

# ARM AOS Processing Status and Aerosol Intensive Properties VAP

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## Abstract

The Atmospheric Radiation Measurement (ARM) Aerosol Observing System (AOS) has been operating at the Southern Great Plains (SGP) Central Facility since 1996. In response to the cross-cutting broadband heating rate profile value added product (VAP), there has been an increasing desire within the ARM community not only for those aerosol products directly measured by the AOS instrumentation, but also for higher-level derived products currently produced by National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL). In light of the aerosol intensive operation period (IOP) coming in May, 2003, the urgency of these efforts is heightened as is the desire for rapid access to results. Balancing the inherent time lag associated with robust calibrations and quality assessment against the desire for near real-time aerosol products has presented the ARM Infrastructure with unique challenges. This poster presents the current status of ARM AOS processing and results from the aerosol intensive properties VAP currently being developed to meet those challenges.

## AOS Measurements

The SGP AOS has been in operation at the SGP Central Facility since 1996. This autonomous system is described by Sheridan, Delene, and Ogren, (2001). Refer to Figure 1 for a subset of the apparatus related to aerosol absorption and scattering measurements.

An upstream impactor alternating between 1- $\mu\text{m}$  and 10- $\mu\text{m}$  size cut precedes the absorption and scattering instruments. The impactor switches between these two size cuts every 6 minutes. The absorption coefficient is measured at 545 nm. The total scattering and hemispheric backscattering coefficients are measured simultaneously by two separate nephelometers. These two nephelometers are connected in series separated by a humidifier. Both nephelometers operate simultaneously, measuring total scattering and hemispheric backscattering coefficients at three wavelengths of 450 nm, 550 nm, and 700 nm. The first of the two nephelometers measures scattering properties at low relative humidity (RH; <40%). Meanwhile, the humidifier is programmed to ramp the RH from about 40% to 85% over

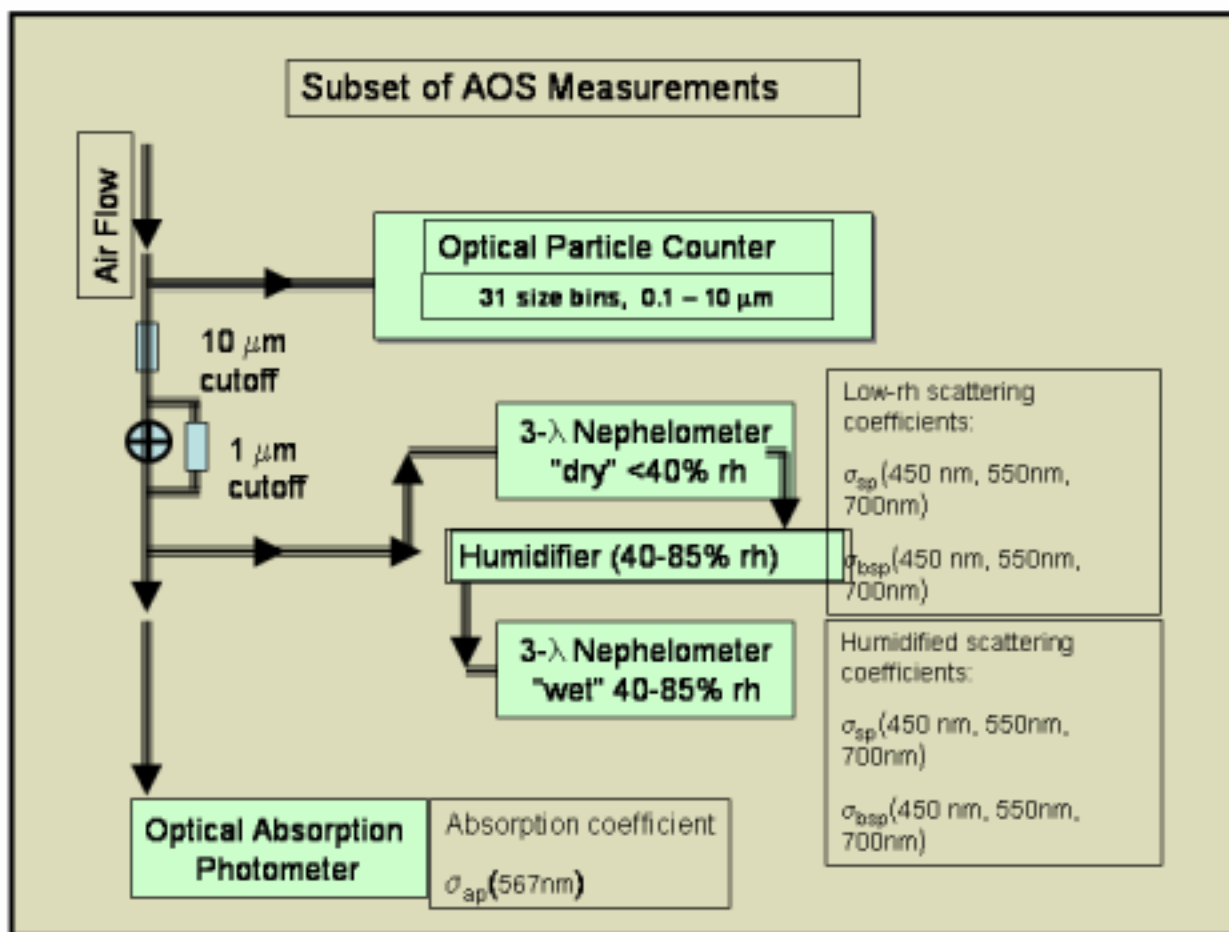


Figure 1. Overview of AOS instrumentation.

the course of an hour. Thus, the second nephelometer measures scattering properties at the same wavelengths as the first nephelometer, but with RH scaling gradually from 40% to 85%.

All told, the absorption photometer and nephelometers yield the following measurements as the impactor alternates between 1-μm and 10-μm size cut-offs:

- Absorption coefficient  $\sigma_{ap}$ (545 nm)
- Total scattering coefficient,  $\sigma_{sp}$ (450 nm, RH <40%)
- Total scattering coefficient,  $\sigma_{sp}$ (550 nm, RH <40%)
- Total scattering coefficient,  $\sigma_{sp}$ (700 nm, RH <40%)
- Hemispheric backscattering coefficient,  $\sigma_{bsp}$ (450 nm, RH <40%)
- Hemispheric backscattering coefficient,  $\sigma_{bsp}$ (550 nm, RH <40%)
- Hemispheric backscattering coefficient,  $\sigma_{bsp}$ (700 nm, RH <40%)
- Total scattering coefficient,  $\sigma_{sp}$ (450 nm, RH 40-85%)
- Total scattering coefficient,  $\sigma_{sp}$ (550 nm, RH 40-85%)

- Total scattering coefficient,  $\sigma_{sp}(700 \text{ nm, RH } 40\text{-}85\%)$
- Hemispheric backscattering coefficient,  $\sigma_{bsp}(450 \text{ nm, RH } 40\text{-}85\%)$
- Hemispheric backscattering coefficient,  $\sigma_{bsp}(550 \text{ nm, RH } 40\text{-}85\%)$
- Hemispheric backscattering coefficient,  $\sigma_{bsp}(700 \text{ nm, RH } 40\text{-}85\%)$

## **CMDL Mentor Review and Processing of AOS Data**

The raw AOS data is collected in ASCII form, and converted to ARM netCDF files which are delivered on a daily basis to the ARM Archive. The raw AOS data files (the ASCII data) are also delivered to the NOAA/CMDL staff on a routine basis. Staff at NOAA/CMDL monitor and process the AOS data, applying the following calibrations and corrections. In addition, the data is manually inspected to exclude anomalous or bad data being excluded from further processing.

### **Absorption Photometer Corrections (Bond et al.)**

- Spot-size correction
- Filter-based scattering correction

### **Nephelometer Corrections for Scattering Coefficients**

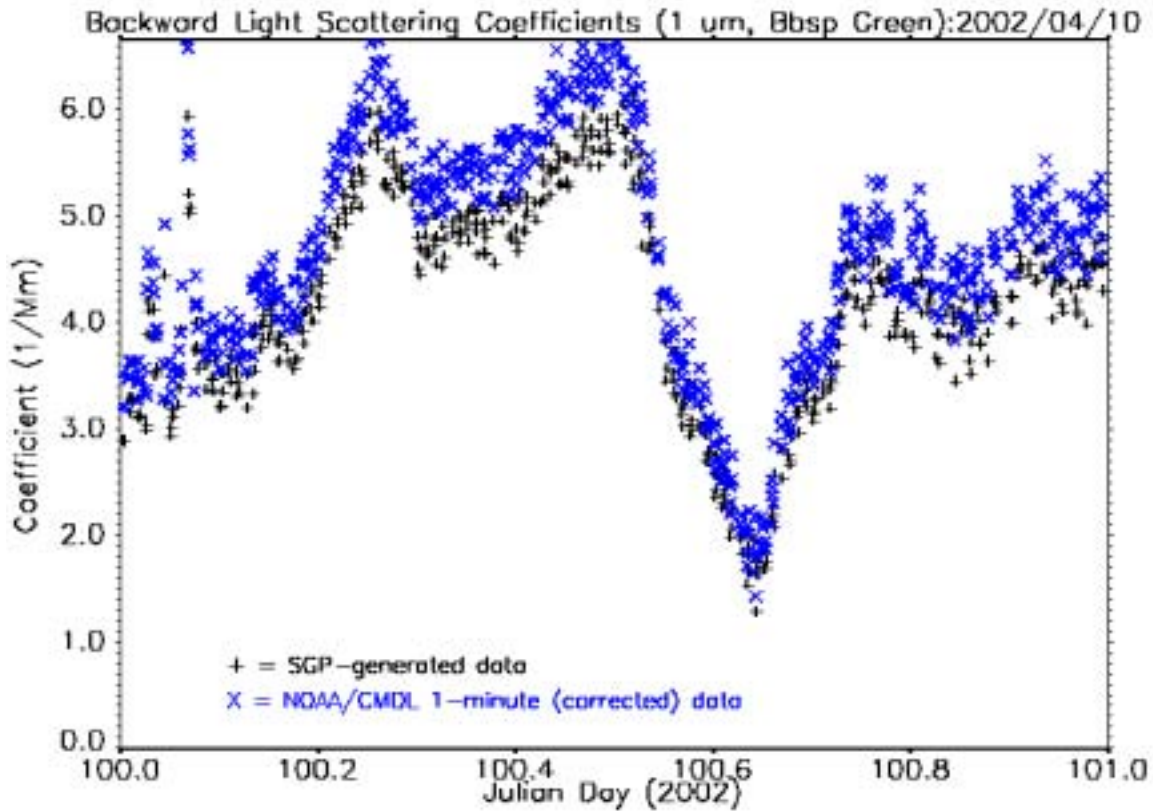
- Adjustment for standard temperature and pressure
- Size-dependent angular truncation correction based on Ångström exponent (Anderson and Ogren 1998)
- Weekly calibrations with air and CO<sub>2</sub>

These corrections are applied in an iterative process along with the calculation of derived products (described later). For example, the size-dependent angular truncation correction for the nephelometer scattering coefficients is dependent on the Ångström exponent. However, the Ångström exponent is itself calculated from the scattering coefficients. Thus, the corrections are repeated until the scattering coefficients and Ångström exponents converge to robust values.

The differences between the raw and corrected AOS data products are significant. Typical differences are shown in the Figure 2 and Figure 3. In these two plots the differences are primarily due to the size-dependent angular truncation corrections.

NOAA/CMDL delivers quarterly packages of mentor-edited AOS data (still in ASCII format) to the ARM External Data Center. In addition to the corrected absorption and scattering coefficients, the CMDL delivery also includes hygroscopic growth factor determinations described later in this document. This quarterly batch of AOS data is then processed via a new ingest (cmdlaos\_ingest) to generate ARM netCDF files, which are delivered to the ARM Archive. Currently, the following datastreams are available from the ARM Archive:

- sgpcmdlaosC1.c1**, 1-minute aerosol data
- sgpcmdlaosftrhC1.c1**, hygroscopic growth factor f(RH) (described below)
- sgpcmdlaosavgC1.c1**, 60-minute averaged aerosol data



**Figure 2.** Comparison of SGP AOS data to NOAA/CMDL mentor-corrected data (backward light scattering coefficients). Figure 2 shows initial and corrected measurements of hemispheric backscattering at 550 nm for the 1 μm size cut.

## AOS Intensive Properties Derived from Measured Properties

The absorption and scattering coefficient values measured by the AOS are referred to as “extensive properties,” because they pertain mainly to the amount of aerosol present. The extensive properties can be used to determine several aerosol “intensive properties.” Rather than being related directly to aerosol loading, intensive properties relate more to the character of the aerosol such as the hygroscopic behavior, albedo, or particle size.

- Hygroscopic growth factor,
- Aerosol single scattering albedo,
- Hemispheric backscatter fraction,
- Ångström exponent,
- Submicron scattering fraction,
- Submicron absorption fraction,

$$f(\text{RH}) = \sigma_{\text{sp}}(\text{RH} = 85\%) / \sigma_{\text{sp}}(\text{RH} = 40\%)$$

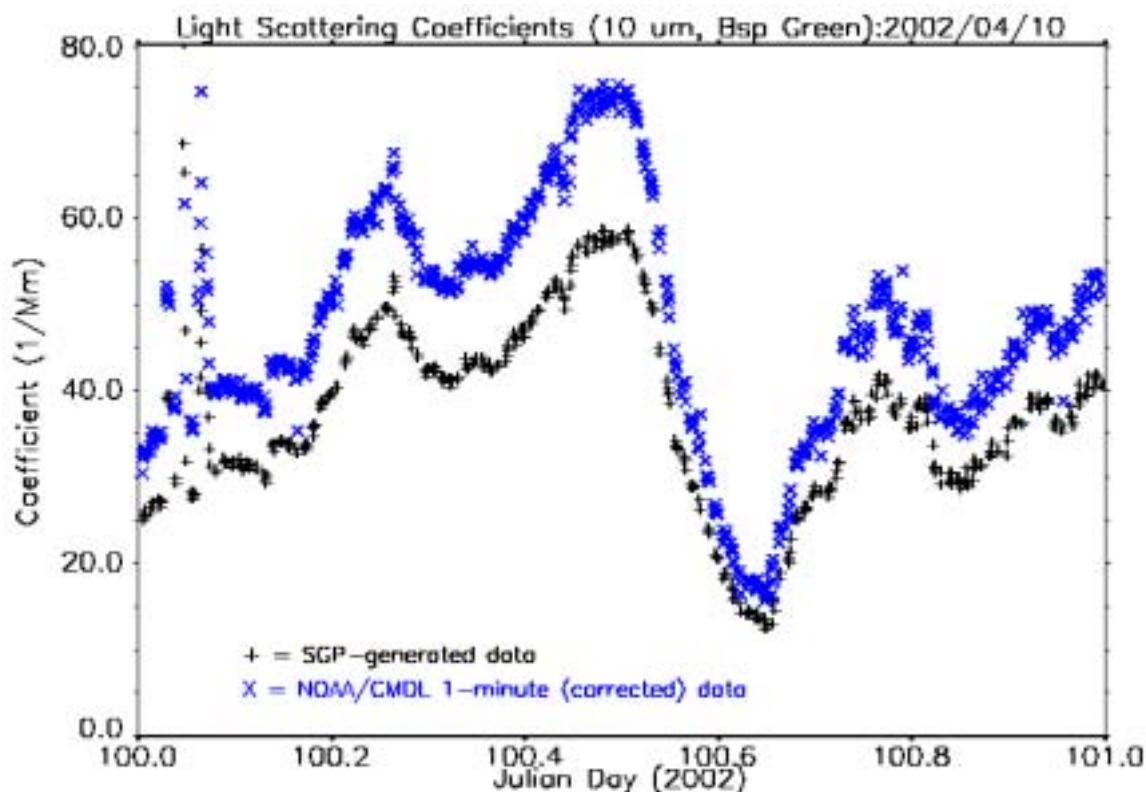
$$\omega_0 = \sigma_{\text{sp}} / (\sigma_{\text{sp}} + \sigma_{\text{ap}})$$

$$b = \sigma_{\text{bsp}} / \sigma_{\text{sp}}$$

$$a = -\log[\sigma_{\text{sp}}(\lambda_1) / \sigma_{\text{sp}}(\lambda_2)] / \log[\lambda_1 / \lambda_2]$$

$$R_{\text{sp}} = \sigma_{\text{sp}}(1\text{-}\mu\text{m}) / \sigma_{\text{sp}}(10\text{-}\mu\text{m})$$

$$R_{\text{ap}} = \sigma_{\text{ap}}(1\text{-}\mu\text{m}) / \sigma_{\text{ap}}(10\text{-}\mu\text{m})$$



**Figure 3.** Comparison of SGP AOS data to NOAA/CMDL mentor-corrected data (light scattering coefficients). Figure 3 shows initial and corrected total scattering at 550 nm for the 10  $\mu\text{m}$  size cut.

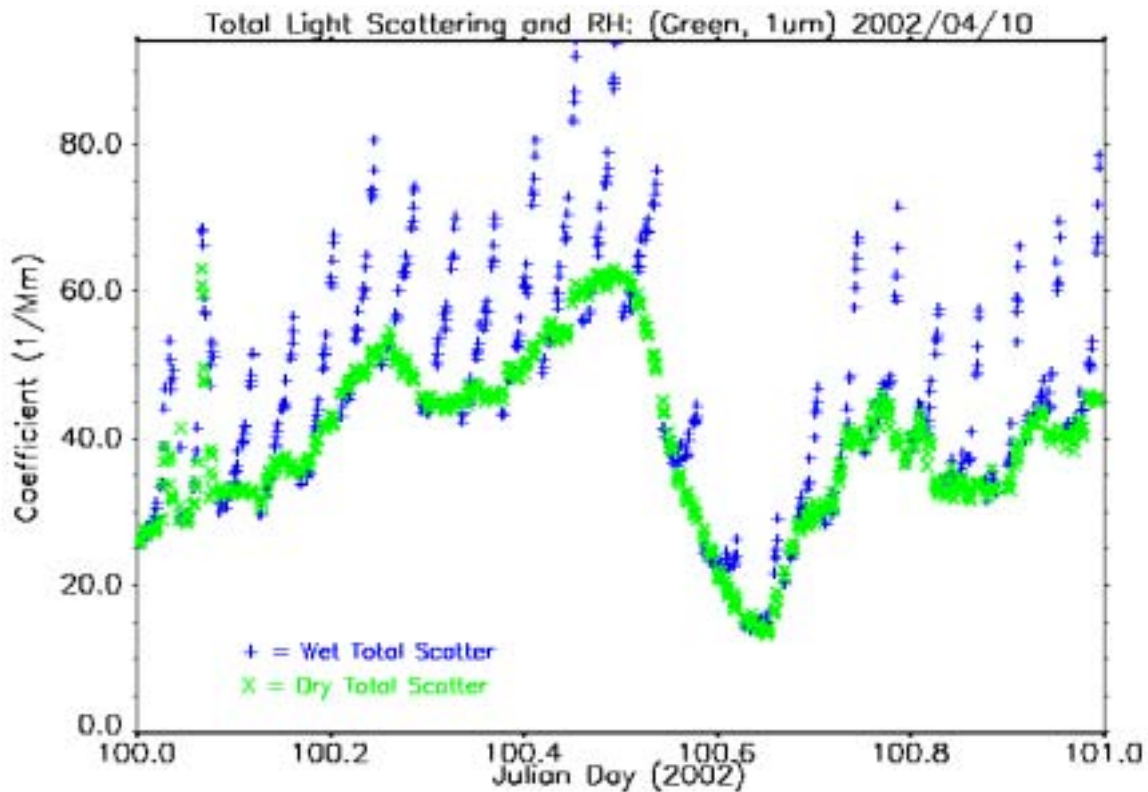
Of these intensive properties, only the hygroscopic growth factor is currently delivered by CMDL to ARM Archive. Data from 1996 through mid-2003 is available.

### Hygroscopic Growth Factor $f(\text{RH})$

Comparisons of scattering under “dry” (less than 40%) and “wet” (varying between 40 to 85%) conditions exhibit the effects of the hygroscopic growth. For example, Figure 4 shows a time series plot of the total scattering coefficient at 550 nm with a 1- $\mu\text{m}$  cut-off measured by the dry (less than 40% rh) along with the corresponding quantity from the “wet” nephelometer (rh ramped from 40% to 85%). Note the agreement between the two measurements (which occurs when the “wet” nephelometer is also at ~40% rh) and also the striking increase in total scattering coefficients measured by the “wet” nephelometer as the RH is ramped up. This noted increase in the “wet” measurements is caused by hygroscopic growth of the aerosol particles.

In Figure 5, plotting the ratio of the “wet” total scattering coefficient vs. the “dry” total scattering coefficient as a function of the “wet” rh illustrates how this effect may be quantified. The relationship between “wet” to “dry” total scattering coefficient may be parameterized. Both a two-parameter and a three-parameter fit of the RH data are provided by CMDL. The two parameter fit is of the form:

$$f(\text{RH}) = a[1-(\text{RH}/100)]^{-b}$$



**Figure 4.**  $\sigma_{ap}$  measurements at varying RH.

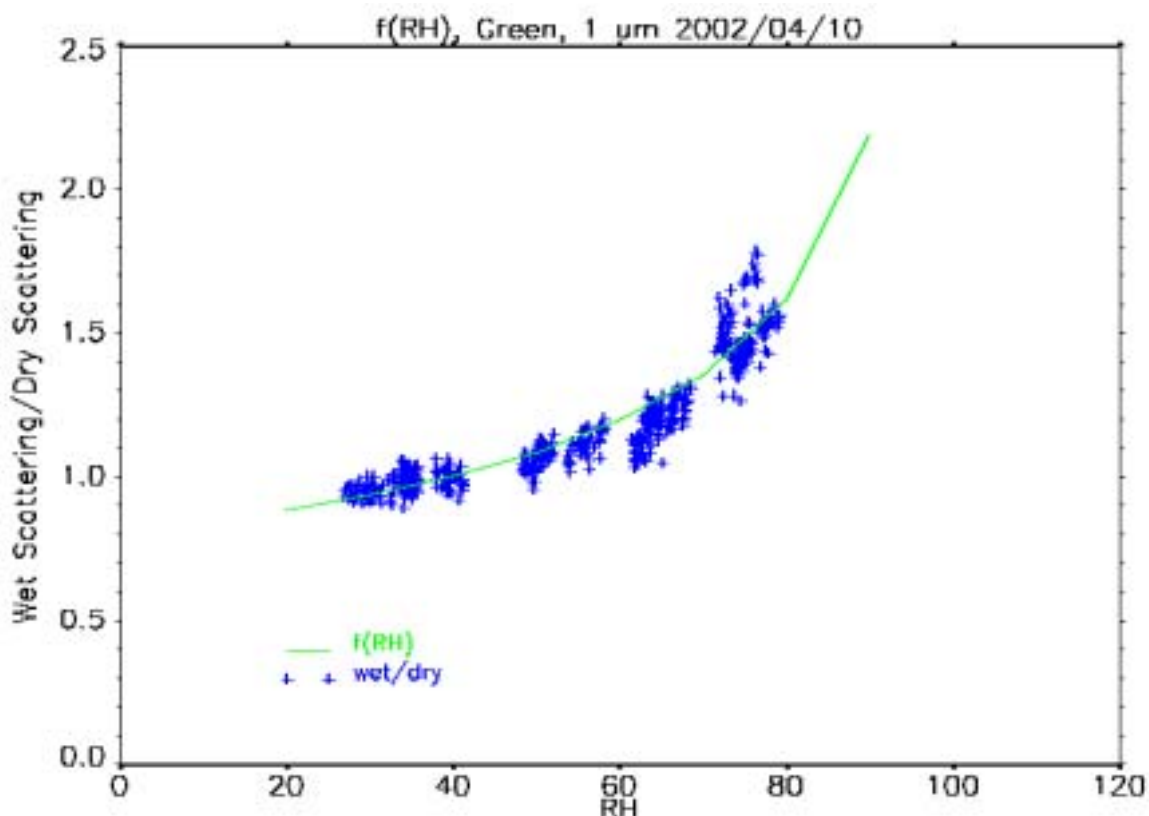
The three-parameter fit is of the form:

$$f(\text{RH}) = a[1+b(\text{RH}/100)]^c$$

This is a work in progress. Most of the time the 2-parameter fit is recommended for use, although there are cases where the 3-parameter fit produces better results. NOAA/CMDL is continuing to evaluate the  $f(\text{RH})$  data and they will provide recommendations as to which situations are best suited for either the 2- or 3-parameter fit. Also note that  $f(\text{RH})$  parameters are supplied for the blue, green, and red wavelengths at both impactor size cuts.

### Aerosol Single Scatter Albedo $\omega_0$

Aerosol single scattering albedo,  $\omega_0$  is a measure of how reflective (white) the aerosol appears. It is calculated as the ratio of the total scattering coefficient to the total extinction (given as total scattering coefficient plus absorption coefficient). Higher values for  $\omega_0$  indicate more scattering of light, lower values indicate more absorption. Because the absorption coefficient is only measured in the green



**Figure 5.**  $f(RH)$  for green wavelength.

(567 nm), we are only able to directly derive the single scattering albedo for that wavelength. Figure 6 shows 10  $\mu\text{m}$  measured data used to calculate the single scattering albedo values shown in Figure 7. Single scattering albedo for both cut-off values of 1  $\mu\text{m}$  and 10  $\mu\text{m}$  values for  $\omega_0$  are shown in Figure 7.

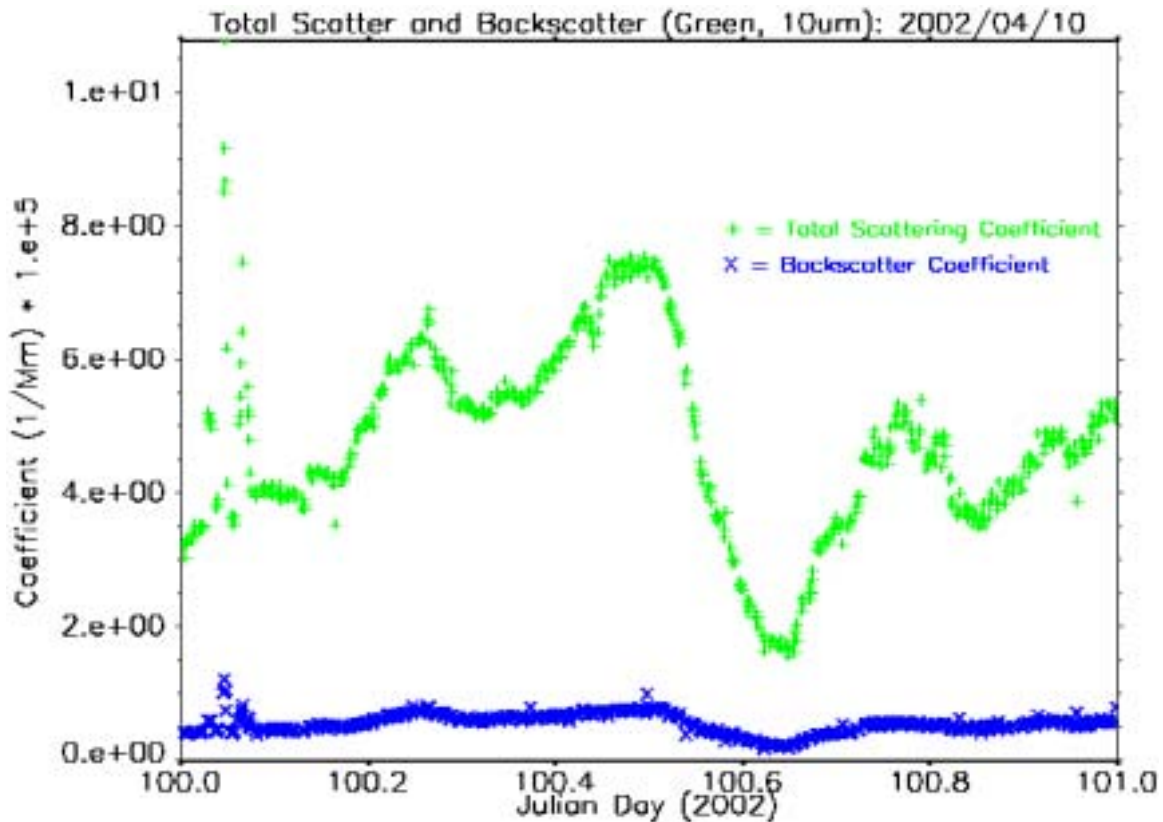
### Hemispheric Backscatter Fraction $b$

The hemispheric backscatter fraction,  $b$ , is the ratio of the backscatter coefficient and the total scattering coefficient, and is an indication of aerosol particle size. Larger particles will tend to have enhanced forward scattering and decreased backscatter. This property will be produced for all three nephelometer wavelengths at both impactor size cuts.

Figure 8 shows the data from which the hemispheric backscatter fraction is computed. Figure 9 shows the computed hemispheric backscatter fraction.

### Ångström Exponent, $\alpha$

The Ångström exponent is another indicator of particle size depending on the relationship between scattering coefficient and wavelength for different particle sizes. Small particles approaching the Rayleigh scattering regime yield Ångström exponent values of two while larger particles tend towards Ångström exponents less than two. Figure 10 shows the measured total scattering coefficients at data,



**Figure 6.** Total scatter and backscatter coefficients.

which are used to compute the Ångström exponent. Figure 11 shows the exponent values, in this case computed from the green/red ratio. The Ångström exponent will be calculated for blue/red, blue/green, and green/red wavelength combinations at both size cut-off settings.

### **Submicron Scattering Fraction, $R_{sp}$ and Submicron Absorption Fraction $R_{ap}$**

The above ratios indicate the significance of submicron contributions to the total scattering and absorption measurements. Values close to unity indicate that the interaction (scattering or absorptions, as the case may be) is dominated by small particles. Figure 12 shows the total scattering coefficients, Figure 13 shows the light absorption coefficients, and Figure 14 shows both  $R_{sp}$  and  $R_{ap}$  for the time period. Submicron scattering fraction values will be reported for all three nephelometer wavelengths. However, because the absorption coefficient is only measured at a single wavelength (567 nm), the submicron absorption fraction is likewise limited to this single wavelength. Additionally, to reduce random noise only hourly averages will be reported.



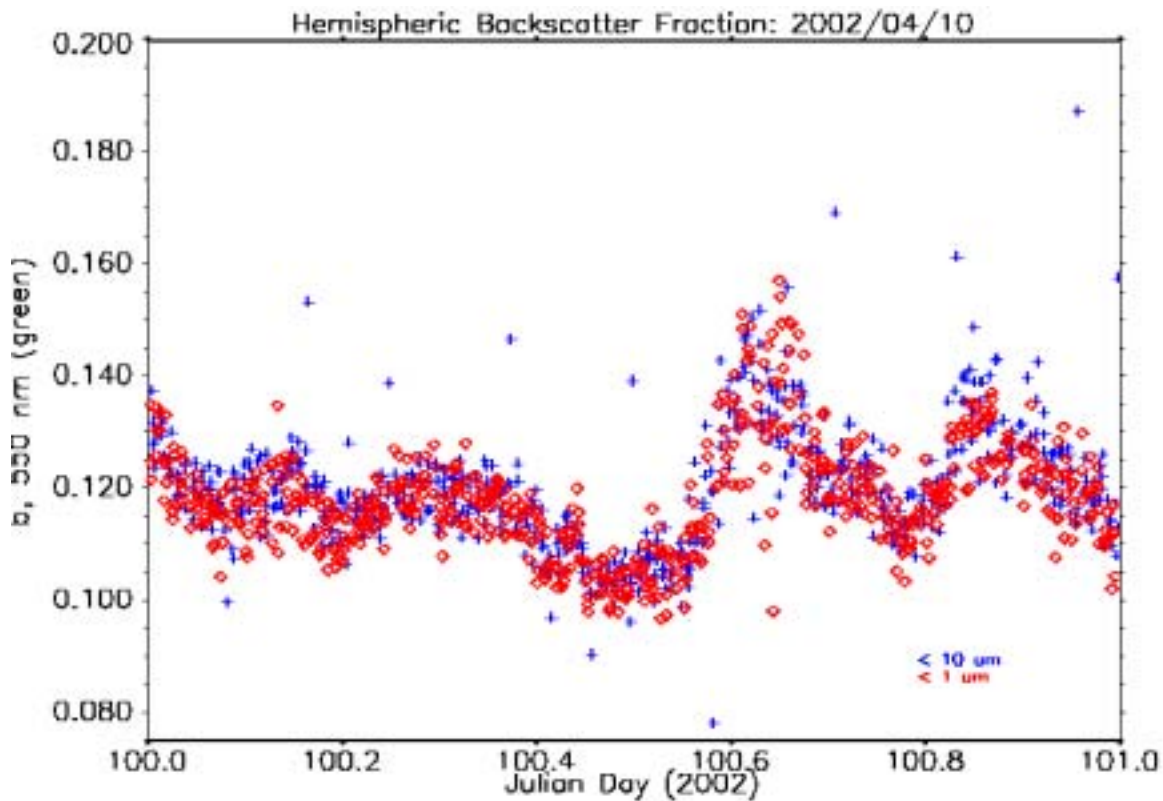


Figure 7. Computed hemispheric backscatter fraction.

## Radiatively Significant Aerosol Intensive Properties

The following properties aerosol properties are of radiative significance. While not directly calculable from AOS measurements, parameterizations have been developed for them in terms of quantities that AOS can provide:

- Average upscatter fraction,  $\beta$  (Wiscombe and Grams 1976)
- Asymmetry parameter,  $g$  (Wiscombe and Grams 1976)
- Aerosol Forcing Efficiency,  $\Delta F/\delta$  (Sheridan and Ogren 1999)

### Average Upscatter Fraction $\beta$

The average up-scatter fraction is related to the backscatter fraction. It describes the averaged fraction of radiation that would be scattered into the upper hemisphere, essentially contributing to a net increase in upwelling radiance. As such, this value is desirable for radiative balance studies. This value has been parameterized in terms of the backscatter fraction  $b$  by Wiscombe and Grams (1976) as:

$$\beta = 0.0817 + 1.8495b - 2.9682b^2$$

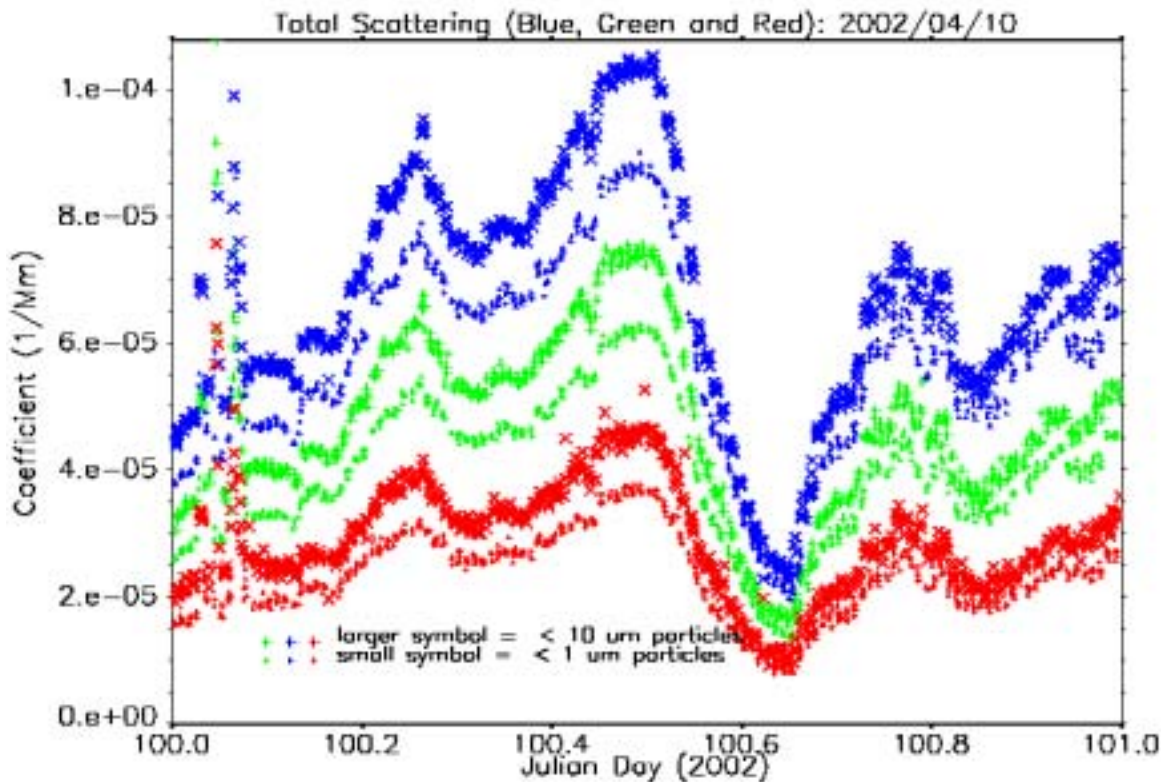


Figure 8. Total scattering coefficients, at two particle sizes.

### Asymmetry Parameter, $g$

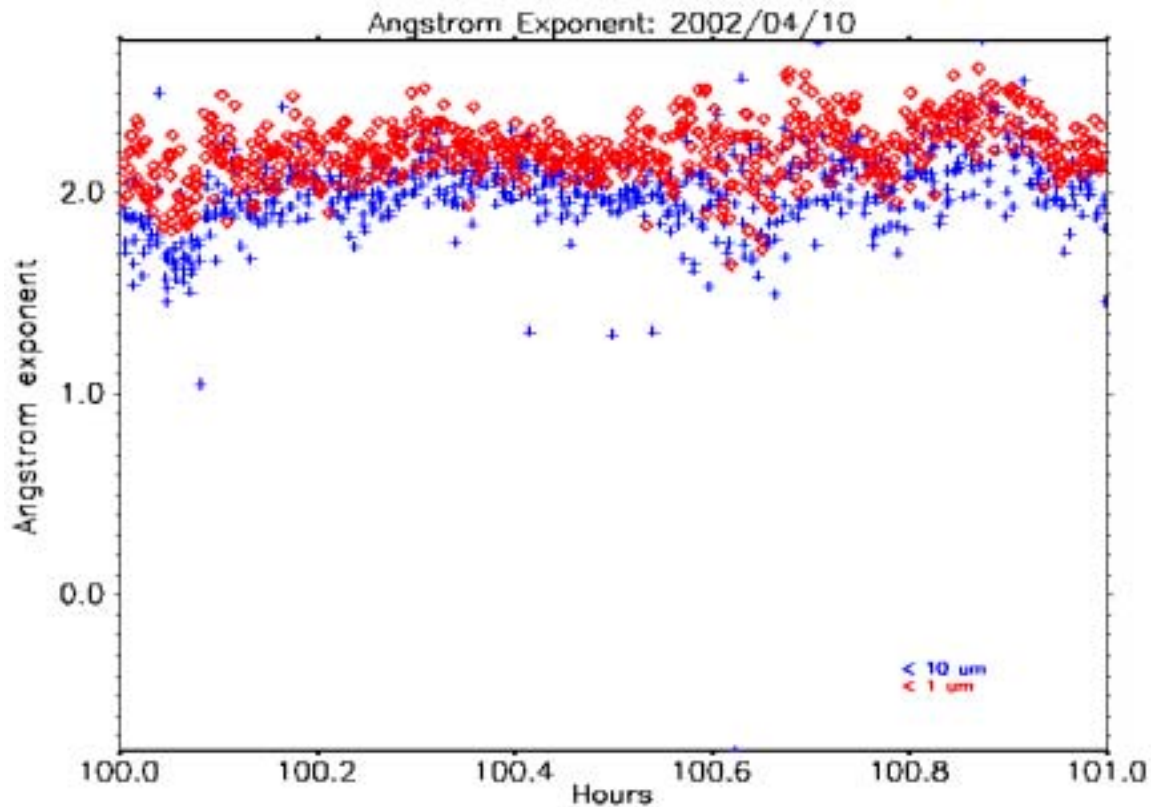
The asymmetry parameter is another valuable determination for radiative forcing calculations. Particles that scatter symmetrically have an asymmetry parameter of zero, particles with more forward scattering approach asymmetry parameter values of 1. The asymmetry parameter cannot be directly calculated from AOS data; however, Wiscombe and Grams (1976) have produced the following parameterization in terms of the backscatter fraction  $b$ :

$$g = 1.011 - 1.036b - 2.005b^2$$

### Aerosol Forcing Efficiency $\Delta F/\delta$

The Aerosol forcing efficiency is a normalized measure of the effective radiative forcing of an aerosol with unit optical depth. It requires only two aerosol parameters, the single scattering albedo (which the AOS can provide directly in the green), and the backscatter fraction (which the AOS can provide at all three nephelometer wavelengths). The formulation below is from (Sheridan and Ogren 1999).

$$\Delta F/\delta = -DS_o T_{at}^2 (1-A_c)\omega_o b [(1-R_s)^2 - (2R_s/b)[(1/\omega_o)-1]]$$



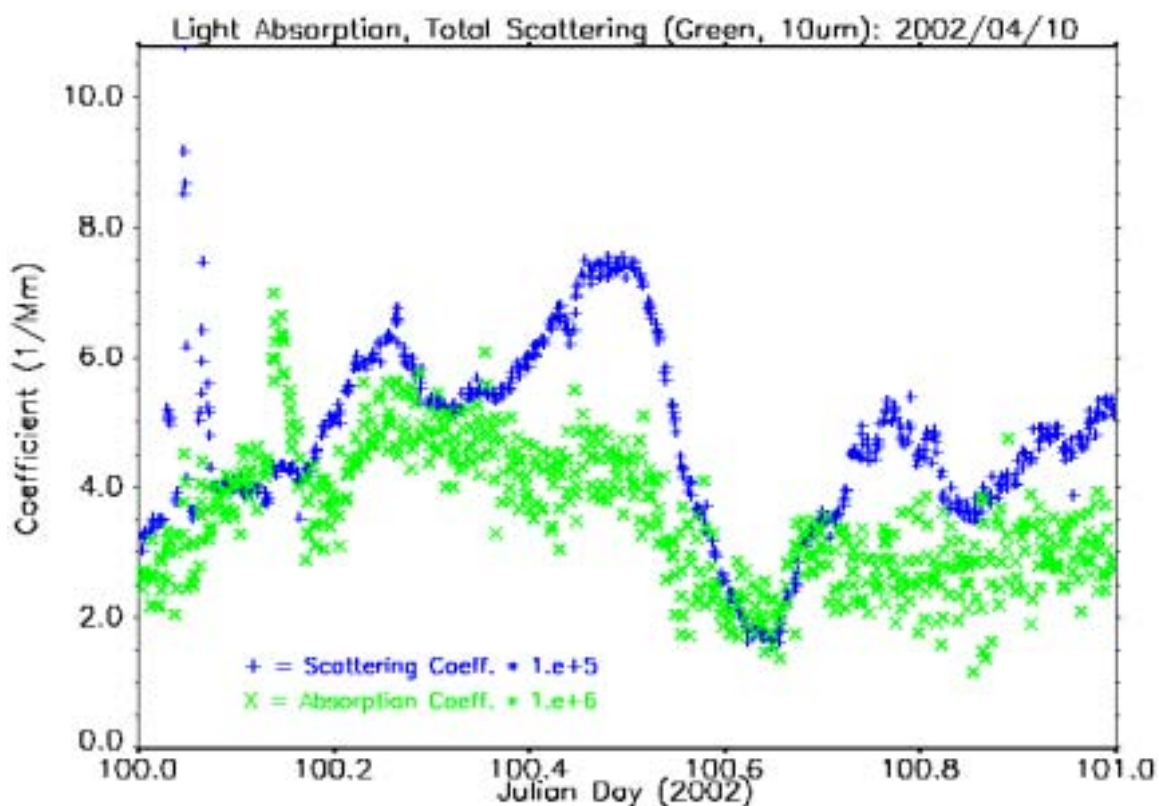
**Figure 9.** Computed Ångström exponents.

where

- D = fractional day length (0.5),
- $S_0$  = solar constant ( $1370 \text{ Wm}^{-2}$ ),
- $T_{\text{at}}$  = atmospheric transmission (0.76),
- $A_c$  = fractional cloud amount (0.6),
- $R_s$  = surface reflectance (0.15)
- $\omega_0$  = single scattering albedo
- b = backscatter fraction

## Future Work

A VAP is in progress to produce all of the aerosol intensive properties discussed in this poster. At present, this VAP requires the CMDL-supplied calibrated data set as input. ARM engineering staff are working together with the NOAA/CMDL staff to incorporate their iterative calibration procedures at the ARM site. This will permit intensive properties to be produced from the above VAP on a next-day basis. The ultimate goal is to provide high-quality calibrated aerosol absorption and scattering coefficients as well as aerosol intensive properties in an automated fashion.



**Figure 10.** Light absorption and total scattering coefficients.

This dataset will comprise a valuable contribution to BBHRP. However, these intensive aerosol properties are surface based measurements. Profiles of these or related quantities would be even more relevant to the BBHRP. The Aerosol Working Group has provided recommendations for combining these products with profiling instrumentation such as the in situ aerosol profiling aircraft (IAP), Raman Lidar, and MPL to address this need.

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## References

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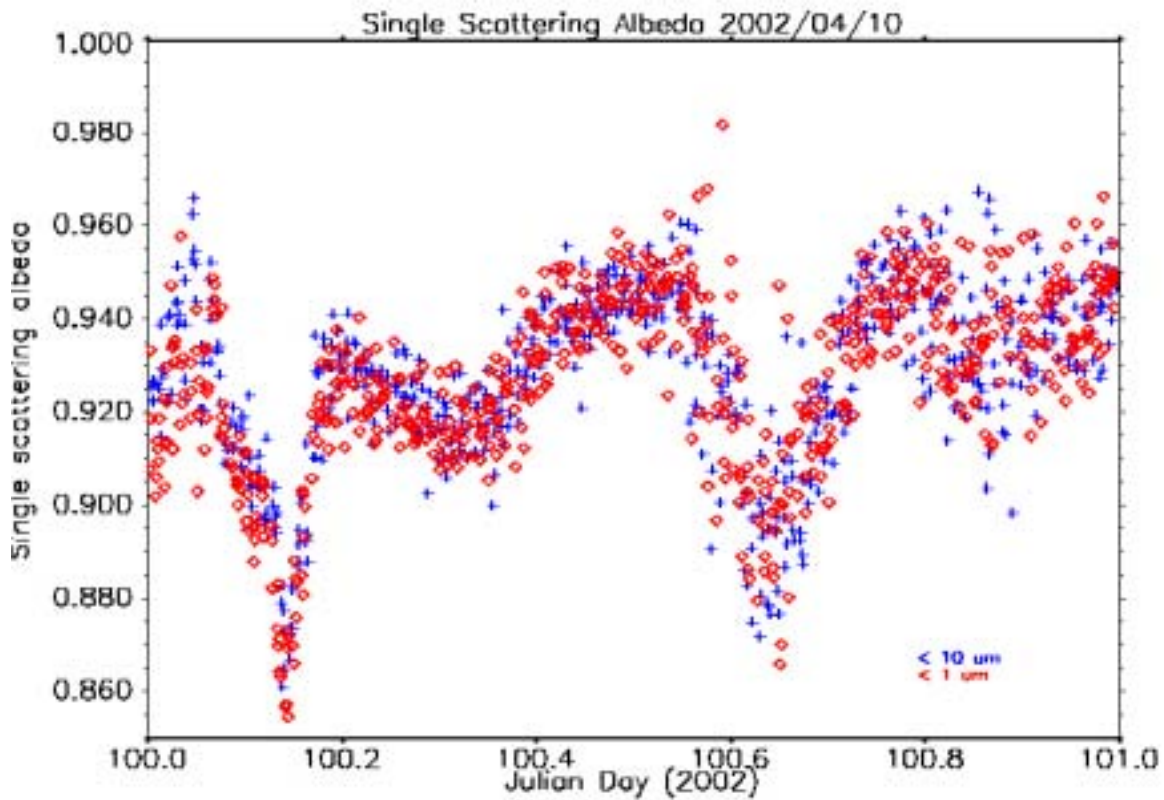


Figure 11. Computed single-scattering albedo.

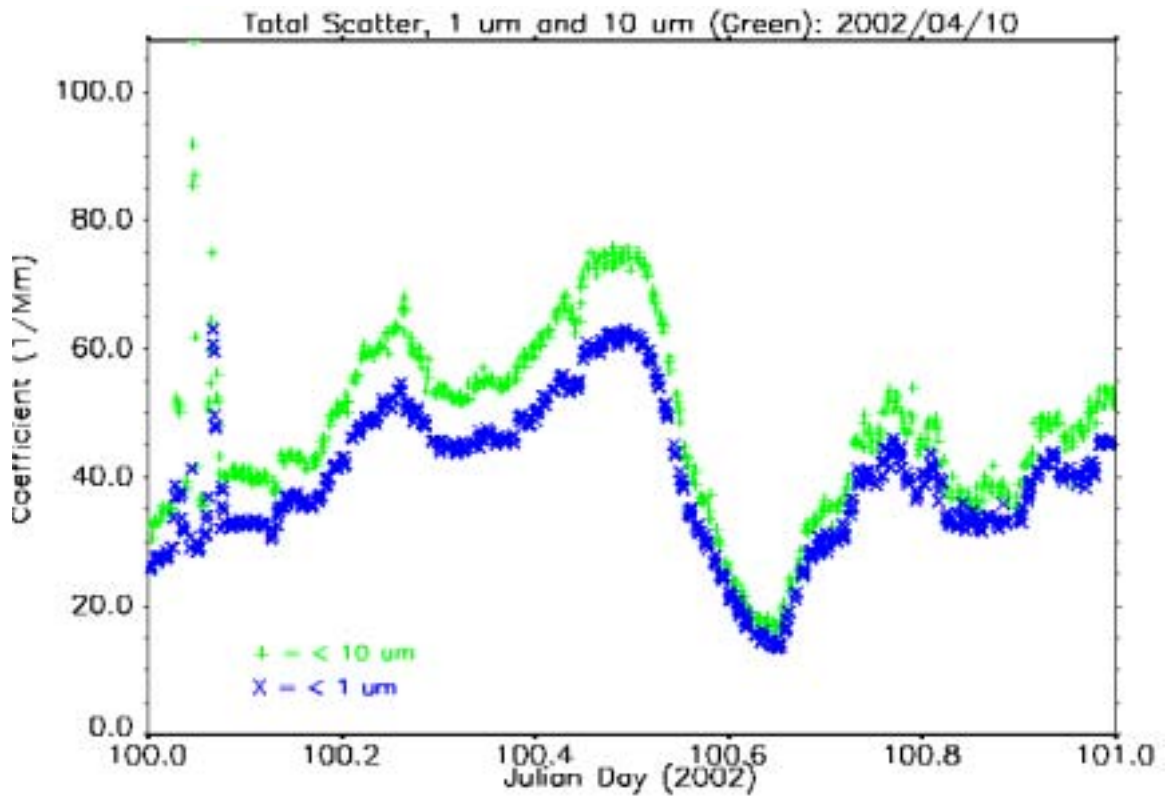


Figure 12. Total scattering coefficients, 1 μm and 10 μm.

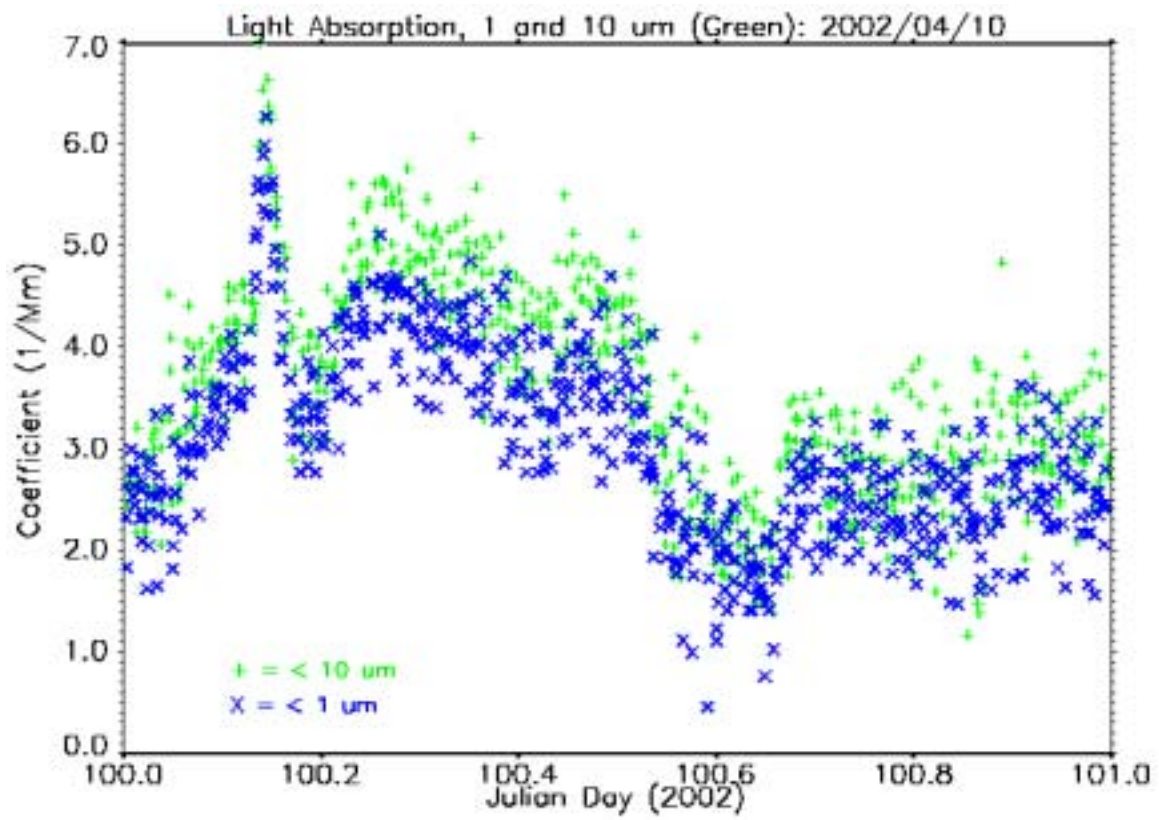


Figure 13. Light absorption, 1  $\mu\text{m}$  and 10  $\mu\text{m}$ .

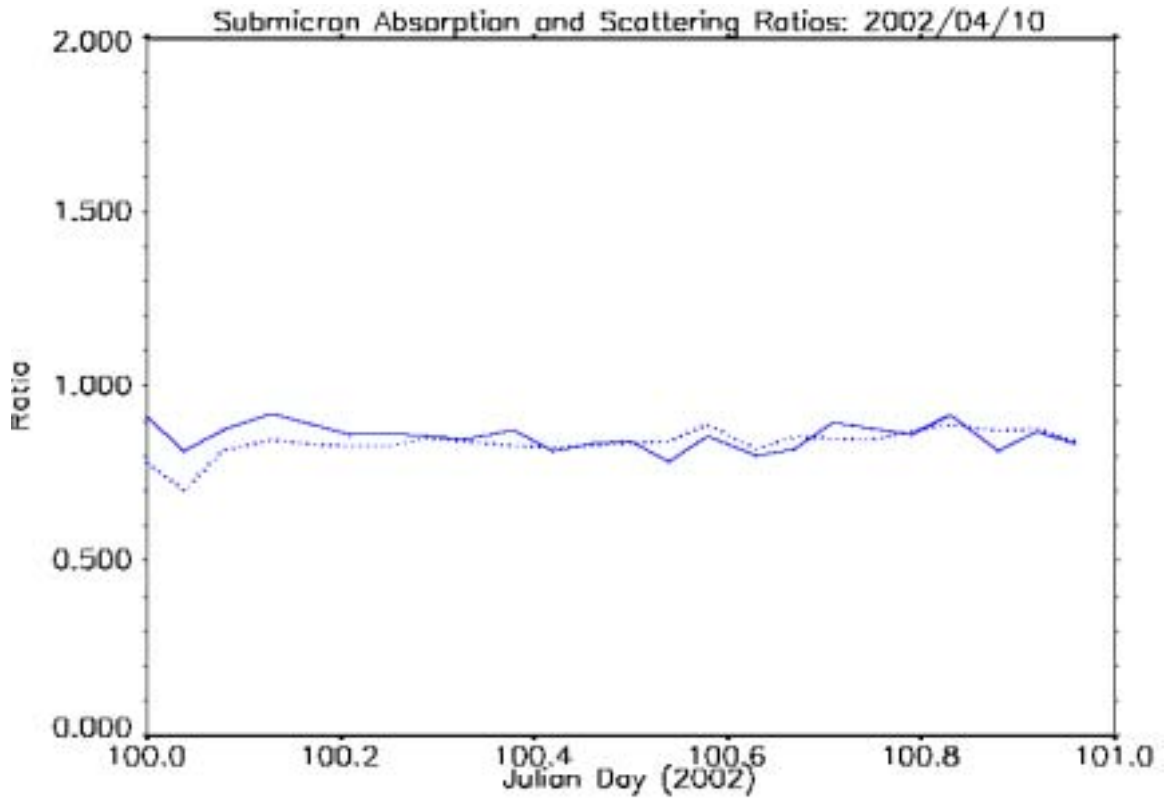


Figure 14.  $R_{ap}$  and  $R_{sp}$ .