Airborne High Spectral Resolution Lidar (HSRL)

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NASA Langley Research Center

Sponsors

Environmental Protection Agency (EPA)

NASA CALIPSO Project

NASA HQ Science Mission Directorate

Department of Energy Atmospheric System Research

Texas Commission on Environmental Quality (TCEQ)

Langley Airborne HSRL

HSRL vs. Standard Backscatter Lidar

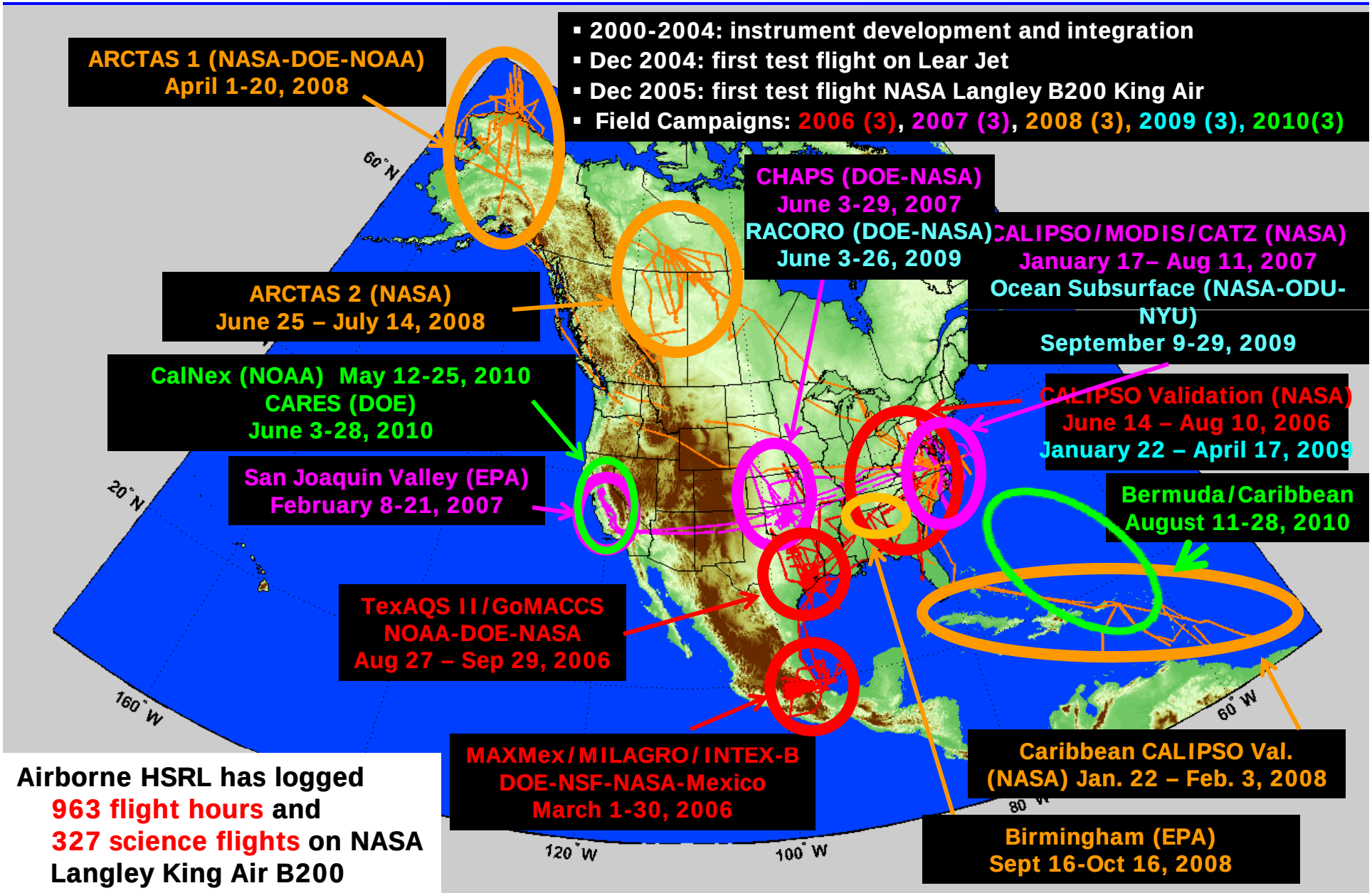
- Standard backscatter lidar measures *total attenuated backscatter* : a combination of backscatter and extinction from both molecules and particles.
  - Requires assumptions to retrieve aerosol backscatter and extinction
  - Assumptions can be prone to error.
- HSRL enables independent retrieval of aerosol backscatter and extinction
  - Internally calibrated
  - Higher accuracy
  - Greater information content

LaRC Airborne HSRL

- HSRL deployed on B200 King Air since 2006
  - 15 field experiments
  - 330 flights; >1000 flight hours
- Fundamental measurements
  - Aerosol extinction: 532 nm
  - Aerosol backscatter: 532, 1064 nm
  - Depolarization: 532, 1064 nm

For a description of system and technique, see Hair et al., Applied Optics, 2008

King Air B200 Field Campaigns with Langley High Spectral Resolution Lidar (HSRL)

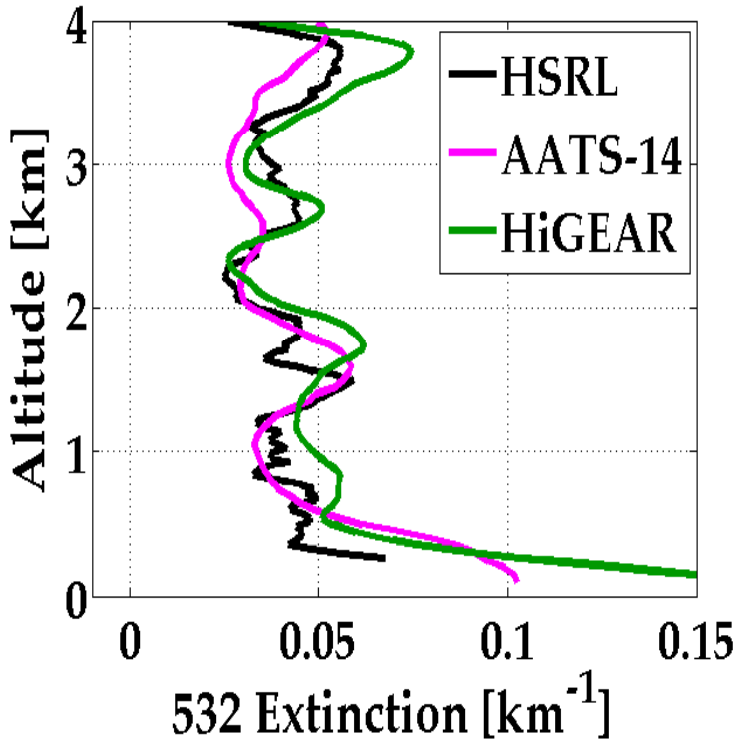


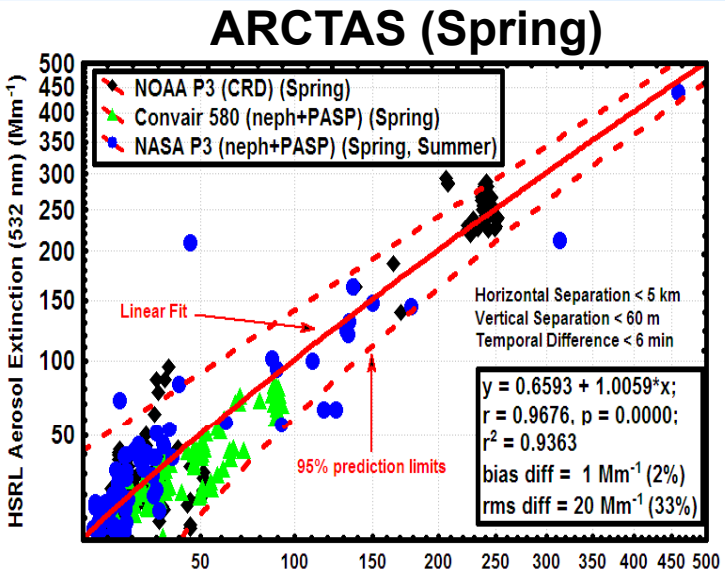
Airborne HSRL has logged
963 flight hours and
327 science flights on NASA Langley King Air B200

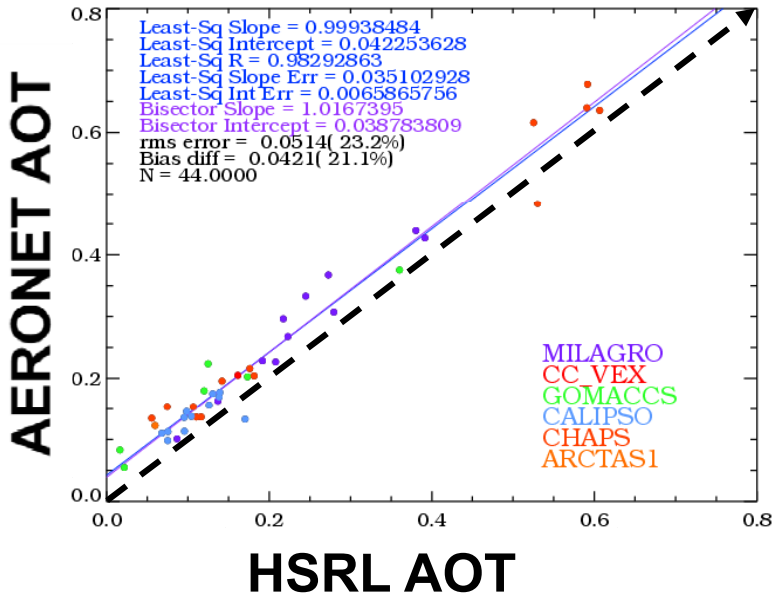
Comparisons of Aerosol Extinction and Optical Depth

- Aerosol extinction and optical depth compared to airborne in situ and remote sensing instruments
- Validation – aerosol extinction
  - bias differences ≤ 3 Mm^{-1}
  - rms differences ≤ 15 Mm^{-1}

Rogers et al., (2009)- MILAGRO







HSRL Data Products

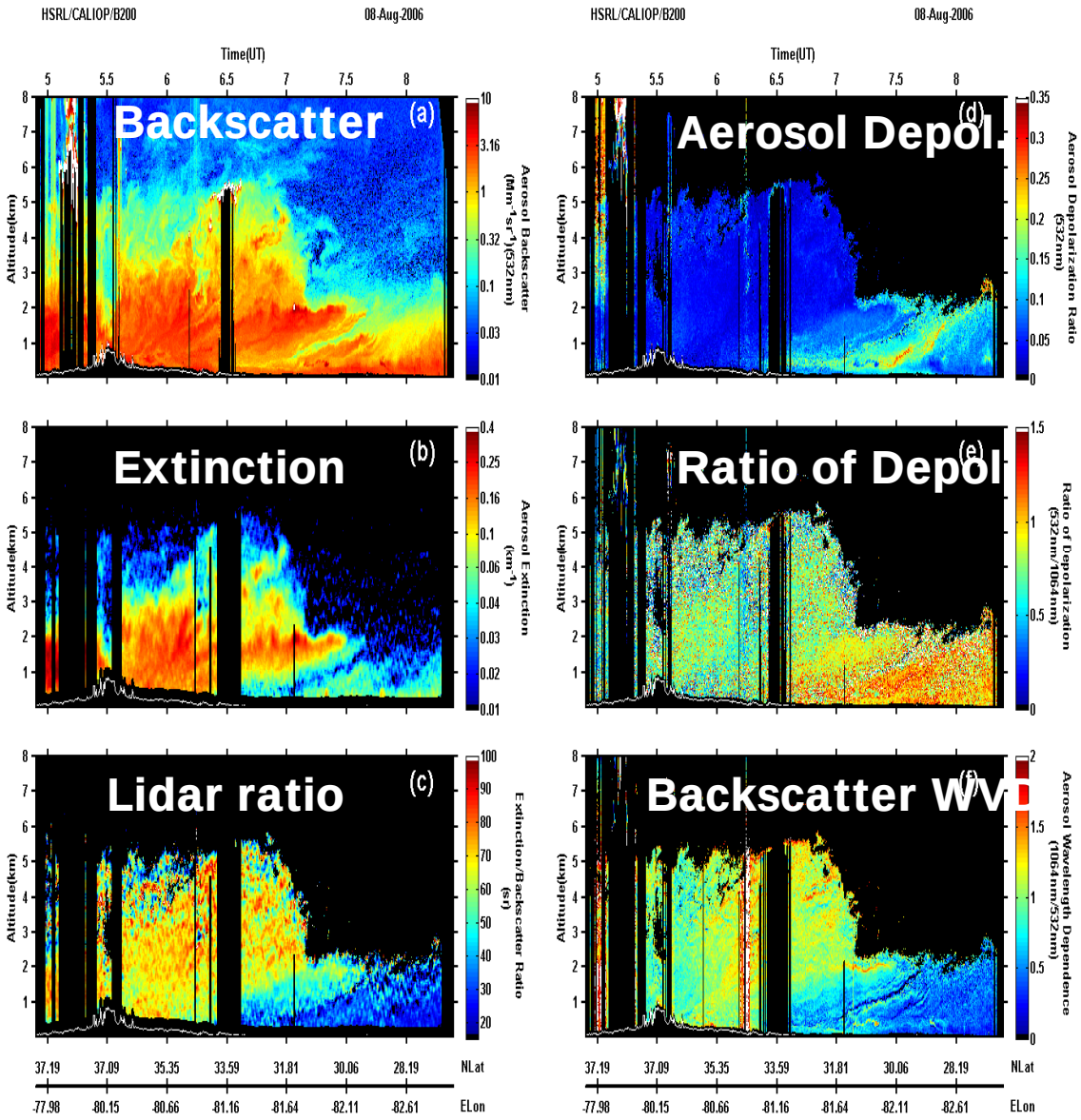
	Product	Horizontal Resolution	Vertical Resolution
Extensive Parameters	Aerosol Backscatter 1064 nm	1 km	60 m
	Aerosol Backscatter 532 nm	1 km	60 m
	Aerosol Extinction 532 nm	6 km	300 m
Intensive Parameters	Lidar Ratio (extinction/backscatter ratio) 532 nm	6 km	300 m
	Aerosol Depolarization Ratio 532 nm	1 km	60 m
	Ratio of Aerosol Depolarization ($\delta_{a,1064}$ /$\delta_{a,532}$)	1 km	60 m
	Aerosol Backscatter Wavelength Dependence	1 km	60 m

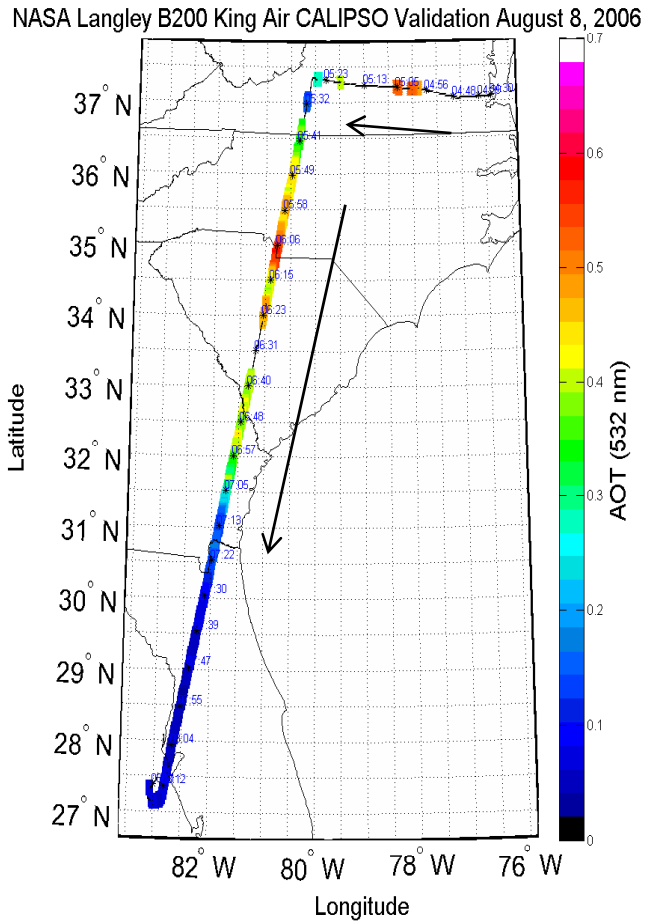
Resolutions listed are nominal: data can be processed to higher resolution.

Horizontal resolutions listed are approximate: depend on aircraft ground speed.

Inference of Aerosol Type
and
Apportionment of Aerosol Optical Thickness to Aerosol Type

Example of Aerosol Classification using HSRL measurements





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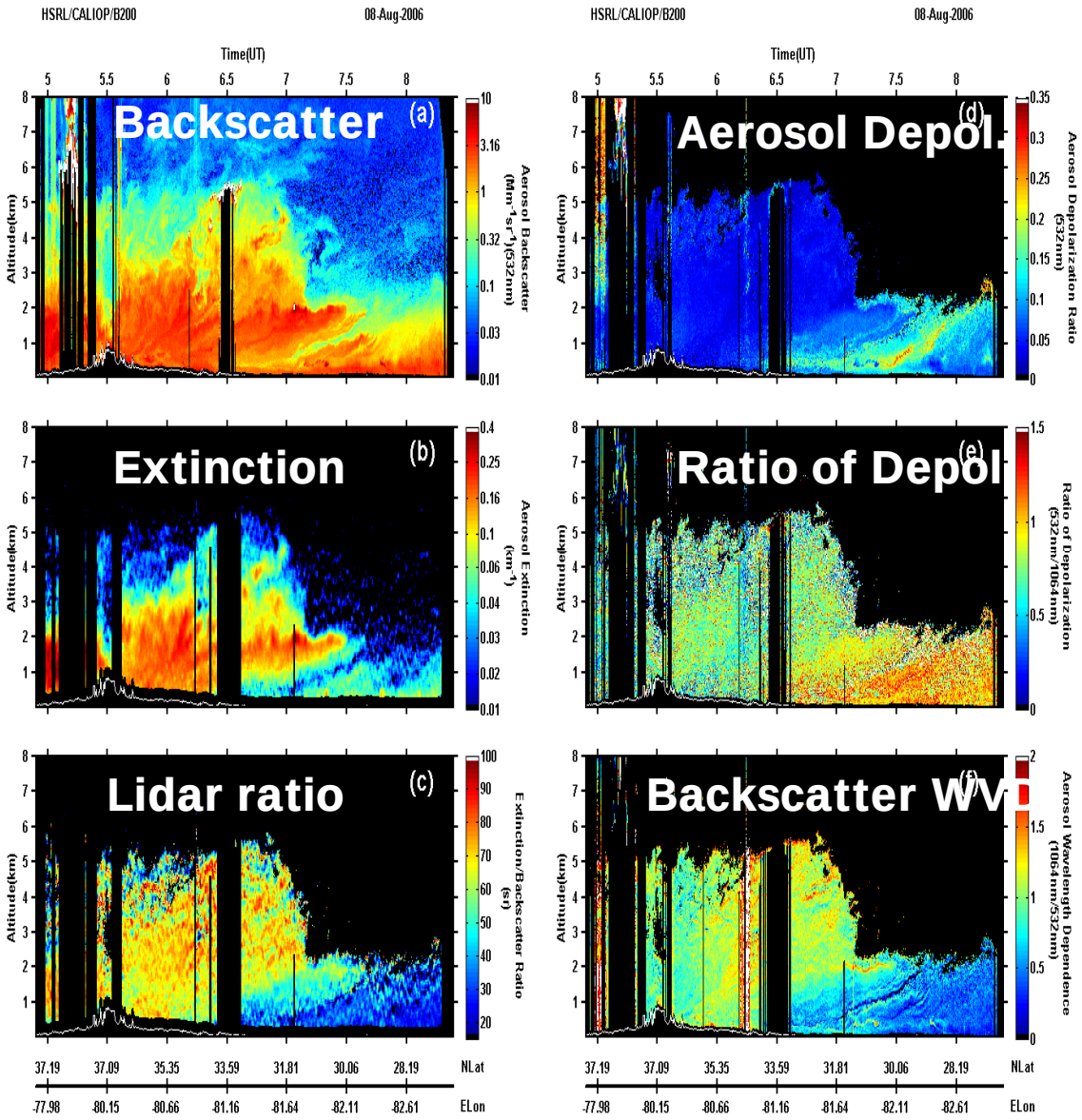
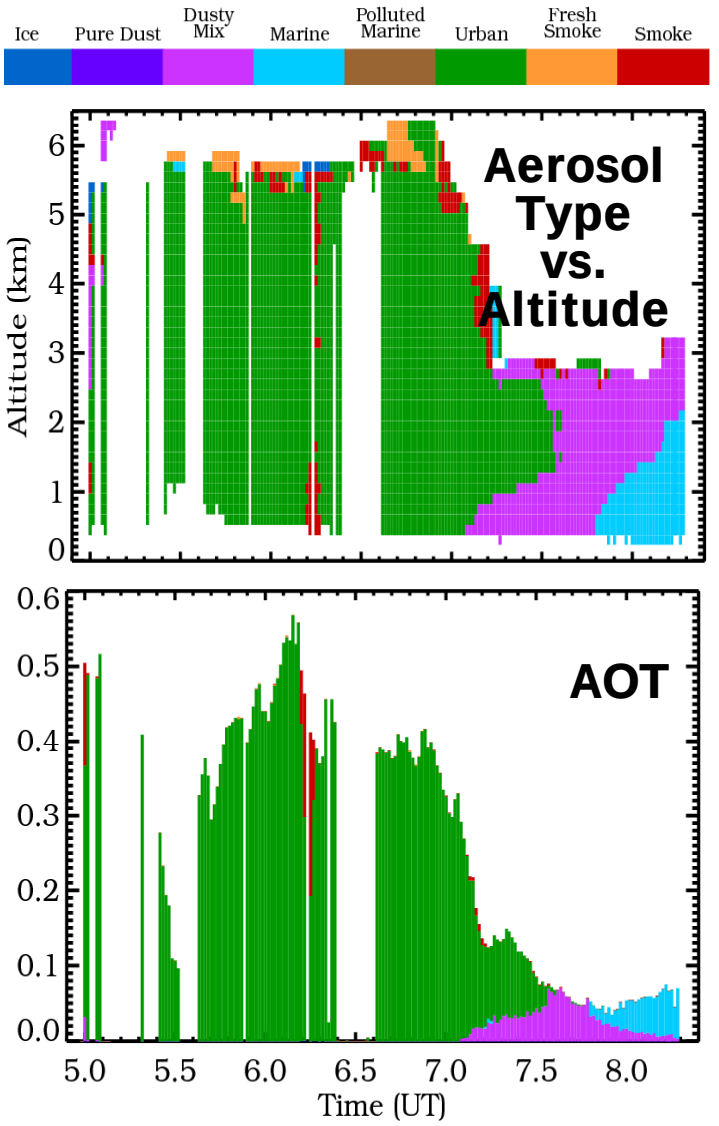
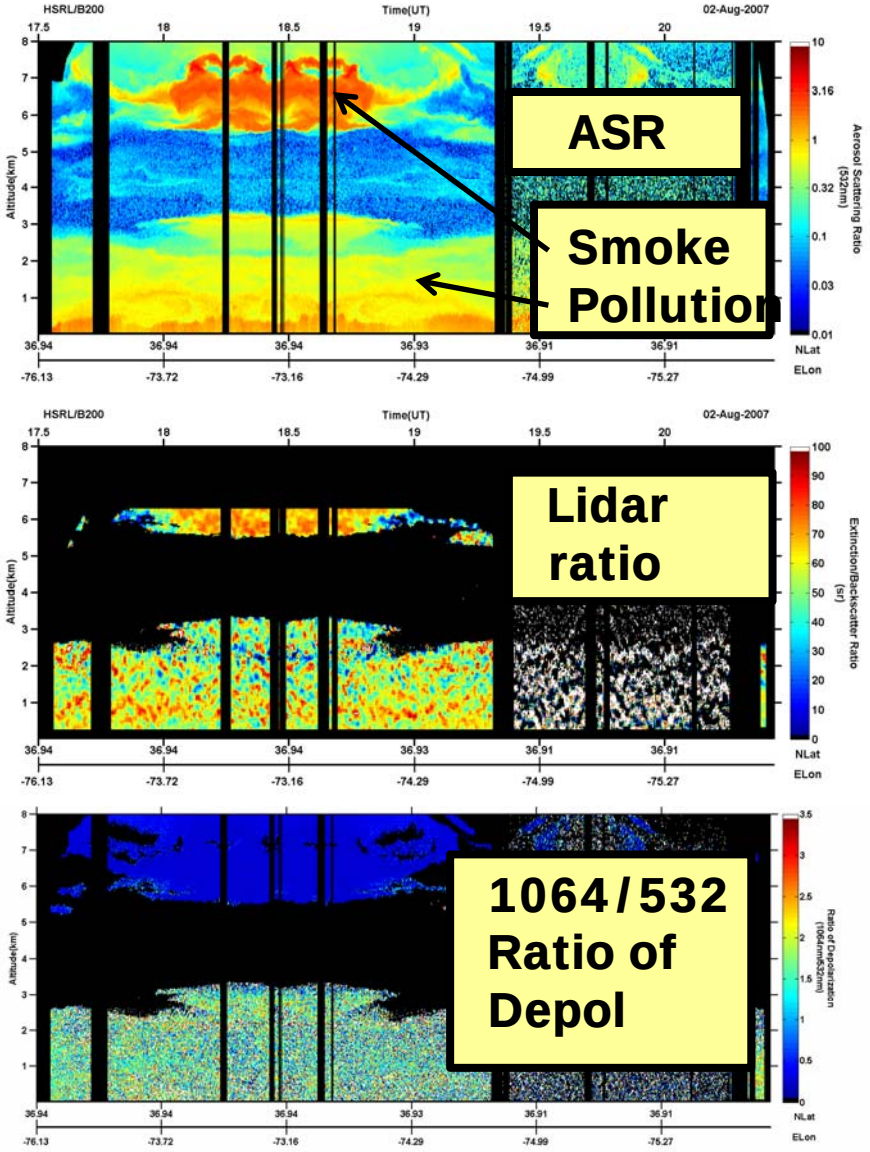
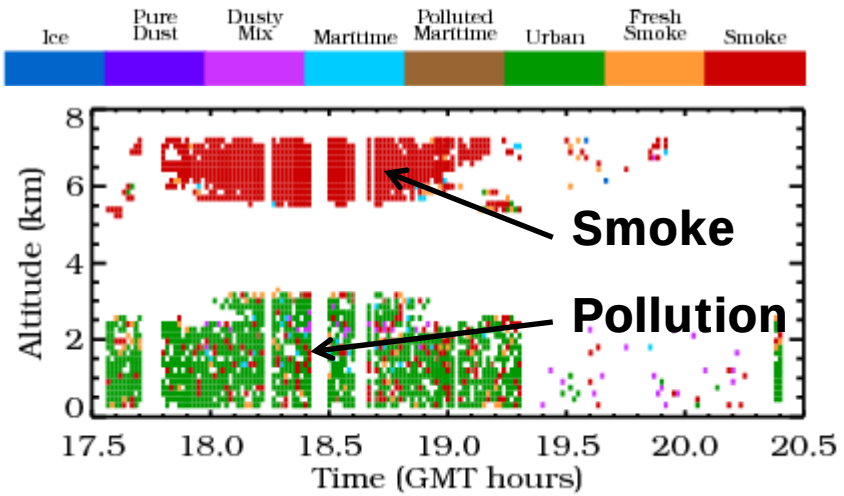




Smoke transport – August 2, 2007





Smoke transported to East Coast from Montana and Idaho on 8/2/2007.

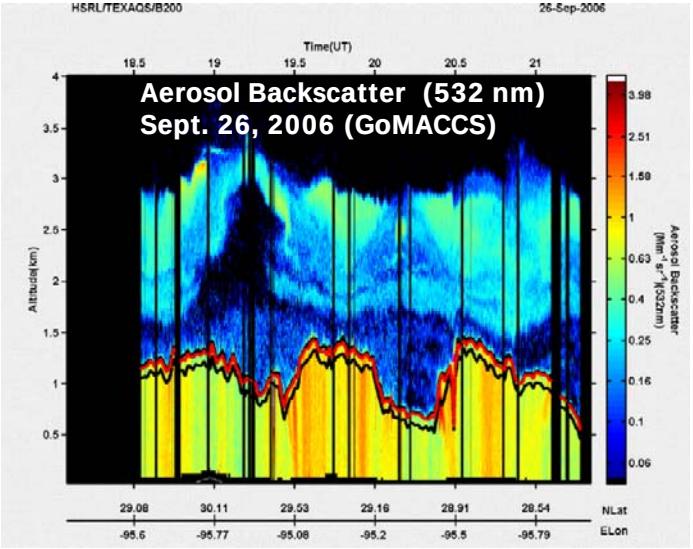
- **High lidar ratio**
- **Separable from pollution by ratio of depolarization at 1064 nm/532 nm.**

Planetary Boundary Layer (PBL) Height Retrievals

Texas Commission on Environmental Quality (TCEQ)

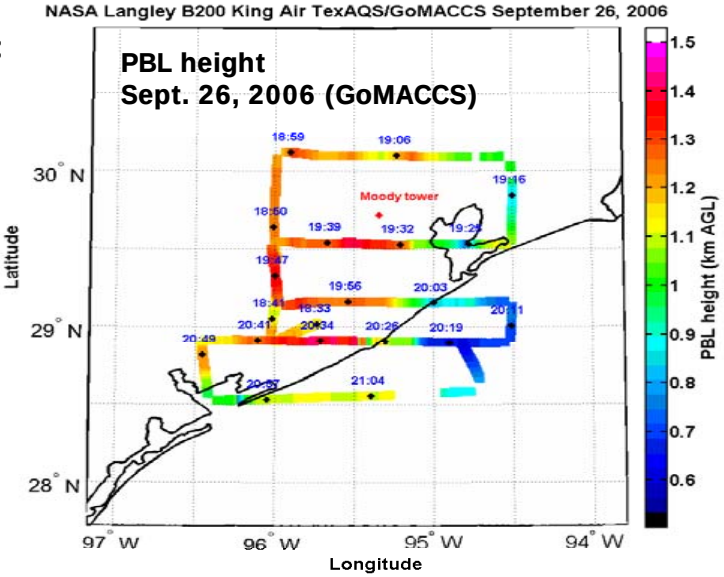
Planetary Boundary Layer (PBL) Height Retrievals and AOT

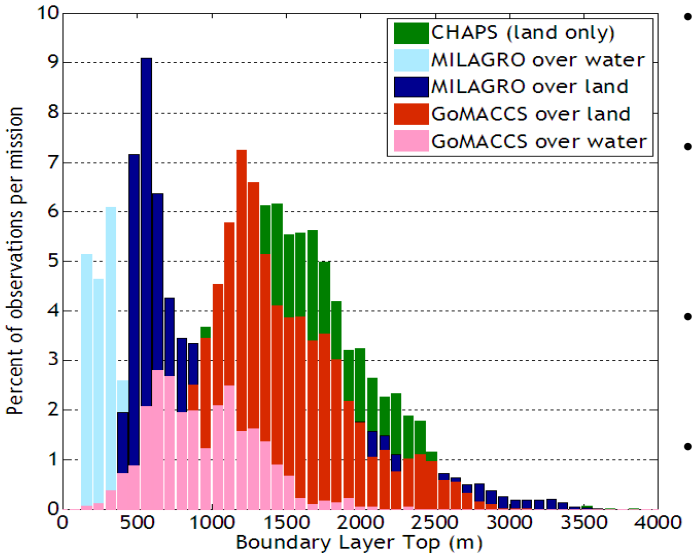
Long range transport of aerosols depends on whether aerosols injected above PBL



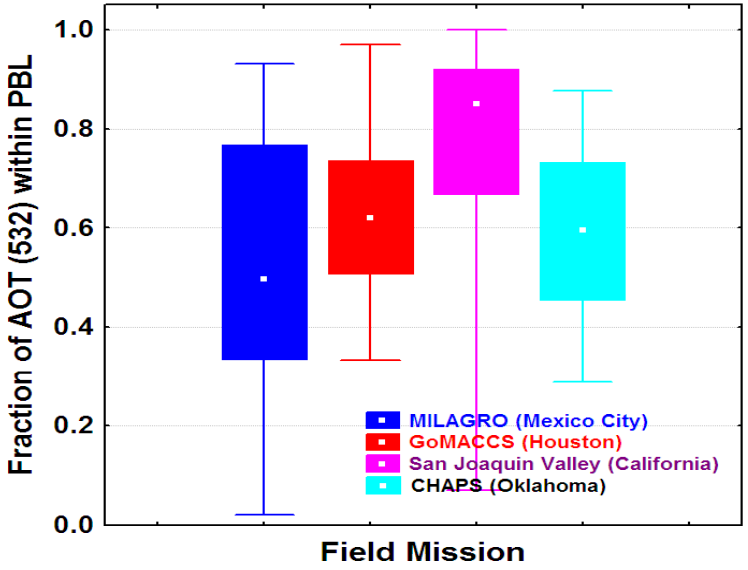
HSRL data used to determine:

- **PBL height**
- **Upper and lower limits of the backscatter transition (i.e. entrainment) zone**
- **Fraction of aerosol optical thickness within PBL**





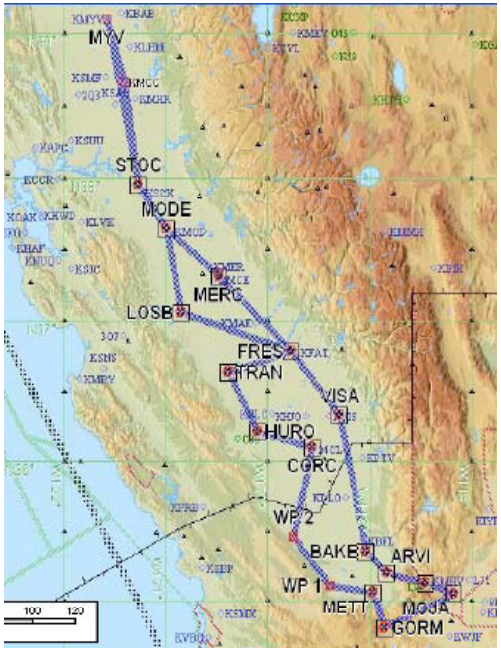
- **PBL heights over water significantly lower than PBL heights over land**
- **Large fraction (40-50%) of AOT above PBL during MILAGRO, GoMACCS, CHAPS**
- **Most (80-90%) of AOT within PBL during San Joaquin Valley Mission**
- **HSRL PBL heights now routinely requested by other investigators**



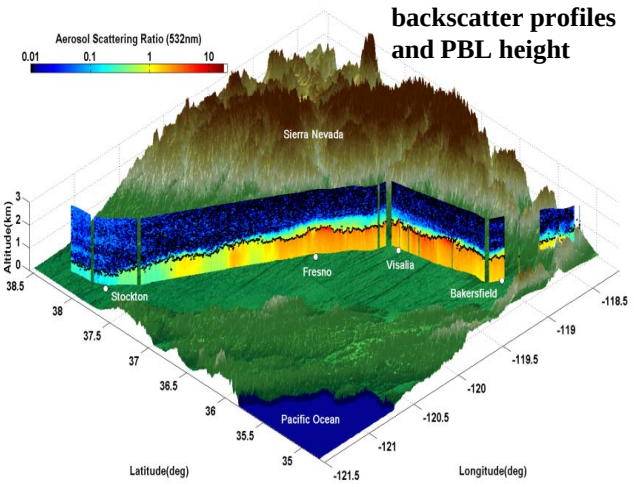
Air Quality – Surface $PM_{2.5}$

(Jay Al-Saadi, Jim Szykman)

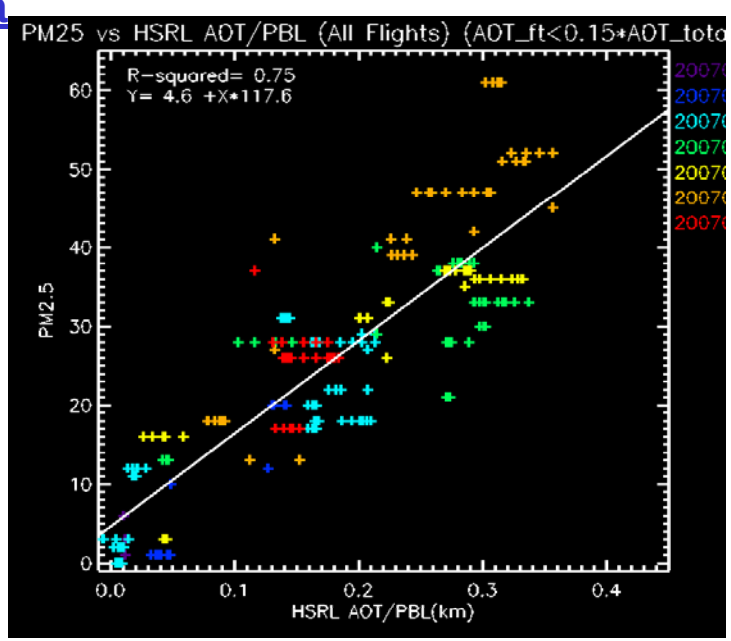
Airborne Aerosol Lidar Measurements for Air Quality Research



San Joaquin Valley, California



HSRL aerosol backscatter profiles and PBL height



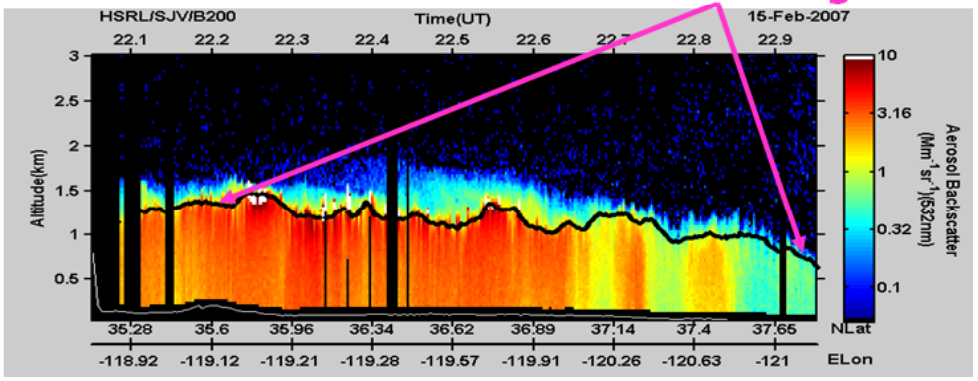
HSRL data used to:

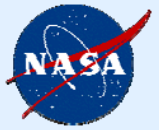
- Define PBL height
- Evaluate MODIS research AOT retrievals
- Determine AOT above/below PBL

Normalizing AOT with PBL height (z_i) significantly improves correlation with surface $PM_{2.5}$

(r^2 increases from 0.36 to 0.75)

HSRL Aerosol Backscatter and PBL heights





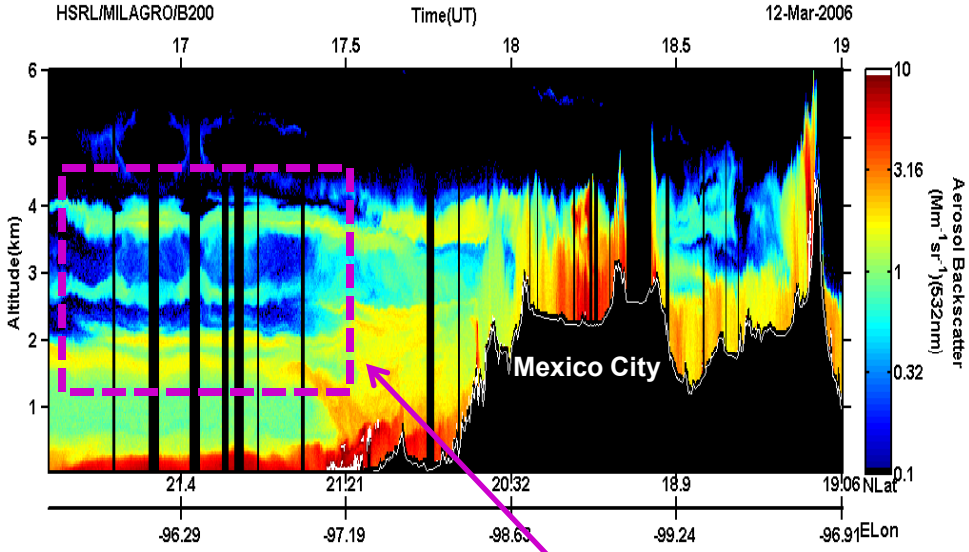
Comparisons with WRF-Chem

(Jerome Fast - PNNL)

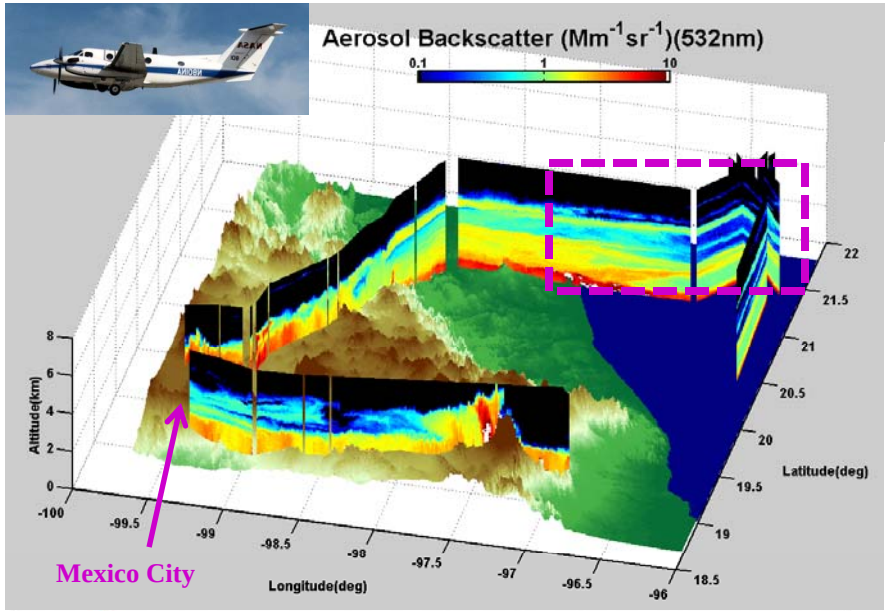
Airborne HSRL Measurements used to Evaluate WRF-Chem Model

Pacific Northwest NATIONAL LABORATORY

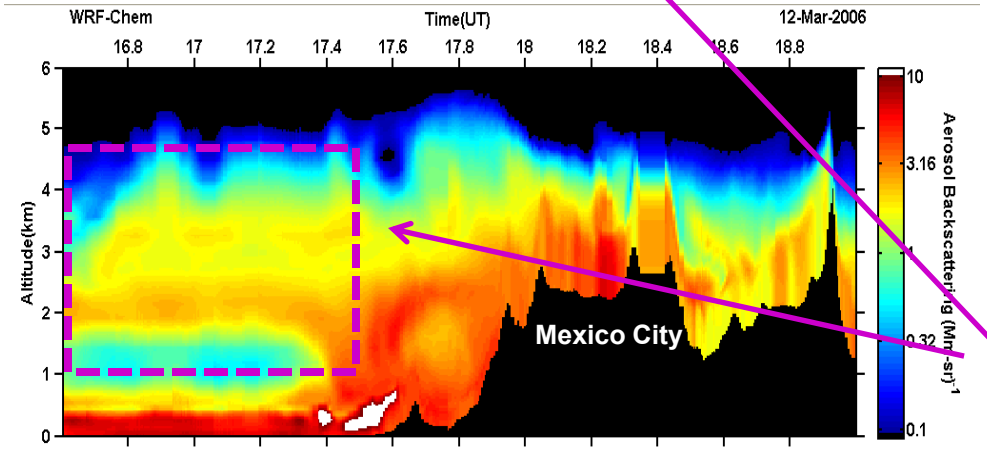
Backscatter measured by airborne HSRL



NASA/LaRC B200/HSRL March 12, 2006



Backscatter predicted by WRF-Chem model



WRF-Chem (Jerome Fast – PNNL)

- **Airborne HSRL data:**
  - **reveal complexity of mixing and transport of particulates**
  - **used to indirectly evaluate meteorological predictions**
- **Model can reproduce most aspects of PBL in vicinity of Mexico City**
- **Model requires smaller vertical grid spacing to resolve shallow layering observed by lidar**

Water Subsurface Measurements

(Yong Hu)

HSRL Ocean Subsurface Measurements (Yong Hu)

What can be measured:

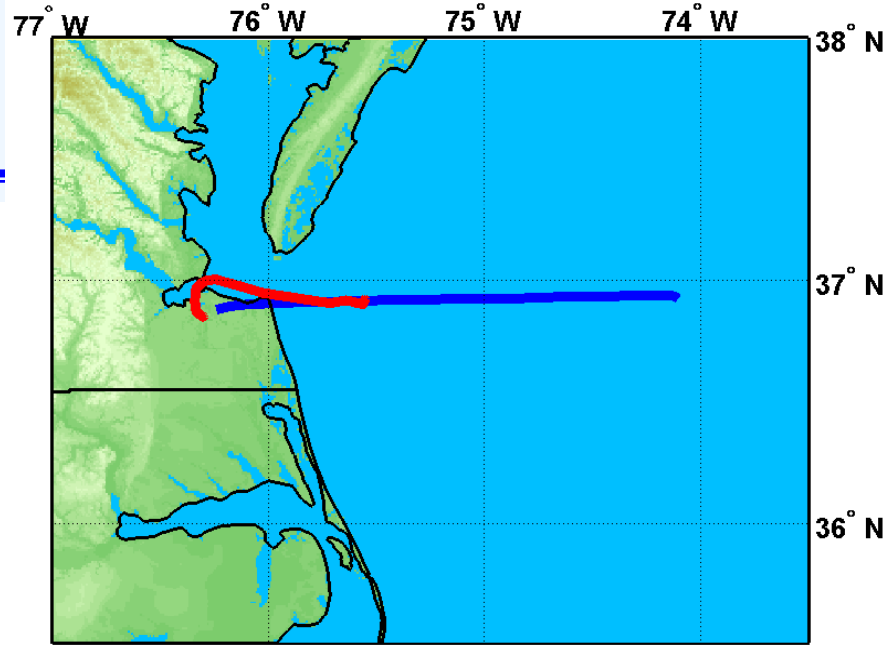
- beam attenuation coefficient
- particulate backscatter

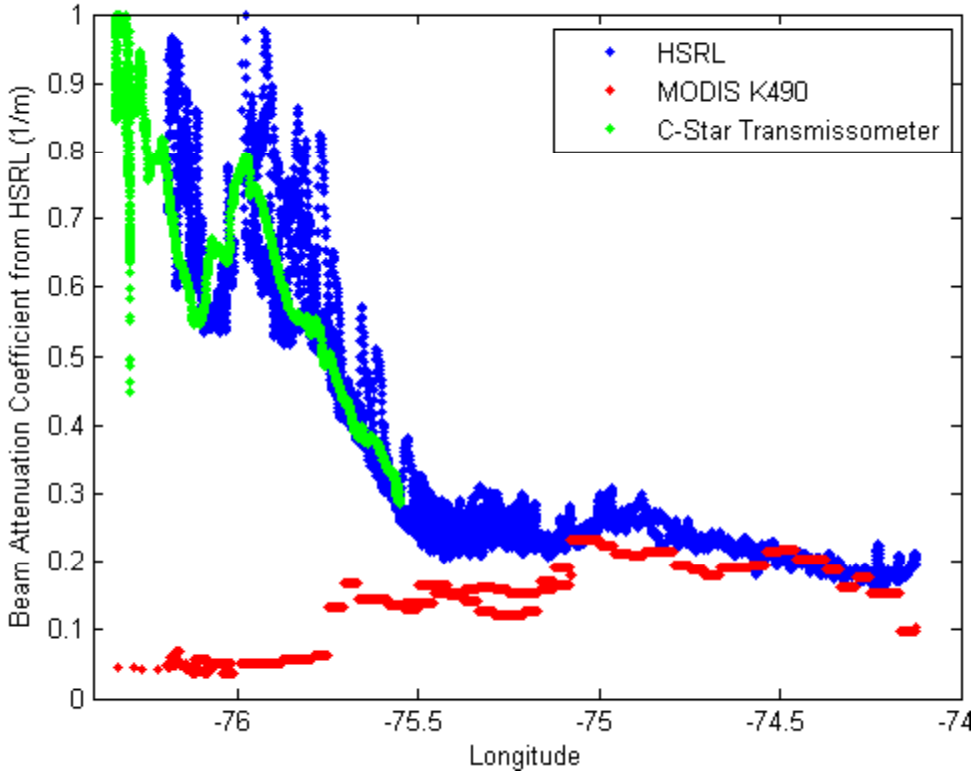
Potential applications:

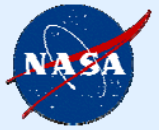
1. Validation of ocean color retrievals
2. Assisting new retrieval algorithm development
3. Reducing uncertainty of net primary productivity

Recent aircraft / boat measurements:

Aircraft: HSRL (LaRC), RSP (Cairns)
Boat: Vertical profiling of optical properties in water (Zimmerman of ODU, Gilerson of CCNY); multi-angle polarization probe (in water and above water) (Gilerson of CCNY)

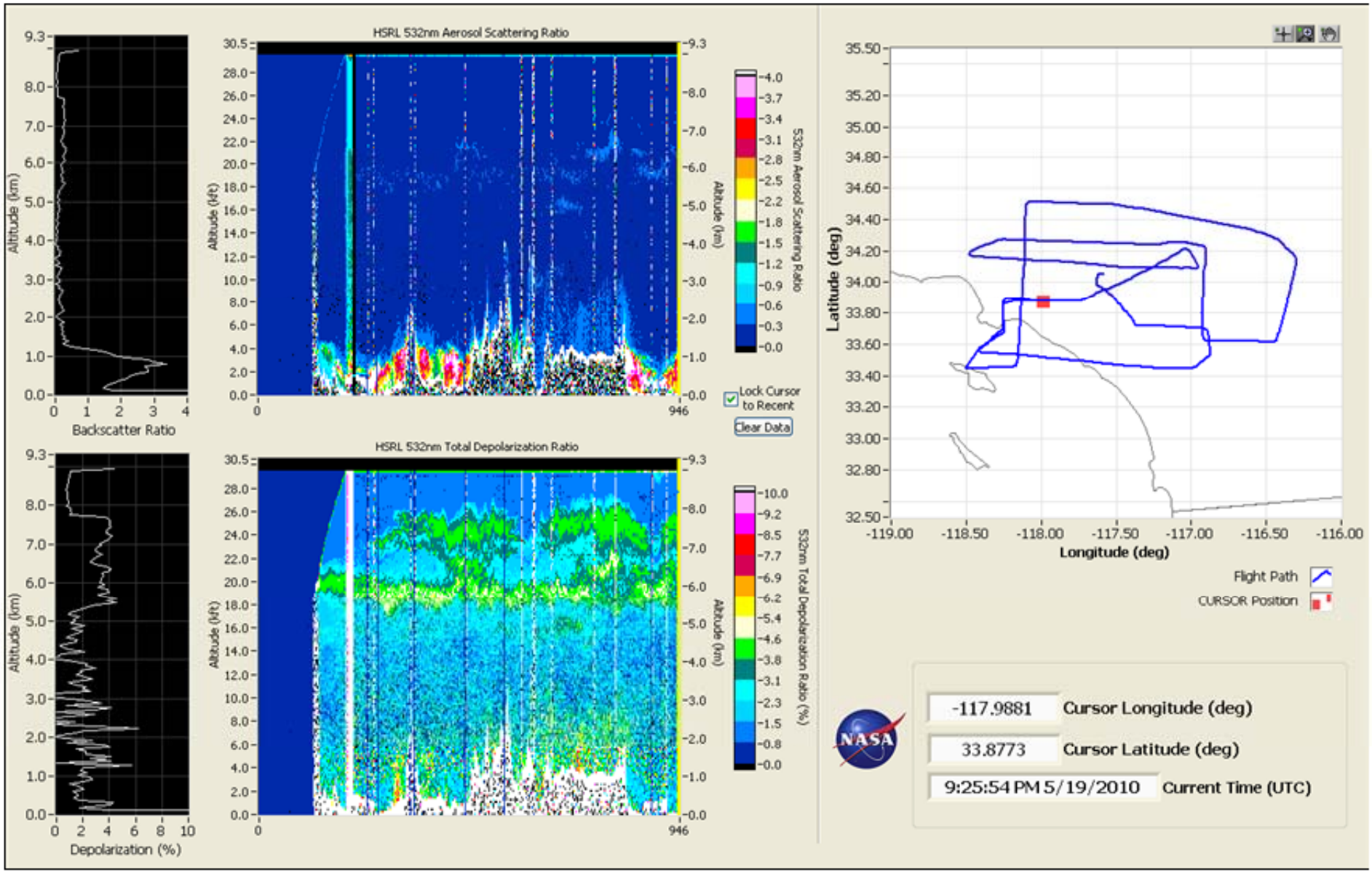






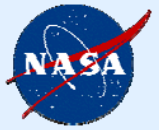
Real-Time Downlink

Downlink Provides Real-time guidance on layer heights and aerosol types



Summary

- HSRL provides quantitative information on extensive and intensive aerosol properties
- Intensive parameters useful for aerosol typing and partitioning aerosol AOT by type
- Intensive and extensive parameters useful for assessing satellite measurements and model predictions
- Aerosol vertical distribution useful for assessing potential errors in scaling column satellite observations to PM 2.5
- Water subsurface measurements useful for ecosystem studies
- Real-time downlink useful for guiding P3 altitude changes

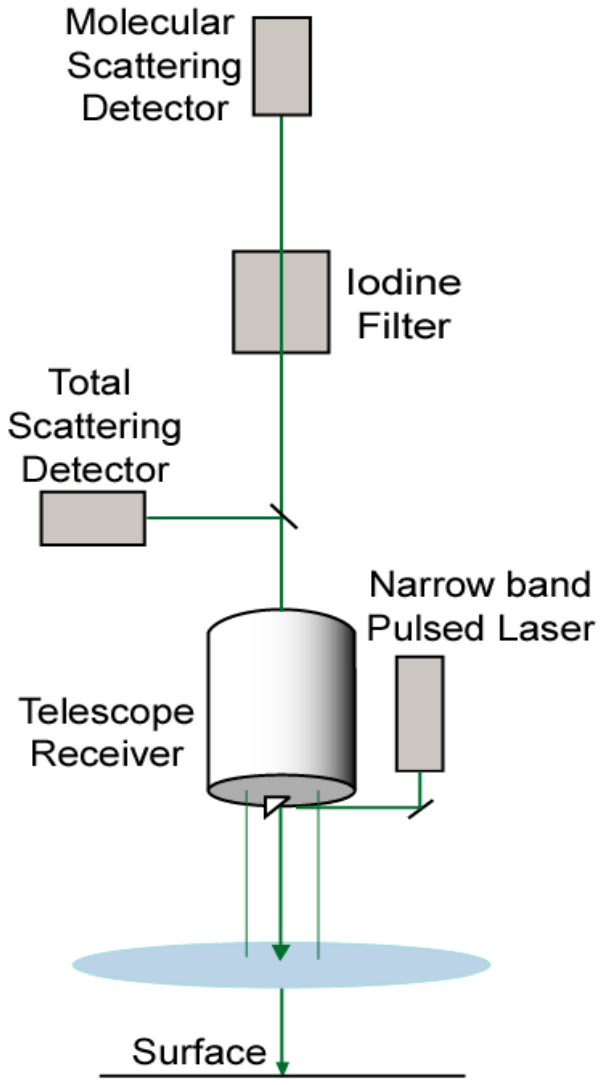


Thank You!

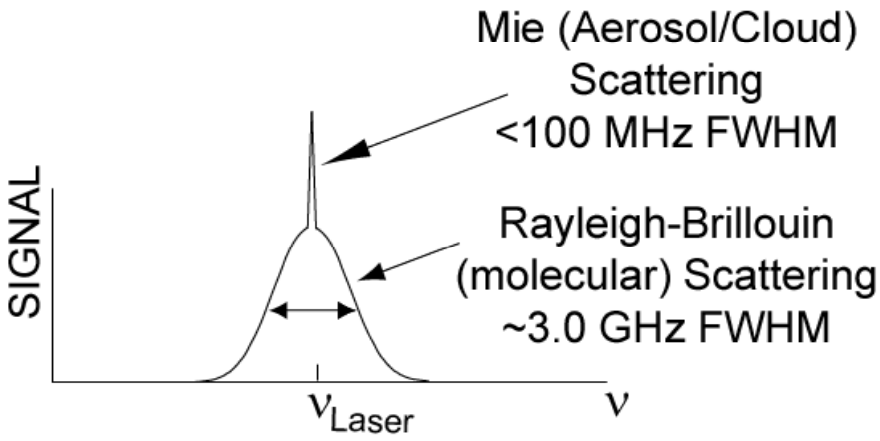
Questions?

Backup

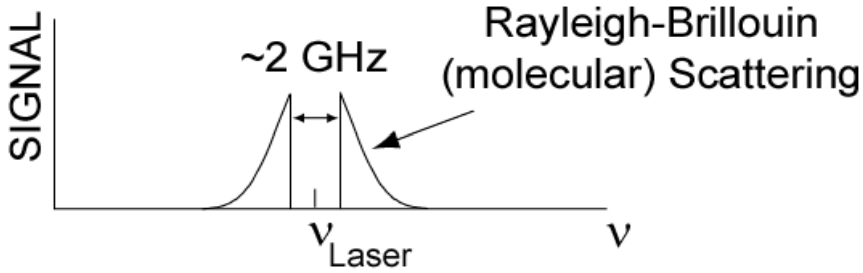
High Spectral Resolution Lidar (HSRL) Technique (Iodine Vapor Filter Implementation)



Atmospheric Scattering



Effect of Iodine Vapor Notch Filter



HSRL: 2 equations, 2 unknowns

Measured Signal on Molecular Scatter (MS) Channel:

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

Particulate Extinction

Measured Signal on Total Scatter (TS) Channel:

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

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

Ext / Backscatter

Particulate Backscatter

Retrieved Parameters

Advantages of HSRL technique

- Higher information content
  - Independent extinction and backscatter estimates
- Internally calibrated
- Highly accurate estimates
  - Aerosol extinction
  - Aerosol backscatter
  - Aerosol depolarization

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Airborne Aerosol Lidar Measurements for Air Quality Research

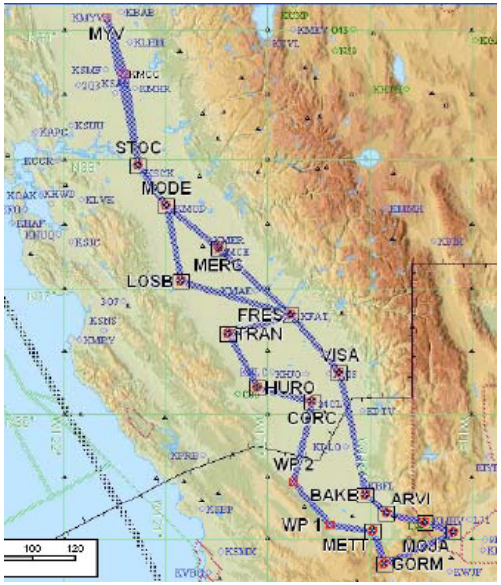
Science Questions:

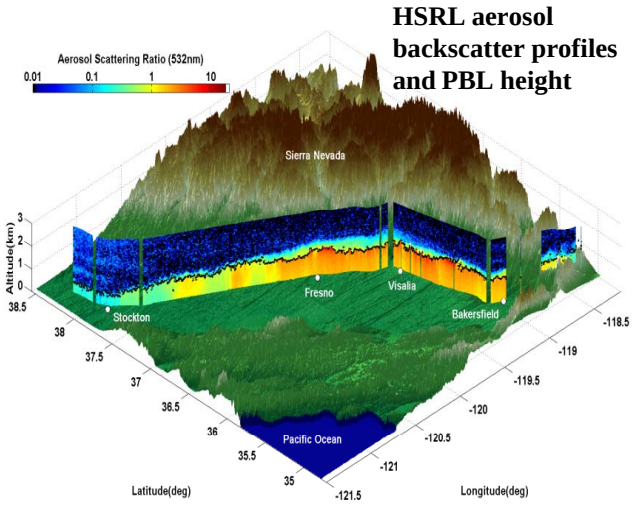
- **What is the relationship between satellite AOD and measured surface $PM_{2.5}$?**
- **Can satellite measurements be used to adequately characterize $PM_{2.5}$ spatial gradients/distributions in SJV?**
- **What are the effects of PBL height and vertical aerosol distributions on the relationship between column AOD and surface $PM_{2.5}$?**

HSRL data used to:

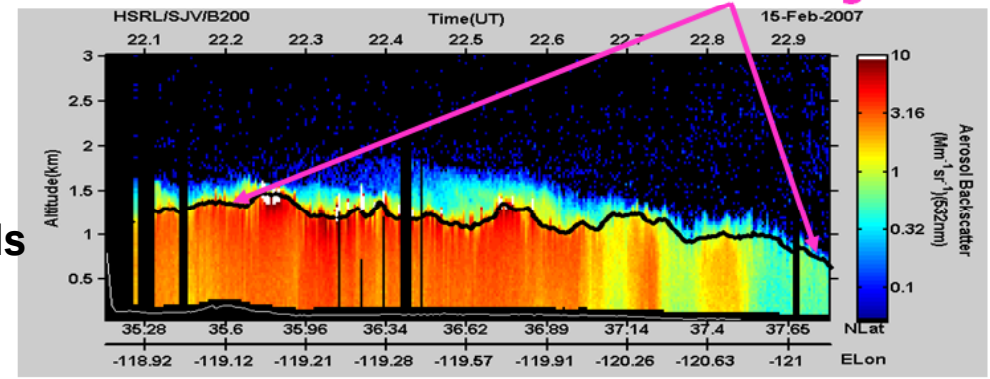
- **define PBL height**
- **evaluate MODIS research AOT retrievals**
- **determine AOT above/below PBL**

San Joaquin Valley, California





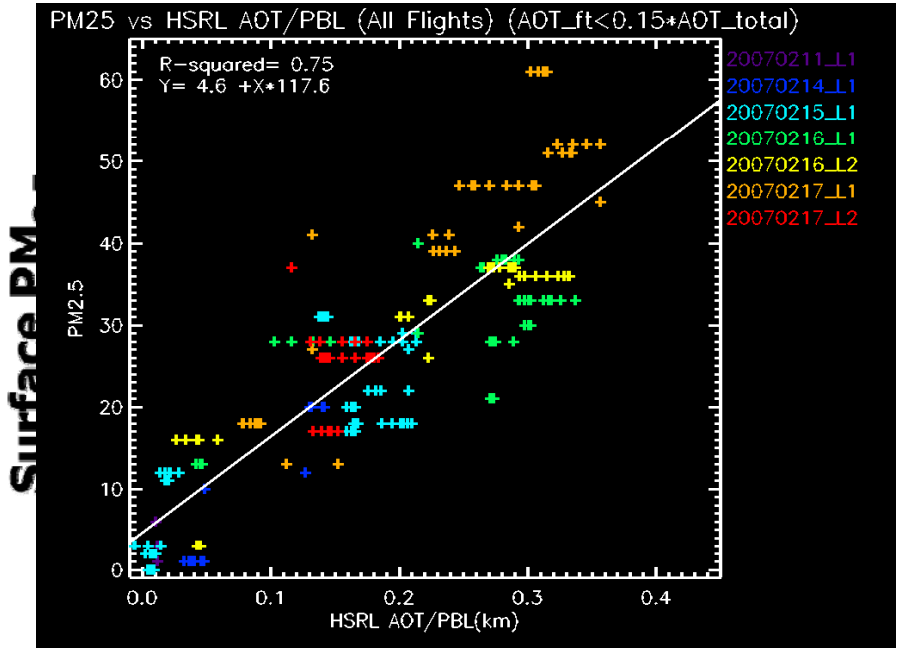
HSRL Aerosol Backscatter and PBL heights



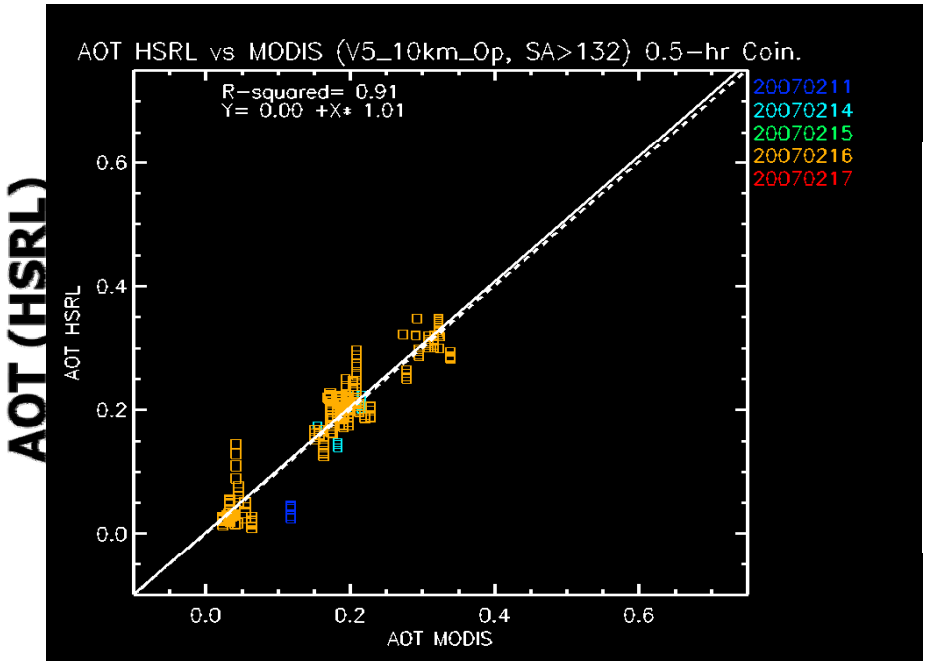
Airborne Aerosol Lidar Measurements for Air Quality Research

- Normalizing AOT with PBL height (z_i) significantly improves correlation with surface $PM_{2.5}$
  (r^2 increases from 0.36 to 0.75)

- Very good correlation between MODIS and HSRL AOT when MODIS retrievals restricted to large (>132 deg) scattering angles – reduces dependence of MODIS AOT on surface reflectance



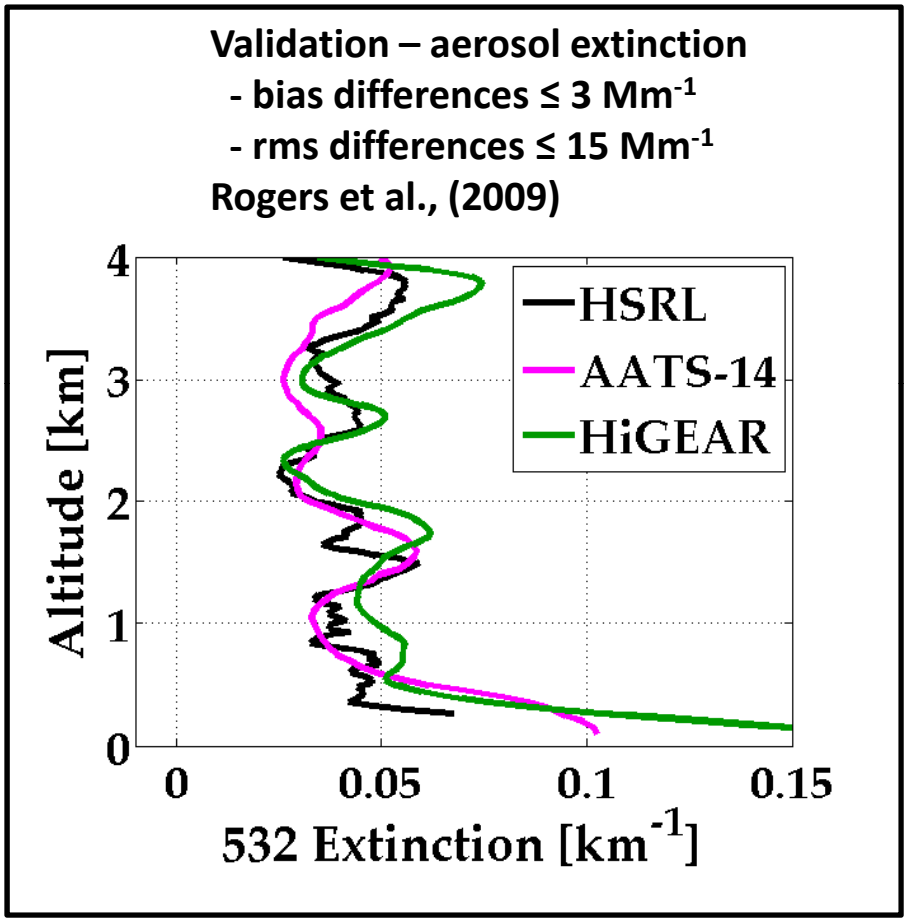
AOT/PBL Height (HSRL)



AOT (MODIS)

Validation of 532 nm aerosol extinction

- Measurements from MILAGRO (2006, Mexico City)
- Coordinated flight of B200, J-31, and NCAR C-130
- HSRL extinction compared to
  - AATS-14 sun photometer
  - HiGEAR in situ aerosol extinction + absorption



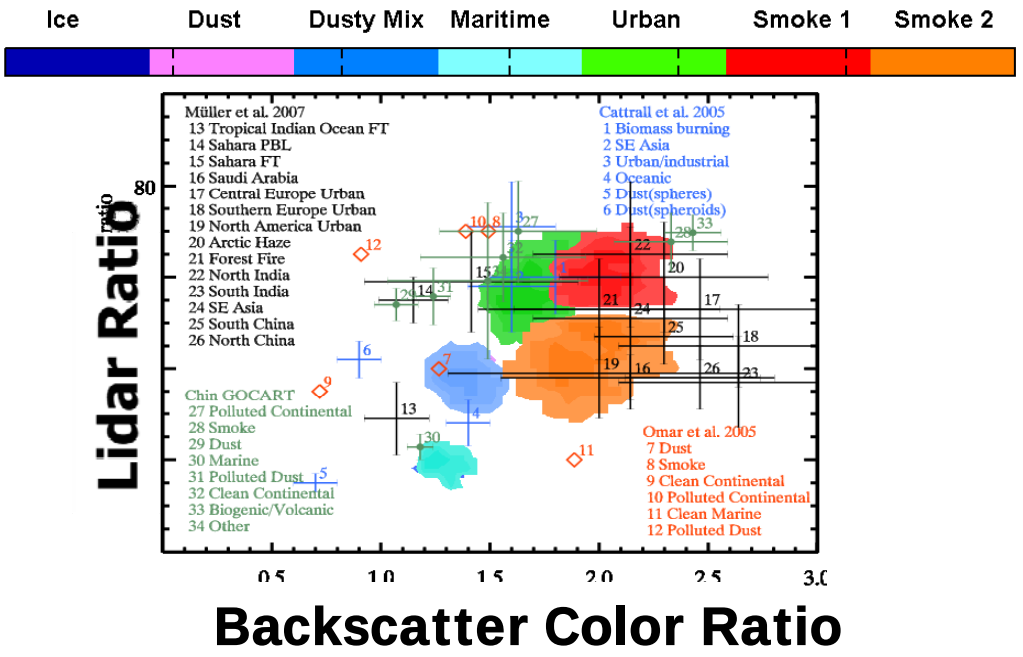
AATS14 data from Jens Redemann
HiGEAR data from Tony Clarke

For more on validation, see Rogers et al. ACP 2009

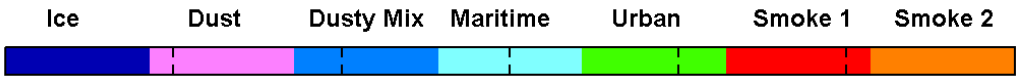
Aerosol Classification using HSRL measurements

Aerosol classification is based on HSRL measurements of aerosol intensive parameters

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



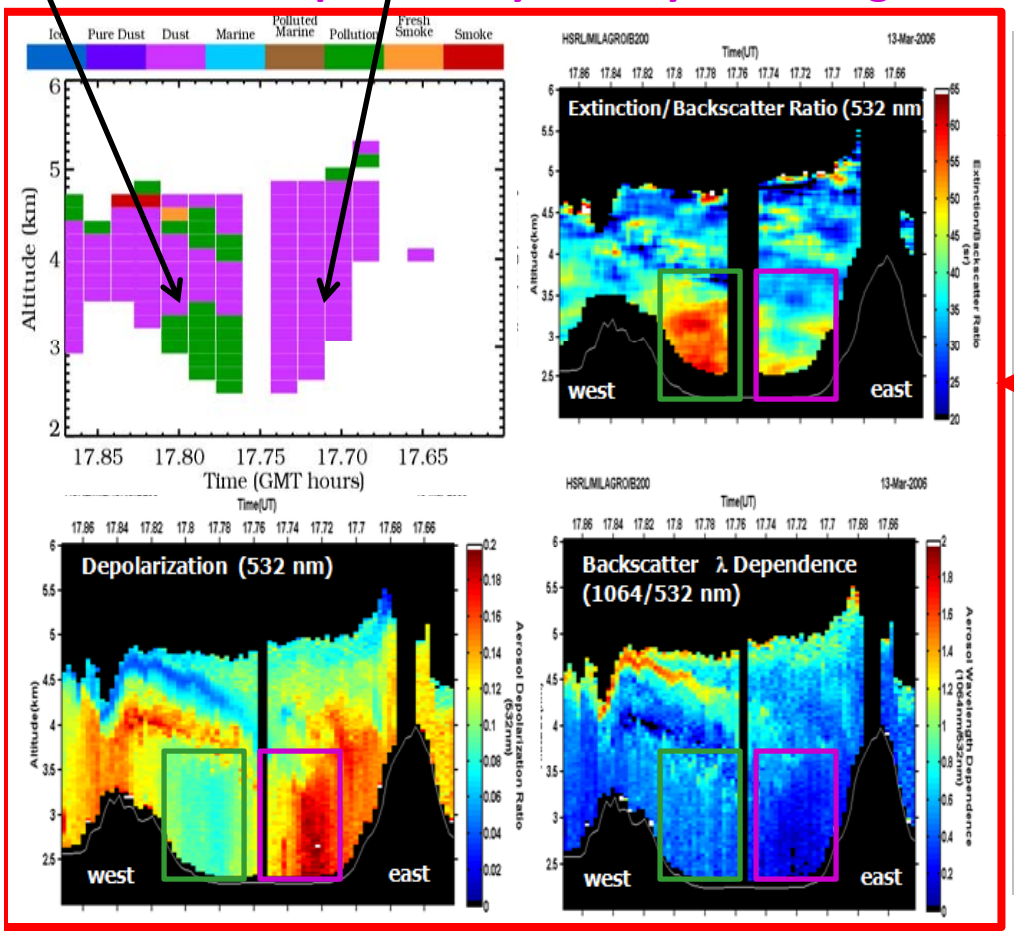
- Aerosol intensive parameter measurements were used in an objective cluster analysis scheme to discriminate aerosol type.
- Aerosol types associated with the clusters were subjectively related to known aerosol types and aerosol types inferred by Cattrall et al. (2005), Omar et al. (2005), and Müller et al. (2007).
- Correction applied to make sure that all ice cases have low temperature. Cases that fail are reassigned to dust.
- Seven "clusters" were obtained:

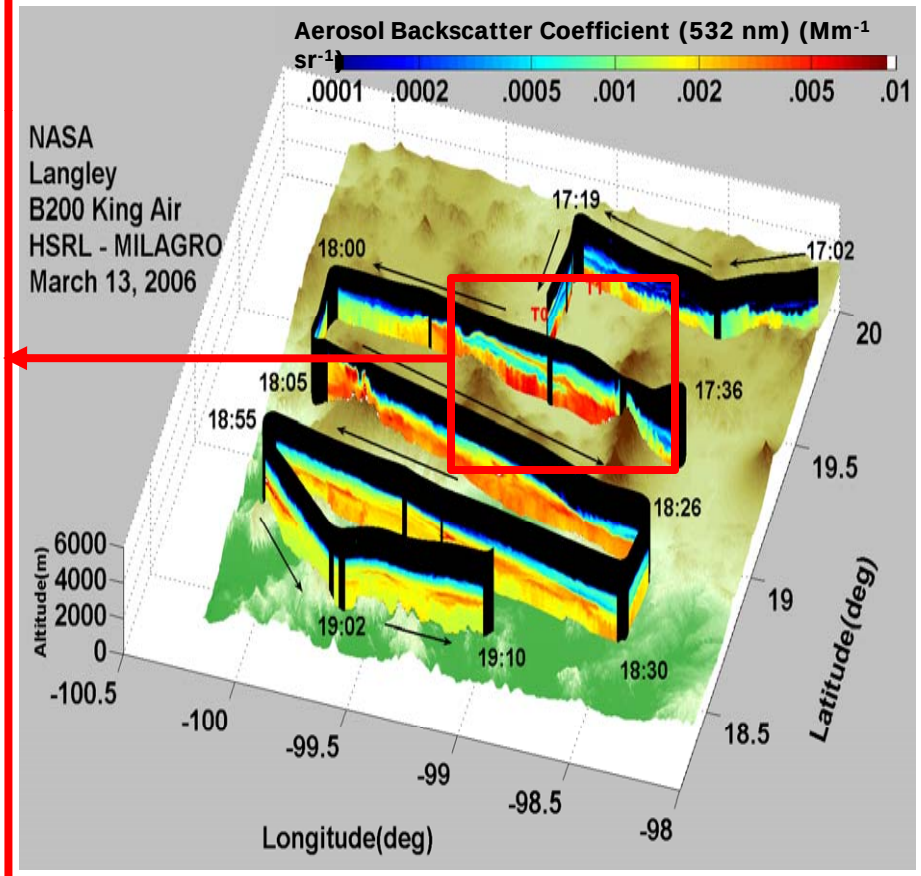


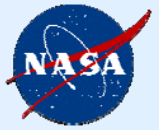
Airborne HSRL Measurements Reveal Variations in Aerosol Type

NASA/LaRC airborne HSRL measurements of aerosol optical properties (depolarization, lidar ratio, backscatter wavelength dependence) over Mexico City on March 13, 2006 reveal variations in aerosol types

- western part of city - urban aerosol – small, spherical particles
- eastern part of city – dusty mix – larger, nonspherical particles

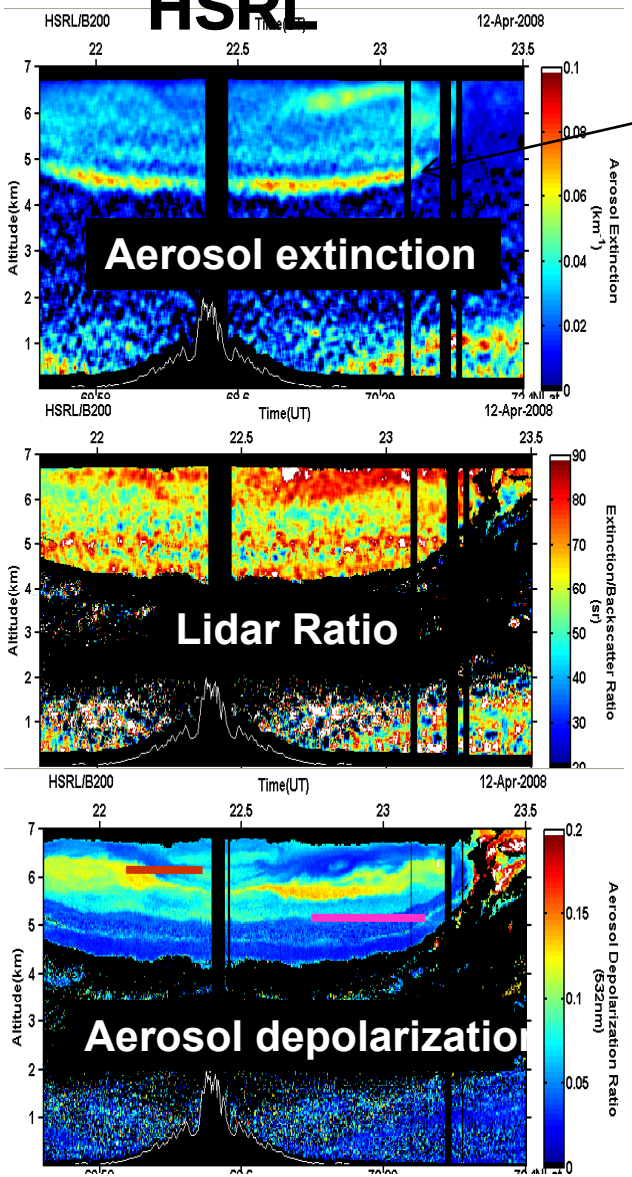




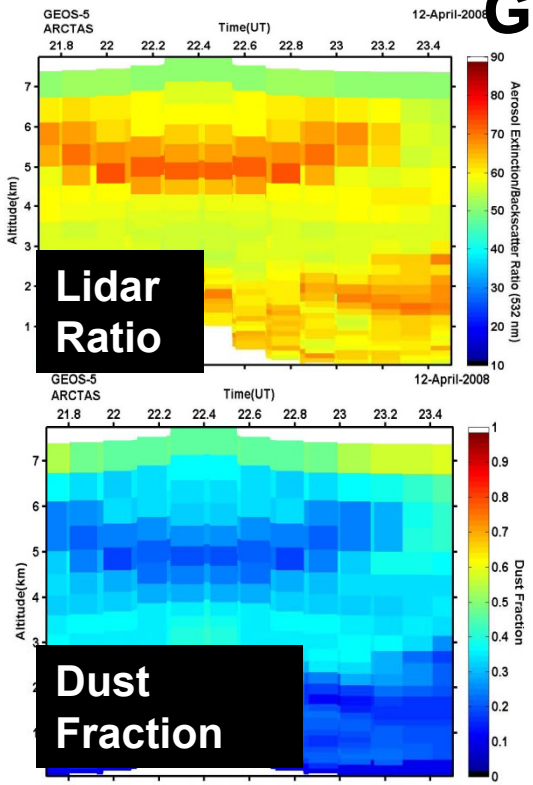


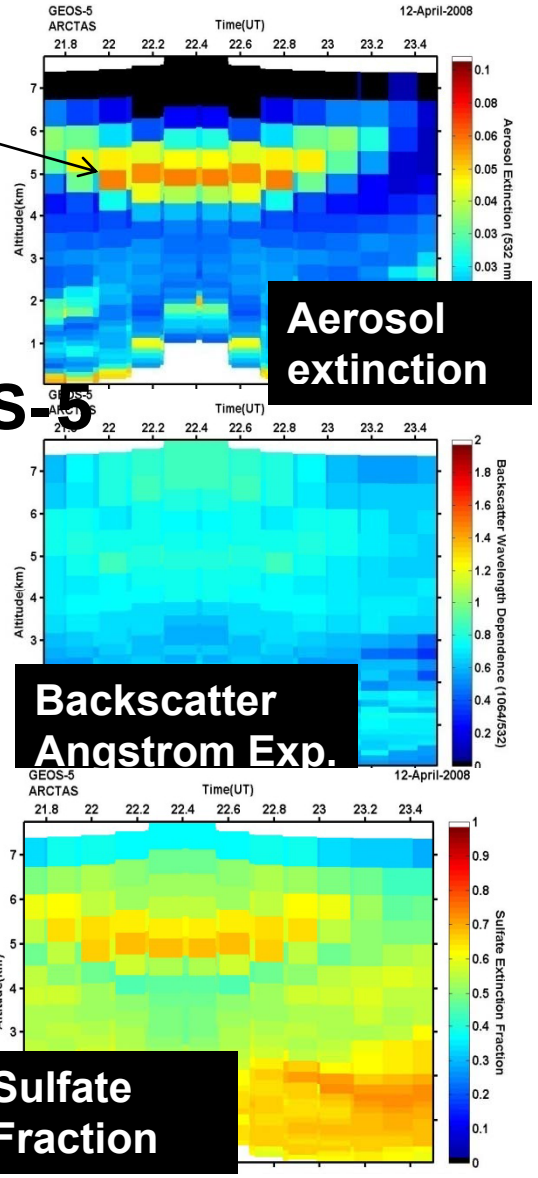
Evaluation / Validation

HSRL / GEOS-5 Comparison on April 12

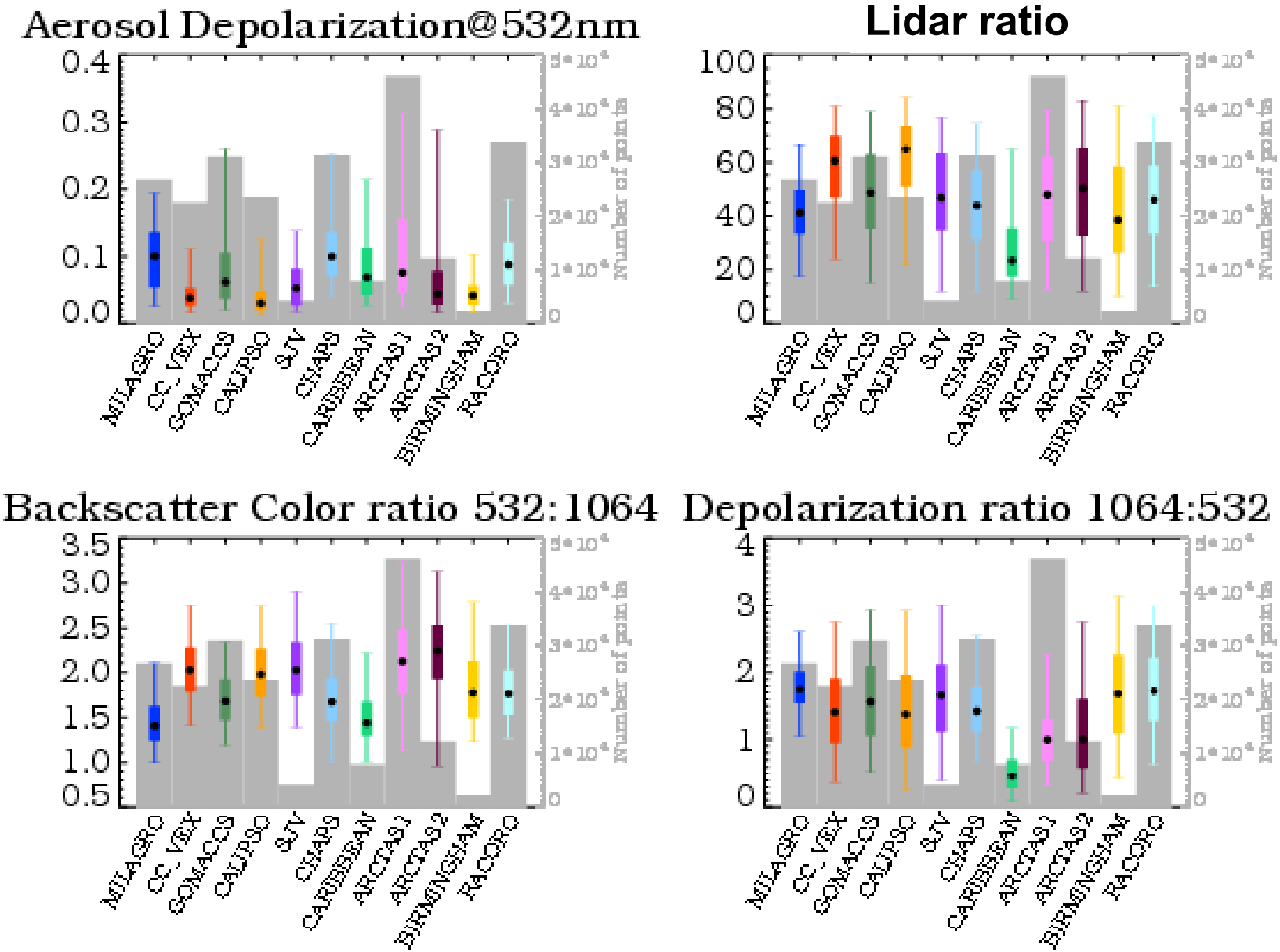


- HSRL and GEOS-5 show high lidar ratio and low depol at bottom of layer –smoke
- HSRL and GEOS-5 show lower lidar ratio and higher depol at higher altitudes in layer
- HSRL and GEOS-5 show differences at top of layer





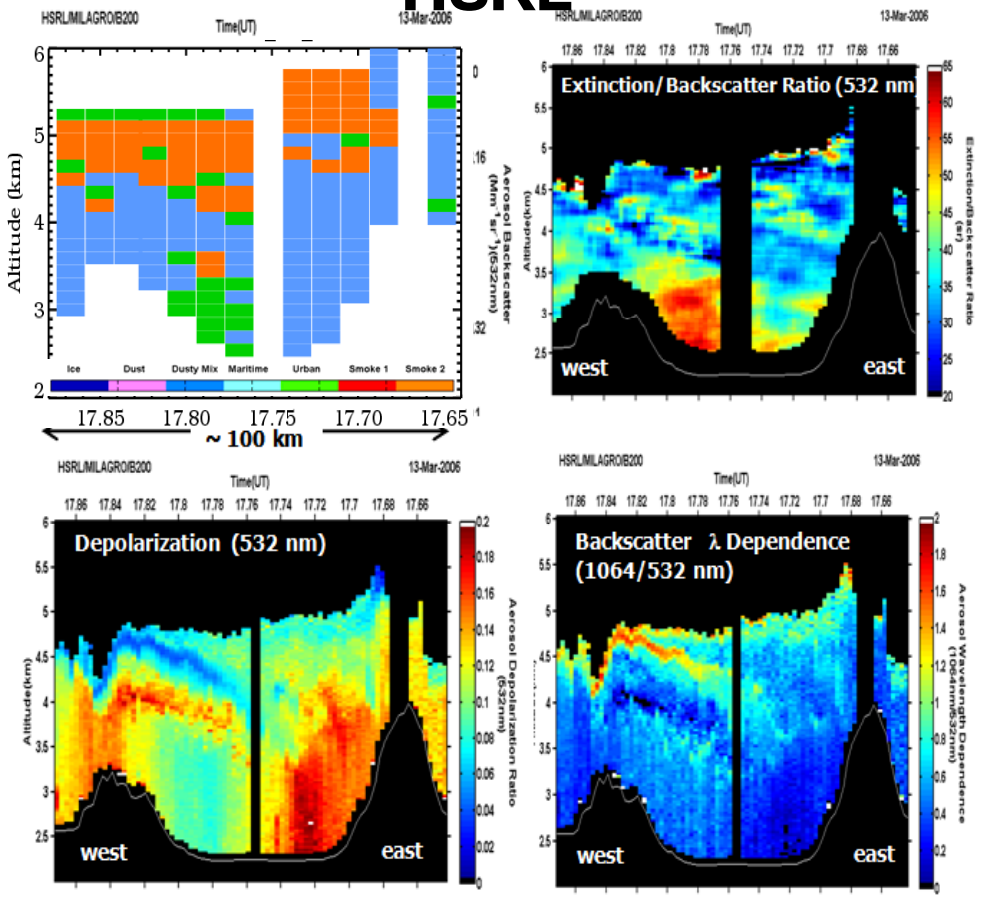
Aerosol Intensive Parameters for Various Campaigns



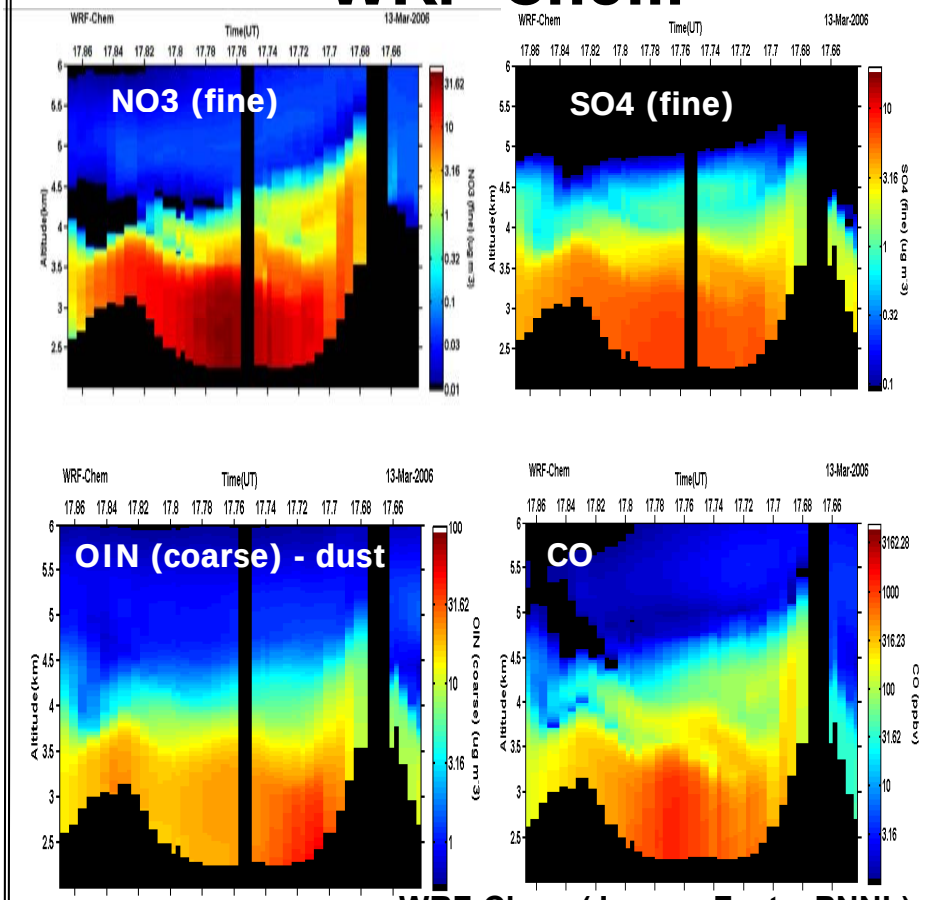
HSRL Aerosol Classification – Comparison to WRF-Chem

- In the vicinity of Mexico City, WRF-CHEM compositions qualitatively agree with aerosol types inferred from HSRL measurements
  - High concentrations of NO_3, SO4, EC -> urban
  - High concentrations of dust (other inorganics, OIN, in the model) -> mix of dust and urban
- Outside of Mexico City, dust and urban pollutants mix together

HSRL

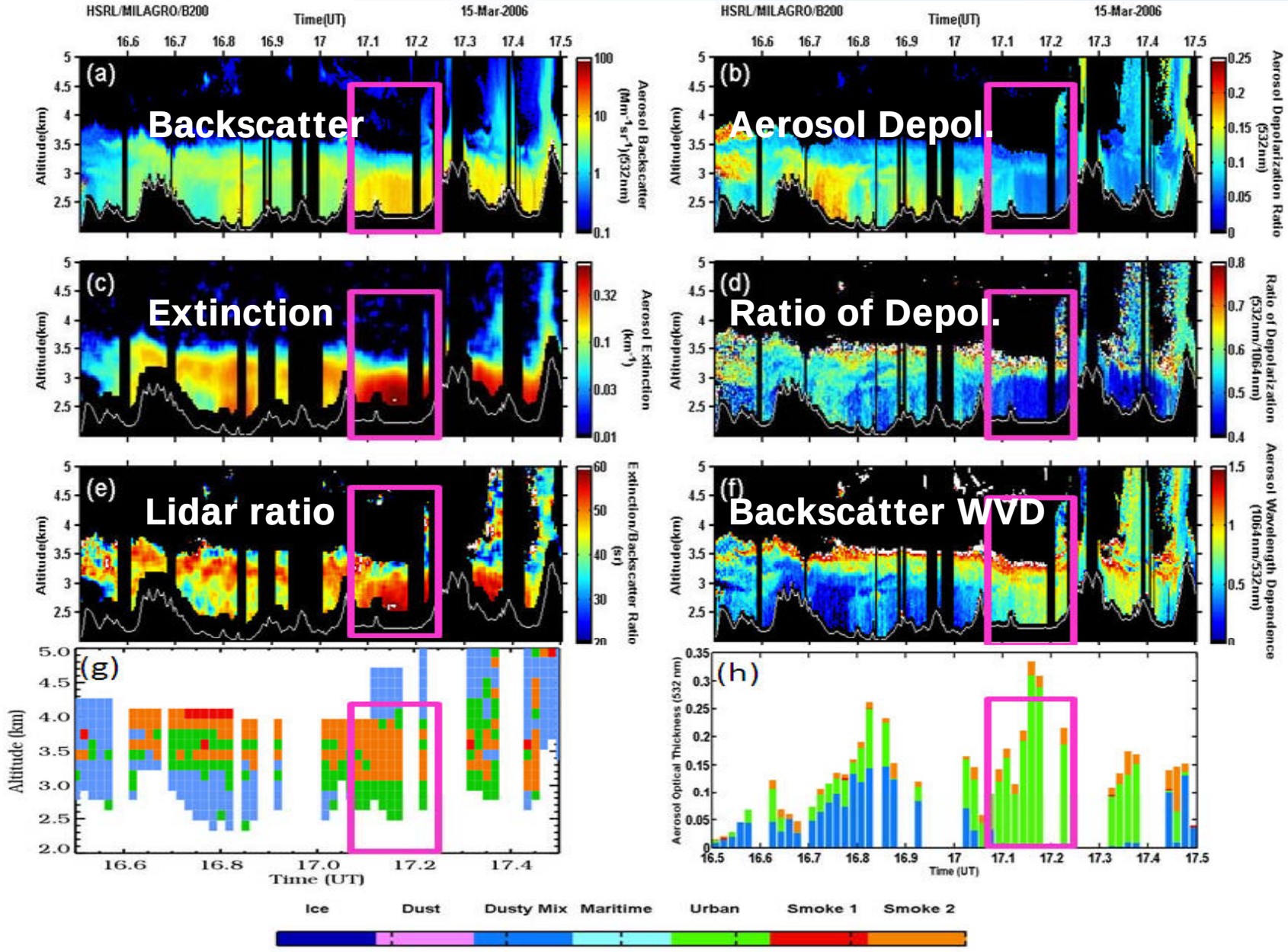


WRF-Chem



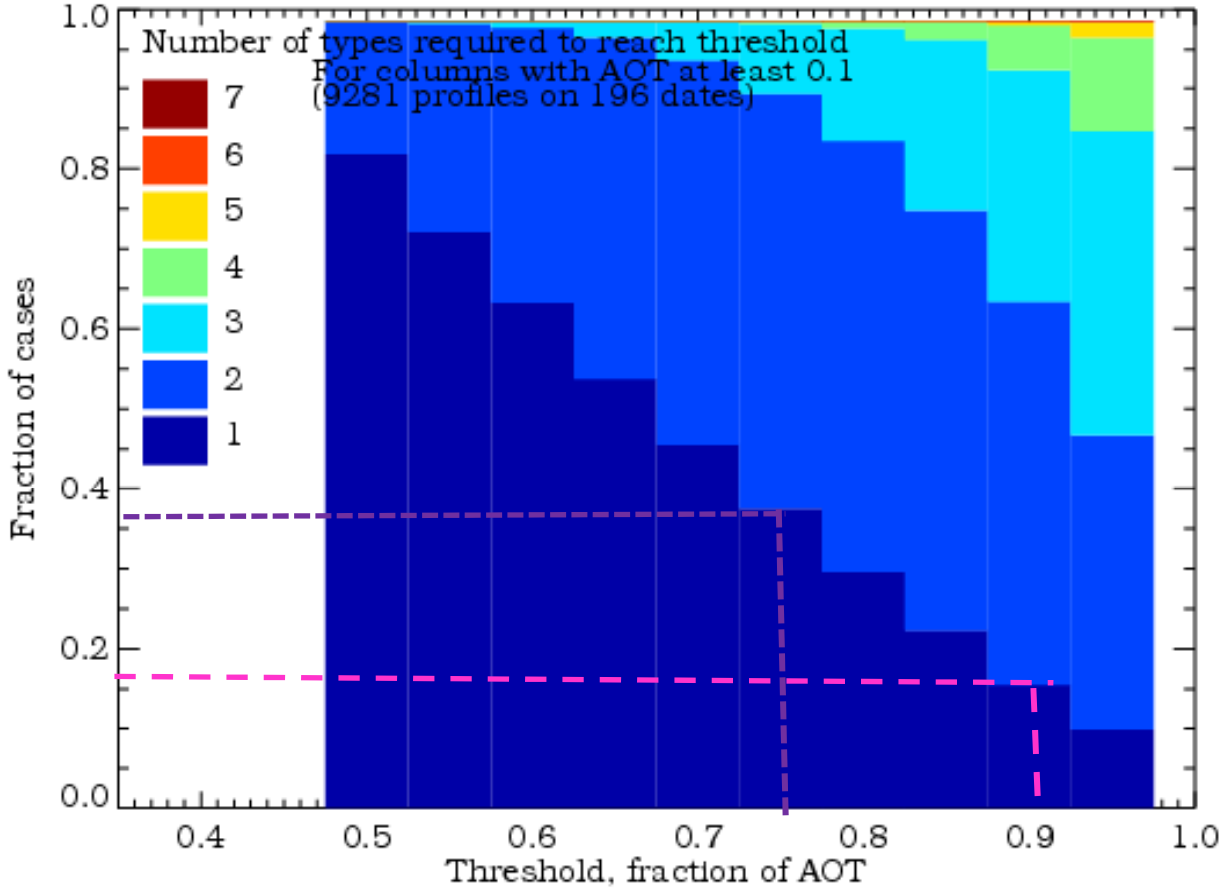
WRF-Chem (Jerome Fast – PNNL)

Example of Aerosol Classification using HSRL measurements: Flight around / over Mexico City



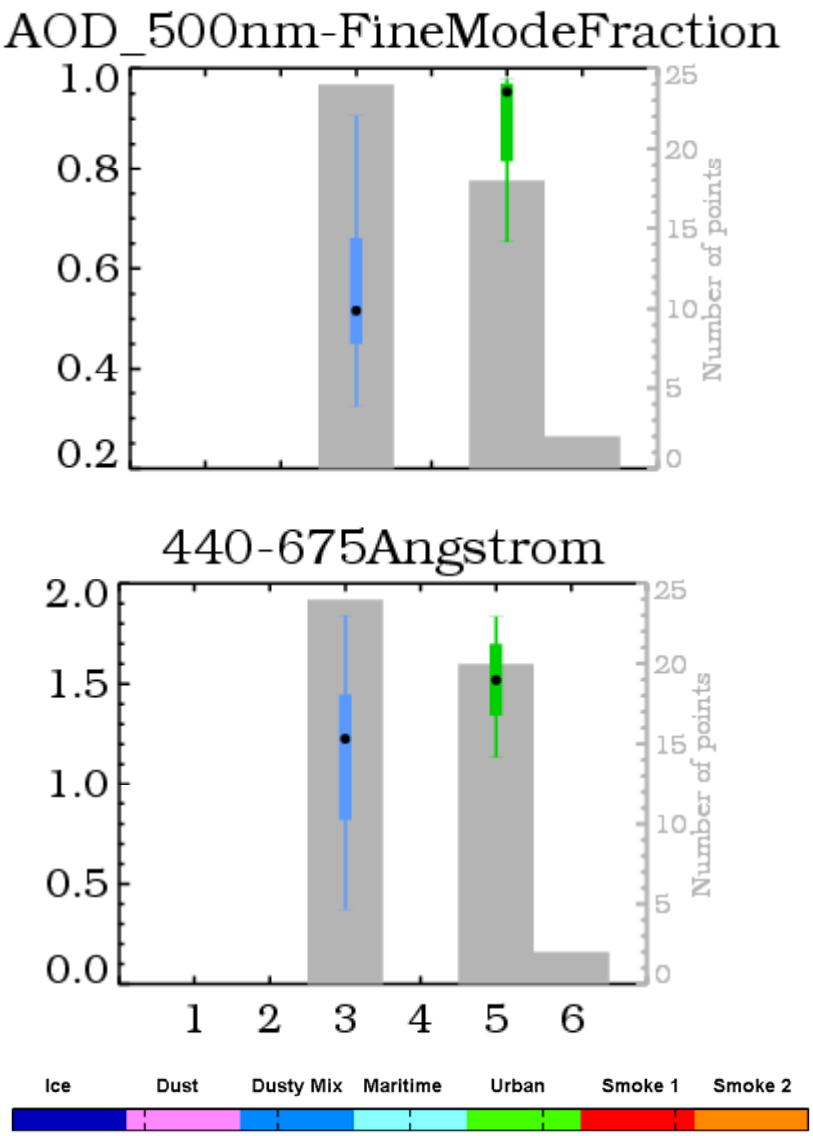
HSRL aerosol typing results show aerosols frequently occur in multiple layers

- **Analysis of HSRL typing results shows that in order to account for 75% of the AOT in the column, two or more aerosol types are required ~63% of the time**
- **Analysis of HSRL typing results shows that in order to account for 90% of the AOT in the column, two or more aerosol types are required ~83% of the time**
- This highlights the need for lidar data with high information content to compliment column-wise measurements



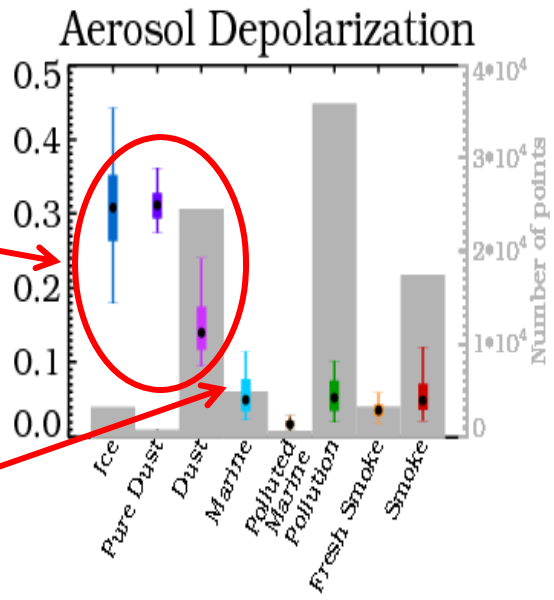
Aerosol Types and AERONET Measurements

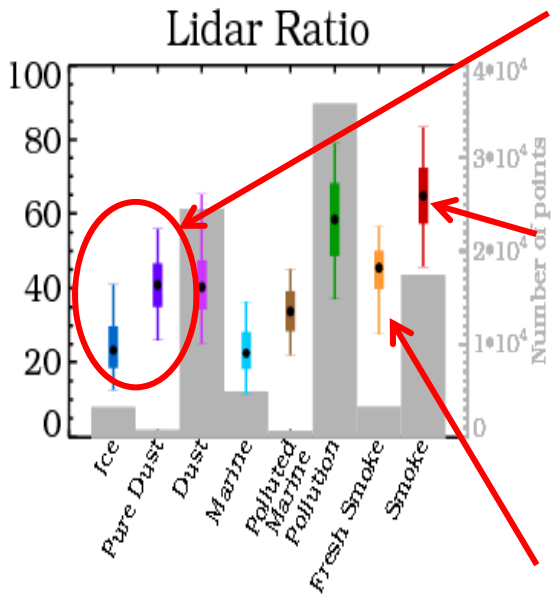
- 45 cases where HSRL measurements indicated that 75% or more of AOT was from a single type
- Ony a few AERONET inversion results regarding refractive index or single scattering albedo that are coincident with HSRL data; sample size too small to draw meaningful conclusions
- Urban – Smaller particles, larger Angstrom Exponent
- Dusty Mix – Larger particles, smaller Angstrom Exponent



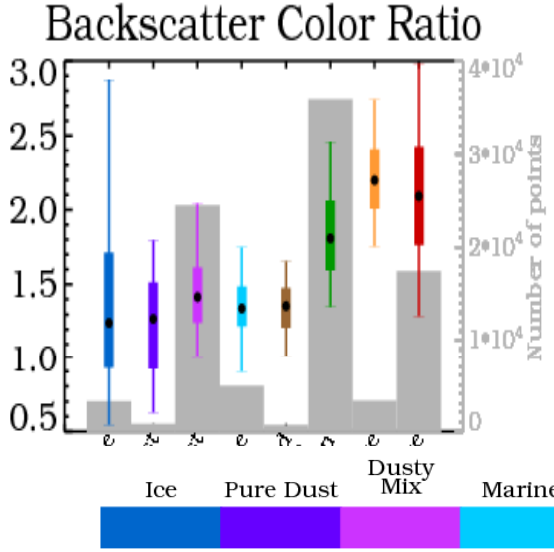
Aerosol Classification using HSRL measurements

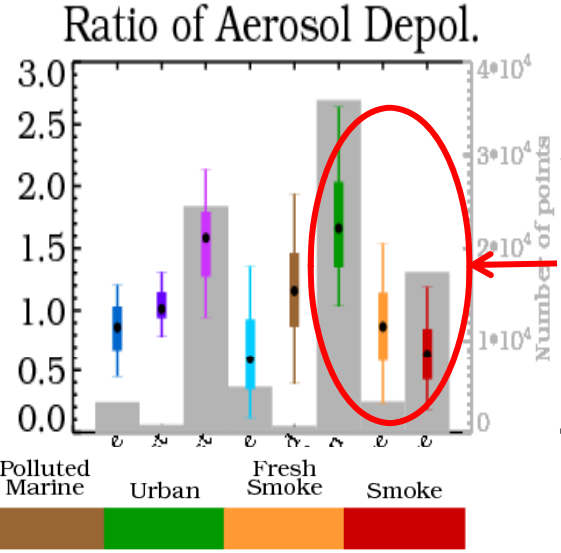
- **Dust and ice, high depolarization, low lidar ratio**
- **Maritime – low lidar ratio, low depolarization**



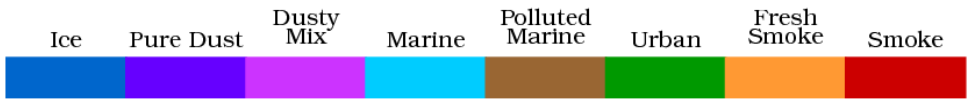


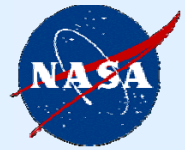
- **Ice – lower lidar ratio than dust**
- **Smoke 1 - higher lidar ratio, more often lofted (aged)**
- **Smoke 2 – lower lidar ratio, closer to surface (fresh)**





- **Smoke – lower ratio of aerosol depolarizations than urban**

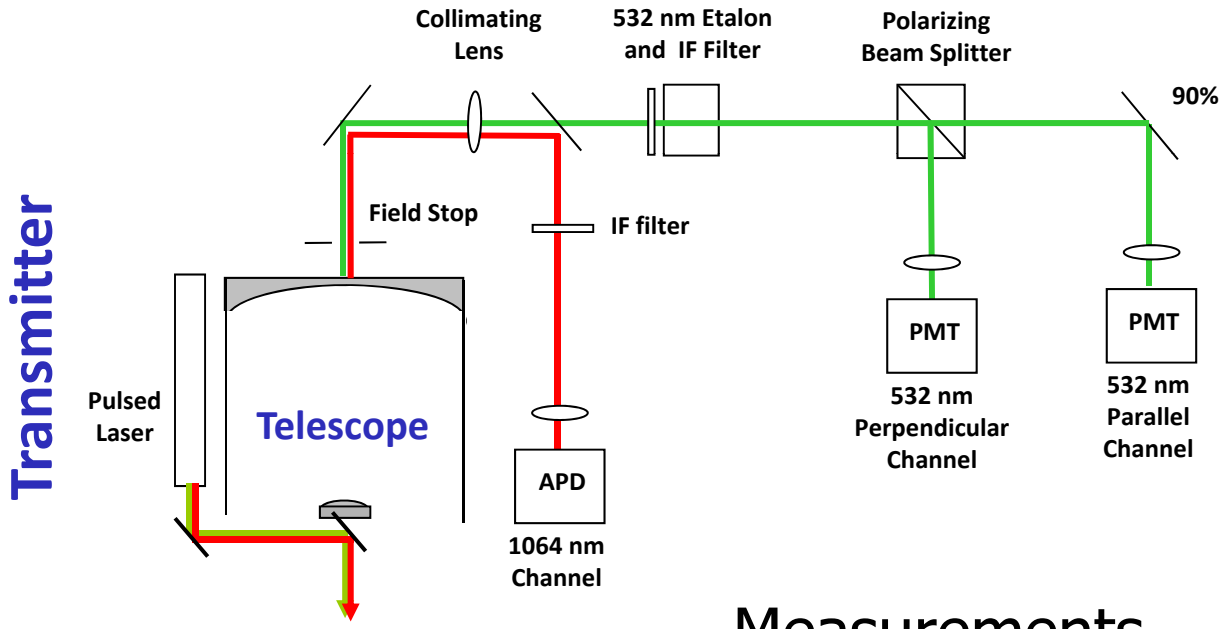




The HSRL Technique

Standard Backscatter Lidar (e.g., CALIPSO)

Aft Optics Assembly

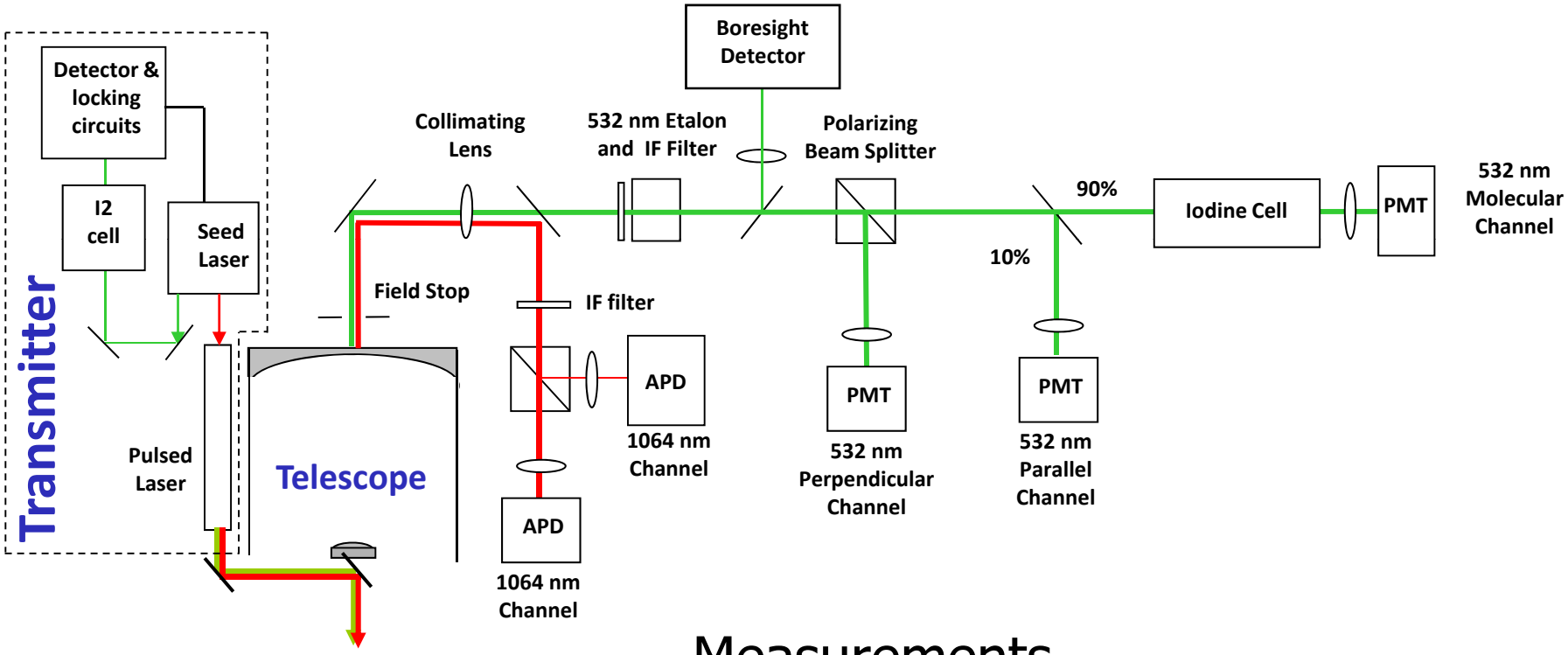


Measurements

- Backscatter: 532, 1064 nm
- Depolarization: 532 nm

LaRC Airborne High Spectral Resolution Lidar

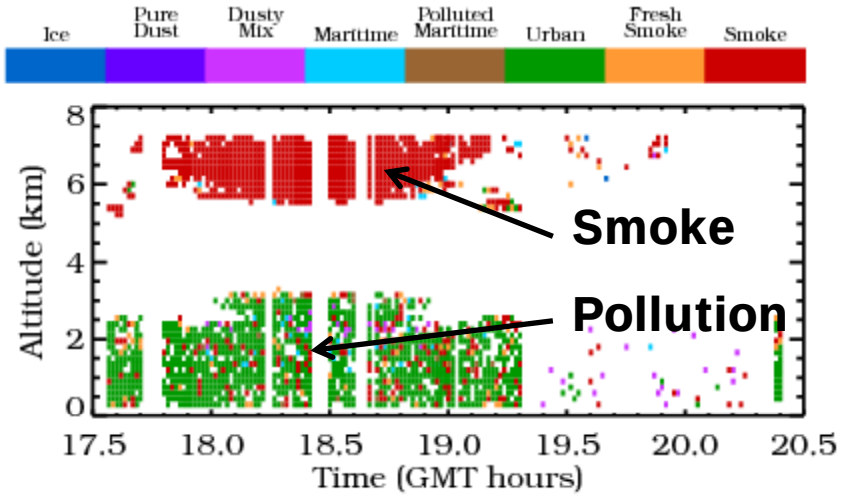
Aft Optics Assembly



Measurements

- Aerosol extinction: 532 nm
- Aerosol backscatter: 532, 1064 nm
- Depolarization: 532, 1064 nm

East Coast - August 2, 2007 (smoke over urban)



Smoke transported from Montana and Idaho

- **High lidar ratio**
- **Separable from pollution by ratio of depolarization at 1064 nm/532 nm.**