A BRIEF APPRECIATION OF THE LIDAR RATIO

Jason Tackett with contributions by Rich Ferrare and Greg Schuster

NASA Langley Research Center

Third-party content from China et al. (2013), Groß et al. (2013), Haarig et al. (2017), Omar et al. (2009), Reid et al. (2003), NASA Earth Observatory, and NASA Ames Sunphotometer Satellite Group.
Full references on last slide.

Lidar ratio

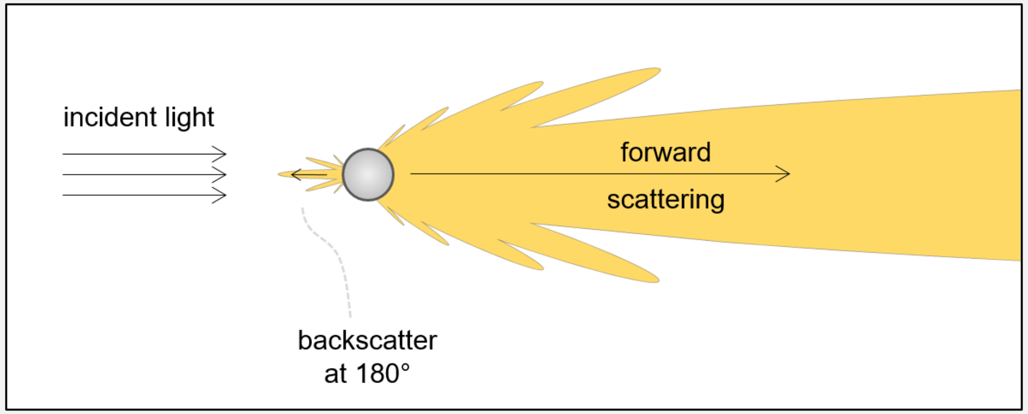
Dry academic definition:

"…the ratio of the extinction-to-backscatter coefficient, for atmospheric scatterers…. It represents the ratio of the volume-extinction cross section… and the 180° volume-backscatter cross section."

- AMS Glossary

https://glossary.ametsoc.org/wiki/Lidar_ratio

$$S_{aer} = \frac{\sigma_{aer}}{\beta_{aer}}$$



Fernald, F., Herman, B., and Reagan, J., "Determination of aerosol height distributions by lidar." Journal of Applied Meteorology and Climatology 11.3 (1972): 482-489.

Representative lidar ratios

Water clouds

19 sr

Sea salt

23 sr

Dust

40-60 sr

Smoke

70 sr

$\lambda = 532$ nm

Representative lidar ratios

Water clouds

9-29 sr

Sea salt

18-28 sr

Dust

40-60 sr

Smoke

55-85 sr

$\lambda = 532$ nm

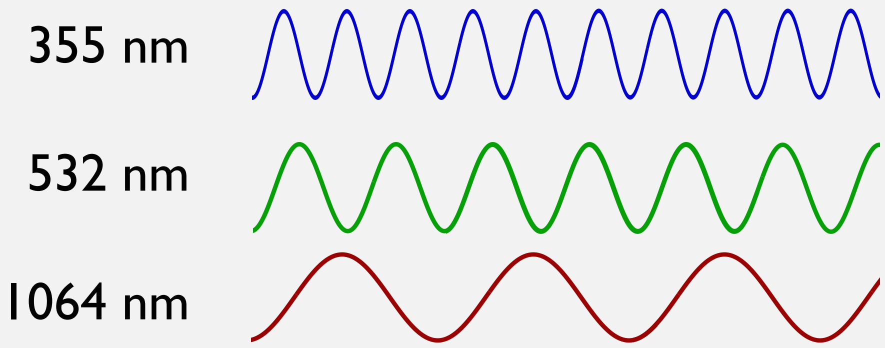
Why do lidar ratios vary?

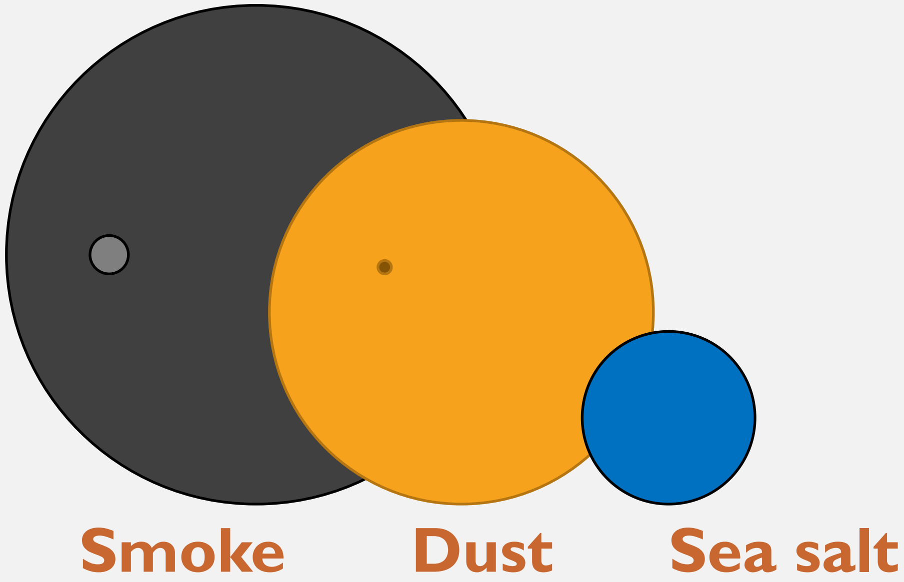
Particle size

Composition

Shape

Light scattering depends on the size of the particle relative to the wavelength of light





Typical sizes relative to wavelength

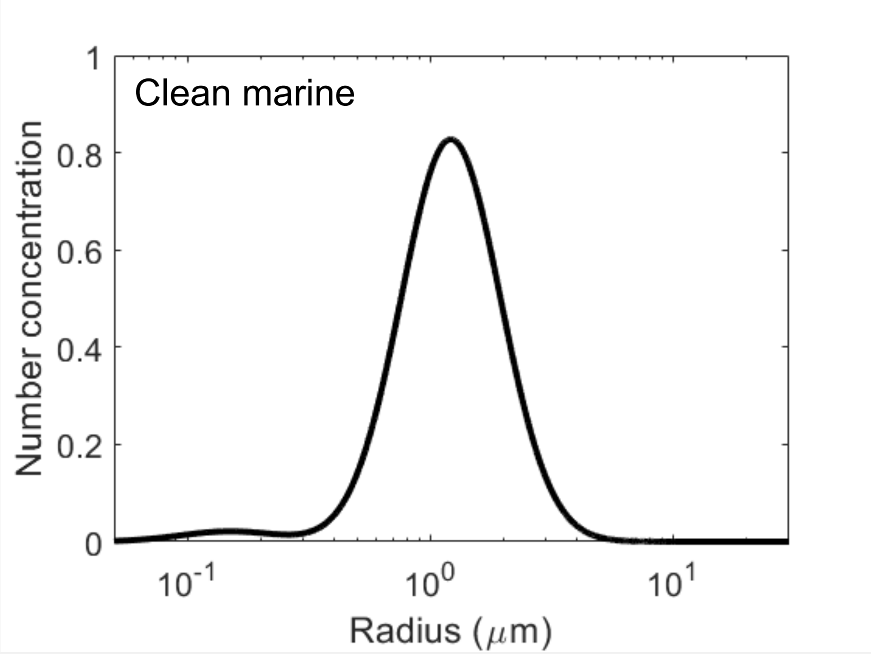
Why do lidar ratios vary?

Particle size *distribution*

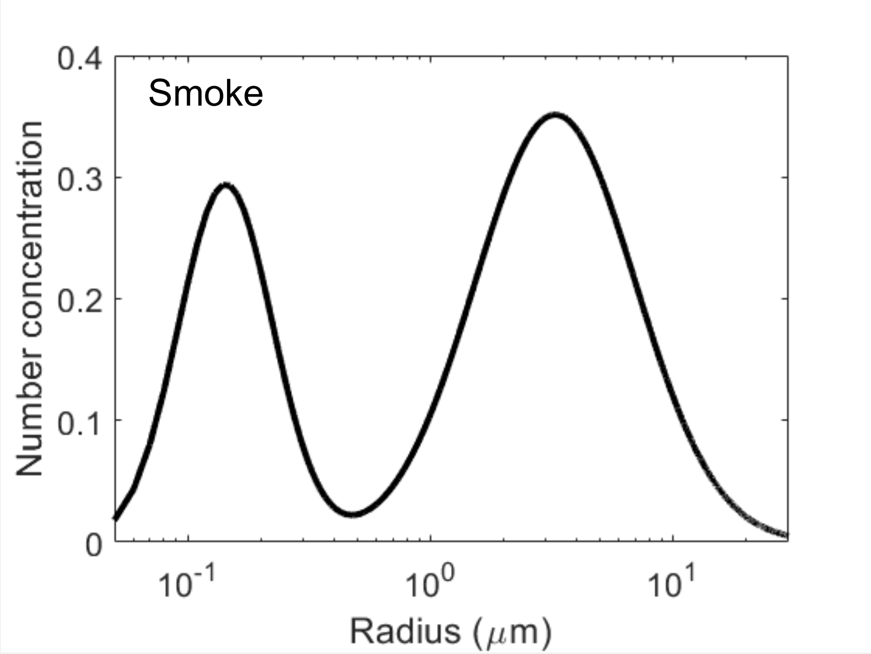
Composition

Shape

Coarse mode dominant



Prominent fine mode



Adapted from size distributions in Table 1 of Omar et al, 2009: **The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm**, J. Atmos. Oceanic Technol., 26, 1994-2014, https://doi.org/10.1175/2009JTECHA1231.1.

Why do lidar ratios vary?

Size distribution

Composition

Shape

Dust

Hematite, calcite, quartz

Sea salt

Sodium chloride

Smoke

Black carbon, brown carbon

Clouds

H_2O

Really, it's just the index of refraction

$$m_\lambda = n + ik$$

Why do lidar ratios vary?

Size distribution

Composition

Shape

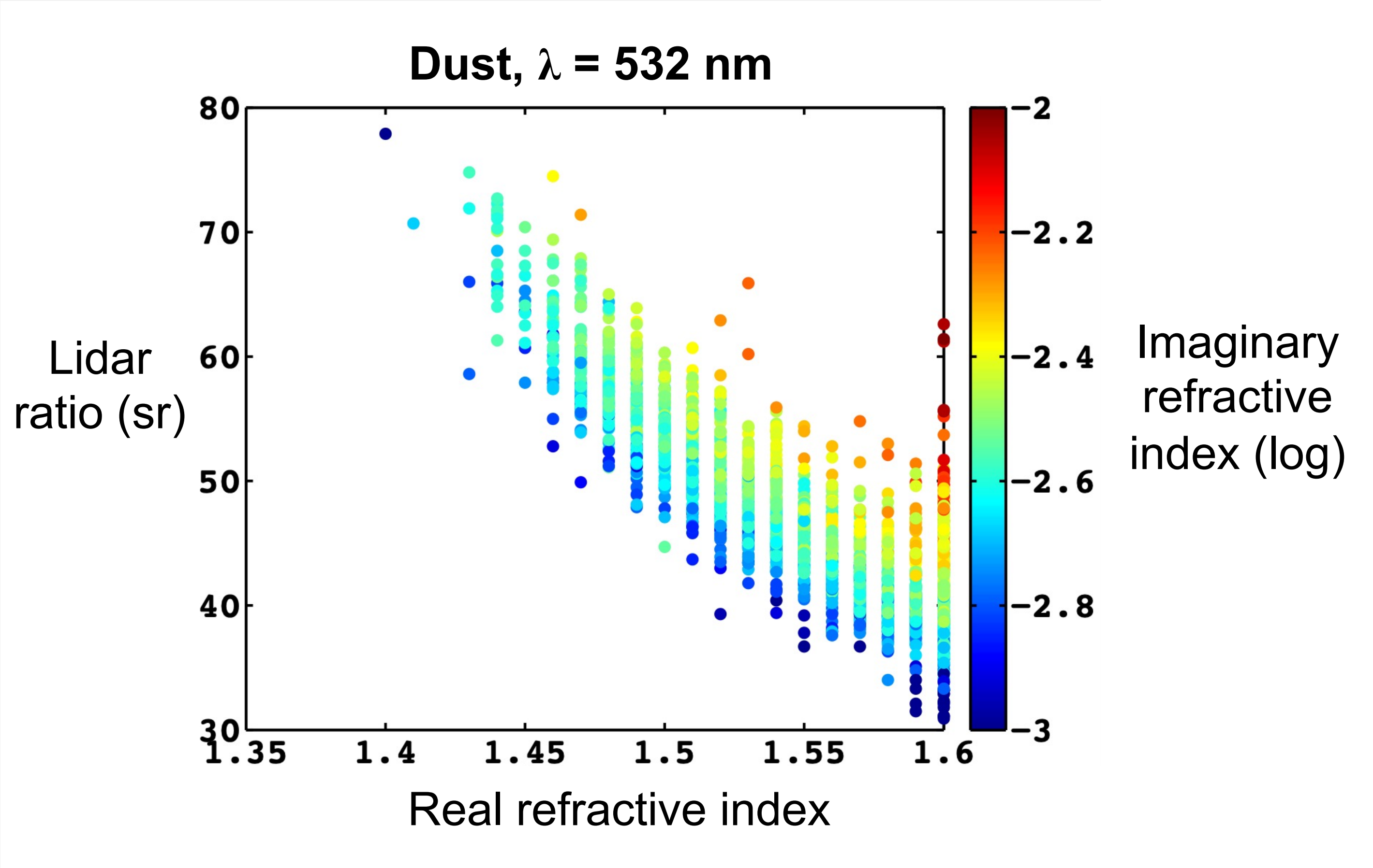


Figure courtesy of Greg Schuster

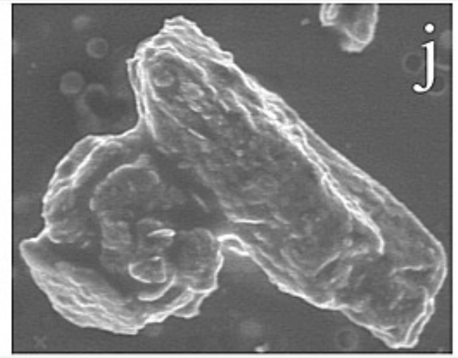
Why do lidar ratios vary?

Size distribution

Composition

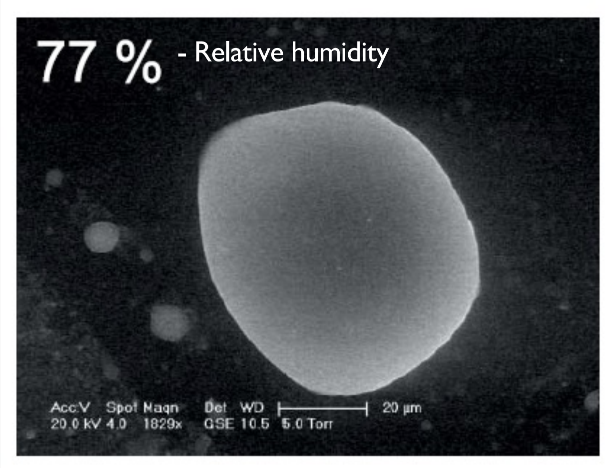
Shape

Dust



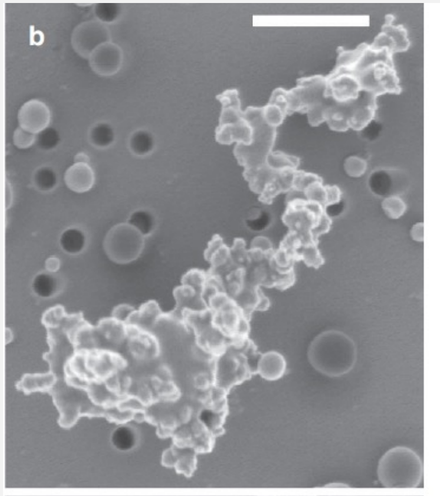
Reid et al., 2003

NaCl (Sea salt)



Haarig et al., 2017

Wildfire smoke



China et al., 2013

Haarig et al., 2017 : Dry versus wet marine particle optical properties: RH dependence of depolarization ratio, backscatter, and extinction from multiwavelength lidar measurements during SALTRACE, Atmos. Chem. Phys., 17, 14199–14217, https://doi.org/10.5194/acp-17-14199-2017.

Reid et al., 2003: Characterization of African dust transported to Puerto Rico by individual particle and size segregated bulk analysis, J. Geophys. Res., 108, 8591, doi:10.1029/2002JD002935, D19.

China et al., 2013: Morphology and mixing state of individual freshly emitted wildfire carbonaceous particles. Nat Commun 4, 2122. https://doi.org/10.1038/ncomms3122

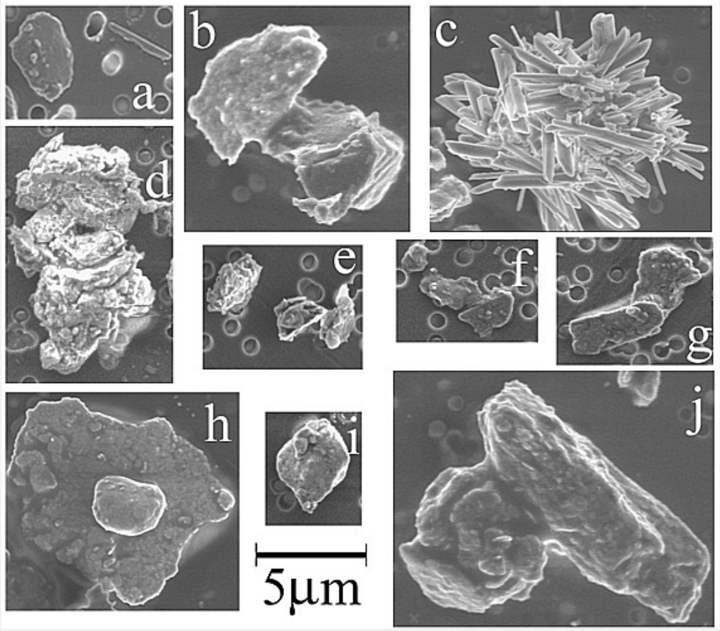
Why do lidar ratios vary?

Size distribution

Composition

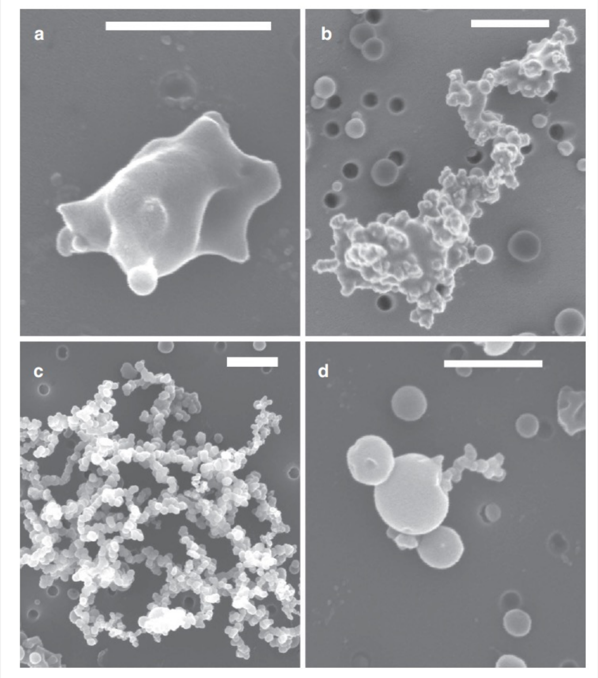
Shape(s)

Dust



Reid et al., 2003

Wildfire smoke



China et al., 2013

China et al., 2013: Morphology and mixing state of individual freshly emitted wildfire carbonaceous particles. Nat Commun 4, 2122. https://doi.org/10.1038/ncomms3122

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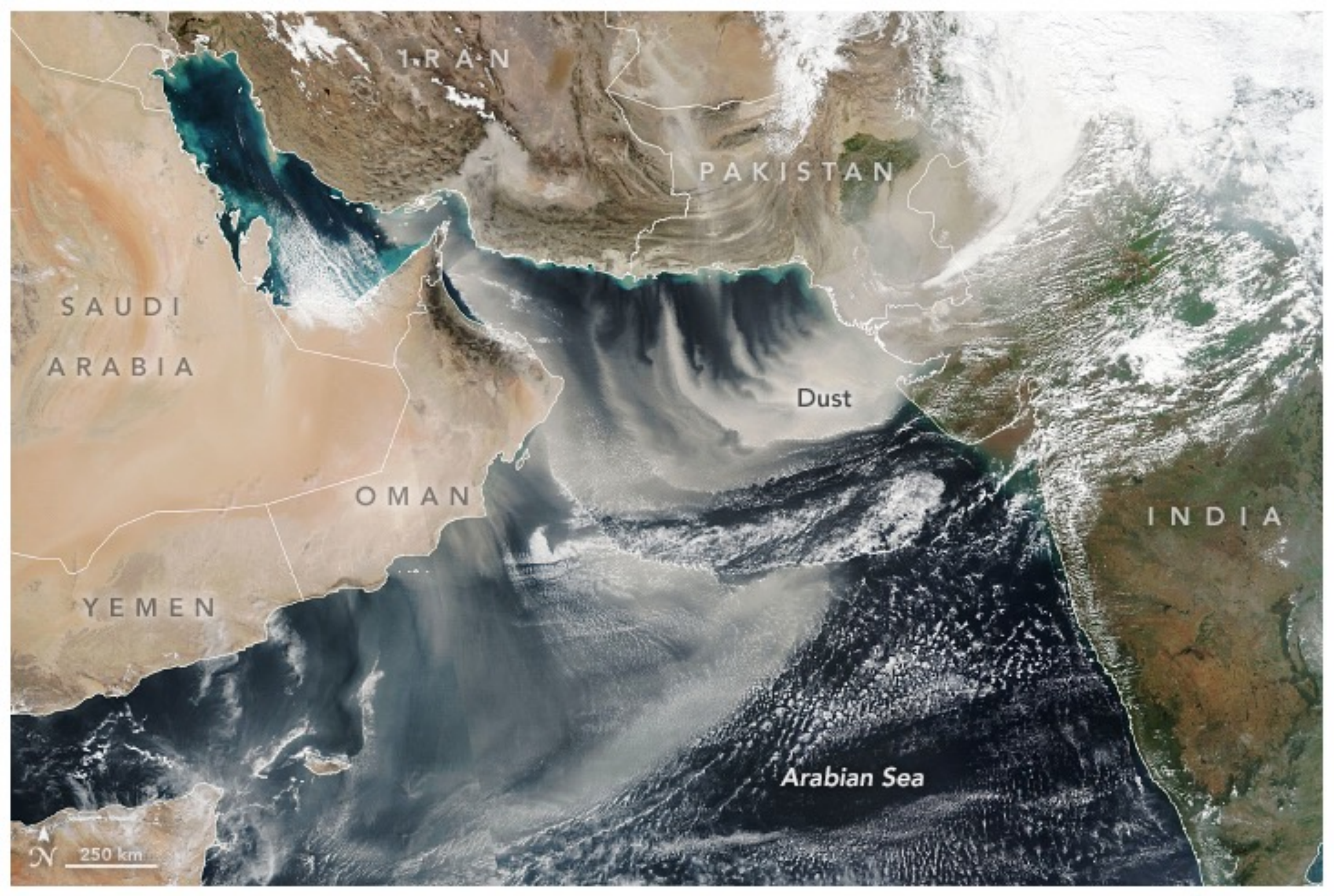
What about lidar ratios for mixtures?

It gets complicated…

Mixtures are a challenge for elastic backscatter lidars
e.g., CALIPSO, CATS

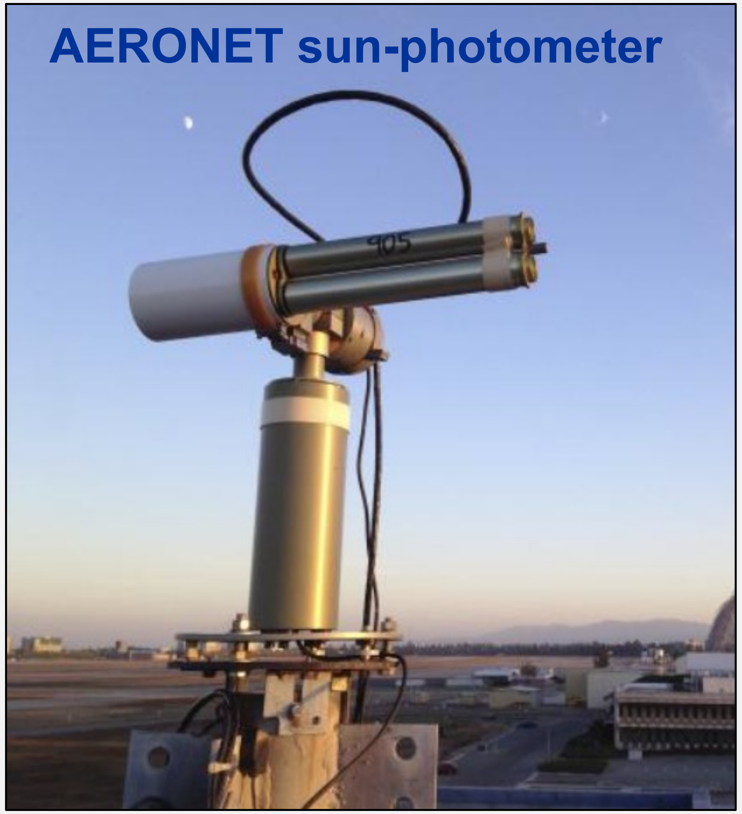


January 22, 2022

Credit: NASA Earth Observatory, Lauren Dauphin
https://earthobservatory.nasa.gov/images/149378/dust-storm-envelops-the-arabian-sea

How do we determine lidar ratios?

- Measurements as constraints with inversion models



Size distribution

Refractive index

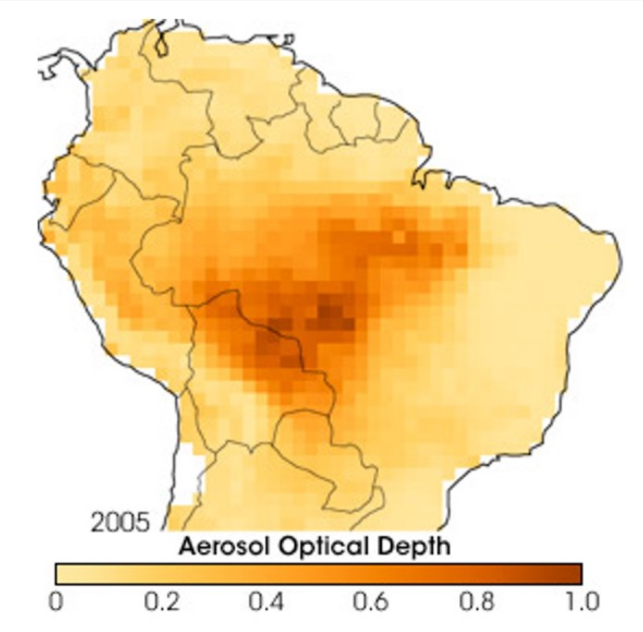
Light scattering model
e.g, Dubovik, et al. 2006
single-scattering spheroids

https://airbornescience.nasa.gov/sunsat/content/SunSat_AERONET

How do we determine lidar ratios?

- Column observations as constraint with Fernald-Klett inversion

MODIS column AOD retrieval



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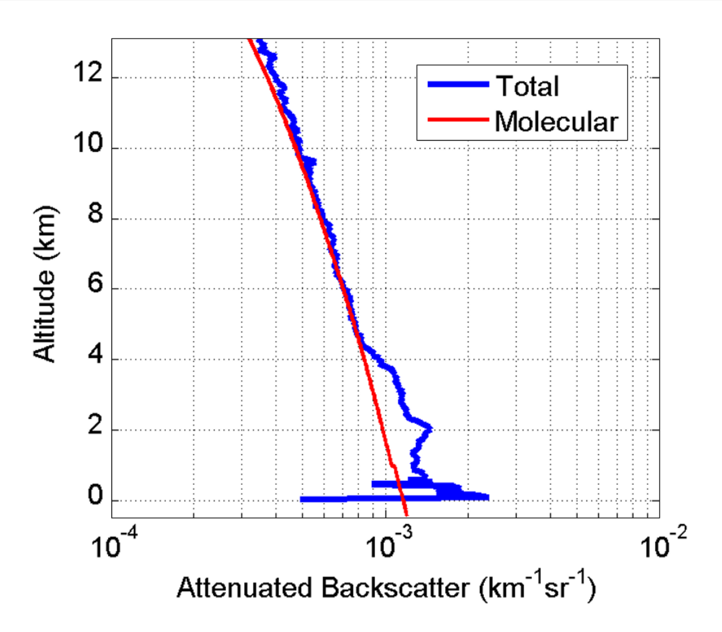
CALIPSO profile measurement



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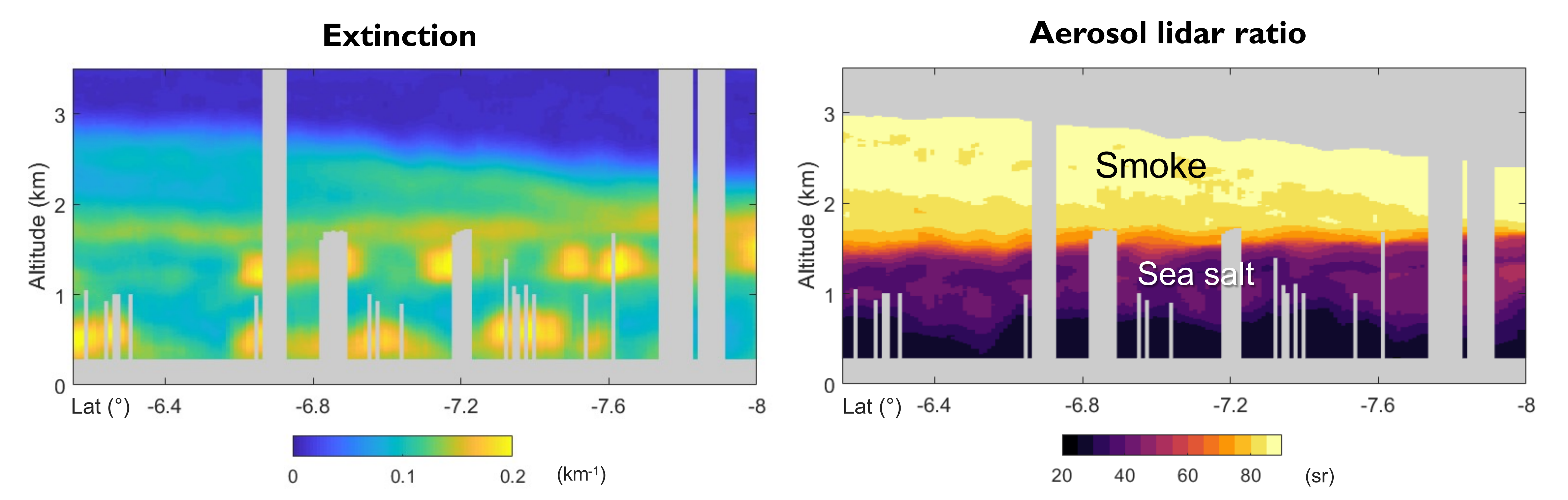
Fernald-Klett inversion to retrieve extinction

$$AOD = \int \sigma \, dz$$

Credit: Robert Simmon and Illan Koren
https://earthobservatory.nasa.gov/features/AmazonFireRise

How do we determine lidar ratios?

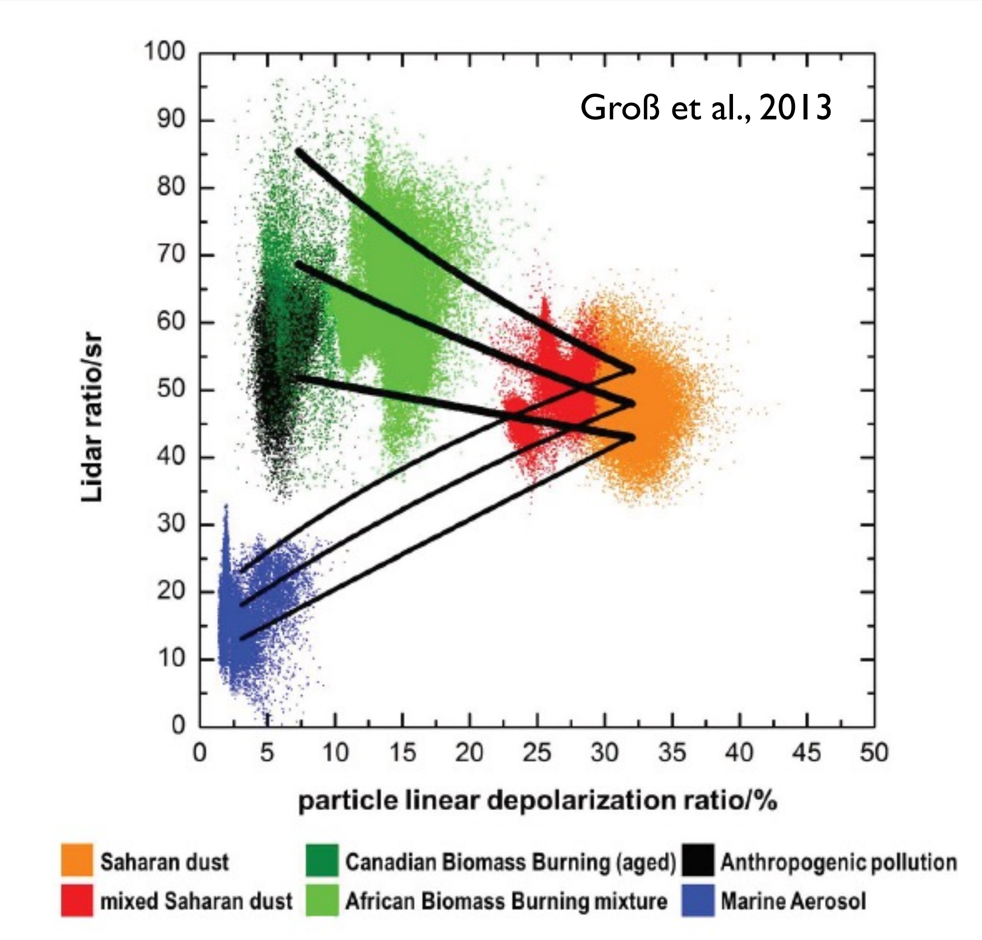
- Direct measurement with high spectral resolution lidar (HSRL) and Raman lidar systems



NASA LaRC Airborne HSRL-2 measurements from ORACLES-2, Aug. 17, 2017. Courtesy of Rich Ferrare

$$S_{aer} = \frac{\sigma_{aer}}{\beta_{aer}}$$

Lidar ratio measurements enable optical aerosol typing



- Aerosol type classification in modern HSRL systems rely on lidar ratio measurements (e.g., ATLID on EarthCARE)

Groß et al., 2013: Aerosol classification by airborne high spectral resolution lidar observations, Atmos. Chem. Phys., 13, 2487–2505, https://doi.org/10.5194/acp-13-2487-2013.

Summary

- Lidar ratio is utilitarian and insightful.
- Greater understanding of true lidar ratios yields more accurate science from lidar-based observations.

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China, S., Mazzoleni, C., Gorkowski, K. et al. **Morphology and mixing state of individual freshly emitted wildfire carbonaceous particles**. Nat Commun 4, 2122 (2013). https://doi.org/10.1038/ncomms3122

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