Investigation of nucleation, growth, sublimation and surface properties of single ice crystals

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Overview

Nucleation and growth of atmospheric ice particles is of importance for both, weather and climate. However, knowledge is still sparse, e.g. when considering the influences of ice particle surface properties on the radiative properties of clouds. Therefore, the influence of the thermodynamic conditions on the growth, shape and surface properties of single ice crystals is investigated at the experimental setup IRIS (Ice Roughness Investigation System), which is based on the laminar flow tube LACIS (Leipzig Aerosol Cloud Interaction Simulator) together with a SID-3 (Small Ice Detector) instrument and an optical microscope.

Experiments

Main parts of the setup IRIS (Fig. 1 and Fig. 2):

- Laminar flow tube (length: 1.0 m, diameter: 15 mm), based on LACIS (Stratmann et al., 2004) with precise thermodynamic conditions control
- Laboratory version of the Small Ice Detector 3 (SID-3, Kaye et al., 2008) called LISA (LACIS Ice Scattering Apparatus, SID-3 equipped with an optical microscope)

Thermodynamical characterization (Fig. 3) by:

- Computational fluid dynamics (CFD) simulations using FLUENT (Ansys Inc., Canonsburg, PA, USA)
- Temperature (PT100, thermocouple), dew-point (DPM MBW973, MBW Calibration, Wettingen, Switzerland) and flow (hot wire anemometry, DANTEC streamline, Dantec Dynamics A/S, Skovlunde, Denmark) measurements

Experiments:

- Single ice nucleus (IN) of about 3-25 μm is attached to a thin glass fiber (Fig. 4), positioned within the optical measuring volume of LISA and exposed to varying thermodynamic conditions (T, RH)
- Visual observation of the particle/droplet/ice crystal with the optical microscope (Fig. 4 and Fig. 5)
- 2-D light scattering patterns recorded by LISA (Fig. 5)
- Data evaluation using GLCM image texture analysis (Ulanowski et al., 2012) gives information about ice crystal size and surface roughness

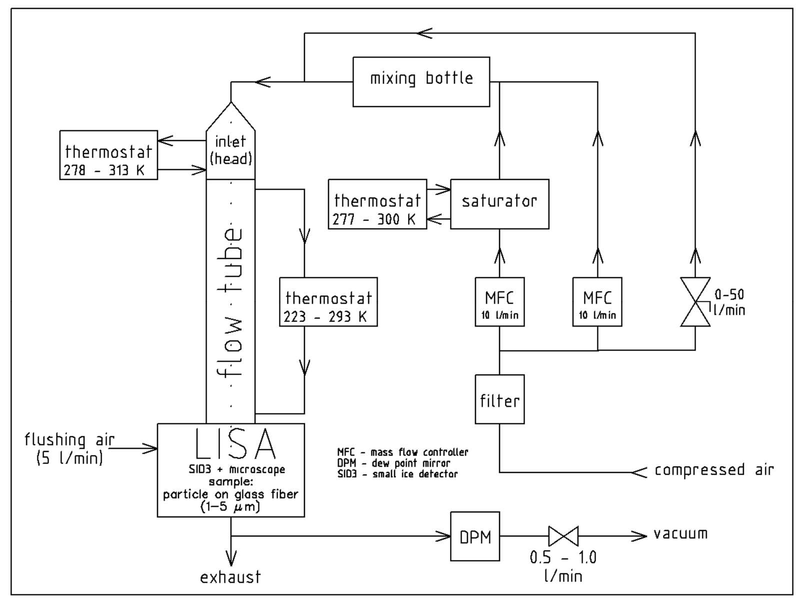


Fig. 1: Schematic diagram of the experimental setup IRIS.

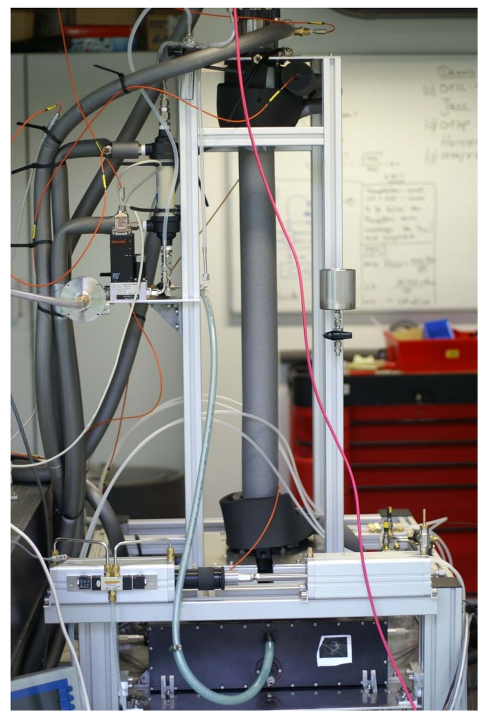


Fig. 2: Picture of the setup.

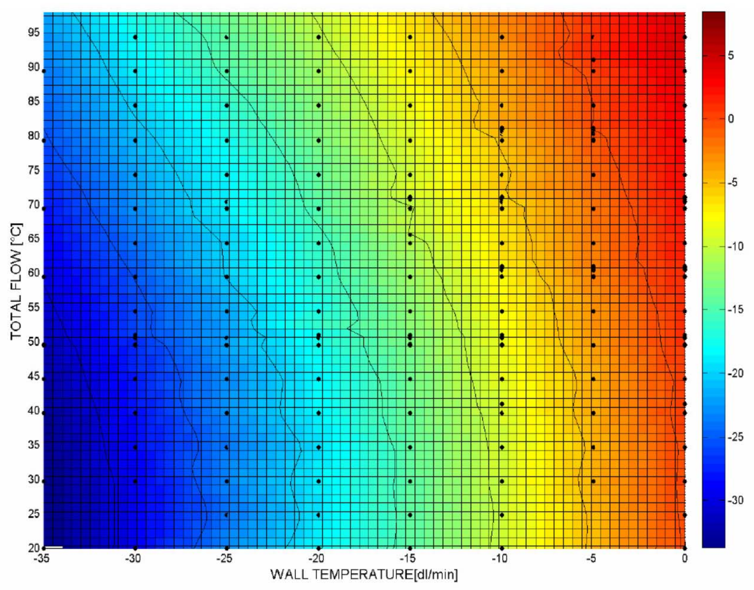


Fig. 3: Measured temperature at the position of the sample.

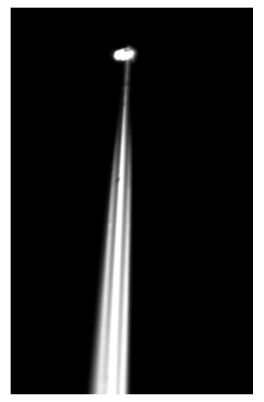


Fig. 4: Microscope picture of a glass fibre with an IN on its tip

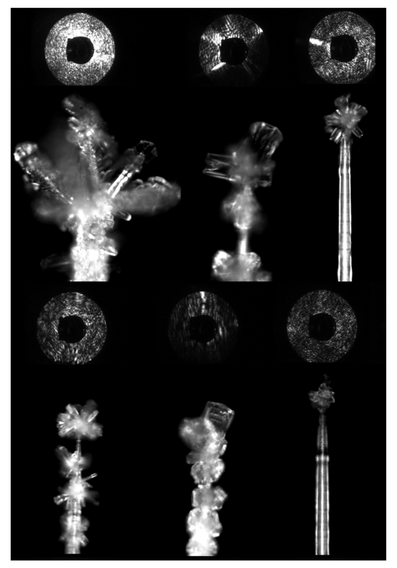


Fig. 5: Examples of microscope images and the corresponding 2D scattering patterns

Results

Macroscopic ice crystal properties (Fig. 6):

- Single ice particle nucleation and growth experiments with Kaolinite, Illite, Arizona Test Dust (ATD), Microcline and Snomax^{TM} particles
- Ice crystal shape and growth rate depend on the thermodynamic conditions (T, rh)
- Ice crystal shape in agreement with literature data

Surface properties (roughness, example in Fig. 7):

- Combined roughness calculated from 2-D LISA scattering images (Ulanowski et al., 2012)
- Complex crystals (such as dendrites) appear as rough
- Combined surface roughness seems to be dependent on the growth history, as it is modified by ice crystal growth or shrinkage

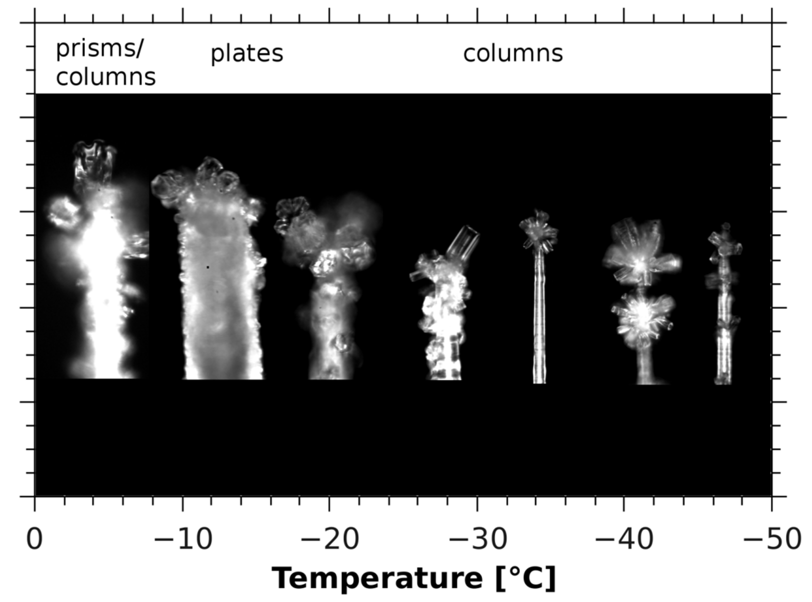


Fig. 6: Selected microscope images recorded at different temperatures and low supersaturation (no dendrites).

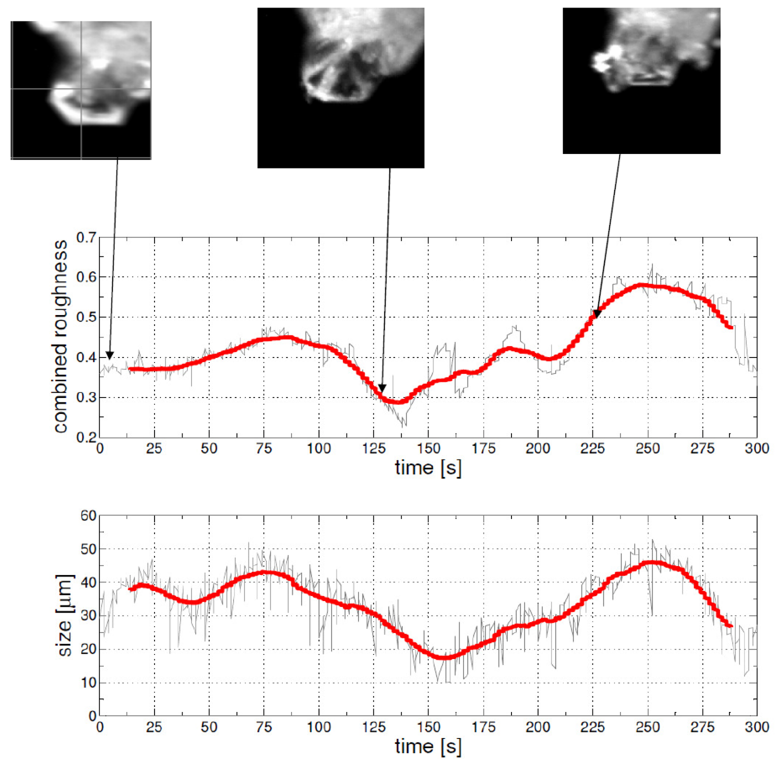
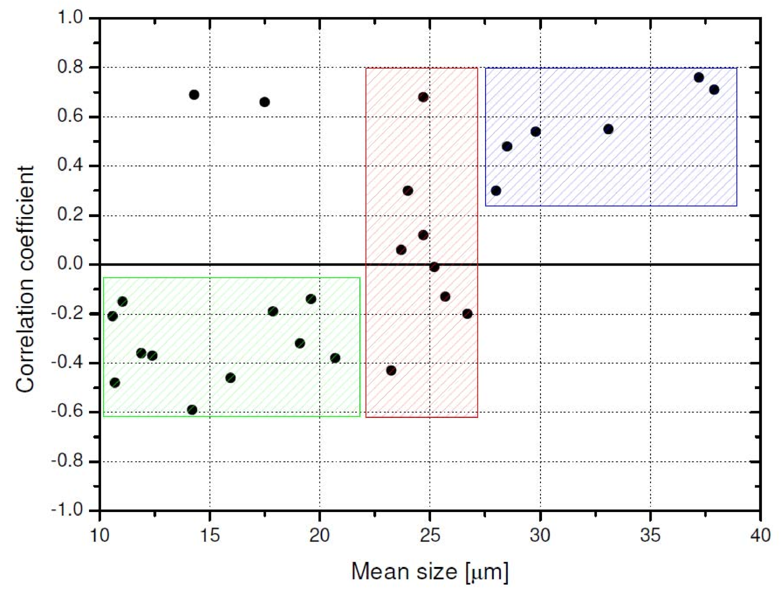


Fig. 7: Example of an ice crystal growth experiment with a soot particle as IN. The Fig. shows the time dependent evolution of ice particle size and calculated combined surface roughness (0 – smooth, 1 – highly rough).

Statistics (Fig. 8 and Fig. 9):

- Ice crystals size (growth rate) correlated with surface roughness
- Different regimes (R > 0 for crystals larger than about 25 µm)



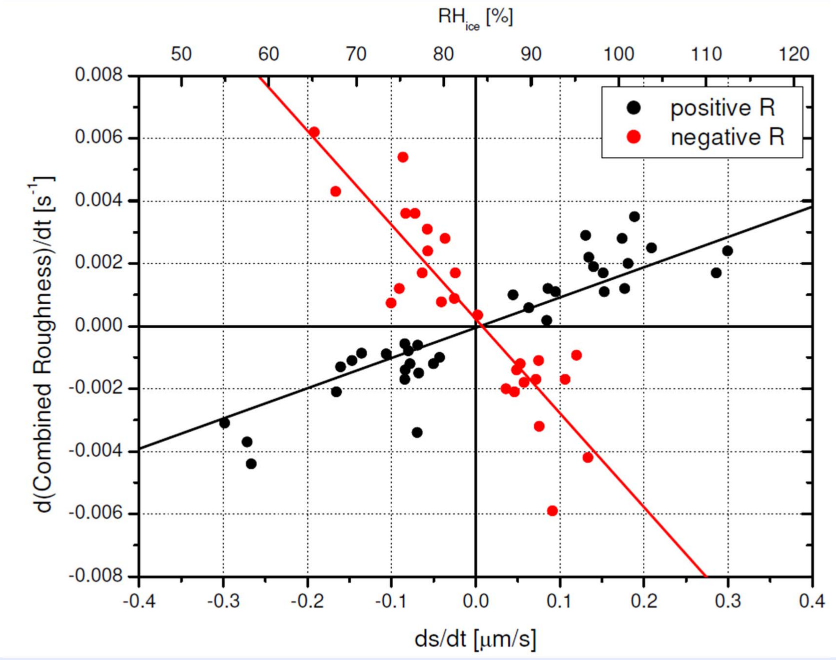


Fig. 8: Correlation between ice crystal size and surface roughness (left)

Fig. 9: Ice crystal growth rate versus the temporal change of the combined surface roughness (right)

Conclusions and Outlook

- Experimental setup to investigate nucleation, growth, sublimation and surface properties of single ice crystals was characterized and successfully applied in first measurements
- Different temperatures and saturation ratios result in different ice crystal growth rates and shapes, but also in different surface properties
- The growth rate for ice crystals larger than 25µm was found to be positively correlated with surface roughness rate of change
- More quantitative investigations of these phenomena follow

Acknowledgements

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