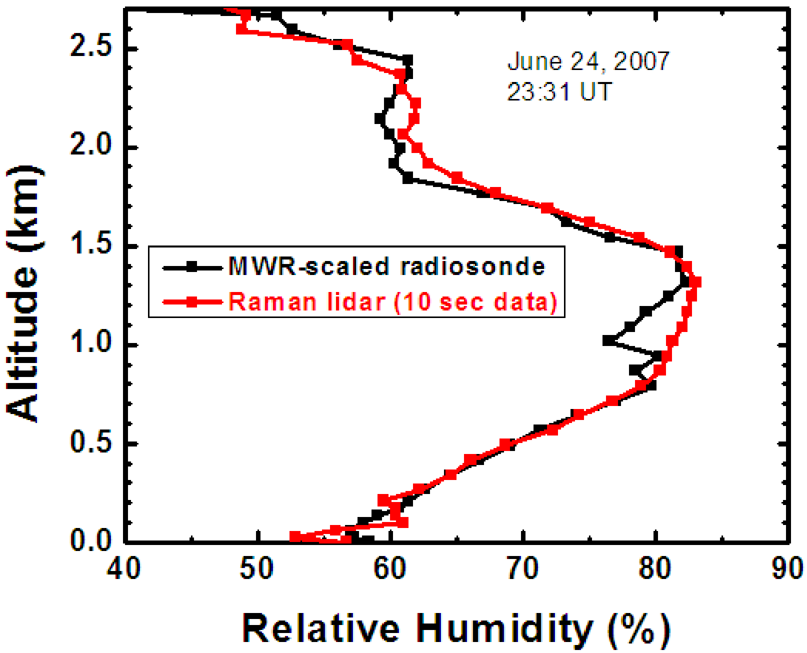


SGP CART Raman Lidar (CARL)

- Water vapor, aerosol, depolarization profiles
- Precipitable water vapor and aerosol optical thickness (355 nm)
- Designed for continuous, autonomous (24/7) operation
- Operational retrievals since 1998
- Hardware (2004) and software (2006-2007) upgrades now permit rapid (10 sec – 1min) water vapor and aerosol profiles



(Turner et al., JAOT, 2002)



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

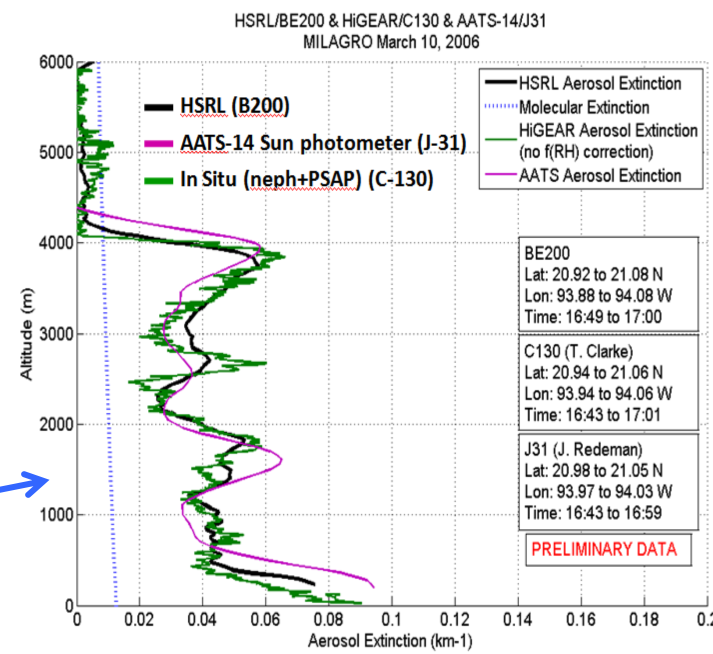
Data Products

- Aerosol scattering ratio (aerosol/molecular backscatter) (532 nm) (Δx ~ 1 km, Δz ~ 60 m)
- Aerosol backscatter coefficient at 532 nm (Δx ~ 1 km, Δz ~ 60 m)
- Aerosol extinction coefficient at 532 nm (Δx ~ 6 km, Δz ~ 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) (Δx ~ 6 km, Δz ~ 300 m)
- Aerosol depolarization (532 and 1064 nm) (Δx ~ 1 km, Δz ~ 60 m)

Extensive – depend on aerosol amount and type

Intensive – depend on aerosol type

Validation – aerosol extinction



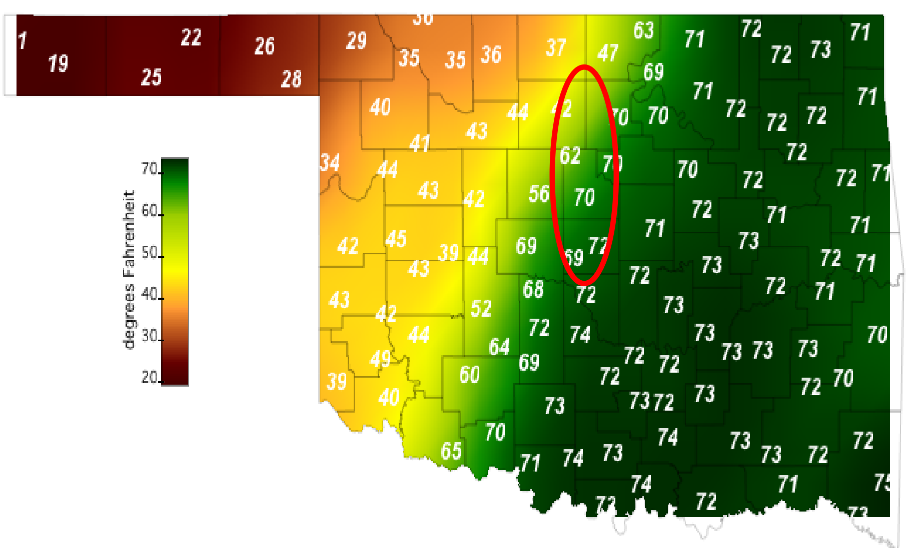
AATS-14 data (Jens Redemann, Phil Russell)

HIGEAR in situ data (Antony Clarke)

Raman Lidar Water vapor and Aerosol Measurements during June 7 Dry Line Passage

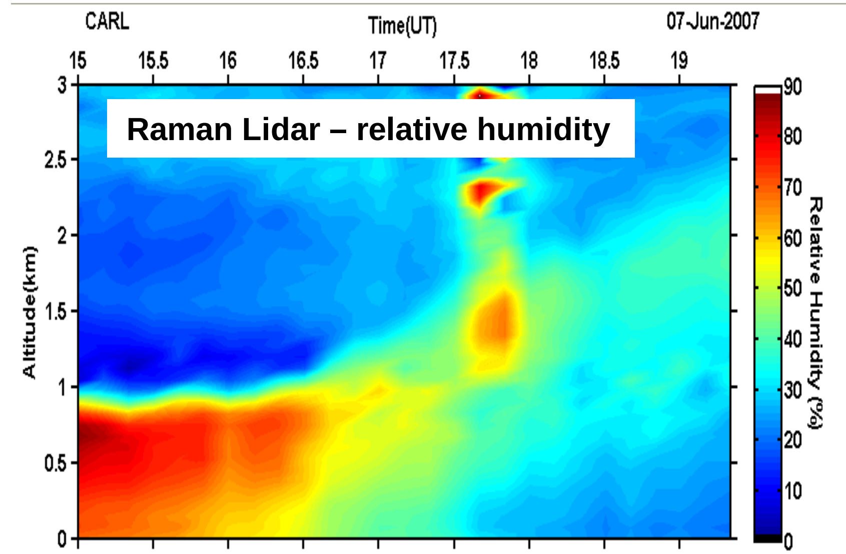
- **Dry line passed from NW to SE over SGP site and crossed the region between the SGP and OKC**
- **Raman Lidar measurements show large decrease in water vapor after passage of dry line**

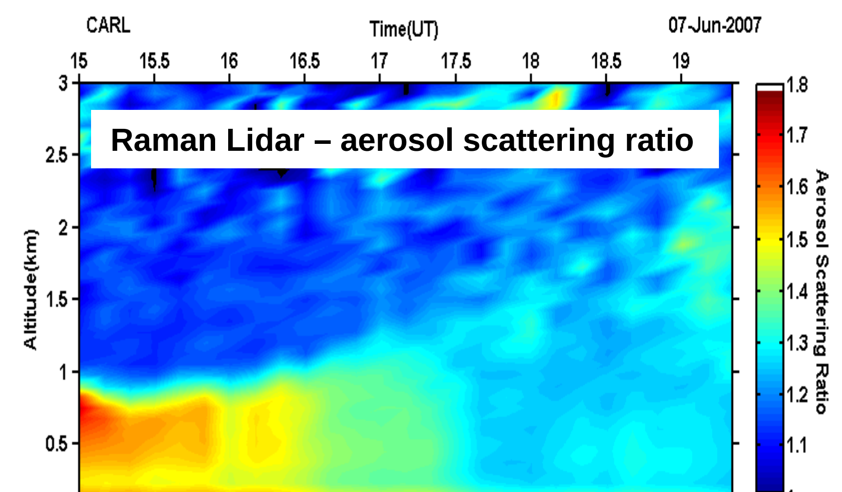
OK Mesonet; Surface Dew Point 20:00 UT



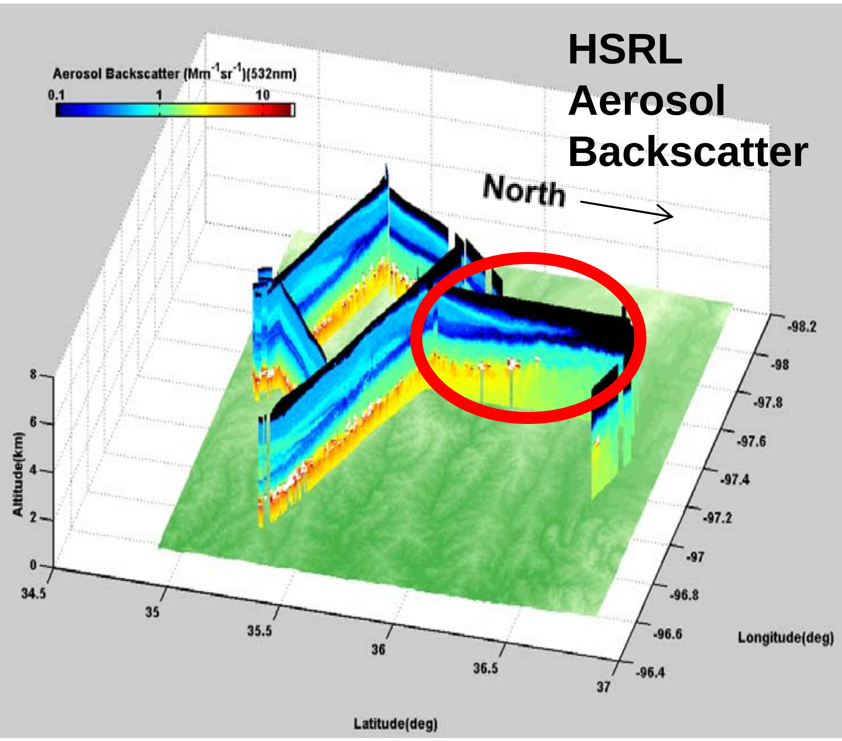
Oklahoma Mesonet

Temperature: Dew Point
06-07-2007 03:00 PM CDT

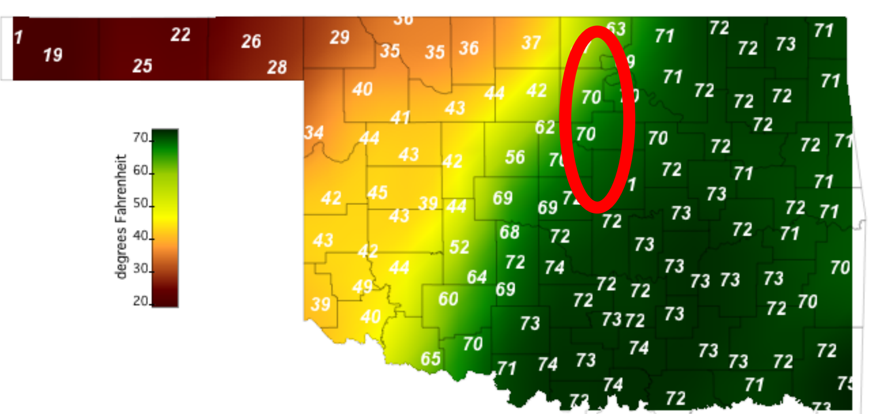




Airborne HSRL Measurements of Dry Line – June 7

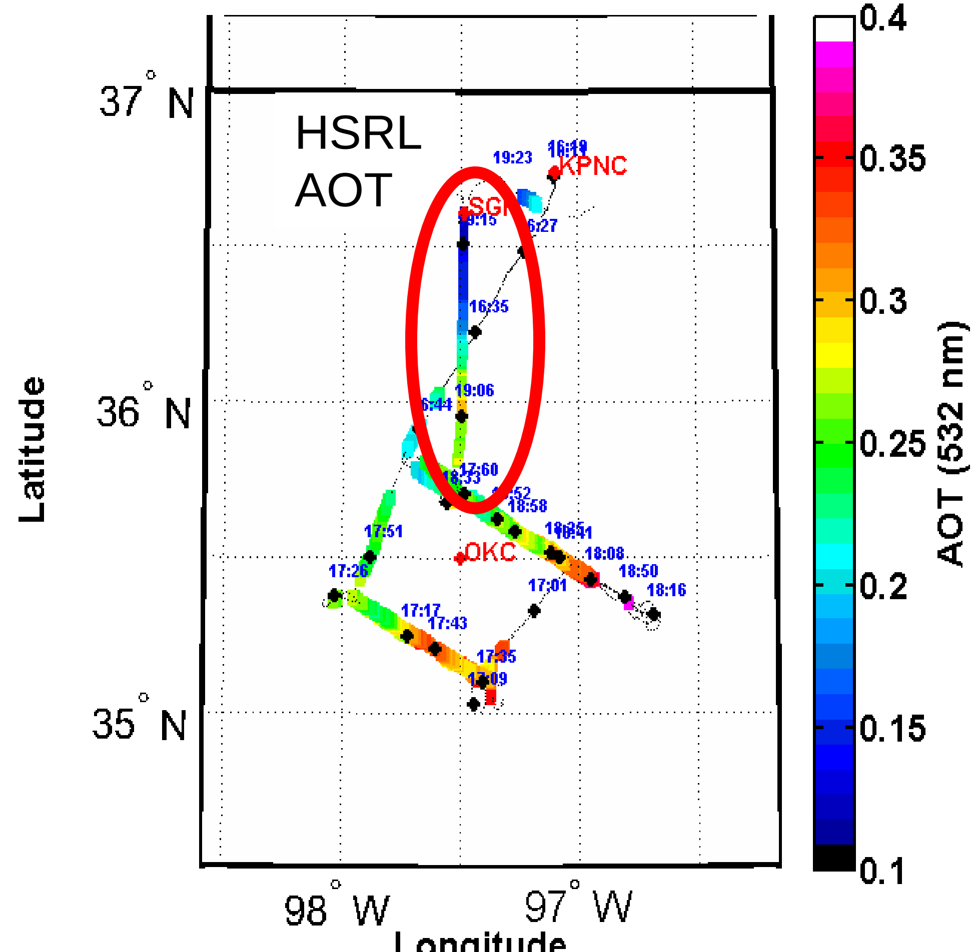


OK Mesonet; Surface Dew Point 20:00 UT



HSRL measurements show:

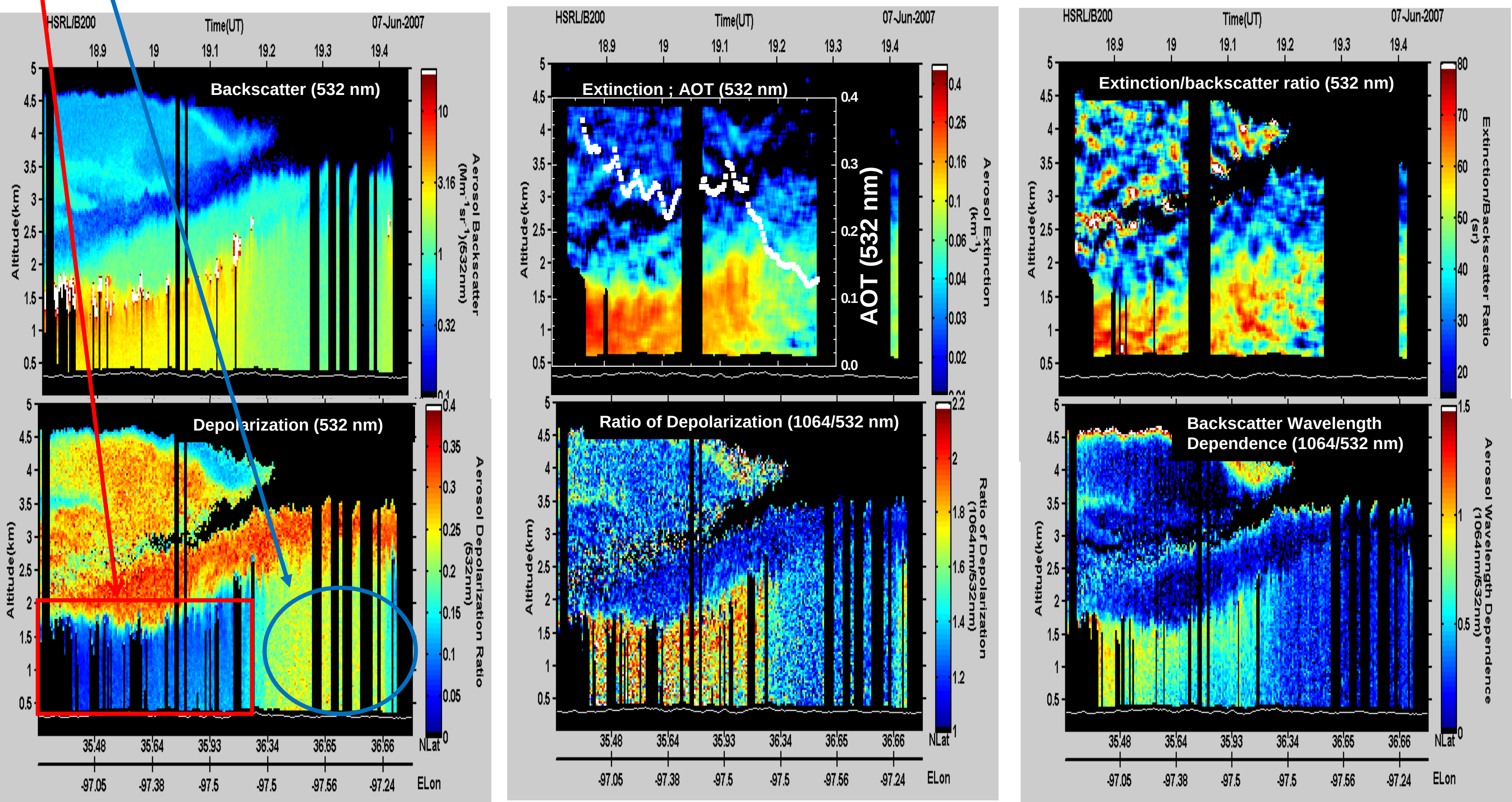
- **High AOT ahead (SE) of dry line in OKC region**
- **Large decrease in AOT behind (NW) of dry line**



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

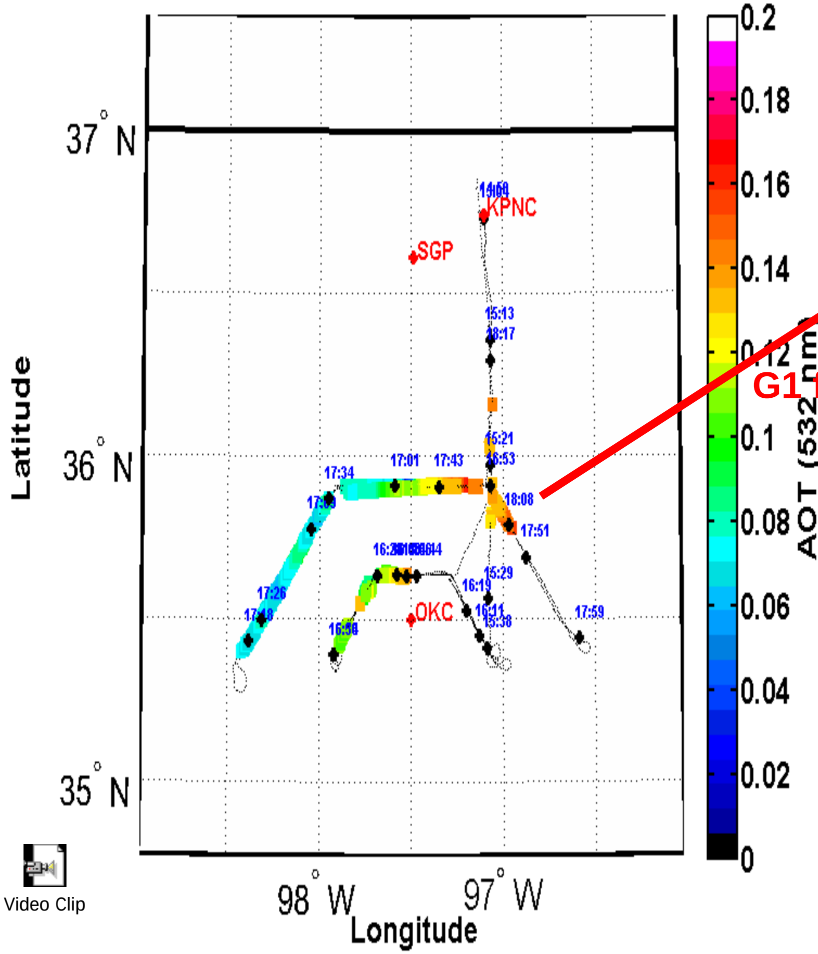


Example of CHAPS B200/G1 Coordinated Flight – June 24

HSRL measurements :

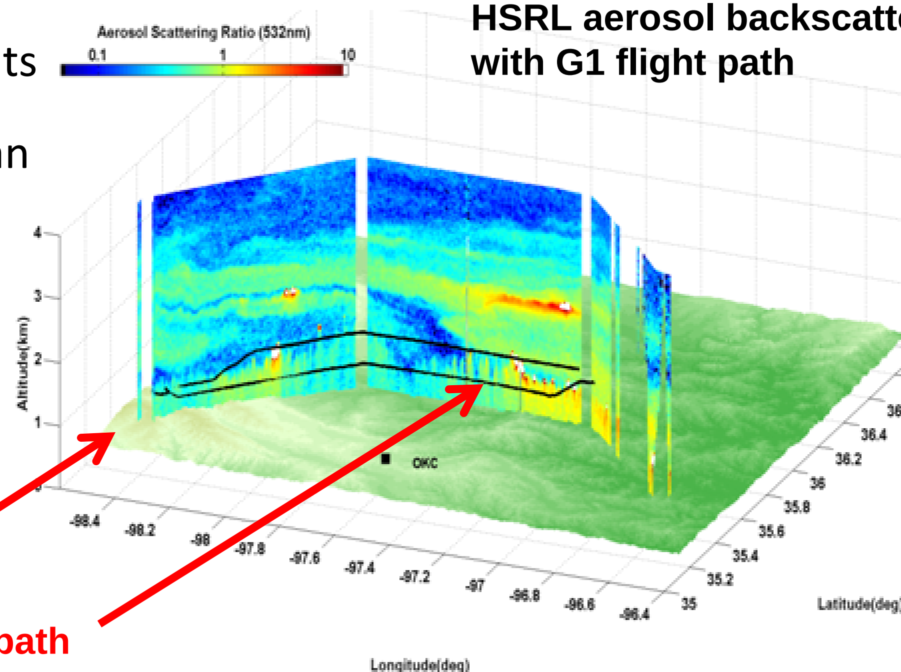
- Provide vertical context for G1 measurements
- Investigate changes in aerosol optical properties as a function of proximity to urban center (ex. upwind vs. downwind of OKC)

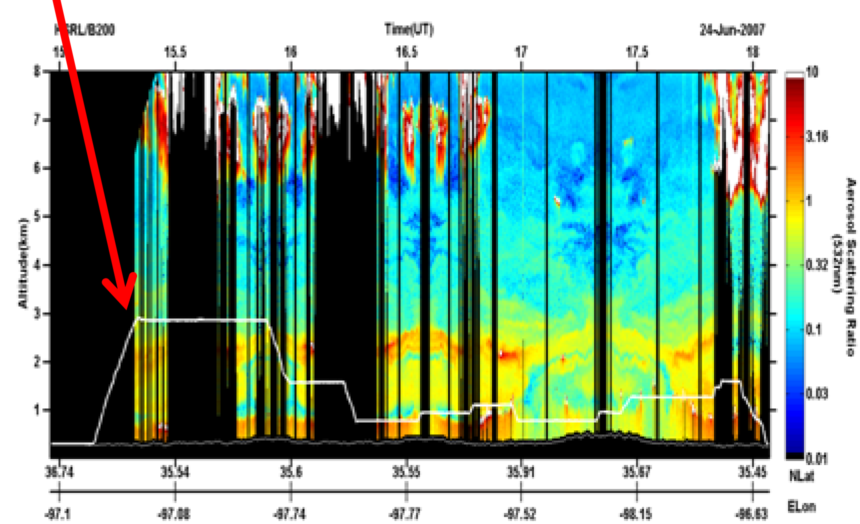
HSRL aerosol backscatter with G1 flight path



Video Clip

G1 flight path



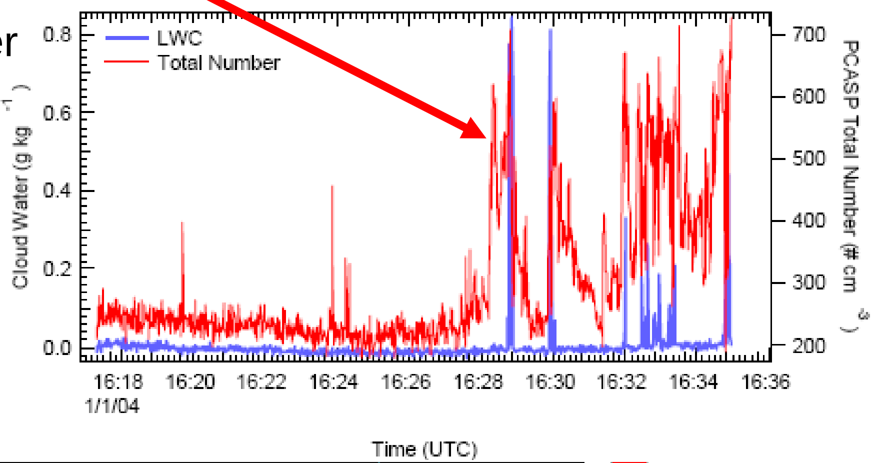


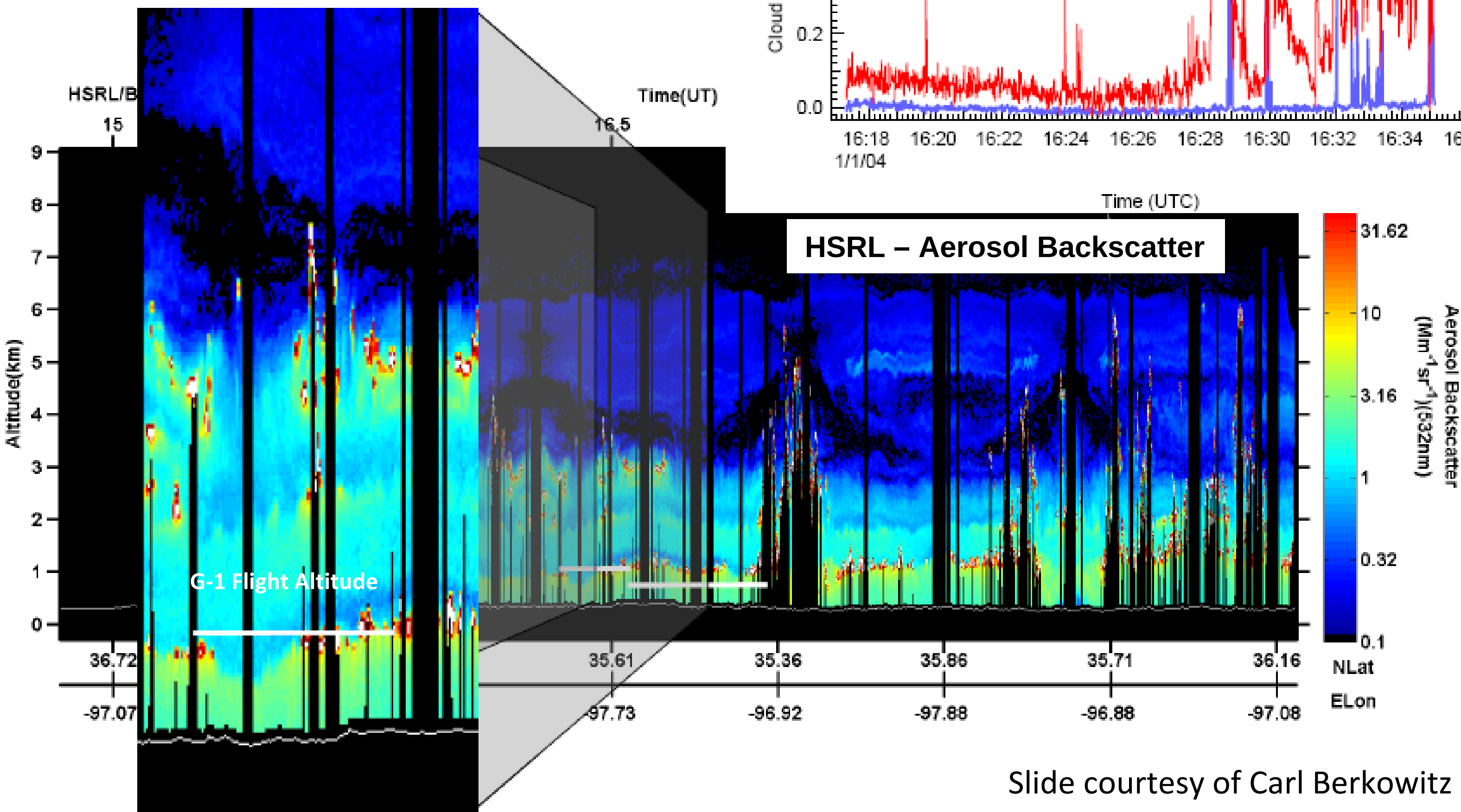
Coordinated B200/HSRL - Airborne in situ Measurements

- 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

June 23, 2007 DOE CHAPS Mission

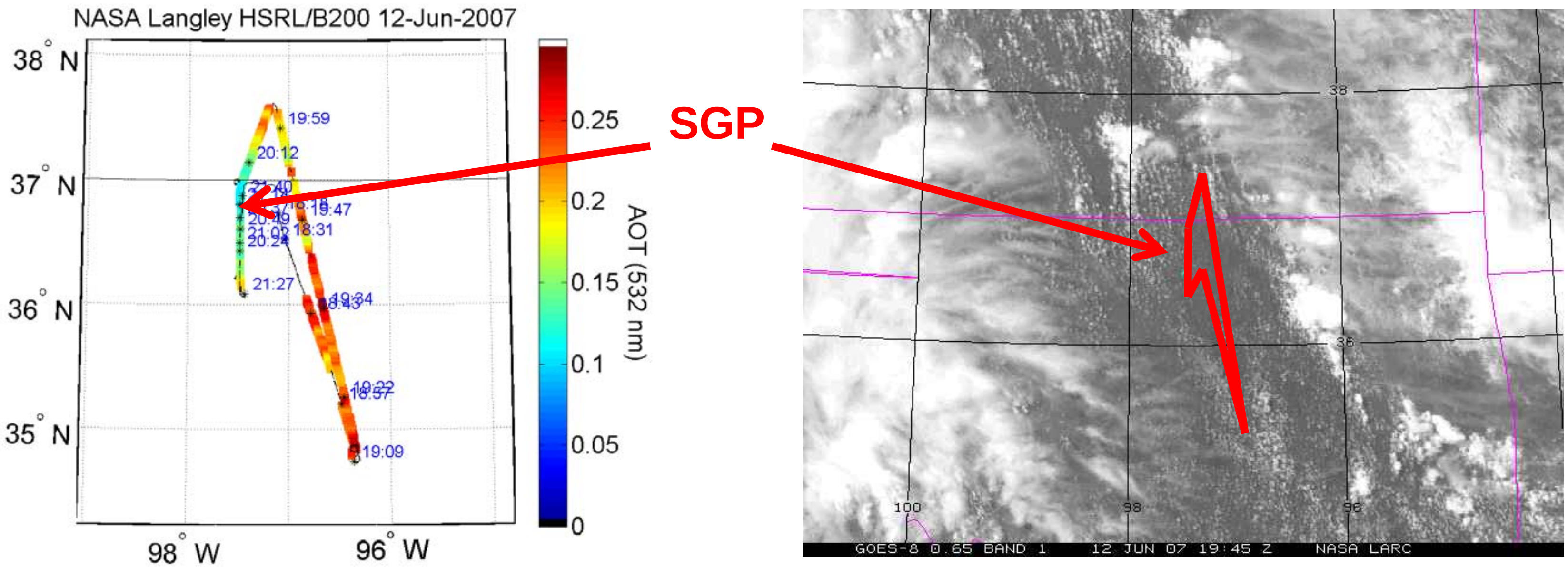
G-1 In situ Measurements

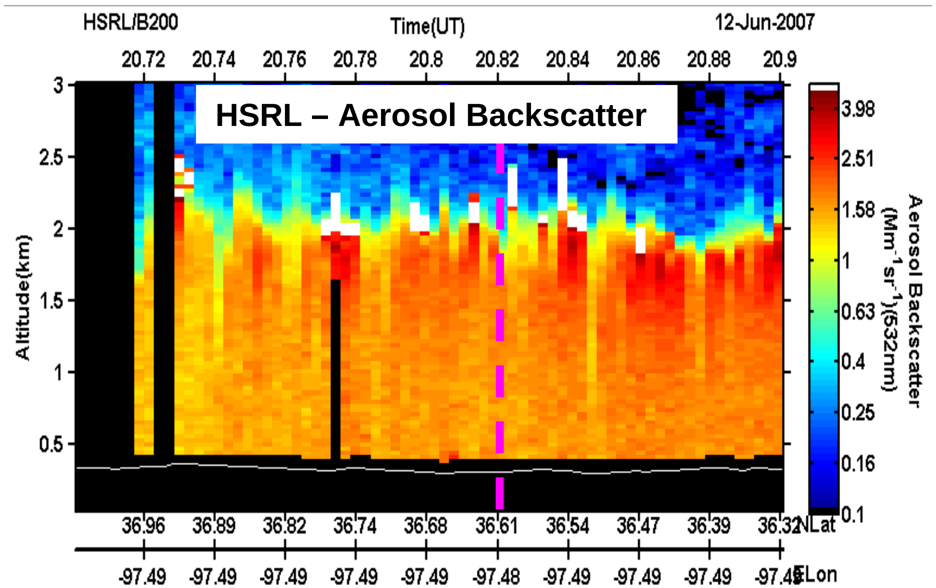




Slide courtesy of Carl Berkowitz (PNNL)

Airborne HSRL flight over SGP – June 12





HSRL measurements acquired over ARM SGP Raman lidar to investigate:

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

Changes in aerosol properties near clouds measured by airborne HSRL

HSRL measurements used to study spatial variations of aerosol optical properties near clouds

- Temporal resolution: 2 sec
- Vertical resolution:
  - 30 m backscatter
  - 300 m extinction
  - Averaged data within +/- 60 m of cloud top
  - Compare aerosol properties adjacent to cloud edge with properties some distance away from cloud edge

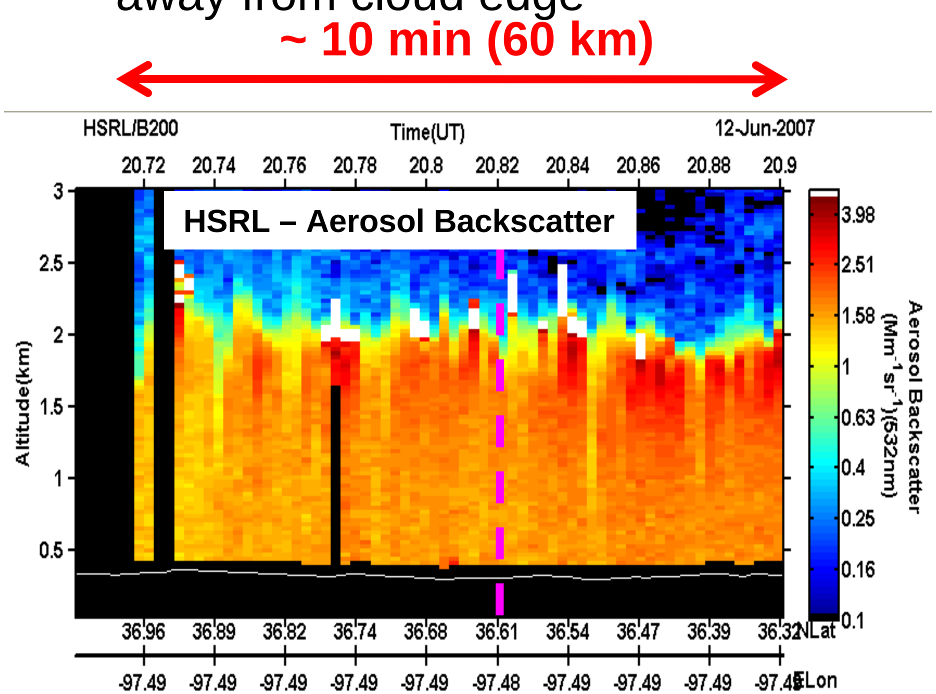
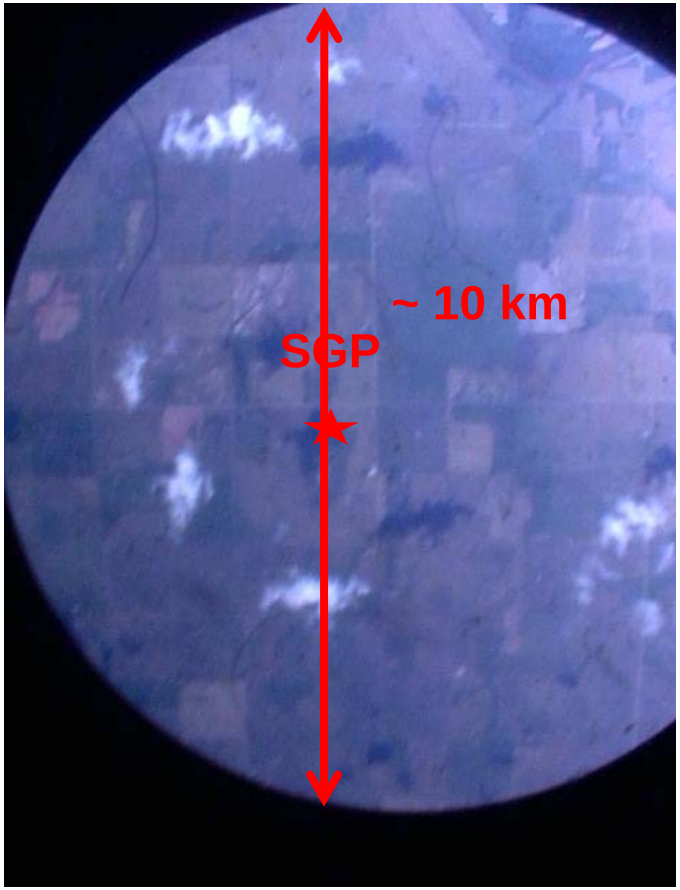


Image from digital camera on NASA B200 King Air

20070612_204915



Changes in aerosol properties near clouds measured by airborne HSRL

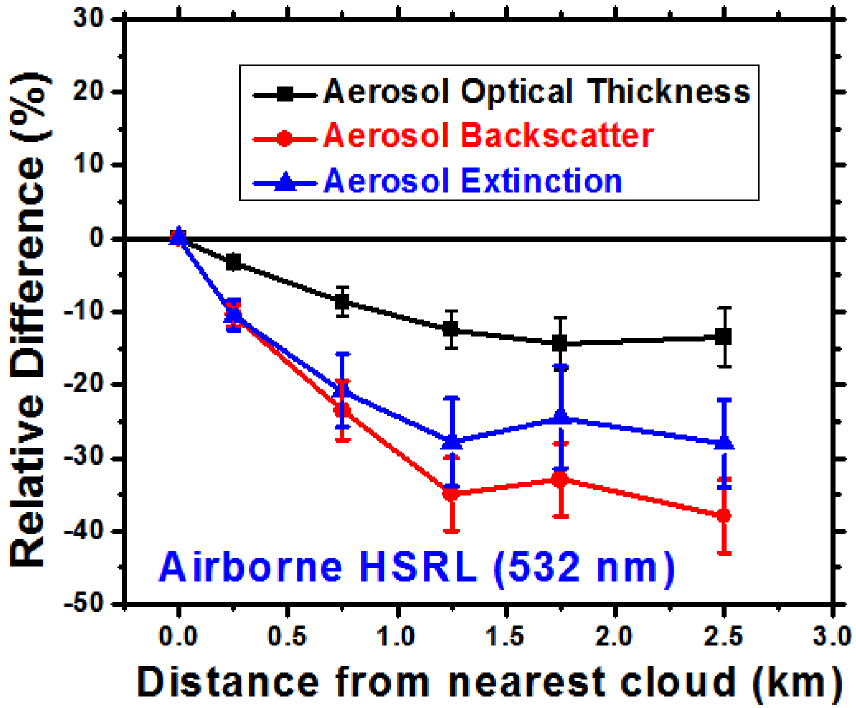
June 12, 2007 case

Significant changes in aerosol properties within 1-2 km of clouds. As distance from cloud increases:

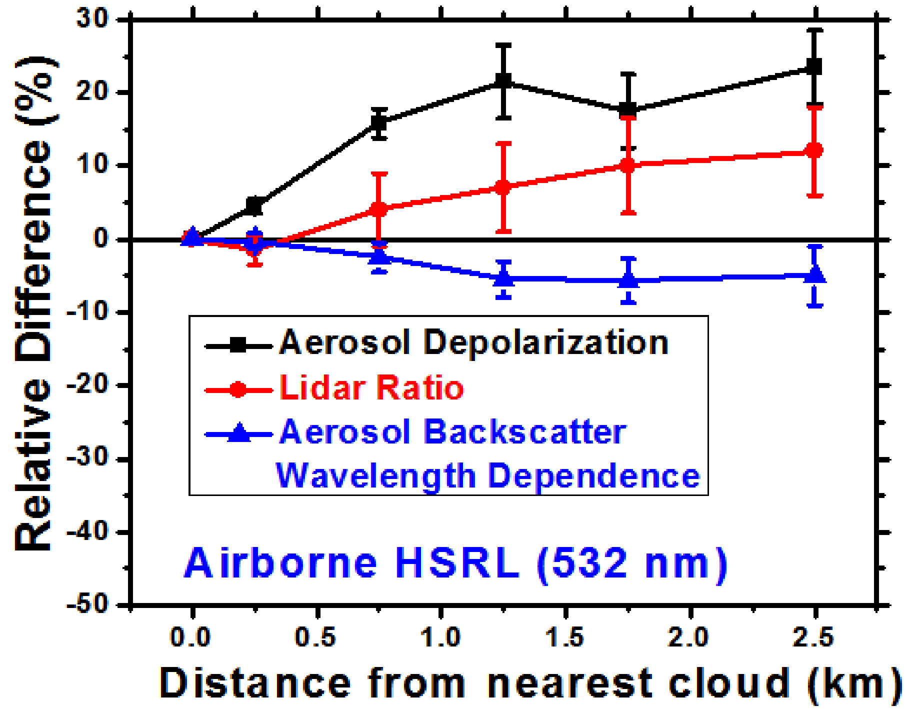
- AOT decreases 10-15%
- Aerosol backscatter and extinction decrease 25-40%
- Aerosol depolarization increases 10-20%
- Lidar ratio increases 5-10%
- Small (~5%) decrease in backscatter wavelength dependence

How much explained by changes in RH?

Aerosol Extensive Parameters

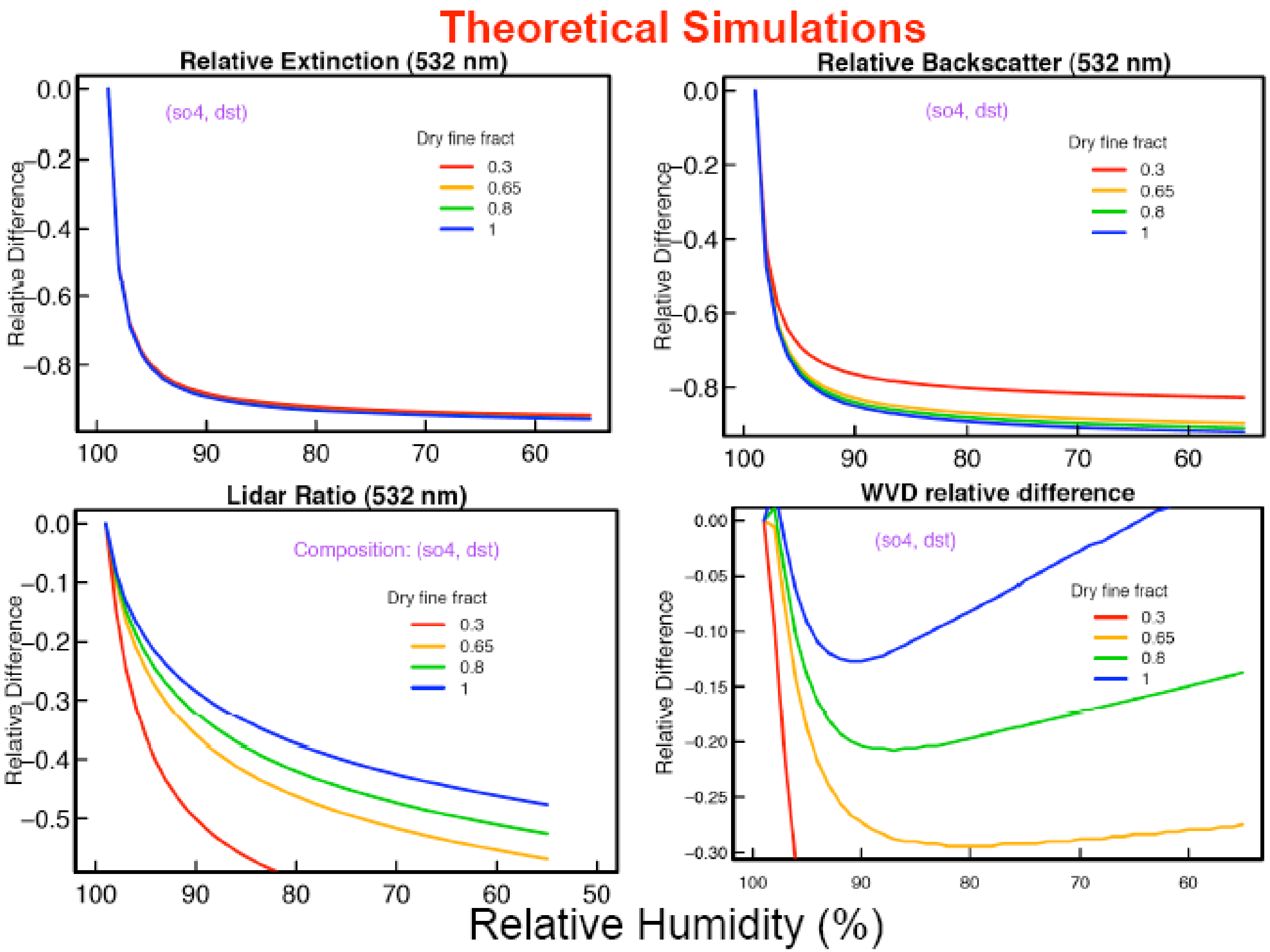


Aerosol Intensive Parameters



Simulated changes in aerosol properties with RH

- Simulations show:
  - significant decrease in aerosol backscatter and extinction with decreasing RH
  - smaller decrease in lidar ratio with decreasing RH
  - wide range in backscatter wavelength dependence behavior with decreasing RH



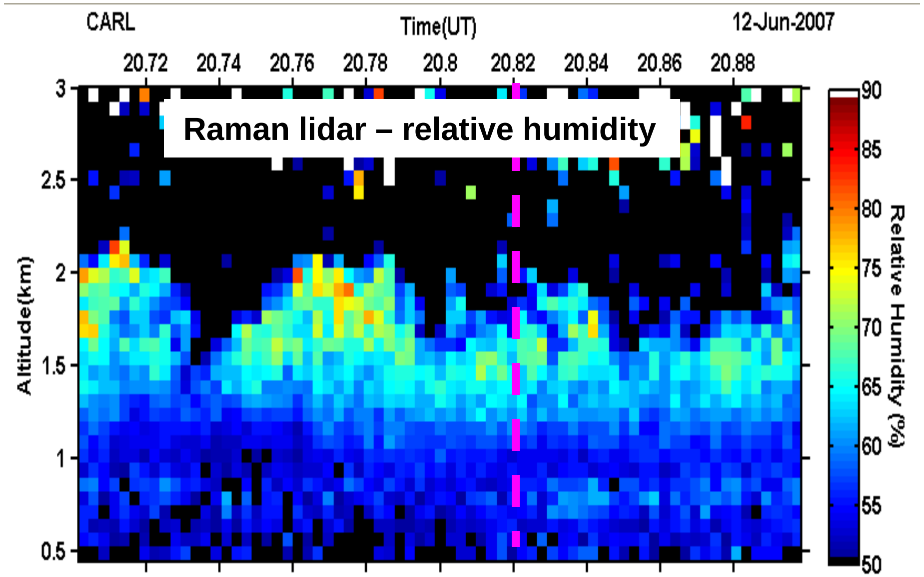
Changes in aerosol properties near clouds measured by SGP Raman Lidar

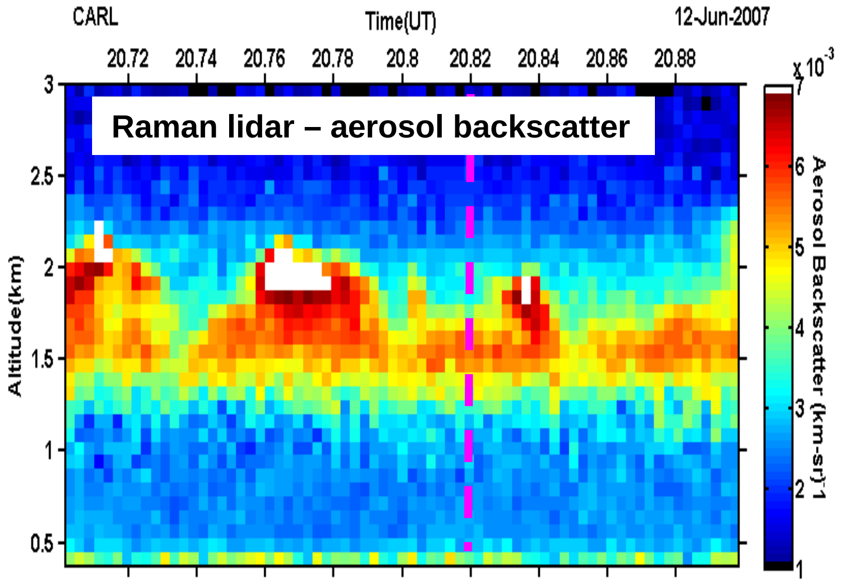
SGP Raman lidar measurements used to study spatial variations of relative humidity and aerosol optical properties near clouds

- Temporal resolution: 10 sec (RH, backscatter)
- Vertical resolution: 75 m (possible to go lower)
- Compare RH and aerosol properties adjacent to cloud edge with properties some time (distance) away from cloud edge
- Examined several altitudes above/below cloud base

SGP TSI image

~ 10 min

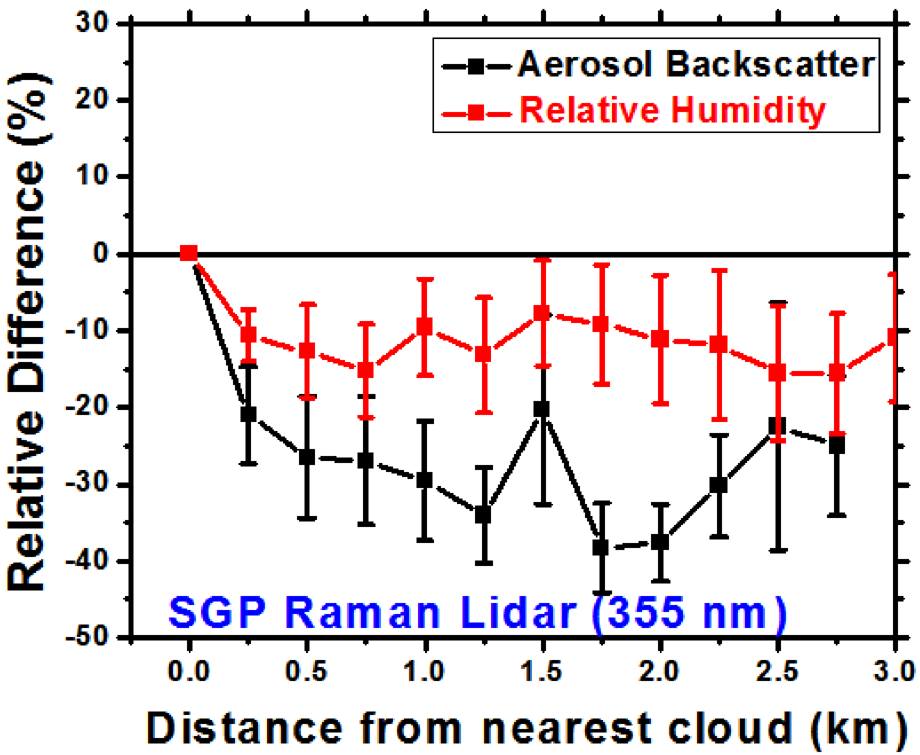


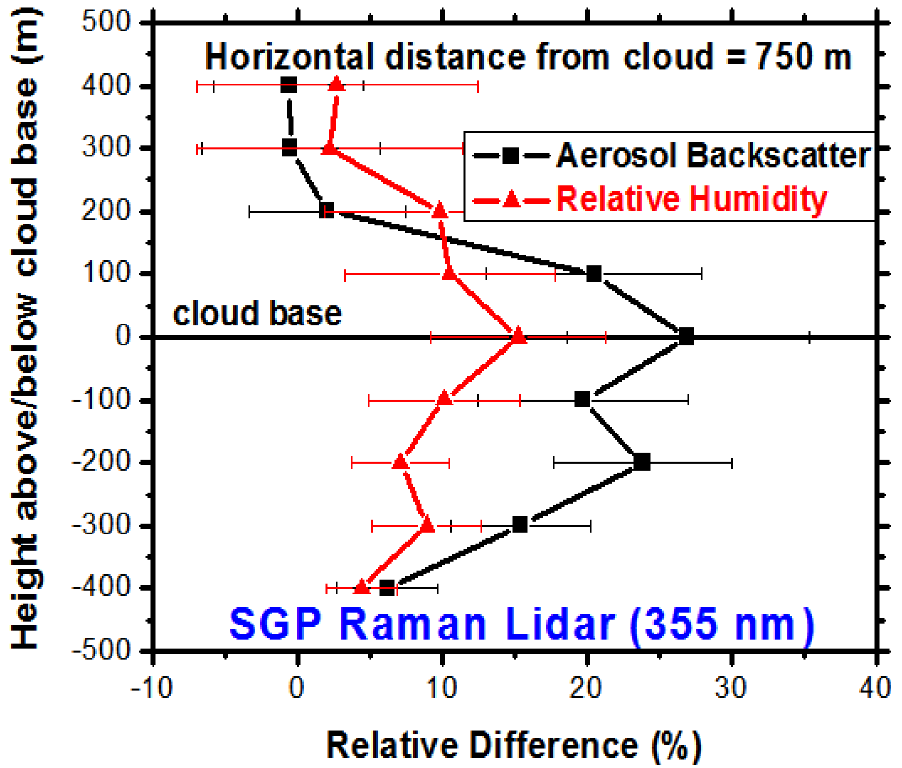


Changes in aerosol properties near clouds measured by SGP Raman Lidar

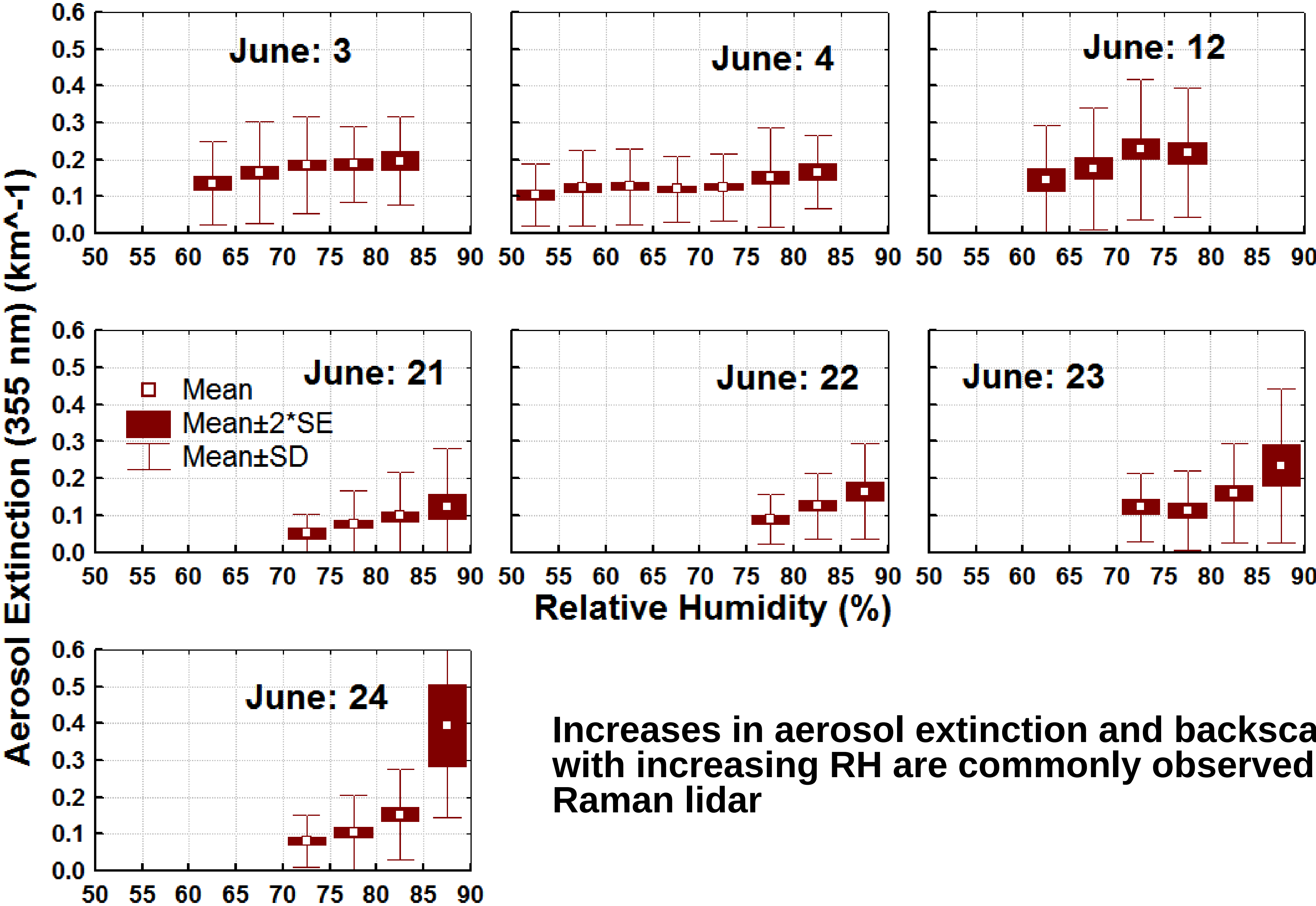
June 12, 2007 case

- Significant changes in aerosol properties within 1-2 km of clouds. As distance from cloud increases:
    - Similar (25-40%) decrease in aerosol backscattering observed from ground
    - Relative humidity decreases 5-15%
- Variations confined to altitudes between ~200-300 m below cloud base to 100-200 m above cloud base





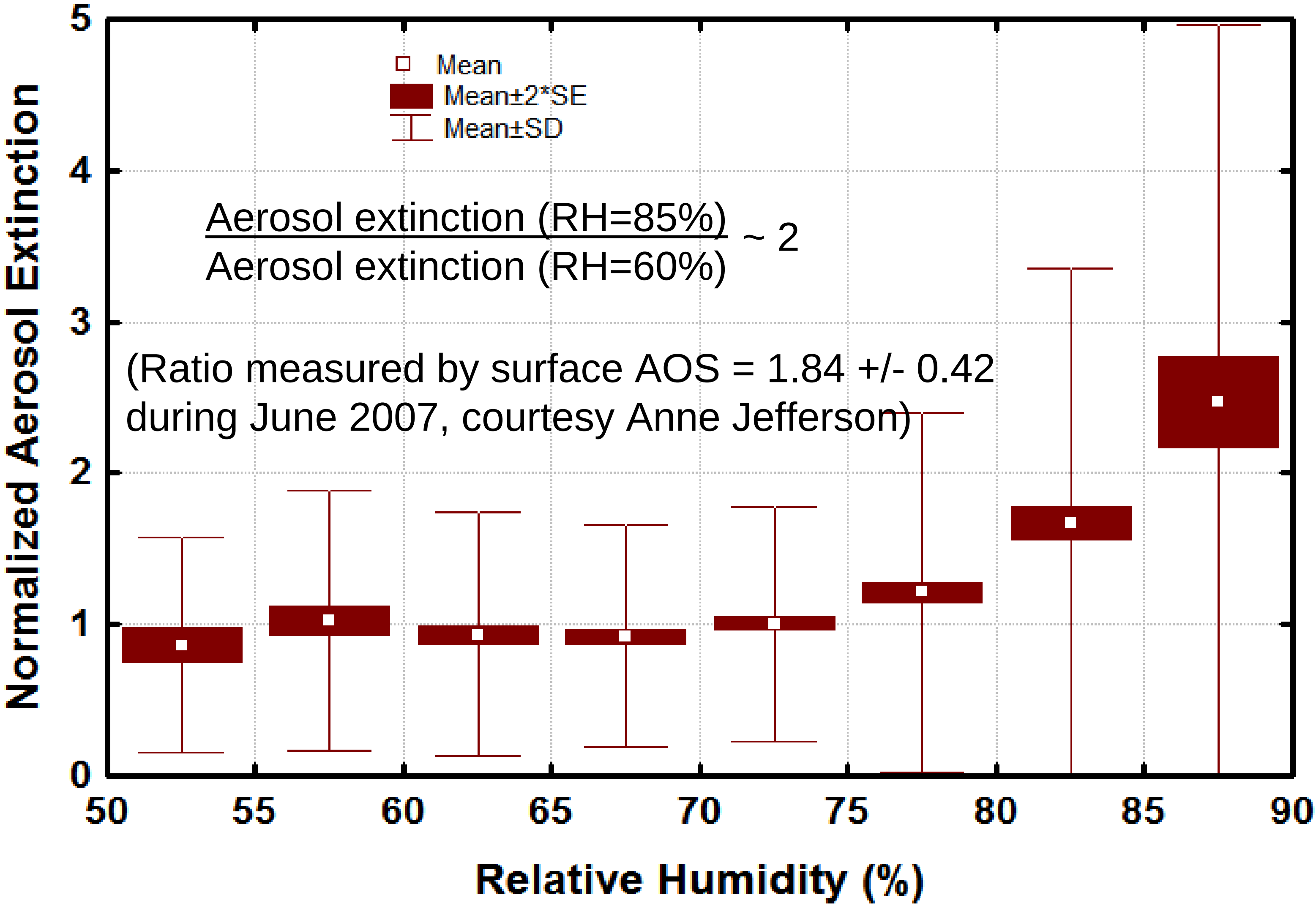
Aerosol Humidification Observed By SGP Raman Lidar



Increases in aerosol extinction and backscatter with increasing RH are commonly observed by Raman lidar

Aerosol Humidification Factor Derived from SGP Raman Lidar Measurements

Average aerosol humidification factor [f(RH)] derived from Raman lidar is slightly higher but consistent with surface AOS measurements

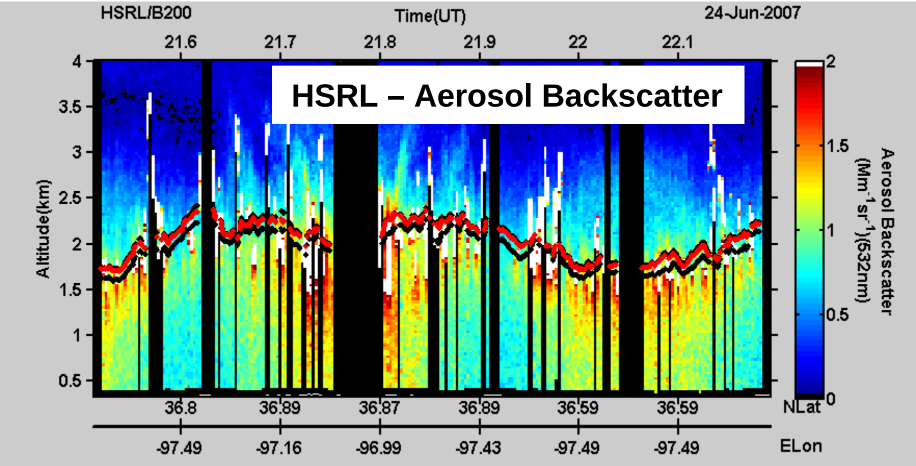


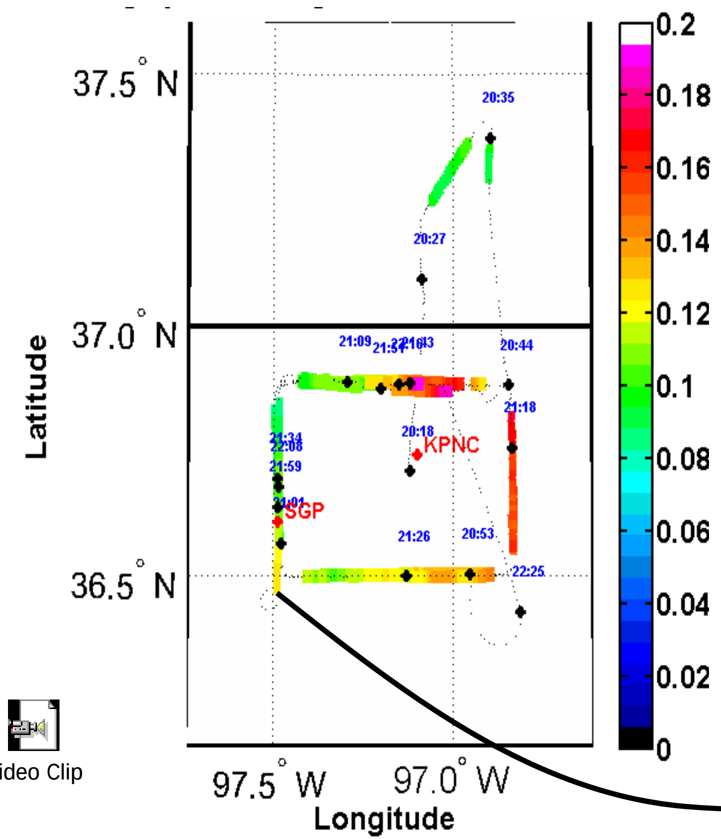
Summary

- Airborne HSRL and SGP Raman lidar data show:
  - significant changes in aerosol backscatter, extinction, AOT, and depolarization within a few km from clouds
  - changes in lidar ratio and backscatter wavelength dependence are smaller and/or less consistent
- Results using HSRL data from CLASIC/CHAPS generally consistent with results over east coast of U.S.
- Aerosol humidification factor [f(RH)] derived from Raman lidar consistent with values derived from surface AOS
- Anticipate additional studies using cloud images and airborne in situ data

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

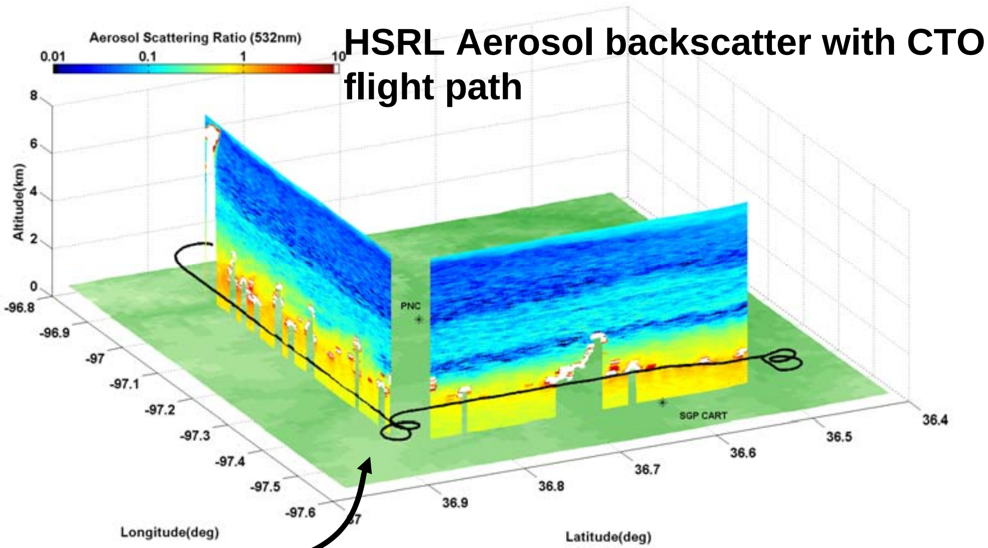
HSRL measurements :
- Provide vertical profiles of aerosol between and above cloud
- Provide vertical context for Twin Otter measurements
- Investigate changes in aerosol optical properties as a function of distance from clouds





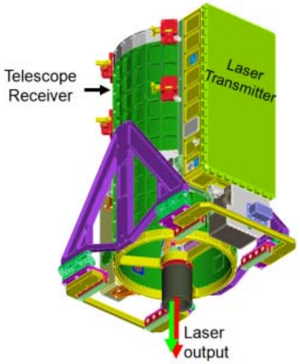
Video Clip

HSRL Aerosol backscatter with CTO flight path



Backup Slides

Airborne and Ground-based Lidar Measurements of Aerosols and Clouds During CLASIC/CHAPS



- Background – changes in aerosol properties near clouds
- Instruments and data – airborne HSRL and SGP Raman lidar
- Results – variability of aerosol and relative humidity near clouds

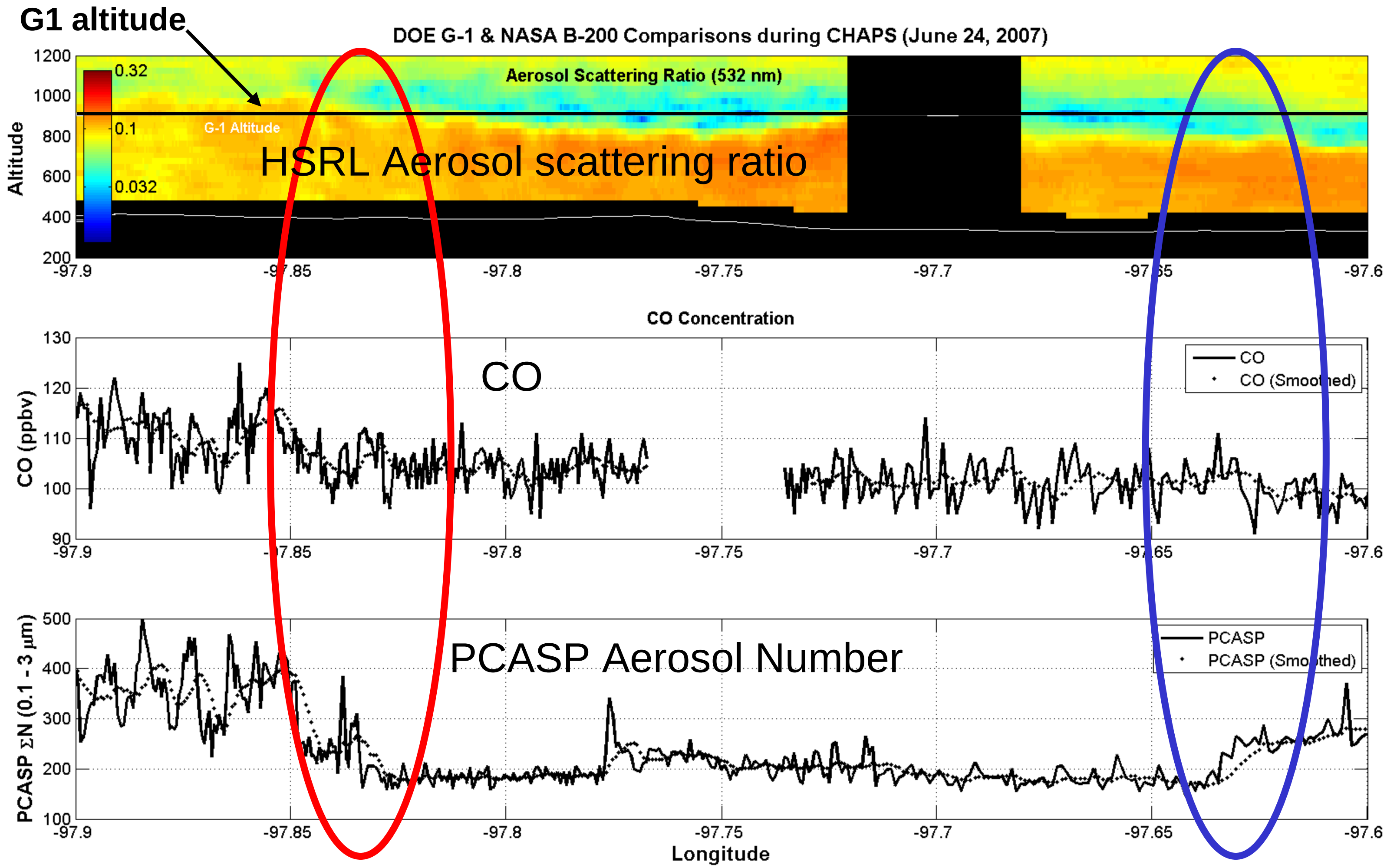
Funded by
NASA HQ Science
Mission Directorate
Radiation Sciences Program

DOE ARM Science Team Meeting
March 11, 2008

Atmospheric Science Program (ASP)

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

Example of CHAPS B200/G1 Coordinated Flight – June 24

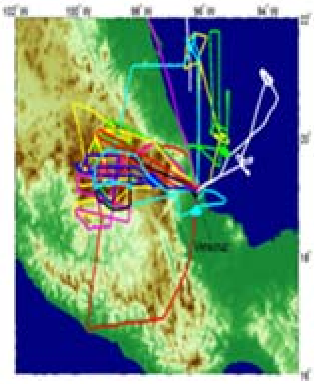


G-1 exiting aerosol layer: Decreasing HSRL Aerosol Scattering Ratio corresponds to decreasing CO and small particle concentration.

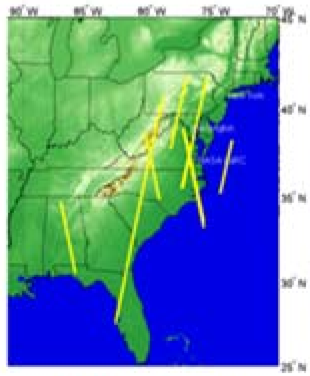
G-1 entering *different* aerosol layer: Increasing HSRL Aerosol Scattering Ratio corresponds to increase in small particle concentration with no change in CO.

NASA Langley Airborne High Spectral Resolution Lidar (HSRL) Missions

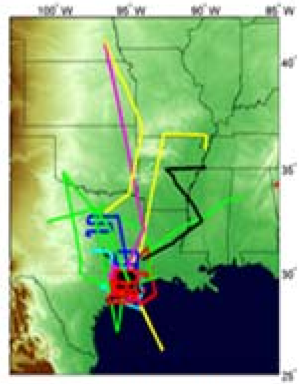
Past Campaigns:



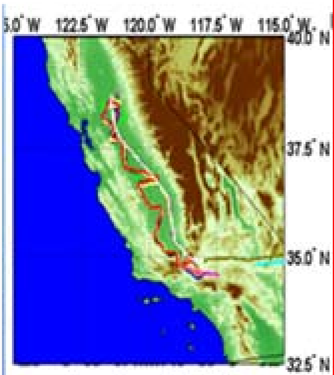
MAXMex/MILAGRO/INTEX-B
Mexico City
March 1-30, 2006



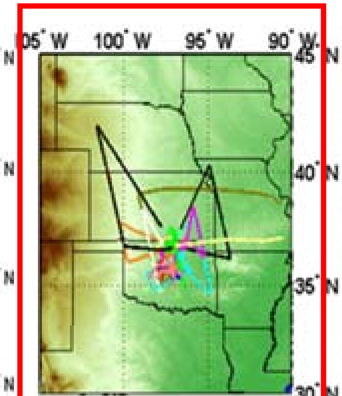
CALIPSO Validation
Eastern U.S.A.
June 14 – Aug 10, 2006



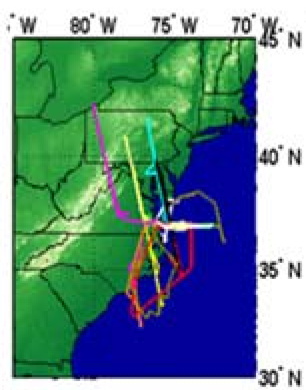
TexAQS II/GoMACCS
Houston
Aug 27 – Sep 29, 2006



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

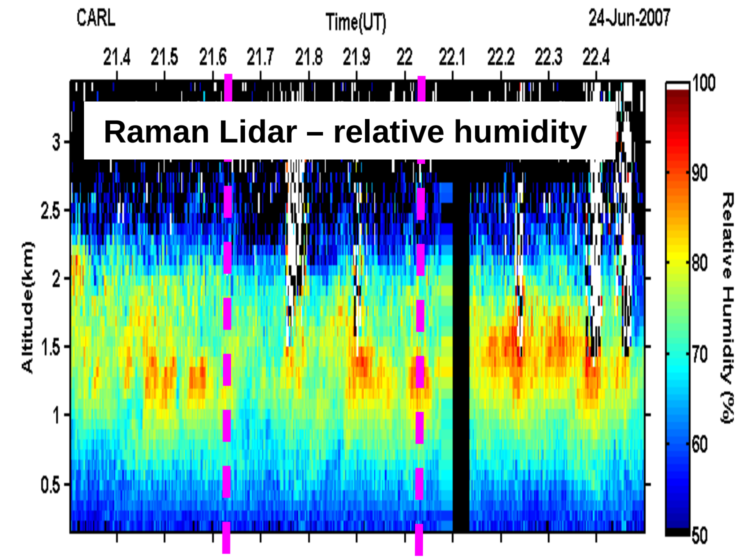
- Capabilities
  - HSRL at 532 nm: *independently* measures aerosol backscatter and extinction at 532 nm
  - Backscatter lidar at 1064 nm
  - Depolarization at both 532, 1064 nm

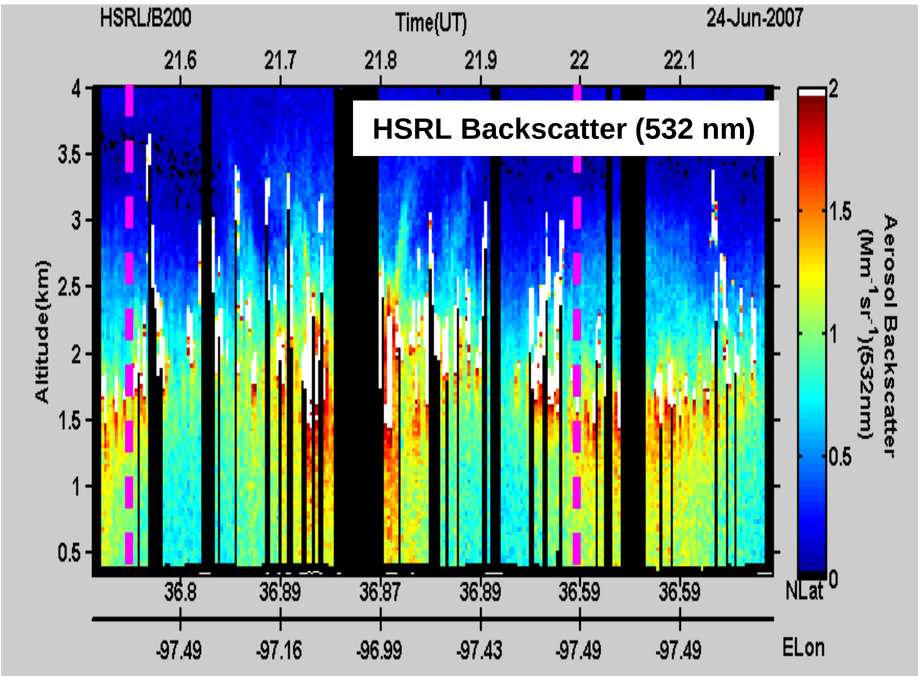
- History
  - 2000-2004: instrument development
  - Dec 2004: first test flight on Lear 25-C
  - Dec 2005: first test flight NASA King Air
  - 2006: flew on 3 major campaigns:
    - MILAGRO (55 hours)
    - TexAQS/GoMACCS (90 hours)
    - CALIPSO Val (51 hours)
  - 2007: flew on 3 campaigns:
    - San 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!

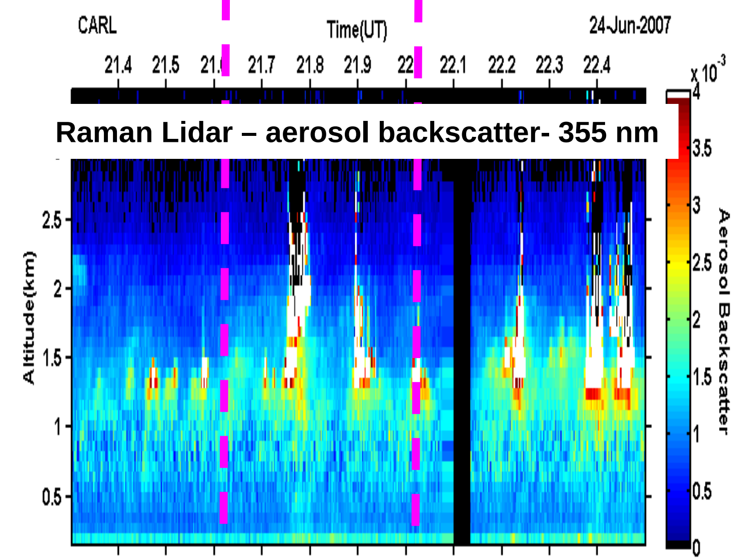
Example of measurements over SGP Raman Lidar - June 24

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

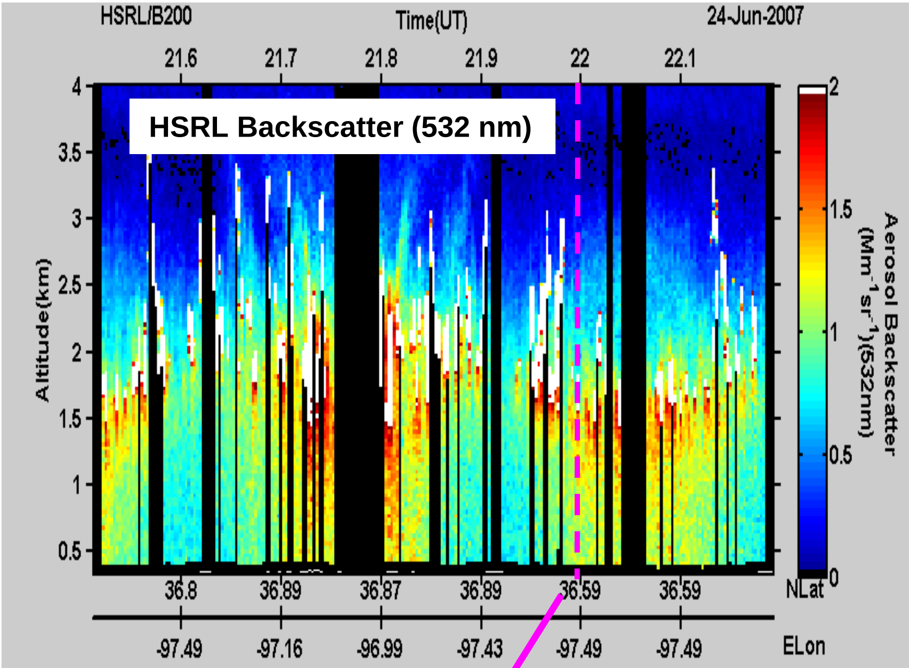
- Investigate changes in aerosol optical properties as a function of
  - RH
  - Distance from clouds
- Advanced, multi-wavelength lidar retrievals



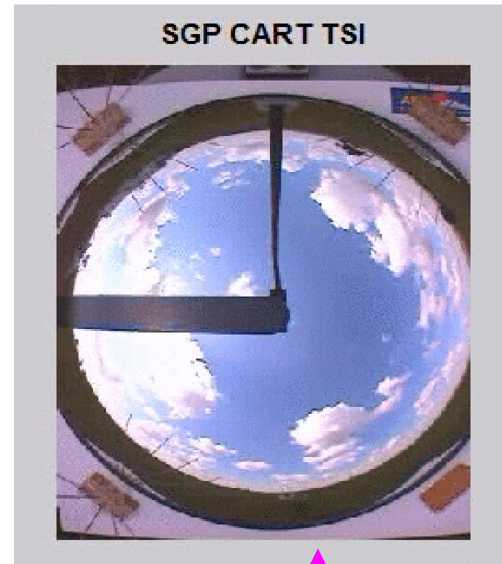


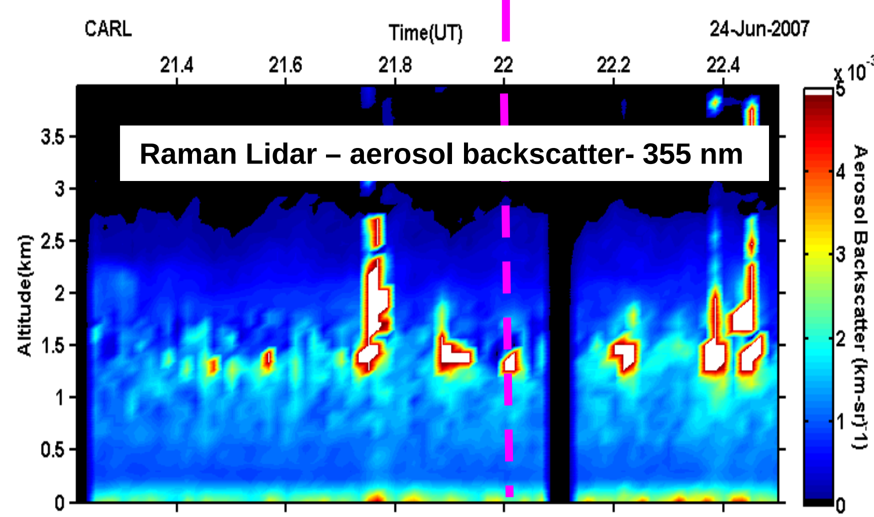


Example of measurements over SGP Raman Lidar - June 24



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





CLASIC/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)
- Provide cloud top and PBL heights
- Locate horizontal extent of OKC plume
- Use HSRL measurements of aerosol intensive parameters to infer aerosol types
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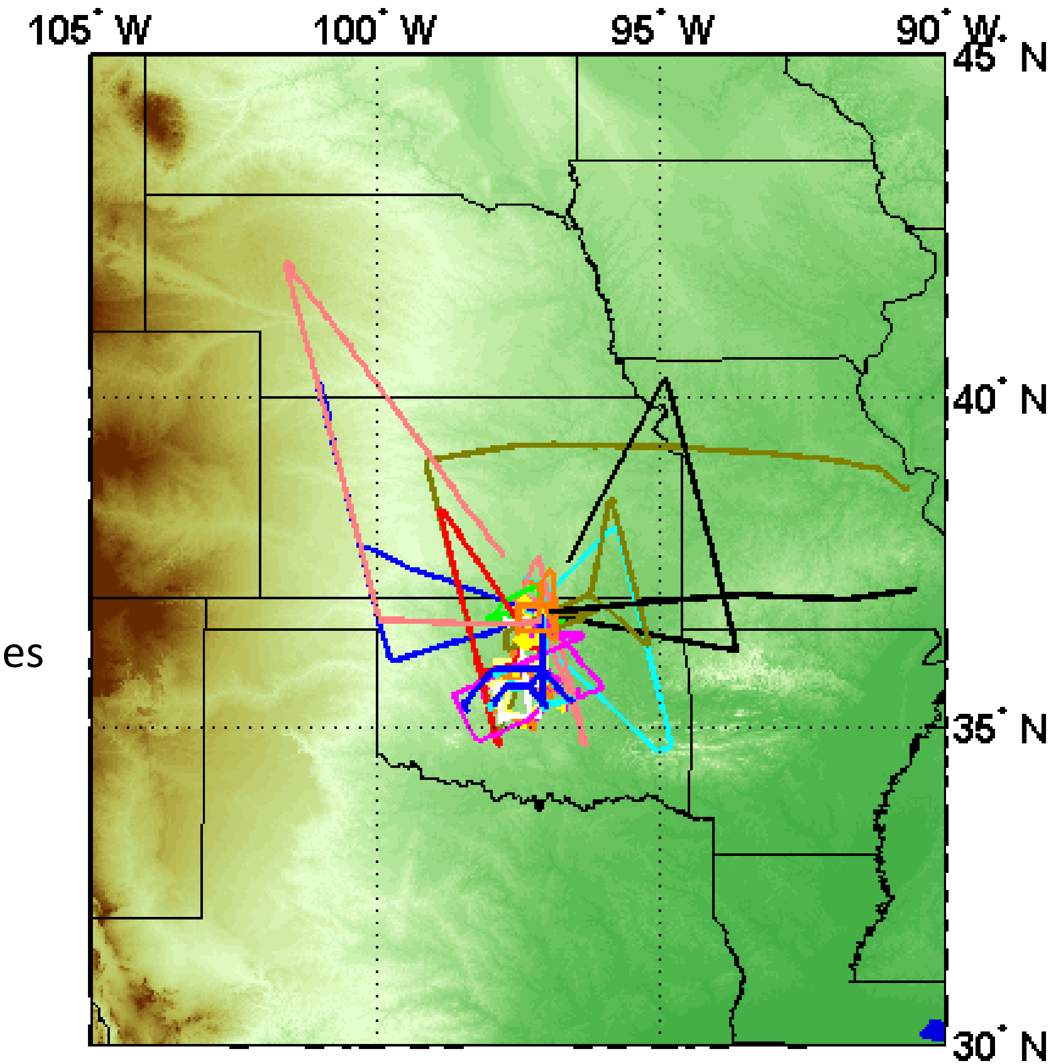
- Acquire data over DOE ARM SGP Raman lidar to investigate advanced, multi-wavelength lidar retrievals



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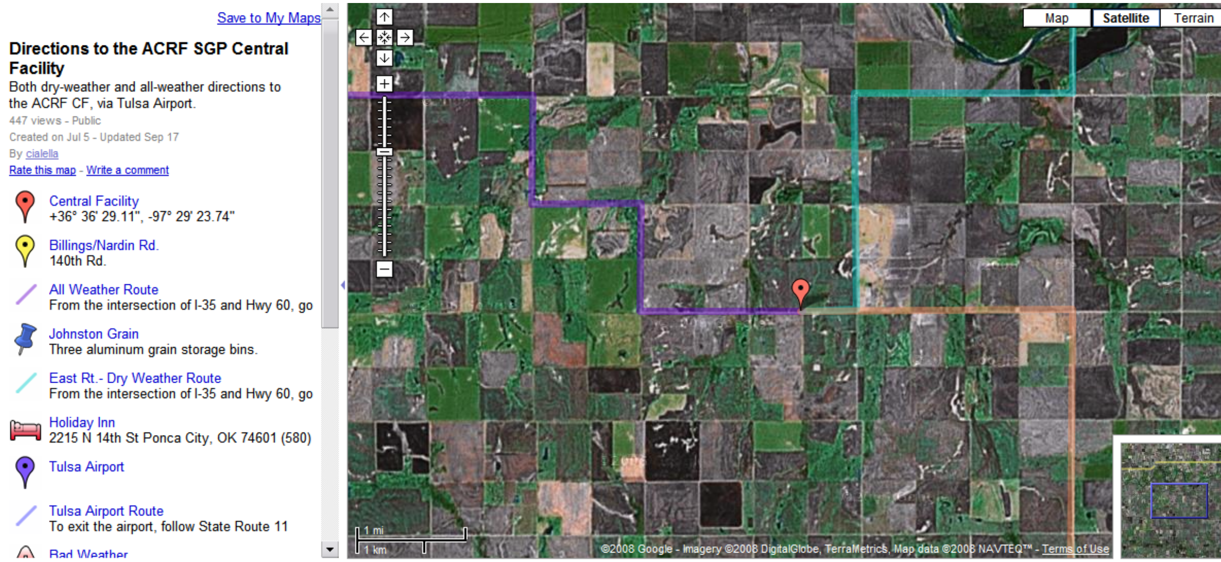
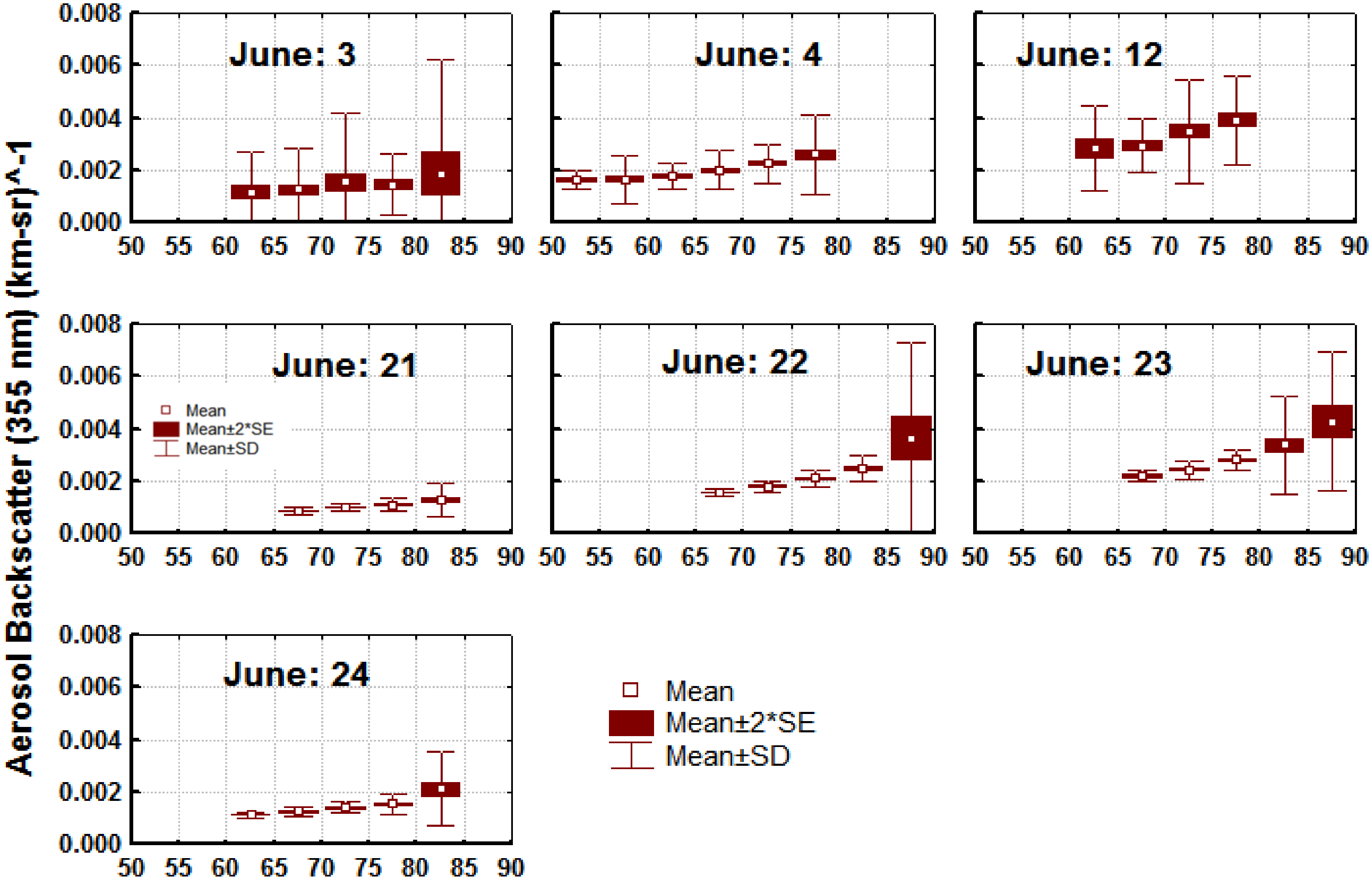




Aerosol Backscatter (355 nm) (km-sr)^-1
June: 3
June: 4
June: 12
June: 21
June: 22
June: 23
June: 24
0.008
0.006
0.004
0.002
0.000
50 55 60 65 70 75 80 85 90
Mean
Mean±2*SE
Mean±SD

Summary and Plans for CHAPS/CLASIC

<u>NASA Langley airborne HSRL</u>: 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
- Provide vertical context for interpretation of G-1 and CTO observations
- 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

HSRL/King Air Flights and Coordination with other Platforms

Green	Aircraft and HSRL flew all or partially coordinated flights
Blue	Aircraft believed to have flown; possibly coordinated
Red	Aircraft and HSRL flew UNCOORDINATED flights
Yellow	Aircraft operations unknown
Hatched	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

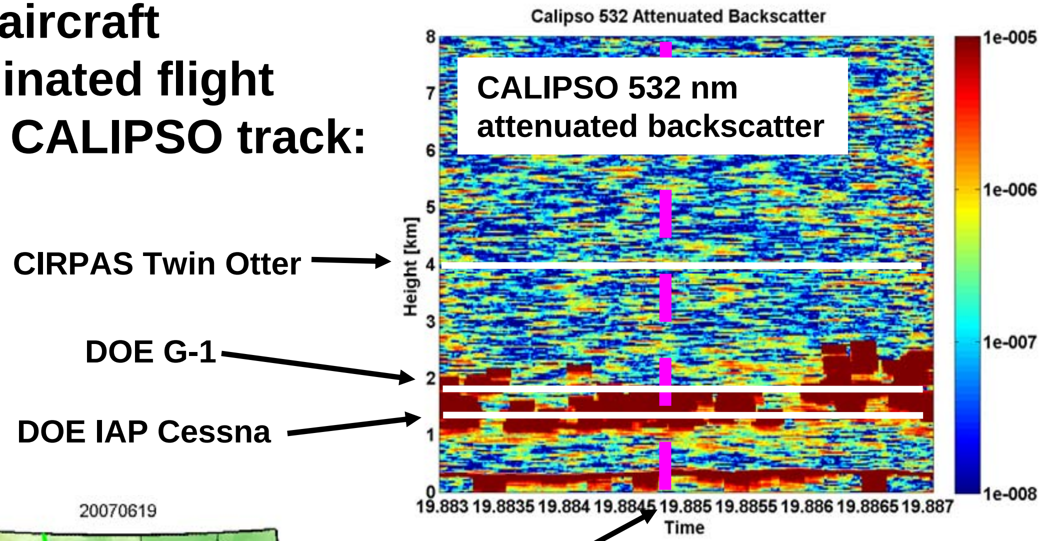
20 science flights, **66** flight hours

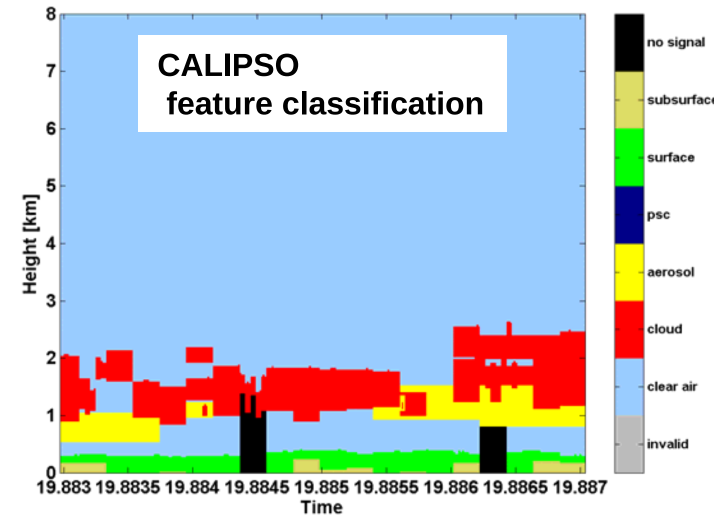
- 15 flights over ARM SGP
- 8 flights included CALIPSO validation
- 8-10 flights coordinated with DOE G-1
- 9-10 flights coordinated with CIRPAS TO
- ~10-12 flights with MODIS/MISR

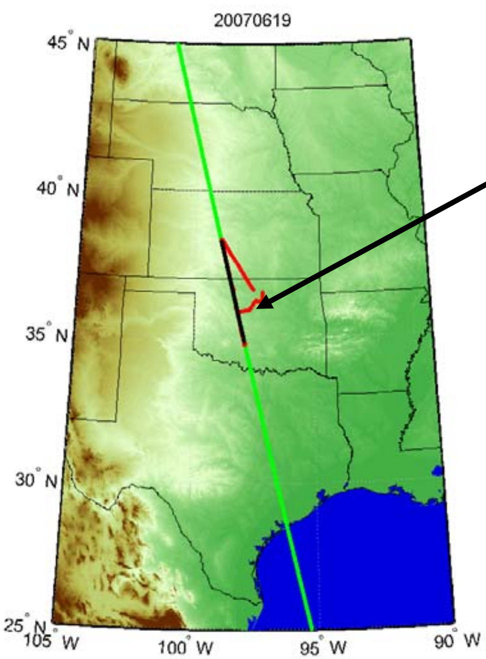
Examples:
1. June 7th
2. June 19th
3. June 24th

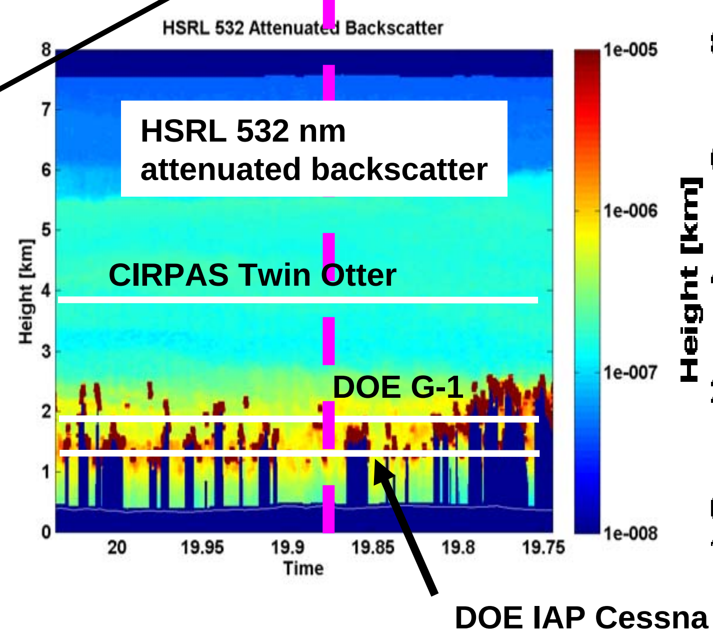
CALIPSO Validation – June 19

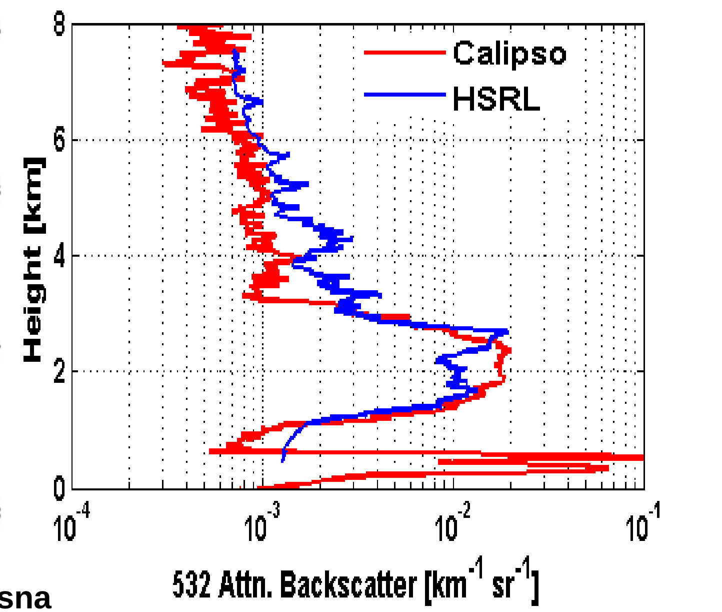
Multi-aircraft coordinated flight along CALIPSO track:





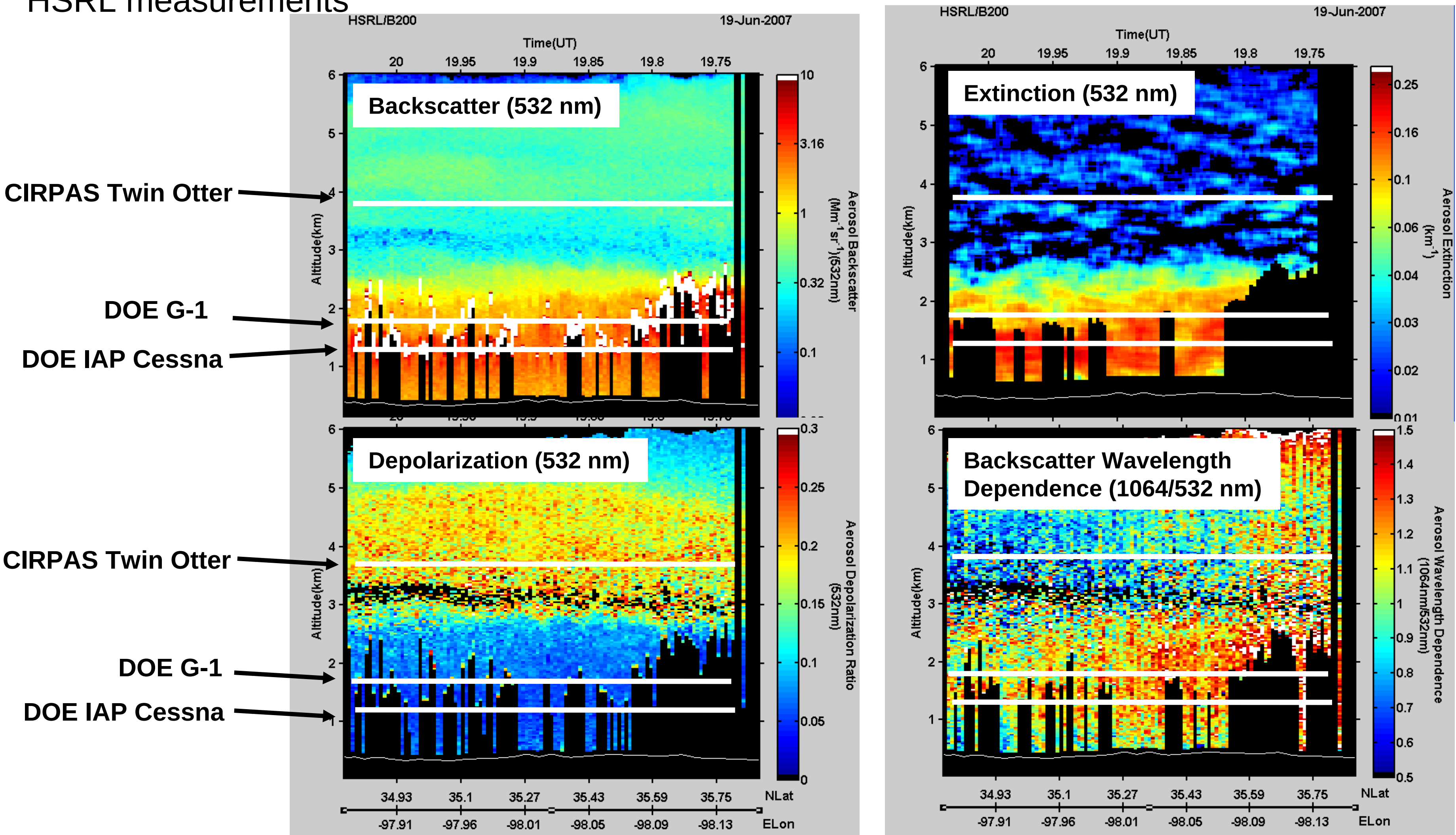






CALIPSO Validation – June 19

- 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



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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(757) 864-9443
richard.a.ferrare@nasa.gov

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.

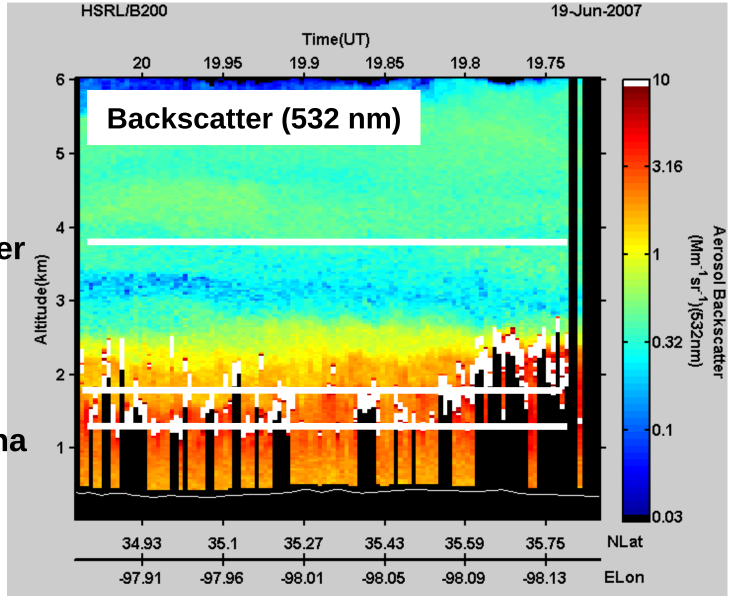
R. Ferrare, C.A. Hostetler, J.W. Hair, A.L. Cook, D.B. Harper, S. Burton, A. Clarke, P.B. Russell, J. Redemann, "Airborne High Spectral Resolution Lidar aerosol measurements during MILAGRO and TexAQS/GoMACCS", Ninth Conference on Atmospheric Chemistry, American Meteorological Society Annual Meeting,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

Aerosol Extinction Comparison CALIPSO Validation – June 19

CIRPAS Twin Otter

DOE G-1

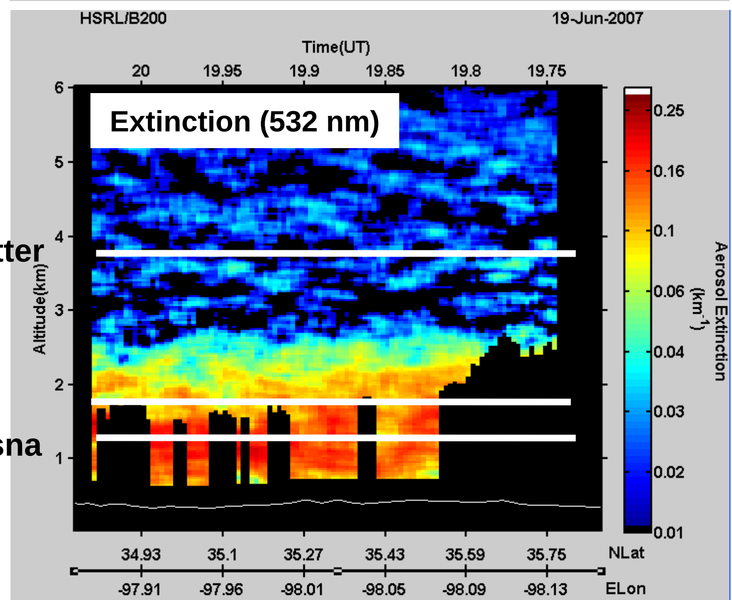
DOE IAP Cessna

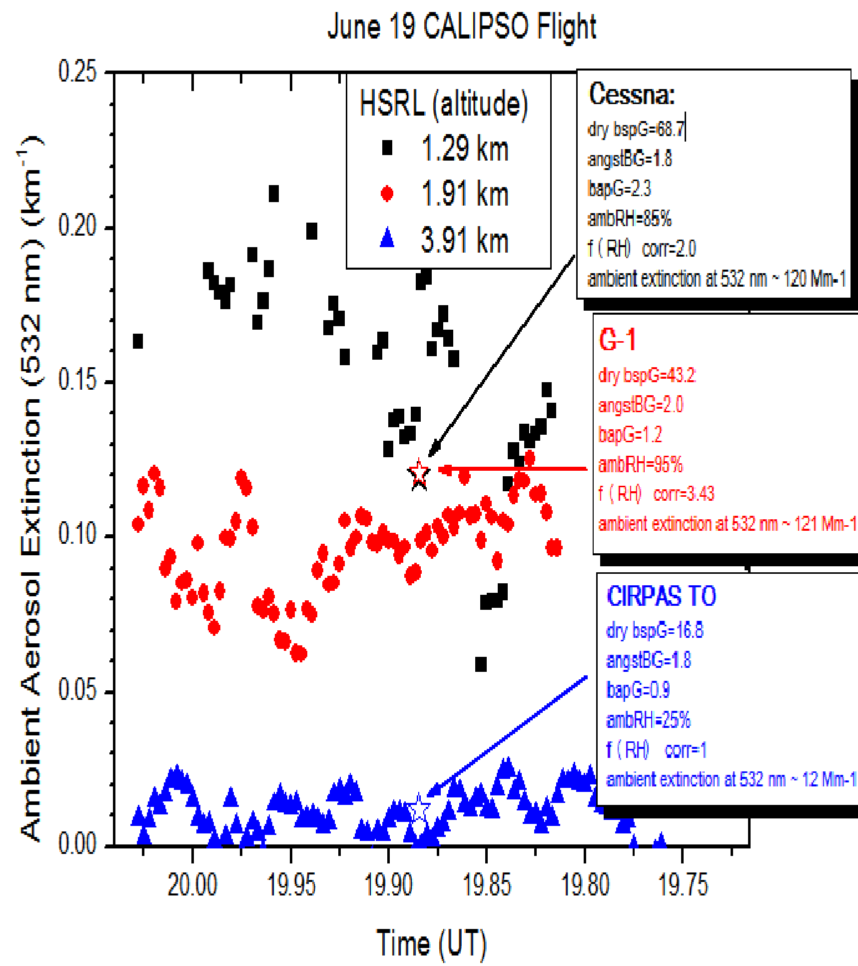


CIRPAS Twin Otter

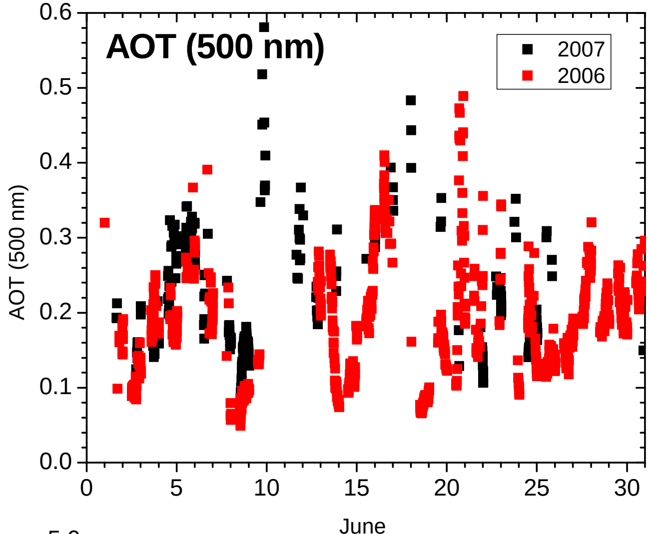
DOE G-1

DOE IAP Cessna

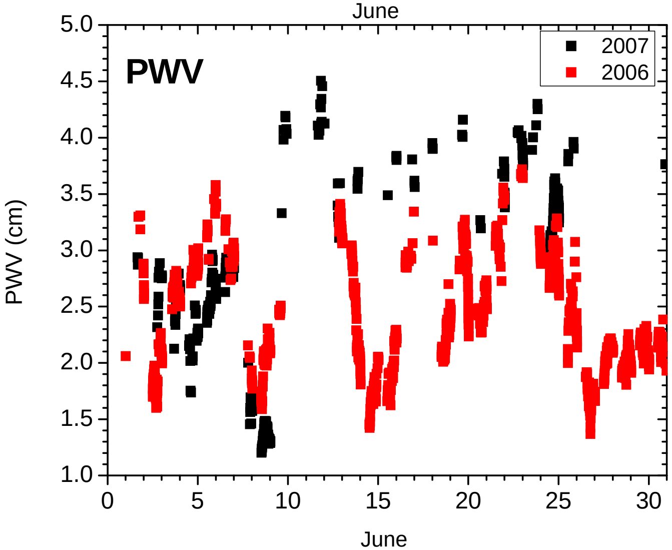


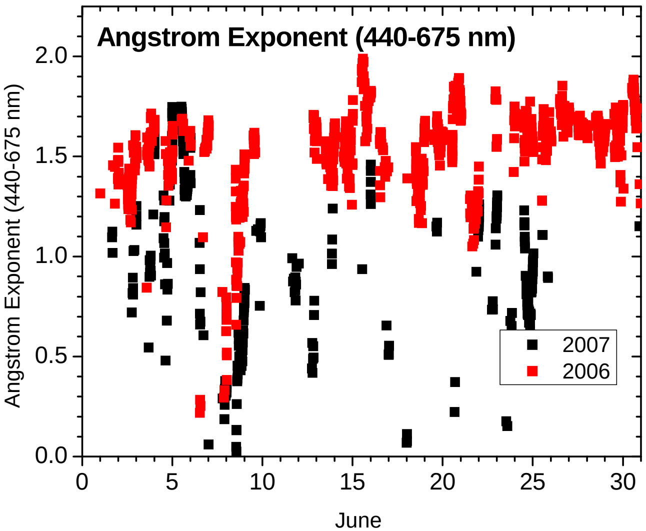


Humidity-corrected in situ data courtesy of Betsy Andrews and John Ogren



- 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

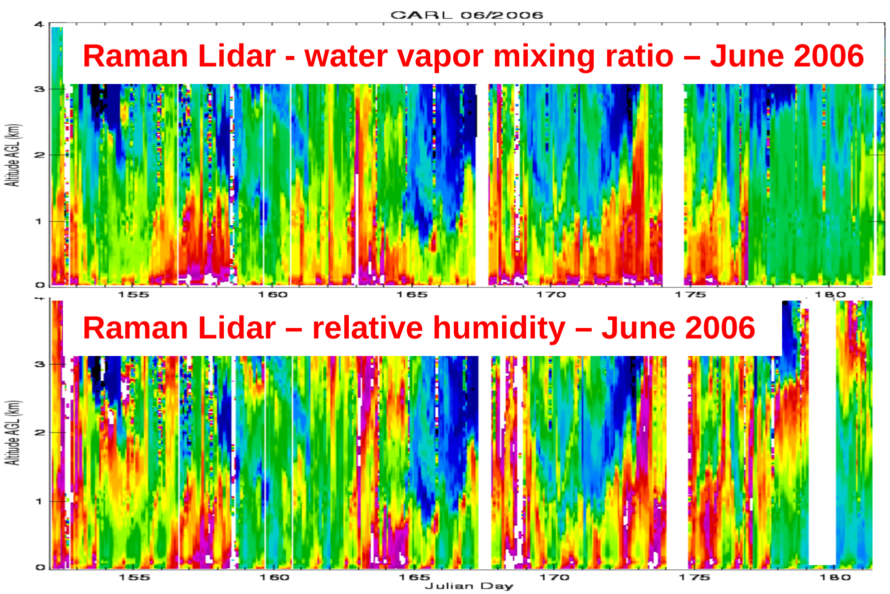


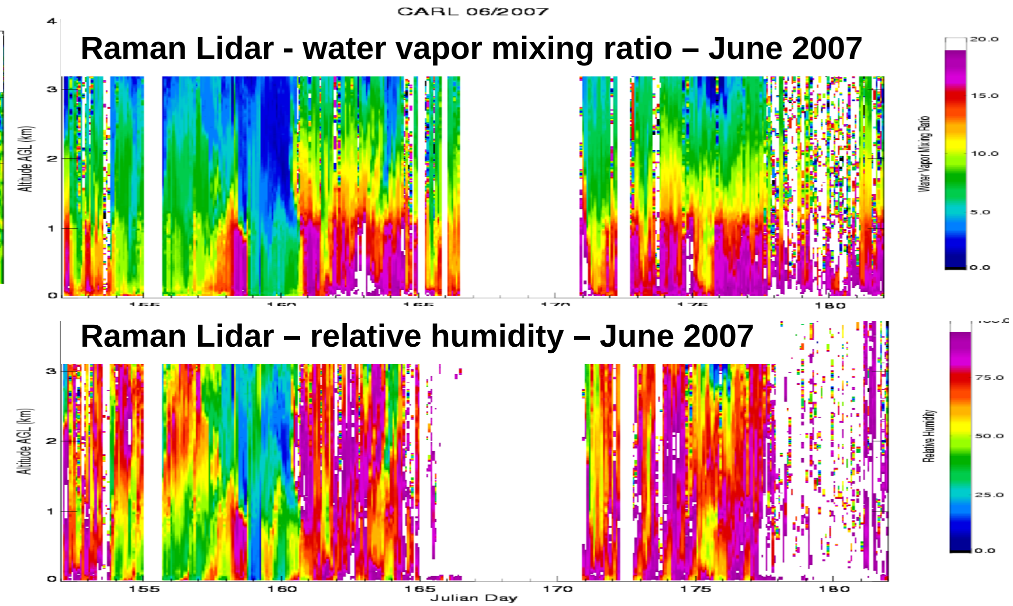


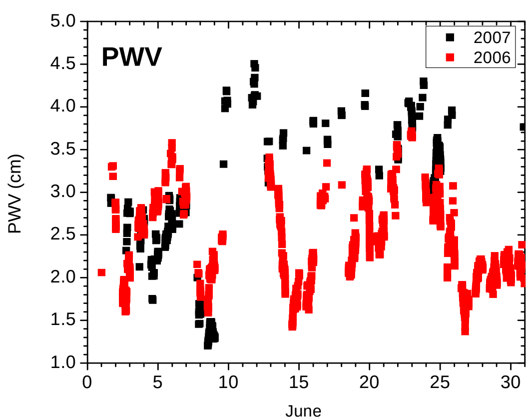
AERONET Cimel Sun photometer data from Brent Holben (NASA/GSFC)

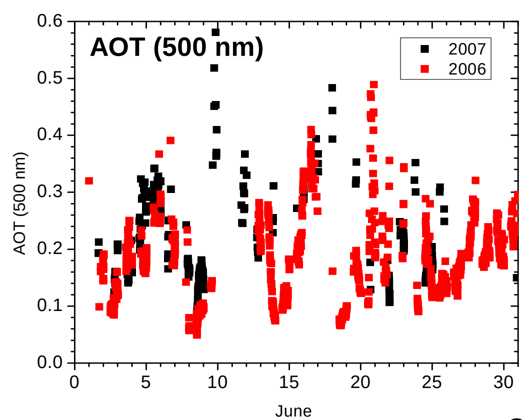
June at SGP: 2006 vs. 2007

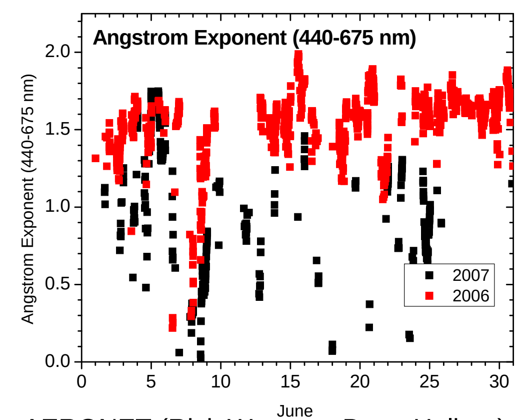
- Significantly higher water vapor and RH during latter 3 weeks of June 2007
- AOT similar but Angstrom exponent generally lower during 2007 – more large particles present during June 2007 than during June 2006





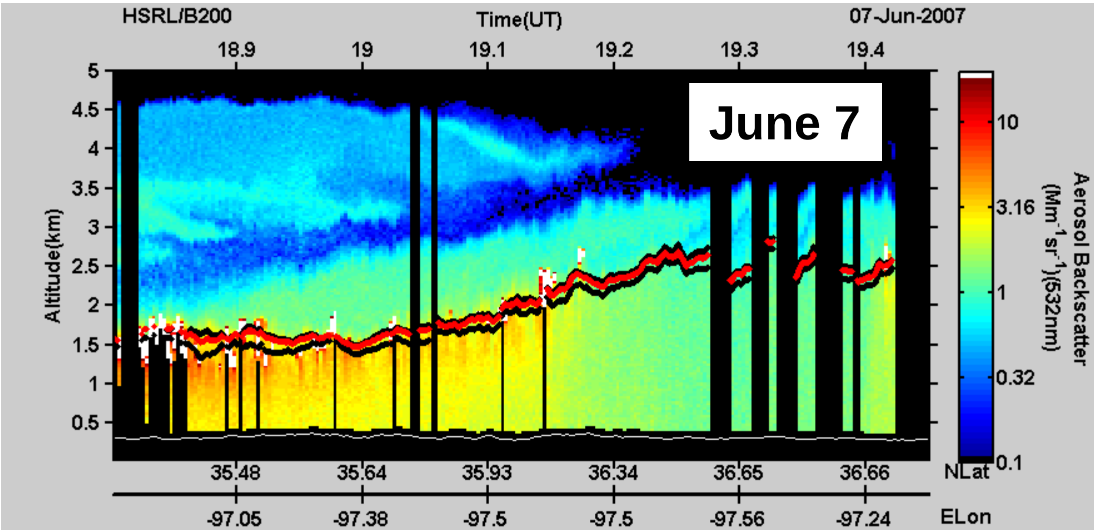


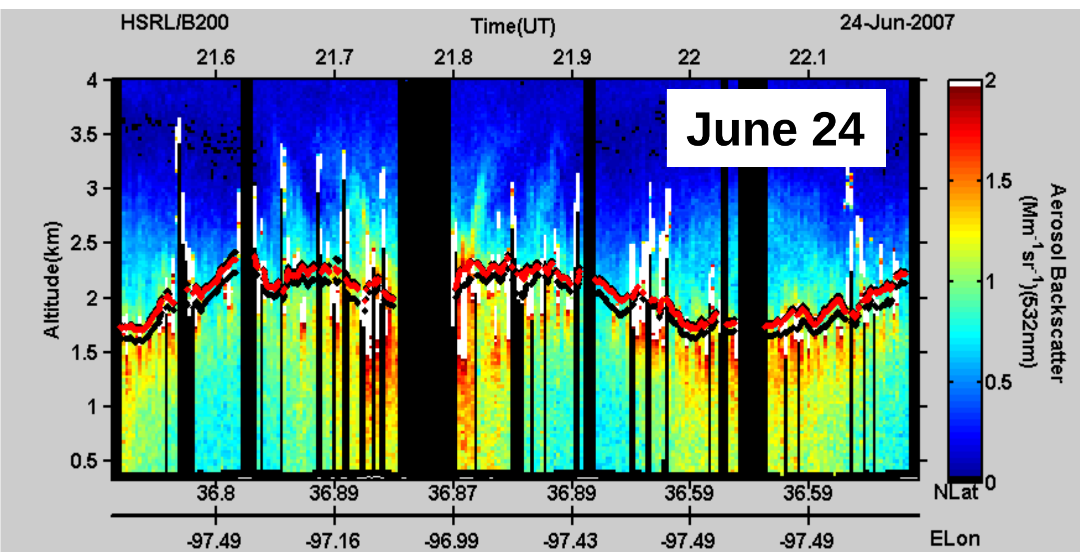




Cimel data from AERONET (Rick Wagener,Brent Holben)

HSRL PBL height retrievals

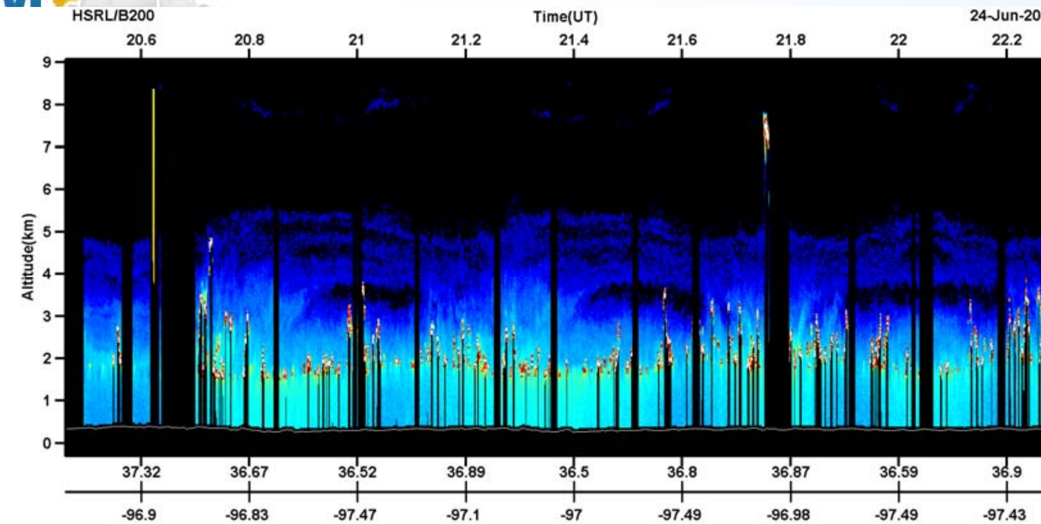


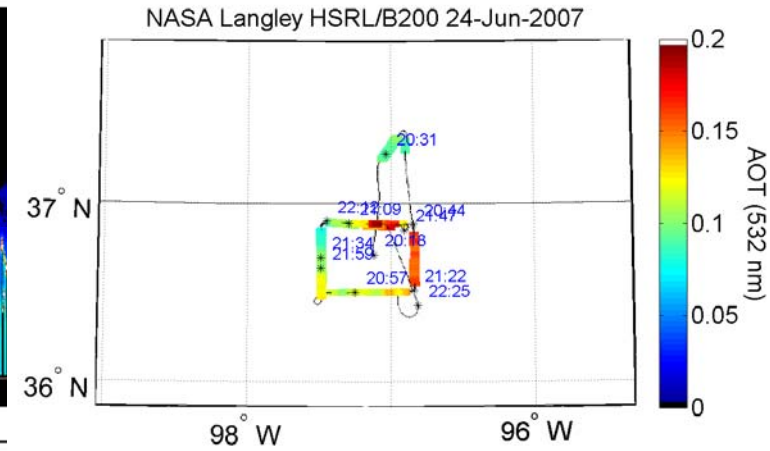


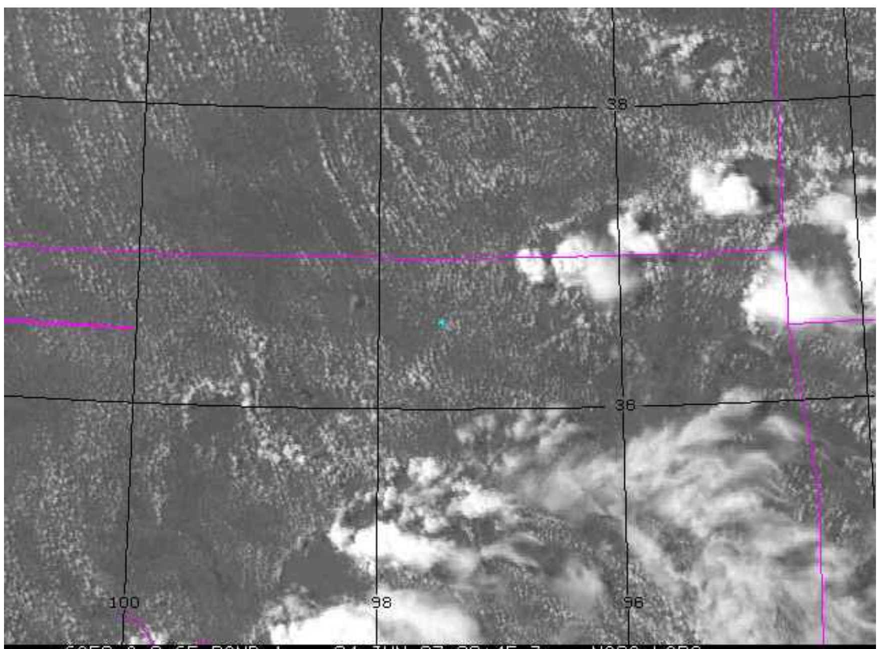
An automated technique that uses a Haar wavelet covariance transform with multiple wavelet dilations (Brooks, 2003) was used to determine:

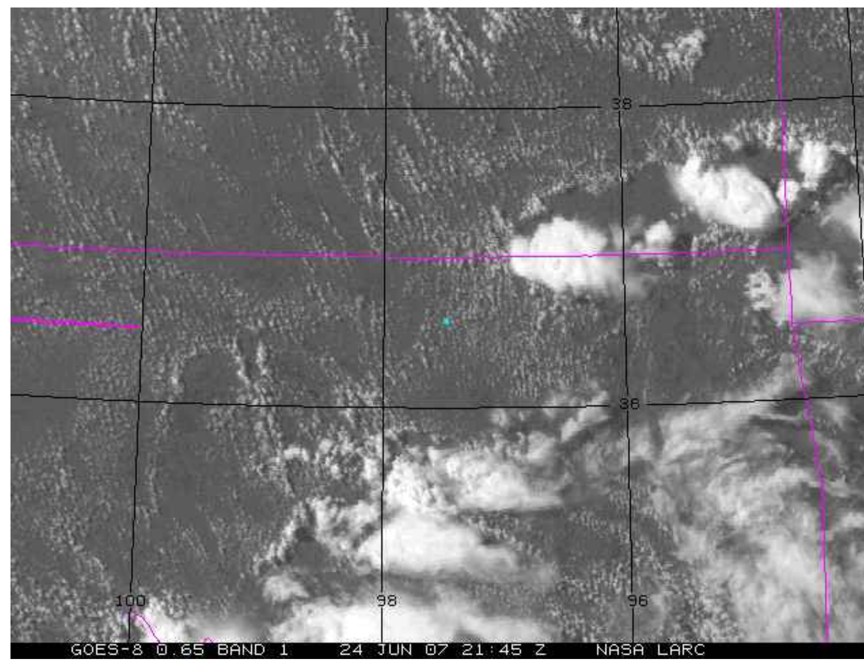
- PBL height
- Upper and lower limits of the backscatter transition (i.e. entrainment) zone

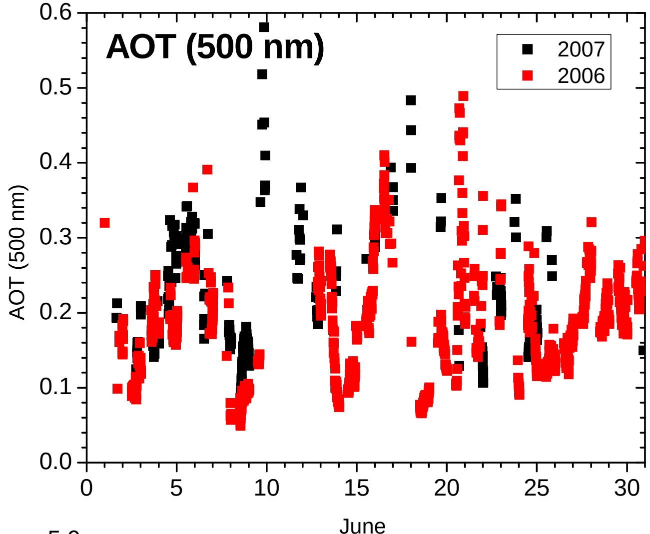
20070624_L2_bsc532.png











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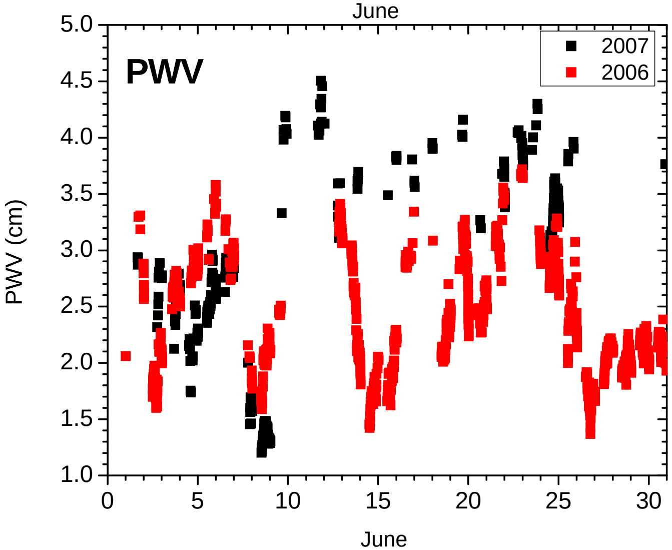

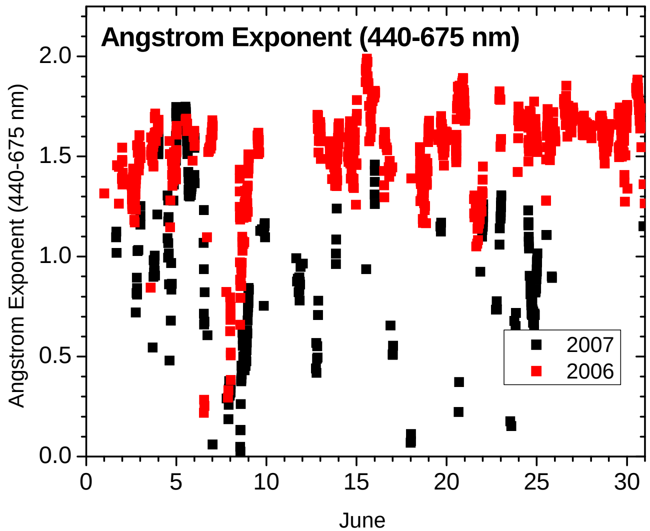

AERONET Cimel Sun photometer data from Brent Holben (NASA/GSFC)

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
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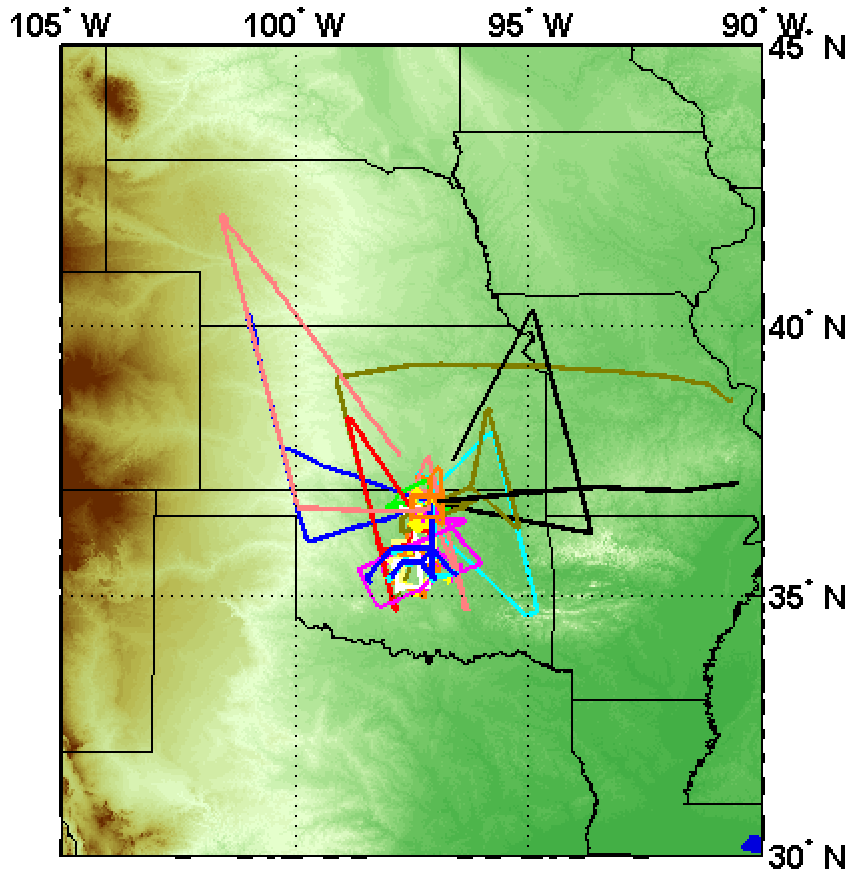
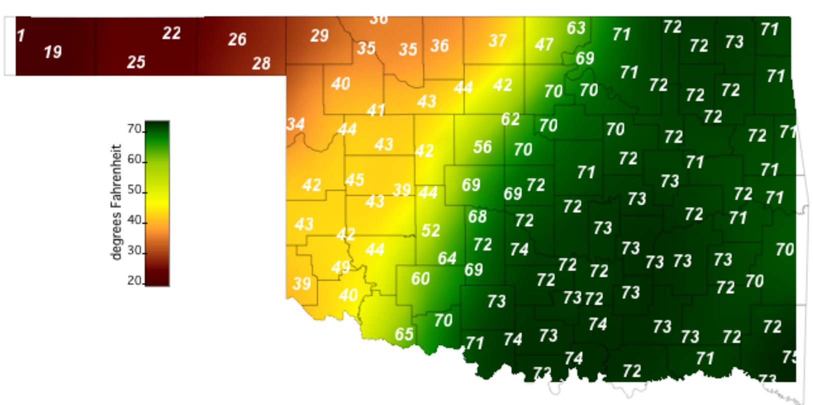


20 science flights, 66 flight hours
- 12 flights over ARM SGP
- 8 flights included CALIPSO validation
- ~8 flights coordinated with DOE G-1
- ~4 flights coordinated with CIRPAS TO
- ~10-12 flights with MODIS/MISR

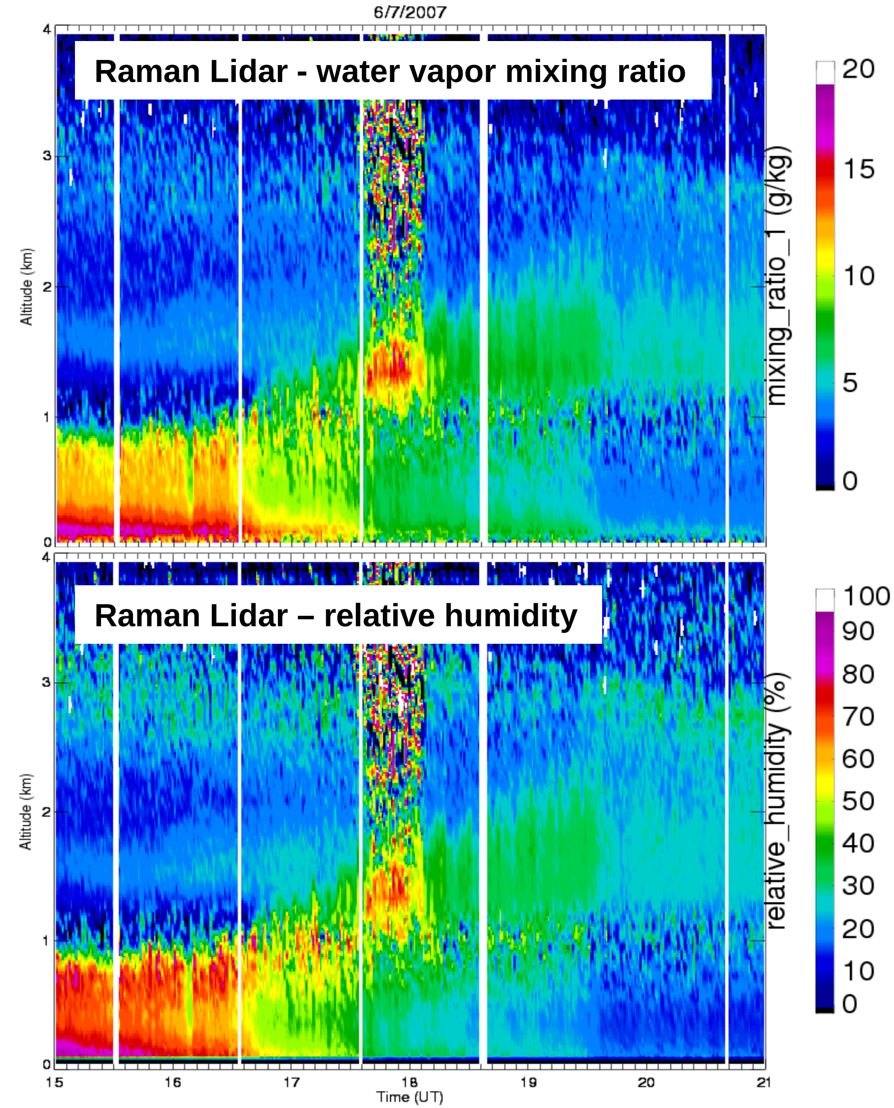
Water vapor and Aerosol Measurements of June 7 Dry Line

- 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



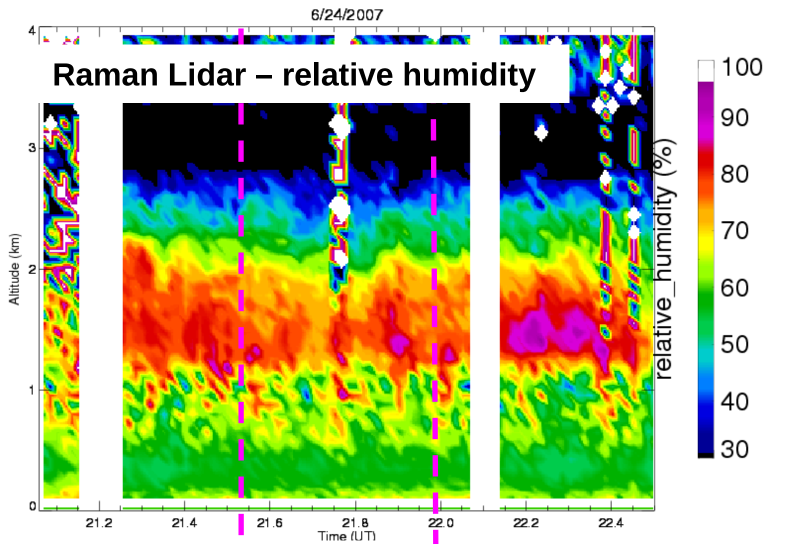
Temperature: Dew Point
06-07-2007 03:00 PM CDT

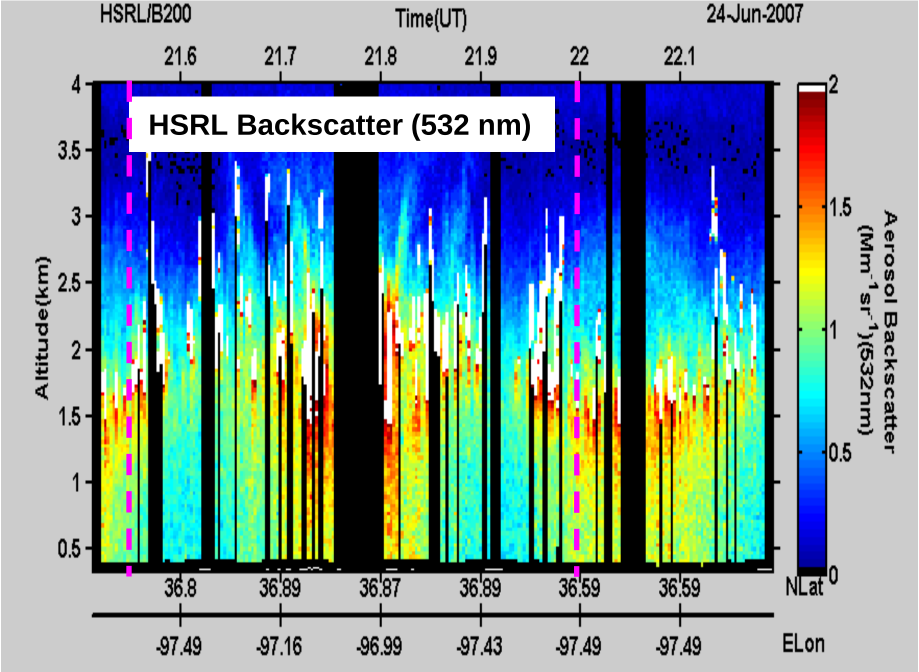


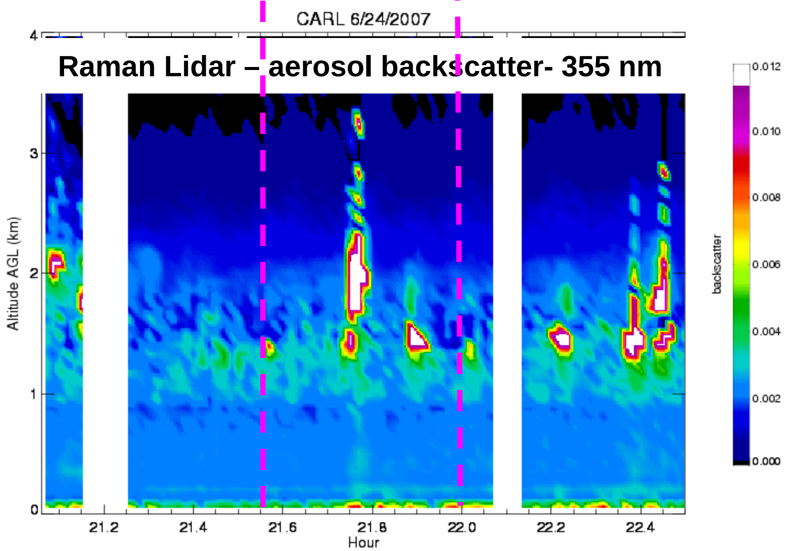
Example of measurements over SGP Raman Lidar - June 24

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

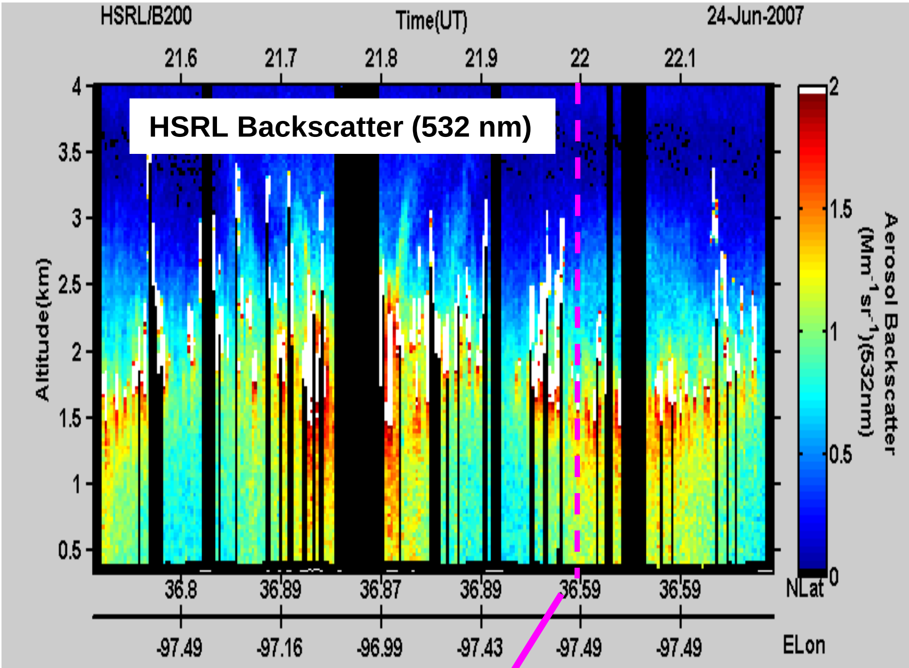
- Advanced, multi-wavelength lidar retrievals
- Investigate changes in aerosol optical properties as a function of
    - RH
    - Distance from clouds



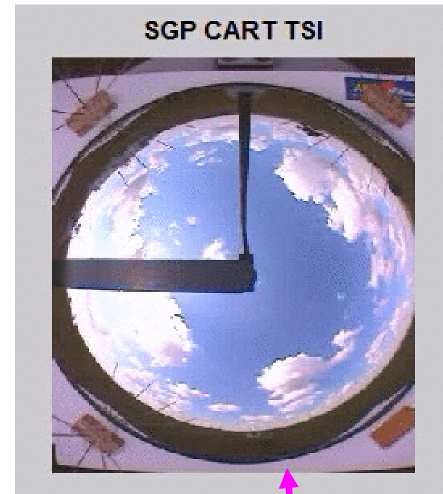




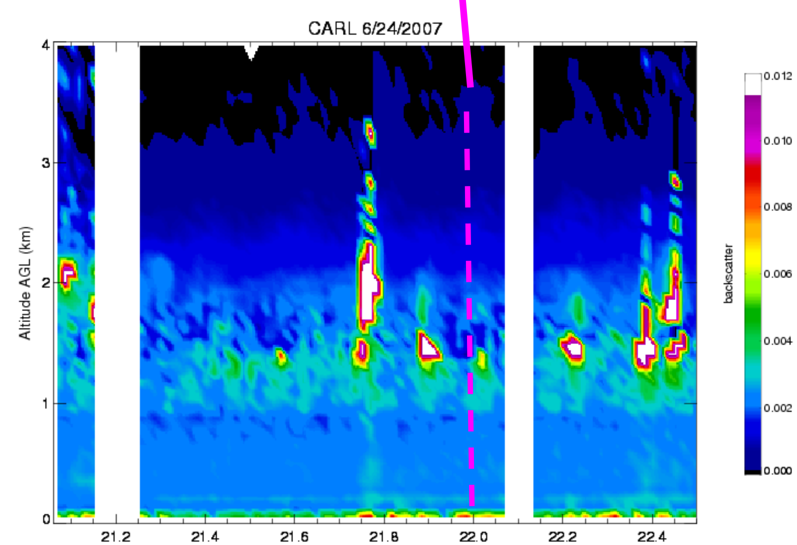
Example of measurements over SGP HSRL/Raman Lidar - June 24



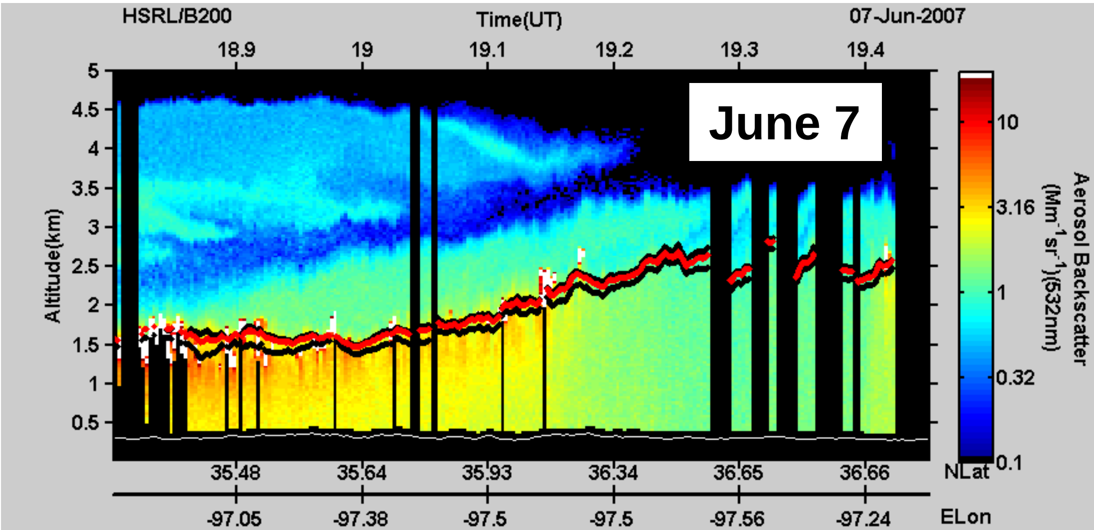
Investigate changes in aerosol optical properties as a function of distance from clouds

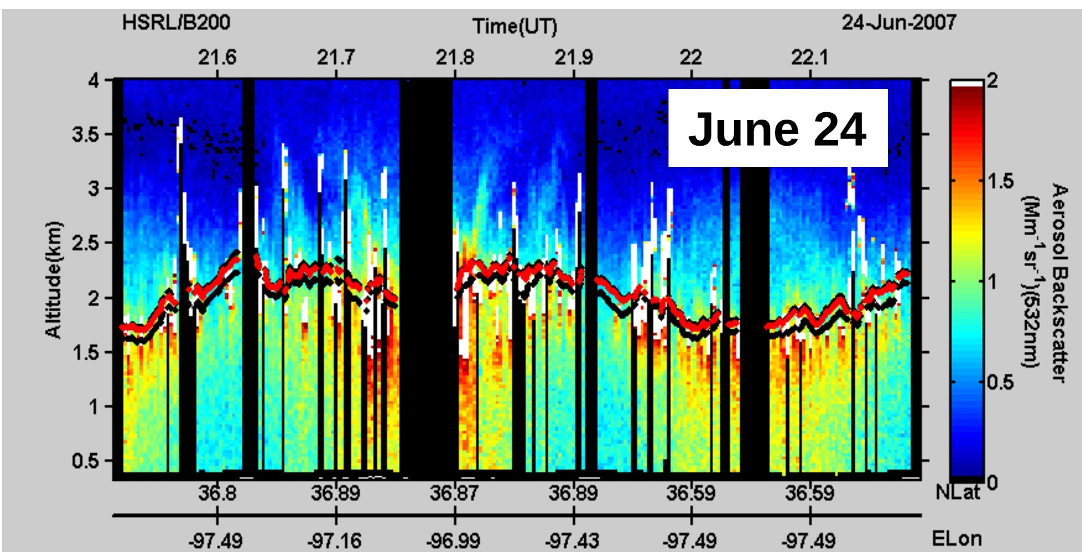


Raman Lidar – aerosol backscatter- 355 nm



HSRL PBL height retrievals





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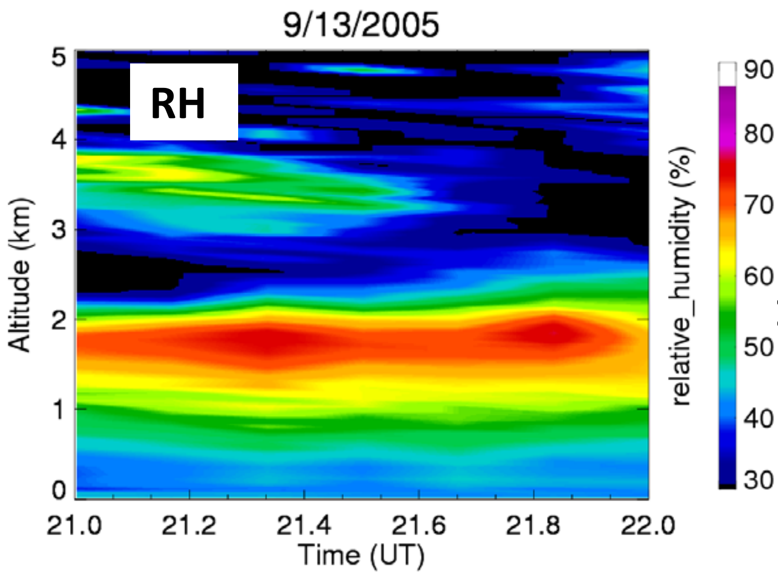
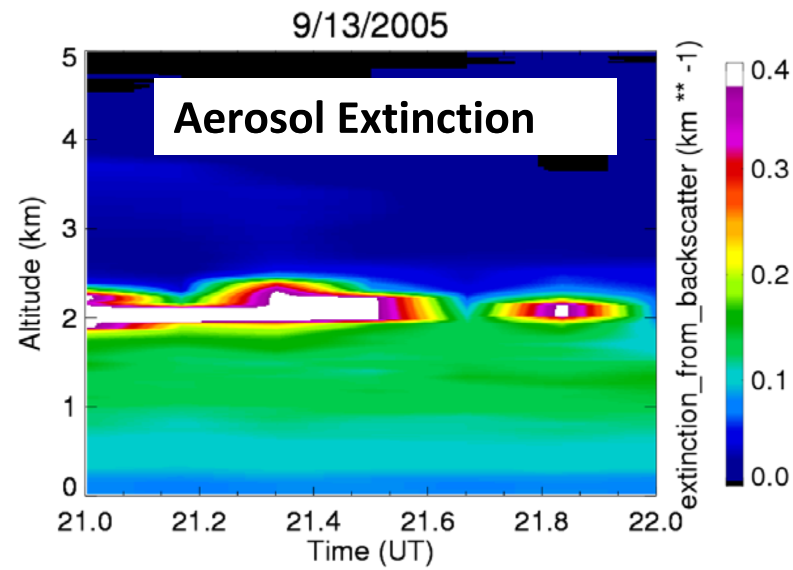
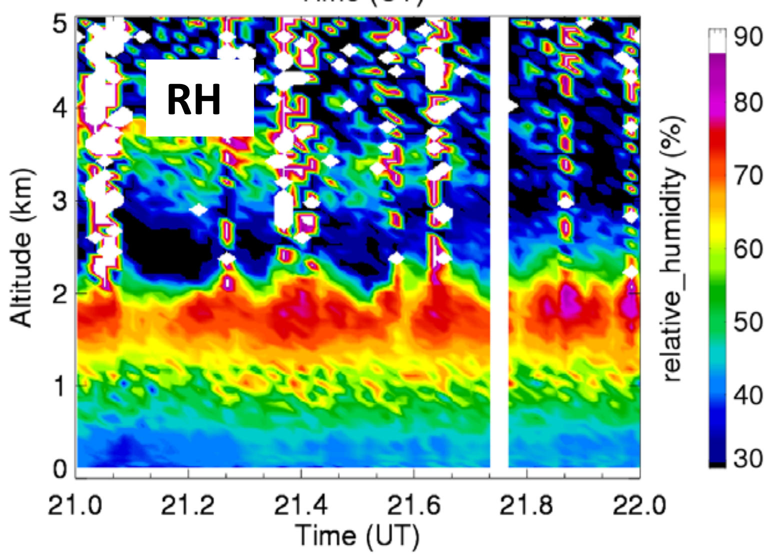
CARL High Temporal Resolution Data

Increased temporal resolution should permit more detailed analyses near clouds

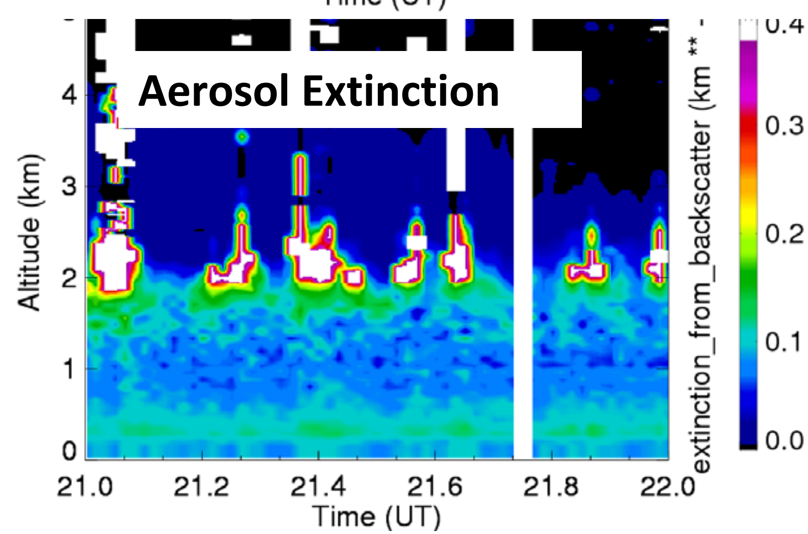




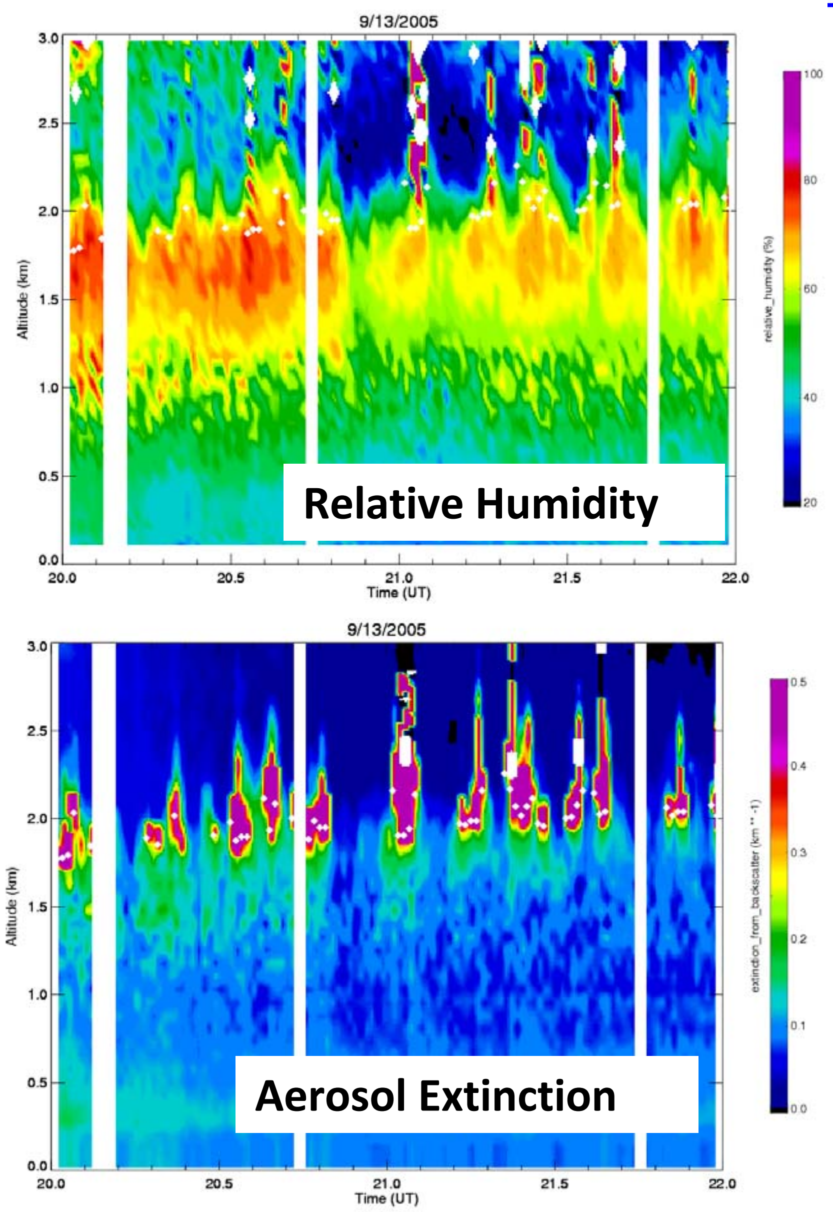
10 min



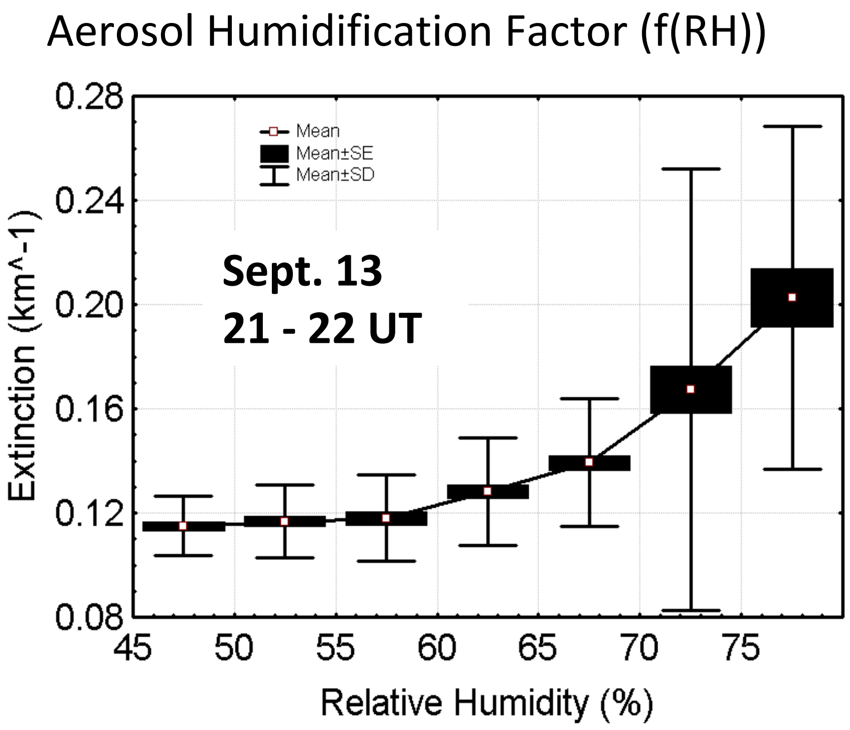
1 min



CARL observations of aerosol hygroscopicity



Increased temporal resolution permit more detailed studies of aerosol hygroscopicity



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

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

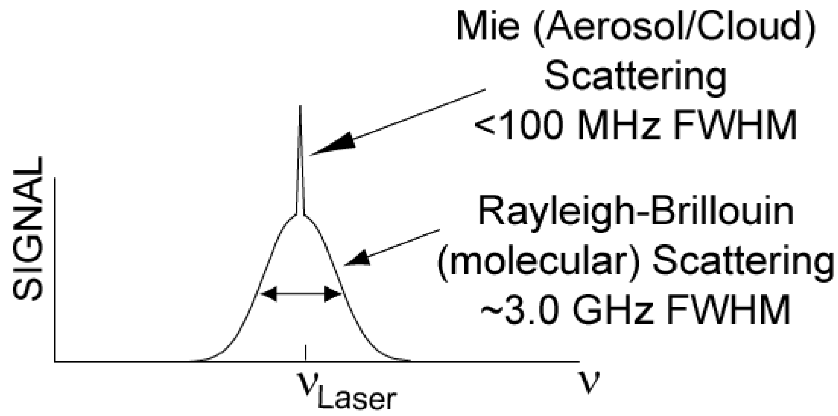
← Retrieved Parameters

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

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

High Spectral Resolution Lidar (HSRL)

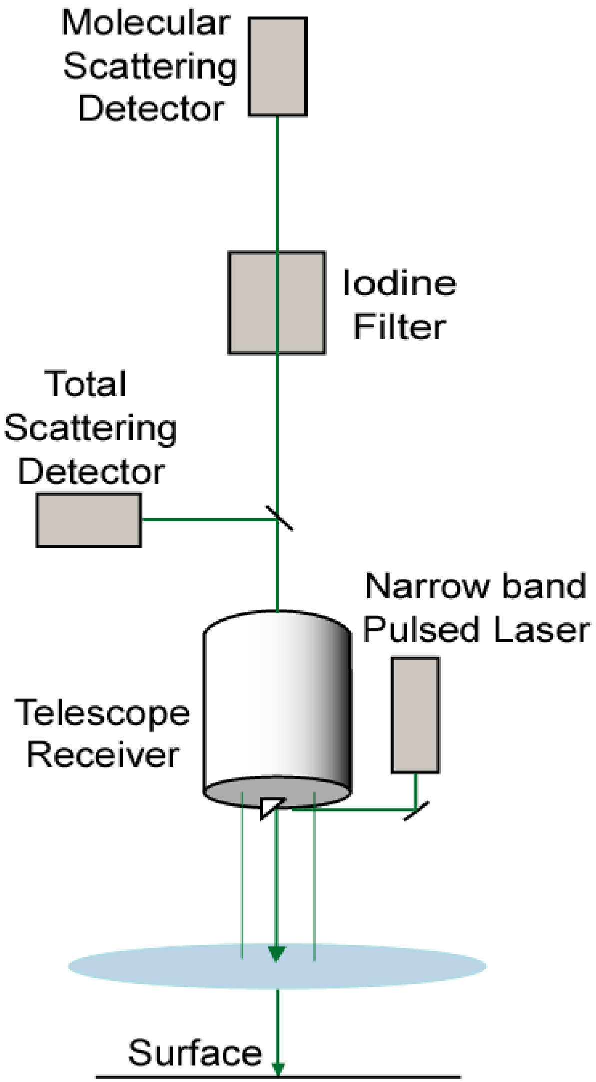
HSRL relies on spectral separation of aerosol and molecular backscatter in lidar receiver.



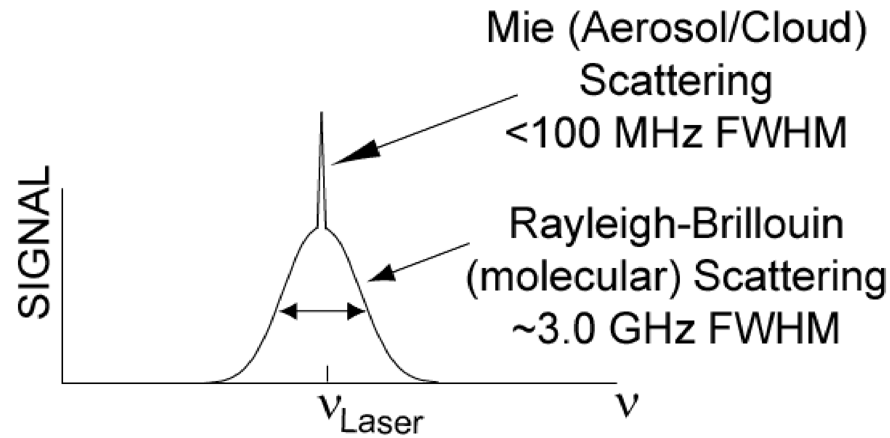
- HSRL independently measures aerosol and molecular backscatter
  - Can be internally calibrated
  - No correction for extinction required to derive backscatter profiles
  - More accurate aerosol layer top/base heights

- 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

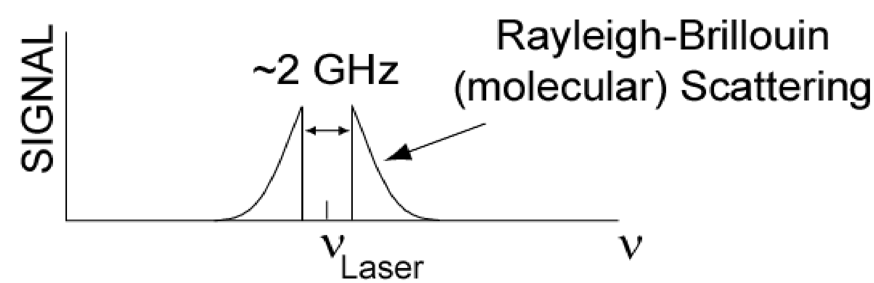
HSRL measurement concept



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:

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

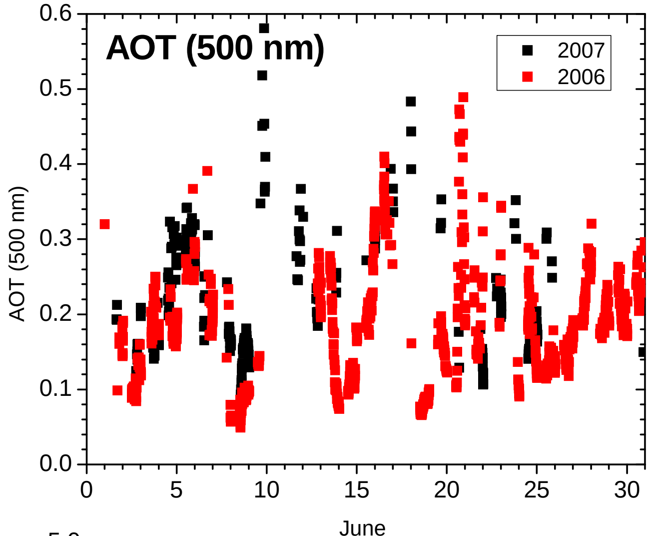
$$\frac{\sigma_p(r)}{\beta_p(r)} = \underline{S_p}$$

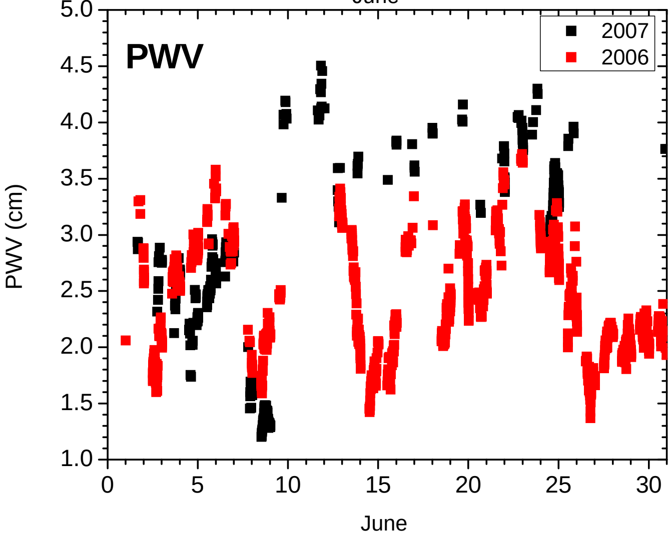
Ext/Backscatter

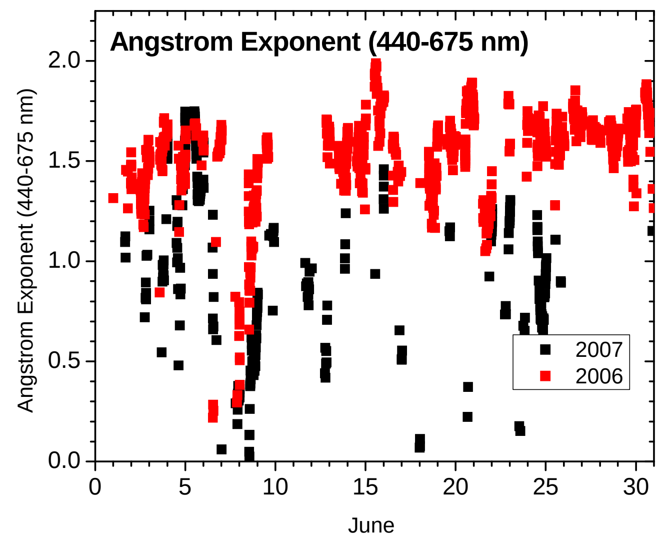
Particulate Backscatter

Retrieved Parameters

- 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)