June 20-22, 2023
Vienna, Austria

SAE INTERNATIONAL

International Conference on Icing

of Aircraft, Engines, and Structures

sae.org/icing

Characterization of atmospheric icing conditions during the HALO-(AC)³ campaign with the Nevzorov probe and the Backscatter Cloud Probe with Polarization Detection

Johannes Lucke, Tina Jurkat-Witschas, Darrel Baumgardner, Frank Kalinka, Manuel Moser, Elena de la Torre Castro, Christiane Voigt

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

TU Delft
Delft University of Technology

In-flight measurements of icing conditions

Outline

1. Instrumentation
2. Overview of the flight
3. Characterization of the BCPD
4. LWC and TWC measurements from Nevzorov and BCPD
5. Comparison to ADWICE

Motivation

- Accurate and timely detection of atmospheric icing conditions is essential for safety of flight.
- Microphysical parameters required:

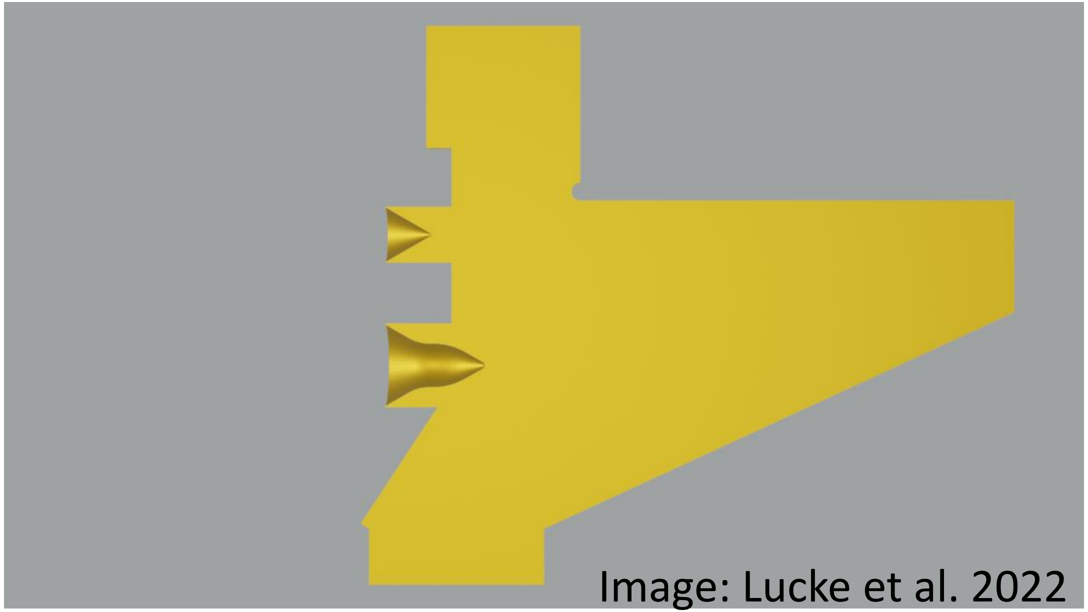
  → **Liquid water content (LWC)**

  → **Particle size distribution (PSD)**
- Real time knowledge of atmospheric conditions could help to optimize flight plans of other aircraft

Instruments used for this study

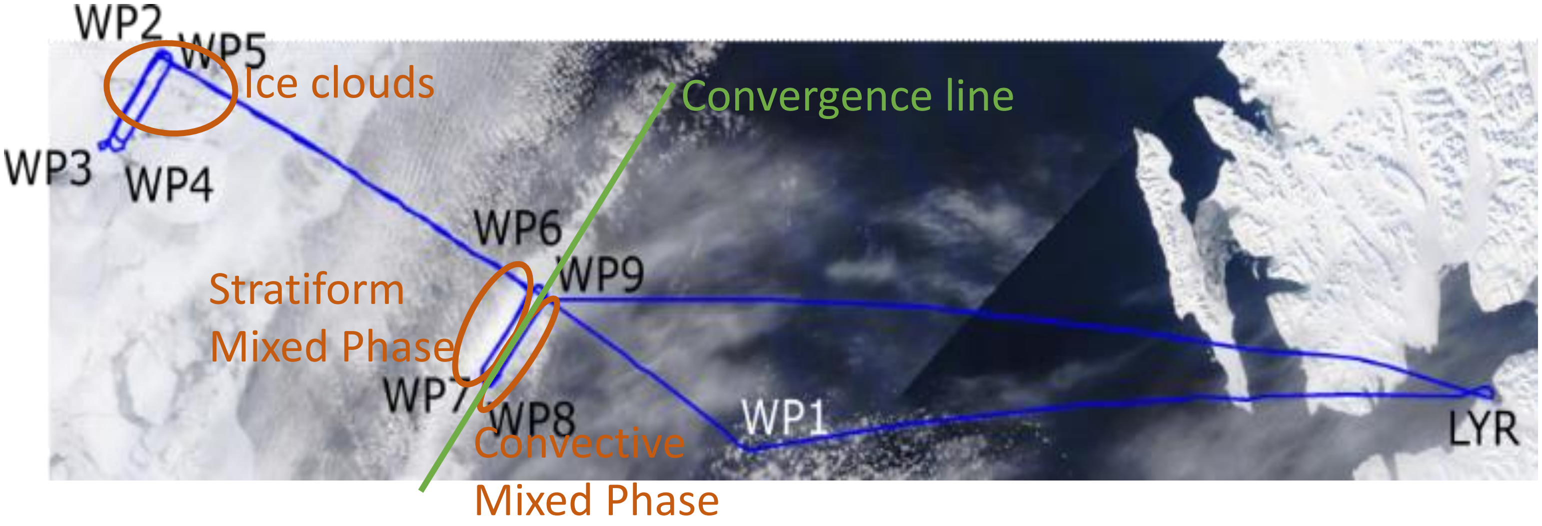
Instrument	Size range [µm]
Backscatter Cloud Probe with Polarization Detection (BCPD)	2 - 42 µm
Nevzorov	n/a
Cloud Droplet Probe (CDP)	2 – 50 µm
Cloud Imaging Probe (CIP)	15 – 960 µm
Precipitation Imaging Probe (PIP)	100 – 6400 µm

Nevzorov 2-cup



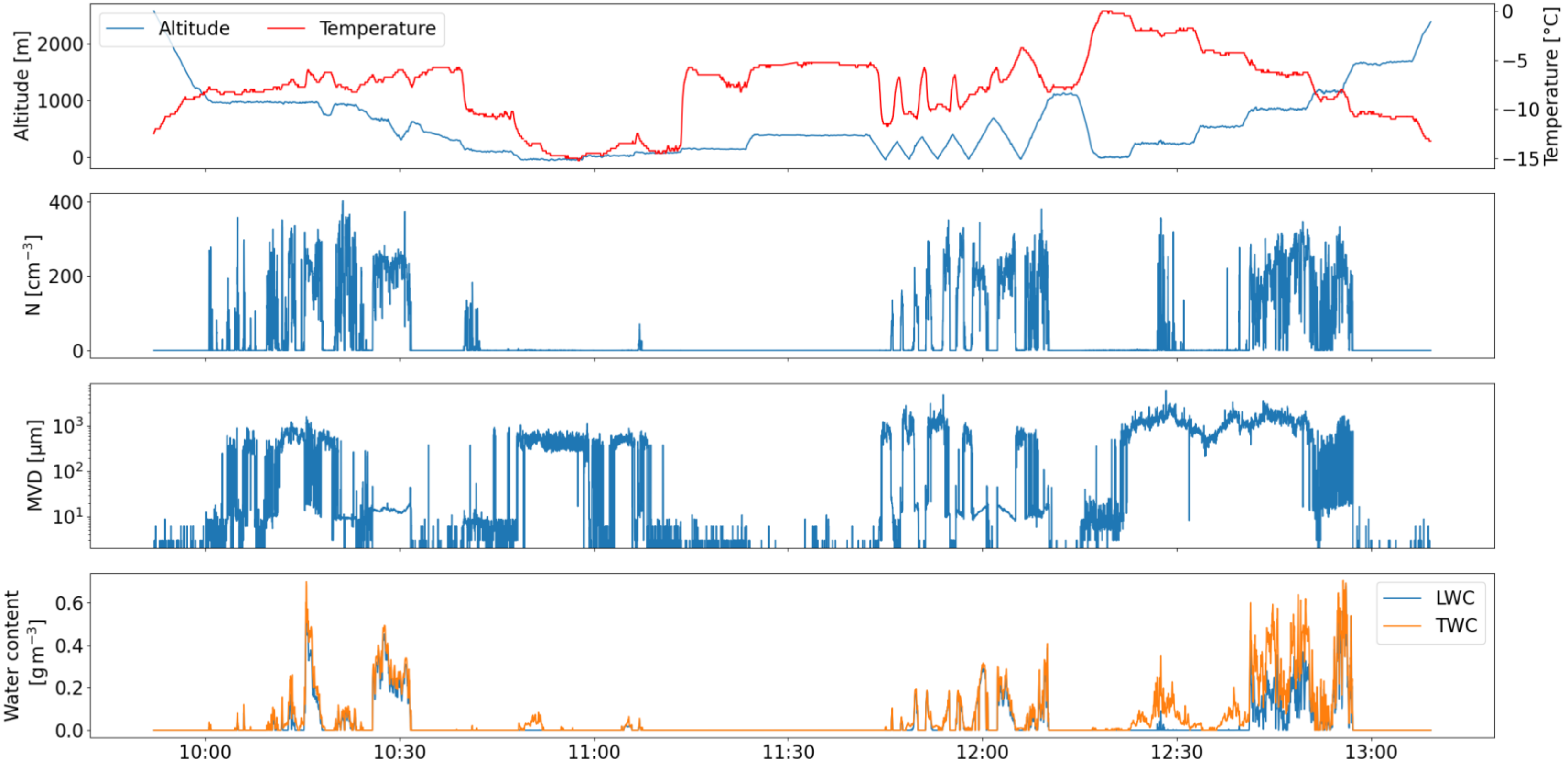
- Nevzorov probe with an 8 and a 12 mm cone.
- Collection efficiency of 12 mm cone from Lucke et al. 2022.

Overview of the research flight

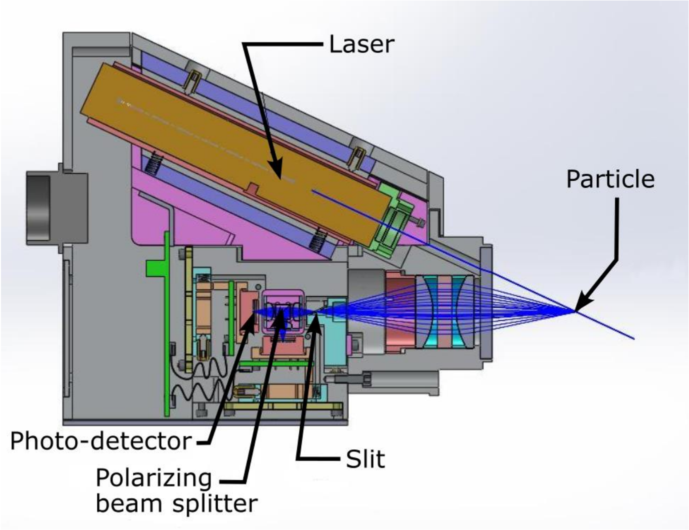


- Large variability of LWC encountered during the flight
- A multitude of different cloud types were measured

Overview of the research flight

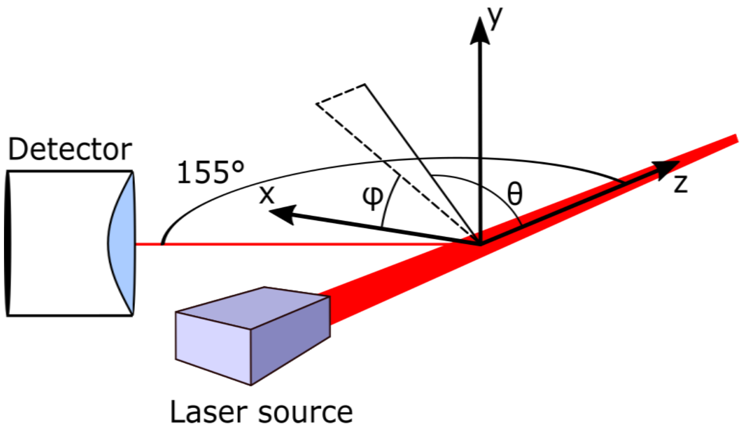


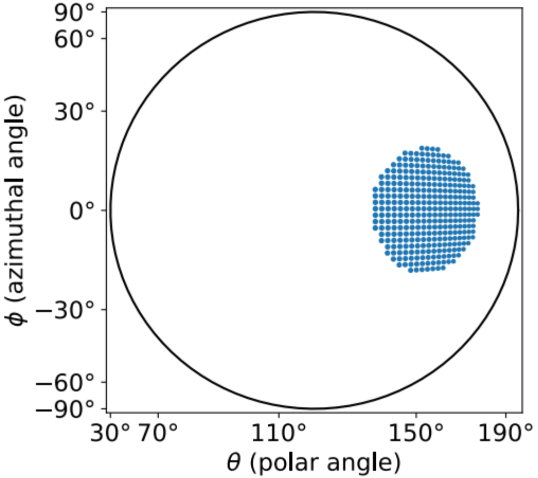
The BCPD



- Small, lightweight instrument, that can be integrated into the fuselage of aircraft
- Precursor instrument (BCP) flies on IAGOS aircraft (Beswick et. al 2014)
- Measures **shape and size** of particles with diameters between 2-42 µm

Properties of the BCPD



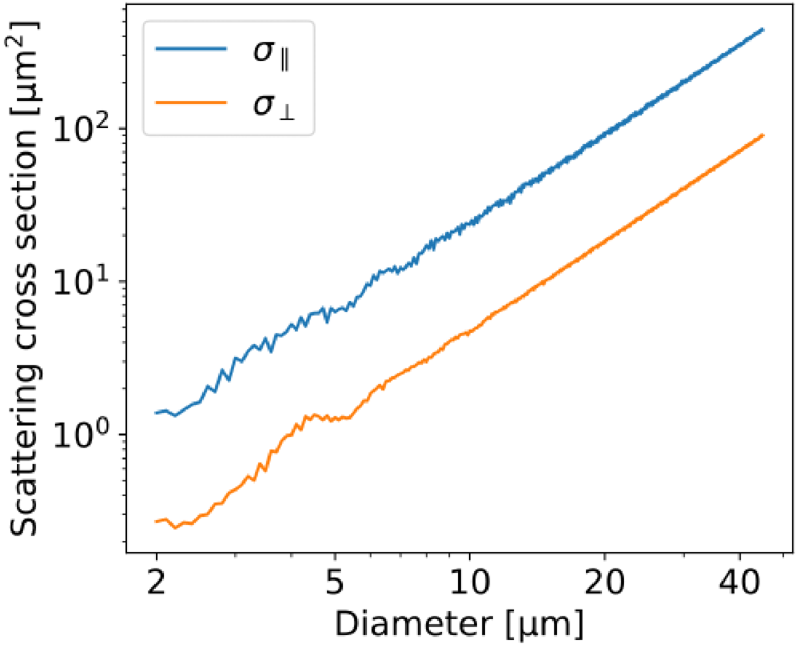


- The BCPD collects light from a solid angle centered on θ = 155°, ϕ = 0
  The apex angle is 18.5°
- The BCPD laser is polarized in the x-z plane
- Spherical particles do not depolarize incident light

BCPD Scattering Cross Section

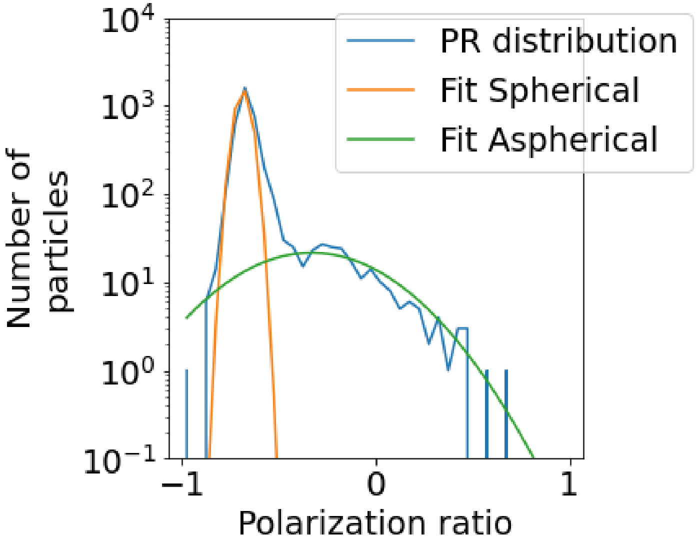
- The Mie scattering response is computed for infinitesimal differential scattering cross sections
- The total scattering response is obtained by integration over all elements
- For the computations a modified version of the pyScatmech program is used

$$\mathbf{S}_{\mathrm{s}} = \int_{\theta_{min}}^{\theta_{max}} \int_{\phi_{min}(\theta)}^{\phi_{max}(\theta)} \mathbf{M}(\theta)\,\mathbf{R}(\phi)\,\mathbf{S}_{\mathrm{i}}\,\mathrm{d}\phi\,\mathrm{d}\theta$$



Differentiation between spherical and aspherical particles

- Spherical particles scatter light with a well defined polarization ratio (PR)
- Aspherical particles scatter light with a wide range of PRs
- Fit of characteristic functions to the depolarization data
- Ratio of spherical to aspherical particles can be determined
- The approach only works for particles with diameters > 10 µm

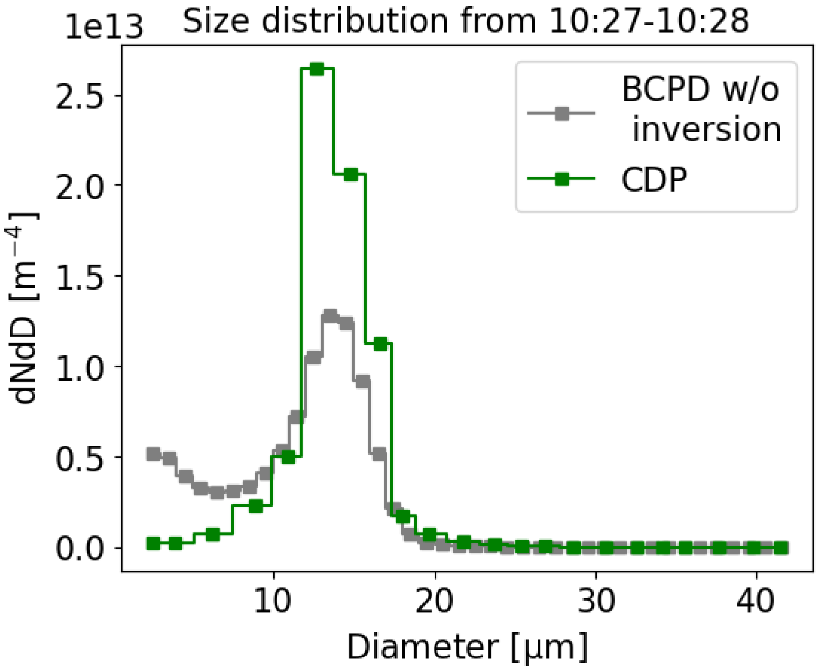


Correction of particle size measurements

- The BCPD laser has a gaussian intensity profile

→Undersizing of particles that pass through the edges of sample area

- Undersizing can be described as: **y = Ax**
- Goal: Retrieve true size distribution **x**

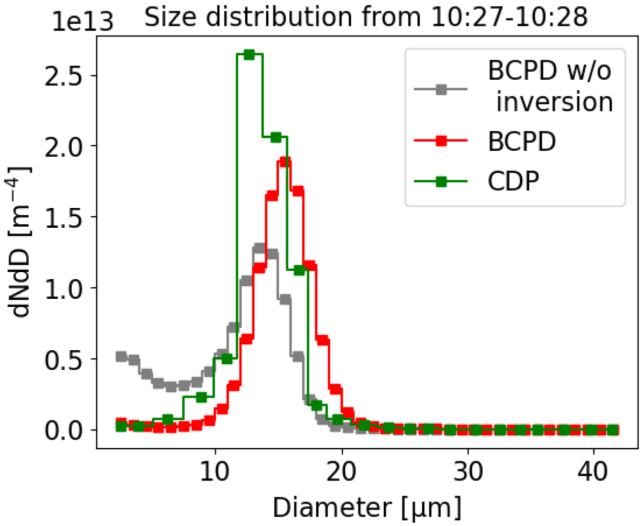


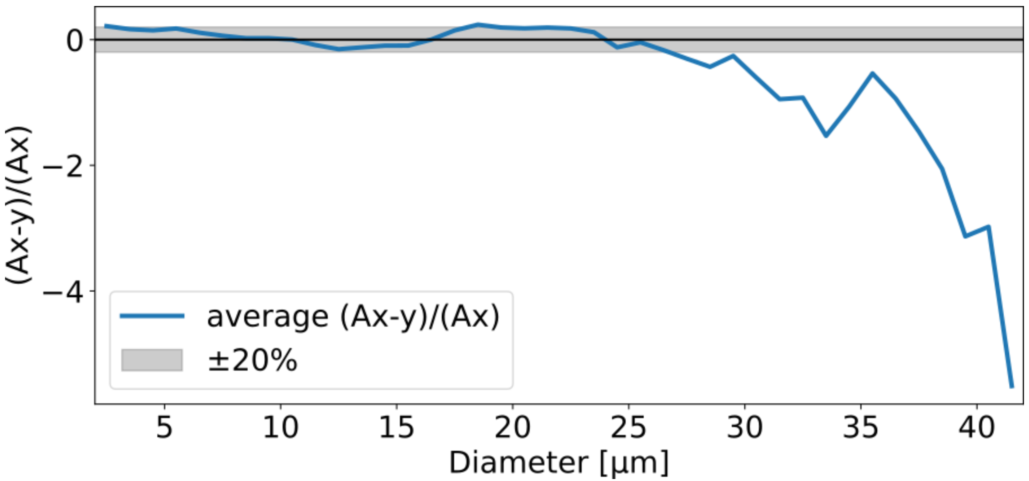
Correction of particle size measurements

- True size distribution: $\mathbf{x} = \mathbf{A}^{-1}\mathbf{y}$

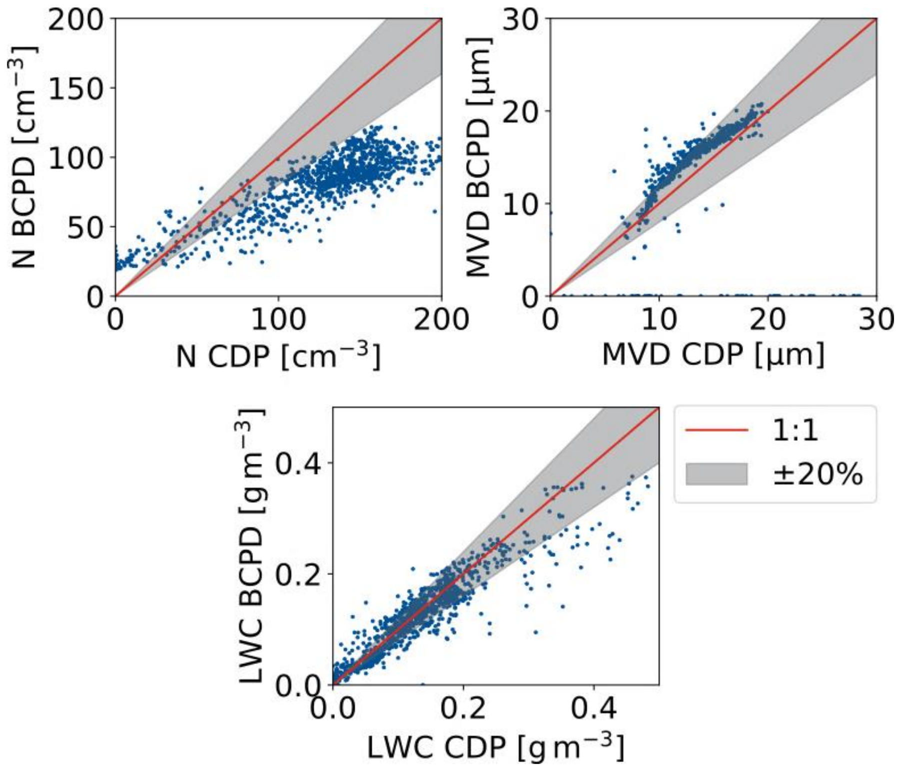
  → ill-posed problem with no exact solution

- We implement the smooth-Twomey algorithm from Beswick et al. (2014)



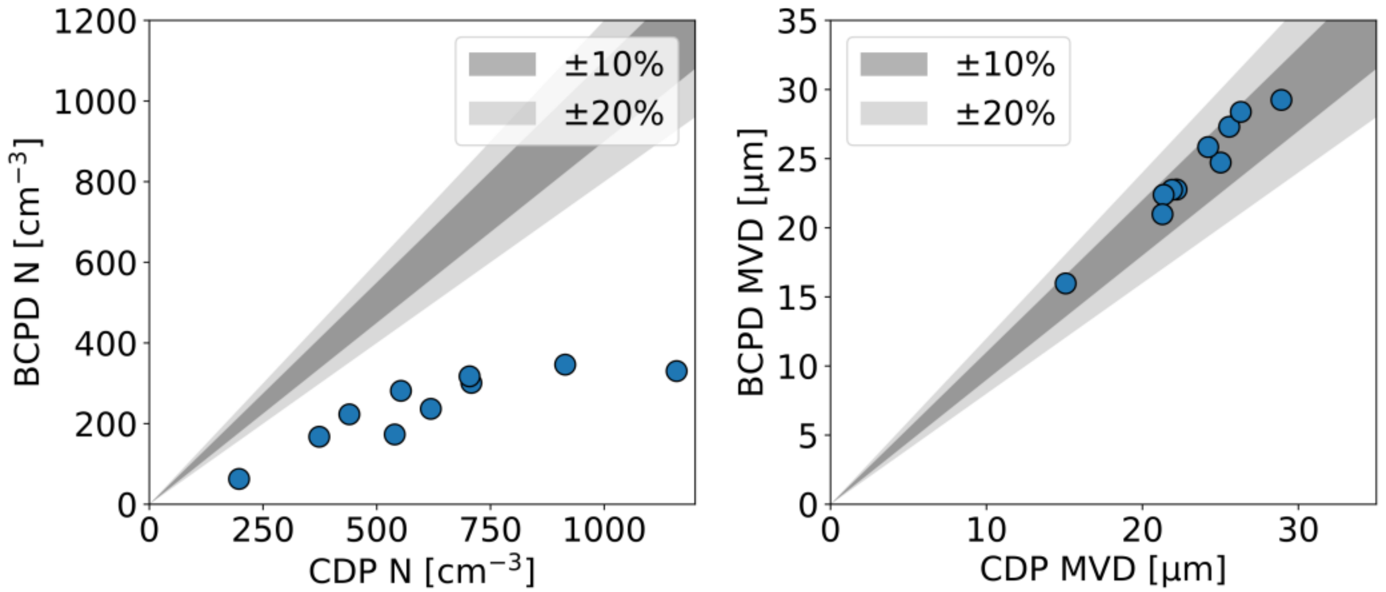


Comparison of microphysical parameters from BCPD and CDP



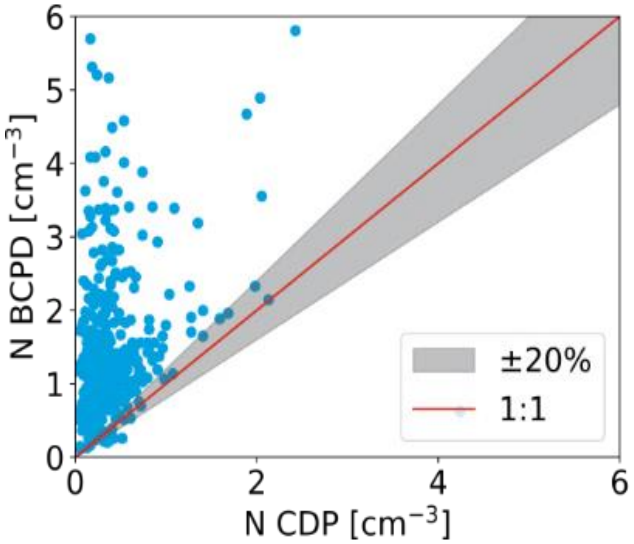
- Number concentrations (N) in disagreement
- BCPD measures only 60% of N of CDP
- MVDs agree within ±20%
- Very good agreement between LWCs.

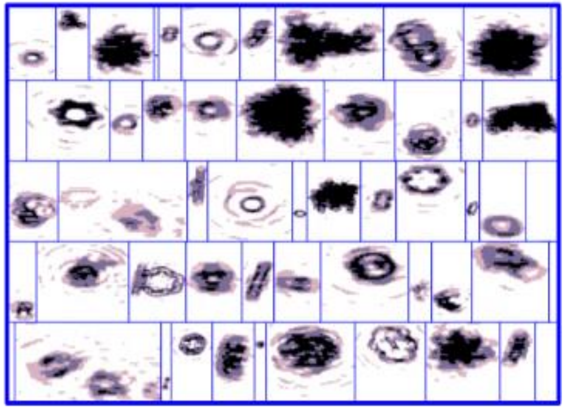
Comparison to Ice Wind Tunnel data



- Also much lower number concentrations of BCPD compared to CDP
- MVDs match perfectly.

Shattering

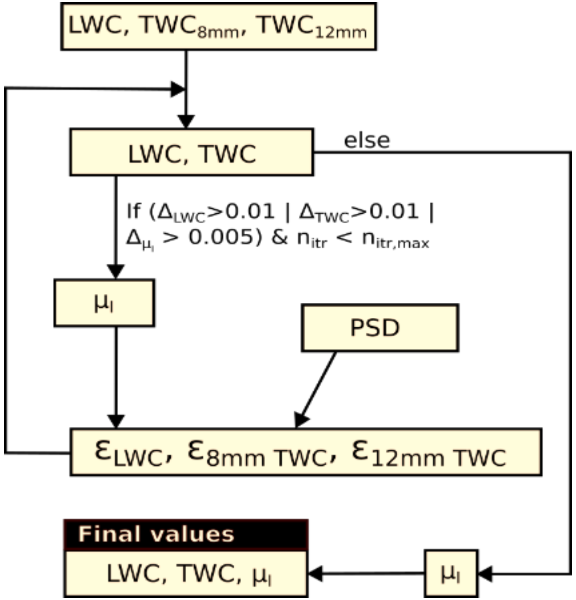


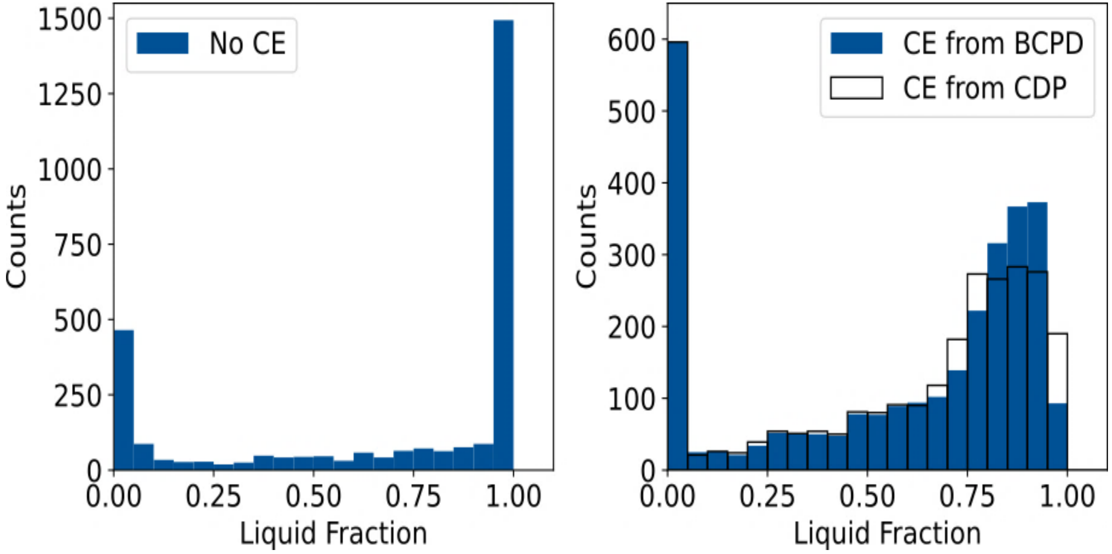


- Ice crystals shatter on the fuselage and are detected by BCPD
- Number of measured ice crystals by BCPD is incorrect, but presence of ice crystals / mixed phase conditions can be detected

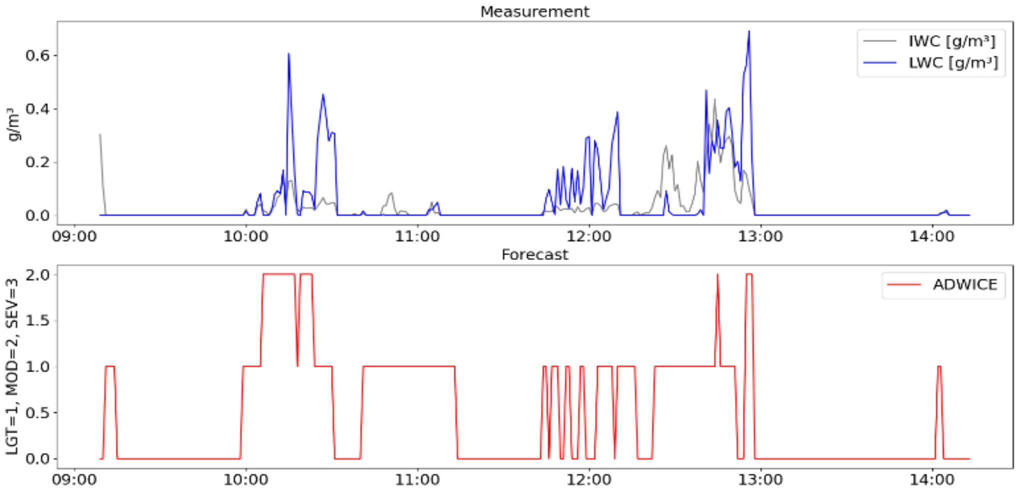
Correcting Nevzorov measurements with data from the BCPD

- Measurements of the Nevzorov probe need to be corrected for collision efficiency effects **to obtain accurate LWC and TWC values**





Comparison of icing detections to ADWICE predictions



- ADWICE predictions of icing encounters are mostly in agreement with in-situ observations
- Predictions of high severity correspond to regions with high LWC
- At times ice clouds are mistaken for liquid clouds

Conclusions

Advantages of the BCPD

- Lightweight, no additional drag
- Few Mie-ambiguities in the scattering cross section curve
- Differentiation of spherical and aspherical particles

Challenges

- Correction of undersizing effects
- Shattering on the fuselage
- Location on fuselage likely alters measured size distributions

Applications

- Suited for research missions where no underwing probes can be deployed
- Detection of mixed-phase and ice
- Size distributions useful for collision efficiency correction of Hotwire probes
- Validation of icing forecast products

Contact Info

Johannes Lucke

Deutsches Zentrum für Luft- und Raumfahrt

Münchener Straße 20

82234 Wessling

Email: Johannes.lucke@dlr.de

Phone: +498153283423