Characterization of Small Ice Crystals Using Frequency Analysis of Azimuthal Scattering Patterns

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Abstract

Azimuthal scattering patterns obtained from ice crystals using the Small Ice Detector 2 are examined. They are converted to frequency spectra using Fast Fourier Transform. To classify the shape of the crystals, the spectra are compared to theoretical ones computed for a range of hexagonal crystal shapes, including hollow ones, of various aspect ratios.

1 Introduction

Cloud particle shape is important from the point of view of both atmospheric dynamics and radiative properties. For this reason, many *in situ* probes for shape characterization have been developed. Most of them rely on direct imaging of particles onto a variety of 1D or 2D sensors, so their resolution is limited by the usual optical constraints. Consequently, large gaps in knowledge exist for smaller ice crystals, where the resolution of imaging probes is insufficient. Yet these particles are highly important, especially in the context of radiative properties of clouds and cloud feedbacks [1]. Moreover, many imaging probes do not reveal fine detail, such as the roughness of crystals or whether they are hollow or not – both highly significant properties [2,3]. The Small Ice Detector 2 (SID-2) probe was developed at University of Hertfordshire to provide information on the size and shape of single particles approximately 1 to 50 µm in size by measuring the spatial distribution of scattering. Discriminating between droplets and non-spherical ice crystals is straightforward, since the former produce highly symmetric scattering patterns and the latter generally do not [4]. It is also possible to derive more detailed information about particle shape [5]. The present work attempts to extend the shape analysis to various classes of ice crystals, with special emphasis on solid and hollow hexagonal prisms of various aspect ratio.

2 Small Ice Detector Mk. 2

SID-2 collects scattering patterns from single particles passing through a 532 nm wavelength laser beam with elliptical cross-section. The detector is a hybrid photodiode (HPD) custom-manufactured by B.V. DEP, Netherlands. The HPD is a segmented silicon photodiode mounted in a vacuum tube with a photocathode, and has photoelectron gain of up to several thousands, depending on the acceleration voltage. It contains 27 independently sensed photodiode elements – Fig. 1. In the present study only the outer detector ring was used, comprising the elements 9 to 32 and subtending scattering angles 10 to 20°.

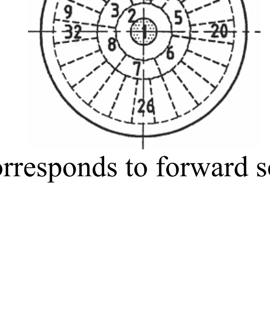

Figure 1: SID-2 detector. The centre corresponds to forward scattering. The elements 3 to 8 are paired.

3 Theoretical scattering patterns

Two dimensional (2D) scattering patterns have been computed using the Ray Tracing with Diffraction on Facets (RTDF) model [6,7]. The fundamental shape was a hexagonal prism with basal faces replaced by inverted (hollow) hexagonal pyramids of varying depth: 0, 10, 25 and 49% of the prism length. The aspect ratio (length to diameter) of the prisms was 3, 1 and 0.2, to represent columns, compact prisms and thin plates, respectively – giving 12 classes in total. For each shape, 2D scattering patterns for 40 different orientations were computed - Fig. 2. The central dark area in the 2D plot in Fig. 2 is due to the exclusion of the scattering on the projected outline of the particle, which in the current versions of the RTDF model is computed as Fraunhofer diffraction on a circular aperture, which would not represent 2D scattering correctly. However, this region is not seen by the outer ring of the SID-2 detector, so the present analysis is not affected. The 2D patterns were converted to the SID-2 detector outer-ring responses by integrating over corresponding angles, to give 24-element azimuthal scattering patterns. The patterns were then converted to angular frequency spectra using fast Fourier transform (FFT) and taking the magnitude of the Fourier coefficients of order 1 to 12 normalized to the coefficient of order 0 – Fig. 2.

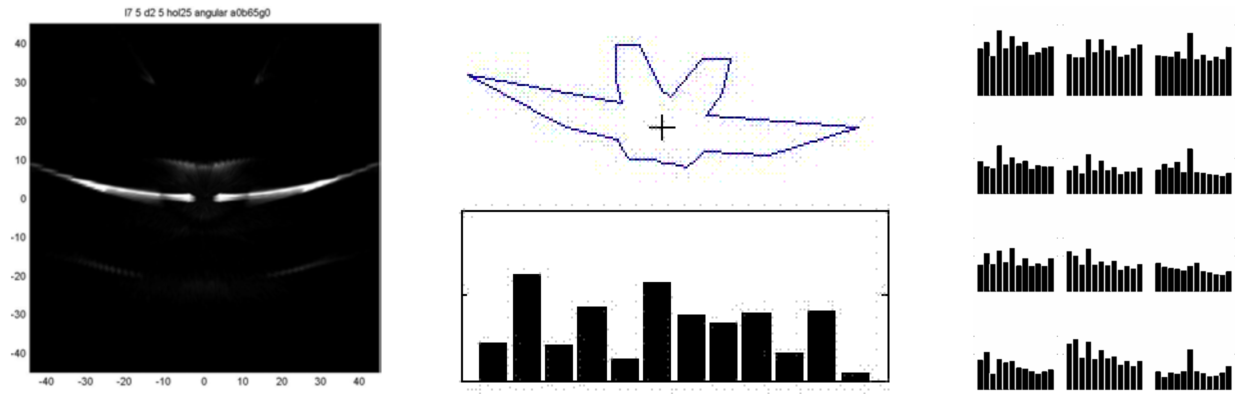

Figure 2: (left) Scattering computed for a prism with 25% basal indentations: 2D pattern extending up to 45°. (centre) Corresponding polar plot of square root of the outer ring response, and FFT coefficients (order 1-12) for the pattern. (right) FFT spectra for the 12 prism shapes averaged over 40 orientations - the aspect ratio decreases from left to right and the cavity depth from bottom to top.

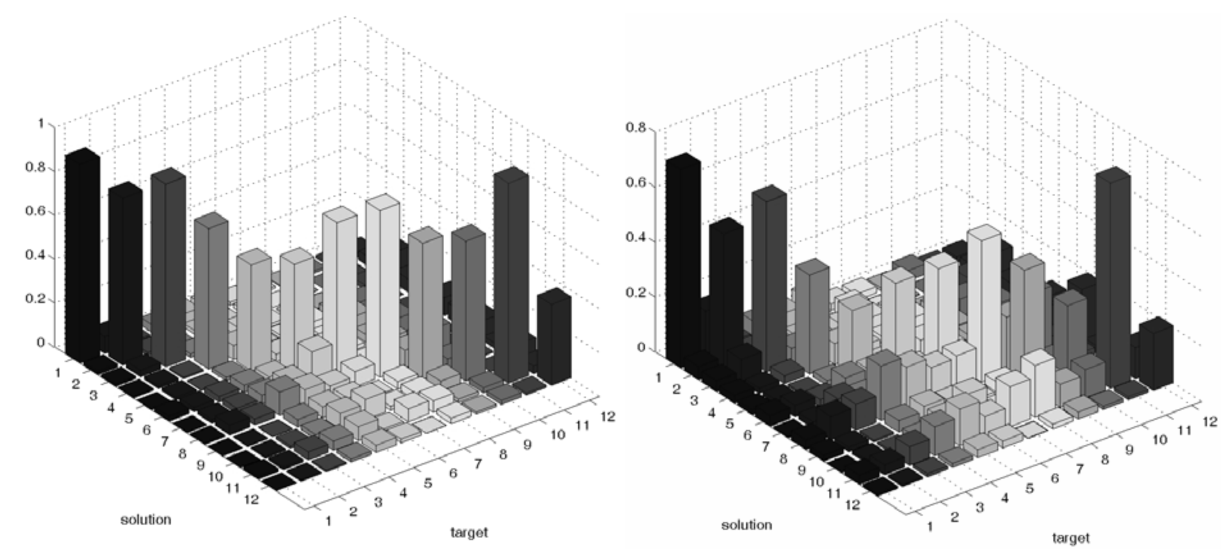

Figure 3: Fitted solution matrix for the 12 computed classes of hexagonal prisms, with 40 orientations in each class, and corrupted by random noise with signal to noise ratio of 2.4 (left) and 1.8 (right).

As a test, each shape class (40 orientations) of the theoretical FFT spectra was corrupted by adding varying amounts of random noise and fitted using a least squares method to uncorrupted spectra. This procedure produced 12x12 "solution matrices" giving proportions of spectra assigned to each class. It was found that the spectra were classified correctly even for large noise levels, but with increasing "leakage" into wrong classes for increasing noise – Fig. 3. The solution matrices were algebraically inverted to produce "deconvolution" matrices for each noise level, to allow the correction of solution sets.

4 Measurements

4.1 Ice analogue measurements

SID-2 scattering patterns were recorded from ice analogue crystals [2,8] by ejecting single crystals from a needle electrode [9]. Examples are shown in Fig. 4, together with the corresponding FFT spectra.

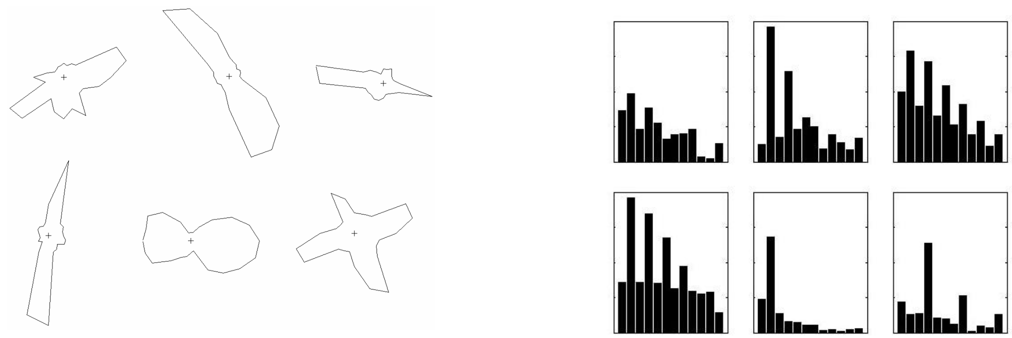

Figure 4: Azimuthal scattering patterns (left) and FFT spectra (right) from 5 ice analogue prisms and a 4-arm rosette (lower right corner).

4.2 AIDA cloud chamber measurements

Ice crystal measurements were done at the AIDA cloud chamber of Forschungszentrum Karlsruhe during the HALO-01 ice nucleation campaign in March 2007. AIDA can be operated as an expansion cloud chamber to study the formation of ice clouds down to temperatures of about -90°C [10]. During experiment 17 hexagonal plates were grown at temperature of –28°C and low supersaturation by injecting seed ice crystals into the chamber. FFT spectra from SID-2 data at time=910s were fitted to theoretical spectra from the 12 shape classes using a least squares method, and then deconvolved. The solutions were consistent with the presence of thick plates with 10% cavities – Fig. 5.

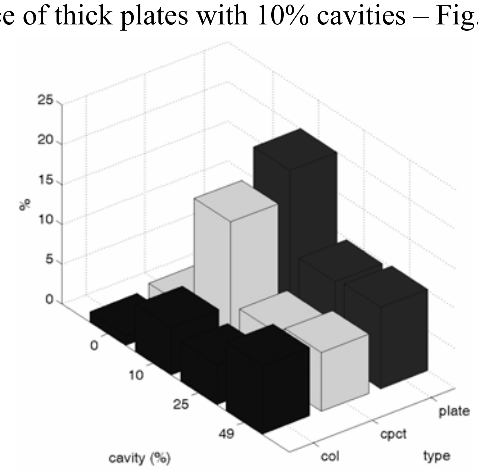

Figure 5: Crystal shape classification for HALO-01 exp. 17 obtained by fitting FFT spectra.

4 Conclusion

A theoretical database of 2D light scattering patterns for 12 classes of hexagonal prisms with different aspect ratios and cavity depth was computed using the RTDF method. The 2D patterns were converted into azimuthal ones and then into angular frequency spectra using FFT. The spectra were found to be characteristic of particle shape and they can be used as a basis for shape classification, even for data strongly contaminated by noise. Experimental spectra from ice crystals were obtained using the SID-2 probe in the AIDA cloud chamber and fitted using a least squares method to the database to derive ice crystal shape. The shape classification can be improved by a deconvolution of solutions using inverted theoretical solution matrices obtained for levels of noise characteristic of the given experimental conditions.

Acknowledgments

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