Airborne High Spectral Resolution Lidar Aerosol Measurements and Comparisons with GEOS-5 Model

Richard Ferrare, Chris Hostetler, John Hair, Anthony Cook, David Harper, Mike Obland, Ray Rogers, Sharon Burton, Amy Jo Swanson
NASA Langley Research Center
Karl Froyd
NOAA/ESRL
Peter Colarco
NASA Goddard Space Flight Center
Norm O'Neill
Université de Sherbrooke, Canada

NASA Langley Airborne High Spectral Resolution Lidar (HSRL)

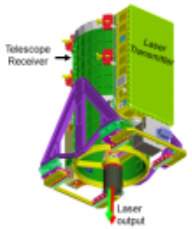
HSRL Technique:

- Relies on spectral separation of aerosol and molecular backscatter in lidar receiver
- Independently measures aerosol backscatter, extinction, and optical thickness
- Internally calibrated
- Provides intensive aerosol parameter to help determine aerosol type

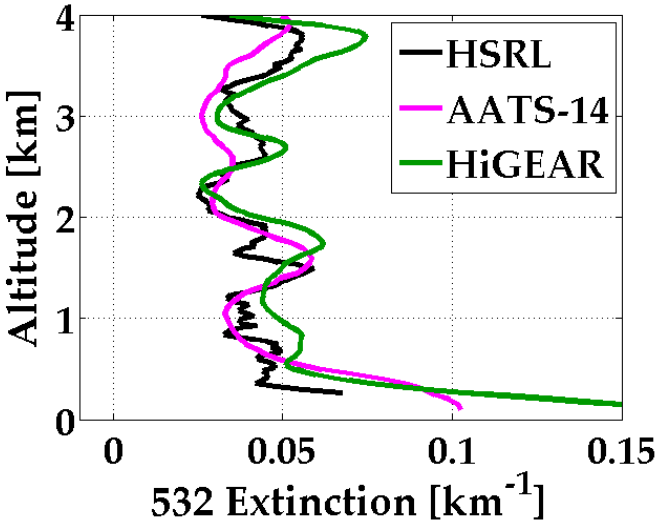
For a description of system and technique, see Hair et al., Appl. Optics, 2008

HSRL Aerosol Data Products:

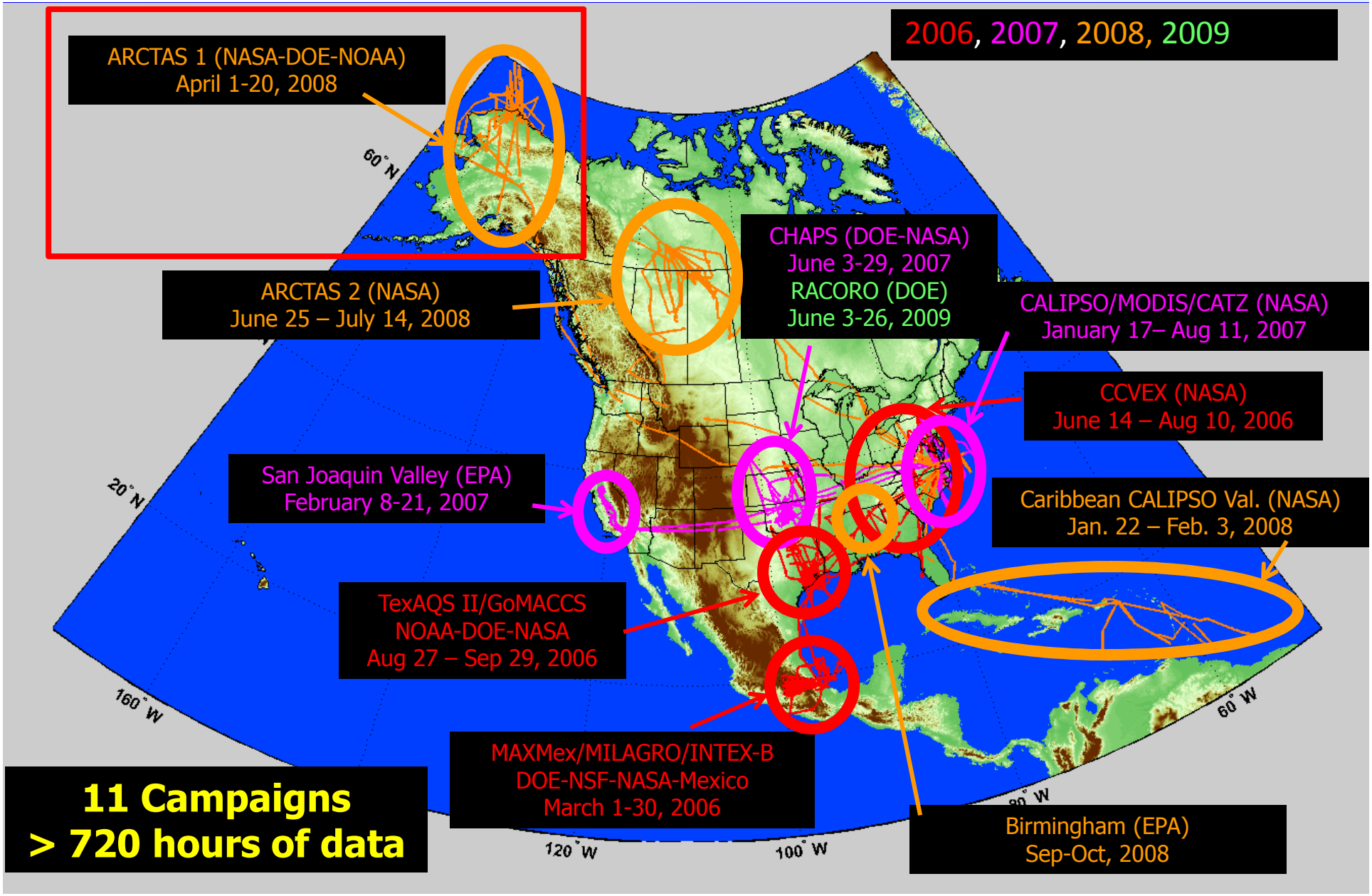
- Scattering ratio (532 nm)
- Backscatter coefficient (532, 1064 nm)
- Extinction Coefficient (532 nm)
- Backscatter Wavelength Dependence (532/1064 nm)
- Lidar ratio (532 nm)
- Depolarization (532, 1064 nm)



Validation – aerosol extinction
- bias differences ≤ 3 Mm^{-1}
- rms differences ≤ 15 Mm^{-1}
Rogers et al., (2009)

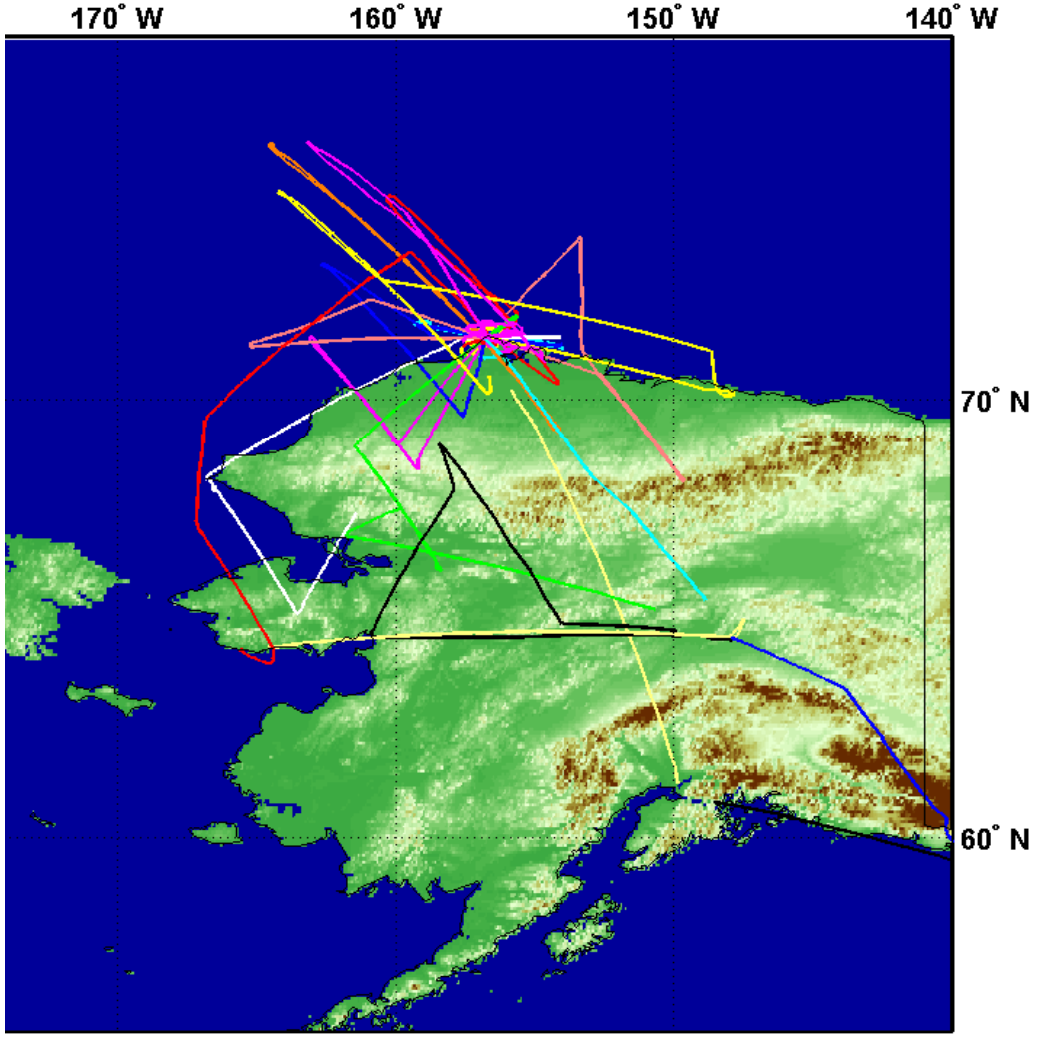


NASA Langley airborne High Spectral Resolution Lidar (HSRL) Field Campaigns



B200/HSRL Deployment During ARCTAS (Spring)

- B200 based in Barrow, Alaska
- 18 flights in Alaska
- 96 hours total, 59 hours science
- 5 flights coordinated with NASA DC-8
- 3 flights coordinated with NASA P-3
- 3 flights coordinated with NOAA P-3
- 5 flights over 4 days coordinated with DOE (Canada) Convair 580
  - April 4, 8, 13, 19
- 12 flights included underpass of CALIPSO and A Train
- Several flights included underpass of Terra MODIS/MISR
- 10 flights included overpass near or over DOE ARM North Slope of Alaska (NSA) Climate Research Facility
  - April 3, 4, 6, 8, 9, 12, 13, 16, 19

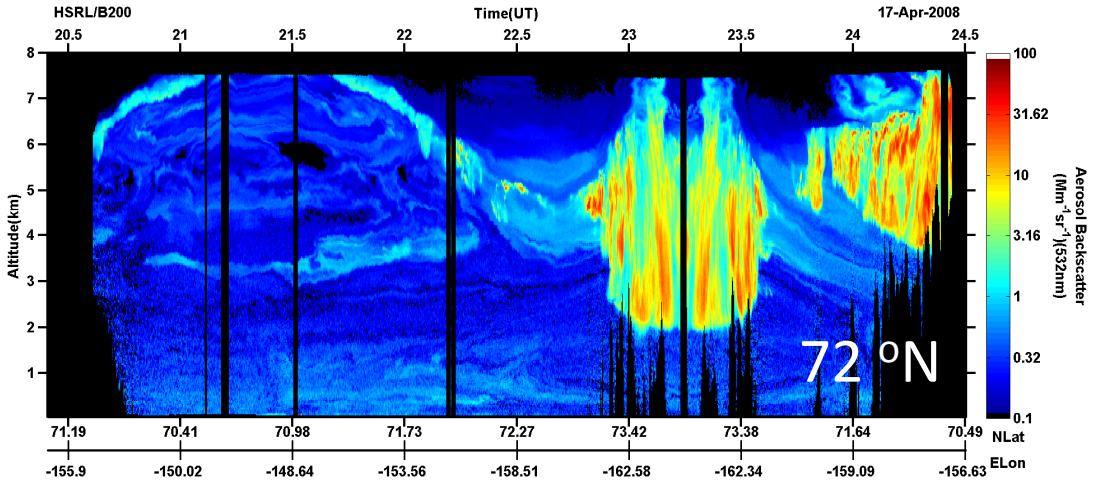


Vertical Distribution of Aerosols

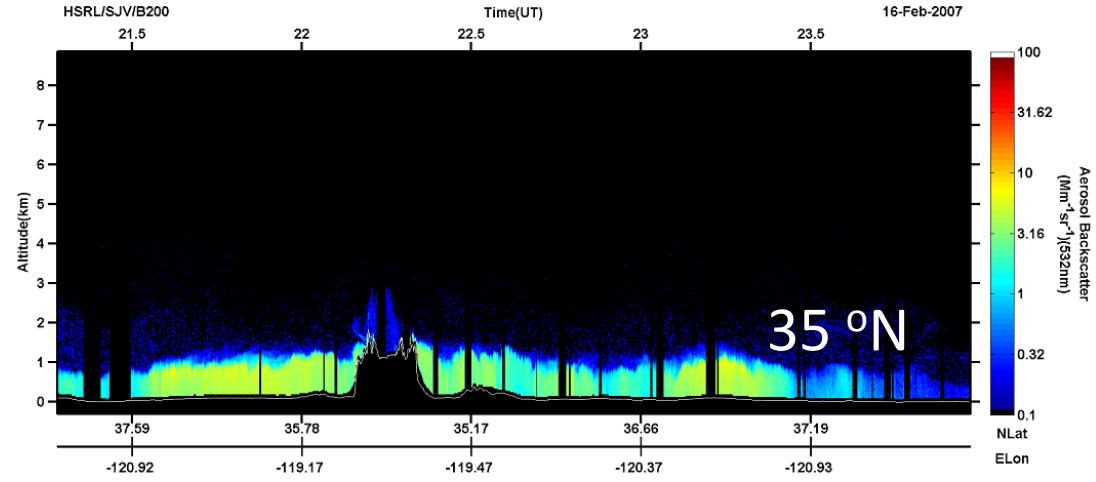
Vertical Distribution of Aerosols

During ARCTAS aerosols were distributed throughout entire troposphere and not primarly located in the lowest 1-2 km, in contrast to previous HSRL missions at lower latitudes

Barrow, Alaska, Apr. 17, 2008

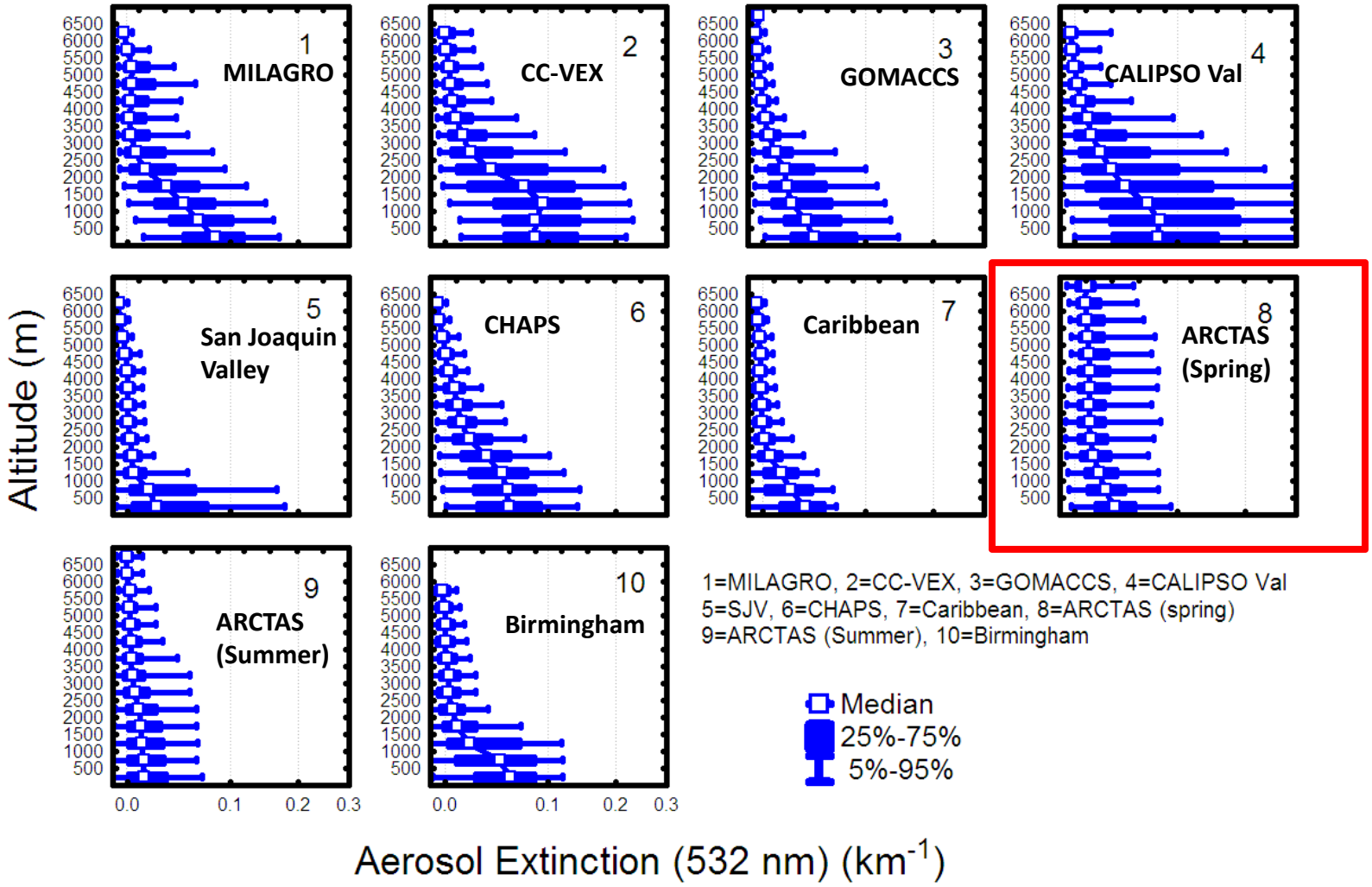


San Joaquin Valley, California, Feb. 16, 2007



Average Aerosol Extinction Profiles

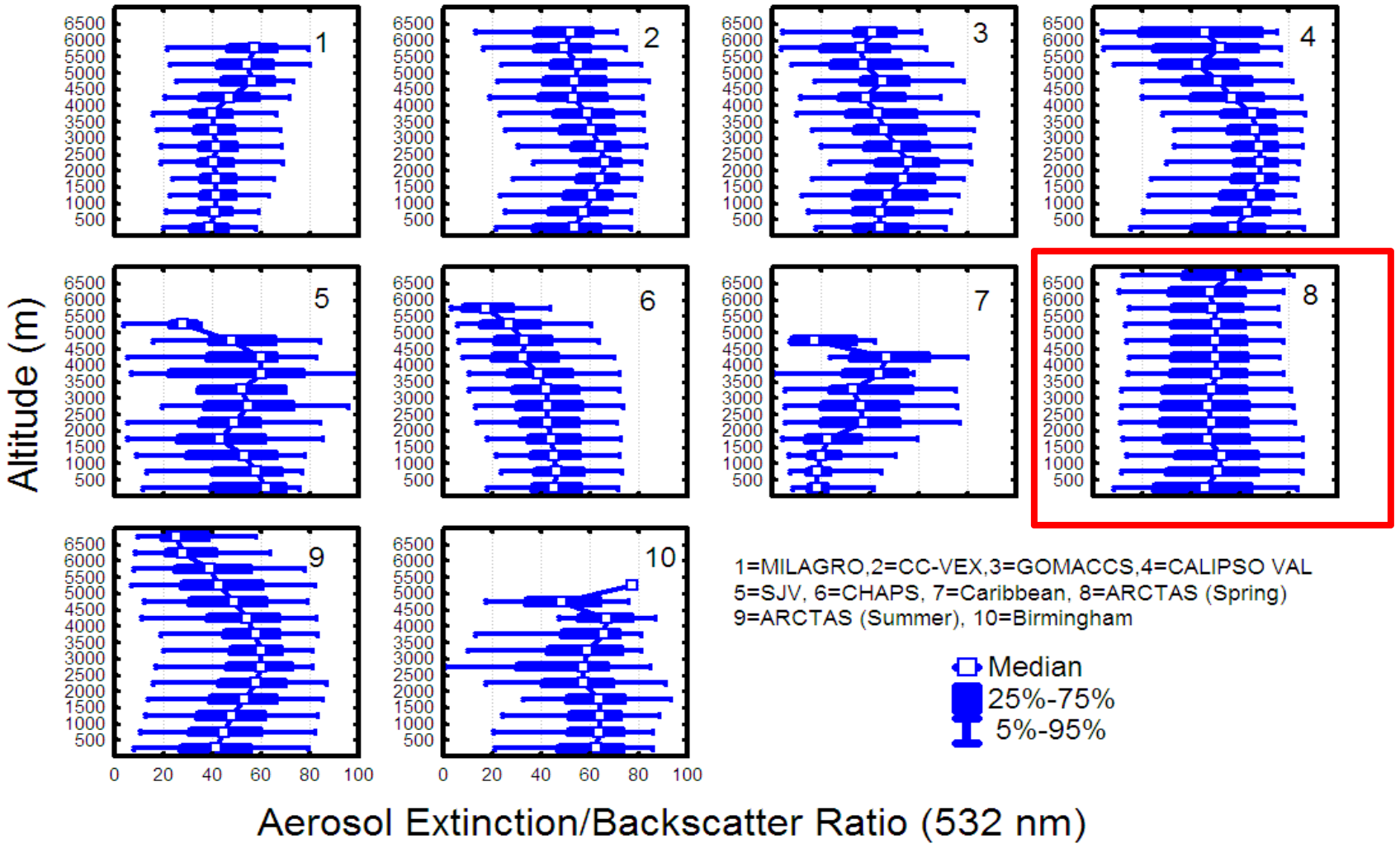
During ARCTAS/ISDAC aerosols were distributed throughout entire troposphere and not primarly located in the lowest 1-2 km, in contrast to previous HSRL missions at lower latitudes



Average Aerosol Extinction/Backscatter Profiles

During ARCTAS (Spring)/ISDAC …

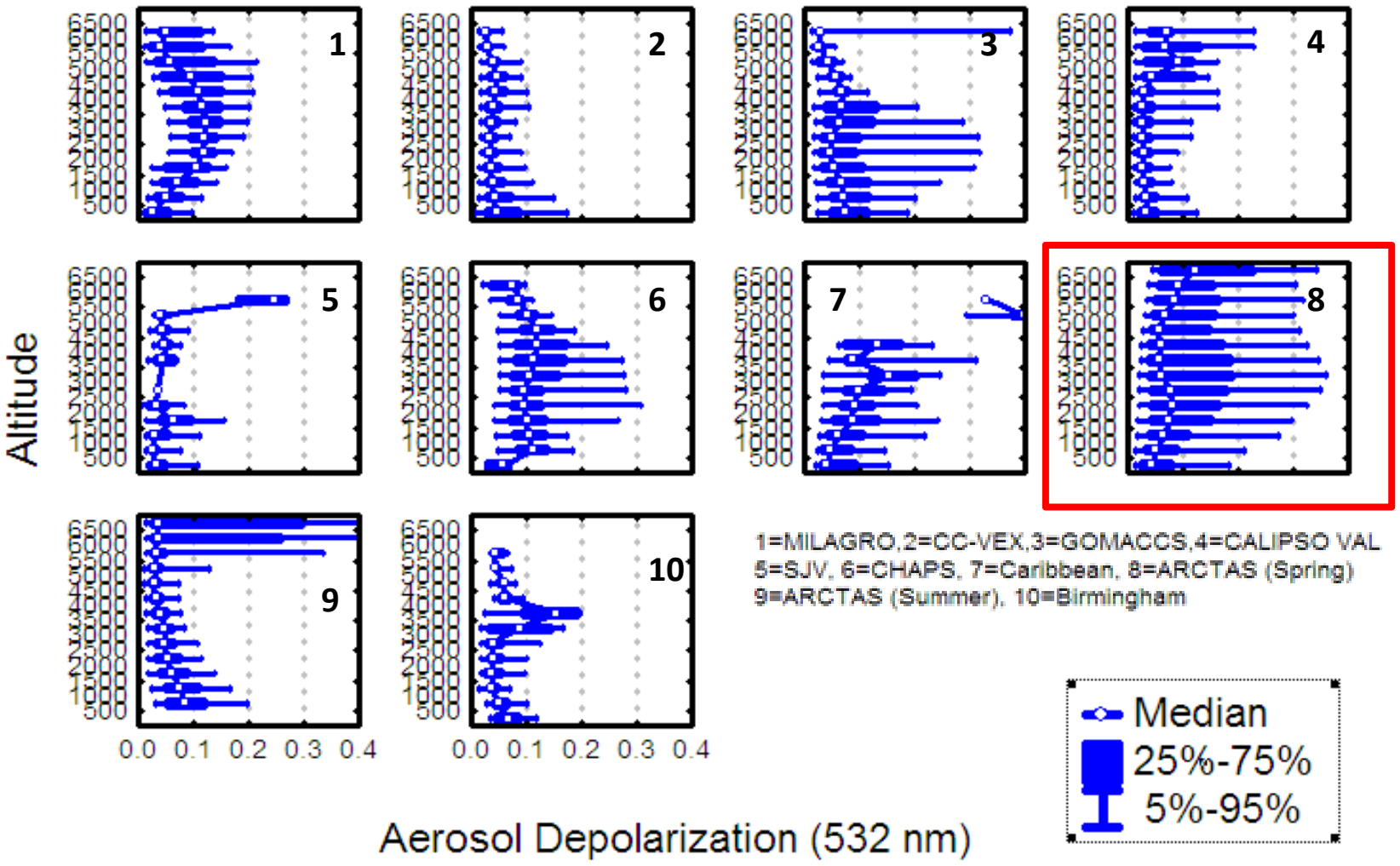
- **On average, little vertical variability in lidar ratio**
- **All altitudes had similar large variability in lidar ratio**

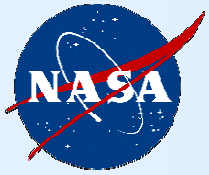


Average Aerosol Depolarization Profiles

During ARCTAS (Spring)/ISDAC …

- **On average, some vertical variability in aerosol depolarization (higher at high altitudes)**
- **Largest variations in aerosol depol when compared to other missions (more ice+dust?)**





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

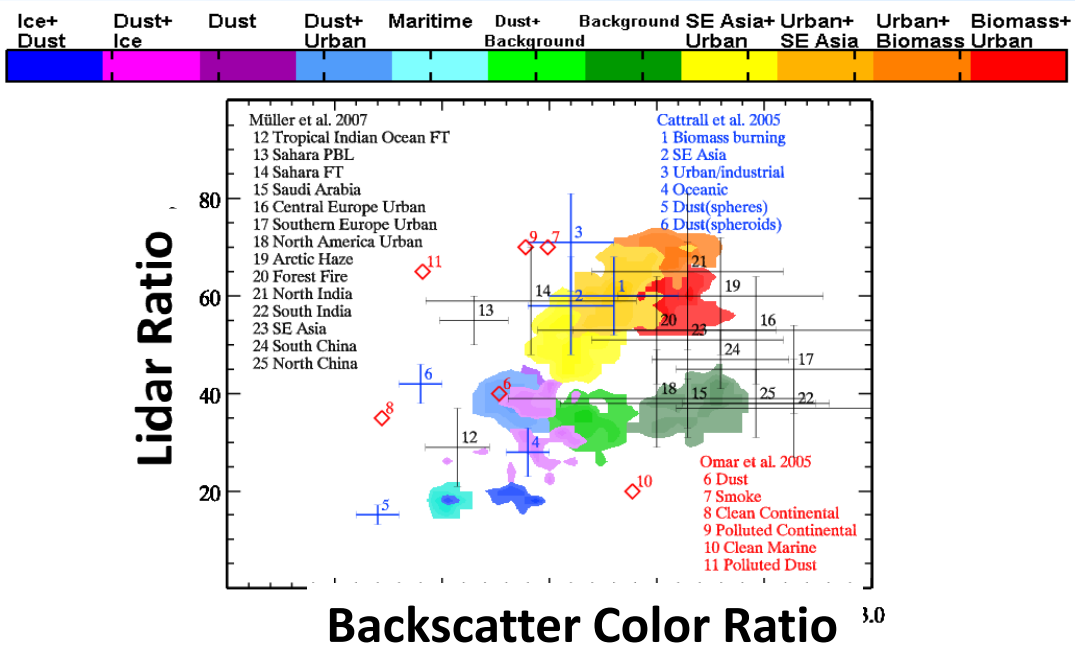
Aerosol Classification using HSRL measurements

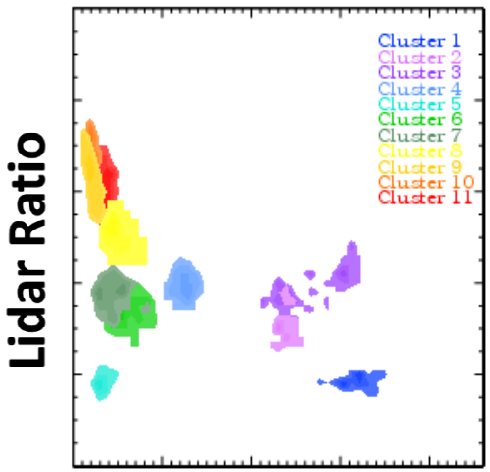
Aerosol classification is based on HSRL measurements of aerosol intensive parameters

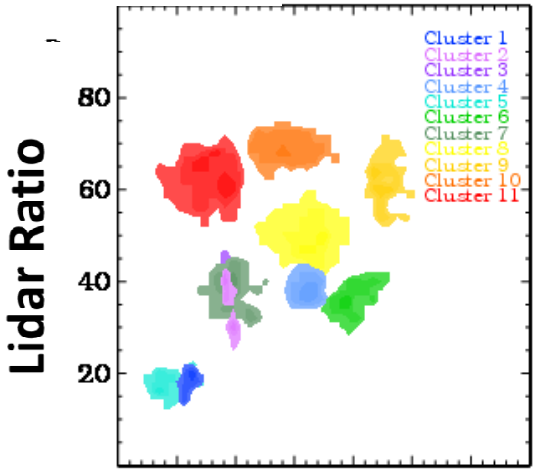
- Extinction/Backscatter Ratio (Lidar ratio) (~absorption)
- Depolarization (~spherical vs. nonspherical – dust/ice)
- Backscatter Color Ratio (~size)
- Depolarization Ratio (1064/532 nm) (~nonspherical/spherical size)

• Aerosol intensive parameter measurements were used in an objective cluster analysis scheme to discriminate aerosol type.

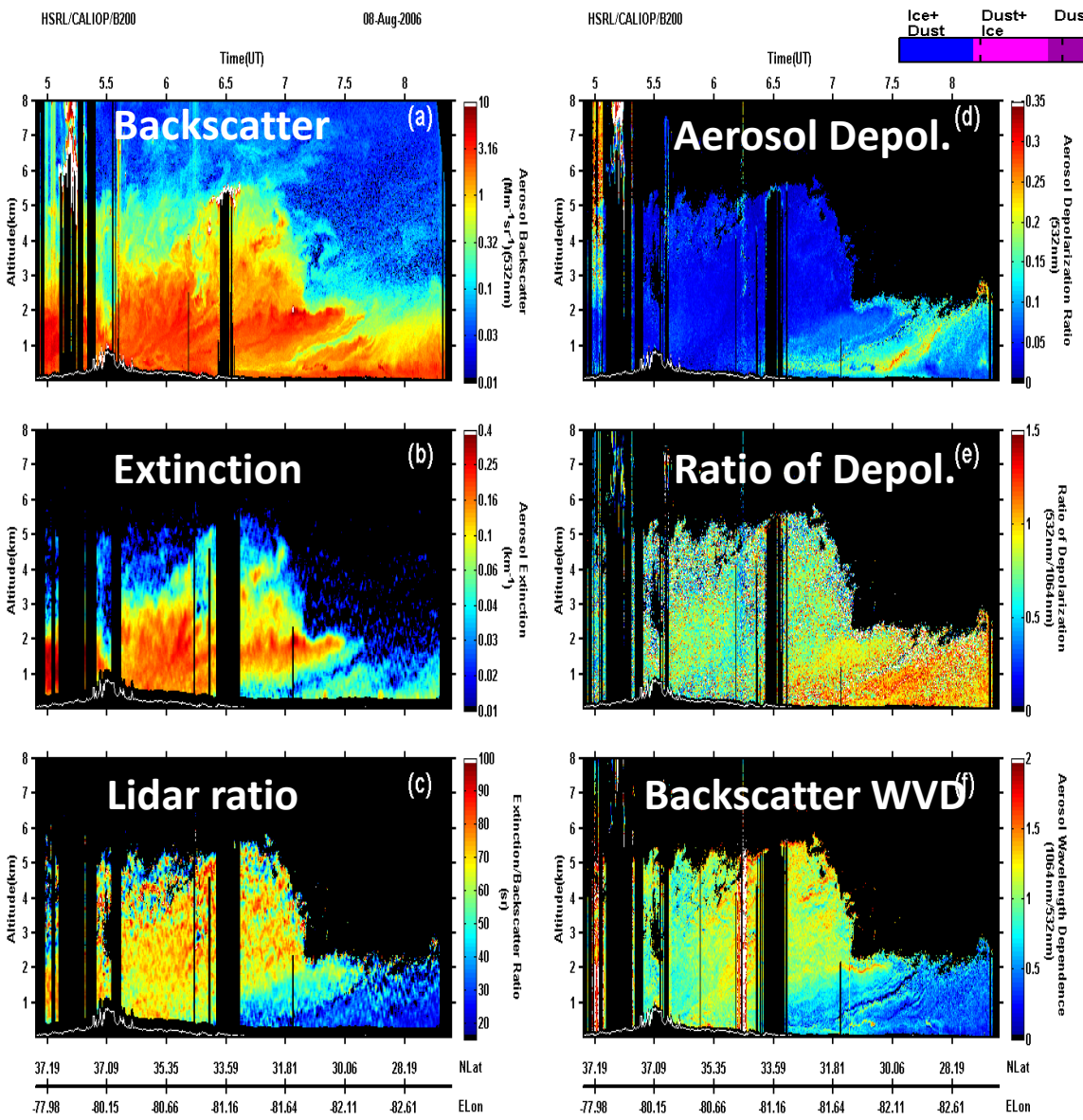
• Aerosol types associated with the clusters were subjectively related to the aerosol types inferred by Cattrall et al. (2005), Omar et al. (2005), and Müller et al. (2007)

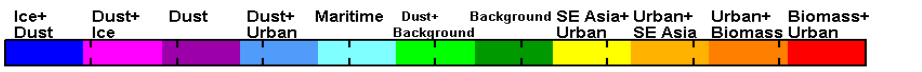


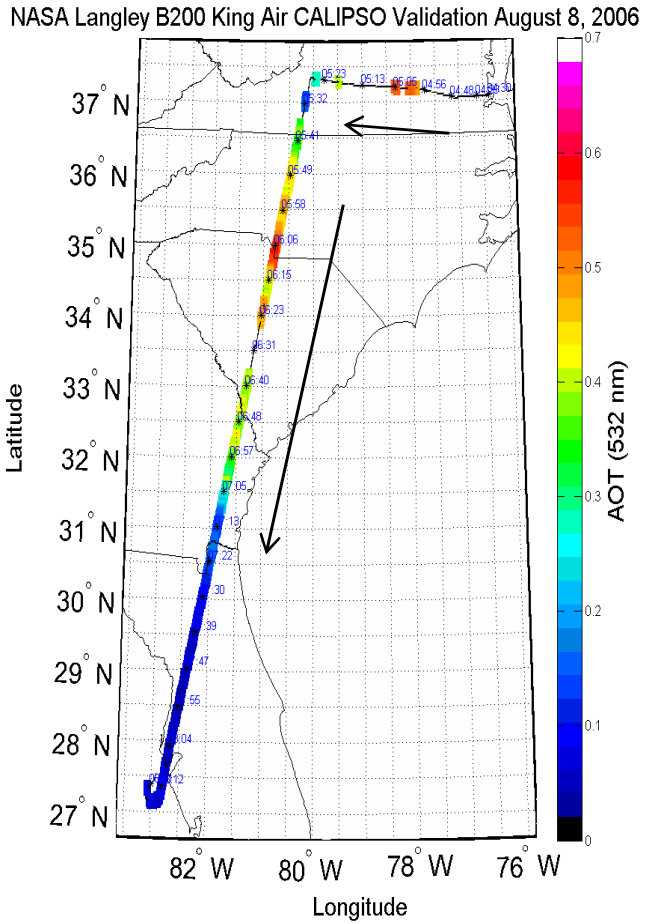




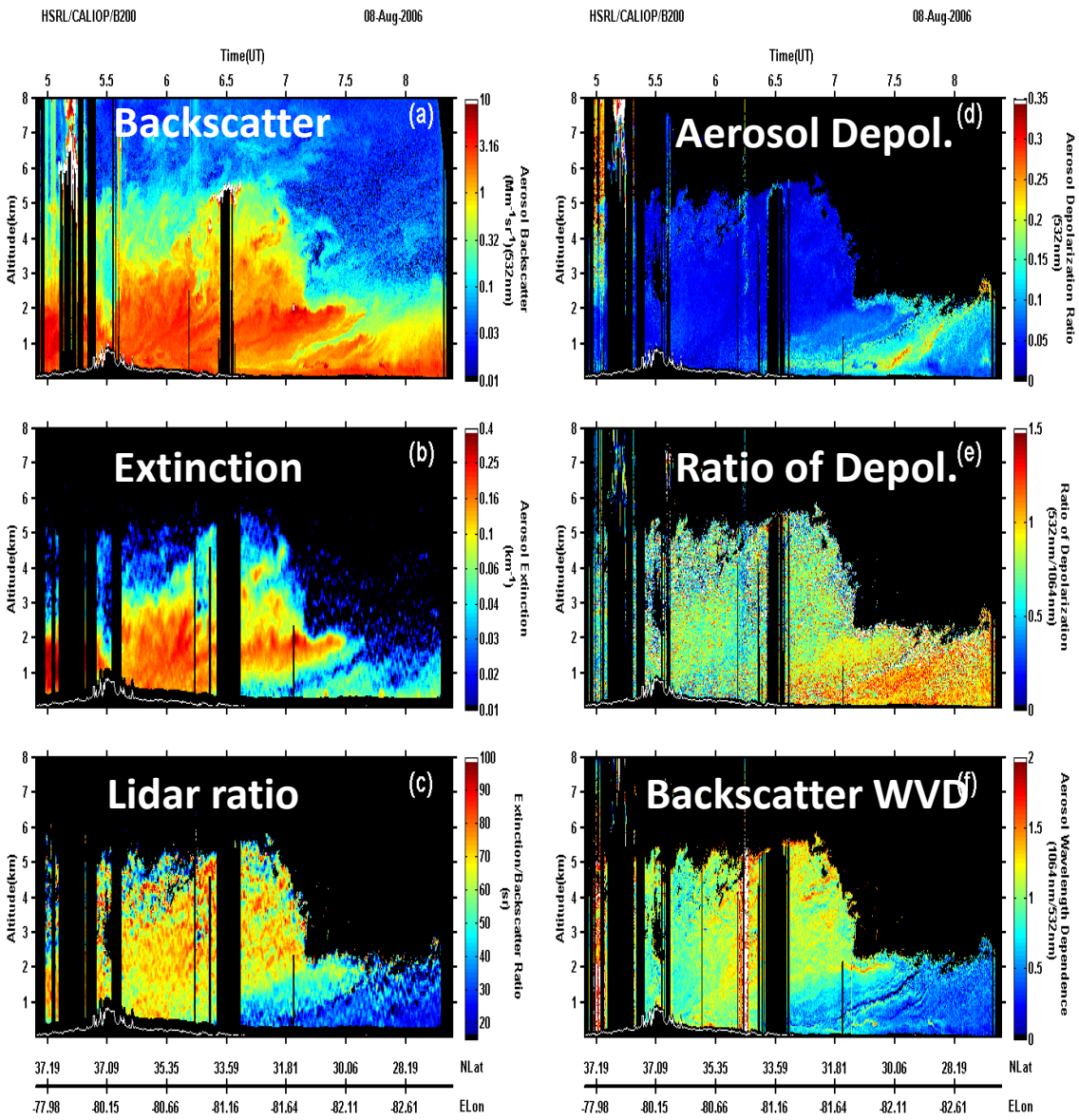
Example of Aerosol Classification using HSRL measurements

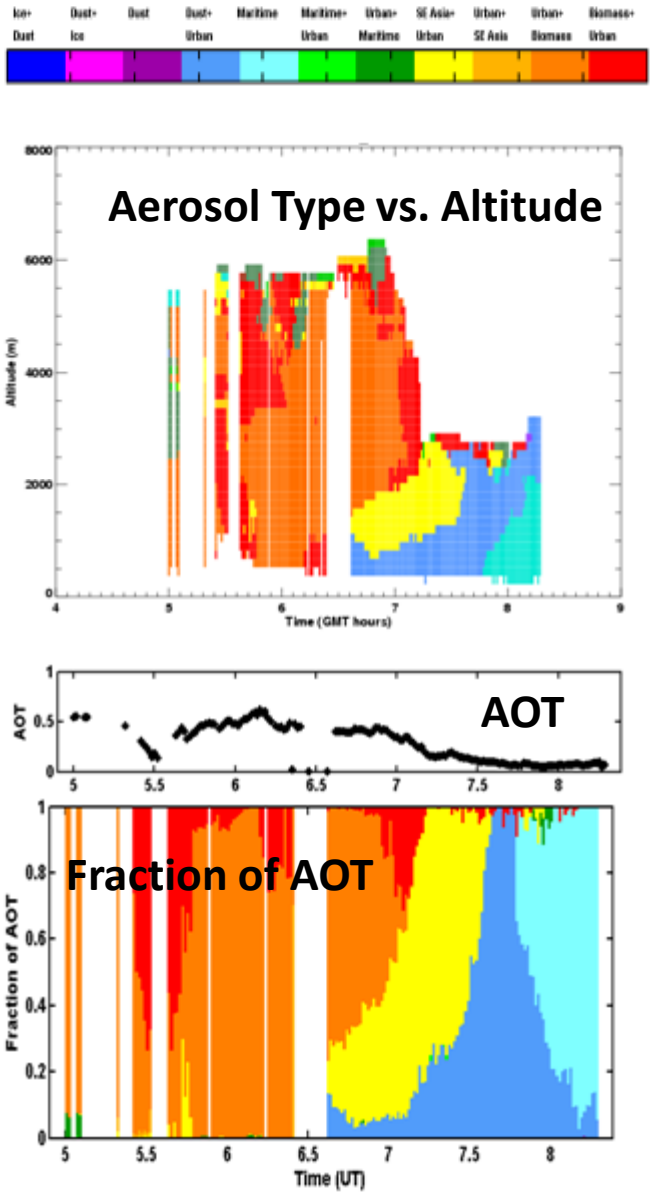




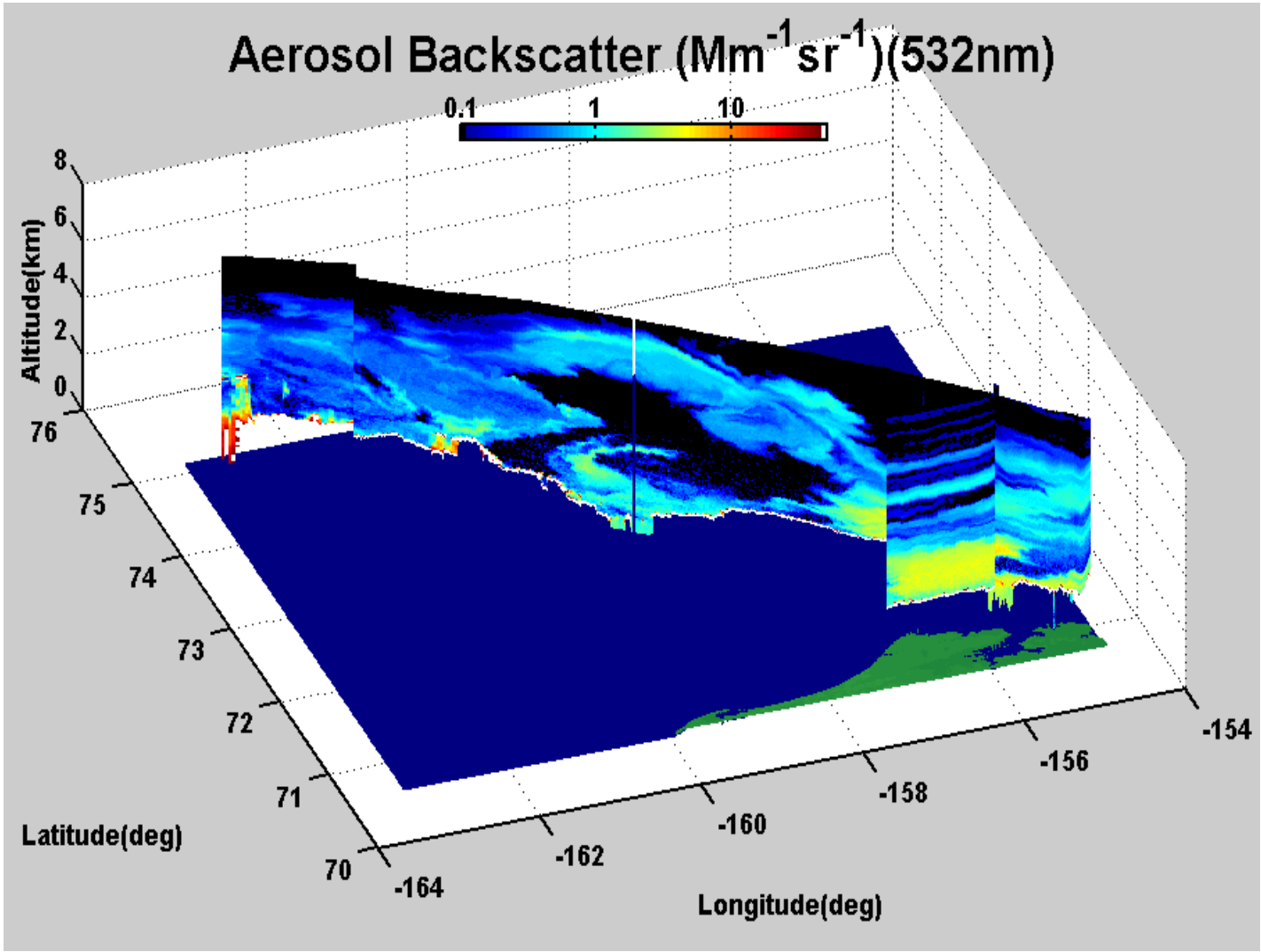


Example of Aerosol Classification using HSRL measurements



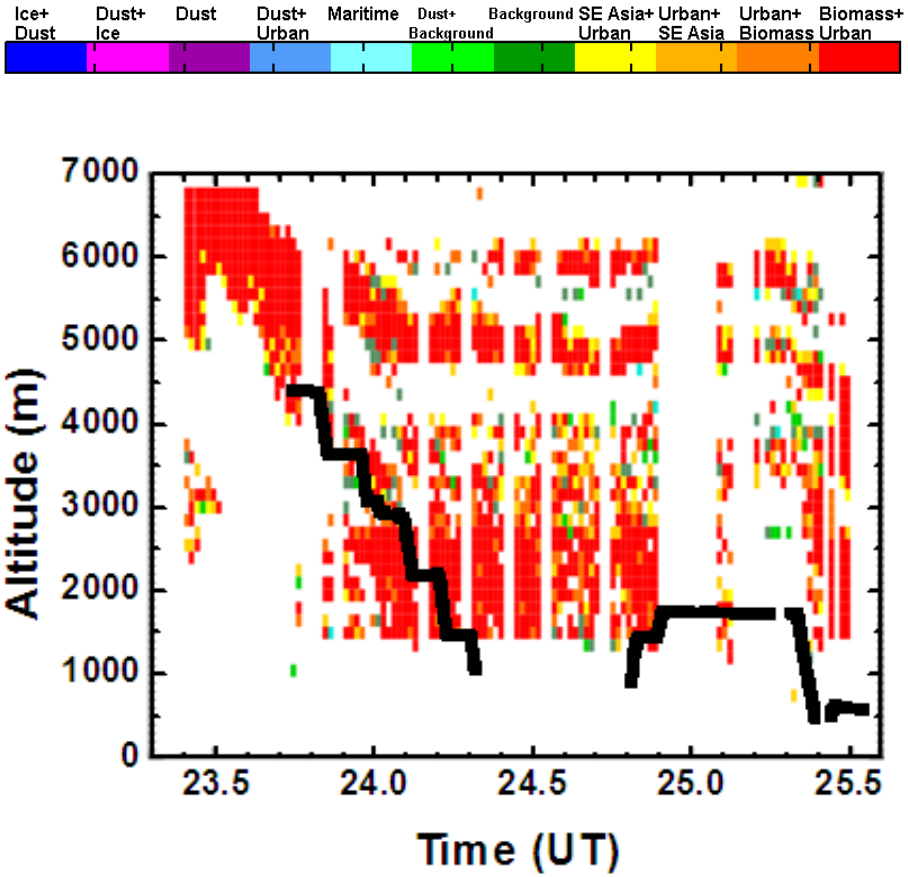


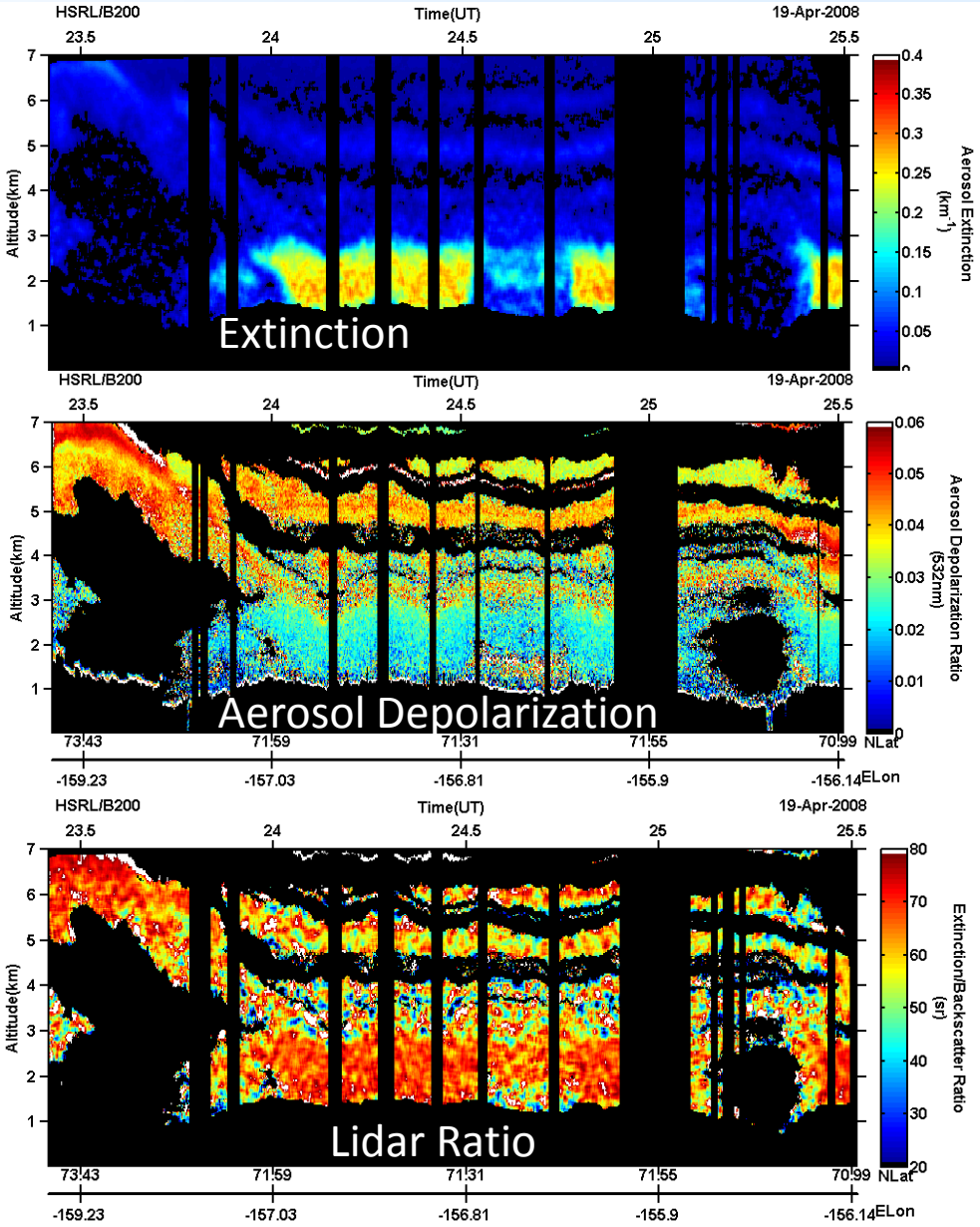
April 19 smoke case



Aerosol Classification - April 19, 2008
ARCTAS/ARCPAC/ISDAC Coordinated Flight

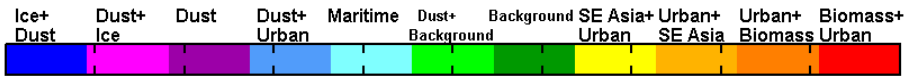
Biomass burning smoke is dominant aerosol type inferred from HSRL measurements of aerosol intensive parameters

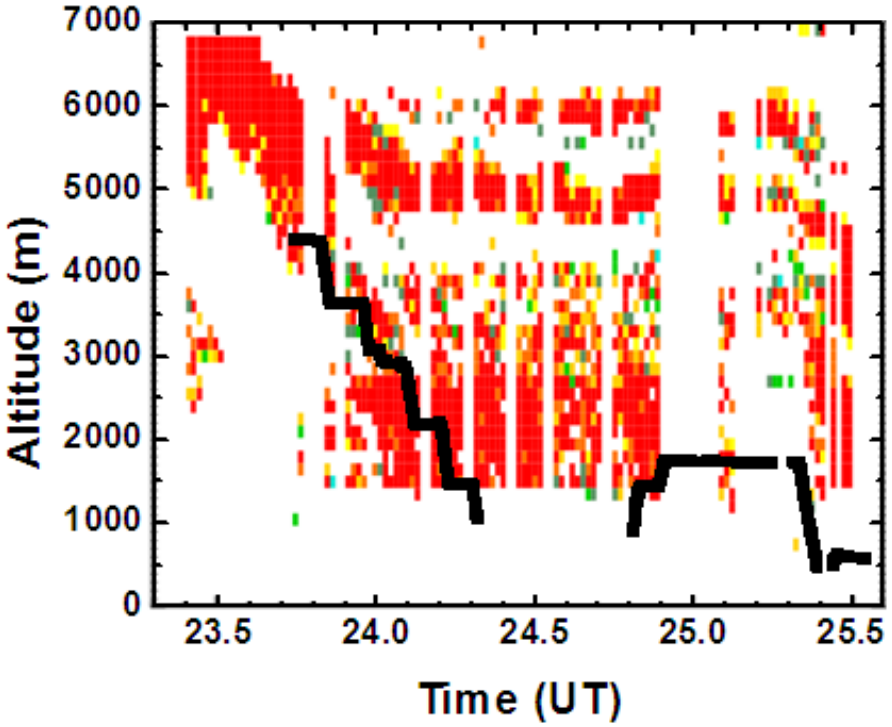




Aerosol Classification - April 19, 2008
ARCTAS/ARCPAC/ISDAC Coordinated Flight

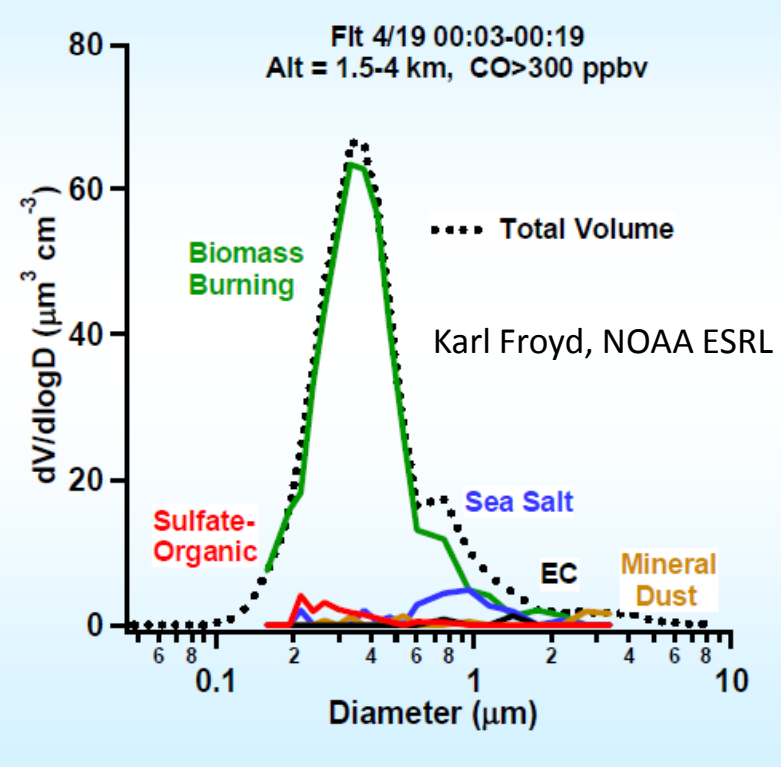
Biomass burning smoke is dominant aerosol type inferred from HSRL measurements of aerosol intensive parameters





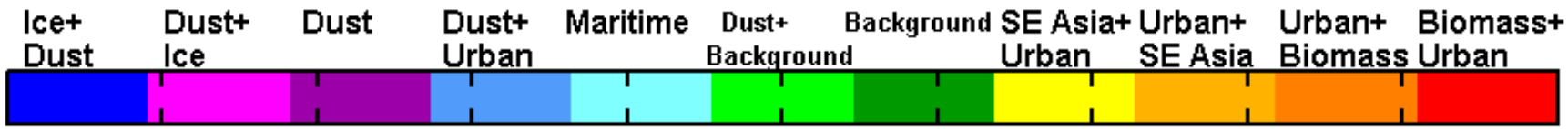
NOAA P-3 PALMS aerosol composition data shows high biomass burn fraction

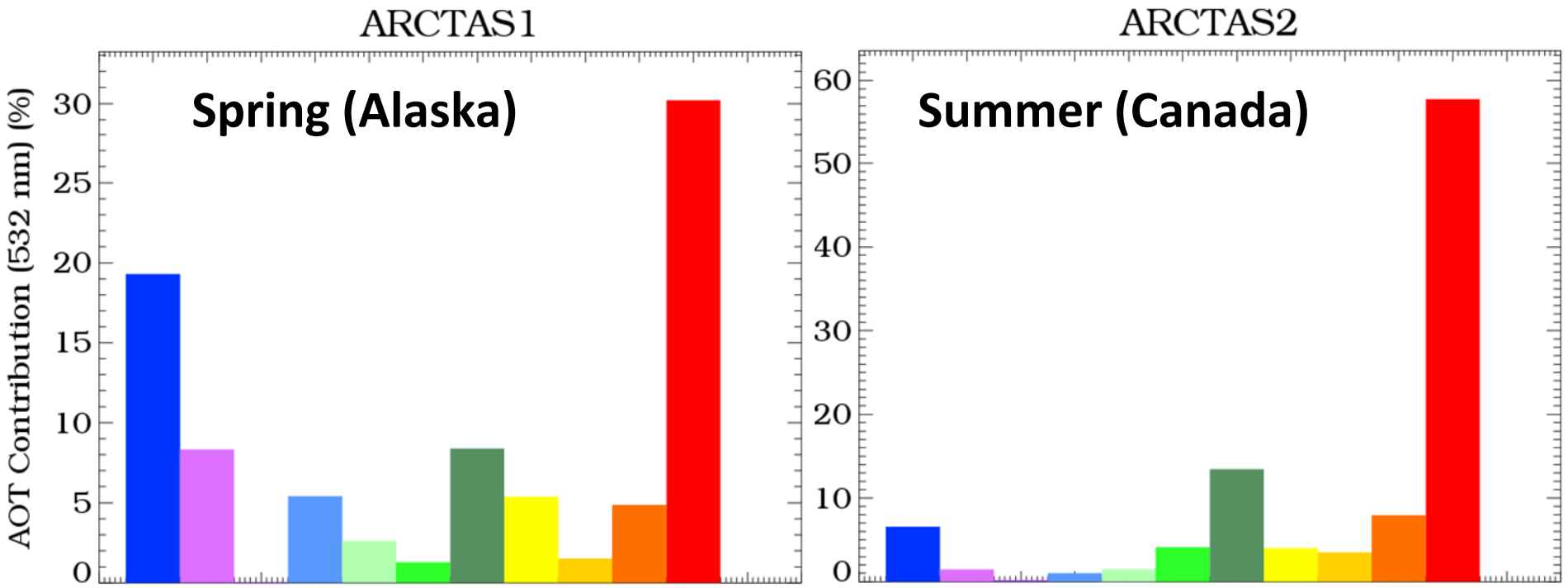
NOAA P-3 PALMS aerosol size/composition



Apportionment of Aerosol Optical Thickness

- ARCTAS 1 and 2 were dominated by the biomass/urban aerosol type
- ARCTAS 1 had fraction significant (~20% or more) of aerosol type classified as ice

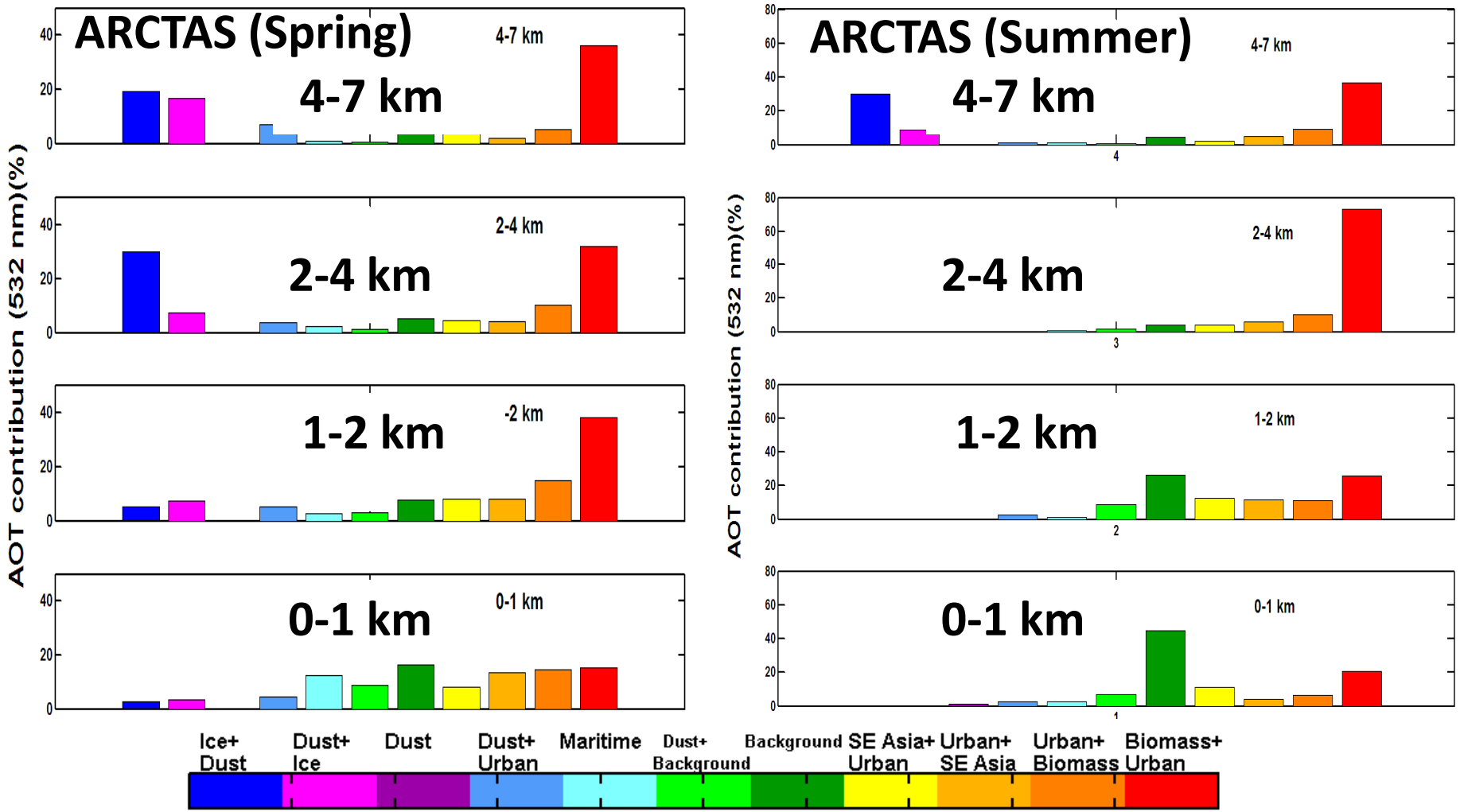




Variation of Aerosol Optical Thickness with Altitude

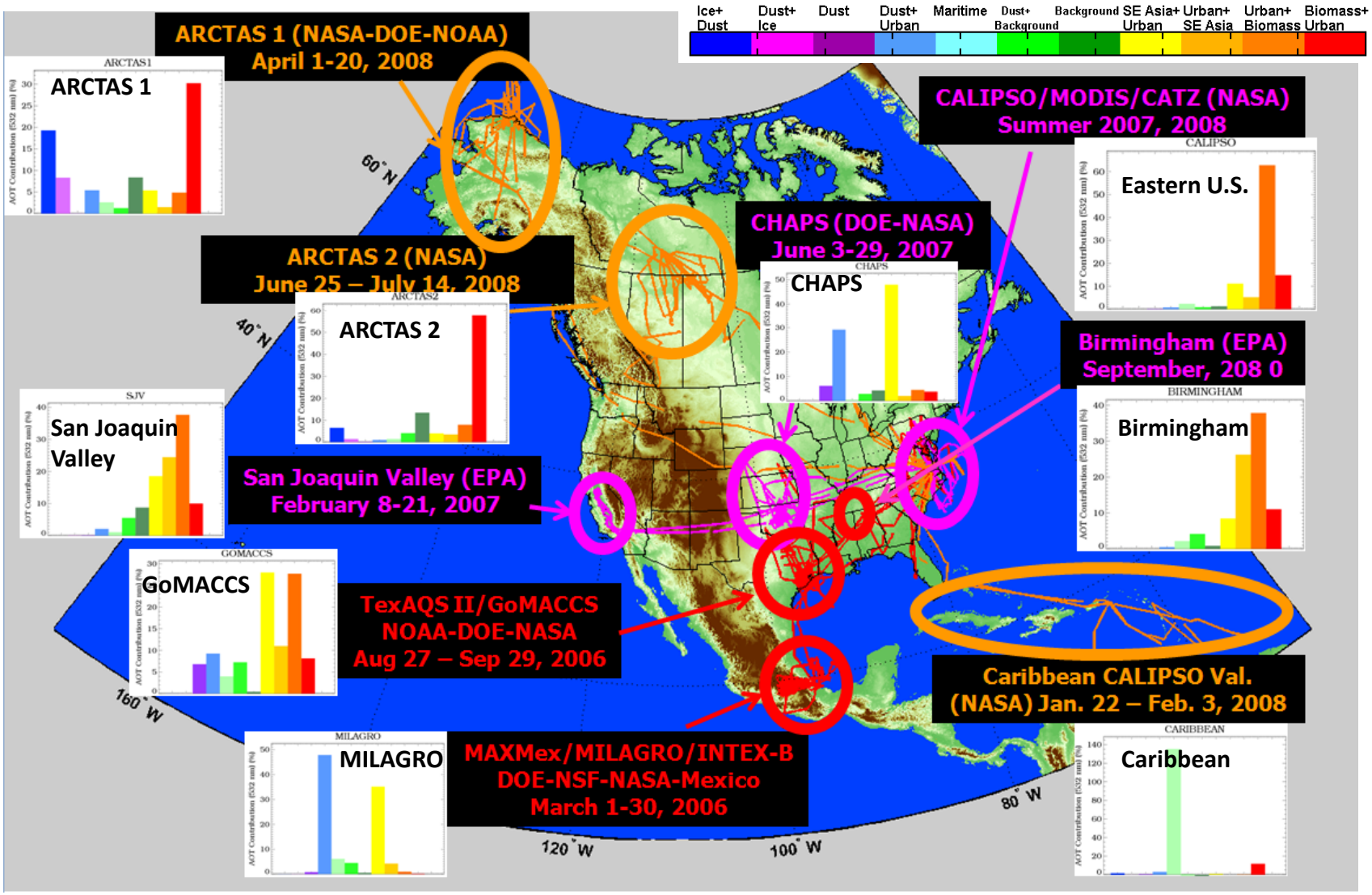
- Ice/dust typically increased with altitude
- Lowest levels had variety of aerosol types
- Urban type was most prominent at lowest levels
- Biomass burning was dominant above 1 km

- Ice/dust found only at high altitude
- Lowest levels (< 1 km) had background and smoke
- Background decreased significantly above 2 km
- Biomass burning was dominant type 2-4 km



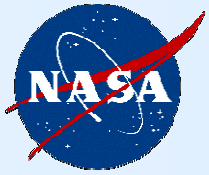
Apportionment of Aerosol Optical Thickness

- ARCTAS/ISDAC was dominated by the biomass/urban aerosol type
- ARCTAS/ISDAC had significant fraction (~20% or more) of aerosol type classified as ice



Comparisons with NASA GEOS-5 Model

GEOS-5 Model

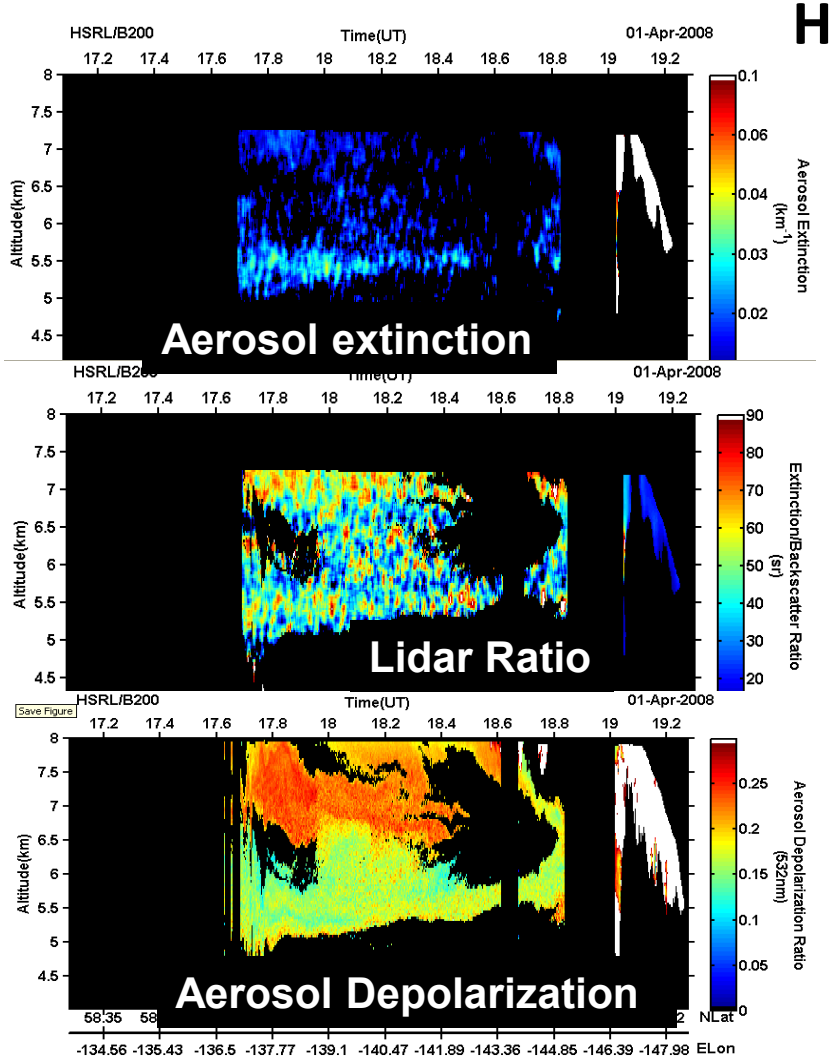


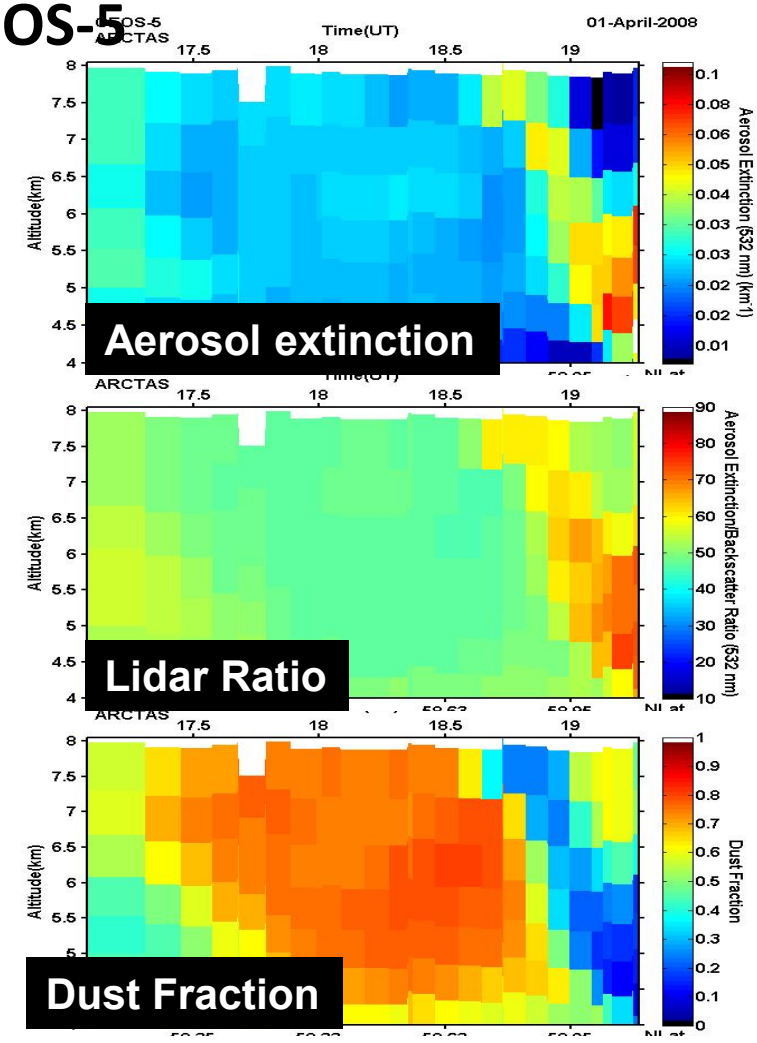
- **Atmospheric general circulation and general circulation model and data assimilation system**
  - **Global model**
  - **0.666 x 0.5 deg horizontal resolution**
  - **72 levels to 85 km**
  - **Met analysis provided by joint NASA/NCEP gridpoint statistical interpolation (GSI) assimilation package**
  - **Aerosols, CO, CO2 simulated using online version of GOCART**
  - **Inventory based emissions of anthropogenic and biogenic aerosol**
  - **Biomass burning emissions are from daily Aqua and Terra MODIS fire counts calibrated with Global Fire Emissions Database**
- **Performed meteorological and chemical forecasts during ARCTAS**
- **Reanalysis results are evaluated using airborne HSRL data**

HSRL/GEOS-5 Comparison on April 1

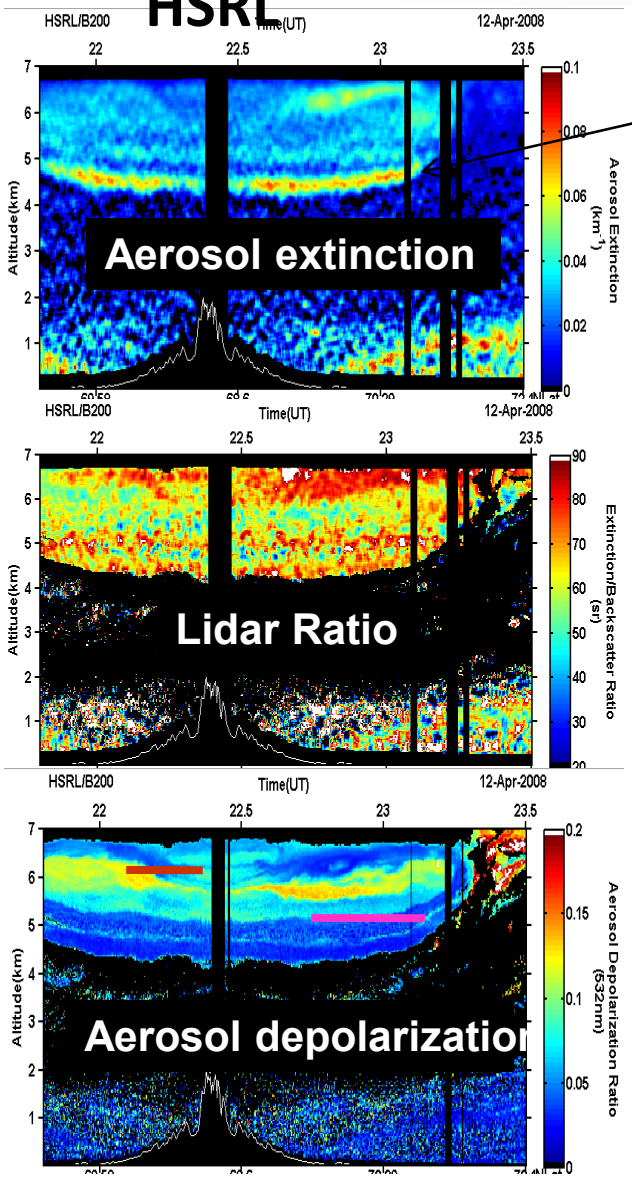
- Low (30-50 sr) lidar ratio, high (20-30%) aerosol depolarization are indicators of dust
- GEOS-5 attributes most of aerosol extinction to dust consistent with HSRL data
- GEOS-5 aerosol extinction values associated with dust are higher than HSRL measurements

HSRL | **GEOS-5**

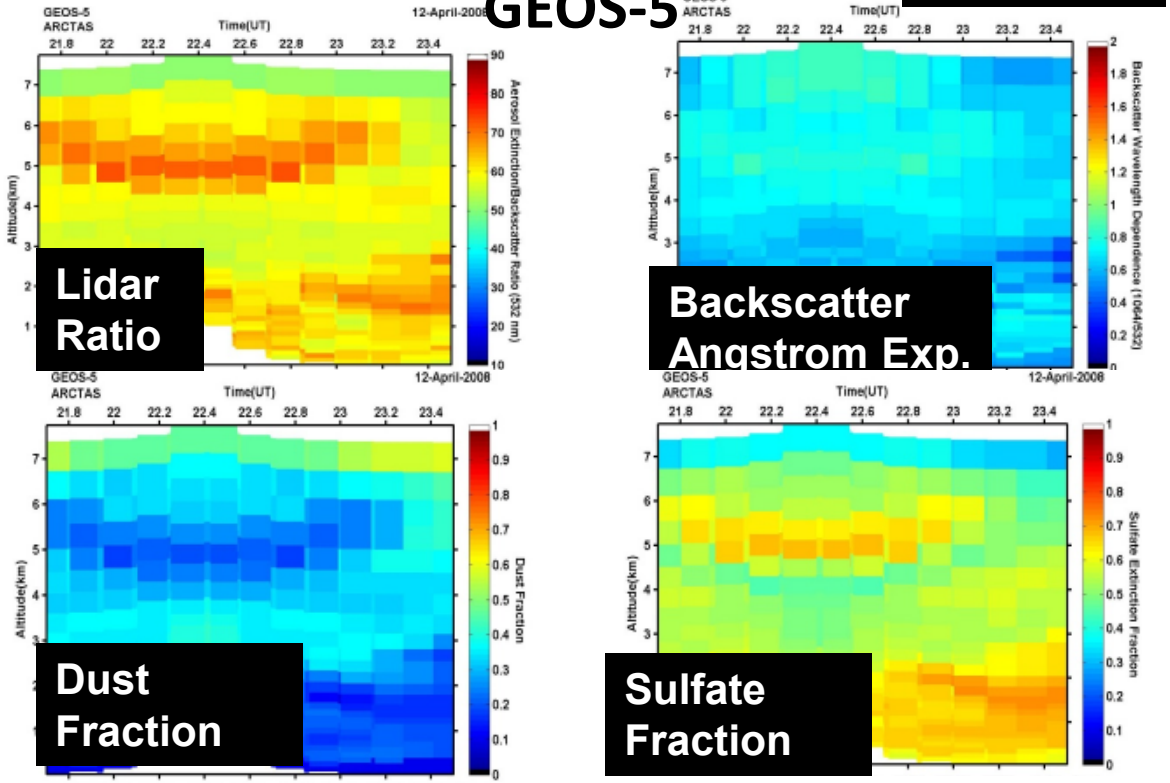




HSRL/GEOS-5 Comparison on April 12

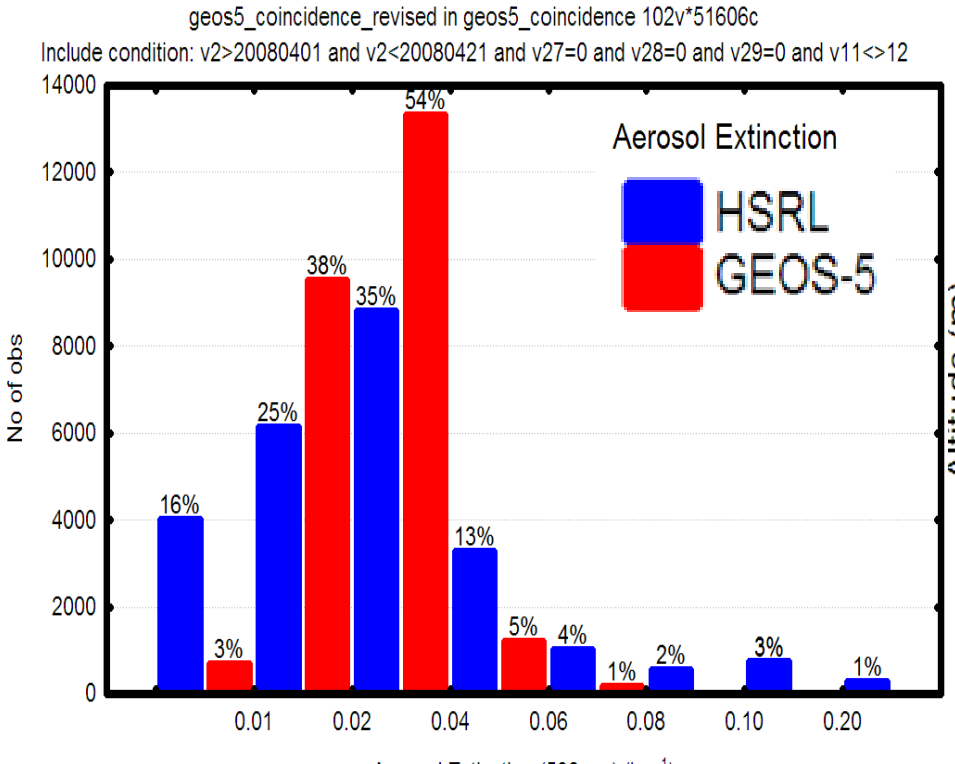


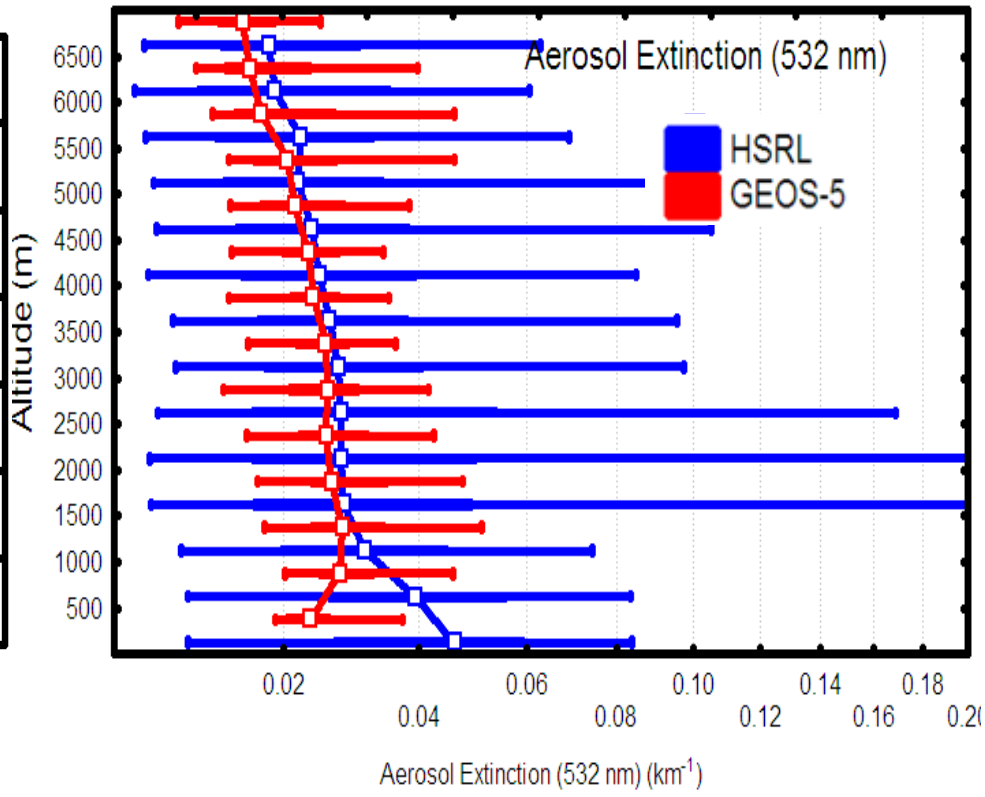
- HSRL and GEOS-5 show high lidar ratio and low depol at bottom of layer –smoke
- HSRL and GEOS-5 show lower lidar ratio and higher depol at higher altitudes in layer
- HSRL and GEOS-5 show differences at top of layer



Comparison of HSRL data and GEOS-5 model

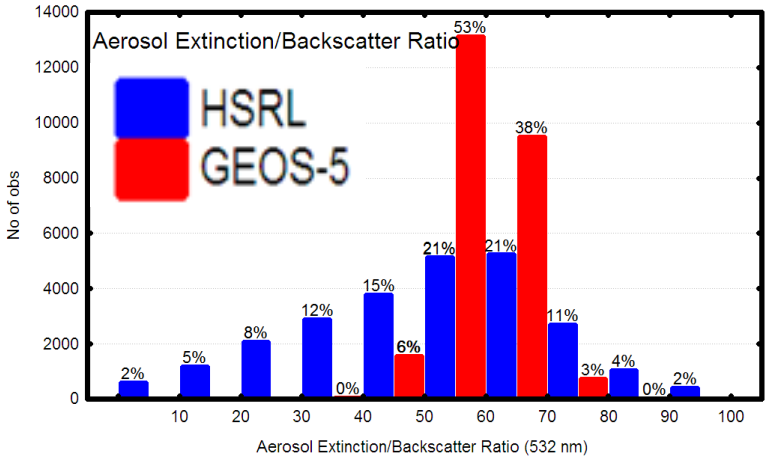
- **Overall, good agreement between average HSRL measurements and GEOS-5 simulations of aerosol extinction**



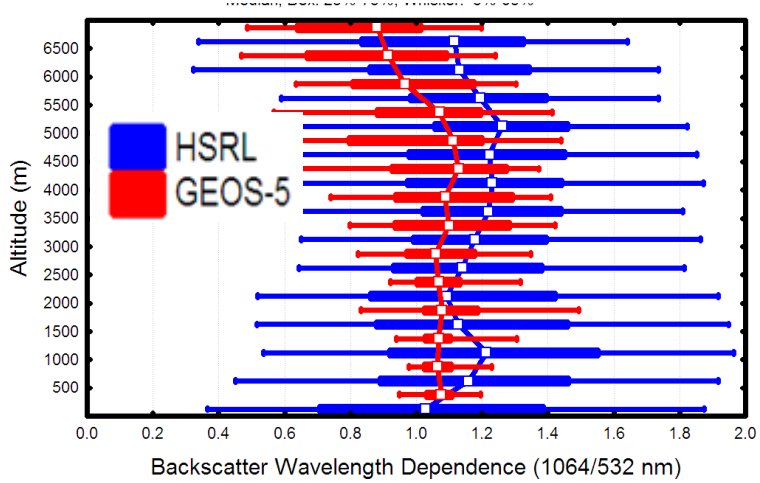


Comparison of HSRL data and GEOS-5 model

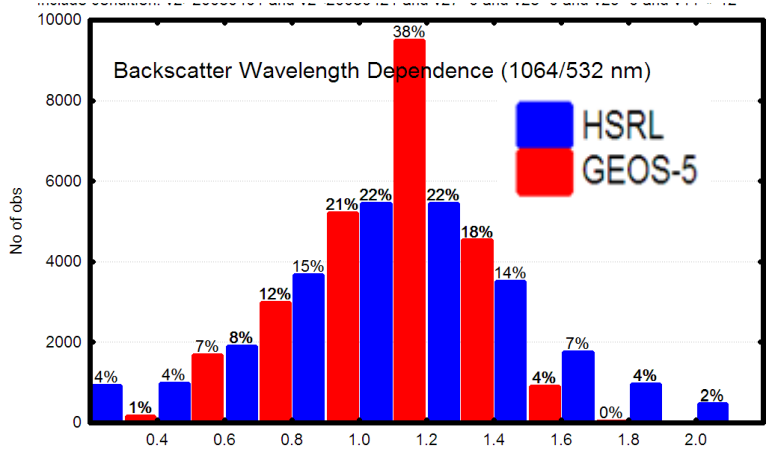
Aerosol Extinction/Backscatter Ratio



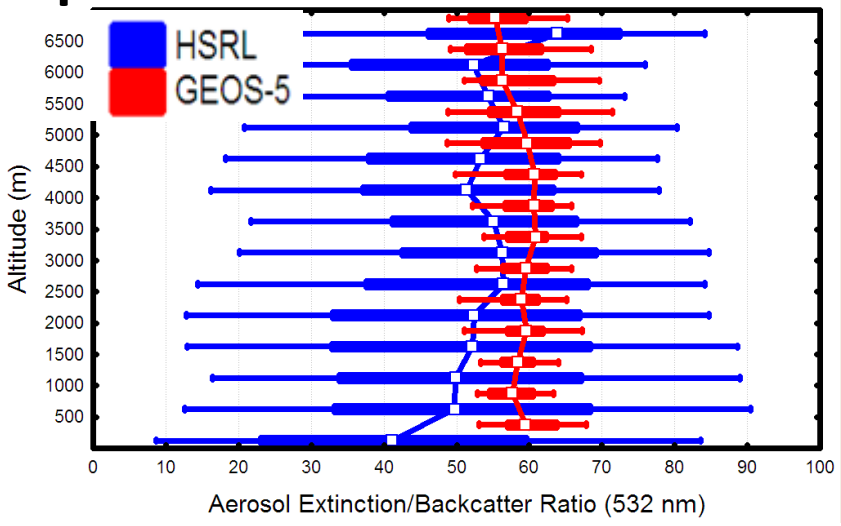
HSRL_Sa532: N = 24853, Mean = 51.7548, StdDv = 19.4747, Max = 99.9906, Min = 0.0207
GEOS5_Total_ext2back: N = 24853, Mean = 58.6849, StdDv = 5.8397, Max = 81.9485, Min = 37.5935



Backscatter Wavelength Dependence



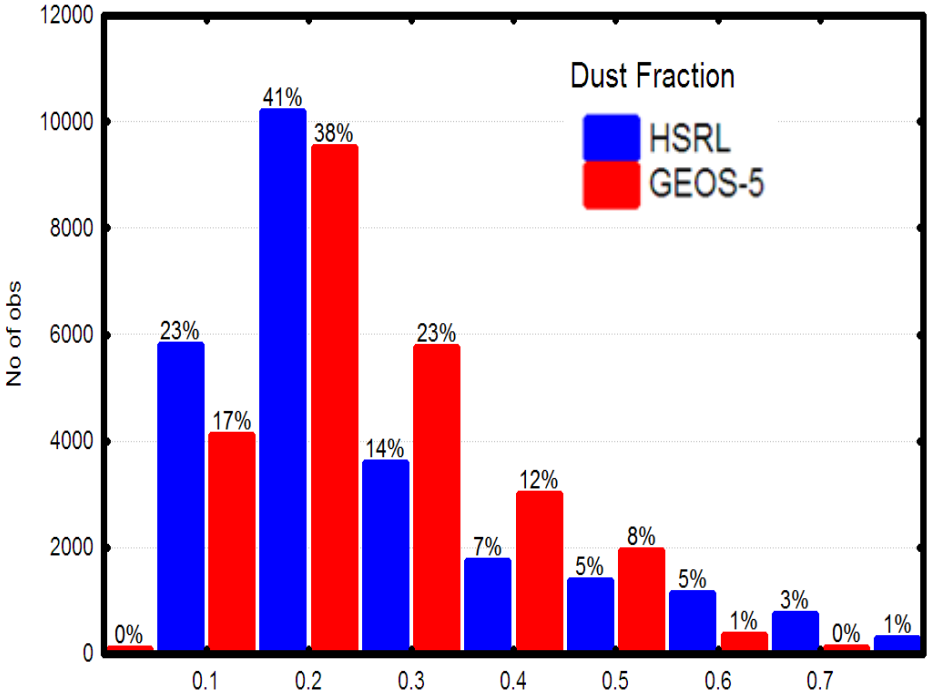
HSRL_WvD_1064_532: N = 24853, Mean = 1.1659, StdDv = 0.4343, Max = 2.5727, Min = -8.247
geso55321064wvd: N = 24853, Mean = 1.0149, StdDv = 0.2406, Max = 1.7928, Min = 0.2512



Comparison of HSRL data and GEOS-5 model

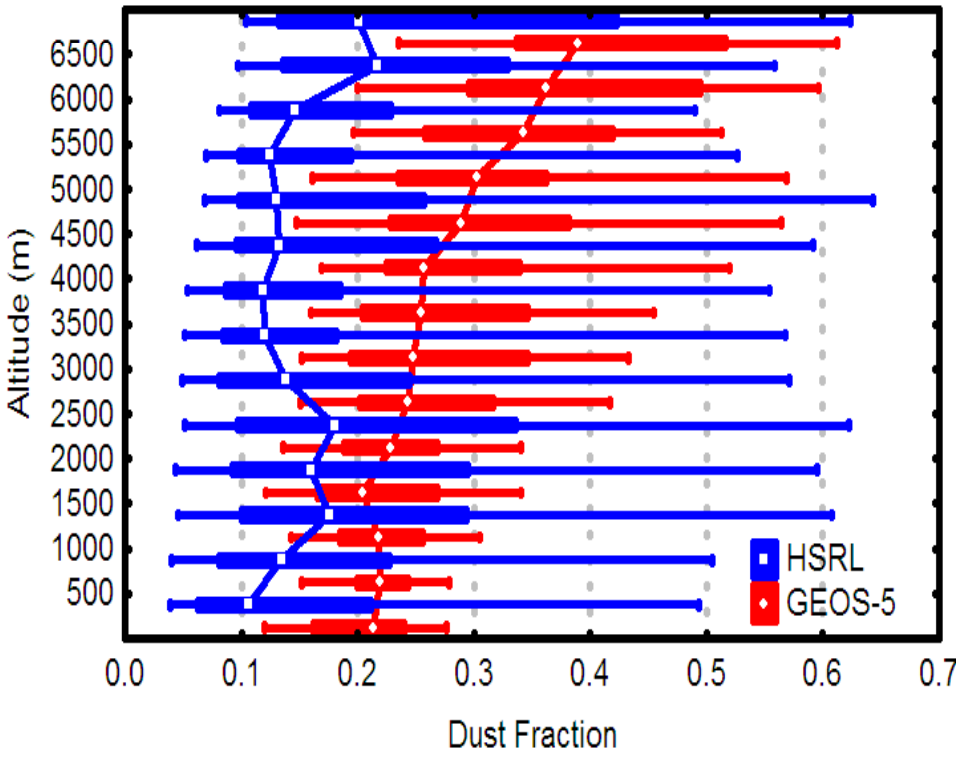
- HSRL measurements of aerosol depolarization used to estimate dust fraction following Sugimoto and Lee (2006)
- GEOS-5 dust fractions are generally higher than HSRL estimates and these differences increase with altitude

Dust Fraction



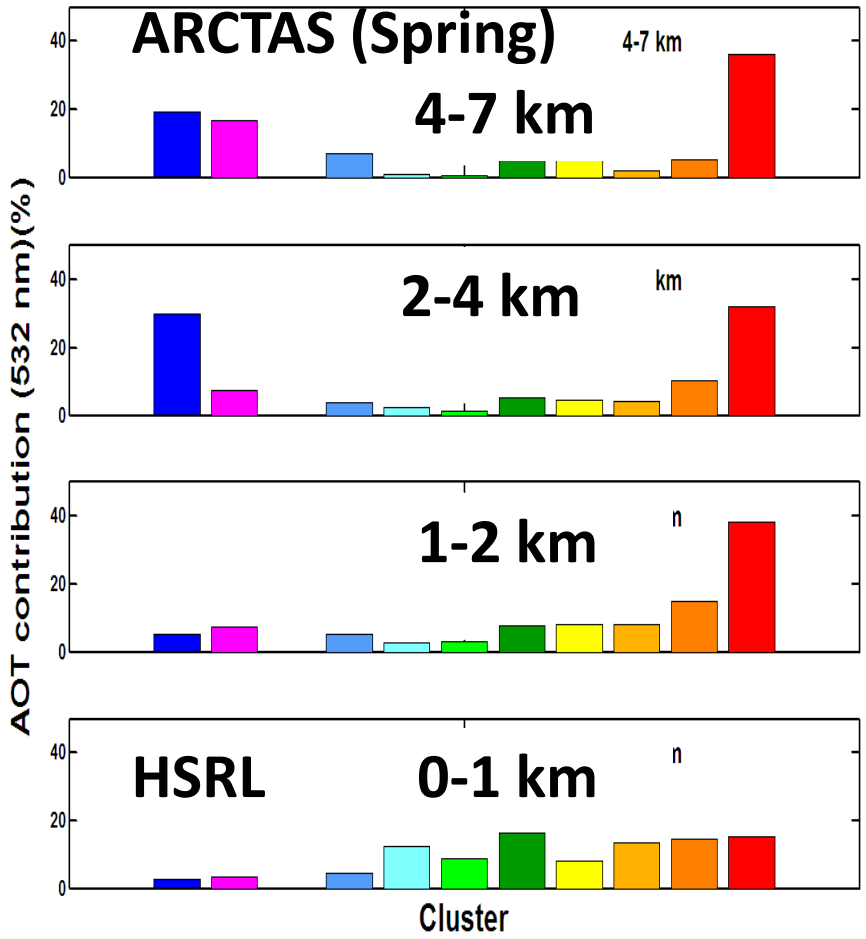
GEOS5_Dust_Frac: N = 24853, Mean = 0.3113, StdDv = 0.1224, Max = 0.7774, Min = 0.0661
hsrldustfraction: N = 24853, Mean = 0.2121, StdDv = 0.1622, Max = 0.9971, Min = 0.0061

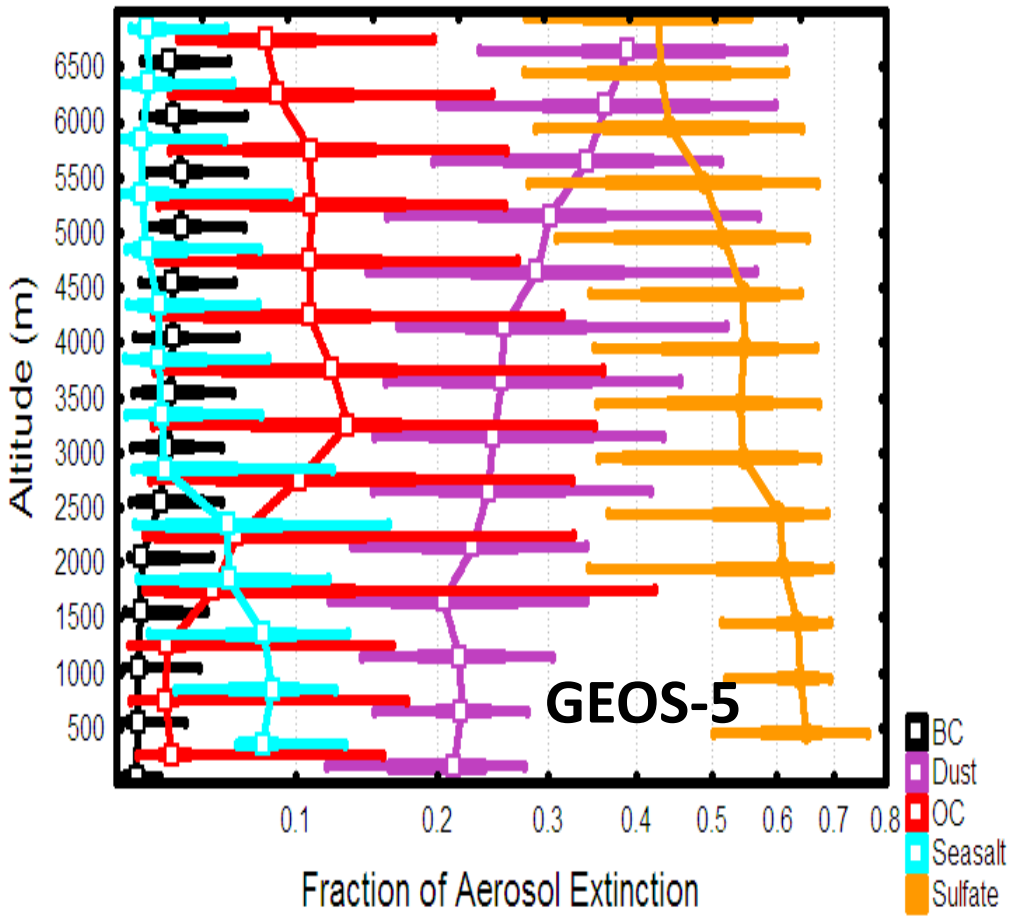
Dust Fraction



Variation of Aerosol Type with Altitude

- GEOS-5 indicates dust fraction increases with altitude; HSRL shows ice/dust increases with altitude
- HSRL indicates biomass burning increases with altitude; GEOS-5 indicates OC increases with altitude

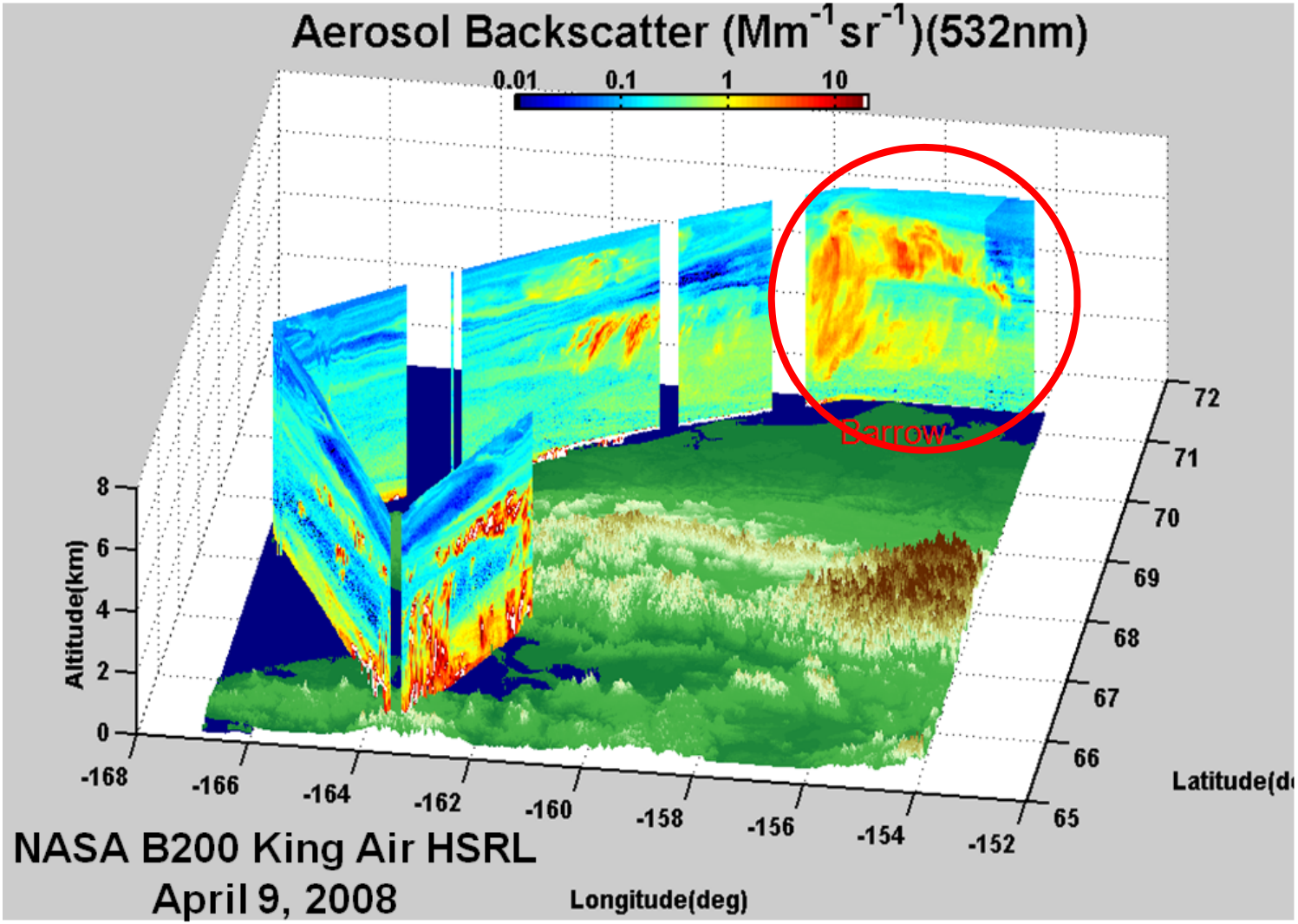




Aerosol/Ice Observations

HSRL Measurements – April 9, 2008

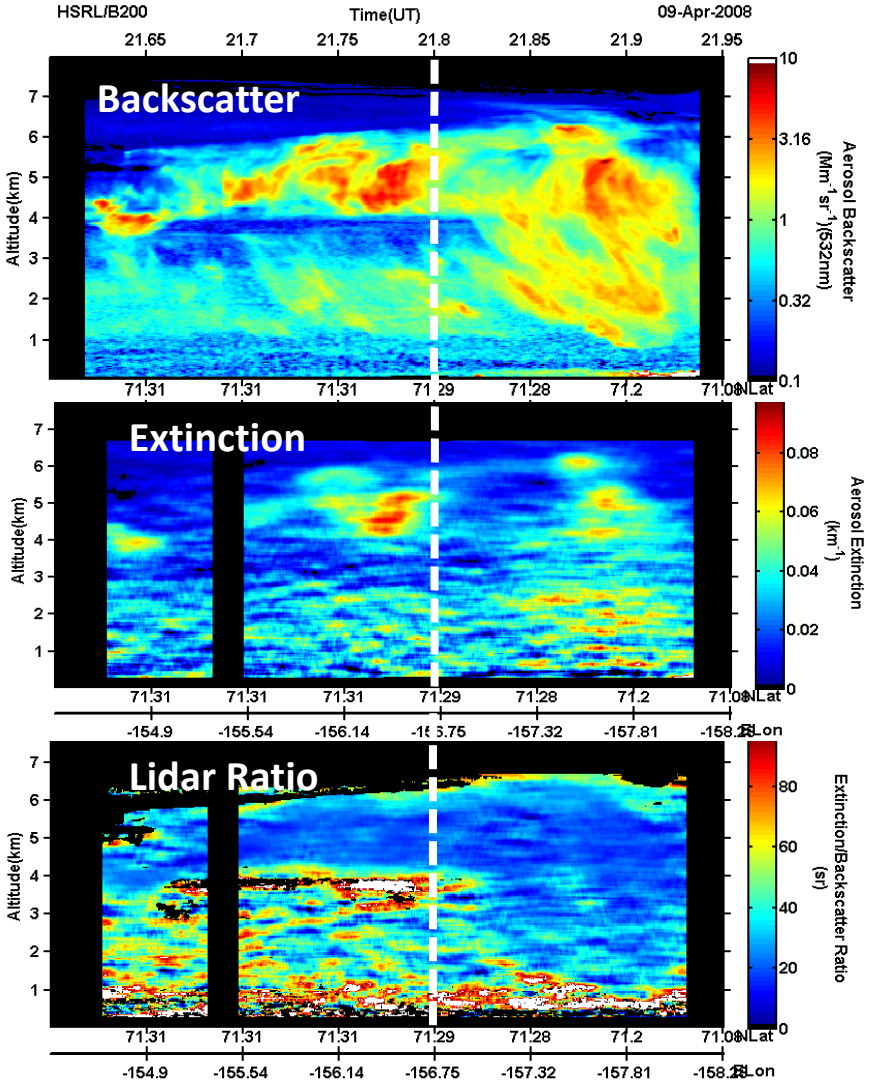
Example of HSRL aerosol backscatter measurements

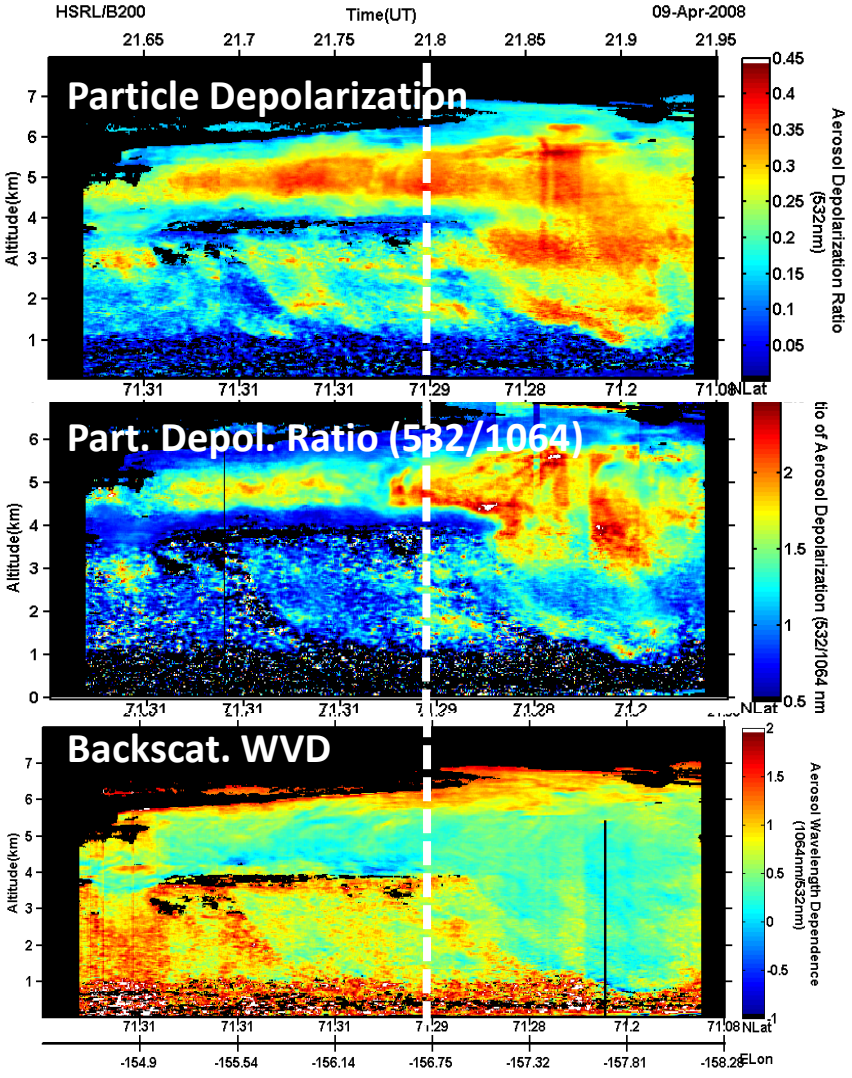


HSRL Observations of Ice Above Barrow (April 9)

Ice indicated by:

- Low lidar ratio ~ 20 sr
- Low Backscatter Wavelength Dependence (-0.5-0.5)
- High Depolarization ~ 30-40+ %
- High ratio of Depolarization (532/1064 nm) >1.5-2.0

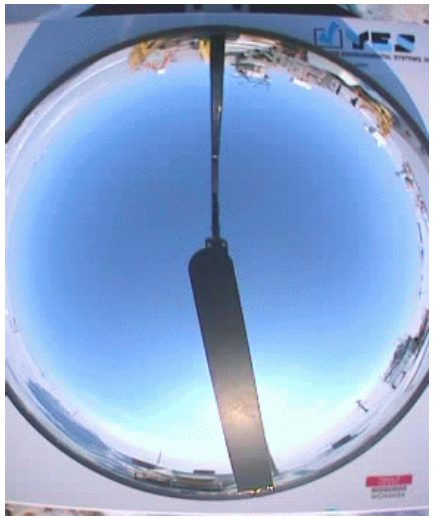


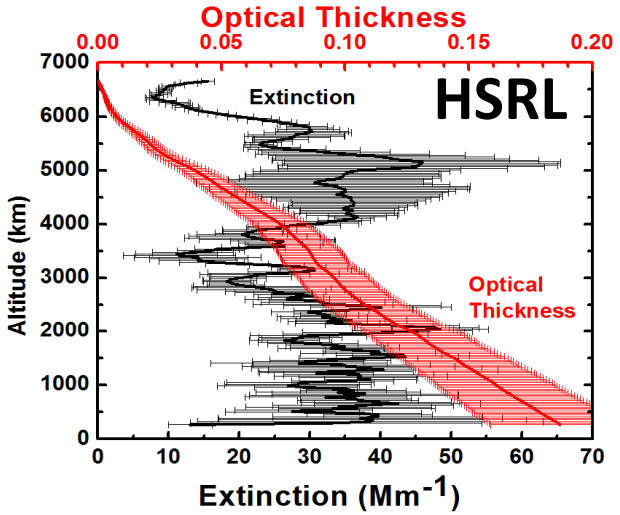


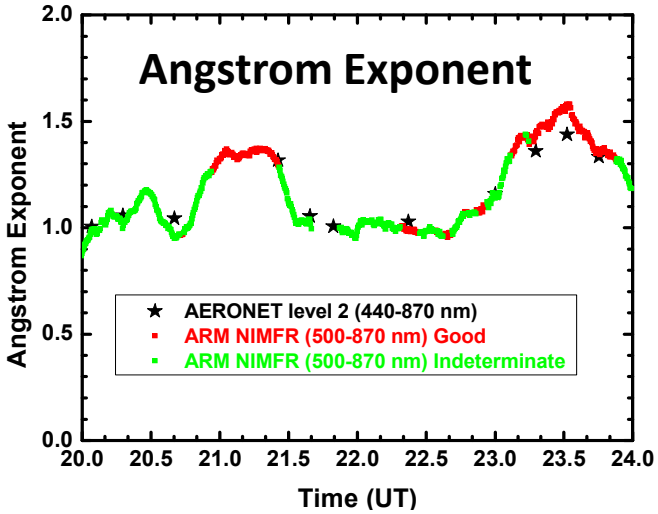
Aerosol/Ice retrievals over ARM NSA site - April 9

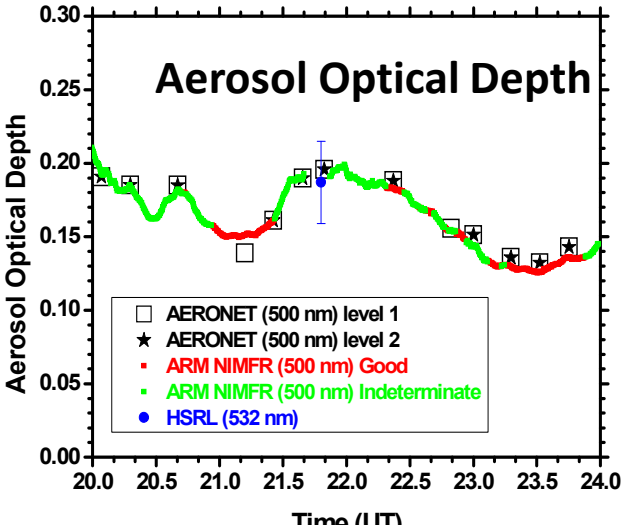
- HSRL data indicate at least 0.05-0.08 (30-40%) of AOT was due to ice
- AERONET Sun photometer, ARM NIMFR, TSI give little or no indication of clouds or ice
- O'Neill retrieval of coarse mode AOT seems to correspond to AOT due to ice

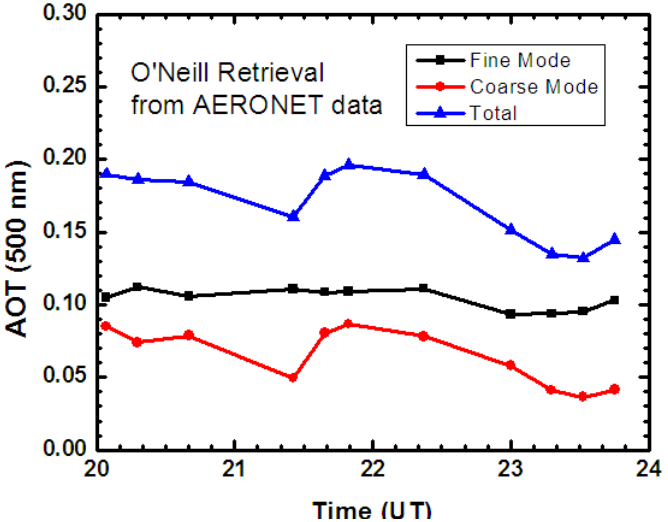
TSI image 21:52 UT



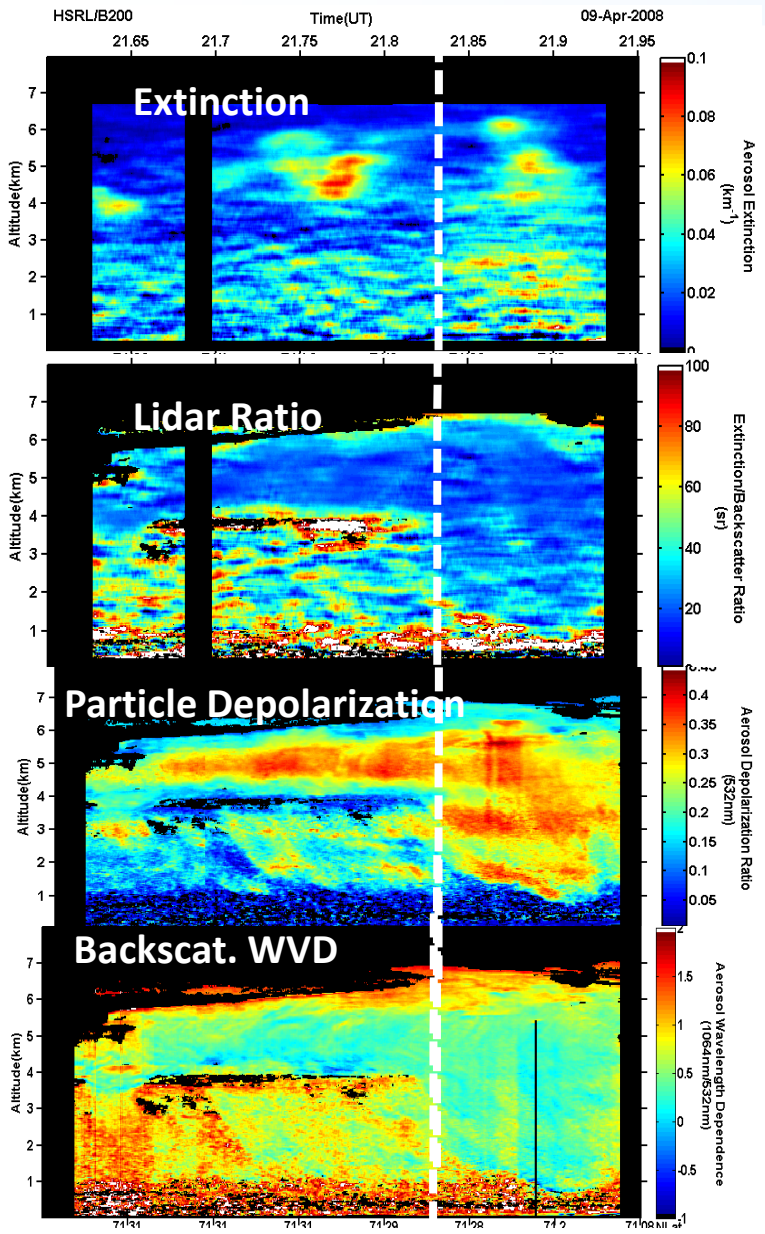


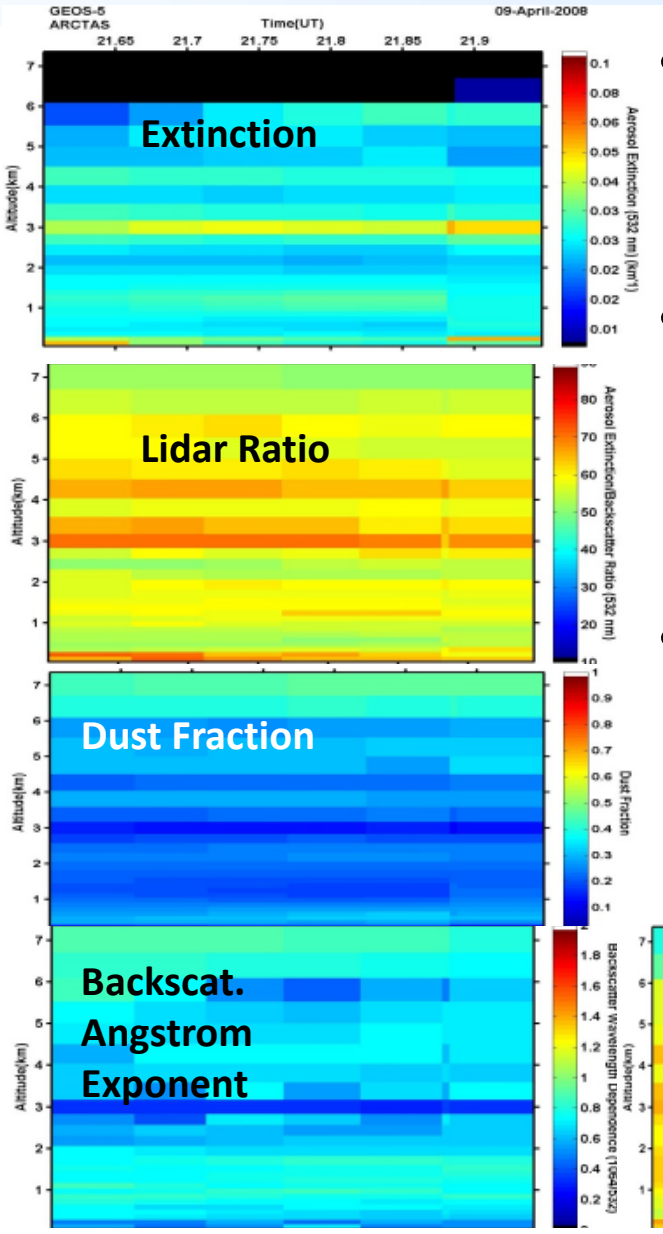






Aerosols/Ice Above Barrow (April 9)



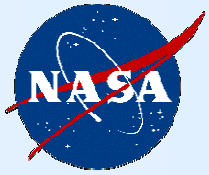


- HSRL measurements indicate much of AOT is due to ice
- GEOS-5 aerosol extinction and AOT simulations agree with measurements
- However, GEOS-5 shows sulfate is dominant source of AOT

Summary of Arctic HSRL Observations

- Aerosols were distributed throughout entire troposphere and not primarly located in the lowest 1-2 km
- On average, little vertical variability of lidar ratio and backscatter Angstrom exponent; small increase in aerosol depolarization with height
- Biomass burning aerosol had largest contribution to AOT
- Ice/dust mix contributed significant fraction to AOT
- Overall, good agreement between average HSRL measurements and GEOS-5 simulations of aerosol
- GEOS-5 dust fractions are generally higher than HSRL estimates and these differences increase with altitude
- AERONET level 2 AOT may contain significant ice contribution

Other ongoing investigations…

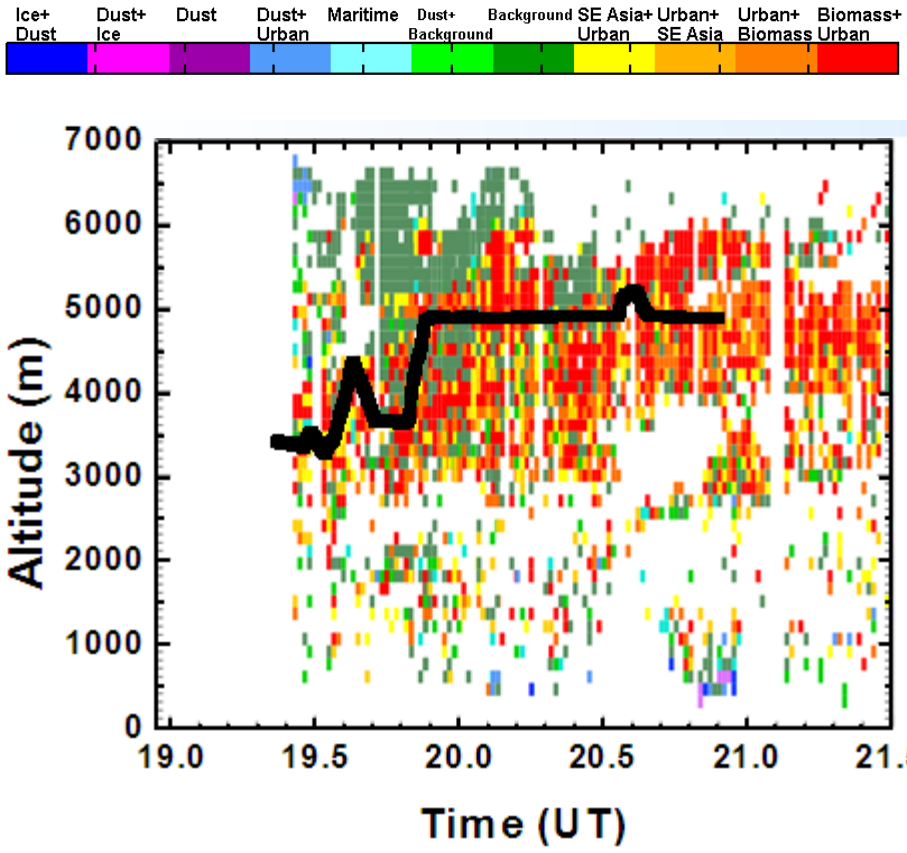


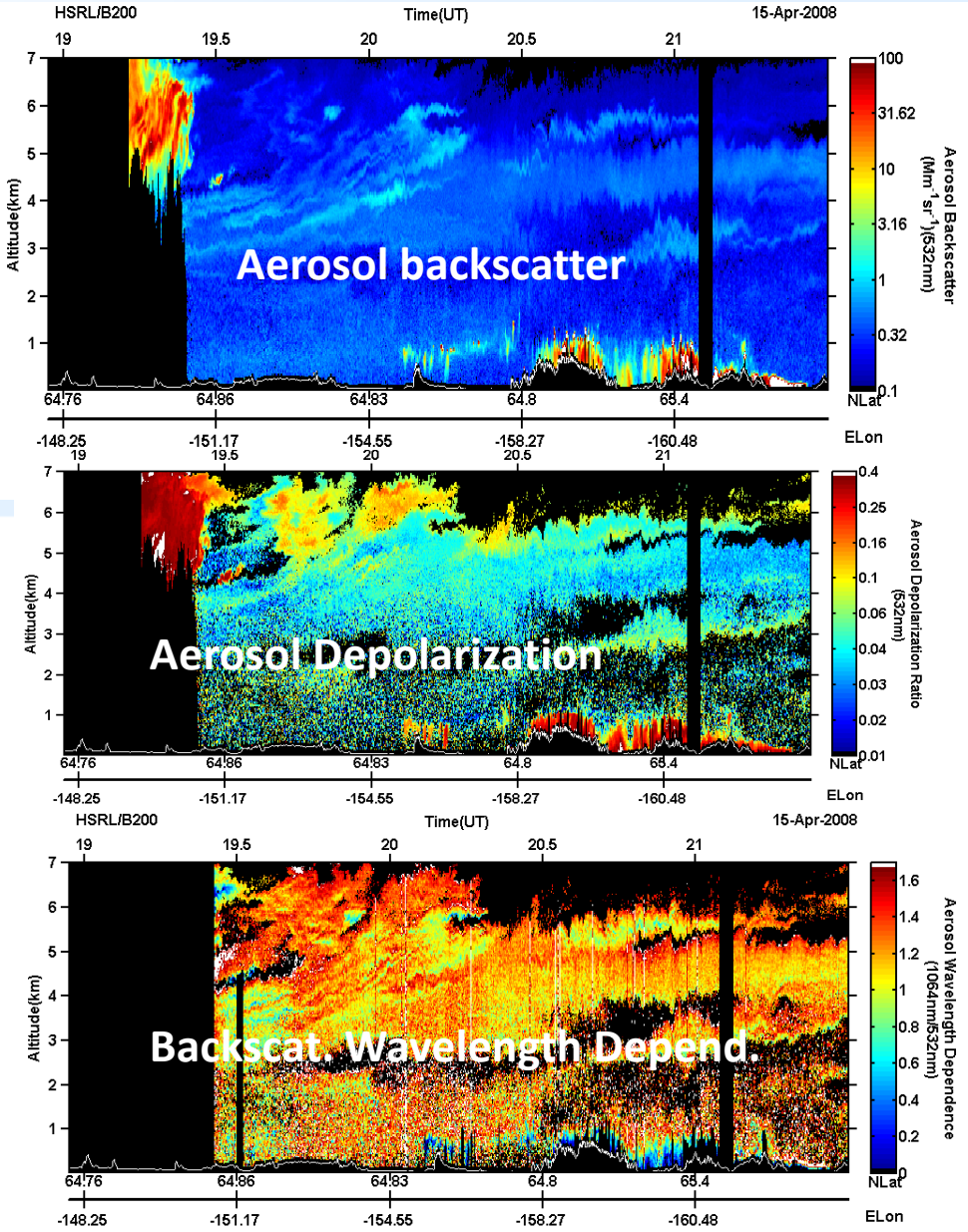
- CALIPSO Validation
- Dust/ice discrimination using HSRL data
- Comparison of HSRL aerosol extinction measurements with various in situ sensors
- Assesment of HSRL inferences of aerosol type using in situ composition data from Convair, NOAA P3, NASA DC-8
- Retrievals of profiles of small mode fraction from HSRL data

Special Thanks to B200 Crew !

Aerosol Classification - April 15 Coordinated Flight

Biomass burning smoke is dominant aerosol type inferred from HSRL measurements of aerosol intensive parameters in the region of coincident P-3 measurements

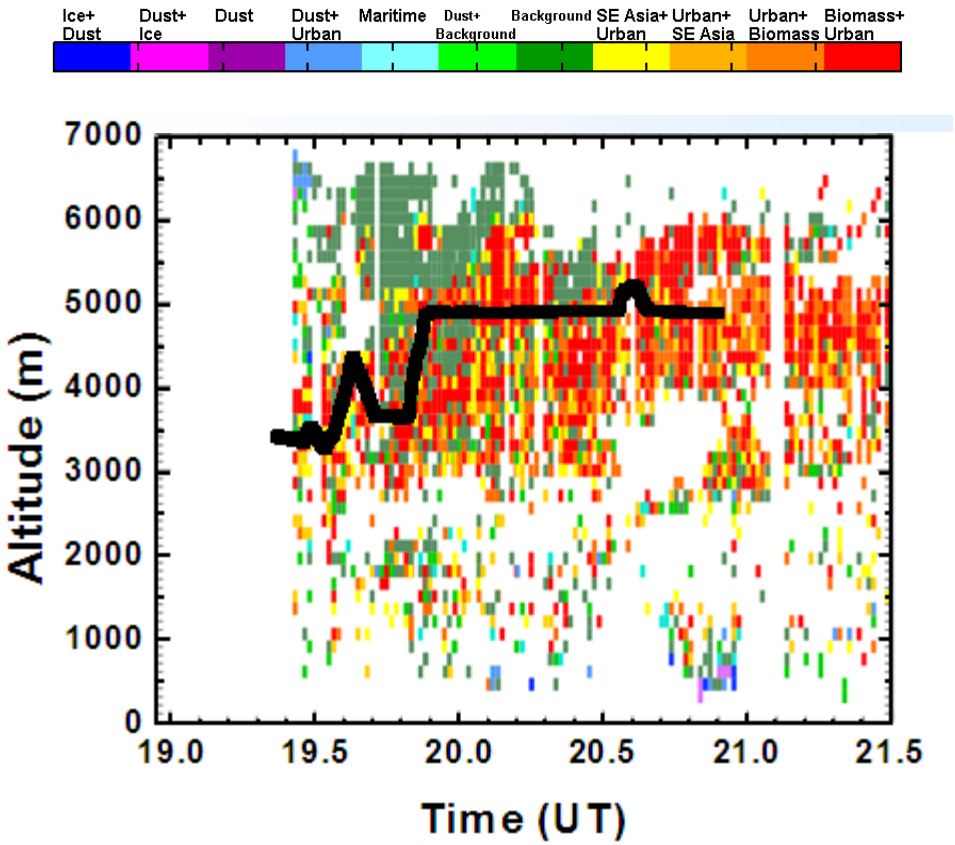


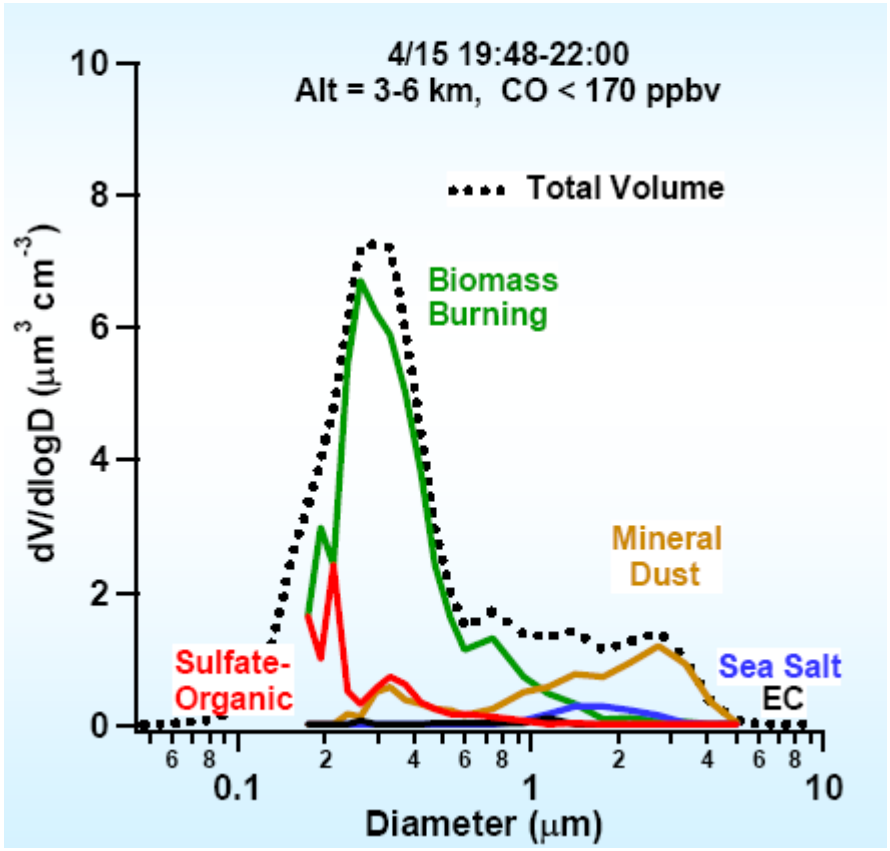


Aerosol Classification - April 15 Coordinated Flight

Biomass burning smoke is dominant aerosol type inferred from HSRL measurements of aerosol intensive parameters in the region of coincident P-3 measurements

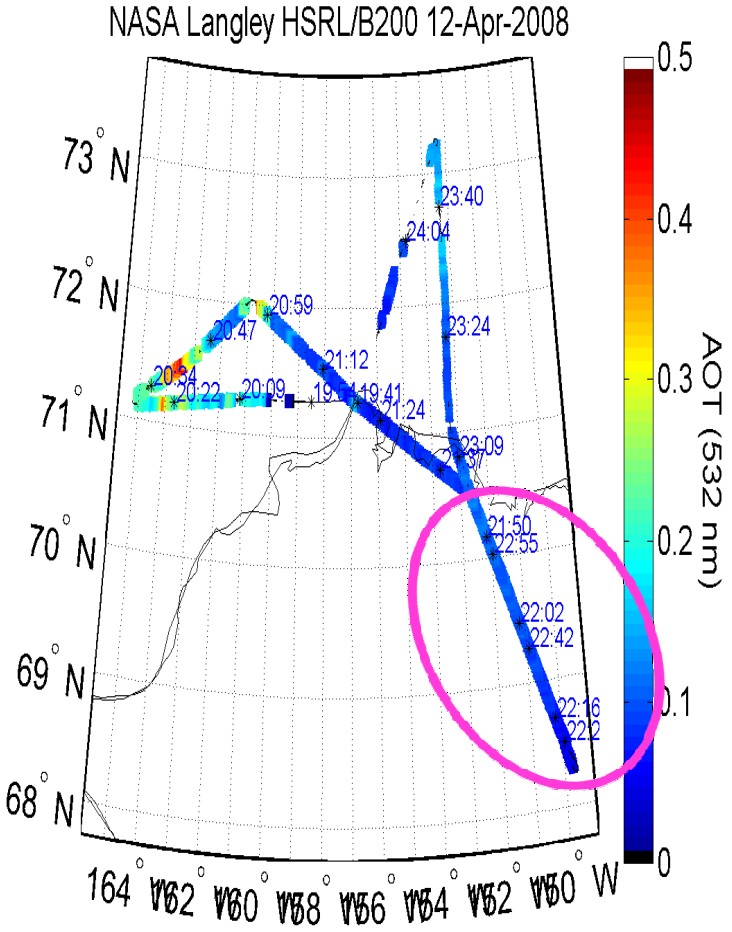
NOAA P-3 PALMS aerosol composition data shows biomass burn had the highest contribution

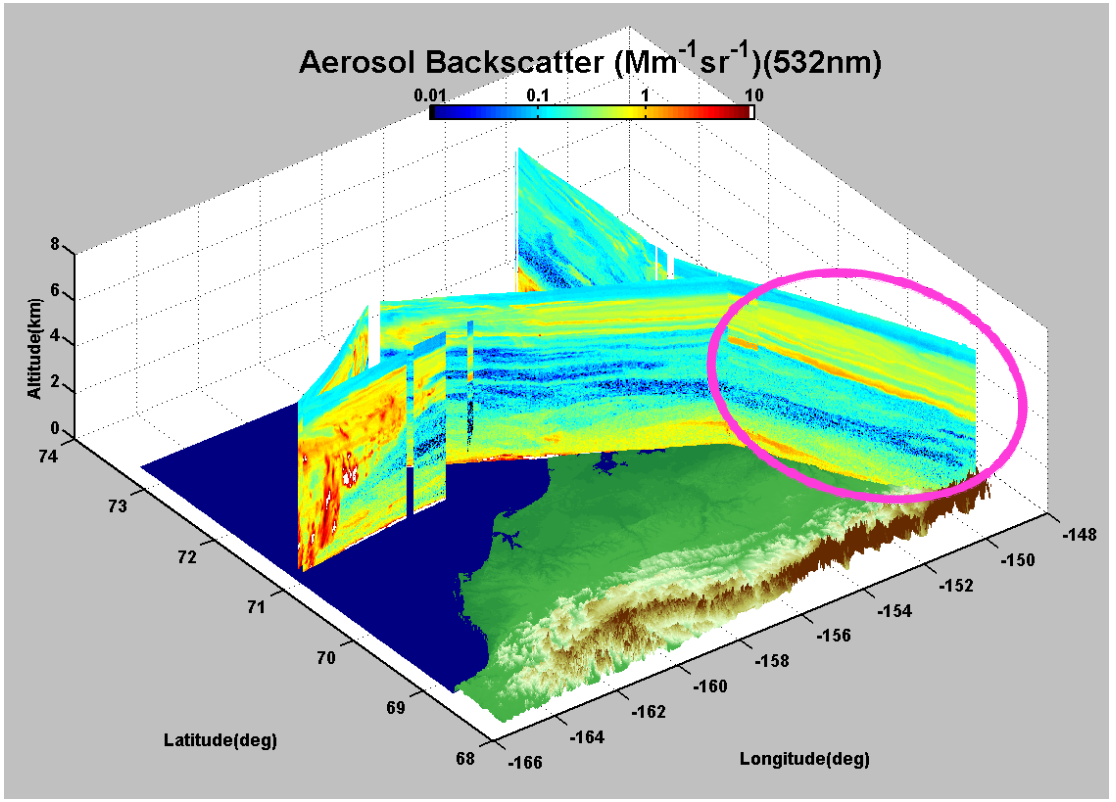




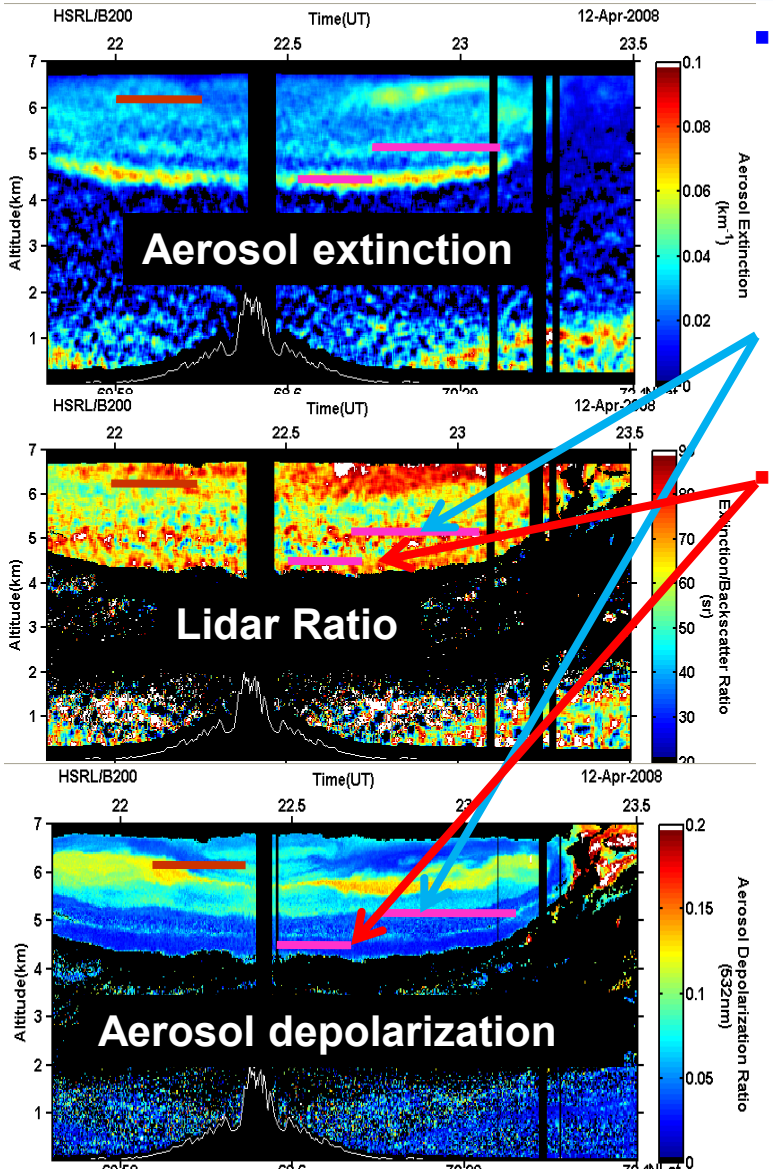
April 12 Flight

- Coordinated B200/DC-8/NOAA P3 flight





April 12 – Elevated Smoke Layer



- Middle of elevated layer
  - Lower lidar ratio and higher depolarization suggests dust
  - NOAA P-3 PALMS data show higher mineral dust fraction than near bottom of layer
- Top and bottom of elevated layer
  - High lidar ratio and low depolarization suggests smoke/pollution
  - NOAA P-3 PALMS data shows higher biomass burning fraction, higher BC, and lower mineral fraction