Calibration of the Passive Cavity Aerosol Spectrometer Probe, Estimation of Refractive Index, and Closure of Light-Scattering Coefficients

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Introduction

Optical counters such as the Passive Cavity Aerosol Spectrometer Probe (PCASP) (PMS, Inc., Boulder, Colorado) are often calibrated with latex particles having a refractive index m = 1.588. Because refractive indices of ambient aerosols are often less than 1.588, the diameters measured by optical counters will be smaller than the real diameters. This underestimation of particle sizes will in turn cause an underestimation of calculated light-scattering coefficients. Such undersizing is a function of particle size and reaches a maximum in the region where particle sizes are comparable to the wavelength of the light used in the measurement (Stolzenburg et al. 1998). The occurrence of the maximum undersizing in this region should be emphasized because particles of this diameter are also the most efficient at scattering sunlight (Waggoner et al. 1981). Here we illustrate an approach for correcting the size distributions measured by the PCASP for the effect of the difference between the refractive index of the latex particles used in the calibration of the PCASP, and that of ambient aerosols. We demonstrate that refractive indices of atmospheric aerosols can be successfully estimated by matching the nephelometer measured-light scattering coefficients with those calculated from size distributions measured by the PCASP, and that the agreement between the measured and calculated light-scattering coefficients can be significantly improved by use of the new approach.

The formulation by Garvey and Pinnick (1983) is used to model the optical response of the PCASP

$$R(D, m) = \frac{\pi}{k^2} \int_{\theta_1}^{\theta_2} \left[|S_1(D, m, \theta)|^2 + |S_1(D, m, \pi - \theta)|^2 + |S_2(D, m, \theta)|^2 + |S_2(D, m, \pi - \theta)|^2 \right] \sin\theta d\theta \quad (1)$$

where D represents the particle diameter; m the refractive index; θ the scattering angle, with subscripts 1 and 2 representing the minimum and maximum angles over which the counter collects light; $k = 2\pi/\lambda$ the wavenumber (λ is the wavelength), and S_1 (.) and S_2 (.) the complex scattering amplitude functions corresponding to light polarized with electric field perpendicular and parallel to the scattering plane, respectively.

The calculated effect of refractive index on the response of the PCASP probe is shown in Figure 1, where the diameter ratio is defined as the ratio of the diameter measured by the PCASP to the true diameter. Also shown are data from Stolzenburg et al. (1998) in which the diameter ratio was measured by a combination of optical and aerodynamic techniques for ambient particles with refractive index estimated to be 1.45. The modeled PCASP response for a refractive index of 1.45 agrees quite well with the experimental data from Stolzenburg et al. (1998), giving confidence that our approach is correct.

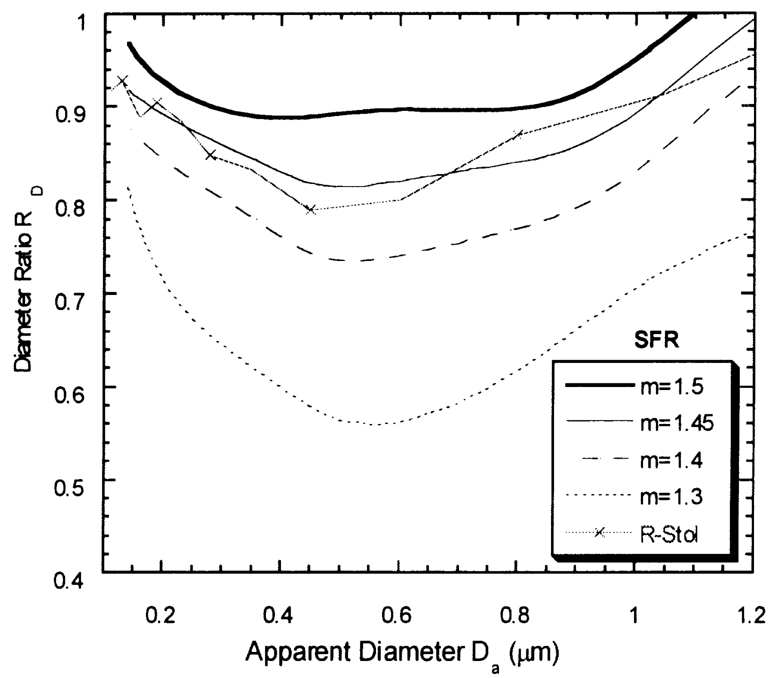

Figure 1. The ratio of the diameter measured by the optical probe to the true diameter as a function of the measured diameter for various refractive indexes. Calculations were made using the formation of Garvey and Pinnick (1983). The crosses are measurements from Stolzenburg et al. (1998).

The integrating nephelometer and PCASP data collected by aircraft during an intensive observation period (IOP) conducted at the Atmospheric Radiation Measurement (ARM) site in northern Oklahoma during April 1997 is used to illustrate the new approach for accounting for the difference between the refractive index of the aerosols used to calibrate the PCASP probe and ambient aerosols. The vertical profile data were averaged over 100 in vertical intervals. The average size distributions measured by the PCASP in these intervals were then adjusted assuming refractive indices in, of 1.3, 1.4, 1.45, and 1.5, using the data in Figure 1. For each of these modified size distributions and their associated refractive indices, the light-scattering coefficient was then calculated using Mie theory. The calculated light-scattering coefficients were then compared to the light-scattering coefficients measured by the nephelometer and the refractive index best fitting the data was chosen. Refractive indices of ambient particles estimated using this procedure were found to vary between 1.3 and 1.5, with an average of 1.41 (Table 1); this is within the range of refractive indices measured, and or estimated for ambient particles by other means. The relationship of the light-scattering coefficients measured by the nephelometer to

Table 1. Summary of estimated refractive indices.

970413a		970414b		970415a		970418a	
H(m)	m	H(m)	m	H(m)	m	H(m)	m
439	1.45	444	1.45	749	1.40	482	1.30
732	1.45	732	1.45	1069	1.40	529	1.40
1044	1.45	1057	1.45	1380	1.45	787	1.30
		1353	1.40	1686	1.45	811	1.30
		1670	1.35	1983	1.45	1121	1.30
		1971	1.35	2014	1.50	1429	1.40
		2281	1.40	2290	1.45	1735	1.40
				2314	1.45	2045	1.40
				2590	1.40	2364	1.40
				2616	1.40	2659	1.45

those calculated from the PCASP measured size distributions corrected by means of our procedure for estimating refractive indexes is shown in Figure 2. Also shown are those calculated from the measured (uncorrected) PCASP size distributions assuming a refractive index of m = 1.45. It is clear from this figure that the use of the PCASP size distributions without correction for the refractive index of the particles being measured can cause as much as ~50% error in calculation of light-scattering coefficients.

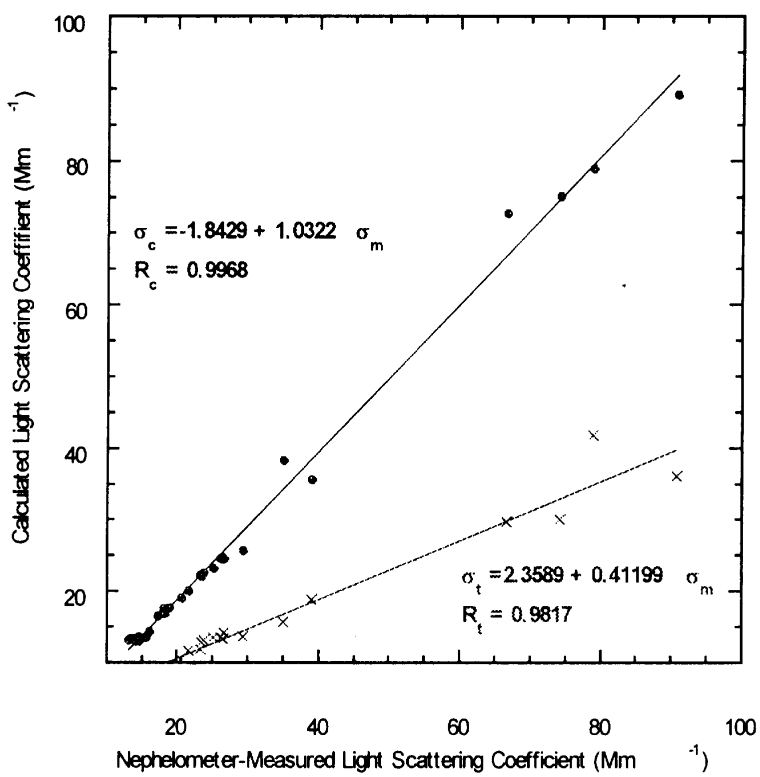

Figure 2. Comparison of light-scattering coefficients calculated using measured PCASP size distributions (crosses), and those calculated using size distributions adjusted for the effect of refractive index (closed circles).

Acknowledgments

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