OBSERVATIONS FROM THE NASA LANGLEY AIRBORNE HIGH SPECTRAL RESOLUTION LIDAR AND PLANS FOR ACTIVE-PASSIVE AEROSOL-CLOUD RETRIEVALS

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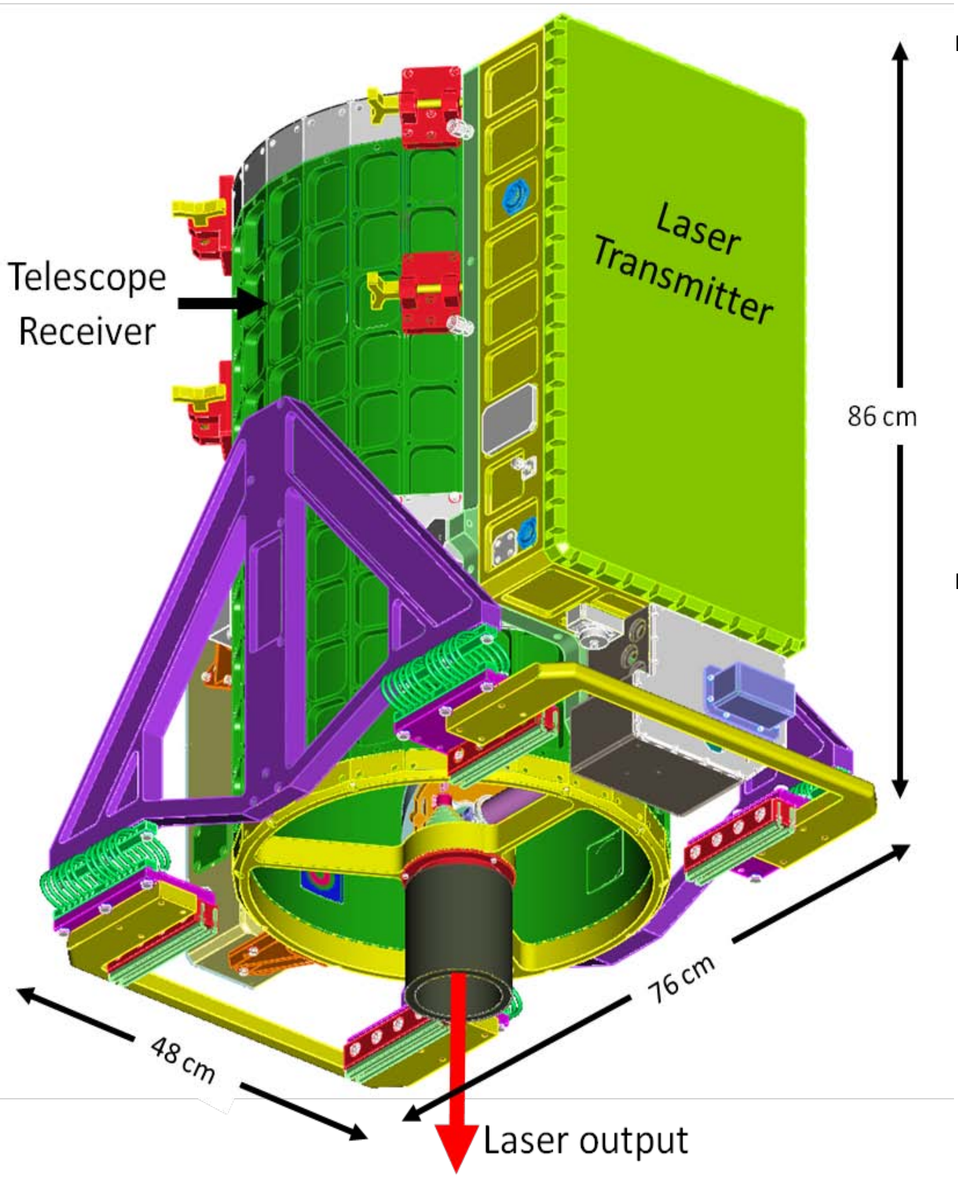
The Instrument

Airborne High Spectral Resolution Lidar (HSRL)



- **Capabilities: *1-α, 2-β, 2-δ***
  - **HSRL at 532 nm: independent aerosol**
    - **Extinction**
    - **Backscatter**
  - **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: 3 field campaigns**
  - **2007: 3 field campaigns**
  - **2008: 3 field campaigns**

Important System Characteristics

- **Calibration**
  - *Internal calibration* of electro-optic gains between parallel and perpendicular polarization channels
  - *Internal calibration* of “molecular” to parallel backscatter channel at 532 nm
    - 532 nm aerosol backscatter, depolarization, and extinction retrieved *without external calibration* to atmospheric target
  - 1064 nm backscatter calibrated using information from 532 nm aerosol backscatter
    - Normalized to estimated total backscatter at “cleanest” point in profile
    - 532 nm aerosol backscatter used to estimate 1064 aerosol backscatter at calibration altitude
- **Alignment**
  - Autonomous bore-sight alignment every 10 sec

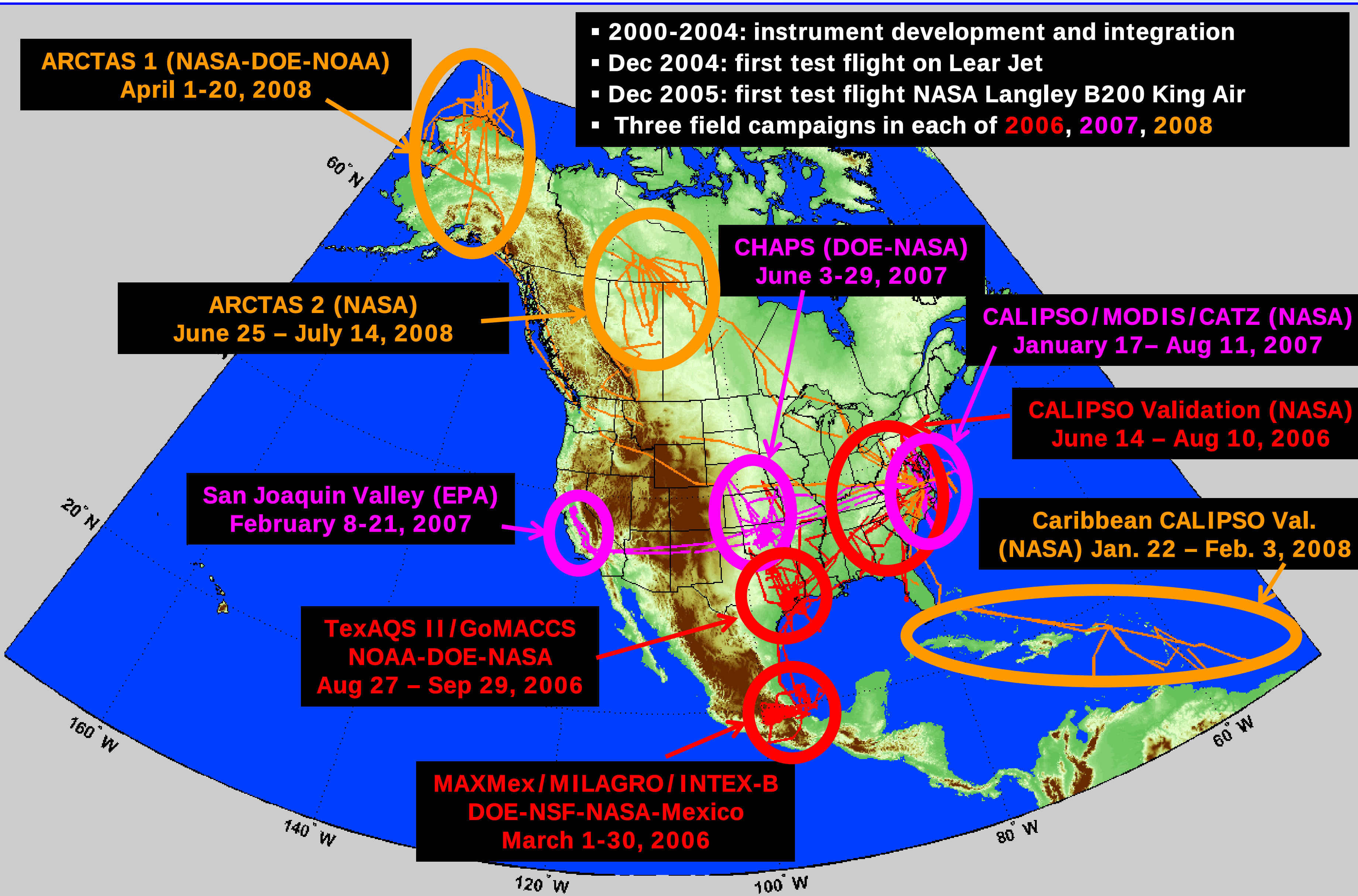
Field Missions

Airborne High Spectral Resolution Lidar (HSRL)

- Airborne HSRL has logged **>630 flight hours** and **>160 science flights** on NASA Langley King Air B200
- **Highly robust:** have never missed a flight due to instrument problems

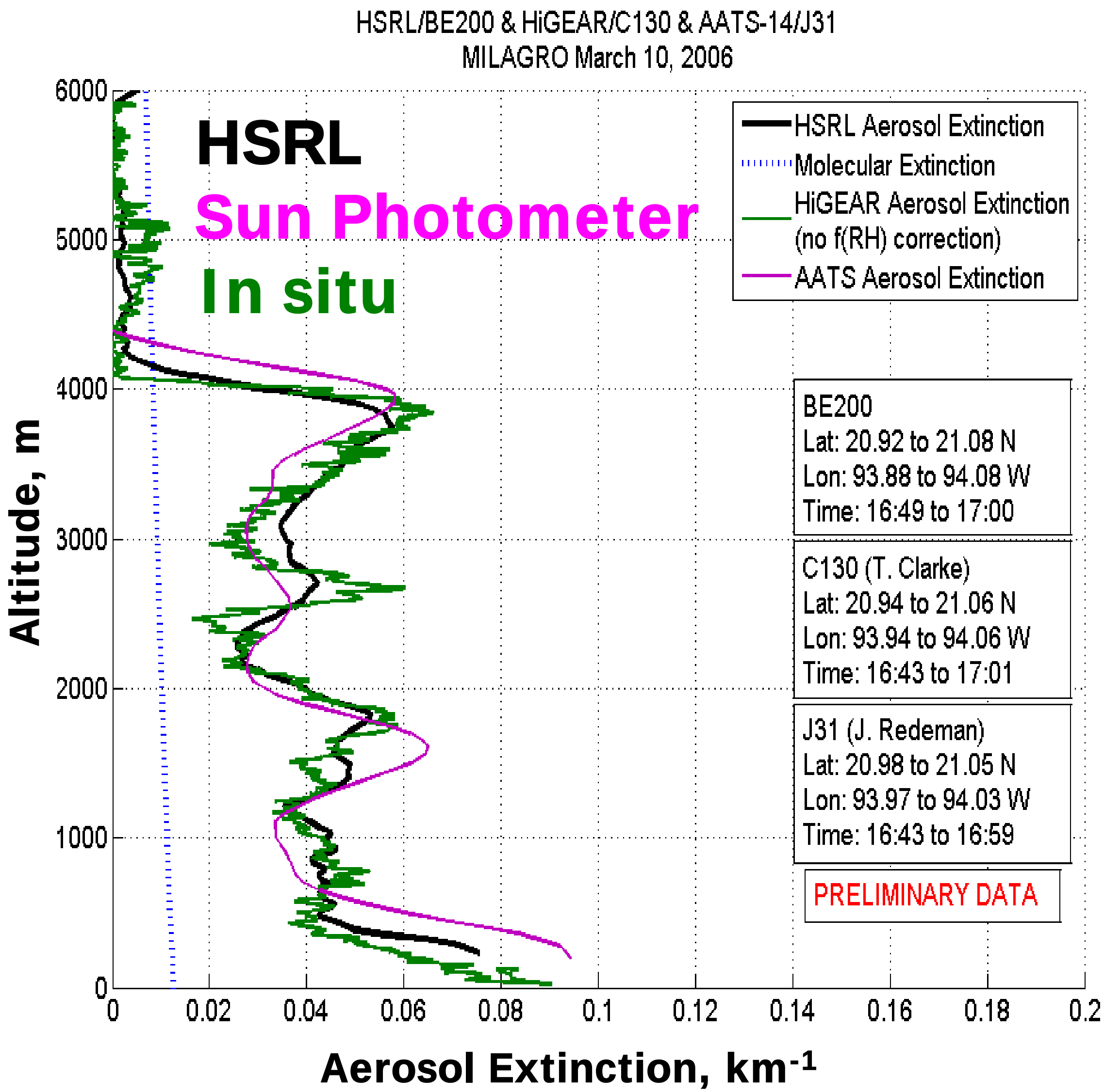
NASA Langley airborne High Spectral Resolution Lidar (HSRL) Field Campaigns

- 2000-2004: instrument development and integration
- Dec 2004: first test flight on Lear Jet
- Dec 2005: first test flight NASA Langley B200 King Air
- Three field campaigns in each of 2006, 2007, 2008



Measurements

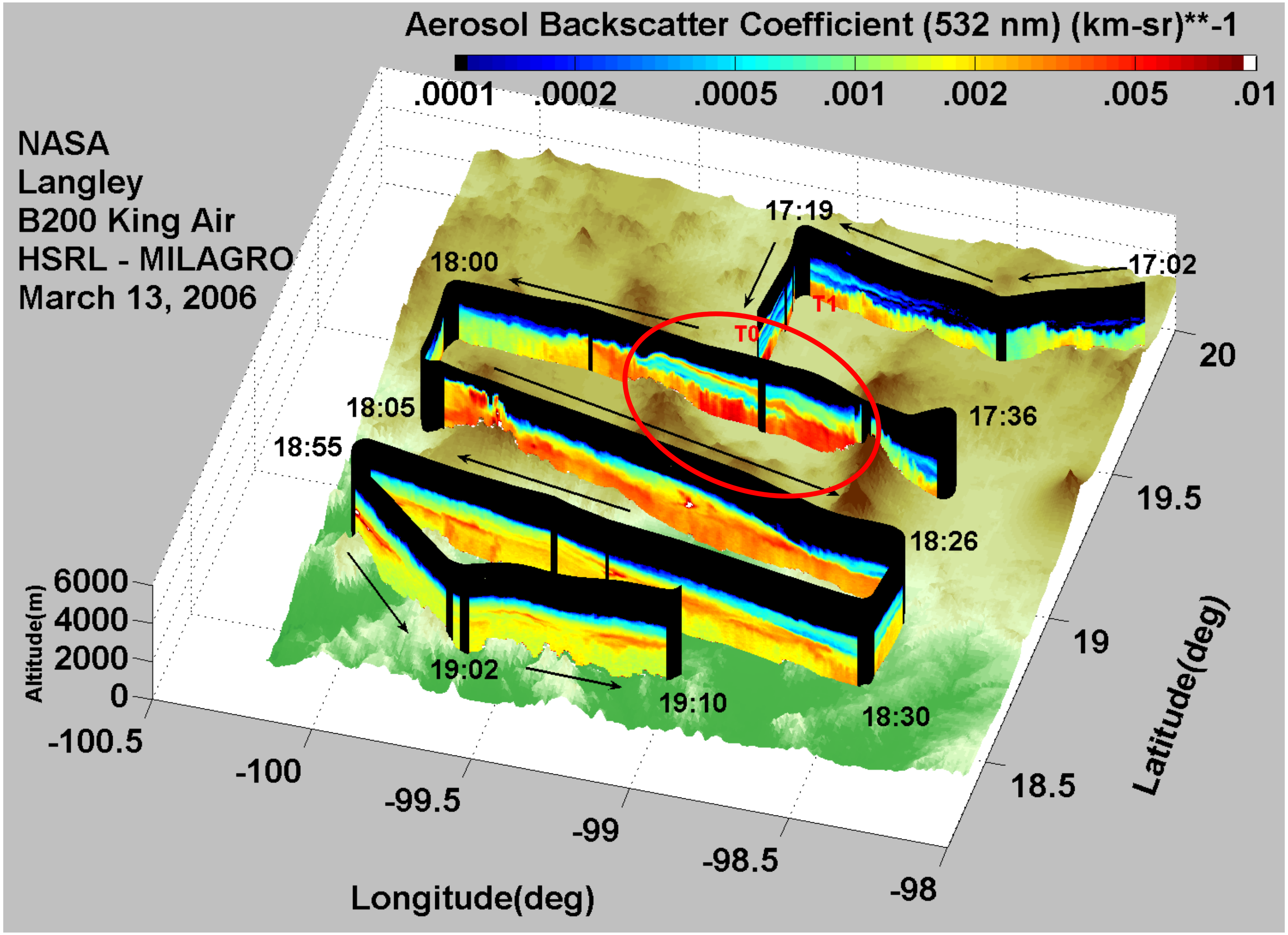
Extinction Profile Comparison from MILAGRO



Independent extinction profiles acquired on coordinated flight of

- NASA King Air with the LaRC **Airborne HSRL**
- J-31 with the **AATS-14** Sun Photometer (P. Russell, J. Redeman),
- NSF C-130 with **HiGEAR** in situ scattering and absorption (T. Clarke)

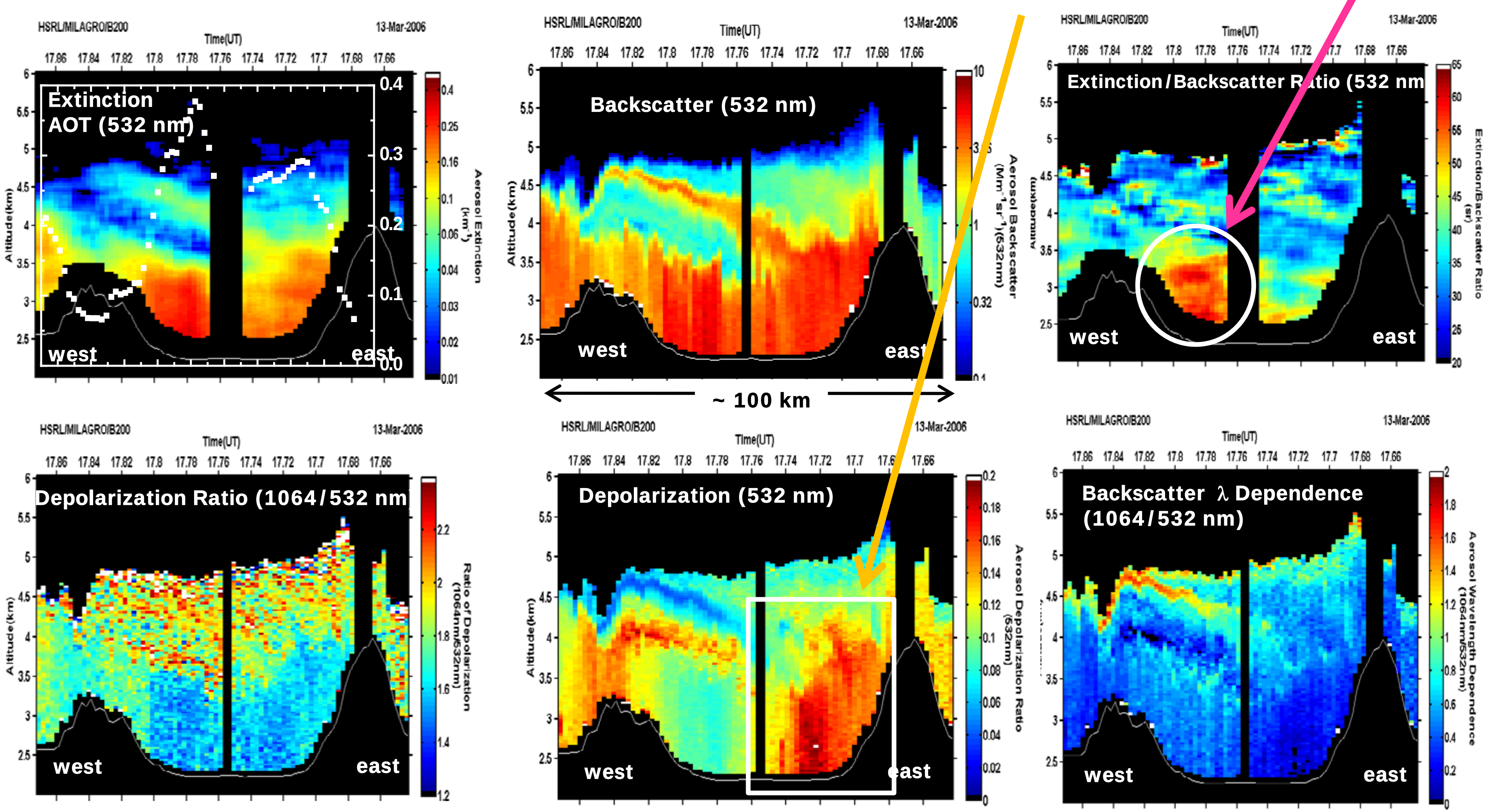
Characterizing Spatial Distribution of Aerosol Optical Properties and Type



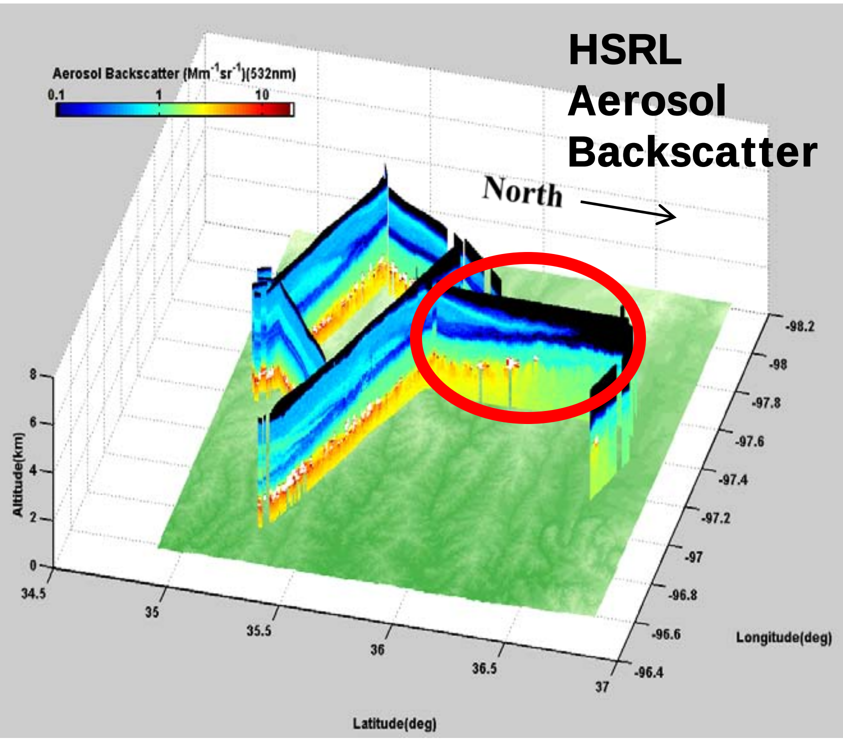
Aerosol Characterization using HSRL aerosol measurement suite

LaRC Airborne HSRL Measurements over Mexico City, March 13, 2006

- western part of city- high S_a, high WVD, low depolarization – urban aerosol
- eastern part of city - low Sa, low WVD, high depolarization – dust

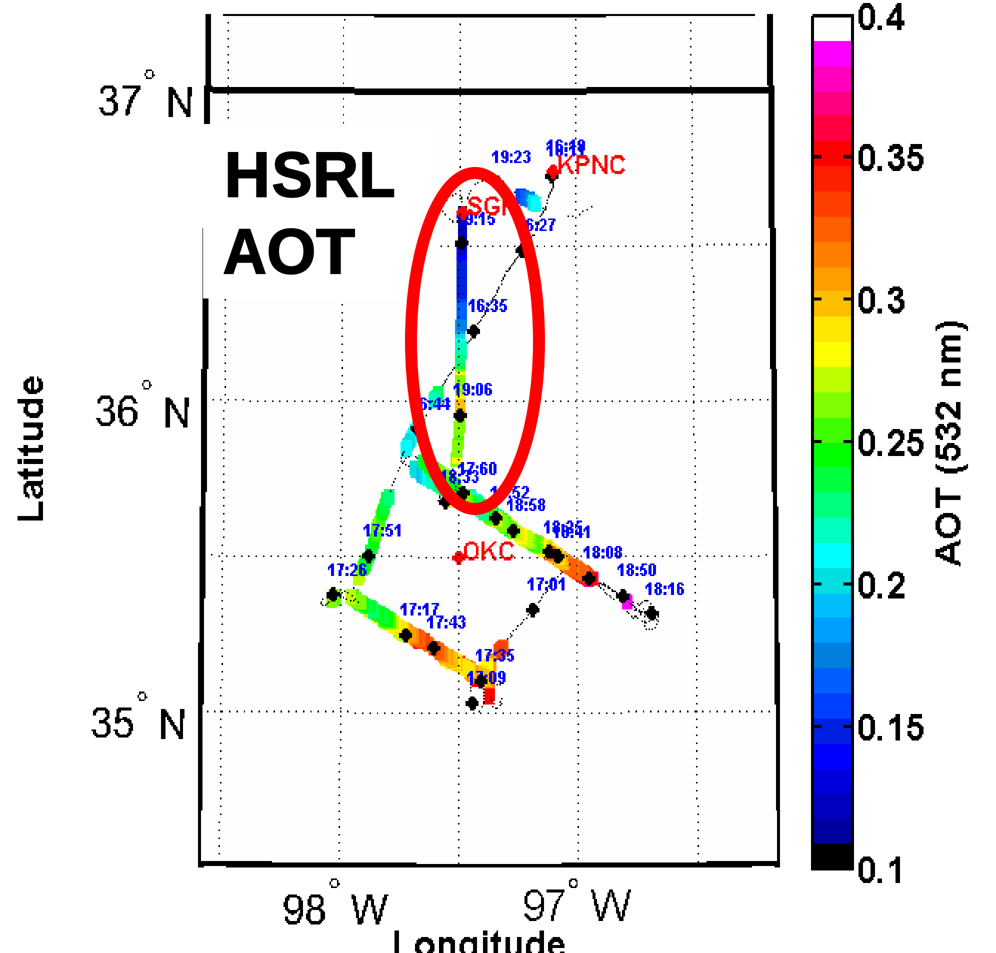


Airborne HSRL Measurements of Dry Line – June 7

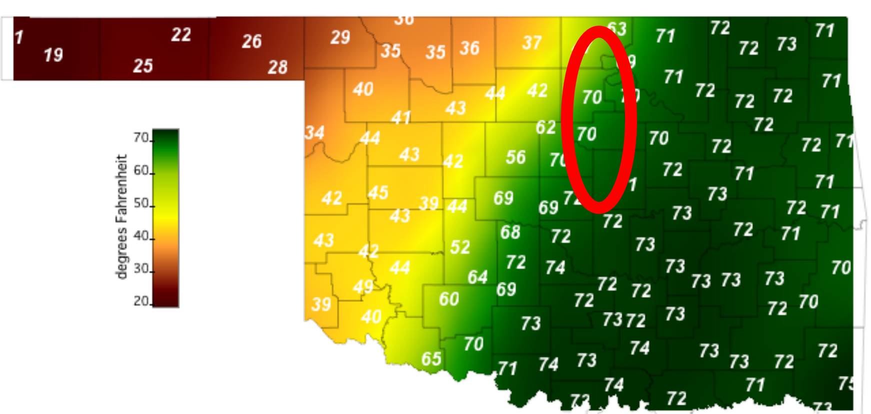


HSRL measurements show:

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



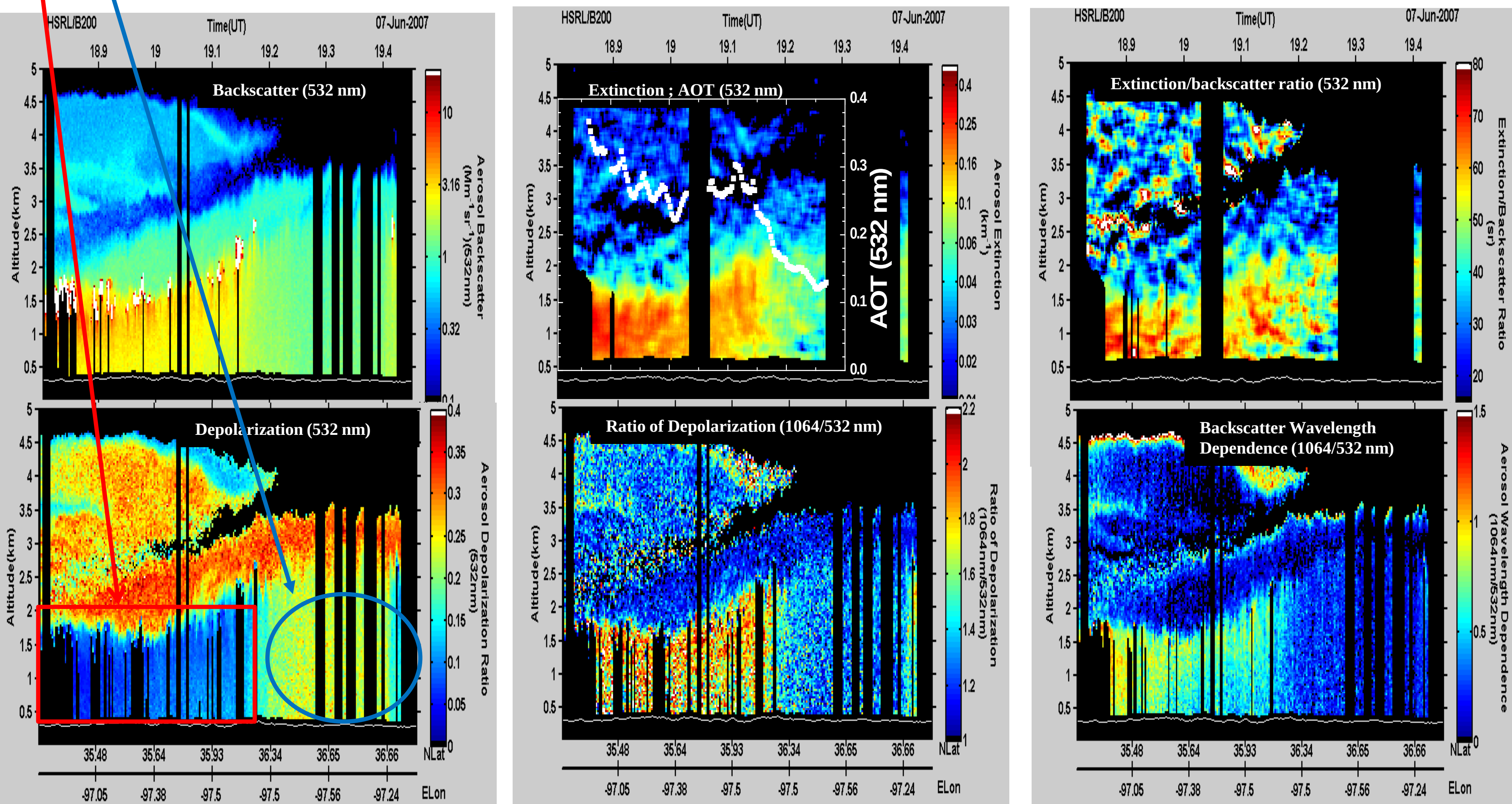
OK Mesonet; Surface Dew Point 20:00 UT



Aerosol Characterization using HSRL aerosol measurement suite

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

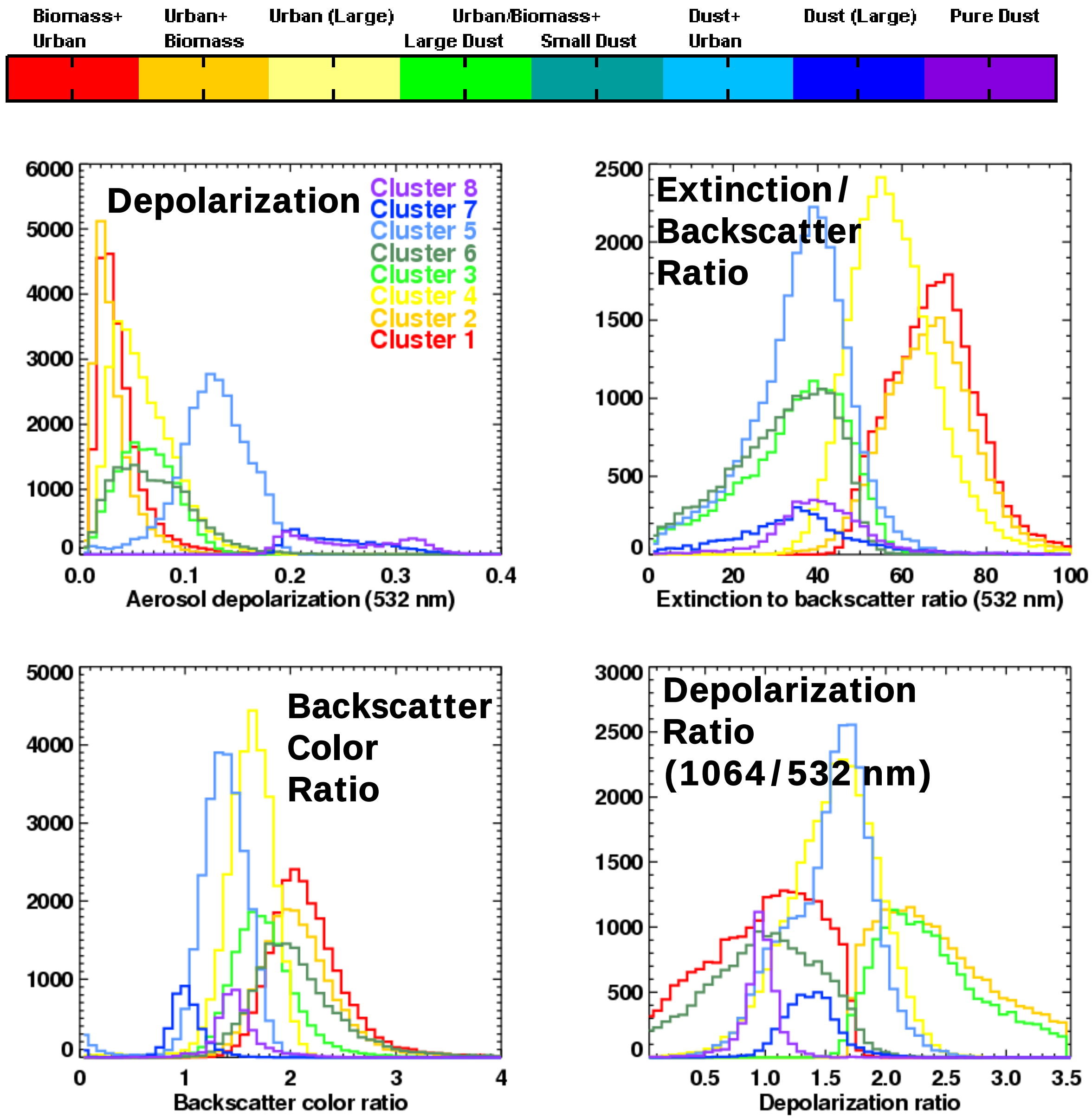


Discrimination of Aerosol Type

Aerosol Classification using HSRL measurements

Aerosol classification is based on HSRL measurements of aerosol intensive parameters

- Extinction/Backscatter Ratio (~absorption)
- Depolarization (~spherical vs. nonspherical – dust/ice)
- Backscatter Color Ratio (~size)
- Depolarization Ratio (1064/532 nm) (~nonspherical/spherical size)



The HSRL measurements of aerosol intensive parameters were used in an objective cluster analysis scheme to discriminate aerosol type. These aerosol types were subjectively related to the aerosol types inferred from AERONET data by Cattrall et al. (2005).

Aerosol Characterization using HSRL aerosol measurement suite

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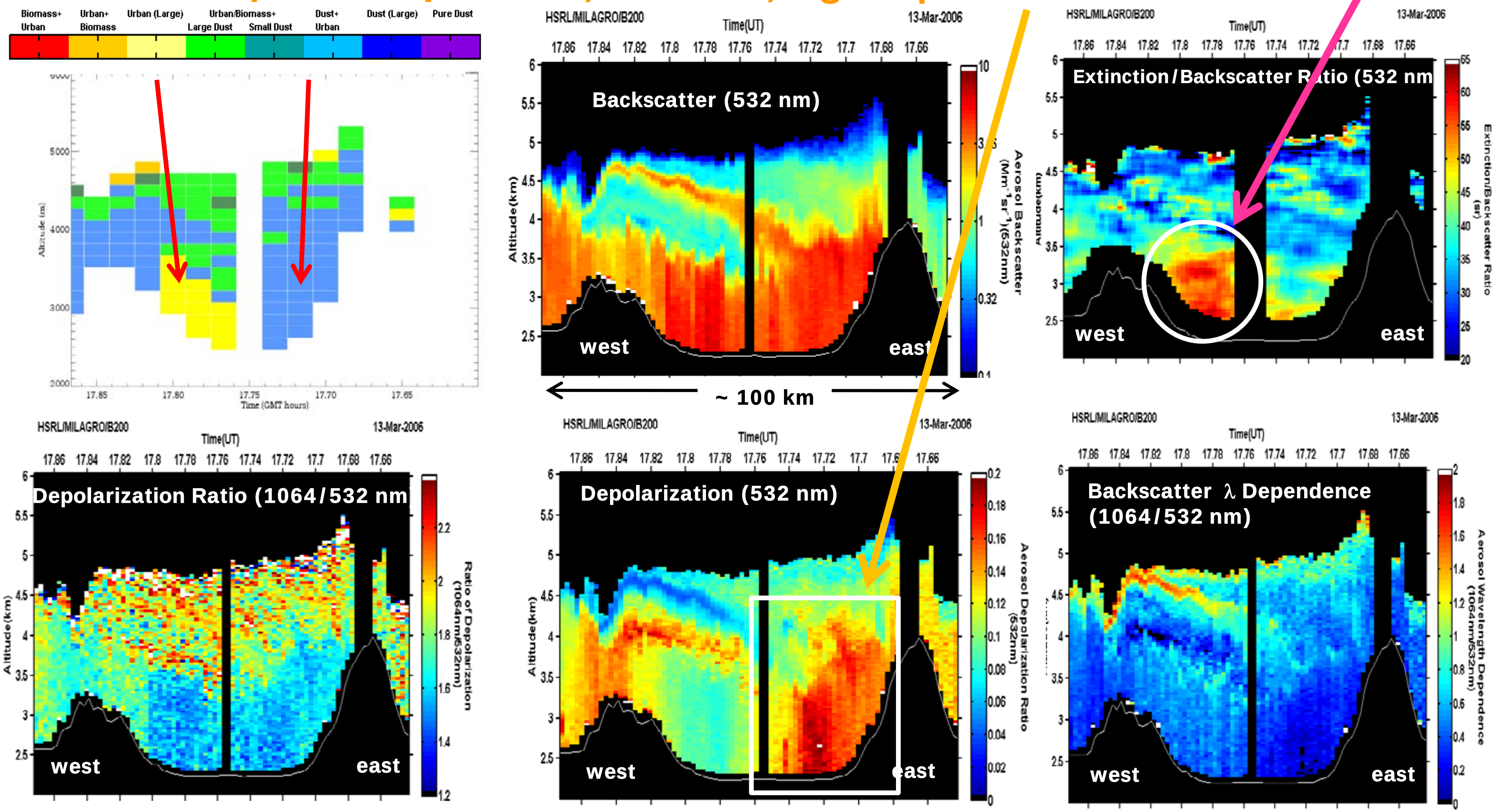

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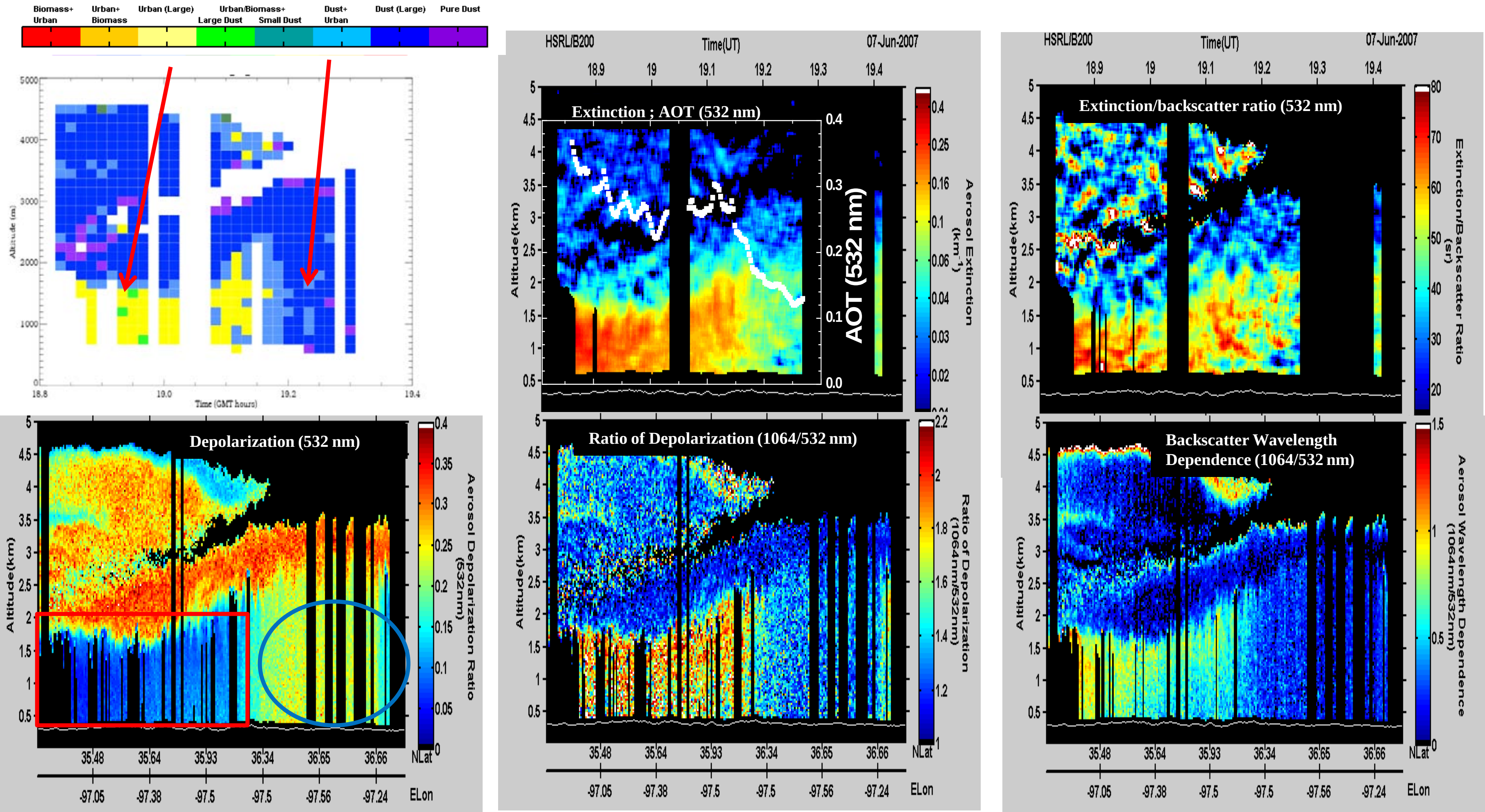
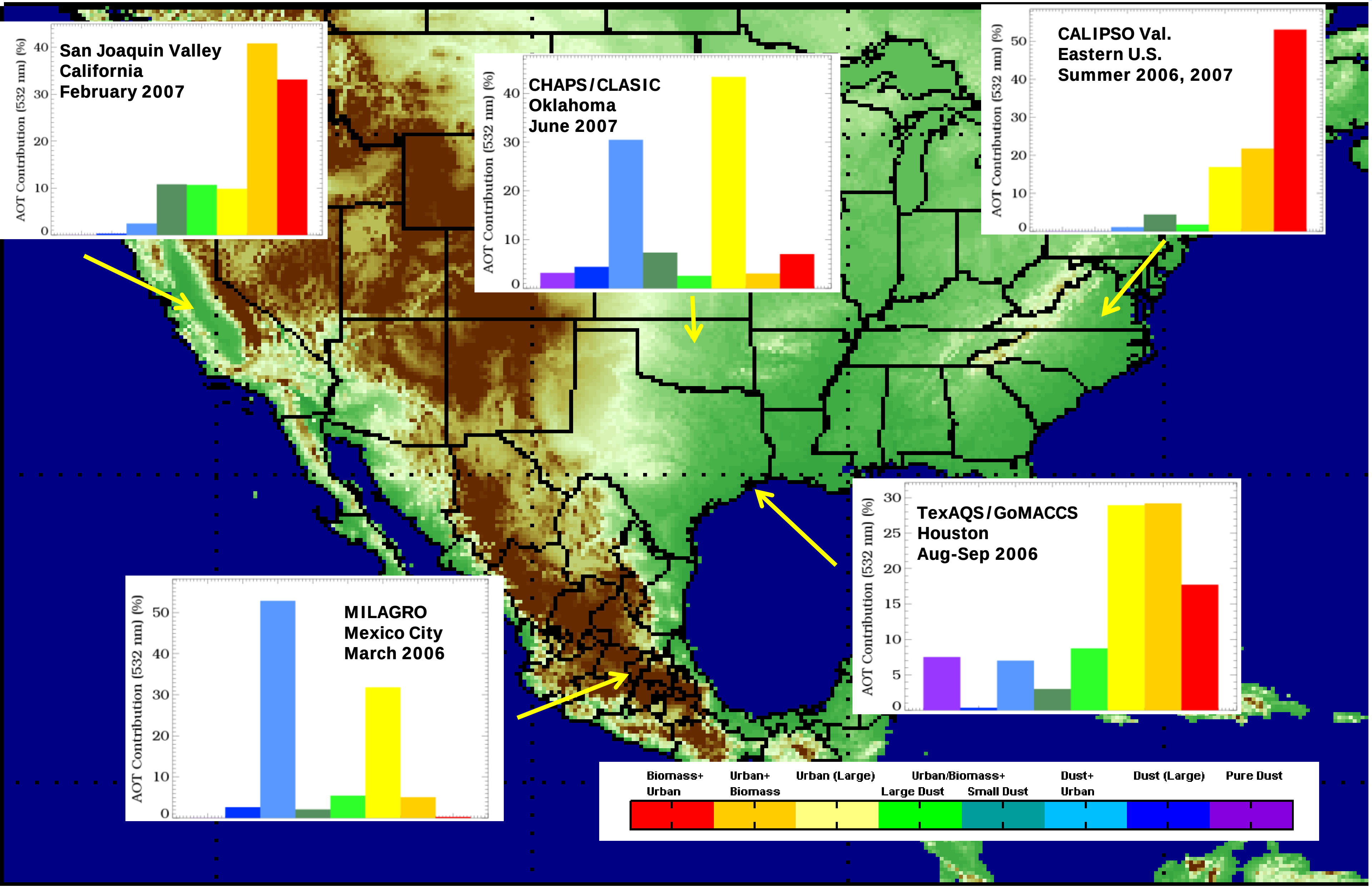


Aerosol Optical Thickness Apportionment

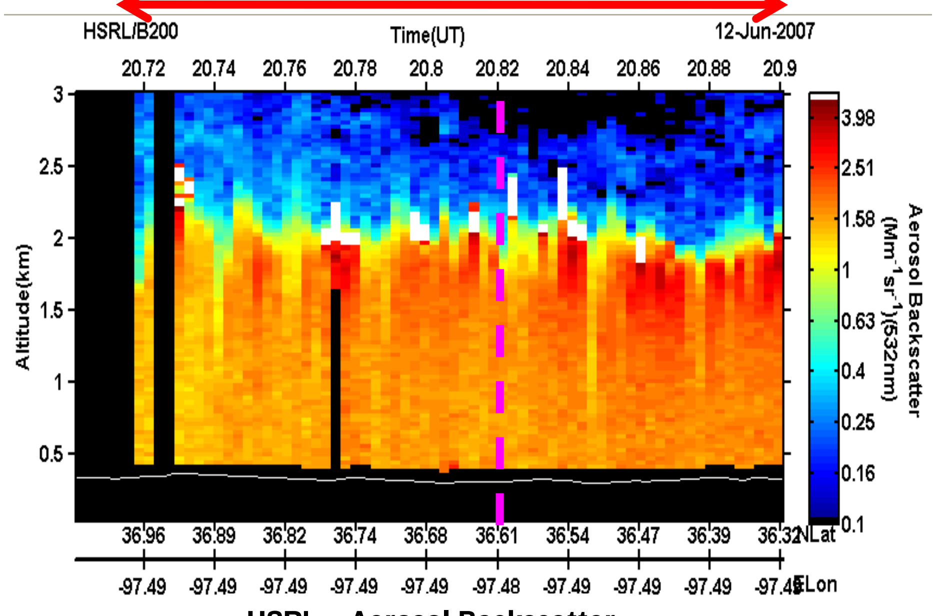


Aerosol-Cloud Interactions

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 (~ 200 m horiz.)**
- **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 – Aerosol Backscatter

Image from digital camera on NASA B200 King Air

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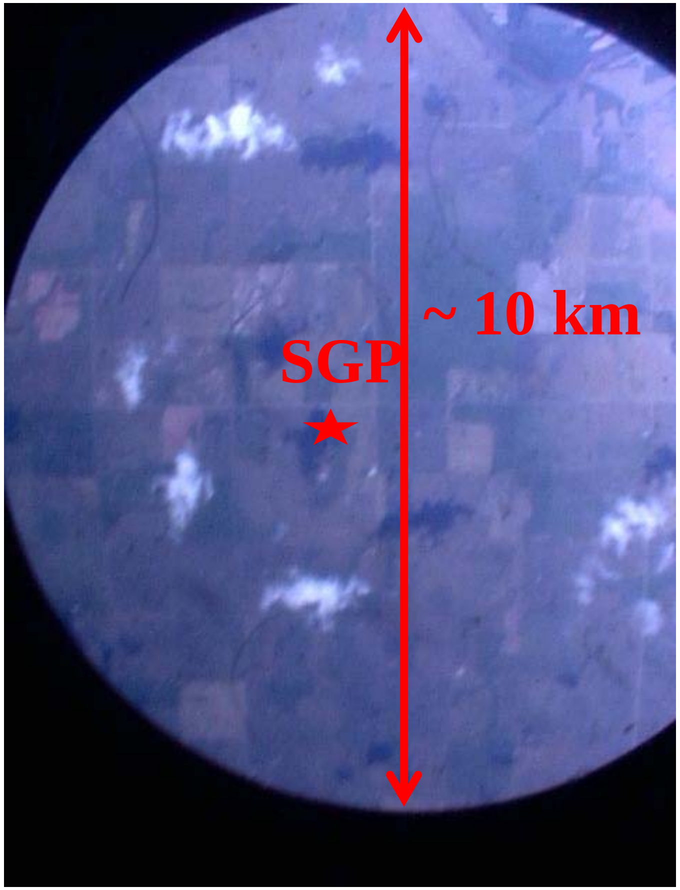
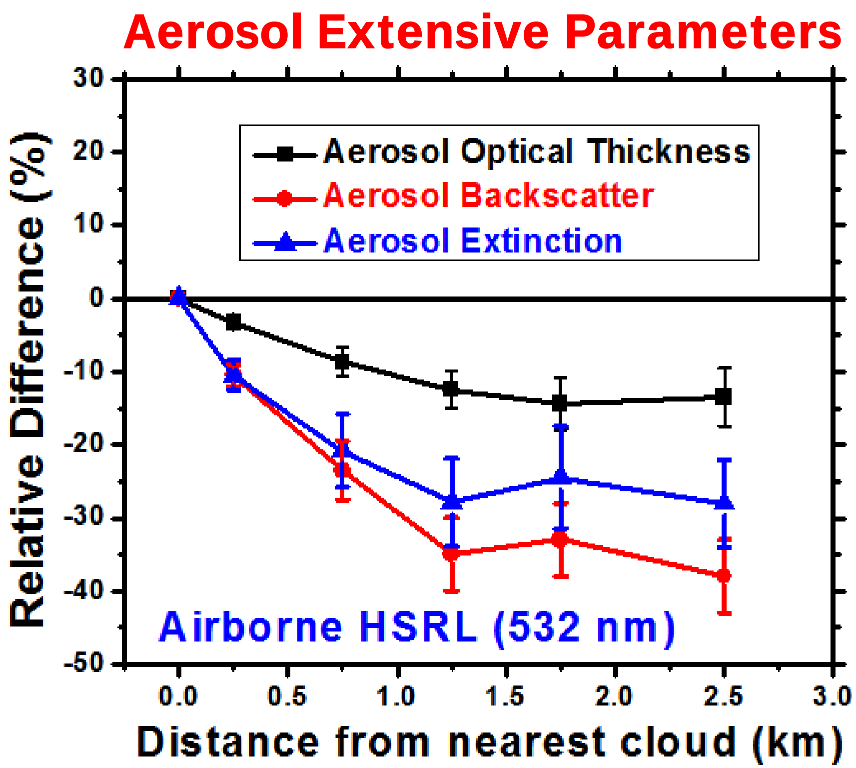
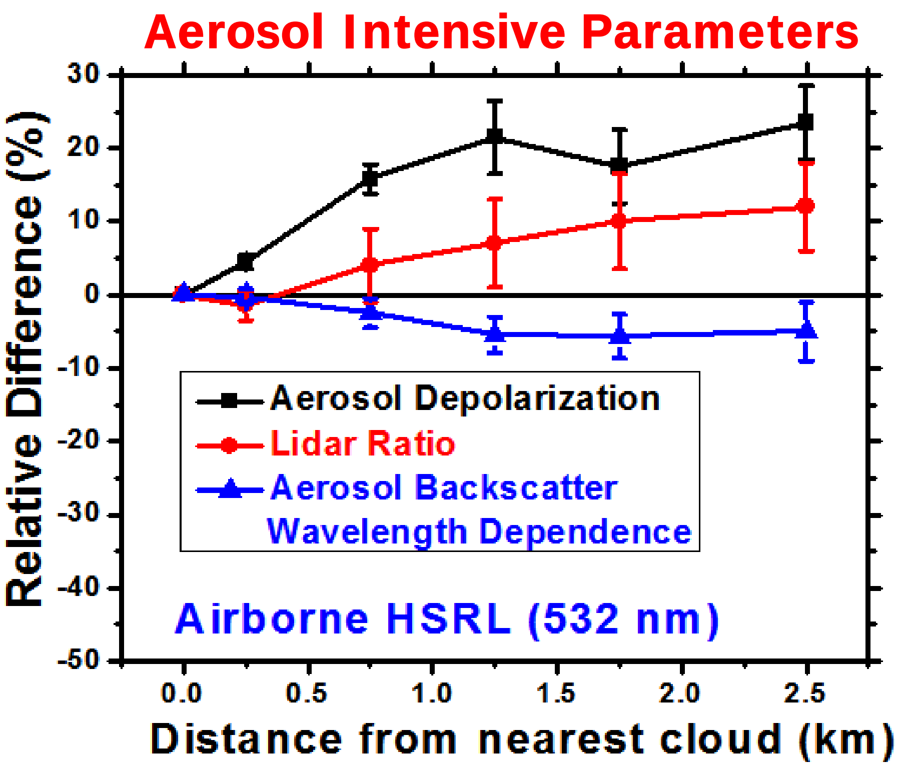


Changes in aerosol properties near clouds measured by airborne HSRL (12 June 2007 case)

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





Combined Active/Passive Retrievals

Exploring lidar-polarimeter retrievals: co-flight of HSRL + RSP

- The Research Scanning Polarimeter (RSP) has been integrated to the NASA King Air along with the Langley Airborne HSRL for the summer phase of ARCTAS (July 2008)
- RSP is the airborne prototype for the Aerosol Polarimetry Sensor (APS) on Glory (launch June 2009)
- Co-flight of sensors support
  - Integrated science applications from ARCTAS-2
  - Algorithm development for combined CALIPSO-APS aerosol/cloud retrievals
  - Validation for APS on Glory
  - Validation of joint CALIPSO-APS retrievals
  - Demonstration of advanced lidar-polarimeter retrievals for ACE

Future Plans

Under development: Multiwavelength HSRL + Ozone DIAL

- Multiwavelength HSRL: ***3β+2α+3δ***
  - Backscatter at 3 wavelengths **(*3β*)** : 355, 532, 1064 nm
  - Extinction at 2 wavelengths **(*2α*)** : 355, 532 nm
  - Depolarization at 3 wavelengths **(*3δ*)**: 355, 532, and 1064
  - Goal: enable layer-resolved, aerosol microphysical and macrophysical retrievals (Müller et al., 1999, 2000, 2001; Veselovskii et al.,2002,2004,) from a high-altitude aircraft
    - Effective and mean particle radius, concentration (volume, surface), complex index of refraction, single scatter albedo
    - **Retrievals to be accomplished via collaboration with Detlef Müller et al.**
  - Anticipate *3β+2α+3δ* data extremely powerful in combined lidar-polarimeter retrieval
- Ozone DIAL
  - Tropospheric ozone DIAL channels at 290 and 300 nm
- Platform: NASA ER-2 high altitude (20 km) aircraft
  - Technology and science demonstration for future satellite mission

Summary

- NASA Langley Airborne HSRL acquired >630 hours of data on >160 flights ranging from 7° to 75° N on 9 recent field missions

- HSRL observations are being used to
  - Infer aerosol type
  - Partition AOT by type
  - Assess chemical transport models
  - Determine PBL height
  - Investigate active-passive retrievals (e.g., lidar+MODIS)
  - Assess aerosol-cloud interactions
  - Validate CALIPSO, MODIS, MISR

- Future Plans
  - Deploy $3\beta+2\alpha+3\delta$ airborne instrument and explore microphysical retrieval techniques
  - Investigate lidar-polarimeter retrieval techniques

Partnering Opportunities on Aerosol-Cloud Interactions Studies

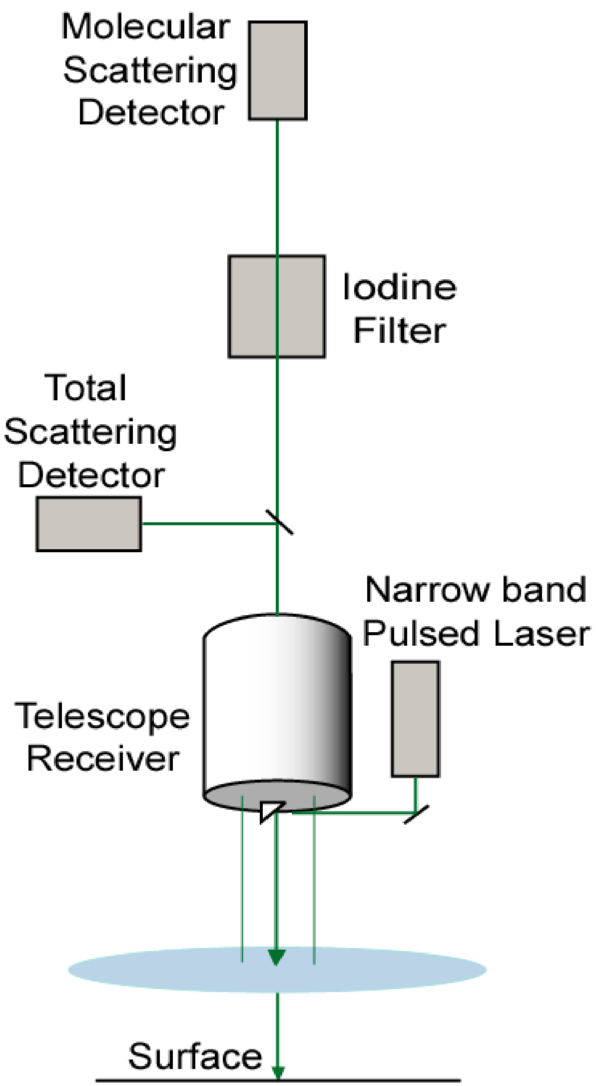
- Seeking to design and fly missions coordinated with other aircraft deploying in situ and remote sensors to study aerosol-cloud interactions
  - E.G., CHAPS and RACORO
  - ACASE proposal: Airborne Cloud-Aerosol Summer Experiment
- Seeking partners with innovative remote sensors to fly on the King Air with the HSRL
- Nadir imager:
  - Seeking expertise in identifying cloud boundaries in nadir camera imagery
  - Seeking partner with small imager that might improve cloud boundary identification and provide cloud properties
- Aircraft: LaRC has 2 identical King Air aircraft that are available for deployment of instrumentation

Thank You

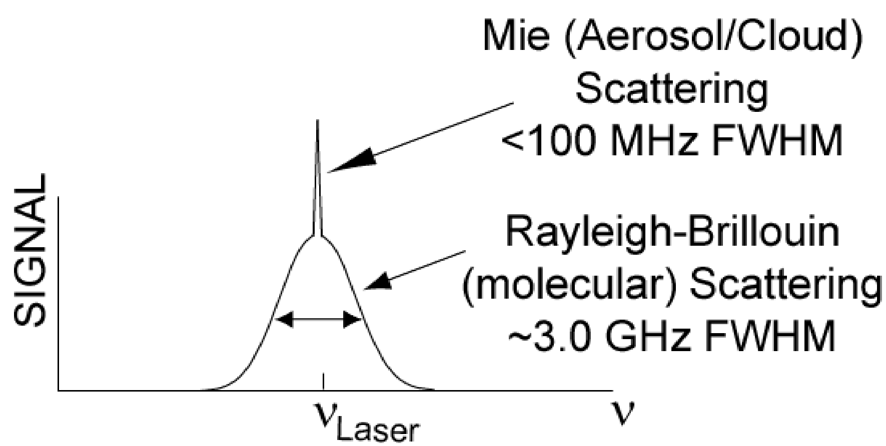
Backups

The HSRL Technique

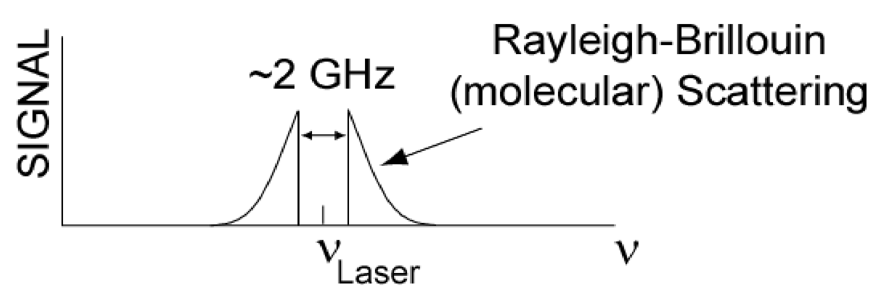
High Spectral Resolution Lidar (HSRL) Technique (Iodine Vapor Filter Implementation)



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

HSRL Aerosol Measurements

Parameter	Wavelength (nm)	Property	Horizontal Resolution (Δx) (km)	Vertical Resolution (Δz) (m)
Aerosol Scattering Ratio	532	Extensive	1	60
Aerosol Backscatter Coefficient	532, 1064	Extensive	1	60
Aerosol Extinction Coefficient	532	Extensive	6	300
Aerosol Backscatter Wavelength Dependence	(1064/532)	Intensive	1	60
Aerosol extinction/backscatter ratio “lidar ratio”	532	Intensive	6	300
Aerosol depolarization	532, 1064	Intensive	1	60
Ratio of Aerosol Depolarization	(1064/532)	Intensive	1	60

Extensive - depends on aerosol amount and type

Intensive – depends on aerosol type