Comparison of Airborne HSRL and Modeled Aerosol Profiles

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Outline

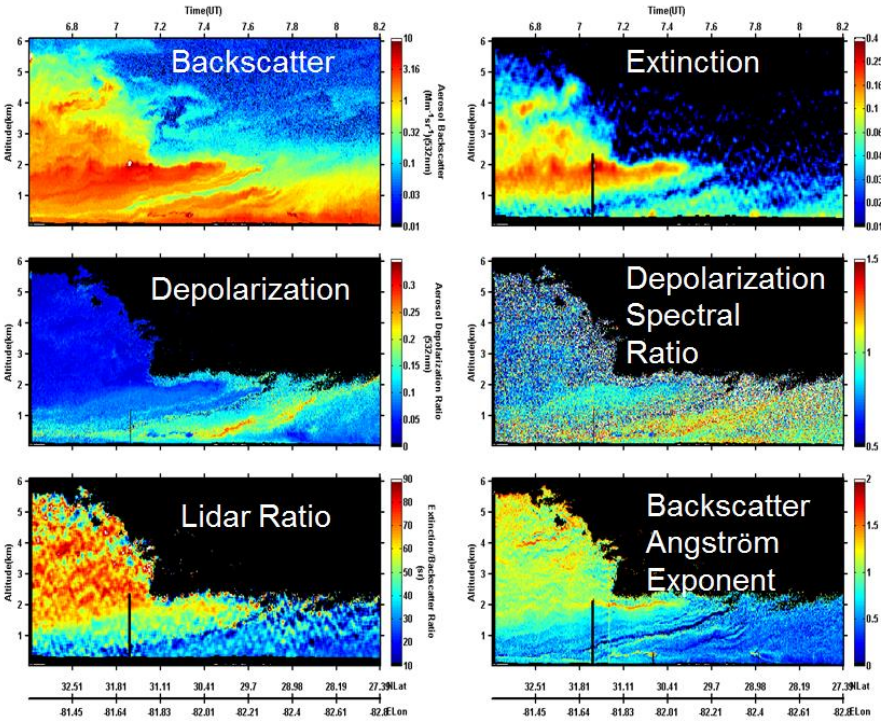
- NASA Langley airborne HSRL systems
  - HSRL-2
  - DIAL/HSRL
- GEOS-5 model
- Comparisons of lidar observables
  - Flight "curtains"
  - Average profiles
- Aerosol classification
- Boundary layer height comparisons
- Advanced HSRL-2 retrievals of aerosol properties

NASA LaRC
Airborne HSRL Systems

NASA LaRC Airborne Multiwavelength HSRL-2

- Independently measures aerosol backscatter, extinction, and optical thickness
- HSRL-2 developed as a prototype of multiwavelength lidar for NASA Aerosol-Clouds-Ecosystem (ACE) mission
- HSRL 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)

Typically deployed on NASA/LaRC King Air
Also flown on NASA P-3
Flight altitude ~ 9 km
Nadir pointing lidar



HSRL-2 Aerosol Data Products:

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

NASA LaRC Airborne Ozone DIAL/HSRL

Ozone Differential Absorption Lidar/ (DIAL)-Aerosol/Cloud High Spectral Resolution Lidar (DIAL/HSRL)

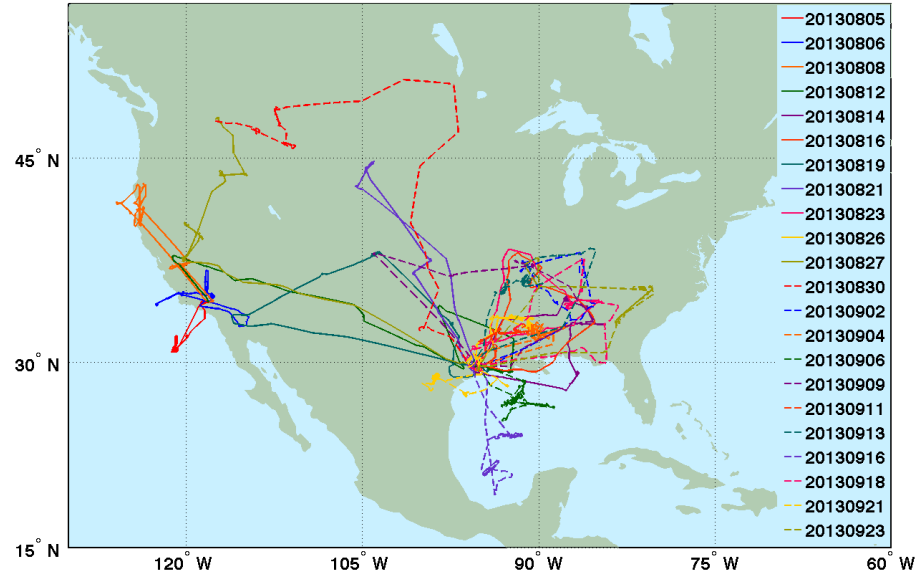
Flown on NASA DC-8

SEAC^{4}RS Field Mission

(2013)

Instrument Summary

Simultaneous Nadir & Zenith measurements
Aerosol/Cloud 355, 532 (HSRL), 1064 nm
Nominal resolutions:
Extinction: 1min (~12 km), 270m
Backscatter/Depol: 10sec (~2 km), 30m

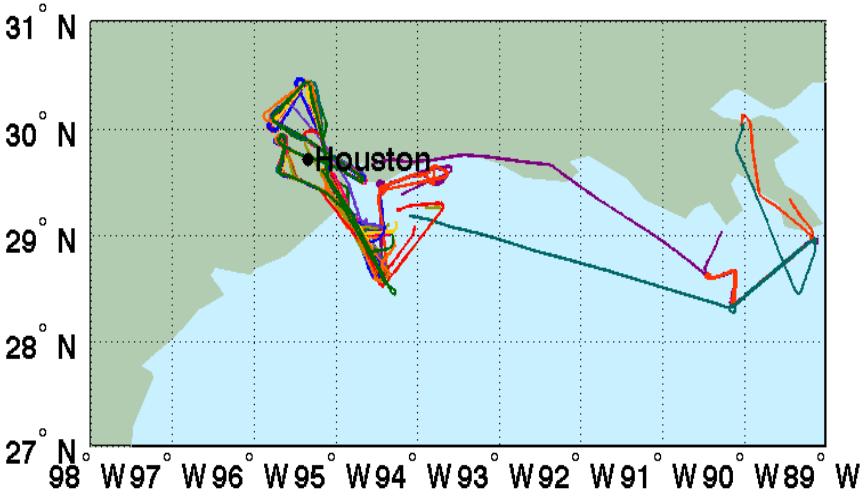


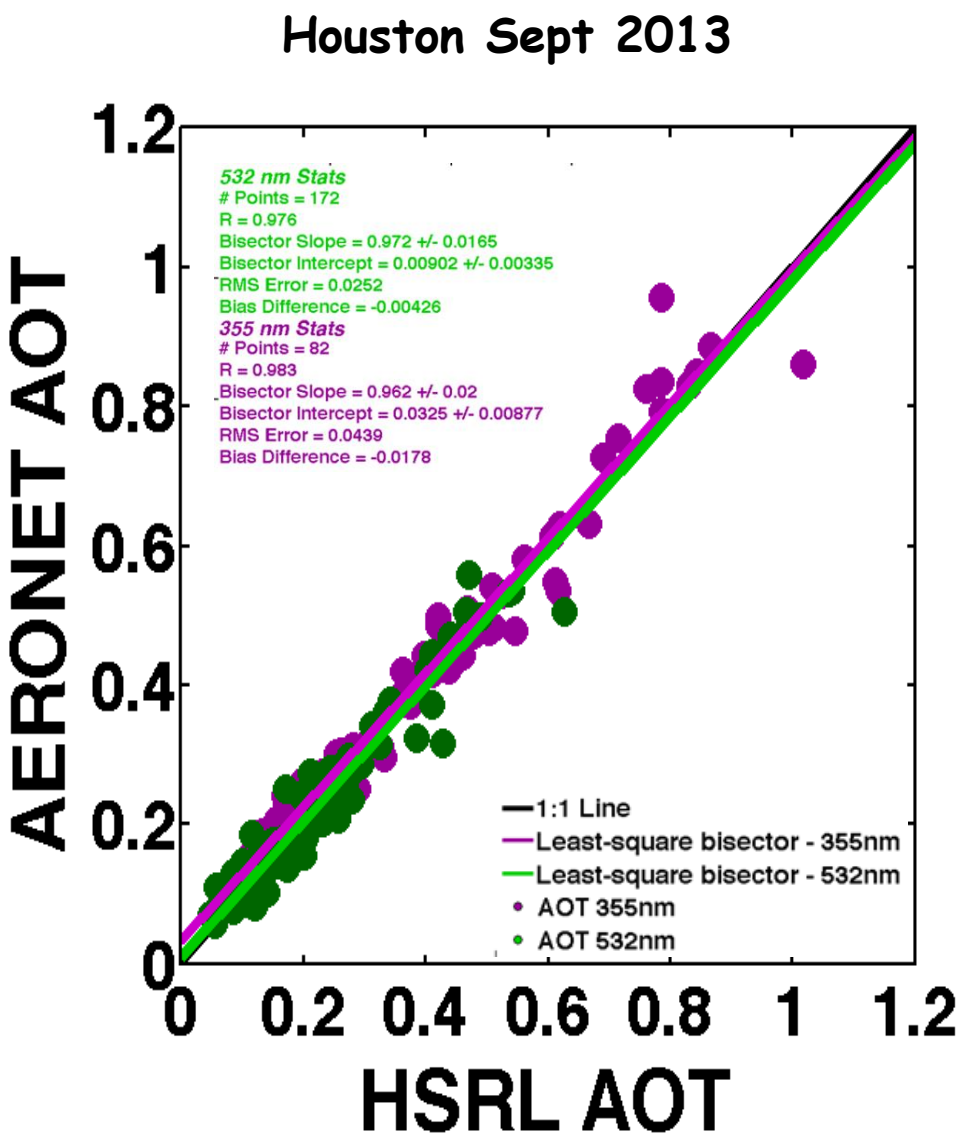
Aerosol Profile Measurements:

Aerosol Extinction (532nm)
Layer AOT, AOT at 532nm (from aircraft altitude)
Aerosol/Cloud Backscatter (532,1064nm)
Backscatter Color Ratio (1064/532nm)
Lidar Ratio (extinction/backscatter) (532nm)
Aerosol/Cloud Depolarization (532,1064nm)
Spectral Depolarization Ratio (1064/532nm)

HSRL-2 and AERONET AOD Comparisons during DISCOVER-AQ (Houston)

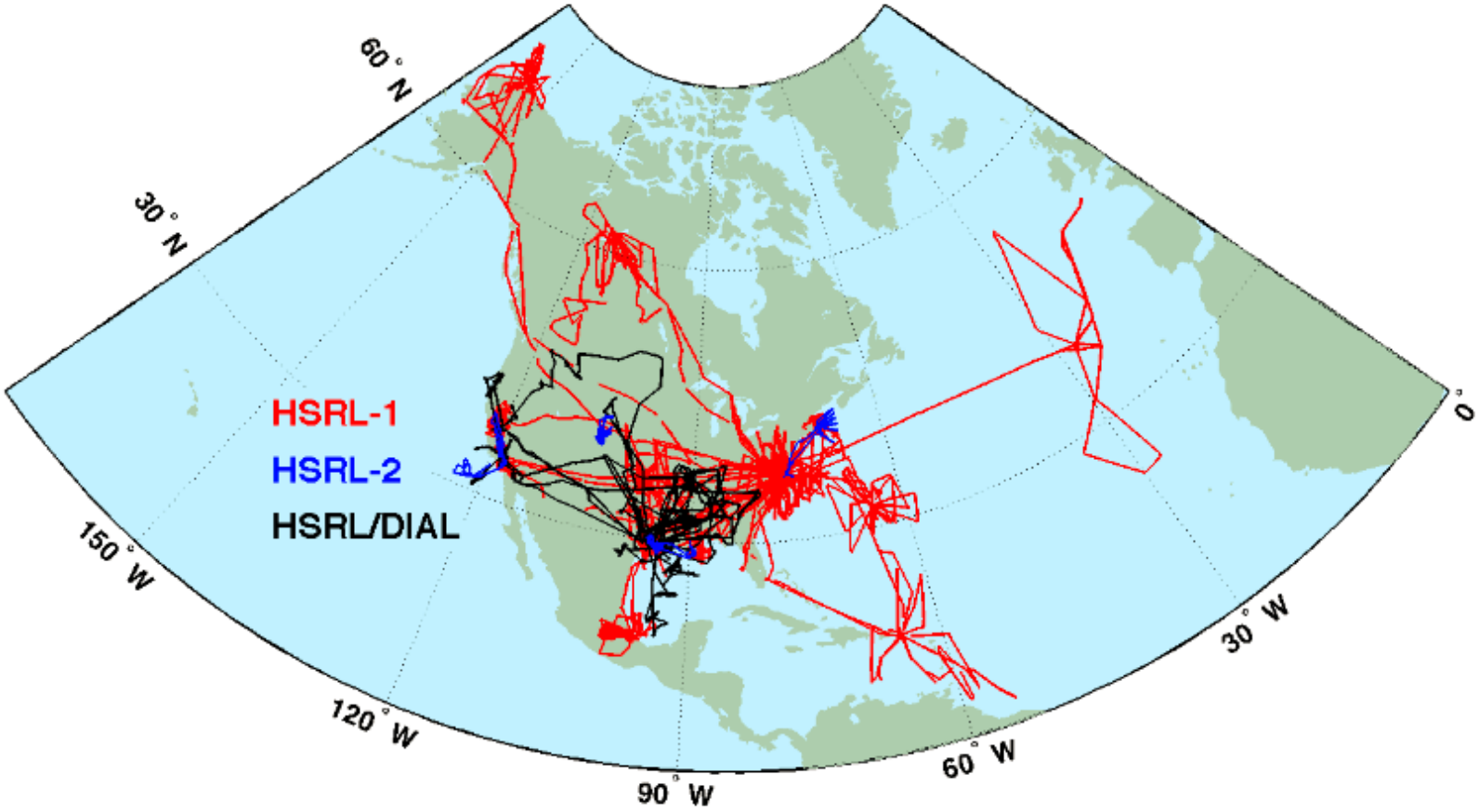
- HSRL 0-7 km layer AOD values were compared with column AOD (355 and 532 nm) values from AERONET "DRAGON" stations when HSRL was within 2.5 km of site and 10 minutes from measurement
- (532 nm) Slope 0.97, Intercept 0.01, R~0.98
- (355 nm) Slopes 0.96, Intercept 0.03, R~0.96



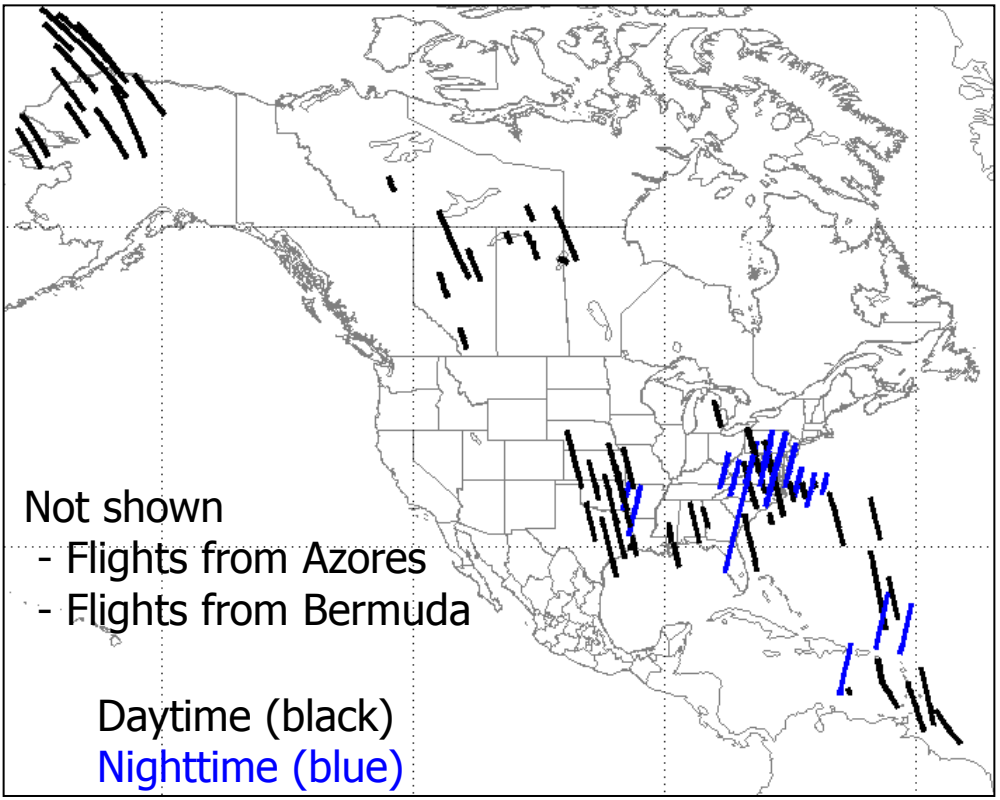


Airborne HSRL Systems have acquired extensive datasets over North America

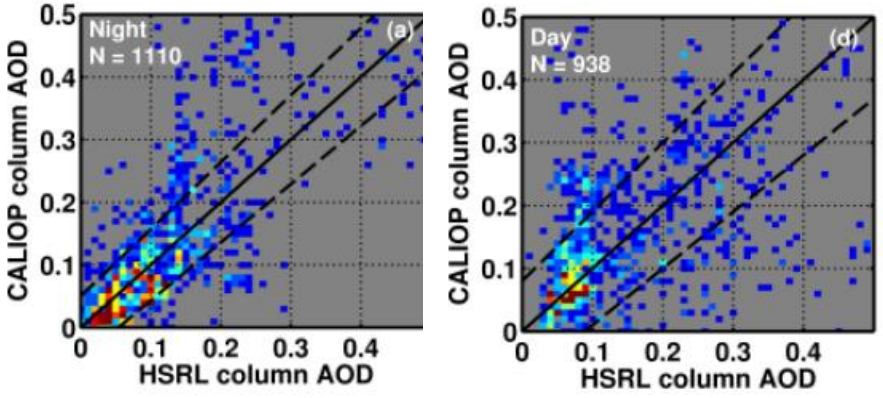
HSRL-1, HSRL-2, DIAL/HSRL have acquired science data on more than 450 flights (1500 hours) since 2006



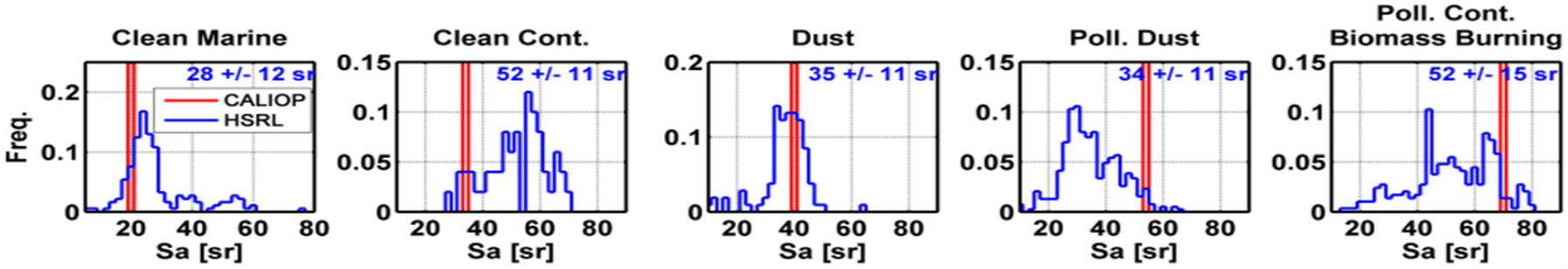
Airborne HSRL datasets acquired during more than 120 CALIPSO underflights are used to evaluate CALIOP profiles



Comparison of CALIOP and HSRL column AOD during nighttime and daytime operations



Comparison of CALIOP and HSRL lidar ratios



Comparison of CALIOP inferred and HSRL measured lidar ratios (532 nm)

(Rogers et al., AMTD, 2014)

GEOS-5 Aerosol Model

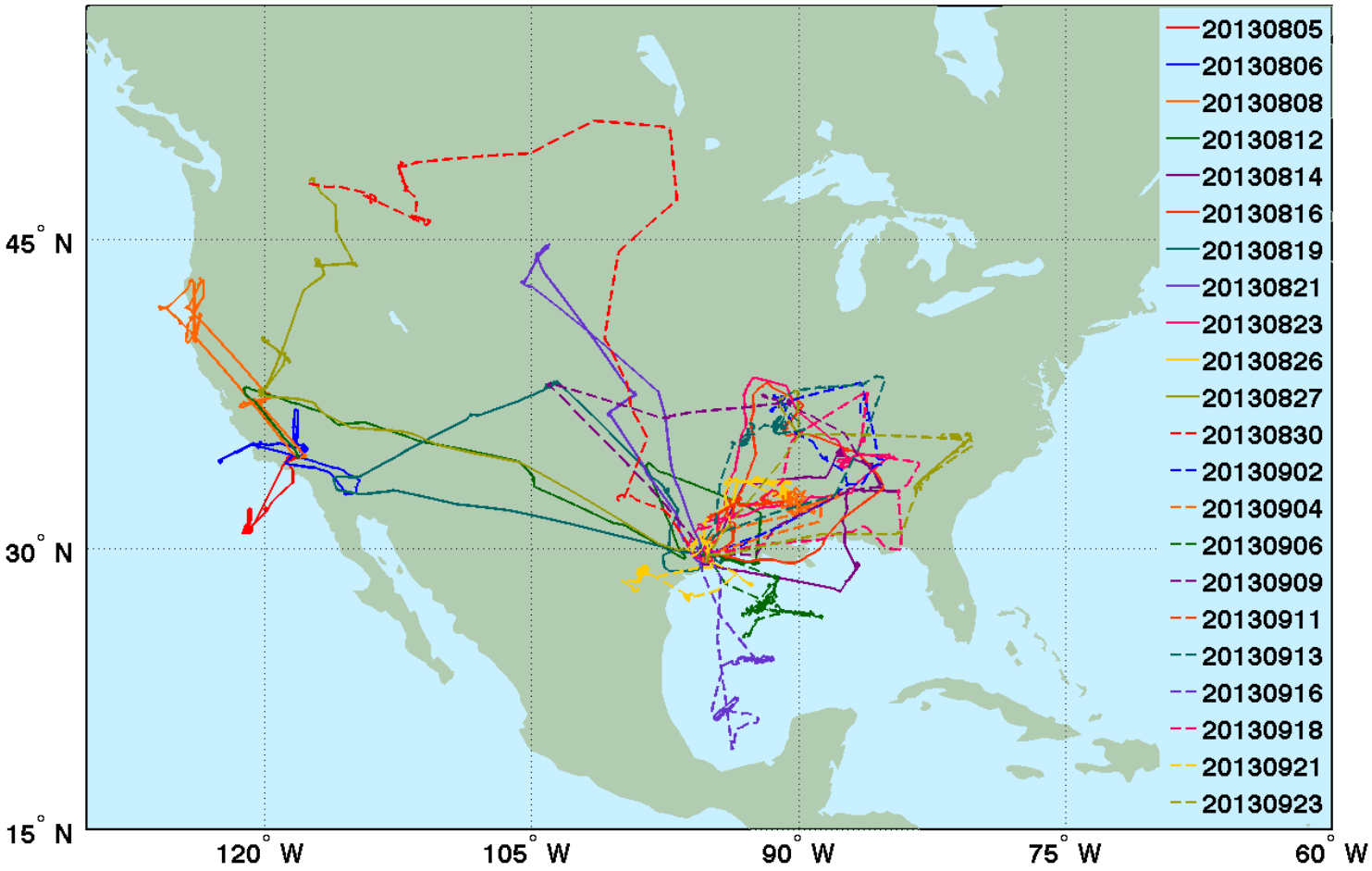
GEOS-5 Atmospheric Data Assimilation System

- GEOS-5 Earth Modeling System, GOCART aerosol module
- Five non-interactive species - dust, sea salt, BC, OC, sulfate
- Convective and large scale wet removal
- Dry deposition and sedimentation
- Optics based on OPAC model (Nonspherical Dust) from Colarco; Kim
- Fire emissions – Quick Fire Emission Dataset (QFED)
  - Based on MODIS Fire Radiative Power
  - Emission factors tuned using MODIS AOD
  - Daily mean emissions
- Aerosol Data Assimilation
  - Terra/Aqua MODIS AOD
  - MISR AOD over bright surfaces
- Resolution
  - Horizontal: 25 km
  - Vertical: 72 layers

dust	wind and topographic source, 5 mass bins
sea salt	wind driven source, 5 mass bins
black carbon	anthropogenic and wildfire source, mass hydrophic and hydrophilic
organic carbon	anthropogenic, biogenic, and wildfire source, mass hydrophic and hydrophilic
sulfate	anthropogenic and wildfire source of SO2, oxidation to SO4 mass

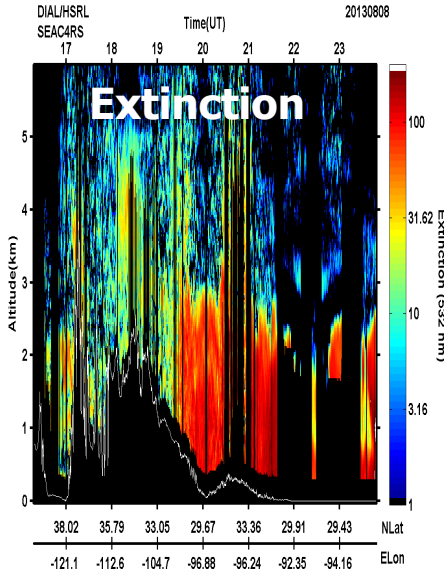
- PBL heights defined when diffusion coefficient falls below threshold
- **GEOS-5 3-hourly results from SEAC4RS reanalysis are examined here**

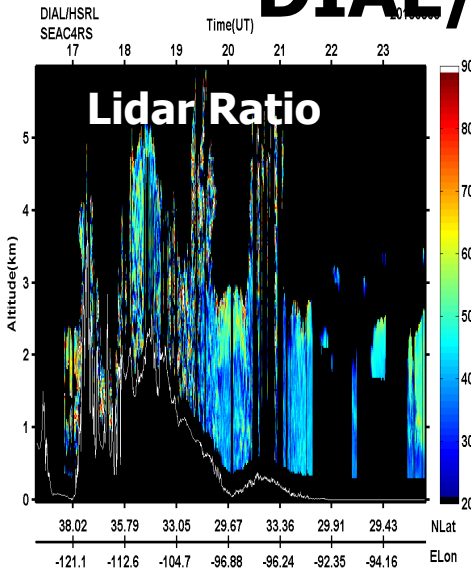
DIAL/HSRL – GEOS-5 Comparisons During SEAC4RS

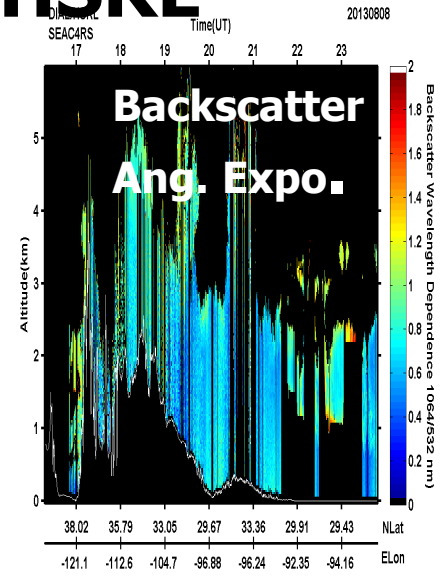


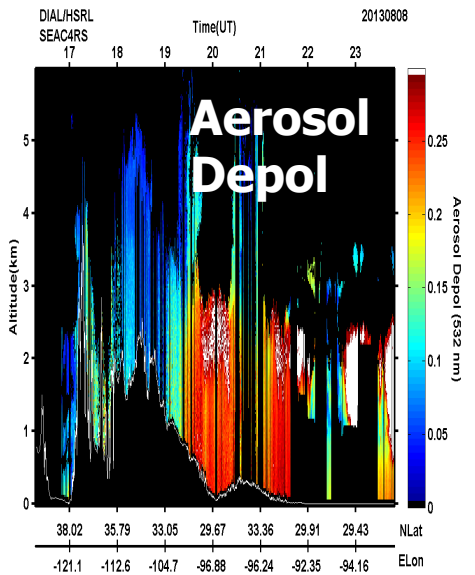
SEAC4RS Aug. 8 DIAL/HSRL Transit from Palmdale, CA to Houston, TX

DIAL/HSRL

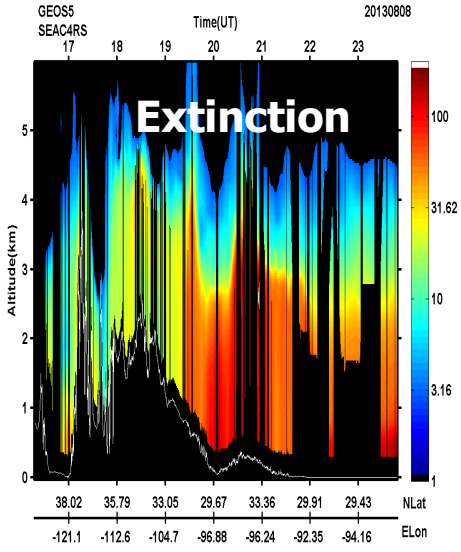


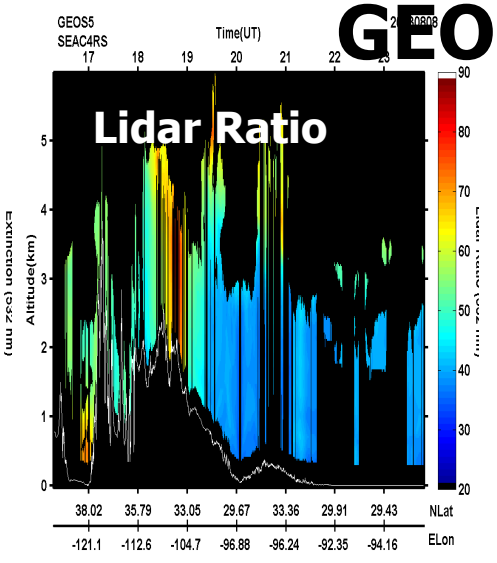


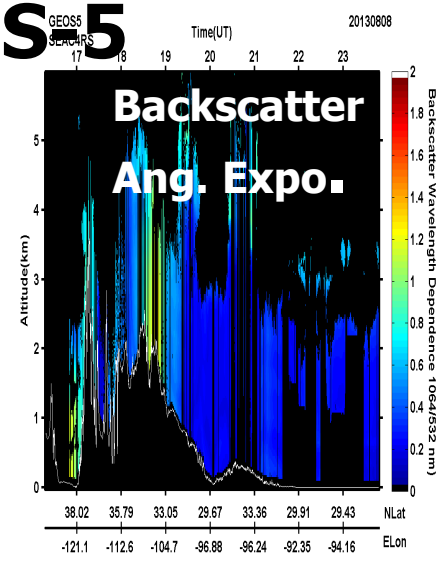


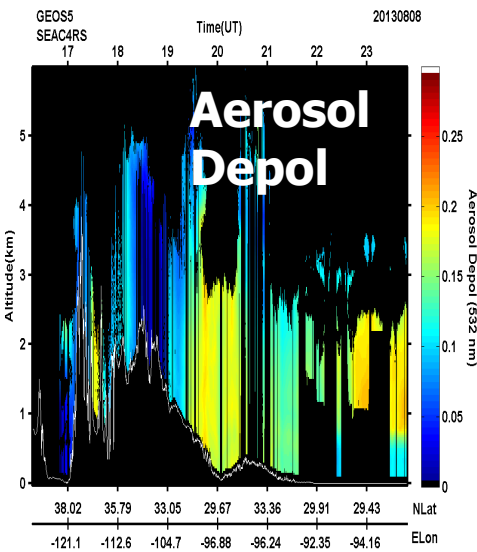


GEOS5



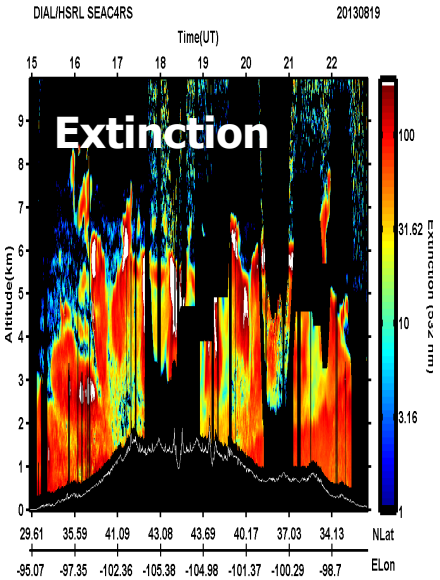


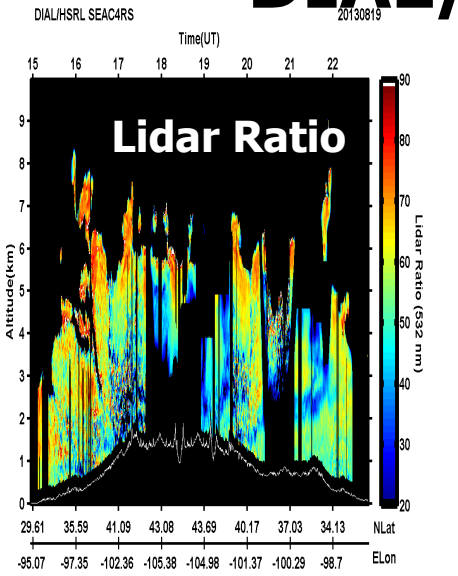


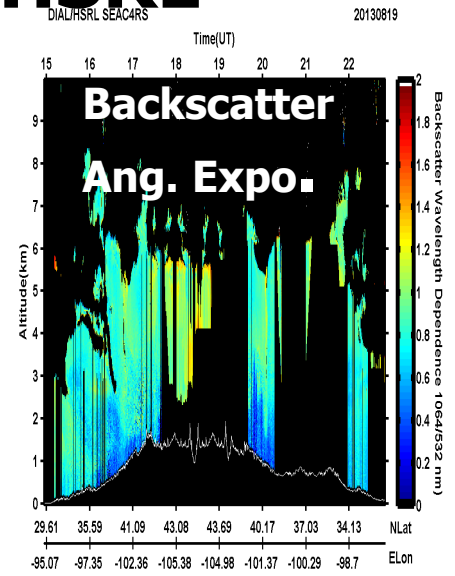


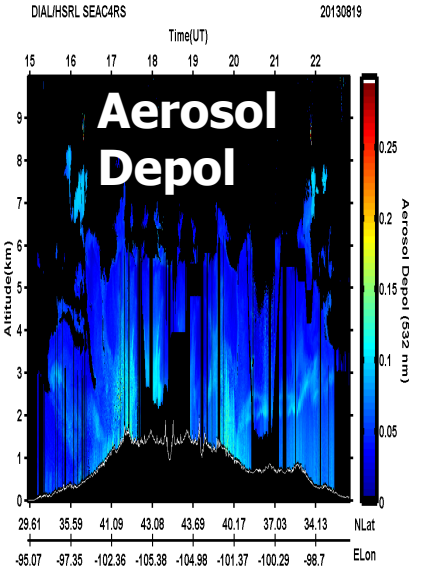
SEAC4RS Aug. 19 DIAL/HSRL Smoke flight over Midwest

DIAL/HSRL

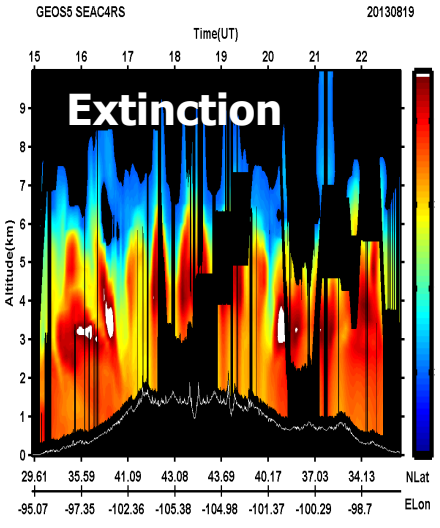


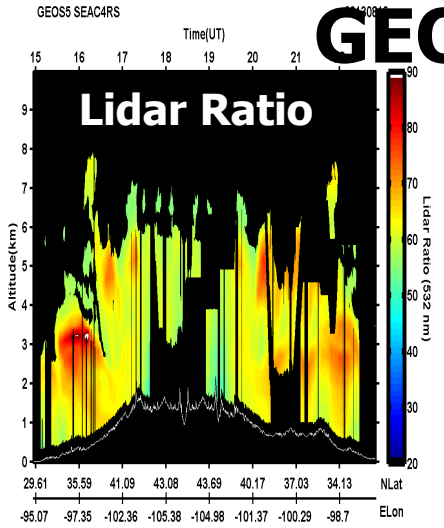


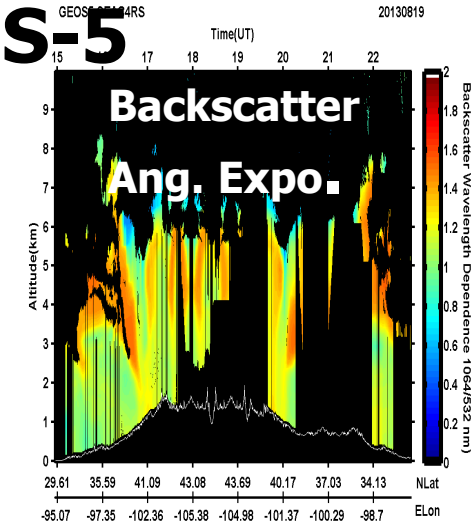


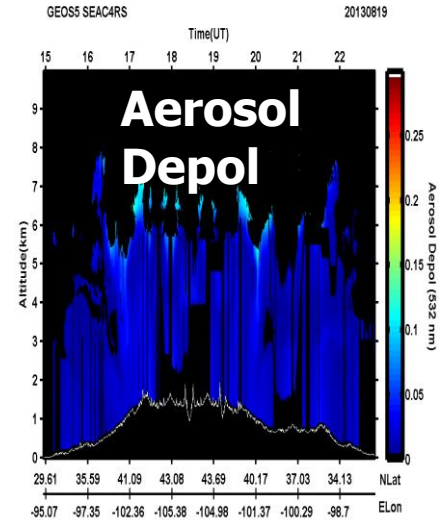


GEOS-5



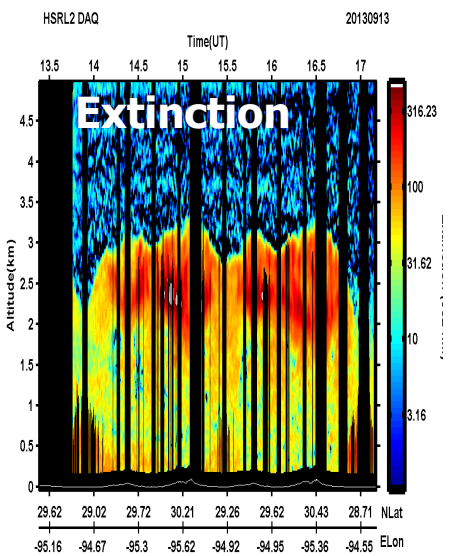


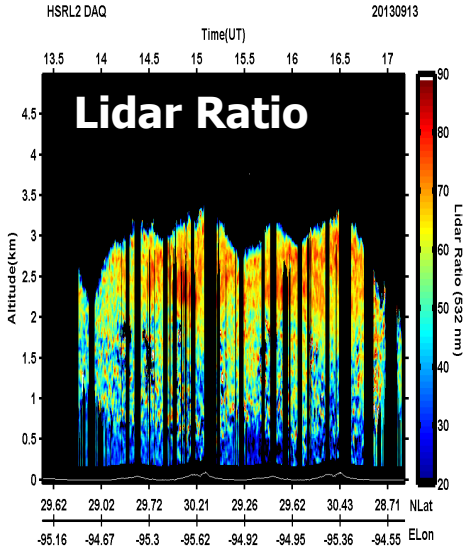


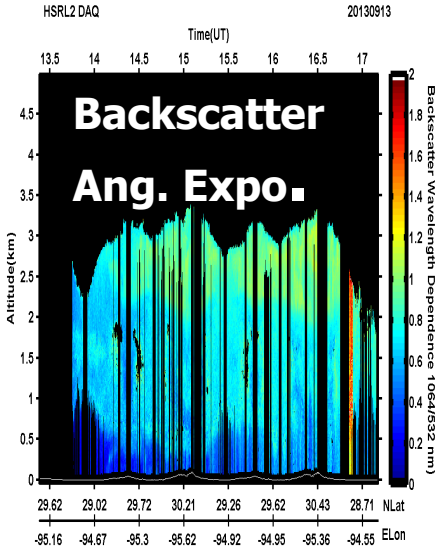


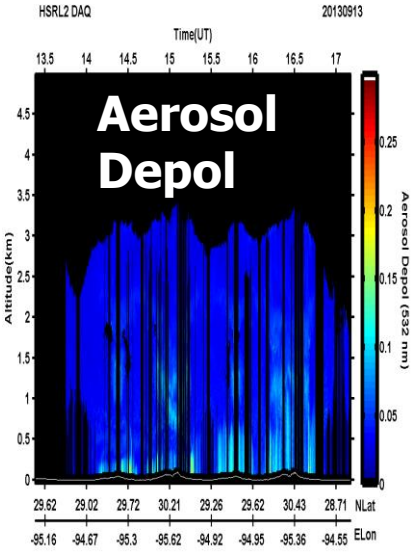
DISCOVER-AQ HSRL-2 Flight on Sept. 13 over Houston

HSRL-2

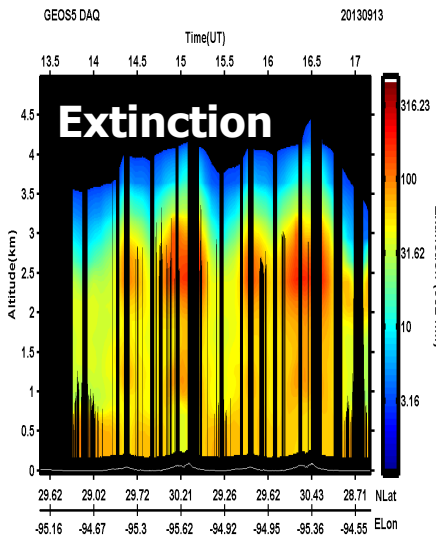


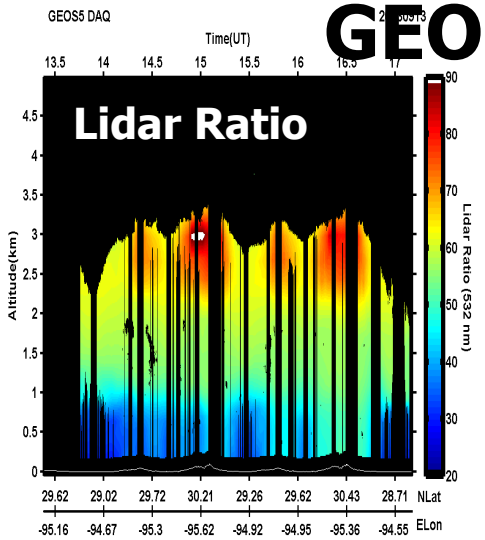


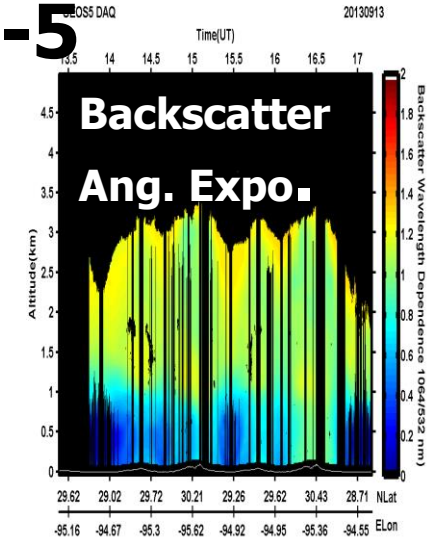


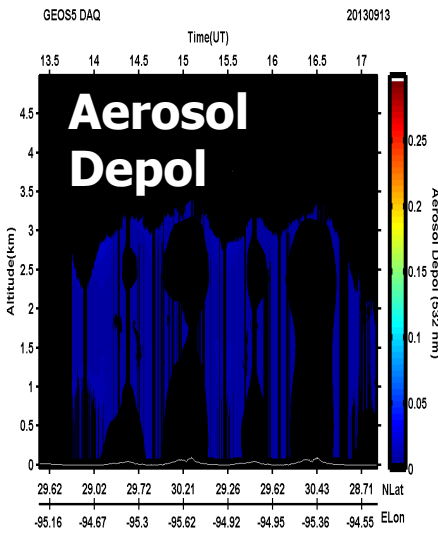


GEOS-5



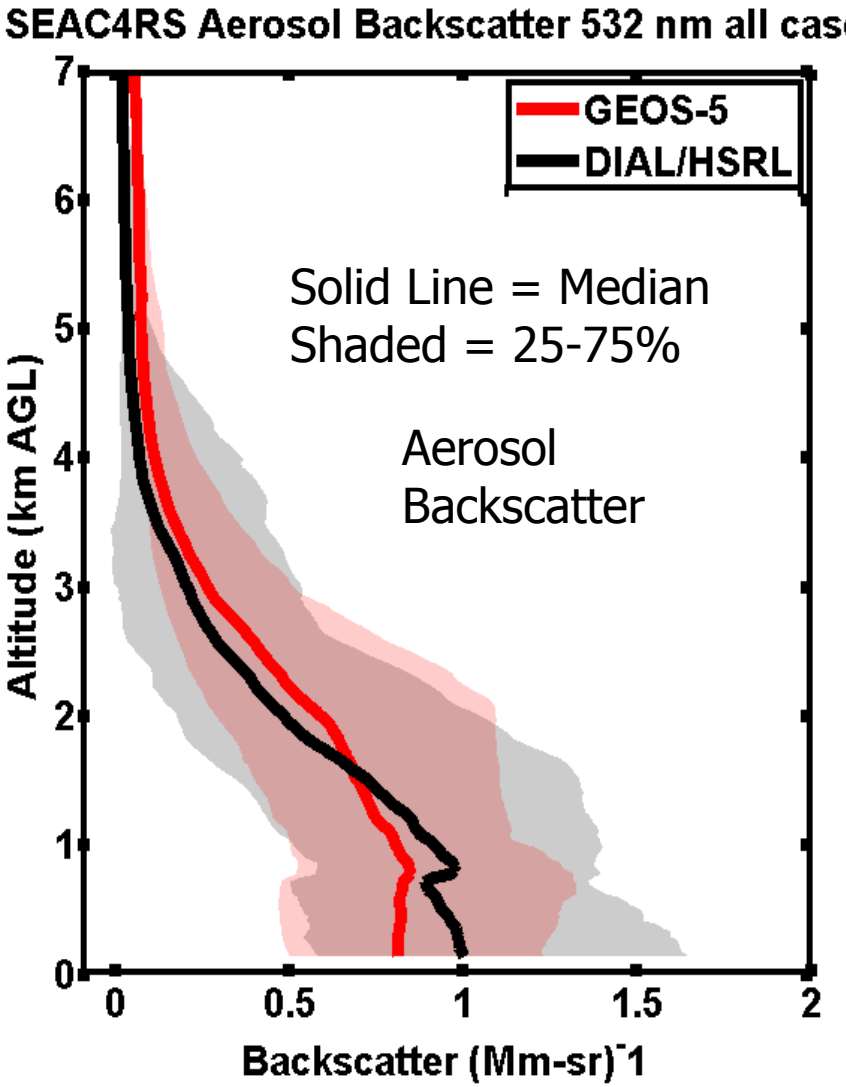


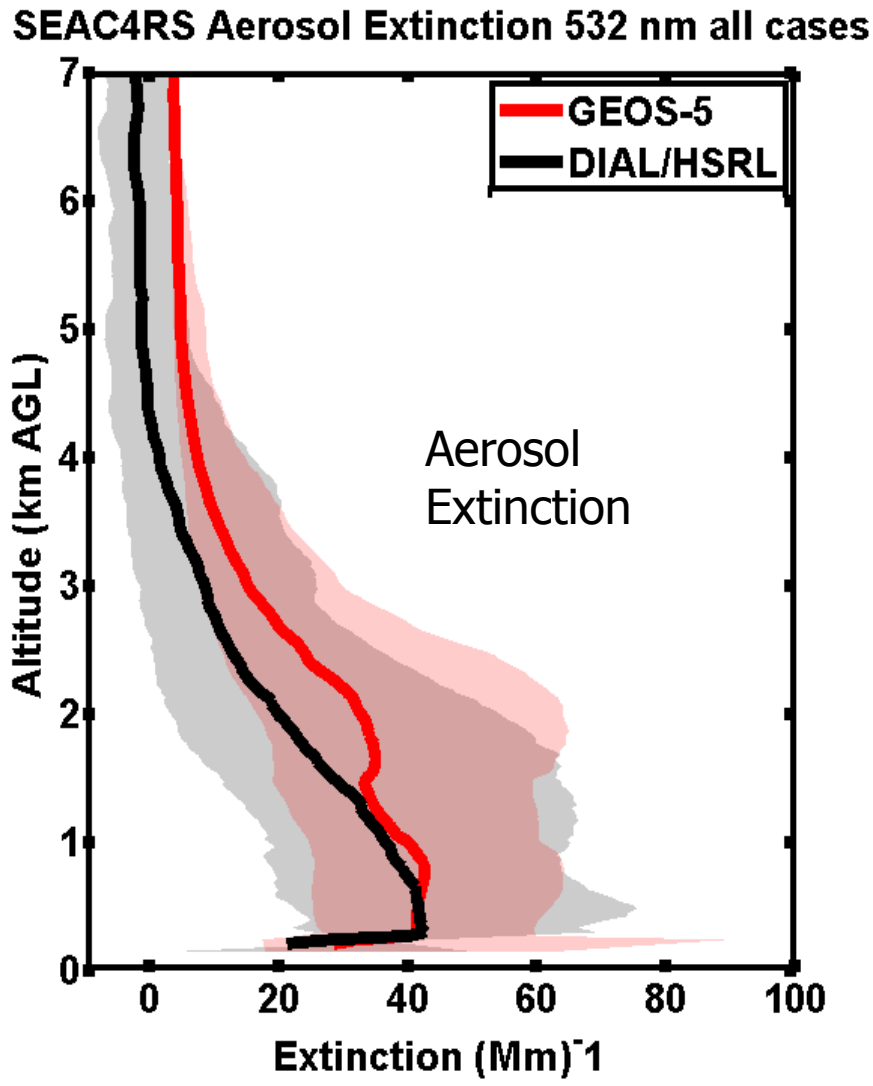




Median Backscatter and Extinction Profiles During SEAC4RS

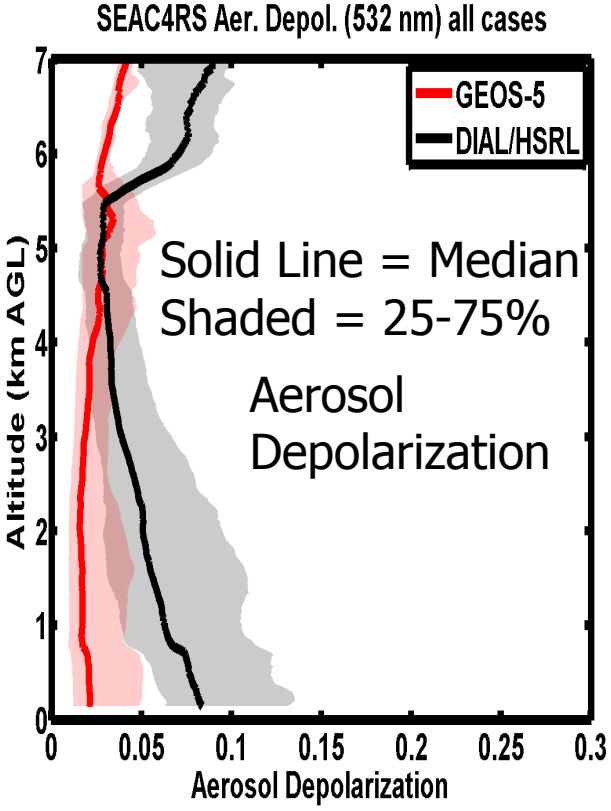
GEOS-5 shows slightly higher backscatter and extinction in free troposphere

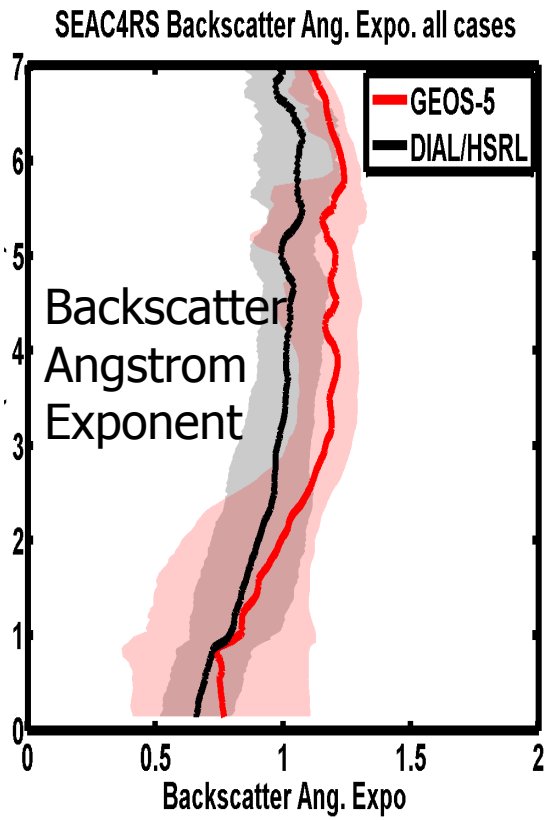


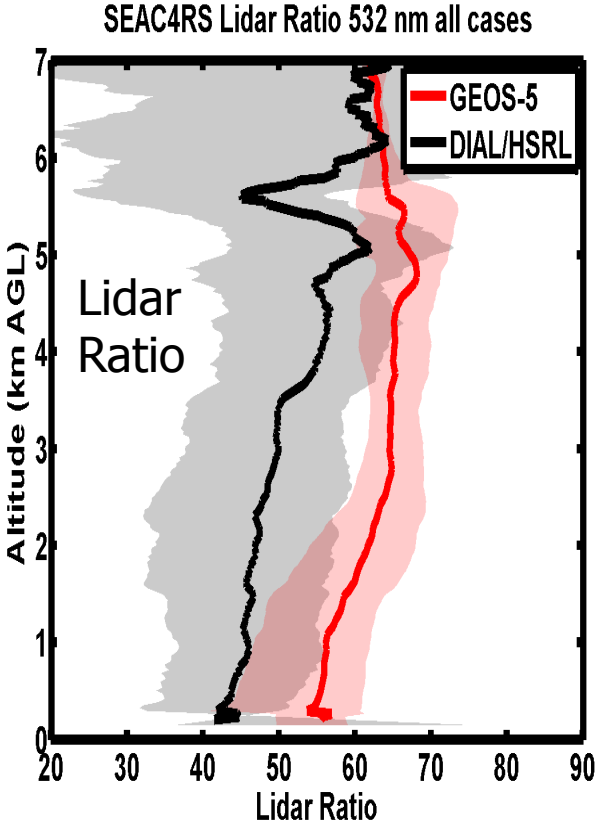


Median Intensive Parameter Profiles During SEAC4RS

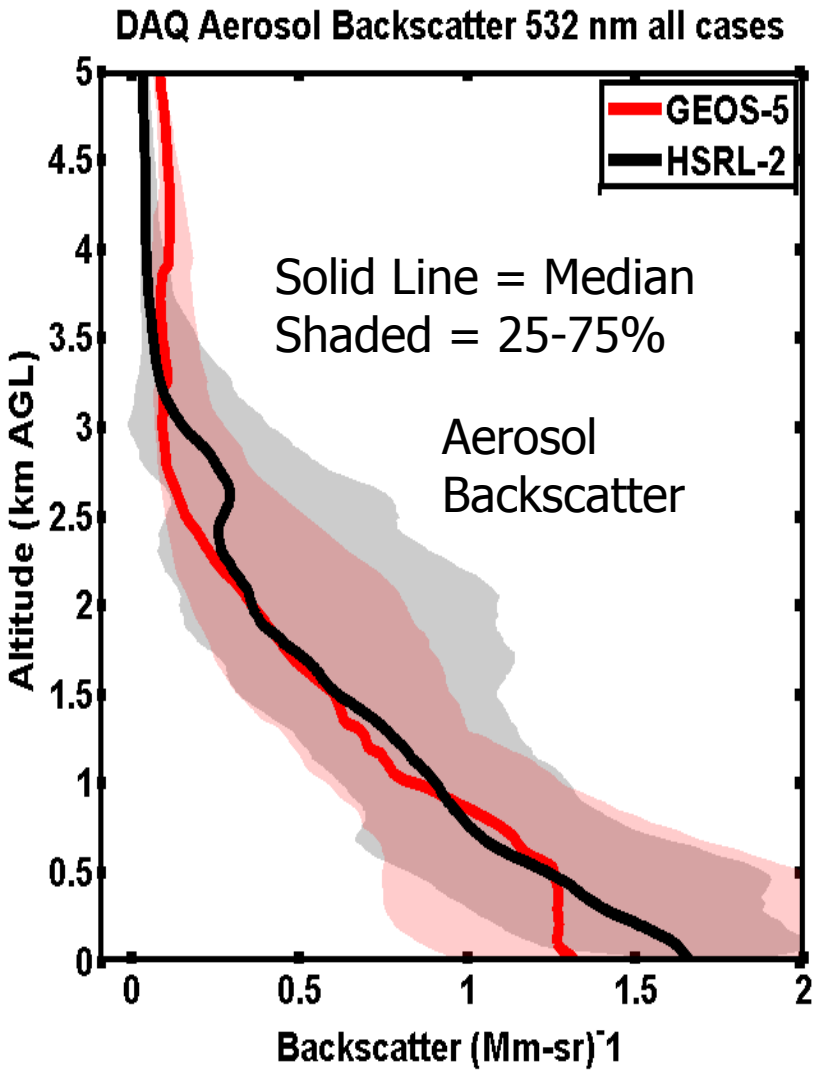
- Both DIAL/HSRL and GEOS-5 intensive parameters vary with altitude suggesting aerosol type varies with altitude
- Backscatter Angstrom exponent increasing with altitude suggests decreasing particle size with height
- GOES-5 lidar ratio higher than DIAL/HSRL
- DIAL/HSRL measured more nonspherical particles (i.e. dust) near the surface than represented by GEOS-5

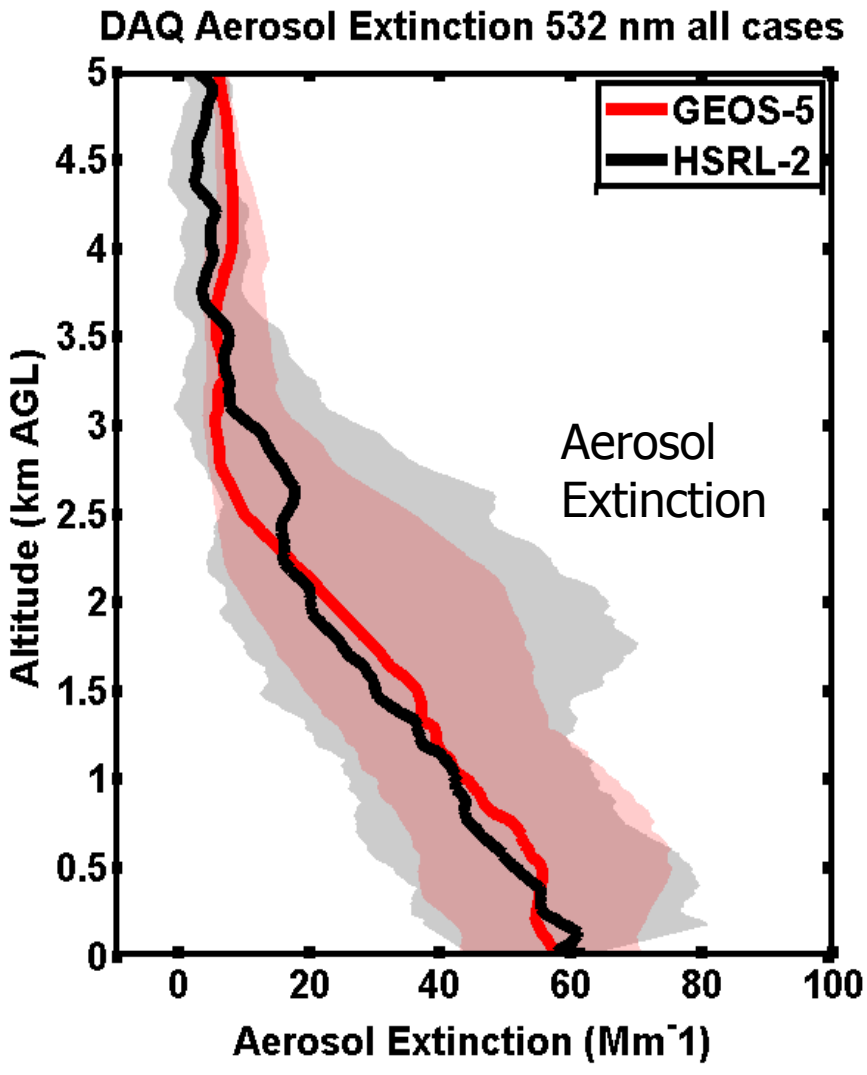




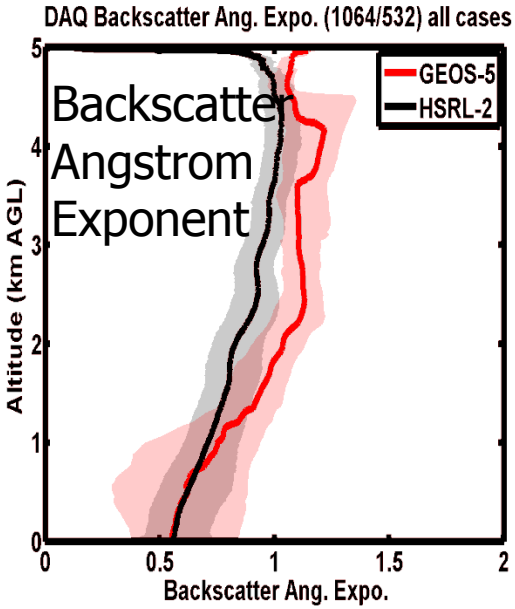


Median Backscatter and Extinction Profiles During DISCOVER-AQ Houston



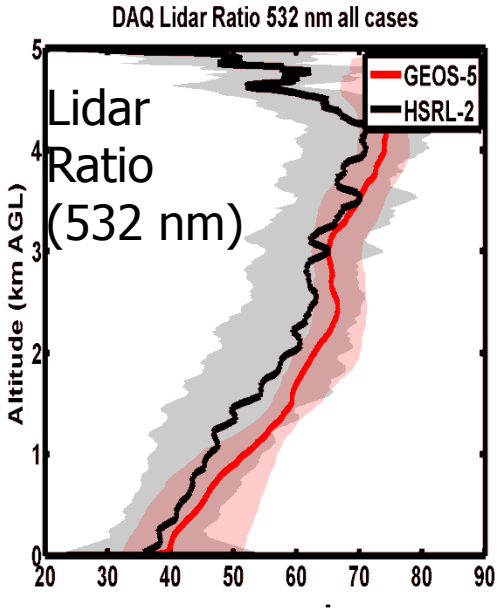


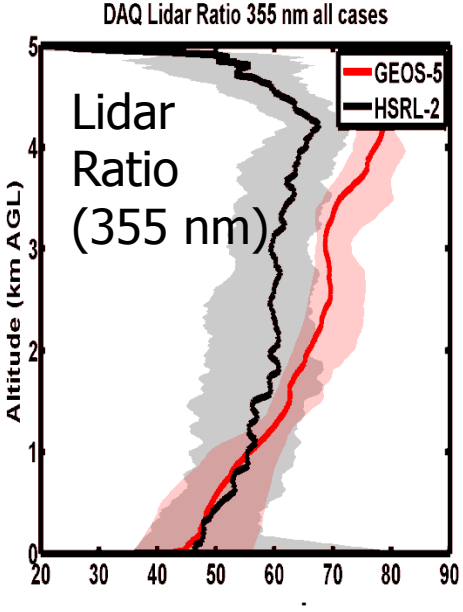
Median Intensive Parameter Profiles During DISCOVER-AQ

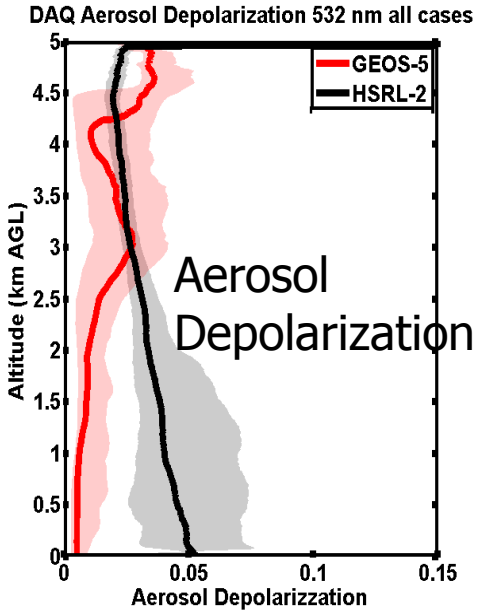


- Backscatter Angstrom exponent increasing with altitude suggests decreasing particle size with height
- Lidar ratio increasing with altitude suggests more pollution/organic/smoke aloft than near surface
- HSRL-2 measured more nonspherical particles (i.e. dust) near the surface than represented by GEOS-5

Solid Line = Median
Shaded = 25-75%

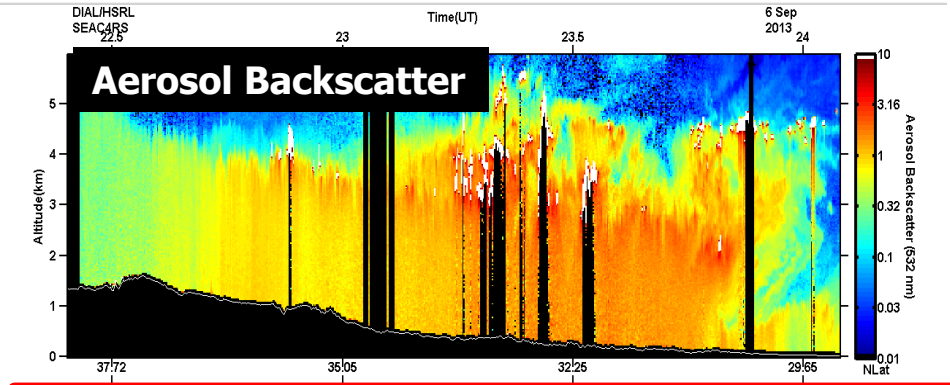




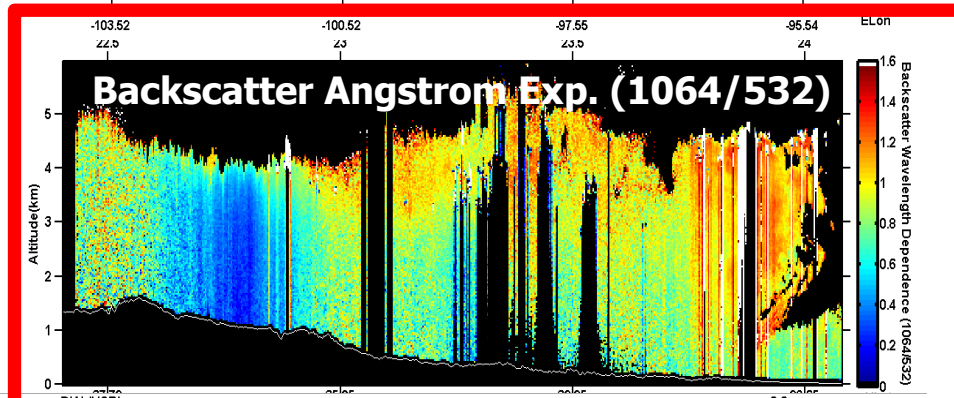


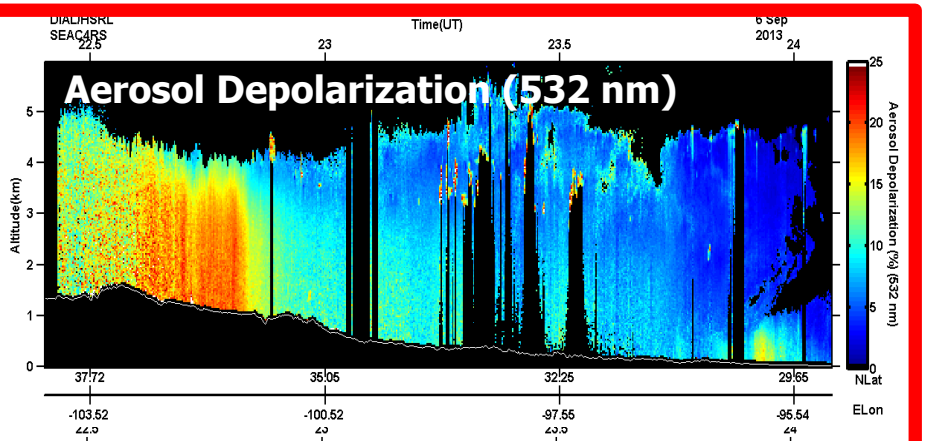
Aerosol Classification

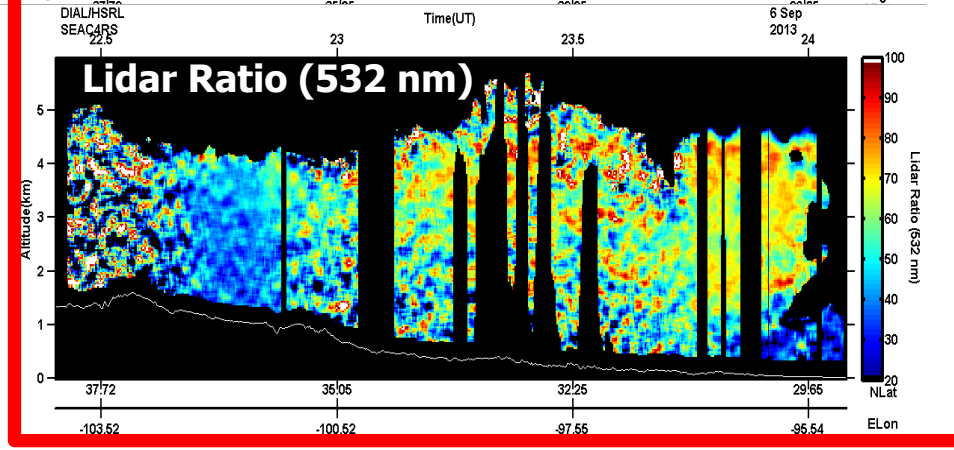
Variation in Aerosol Optical Properties (Sep. 6) Colorado to Houston

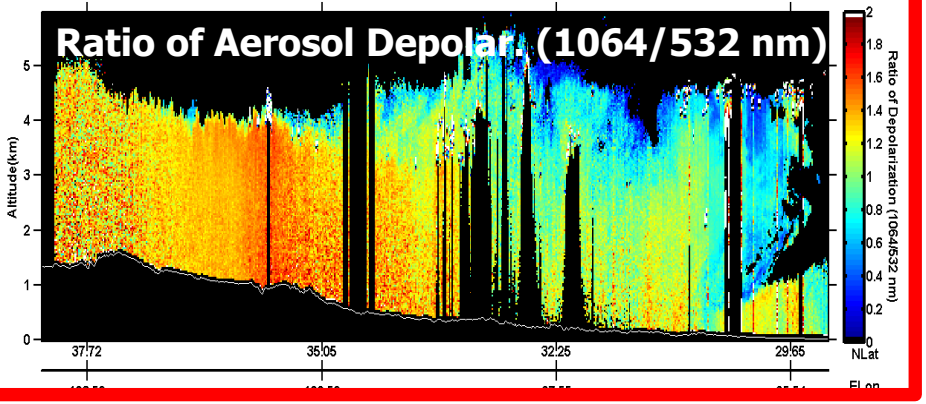


- Final Portion of flight from SE Colorado to Houston
- Variability of aerosol intensive parameters indicates change in aerosol types



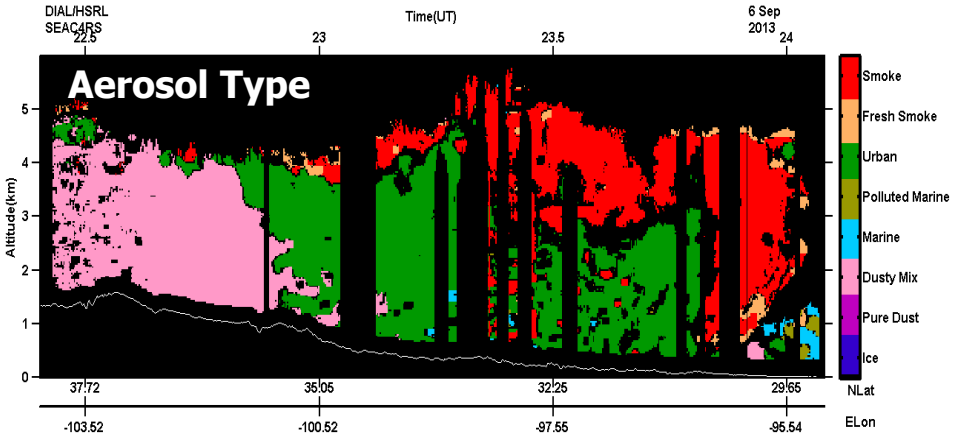


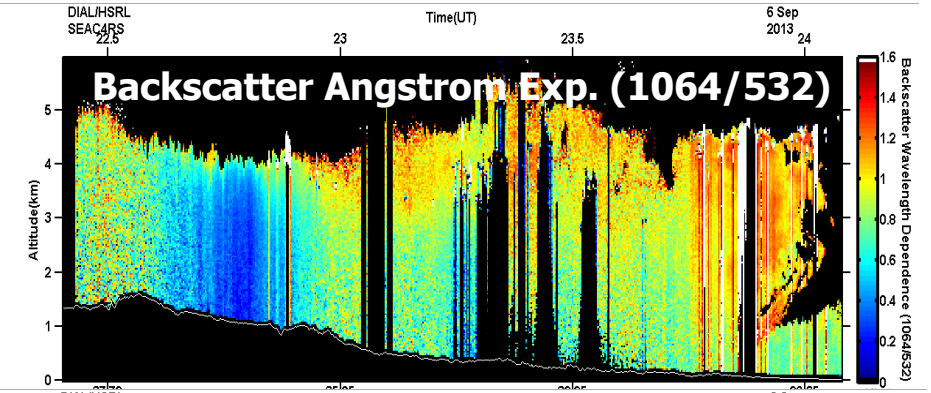


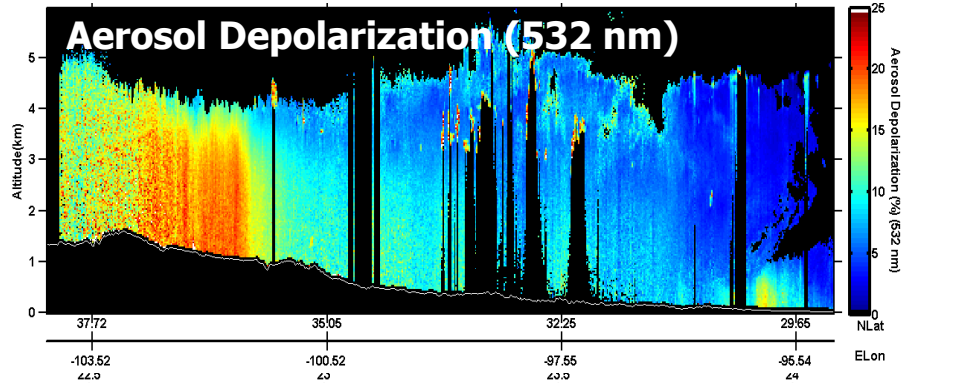


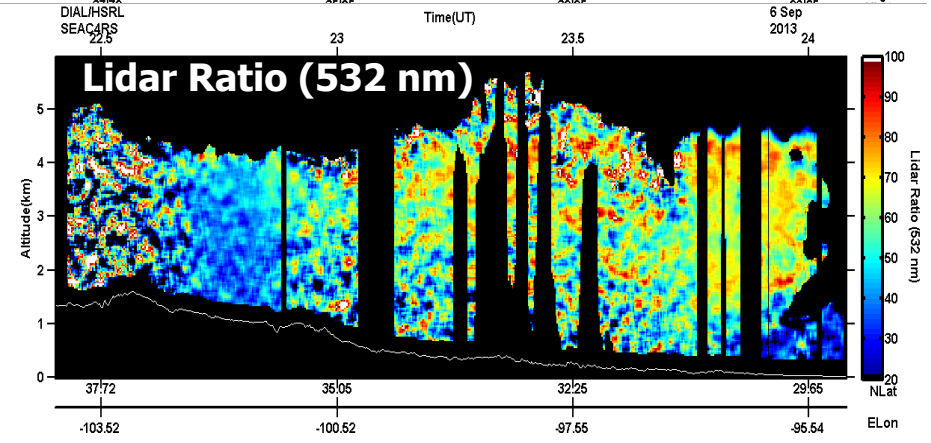
Aerosol Classification (Sep. 6) Colorado to Houston

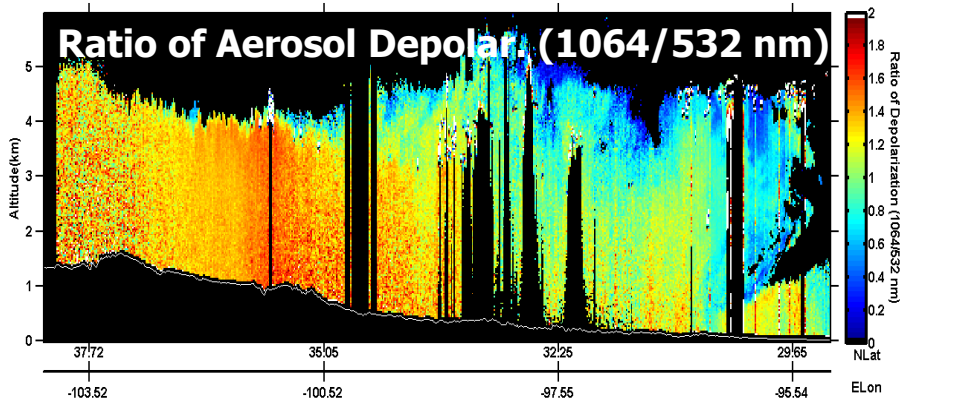
- Aerosol intensive parameters are used to classify aerosol type as described by Burton et al. (2012, 2013)
- Transition from dusty mix to mixture of urban and smoke near Houston





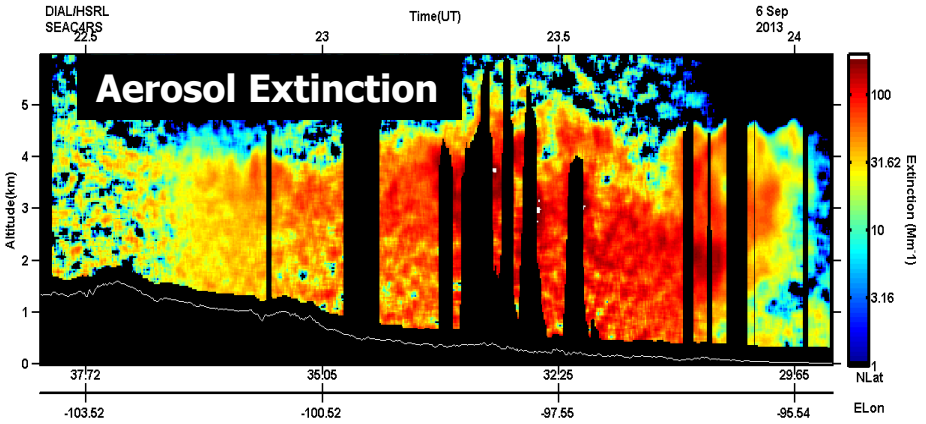


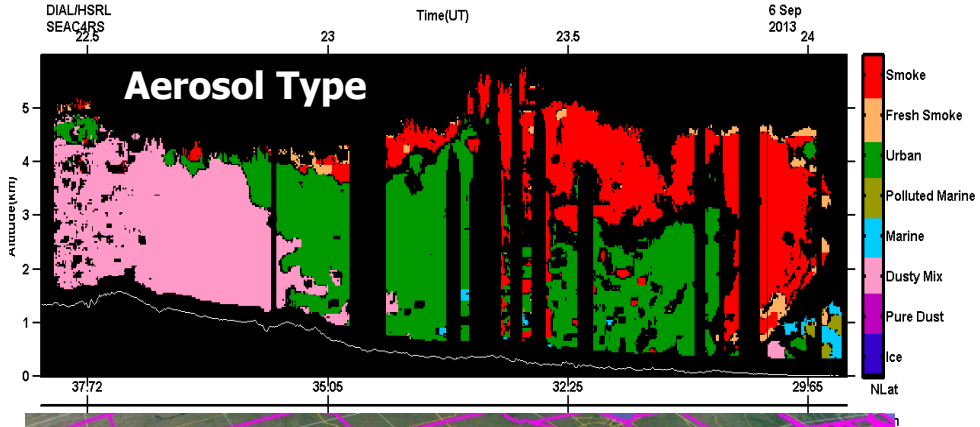


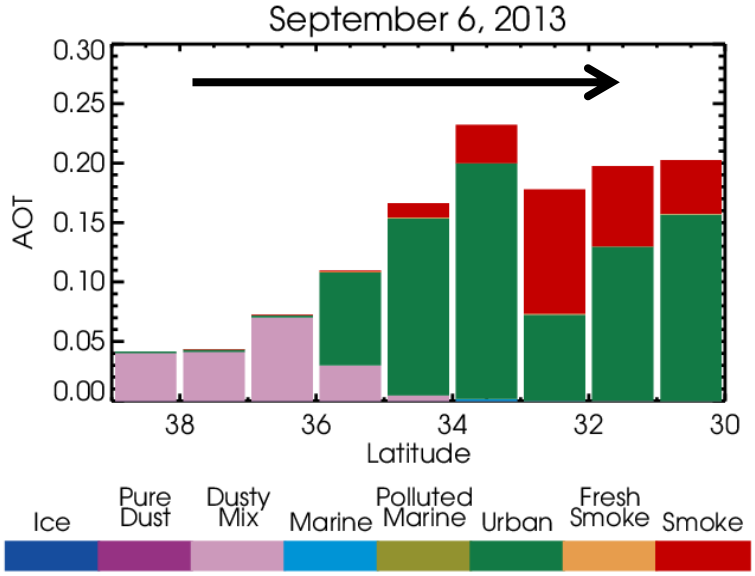


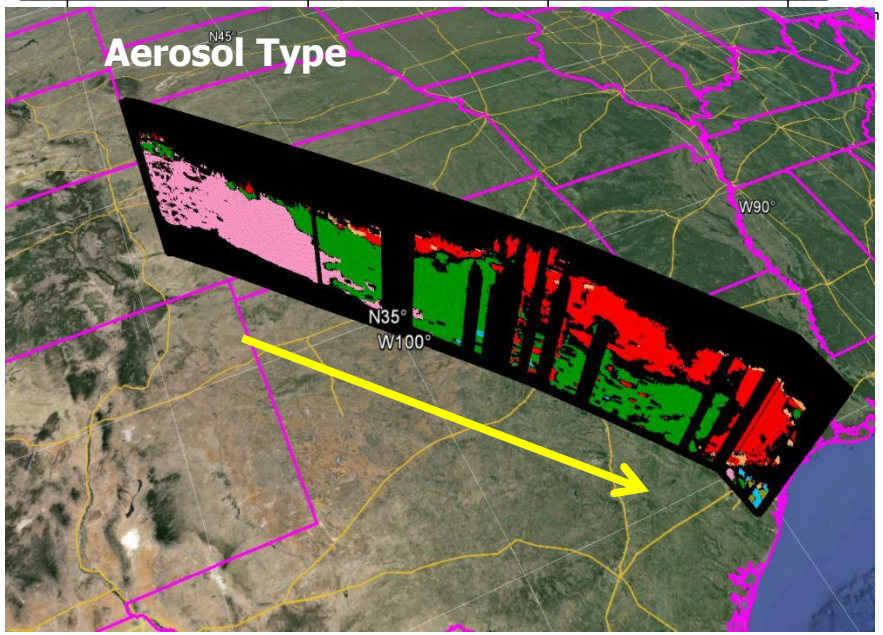
AOT Apportionment to Aerosol Type (Sep. 6) Colorado to Houston

- DIAL/HSRL data were used to apportion AOT to aerosol type
- Low AOT over SE Colorado comprised entirely of dusty mix
- Higher AOT over SE Texas comprised of combination of urban and smoke



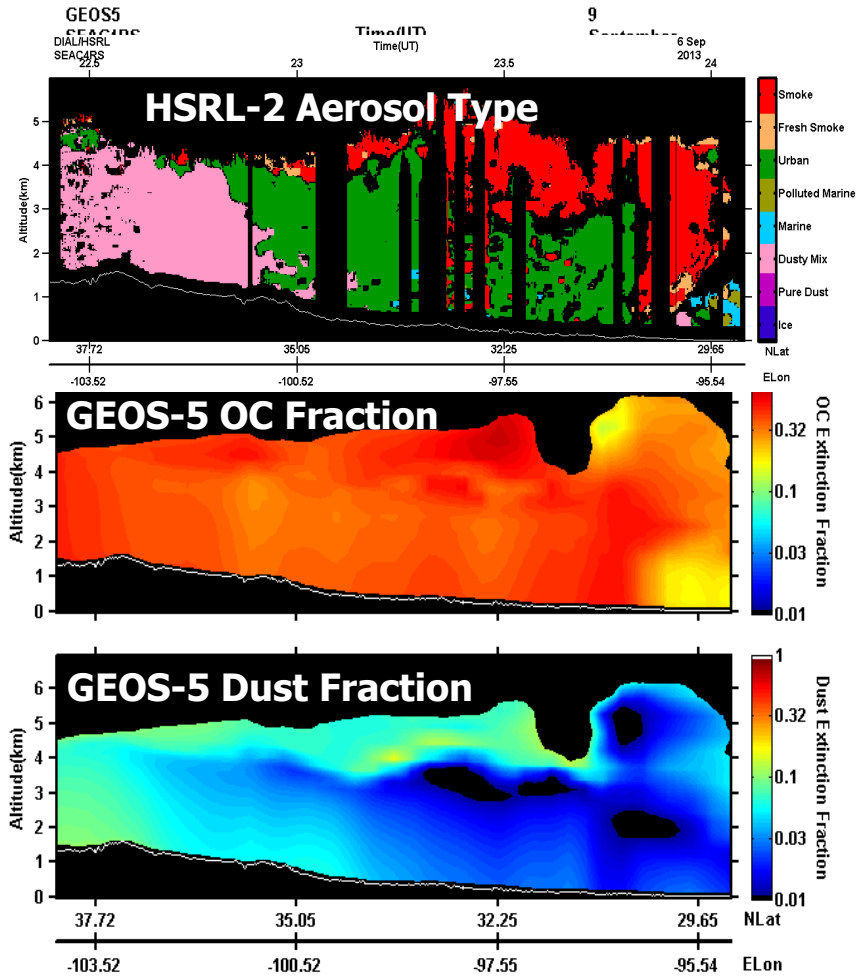


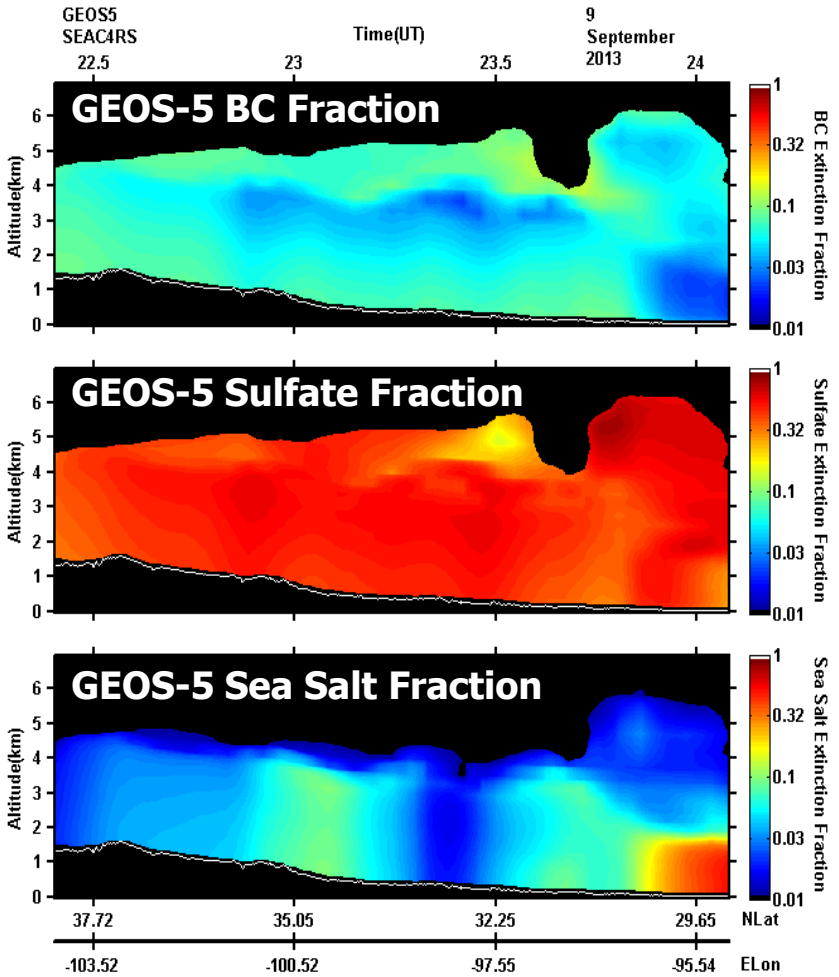




Aerosol Classification and GEOS-5

We are investigating relationship between HSRL-2 aerosol types and GEOS-5 aerosol species





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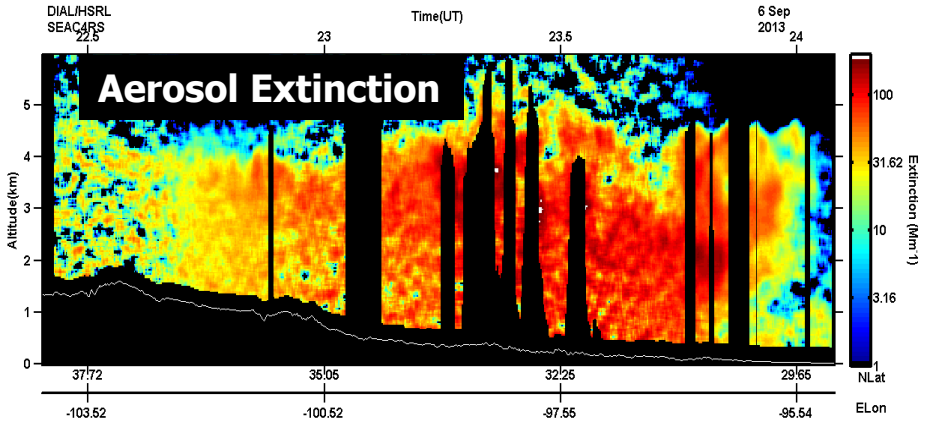
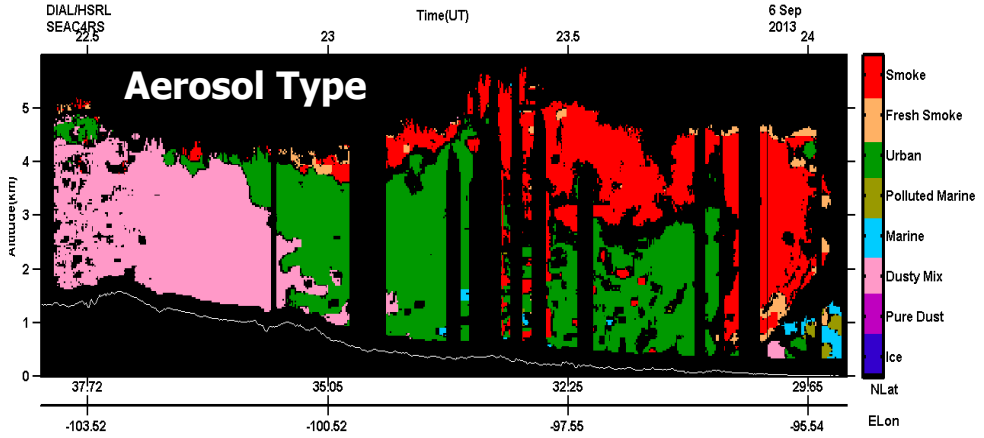
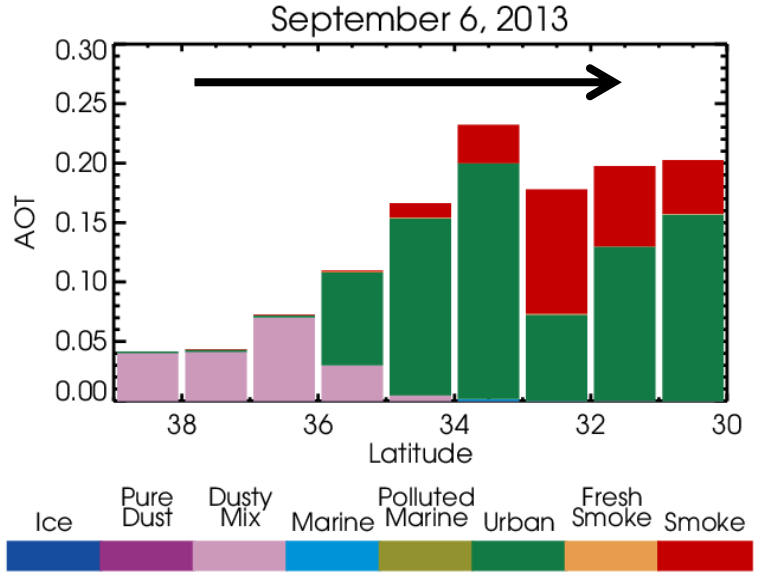
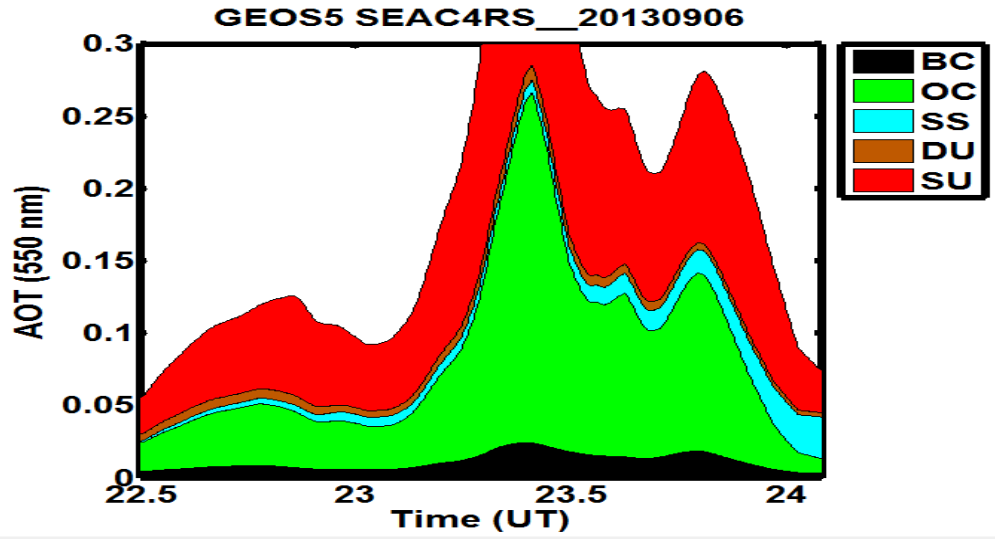
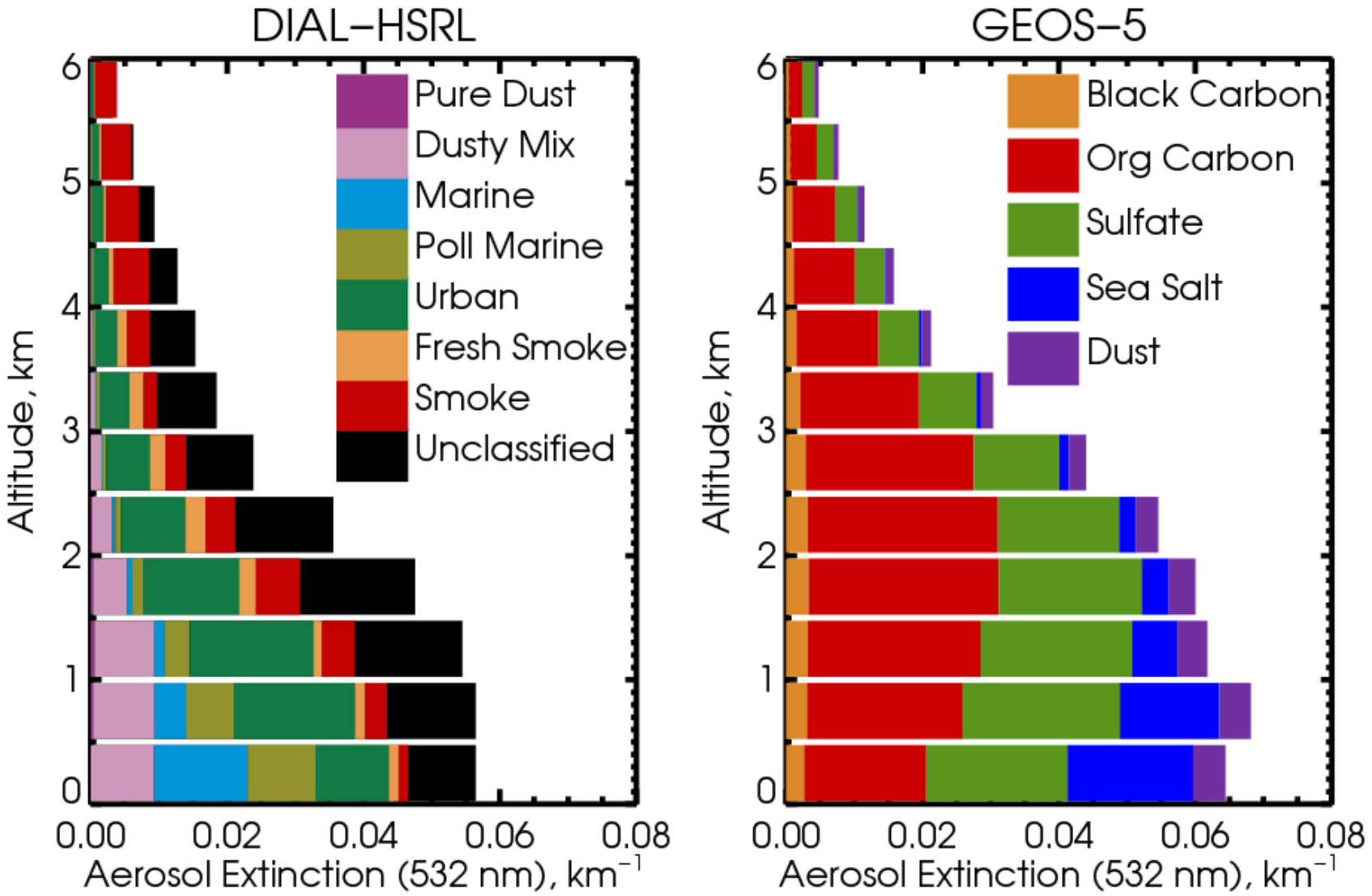








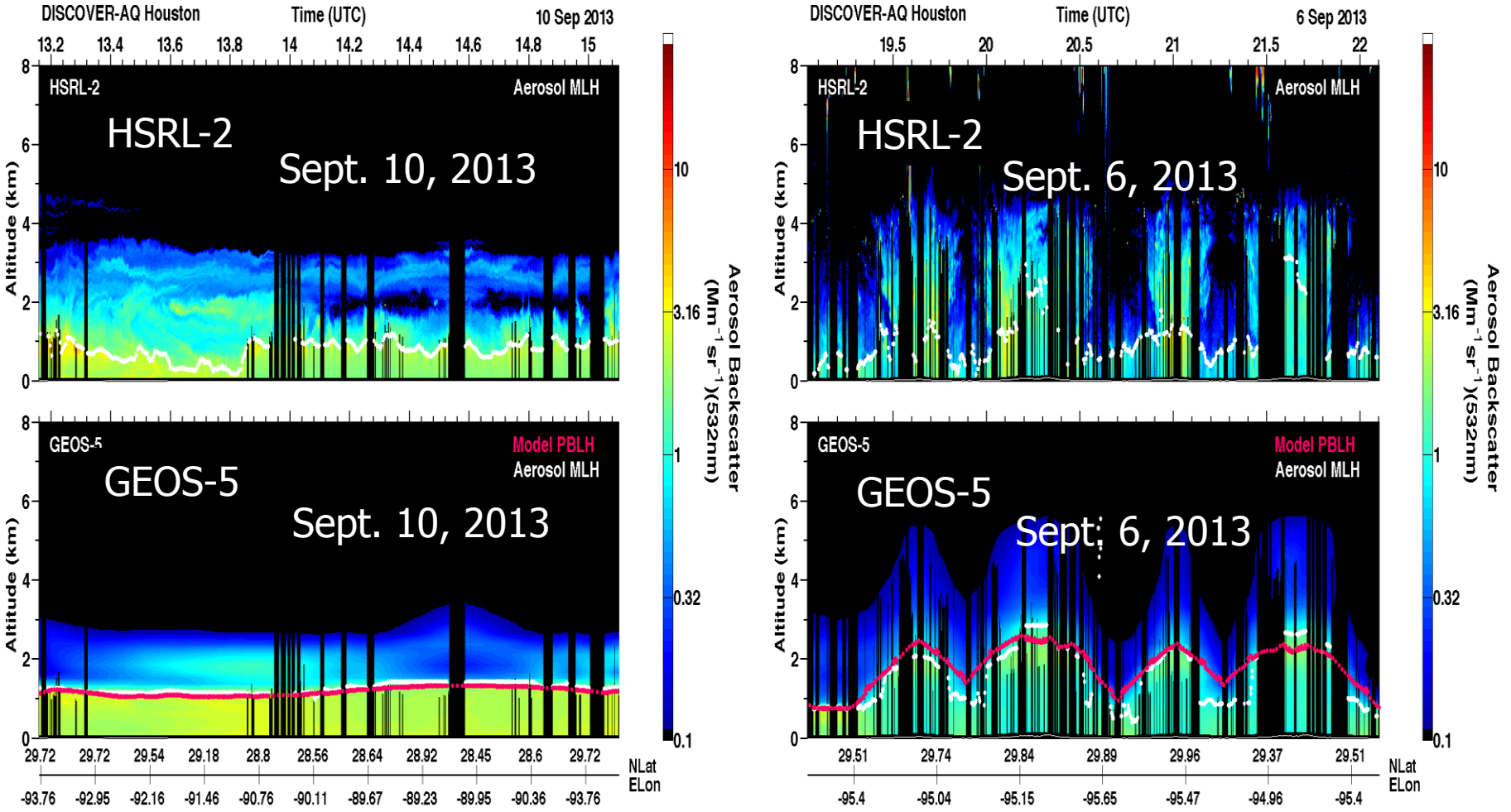
Preliminary SEAC4RS vertical apportionment of aerosol extinction to aerosol type (species)



Boundary Layer Heights

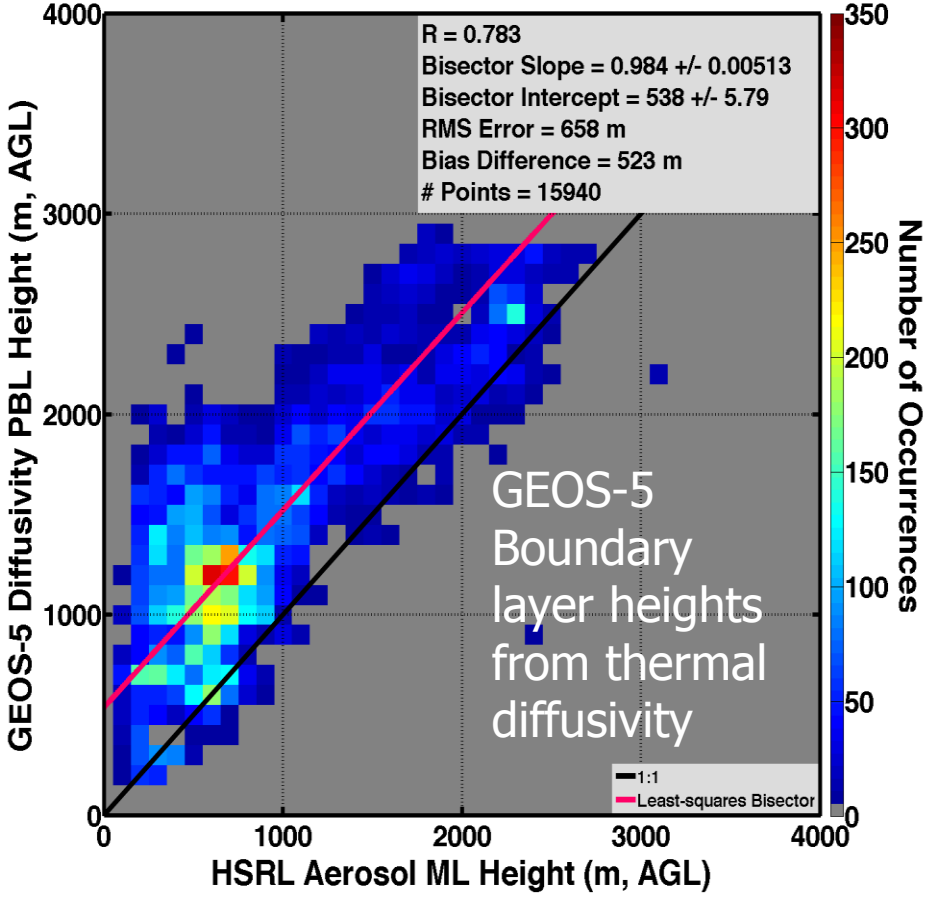
Boundary Layer Heights from HSRL-2 and GEOS-5 over Houston

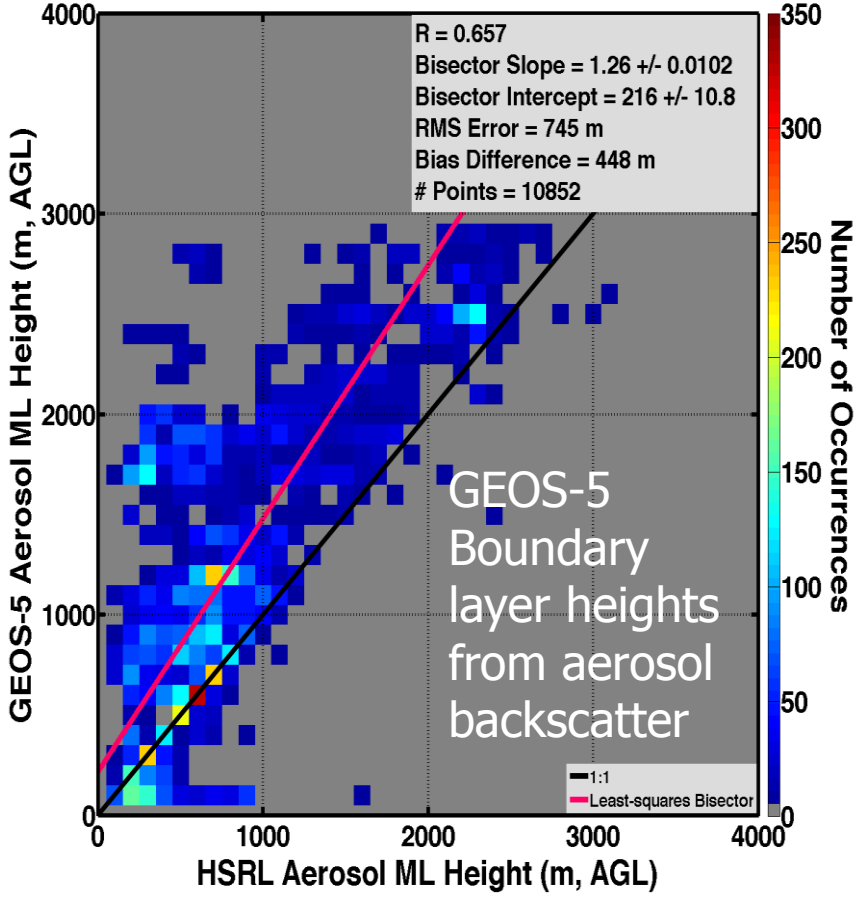
- HSRL-2 boundary layer heights from aerosol backscatter gradients
- GEOS-5 boundary layer heights from thermal diffusivity and aerosol backscatter gradients



Boundary Layer Height Comparisons

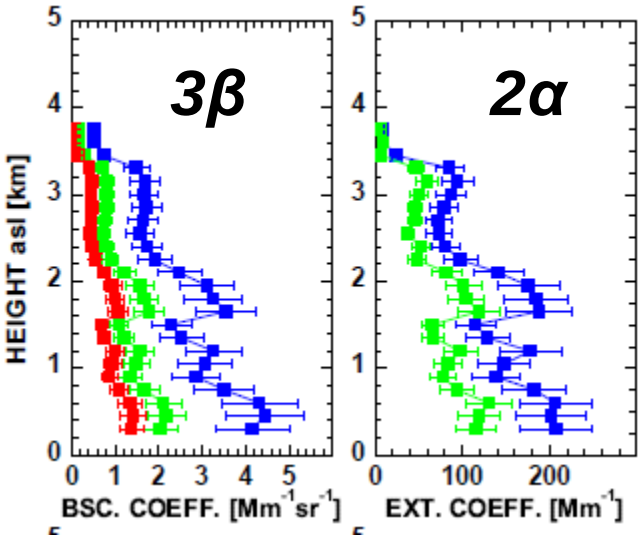
GEOS-5 Boundary layer heights larger than those derived from HSRL-2





Advanced HSRL-2 Aerosol Retrievals

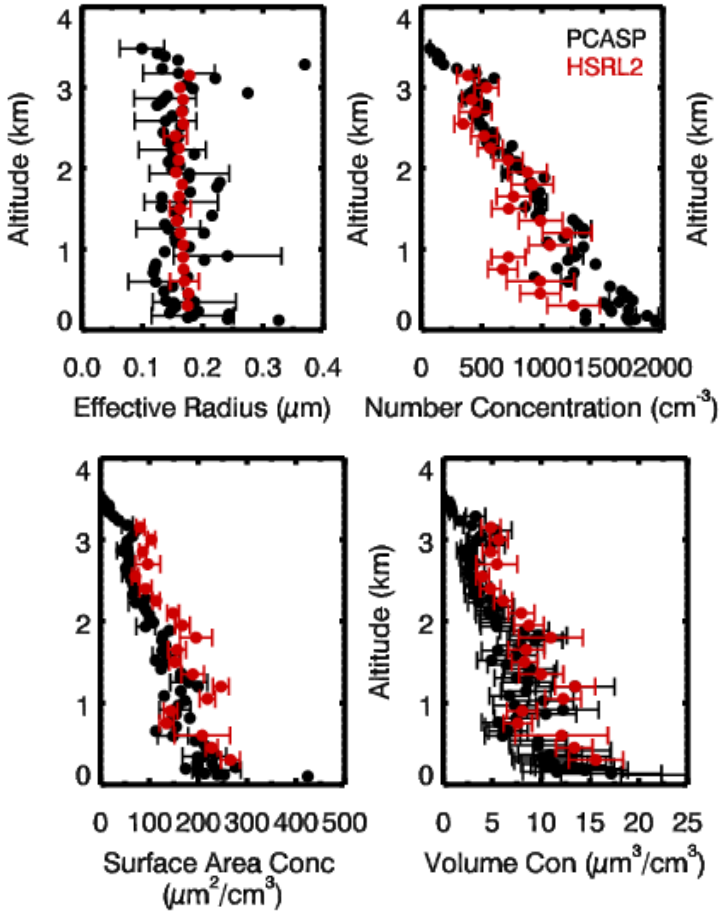
Multiwavelength "3β+2α" retrievals using data from airborne HSRL-2



Aerosol Backscatter:
355 nm
532 nm
1064 nm

+

Aerosol Extinction:
355 nm
532 nm

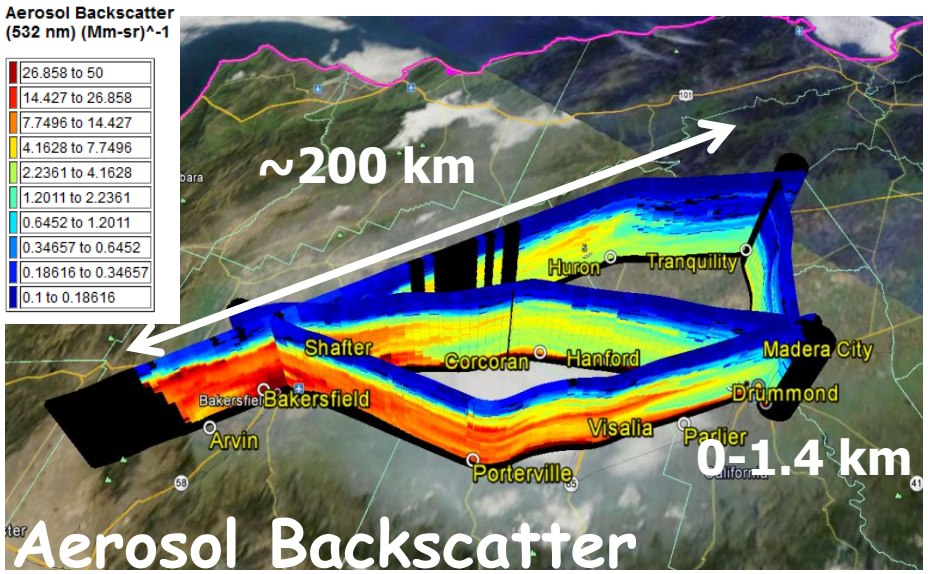


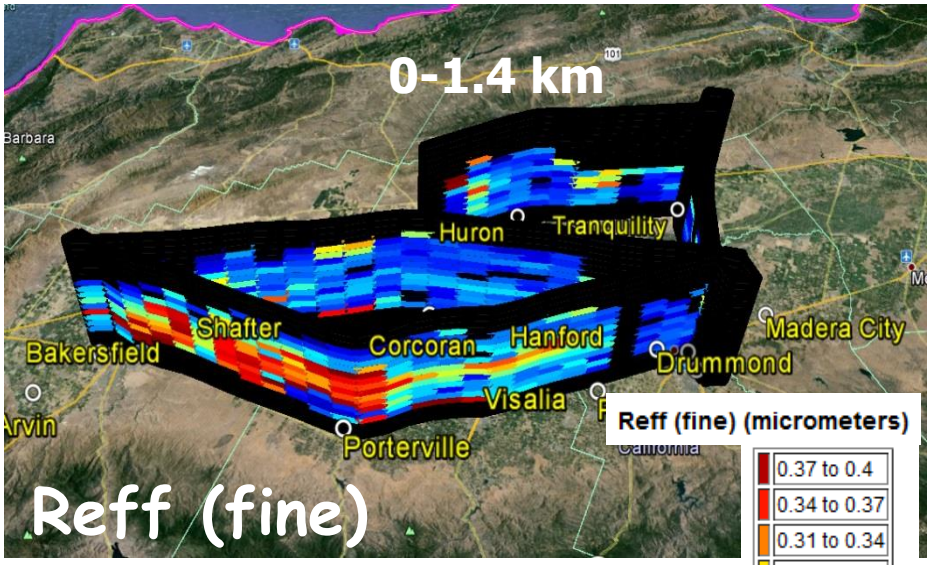
Multiwavelength lidar retrieval algorithms (Müller et al, 2001, 2002; Veselovskii et al. 2002; Wandinger et al., 2002; etc.)

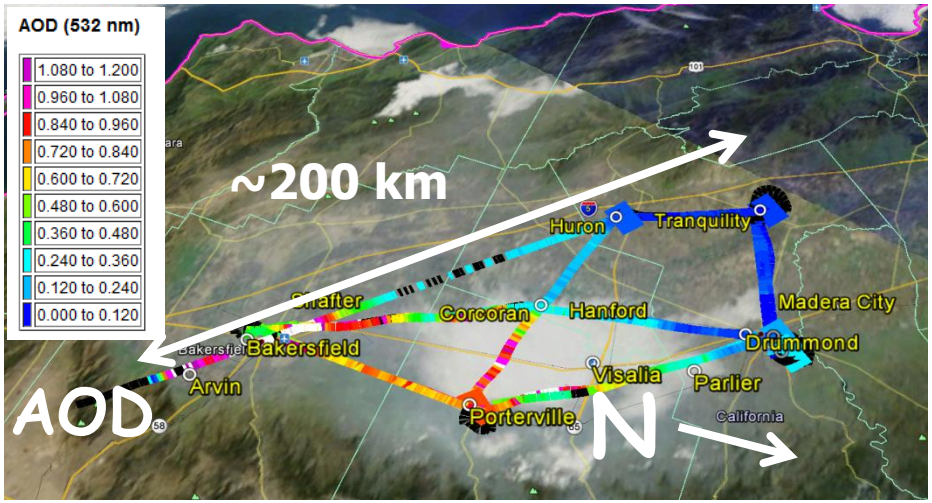
Lidar microphysical retrievals of effective radius and concentration compare well to in situ measurements made on DOE G-1 aircraft during the TCAP mission in 2012 (Müller et al., 2014, AMT)

Spatial and vertical variability of aerosol distribution and particle size revealed by HSRL-2

- Higher aerosol loading and larger effective radius along SE portion of pattern
- Good agreement between AERONET and HSRL-2 retrieved fine mode effective radius

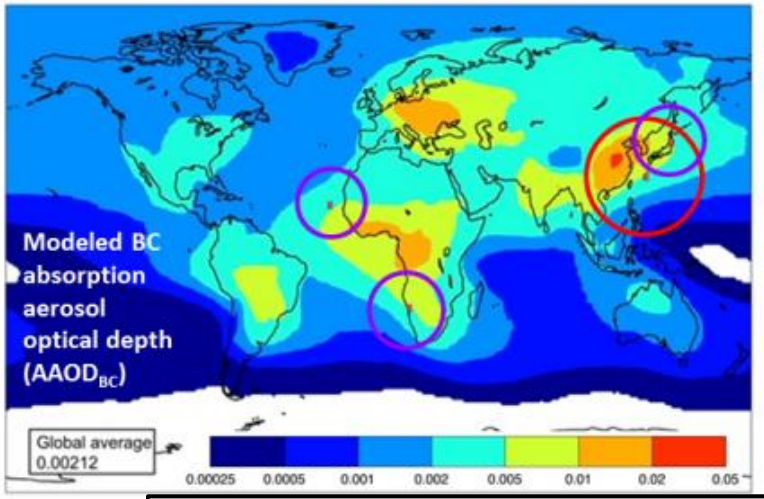






Atmospheric BlAck Carbon Study (ABACuS)

- Airborne campaigns proposed to NASA EV-S program
- Objectives:
  - Characterize evolution of aerosols downwind of key BC source regions
  - Improve constraints on factors controlling spatial distribution of BC aerosols
  - Assess and improve remote sensing techniques for retrieving absorbing aerosol properties
- Four campaigns proposed during 2016-2019 (SE Asia, SW Africa, NW Africa, Asia)
- Combination of in situ and remote sensing instruments carried on NASA P-3B or DC-8 aircraft
- Organizers:
  - **PI:** Ferrare; **Project Scientists:** Doherty, Bond
  - **Co-I's:** (Measurements) Anderson, Cairns, DeMott, Hair, Hostetler, Redemann, Sedlacek, Schmidt, Zelenyuk; (Analysis/Modeling) Barahona, Bauer, Colarco, daSilva, Fast, Ghan, McComiskey, Nenes, Schuster
  - **Collaborators:** Kinne, Kondo, Schulz, Winker



ABACuS Instruments

- **LARGE:** *In situ* - aerosol size, composition, optical, BC mass and size, CCN, trace gas
- **PTI:** *In situ* – aerosol absorption
- **Mini-SPLAT:** *In situ* – aerosol composition
- **CFDC:** *In situ* – IN
- **HSRL-2:** Multiwavelength lidar – aerosol extinction, backscatter, depolarization, microphysical properties
- **4STAR:** Sun/sky radiometer – AOD, AAOD, microphysical properties
- **RSP:** Polarimeter – polarized radiances, AOD, aerosol microphysical properties
- **SSFR:** Radiometer – aerosol absorption

Core Models (*Type*)

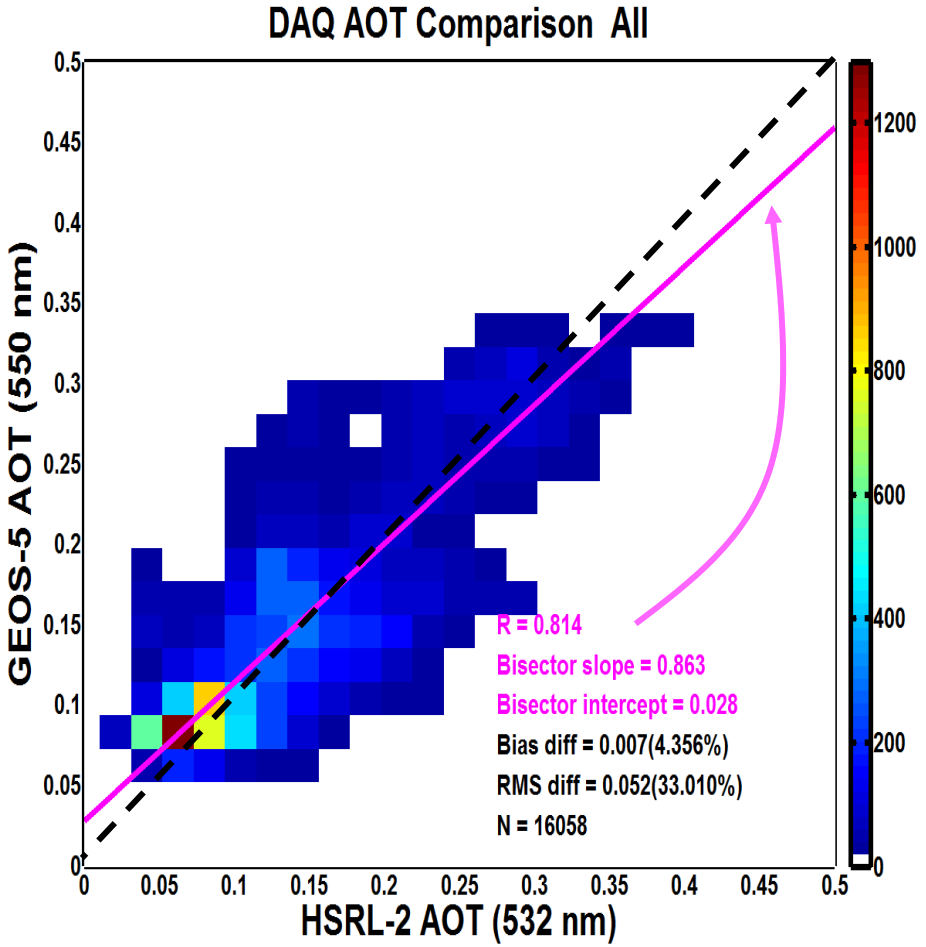
- **WRF-Chem** (*Regional*)
- **PartMC-MOSAIC** (*Process*)
- **GISS-Model E** (*Global*)
- **GEOS-5** (*Global*)
- **CAM5** (*Global*)

Summary

- Airborne HSRL-2 and DIAL/HSRL data used to evaluate GEOS-5 vertical profiles of aerosol extensive and intensive parameters
- On average, GEOS-5 profiles of aerosol extinction and backscatter are in good agreement with HSRL measurements
- GEOS-5 simulations of aerosol depolarization are biased low
- Both GEOS-5 and airborne HSRL data show aerosol intensive properties vary with altitude during both SEAC4RS and DISCOVER-AQ Houston
- GEOS-5 Boundary layer heights during DISCOVER-AQ Houston are biased high relative to boundary layer heights derived from airborne lidar data
- Future work will:
  - Compare with other models (NRL, ECMWF) as well as GEOS-5
  - Investigate and develop model representations of dust and smoke particle shape
  - Correlate HSRL aerosol classification with GEOS-5 aerosol speciation
  - Evaluate AEROCOM climate model depictions of aerosol extinction profiles, especially relative to CALIOP comparisons
  - Continue development and assessment of advanced HSRL-2 retrievals

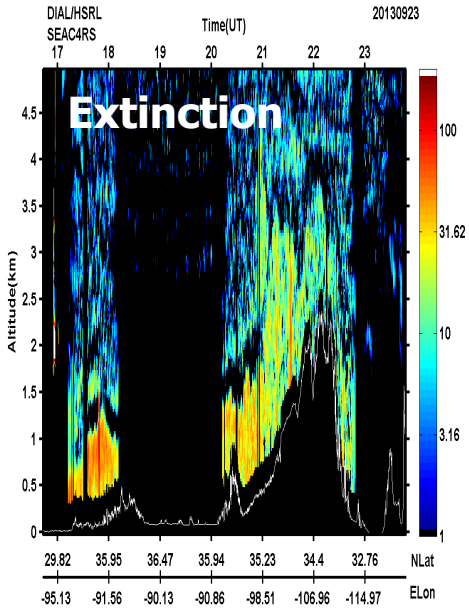
HSRL-2 and GEOS-5 AOT Comparison During DISCOVER-AQ Houston

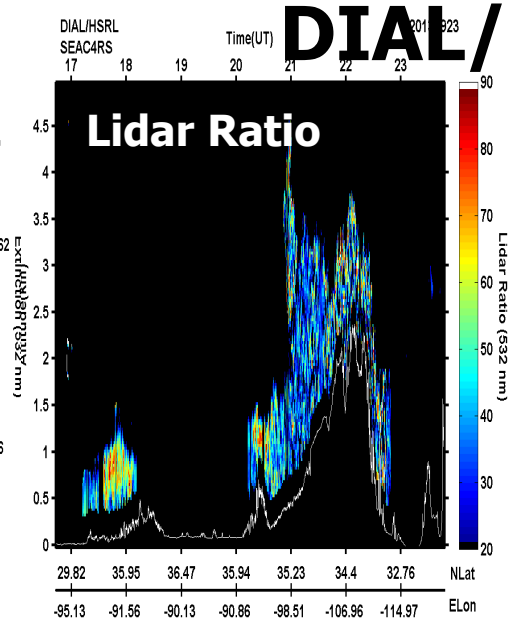
- AOT derived from HSRL-2 data when King Air flew at 9 km
- HSRL-2 and GEOS-5 in generally good agreement
- GEOS-5 AOT higher than HSRL-2 at low values; likely due to AOT above HSRL-2 column max altitude of 7 km
- GEOS-5 AOT slightly lower than HSRL-2 at higher values of AOT because of wavelength difference

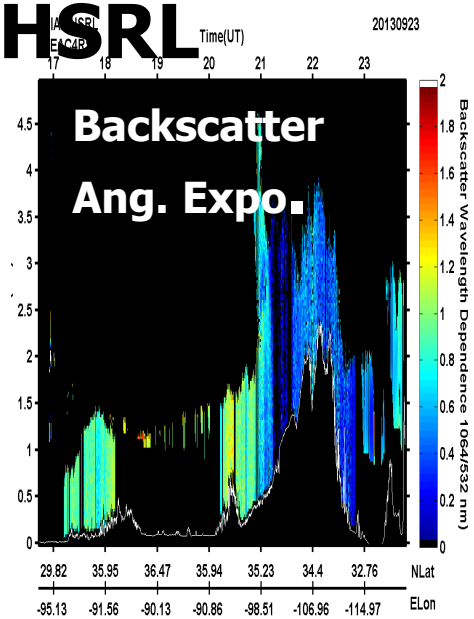


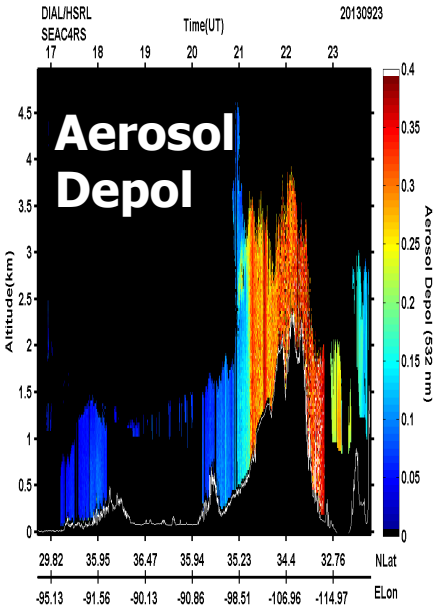
SEAC4RS Sept. 23 DIAL/HSRL Transit from Houston to Palmdale

DIAL/HSRL

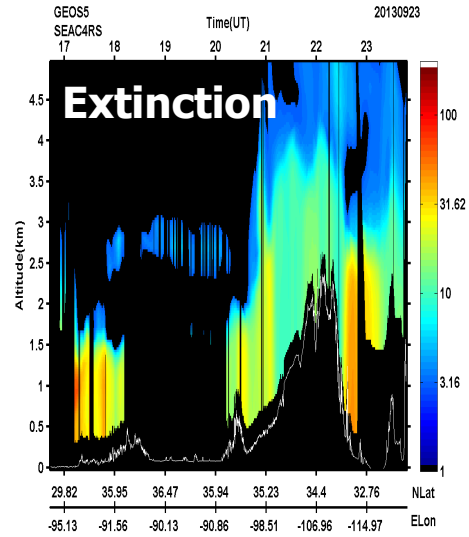


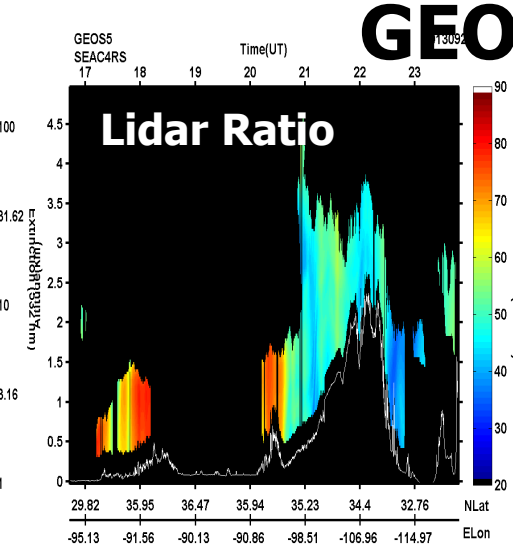


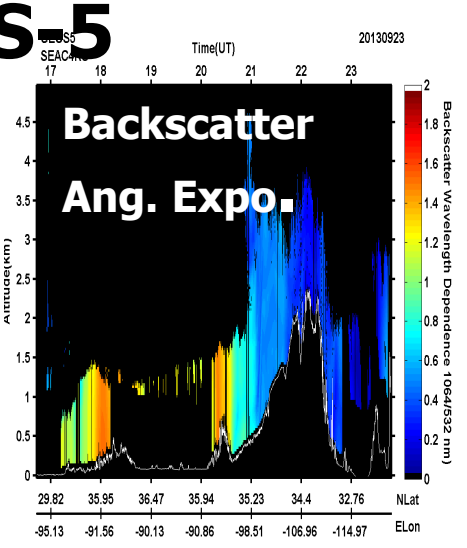


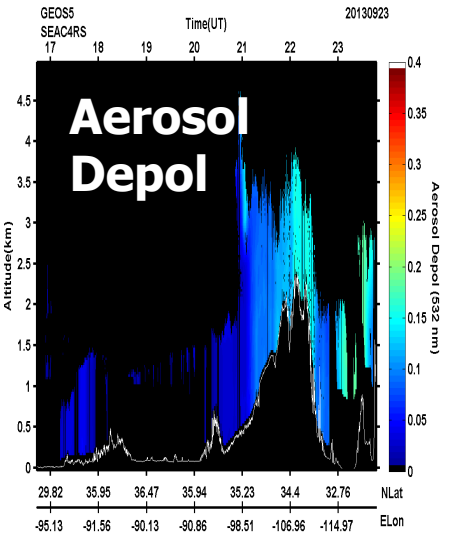


GEOS-5

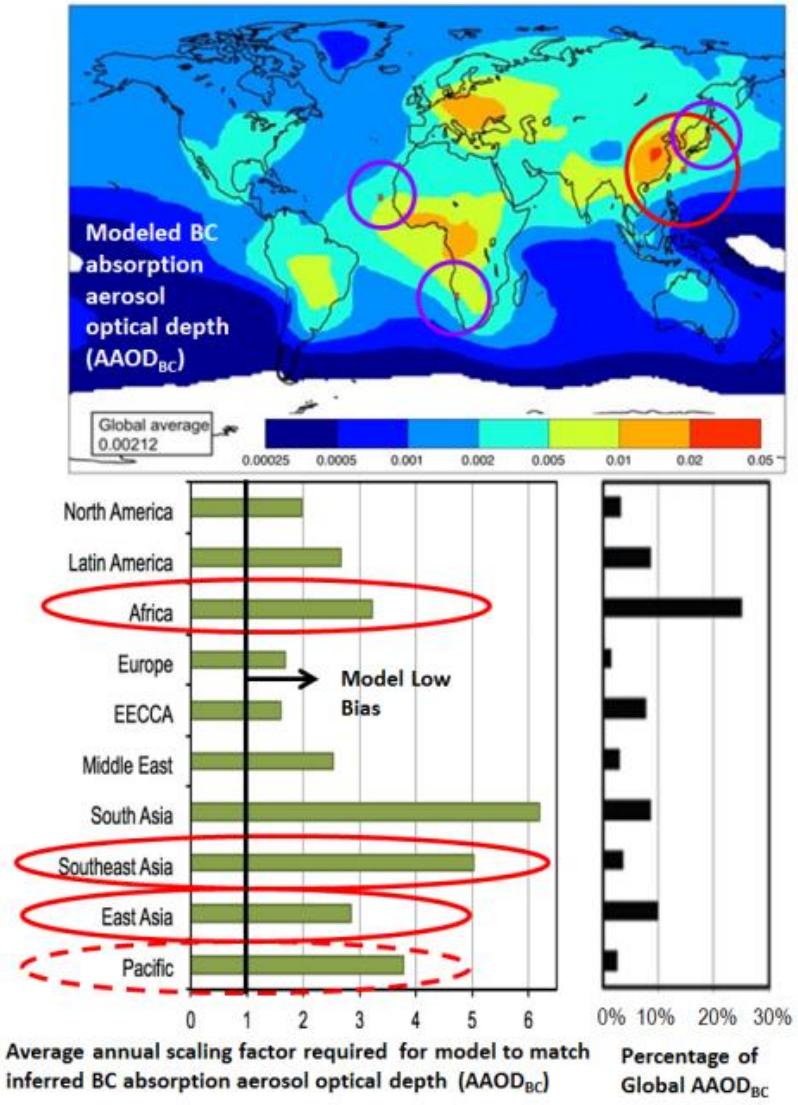








Proposed ABACUS Study Regions



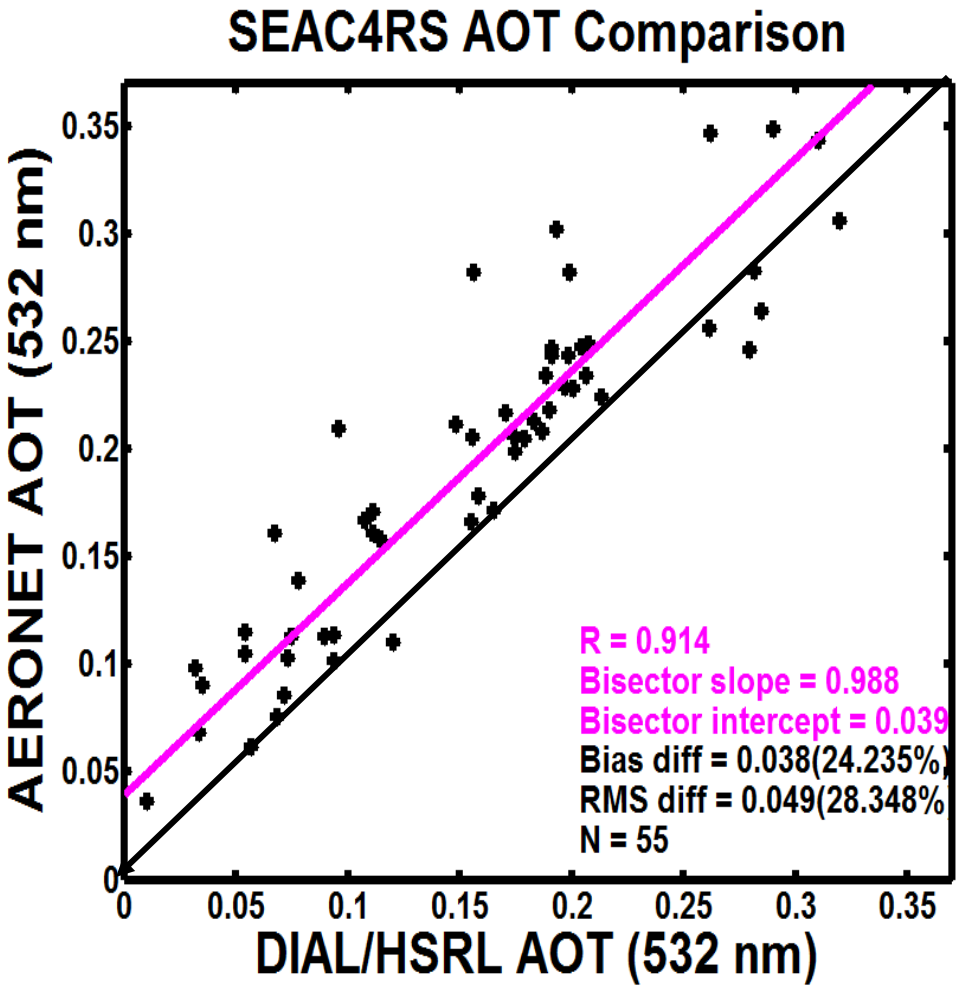
(Bond et al., 2013, JGR)

Will study black carbon in outflow from key regions:

- SE Asia (from Okinawa, Japan) (Sept. 2016)
- SW Africa (from Walvis Bay, Namibia) (Sept. 2017)
- NW Africa (from Sal, Cape Verde) (Feb. 2018)
- Asia (from Fussa, Japan) (April, 2019)

DIAL/HSRL AOT comparison with AERONET during SEAC4RS

- AOT derived from DIAL/HSRL nadir data when DC-8 flew at or above 5 km
- AOT compared with AERONET level 2.0 AOT within 30 min and 30 km
- DIAL/HSRL AOT slightly lower than AERONET, possibly due to AOT not included above (> 5 km) or below (<150 m) profile



AERONET data – thanks to Brent Holben, Rick Wagener, Joe Shaw, Kevin Repasky, Kevin Knupp, Doug Moore