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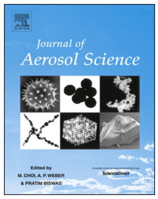

Relationship between fraction of backscattered light and asymmetry parameter

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ABSTRACT

A set of 6500 angular scattering function data have been obtained at various locations of the world: Vienna (Austria), Kyoto (Japan), Granada (Spain) and Palencia (Spain). The aerosols in these locations were considerably different, ranging from continental, urban, maritime, to desert dust. The volume scattering function has been measured between 5° and 175°, the values for 0–5° and 175–180° have been obtained by extrapolation of the shape of the curve, thus the whole range of scattering angles was available for calculating the backscattered fraction and the asymmetry parameter of the aerosol. The majority of the data points suggest an unanimous relation between backscattering and asymmetry parameter. The location where sampling took place and the type of aerosol seems to be of minor importance. These data have been compared with results of calculations for spherical or ellipsoidal particles having a lognormal monomodal size distribution of various sizes as well as several approximations for the relationship asymmetry vs backscattering available from the literature. With one exception it appears that an unanimous relation, fairly independent of location and type of aerosol, has been found between asymmetry parameters and backscattering ratio. The assumption of spherical particles seems to be a good assumption. Only for aerosols dominated by coarse mode particles the data points fall outside of the general trend, but again Mie calculations for spherical particles explain the behaviour.

1. Introduction

The fraction of backscattered light is defined as the ratio of the integral of the volume scattering function over the backward half solid angle divided by the integral of the volume scattering function over the full solid angle. It can be measured with an integrating nephelometer since it only is needed to exclude the forward scattered light by a shutter (small angular truncation occurs). On the other hand the asymmetry parameter is the integral over the full solid angle of the volume scattering function weighted with the cosine of the scattering angle divided by the integral of the volume scattering

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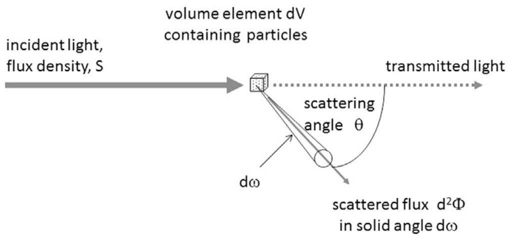

Fig. 1. Definition of the scattering function.

function. To determine the asymmetry parameter the measurement of the angular dependence of the volume scattering function is needed, which can be obtained e.g. with a polar nephelometer.

The asymmetry parameter is an important input parameter for radiative transfer calculations in order to obtain information of effects of the atmospheric aerosol (climate, screening, visibility, and others). Unfortunately measurements of the asymmetry parameter of the atmospheric aerosol are scarce. It is obvious, that a relation between the asymmetry parameter and the backscattered fraction should exist: the smaller the backscattered fraction, the more asymmetric the scattering, thus the larger the asymmetry parameter.

2. Definitions

A volume element dV be illuminated by parallel light with flux density S, see Fig. 1. The light flux $d^2\Phi$ scattered by the particles of this volume element into a cone of angular extent $d\omega$ in the direction characterized by the scattering angle θ (which is the angle between the considered direction of the scattered light and the direction of the transmitted light) is $d^2\Phi = S \cdot \gamma(\theta) \cdot dV \cdot d\omega$ with $\gamma(\theta) = \frac{d^2\Phi}{S \cdot dV \cdot d\omega}$ the volume scattering function. Rotational symmetry around the direction of the incident light beam is assumed. This is the case for spherical particles or particles undergoing Brownian rotation.

Integrating the volume scattering function over the full solid angle yields the scattering coefficient $\sigma_s = \int_\omega \gamma(\theta) d\omega = 2\pi \int_0^\pi \gamma(\theta) \sin\,\theta \cdot d\theta$, which characterizes the totally scattered light by the volume element. The fraction of light scattered in the backward direction (also called hemispheric backscattering) is obtained as $b = 2\pi \int_{\pi/2}^{\pi} \gamma(\theta) \sin\,\theta \cdot d\theta \,/ 2\pi \int_0^\pi \gamma(\theta) \sin\,\theta \cdot d\theta = 2\pi \int_{\pi/2}^{\pi} \gamma(\theta) \sin\,\theta \cdot d\theta \,/ \sigma_s$. The asymmetry parameter g is obtained by weighing the volume scattering function with the cosine of the scattering angle: $g = 2\pi \int_0^\pi \gamma(\theta) \sin\,\theta \cdot \cos\,\theta \cdot d\theta \,/ \sigma_s$. For isotropic scattering or symmetric scattering such as Rayleigh scattering the asymmetry parameter is $g=0$ and $b=\frac{1}{2}$; for scattering in the forward direction ($\theta = 0$) only, we obtain $g=1$ and $b=0$, for backscattering only ($\theta = \pi$) the asymmetry parameter is $g=-1$ and $b=1$.

If the phase function $P(\theta) = 4\pi\frac{\gamma(\theta)}{\sigma_s}$ is used, the relations are as follows: $g = \frac{1}{2}\int_0^\pi P(\theta) \sin\,\theta \cdot \cos\,\theta \cdot d\theta$ and $b = \frac{1}{2}\int_0^\pi P(\theta) \sin\,\theta \cdot d\theta$. Both the asymmetry parameter, the backscattered fraction, and the phase function are intensive parameters of the aerosol. The scattering coefficient and the volume scattering coefficient can be made intensive by dividing by the density of the aerosol (i.e. mass of particles per volume of air), yielding the specific scattering coefficient, or more systematically the specific cross section and the specific volume scattering coefficient. The usual units are $m^2\,g^{-1}$ and $m^2\,g^{-1}\,sr^{-1}$.

For an aerosol the scattering coefficient can be measured e.g. with a nephelometer, or calculated when knowing the size distribution, shape, and refractive index of the particles. The scattering coefficient is an extensive property, depending on the size of the system (e.g. the mass of particles per unit volume). Dividing the scattering coefficient σ_s by the mass m of the particles per volume of suspended medium, the specific scattering cross section $\left(\frac{d\sigma_s}{dm}\right)$ is obtained. The scattering coefficient of an aerosol of mass m per volume and specific scattering cross section $\left(\frac{d\sigma_s}{dm}\right)$ is obtained as $\sigma_s = m \cdot \left(\frac{d\sigma_s}{dm}\right)$.

3. Instruments and methods

The volume scattering function is obtained with a polar nephelometer. Its design is similar to Waldram (1945). In principle it uses the definition of the volume scattering function (see Fig. 1). The scattering volume is illuminated by a green laser (532nm, 20mW) and the flux of scattered light is measured by a photodetector (photo multiplier in photon counting mode), which rotates from 5.5° to 172.5°. A scan starts at 5.5° going to 172.5° and back in intervals of 5°, but uses smaller intervals in the near forward and backward region. The volume scattering function is obtained by averaging the forward and the back scan, rejecting measurements with discrepancies between the scans in the two directions. Calibration of the nephelometer is done by a Rayleigh scattering gas, in particular CO_2. The instrument thus can measure the volume scattering coefficient for scattering angles between 5.5° and 172.5°. For the determination of the backscattered fraction and the asymmetry parameter the volume scattering function has to be extrapolated to 0° and 180°, a common problem (Middleton, 1968). Only a small angular range of the scattering function cannot be determined by the polar nephelometer used in this study, therefore the extrapolation is possible with a high degree of accuracy; the shape of the measured curve can be used as