The Tables of Aerosol Optics (TAO) Project

Greg Schuster, Richard Moore, Snorre Stamnes — NASA Langley Research Center. Bastiaan Van Diedenhoven — SRON Netherlands Inst. for Space Research.
Elisabeth Andrews — NOAA, U. Colorado CIRES. Joshua Schwarz — NOAA. Masanori Saito, Ping Yang — Texas A&M University.
Ben Johnson — University Corporation for Atmospheric Research, Joint Center for Satellite Data Assimilation. Arlindo Da Silva, Mian Chin — NASA Goddard Space Flight Center.

What TAO has now, and how you can get it

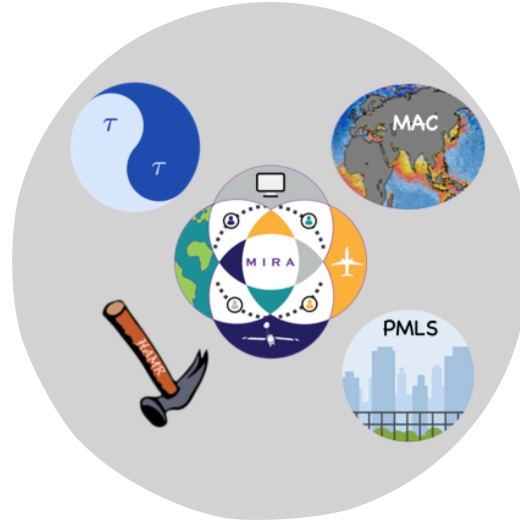
We have created aerosol optical tables that include mass extinction, absorption, and backscatter coefficients, single-scatter albedos, asymmetry parameters, lidar ratios, etc. But we are still building, and we seek your help in establishing a community database.

- Computations at 61 OPAC wavelengths from 0.25 to 40 um and 12 common remote sensing wavelengths.
- We will eventually make recommendations about how to proportion species for the different aerosol types.
- TAO is located on a NASA google drive while we get started. Contact gregory.l.schuster@nasa.gov or mira_crew@lists.nasa.gov for access.

TAO Aerosol Species	Aerosol Type					Citations
	Bio Burn	Urban	Dust	Marine	Bckgrnd	
Externally-mixed Black Carbon	√	√			√	**3 BC SDs & 1 BC Complex RI:**
Internally-mixed Black Carbon	√	√			√	Schwarz (GRL, 2008), Bond & Bergstrom (AST, 2006)
Water-insoluble Brown Carbon	√				√	**36 SDs & hygroscopicities:** Rissler (ACP 2006)
Water-insoluble White Carbon	√	√		×	√	**4 complex refractive indices:**
Water-soluble Brown Carbon	√				√	Sun (GRL 2007), Sutherland and Khanna (AST 1991)
Water-soluble White Carbon	√	√		×	√	Dick (JGR 2000; AST 2007), Dinar (Faraday Discuss. 2008)
Sulfates		×		×	×	Gosse (Appl Opt, 1997)
Nitrates		×			×	Gosse (Appl Opt, 1997), Jarzembski (Appl Opt, 2003)
Sodium Chloride				×	×	Irshad (ACP, 2009)
Internal mix of clays + FeO_x			√			**8 GEOS-GOCART SDs:** Chin (Ann Geophys, 2009)
						2 Complex RI and Hexahedras: Saito (JAS, 2021)

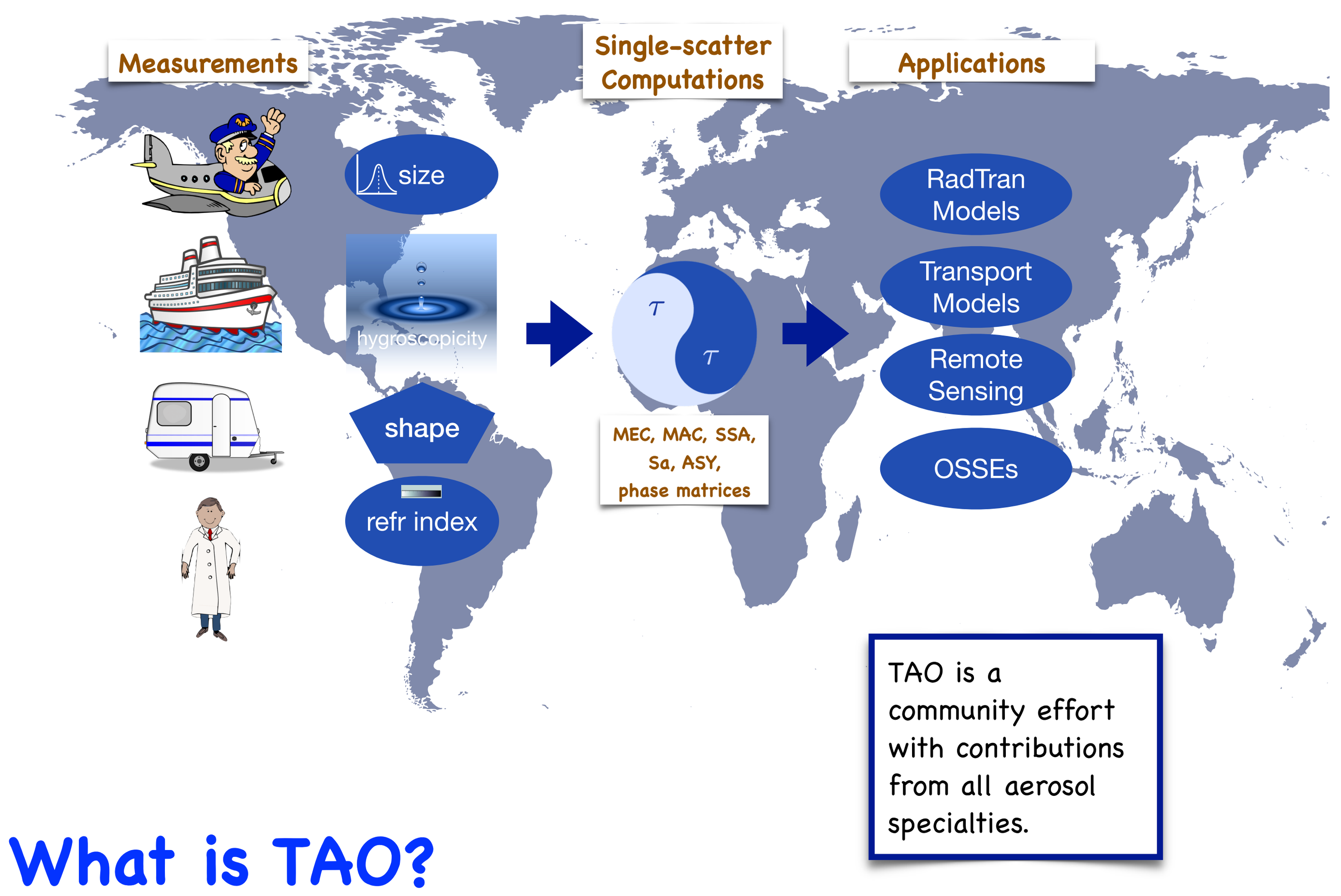
✓ symbols — at least one calculation available in TAO; X symbols — species that still need to be calculated.

TAO is part of MIRA
Models, In situ, and Remote sensing of Aerosols



https://science.larc.nasa.gov/mira-wg/

https://espo.nasa.gov/lists/listinfo/mira



What is TAO?

- TAO is an extensive set of aerosol single-scatter computations (e.g., Mie theory) that transform particle size and composition into mass-normalized optical properties like extinction, absorption, and angular scattering.
- Global models use such tables to quickly compute upwelling and downwelling radiative flux at wavelengths that range from ~0.25 to 40 um.
- These optical tables must also accommodate the full range of relative humidities for hygroscopic particles.
- The most common optical tables used by modelers today are the Optical Properties of Aerosols and Clouds, or OPAC (Hess etal, BAMS 1993).
- TAO is an update to OPAC.

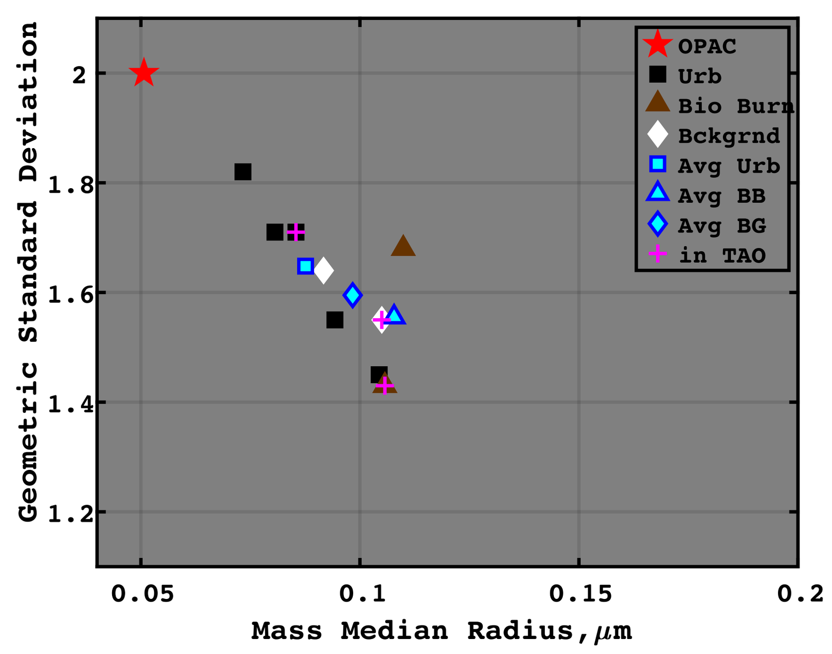
Why we need TAO

- OPAC was published more than two decades ago, so it pre-dates all of the atmospheric measurements obtained in this century.
- These early datasets were sparse, so OPAC was unable to account for regional variations of intrinsic aerosol properties (i.e., the composition of smoke, dust, and pollution are considered as identical everywhere).
- Measurement and retrieval techniques have advanced significantly since OPAC (e.g., AERONET SSA, SP2 rBC mass, and Cavity Ringdown extinctions, to name a few).
- Single-scatter computations for complex (non-spherical) shapes have advanced significantly in recent years.

What TAO seeks from the community

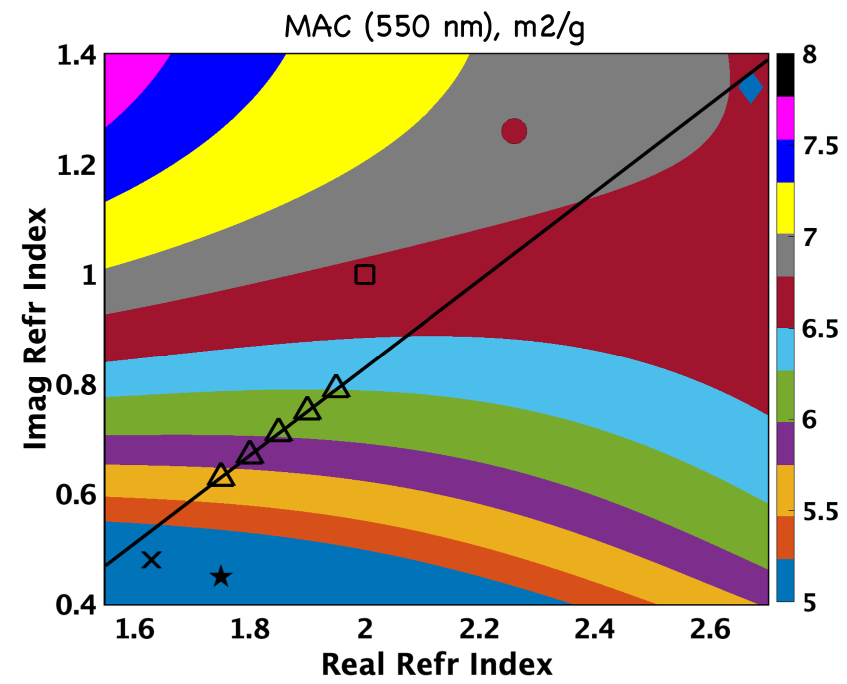
- Measurements of aerosol size distributions and complex refractive indices that are regionally representative.
- Single-scatter computations, especially for complex shapes.
- Special orders — if your favorite global model needs something and it is missing in TAO, please let us know!

Black Carbon Issues in OPAC



OPAC size distributions for black carbon are smaller and wider than modern SP2 measurements and do not differentiate between urban, biomass burning, and background conditions.
Data from Hess (BAMS 1998; OPAC), Moteki (GRL 2007), Schwarz (GRL 2008, 2010; + used for TAO), Kondo (Aer Sci Tech 2011)

MAC and Complex Refractive Index
Mie theory computations of the Mass Absorption Coefficient (MAC) using Schwarz (GRL 2008) BC size distributions. Newer complex refractive index measurements for black carbon result in much higher MACs than OPAC when reasonable BC densities are used. Recall that the BB06 recommends 6.5-8.5 m2/g.*
Contour parameters:
Count Median Radius (CMR) = 0.072,
Geometric Std. Dev = 1.430
BC density = 1.7 g/cm³

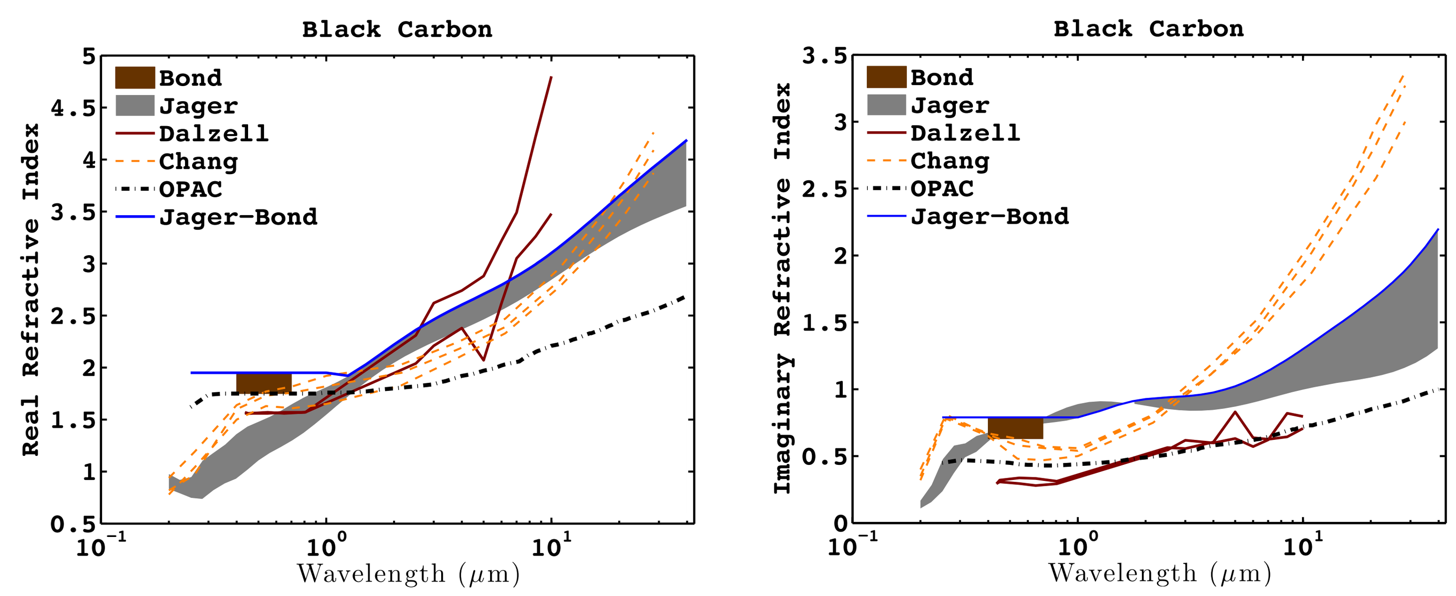


Symbol Key

Symbol	Source	Density (g/cm³)	n - ki	Comment
◇	Borghesi and Guizzetti (1991)	2.26	2.67 - 1.34i	Graphite
○	Moteki et al (2010)	1.8	2.26 - 1.26i	Technique sensitive to density. Measured CRI at 1064 nm, but applied here at 550 nm
□	Janzen (1979)	1.7	2 - 1i	Carbon Blacks
△	*Bond and Bergstrom (2006)	1.7	1.96 - 0.79i	Literature review.
★	Hess et al. (1998)	1.0	1.75 - 0.44i	OPAC; density is unrealistic
×	Chang and Charalampopoulos (1990)	1.7	1.63 - 0.48i	

Finding complex refractive index spectrums for black carbon remains a challenge

TAO uses the blue Jager-Bond line below, given the limited options.

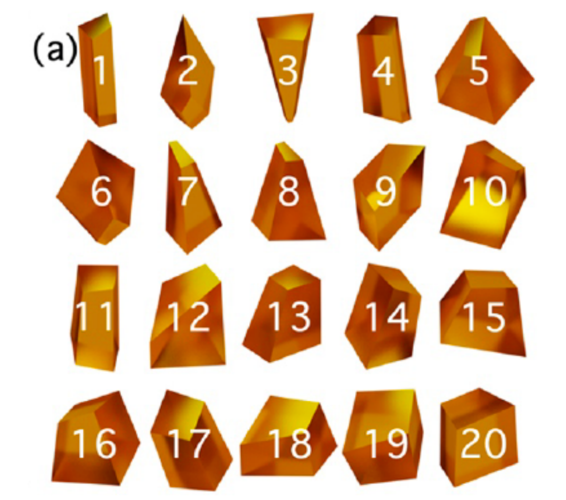


Bond and Bergstrom (AST 2006), Jager et al (Astron. Astrophys 1998), Dalzell and Sarofim (J. Heat Trans 1969), Chang and Charalampoulos (Proc. Roy. Soc. London 1990), OPAC (Hess, BAMS 1998).

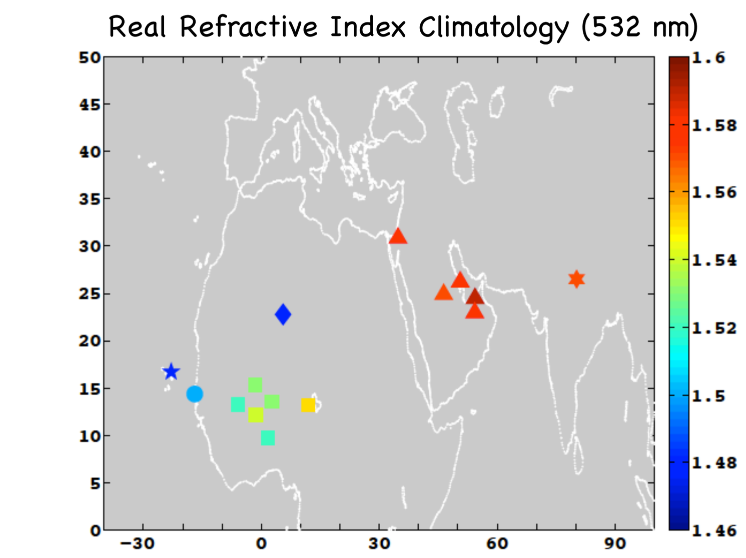
Texas A&M Hexahedrals

First Irregular Shapes for TAO

8 lognormals (GEOS-GOCART) and 2 sets of complex refractive indices to differentiate W African and Middle East dust.



The new Texas A&M kernel database for hexahedra. Saito et al (JAS 2021), Saito and Yang (GRL 2021)

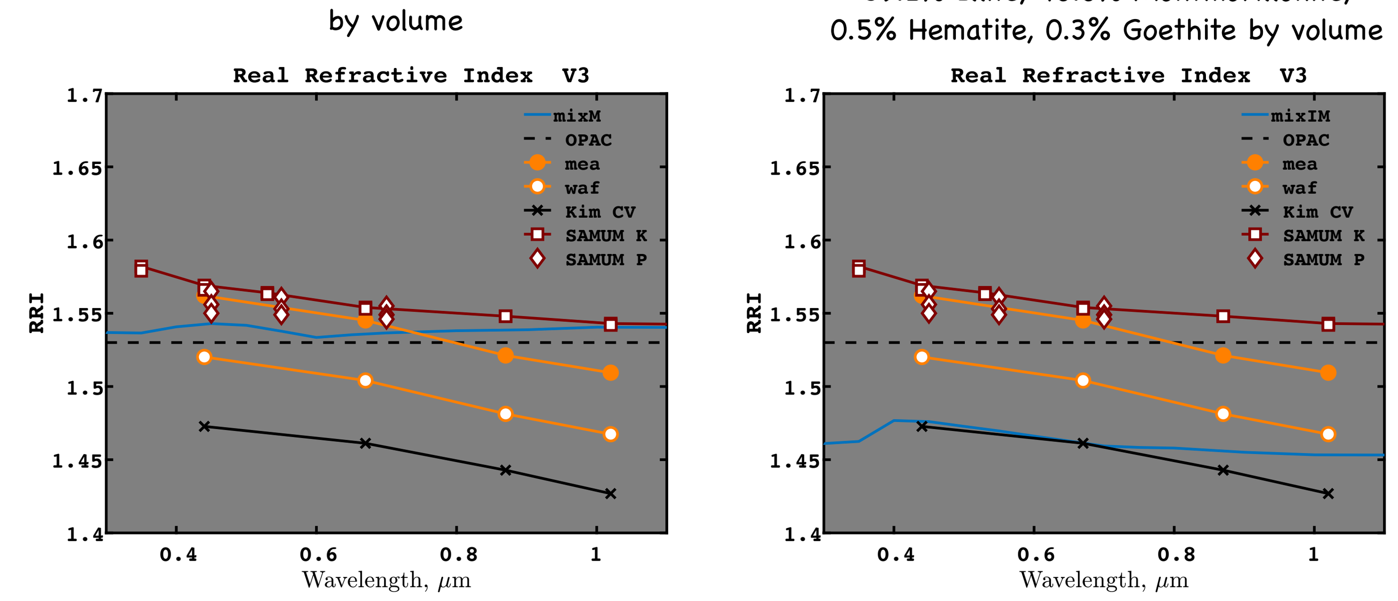


AERONET RRI varies because of regional mineralogy. Schuster et al (ACP 2012).

Different mineral mixtures are required to simulate the range of dust real refractive index found in the literature.

Montmorillonite (mixM)
98.8% Montmo., 0.7% Hematite, 0.5% Goethite by volume

Illite & Montmorillonite (mixIM)
59.2% Illite, 40.0% Montmorillonite, 0.5% Hematite, 0.3% Goethite by volume



The blue line in the left panel is a simulated mixture dominated by montmorillonite and approximates the upper range of observations, whereas the blue line in the right panel contains a significant amount of illite as well as montmorillonite to approximate the lower range.
Mineral refractive indices from Egan and Hilgeman, 1979, Bedidi and Cervelle (JGR 1993), Chen and Cahan (JOSA 1981). Legend key — OPAC: Hess (BAMS, 1998); mea, waf: Schuster (ACP, 2012); Kim CV: Kim (ACP, 2011); SAMUM K: Kandler (Tellus, 2009); SAMUM P: Petzold (Tellus, 2009).

Apply Texas A&M hexahedra calculations to the above mixtures:
Lognormal parameters:
Effective Radius, um: 0.450 Geometric Standard Deviation: 2.0
Mode Radius, um: 0.135 Mineral mass density (g/cm^3): 2.6