

Measurement and modelling of light scattering by small particles

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Abstract

At the University of Hertfordshire we measure and model light scattering by small particles, in particular by such relevant for climate research. The measurements comprise phase functions, linear polarization of single levitated particles (ice analogues, Saharan dust) and 2D scattering patterns for interpretation of airborne instrument data (SID, PPD1). In order to extend the applicability of geometric optics towards lower size parameters, we have developed the ray tracing with diffraction on facets (RTDF) model. It combines ray tracing with diffraction on flat facets, and is suitable for rapid computation of scattering on faceted dielectric objects such as ice crystals. or by faceted approximations of more complex shapes. Due to its low computational cost it allows the calculation of 2D scattering patterns, which are useful for interpretation of nephelometric data.

1. Introduction

The importance of ice and mixed-phase clouds to the earth-atmosphere radiation balance and climate is well established. Though studied for many years, there is still a large uncertainty over the radiative properties of cirrus clouds [1]. This is partly due to inadequate theoretical models of light scattering by the constituent ice crystals of realistic shapes and sizes. Therefore, laboratory measurements of single particle scattering properties as well as the development of suitable light scattering models - capable of predicting scattering properties of complex particle geometry of intermediate size - are important.

2. Measurements on single particles levitated in an electrodynamic balance

An electrodynamic balance (EDB) of the double ring double disc type has been designed for studying single microparticles [2]. The EDB has small dimensions in order to facilitate the use of high resolution objectives (14mm focal length). It allows electrostatic particle injection and recovery. By applying suitable ac-parameters to the EDB, elongated particles can be aligned randomly or at certain fixed orientations. Before injection into the trap, the selected particle is picked up by a sharp tungsten needle and contact charged. Light scattering measurements are carried out using a laser diffractometer [3]. Results for ice analogue crystals (which are stable at room temperature and have the same refractive index and hexagonal crystal structure as water ice [4]), and Saharan dust particles will be presented.

3. The RTDF model

The ray tracing with diffraction on facets (RTDF) model, which was developed at the University of Hertfordshire [5-7], is suitable for rapid computation of scattering on faceted dielectric objects such as ice crystals. It combines ray tracing with diffraction on flat facets. The model calculates diffraction using an approximation for the far field direction of the Poynting vector. Phase functions for near random orientation of hexagonal columns have been compared with SVM [8], which is an analytical method, and with GO with projected area diffraction [9]. The RTDF results approximate those by SVM much better than GO over the whole angular range, and in particular in near direct forward and backscattering, in the halo region and in the backscattering region between 142° and 160°. The method can be applied to arbitrary faceted objects and can be used to calculate 2D scattering patterns for fixed and random orientation.

4. Measurements and modelling of 2D scattering patterns – Interpretation of nephelometric data

Most in situ probes for shape characterization of cloud particles rely on direct imaging of particles onto 1D or 2D sensors. Therefore, resolution is limited due to diffraction, optical aberrations, and constrained depth-of-field. However, light scattering patterns of single particles are not bound by depth-of-field and optical resolution constraints. The spatial distribution of the light depends on particle size, shape, orientation and internal structure. This approach has been used for a series of detectors developed at the University of Hertfordshire (Small Ice Detectors SID -1 and SID-2). A new instrument employs a gated intensified charge coupled device camera (ICCD) to record particle light scattering patterns with single photon sensitivity [10]. Discriminating between droplets and nonspherical ice crystals is straightforward, since the former produce highly symmetric scattering patterns and the latter generally do not [11]. Frequency analysis can be used to group recorded images into various classes of ice crystal habits [12]. To develop this method further, reference scattering patterns from known particles, such as ice analogs [4] and 2D scattering patterns modeled using RTDF can be used.

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