Understanding the absorption Angstrom exponent provided in the AERONET database

Gregory L. Schuster
NASA Langley Research Center

Oleg Dubovik
Universite de Lille

Antti Arola
Finnish Meteorological Institute
Motivation: The AAE approach for speciating absorbers

Observationally constrained estimates of carbonaceous aerosol radiative forcing

Chul E. Chung⁠¹, V. Ramanathan⁠², and Damien Decremer⁠³

¹School of Environmental Science and Engineering, Gwangju Institute of Science and Technology, Gwangju 500-712, Korea; and ²Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093

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Separate absorption AOD into carbon and dust components:

$$AAOD = \xi(\lambda) = \xi_d(1)\lambda^{-AAE_d} + \xi_{BC}(1)\lambda^{-AAE_{BC}} + \xi_{BrC}(1)\lambda^{-AAE_{BrC}}$$

where:

- $AAE_{dust} = 2.4$ Dust
- $AAE_{carbon} \approx 1$ Carbonaceous (0.84 to 1.16, depending upon region)
- $AAE_{BC} = 0.5$ Black Carbon
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**Problems with the AAE approach:**

1. Assumes that all absorbers are externally mixed.
2. Uses AAE for BC is much lower than our traditional value of \(AAE_{BC} = 1\).
3. It does not account for the variability in the AAE of dust (0 to 3.5).
Main Points

1. All aerosols are *always* internally mixed in the AERONET retrieval.

2. AAE = 0.5 cannot represent BC in the AERONET database, unless $\frac{dk}{d\lambda} > 0$ for BC.

3. The AAE of dust can be anything (~0 to 3.5).
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If the atmosphere looks like this...
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AERONET uses an internal mixture like this to **compute** AAOD and AAE.
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AERONET uses an internal mixture like this to **compute** AAOD and AAE

**Repurcussions:**

- **All BC is internally mixed. Always!**
- **BC absorption contained in a small percentage of particles is redistributed to all particles in both fine and coarse modes.**
- **We can’t use complicated morphologies to explain AERONET AAE (i.e, fractals, or even core-shell).**
- **Single scatter albedo \( \leq 1 \). Always!**
AERONET Retrieval Schematic

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Absorption Angstrom Exponent (AAE) and AAOD

Size Distribution

Refractive index

Aerosol Optical Depth, Single Scatter Albedo, Phase Fcn

Radiative transfer model

Modeled aerosol optical depth and radiances match measurements?

Iterate refractive index and/or size distribution

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AAE calculations for bimodal lognormals with spectrally invariant $k$ (i.e., $dk/d\lambda = 0$)

\[
\frac{dV}{d\ln r} \propto \sum_{i=1,2} \exp \left[ - \frac{(\ln r - \ln R_i)^2}{2\sigma_i^2} \right]
\]

\[
R_{fin} = 0.12 \, \mu m, \quad R_{crs} = 3.2 \, \mu m, \quad \sigma_{fin} = 0.38, \quad \sigma_{crs} = 0.75
\]

\[
n = 1.49
\]

See also
Bond, GRL (2001),
Gyawali ACP (2009),
Lack and Langridge, ACP (2013)
AERONET AAE, filtered for $\delta k \leq 10\%$

West Africa:
Agoufou, Banizoumbou, IER_Cinzana, Capo_Verde, Dakar, Ilorin, Quarzazete, Santa Cruz Tenerife, Tamanrasset

Middle East:
Solar Village, Nes Ziona, Sede Boker, Dhabi, Hamin

South Africa:
Mongu, Skukuza

S. America:
Alta Floresta, Cuiaba, Cuiaba-Miranda, Abracos Hill, Balbina, Belterra, Santa Cruz

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AERONET AAE (L2), filtered for $\delta k \leq 10\%$

$R = 0.86$

$N = 1148$
**West Africa:**
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**AERONET AAE (L2), filtered for \( \delta k \leq 10\% \)**

\[ \delta k \leq 10\% \]

\[ R = 0.86 \]

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AAE < 1 requires spectrally variable k for small particles
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Absorption attributable to “pure” BC mixed with scatterers expected only in this region.

Medians
sam:
AAE: 1.38
krat: 1.21
waf
AAE: 2.13
krat: 2.66
AAE < 1 requires spectrally variable $k$ for small particles

94% of retrievals with AAE < 1 also indicate that $k_{440} < k_{\text{rnir}}$. 

**Medians**
- **sam**: AAE: 1.38, krat: 1.21
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AAE < 1 requires spectrally variable k for small particles

**Fine Volume Fraction**

- **SAM**
  - Aug – Sep
  - > 90% spheres
  - $R_{\text{sam}} = 0.94$

- **WAF**
  - $fvf < 0.05$
  - depolarization > 0.2
  - $R_{\text{waf}} = 0.95$

**Medians**

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  - AAE: 1.38
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**Broken Area Equivalent (AAE)**

$k_{440} / k_{\text{rnir}}$

(spectral variability)
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What about spectrally variable imag indices (i.e., $dk/d\lambda \neq 0$)

BC: $AAE = 1$ for small particles.

Hematite: $AAE > 1$. 
What about spectrally variable imag indices (i.e., $dk/d\lambda \neq 0$)

BC: AAE = 1 for small particles.

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Goethite: AAE < 1.
What about spectrally variable imag indices (i.e., $dk/d\lambda \neq 0$)

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The goethite fraction of iron oxide in dust varies from 0.4 to 0.7 (Lafon, JGR 2006; Shi, Aeolian Res, 2012).
AAE for dust can be anything!

Dust and carbonaceous aerosols can not be separated with confidence using AAE

were the biomass sites filtered for 90% spheres in these slides? YES!

mea: Middle East
sam: South America
waf: West Africa
saf: Southern Africa

Lev20
AAE for dust can be anything!

Dust and carbonaceous aerosols can not be separated with confidence using AAE

Absorption Angstrom Exponent, 870–440

11% of West Africa dust have AAE < 1

13% of S. America smoke have AAE < 1

mea: Middle East
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Conclusion: AAE < 1 not an indicator of carbonaceous aerosol
**AAE for dust can be anything!**

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**Strong separation exists in imaginary refractive index space.**

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Conclusions

• AERONET AAE and AAOD are computed from size and refractive index!
• External mixture assumption of AAE approach is inconsistent with AERONET retrievals.
• The value of $AAE_{BC} = 0.5$ is inconsistent with the Bond (2013) definition of BC.
• $AAE < 1$ can be caused by coarse mode particles or $dk/d\lambda > 0$, but not carbon particles.
• Coming soon to ACPD!
• gregory.l.schuster@nasa.gov

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- **Size Distribution**
- **Refractive index**
- **Aerosol Optical Depth, Single Scatter Albedo, Phase Fcn**
- **Radiative transfer model**
- **Modeled aerosol optical depth and radiances match measurements?**
- **Iterate refractive index and/or size distribution**
- **Modeled aerosol composition matches refractive index?**
- **Iterate aerosol composition**

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The AAE approach for speciating absorbers

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\[ \xi = \xi_c + \xi_d \]
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Apply Angstrom Eq to each component:

\[ \xi(1)\lambda^{-AAE} = \xi_c(1)\lambda^{-AAE_c} + \xi_d(1)\lambda^{-AAE_d} \]
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Carbonaceous component is further separated into BC and BrC:

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Much lower than traditional value of \( AAE = 1 \).
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\[ \xi = \xi_c + \xi_d \]

Apply Angstrom Eq to each component:
\[ \xi(1)\lambda^{-AAE} = \xi_c(1)\lambda^{-AAE_c} + \xi_d \]

where:
- \( AAE_d = 2.4 \) (dust) *Always!*
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Carbonaceous component is further separated into BC and BrC:
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But, the AAE of dust can be anything (< 0 to 3.5)

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Clearly, AAE < 1 does not represent carbonaceous aerosol in Africa.

Symbols indicate that:
- 86% of the fvf are less than 0.2,
- 56% of the dp are greater than 0.2,
- and 94% of the AE are less than 1.0.

11% of retrievals