

SENSITIVITY OF RADIATIVE IMPACT OF DUST TO PARTICLE SHAPE: COMPARISON OF SPHERES AND SPHEROIDS

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ABSTRACT. The shortwave radiative impacts of dust based on spherical and spheroidal dust particles are compared. For spheroids, two different shape distributions are considered. The size distribution, optical thickness, and the solar zenith angle are varied and the dust is assumed to reside over an ocean. At the top of the atmosphere the radiative impact computed with spheres and spheroids differs by up to 12%.

1. Introduction

Mineral dust particles play an important role in Earth's climate system through their direct and indirect radiative effects. However, there are still large uncertainties in the optical properties of dust particles and thus also in their radiative impacts. These are due to our inability to determine accurately their sizes, shapes, concentrations, and spatial distributions, as well as difficulties in modeling their single-scattering properties accurately.

Various in situ and laboratory measurements reveal that light scattering by desert dust aerosols differs significantly from that based on spherical model particles [1]. However, in climate and radiative transfer simulations, and in remote sensing applications, these particles are often described using spheres. Recently, considerable efforts have been made to quantify the error caused by modeling optical properties of nonspherical particles using spheres. For example, several studies indicate that model particles as simple as spheroids can reproduce the optical properties of dust particles significantly better than spheres. In particular, a shape distribution of spheroids that gives more weight to the aspect ratios that deviate most from the sphere describes the laboratory-measured scattering matrices of dust better than the often used equiprobable shape distribution [2]. The impact of nonsphericity on remote sensing applications by using spheroids have been investigated by, e.g., [3]. Here, we investigate how much the shortwave radiative impacts of dust differ when based on spherical or spheroidal model particles.

2. Modelling approach

Two different shape distributions of spheroids are considered, one based on equiprobable weights for all spheroids “the $n = 0$ distribution” and the other giving more weight

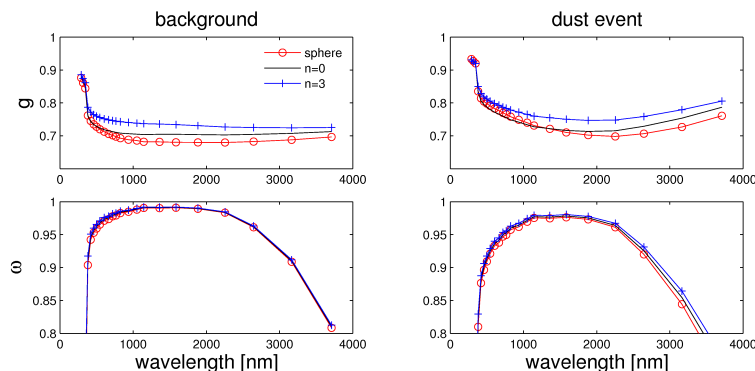


Figure 1. Asymmetry parameter (g) and single-scattering albedo (ω) of spheres and shape distributions of spheroids in the background and dust event cases as a function of wavelength.

to spheroids with larger elongation “the $n = 3$ distribution” [2]. Altogether 19 aspect ratios of spheroids, varying from 1.0 to 2.8 with increments of 0.2 for both oblates and prolates, are used for their shape distributions. Likewise, two lognormal size distributions with geometric standard deviation of 2.0 and effective radii $r_{\text{eff}} = 1.5 \mu\text{m}$ (background) and $r_{\text{eff}} = 4.0 \mu\text{m}$ (dust event) are used. The single-scattering properties of dust are obtained from a database by [4]. In this study, 18 wavelength bands covering the wavelength range from 0.28 to $4 \mu\text{m}$ are considered. The dust refractive indices are taken from the ECHAM-HAM model.

The shortwave radiative fluxes are simulated using the libradtran radiative transfer package [5]. The radiative impact of dust is obtained by taking the difference between corresponding fluxes in dusty and dust-free simulations and it is considered here at the surface and at the top of the atmosphere (TOA). In the simulations the dust cloud is assumed to reside over ocean, to be both horizontally and vertically homogeneous, and to extend from the ground up to 3 km altitude. In addition, its vertically integrated optical thickness for spheres at wavelength of 545 nm is fixed at $\tau_1 = 0.1$ or $\tau_2 = 0.3$ in the background case, and $\tau_3 = 1.0$ or $\tau_4 = 3.0$ in the dust event case. At other wavelengths and for other shapes, τ varies according to their respective extinction cross sections C_{ext} .

3. Results

Asymmetry parameter (g) and the single-scattering albedo (ω) of spheres and two different distributions of spheroids in background and dust event cases are illustrated in Fig. 1 as a function of wavelength. As can be seen, both g and ω are largest for the $n = 3$ distribution, and in the dust event case g of the $n = 0$ distribution and spheres intersect at short wavelengths.

Figure 2 shows the simulated broadband radiative impacts at the TOA and at the surface, as well as the impact on the atmospheric absorption for all the studied shape distributions, in both the background and dust event cases as a function of solar zenith angle (sza). It is

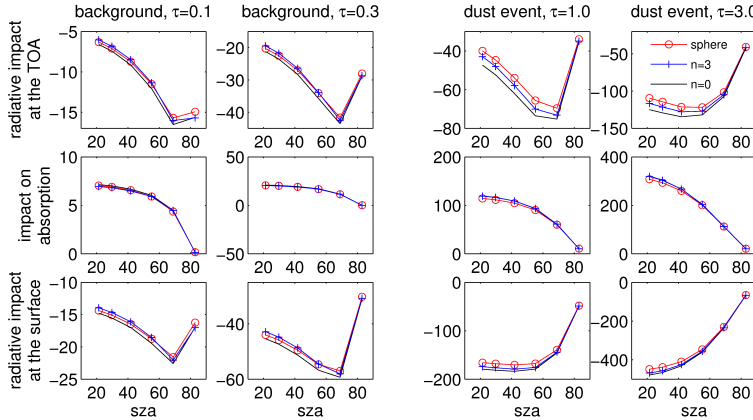


Figure 2. SW radiative impact [W/m^2] of dust at the TOA and at the surface as well as the atmospheric absorption [W/m^2] as a function of the solar zenith angle.

noted that the impacts have a strong dependence on *sza* and the differences between the shapes get smaller when the *sza* increases. In the background case, forcings obtained by using spheres and the $n = 3$ distributions can intersect. Thus, at small r_{eff} the effect of nonsphericity on the radiative impacts can be either positive or negative, depending on the spheroids' shape distribution adapted.

Table 1 shows how much the diurnally averaged shortwave radiative impact of dust obtained by using the $n = 0$ and $n = 3$ shape distributions of spheroids differs from that obtained by spheres. Both the absolute ($\Delta F_{\text{spheroids}} - \Delta F_{\text{sphere}}$) and relative differences ($[\Delta F_{\text{spheroids}} - \Delta F_{\text{sphere}}] / \Delta F_{\text{sphere}}$) are shown. Of the spheroidal cases, the $n = 0$ distribution yields fluxes that differ more from spheres, and the differences are larger when the dust cloud is optically thicker. In addition, the particle shape has stronger influences on the radiative impacts in the dust event than in the background case: At the surface and at the TOA the influences vary between -1.5 and -8.5 W/m^2 in the dust event case, and between -1 and 0.1 W/m^2 in the background case. Atmospheric absorption is generally higher for the non-spherical shape distributions due to their larger cross-sectional areas. This is especially true in the dust event case, where the absolute differences to the spherical distributions range from 1.4 to 2.7 W/m^2 . However, it is noted that the radiative impacts of dust are also much smaller during background case (less than 25 W/m^2 for spheres) than during the dust events when the impact can reach almost 50 W/m^2 at the TOA and up to 160 W/m^2 (for spheres) at the surface.

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Table 1. The difference in atmospheric absorption (Abs) and radiative impacts at the TOA and the surface between the $n = 0$ and $n = 3$ shape distributions and spheres in the background (τ_1 and τ_2) and the dust event (τ_3 and τ_4) cases.

		TOA [W/m ²]	Abs [W/m ²]	Surface [W/m ²]
τ_1	$n = 0$	-0.26 (4.8%)	0.04 (1.7%)	-0.32 (3.8%)
	$n = 3$	-0.01 (0.1%)	-0.02 (-0.6%)	+0.01 (-0.1%)
τ_2	$n = 0$	-0.63 (4.4%)	0.12 (1.6%)	-0.81 (3.4%)
	$n = 3$	+0.07 (-0.5%)	-0.05 (-0.7%)	+0.13 (-0.6%)
τ_3	$n = 0$	-3.15 (12.3%)	1.42 (3.5%)	-4.92 (6.9%)
	$n = 3$	-1.60 (6.2%)	1.47 (3.6%)	-3.30 (4.6%)
τ_4	$n = 0$	-5.08 (10.0%)	2.7 (2.7%)	-8.37 (5.2%)
	$n = 3$	-2.52 (5.0%)	2.72 (2.8%)	-5.66 (3.5%)

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