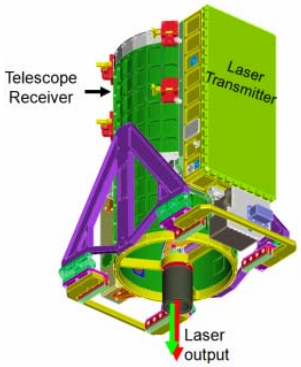
Airborne and Ground-based Lidar Measurements of Aerosols near Clouds



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DOE ARM Aerosol Working Group Meeting
March 12, 2008

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Mission Directorate
Radiation Sciences Program

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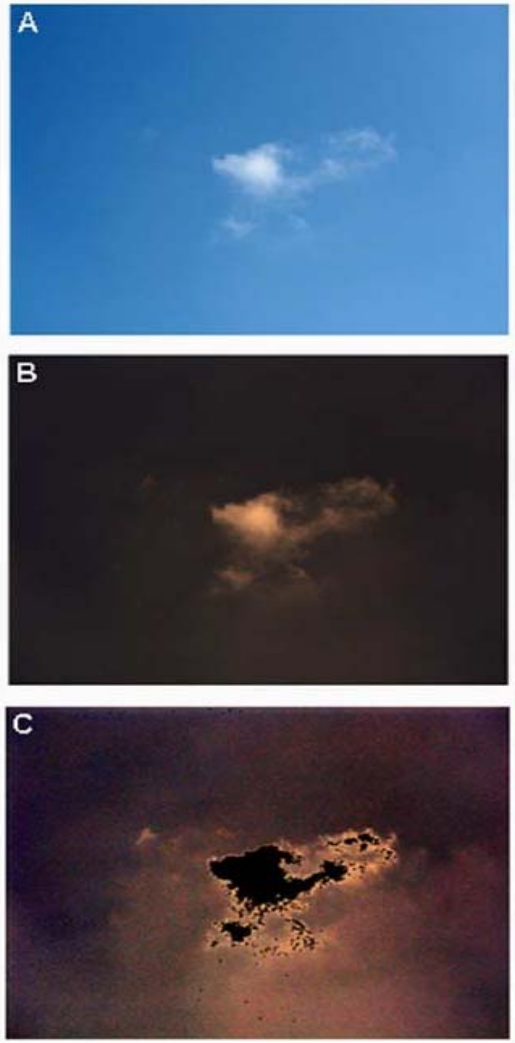
Atmospheric Science Program

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

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**

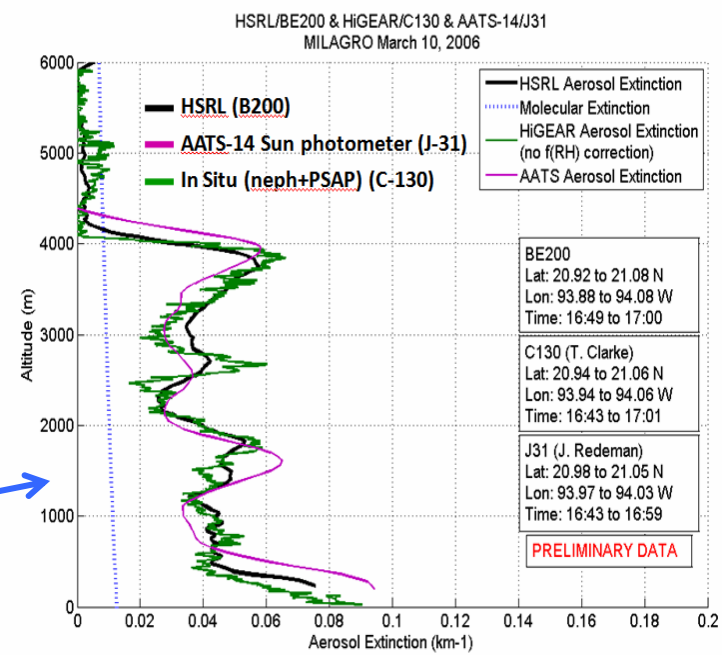
Data Products

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

Extensive – depend on aerosol amount and type

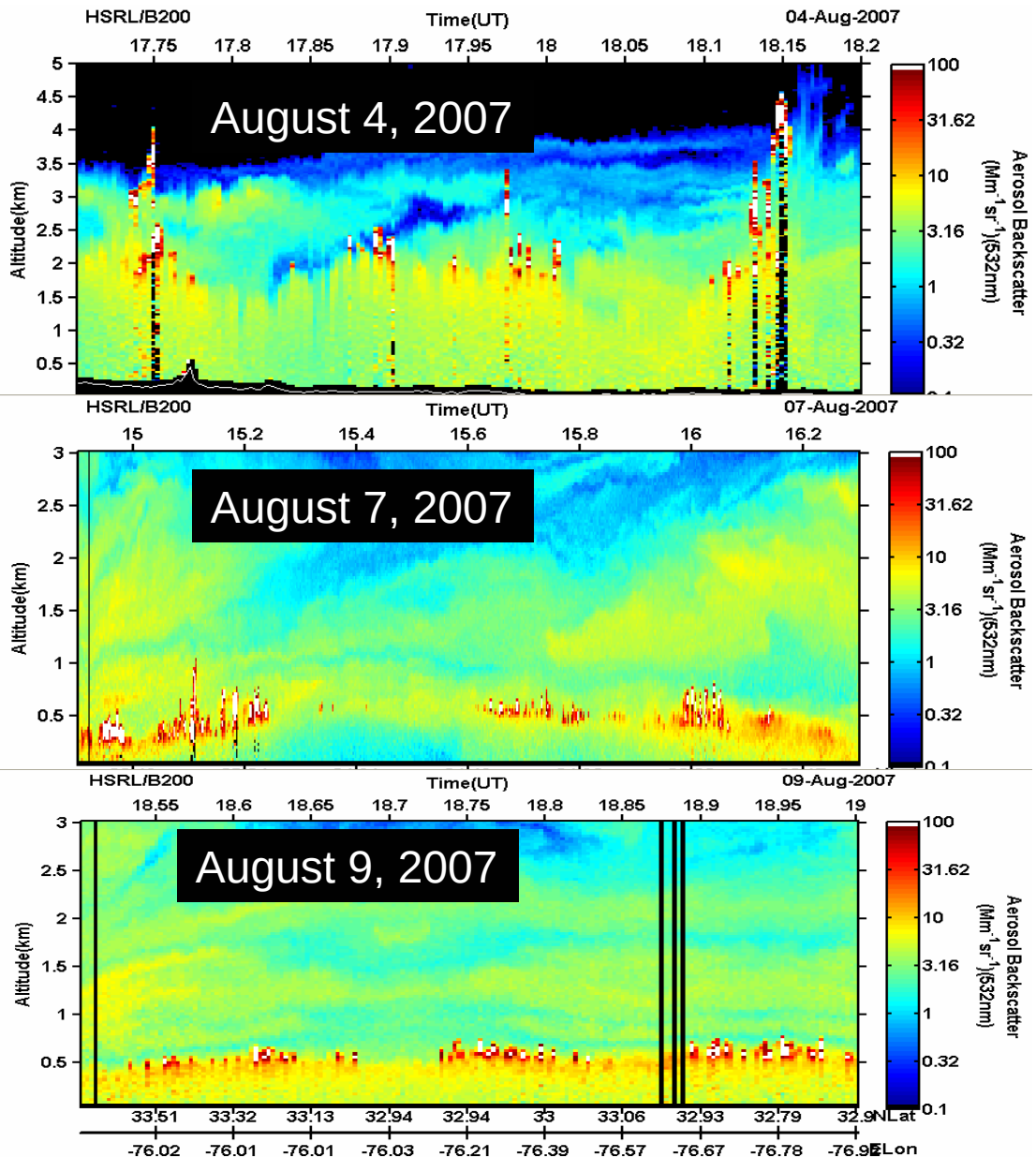
Intensive – depend on aerosol type

Validation – aerosol extinction



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

HSRL measurements of aerosols near clouds



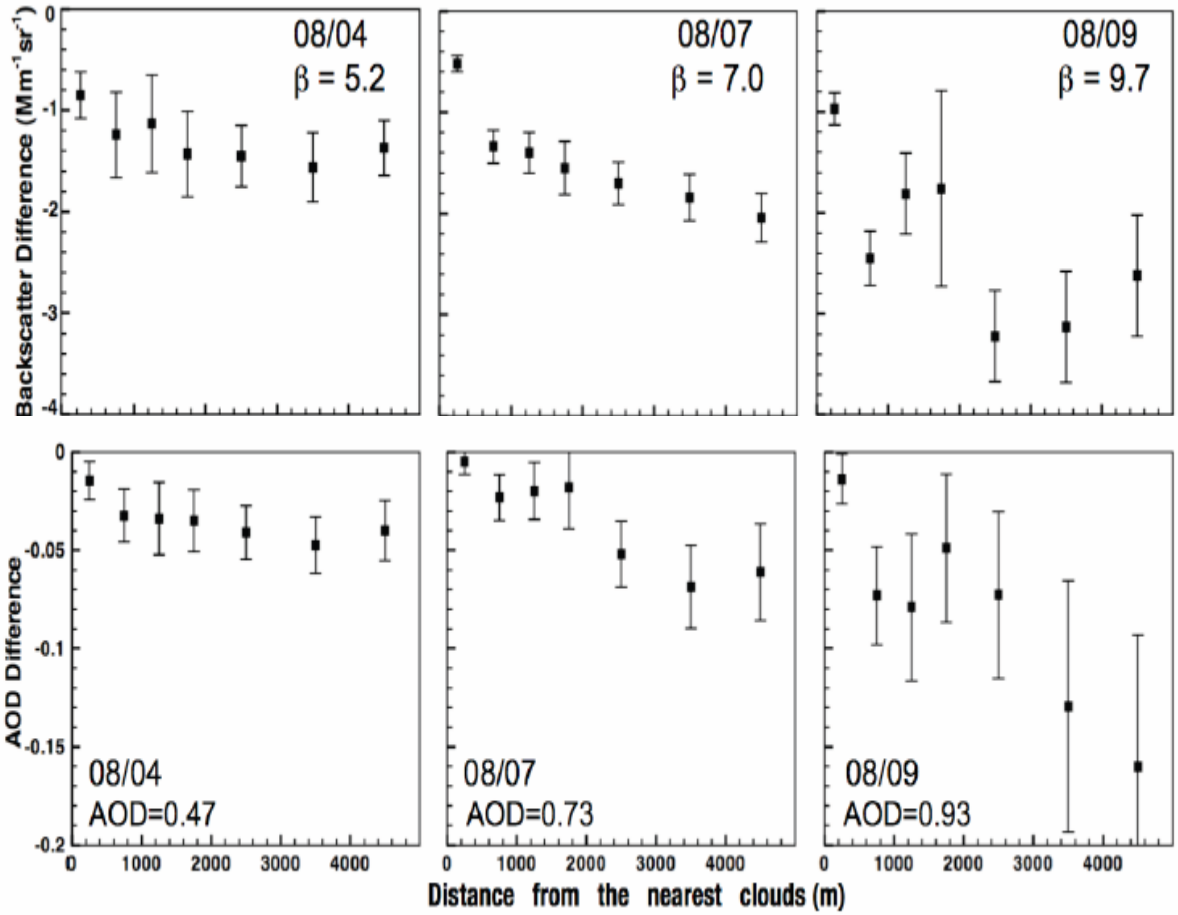
Study by Su et al. (2008, JGR, in press) used HSRL measurements over the eastern U.S. to study spatial variations of aerosol optical properties near clouds

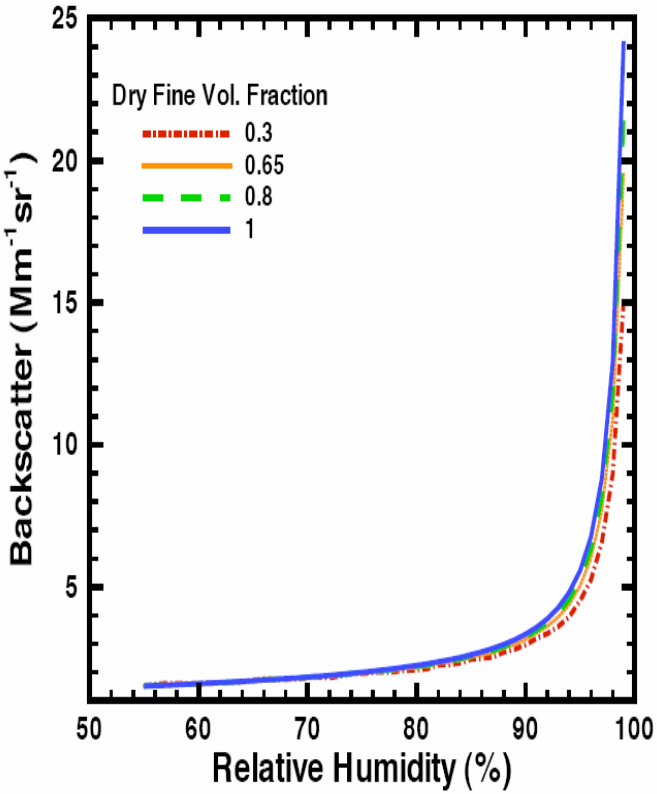
- Temporal resolution: 2 sec
- Vertical resolution:
  - 30 m backscatter
  - 300 m extinction
  - Averaged data within +/- 60 m of cloud top
  - Compare aerosol properties adjacent to cloud edge with properties some distance away from cloud edge

HSRL measurements of aerosols near clouds

Study by Su et al. (2008, JGR, 2008 in press) found using HSRL data…

- Aerosol backscatter and extinction ~ 20-30% higher in proximity to clouds as compared to 4-5 km away
- Aerosol optical thickness ~ 8-17% higher
- Changes are consistent with hygroscopic swelling

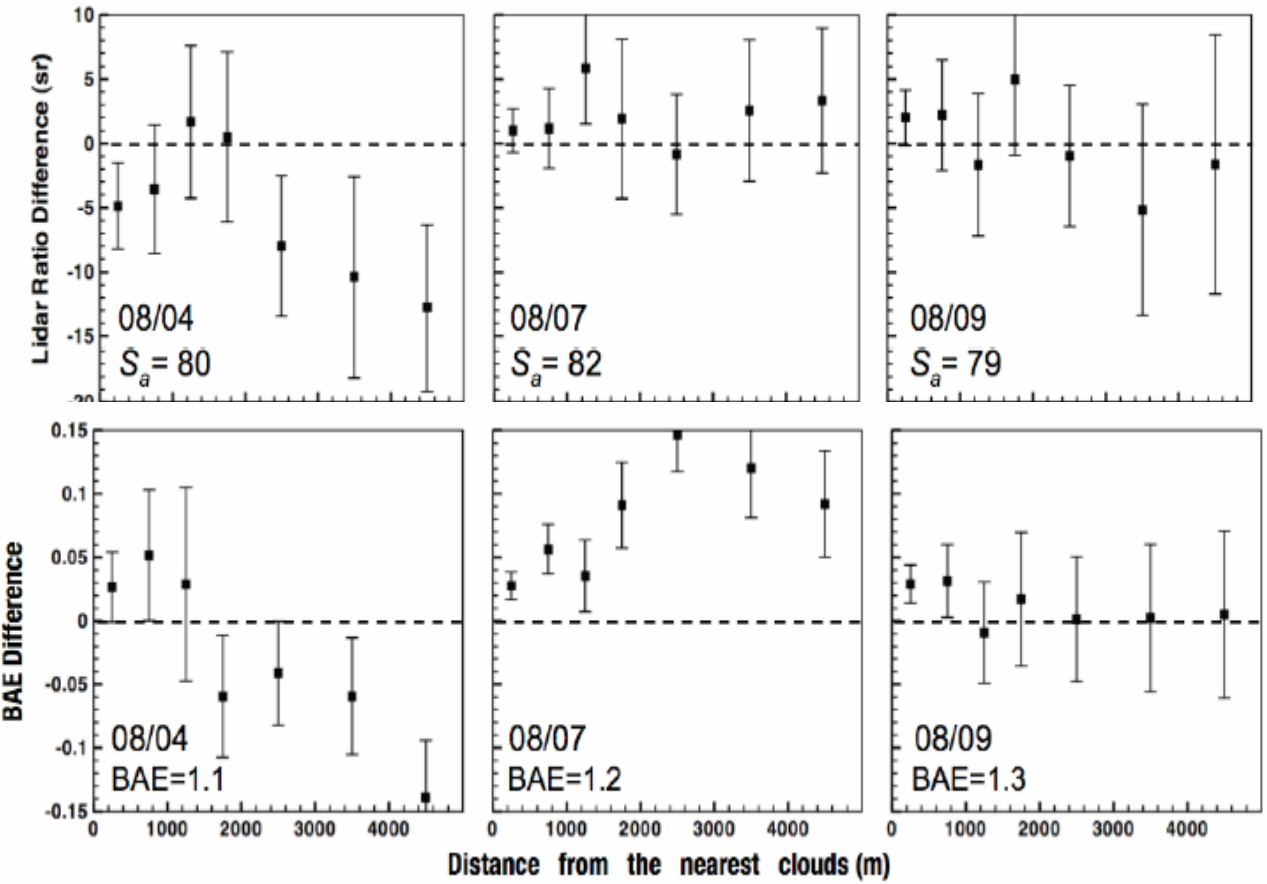


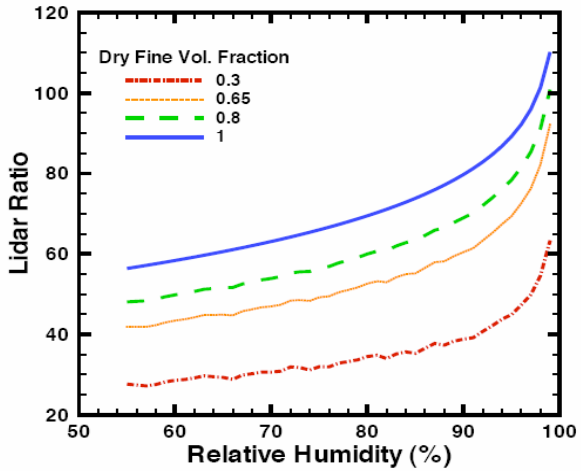


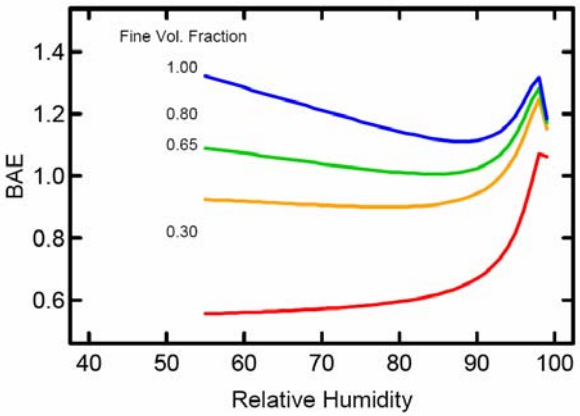
HSRL measurements of aerosols near clouds

Study by Su et al. (2008, JGR, 2008 in press) found using HSRL data…

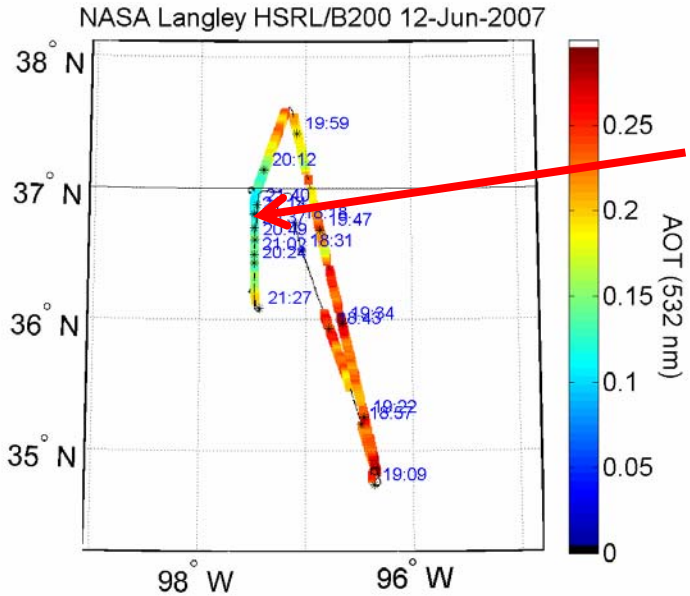
- No clear systematic trend in extinction/backscatter ratio or BAE
  - Effect of aerosol swelling offset by in cloud processing increasing coarse mode fraction
  - Changes in BAE depend on RH and size distribution
  - ➢ **Need concurrent RH and aerosol size distribution measurements**



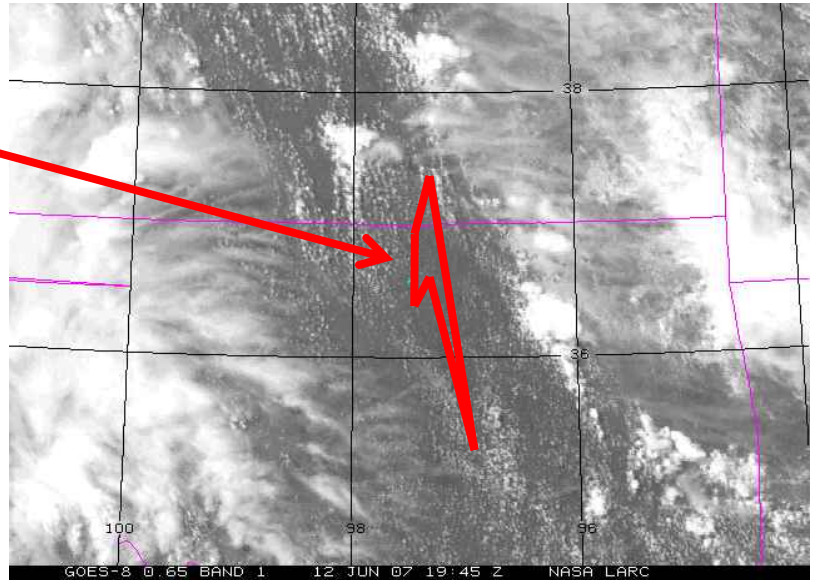


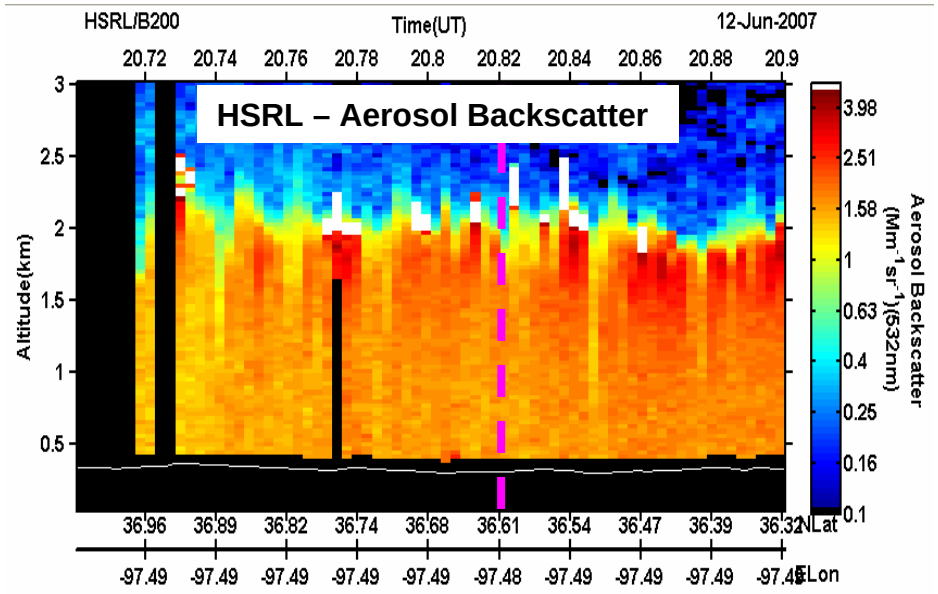


Airborne HSRL flight over SGP during CLASIC/CHAPS – June 12



SGP





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

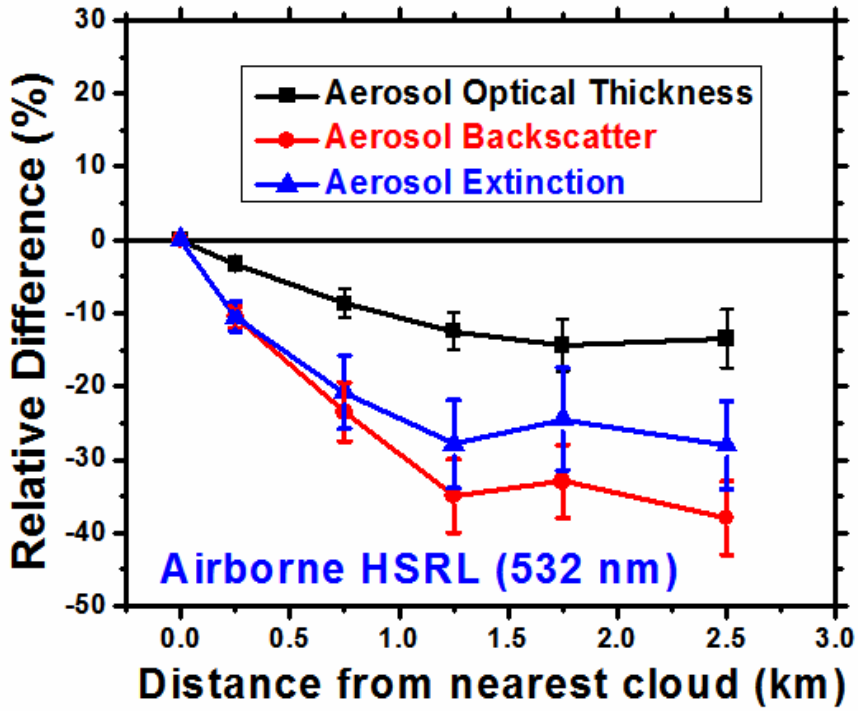
June 12, 2007 case

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

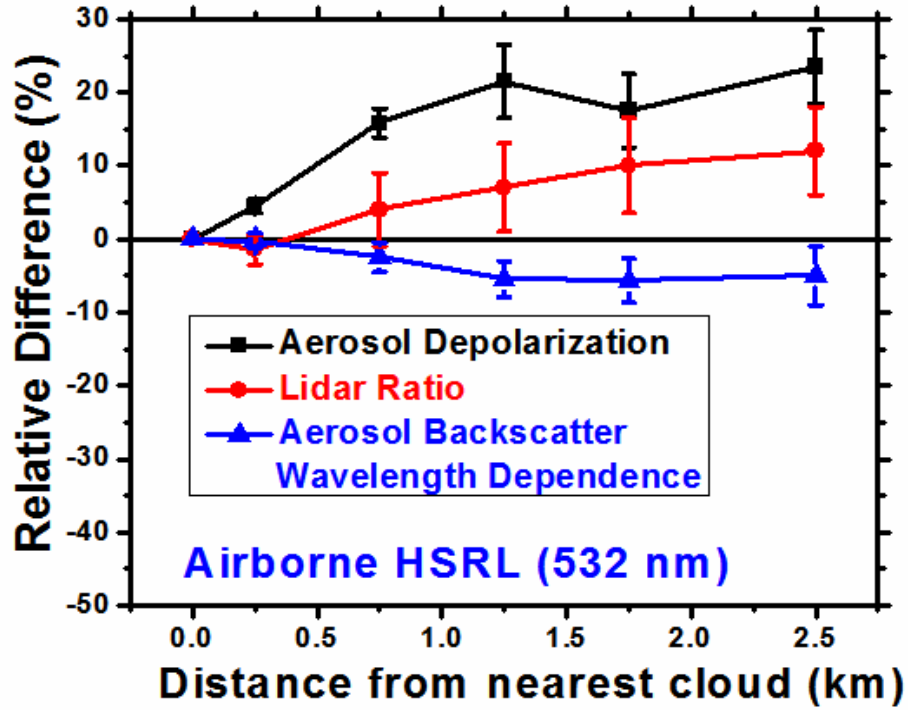
- AOT decreases 10-15%
- Aerosol backscatter and extinction decrease 25-40%
- Aerosol depolarization increases 10-20%
- Lidar ratio increases 5-10%
- Small (~5%) decrease in backscatter wavelength dependence

How much explained by changes in RH?

Aerosol Extensive Parameters



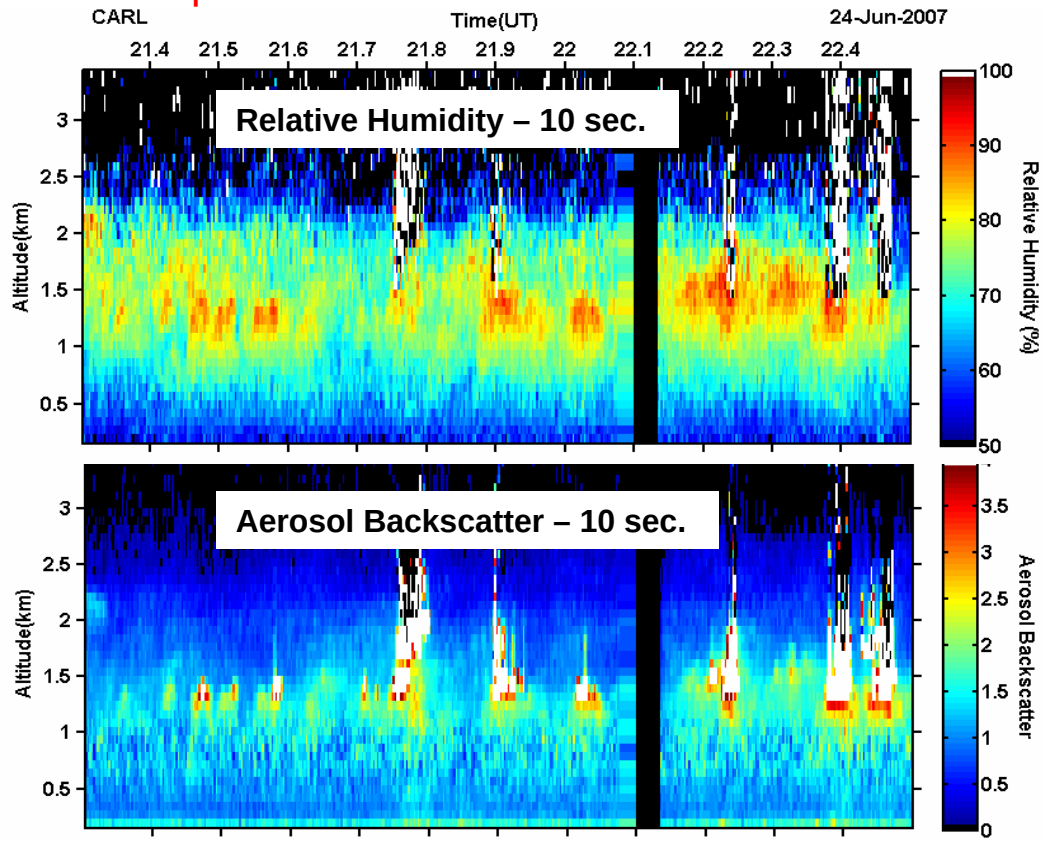
Aerosol Intensive Parameters

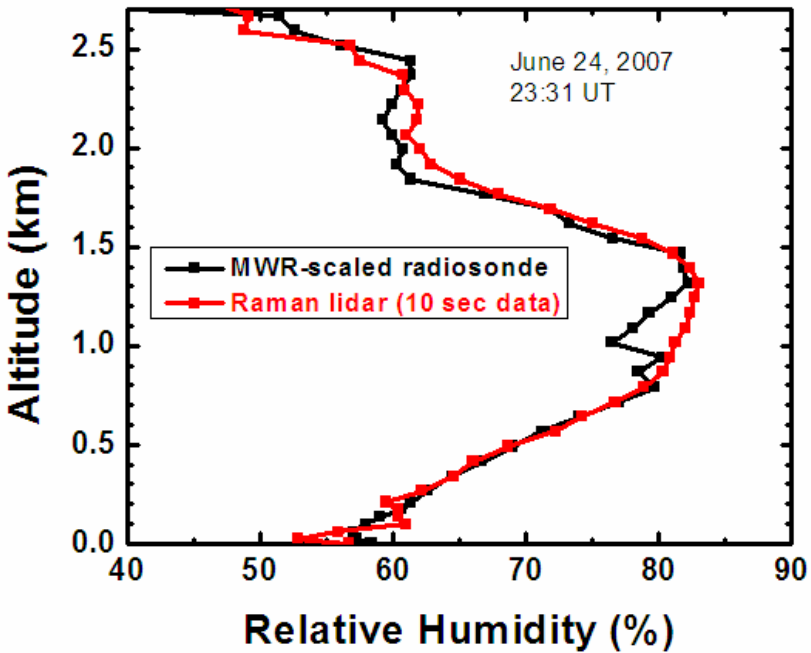


SGP CART Raman Lidar (CARL)

- 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)





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

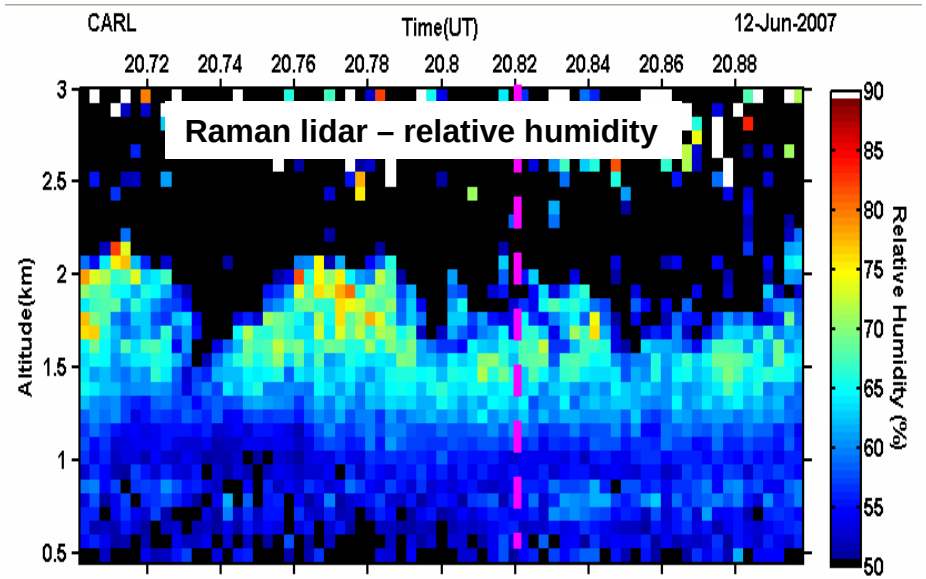
- Temporal resolution: 10 sec (RH, backscatter)
- Vertical resolution: 75 m (possible to go lower)
- Compare RH and aerosol properties adjacent to cloud edge with properties some time (distance) away from cloud edge
- Examined several altitudes above/below cloud base

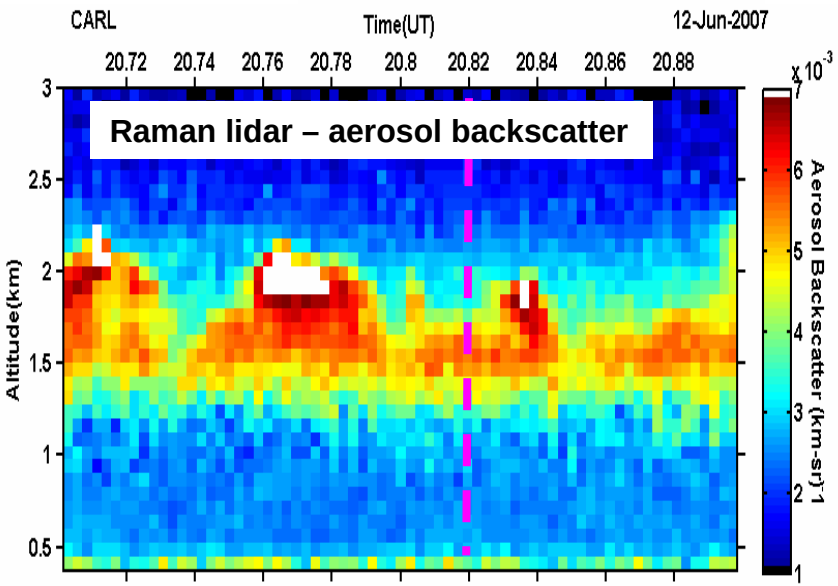
➢ **Updated analyses now uses both CARL data and TSI images to determine time (distance) from cloud**

~ 10 min

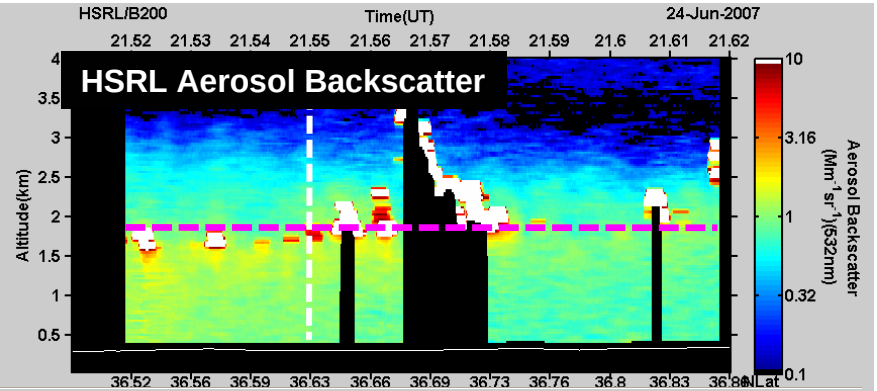
SGP TSI

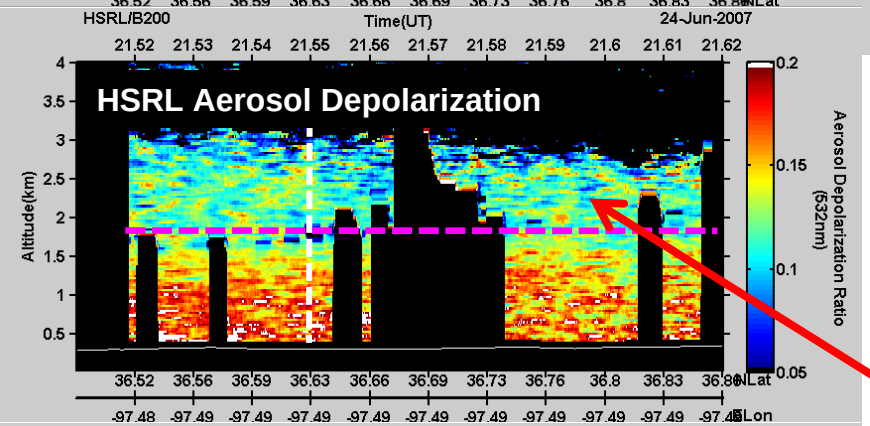
20070612_204900

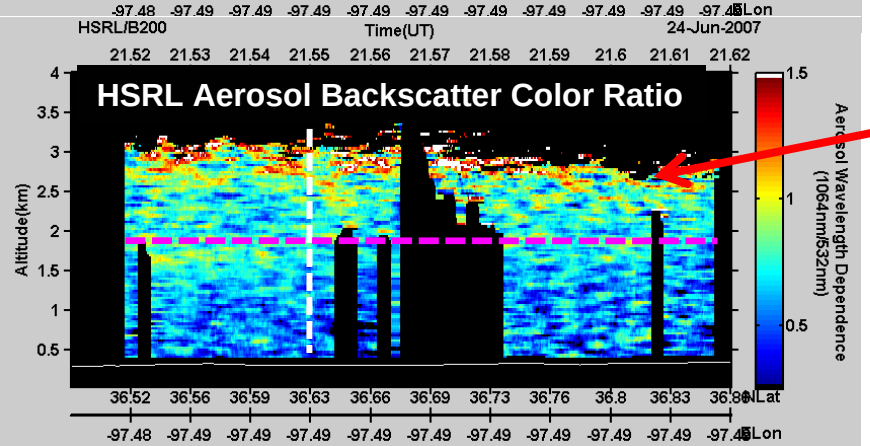


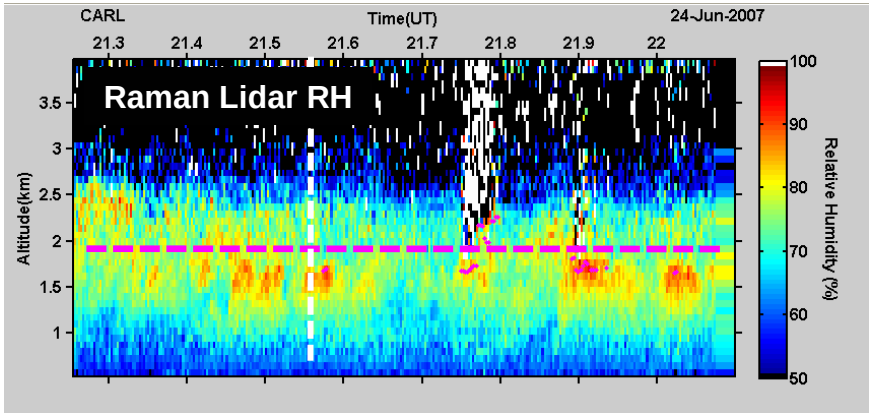


Changes in aerosol properties near clouds associated with RH









Coincident HSRL and Raman Lidar measurements during CHAPS/CLASIC June 24, 2007

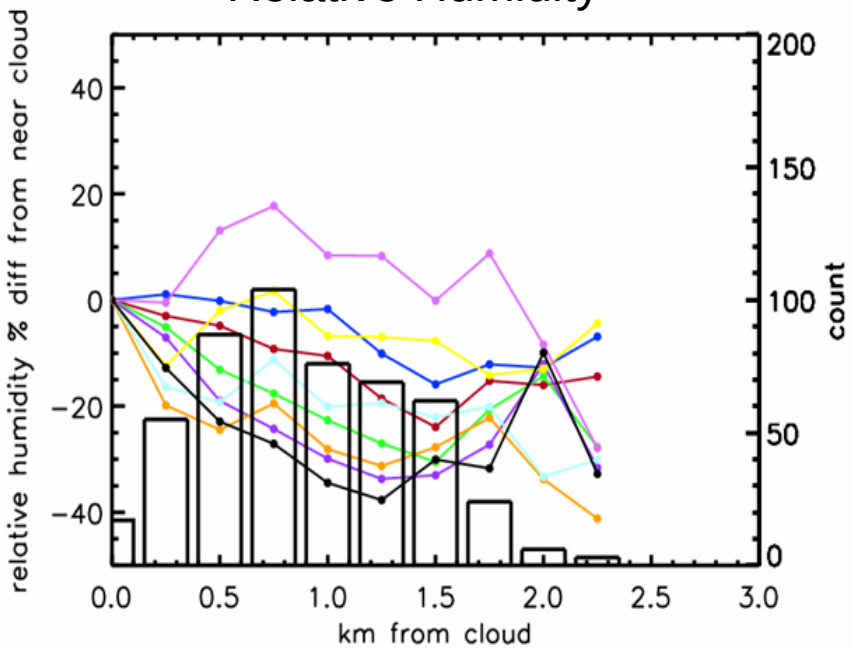
Decrease in aerosol depolarization and increase in backscatter color ratio in HSRL data may be due to increase in RH as shown by Raman lidar data

Changes in aerosol backscatter and RH near clouds measured by SGP Raman Lidar

June 12, 2007 case

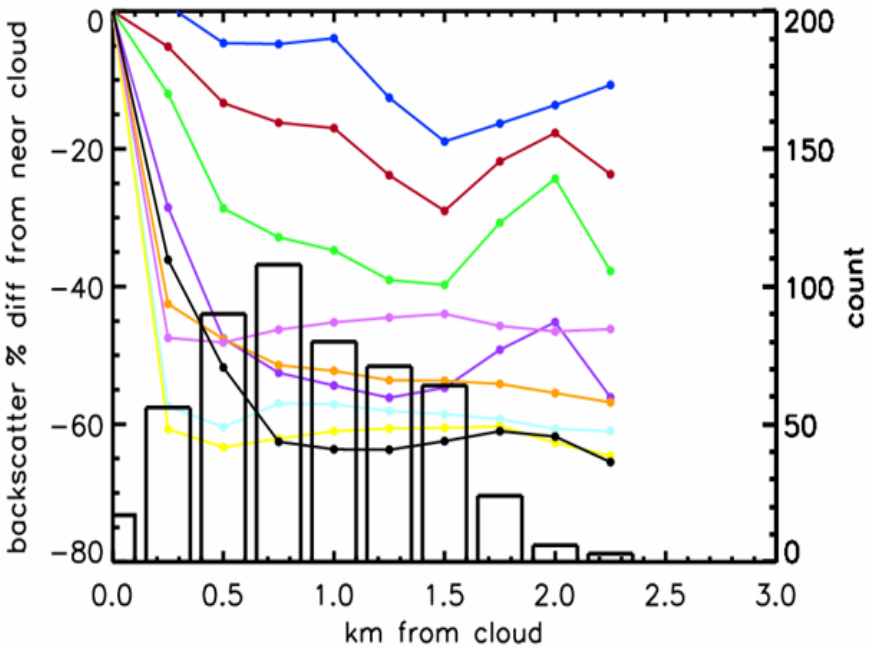
- Significant changes in aerosol properties within 1-2 km of clouds. As distance from cloud increases:
  - Similar (25-40%) decrease in aerosol backscattering observed from ground
  - Relative humidity decreases 5-15%
- Variations confined to altitudes between ~200-300 m below cloud base to 100-200 m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

Relative Humidity



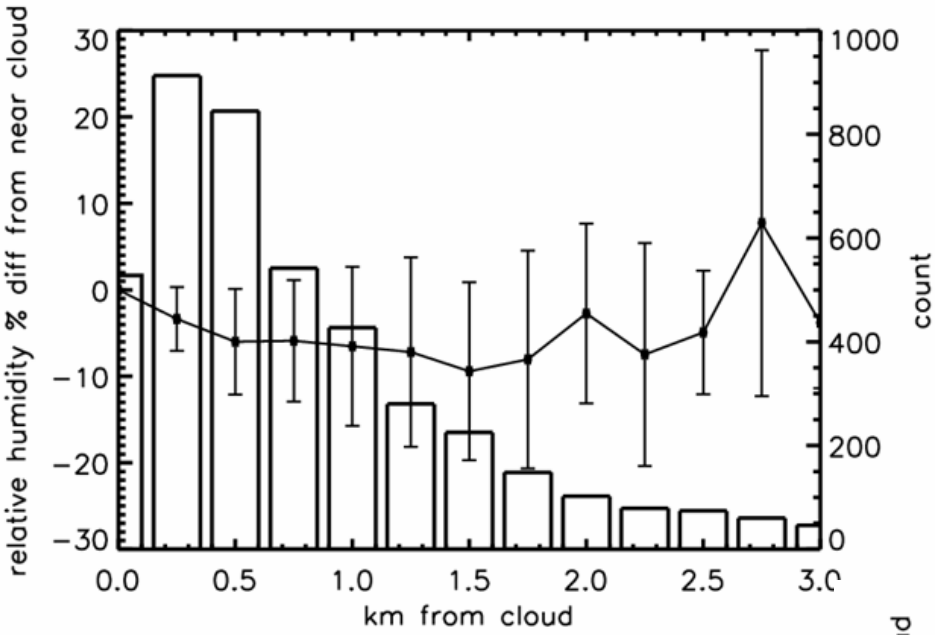
−400m −300m −200m −100m 100m 200m 300m 400m at cloud alt

Aerosol Backscatter



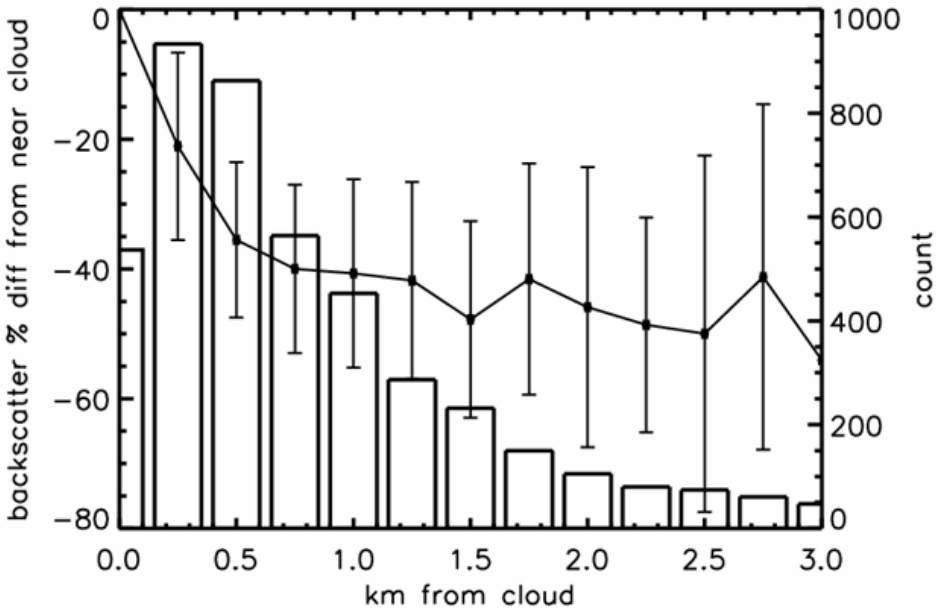
−400m −300m −200m −100m 100m 200m 300m 400m at cloud alt

Changes in aerosol backscatter and RH near clouds measured by SGP Raman Lidar



- Results from 10 days in Sept. 2005 and June 2007

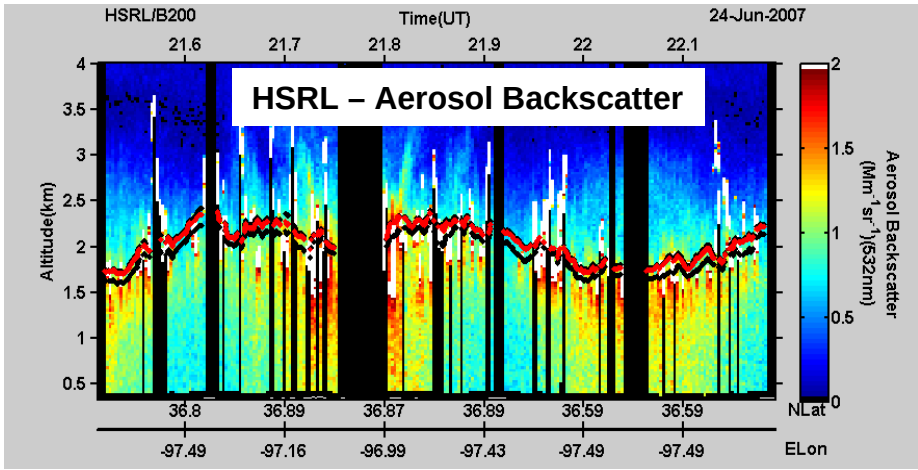
- Significant changes in aerosol properties within 1-2 km of clouds. As distance from cloud increases:
  - Similar (25-40%) decrease in aerosol backscattering observed from ground
  - Relative humidity decreases 5-15%

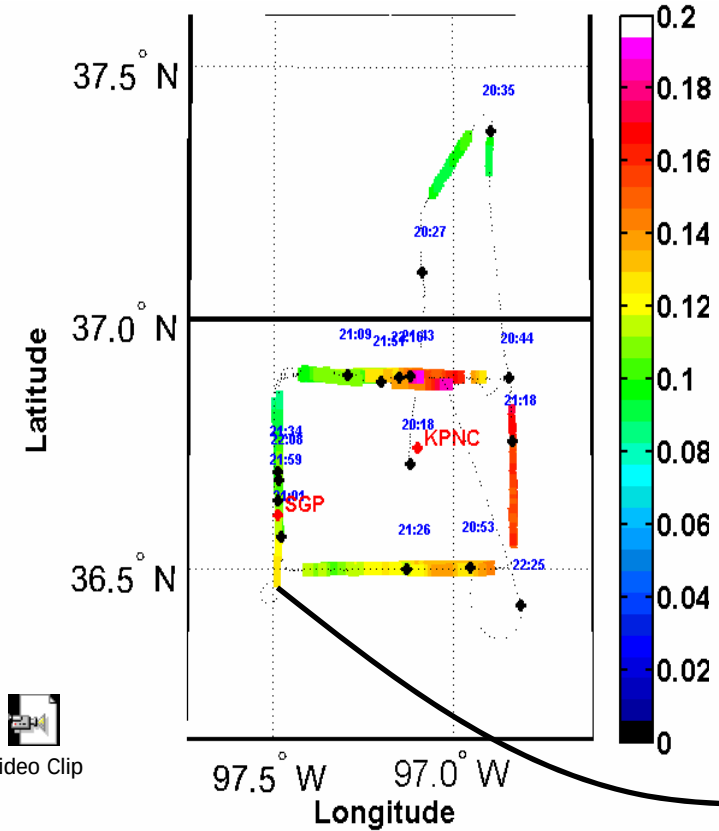


Example of CLASIC B200/CIRPAS Twin Otter Coordinated Flight – June 24

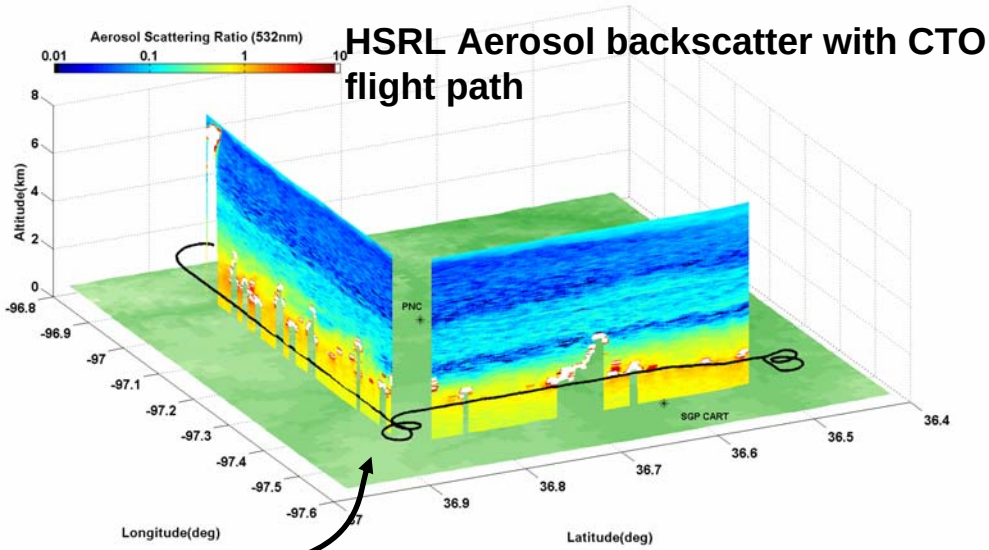
To look at concurrent RH and aerosol size distribution measurements, we examine airborne in situ measurements from:

- **CIRPAS Twin Otter (CLASIC)**
- **G1 (CHAPS)**

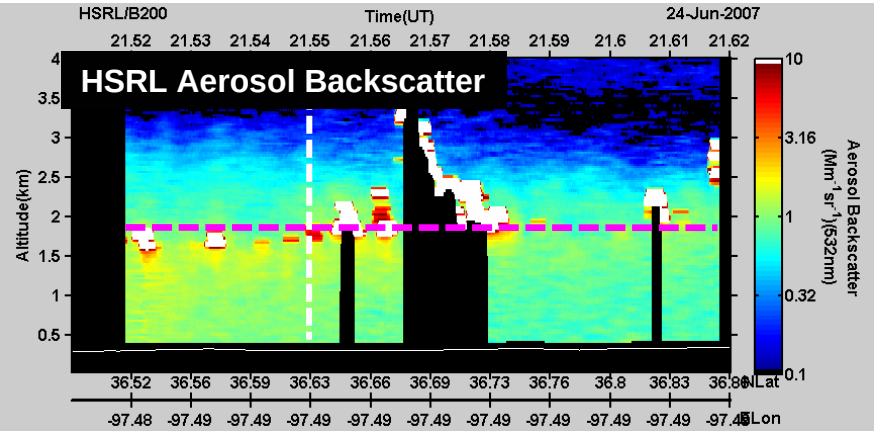


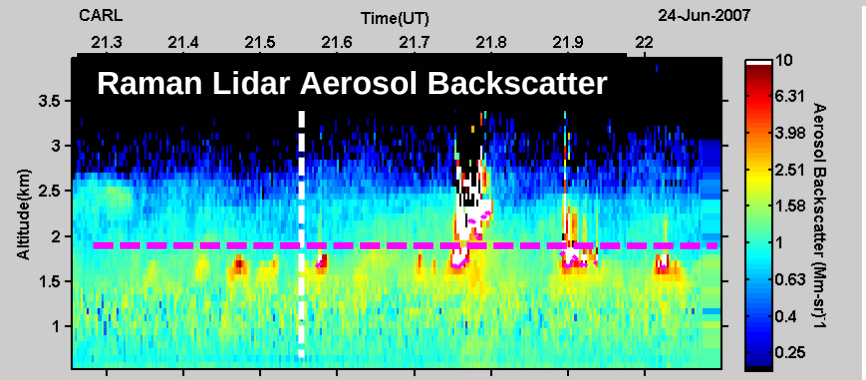


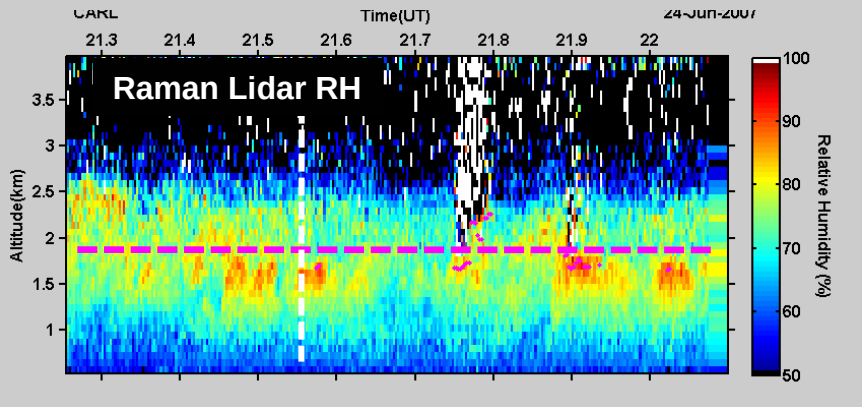
Video Clip



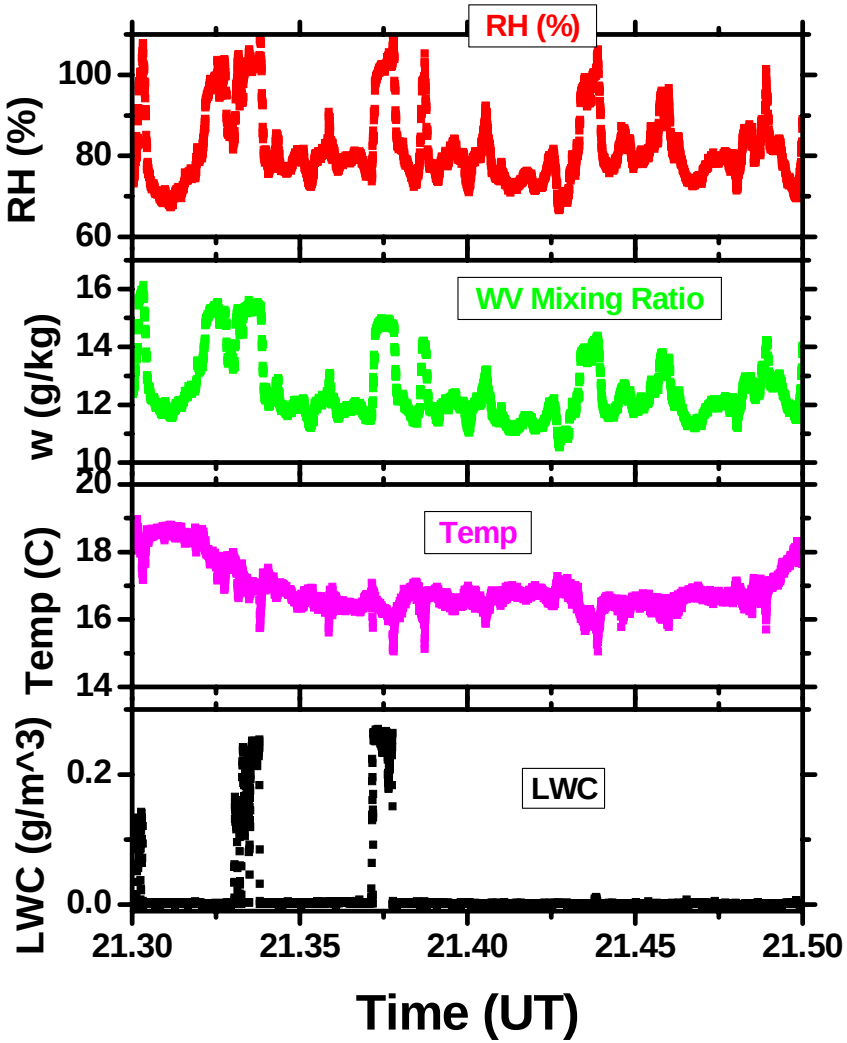
Example of CLASIC B200/CIRPAS Twin Otter Coordinated Flight – June 24





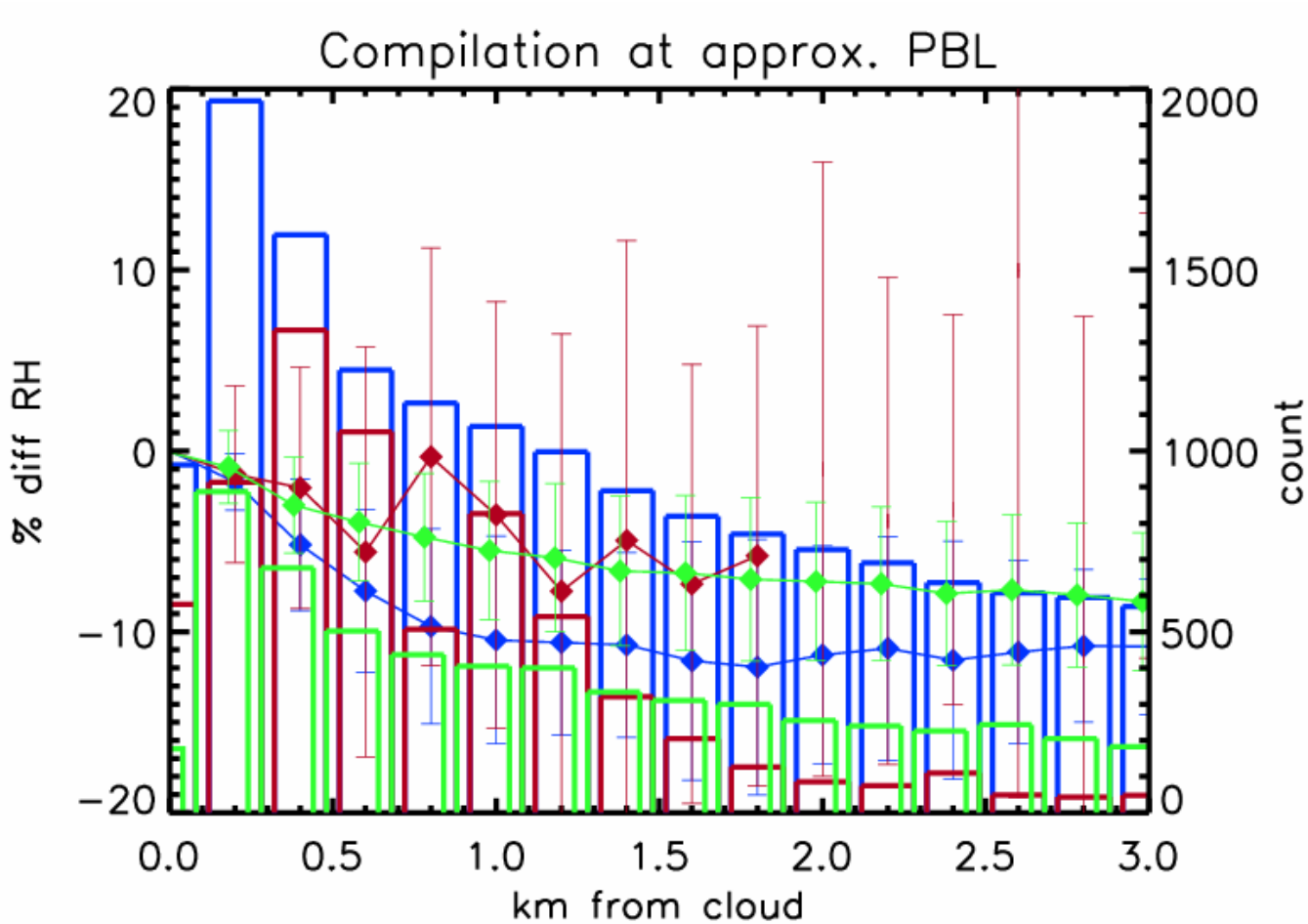


CIRPAS Twin Otter 1.9 km



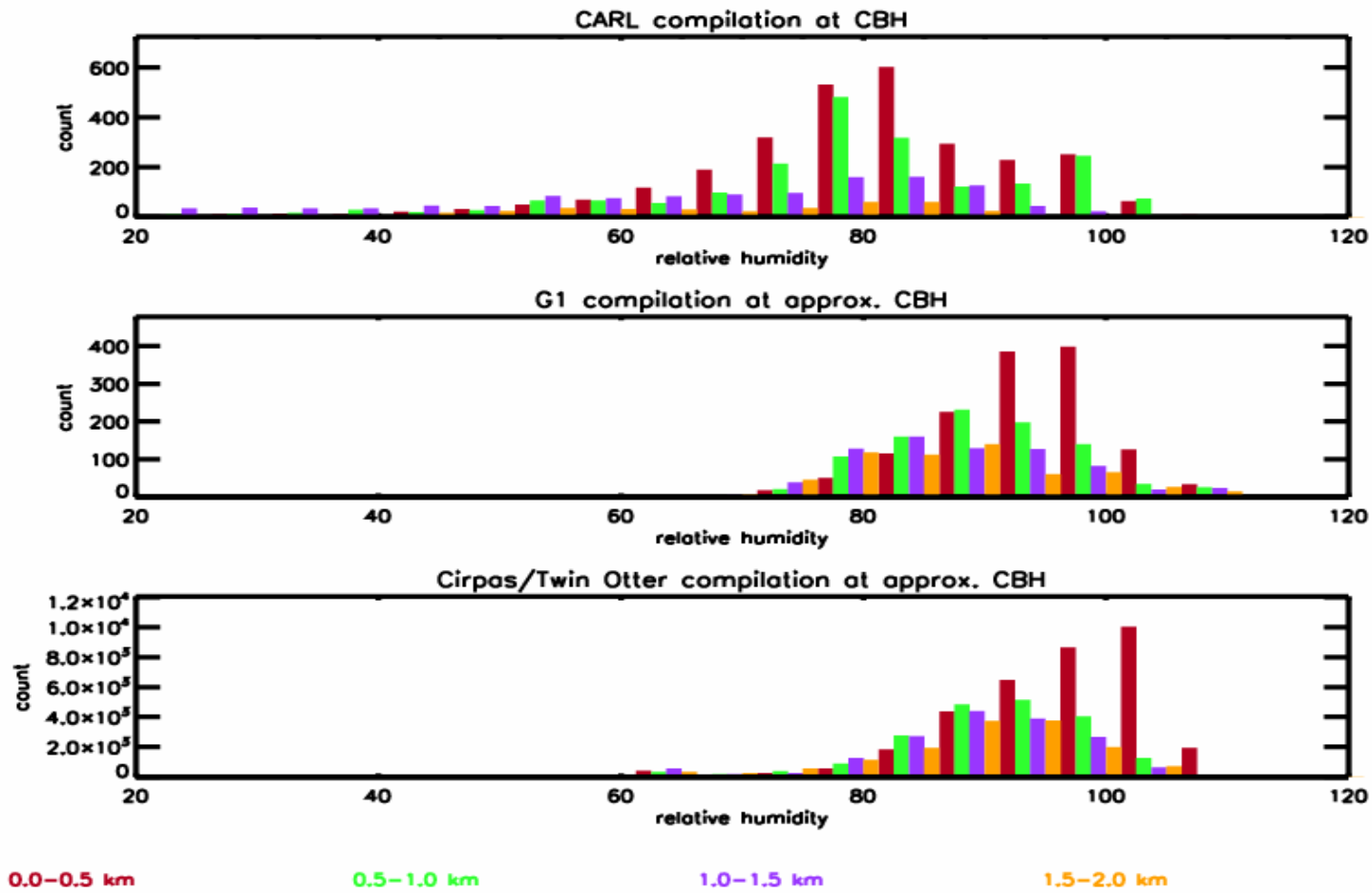
Change in RH near clouds

Raman lidar, Twin Otter, G-1 measurements show relative humidity ~ 5-10% higher in proximity to clouds as compared to 4-5 km

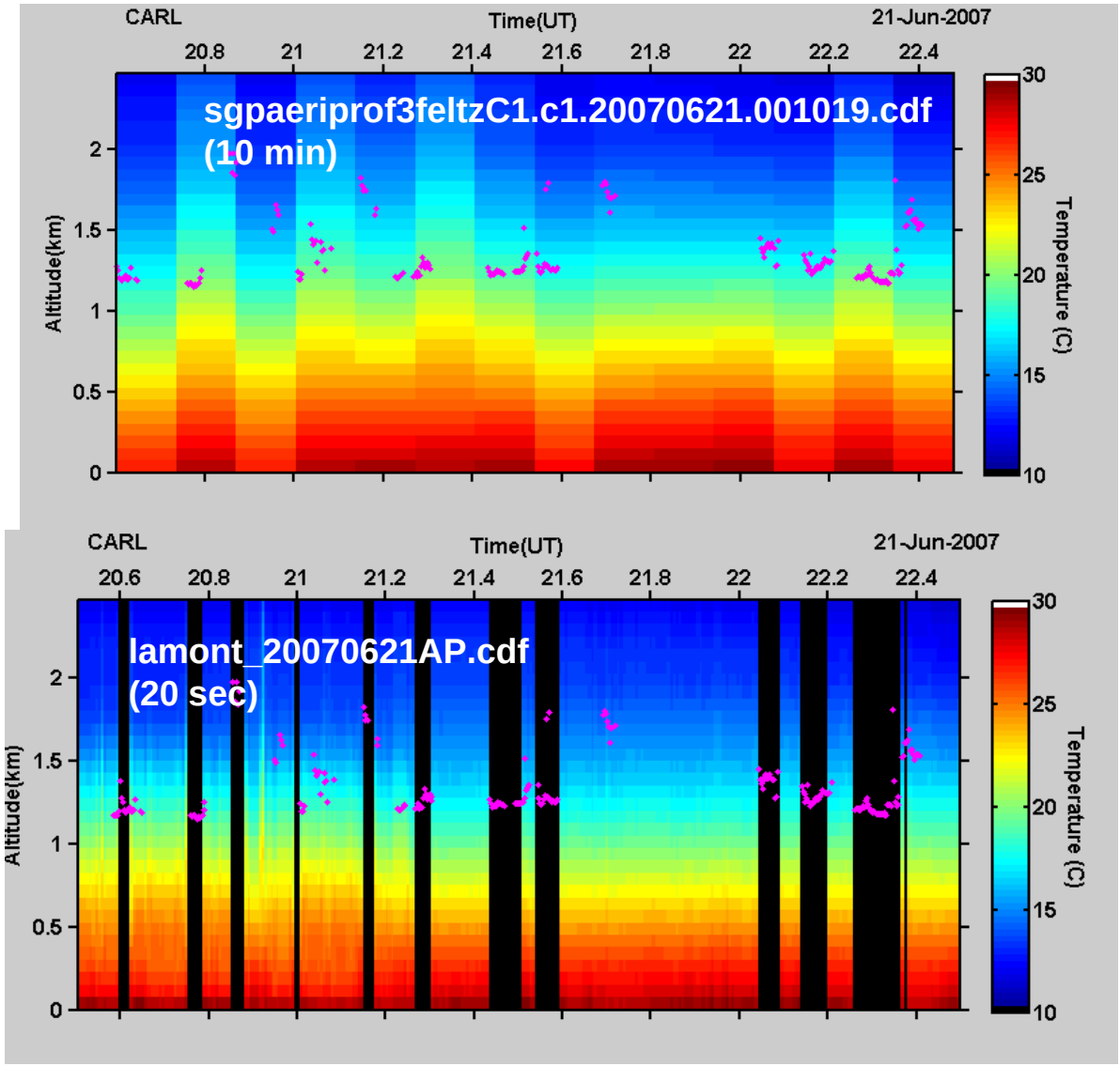


RH Distribution Near Clouds

- Raman lidar RH near clouds is lower than corresponding RH measured by aircraft in situ measurements
- Different RH behavior may be related to:
  - difference in defining cloud boundary
  - temperatures derived from AERI retrievals



AERI Temperature Retrievals



- Nominal 10 min AERI temperature retrievals show indications of cloud contamination
- Cloud contamination introduces a high bias in temperature and low bias in RH derived from Raman lidar water vapor
- New rapid sampling AERI retrieval with improved cloud screening offers hope for more accurate temperatures and RH near clouds

Summary

- HSRL measurements have shown:
  - increased aerosol backscatter and optical thickness near clouds
  - no systematic behavior in lidar ratio and backscatter color ratio near clouds
- Raman lidar measurements have shown:
  - Increased aerosol backscatter and RH near clouds
- Aircraft measurements have also noted increase RH near clouds

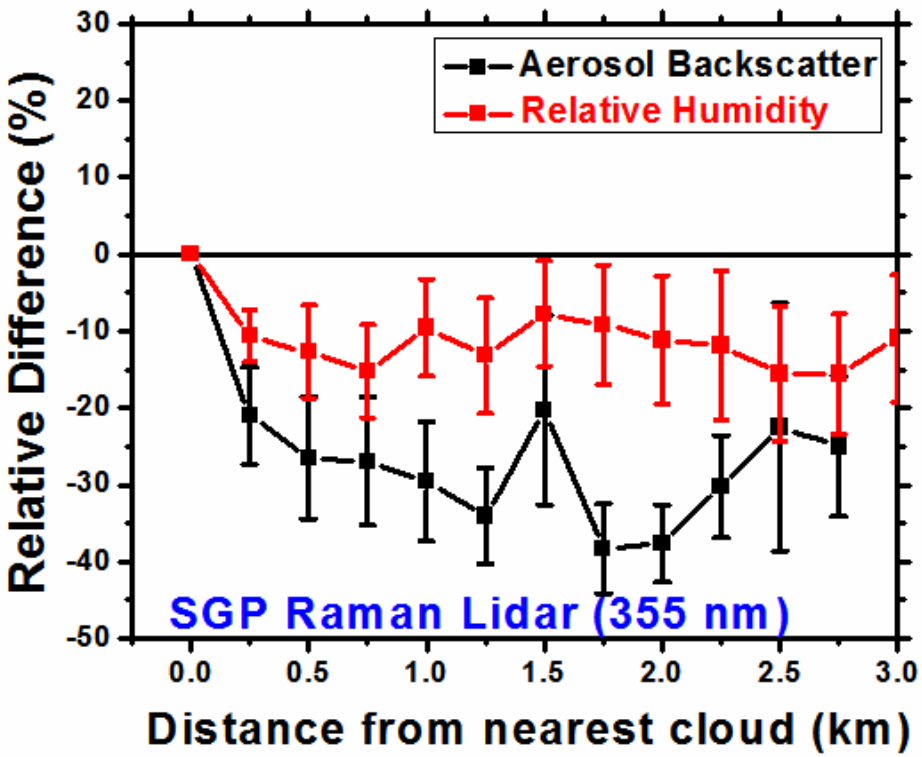
Future

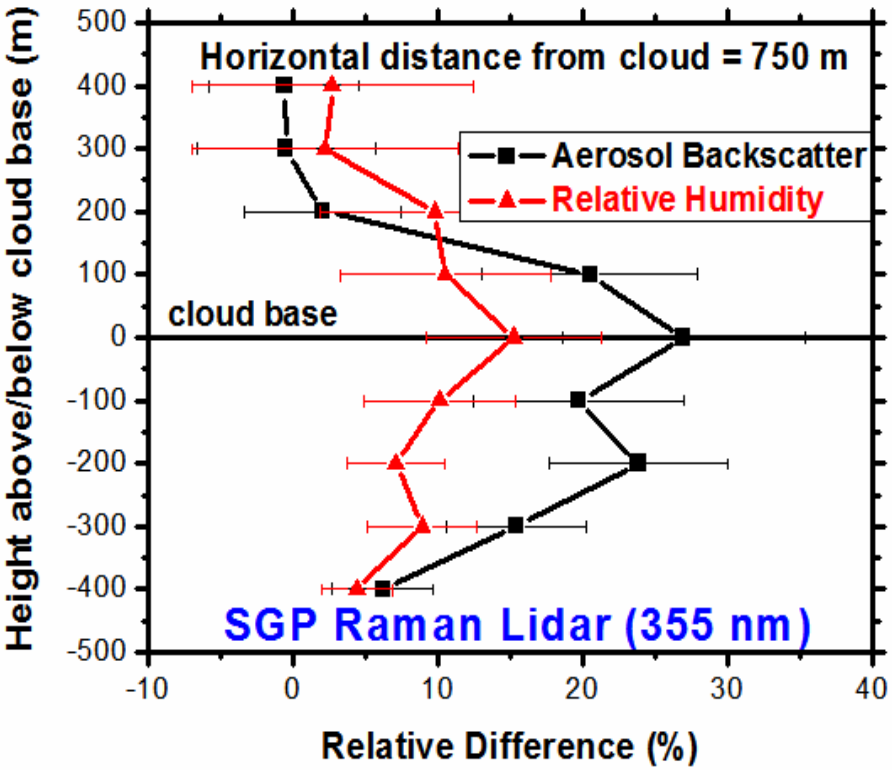
- Use advanced AERI rapid temperature profiling capability for improving RH derived from Raman lidar water vapor measurements
- Examine changes in aerosol optical properties and size distribution as recorded by aircraft in situ measurements

Changes in aerosol properties near clouds measured by SGP Raman Lidar

June 12, 2007 case

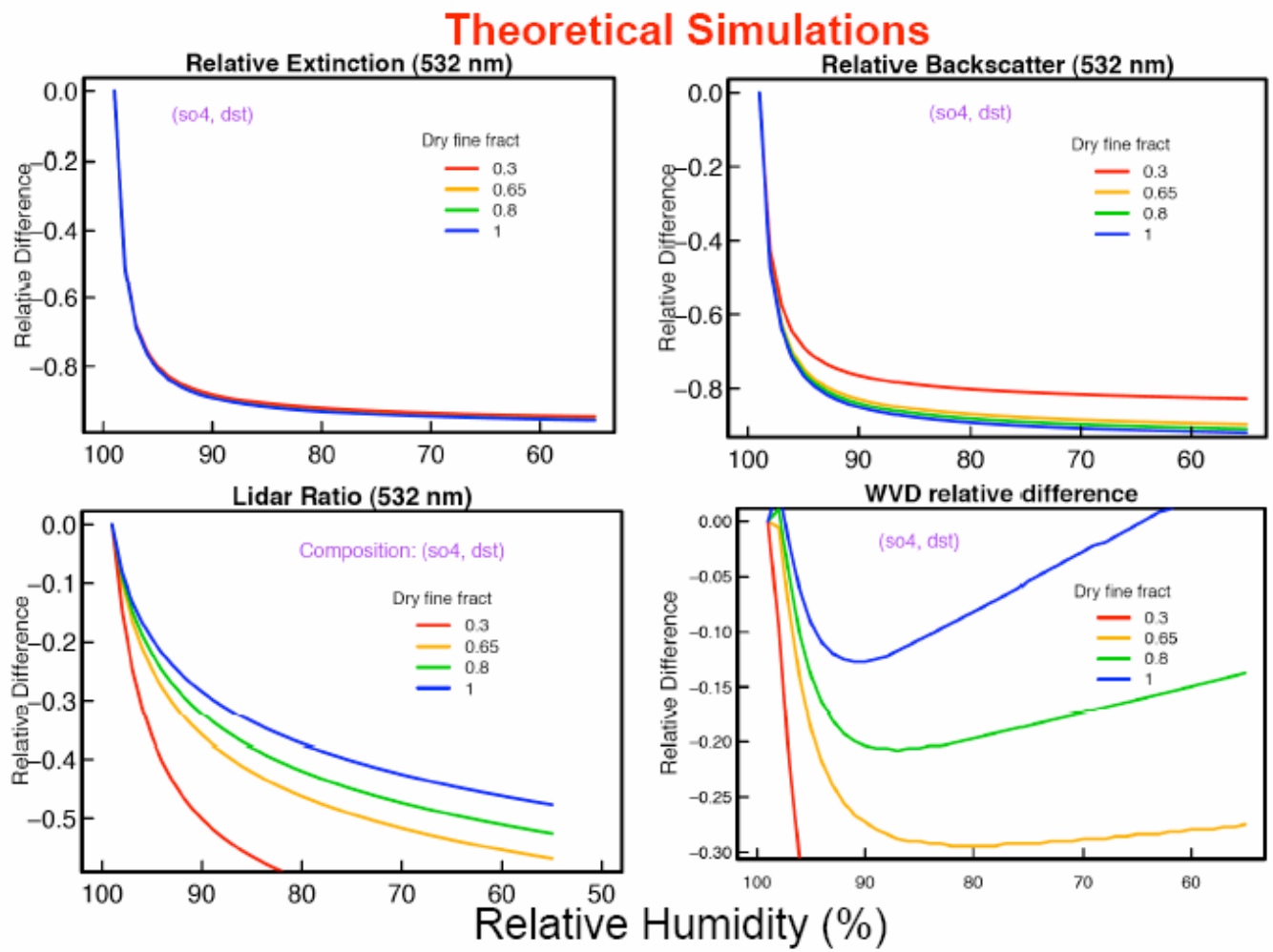
- Significant changes in aerosol properties within 1-2 km of clouds. As distance from cloud increases:
  - Similar (25-40%) decrease in aerosol backscattering observed from ground
  - Relative humidity decreases 5-15%
- Variations confined to altitudes between ~200-300 m below cloud base to 100-200 m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



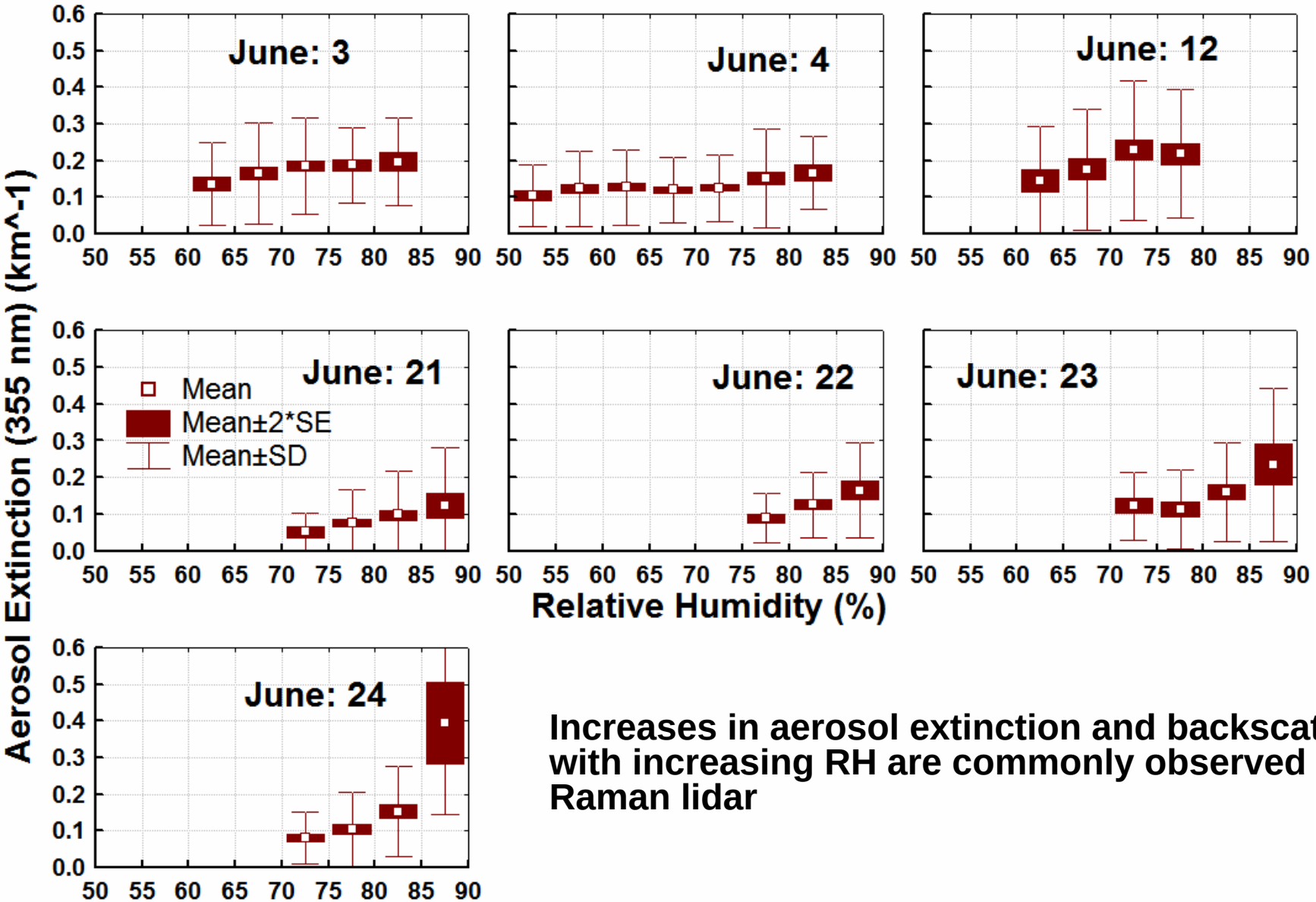


Simulated changes in aerosol properties with RH

- 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



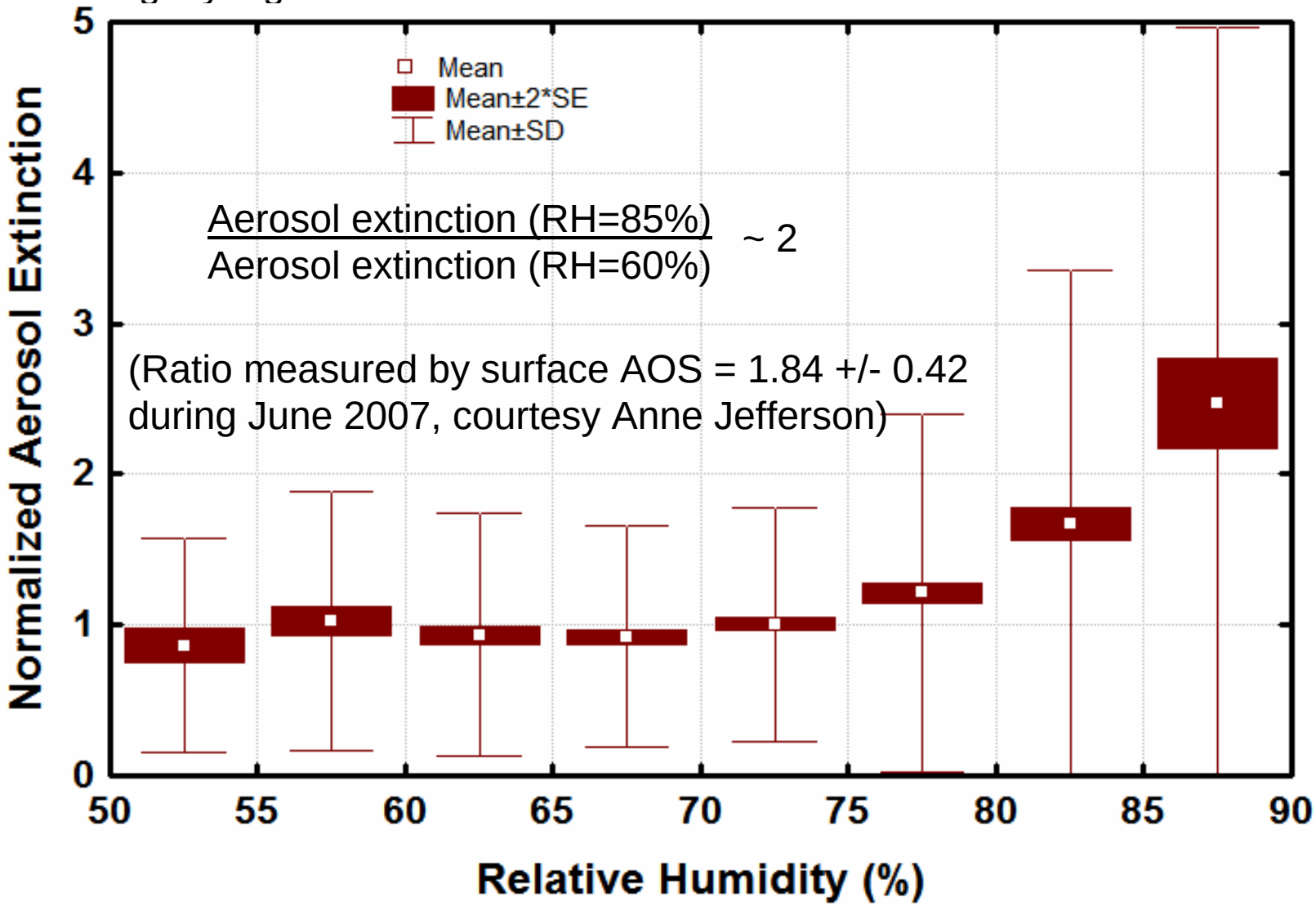
Aerosol Humidification Observed By SGP Raman Lidar



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

Aerosol Humidification Factor Derived from SGP Raman Lidar Measurements

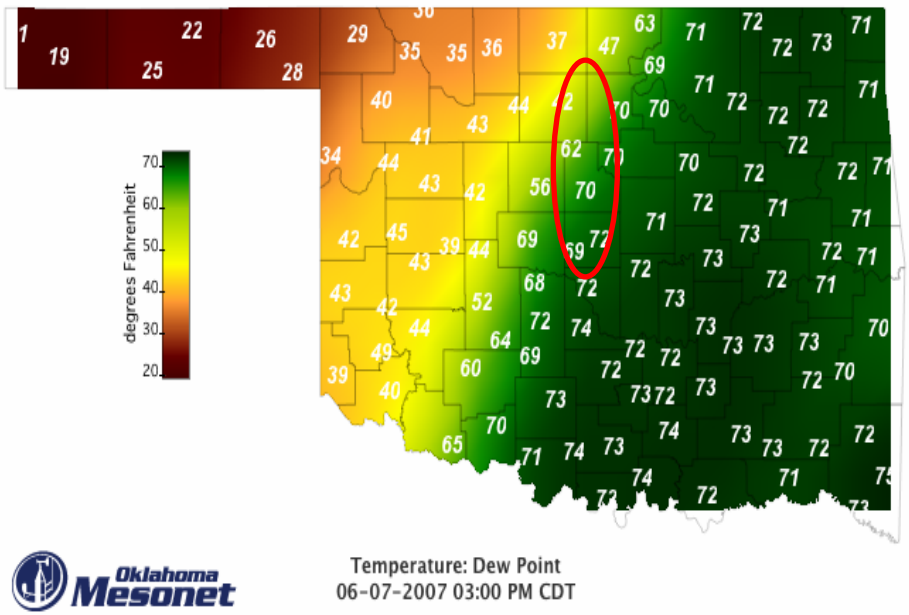
Average aerosol humidification factor [f(RH)] derived from Raman lidar is slightly higher but consistent with surface AOS measurements

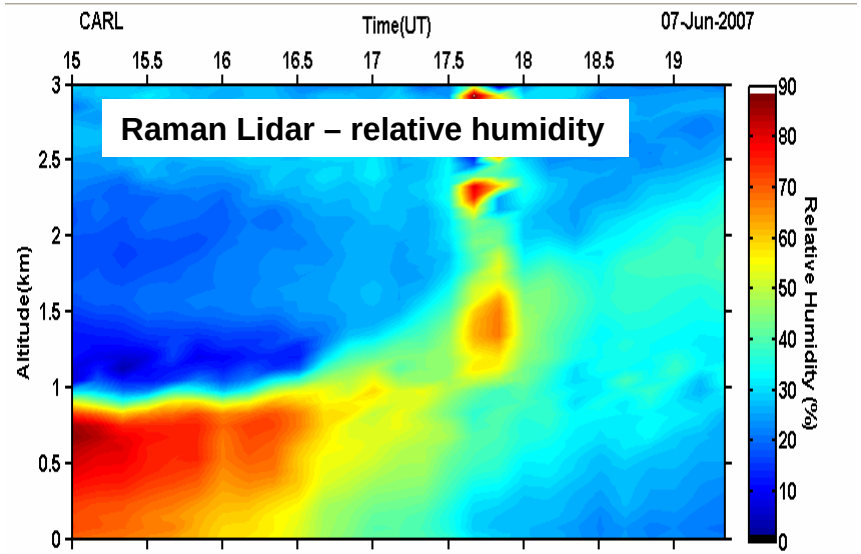


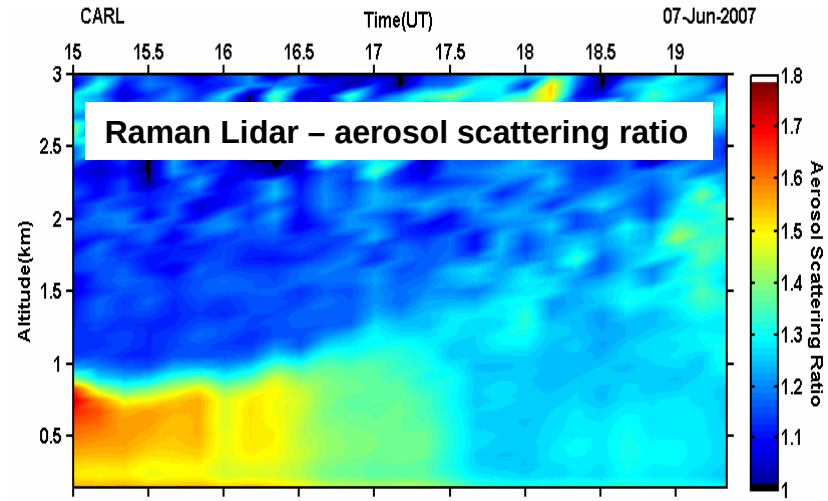
Raman Lidar Water vapor and Aerosol Measurements during June 7 Dry Line Passage

- 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

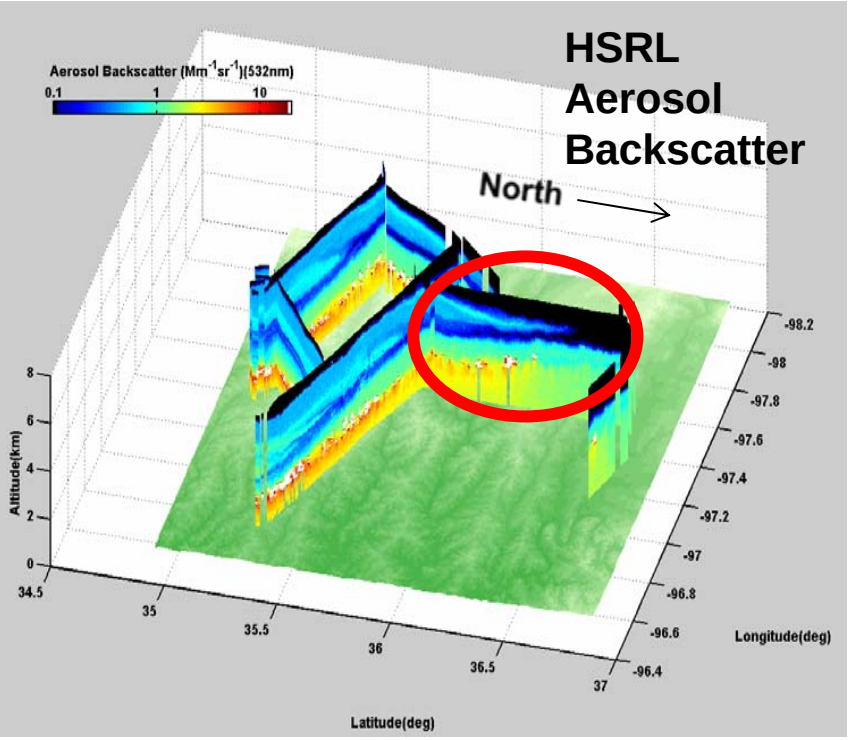
OK Mesonet; Surface Dew Point 20:00 UT





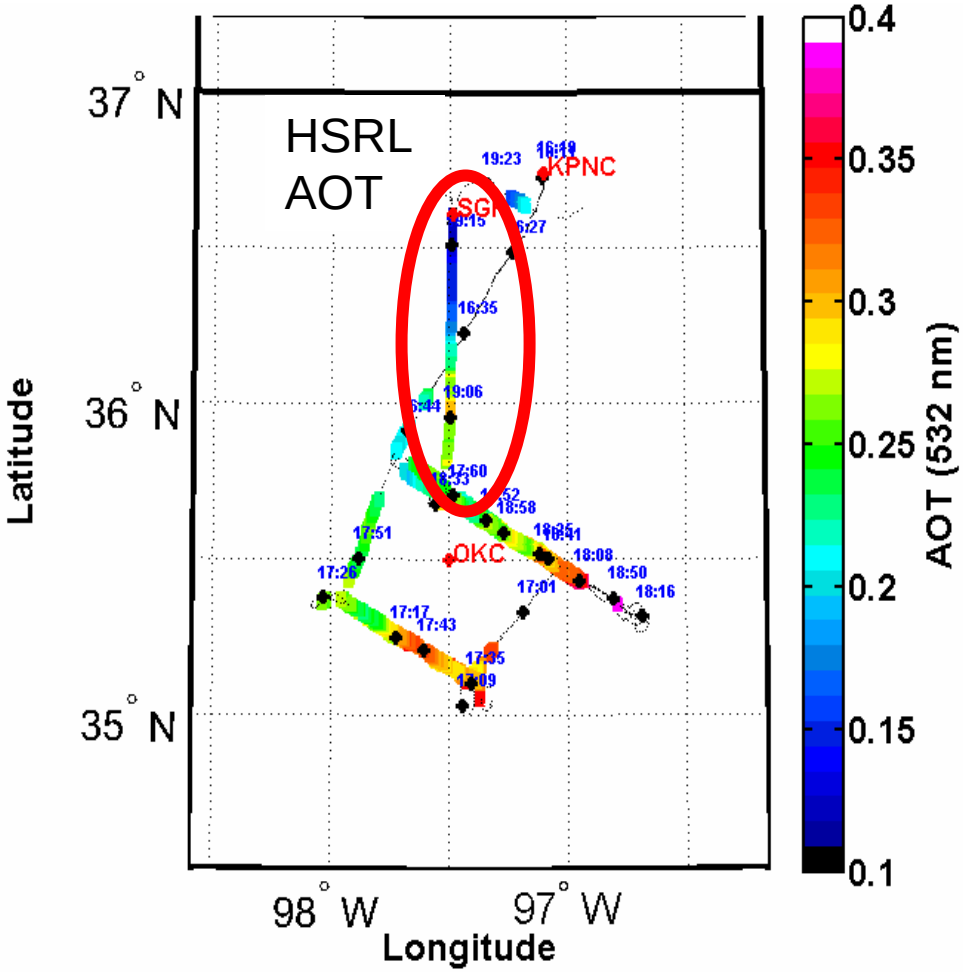


Airborne HSRL Measurements of Dry Line – June 7

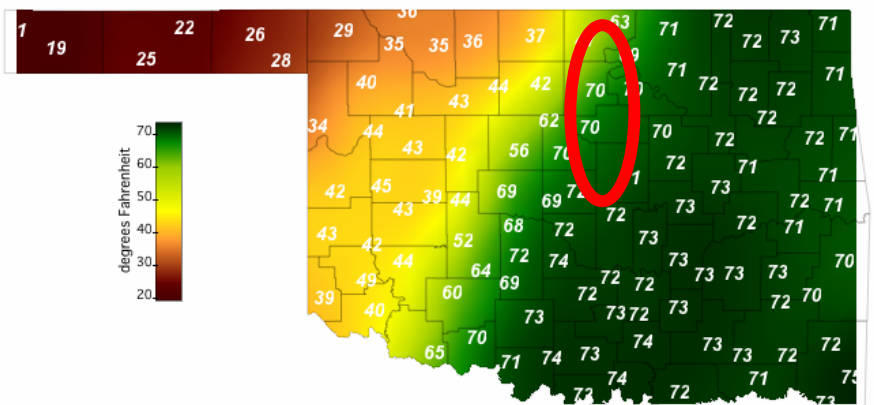


HSRL measurements show:

- **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

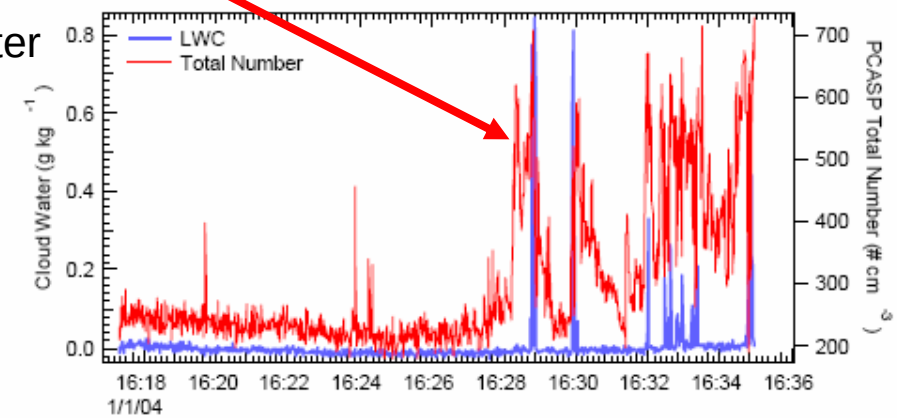


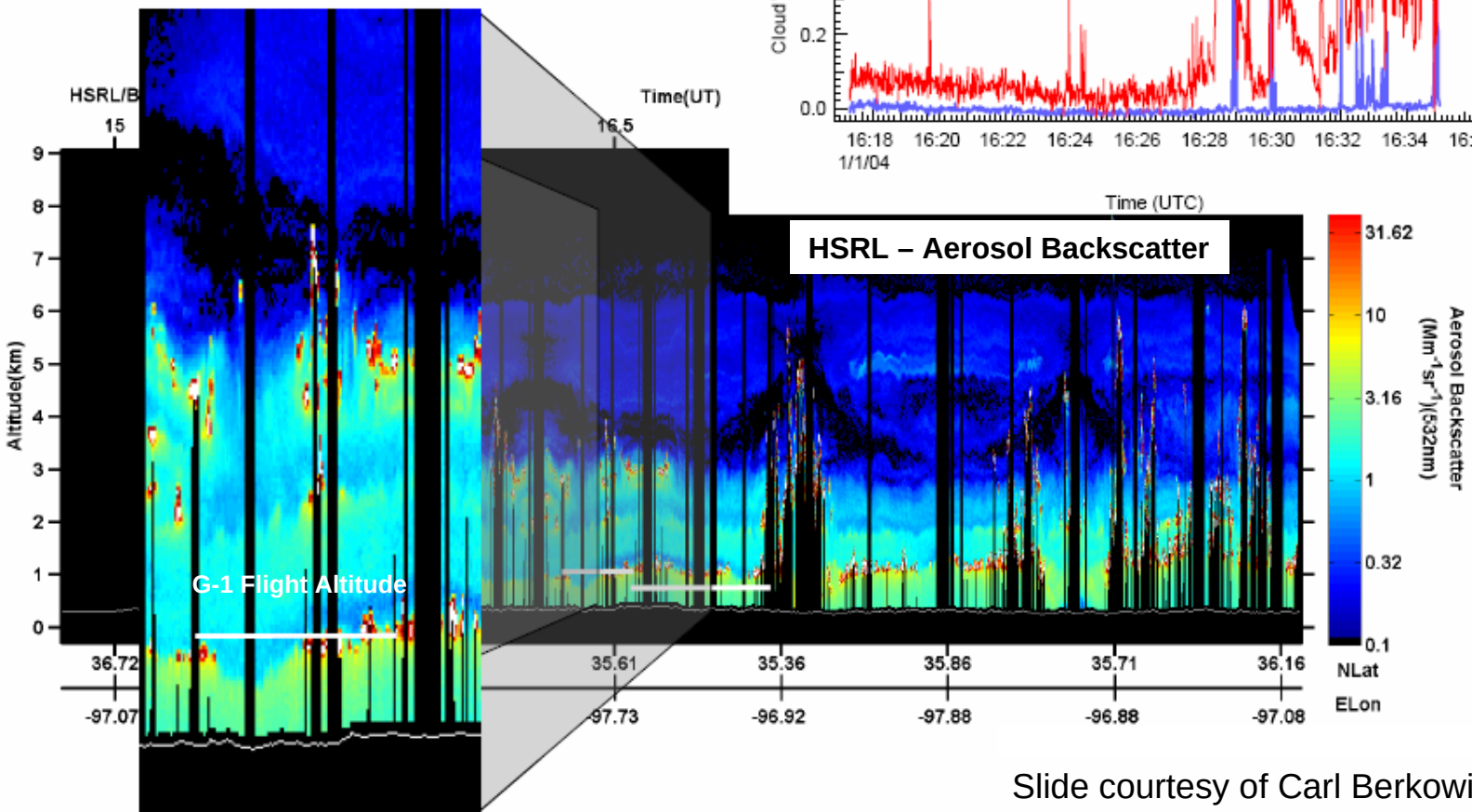
Coordinated B200 / HSRL - Airborne in situ Measurements

- 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



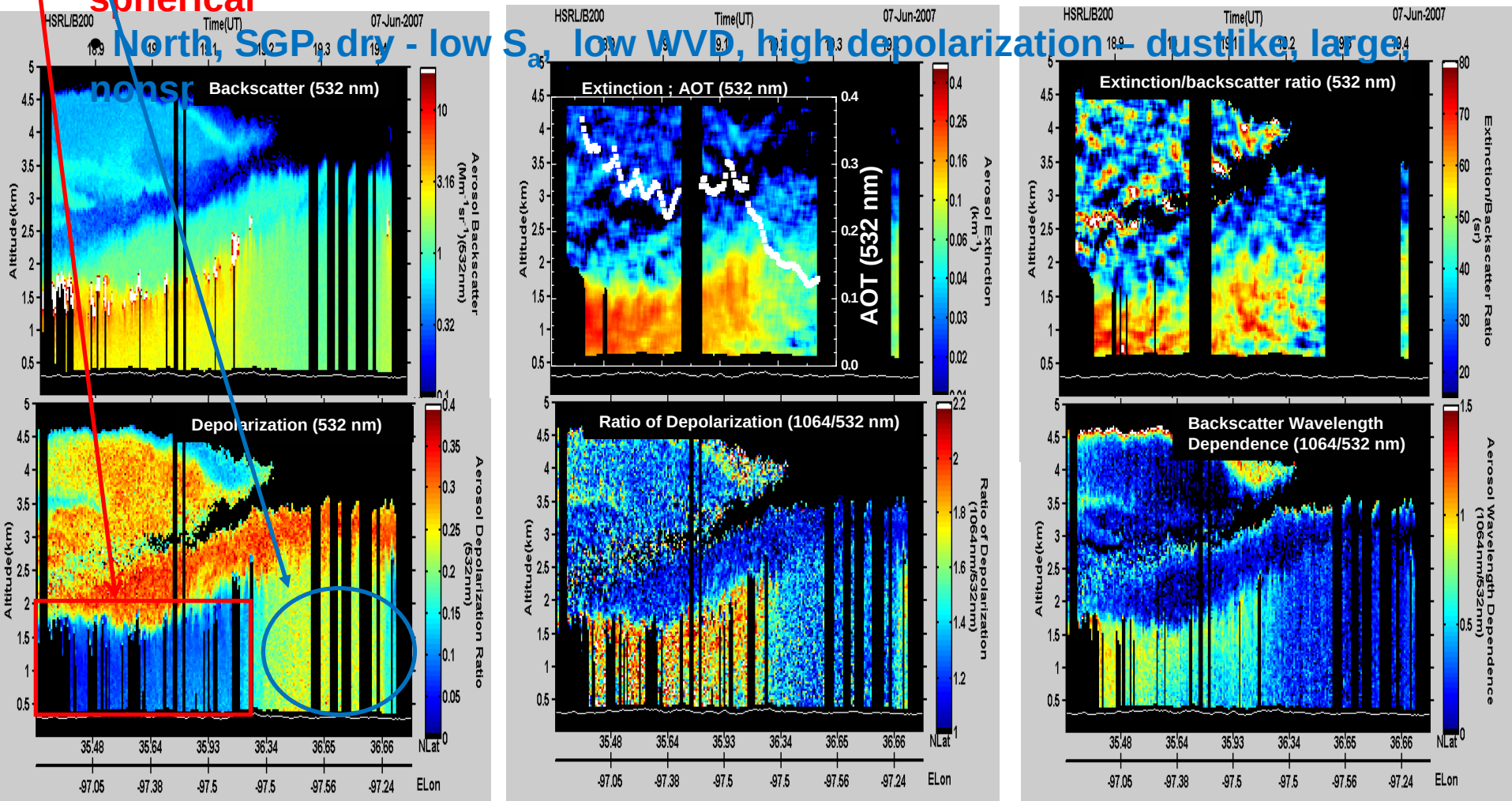


Slide courtesy of Carl Berkowitz (PNNL)

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

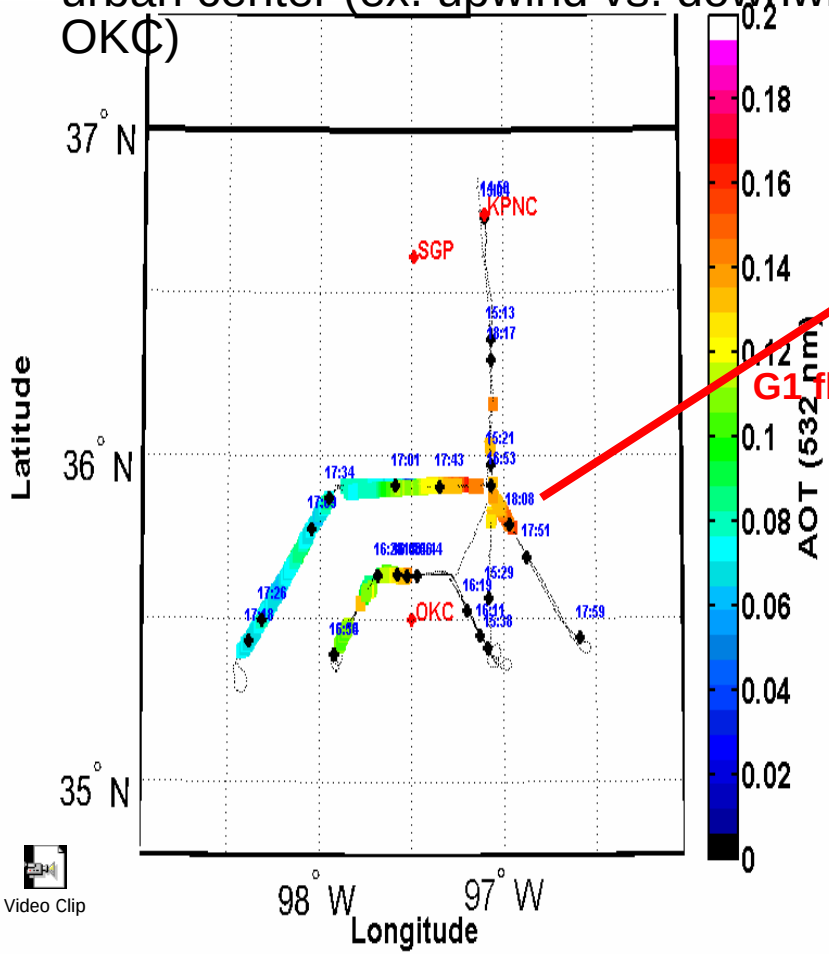
- **South, OKC, humid - high S_a, high WVD, low depolarization – urban, small, spherical**
- **North, SGP, dry - low S_a, low WVD, high depolarization – dust like, large, nonspherical**



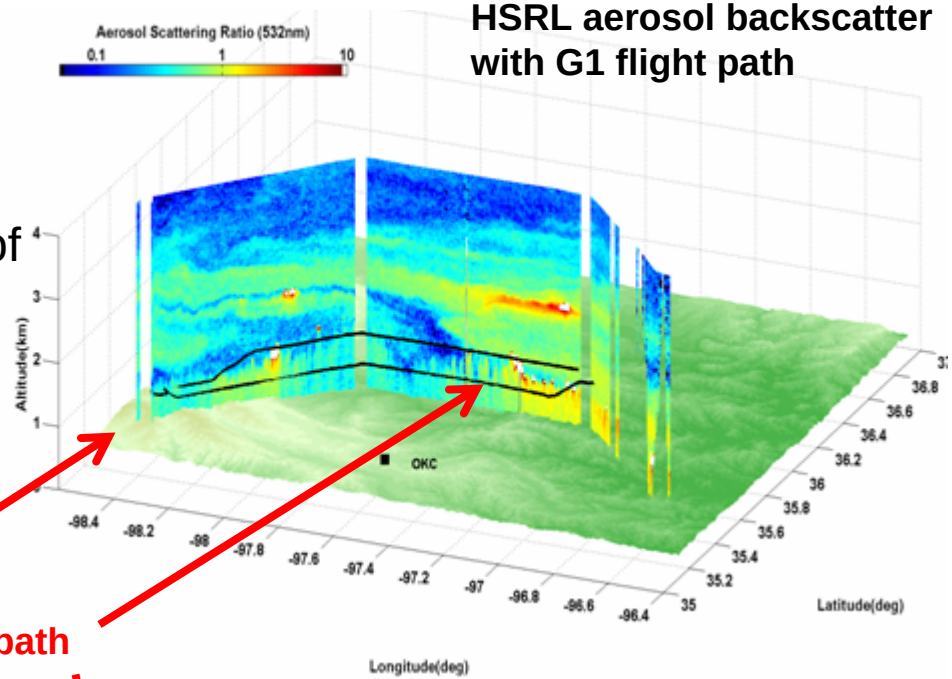
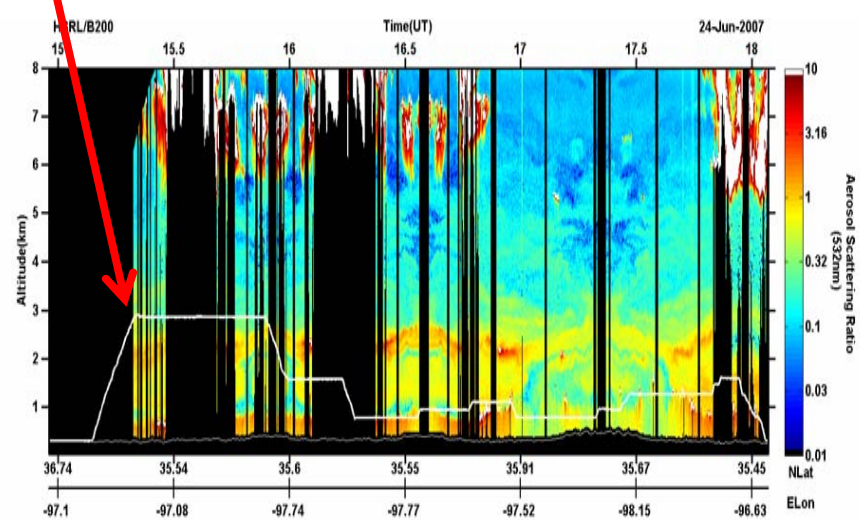
Example of CHAPS B200/G1 Coordinated Flight – June 24

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)



Video Clip

G1 flight path

HSRL aerosol backscatter with G1 flight path