Investigation into Single Scattering Properties of Airborne Saharan Dust Particles

D.S. McCall, [1] Z. Ulanowski, [1] E. Hesse, [1] C. Stopford, [1] K. Kandler, [2] P.H. Kaye, [1]

[1] *STRI, University of Hertfordshire, Hatfield AL10 9AB, United Kingdom*
[2] *Inst. fuer Angewandte Geowissenschaften, Technische Universität Darmstadt, Schnittspahnstr. 9, D-64287 Darmstadt, Germany*

Abstract

The phase functions of single mineral dust particles levitated in an electrodynamic balance have been measured. Normalized phase functions and the asymmetry parameter could be determined because nearly the full range of scattering angles was available: 0.5° to 177°. The particles have been characterized using microscopy.

1 Introduction

The importance of airborne particulates to the Earth-atmosphere radiation balance is well established. Aerosols such as Saharan dust particles have direct effects on the Earth's energy budget by scattering and absorbing radiation, and indirect effects, such as acting as cloud condensation nuclei [1]. Estimates of the amount of atmospheric dust originating from northern Africa range from 260 to 1500 x 10^6 tons per year [2]. These dust particles cause large uncertainties in assessing the effect of atmospheric aerosols on climate forcing. Therefore, it is important to obtain accurate scattering data from representative Saharan dust particles. In the past, scattering matrices of distributions of mineral dust grains have been measured [3]. Here, we use an Electro Dynamic Balance (hereafter EDB) [4] to levitate single dust grains during scattering measurements. Single dust grains are isolated and characterized by microscopy before carrying out the light scattering measurements. It is therefore possible to do a rigorous comparison with scattering models and, once data for a range of sizes is available, with remote sensing observations.

2 The Experimental Setup

The EDB has been developed for studying single microscopic particles. A single microparticle can be charged, injected into the trap and then levitated [4]. In order to randomize particle orientation during the experiment, angular instabilities and particle rotation were induced [5]. This was achieved by increasing the amplitude and decreasing the frequency of the AC-voltage. Upon illumination with a laser of wavelength 0.5145 μm, an array of 175 optical fibres placed at one degree intervals collects scattering data for scattering angles between 3° and 177°. These optical fibres pass the scattered flux to a photomultiplier, and after digitization to a computer, where scatterings pattern are recorded for different states of incident polarization, as well as for background scattering (stray light in the absence of the particle) [6]. A CCD photodiode array measures the forward scattering between approximately 0.5 and 5 degrees with angular resolution of 0.01061° per pixel [5].

3 Saharan Dust Particles

Samples of mineral dust were obtained from various sites. The sample in the example shown below was sourced from a hamada in Morocco, at 29.84957°N, 6.01508°W. This sample had been sieved to contain particles of sizes 20-75 μm. The mineralogy of the sample was identified and semi-quantified by X-ray Diffraction. The sample has a mineral content composed of quartz, albite, calcite, microcline, hematite and the clay minerals chlorite and kaolinite, with quartz, microcline and chlorite predominant. One of these particles was selected for levitation. The particle was examined under an optical microscope in different orientations to obtain size and shape information. Some particles were also examined by scanning electron microscopy to show detail of surface structure. If the particles were to be used for scattering measurements, they would be imaged without coating. The particles were in general found to have rough surfaces as is shown in Figure 1.

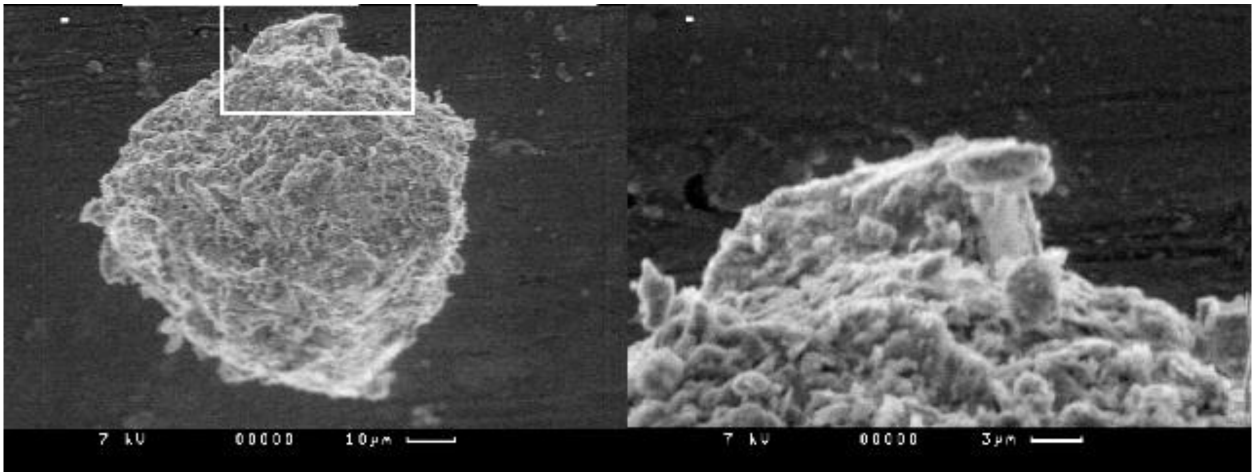

Figure 1: A dust particle as seen under the scanning electron microscope. The image on the right is a magnification of the area shown in the first image. The dust particle was not coated prior to electron microscopy.

From the optical microscopy, the selected particle was found to have the longest dimension of 37.5 µm. In the orientation of the particle seen in Figure 2.1, the measured breadth was 17.5 µm. In the orientation in Figure 2.2, the measured breadth was 21 µm.

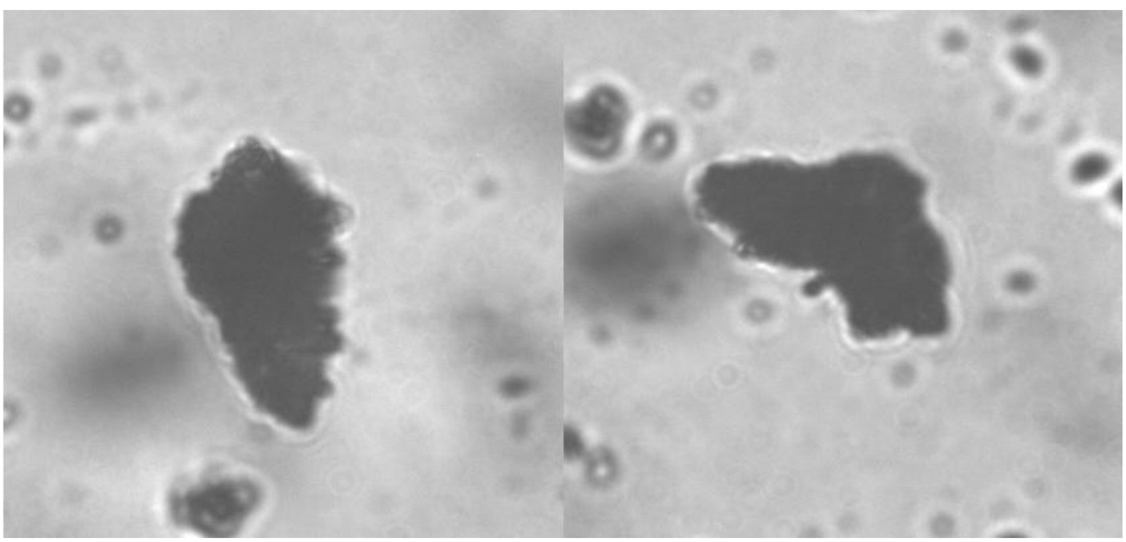

Figure 2: From left to right: 2.1 – Dust particle as seen under an optical microscope. Dimensions are approximately 17.5 µm x 37.5 µm. 2.2 – Same particle as in 1.1 turned by 90° along its long axis. The dimensions are approximately 37.5 µm x 21 µm.

4 Phase Function

Figure 3 shows the normalized phase function for the dust particle shown in Figure 2. The actual measured range of angles for this particle extends down to 0.6°. The inset in Figure 3 shows the low angle measurements made by the CCD, extending from 0.6° to 5.1°. The laser diffractometer data extends from 3° to 177°.

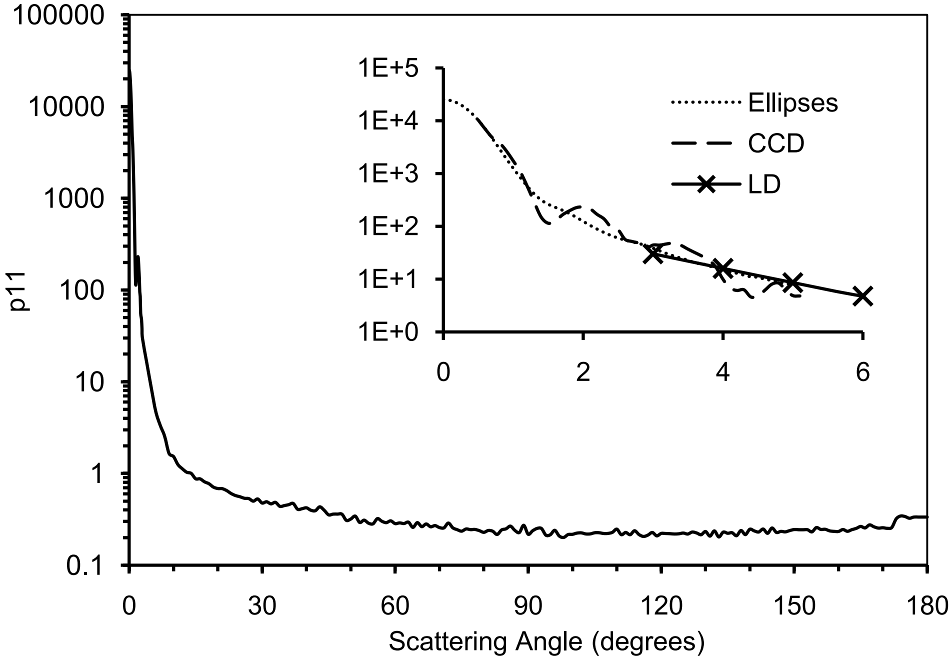

Figure 3: Normalized phase function for the dust particle shown in Figure 2. The results were extrapolated between 0° and 0.6° using diffraction on an elliptical aperture averaged over a range of radii between 9 μm and 19 μm. The inset shows the relationships between the laser diffractometer results, the CCD array results and the elliptical aperture data between 0° and 6°.

In order to complete the phase function so that it can be normalized and the asymmetry parameter can be computed, it is necessary to extrapolate the data between 0° and 0.6°. For low angles, the scattering from a particle is largely dependent on diffraction. If the particle was more spherical, it would be suitable to use Lorenz-Mie theory averaged across a range of spheres corresponding to the changing cross-section of the rotating particle. However, as the particle is highly aspherical, a suitable approach at low scattering angles is to use Fraunhofer diffraction on a collection of randomly-oriented elliptical apertures [7,5]. This can be seen in the inset in Figure 3, and allows extrapolation of the scattering data for the angles 0° to 0.6°. With the full range of scattering data, the normalized phase function has been completed as shown in Figure 3, and the asymmetry parameter has been calculated, g=0.76. The phase function has some diffraction features in the near forward scattering region, as detected by the CCD. However, the rest of the phase function is almost featureless between approximately 80° and 170° - it is almost constant. A slight increase in backscattering between 170° and 180° is observed.

5 Conclusion

The phase functions for levitated single mineral dust particles have been obtained. A laser diffractometer and a CCD have been used to capture scattering data down to as little as 0.6°. The remaining 0.6° has been extrapolated using Fraunhofer diffraction on a distribution of elliptical apertures. Having the full phase function has enabled normalization and the calculation of the asymmetry parameter, which was 0.76 for the example show here. The phase function is flat and featureless at large angles, as determined previously for distributions of mineral dust grains [3]. This result will enable comparison and rigorous verification of data generated by computer models. The Ray Tracing with Diffraction on Facets (RTDF) [8] code has already been tested for particles with curved surfaces down to size parameter 40 [9], and it could be applied to an approximation of the particle seen in Figure 1.

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