Stratospheric measurements of aerosols: A comparison of *in situ* and remote sensing techniques

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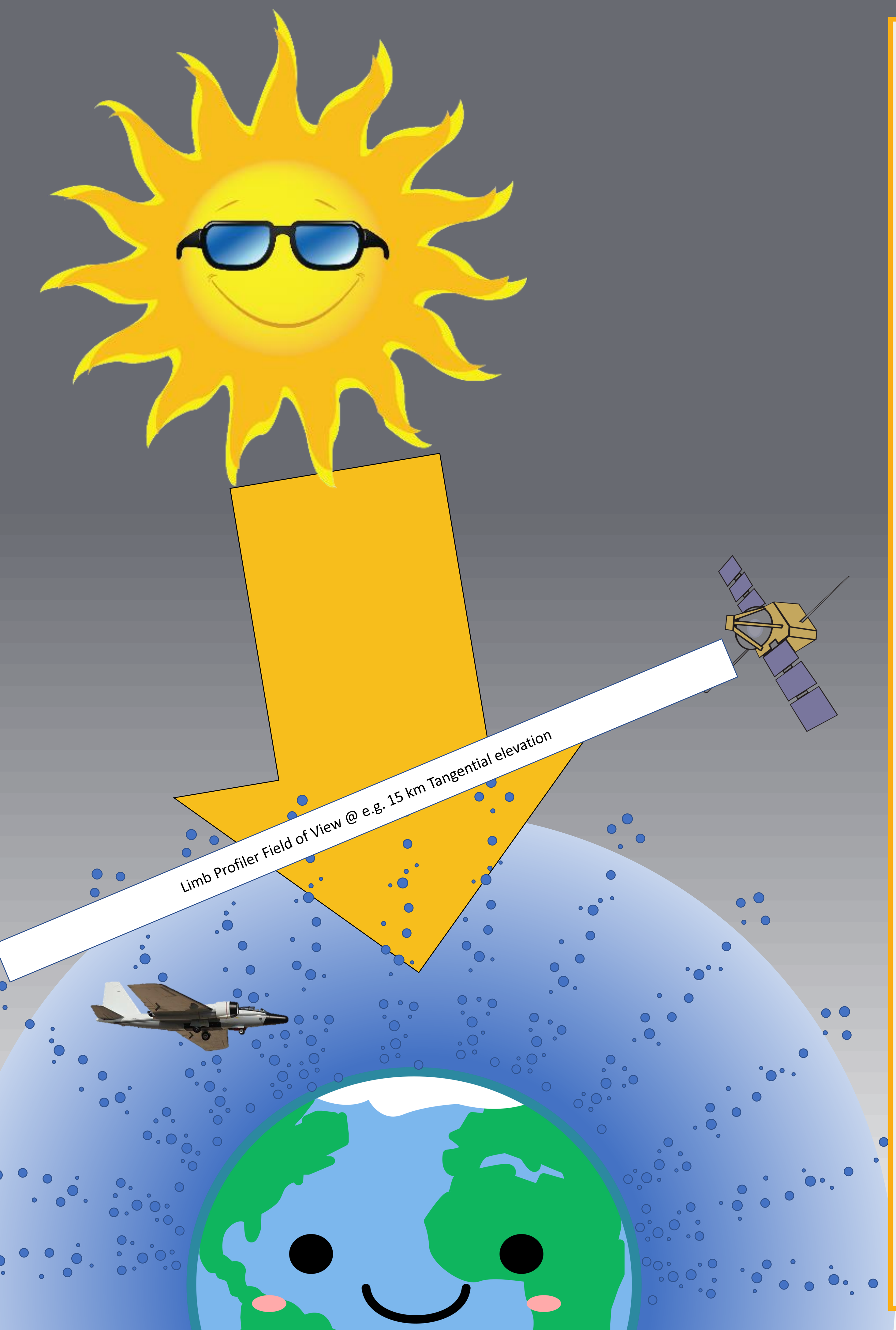
Before we start, here's what you need to know:

- Aerosols in the stratosphere occur naturally but can the number and size of the particles can be affected by human activity.
- There aerosols can mask global warming by scattering energy back into space and can affect the ozone layer that protects us from UV radiation.
- It's hard to measure the number and size of these stratospheric particles, so there are relatively few measurements with limited seasons and locations having been observed directly.
- However, satellites can infer information about the stratospheric aerosols by measuring the sunlight they scatter.
- Although these measurements have global coverage and long measurement histories, converting the amount of light scattered by particles into a meaningful account of particle size, number, and location (e.g. altitude) is difficult.
- In this work, we measured the particle size distribution directly and used Mie theory to predict how much light would be scattered and compare this to direct measurements of light scattering and the retrieved values from satellite measurements (OMPS/LP.)

Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP)

- The OMPS was designed to measure global daily ozone profiles using backscattered UV radiation. However, to correctly interpret the backscattered light, one must account for the backscatter that is induced by species other than ozone, e.g. stratospheric aerosols.

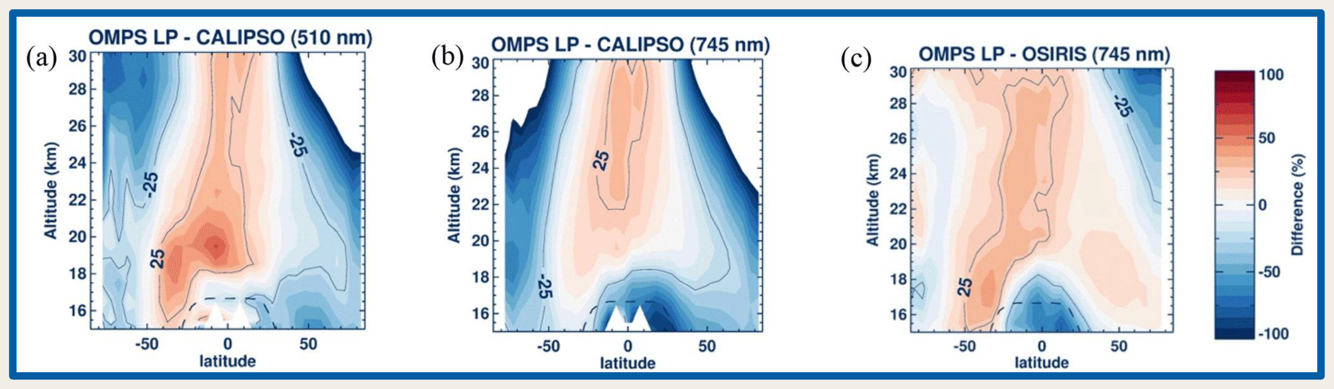
- The OMPS Limb Profiler (LP) consists of 3 vertical parallel slits that look backwards along the orbit track to measure light scattered by stratospheric aerosol with ~1 km vertical and 125 km along-track resolution at six wavelengths.
- Compared to occultation methods, **the limb profiling technique requires a more complex retrieval algorithm, but represents an opportunity for significantly greater spatial and temporal coverage.**



Challenges for retrieving extinction profiles from Limb Profile measurements

1) **Assumed size distribution and composition**
   - **Based on measurements from balloon-based optical measurements (Deshler *et al.* 2003, 2019)**
2) Unknown upwelling radiation based on surface albedo
3) Heterogeneity of aerosol and/or albedo within a single pixel

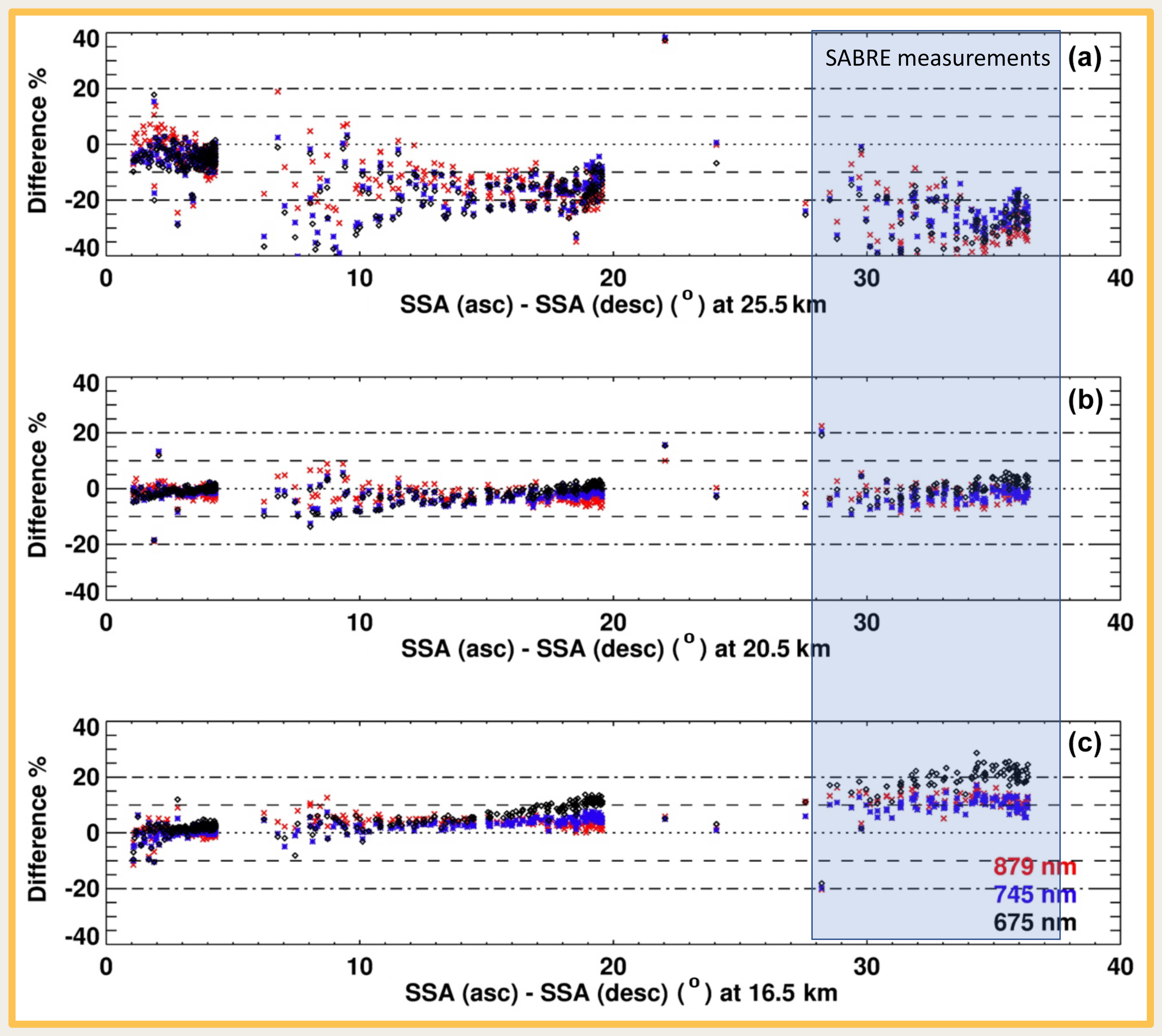
Comparison of OMPS-LP retrieved profiles with those from CALIPSO show the importance of using correct size distribution.



- Figure 15 from Taha *et al.* shows a comparison of the OMPS-LP retrieved extinction with co-located lidar measurements from CALIPSO show CALIPSO under-predicting extinction by 50-100%, likely due to an incorrect assumption about aerosol optical properties, i.e. lidar ratio.
- OSIRIS is another limb sounding measurements and generally agrees with the retrievals by OMPS-LP.
- In general, retrievals of aerosol extinction is expected to be more robust in higher latitudes for limb profiling techniques to the prevalence of forward scattering (and thus, more measurable signal.)

Validity of assumed aerosol size distribution is tested by comparing retrieval values with different scattering angles

- If the assumed aerosol model is correct, than Mie theory can be used to predict the direction and amount of light scattering. Then one can use a nonlinear Chachine relaxation method to find an extinction profile that fits with the measured radiance and known scattering geometry.
- To test whether the assumed geometry is correct, the retrieval is evaluated for the same air parcel on the ascending and descending orbit. If the retrieval gets the same extinction profile for different viewing geometries, its likely that the aerosol model is valid.



- Figure 3 from Taha *et al.* shows the difference in the extinction profiles on the ascending and descending orbit as a function of the difference in single-scatter angle at different altitudes (panels) and wavelengths (colors.) The largest disagreement is when SSA (asc) – SSA (desc) is large, which corresponds to higher latitudes.

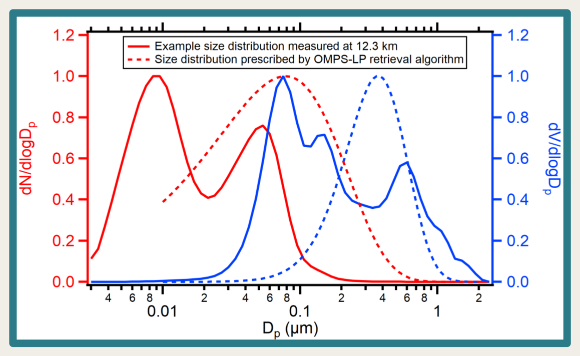
In situ measurements at mid latitudes

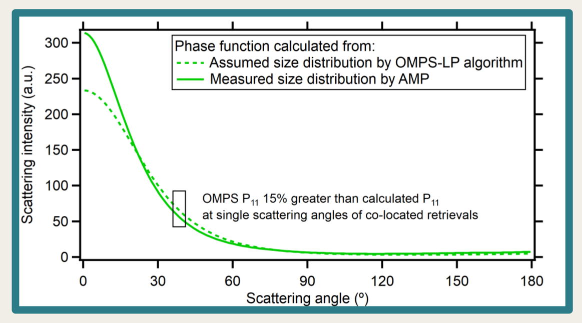
SABRE

- The 2023 Stratospheric Aerosol processes, Budget and Radiative Effects (SABRE) campaign took place Feb-Mar 2023 with 21 sorties flown from Houston TX and Fairbanks AK.
- The NASA WB-57F, shown above, contained an instrument payload for measuring gas-phase species, particle size distributions, and aerosol optical properties.
- The Aerosol Microphysical Properties instrument suite consists of three instruments for measuring nucleation, accumulation, and coarse mode aerosol size distributions. Unique challenges at each mode require different techniques to get a comprehensive size distribution.
- The Spectrometers for Optical Aerosol Properties (SOAP) instrument measures extinction directly at 532 nm.

Measured vs assumed size distributions and the effect on phase functions

- OMPS/LP V2 aerosol extinction retrieval uses an assumed aerosol size distribution based on balloon measurements (Summer average, 40°N, 20 km) and the CARMA aerosol microphysical model output.
- The measured size distributions shown here are the combined product from the three instruments the comprise the AMP instrument suite.
- From the size distributions, we can calculate the phase function which describes the probability that light will be scattered in a different direction. **This is the fundamental mechanism by which the limb profile measured radiance is converted into extinction.**

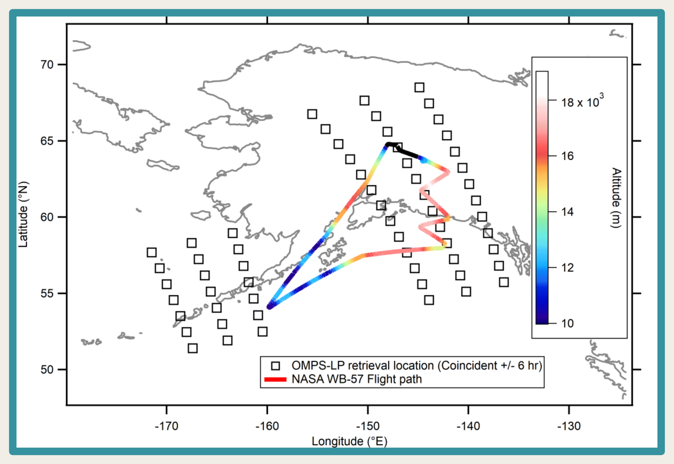


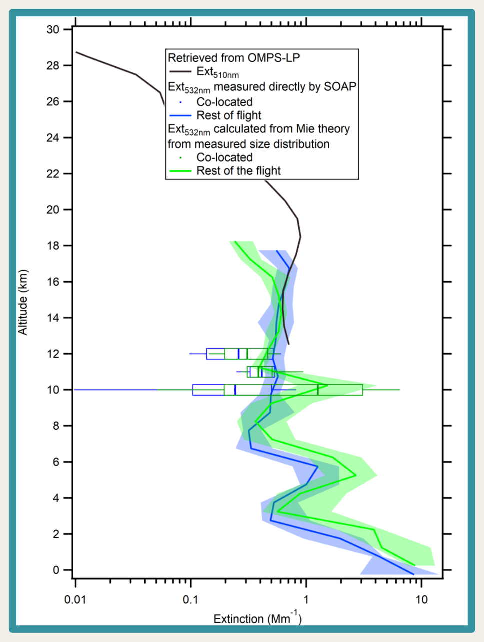


- The number weighted size distribution highlights the presence of Aitken mode particles that are not included in the OMPS/LP model, and which have negligible scattering cross section.
- The Volume weighted (similar to a scattering cross section weighting) size distribution shows a mode at 380 (600) nm for the OMPS (measured) size distribution. This suggests that light will be scattered forward more efficiently than the OMPS model assumes.

Measured vs Mie calculated vs retrieved aerosol extinction

- Within 6 hours of the 2023-03-05 research flight, the OMPS/LP instrument overflew nearby airmasses.
- These airmasses were predicted in a RAQMS model to have been heavily influenced by dust.





- Within 6 hours of the 2023-03-05 research flight, the OMPS instrument overflew nearby airmasses shown above.
- These airmasses were predicted in a RAQMS model to have been heavily influenced by dust.
- Extinction measured by the SOAP agreed with Mie theory calculations based on in situ size distribution measurements on average within 10%.
- There is decent agreement in extinction above 12km, although below 12km the aerosol optical thickness prevents a successful retrieval.

Acknowledgements

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