Correction factors for a total scatter/backscatter nephelometer

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Abstract

Total aerosol scattering and backscattering atmospheric values are typically obtained with an integrating nephelometer. Due to design limitations, measurements usually do not cover the full (0º-180º) angular range, and correction factors are necessary. The effect of angle cutoff is examined for a range of particle size distributions and refractive indices. Scattering data for sub-micron particles can be corrected by the use of a modified Anderson approximation, while data for larger particle distributions can be approximated by a function of the effective size parameter. Such approximation will help more accurate corrections for angle range.

1 Introduction

In order to determine the influence of atmospheric aerosols on climate, visibility and photochemistry, several key aerosol properties are required. These include the aerosol light extinction, single scattering albedo, backscattering fraction and asymmetry parameter. Integrating nephelometers are well suited for this kind of measurements., but only on the condition that operation procedures are followed to minimize practical limitations. Such procedures include accurate calibration and consistent sampling practice, as well as corrections for nonlambertian and truncation errors.

In this paper, the influence of limited angular range measurement (7º-170º) on scattering and backscattering values is analyzed. The need for a correction factor to account for such truncation has been studied [1], but only a limited set of refractive indices and particle size distributions (PSD) was considered, and nonsphericity effects were neglected. An alternative approach, based on the assumption that the diffraction forward-scattering peak is the same for spherical and nonspherical particles of the same projected area, combines experimental measurements in the 5º-173º angular range with a Lorenz-Mie calculations of the forward scattering (0º-5º) peak. The resulting phase function and that determined experimentally yield similar values for the asymmetry parameter [2].

The purpose of the present work is to provide a more complete set of correction factors for scattering measurements on particle size distributions of both spheres and spheroids.

2 Theory

Light scattering values (extinction, scattering, backscattering coefficients) were calculated at five different refractive indices. Mie theory was used for spheres, and T-matrix was used for randomly oriented prolate and oblate spheroids. The numerical angle integration needed to calculate the correction factors was done by substraction of the forward (0º-7º) and the backward (170º-180º) contributions from the full integrals, e.g.:

$$C^*_{sca} = \tfrac{1}{2} C_{sca}\left(1 - \int_{0^\circ}^{7^\circ} p(\vartheta)\sin\vartheta\, d\vartheta - \int_{170^\circ}^{180^\circ} p(\vartheta)\sin\vartheta\, d\vartheta\right) \tag{1}$$

for the scattering cross section. Results were then size-averaged assuming a power-law distribution:

$$p(x) = \begin{matrix} Cx^{-3} & x_1 \le x \le x_2 \\ 0 & otherwise \end{matrix} \tag{2}$$

where x stands for the equivalent-volume size parameter in the case of spheroids. A correction ratio F_s=Csca/Csca* was adopted as a measure of the effect of angular range limitation. Instead of using integration limits (x_1,x_2), PSDs are represented by the effective size parameter x_{eff} and the effective variance $<_{eff}$, as they have been found to best characterize any plausible PSD [3]:

$$x_{eff} = \frac{\int_{x_1}^{x_2} x^3 p(x)dx}{\int_{x_1}^{x_2} x^2 p(x)dx} \qquad \nu_{eff} = \frac{\int_{x_1}^{x_2} x^2 (x - x_{eff})^2 p(x)dx}{x_{eff}^2 \int_{x_1}^{x_2} x^2 p(x)dx} \tag{3}$$

The maximum $x_{eff,}$ $<_{eff}$ values for spherical PSDs were chosen as 100 and 10, respectively. Large as they might seem, they are sometimes found airborne, for instance as the combustion products of powdered coal in a power plant, or in the aftermath of large volcanic eruptions [4]. For the case of nonspherical scatterers, computer limitations impose a maximum equivalent-sphere-volume size parameter restriction of about 61-62, thus limiting the range of effective value parameters. In all cases, light scattering parametere were calculated to a minumum accuracy of 10^{-5}.

2 Results

Correction factors for scattering F_s have been compared to the Angstrom exponent over the 8_1 to 8_2 range, defined as follows:

$$\alpha = \frac{-\ln\left[C_{sca}(\lambda_1)/C_{sca}(\lambda_2)\right]}{\ln(\lambda_1/\lambda_2)} \tag{4}$$

(for the present work, 8_1=450 nm, 8_2=700 nm). The near-forward (0-7º) scattering is quite insensitive to shape effects for moderately wide PSDs, so the dependence of nonsphericity on the correction factor can be expected to be small. This effect has been observed in our results. For all but the narrowest size distributions, F_s values for equivalent-volume-size spheroidal particle distributions are identical to those for spheres to within 1-2%. This result has been confirmed for all five refractive index values, at sizes for which T-matrix calculations converged, and for $<_{eff}$∃0.2. This supports the view that particle populations of interest can be regarded as spheres as far as scattering correction factors is concerned.

The correction factor F_s can be partially approximated in the form F_s=a+b∀ (Anderson approximation), as Fig 1 shows (∀>0.5 zone). The validity of this approximation depends on both $<_{eff}$ and *m*, and covers only the sub-micrometer size range, but the approximation itself is $<_{eff}$-independent and depends on the value of the refractive index alone. For the smallest size distributions, the correction factor can be better approximated by the Rayleigh-limit value 1.01717.

For lower ∀ values, (higher effective size parameters), an Anderson-like approximation is unworkable. The reasons are clear from Fig. 1. First, the functions become multivalued. Second, even in the case of the widest PSDs (where the curve can be represented as another lineal function), such a fitting would have a large slope, so a small uncertainty in the value of ∀ could results in large F_s errors. In those cases, the monotonic behavior of the F_s -x_{eff} curve allows for an approximation in the form F_s =a+bLn(x_{eff}) or F_s =c+d*x_{eff}, the range of validity depending on the PSD and *m* value.

The correction factor for backscattering F_b is not monotonic and cannot be easily represented by a lineal function of either x_{eff} or Ln(x_{eff}), but it is in general a small amount. For nonspherical scatterers, it has values in a small range, F_b =1.01-1.02 for nonspherical particles, as the example of Fig. 2 shows. Only for the smallest PSDs (x_{eff}<1) is a higher correction factor needed, as it slowly increases towards the Rayleigh limit 1.02314. Spherical scatterers show a larger F_b range (except the high-absorbing case, *m*=1.6+i0.6). This result suggests that a correction based on Mie theory yields worse results than not correcting at all. Only when a natural particle population can be regarded as spherical should Mie-based corrections be considered.

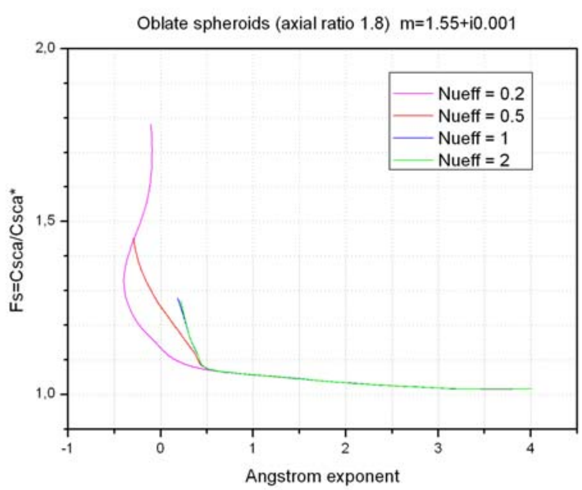

Figure 1: Scattering correction factor

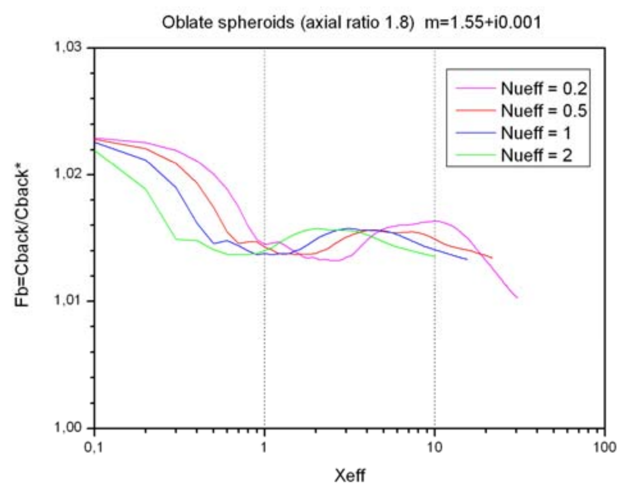

Figure 2: Backscattering correction factor

Acknowledgments

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