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MODELLING MINERAL DUST USING STEREOPHOTOGRAMMETRY

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ABSTRACT. The real, three-dimensional shape of a dust particle is derived from a pair of scanning-electron microscope images by means of stereophotogrammetry. The resulting shape is discretized, and preliminary discrete-dipole-approximation computations for the single dust particle reveal that scattering by such an irregular shape differs notably from scattering by a sphere or a Gaussian random sphere which both are frequently used shape models for dust particles.

1. Introduction

Mineral dust particles continue to be an important and intriguing subject of light scattering research because of the abundance of atmospheric dust and, also, the lack of trivial solutions. One of the complications is the vast variety of shapes of mineral dust particles: they can be, for instance, roundish, faceted, platy, or aggregated; and can have unique surface structures. Accurate light-scattering computations require accounting for the particles' nonspherical shapes.

Several mathematical shape models for dust have been previously introduced; some of them mimicking the real shapes of dust and some of them merely producing similar scattering features when considering a shape-size distribution of particles [1]. In this study, we choose a different approach: we derive the shape of one Saharan dust sample particle directly from the scanning-electron microscope (SEM) images by means of stereophotogrammetry, without applying any mathematical shape model.

2. Dust sample and SEM imaging

The Saharan mineral dust sample, from which the modeled particle was selected, was collected during the SAMUM campaign over Morocco on 6th June 2006 by an airborne cascade impactor particle collection system (for details, see [2]). The sample was sputter-coated with gold (thickness approximately 10 nm). Single particles were imaged with a FEI ESEM Quanta 200 FEG at different angles by tilting the specimen stage at a working distance of 10 mm. Secondary and backscatter electron images were collected. An acceleration voltage of 20 kV and a spot size 4 were used, resulting in a nominal lateral

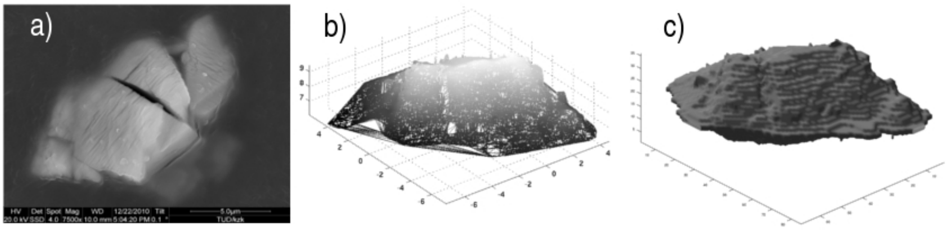

Figure 1. Deriving the 3D shape of a dust particle: a) SEM image of a micron-scale dust particle, b) topography retrieved using stereophotogrammetry, and c) volume-discretized shape, the lower half obtained by mirroring the shape with respect to the xy-plane.

resolution better than 3 nm. In addition, characteristic X-ray fluorescence was measured with an energy-dispersive detector.

The particle chosen for this work consists of the elements Ca, S, and O, determined by elemental mapping. From the composition and characteristic shape we conclude that it is a pure gypsum/anhydrite particle. In the secondary electron image (Fig. 1a), some small flakes are visible on top and to the lower left of the particle. Though they are too small to yield a reliable chemical signal, they probably consist of clay minerals.

3. Particle shape retrieval

The surface topography of the dust particle is determined from a stereo pair of SEM images. The core of the stereo algorithm is image matching based on normalized cross-correlation, where the task is to find automatically the corresponding points in the left and right images. Corresponding points are searched for interest points extracted from the left image by Canny edge detection. The corresponding points found by image matching using an epipolar constraint [3] are refined to subpixel accuracy by finding the maximum of a surface of second degree fitted to the correlation values.

The 3D coordinates of the points on the surface of the particle are computed using formulas in [3] for the horizontal coordinates x and y and a formula in [4] for the elevation z. In the last formula, it is assumed that there is a parallel projection geometry in the SEM, which is well satisfied with images taken with magnification factors above 1000. The 3D points are triangulated into a TIN (triangulated irregular network) model, shown in Fig. 1b, and then interpolated into a regular grid of elevations. Some manual and automated editing is finally performed to remove outliers left in the model.

The interpolated regular grid of elevations showing the derived, three-dimensional particle shape is then divided into discrete volume elements called dipoles (Fig. 1c). Since the stereophotogrammetry-retrieved shape can, at this point, only cover half of the particle geometry, the other half is constructed by assuming a mirror symmetry with respect to the xy-plane. Before adding the mirrored dipoles to the shape, a thin layer of dipoles in and near the xy-plane are removed to eliminate the seemingly large number of shape-retrieval artefacts in the vicinity of the plane.

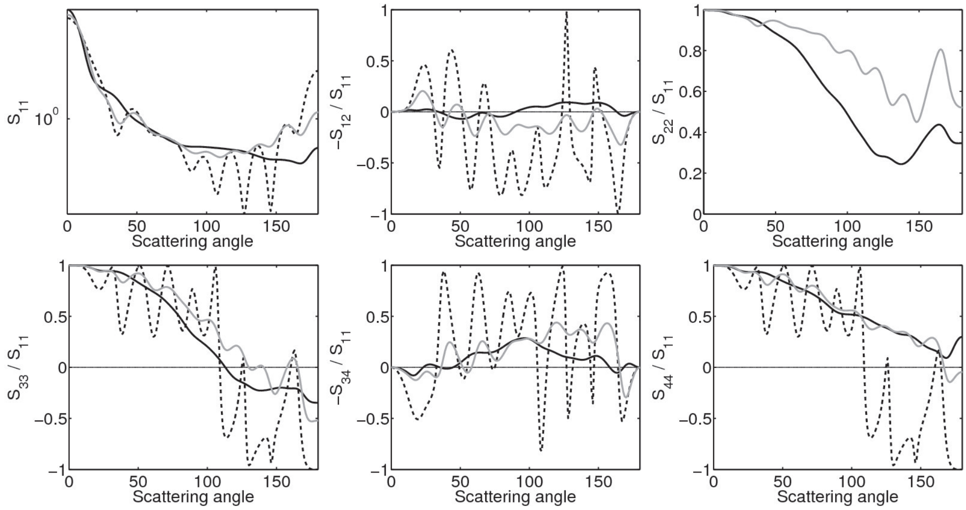

Figure 2. Comparison of scattering by single particles of different shapes. Scattering-matrix elements for the stereophotogrammetry-retrieved dust particle (solid black line) of size parameter $x = 8.0$ are shown together with those of an equal-volume Gaussian random sphere (solid gray line) and a spherical particle (dashed line).

4. Results and discussion

Light scattering by the dust particle is computed using the discrete-dipole approximation (DDA) approach by [5]. The refractive index of the dust particle is fixed at $m = 1.55 + 10^{-5}i$ which is a plausible estimate for a gypsum/anhydrite composition with a hint of absorption. The computations are performed for monochromatic, visible light at a wavelength $\lambda = 0.628\,\mu$m, and the size of the particle is fixed at a size parameter $x = 2\pi a_{\rm eq}/\lambda = 8.0$, where $a_{\rm eq}$ is the radius of an equal-volume sphere. DDA accuracy criterion $|m|kd < 1$, where $k = 2\pi/\lambda$, is satisfied when the interdipole distance d is small enough, i.e., the particle is modeled with a sufficiently large number of dipoles; here, we use approximately 55000 dipoles. The scattering results are averaged over 3000 orientations to mimic random orientation.

Preliminary single-scattering results (Fig. 2) for the dust particle show a very smooth angular dependence of the scattering-matrix elements. For comparison, we also show the scattering-matrix elements for an equal-volume Gaussian random sphere with shape parameters $\sigma = 0.2$ and $\nu = 4.0$ (for explanation, see [6]) and for a sphere, where scattering is computed using the Lorenz-Mie theory [7]. An immediate observation of the comparison is that scattering by the Gaussian random sphere preserves traces of the resonances that are characteristic of scattering by a sphere but, for our retrieved dust shape, these are not observed. This implies that the derived shape lacks particle symmetries that would give rise to clear resonance features.

5. Conclusion

Preliminary results with stereophotogrammetric shape retrieval indicate that the method will be useful for deriving real 3D shapes of dust particles from electron microscope images. Since the derived shape lacks symmetries that often occur in mathematical model shapes, the computed scattering-matrix elements do not show any resonances in scattering-matrix elements, contrary to scattering by a sphere and, to a lesser extent, by a Gaussian random sphere.

An even more realistic mineral dust particle model is achieved when any inhomogeneities in the composition are taken into account. Scanning-electron microscope images of the dust particles provide us with detailed maps of the surface composition of the dust particles. These are straightforward to add to real dust particle shapes obtained.

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References

[1] T. Nousiainen, "Optical modeling of mineral dust particles: a review", *JQSRT* **110** (2009).
[2] K. Kandler, L. Schütz, C. Deutscher, H. Hofmann, S. Jäckel, P. Knippertz, K. Lieke, A. Massling, A. Schladitz, B. Weinzierl, S. Zorn, M. Ebert, R. Jaenicke, A. Petzold, and S. Weinbruch, "Size distribution, mass concentration, chemical and mineralogical composition, and derived optical parameters of the boundary layer aerosol at Tinfou, Morocco, during SAMUM 2006", *Tellus* **61B** (2009).
[3] A. Kayaalp, A.R. Rao, and R. Jain, "Scanning electron microscope-based stereoanalysis", *Machine Vision and Applications* **3** (1990).
[4] P. Podsiadlo and G. W. Stachowiak, "Characterization of surface topography of wear particles by SEM stereoscopy", *Wear* **206** (1997).
[5] B. T. Draine and P. J. Flatau, "Discrete-dipole approximation for scattering calculations", *J. Opt. Soc. America* **11**, 4 (1994).
[6] K. Muinonen, E. Zubko, J. Tyynelä, Y. G. Shkuratov, and G. Videen, "Light scattering by Gaussian random particles with discrete-dipole approximation", *JQSRT* **106** (2007).
[7] M. I. Mishchenko, L. D. Travis, and A. A. Lacis, *Scattering, Absorption, and Emission of Light by Small Particles* (Cambridge University Press, Cambridge, 2002).

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