Aerosol Characterization using Airborne HSRL Measurements

Richard Ferrare[1], Chris Hostetler[1], John Hair[1], Sharon Burton[1], Ray Rogers[1], Mike Obland[1], Carolyn Butler[2], Amy Jo Swanson[2], Anthony Cook[1], David Harper[1], Bruce Anderson[1], Lee Thornhill[2], Antony Clarke[3], Cam McNaughton[3], John Ogren[4], Elisabeth Andrews[4], Charles Brock[4], Dan Lack[4], Justin Langridge[4], Karl Froyd[4], John Hubbe[5], Alex Laskin[5], Jerome Fast[5], Stephen Springston[6], Haflidi Jonsson[7]

[1]NASA/LaRC; [2]SSAI; [3]SOEST-Univ. Hawaii; [4]NOAA ESRL; [5]PNNL; [6]BNL; [7]CIRPAS-NPS

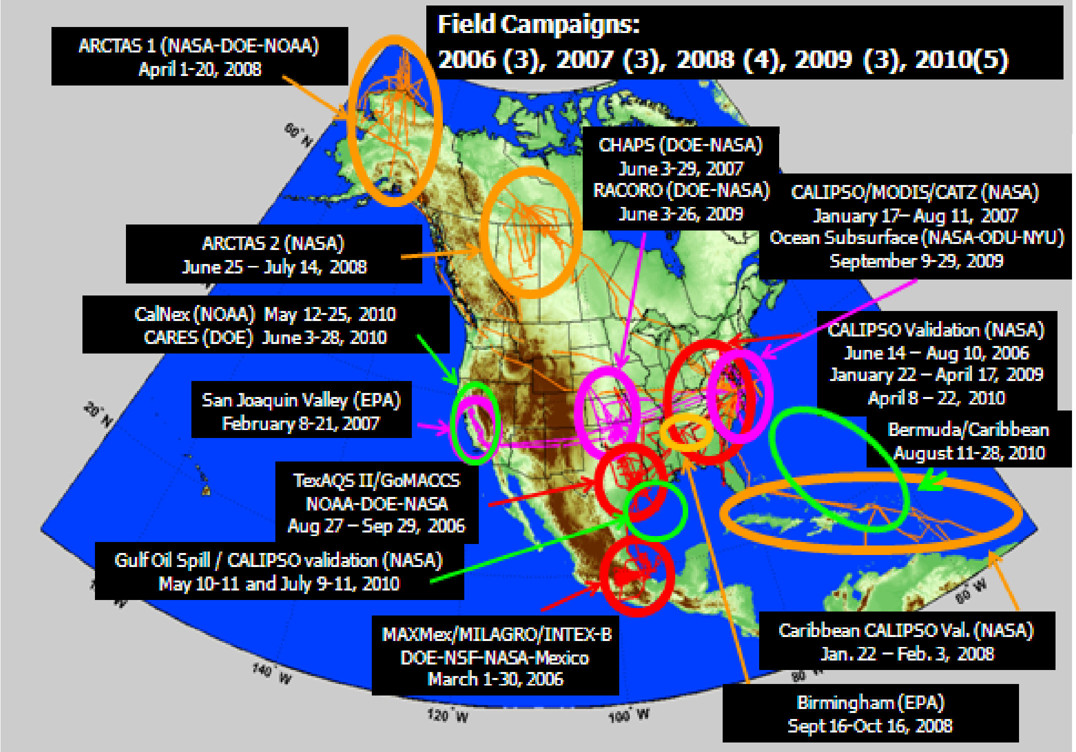
NASA HQ Science Mission Directorate Radiation Sciences Program

HSRL MEASUREMENTS AND AEROSOL CLASSIFICATION

NASA Langley Airborne High Spectral Resolution Lidar (HSRL)

NASA LaRC airborne HSRL:

- Independently measures aerosol backscatter, extinction, and optical thickness
- Provides intensive aerosol parameters to help determine aerosol type
- Deployed on NASA LaRC B200 King Air
- Nadir viewing from 9 km flight altitude



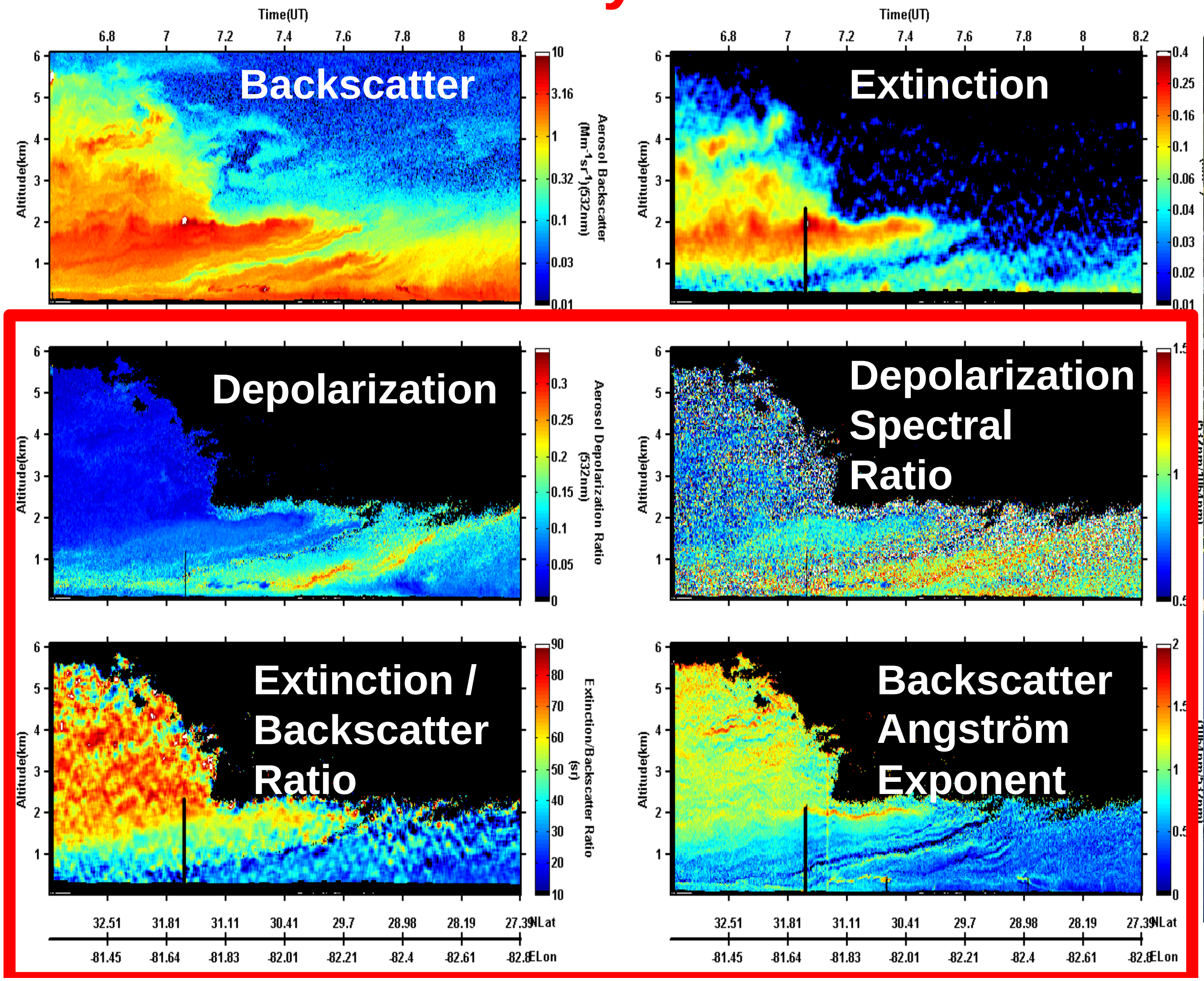
HSRL Aerosol Data Products:

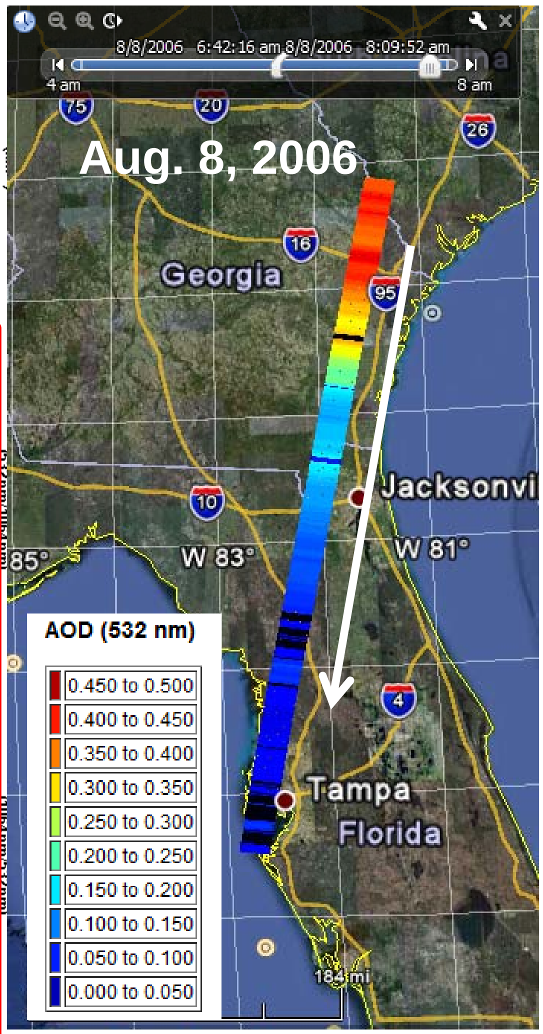
- Scattering ratio (532 nm)
- Backscatter coefficient (532, 1064 nm)
- Extinction Coefficient (532 nm)
- Backscatter Wavelength Dependence (532/1064 nm)
- Extinction/Backscatter Ratio ("lidar ratio") (532 nm)
- Depolarization (532, 1064 nm)

Airborne HSRL has logged
>1077 science flight hours
> 330 science flights

HSRL Aerosol Measurements

Note the variability in aerosol intensive parameters

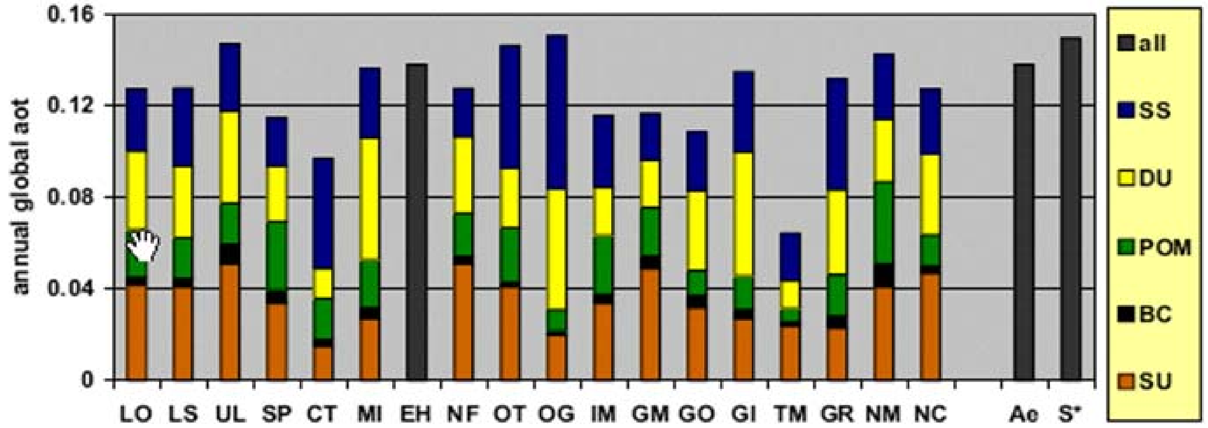




Aerosol Classification

Motivation:

AEROCOM aerosol transport model intercomparisons have found large diversity in partitioning of AOT among the major aerosol types

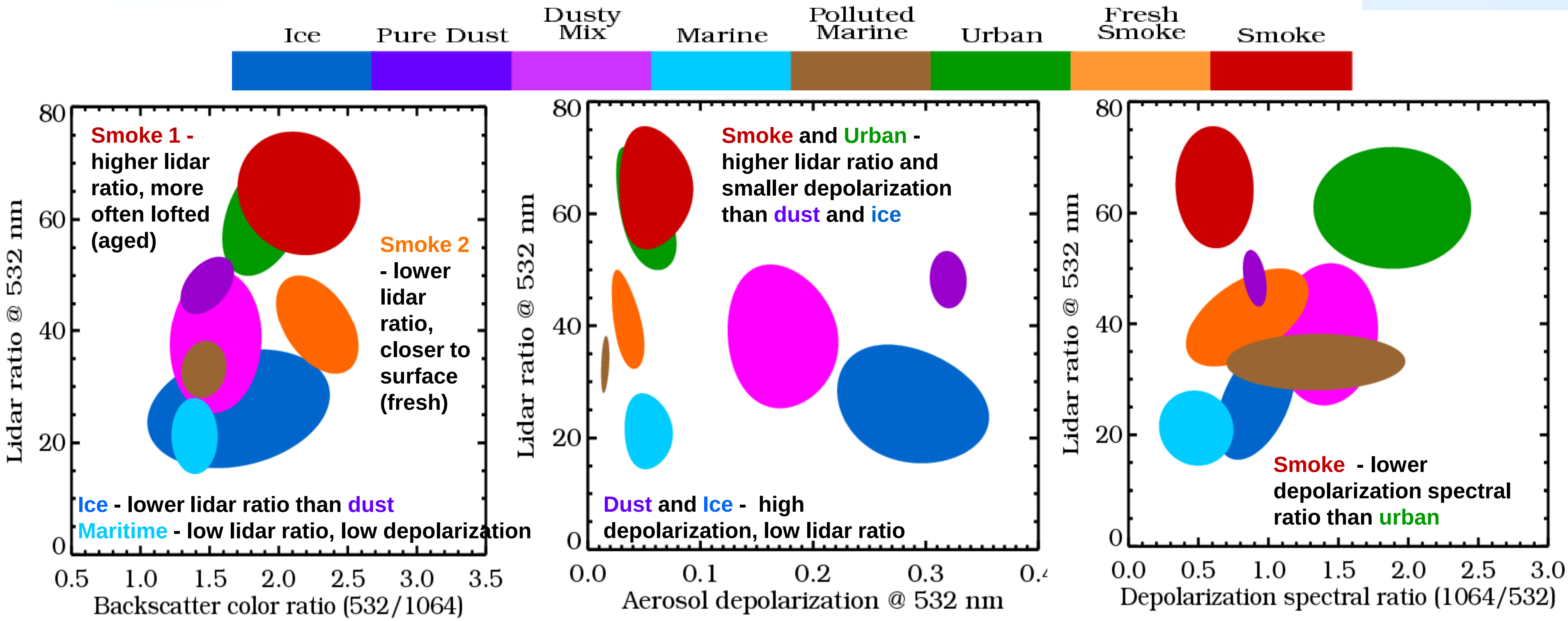


Kinne et al., 2006

Objective:

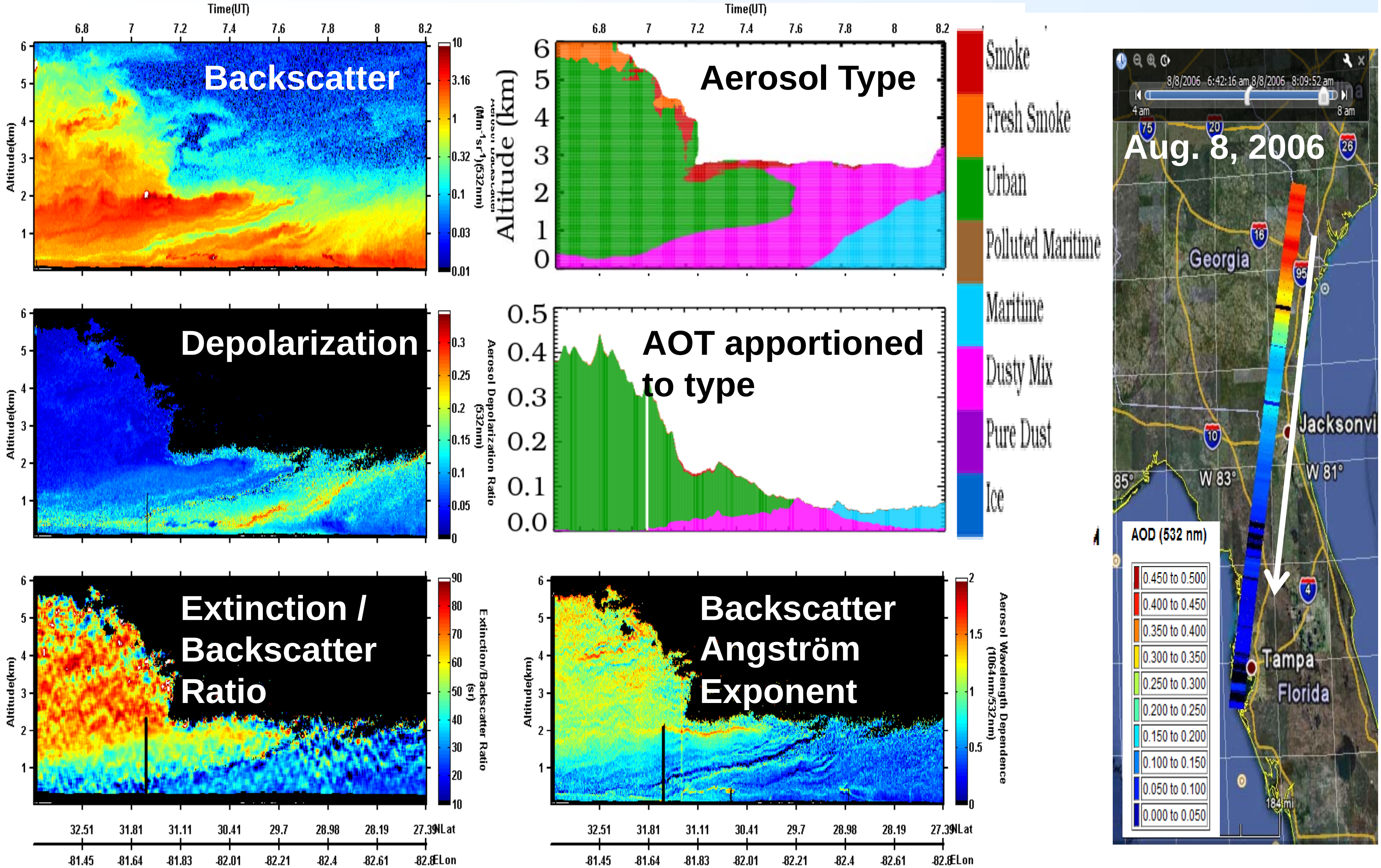
Use airborne HSRL measurements to infer aerosol type and apportion aerosol optical thickness to type to help assess model simulations of aerosol type

Aerosol Classification Using HSRL Measurements



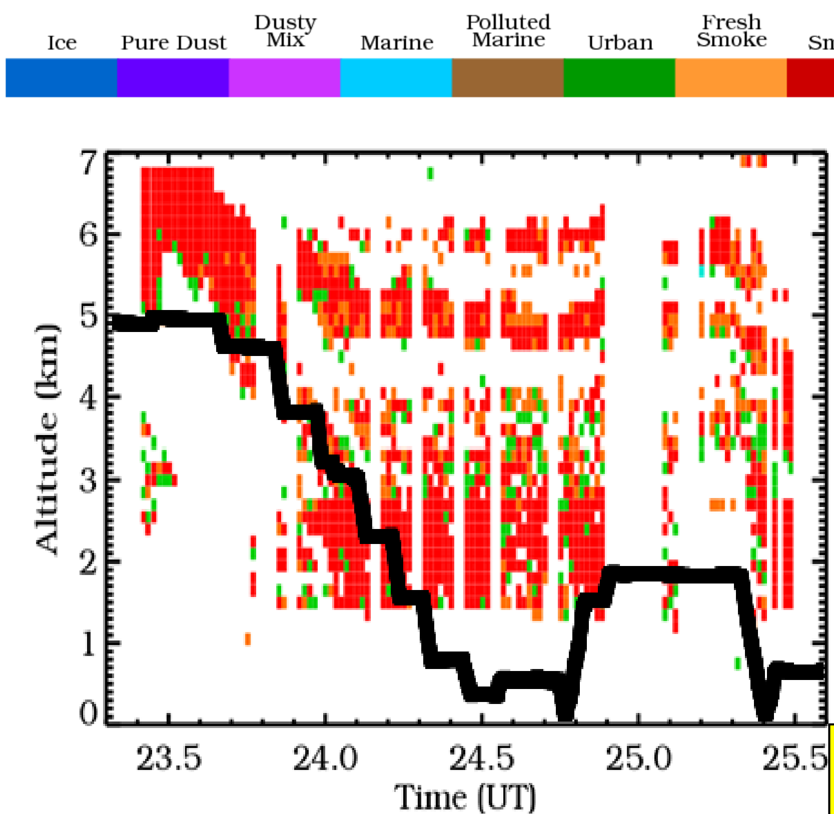
- Uses four aerosol intensive parameters to classify aerosols
- Employs a training set of known types
- Estimates the 4-D normal distributions of classes from labeled data
- Computes Mahalanobis distance to compute probability of each point belonging to each class
- HSRL data acquired from 2006-2010 are classified
- Technique described by Burton et al. (2011) (AMTD)

Aerosol Classification using HSRL Measurements



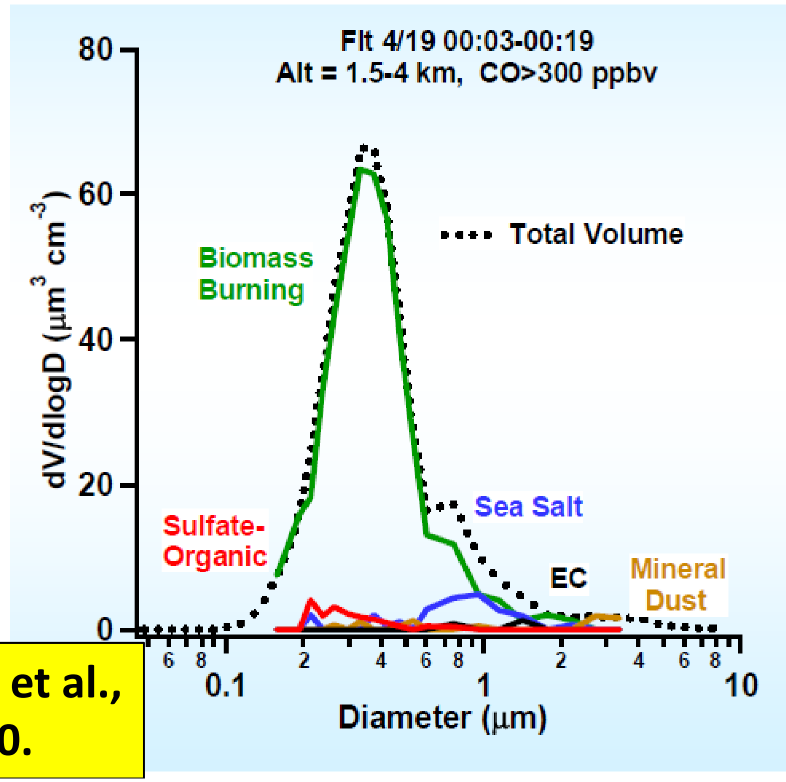
Evaluation of HSRL classification of aerosol type using airborne in situ data - April 19, 2008 – ARCTAS/ARCPAC

Biomass burning smoke is dominant aerosol type inferred from HSRL measurements of aerosol intensive parameters



NOAA P-3 PALMS aerosol composition data shows high biomass burn fraction

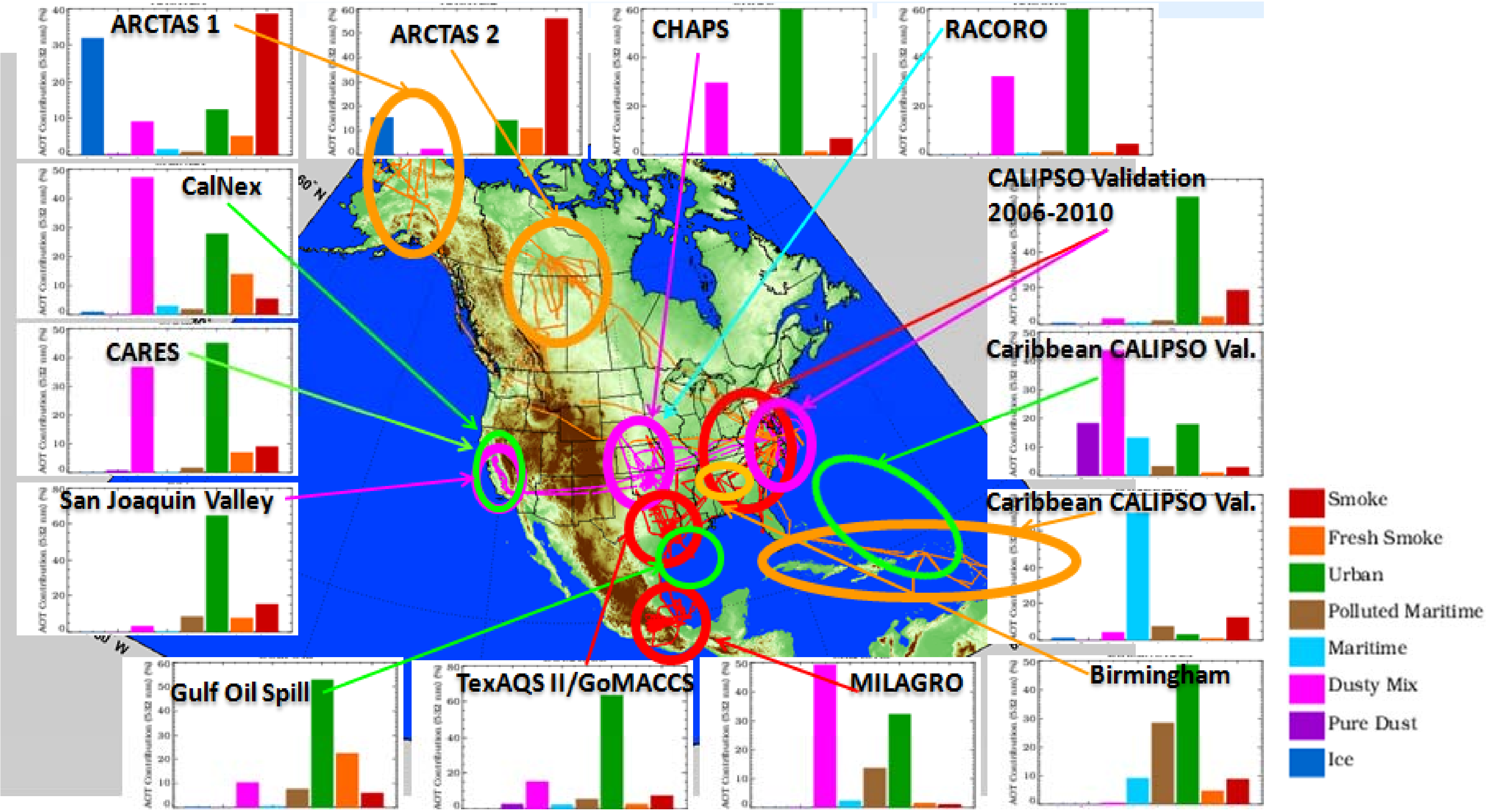
NOAA P-3 PALMS
aerosol size/composition



Warneke et al., GRL, 2010.

Apportionment of AOT to Aerosol Type

Fraction of AOT contributed by various aerosol types varies with location



(Warneke et al., 2010; Molina et al., 2010; deFoy et al., 2011)

VERTICAL VARIABILITY OF AEROSOL TYPES

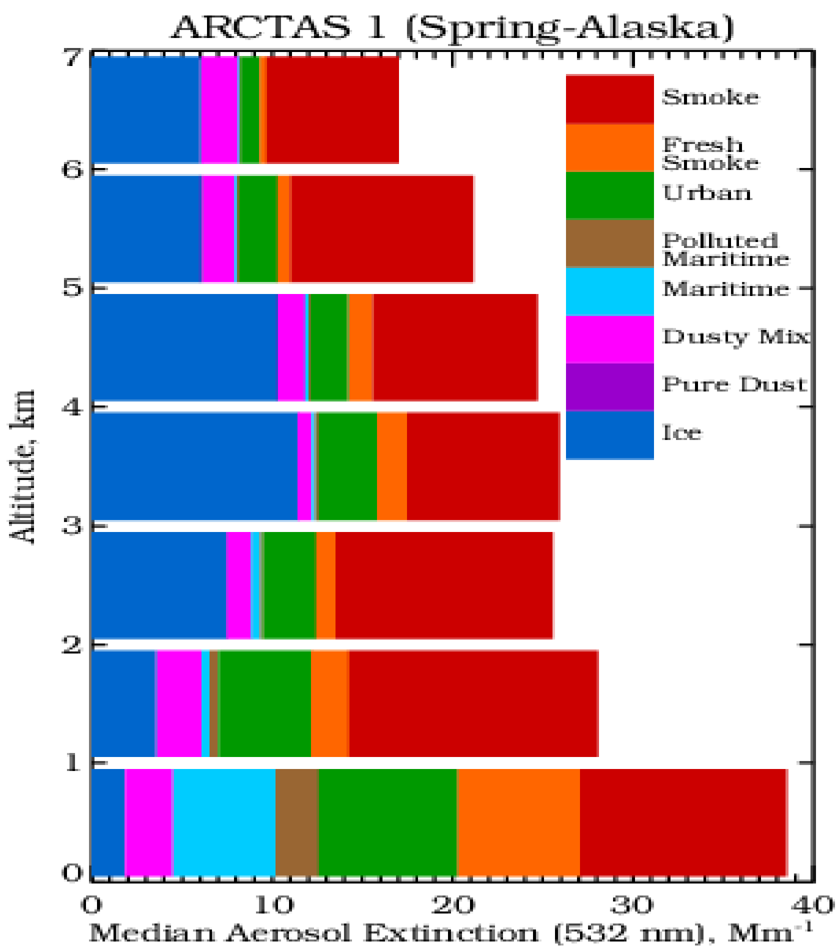
Apportionment of Aerosol Extinction Profile to Type - ARCTAS

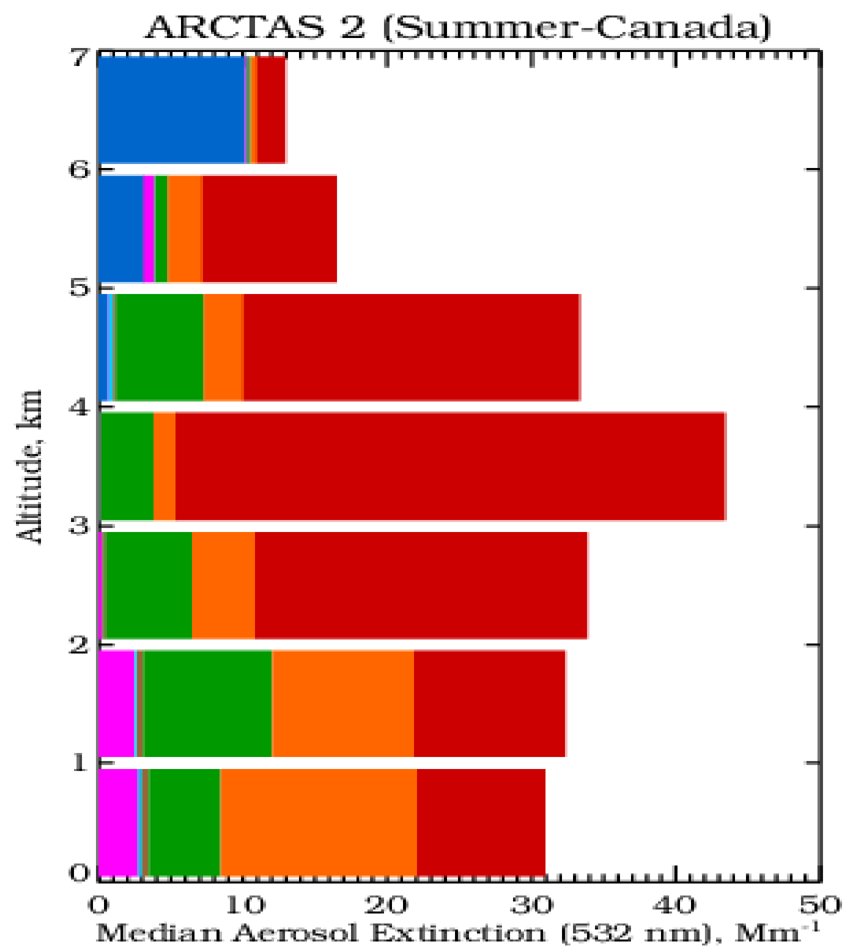
ARCTAS 1 (Spring – Alaska)

- Ice was pronounced from 2-5 km
- Smoke found at all altitudes
- Lowest levels had variety of aerosol types
- Urban type was most prominent at lowest levels

ARCTAS 2 (Summer – Canada)

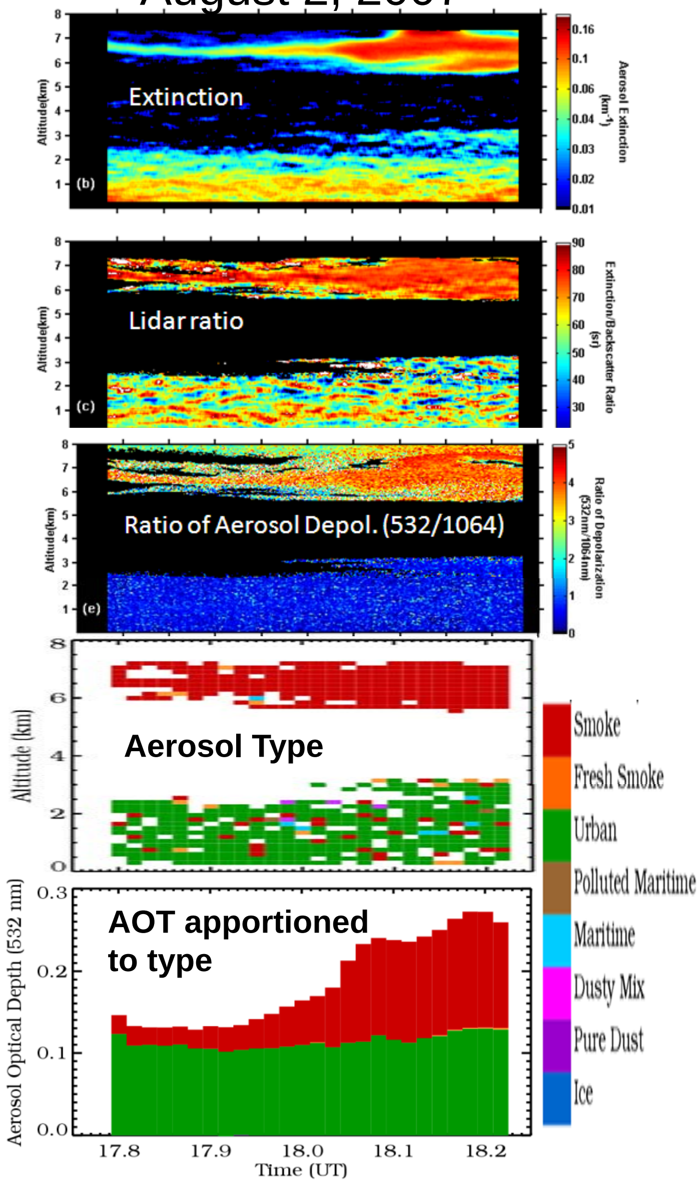
- Ice/dust found only at high altitude
- Lowest levels (< 2 km) smoke 2 (fresh smoke)
- Biomass burning was dominant type 2-6 km
- Smoke 1 (aged smoke) was dominant 2-5 km





Vertical Variability of Aerosol Types

August 2, 2007



- Multiple aerosol types are often found in a given profile (example - August 2, 2007 over Atlantic Ocean east of Norfolk)
- HSRL observations (2006-2009) show that:
  - multiple aerosol types are required to account for most (67% - 90%) of AOT in about 40%-75% of cases
- CALIPSO observations and GOCART simulations coincident with HSRL measurements also show multiple aerosol types are often required

INFERRING FINE MODE FRACTION FROM HSRL DATA

Inferring Profiles of Submicrometer Fraction (SMF) from HSRL data

Motivation:

- **Anthropogenic aerosols are predominantly submicrometer**
- **Fine mode fraction (FMF) retrievals from satellite sensors have been used as a tool for deriving anthropogenic aerosols**
- **Although satellite data from passive sensors have provided column-averaged FMF over the ocean, satellite retrievals of FMF <u>profiles</u> have not been demonstrated over land**

Definitions:

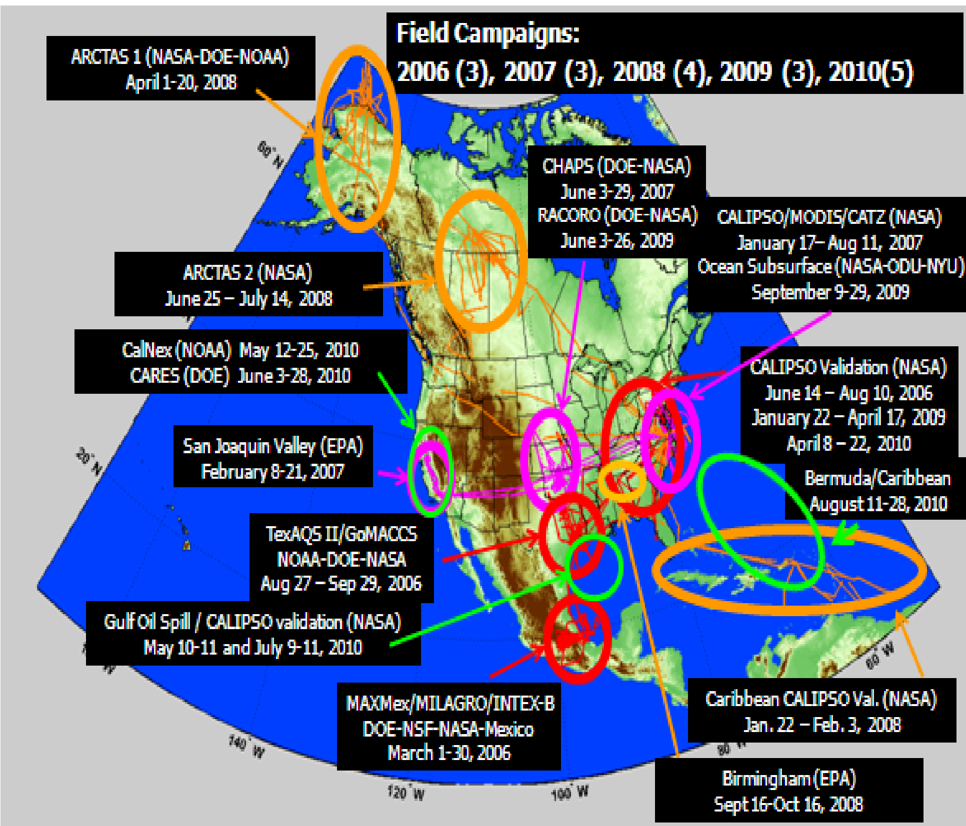
- **Fine Mode Fraction (FMF) is the fraction of aerosol optical depth associated with the fine aerosol mode.**
- **Submicrometer fraction (SMF) is the fraction of aerosols with diameters less than 1 micrometer and is closely related to FMF**

Objective:

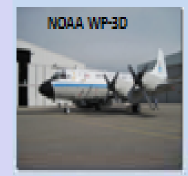
- **We examine the feasibility of using airborne lidar data to infer <u>profiles</u> of SMF**

Coincident HSRL, RSP, and Airborne In Situ Aerosol Measurements used to investigate retrievals of SMF

During several experiments, airborne in situ aerosol data were acquired within the HSRL "curtains" thereby facilitating direct correlations of the lidar observables to in situ measurements of particle size and composition



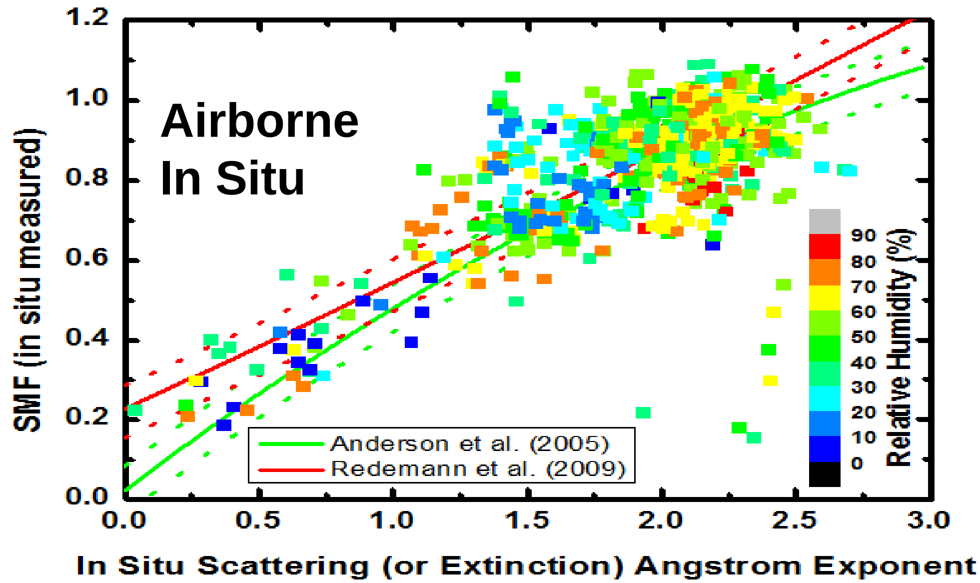
Field Mission	Location	Period	Measurements Coincident with HSRL		
			Aircraft	CALIPSO	RSP
MILAGRO[1]	Mexico City	March 2006	NSF C130, DOE G1, J-31		
CALIPSO Validation	Eastern USA	Summer 2006		X	
TexAQS/GoMACCS[2]	Texas	Aug-Sep 2006	NOAA P3, CTO[3]	X	
San Joaquin Valley	California	Feb 2007			
CHAPS/CLASIC[4]	Oklahoma	Jun 2007	DOE G1, CTO[3]	X	
CATZ[5]	Eastern US	Aug 2007		X	
CALIPSO Validation	Caribbean	Feb 2008		X	
ARCTAS[6] Spring	Alaska	Apr 2008	Convair 580, NASA P3, NOAA P3, NASA DC8	X	
ARCTAS[6] Summer	Canada	Jun-Jul 2008	NASA P3, NASA DC8	X	X
EPA Birmingham	Birmingham AL	Sep-Oct 2008			X
RACORO[7]	Oklahoma	Jun 2009	CTO[3]	X	XX
Ocean Subsurface	Norfolk	Sept 2009		X	XX
CALNEX[8]	California	May 2010	DOE G1, NOAA P3, CTO[3]		XX
CARES	California	Jun 2010	DOE G1, NOAA P3		XX
Gulf Oil Spill	Gulfport MS	Summer 2010		X	XX
CALIPSO Validation	Caribbean	August 2010		X	XX
CALIPSO Validation	Eastern USA	March 2011		X	(night
DISCOVER-AQ	Baltimore-DC	July 2011	NASA P3		



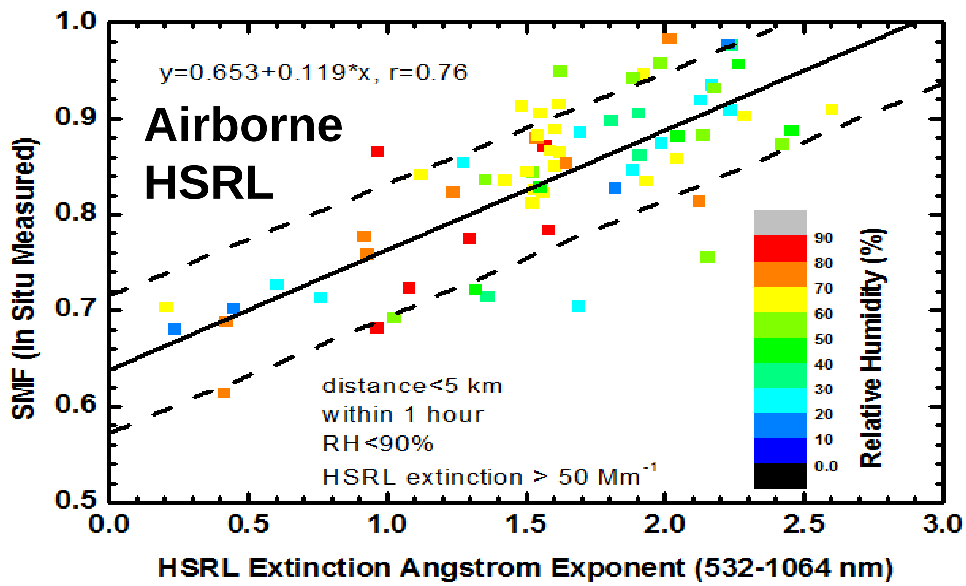
Extinction Angström Exponent and SMF

Data from these missions show:

- **Airborne in situ measurements of SMF are correlated with Angström exponents derived from in situ measurements of scattering or extinction in a manner similar to those found from previous missions**



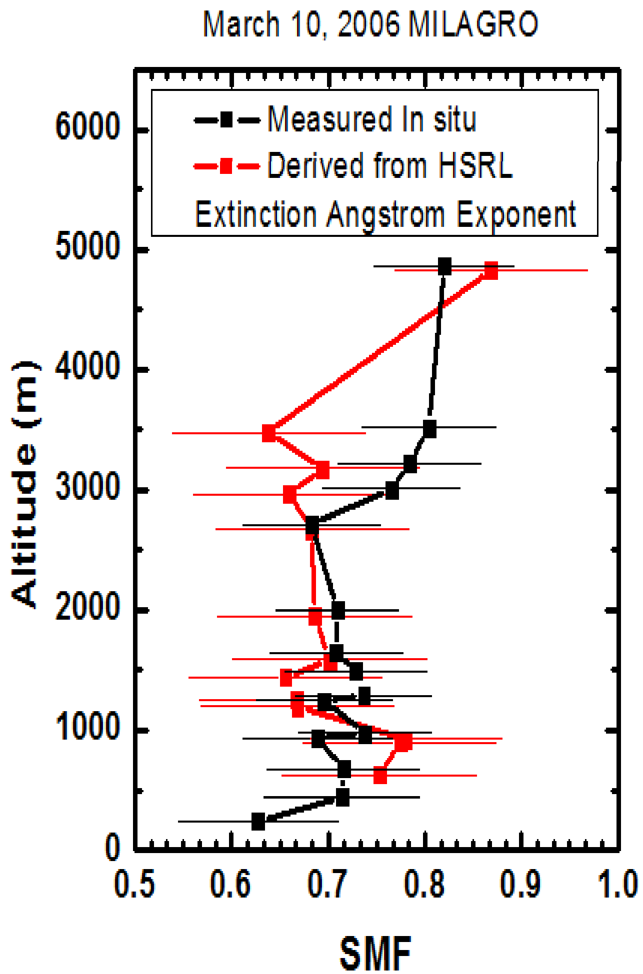
- **HSRL measurements of extinction Angström exponent are correlated with in situ measurements of SMF**

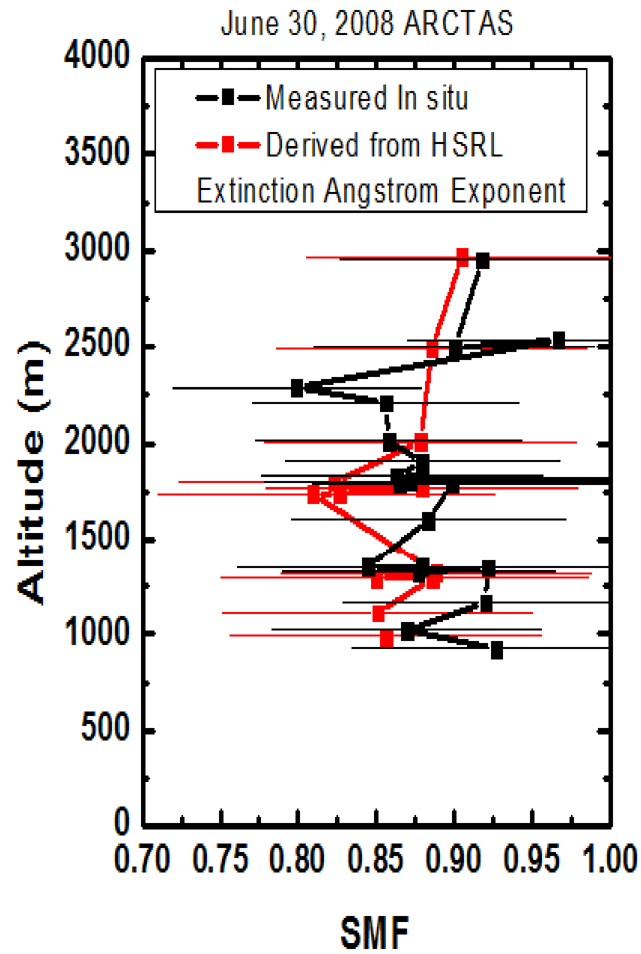


➢ **HSRL measurements of extinction Angström exponent may be used to infer SMF**

Inferring profiles of SMF from HSRL Measurements of Extinction Angstrom Exponent

HSRL measurements of aerosol extinction Angström exponent are used to infer profiles of SMF during MILAGRO and ARCTAS

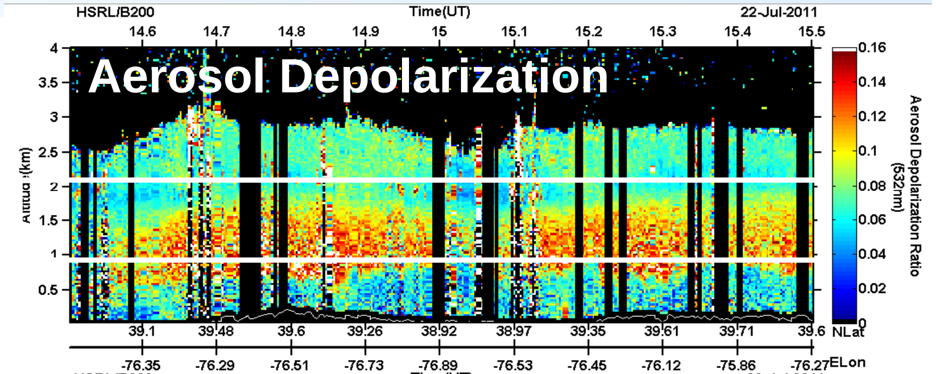


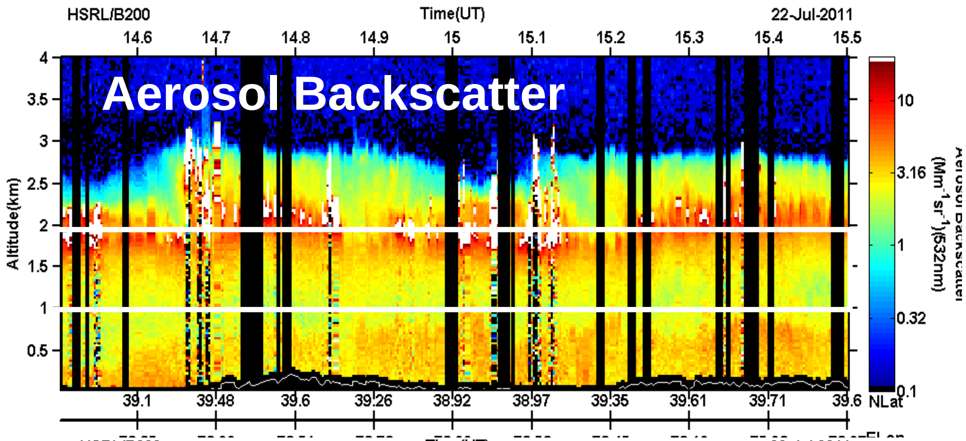


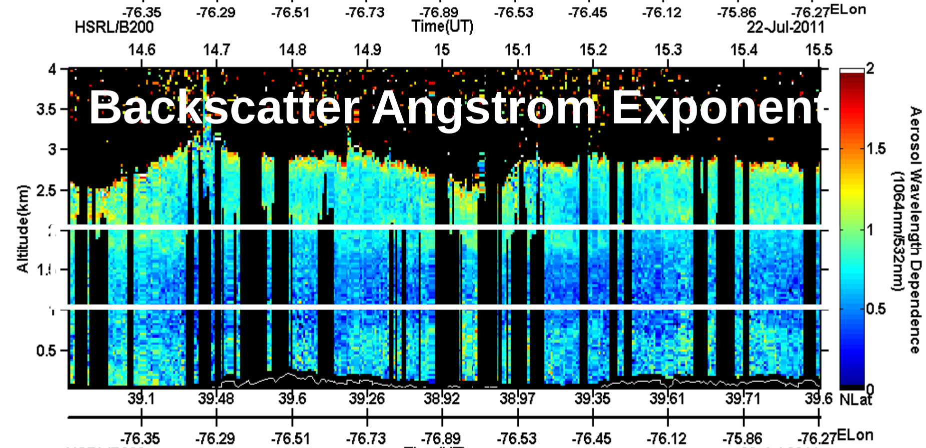
HSRL MEASUREMENTS OF HUMIDIFICATION IMPACTS ON AEROSOL OPTICAL PROPERTIES

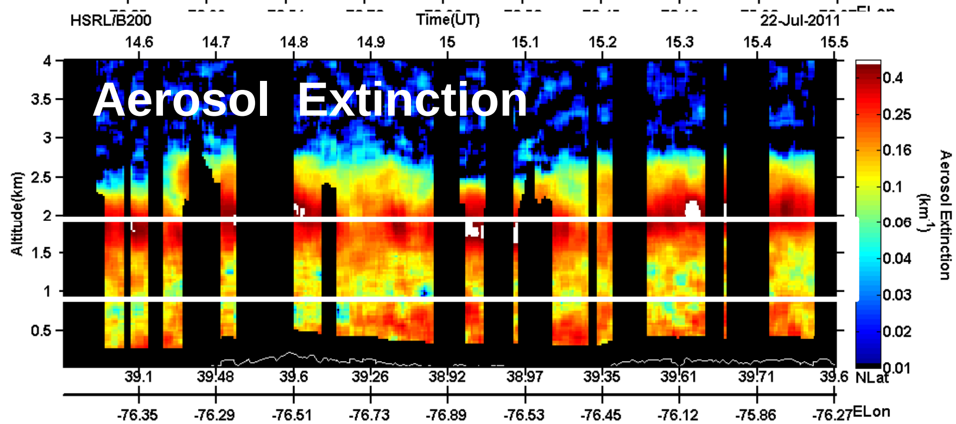
HSRL measurements of Changes in Aerosol Properties associated with Humidification

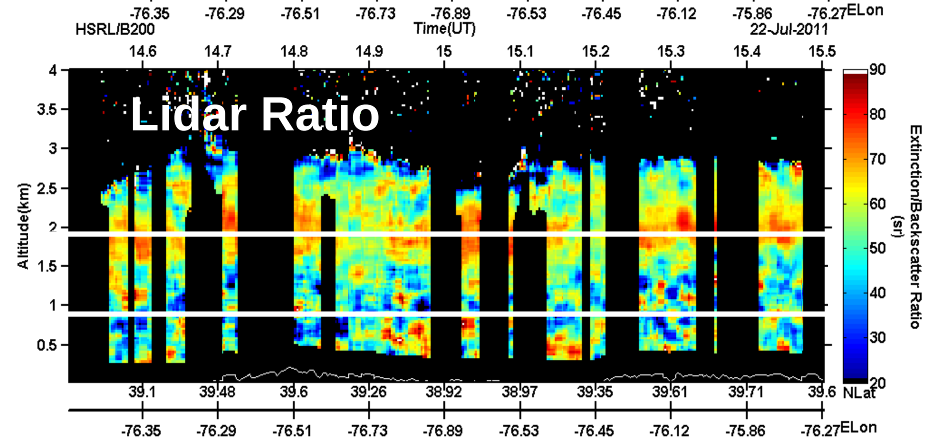
- **DISCOVER-AQ July 22, 2011**
- **Large increase in aerosol backscatter and extinction associated with increase in RH from 1 to 2 km**
- **Increase in RH also caused variations in aerosol intensive parameters**





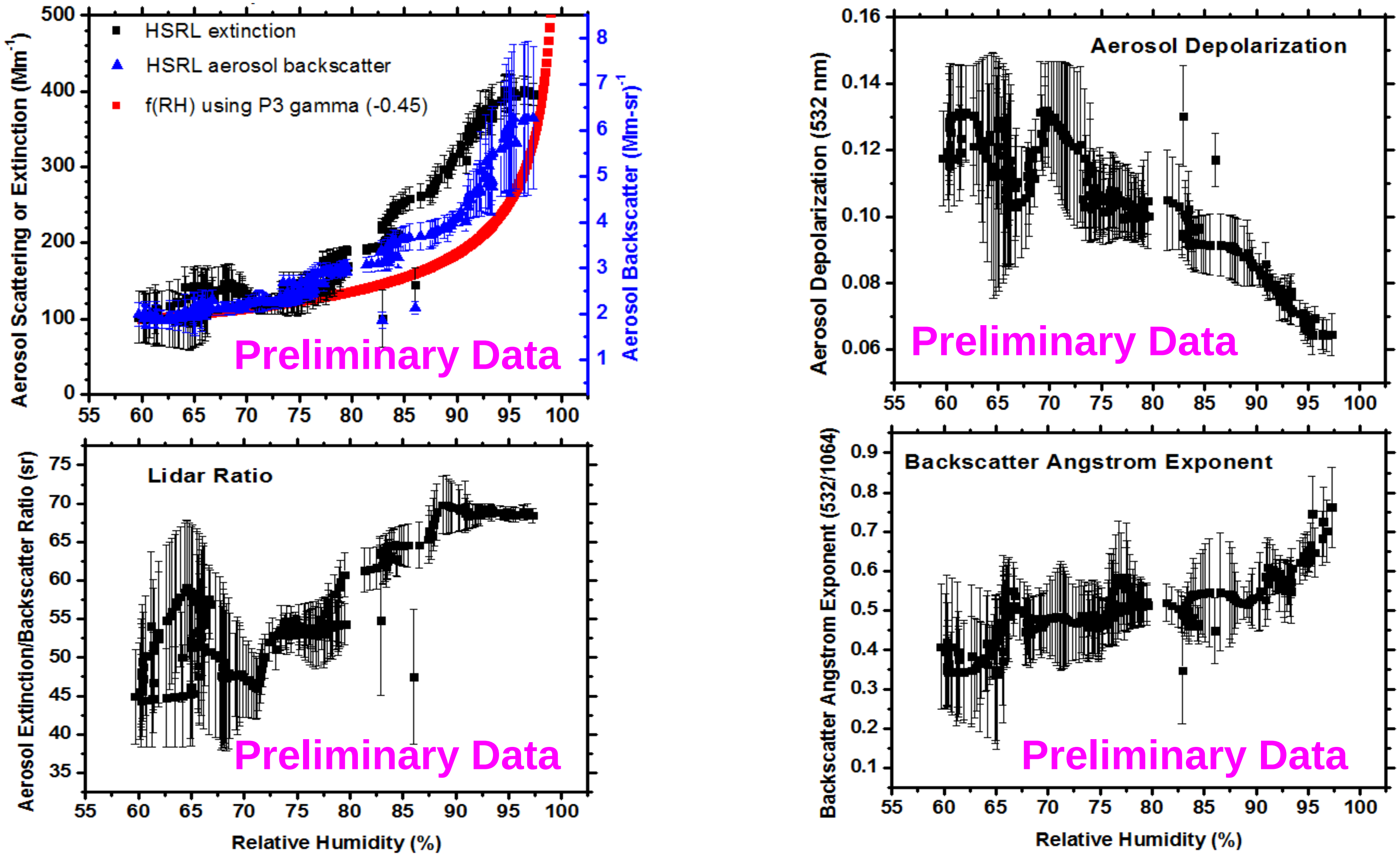






Humidification impacts on aerosol optical parameters

- At high (>85%) RH, HSRL data show larger increases in backscatter and extinction than derived from in situ f(RH)
- Decrease in Aerosol Depolarization with RH associated with particles becoming more spherical
- Increase in Backscatter Angstrom Exponent with RH associated with increased scattering in accumulation (fine) mode relative to coarse mode aerosols



Summary – Airborne HSRL Measurements

- Retrieve profile measurements of aerosol extinction, backscatter, and aerosol optical depth
- Qualitatively classify aerosol type and apportion aerosol optical depth to type
- Infer of profiles of submicrometer fraction
- Quantify effects of aerosol humidification on aerosol extensive and intensive parameters

➢ **Goals**
  - **Combine HSRL and passive measurements to better quantify profile of aerosol optical and microphysical parameters**
  - **Retrieve aerosol optical and microphysical parameters from advanced multiwavelength airborne HSRL under development**

Thanks for your attention!

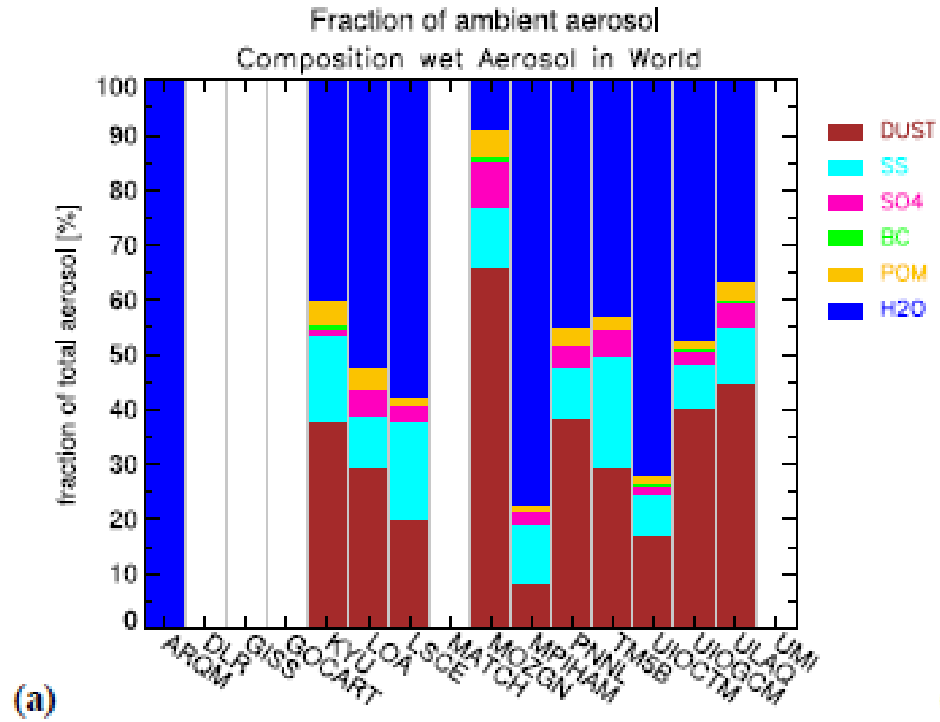
Questions ?

Extra Slides

Aerosol Humidification Effects

Motivation:

- Hygroscopic growth can have a large impact on measured aerosol optical properties
- Difficult for in situ instruments to characterize hygroscopic growth at high (>85%) RH
- Very high diversity among models for water uptake



Textor et al. (2006)

Objective:

- Quantify effects of aerosol humidification using HSRL measurements

Summary – Airborne HSRL Measurements

- Retrieve profile measurements of aerosol extinction, backscatter, and aerosol optical depth
- Qualitatively classify aerosol type and apportion aerosol optical depth to type
- Infer of profiles of submicrometer fraction

➢ **Goals**

  – **Combine HSRL and passive measurements to better quantify <u>profile</u> of aerosol optical and microphysical parameters**
  – **Retrieve aerosol optical and microphysical parameters from advanced multiwavelength airborne HSRL under development**

Planetary Boundary Layer (PBL) Height Retrievals and Aerosol Optical Thickness (AOT)

Motivation:

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

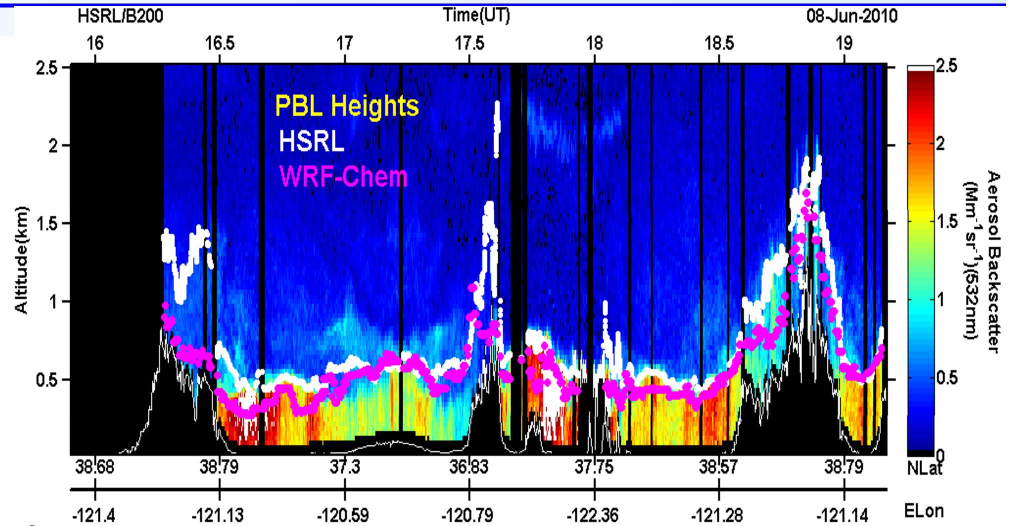
Objective:

Use airborne HSRL measurements to derive PBL height and fraction of Aerosol Optical Thickness (AOT) within PBL

Planetary Boundary Layer (PBL) Height Retrievals and AOT

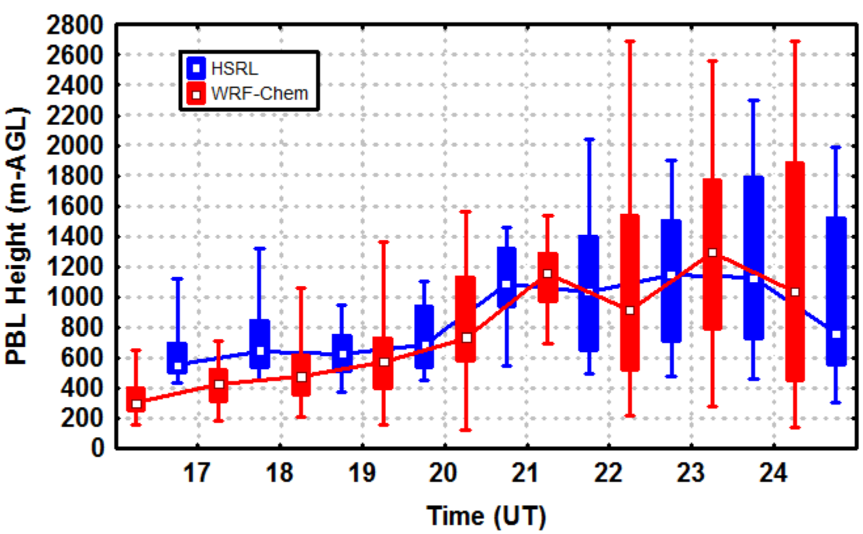
HSRL data used to determine:

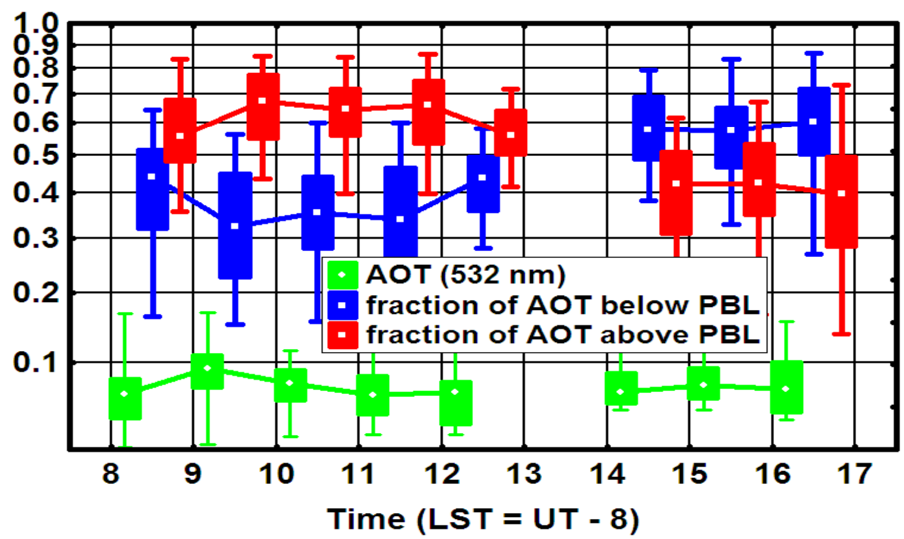
- **PBL height**
- **Upper and lower limits of the backscatter transition (i.e. entrainment) zone**
- **Fraction of aerosol optical thickness within PBL**



During DOE CARES Mission(Sacramento)

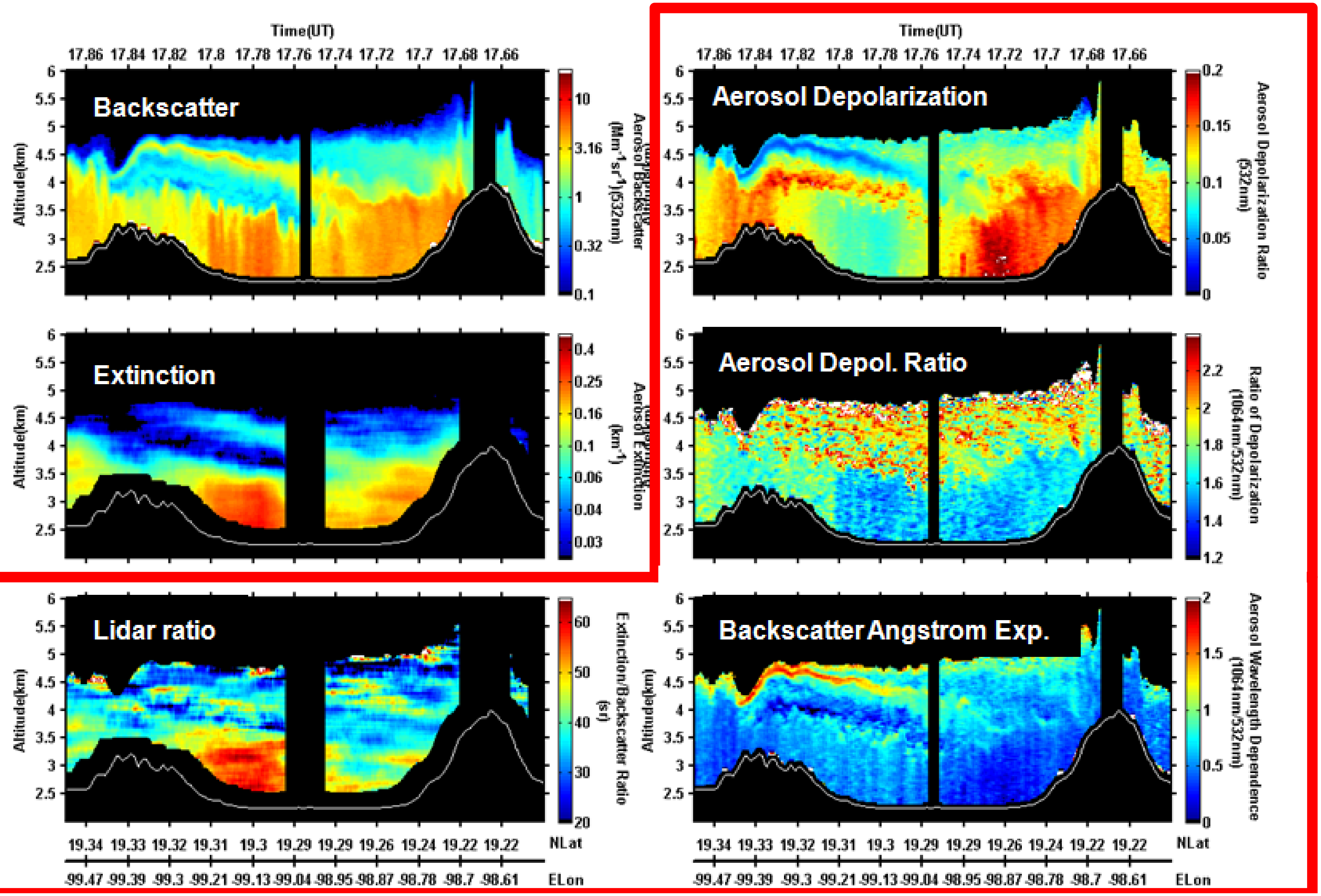
- **HSRL and WRF-Chem PBL heights are in reasonably good agreement in afternoon**
- **Much of AOT remains above PBL**





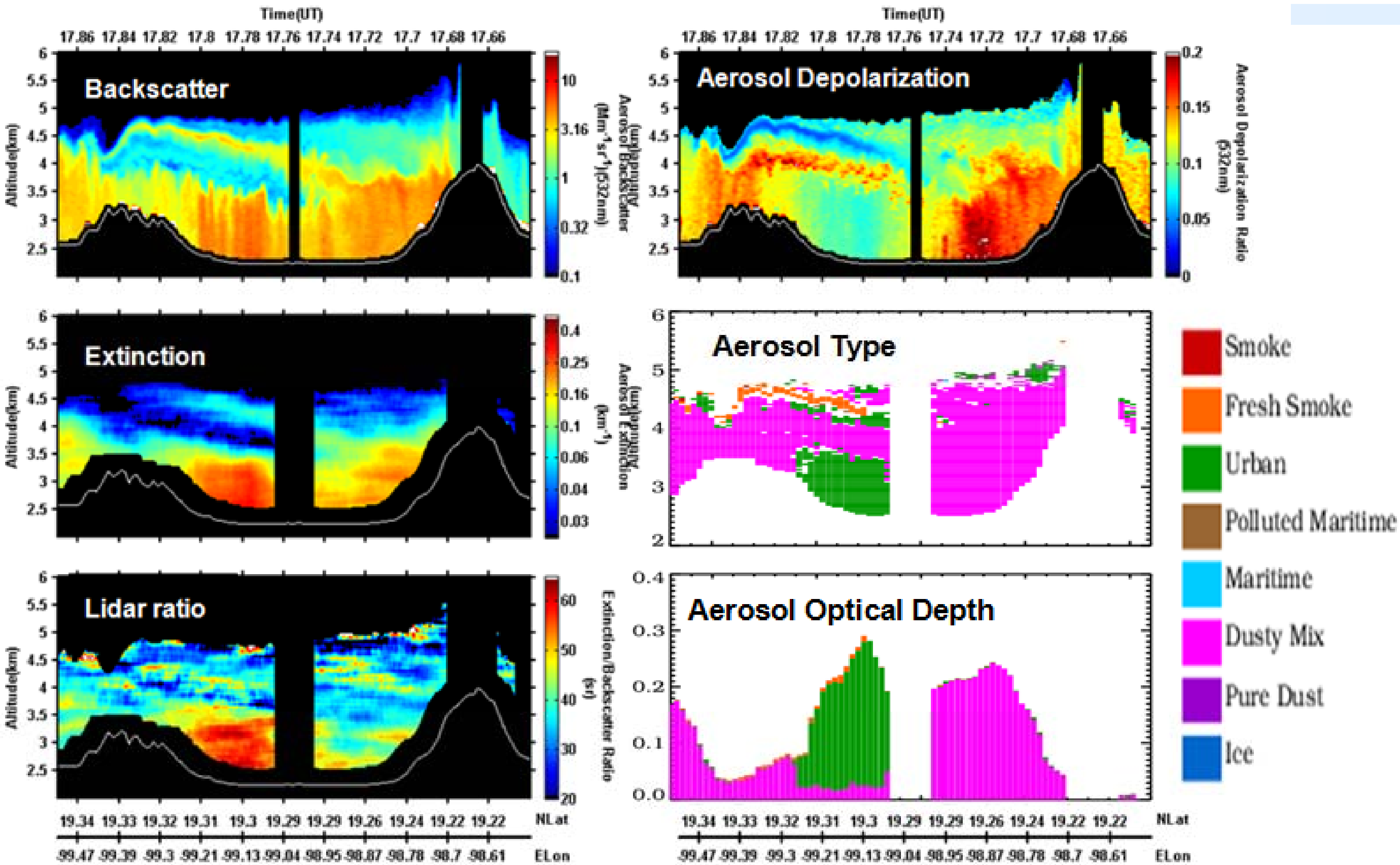
Aerosol Variability Measured by HSRL

Note the variability in aerosol intensive parameters over Mexico City



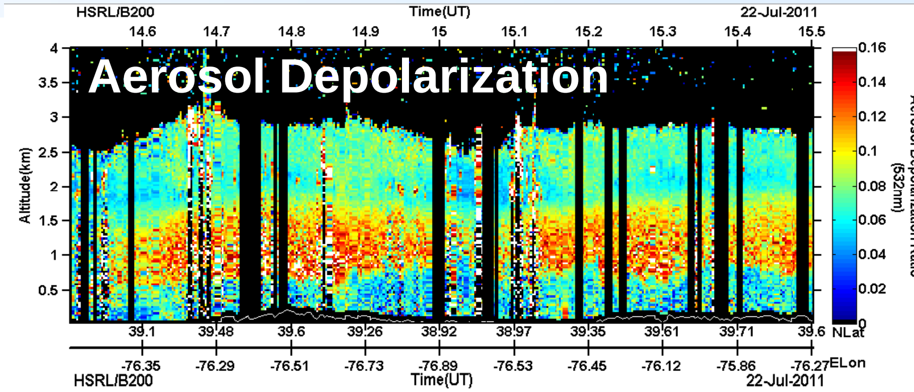
Example of Aerosol Classification using HSRL measurements

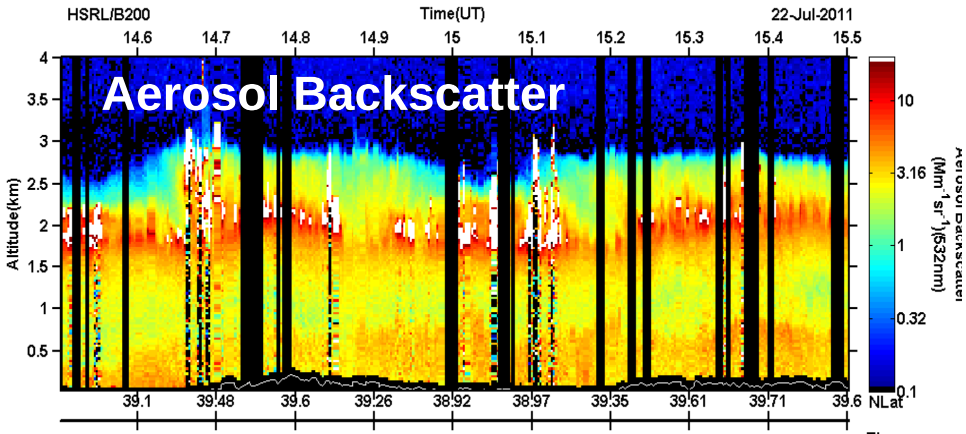
Apportionment of aerosol AOT to type over Mexico City – March 13, 2006

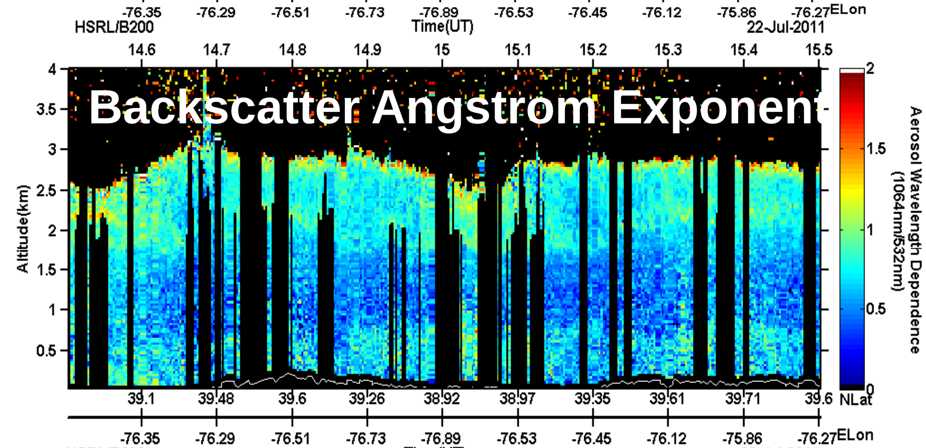


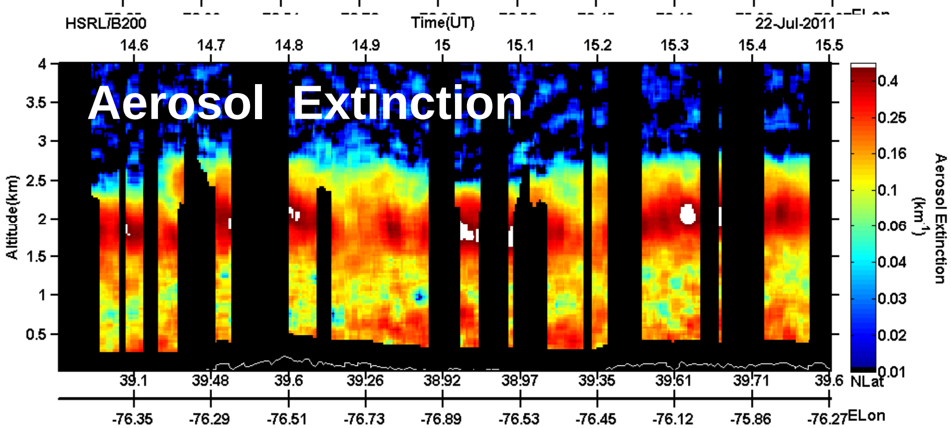
HSRL measurements of Aerosol Humidification

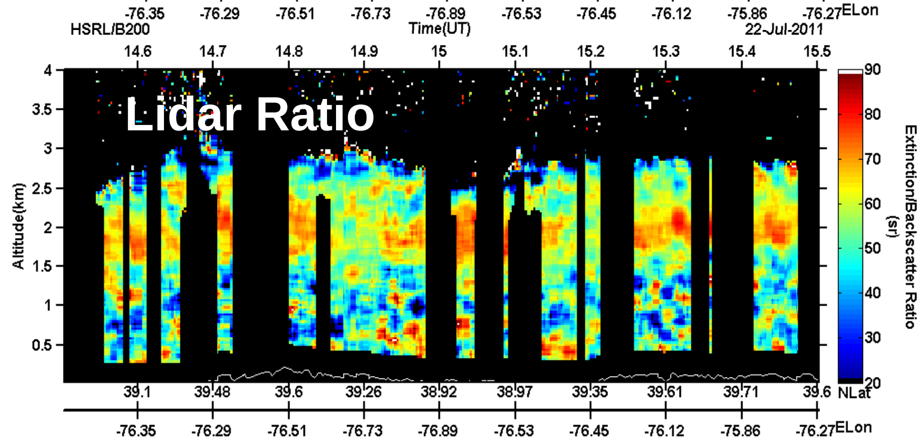
- **DISCOVER-AQ July 22, 2011**
- **Large increase in aerosol backscatter and extinction associated with increase in RH from 1 to 2 km**
- **Increase in RH also caused variations in aerosol intensive parameters**



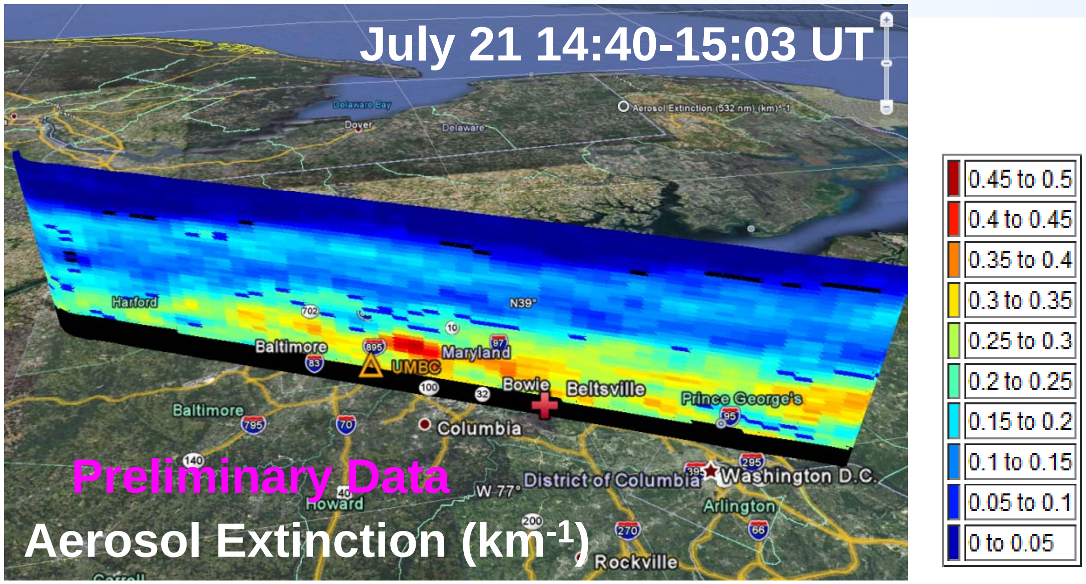


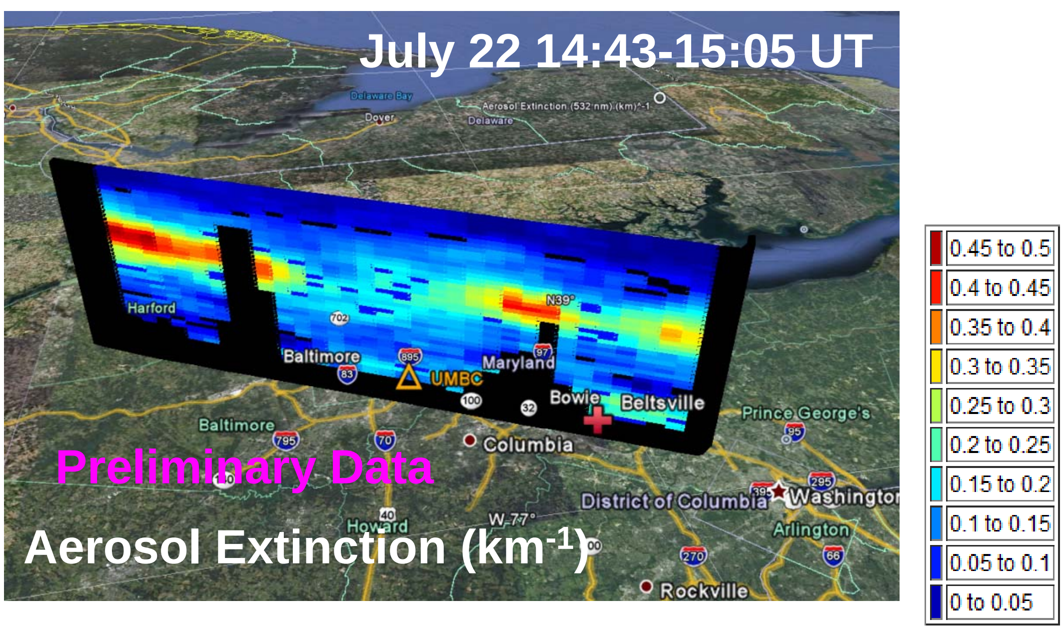






Variability in the Vertical Distribution of Aerosols – DISCOVER-AQ - July 2011



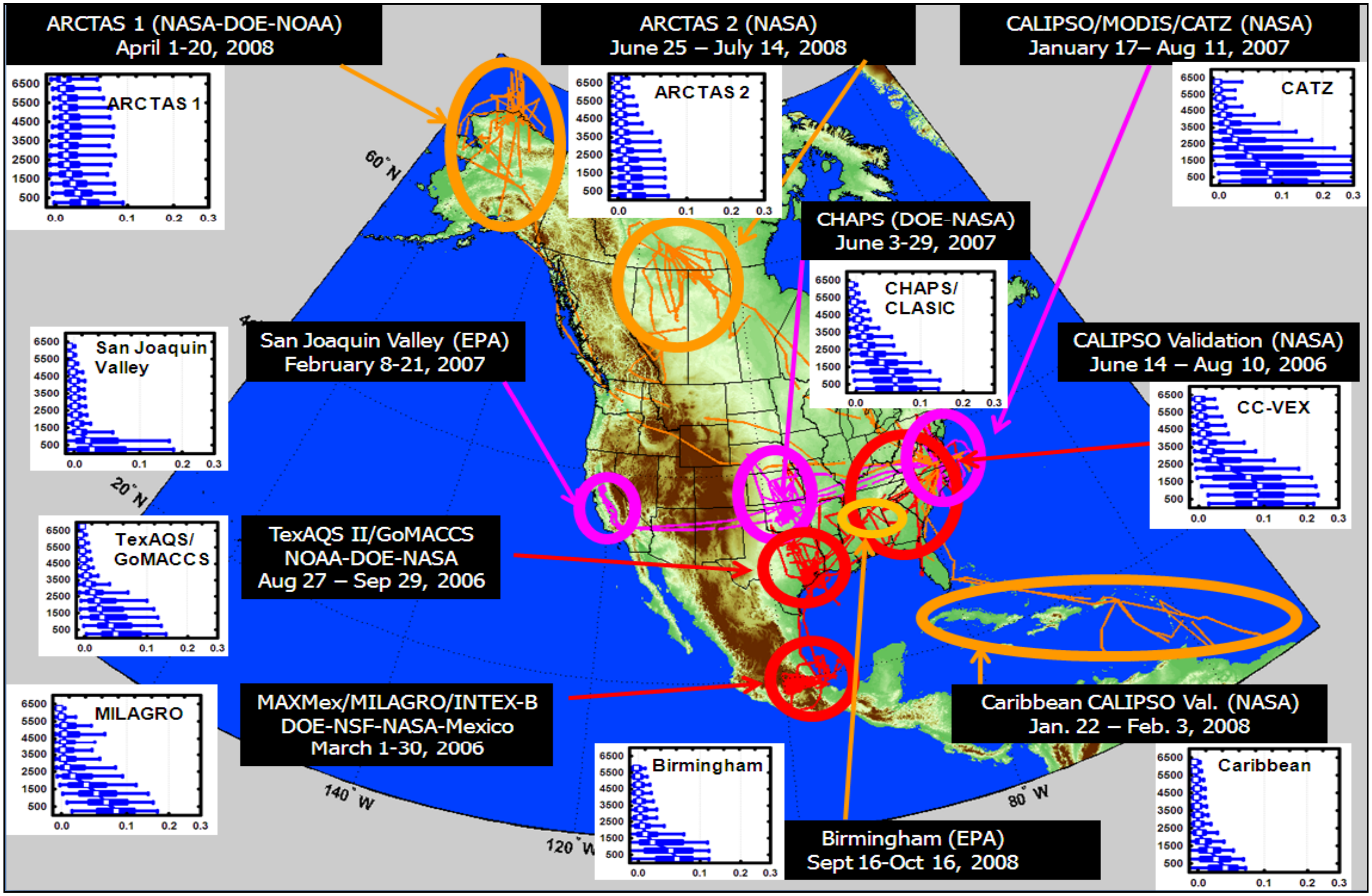


- Aerosol extinction between 0-3 km over Baltimore – Washington, DC. during DISCOVER-AQ
- Similar AOT values on July 21 and 22
- July 21
  - Decrease in aerosol extinction with altitude
  - Highest aerosol extinction within the lowest kilometer
- July 22
  - Increase in aerosol extinction with altitude
  - Highest aerosol extinction found about 2 km above surface

Vertical distribution of aerosols changed appreciably on consecutive days

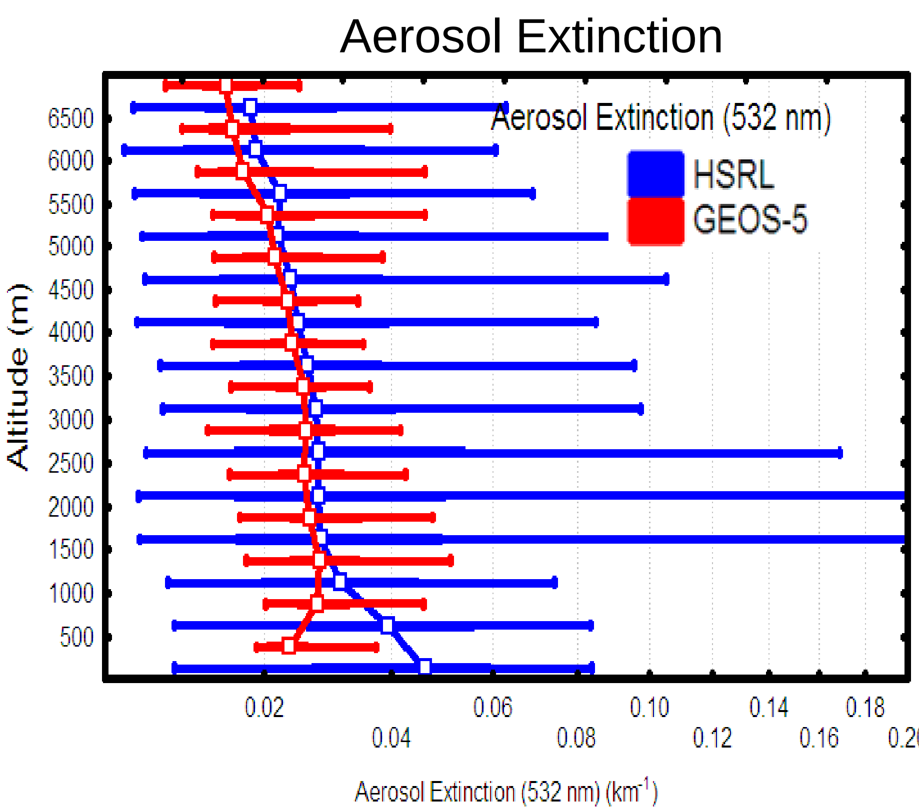
Vertical Distribution of Aerosols

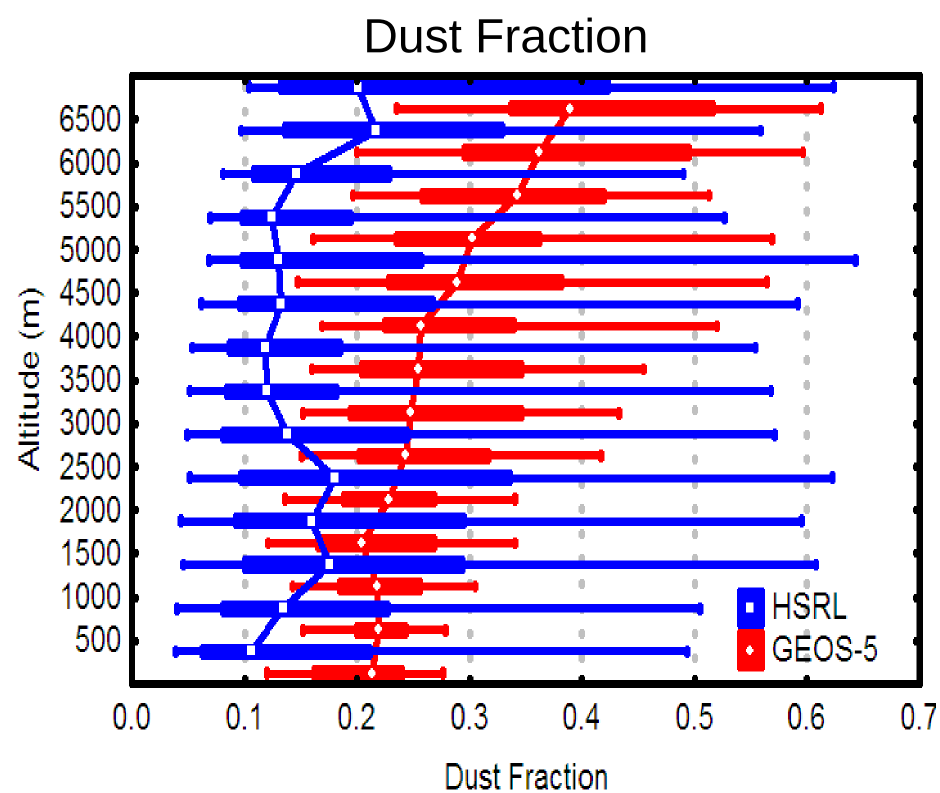
Median Aerosol Extinction Profiles



Comparison of HSRL data and GEOS-5 model – ARCTAS - 2008

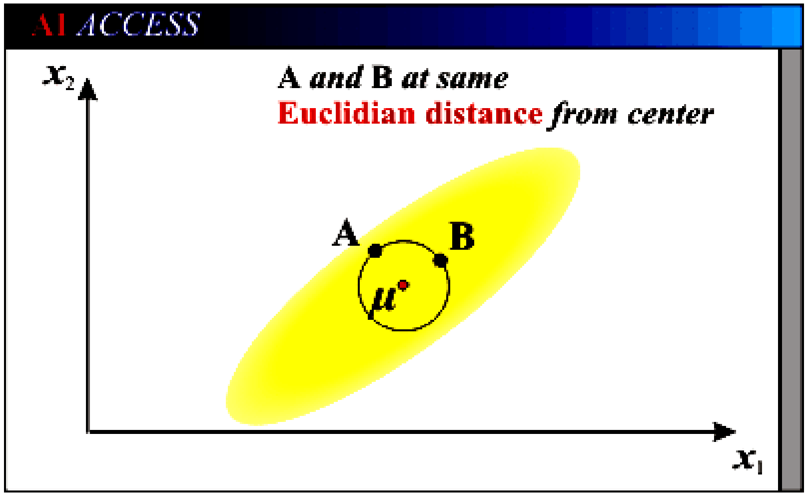
- Overall, good agreement between average HSRL measurements and GEOS-5 simulations of aerosol extinction
- HSRL measurements of aerosol depolarization used to estimate dust fraction following Sugimoto and Lee (2006)
- GEOS-5 dust fractions are generally higher than HSRL estimates and these differences increase with altitude

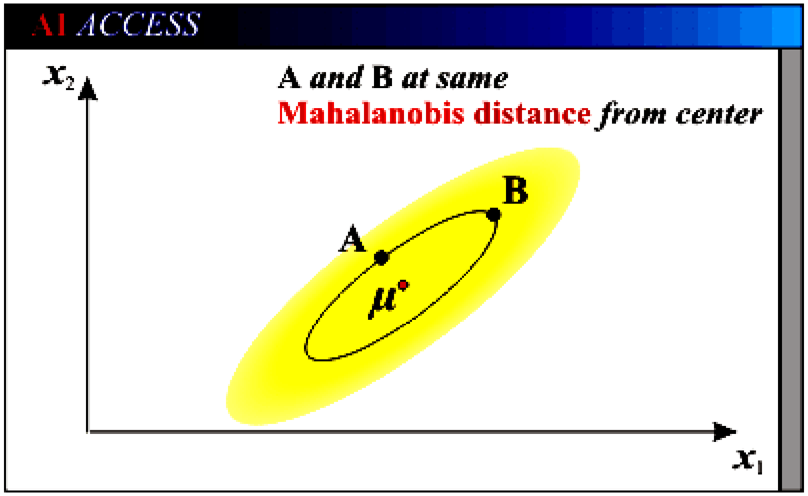




HSRL Aerosol Classification Method

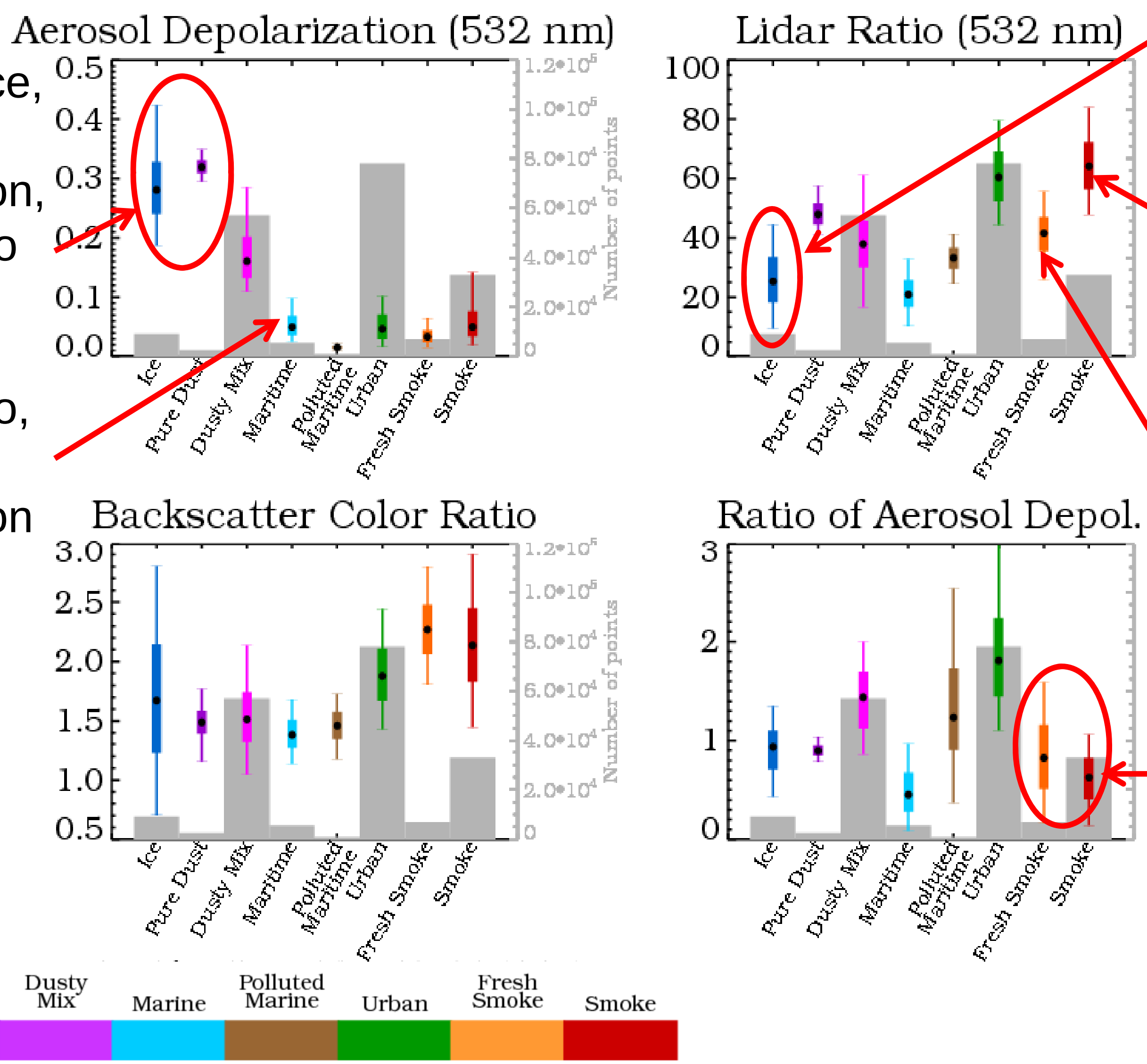
- Uses four aerosol intensive parameters (i.e. parameters that depend only on aerosol type, not amount)
- Computes Mahalanobis distance, instead of Euclidean distance, to sort points into classes
- Employs a training set comprised of 24 labeled samples (over 26000 points, about 0.35% of all data)
- Estimates the 4-D normal distributions of classes from labeled data, then calculates Mahalanobis distance from each point to each class





Classification results for all 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 depolarization than urban

Vertical Distribution of Aerosols

Motivation:

- Vertical distribution of aerosols impacts:
  - aerosol transport
  - air quality
  - direct and indirect effects on radiation
- Considerable diversity among model simulations of vertical profiles of aerosols

Objective:

Use airborne HSRL measurements to examine and quantify vertical profile of aerosols for use in assessing models and interpreting column measurements

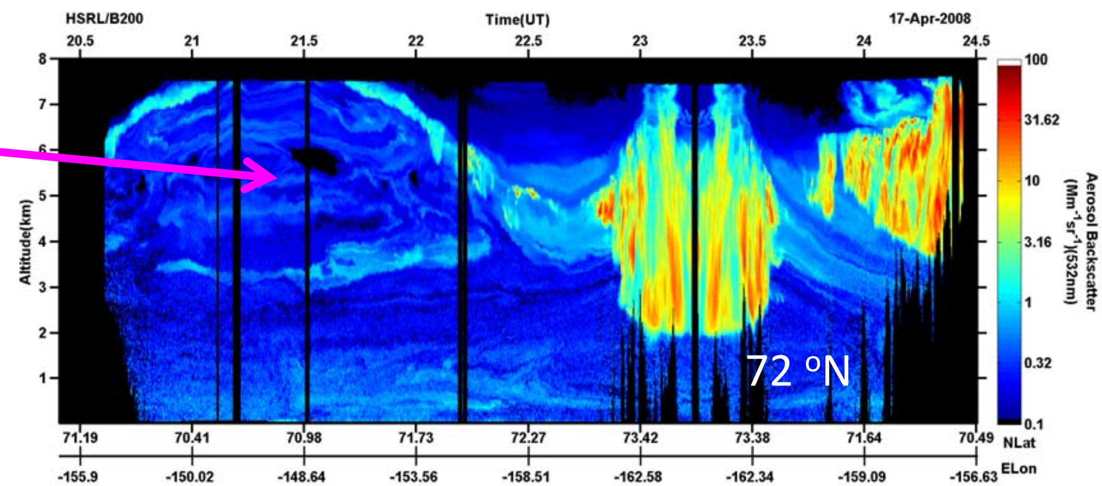
Variability in the Vertical Distribution of Aerosols

Arctic – aerosols spread throughout troposphere

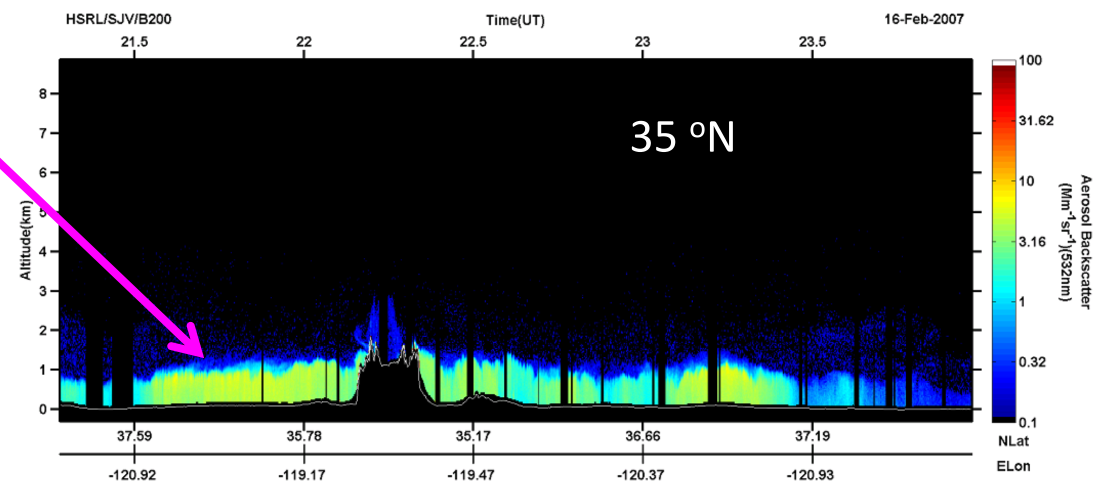
California San Joaquin Valley – aerosols concentrated in PBL

Vertical distribution of aerosols varies widely and depends on many factors

Barrow, Alaska, Apr. 17, 2008

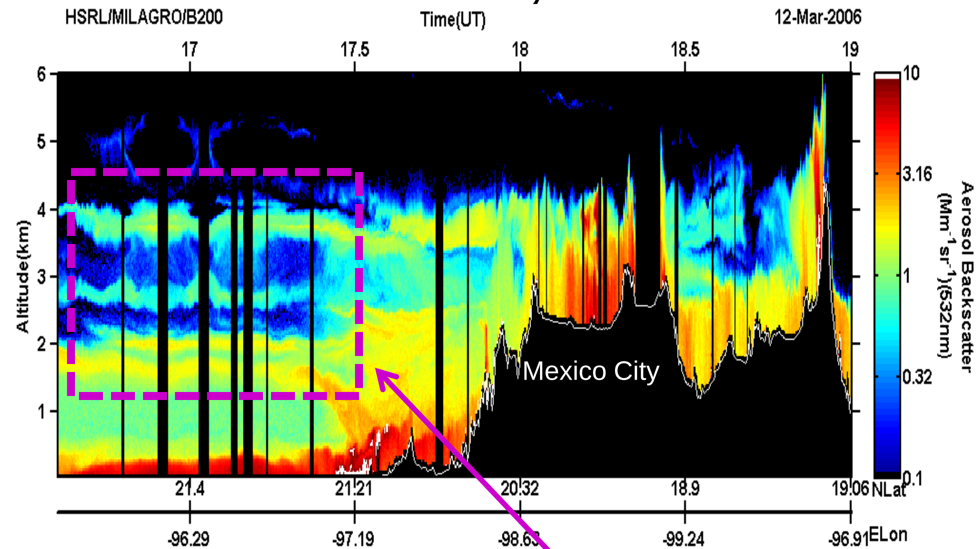


San Joaquin Valley, California, Feb. 16, 2007

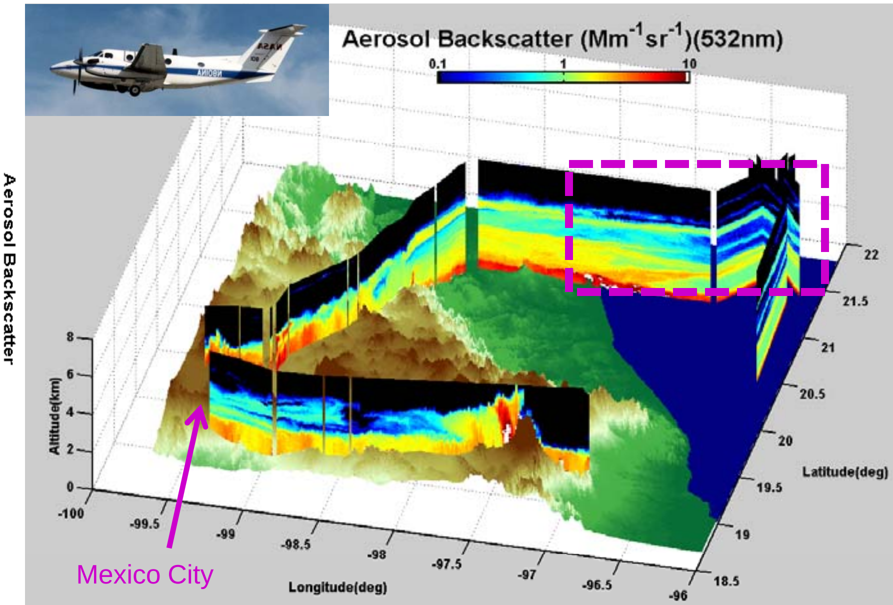


HSRL Profiles of Aerosol Backscatter are used to Evaluate WRF-Chem Model

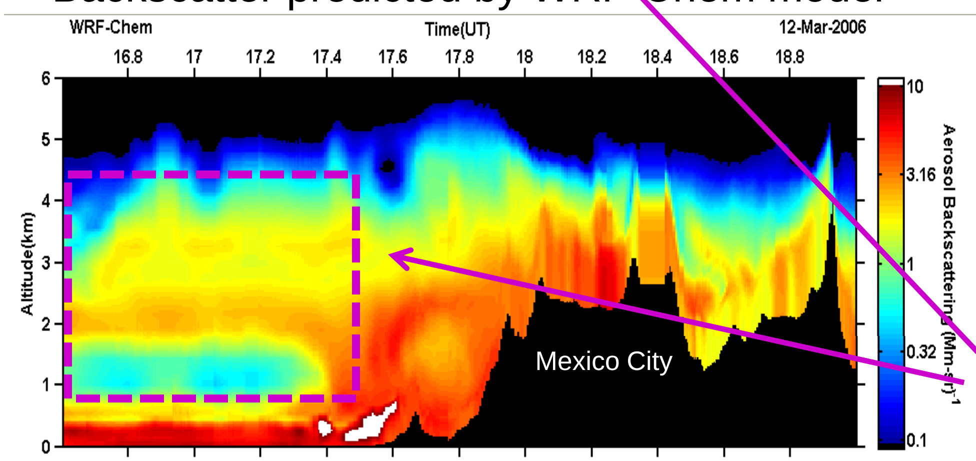
Backscatter measured by airborne HSRL



NASA/LaRC B200/HSRL March 12, 2006



Backscatter predicted by WRF-Chem model



Fast et al., 2011

- 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