Airborne High Spectral Resolution Lidar Measurements of Aerosol Distributions and Properties during the NASA DISCOVER-AQ Missions

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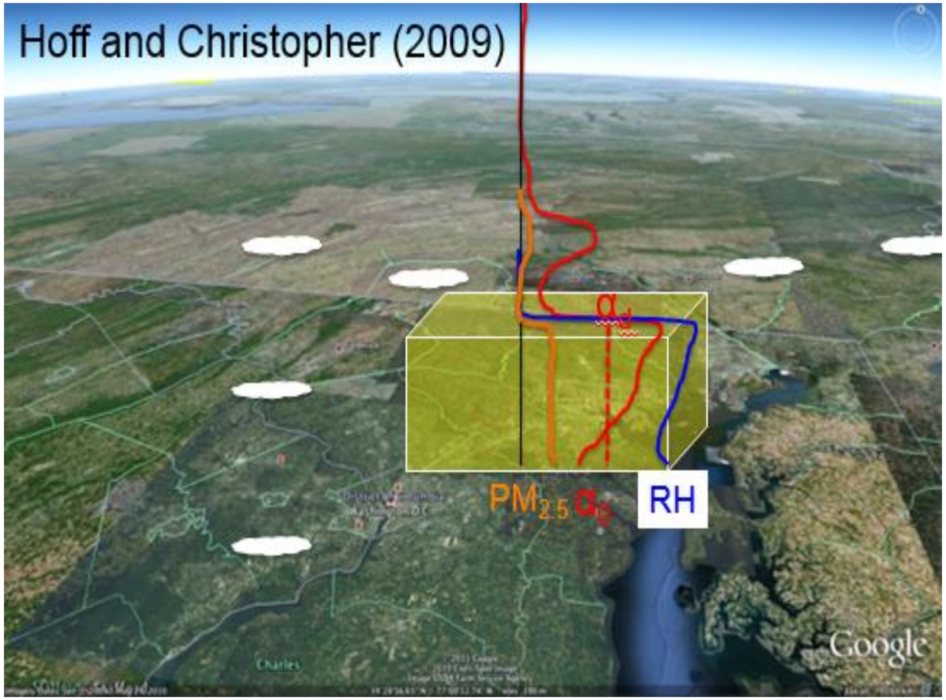
Inferring surface air quality from space

Currently, near-surface air quality information (e.g. $PM_{2.5}$) must be inferred from column-integrated quantities (i.e. Aerosol Optical Thickness – AOT) obtained by passive remote sensing from downward-looking satellite instruments.



Such retrievals must address the following questions:

What do we use for the height of the aerosols? Mixed Layer (ML) height?

Can we assume that near-surface aerosol extinction is about the same as the mean aerosol extinction in the ML?

How well is near-surface extinction related to surface $PM_{2.5}$?

How well can column AOT be used to infer near-surface aerosol extinction and $PM_{2.5}$?

NASA DISCOVER-AQ Mission

<u>D</u>eriving <u>I</u>nformation on <u>S</u>urface Conditions from <u>Co</u>lumn and <u>VER</u>tically Resolved Observations Relevant to <u>A</u>ir <u>Q</u>uality

A NASA Earth Venture campaign intended to improve the interpretation of current and future satellite observations to diagnose near-surface conditions relating to air quality

<u>Objectives:</u>

1. Relate column observations to surface conditions for aerosols and key trace gases O_3, NO_2, and CH_2O

2. Characterize differences in diurnal variation of surface and column observations for key trace gases and aerosols

3. Examine horizontal scales of variability affecting satellites and model calculations

<u>Deployments and key collaborators</u>

Maryland, July 2011 (EPA, MDE, UMD, UMBC, Howard U.)

California, January 2013 (EPA, CARB, UC-Davis&Irvine)

Texas, September 2013 (EPA, TCEQ, U. of Houston)

Colorado, Summer 2014 (EPA, NSF, NOAA, CDPHE)

Airborne HSRL Aerosol Measurements

- NASA/LaRC King Air
- Flight altitude ~ 9 km
- Nadir pointing lidar

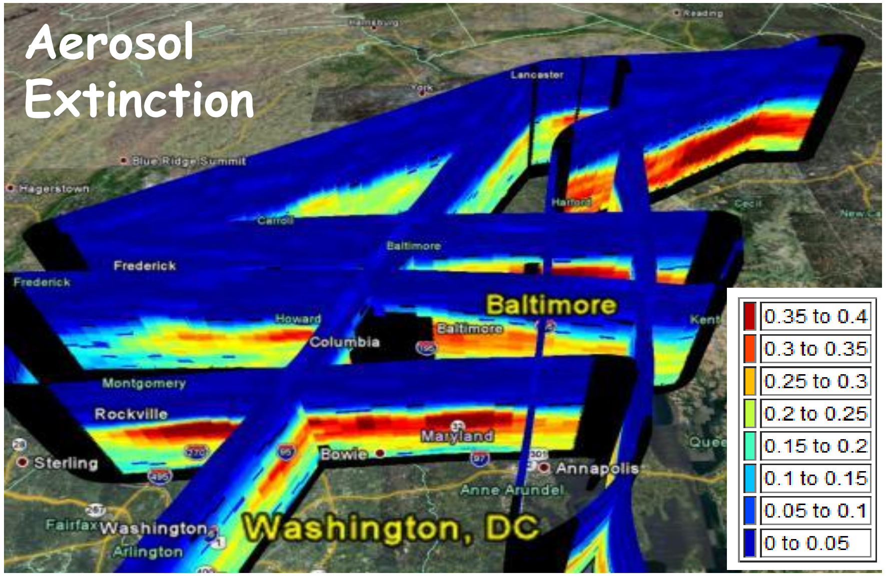
HSRL Technique:

- Independently measures aerosol backscatter, extinction, and optical thickness

HSRL(-2) Aerosol Data Products:

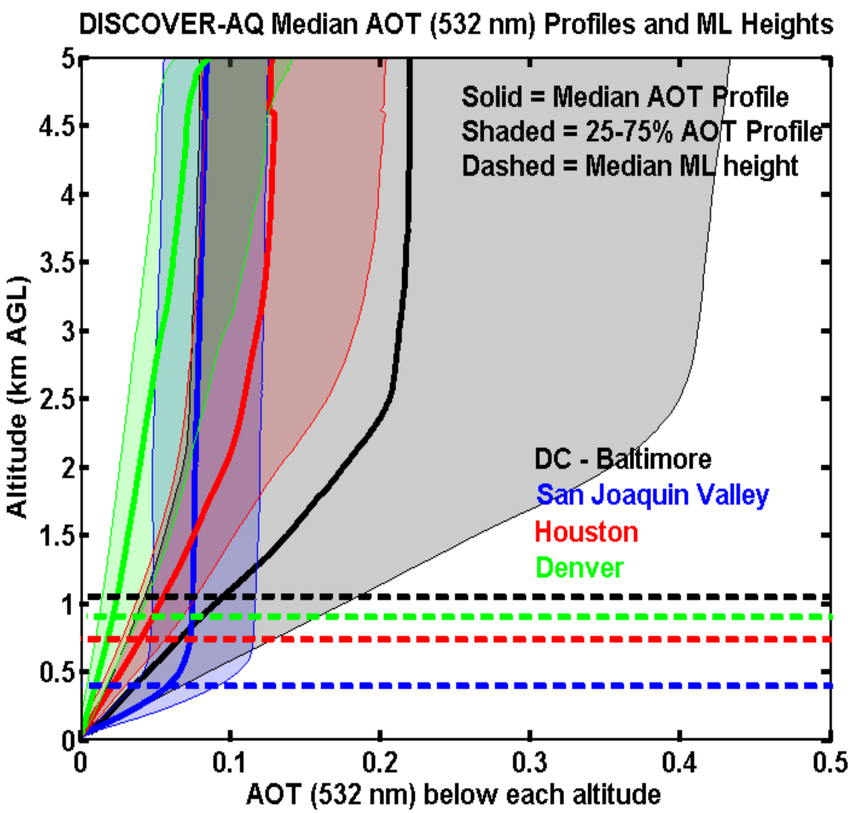
- Backscatter coefficient (355, 532,1064 nm)
- Depolarization (355,532,1064nm)
- Extinction Coefficient (355,532nm)
- Optical Depth (AOD) (355,532nm)
- Aerosol Typing
- Mixed Layer (ML) Heights

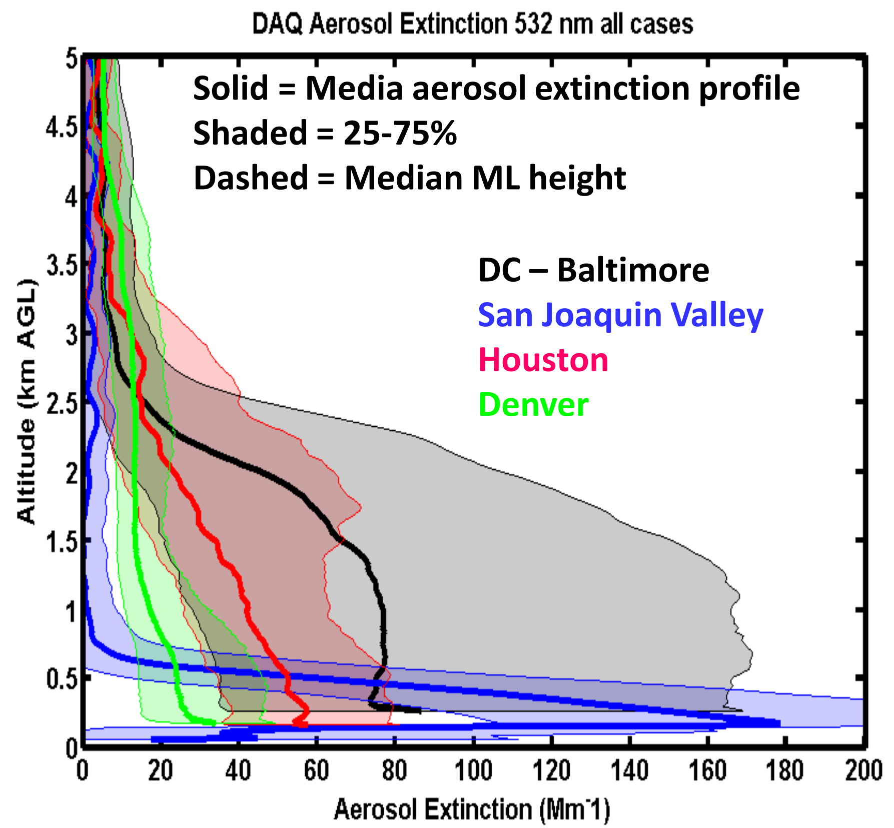
- HSRL-1 deployed for DAQ-1 (DC-Baltimore)
- HSRL-2 developed as a prototype of multiwavelength lidar for NASA Aerosol-Clouds-Ecosystem (ACE) mission
- HSRL-2 capability at 355, 532 nm
- Provide "$3\beta+2\alpha$" suite of measurements for aerosol microphysical retrievals
- HSRL-2 used for final three DISCOVER-AQ deployments (California, Houston, Denver)



Median Aerosol Profiles

HSRL measurements show much of AOT is often above the daytime mixed layer

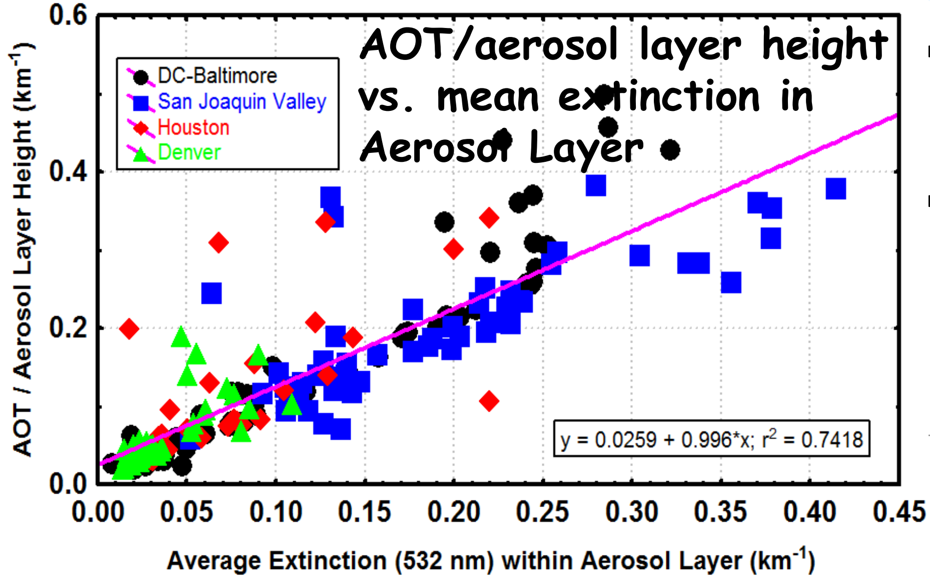


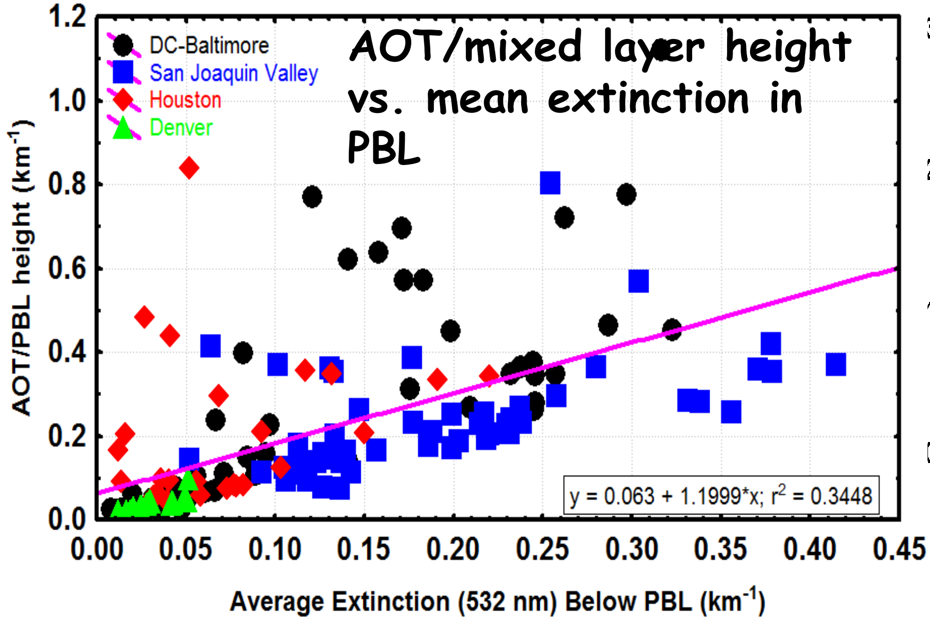


- AOT profiles and ML heights computed for four DISCOVER-AQ missions
- DC-Baltimore had largest median column AOT values
- Median AOT values in the later three campaign were comparable
- With exception of San Joaquin Valley, median profiles show that about only about 20-65% of AOT was within mixed layer; much of AOT was above mixed layer
- In San Joaquin Valley, most (>80%) of AOT was within mixed layer

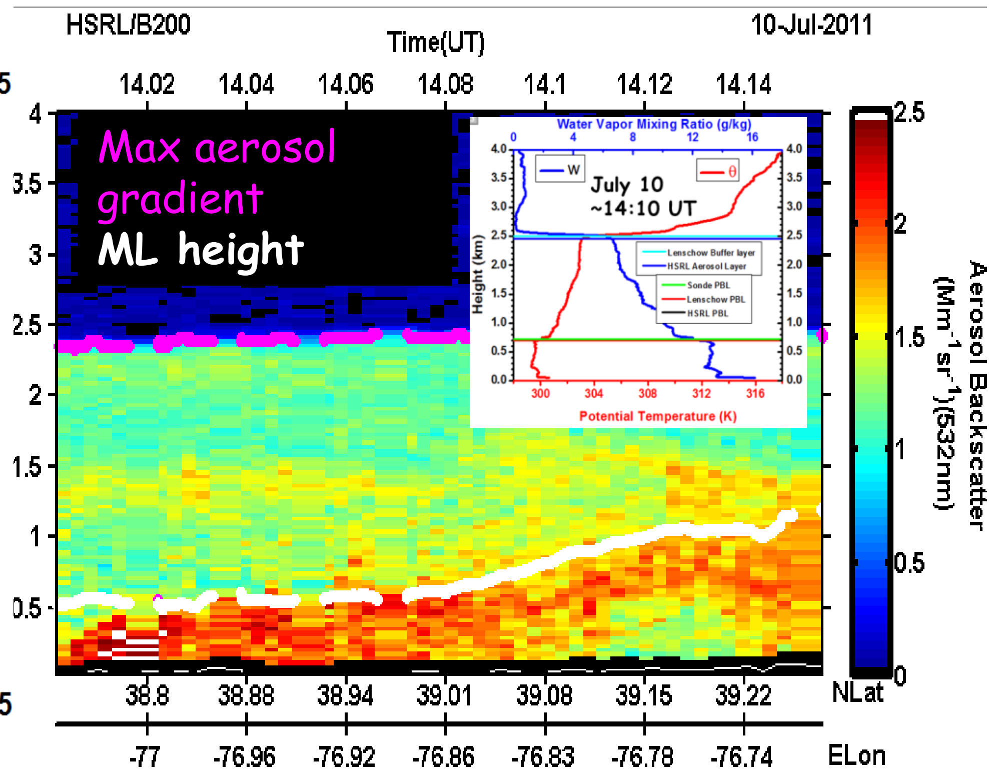
HSRL Measurements and Surface $PM_{2.5}$

Aerosol Layer Height and Mixed Layer Heights



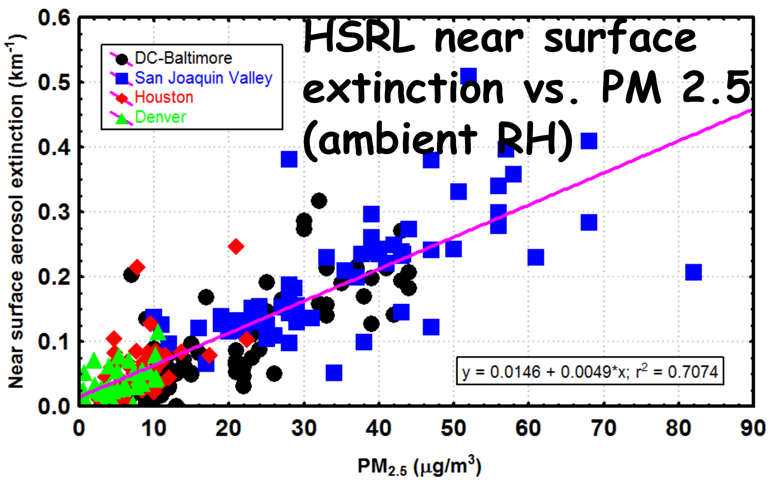


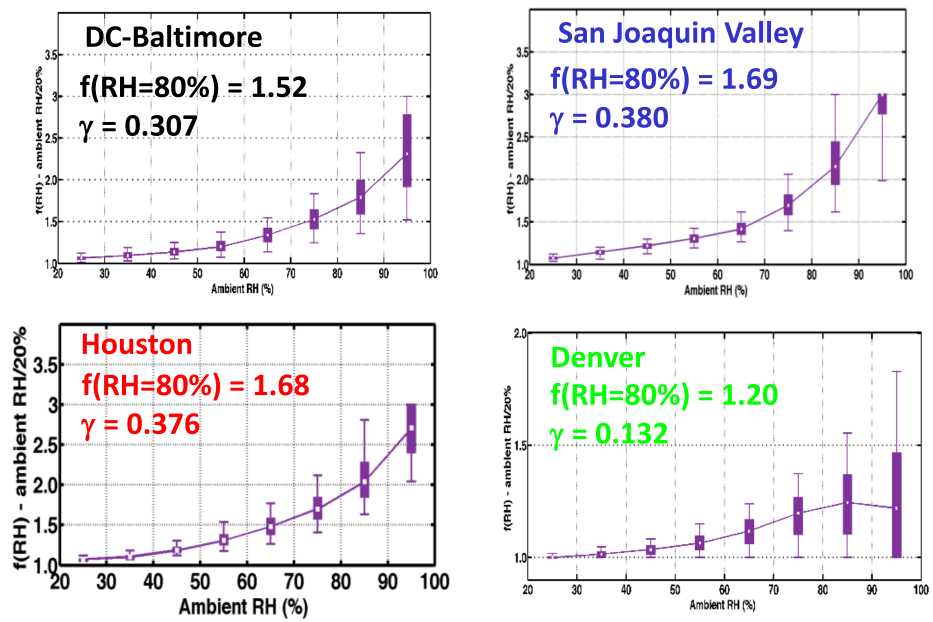
- We examine the correlation between AOT and mean extinction within ML and aerosol layer
- Height of the maximum aerosol gradient (which we call aerosol layer height) is a better measure of scale height than ML height

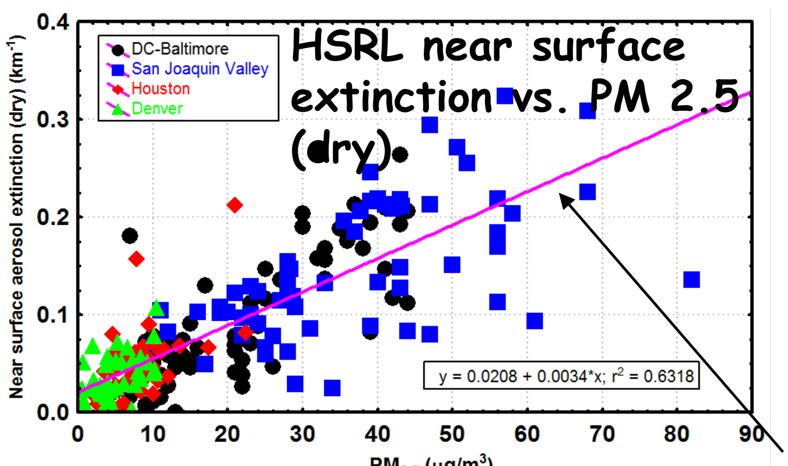


Correlation between near-surface extinction and surface $PM_{2.5}$ concentrations

- HSRL measurements of extinction near the surface were correlated with hourly surface $PM_{2.5}$ data
- $PM_{2.5}$ correlate well with both ambient and dry aerosol extinction







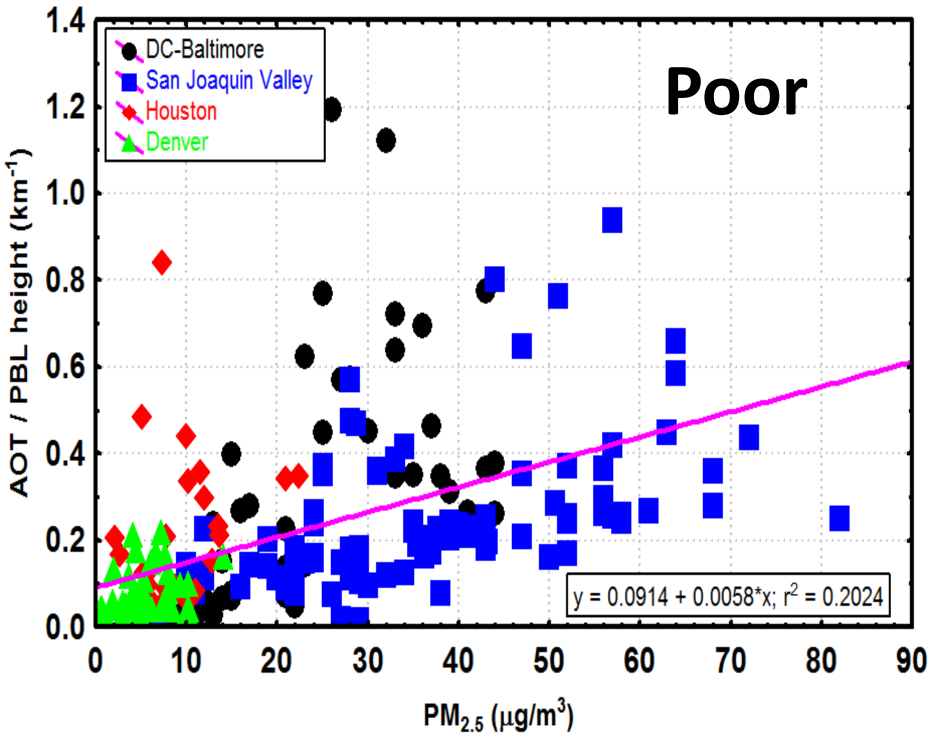
Dry aerosol extinction was derived from HSRL measurements of ambient extinction and airborne in situ measurements of aerosol humidification factor

Slope = 3.4 m^2/g ~ Specific scattering coefficient (SSC)

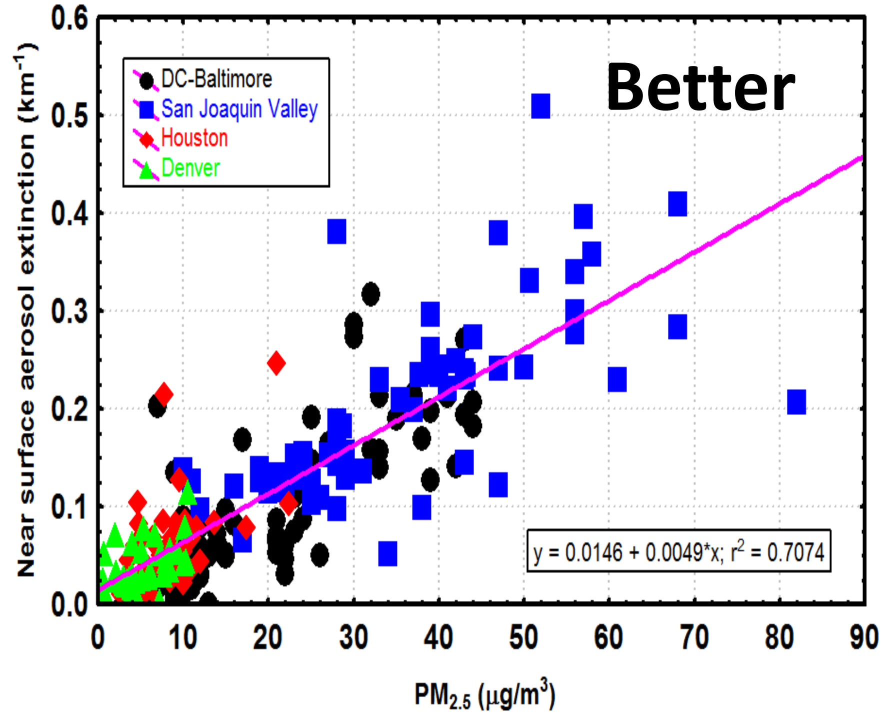
Correlation between HSRL AOT and $PM_{2.5}$

- In some cases, surface $PM_{2.5}$ can be inferred from measurements of AOT and height of the aerosol layer
- However, HSRL data show PM2.5 is much better correlated with near surface extinction than AOT scaled by aerosol layer or PBL heights

(HSRL AOT / ML height) vs. PM 2.5

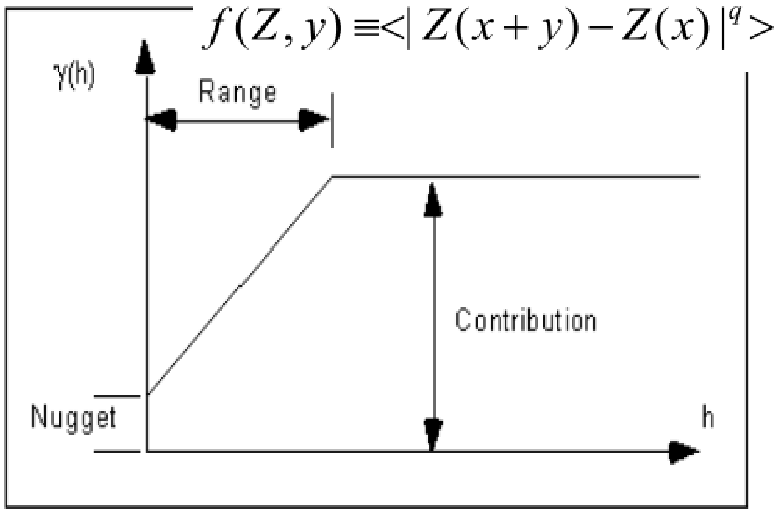


HSRL near-surface extinction (ambient RH) vs. PM 2.5



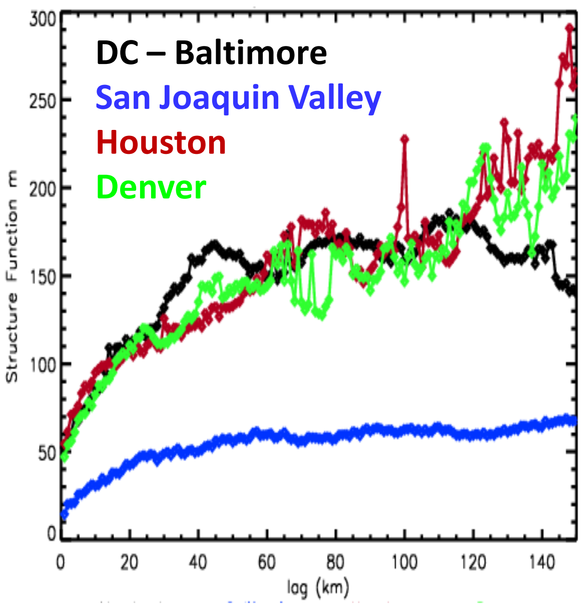
Spatial Variability

Spatial Variability of ML Height, AOT, Near-surface aerosol extinction

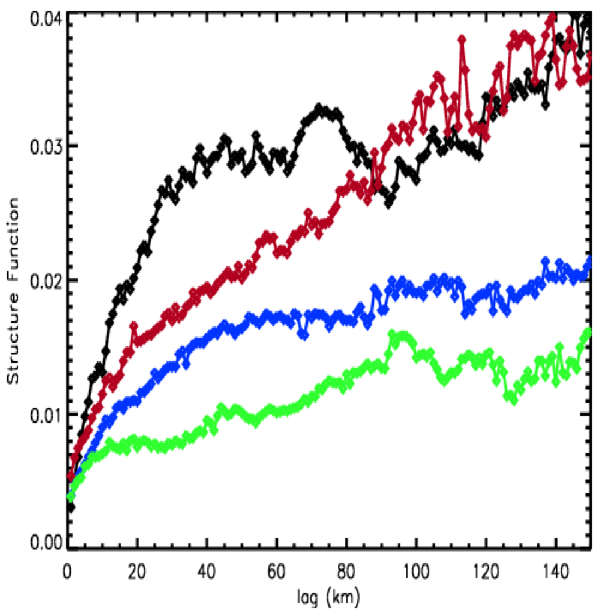


- First order structure function
- San Joaquin Valley had smallest variability in ML heights (shallow ML), but largest variability in near surface extinction
- AOT uncorrelated (range) after 40-80 km
- ML heights uncorrelated (range) after 40-60 km
- Near surface aerosol extinction uncorrelated (range) after 20-40 km

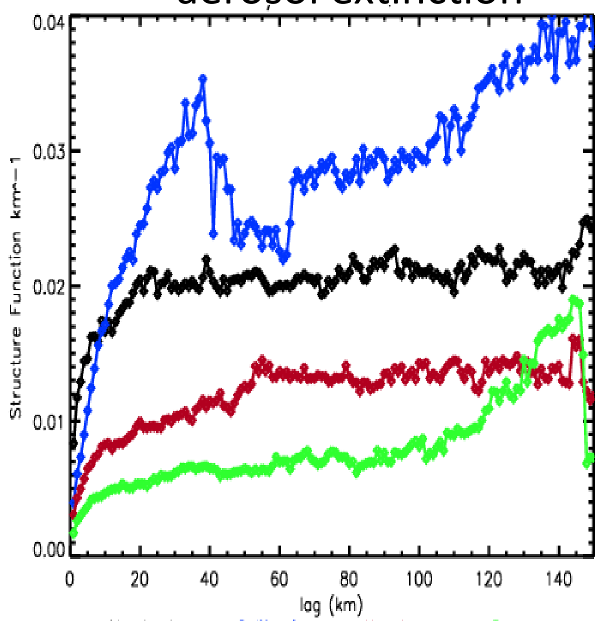
ML Height



AOT

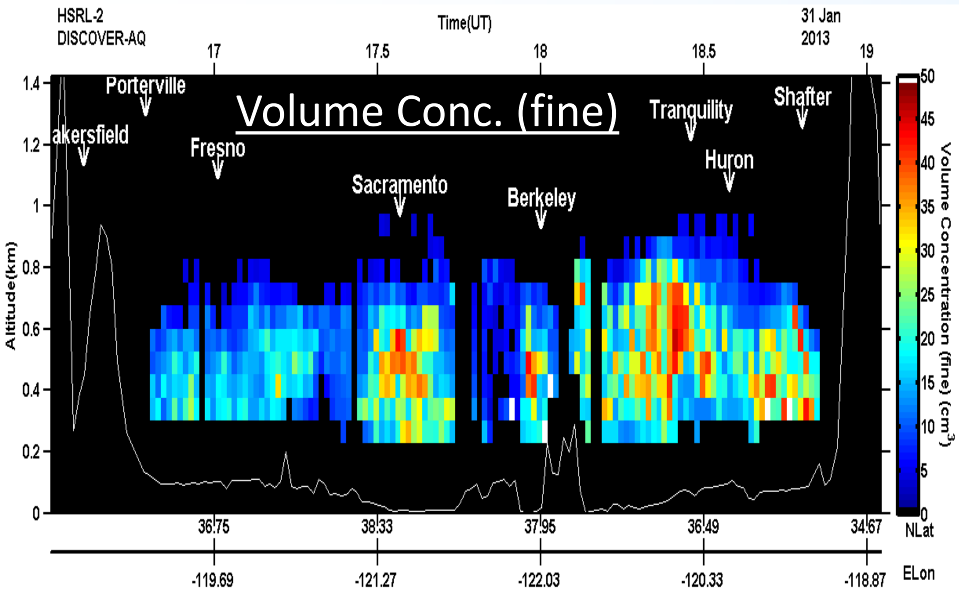


Near-surface aerosol extinction

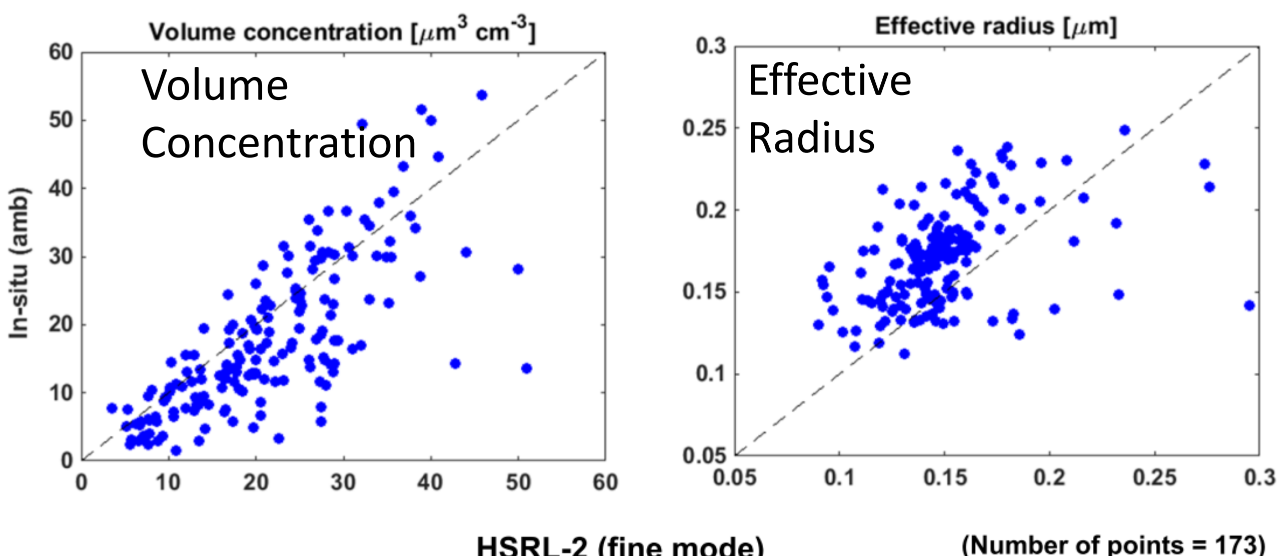


Multiwavelength Aerosol Retrievals and Surface $PM_{2.5}$

HSRL-2 Multiwavelength Aerosol Retrievals

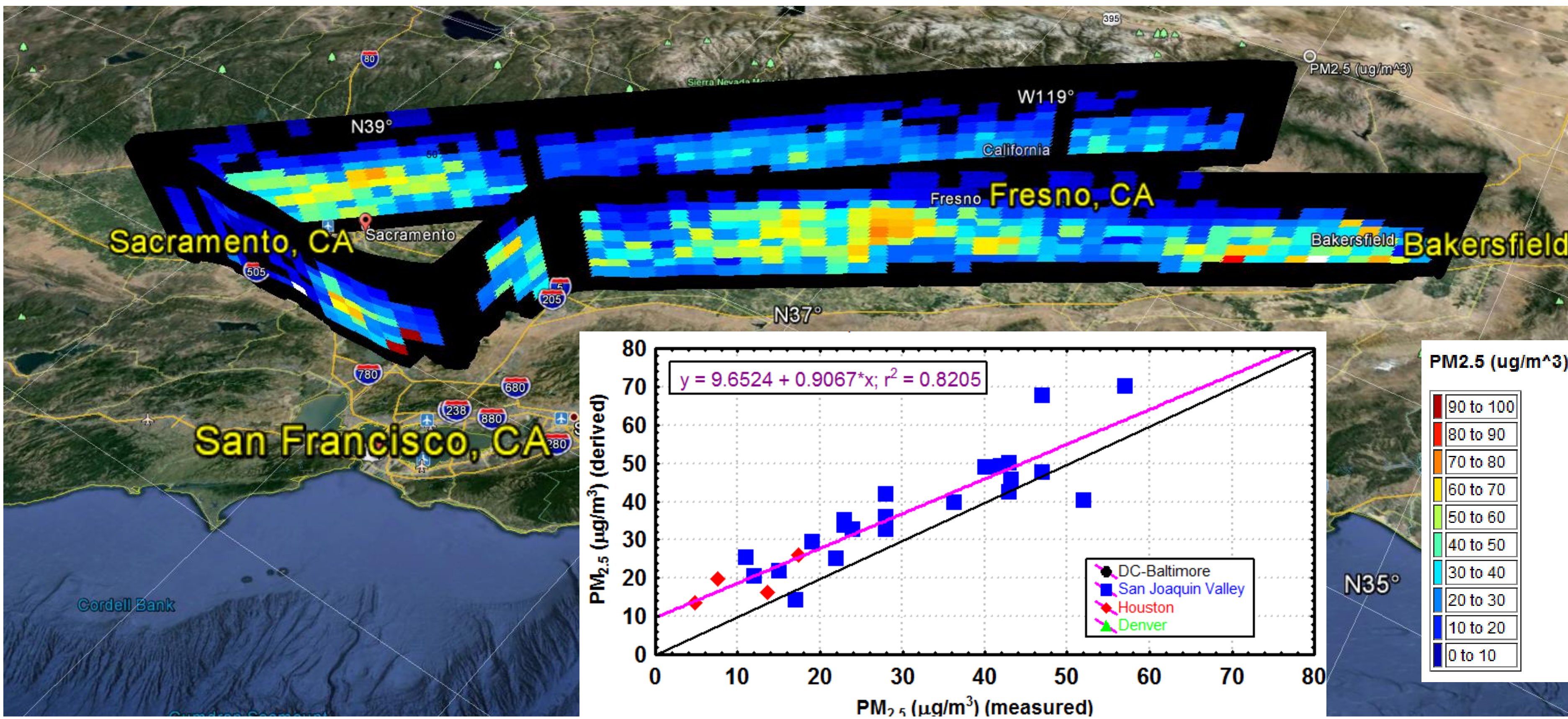


- HSRL-2 multiwavelength measurements of aerosol backscatter and extinction were used to retrieve fine mode aerosol volume concentration and effective radius (e.g. Müller et al., 2014) (see poster by Sawamura et al. for evaluation of these retrievals)
- Note changes in particle size and concentration in SJV
- Sawamura et al. poster shows the retrievals compare reasonably well with P-3 in situ data



HSRL-2 Retrieval of $PM_{2.5}$

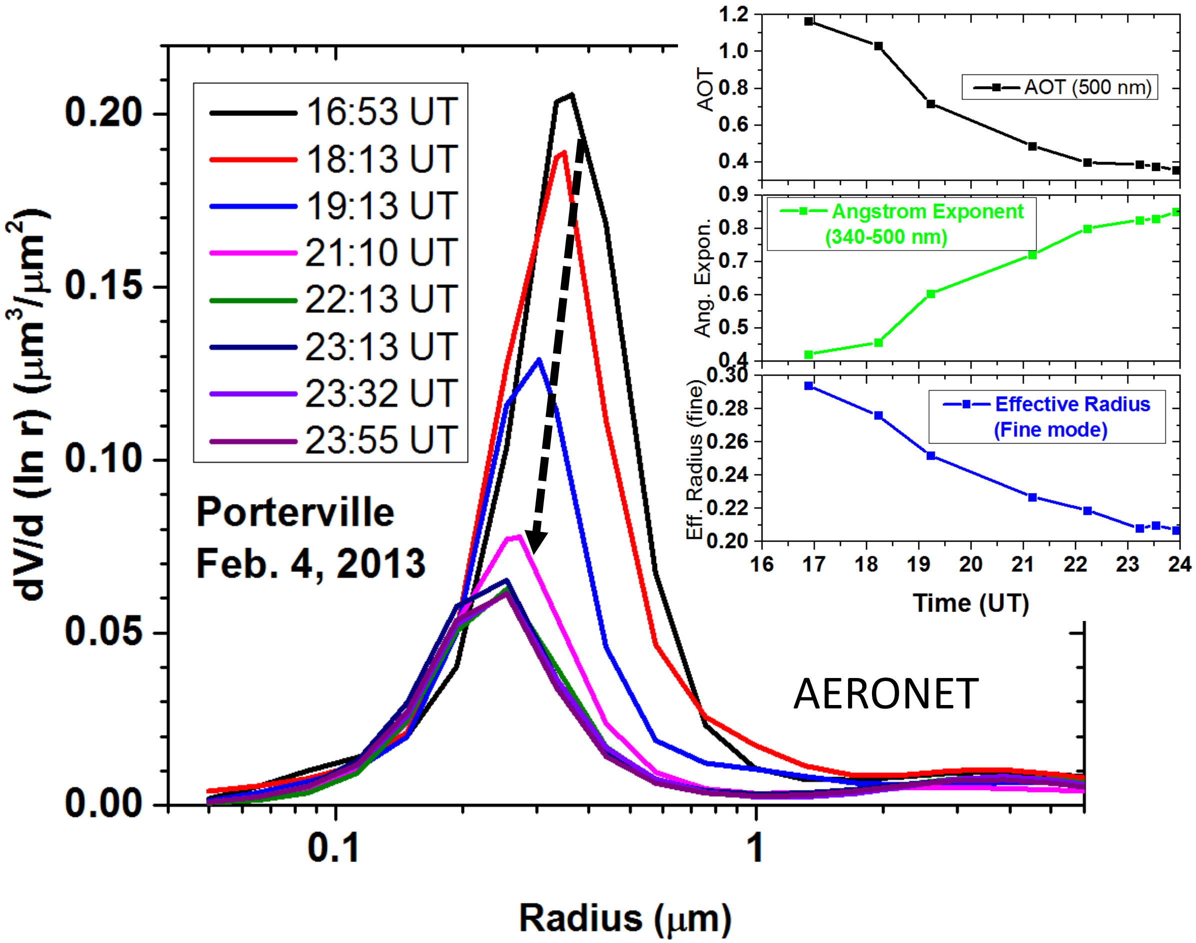
- HSRL-2 multiwavelength retrievals of fine mode volume concentration were used with assumed particle density of 1.65 g/cm^3 to derive $PM_{2.5}$ concentrations
- $PM_{2.5}$ near surface concentrations compare reasonably well with hourly values measured near the surface

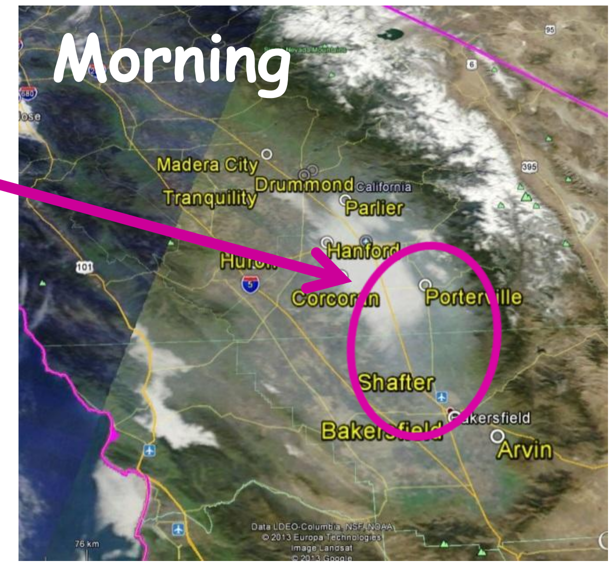


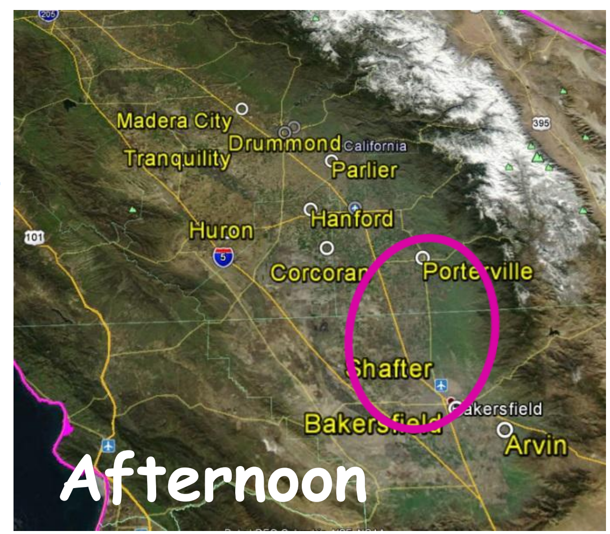
Multiwavelength Aerosol Retrievals Used to Investigate RH Effects

Decrease in fine mode particle size due to decrease in RH

- In his Fall 2013 AGU presentation, Tom Eck noted the decrease in AOT and fine mode size over the southern portion of DRAGON on Feb. 4
- This decrease occurred as fog processed and/or humidified aerosols transitioned to dried aerosol

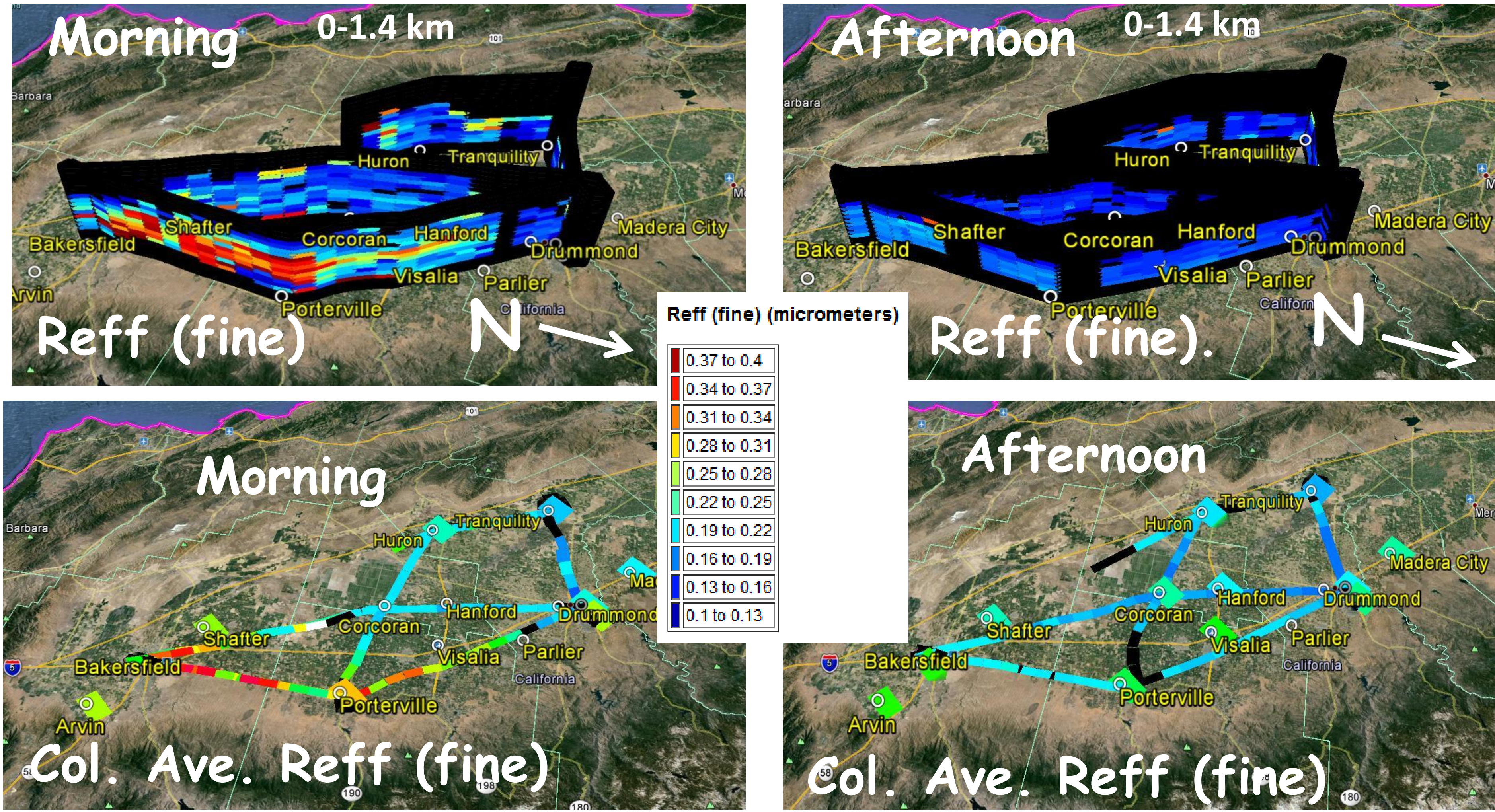






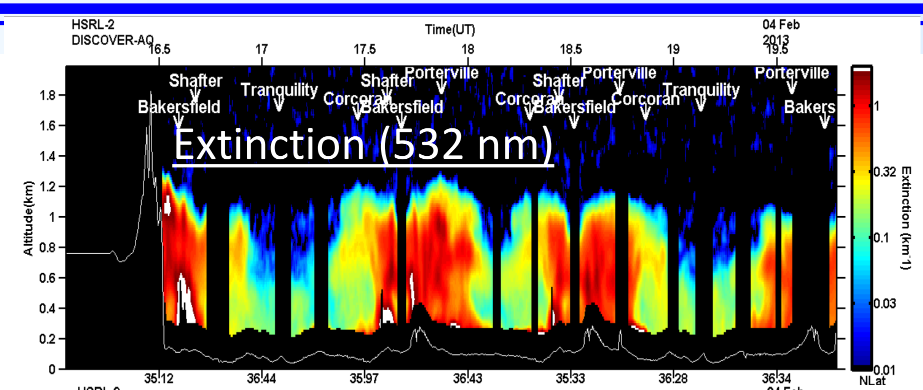
HSRL-2 reveals temporal, horizontal, and vertical variability in fine mode effective radius

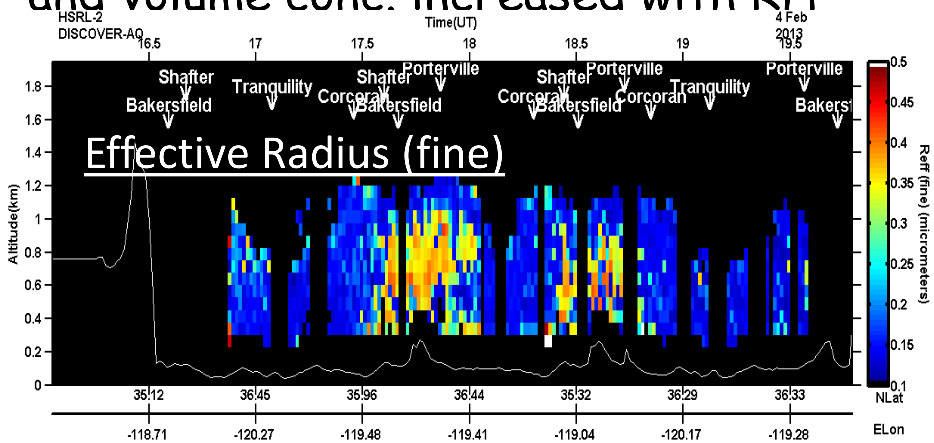
- Morning – Larger fine mode aerosols over southeastern portion (Porterville, Bakersfield)
- Afternoon – Decrease in fine mode particle size over southeast as RH decreased
- Northwestern portion (Tranquility) – consistently smaller fine mode particles associated with lower RH

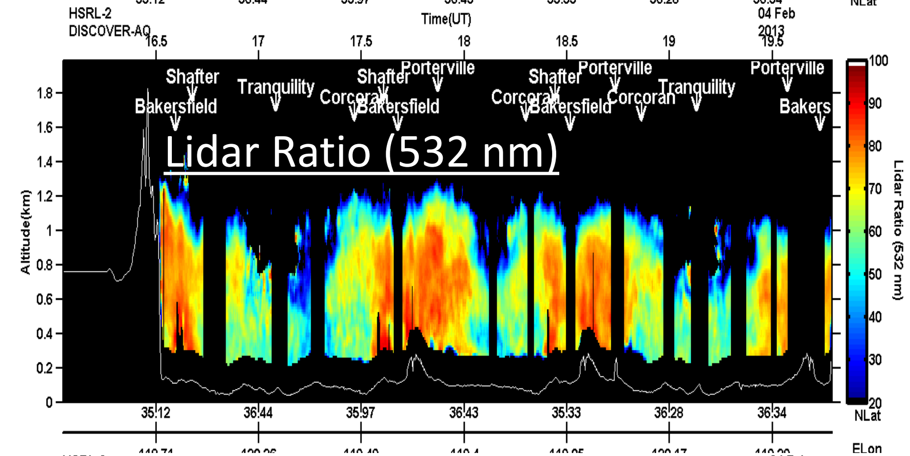


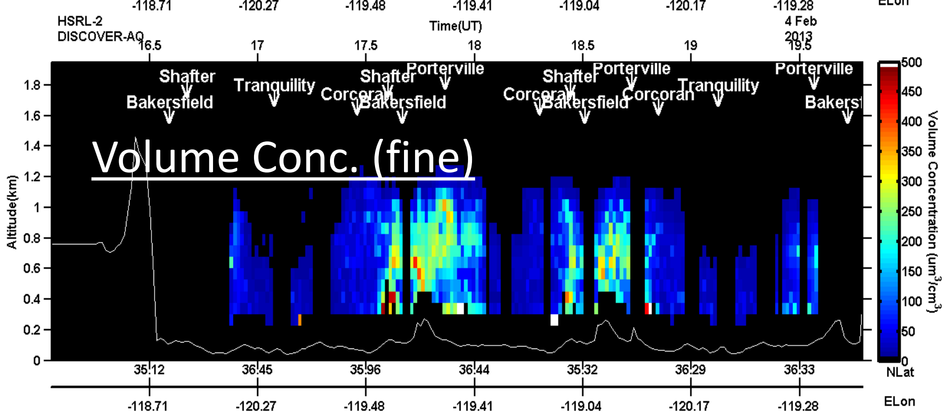
RH Impacts on Aerosol Optical and Microphysical Properties

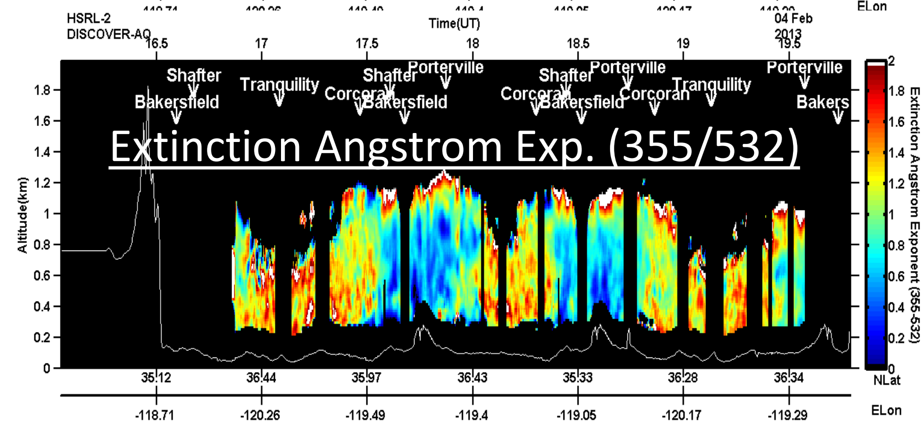
- Extinction and lidar ratio also increased with high RH
- Extinction Angstrom exponent (355-532) decreased with RH
- Retrieved fine mode effective radius and volume conc. increased with RH





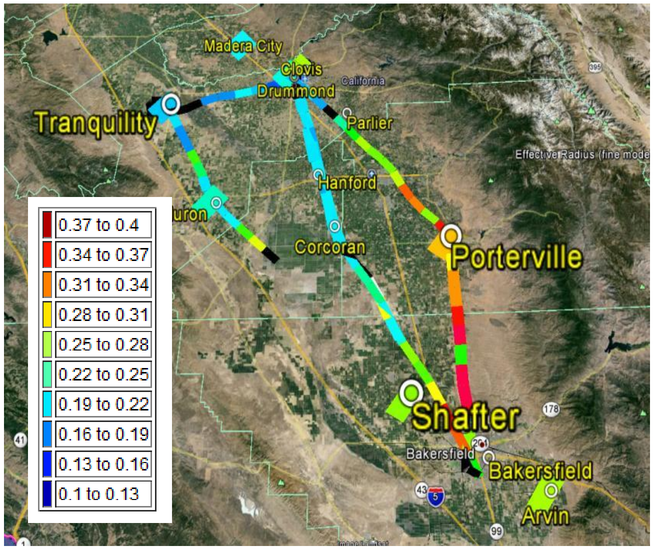




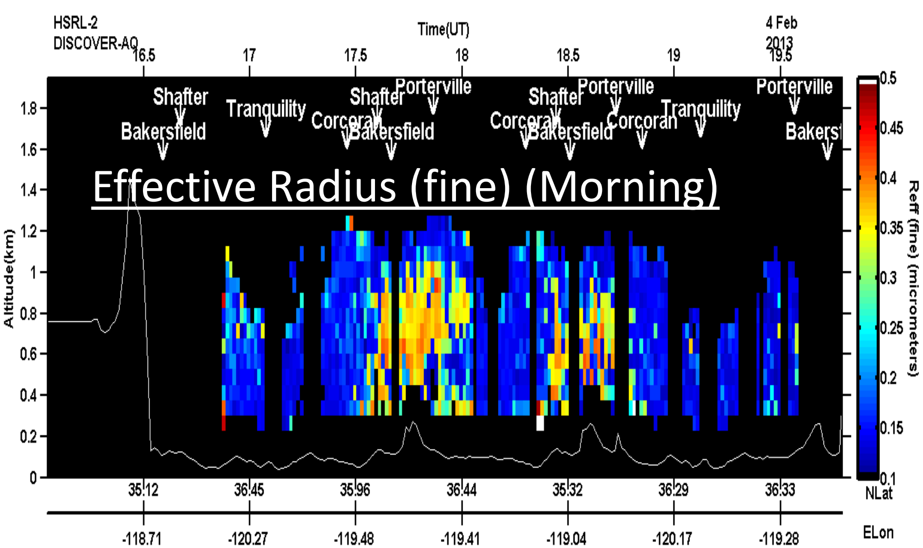


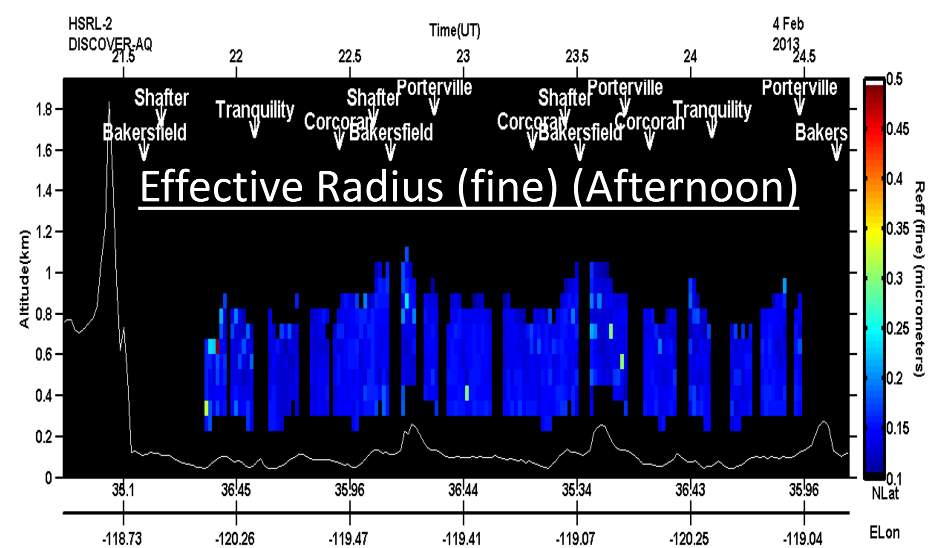
Temporal and spatial variability in column average fine mode effective radius

Column Average Reff (fine)



- Highest RH occurred over the southeastern portion (Porterville, Shafter) and this RH decreased with time
- Consequently, fine mode particle size was largest the southeastern portion and decreased with time
- Both HSRL-2 and AERONET found:
  - Decrease in fine mode effective radius associated with decrease in RH over the southeastern portion
  - No change in particle size over the northwestern portion where RH was lower





Summary

- Height of the maximum aerosol gradient (which we call aerosol layer height) is a better measure of scale height than PBL height
- HSRL data show PM2.5 is better correlated with near surface extinction than AOT scaled by aerosol layer or PBL heights
- With exception of San Joaquin Valley, median profiles show that about only about 20-65% of AOT was within mixed layer; much of AOT was above mixed layer
- In San Joaquin Valley, most (>80%) of AOT was within mixed layer
- $PM_{2.5}$ near surface concentrations derived from HSRL multiwavelength aerosol measurements compare reasonably well with hourly values measured near the surface
- High RH can have dramatic impacts on aerosol optical and microphysical properties