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EXPLORING THE SURFACE ROUGHNESS OF SMALL ICE CRYSTALS BY MEASURING HIGH RESOLUTION ANGULAR SCATTERING PATTERNS

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ABSTRACT. Surface roughness of atmospheric ice particles is an important yet poorly investigated microphysical property in the context of the climate impact of cirrus and mixed-phase clouds. Measurements of single particle two-dimensional light scattering patterns have been shown to be a promising method to identify particle roughness in natural clouds. This method was applied in a laboratory study on the surface roughness properties of small ice particles that have been grown under simulated cirrus conditions.

1. Introduction

The microphysical properties of ice crystals play an important role for the radiative impact of cirrus and mixed-phase clouds as they determine the angular single scattering phase function of the particles and in this way the shortwave bulk optical properties of the clouds [1, 2]. In order to compile representative parameterisations of single scattering properties of natural ice particles, detailed *in situ* microphysical and optical measurements are therefore required which are also prerequisites for the evaluation of remote sensing measurements. Such *in situ* investigations are mostly restricted to particles larger than about 50 μm, mainly because of optical resolution limitations and potential impacts by ice crystal breakup on the probe inlets. Furthermore, the ice particle surface roughness is by far the least investigated microphysical property addressed by *in situ* measurements and is mainly limited to indirect evidence like the shape of the scattering function [3, 4].

The use of high resolution measurements of the two-dimensional (2D) single particle scattering pattern is a promising way to close these gaps [5]. The latest version of the Small Ice Detector, named SID-3, which has been developed at the University of Hertfordshire is the first *in situ* cloud probe that measures highly resolved 2D scattering patterns. First *in situ* SID-3 scattering patterns of atmospheric ice particles have been analysed to identify surface roughness using statistical measures of the Grey-Level Co-occurrence Matrix

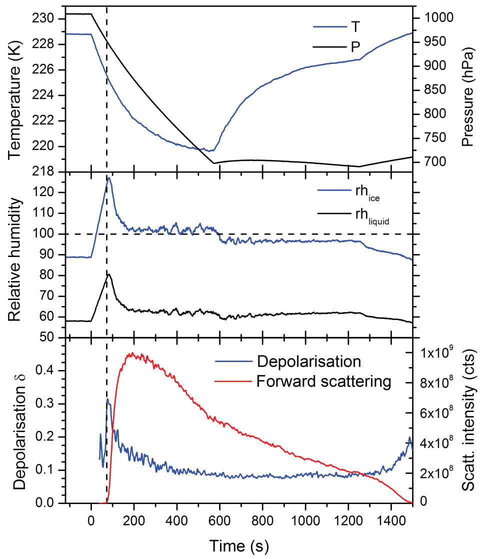

Figure 1. Time evolution of the AIDA ice cloud characterisation experiment HALO06 #47. Expansion cooling was started at t=0 sec and stopped at t=570 sec. The nucleation of ice by deposition freezing on the surface of the pre-existing soot particles was initiated at t=73 sec when the relative humidity with respect to ice had been reached a saturation ratio of 125%. The ice cloud formation and evaporation is clearly reflected by the time evolution of the scattering and depolarisation measurements.

(GLCM) [6]. Here, we examine the GLCM analysis to extract surface roughness parameters from 2D scattering patterns in case of small ∼10 micrometer-sized ice crystals that have been generated under controlled conditions in the laboratory.

2. Results

Ice cloud characterisation experiments were conducted at the large cloud simulation chamber AIDA of the Karlsruhe Institute of Technology [7]. Figure 1 shows the temporal evolution of the thermodynamic conditions of the cloud expansion experiment discussed herein. The experiment was conducted at an initial temperature of 229 K and with submicron soot particles as nuclei for the ice crystal formation. During the expansion cooling of the chamber volume the relative humidity with respect to ice increased to about 125 % before the ice cloud started to form. The growing ice particles reduced the supersaturation and confined the relative humidity to ice saturated conditions before the expansion was stopped at 570 s experiment time. Corresponding results of SID-3 measurements are shown in Figure 2. The comparison of particle sizes deduced from the intensity of the individual 2D scattering patterns and retrieved from FTIR extinction spectroscopy of the ice cloud shows good agreement and reveals a mean equivalent particle size of about 10 μm when the cloud has been fully evolved. The mean azimuthal intensity profile from each

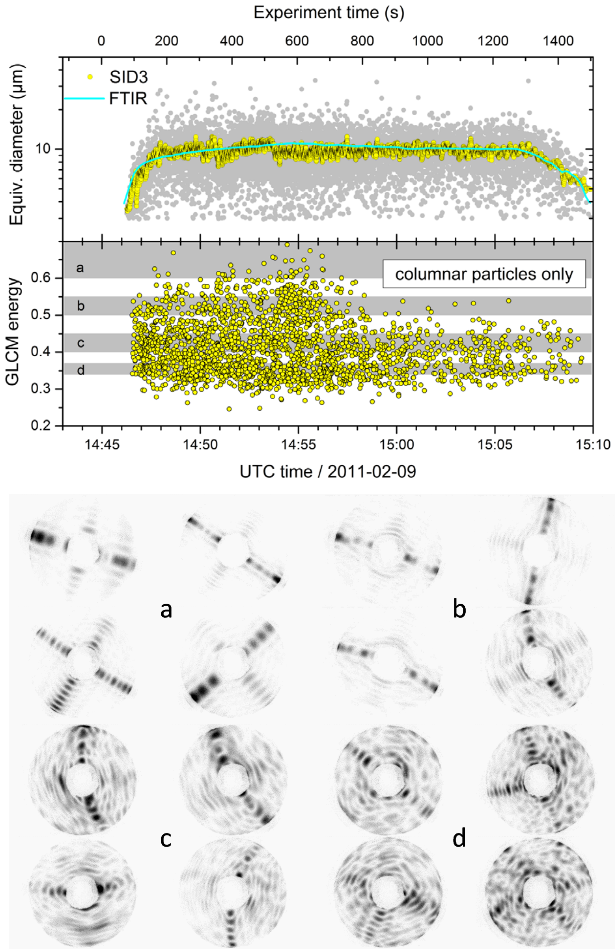

Figure 2. Analysis of the single particle 2D scattering patterns acquired by the SID-3 probe during the AIDA cloud experiment HALO06 #47. Upper panel: The size and shape analysis of the cloud particles reveals a dominating presence of small columnar ice crystals with a mean volume equivalent diameter of about 10 μm. The GLCM texture feature energy - which is the sum of squared elements of the GLCM - shows a useful discrimination according to the degree of surface roughness of the columnar ice crystals. Lower panel: Representative 2D patterns of the four GLCM energy ranges >0.6 (a), 0.5-0.55 (b), 0.4-0.45 (c), and 0.34-0.37 (d), indicated as shaded areas in the upper panel. Each individual image covers an angular range from 7° to 24°.

individual 2D scattering pattern image was calculated and Fourier transformed in order to get a shape discrimination, i.e. selecting columnar particles [8]. We investigated five statistical features of the GLCM – entropy, dissimilarity, contrast, homogeneity, and correlation

– for their surface roughness discrimination capability for this particle subset. Energy was found to be a very robust measure of particle roughness with the potential to effectively discriminate particles with different degrees of roughness.

Acknowledgments

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