Comparison of Airborne HSRL and ECMWF Aerosol Profiles

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Motivation and Objectives

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Motivation:

- Global forecasting centers (e.g. ECMWF, NASA, NRL, NOAA, JMA) are increasingly using lidar data to constrain aerosol vertical distributions
- Aerosol model verification using lidar data is also of great interest
- Techniques for verification are under development – model developers require help and seek new "unconventional" data for these activities (e.g. Benedetti et al., 2011, BAMS)

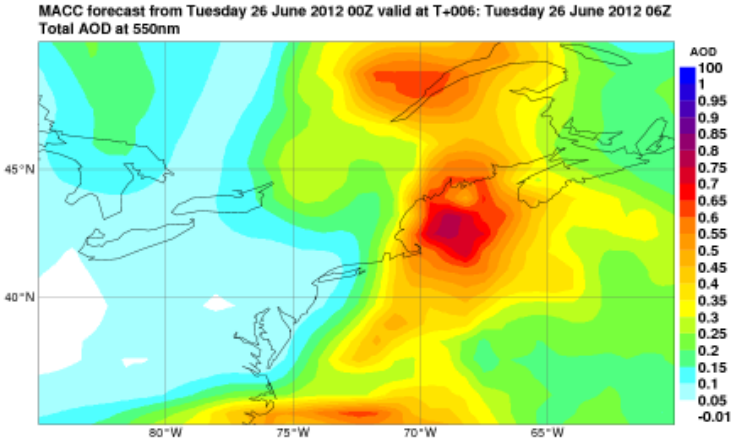
Objectives:

- Examine and evaluate ECMWF/MACC aerosol model products using aerosol profiles acquired by the NASA Langley Research Center (LaRC) airborne High Spectral Resolution Lidar (HSRL)
  - Aerosol optical thickness (AOT)
  - Aerosol extinction profiles
  - Planetary Boundary Layer (PBL)
  - Anthropogenic/natural component fractions

ECMWF/MACC Aerosol Model

ECMWF/MACC Aerosol Model

- Daily 5-day forecasts of aerosol fields
- Components
  - 3 bins of sea salt (0.03 – 0.5 – 5 – 20 μm)
  - 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
  - Black carbon (hydrophilic and –phobic)
  - Organic carbon (hydrophilic and –phobic)
  - SO_2 -> SO_4



- Horizontal resolution ~ 0.8 deg, 60 vertical levels
- 4D-var aerosol assimilation – MODIS AOT at 550 nm
- Natural and anthropogenic components provided
- Diagnostic PBL height based on bulk Richardson number
- Verified routinely using AERONET AOT

➢ **Airborne HSRL data can provide evaluation of vertical profiles of aerosol extinction, type, and PBL height**

Airborne HSRL System

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 parameters to help determine aerosol type

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

HSRL Aerosol Data Products:

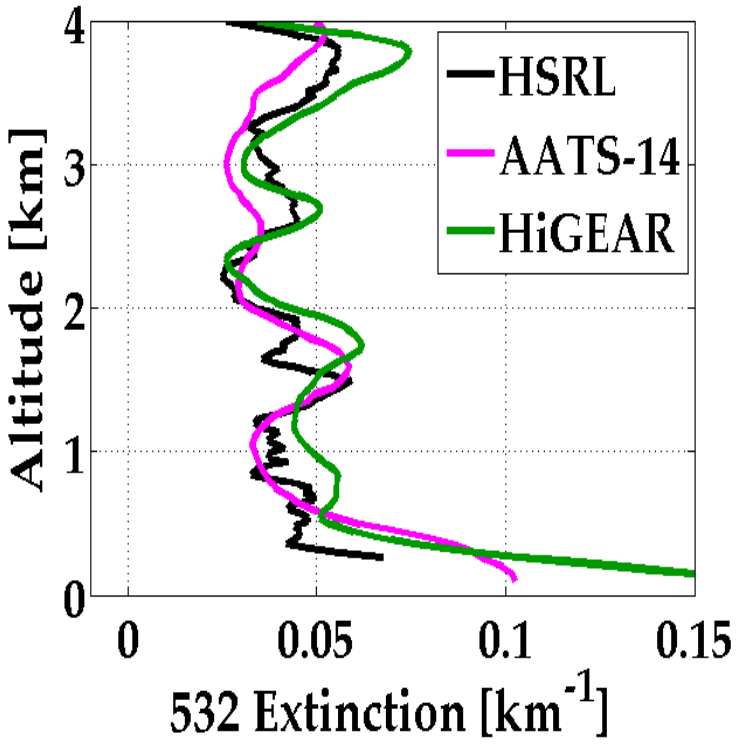
- Scattering ratio (532 nm)
- Backscatter coefficient (532, 1064 nm)
- Extinction Coefficient (532 nm)
- Optical depth (532 nm)
- Backscatter Wavelength Dependence (532/1064 nm)
- Extinction/Backscatter Ratio ("lidar ratio") (532 nm)
- Depolarization (532, 1064 nm)
- Mixed Layer Height from aerosol backscatter gradients; HSRL ML heights are a good proxy for PBL height during the daytime

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

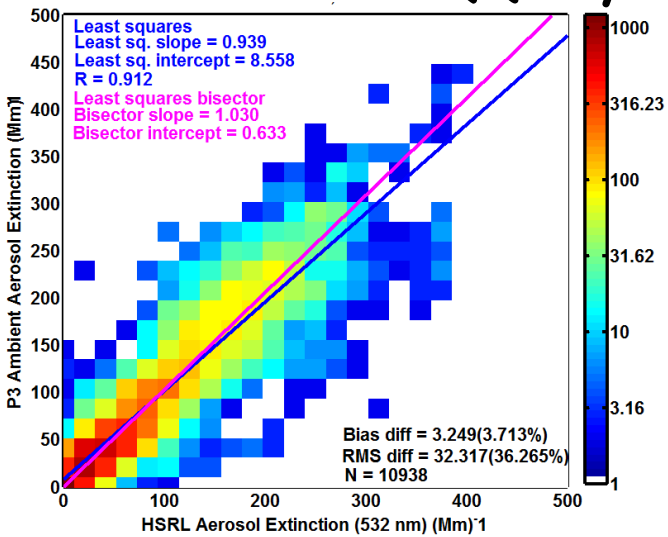
Validation of HSRL Measurements of Aerosol Extinction and Optical Depth

- 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}

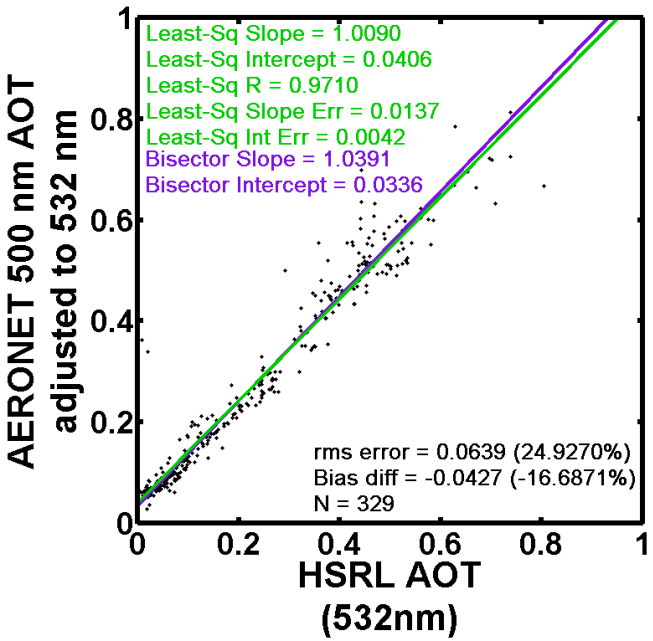
Rogers et al., (2009)- MILAGRO



DISCOVER-AQ (July 2011)



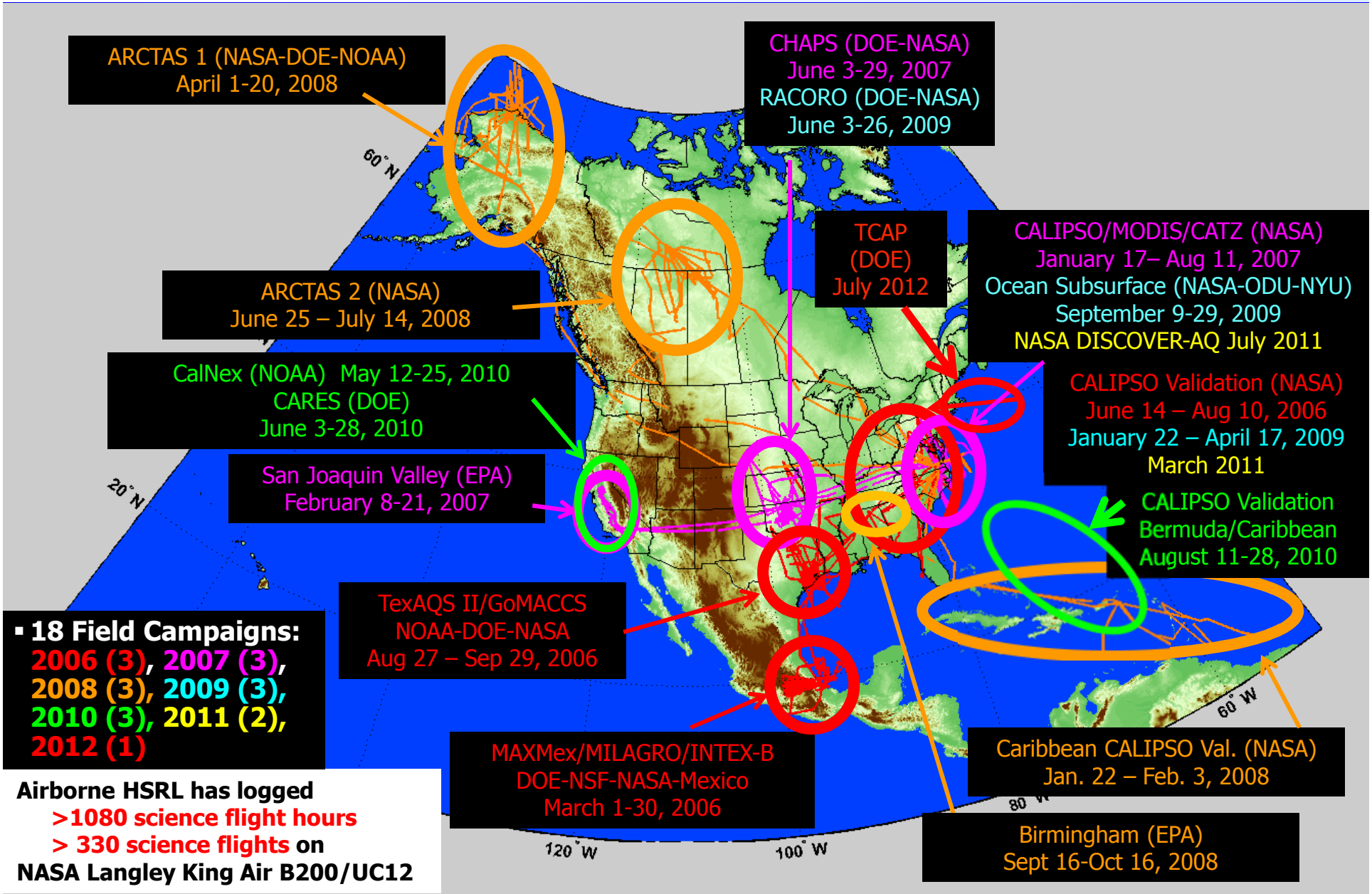
Aerosol Extinction



AOT

Airborne HSRL Field Missions

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



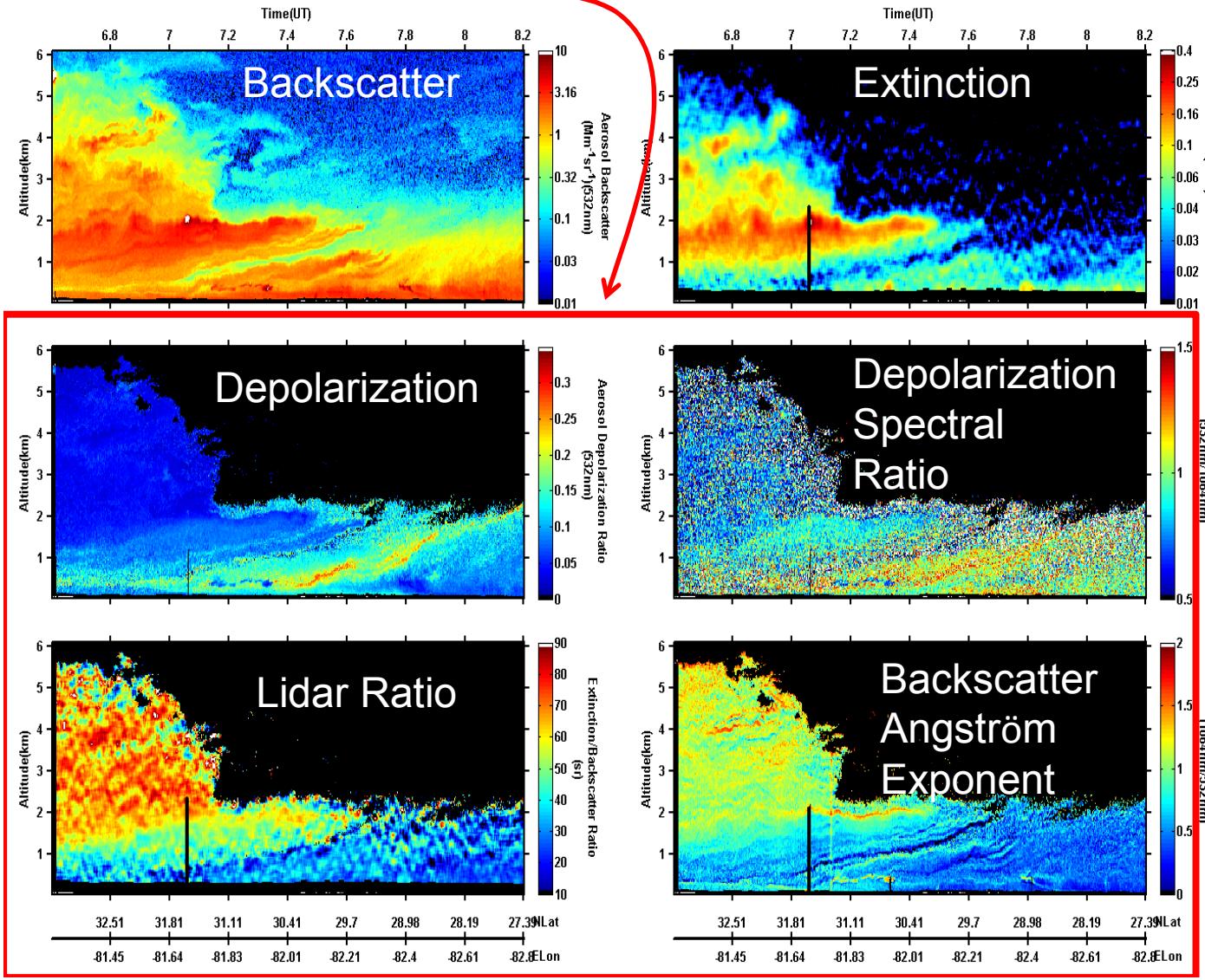
- **18 Field Campaigns:**
  2006 (3), 2007 (3), 2008 (3), 2009 (3), 2010 (3), 2011 (2), 2012 (1)

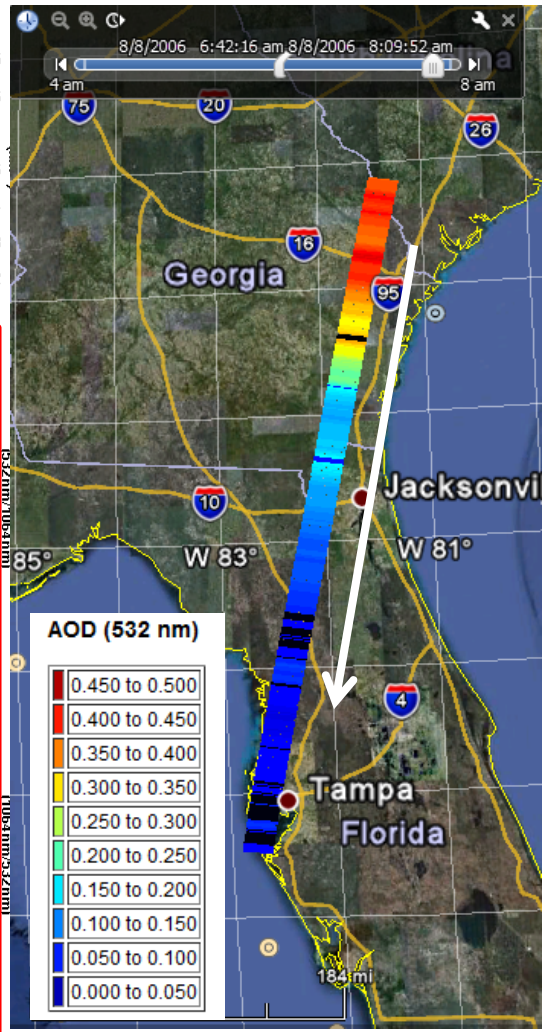
Airborne HSRL has logged
>1080 science flight hours
> 330 science flights on
NASA Langley King Air B200/UC12

Airborne HSRL Measurements

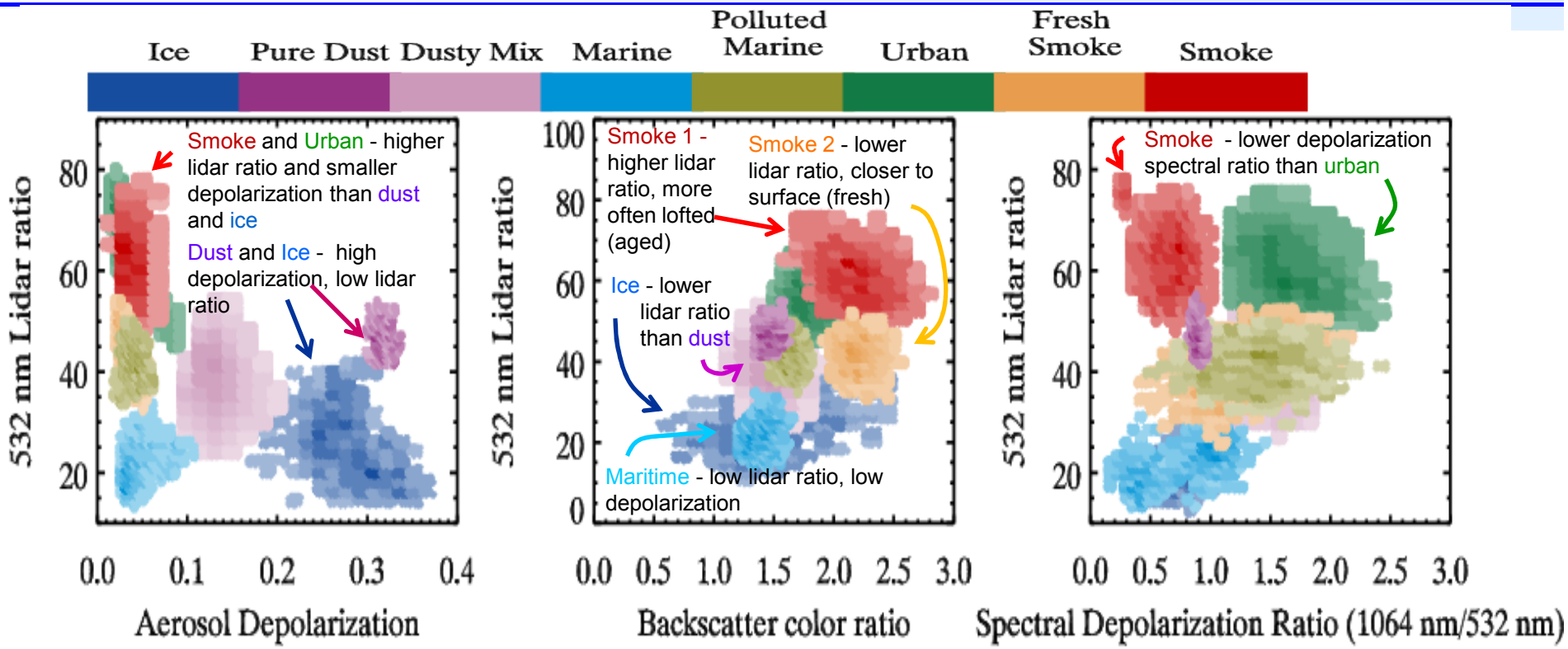
Airborne HSRL Aerosol Data Products

Note the variability in aerosol intensive parameters



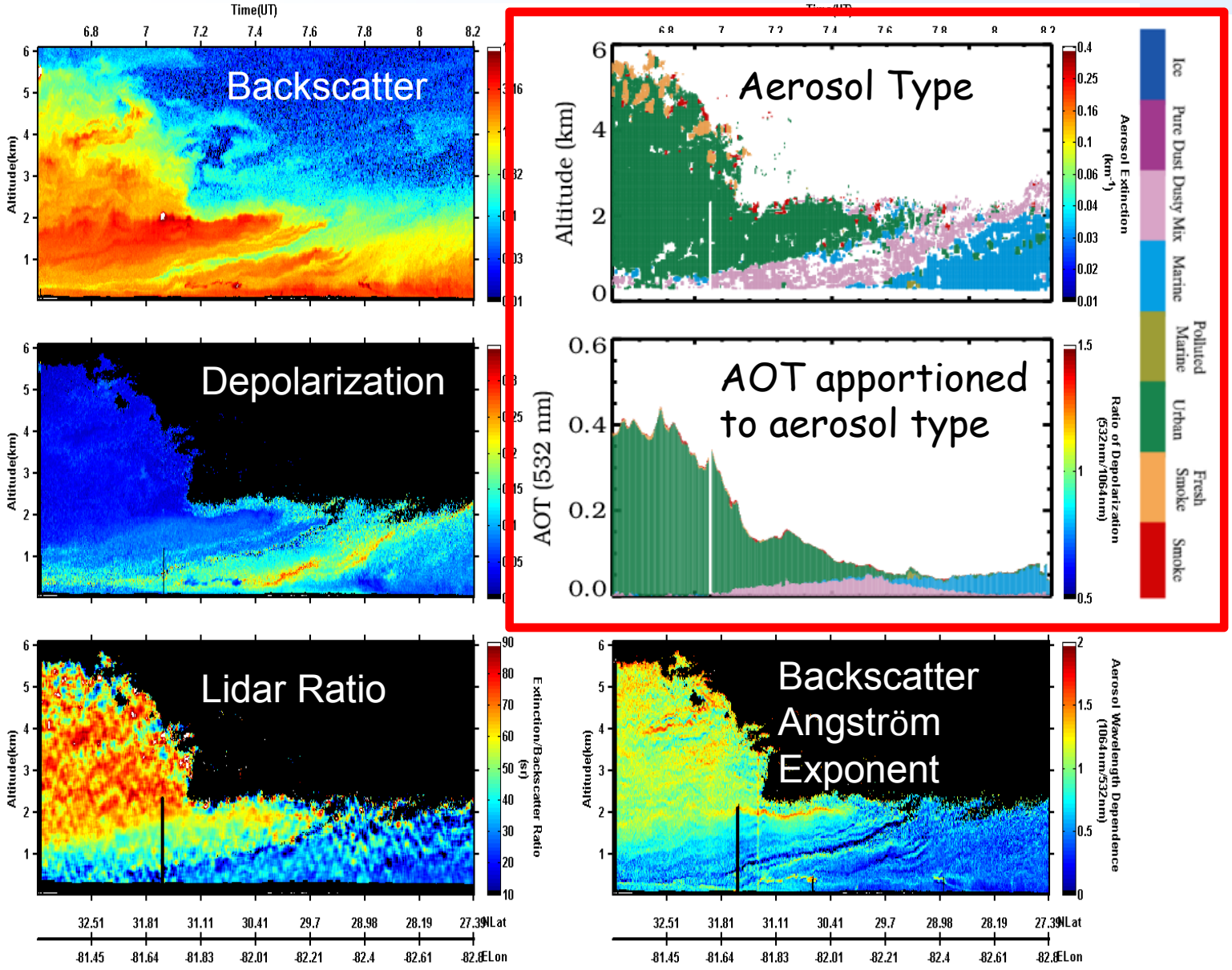


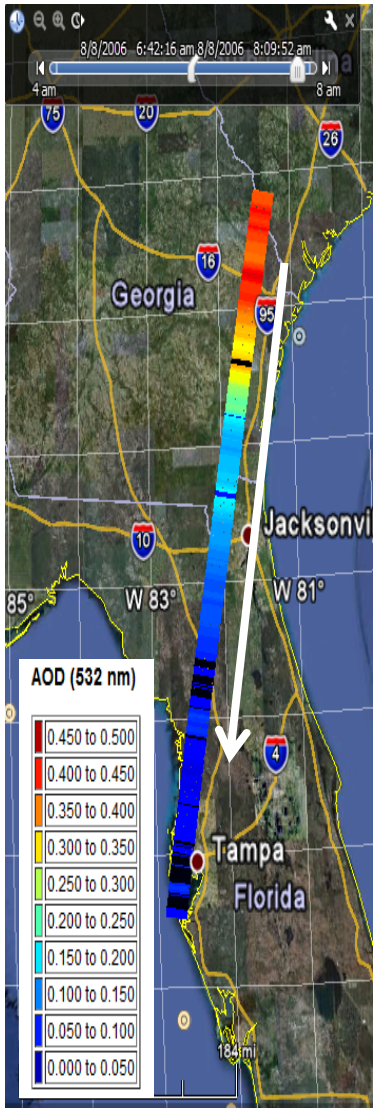
Aerosol Classification Using HSRL Measurements



- 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 2006-2012 are classified
- Technique described by Burton et al. (2012) (AMT)

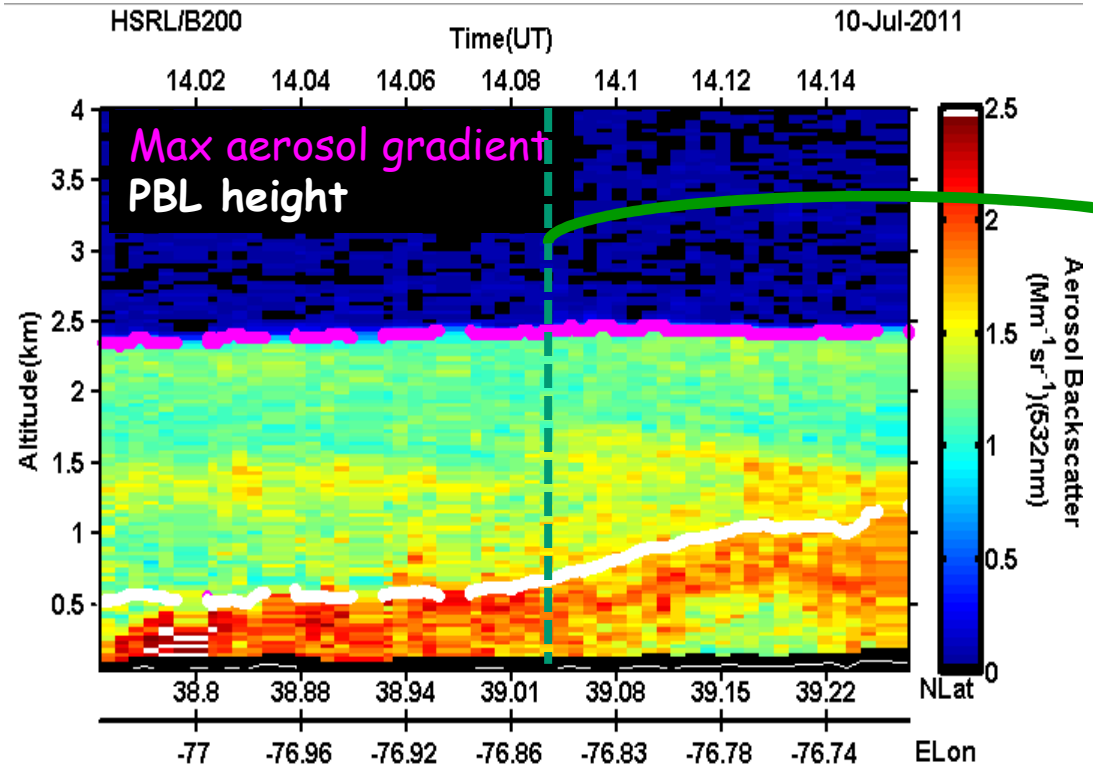
Aerosol Classification using HSRL Measurements

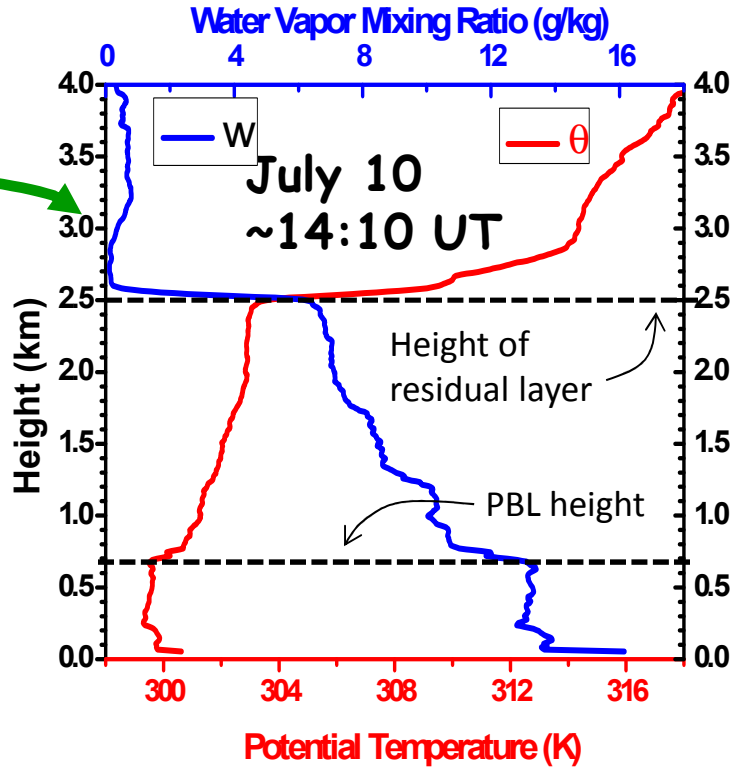




HSRL data used to find height of Mixed Layer (~ PBL height)

- Mixed Layer (ML) heights derived from HSRL aerosol backscatter profiles
- Haar wavelet covariance transform identifies aerosol gradients at the top of the ML
- "Best-Estimate" HSRL ML heights combine results from automated algorithm and manual inspection of HSRL backscatter profiles
- Height of maximum aerosol gradient was also identified to provide an alternative height to describe the depth of the aerosol layer
- These heights often correspond to gradients in potential temperature and water vapor
- During daytime, ML height is normally good proxy for PBL height





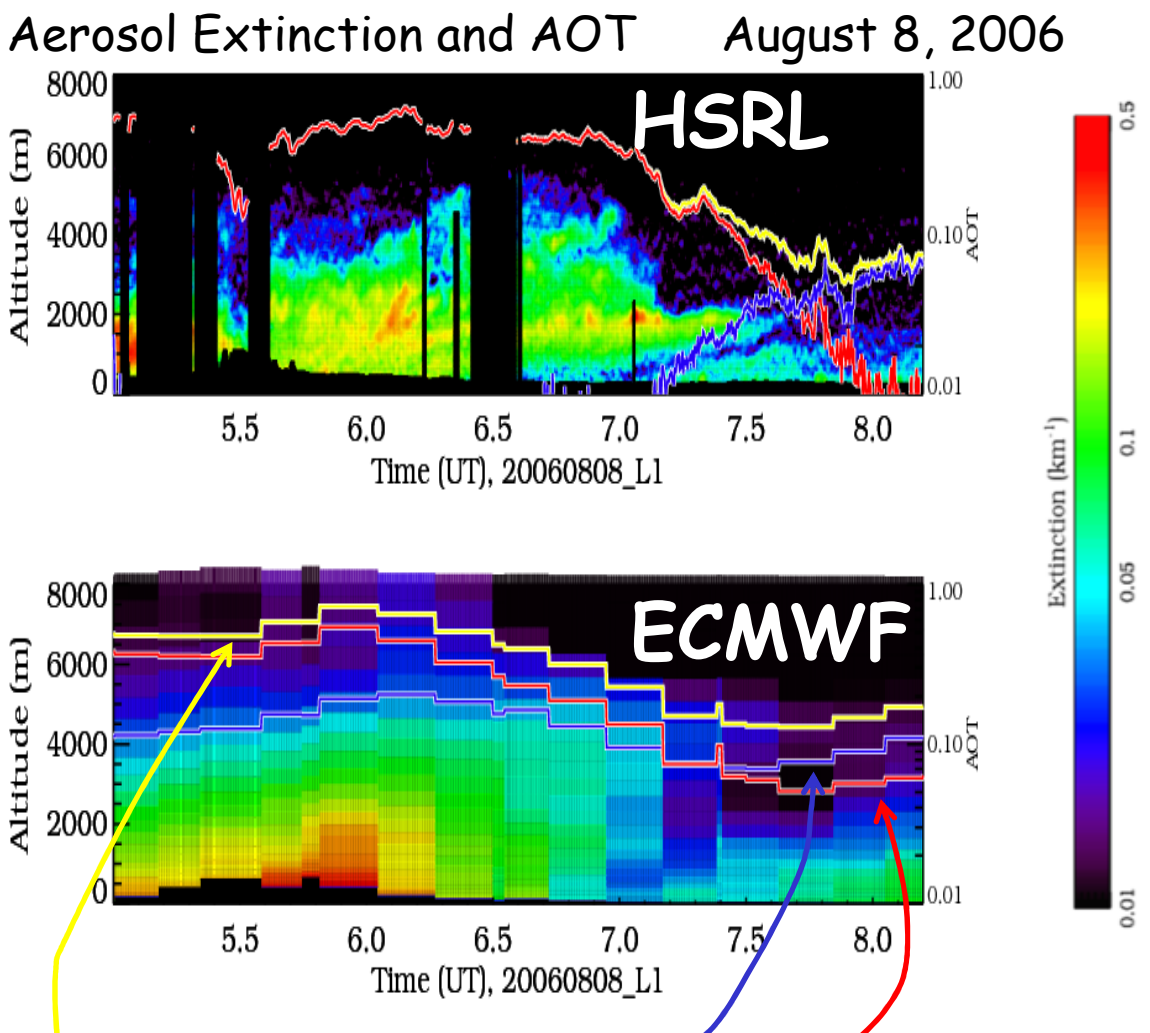
HSRL – ECMWF Comparisons

HSRL and ECMWF Model Comparison Methodology

ECMWF model results and HSRL measurements were compared along the King Air flight tracks for 17 field missions conducted over North America since 2006

Comparisons include:

- AOT in the 0-7 km column
- Aerosol extinction profiles
- Fraction of AOT and extinction due to natural (ice, pure dust, marine) and anthropogenic (polluted marine, urban, smoke, fresh smoke) aerosols
- PBL height (mixed layer height from HSRL used as proxy for PBL height)
- Fraction of AOT within the PBL



Total (yellow), natural (blue), anthropogenic (red) AOT values are shown

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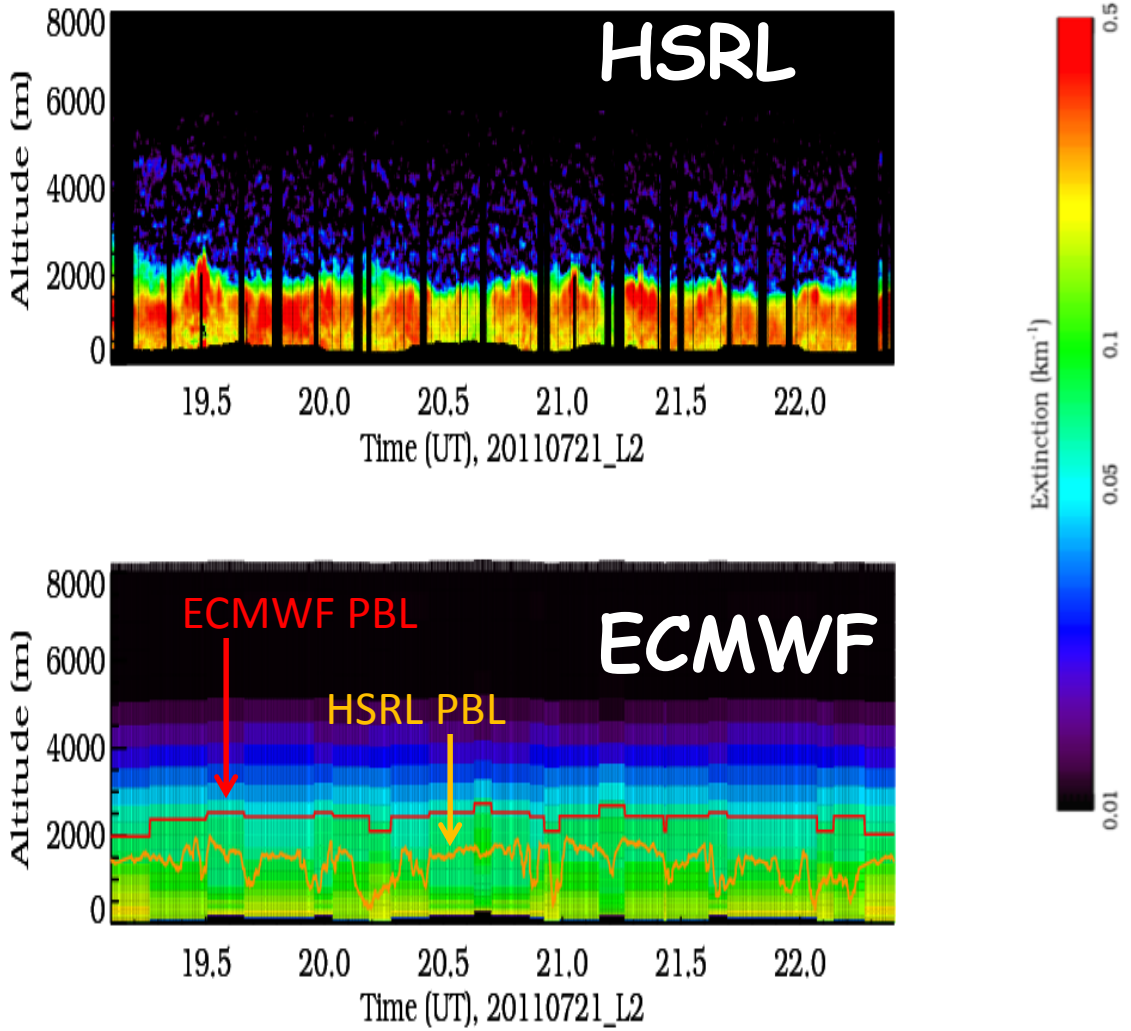
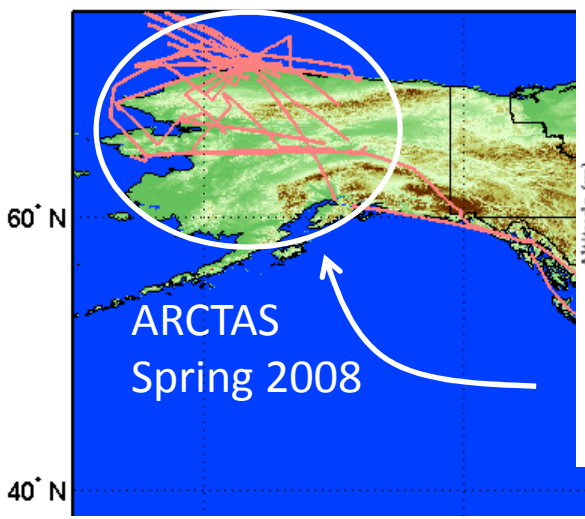
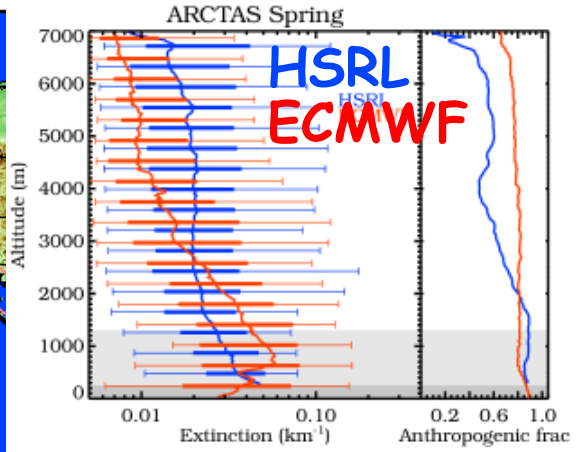
Aerosol Extinction and PBL height July 21, 2011

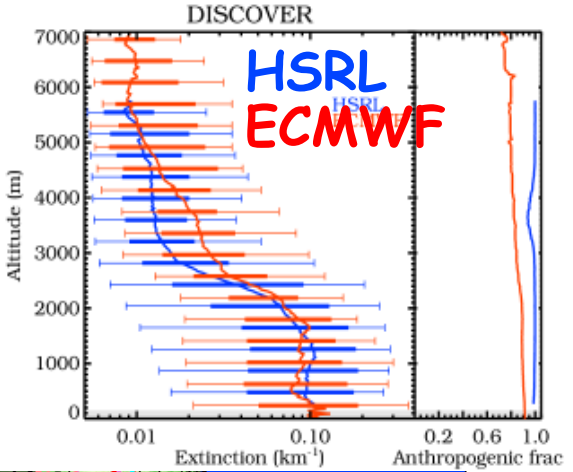


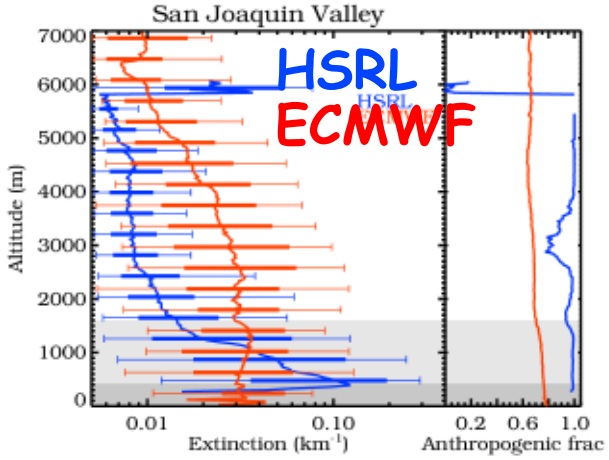
Aerosol Extinction Profile Comparison

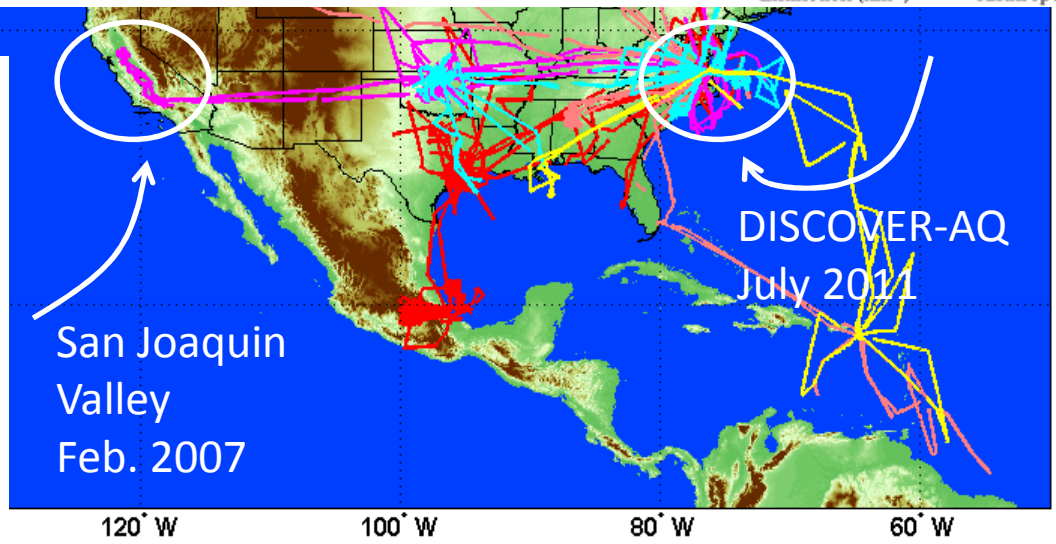
- Considerable variability in aerosol extinction profile comparisons
- Best agreement found in the PBL
- ECMWF often has higher extinction in free troposphere, especially over the western USA





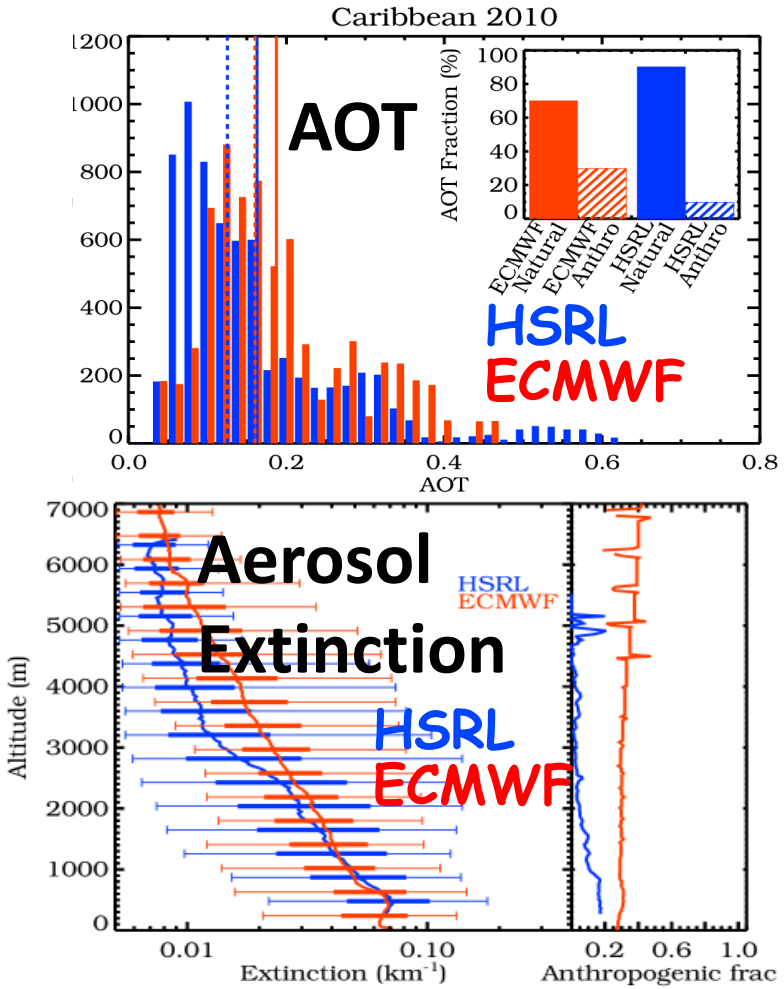


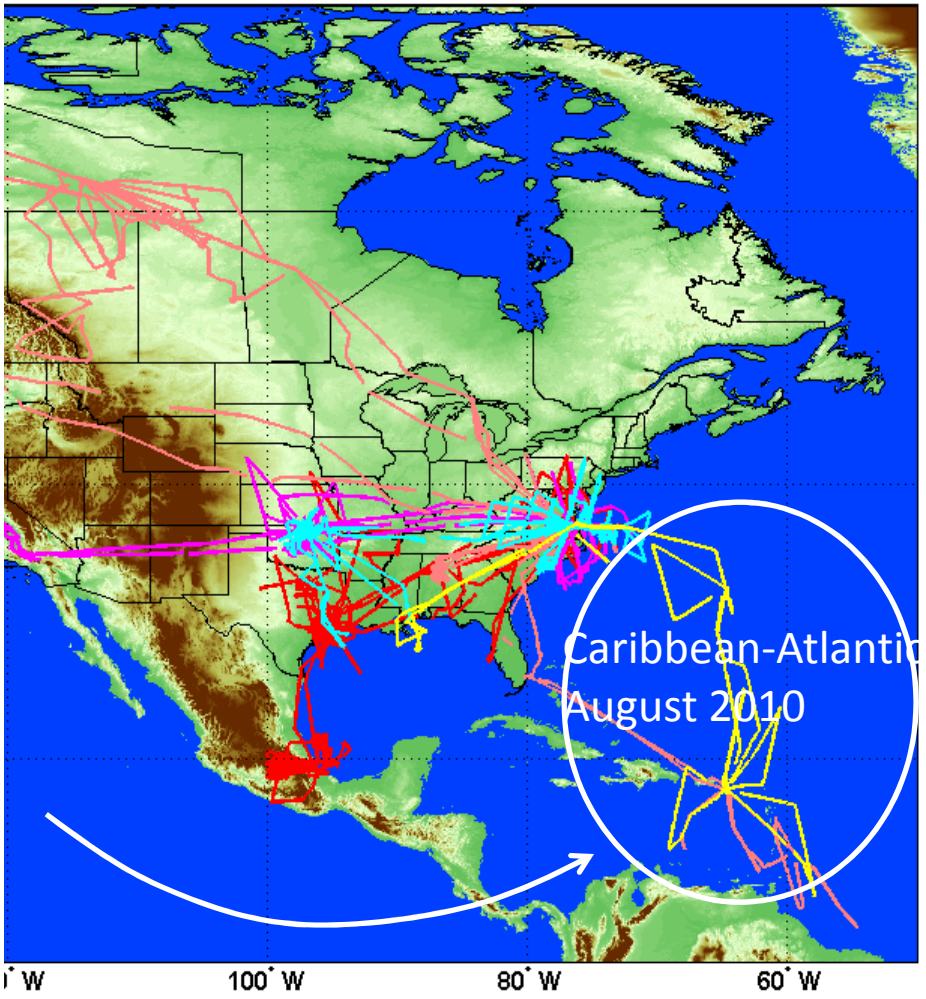




Saharan Dust over the Caribbean and Atlantic Ocean

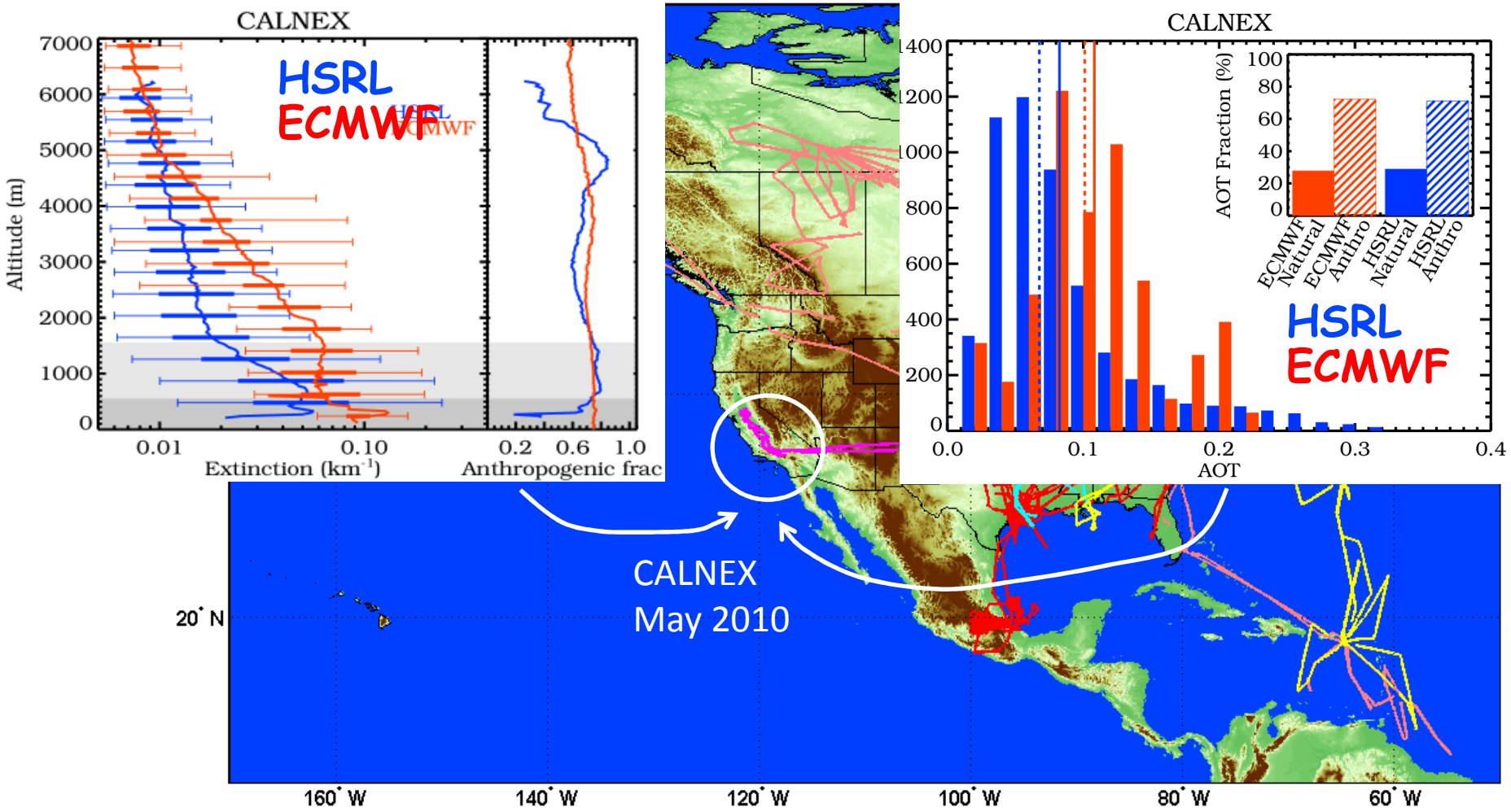
- Good agreement in AOT and aerosol extinction profiles associated with Saharan dust
- Good agreement in the large fraction of natural aerosols





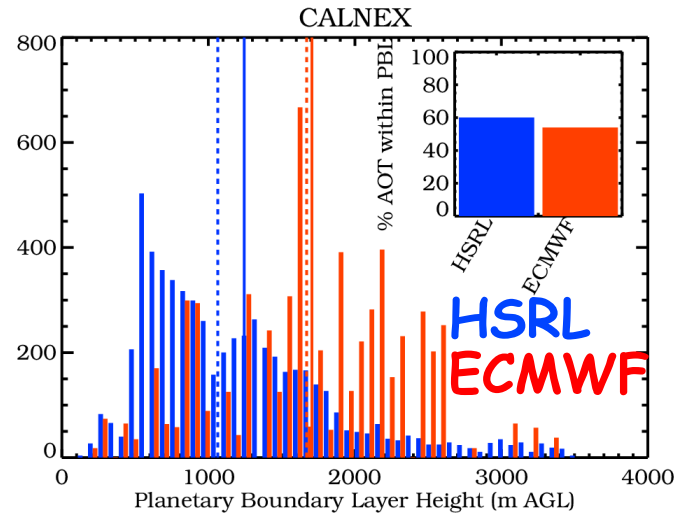
Larger differences over Los Angeles and Western USA

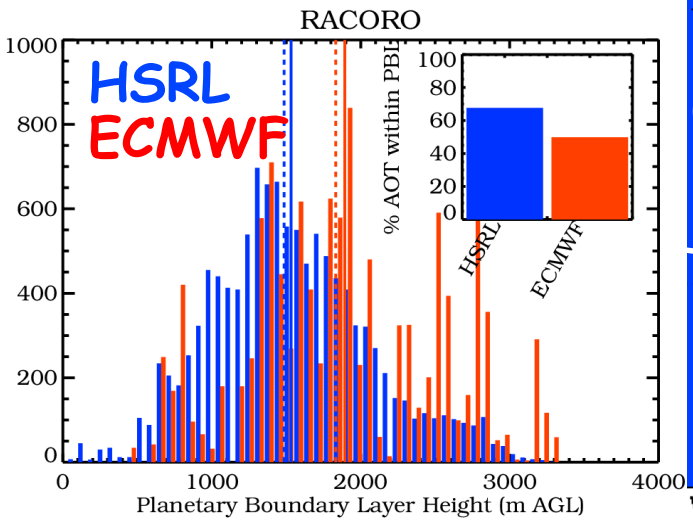
- Larger differences in AOT and aerosol extinction over Los Angeles and California likely associated with: small scale variability, accuracy and availability of assimilated MODIS AOT, local emission sources not well resolved, lack of nitrates in model

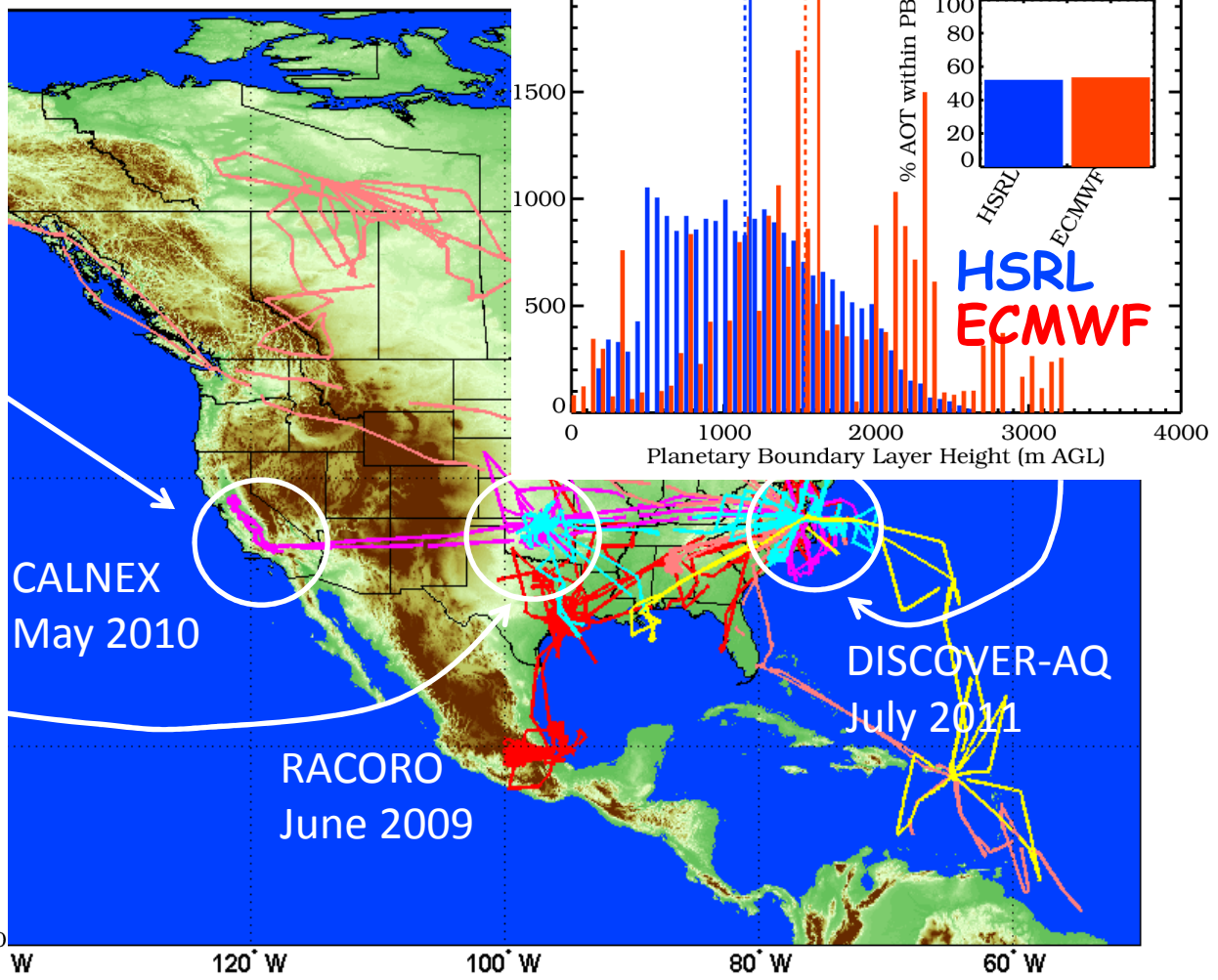


PBL Height Comparisons

- Overall, ECMWF PBL heights are generally about 100-200 m higher than HSRL ML heights
- Fraction of AOT within the PBL is about the same

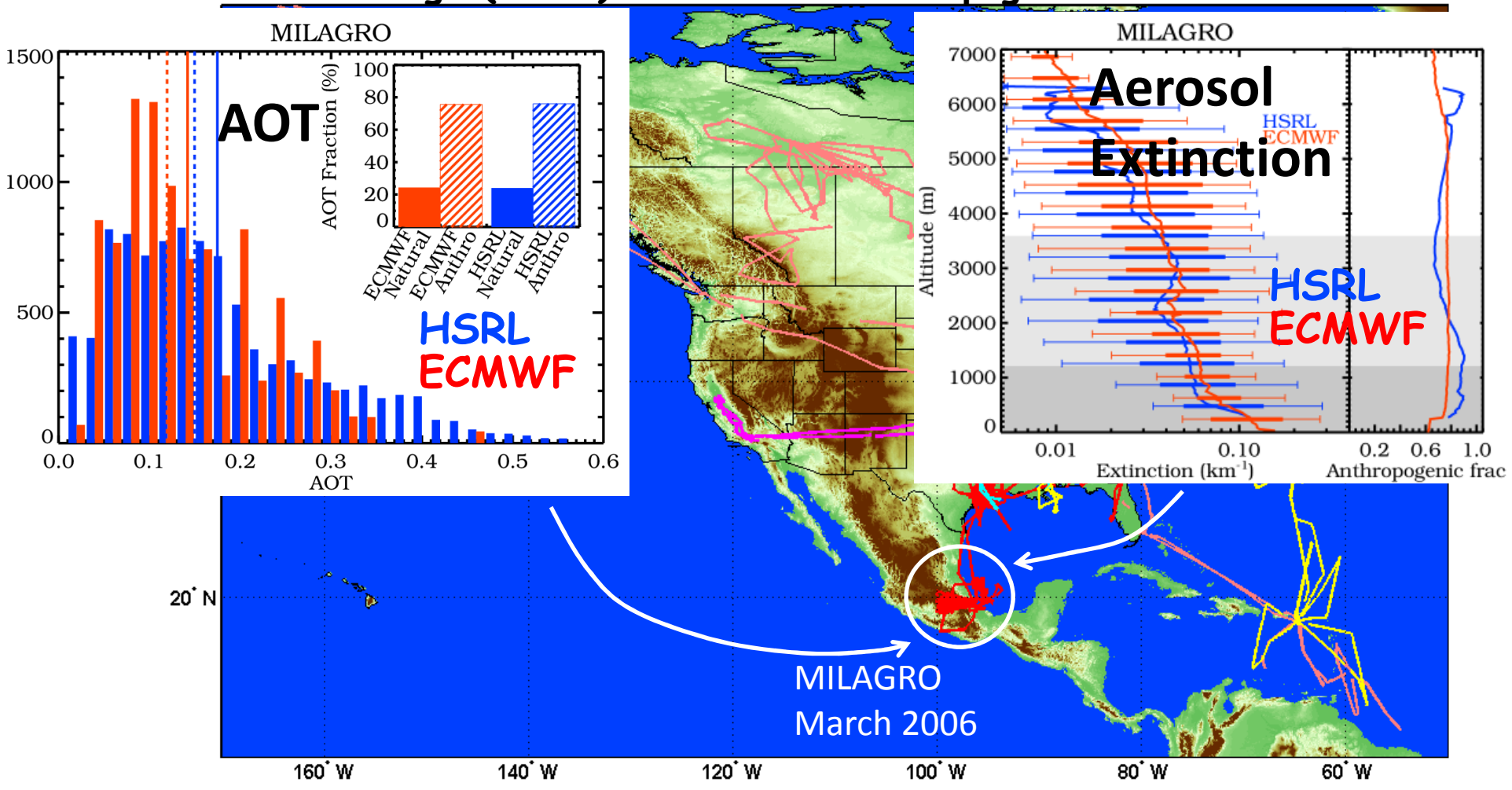






Natural vs. Anthropogenic Aerosols

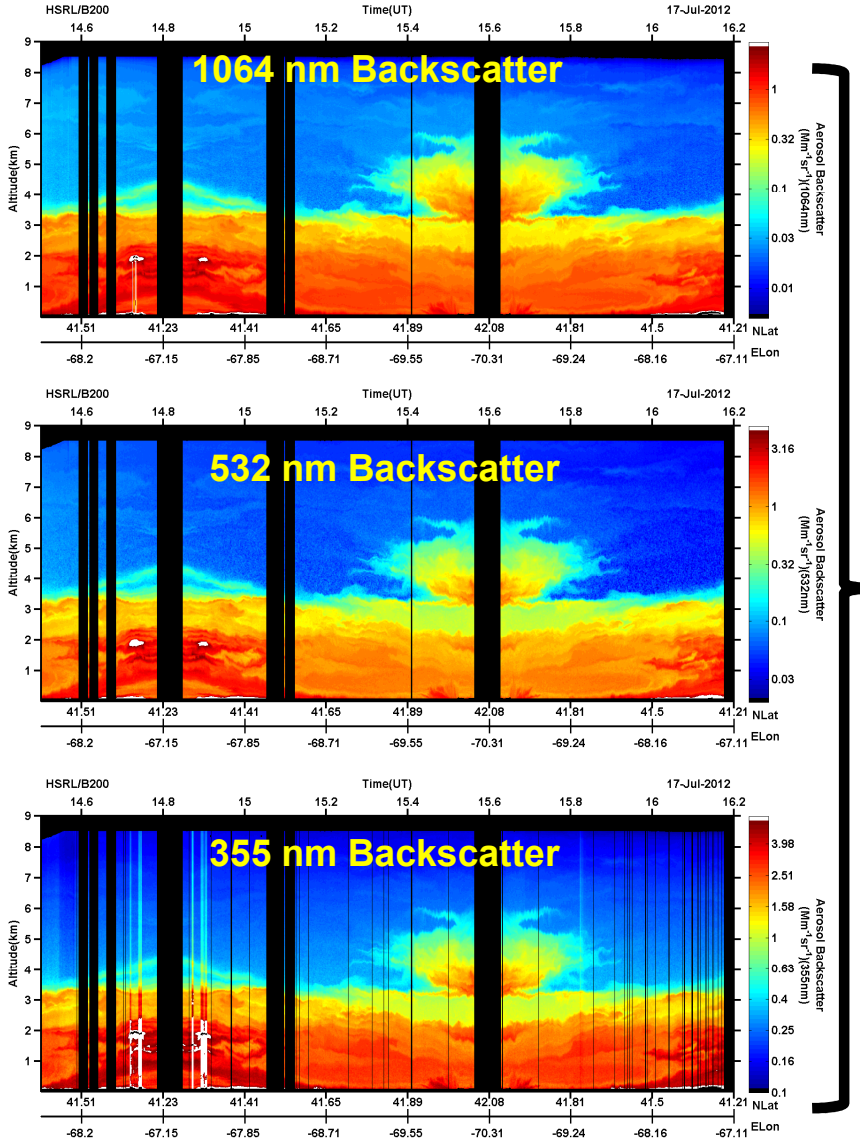
- Overall, very good agreement in fractions of AOT and aerosol extinction contributed by natural and anthropogenic aerosols
- HSRL anthropogenic fraction is about 5-10% higher than ECMWF
- Most missions saw high (>75%) fraction of anthropogenic aerosols



New Advanced Airborne HSRL-2 Measurements

LaRC Airborne HSRL-2: World's First Airborne Multi-wavelength HSRL

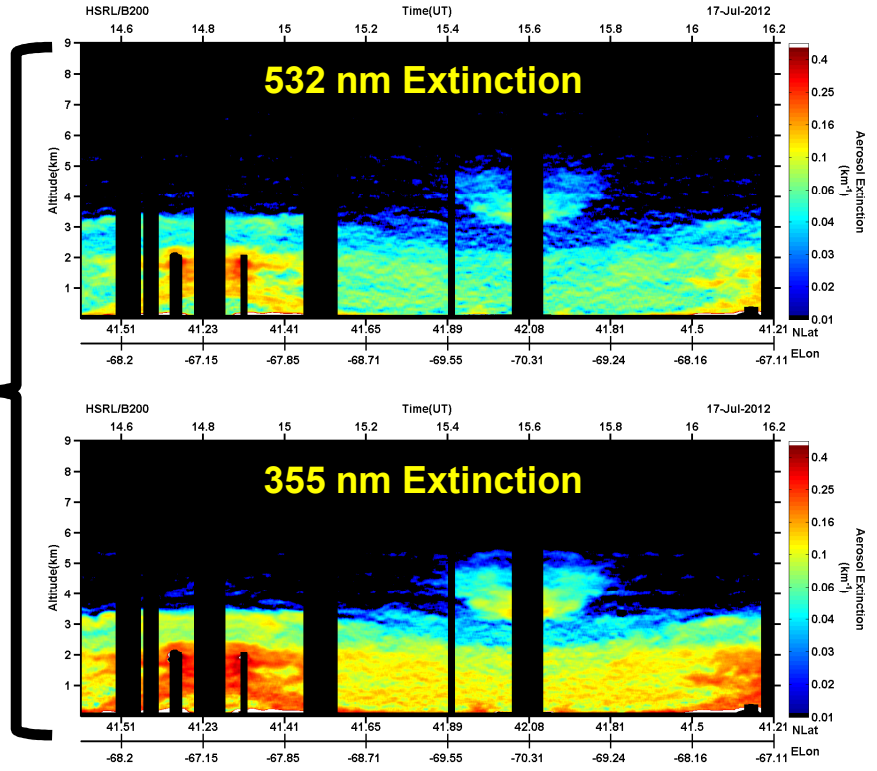
07/17/2012 TCAP flight on B200 aircraft



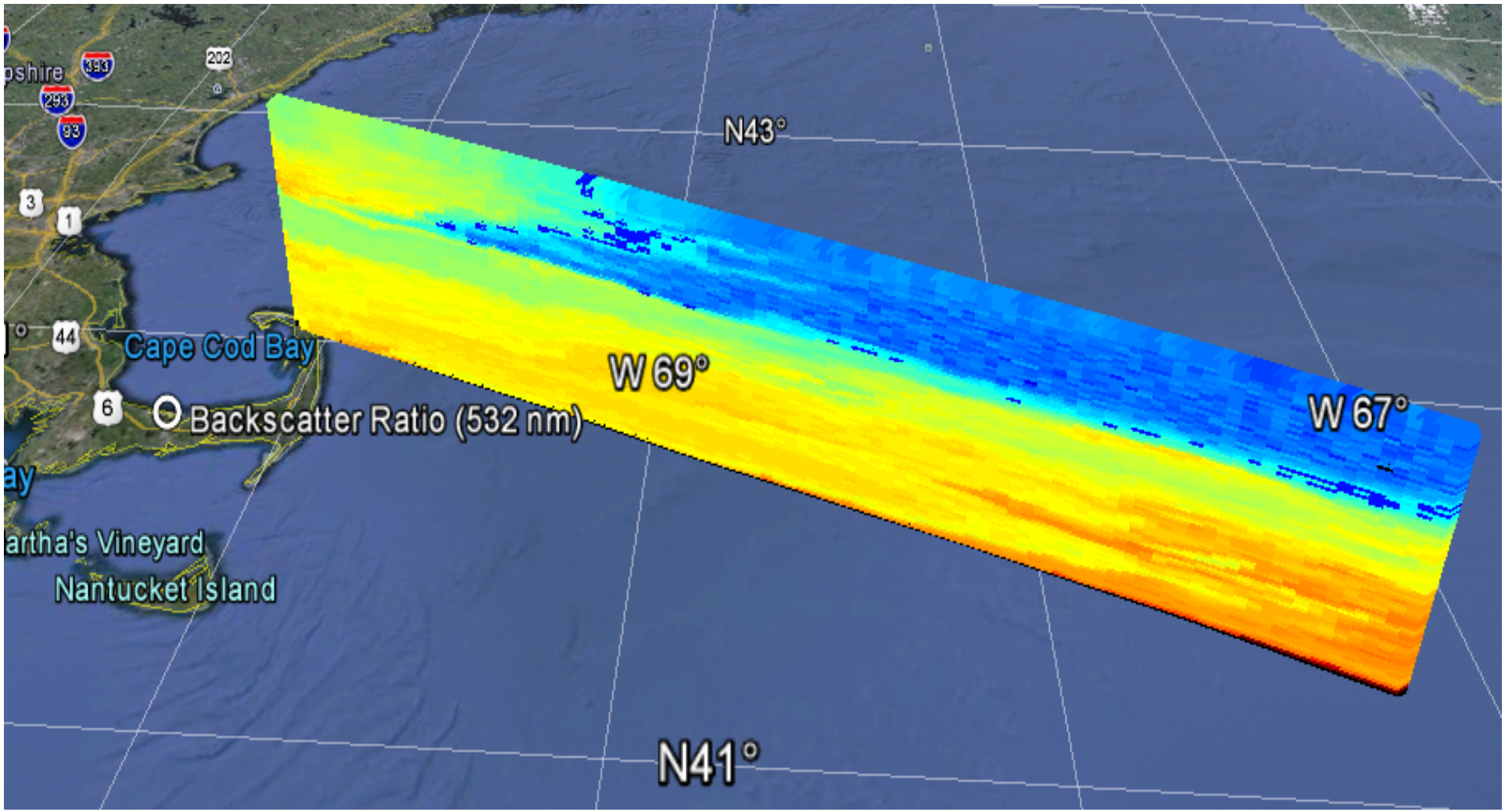
3β

2α

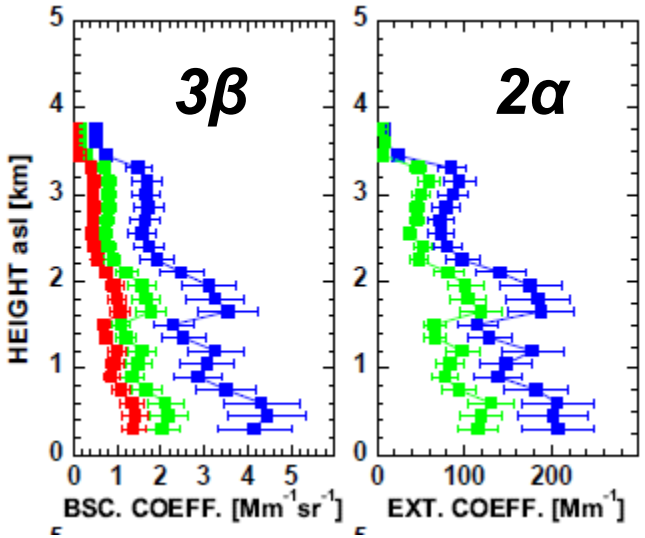
- High Spectral Resolution Lidar (HSRL) provides independent retrievals of aerosol extinction and backscatter
- HSRL-2 Capabilities
  - Backscatter at 355, 532, and 1064 nm
  - Extinction at 355 and 532 nm (HSRL)
  - Depolarization at 355, 532, 1064 nm

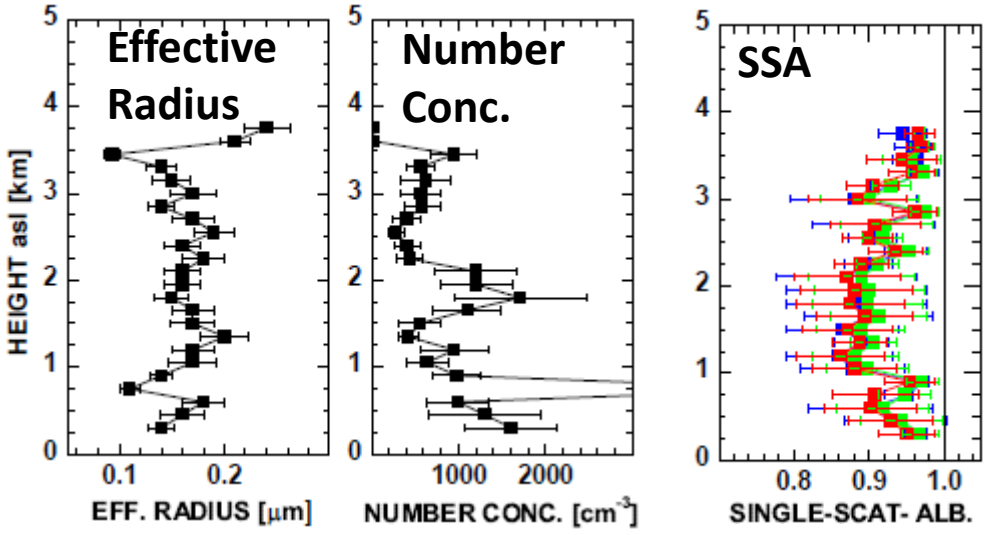


HSRL-2 Measurements of 532 nm ASR 17 July 2012



Preliminary Multiwavelength "3β+2α" retrievals using data from airborne HSRL-2





Aerosol Backscatter:
355 nm
532 nm
1064 nm

+

Aerosol Extinction:
355 nm
532 nm

Multiwavelength lidar retrieval algorithms (Müller et al, 2001, 2002; Veselovskii et al. 2002; Wandinger et al., 2002; etc.)

Also:

- Real and imaginary index of refraction
- Scattering coefficient
- Absorption coefficient
- Surface concentration
- Volume concentration

(Multiwavelength lidar retrievals provide vertically resolved quantitative aerosol information for model evaluation, assimilation, etc.)

Summary

- Comparisons between airborne HSRL and ECMWF/MACC aerosol model
  - Aerosol extinction and AOT
    - Considerable variability
    - ECMWF model often has higher extinction in free troposphere
    - Better agreement in eastern USA; larger differences over the west
  - Anthropogenic vs. Natural
    - Generally good agreement
    - ECMWF aerosol model anthropogenic about 5-10% lower than HSRL
    - Fairly good agreement in representing Saharan dust over Caribbean
  - PBL height
    - ECMWF PBL generally about 100-200 m higher than HSRL ML
- Advanced HSRL-2 multiwavelength aerosol retrievals can help evaluate model aerosol optical and microphysical parameters