Impact of particle shape on composition dependence of scattering

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Abstract

The impact of particle shape on how scattering depends on the refractive index m is studied. The goal is to find out whether spherical model particles provide an accurate estimate for the m-dependence of scattering by nonspherical particles. The results indicate that this is very unlikely especially when small m intervals are considered.

1 Introduction

The assumption of spherical shape is still widely used in many applications where the single-scattering properties of nonspherical particles are involved. For example, all climate models presently use aerosol optics based on spherical aerosol particles. Kahnert et al.[1] show that this is likely to be a major error source in climate simulations.

The same spherical-particle approximation (SPA) is also used when estimating the impact of other error sources connected to aerosol particles, such as their uncertain refractive index m. The m-uncertainty has been considered the single most important source of error in assessing the direct climate forcing effect of dust aerosols[2]. This conclusion has been reached by use of the SPA, yet it is altogether unclear how well spherical model particles can represent the m-dependence of scattering by nonspherical particles. The shapes of dust particles vary, and it seems plausible to expect a shape distribution to smooth out different dependencies, implying that the SPA might over-estimate the m-dependence. The purpose of the present study is to assess the m-dependence of nonspherical particles and the ability of the SPA to estimate it.

2 Modeling aspects

To address the issue, the m-dependence of scattering was computed for a variety of spheroids, including spheres. Scattering simulations were carried out using the T-matrix implementation of the exact Extended Boundary Condition Method by Mishchenko[3].

The computations were performed for four different size parameters, 17 different shapes, and 14 different refractive indices (seven different values for both the real and the imaginary part of the refractive index, one being fixed when the other was varied). The values used are given in Table 1. The size parameter $x = kr$, where k is the wavenumber

Table 1: Parameters defining the properties of model particles used in the simulations.

Parameter	Values
x	1, 5, 10, 20
$\mathrm{Re}(m)$	1.45, 1.50, 1.55, 1.60, 1.65, 1.70, 1.75
$\mathrm{Im}(m)$	0.0001, 0.0002, 0.0005, 0.001, 0.002, 0.005, 0.01
ϵ	1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6

in vacuo, was based here on the surface-equivalent radius r; control runs with volume-equivalent radius in selected test cases showed that the results of the investigation are not significantly affected by the choice of size equivalence. The spheroid shapes were defined using the aspect ratio ϵ, which is the ratio of major-to-minor axis. The same ϵ were used for both oblate and prolate spheroids. A narrow, uniform size distribution within $\pm 1\%$ of the speficied size was used to damp interference effects.

3 Results

The analysis described here is limited to the asymmetry parameter g, which is an important parameter for radiative fluxes and sensitive to particle shape.

The results showed that the m-dependence of g varies for different spheroids. For many spheroids it was actually stronger than for spheres, so it was not obvious that the dependence would be weaker for a shape distribution of spheroids than for the corresponding spheres. To address that, two different shape distributions were used for shape averaging, an equiprobable and a weighed shape distribution. In the former, all different spheroids were added together by weighing only by their corresponding scattering cross sections. The latter is the '$n = 3$' shape distribution introduced in [4], which gives much more weight to strongly elongated spheroids, and appears to mimic single-scattering properties of an ensemble of irregularly shaped particles quite well.

Figure 1 shows the results obtained regarding the dependence on the imaginary part of the refractive index, $\mathrm{Im}(m)$. It is seen that for $x \leq 5$, g depends on $\mathrm{Im}(m)$ similarly in each case. For $x \geq 10$, both distributions of spheroids are more sensitive to $\mathrm{Im}(m)$ than the sphere is. In each case, g is a monotonic function of $\mathrm{Im}(m)$.

Figure 2 illustrates the dependence of g on the real part of the refractive index, $\mathrm{Re}(m)$. Again, for $x \leq 5$, the dependence is simple and monotonous, but now it is spheres that show higher sensitivity (quite extreme at $x = 5$, actually). For larger x the dependencies become more complicated; neither spheres nor spheroids show monotonic dependence. At $x = 10$, the dependence for the weighed spheroid distribution seems to have the opposite sign to that for spheres or the equiprobable shape distribution of spheroids. At $x = 20$ both spheroid distributions have only a weak g-dependence on $\mathrm{Re}(m)$, g decreasing with increasing $\mathrm{Re}(m)$, while g for spheres is a non-monotonous and quite varying function of $\mathrm{Re}(m)$.

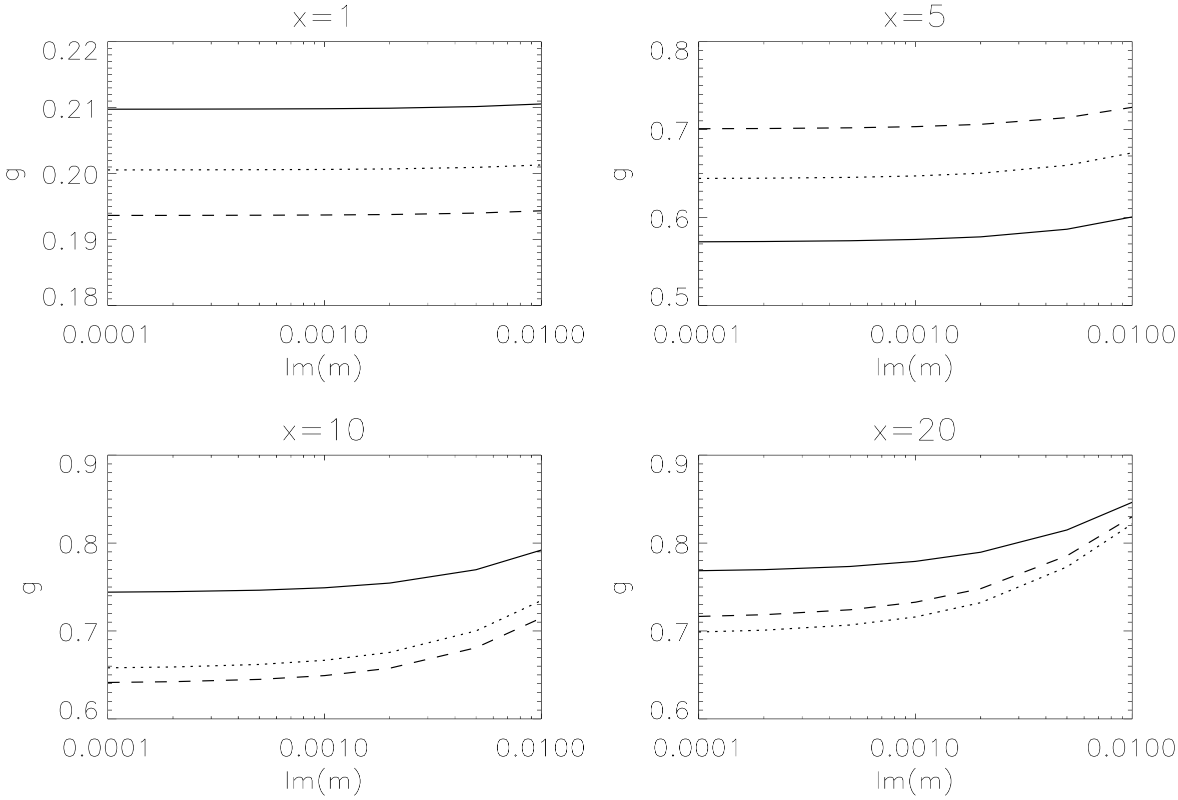

Figure 1: Dependence of the asymmetry parameter g on the imaginary part of the refractive index, Im(m), for spheres (solid line), equiprobable shape distribution (dotted line), and weighed shape distribution (dashed line).

4 Conclusions

The results show that, somewhat surprisingly, the dependence of the asymmetry parameter g on the refractive index m is not necessarily stronger for spheres than for a shape distribution of spheroids. Spheroids appear to be more sensitive to changes in Im(m) than spheres are, whereas for Re(m) the opposite tend to be true. Moreover, the dependence of g on m seems to depend much on the size parameter x.

However, the m-dependence of g is much more consistent and conservative for spheroids than for spheres. This is especially true for the dependence on Re(m) at large x, where g for spheres can change very fast as a function of Re(m). Thus, for example, if one uses spheres to estimate how much an uncertainty in m affects the impact of non-spherical particles on radiative fluxes, the result obtained may even have the wrong sign. Of course, in most practical applications one need to consider dependencies over a size distribution, which is likely to improve the performance of spheres to some degree.

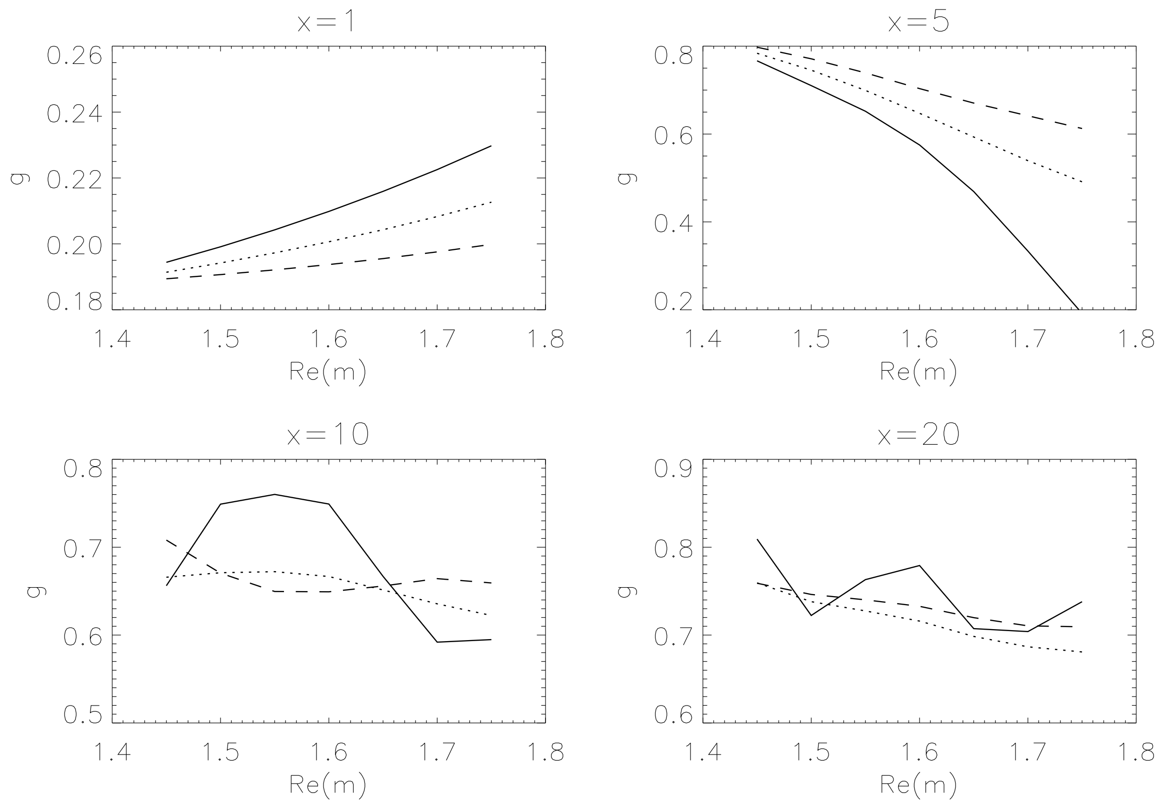

Figure 2: Same as Fig. 1 but for the real part of the refractive index, Re(m).

References

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