IRS2012-310
International Radiation Symposium 2012
Dahlem Cube, Berlin, Germany, 06 – 10 August 2012

Stereophotogrammetry - a new way of modeling mineral dust aerosols

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Mineral dust aerosols, their scattering properties and radiative impact pose an important modeling challenge because of the abundance of atmospheric dust: it covers a vast range of sizes, morphologies, mineralogical compositions, and small-scale surface structures. These physical features largely determine the light scattering properties of wavelength-scale particles but are problematic to model accurately. However, a detailed shape model is necessary since the radiative properties of such complicated geometries are best solved by integrating the internal electric field over small volume elements using numerical methods, e.g., the discrete dipole approximation (DDA).

In this study, the shapes of several micron-scale mineral dust samples are derived from scanning-electron microscope (SEM) images by means of stereophotogrammetry. This approach directly utilizes the observations and thus differs from the more conventional method of applying a mathematical model for the shape. In stereophotogrammetry, the surface topography of the dust particle is determined by matching a stereo pair of SEM images and solving for the 3D coordinates of the surface points, which are then transformed into a volume-discretized shape. Currently we are able to cover only about half of the particle geometry and, therefore, construct the other half by assuming mirror symmetry with respect to the horizontal plane.

We have investigated the effect of shape on scattering in the first DDA computations for four dust particle types (calcite, dolomite, silicate, and gypsum/anhydrite): the differences between the mineral dust species, the performance of two traditionally used dust shape models (a sphere and a Gaussian random sphere), and the magnitude of the errors in shape retrieval resulting from mirroring. To exclude effects rising from the different composition of the particles, a constant refractive index ($m = 1.55 + \mathrm{i}10^{-5}$) is used. The main shape-related feature that causes differences in scattering by the four dust types appears to be the particle aspect ratio; elongated geometries promote positive degree of linear polarization, increase depolarization, and decrease the amount of backscattered light, i.e. increase the asymmetry parameter. A common factor is that scattering by dust particles shows little resonances in the scattering-matrix elements since the stereophotogrammetry-retrieved shapes lack symmetries that typically remain in mathematical model shapes. Consequently, spheres poorly model scattering by dust, even as a distribution of sizes. Gaussian random spheres perform better and are almost able to reproduce the scattering by less-elongated dust particles, especially dolomite. Mirroring is expected to be the largest potential error source in the shape retrieval but when systematically studying its impact on light scattering, it appears to have surprisingly little effect.

When the stereophotogrammetry-based shape modeling is combined with the detailed elemental maps of the surface composition of the mineral dust particles, a most realistic model for a single dust particle is obtained. Light-scattering computations for such particles are excellent benchmarks when evaluating the applicability of simpler shape models or comparing theoretical results to light-scattering measurements of atmospheric dust.