Characterizing the vertical distribution of aerosols using multiwavelength lidar data: Preliminary results from the Combined HSRL And Raman lidar Measurement Study (CHARMS) at SGP

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Motivation and Objective

- Aerosol optical and microphysical properties are required to:
  - Impacts on radiation
  - Aerosol-cloud interactions
  - Develop and evaluate model parameterizations

- Currently, ARM measures and/or derives aerosol properties at the surface and column average properties but does not operationally measure vertical properties

- Multiwavelength lidar retrievals
  - Potential for operational aerosol microphysical and optical properties
  - Algorithms developed by NASA LaRC for future NASA ACE satellite mission may be suitable for DOE ARM use
    - Have been applied to numerous NASA LaRC airborne HSRL 3+2 datasets

- **CHARMS Objective:** Investigate use of combined ground-based Raman and High Spectral Resolution Lidar (HSRL) measurements to improve ARM observational capability of aerosols and clouds
  - July 18 to September 30 2015 at SGP
Tikhonov Advanced Regularization Algorithm (TiARA)
Multiwavelength Lidar Aerosol Retrievals

- **Input**: aerosol backscatter (3\(\lambda\)) and extinction (2\(\lambda\)): “3\(\beta\)+2\(\alpha\)” profiles
- **Data inversion with regularization** (Müller et al., 1998, 1999, 2001; Veselovskii et al., 2002)
  - Assumes spherical particles; nonspherical particles retrievals are under investigation

- **Lidar Measurements**
  - **Backscatter** \(\beta(\lambda) = \int_0^\infty K_\beta(r, m, \lambda, s) v(r) \, dr\)
  - **Extinction** \(\alpha(\lambda) = \int_0^\infty K_\alpha(r, m, \lambda, s) v(r) \, dr\)

- **Outputs**: effective radius (total, fine, coarse), concentration (number, surface, volume), scattering, absorption coefficients
Multiwavelength Lidar Aerosol Retrieval Outlook

- **Tikhonov regularization**: absorption biased high relative to in situ measurements
- Burton et al. (AGU – 2015) study on information content in lidar measurements alone
  - Good retrievals of size and concentration parameters
  - Have only limited ability to produce accurate absorption

  ![Graph](Liu_et_al_2015_AGU.png)

- Higher accuracy in absorption measurements requires additional constraints
  - **Arrange and Average** (Chemyakin et al., 2015) adds additional constraint/assumption on size distribution (monomodal)
  - **Optimal Estimation** retrieval methodology also being pursued at NASA LaRC
    - Leverage retrieval of aerosol type
    - Add other measurements (ex. polarimeter, Sun photometer) as constraints
CHARMS Merged HSRL and Raman Lidar Datasets

**Measurements \((3\beta+2\alpha)\)**

**SGP Raman lidar:**
- Aerosol backscatter (355nm)
- Extinction (355nm)
- *Depolarization (355nm)*

**Univ. Wisconsin HSRL**
- Aerosol backscatter (532, 1064nm)
- Extinction (532 nm)
- *Depolarization (532 nm)*

*Aerosol type classification (Burton et al., 2012, 2013, AMT)*

- Process extinction/backscatter from both instruments consistently using the FEX algorithm (Thorsen et al.; Thorsen and Fu 2015)
- 10min, 60m vertical resolution (120m for the microphysical retrievals)
- Images of results:
  - [http://www.tylerthorsen.com/bagohsrlfex_charms/](http://www.tylerthorsen.com/bagohsrlfex_charms/)
CHARMS Processing

- All images and results that follow are preliminary!
- Some artifacts in Raman (mostly) and HSRL data due to temperature and alignment fluctuations
- SGP Raman lidar performance improved after CHARMS and now comparable to ENA Raman lidar

![Backscatter (355) (Raman)](image1)

![Extinction (355) (Raman)](image2)

![Backscatter (532) (HSRL)](image3)

![Extinction (532) (HSRL)](image4)
Good agreement between CHARMS and AERONET Aerosol Optical Depth (AOD)

Aerosol Optical Depth computed using extinction profiles at 355 and 532

**355nm (6.11%)**
- \( R = 0.96 \)
- Bisector Slope = 1.07
- Bisector Intercept = -0.004
- Bias diff = 0.02 (6.11%)
- RMS diff = 0.053 (16%)
- \( N = 1289 \)

**532nm (-5.9%)**
- \( R = 0.94 \)
- Bisector Slope = 1.02
- Bisector Intercept = -0.015
- Bias diff = -0.012 (-5.9%)
- RMS diff = 0.036 (19%)
- \( N = 1256 \)
Difficulty in producing accurate 1064 nm aerosol backscatter profiles has delayed retrievals

Microphysical retrievals performed for Sept 3-7

- Aerosol backscatter color ratio (532/1064) was much higher (>3) than expected
  - 1064 nm aerosol backscatter was too low
  - Difficulty in calibration the UW HSRL 1064nm aerosol backscatter (see Eloranta poster)
CHARMS data used for aerosol retrievals currently limited to test period (Sept. 3-7)

- Note variability in both aerosol loading (extinction) and type (aerosol depolarization)
- High depolarization in the afternoon (>10%: too high for reliable microphysical retrievals)

Aerosol Extinction (532 nm)

Aerosol Depolarization (532 nm)
Tikhonov Advanced Regularization Algorithm (TiARA) - Retrieval Results (ex. Sept. 6)

- Depolarization > 10% → retrievals unreliable
- TiARA expected to give good performance for size and concentration retrievals
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Arrange and Average Algorithm (A&A) - Retrieval Results (ex. Sept. 6)

- **Extinction (532nm)** [1/km]
- **Scattering (532nm)** [1/km]
- **Absorption (532nm)** [1/km]
- **Single Scattering Albedo (532nm)**

- **Depolarization > 10%** → retrievals unreliable
- **A&A expected to give better performance for absorption retrievals**
Comparisons of Column Averages with AERONET - Effective Radius and Volume Concentration

- TiARA expected to give better performance for size and concentration retrievals

Thanks to Rick Wagener for maintaining AERONET site. Thanks to Brent Holben and AERONET team for retrievals
- A&A performs better for absorption retrievals (as expected)
- Can only compare to Level 1.5 AERONET retrievals (No Level 2 since AOD<0.4)
CHARMS campaign successfully captured joint Raman and HSRL dataset (July 18-September 30, 2015)

- Aerosol backscatter, extinction profiles (355, 532 nm) produced for entire period – acceptable quality for aerosol retrievals
- Producing accurate aerosol backscatter profiles (1064 nm) is the current rate-limiting analysis step – currently preliminary profiles exist for only Sept. 3-7
- Initial multiwavelength aerosol retrievals performed for Sept. 3-7; column average results appear mostly consistent with AERONET
- Additional retrieval development and evaluations planned

CHARMS demonstrates the potential for (the only) continuous dataset of (unique) vertical profiles of aerosol optical and microphysical properties