Aerosol characterization using airborne HSRL and some applications

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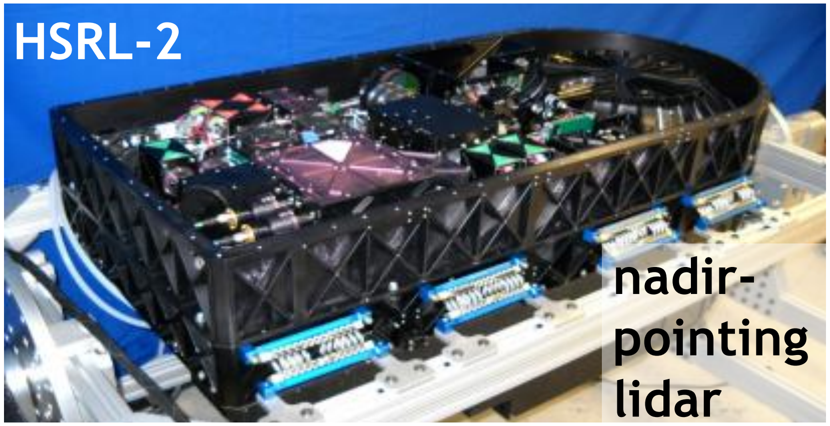
High Spectral Resolution Lidar, HSRL-2



High Spectral Resolution Lidar 2—

- measures aerosol extinction at 355 nm and 532 nm, backscatter and depolarization at 3 wavelengths
- flown on four field missions so far (B200)
- next mission ORACLES (ER-2)
- follow-on instrument to HSRL-1, >20 field missions

Uses —

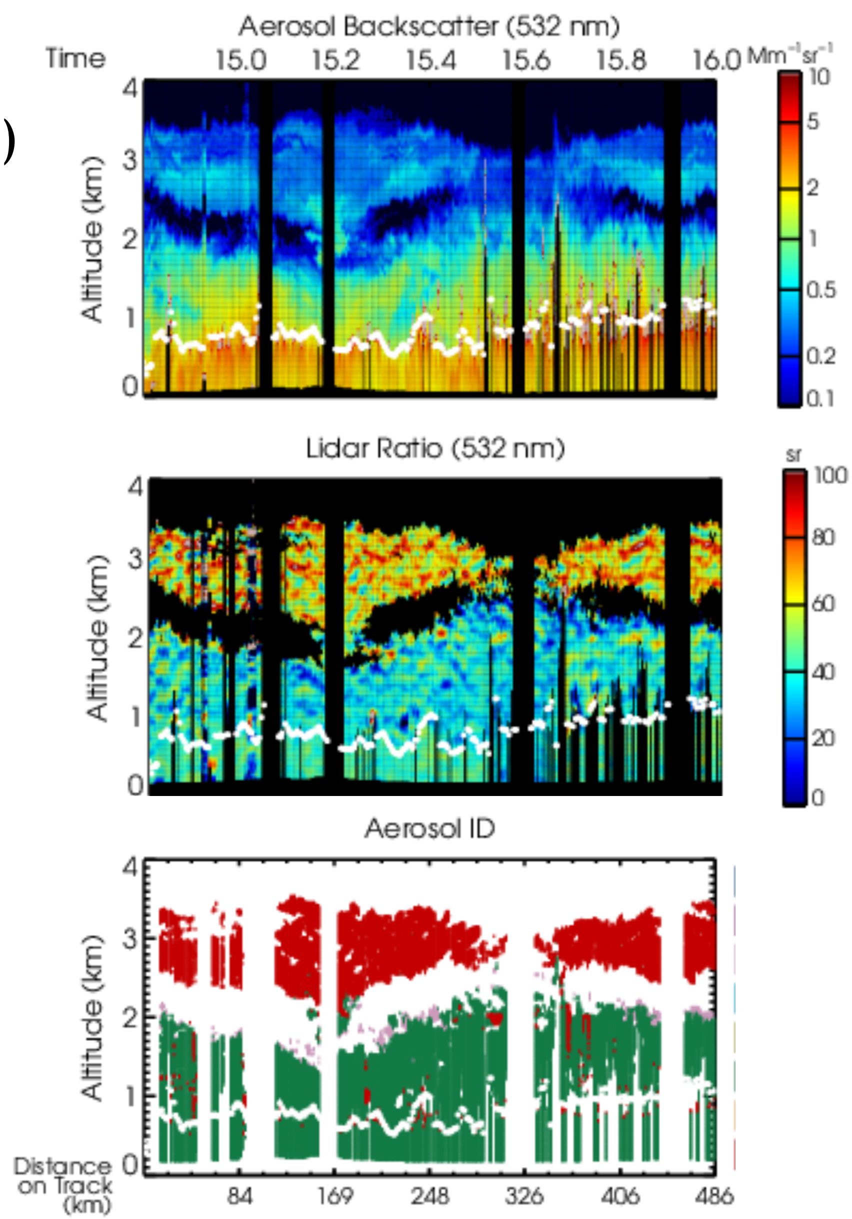
- Satellite Validation
- Testbed for future space instruments and retrievals
- Overview and context during field missions
- Input to and validation of models

HSRL-2 measurements

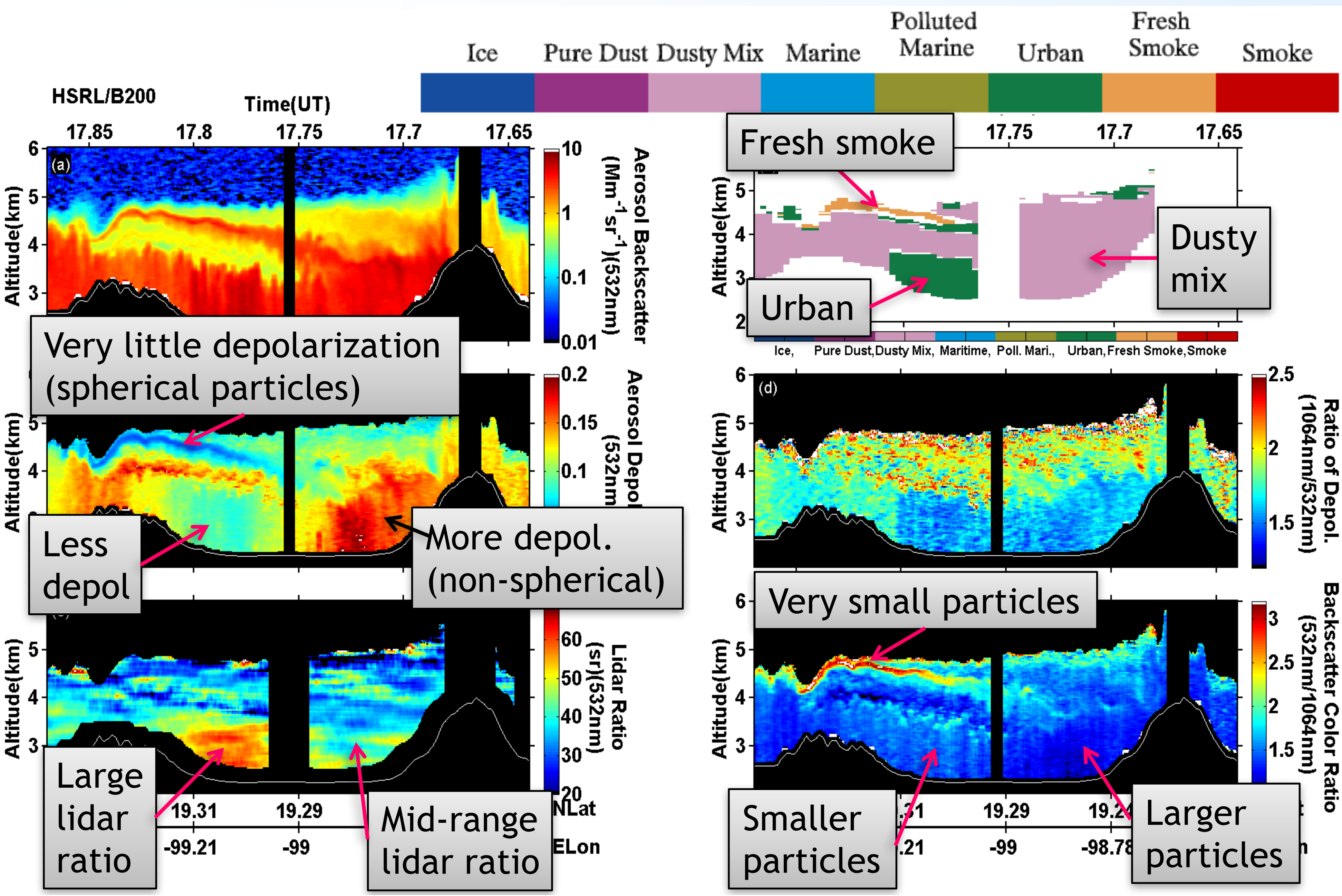
- Measurement products:
  - Aerosol extinction (355, 532 nm)
  - Aerosol backscatter (355, 532, 1064 nm)
  - Particle depolarization (355, 532, 1064)
  - Lidar ratio (355 nm, 532 nm)
  - Color ratios/Angstrom exponents
  - Aerosol typing
  - Aerosol mixed layer height

- Benefit of lidar over passive: vertically resolved measurements. Information about aerosol layer heights, vertical distribution.

- Benefit of HSRL over elastic backscatter: quantitative aerosol extinction, more information content relevant to aerosol type

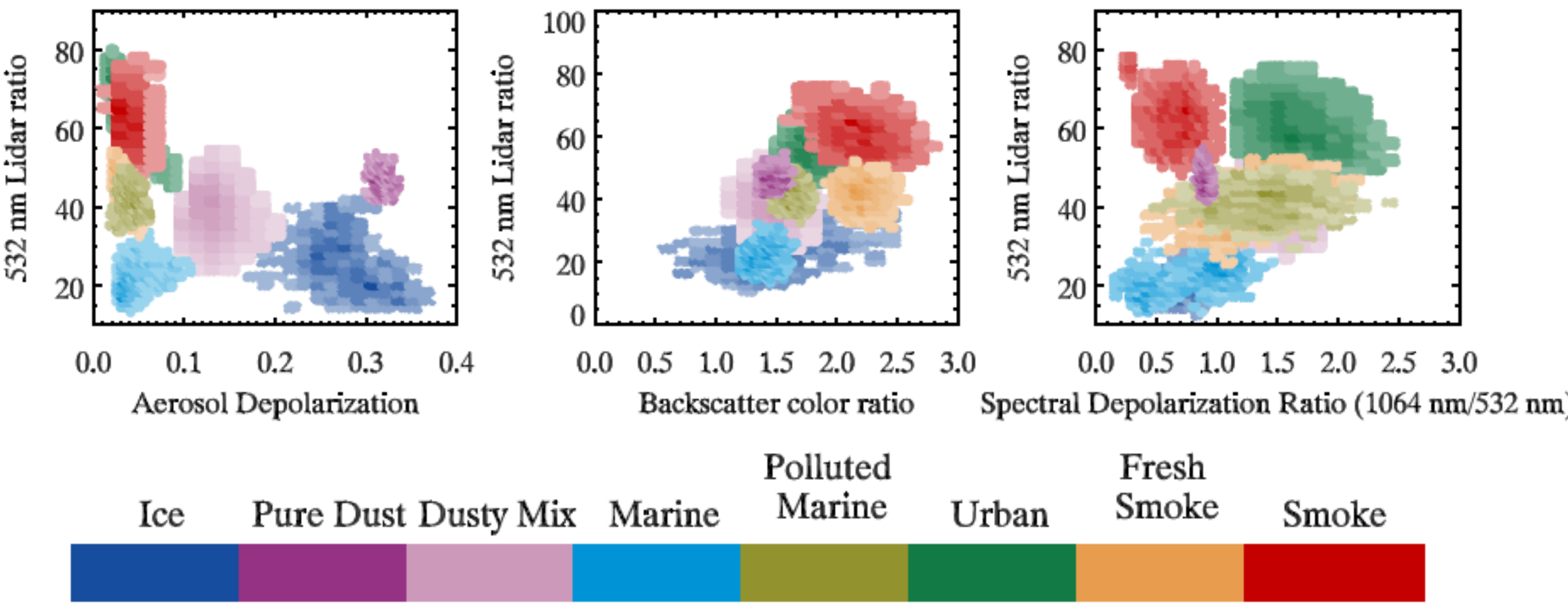


Classification Example – Mexico City



HSRL aerosol types

- Four dimensions = aerosol intensive properties
- Semi-supervised classification in 4D using labeled samples

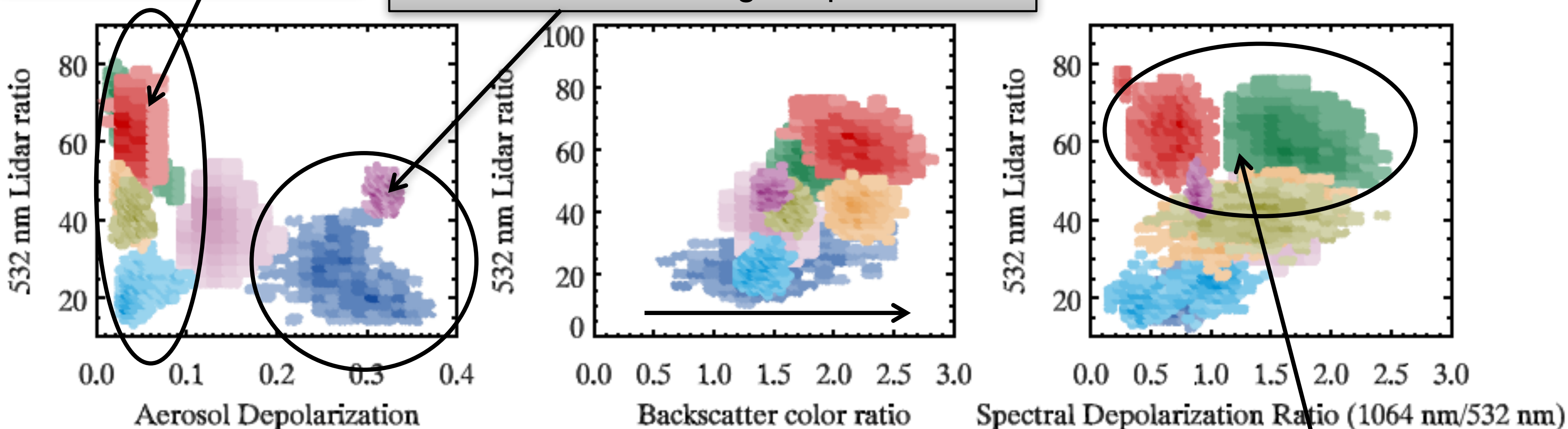


See also: Burton et al. "Aerosol classification of Airborne High Spectral Resolution Lidar Measurements – Methodology and Examples", *AMT* 2012

HSRL aerosol types

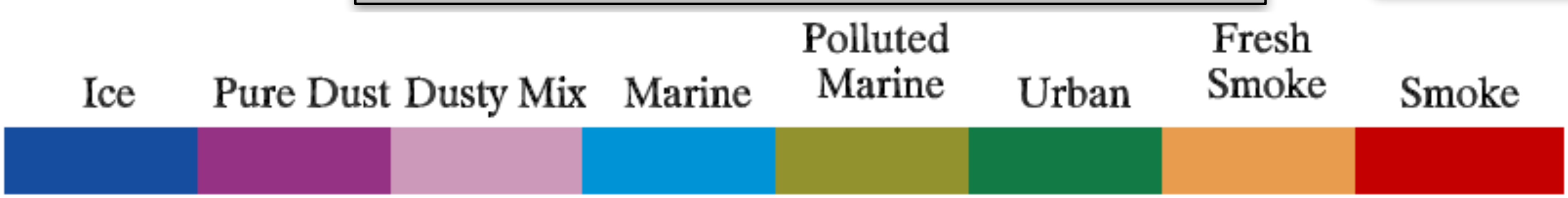
Lidar ratio: large for smoke and urban, small for marine

Dust & Arctic Ice – high depolarization

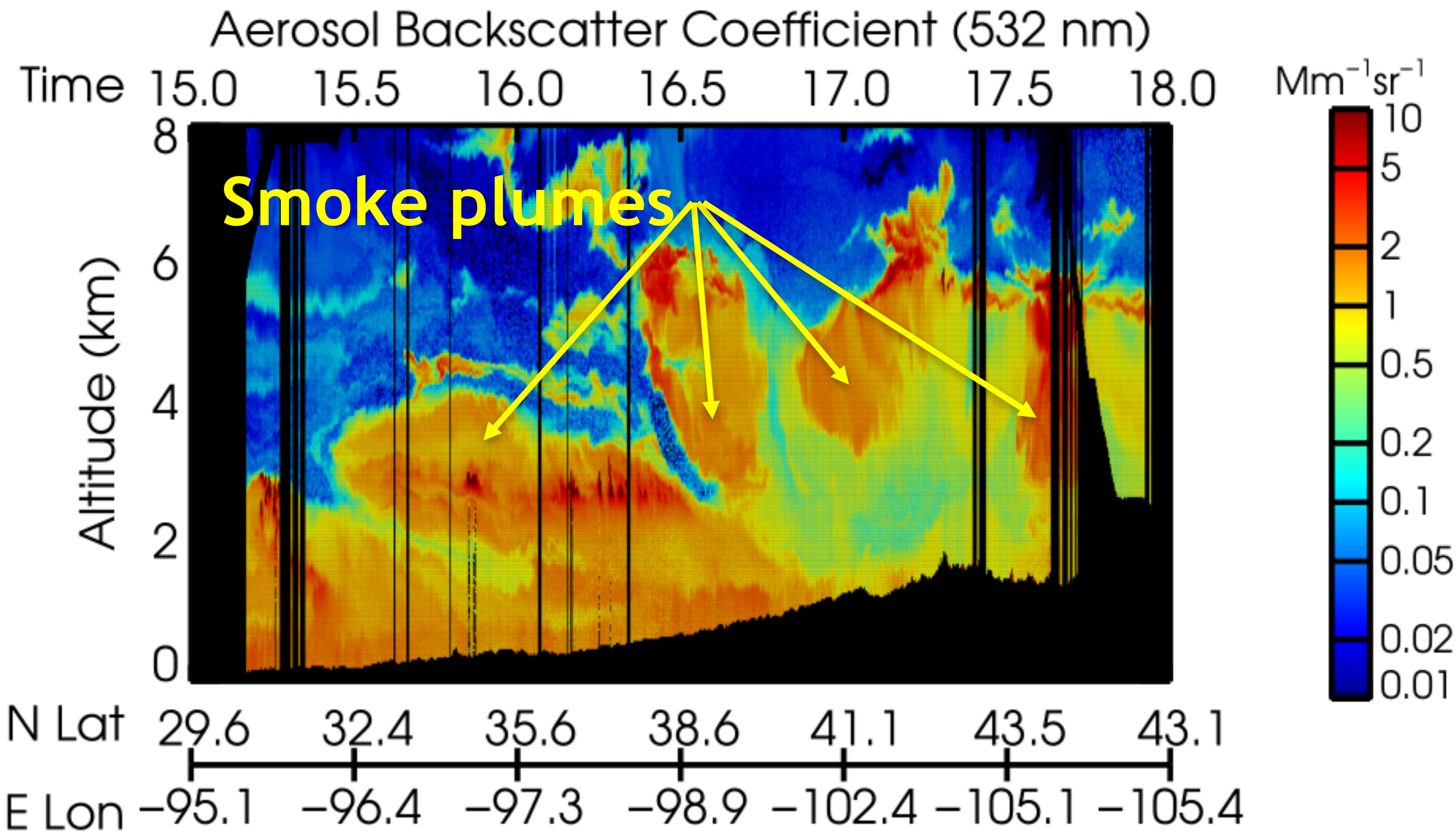


Backscatter color ratio varies with particle size: (marine & dust = large particles; smoke & urban = small particles)

Spectral ratio of depol separates smoke and urban

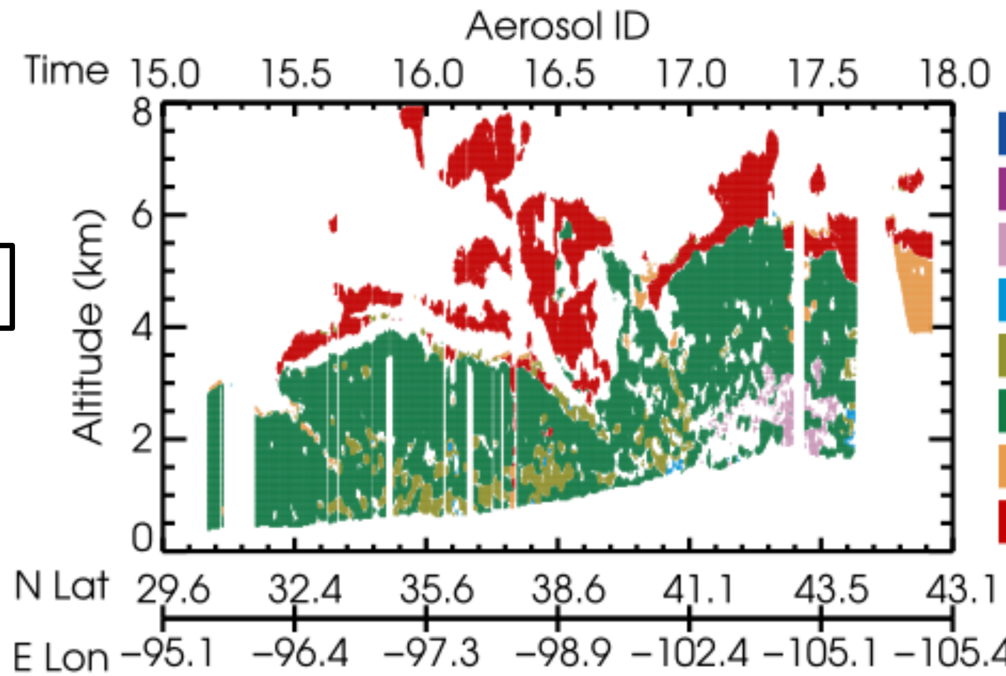


August 19, 2013 SEAC4RS Smoke Case

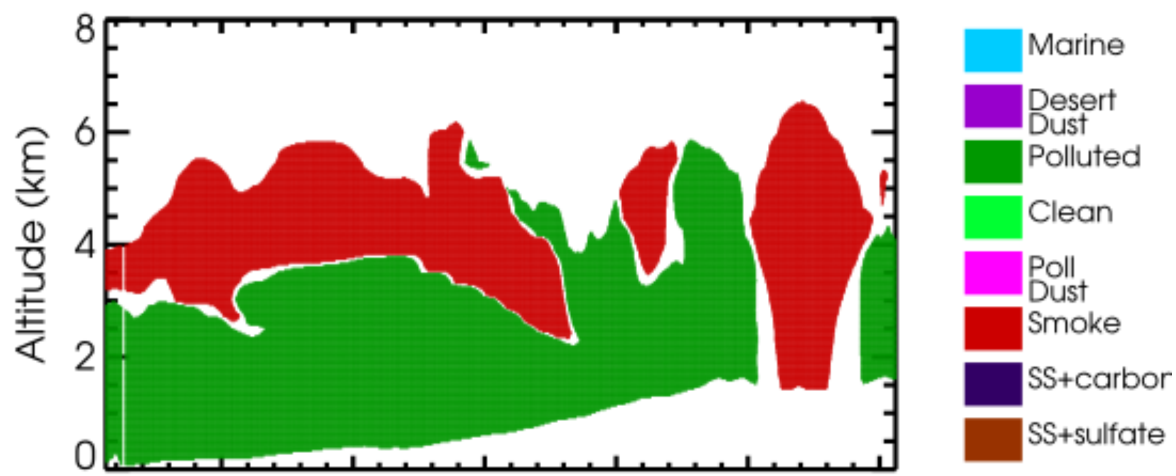


HSRL-DIAL and GEOS-5 Type Comparison

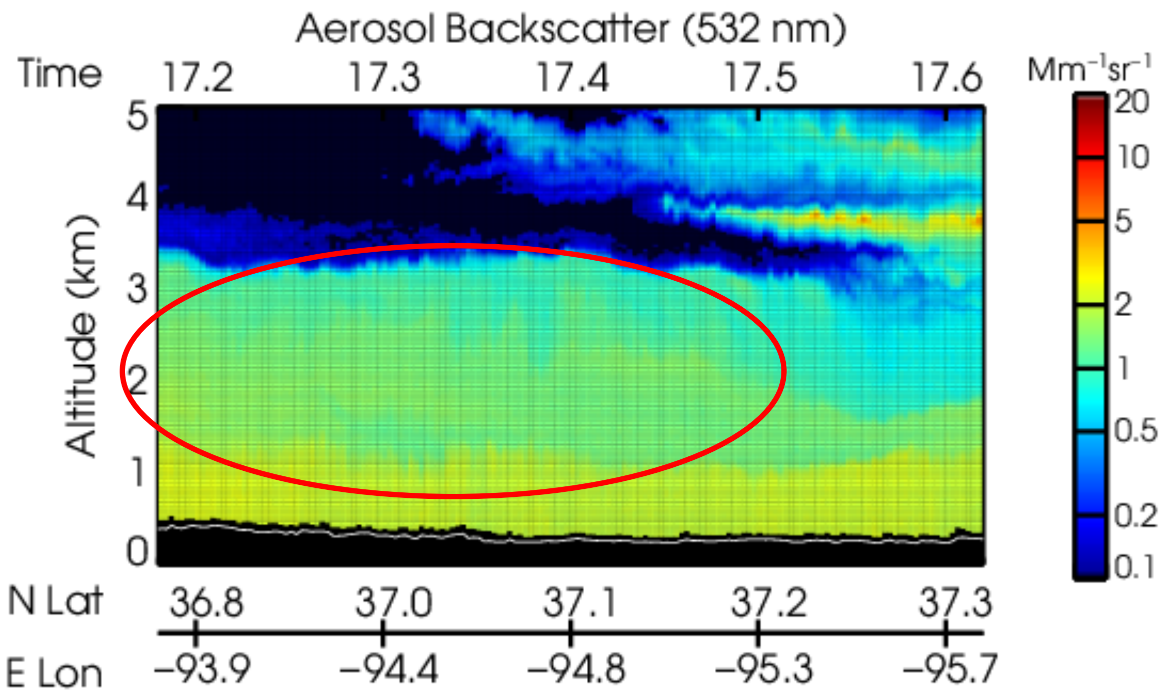
HSRL-DIAL aerosol type



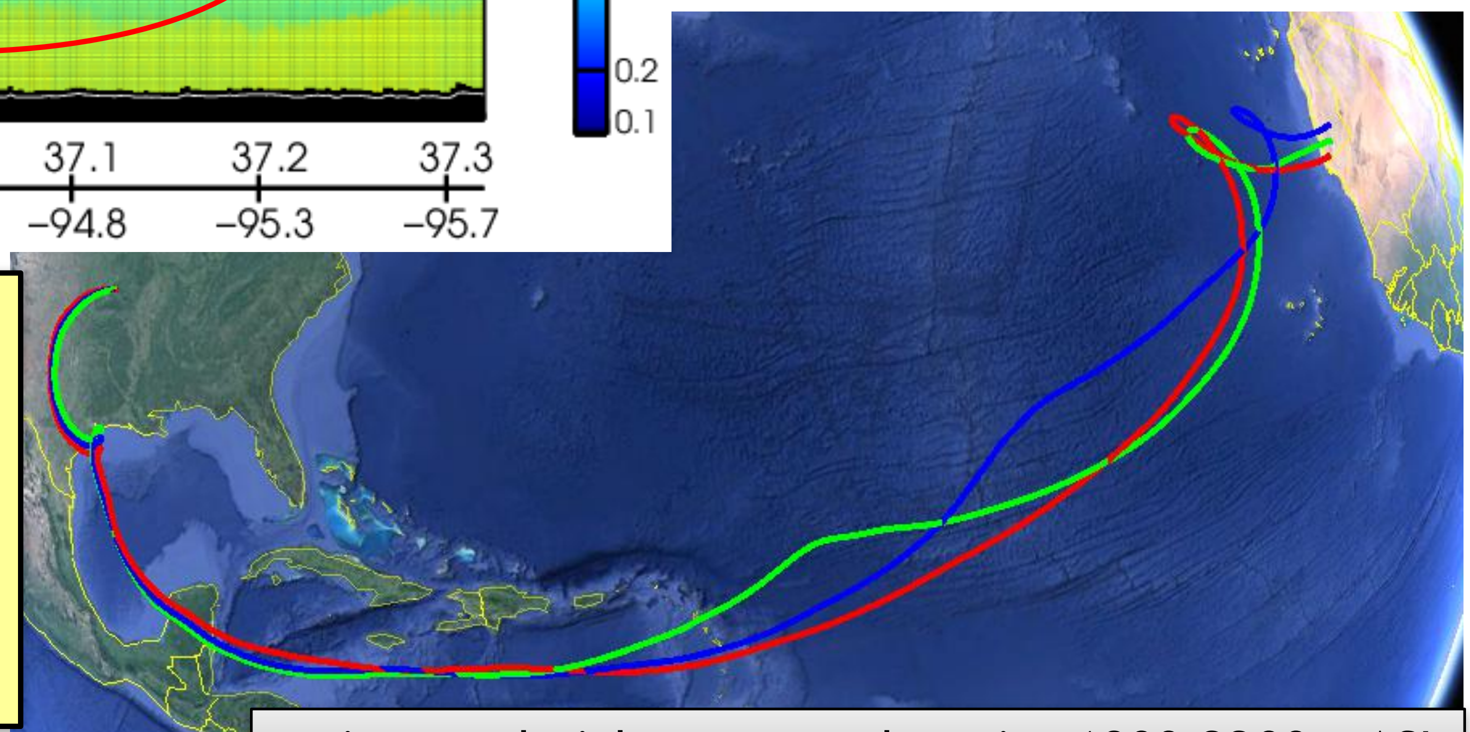
GEOS-5 aerosol species converted to type using method of *Nowottnick et al*. 2015



A Tale of Two Dust Layers
1. Transported Saharan dust



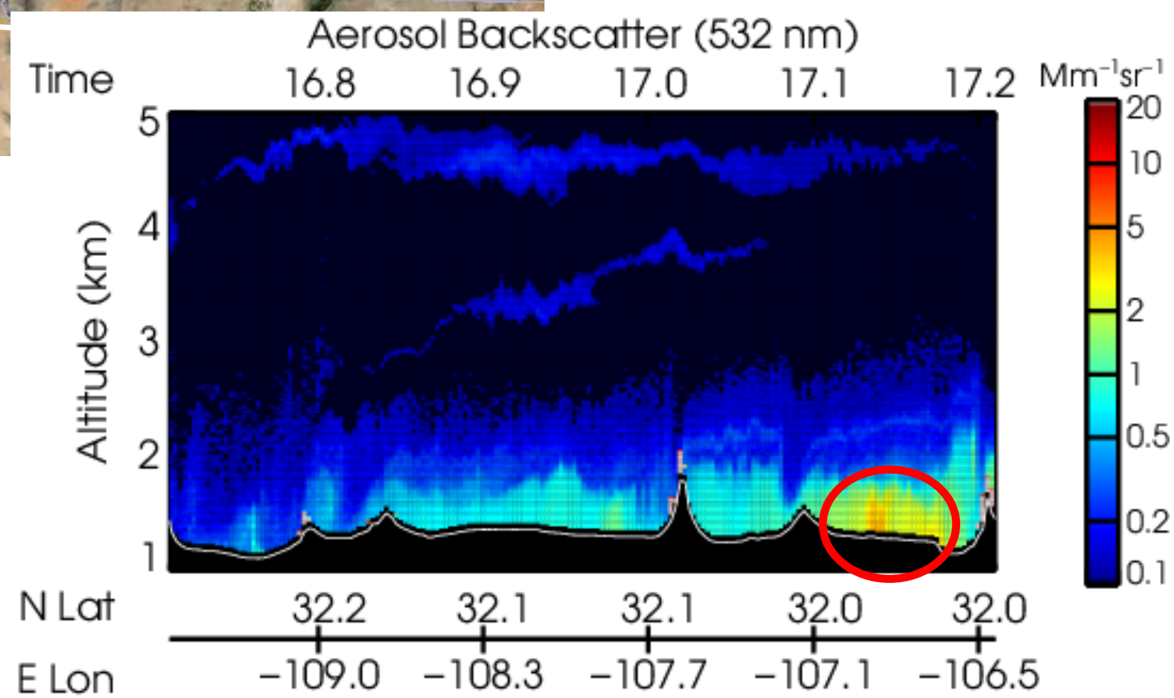
Observed **July 13, 2014** by HSRL-2 in Missouri and Kansas, probably Saharan origin and transported approximately 14 days.



trajectory heights at sample point 1800-2200m ASL

Observations of the spectral dependence of linear particle depolarization ratio of aerosols using NASA Langley airborne HSRL-2
Burton et al. *ACP 2015*

2. Chihuahuan desert, dust at the source



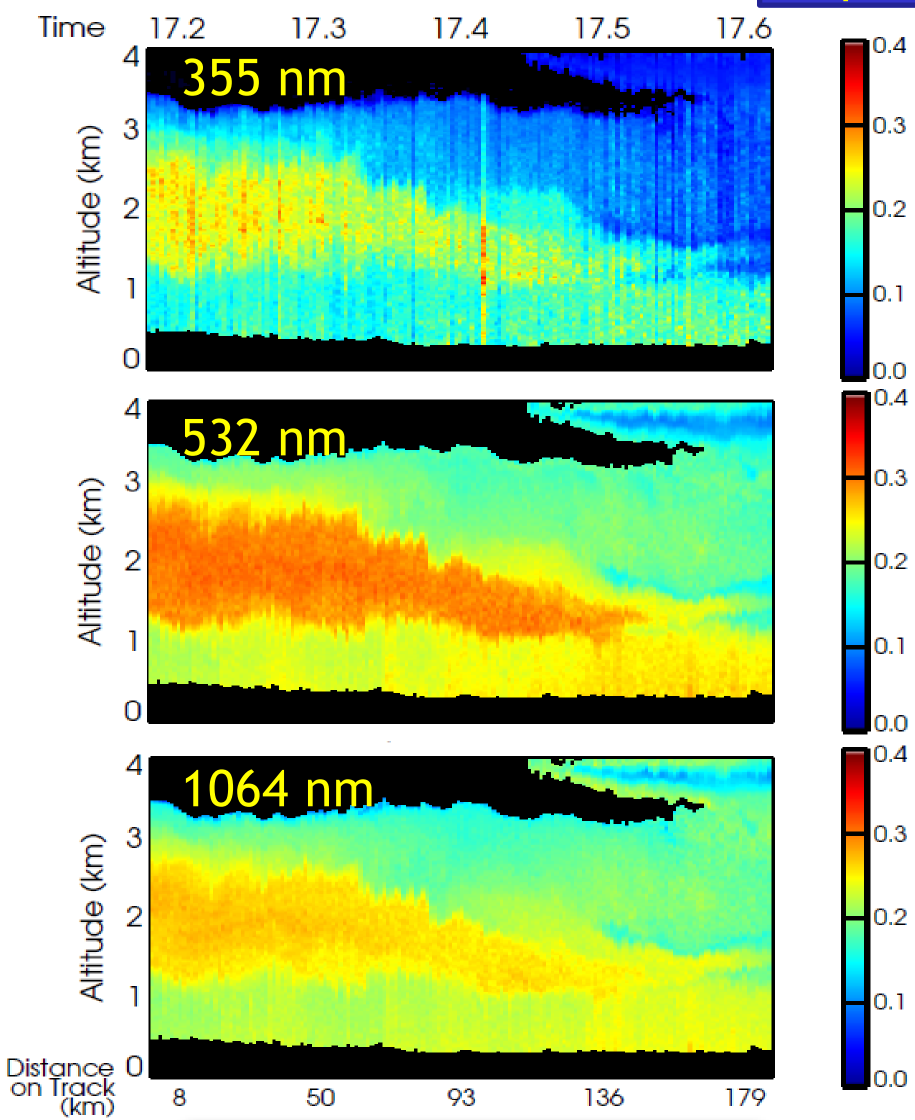
February 8, 2013

- Chihuahuan desert in southern New Mexico
- Low altitude and concentrated backscattering imply observation is close to the source.

Linear particle depolarization ratio at 3 wavelengths measured by HSRL-2

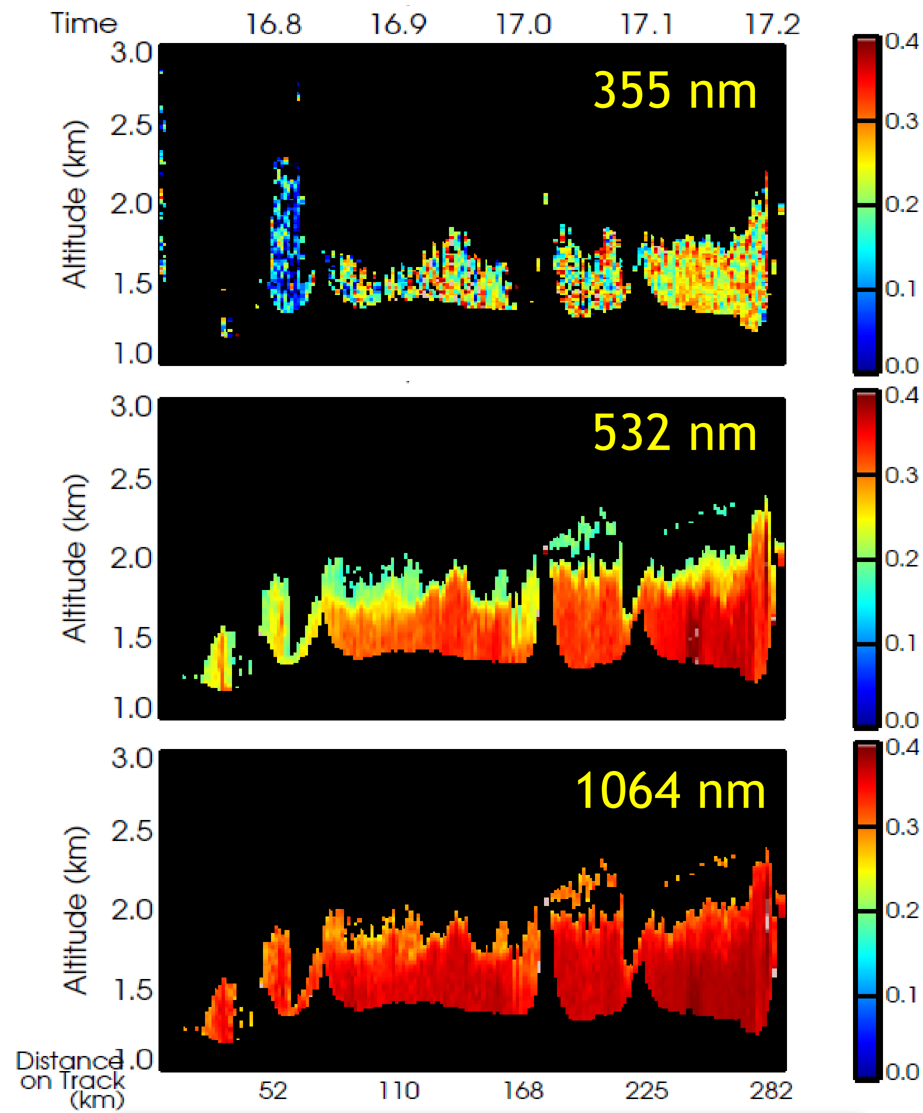
Linear Particle Depolarization Ratio

Transported Saharan dust



peak of **0.30** at **532 nm**

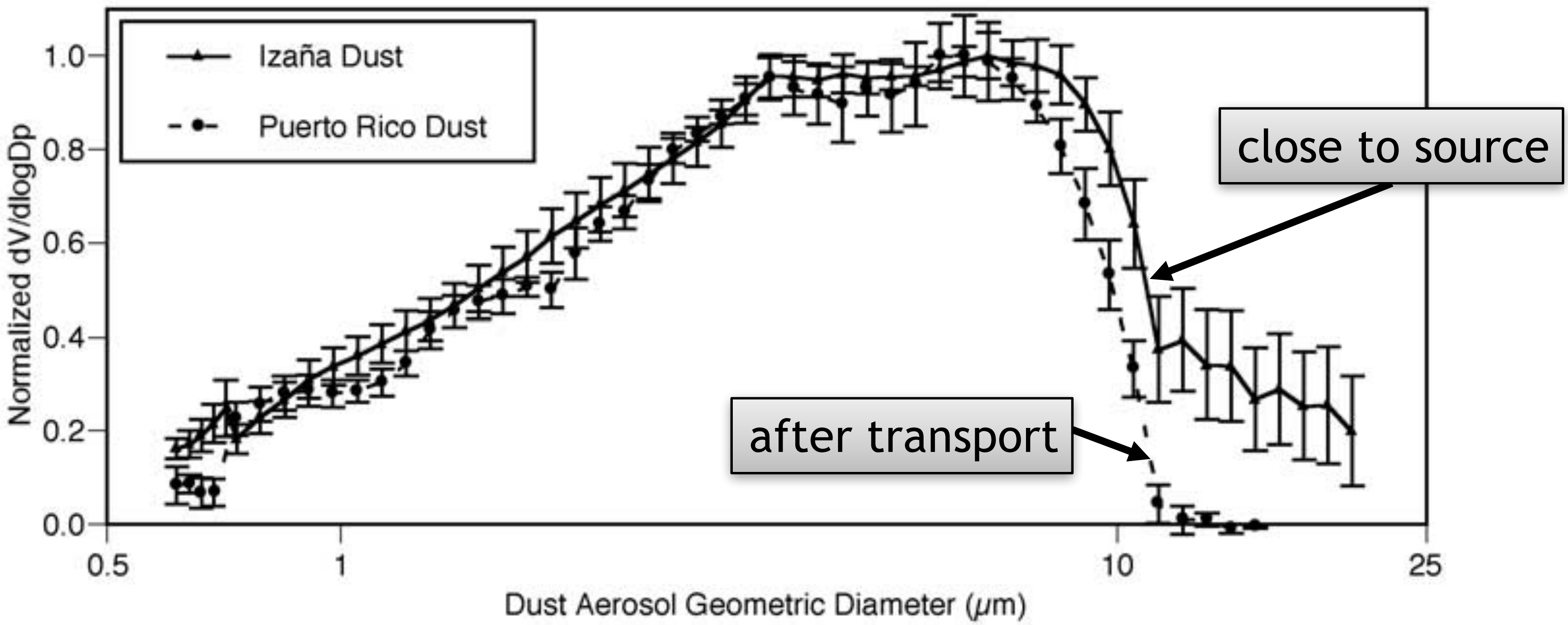
Local Dust



largest values **0.38** at **1064 nm**

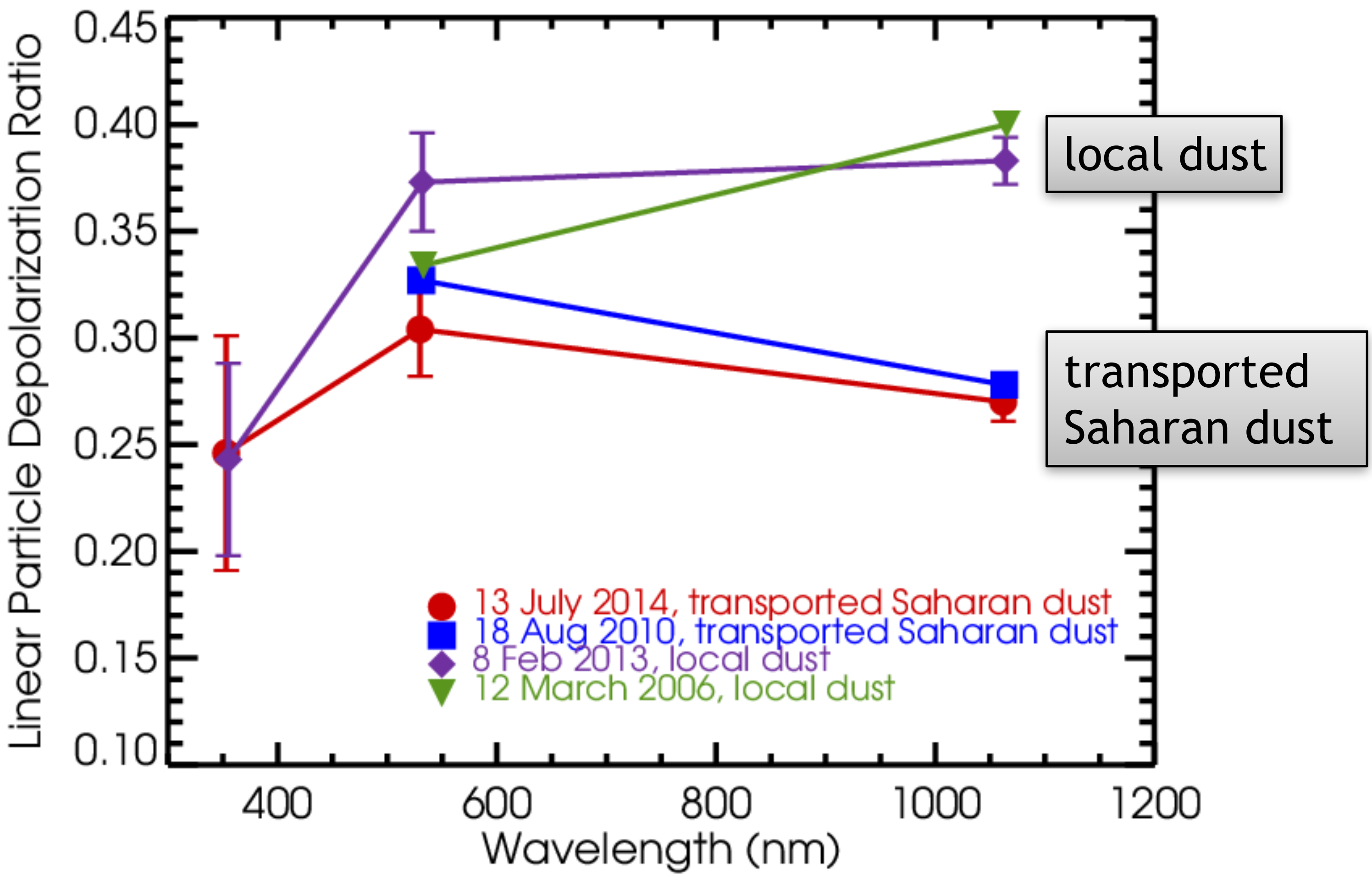
Particle size and transport

- Dust particle size distribution loses largest particles during transport
  – Maring, et al.: "Mineral dust aerosol size distribution change during atmospheric transport", *JGR*, 2003

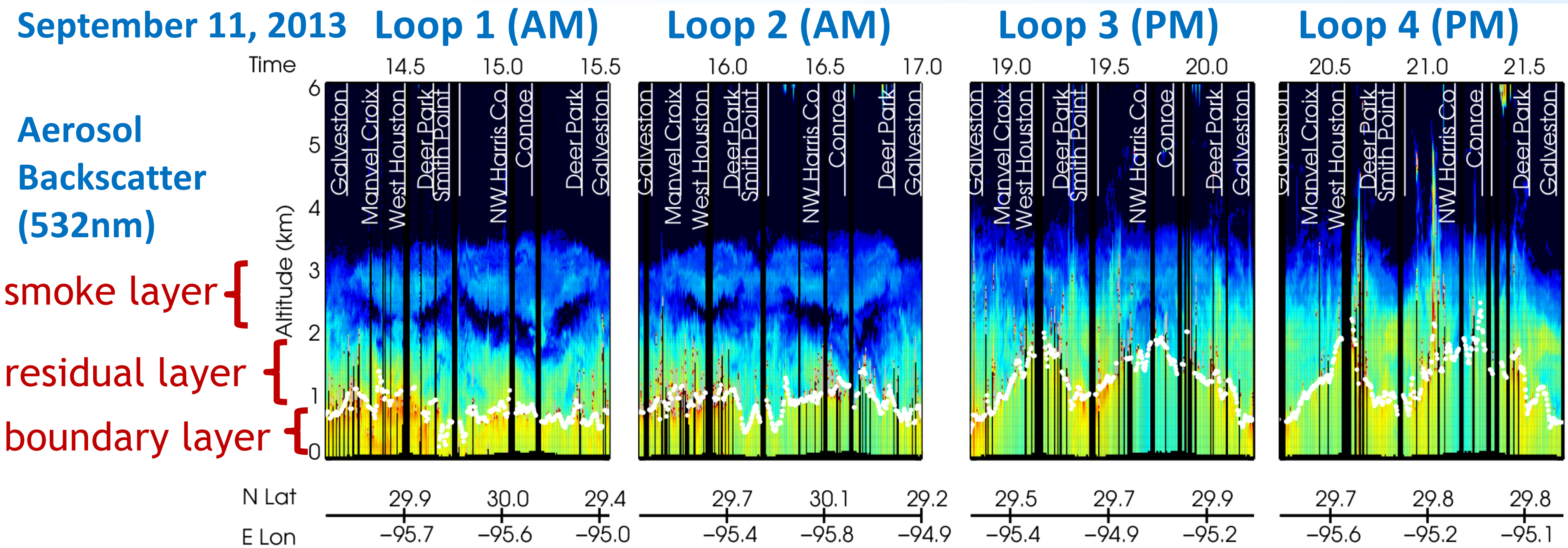


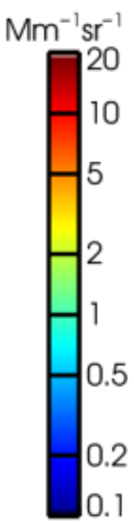
Dust depolarization wavelength dependence

- Both HSRL-2 dust cases have analogs in HSRL-1 record (2 wavelengths)
- Transported Saharan dust: peak at 532 nm
- Local dust: increasing spectral dependence
- Likely conclusion: larger particles present in the local cases

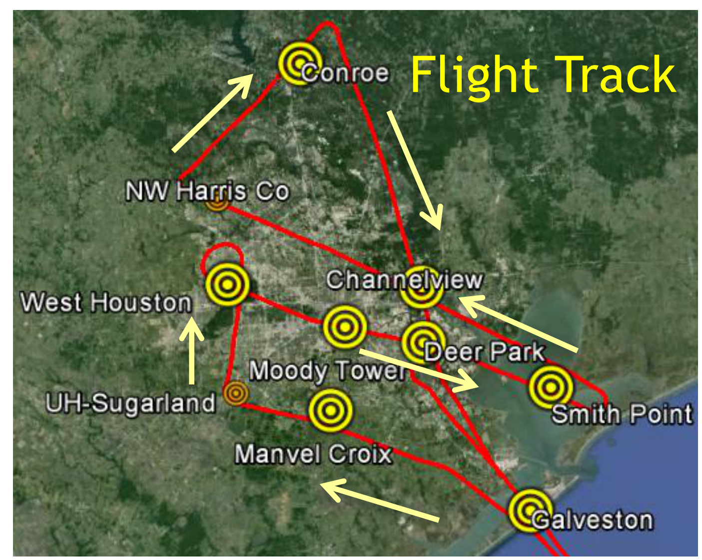


Case study: HSRL-2 observations of aerosol layers September 11, 2013, Houston TX

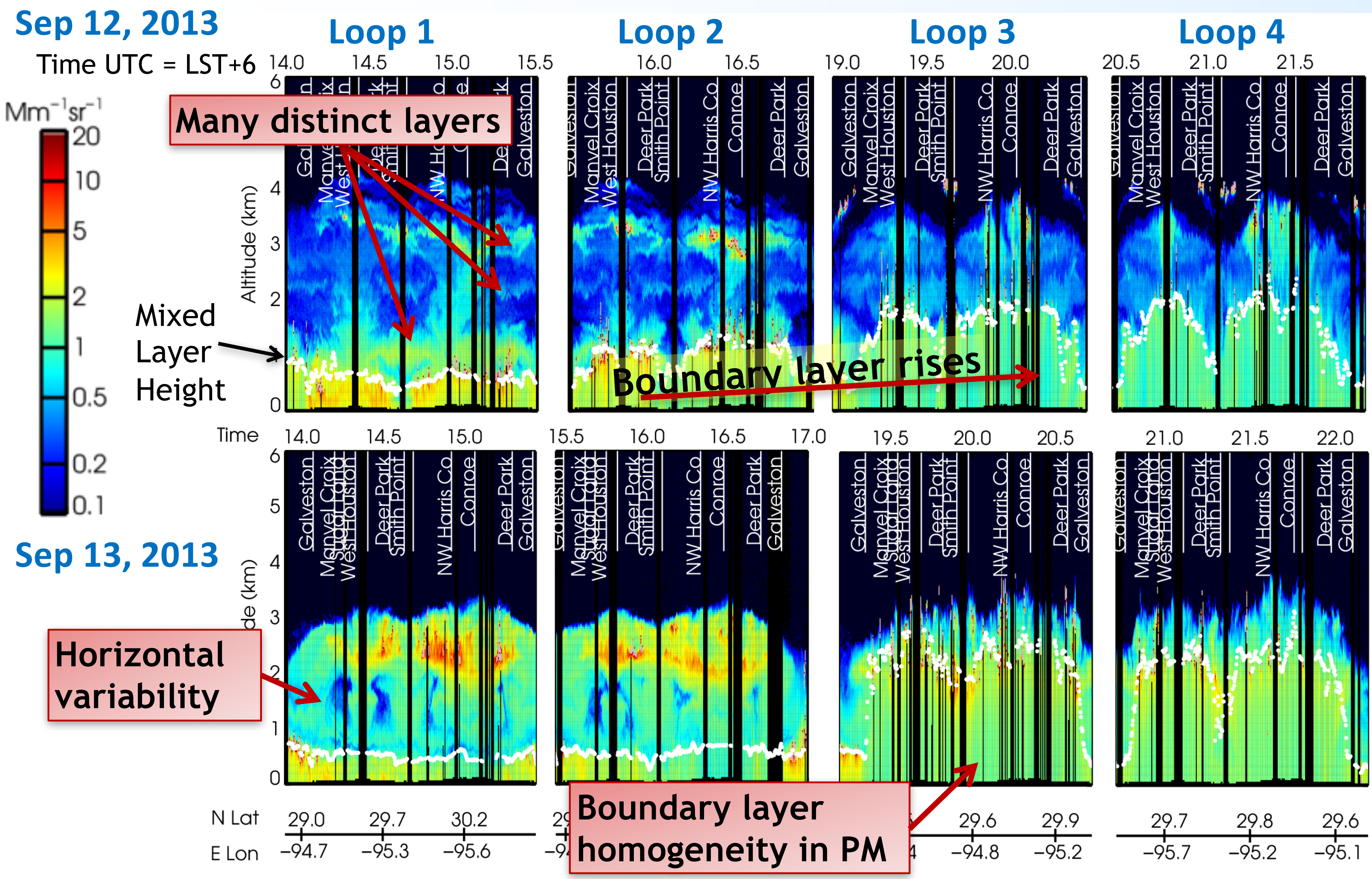




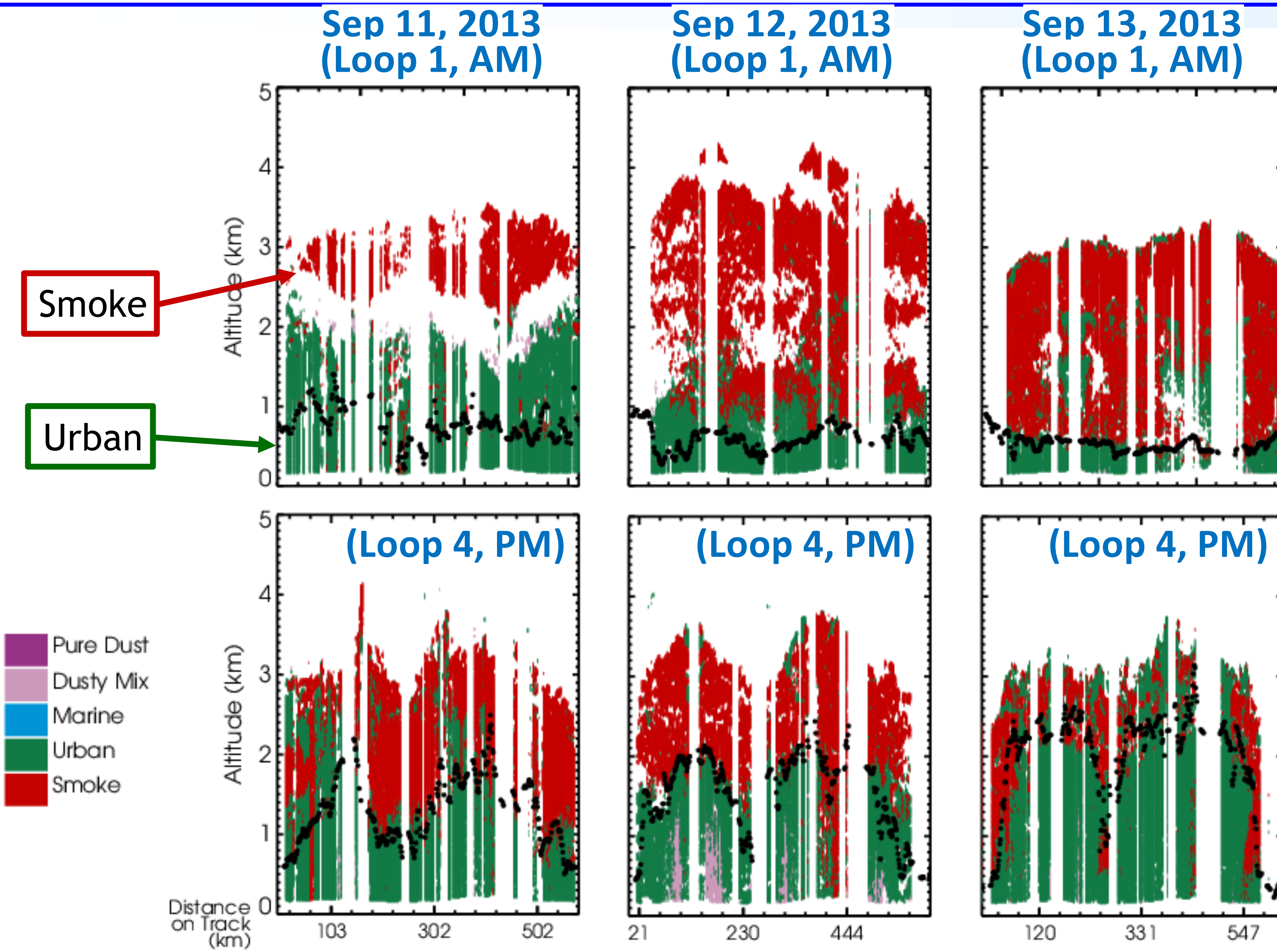
- HSRL-2 airborne lidar provides vertically resolved measurements of aerosol layers
- During DISCOVER-AQ, flight track thoroughly covered Houston and surrounding regions
- Loop repeated 4x per day, frequently sampling several days in a row
- This is a rare opportunity to observe diurnal and day-to-day evolution in so much detail



Smoke and Boundary Layer evolution, Sep 11-12



HSRL-2 Aerosol Type Sep 11-13

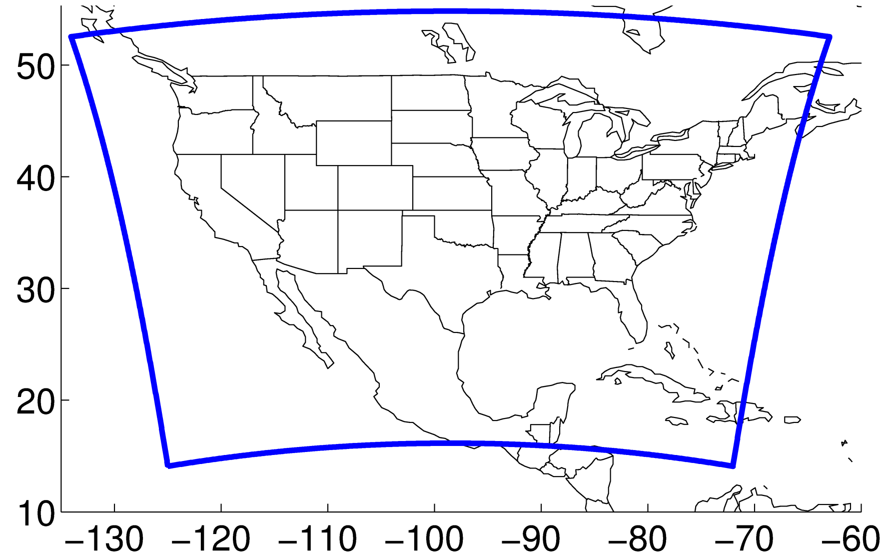


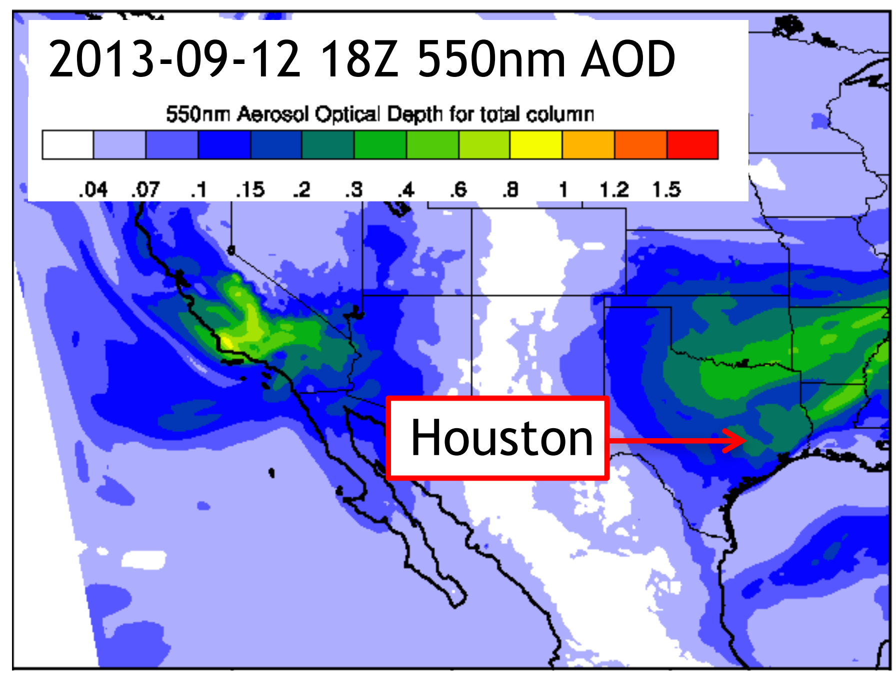
WRF-Chem Forecasting – Pablo Saide

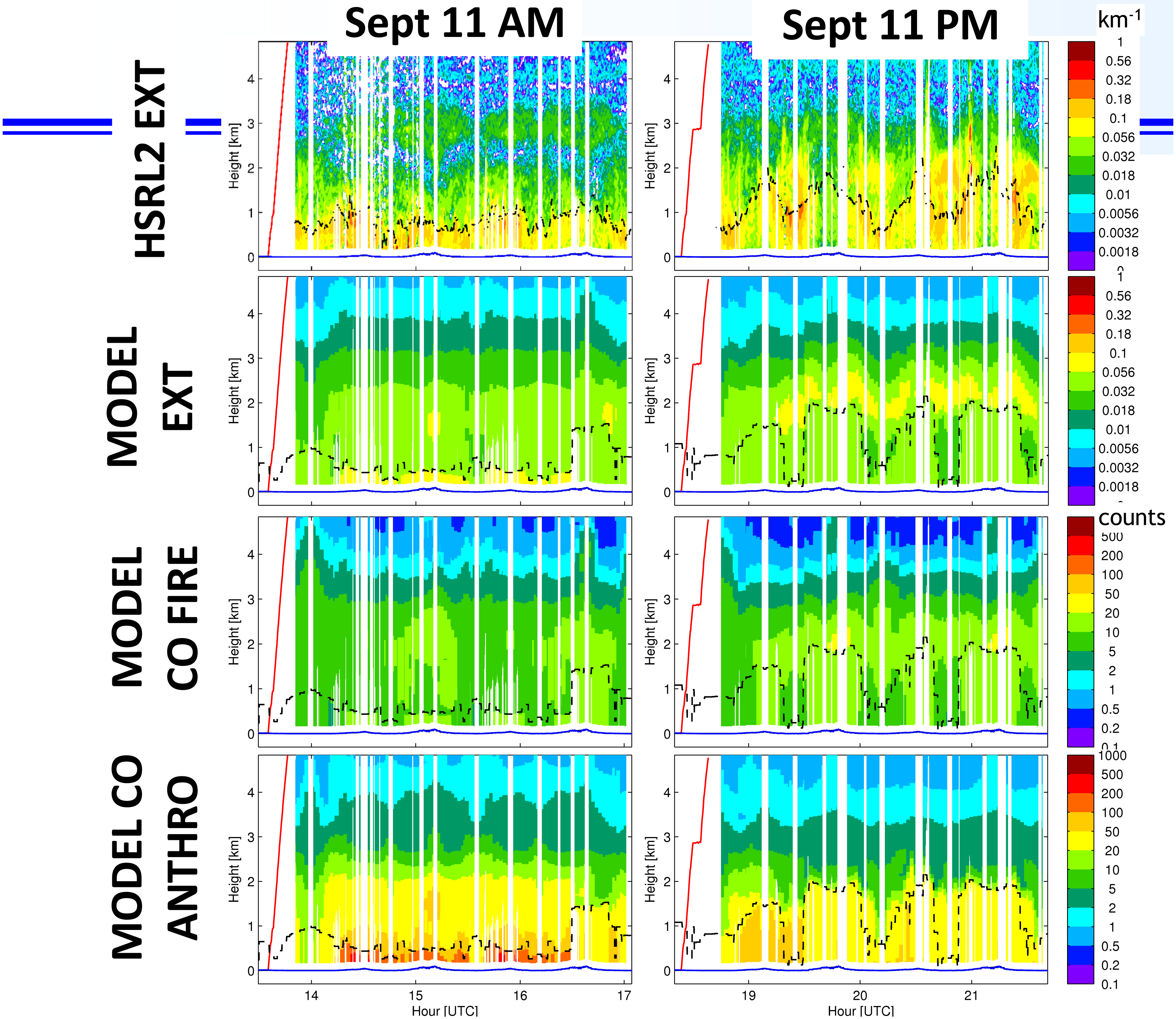
WRF-Chem model run performed by Pablo Saide, U. Iowa, for the SEAC4RS campaign, to provide guidance for flight planning and evaluate model in near-real time

Domain includes the DISCOVER-AQ Houston campaign as well

- WRF-Chem v3.5 CBMZ, 4bin MOSAIC, 12km dx, 52 vertical lvls, and WRF-tracer for emission regions/sectors
- Emissions: anthropogenic, biomass burning (FINN, QFED2) with plume-rise, MEGAN biogenics, dust & sea-salt. MACC boundary conditions
- AOD assimilation (NRL product) every 3 hours, 1 cycle a day (Saide et al., ACP 2013)







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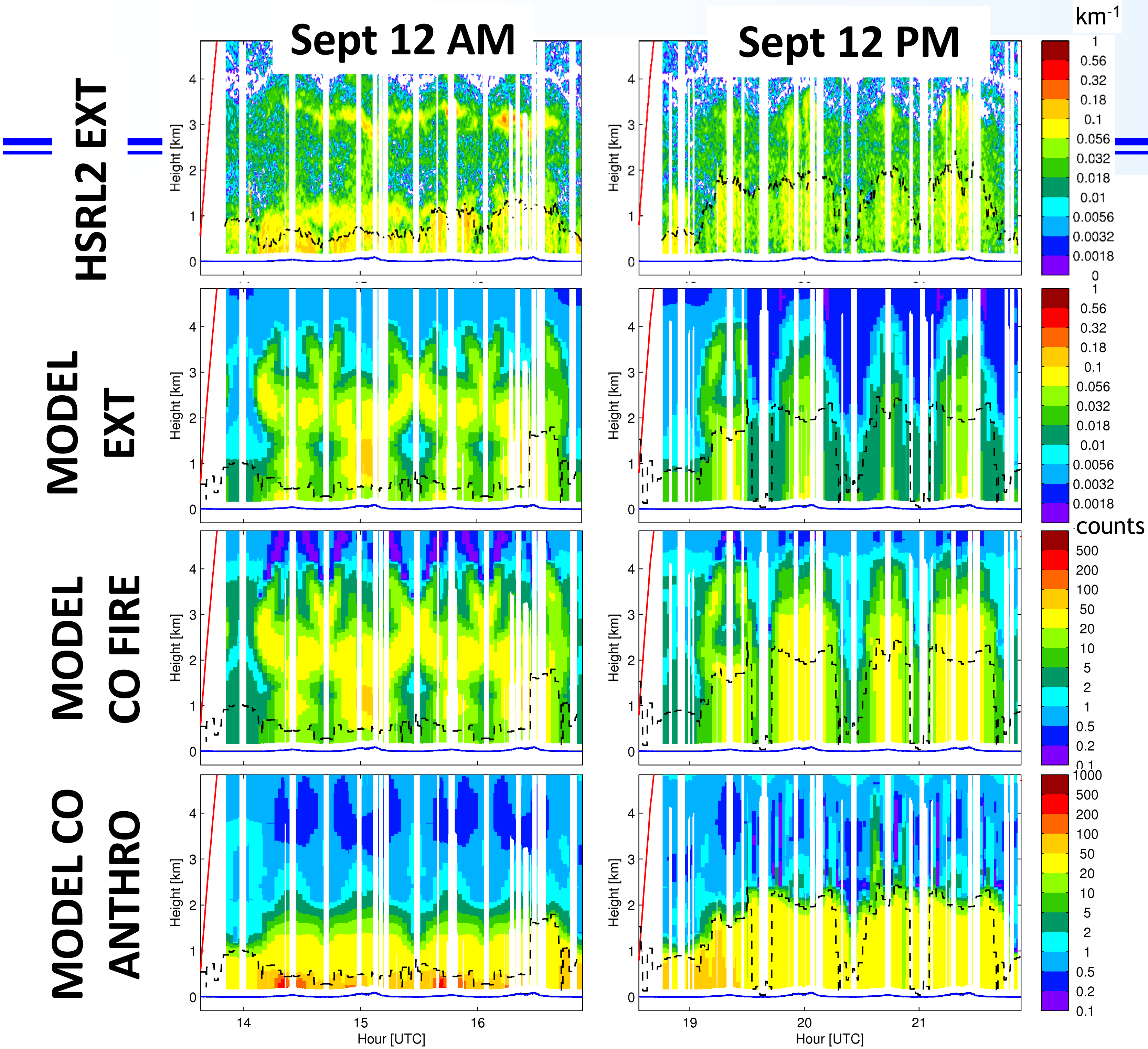

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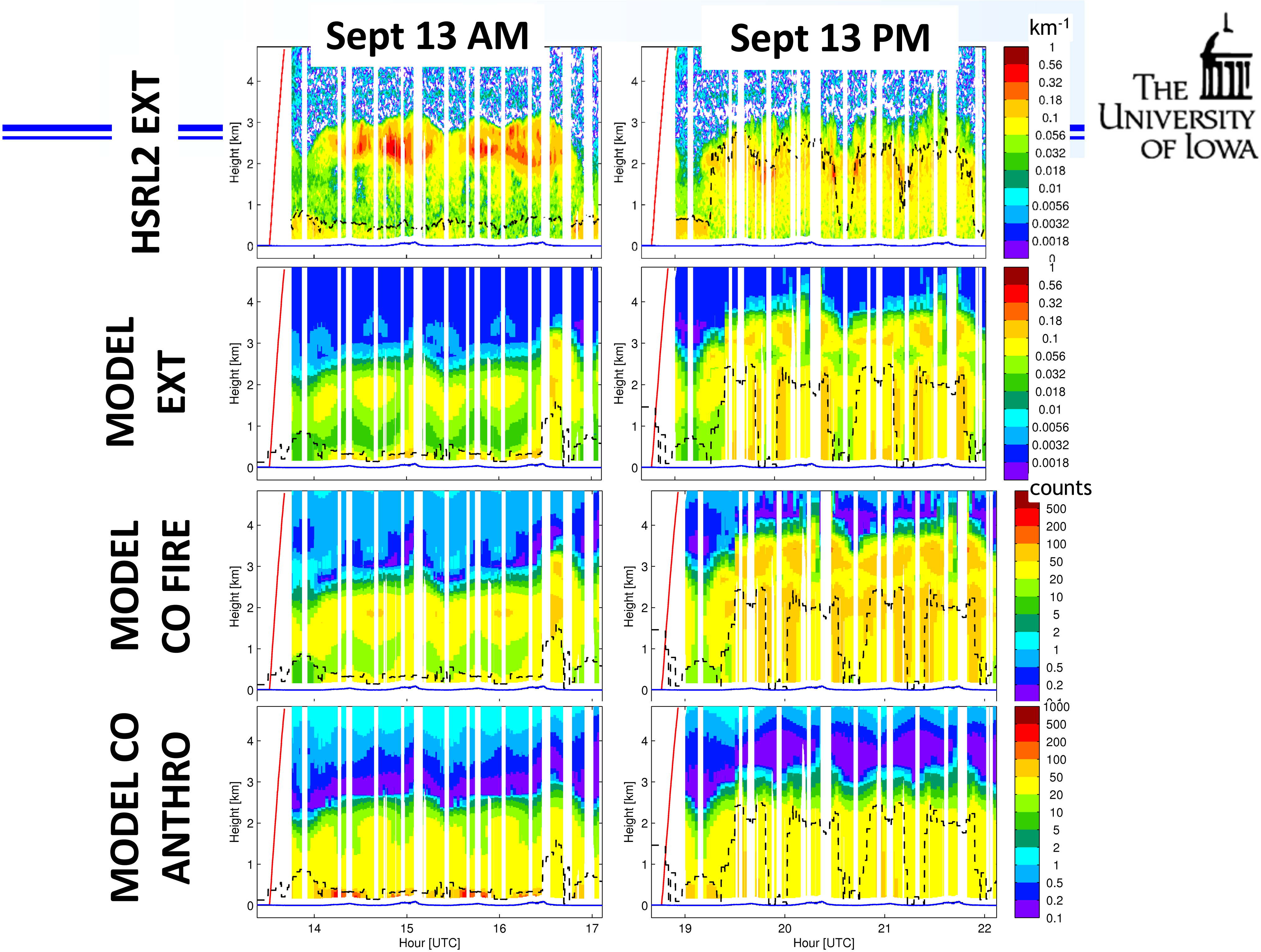
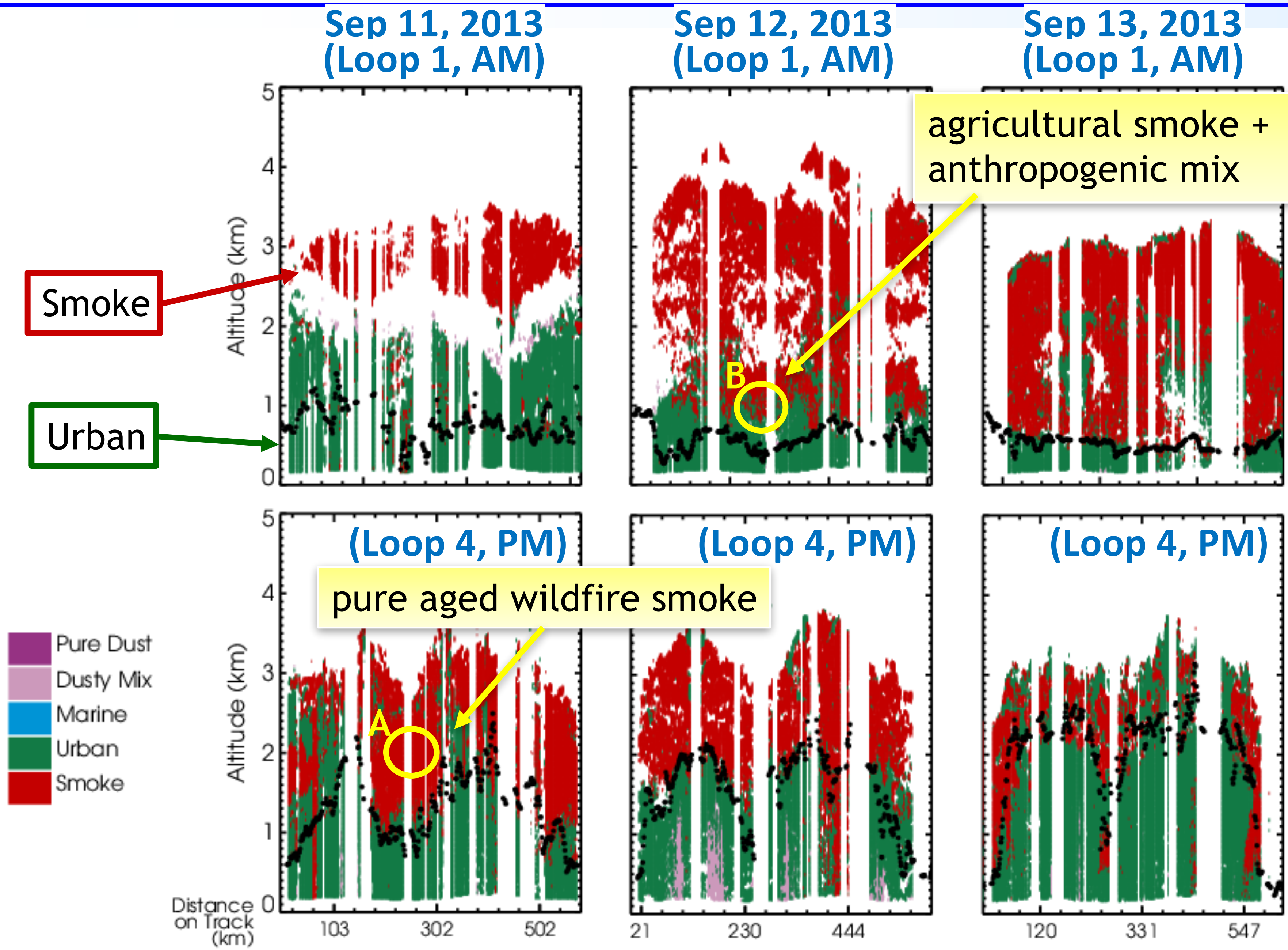


Sept 13 AM
Sept 13 PM
HSRL2 EXT
MODEL EXT
MODEL CO FIRE
MODEL CO ANTHRO
Height [km]
Hour [UTC]
km-1
counts

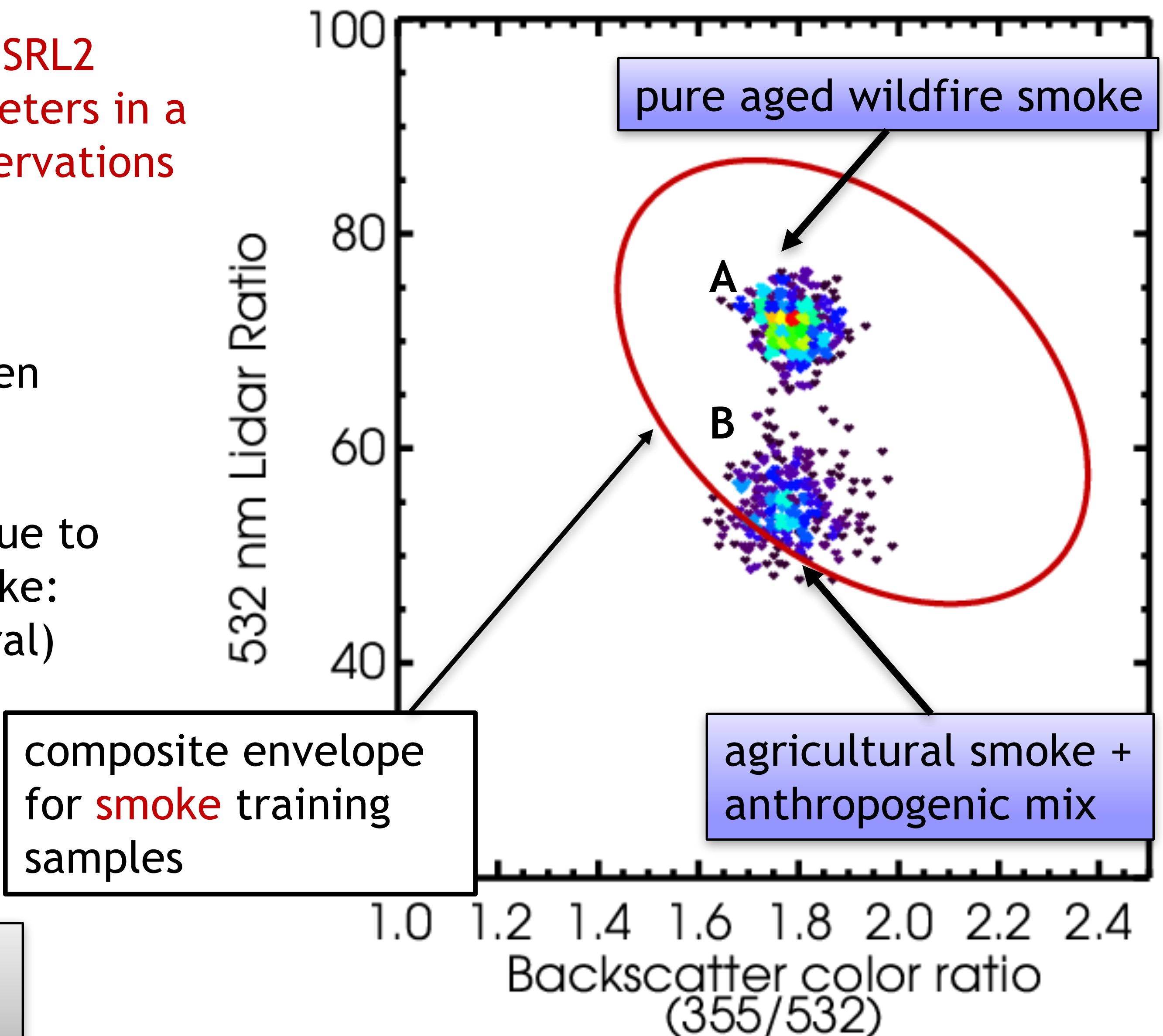
Aerosol Type samples



Variability of lidar intensive properties within a class

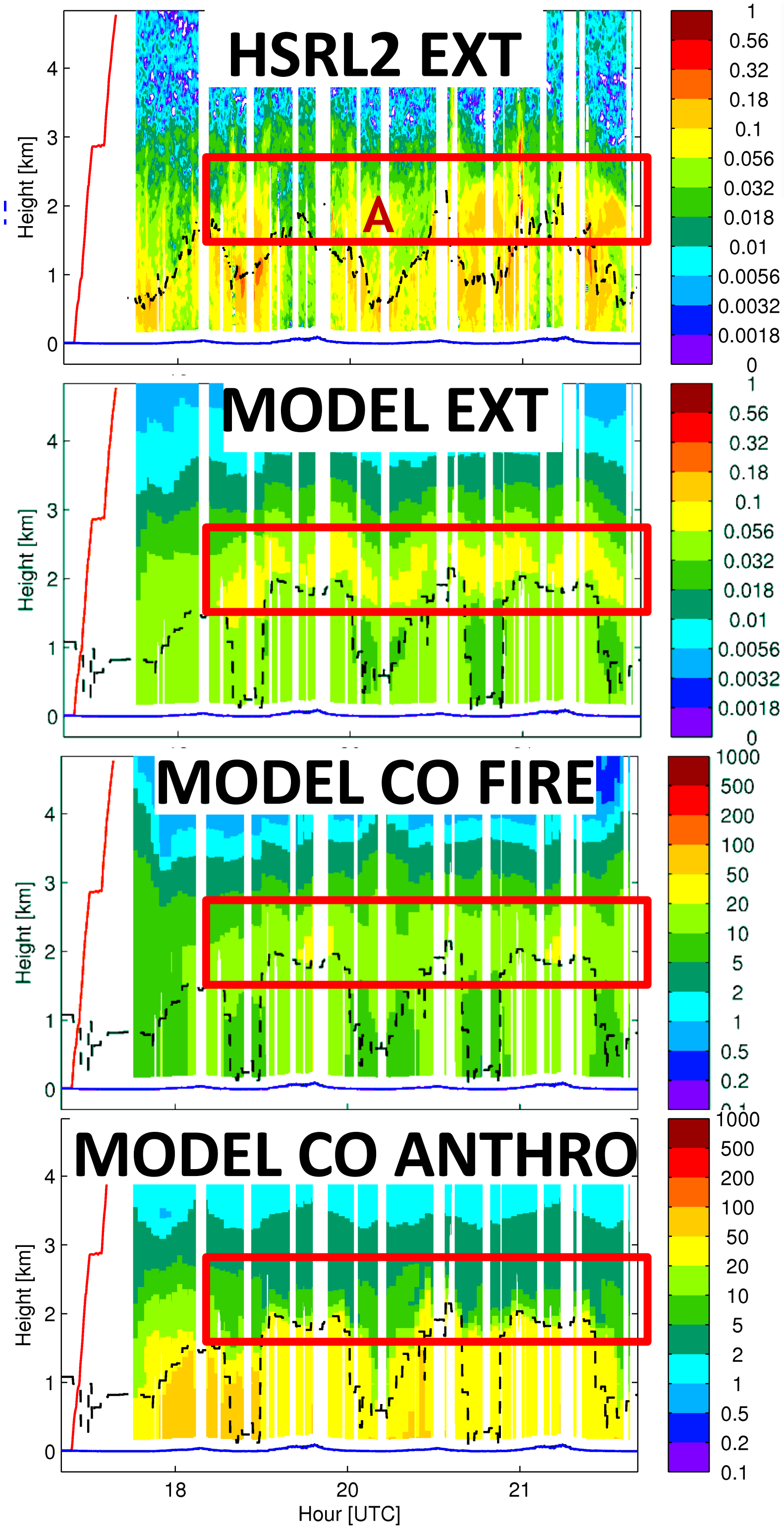
Aerosol typing from HSRL1/HSRL2 uses aerosol intensive parameters in a 4D or 5D space to match observations to the nearest aerosol class. (*Burton et al. AMT 2012*)

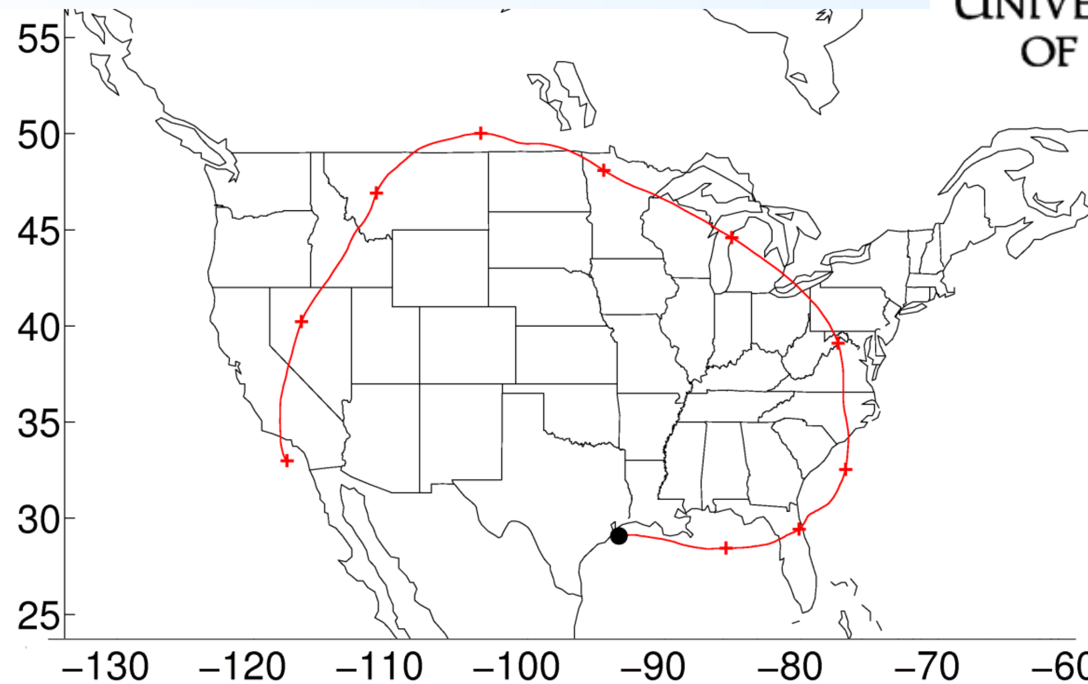
Specific samples can vary even within a type, due to
- mixing
- composition differences due to different sources (for smoke: e.g. wildfire vs. agricultural)
- humidification
- aging & processing, etc.
- ???



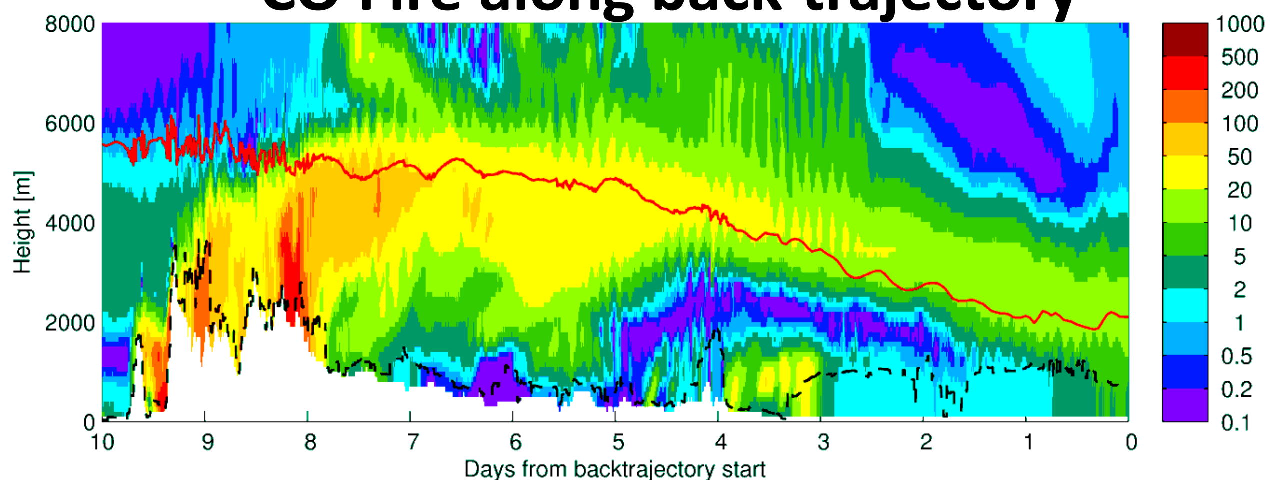
(caveat: smoke class shown here differs somewhat from published HSRL data, due to improved choice of training samples.)

Sept 11 PM





CO Fire along back-trajectory



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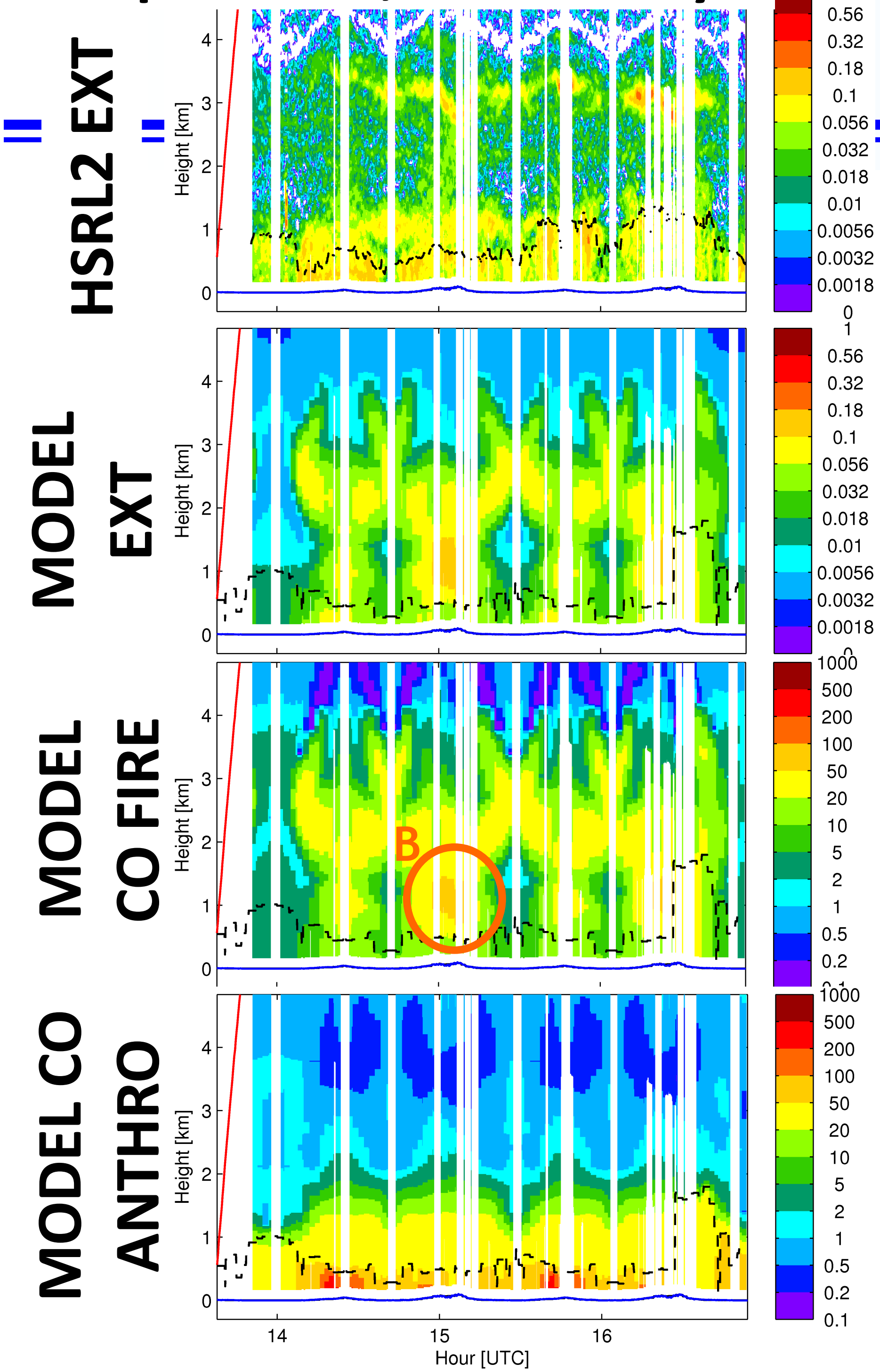
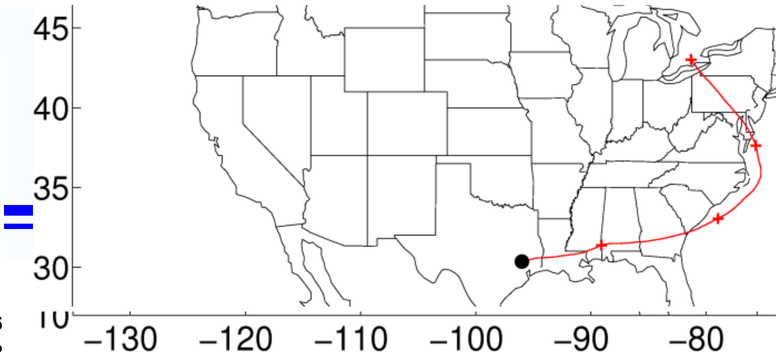
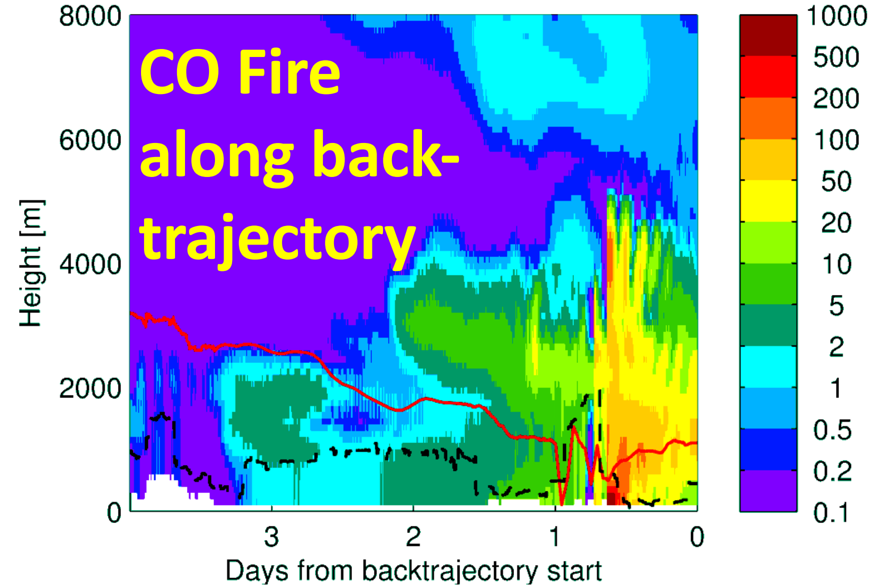
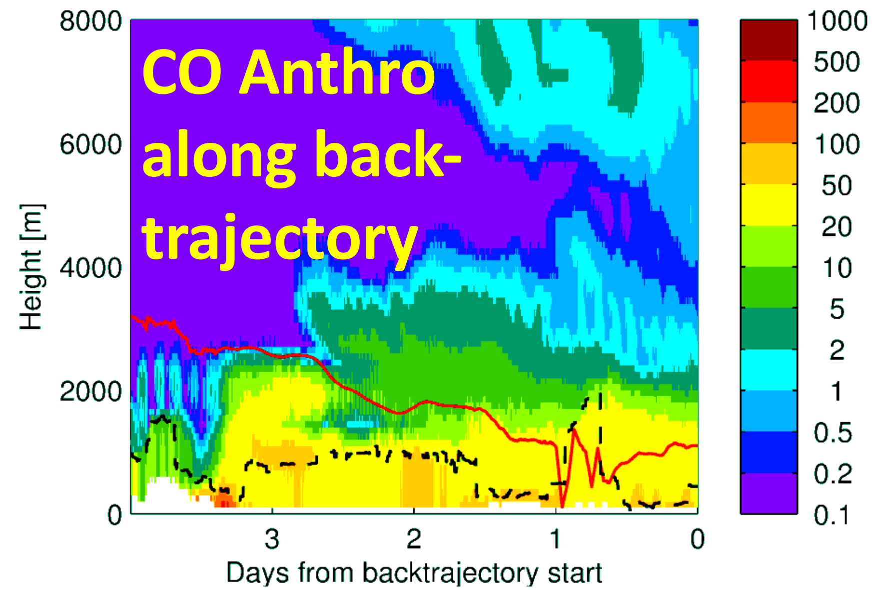
Sept 12 AM, residual layer

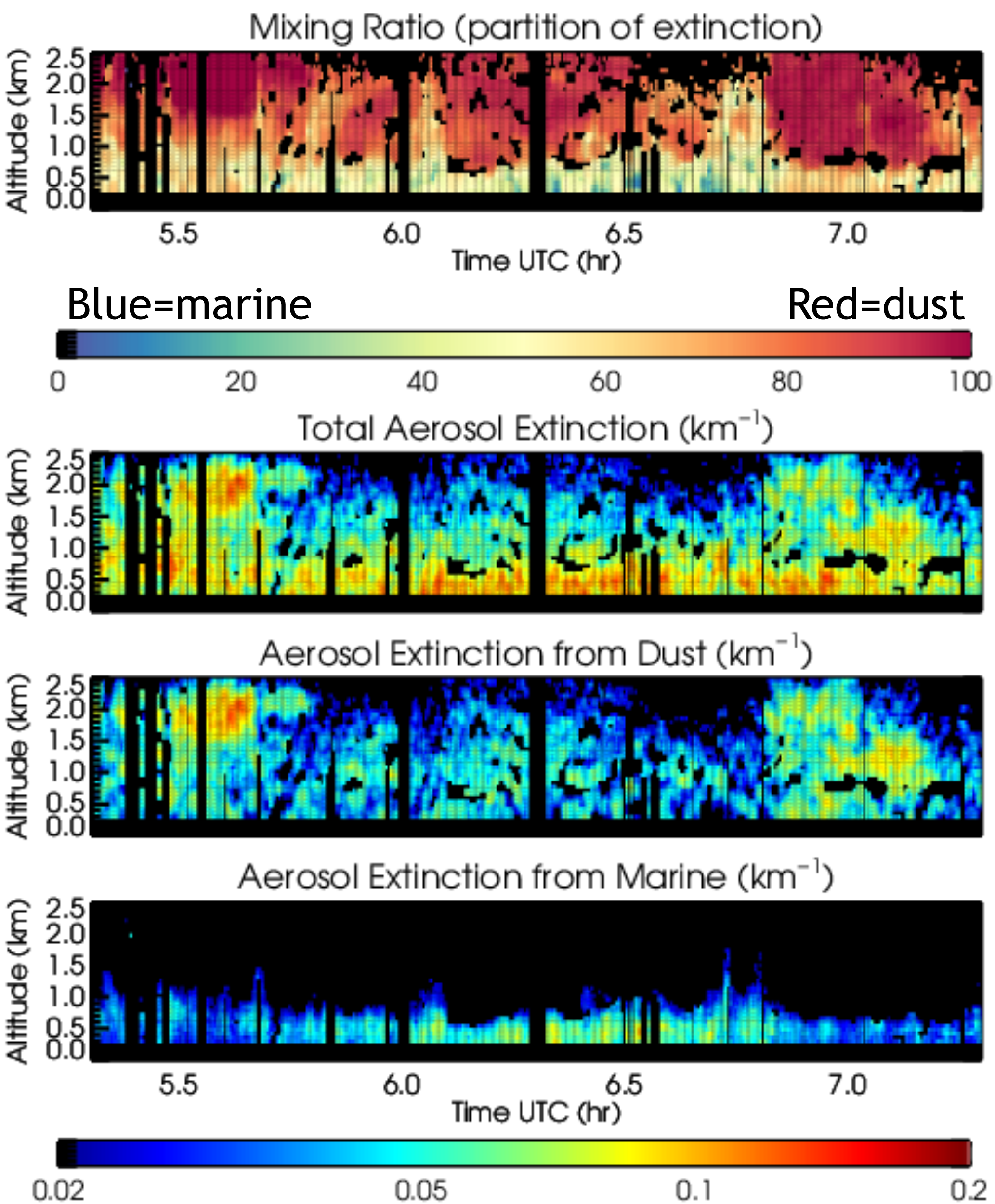








HSRL enables vertically resolved quantification of external mixtures of aerosol type



- Aerosol often occurs as mixtures
- Derived mixing rules for lidar

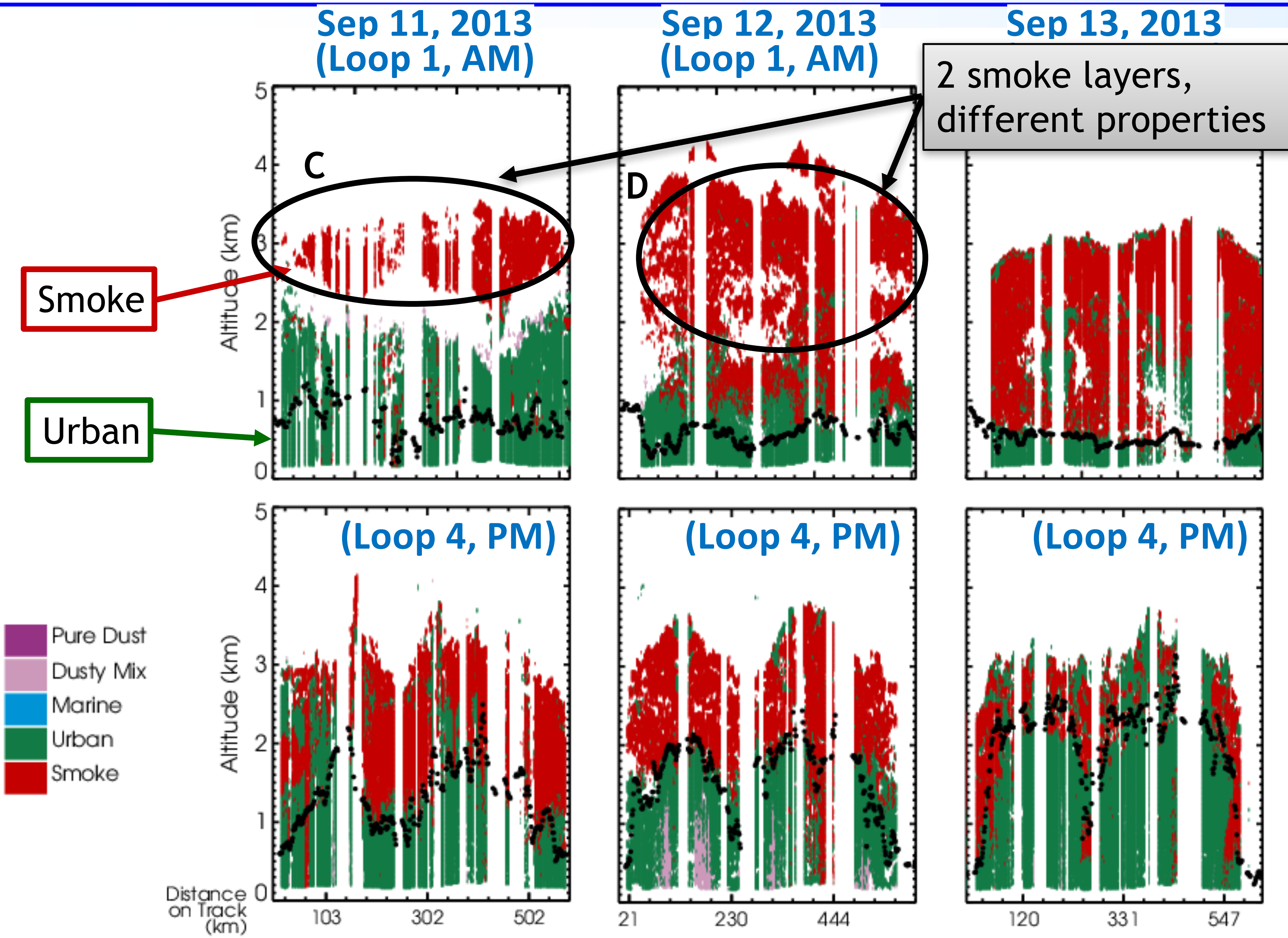
$$X = PA + (I - P)B$$
$$\Sigma_X = P\Sigma_A P^t + (I - P)\Sigma_B (I - P)^t$$

- Mixing methodology produces vertically resolved estimates of mixing ratio and partition of extinction

See also: Burton et al. "Separating mixtures of aerosol types using airborne HSRL" *AMT* 2014

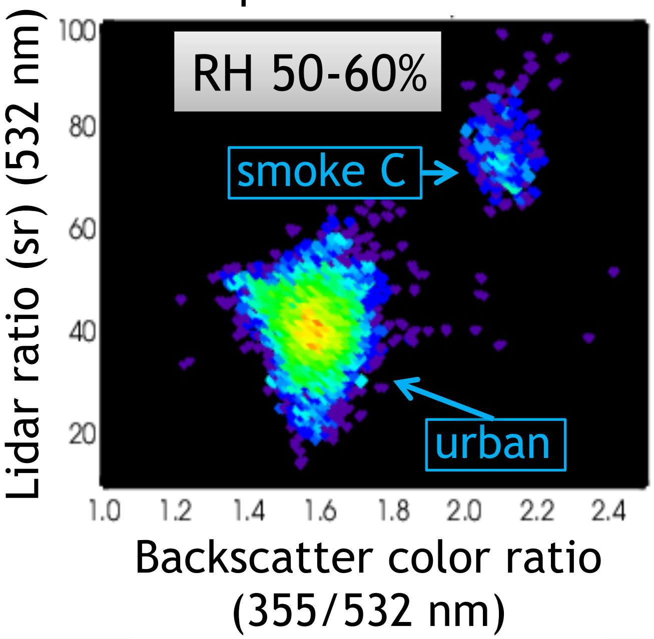
Case: Saharan Dust mixing with Marine Boundary Layer, Caribbean Sea, 8/22/2010

Aerosol Type, smoke samples

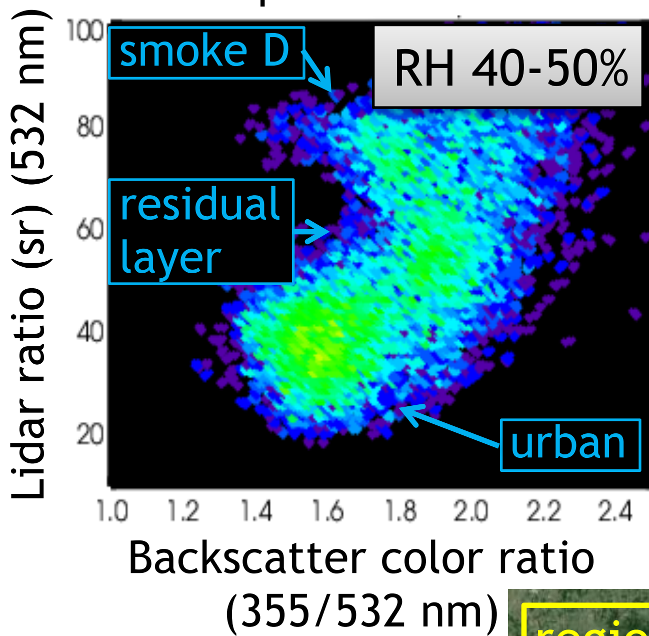


HSRL-2 Intensive variables for smoke are different each day

September 11 AM



September 12 AM

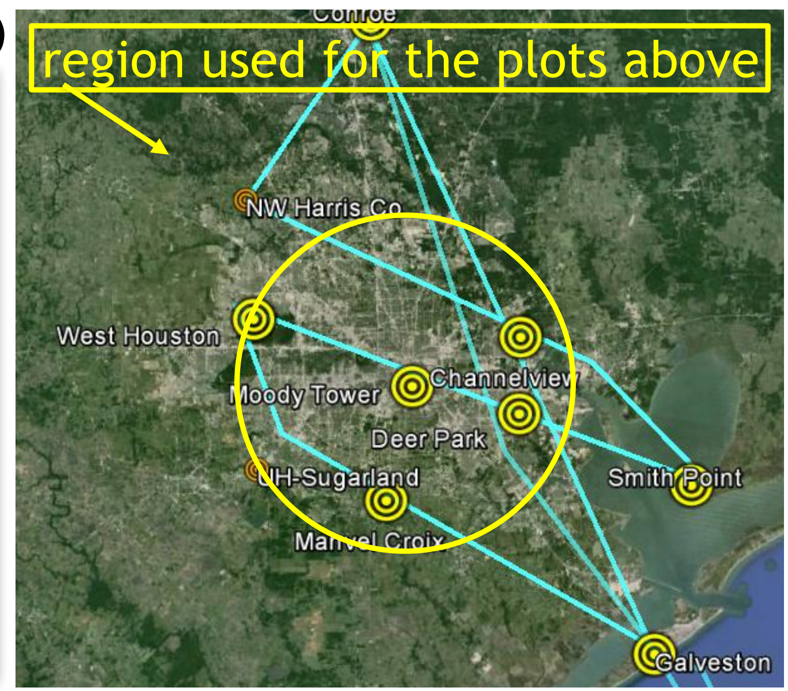


Differences in smoke intensive properties, particularly 355/532nm backscatter ratio

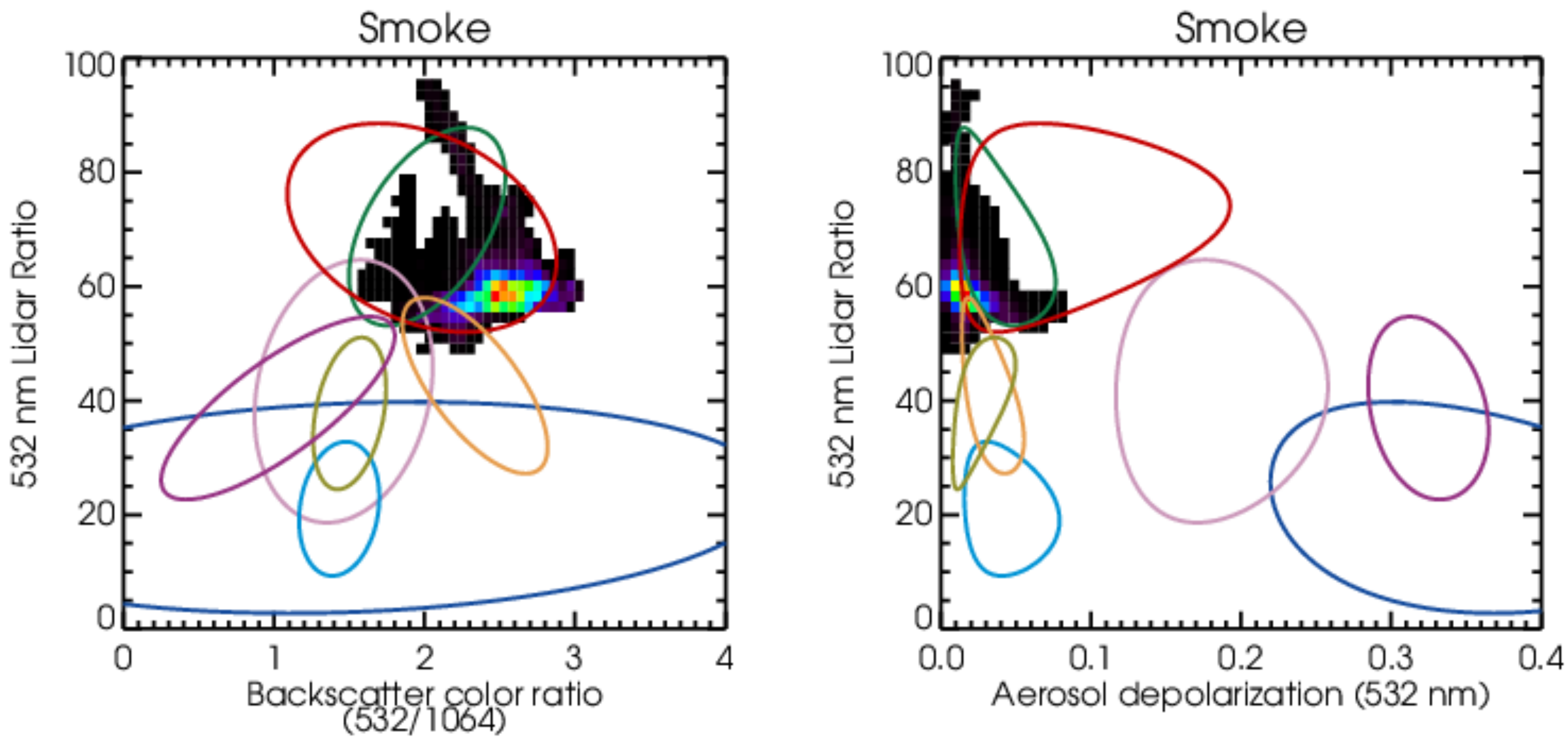
- Reflect probable difference in refractive index, SSA, and size distribution

Differences could be due to

- different sources or combustion types
- humidification
- aging & processing
- ?



GEOS-5 Smoke optical properties



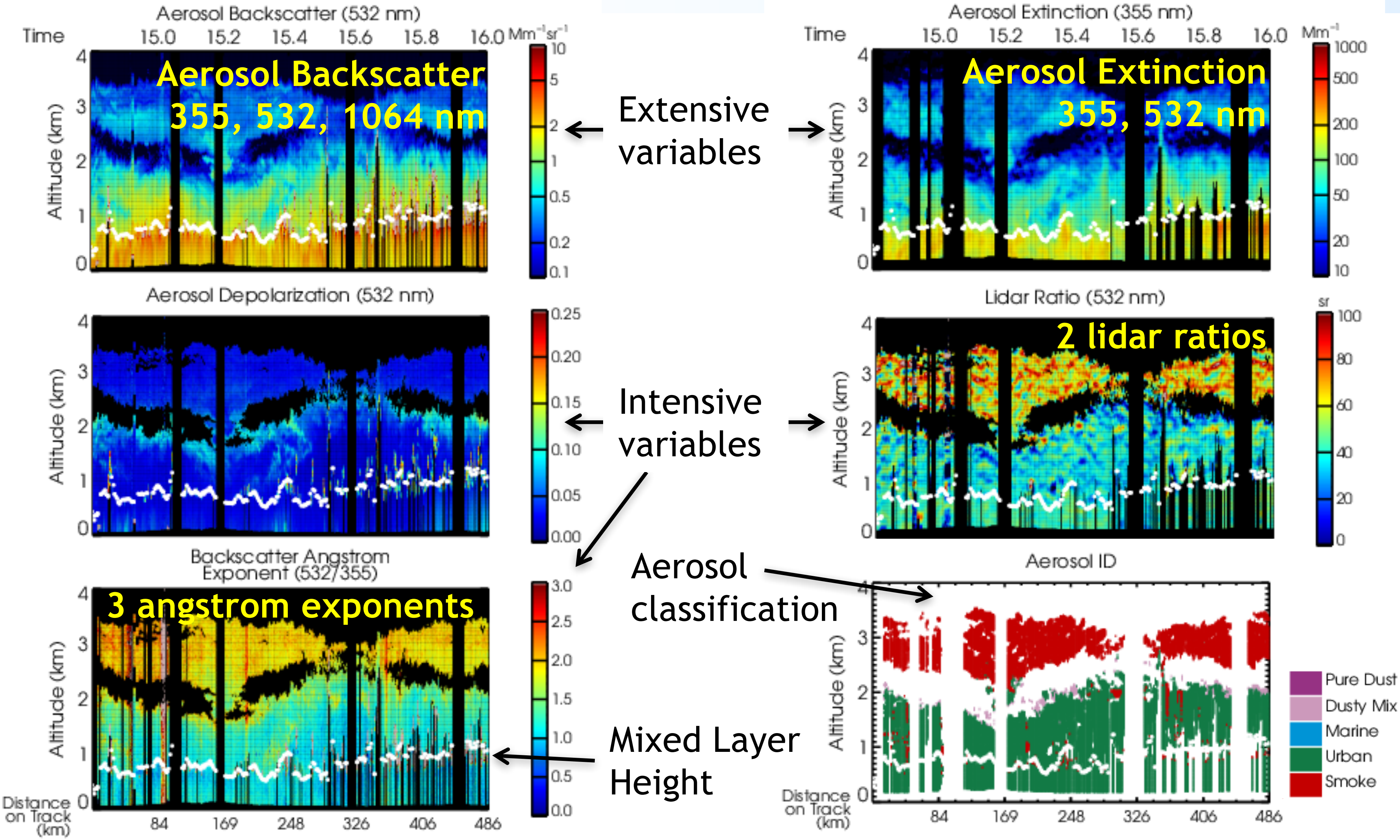
- Coincident data for all SEAC4RS flights
- Subset of data with GEOS-5 classification of smoke: $F_c \geq 0.75$ (Nowottnick et al., 2015)
- Red ellipse is envelope of values from HSRL classification (Burton et al. 2012)
- Good agreement in lidar ratio, backscatter color ratio
- HSRL observations show some depolarization in smoke, none in model

Summary

- HSRL-2 airborne lidar measurements provide vertically resolved aerosol measurements with high information content useful for validating models and model assimilation
- Includes multiple products with varying levels of detail for validating models
  - Layer heights, including mixed layer height for validation of model processes and transport
  - Aerosol extinction and backscatter for validation of aerosol abundance, vertical distribution and transport
  - Aerosol classification product for non-quantitative validation of aerosol sources and composition
  - Aerosol intensive parameters (lidar ratios, angstrom exponents, depolarization ratios) for advanced quantitative validation of aerosol properties

BACKUP

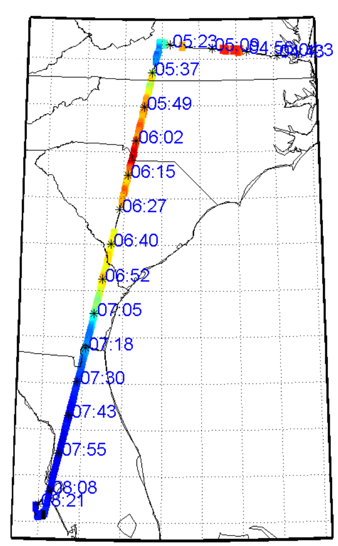
HSRL-2 measurement products

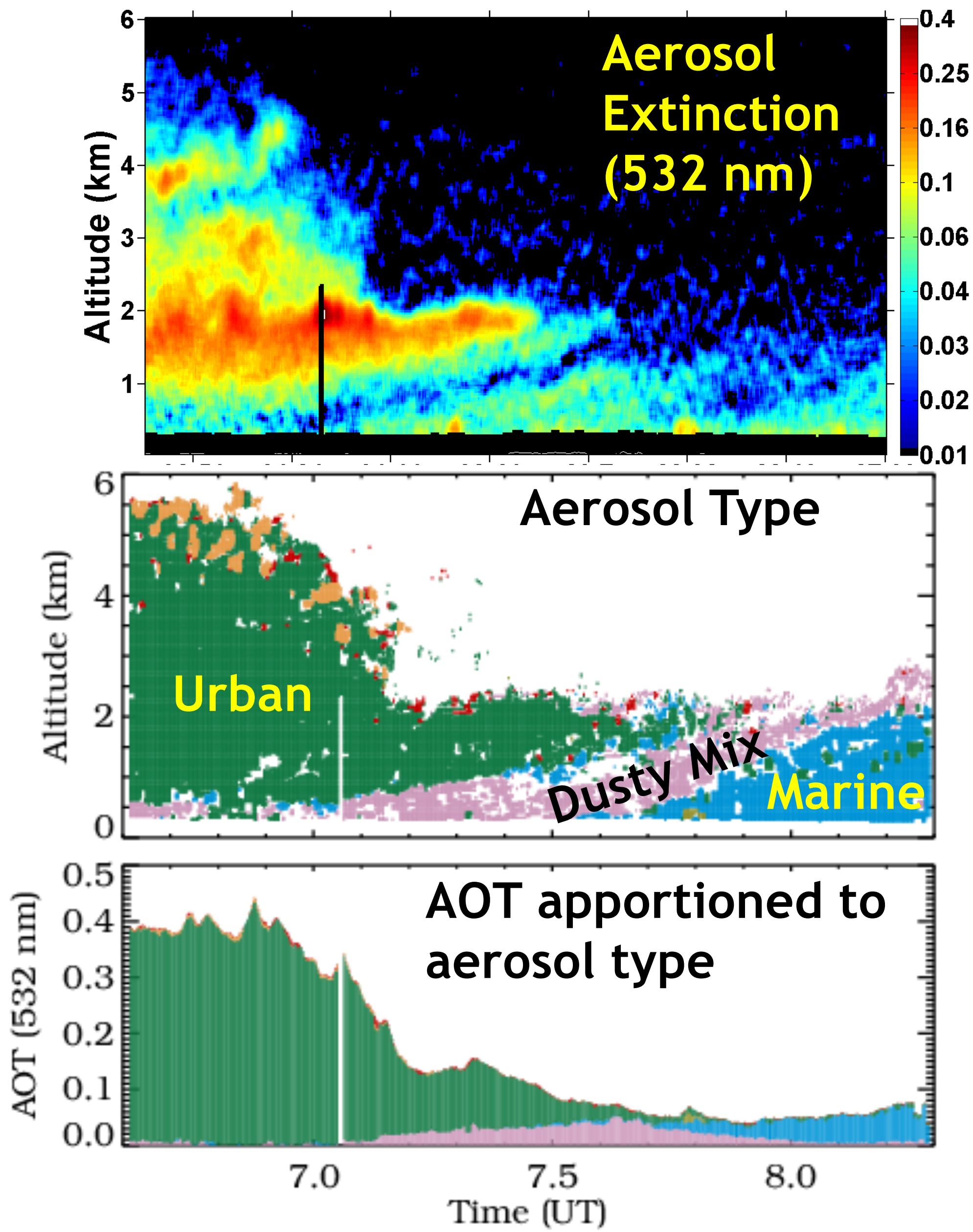


+Microphysics retrieval (not shown). See Rich Ferrare's talk.

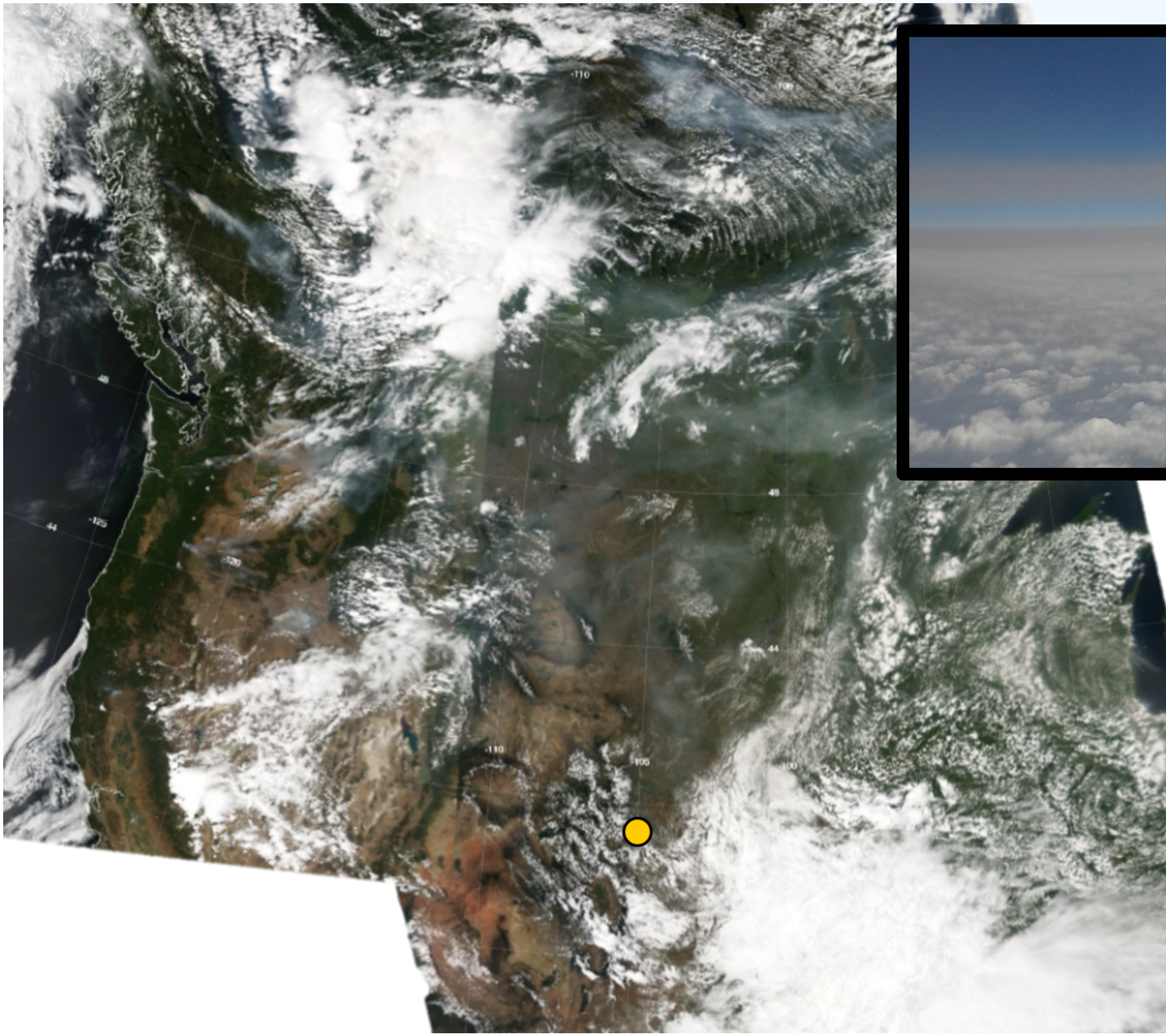
Benefits of HSRL-2 lidar

- Benefit of lidar over passive: vertically resolved measurements. Information about aerosol layer heights, vertical distribution.
- Benefit of HSRL over elastic backscatter: quantitative aerosol extinction, more information content relevant to aerosol type
- Airborne HSRL: since airborne tracks are not of interest for global assimilation, provides independent higher information-content data set for model validation





Case: transported smoke observed by HSRL-2 in Denver, 17 July 2014



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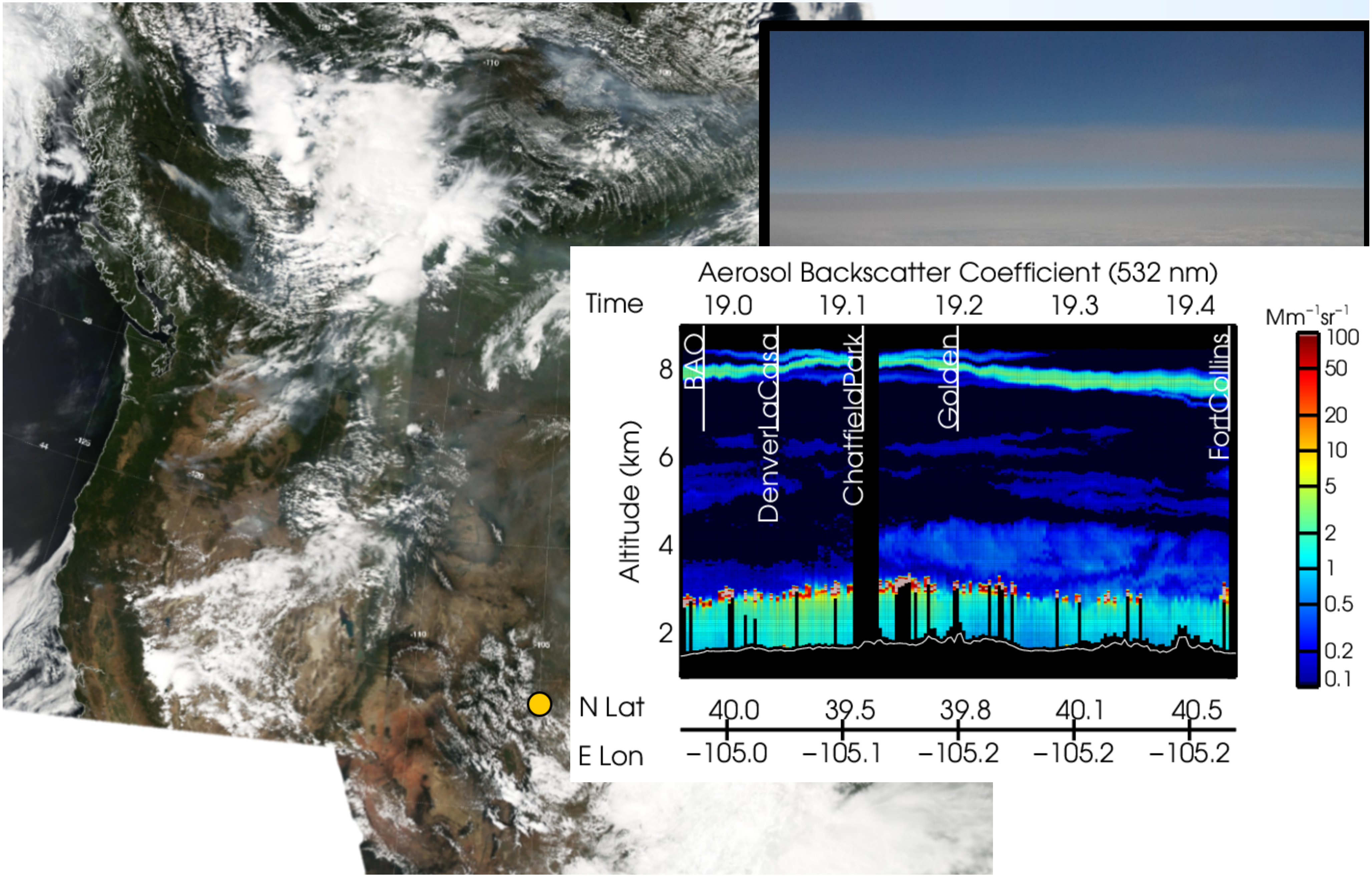
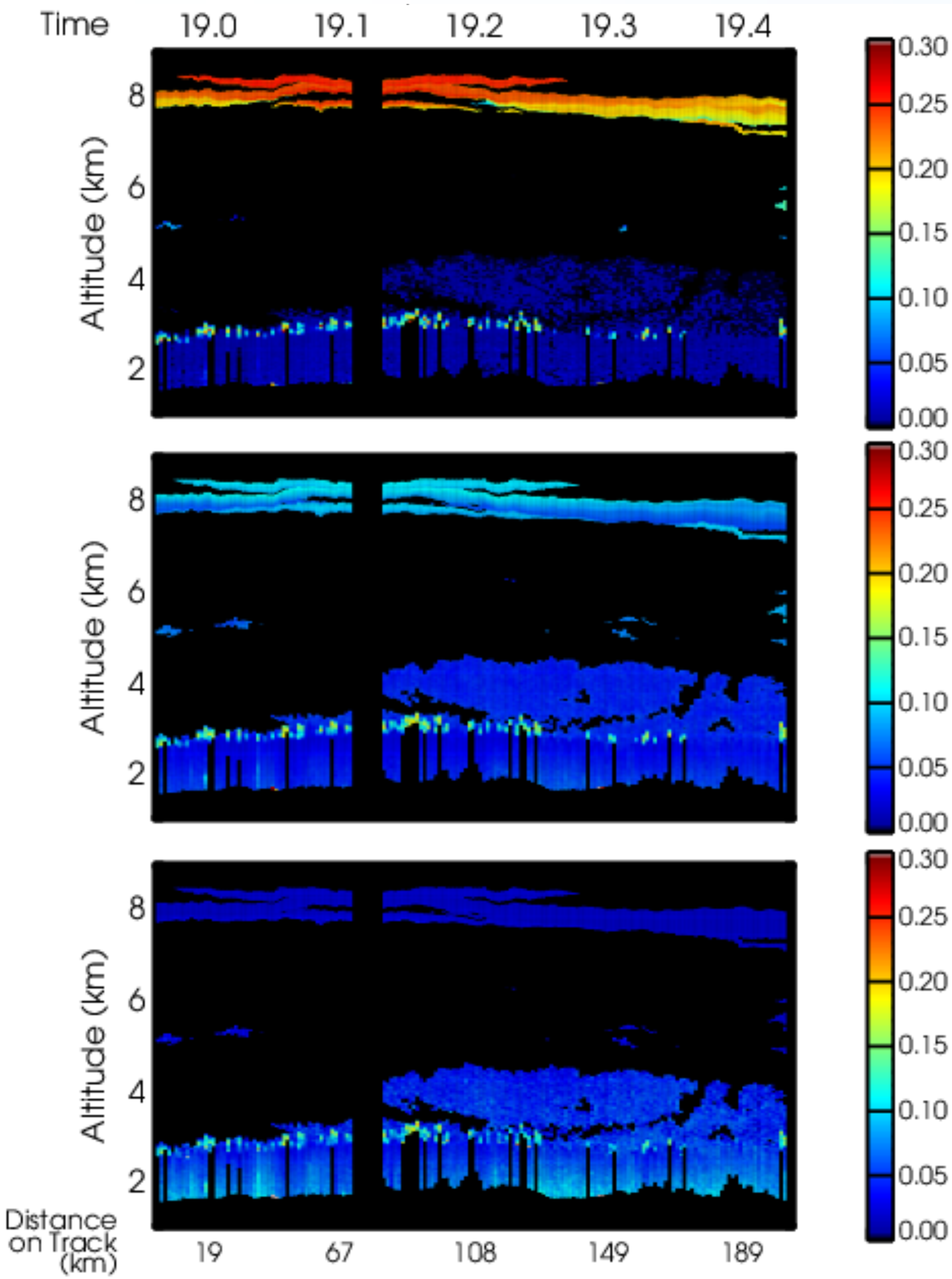


Surprising spectral dependence of particle depolarization ratio

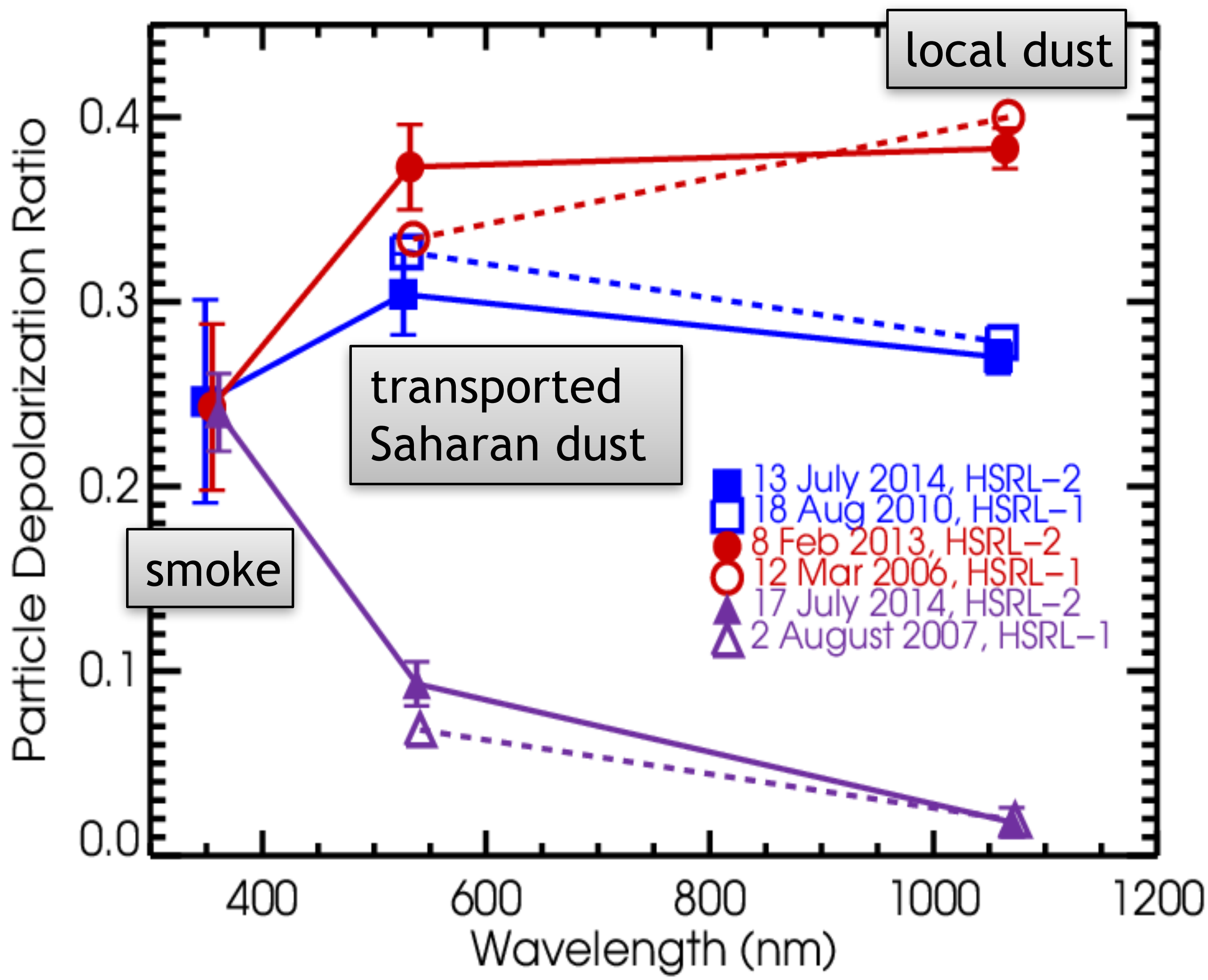


- Particle depolarization ratio of 0.09 at 532 nm consistent with aged smoke
- Biggest particle depolarization ratio of 0.24 at 355 nm
- Probably indicates that the non-spherical particles are small. Possibilities include
  - Fine mode soil/dust (Nisantzi et al. 2014)
  - Chain aggregates of soot in a sulfate shell (Kahnert et al. 2012)
  - Non-sphericity in another component of smoke?

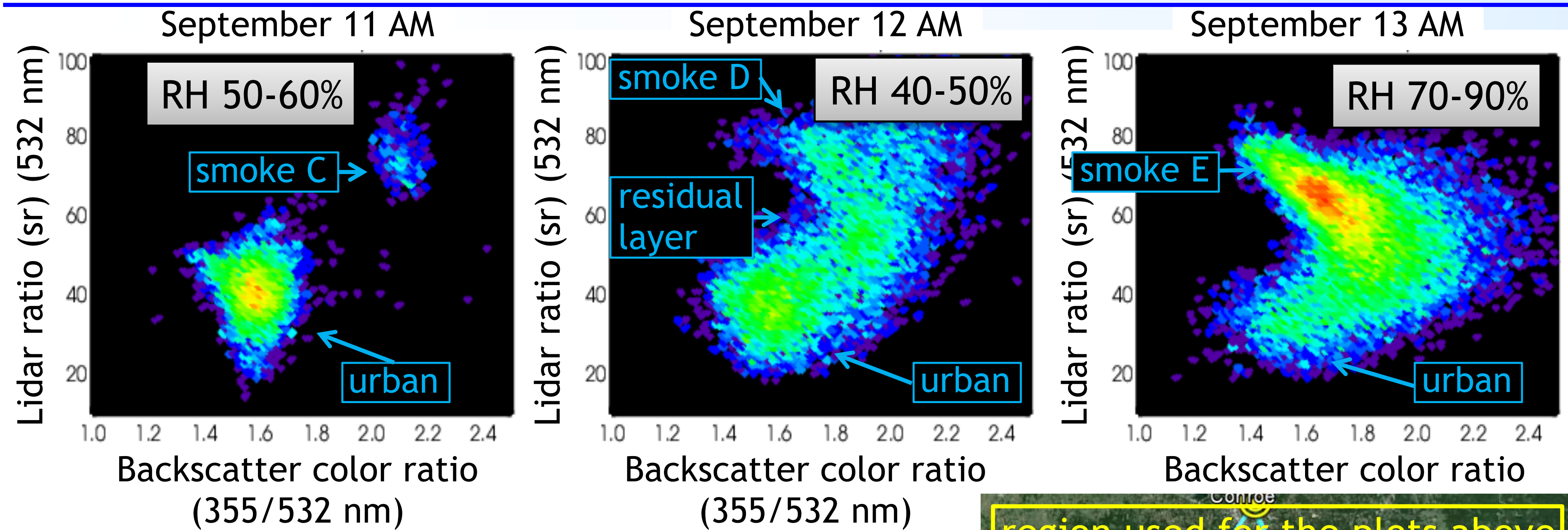
Summary of wavelength dependence of particle depolarization ratio

Observations of the spectral dependence of linear particle depolarization ratio of aerosols using NASA Langley airborne HSRL-2 Burton et al. *ACP 2015*

- Note similar 355 nm particle depolarization ratio for smoke and dust
- Implications for using only 355 nm particle depolarization ratio for aerosol typing



HSRL-2 Intensive variables for smoke are different each day

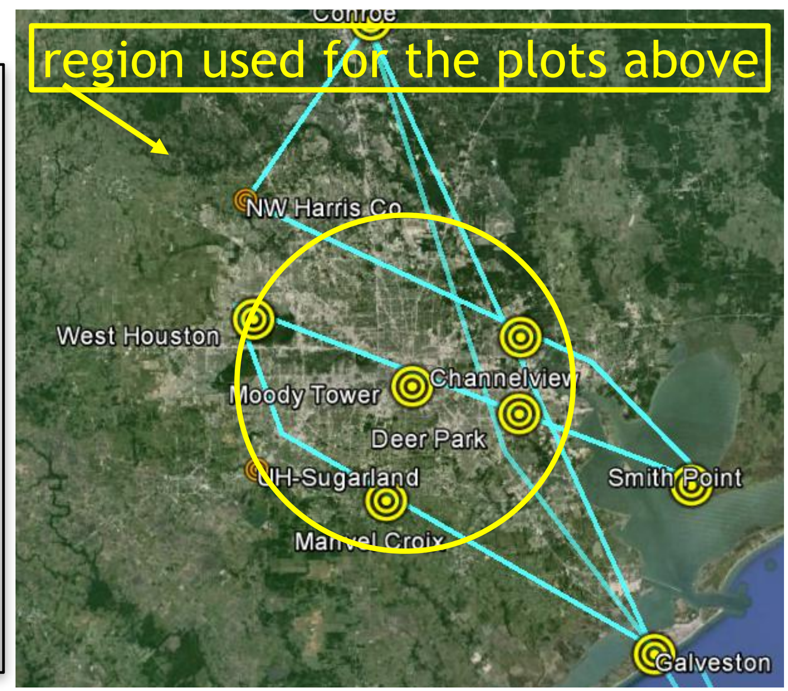


Differences in smoke intensive properties, particularly 355/532nm backscatter ratio

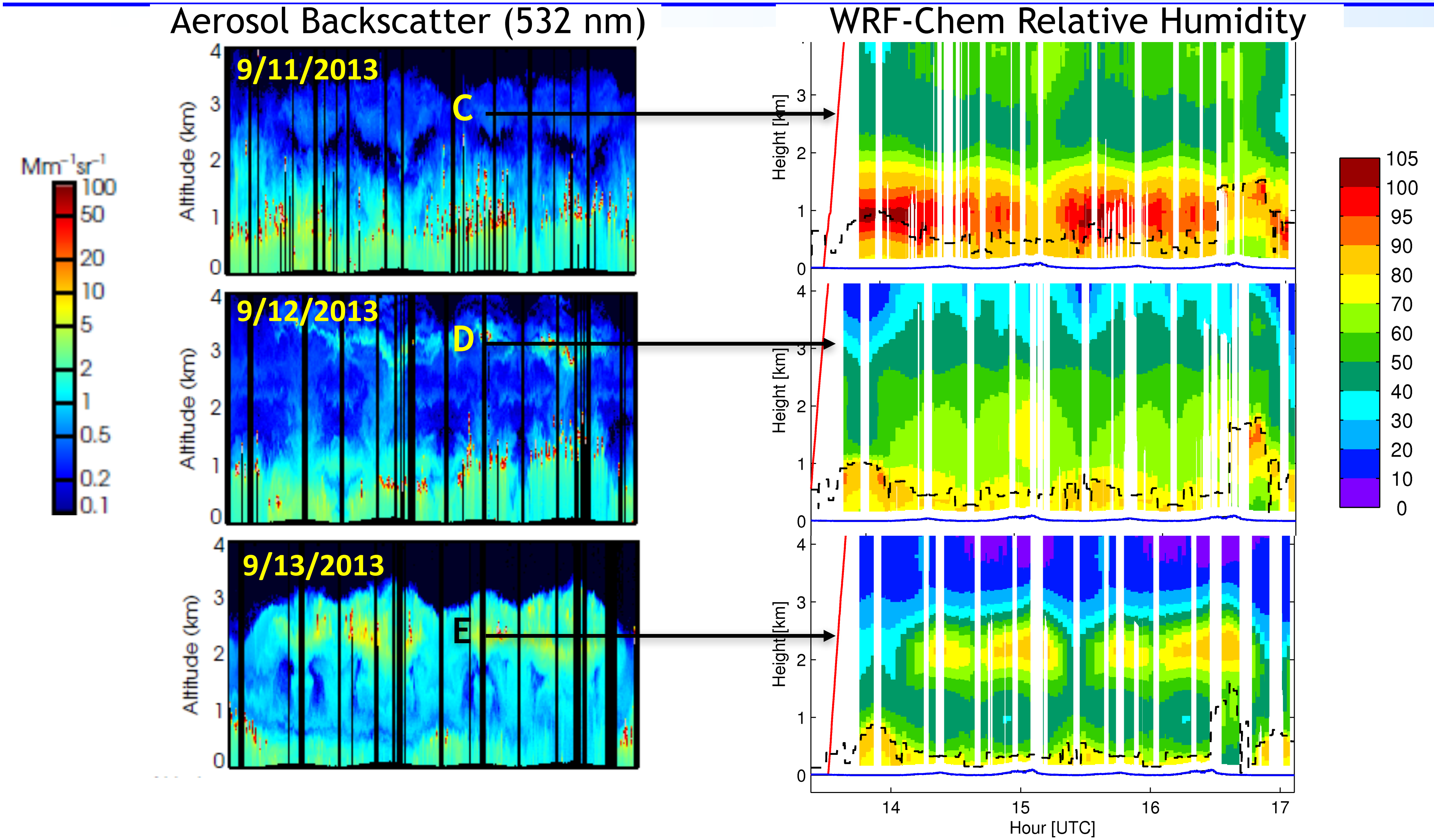
- Reflect probable difference in refractive index, SSA, and size distribution

Differences could be due to

- mixing
- different sources (e.g. wildfire vs. agricultural)
- aging & processing
- humidification



Relative humidity: another potential factor



• known from theory (Mie modeling) that lidar intensive variables vary with relative humidity — *Loeb and Schuster, JGR, 2008* and *Su et al. JGR 2008*