The Effect of Particle Size, Composition, and Shape on Lidar Backscattering

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Abstract

The optical properties of urban aerosol particles are calculated using exact methods at 910 nm wavelength under different assumptions about particle composition and shape. Results show that spherical particles backscatter light on the average about 40 percent more than the corresponding nonspherical particles, the difference generally being larger for larger particles. In contrast, changing the particle composition from water to silicate increases backscattering by about a factor of three. Typical values for absorptivity seem to have negligible impact on backscattering.

1 Introduction

Accurate modeling of light scattering properties of aerosol particles is essential to conduct reliable remote sensing observations. Although it is well known that the scattering properties of nonspherical particles can be significantly different from those of spherical particles, assumption of spherical particles is still widely used in remote sensing applications. This can lead to large errors when retrieving aerosol optical properties with lidar inversions, especially if dust particles are present (e.g [1]).

The aim of this work was to study the effect of particle size, shape, and composition on lidar backscattering in an urban environment. On one hand, sensitivity studies based on optical modelling were conducted to estimate the relative importance of different physical factors affecting backscattering of light by aerosol particles. On the other hand, modeled backscattering values were compared with lidar measurements. To facilitate the comparison, the lidar measurements were conducted in a vicinity of aerosol in situ measurement site.

2 Methods

A lidar measures backscattering that is the sum of all scatterers - air molecules, aerosol particles and hydrometeors - within the measurement volume. To solve the lidar equation (e.g. [2]), the relation between volume backscattering coefficient β, and volume extinction coefficient σ has to be known. Physically β describes how much light is scattered in the backward direction from a measurement volume and is defined ultimately by particles' phase function and scattering cross section. Similarly, σ describes the total amount of energy removed from the incident field and is defined by particles' extinction cross section. Most common solution to the lidar equation is to assume a linear relation between β and σ, which is usually called the lidar ratio R (e.g. [2]).

To study how physical properties of aerosol particles affect the lidar signal (or β, σ, and R), we need to know how the optical properties of the particles (e.g. phase function, scattering and extinction cross sections) depend on their physical properties, i.e. particles' composition and shape. For simplicity, the effect of particle composition was only studied for spheres. Mie simulations were carried out varying both the real and the imaginary part of the refractive index. For the real part, values of 1.5 and 1.3 were used. The former value is representative of many dust aerosol types as well as sea salt and ammonium sulphate, whereas the latter is close to that for liquid water. For the imaginary part, values of 0.0 and 0.001 were used. The former is used for nonabsorbing aerosol, whereas the latter is considered a representative effective value for the expected mixture of the aerosol in Urban Helsinki.

Likewise, when the effect of particle shape was studied, particle composition was assumed to be fixed. Since no shape information was available, a modeling approach for solid urban aerosol particles could not be developed. Thus, we assumed that their optical properties can be computed using the modeling approach for dust aerosol as in [3]. The optical properties of irregularly shaped urban aerosol particles were described by a distribution of randomly oriented spheroids. As suggested in [3] for dust particles, we used the shape distribution that weights most heavily the most elongated spheroids in the distribution.

The measurements were conducted at the Kumpula campus of the University of Helsinki, which is located in a heterogeneous urban area about 5 km away from the center of Helsinki. The lidar measurements were carried out using a vertically pointing Vaisala CL31 ceilometer, which is an elastic backscatter lidar that operates at 910 nm wavelength. Particle *In Situ* measurements at ground level were conducted 250 m from the lidar site. Aerosol size distributions were obtained by combining results from two different instruments (Differential Mobility Particle Sizer DMPS and Aerosol Particle Sizer APS) that together covered particle diameters ranging from 3 nm to 20 µm.

3 Results

Three rainless days from summer 2005 were selected to these sensitivity studies. For each day the effective radius r_{eff} and variance υ_{eff} from the measured size distribution was calculated, as well as the values of β, σ, and R. In addition the value of β measured with lidar was determined.

Both the composition (excepting absorption) and shape had a substantial effect on backscattering. The values of β, σ, and R for water droplets were on average 0.33, 0.53, and 0.62 times the values for spherical silicates, respectively. Similarly, for nonspherical particles the values of optical parameters were on average 0.60, 0.79, and 0.76 times the values for spherical particles. In Fig. 1 the difference in these quantities due to composition and shape are expressed as a water/silicate and nonspherical/spherical ratios. In both cases the results also depended on the particle size but in different way. The effect of composition on σ increased with decreasing values of r_{eff}, whereas the effect of particle shape on β increased with increasing values of r_{eff}.

In addition theoretically calculated values for β were compared with backscattering measured with lidar, denoted as β_{meas}. To define only the aerosol contribution to β_{meas} , backscattering from hydrometeors and molecules had to be excluded. The molecular contribution to β_{meas} was assumed to be constant, at sea level and at 910 nm wavelength $1.855 \cdot 10^{-7}$ $m^{-1}srad^{-1}$ [4]. Hydrometeors were excluded simply by choosing to study days when no rain, drizzle or mist was observed. The comparisons revealed that theoretically calculated values for β were on average 3.6 and 2.1 times higher than β_{meas}, if aerosol particles were assumed to be spherical or nonspherical silicates, respectively.

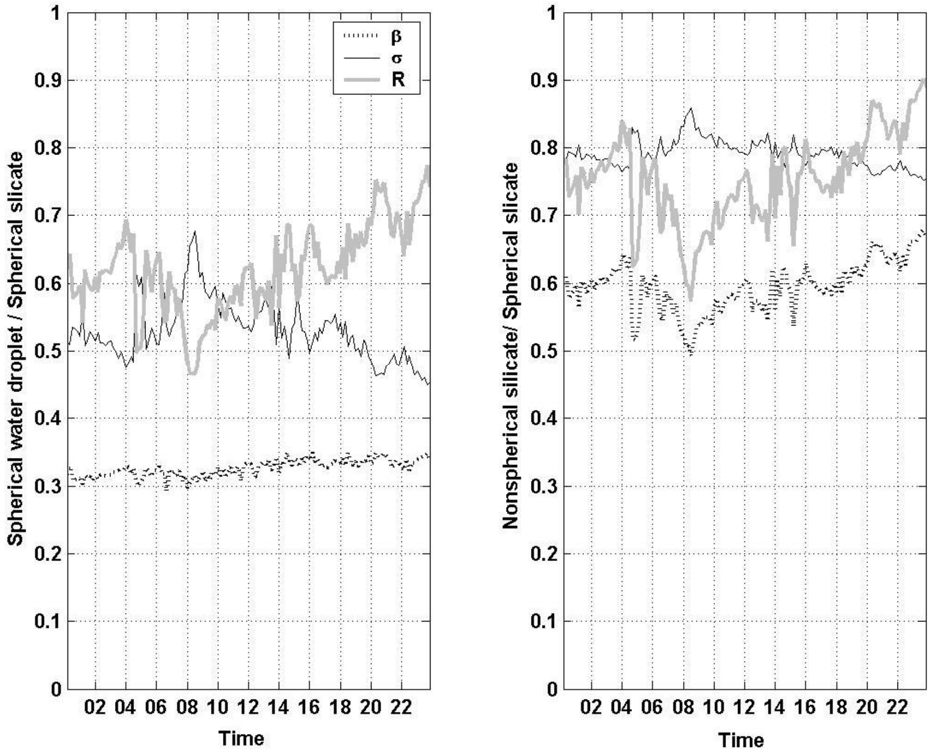

Figure 1. The effect of particle composition (right panel) and shape (left panel) on theoretically calculated *β*, *σ*, and *R* during one example day, represented as a water/silicate and nonspherical/spherical ratios. For water droplets the value of refractive index was *m*=1.3+*i*0.0 and for silicates *m*=1.5+*i*0.0.

4 Conclusion

Results showed that particle composition (with the exception of absorption) and shape had substantial effect on backscattering. A connection of these effects to the variation in size distribution was also observed.

The agreement between theoretically calculated and lidar measured backscattering was found to be better for nonspherical than for spherical silicates. It should be noted, however, that such a comparison is meaningful only if the in situ-measured particle size distribution can be considered representative for the particle size distribution in the lidar's measurement volume. In our case, this depends not only on possible local aerosol sources, but also on ambient meteorological conditions. Further, differences could be caused by calibration-related issues related to lidar, or an uncertain sampling efficiency for the DMPS and APS instruments.

References

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