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Light scattering from diatomaceous earth aerosol

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ABSTRACT

The light scattering and extinction properties of mineral aerosol are strongly affected by dust particle shape. In this work, scattering phase function and polarization profiles of diatomaceous earth aerosol are measured at a wavelength of 550 nm, and the results are compared to *T*-matrix theory based simulations using uniform spheroid models for the particle shape. The particle shape distribution is determined by spectral fitting of the experimental infrared (IR) extinction spectral line profile for diatomaceous earth dust. It is found that a particle shape model that peaks toward both extreme rod-like and disk-like shapes results in the best fits to the IR spectral data. This particle shape model is then used as a basis for modeling the visible light scattering properties. While the visible simulations show only modestly good agreement with the data, the fits are generally better than those obtained using more commonly invoked particle shape distributions.

1. Introduction

Northern Africa is the largest source of atmospheric mineral dust, contributing an estimated 1087 Tg of dust per year to the global dust budget [1], and much of that originates from the Bodélé Depression in northern Chad [2–4]. Atmospheric dust can greatly affect the earth's radiation balance and climate [5]. However, in order to understand and accurately model dust radiative transfer effects, the light scattering and extinction properties of the dust particles must be known. The purpose of this work is to measure and model the optical properties of a sample of diatomaceous earth, which is a major mineral component of the dust from the Bodélé Depression [2,4].

Diatomaceous earth (DE), also called diatomite, consists of the skeletal remains (frustules) of diatoms, microscopic one celled organisms that can live in both fresh water and salt water [6,7]. These skeletal remains consist primarily of hydrated amorphous silica ($SiO_2 \cdot nH_2O$) [7]. DE particles can have intricate structures with very complex shapes ranging from thin plates to sharp rods (vide infra).

Particle shape can have a huge impact on the optical properties (light scattering and extinction) of mineral dust in both the IR and visible regimes. If dust particle shape effects are not properly accounted for, large errors can occur in climate forcing calculations or when modeling remote sensing data from space or ground based platforms [8–17]. Many theoretical models used to simulate the optical properties of mineral dust assume a relatively moderate range of particle shape factors [18]; some even use Mie theory which simply assumes the particles to be spheres [19]. However, previous studies have found that in order to accurately model the optical properties of several of the most common constituents of atmospheric mineral dust, more extreme particle shapes must be included in the analysis [20–23]. For example, Kleiber et al. [23] used *T*-matrix theory to model the optical properties of quartz aerosol where it was found that fitting the infrared (IR) extinction spectra required a broad distribution of prolate and oblate spheroids with highly eccentric shape factors.

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Furthermore, simulations of the visible scattering properties, based on the particle shape distribution deduced through IR spectral analysis, showed good agreement with the measured phase function and linear polarization profiles for the quartz sample [20]. This led to the suggestion that fitting IR extinction spectral line profiles could give insight into the particle shape distributions needed to model other optical properties.

It should be noted that there is a great deal of uncertainty about whether the particle shape distributions determined through fitting the optical properties are related to the actual physical shapes of the particles. Indeed, there is compelling evidence to suggest that no such simple correlation exits [24]. However, in some cases, such as for clay particles in the accumulation size mode, there is evidence that indicates that a correlation may exist between the measured mineralogical properties of small silicate clay particles and the particle shape distributions deduced from the optical properties [21].

The purpose of this study is to measure the visible scattering properties of silaceous diatomaceous earth including the scattering phase function and the linear polarization profiles at a wavelength of 550 nm. An additional goal is to test if the spectral modeling approach used by Meland et al. [20] for analysis of the quartz dust optical properties may be extended to the case of diatomaceous earth. Using *T*-matrix theory with the spheroid approximation, simulations of the IR extinction spectra and visible scattering properties for DE will be compared with experimental data. An “IR based” particle shape distribution will be determined by optimizing the fit of the simulation to the experimental IR extinction spectra. This IR based shape distribution will then be applied to visible simulations for comparison to the experimental measurements as a test of the method. The results will also be compared with simulations using a more commonly applied equiprobable distribution of moderate shape factors [18], and with the particle shape distribution previously optimized for quartz [20], since quartz and DE are related tectosilicate minerals [6].

2. Experimental methods and results

A description of the experimental setup has been given by Curtis et al. [25]. Briefly, an aerosol flow of diatomaceous earth is directed through a visible light scattering chamber for measurements of the scattered light intensity and polarization at 550 nm. Infrared extinction data for DE aerosol has been taken from Laskina et al. [26]. The particle size is limited by the flow system to a maximum volume equivalent diameter of ~2.5 μm. Aerosol size distributions are measured concurrently with the optical properties measurements in the IR and visible. It is important that the size distribution and the optical measurements be carried out simultaneously because the particle size distribution varies somewhat with time and with different aerosol flow conditions. For these studies the DE sample was found to have mass weighted mean diameter $MWMD = 0.88\ \mu m$ for the IR experiments and $MWMD = 0.56\ \mu m$ for the visible experiments. Aerosol samples were also collected from the particle flow in order to obtain scanning electron microscope (SEM) images using a Hitachi S-4800 instrument.

The DE sample used in this study was purchased commercially from Alfa Aesar (Item 89381). The sample is used as a simulant that reflects the general characteristics of DE field samples from the Bodélé Depression of North Africa. An SEM image of the DE aerosol sample is shown in Fig. 1. As seen in this image, diatomaceous earth particles can have extremely complex structures and include both extreme rod-like and disk-like particle shapes. Some of the plate-like particles also have obvious regular hole patterns. Other particles show clear evidence for fine scale surface roughness. These are among the most complex and intricate particle shapes that we have observed in our studies of mineral dust properties.

Experimental data for the IR spectra of DE have been previously published by Laskina et al. [26] and are shown

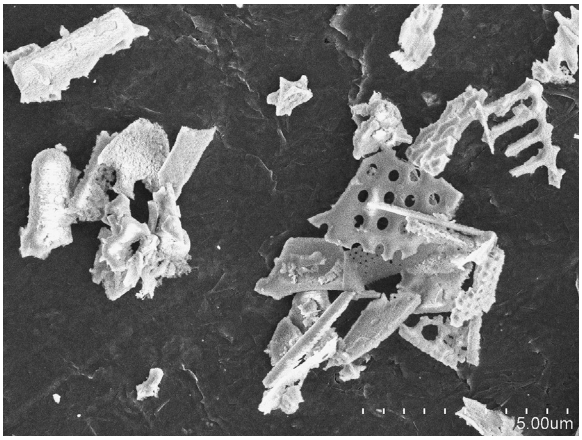

Fig. 1. A scanning electron microscope image of a sample of diatomaceous earth dust.

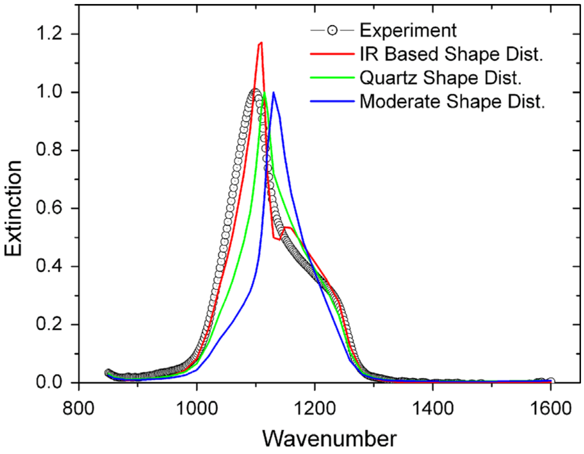

Fig. 2. Comparison of the experimental resonance extinction spectrum for diatomaceous earth (points) with model simulations using different shape distributions as discussed in Section 3. The *T*-matrix simulation results use an IR based shape distribution (red line), the quartz shape distribution studied by Meland et al. [20] (green line), and a moderate shape distribution (blue line), as discussed in further detail in Section 3. (For interpretation of references to color in this figure legend, the reader is referred to the web version of this article.)