Characterizing the Vertical Distribution of Aerosols using Ground-based Multiwavelength Lidar Data

SAND2016-12755C

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Combined HSRL and Raman lidar Measurement Study (CHARMS)

Motivation

- Aerosol optical (extinction, scattering, absorption) and microphysical (size, concentration, composition) properties are required to:
  - Assess aerosol impacts on radiation (direct effect)
  - Investigate aerosol-cloud interactions (indirect effect)
  - Develop and evaluate model parameterizations
- NASA/LaRC multiwavelength "$3\beta+2\alpha$" automated aerosol retrievals, developed for airborne HSRL and possible future NASA ACE satellite mission, provide a method to remotely derive profiles of aerosol properties not captured by surface & column-averaged data

Question

- Can these aerosol retrieval algorithms be used with ground-based DOE ARM lidar data?

Objectives

- **Acquire "$3\beta+2\alpha$" dataset from DOE ARM lidars to test aerosol retrieval algorithms**
- **Investigate how combined ground-based Raman and High Spectral Resolution Lidar (HSRL) measurements can improve ARM observational capability of aerosols**

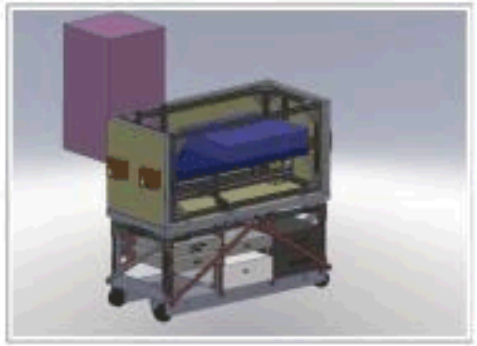
CHARMS Instruments and Data

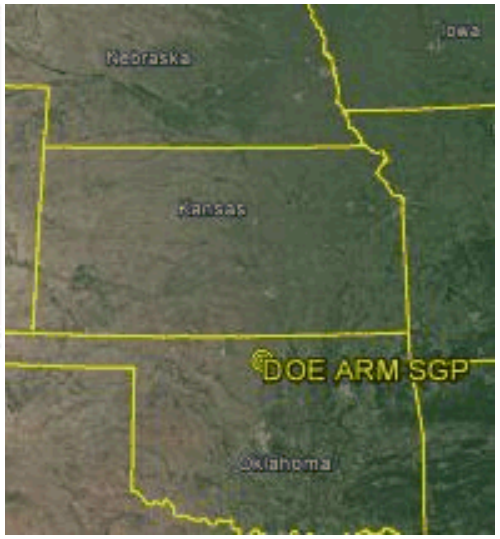
CHARMS → SGP Raman Lidar + Univ. Wisconsin HSRL = 3β+2α

Raman Lidar

Measurements (3β+2α)

UW HSRL



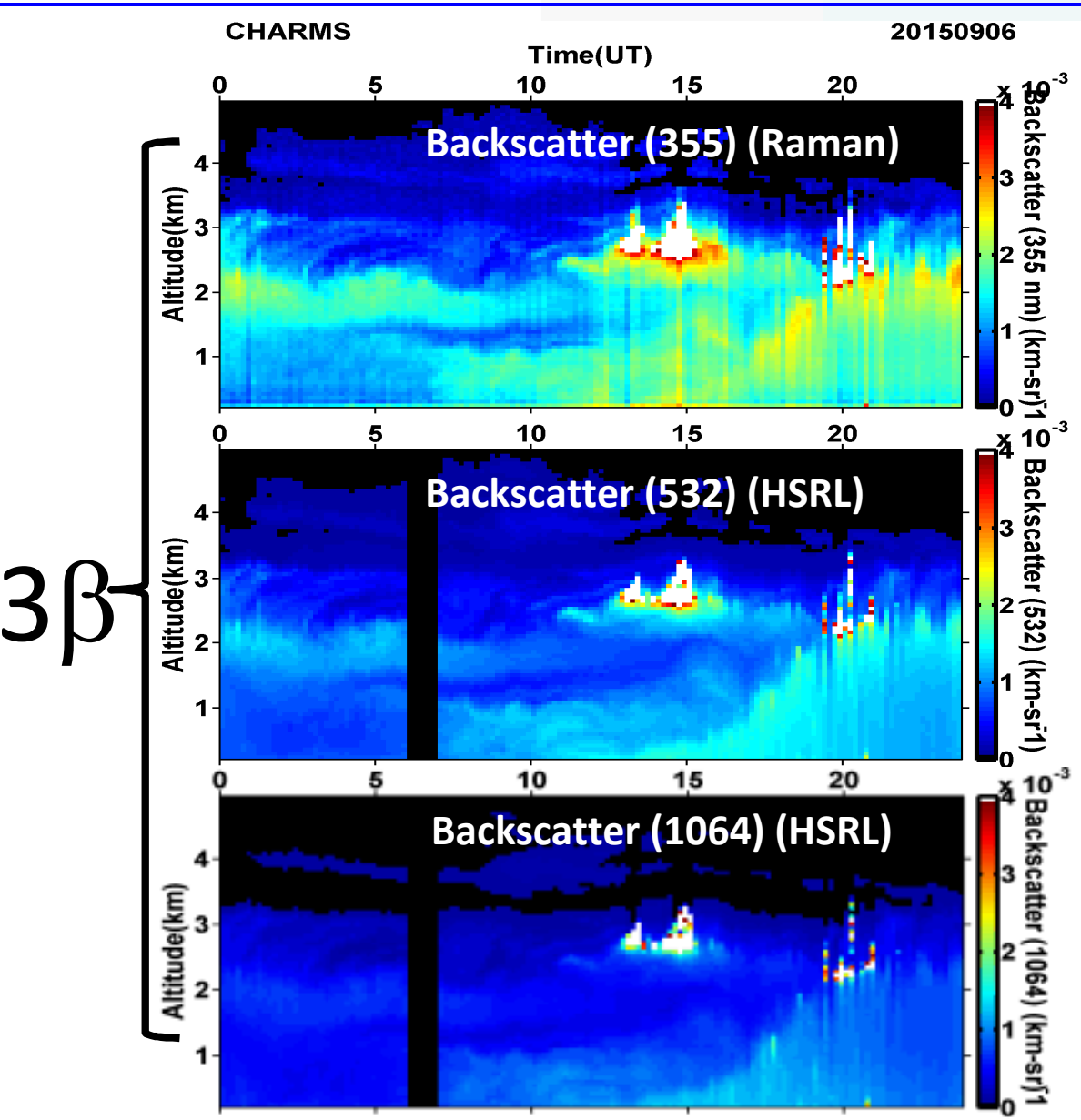


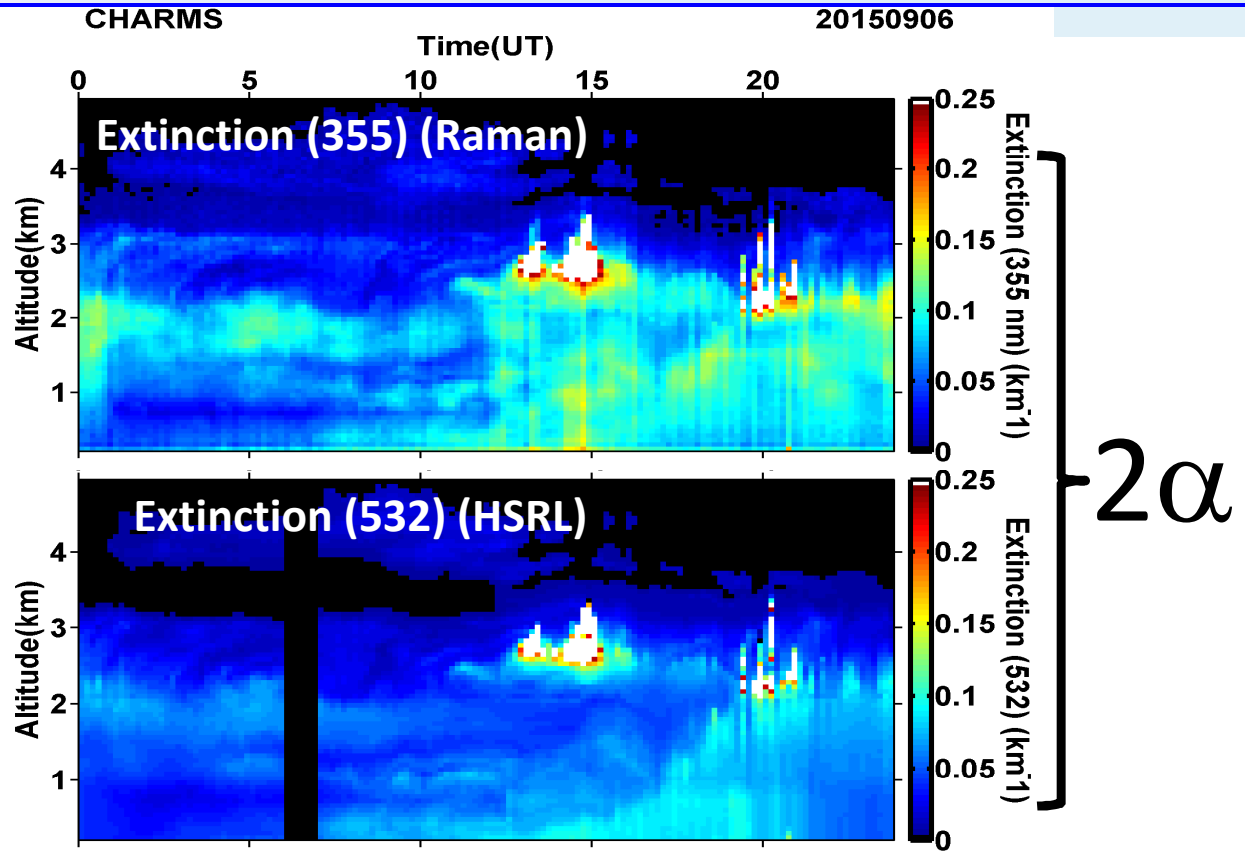
- Aerosol backscatter, extinction, depolarization (355 nm)
- Water vapor mixing ratio
- Temperature
- Relative Humidity

- Aerosol backscatter (532, 1064 nm)
- Aerosol extinction (532 nm)
- Depolarization (532 nm)

- Data collected from July 18 through September 30, 2015 at DOE ARM SGP site (northern Oklahoma)
- Aerosol extinction and backscatter profiles from both lidars were processed consistently using the FEX algorithm (Thorsen et al. 2015; Thorsen and Fu 2015)
- Difficulty in calibrating 1064 nm backscatter has currently limited 3+2 retrieval dataset to 25 days
- Images of results:
  - http://www.tylerthorsen.com/bagohsrlfex_charms/
- Processed 3+2 datasets available from DOE ARM Archive (PI product)
  - http://iop.archive.arm.gov/arm-iop/0pi-data/?uid=FerrareR1&st=5845b00b&home=arm-archive

Example 3β+2α CHARMS Dataset (Sept. 6, 2015)

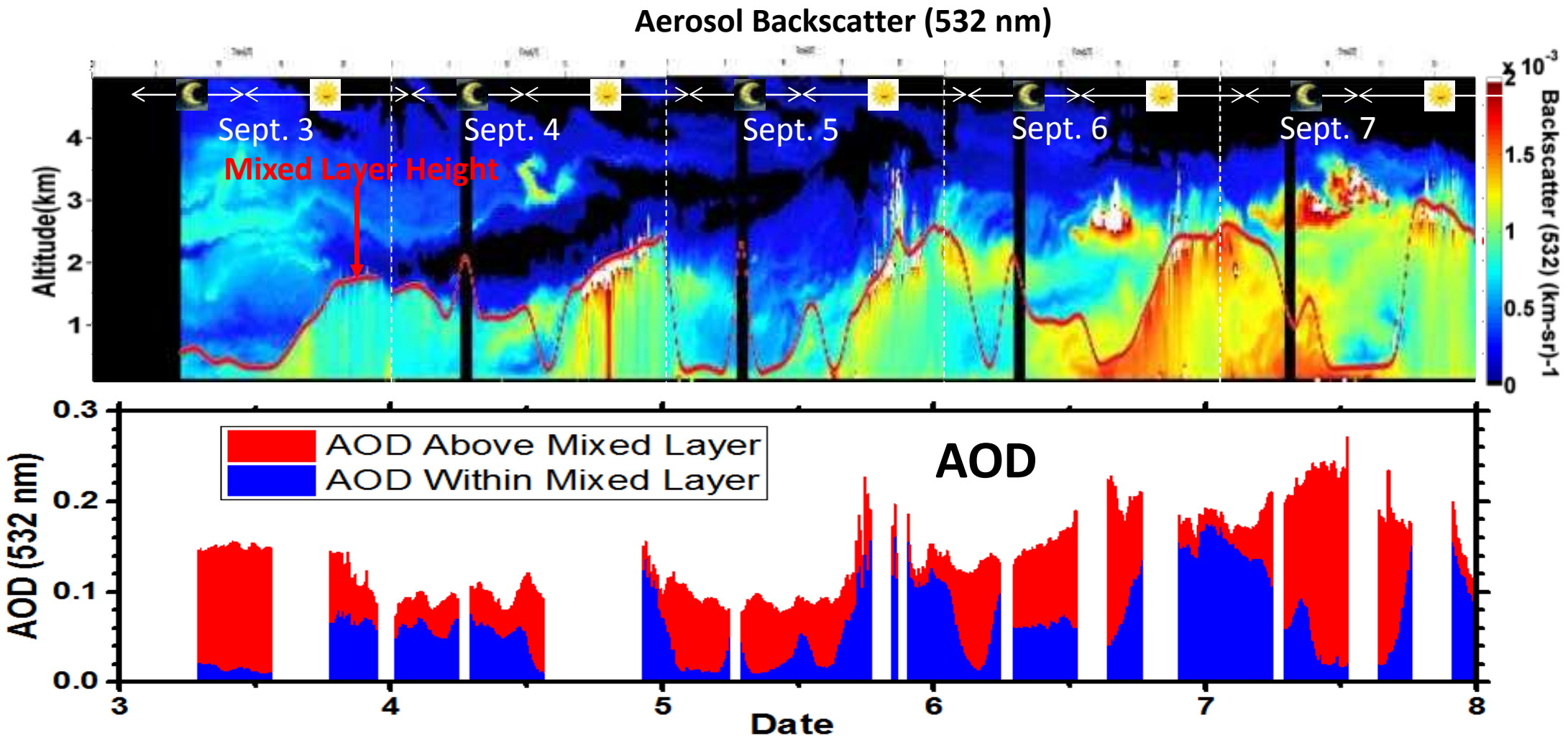




- 10min, 60m vertical resolution (120m for the microphysical retrievals)
- Some artifacts in Raman and HSRL data due to temperature and alignment fluctuations
- Raman lidar performance improved after CHARMS

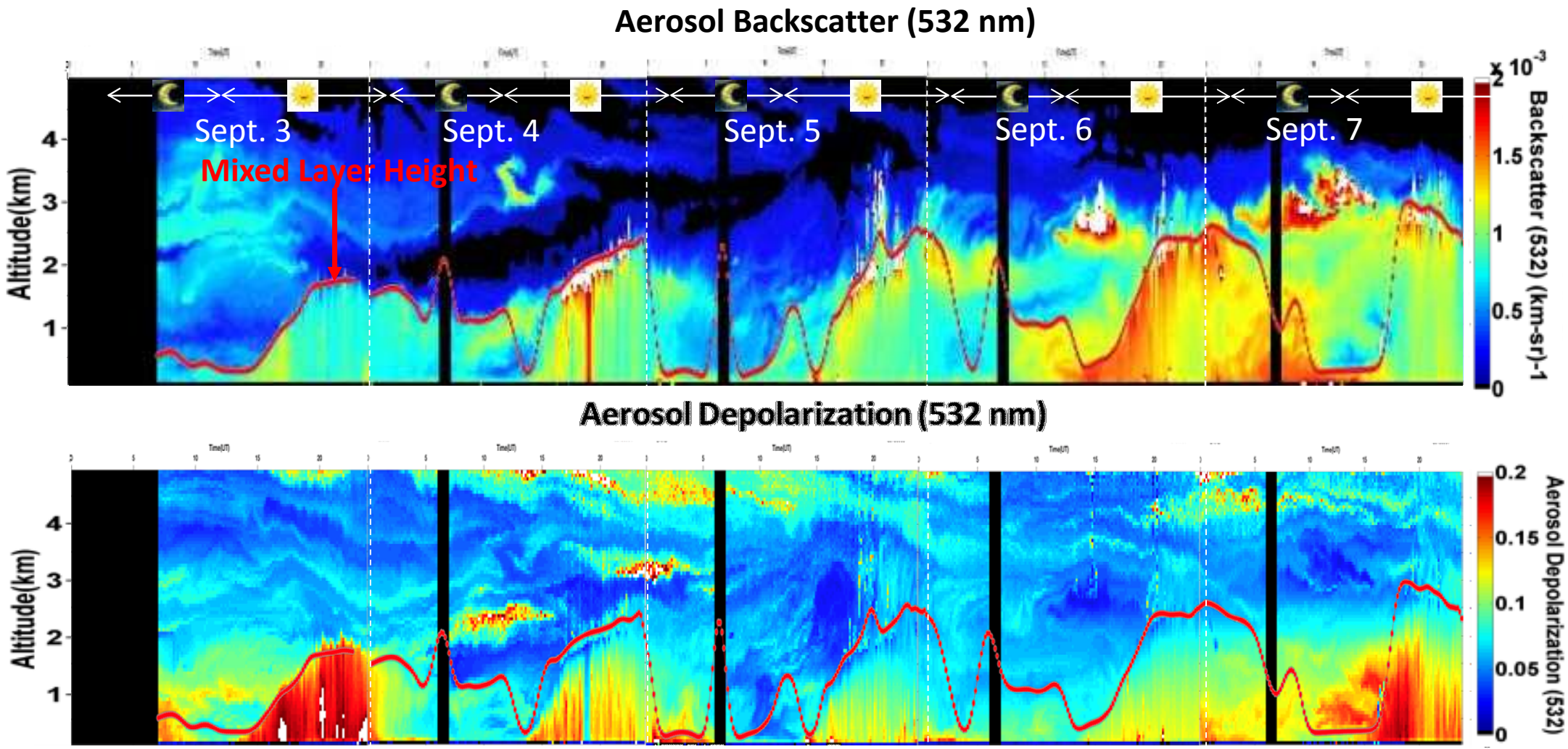
Significant aerosol optical depth above Mixed Layer

- Significant diurnal variability in aerosol vertical structure
- Backscatter profiles used to derive Mixed Layer Height which is often a good proxy for PBL height
- Significant amount of aerosol extinction and aerosol optical depth above ML (PBL)



CHARMS data reveal aerosol variability and presence of nonspherical aerosols (dust)

- Note variability in both aerosol loading (extinction) and type (aerosol depolarization)
- High depolarization in the afternoon denotes significant presence of nonspherical particles (dust)

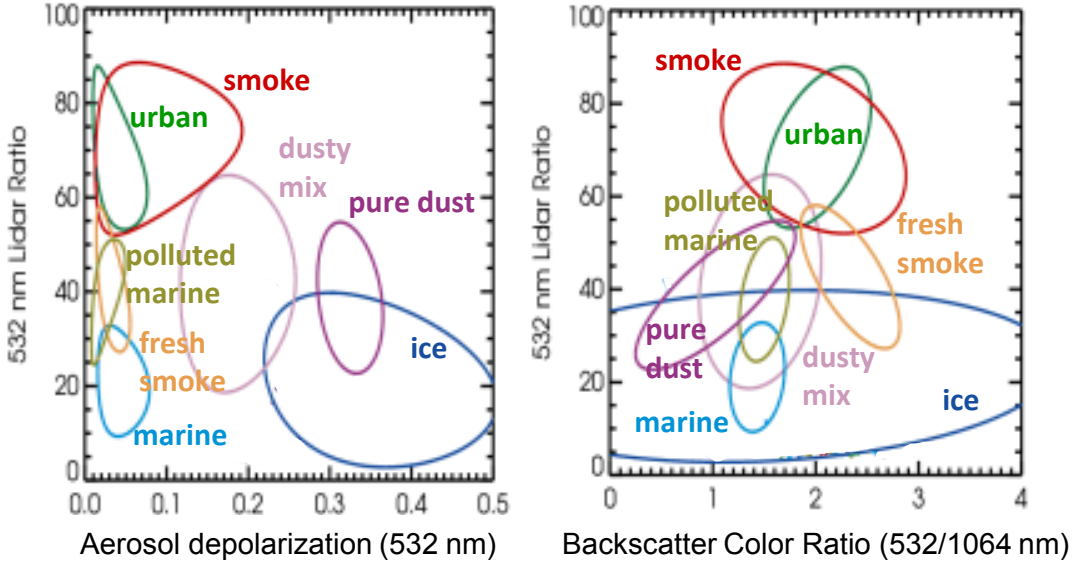


Aerosol Classification

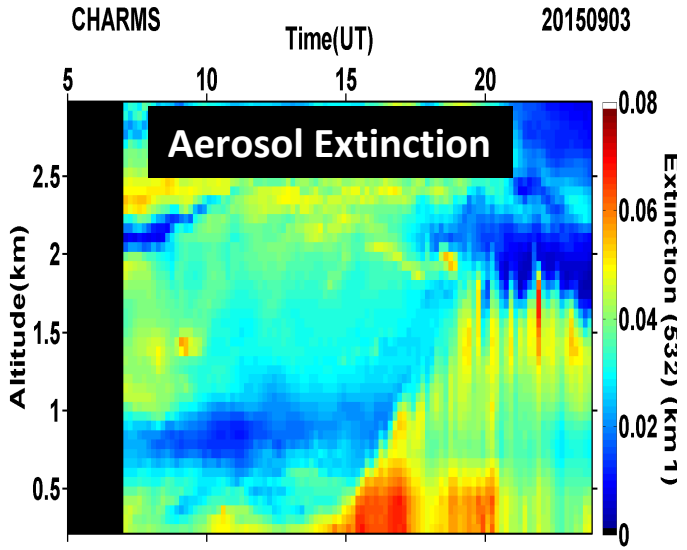
Aerosol Classification using CHARMS Data

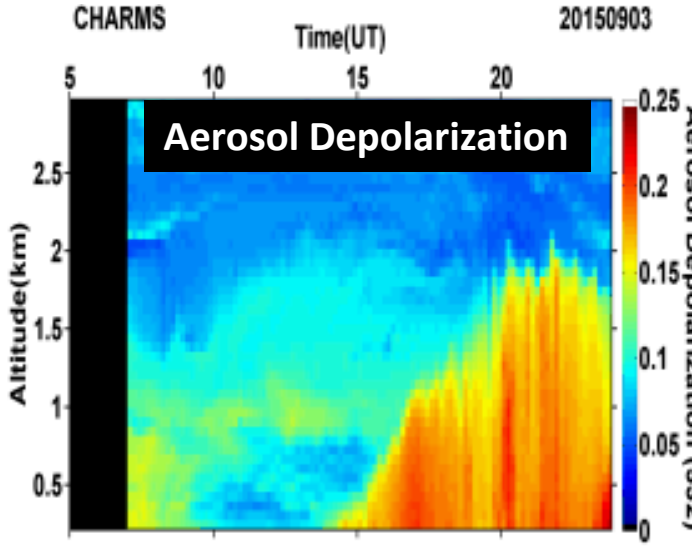
- Aerosol classification via multiwavelength lidar aerosol classification algorithm developed using airborne HSRL data (Burton et al., 2012, 2013, AMT)
- Current algorithm uses 532 & 1064 nm data
- Intensive parameters: (lidar ratio, depolarization, backscatter color ratio)

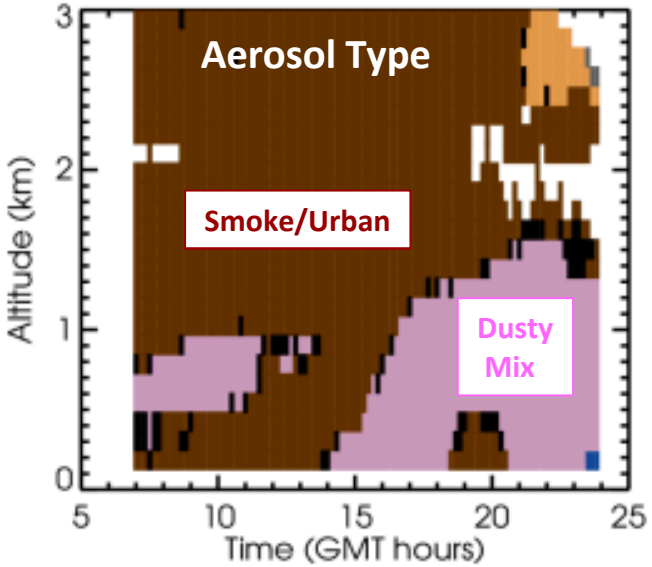
Ellipses represent aerosol types

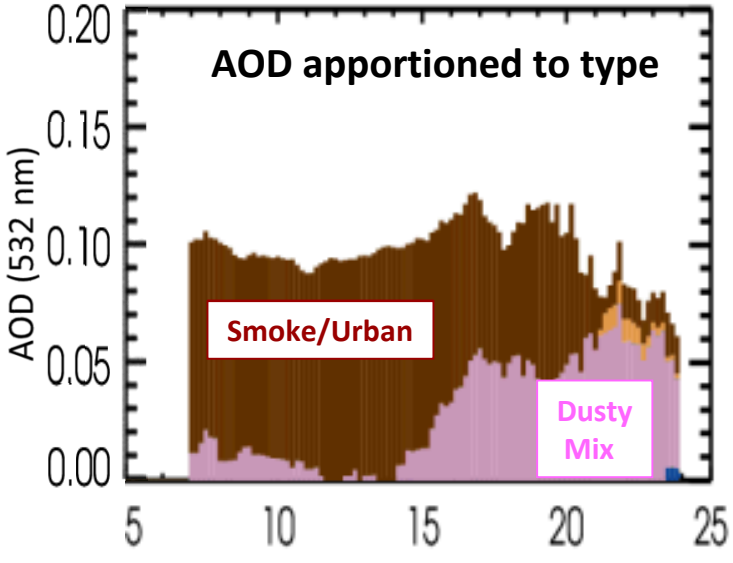


Aerosol Classification (September 3, 2015)



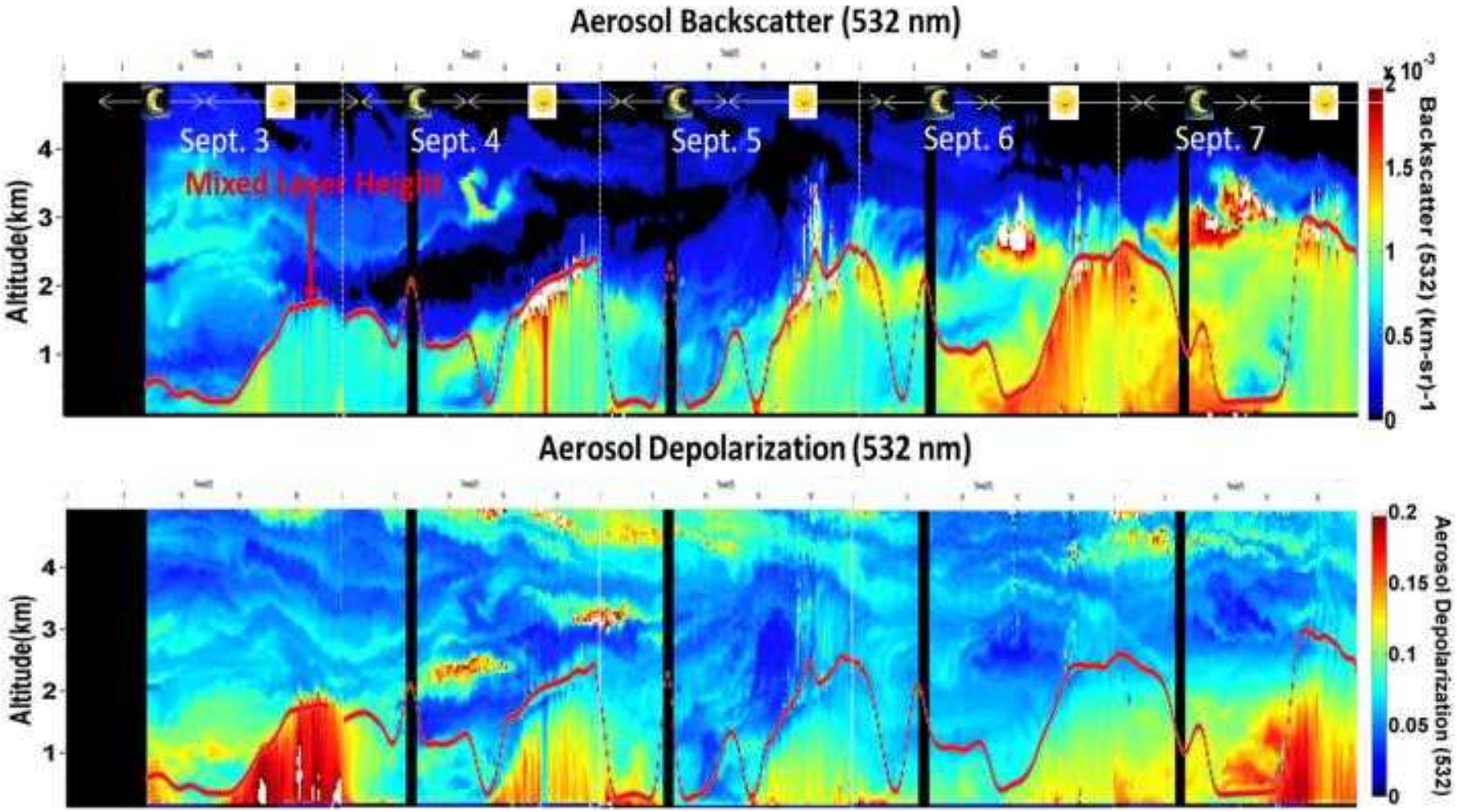


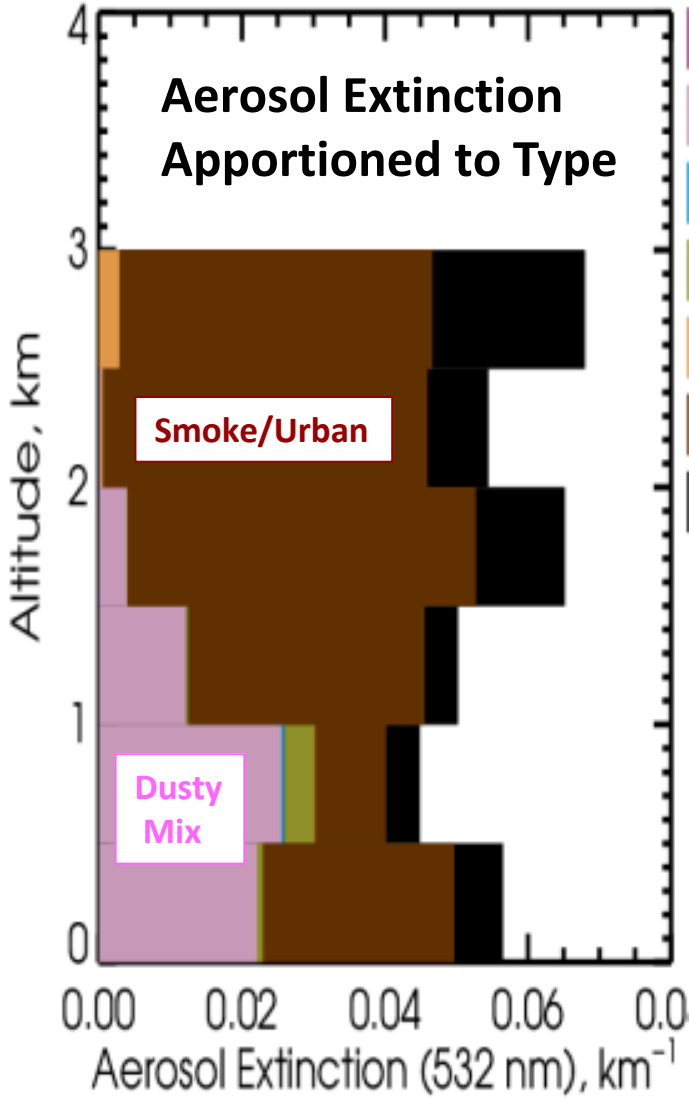




Aerosol classification for Sept. 3-7 period

- Near the surface aerosols are either dusty mix or smoke/urban mixture
- Aerosols aloft are dominated by smoke/urban mix

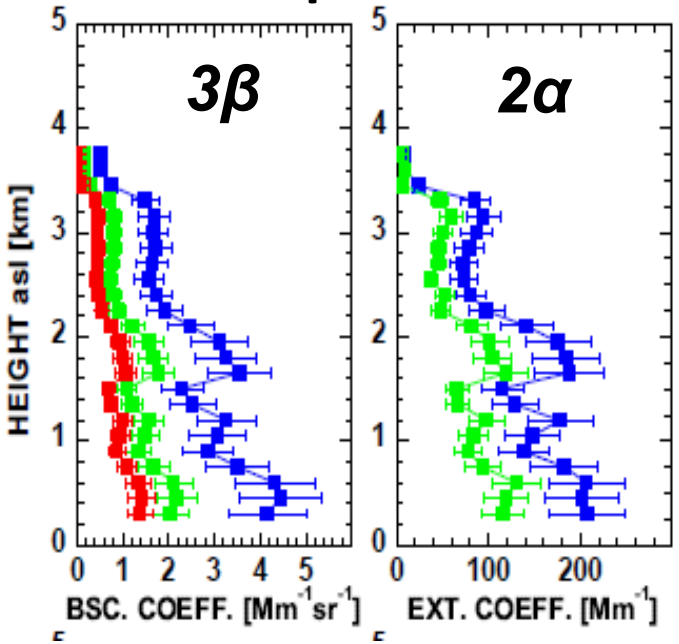




Multiwavelength Lidar Aerosol Retrievals

Multiwavelength "3β+2α" lidar retrievals provide vertically-resolved quantitative aerosol information

Input

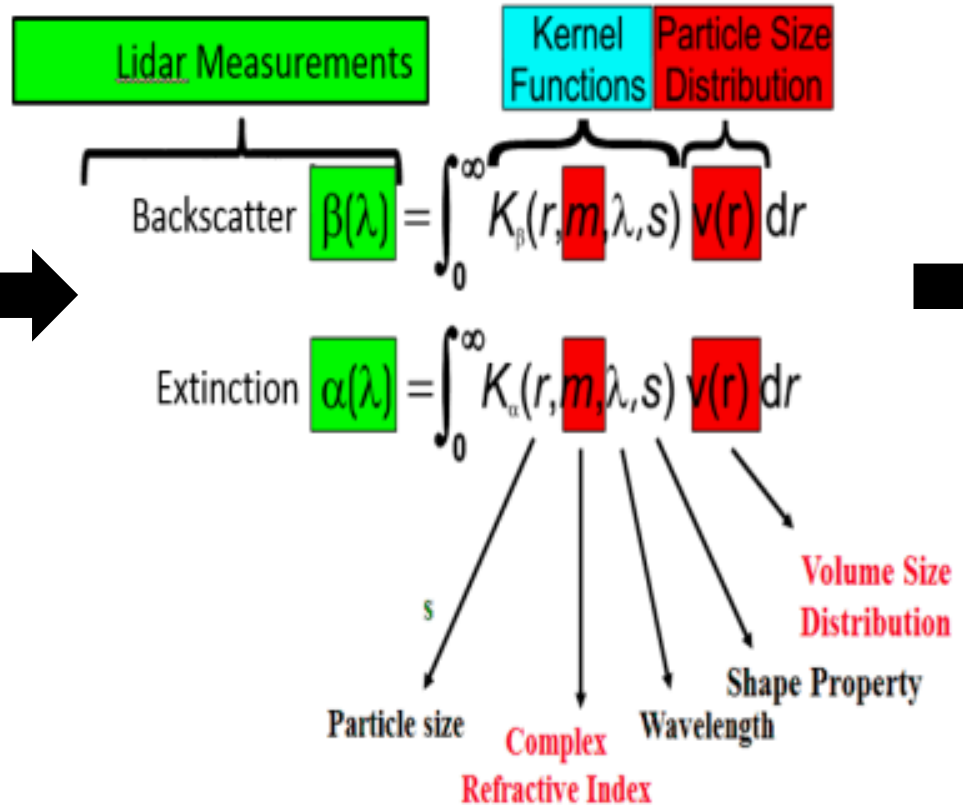


Aerosol Backscatter:
355 nm
532 nm
1064 nm

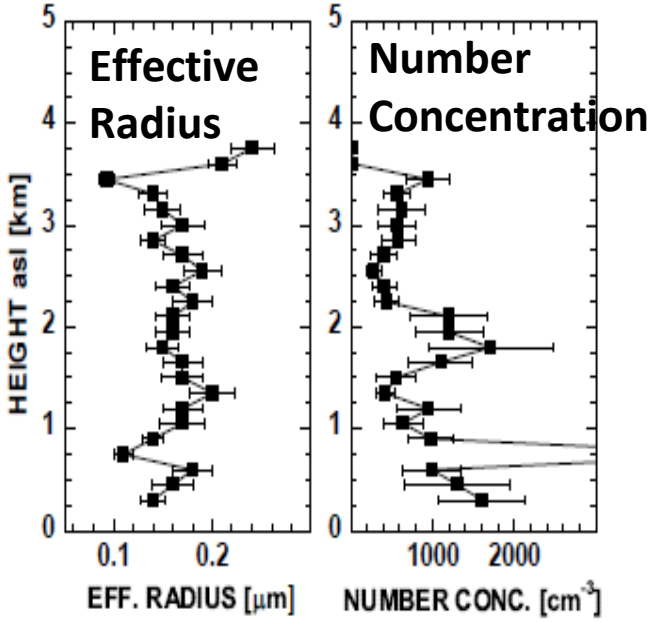
+

Aerosol Extinction:
355 nm
532 nm

Inversion



Output



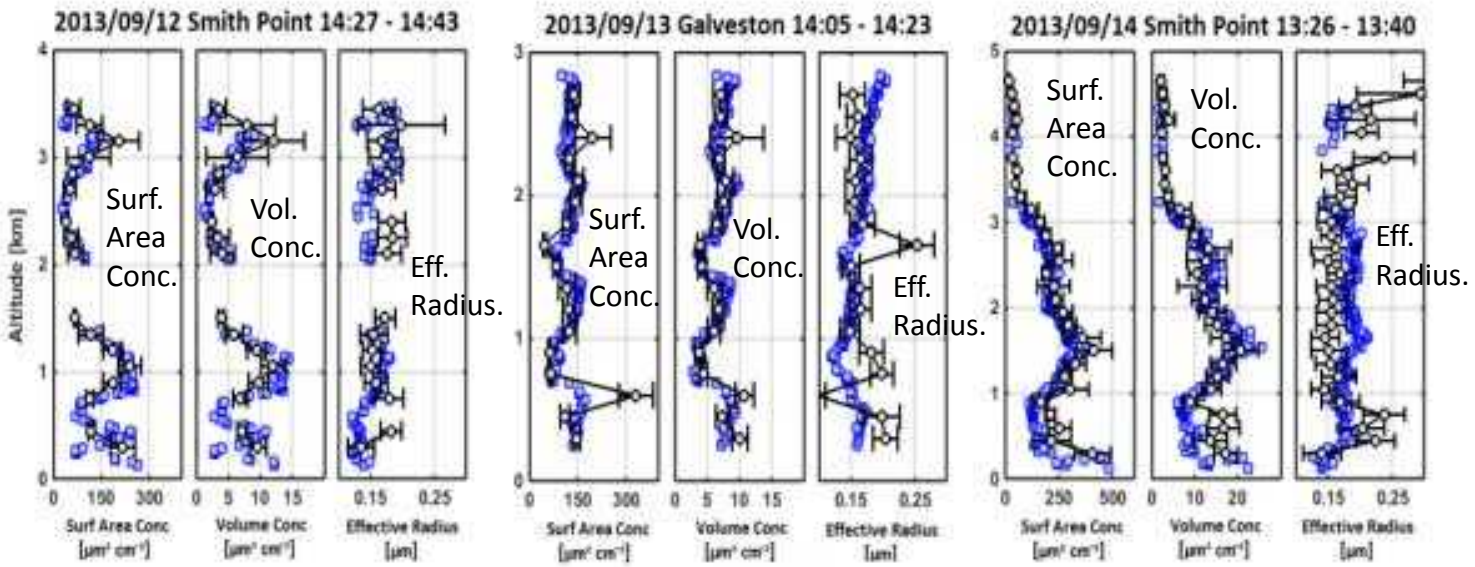
Output (lidar-only):
- Concentrations (number, surface, volume)
- Effective radius

Output (lidar+constraints)
- Scattering, absorption
- Refractive index

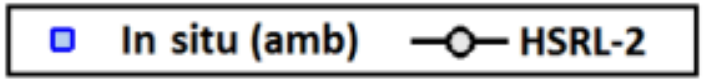
Multiwavelength lidar retrieval algorithms; Müller et al, 1998, 1999, 2001, 2014; Veselovskii et al. 2002; several application papers

Multiwavelength Lidar Aerosol Retrieval Summary

- Information content in lidar data alone (Burton et al., AMT, 2016)
  - Good retrievals of size and concentration parameters possible
  - Accurate absorption retrievals require additional constraints
- Tikhonov regularization (Müller et al., 2014): retrievals of effective radius, concentration show good agreement with airborne in situ measurements

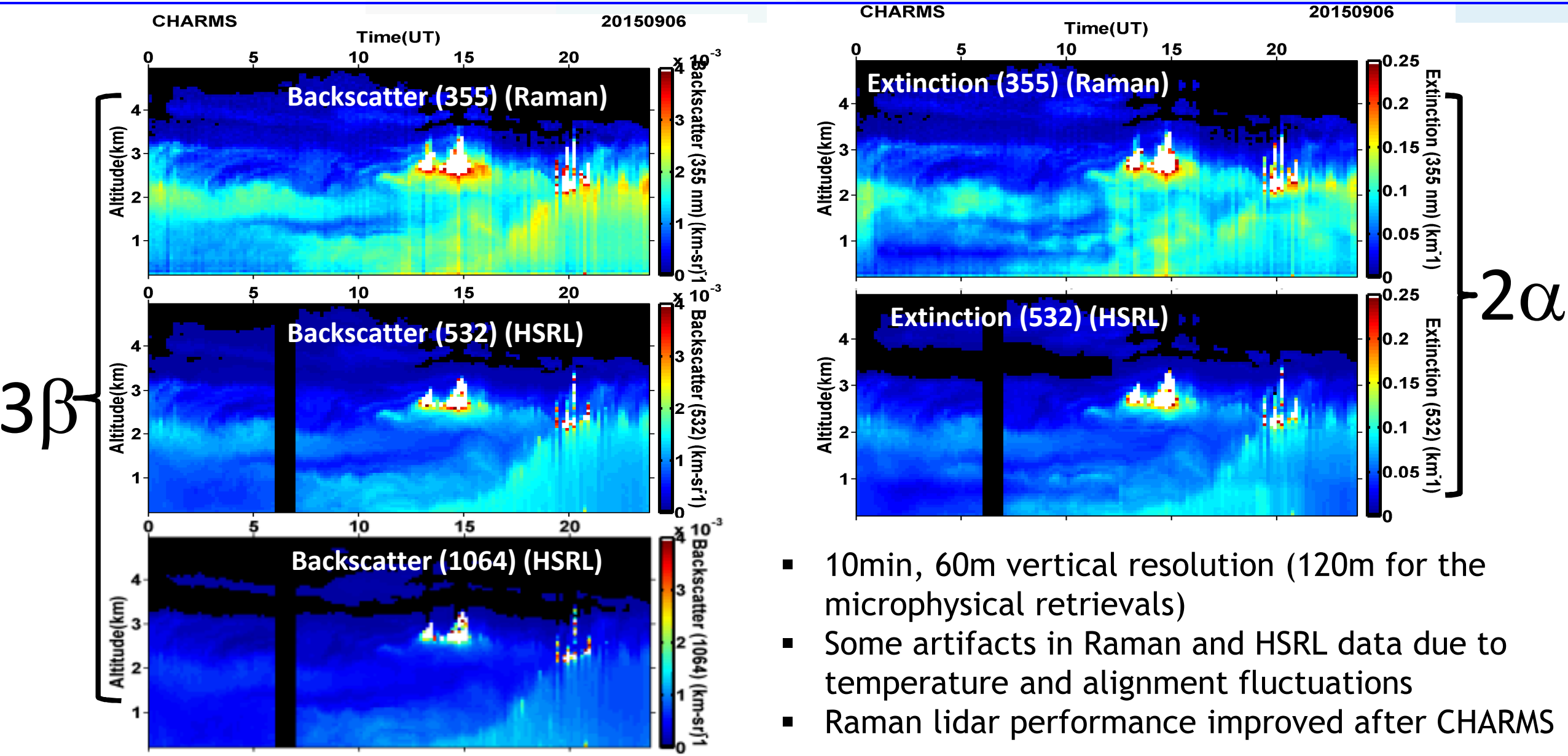


Comparisons of NASA/LaRC airborne HSRL retrievals with airborne in situ measurements during NASA DISCOVER-AQ mission (Houston, TX) (Sawamura et al., in prep)



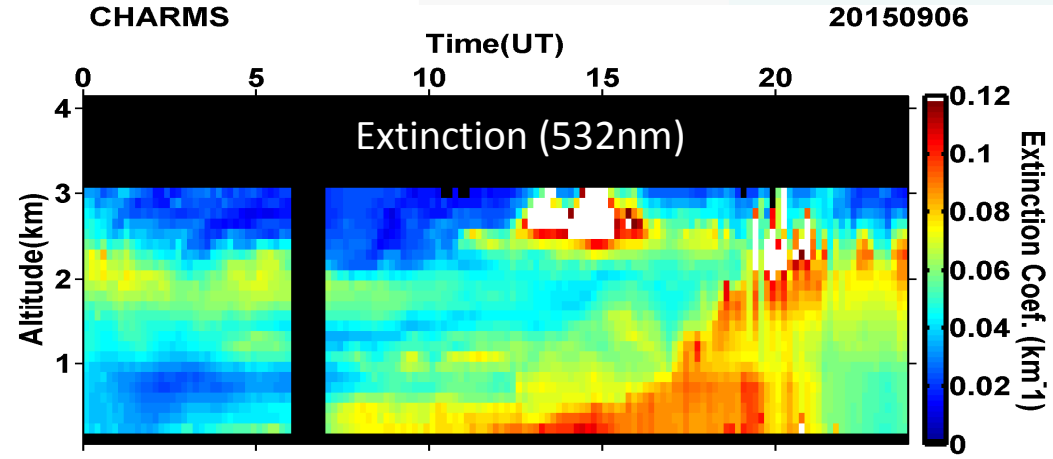
- Arrange and Average (Chemyakin et al., 2014): adds additional constraint/assumption on size distribution (monomodal)
- Optimal Estimation (see Liu et al. Friday A54E-06, 17:20): framework for combining lidar data with additional data constraints (e.g. Sun photometer, polarimeter)

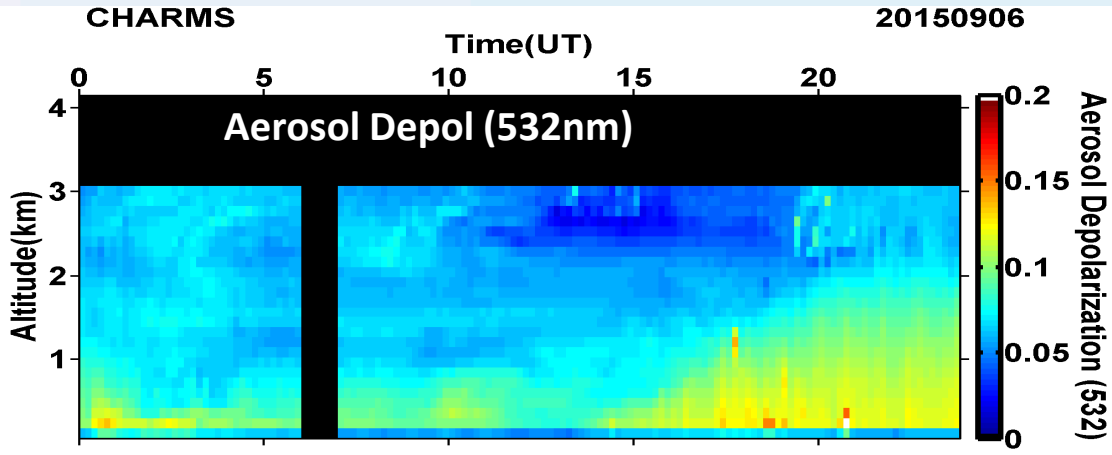
Example 3β+2α CHARMS Dataset (Sept. 6, 2015)

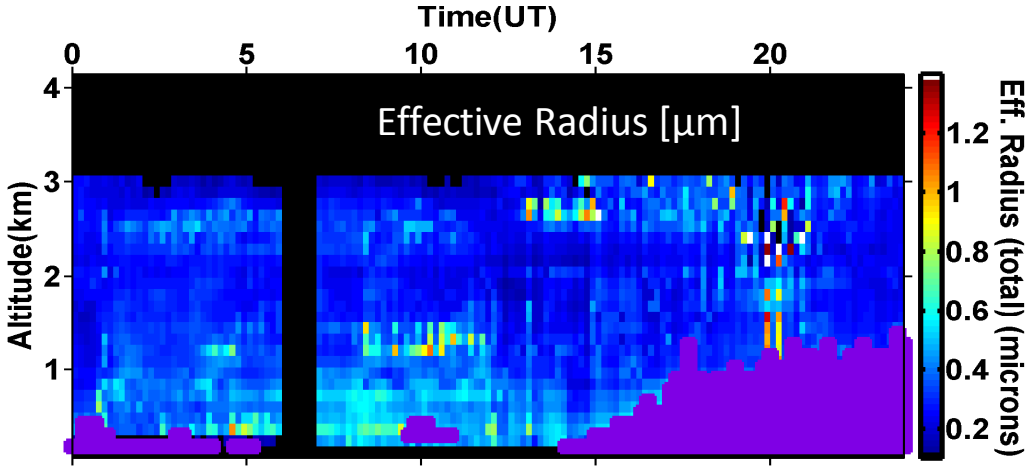


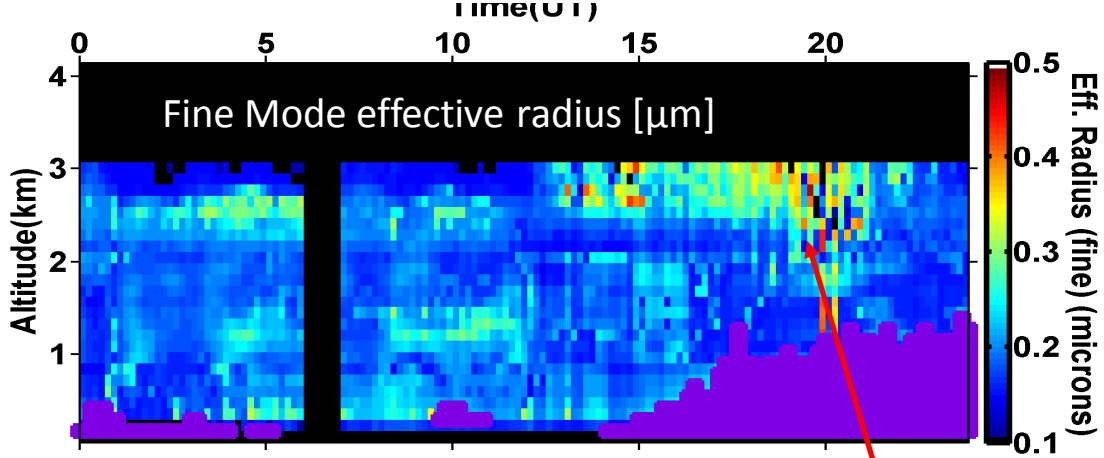
- 10min, 60m vertical resolution (120m for the microphysical retrievals)
- Some artifacts in Raman and HSRL data due to temperature and alignment fluctuations
- Raman lidar performance improved after CHARMS

AA-Tikhonov Advanced Regularization Algorithm - Retrieval Results (ex. Sept. 6) - Effective Radius



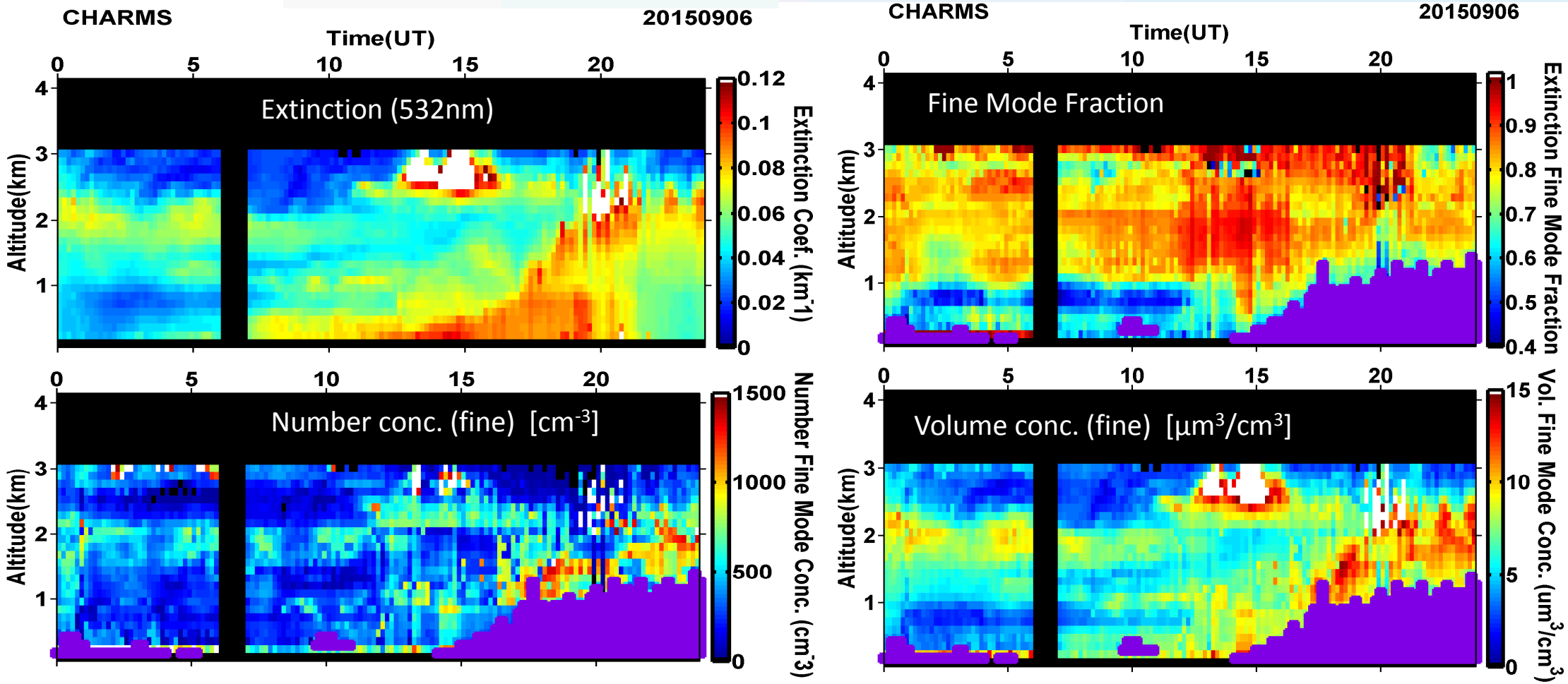






- Depolarization > 10% → nonspherical particles → retrievals unreliable
- Retrievals expected to give good performance for size and concentration
- Some increase in fine mode effective radius with high relative humidity near cloud

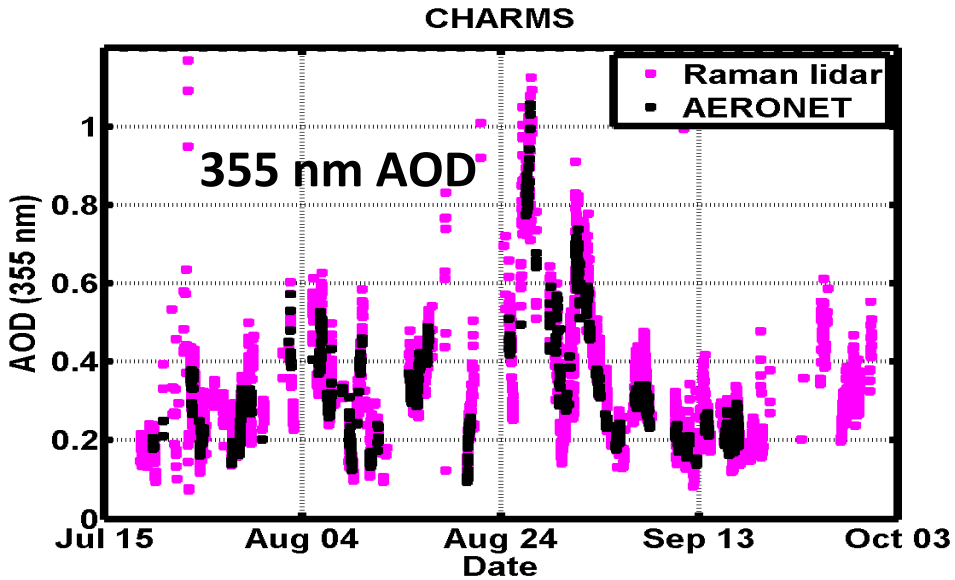
AA-Tikhonov Advanced Regularization Algorithm - Retrieval Results (ex. Sept. 6) - Concentration and Fine Mode Fraction

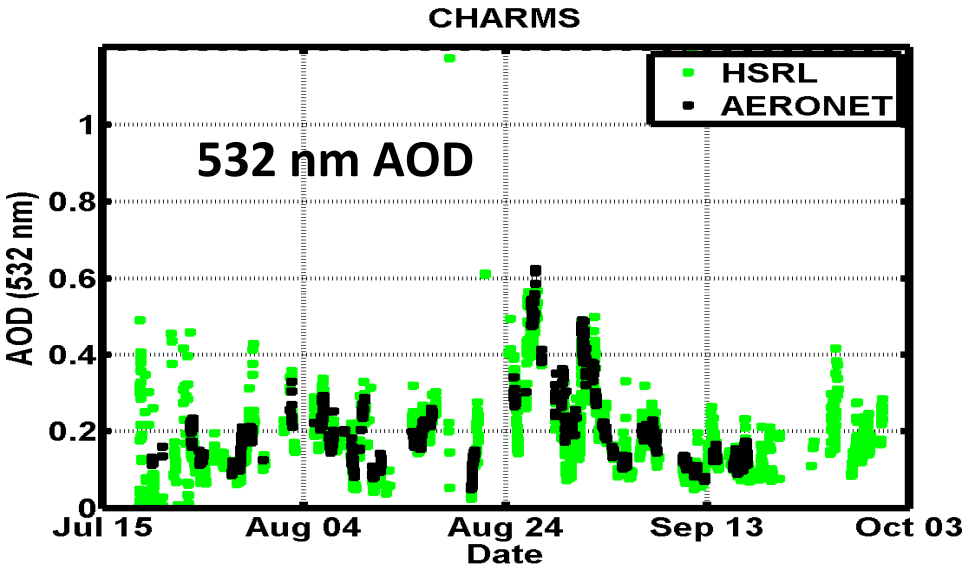


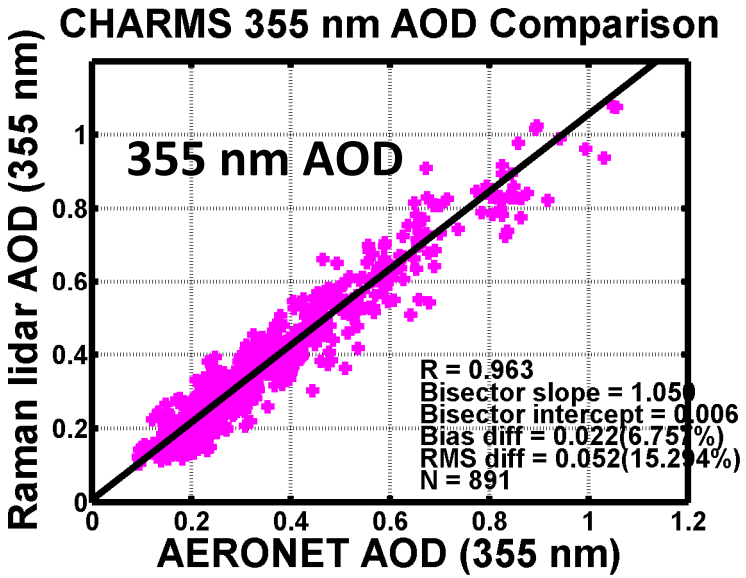
- Fine mode fractions increase aloft; coarse mode particles typically closer to surface
- High concentrations of particles near top of mixed layer and near clouds

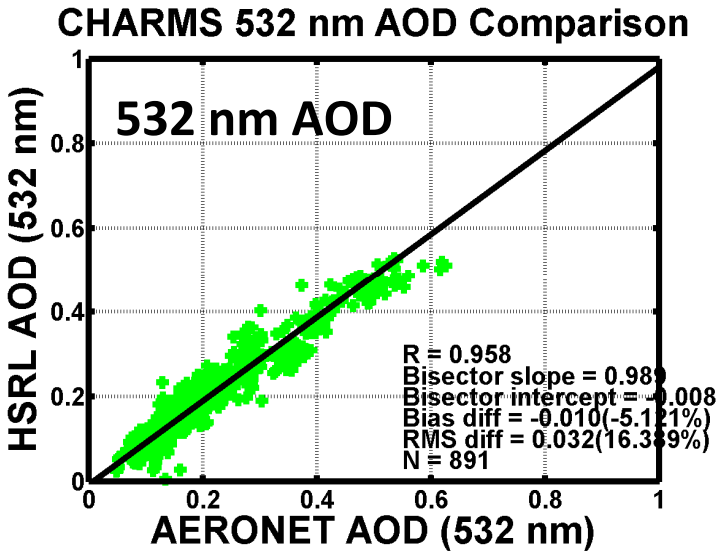
Comparisons with AERONET

Good agreement between CHARMS and AERONET Aerosol Optical Depth (AOD)







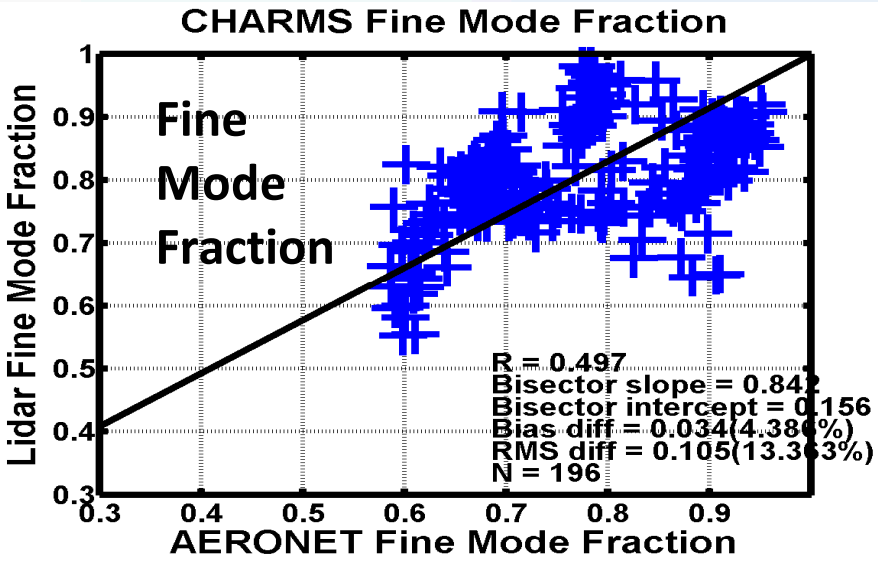


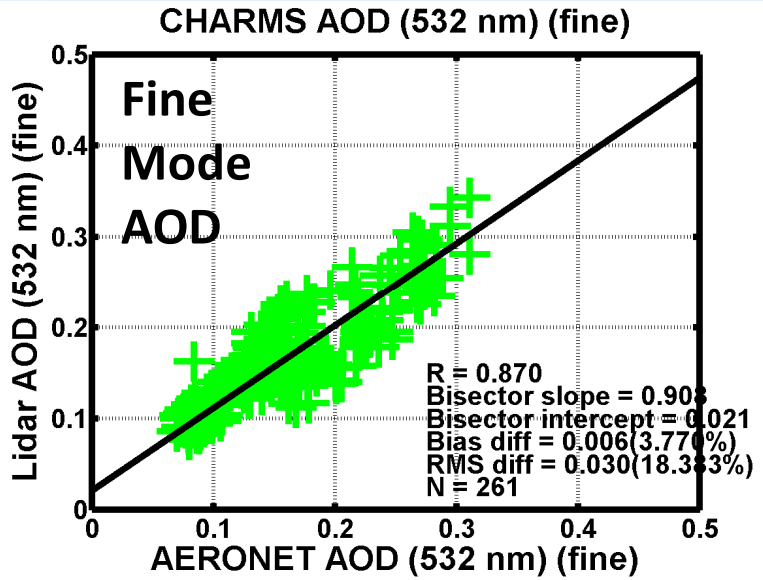
- Aerosol Optical Depth computed using extinction profiles at 355 and 532 nm
- Comparisons limited to:
  - AERONET level 2
  - No clouds

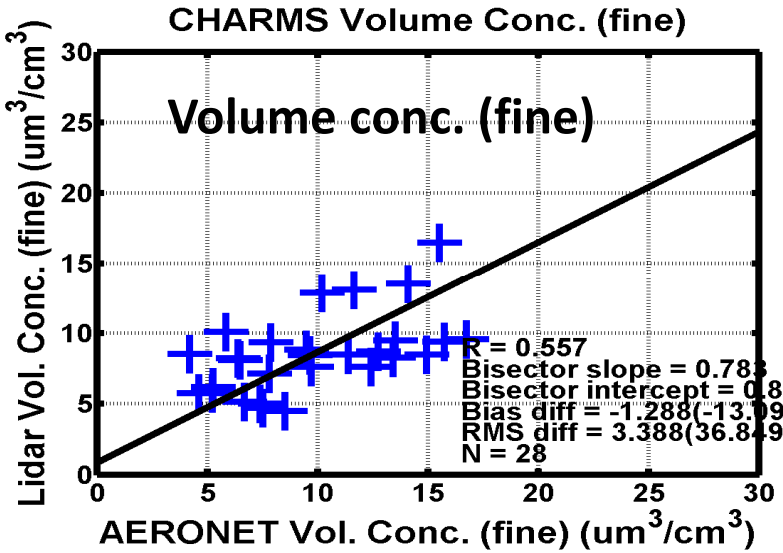
Thanks to Rick Wagener for maintaining SGP AERONET site.

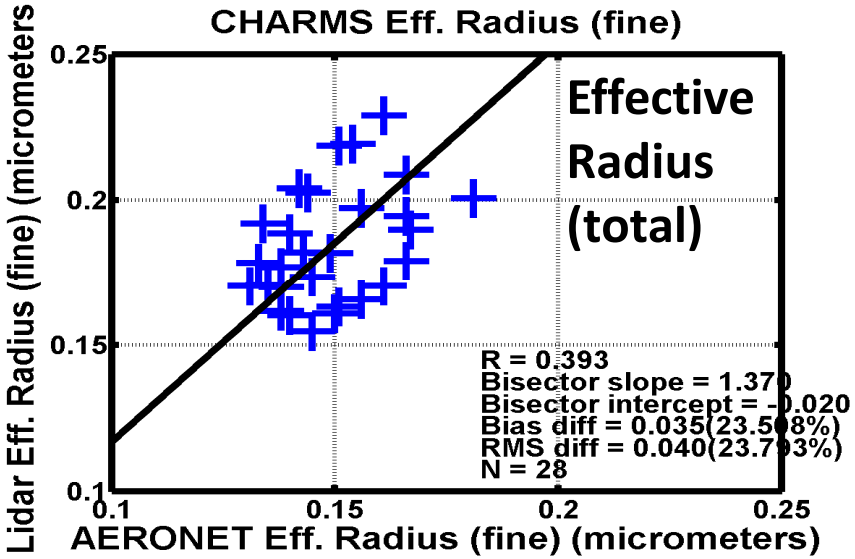
Comparisons of Column Averages with AERONET - Effective Radius and Volume Concentration

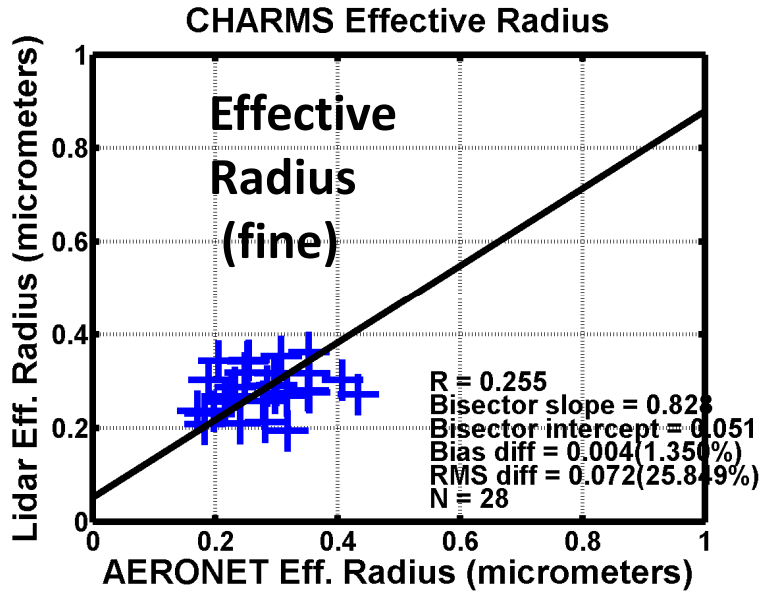
- Comparisons limited to:
  - AERONET level 2
  - Depolarization < 10%
  - No clouds











Summary and Future Work

Summary

- CHARMS campaign successfully acquired joint Raman and HSRL dataset (July – September, 2015)
- Aerosol classified using lidar data: smoke/urban and dust mix are dominant types
- Multiwavelength aerosol retrievals performed; column-averaged comparisons of
  - Fine mode effective radius
  - Fine mode fraction
  - Volume concentration

  with AERONET show generally good agreement

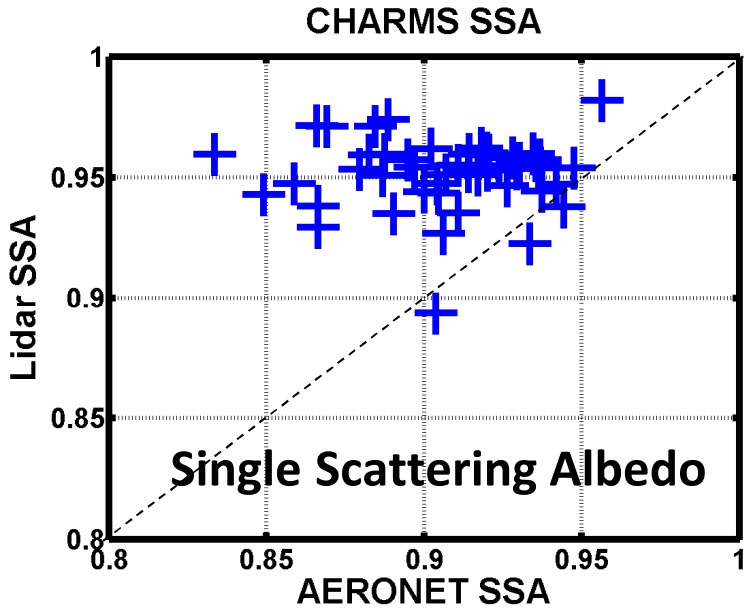
Future Work

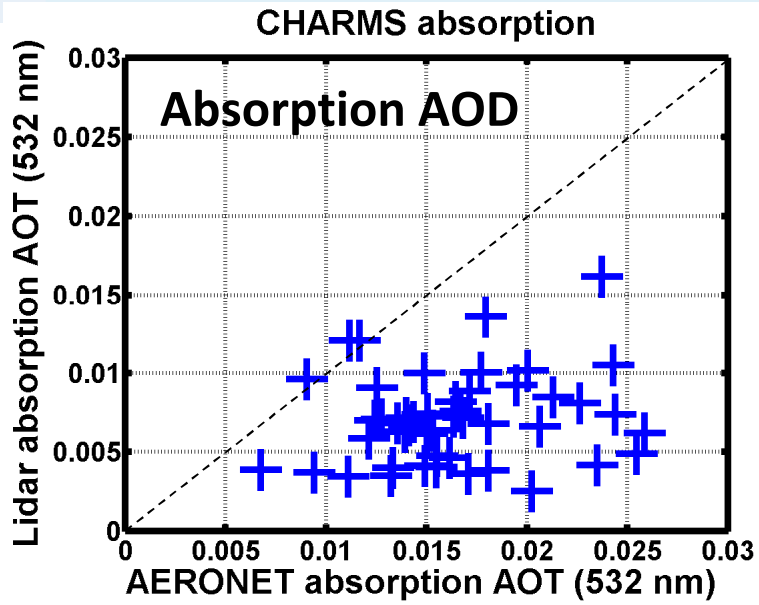
- Apply Optimal Estimation retrieval to CHARMS dataset
- Characterize aerosol behavior near and below clouds
- Relate retrieved aerosol properties to cloud condensation nuclei (CCN)
- Evaluate model simulations of aerosol type

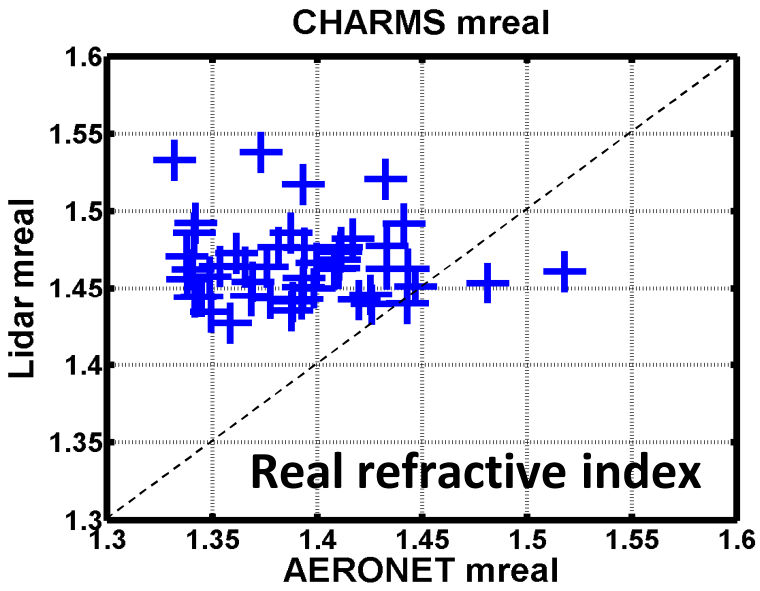
CHARMS demonstrates the potential for continuous dataset of vertical profiles of aerosol optical and microphysical properties

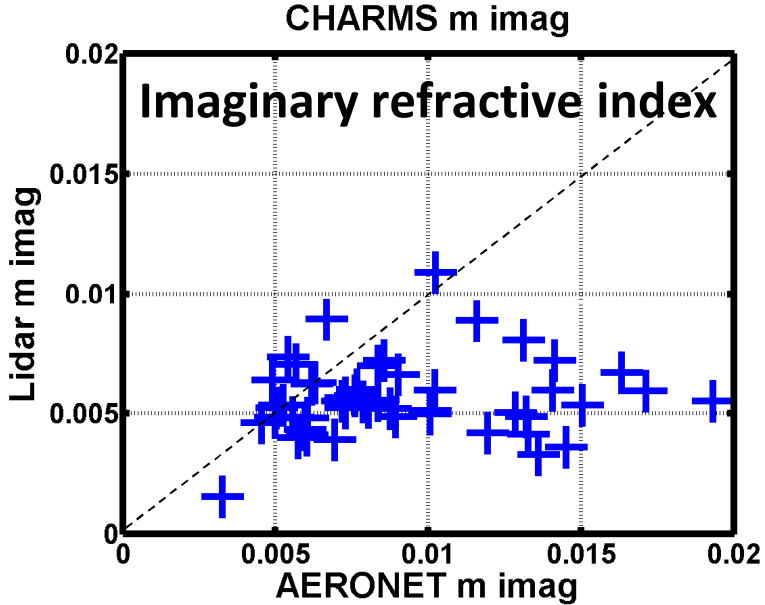
Comparisons of Column Averages with AERONET - Absorption and Refractive Index

- Comparisons limited to:
  - AERONET level 1.5 (AOD<0.4 so no level 2)
  - Depolarization < 10%
  - No clouds









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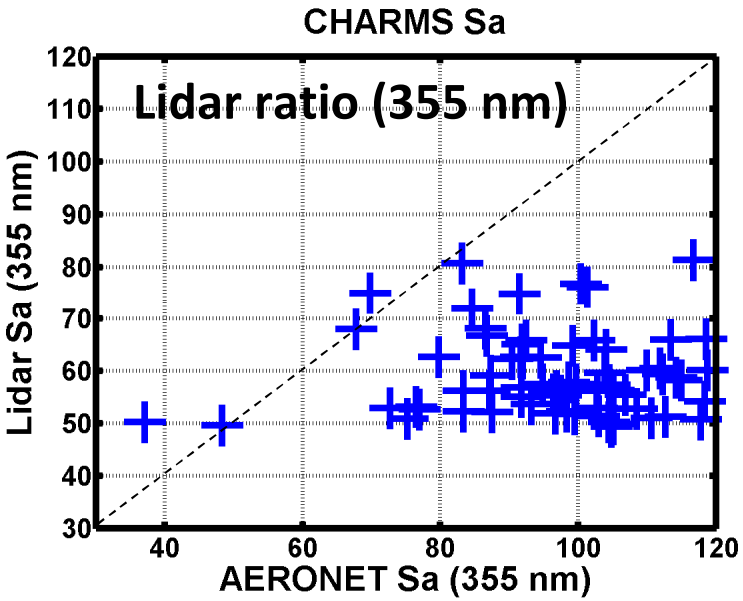

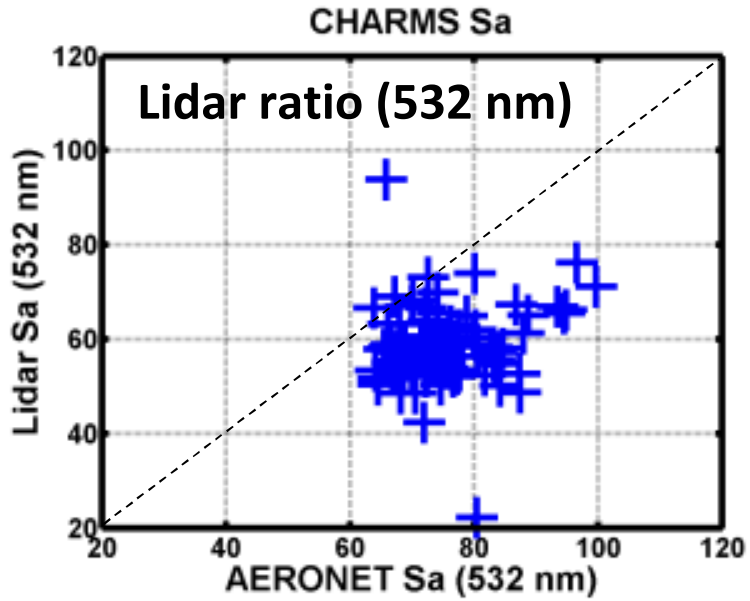

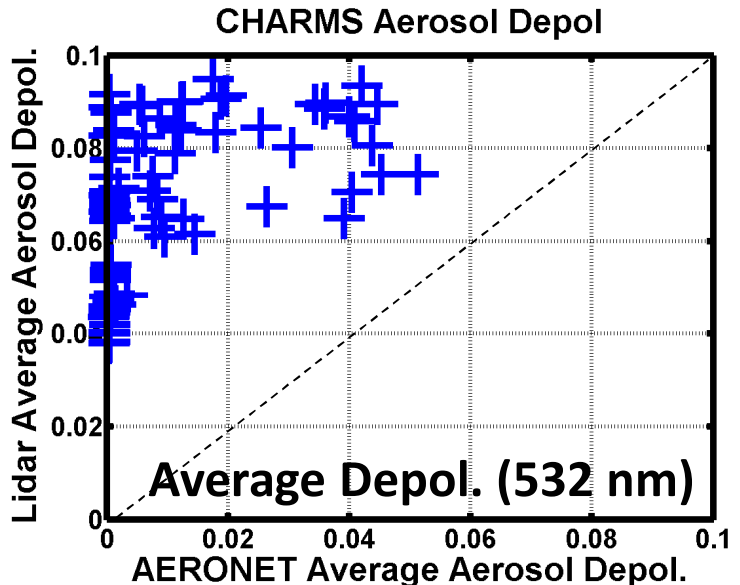

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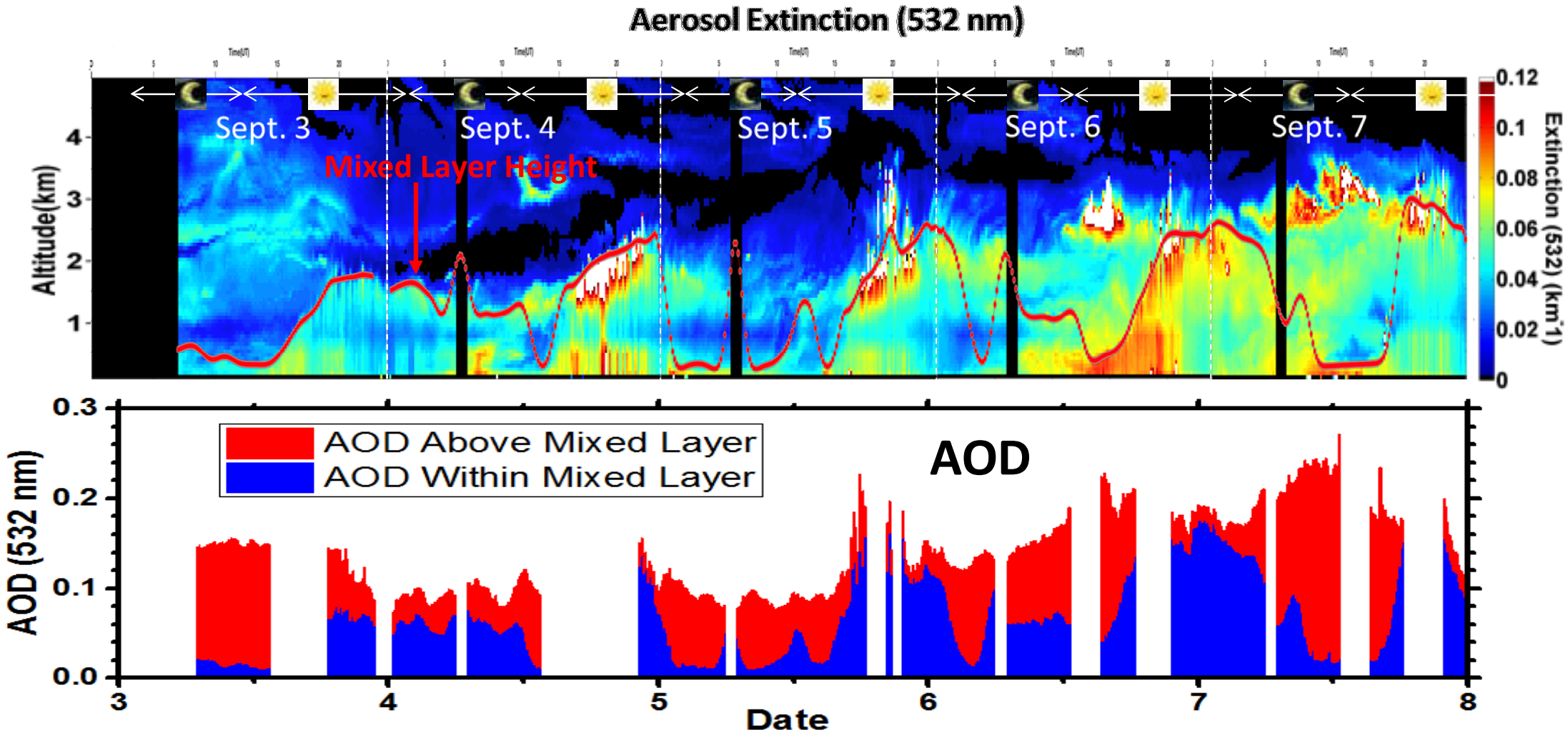

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