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SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Detection of Appendix O conditions with the CM2D

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Motivation

An ATR-72 aircraft crashed in 1994 after flying for a prolonged time in Appendix O conditions

- **Consequence:** Appendix O conditions must be avoided by certain type of aircraft. If such an aircraft enters into Appendix O conditions it must promptly exit these conditions.
- **Problem:** Not all icing conditions are Appendix O conditions. Avoiding icing conditions altogether comes at an unnecessary cost.
- **Solution:** An instrument that informs the pilot whether Appendix O or Appendix C conditions are present.

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Cloud Multi-Detection Device (CM2D)

CM2D (Cloud Multi-Detection Device)

For the detection and discrimination of Appendix O in the scope of the SENS4ICE program, **DLR proposes the CM2D:**

- It consists of **two sensor components**:

  1. Nevzorov hot-wire probe
  2. BCPD (Backscatter Cloud probe with Polarization Detection)

Nevzorov probe: Principle of operation

The sensors try to maintain a constant temperature

↓

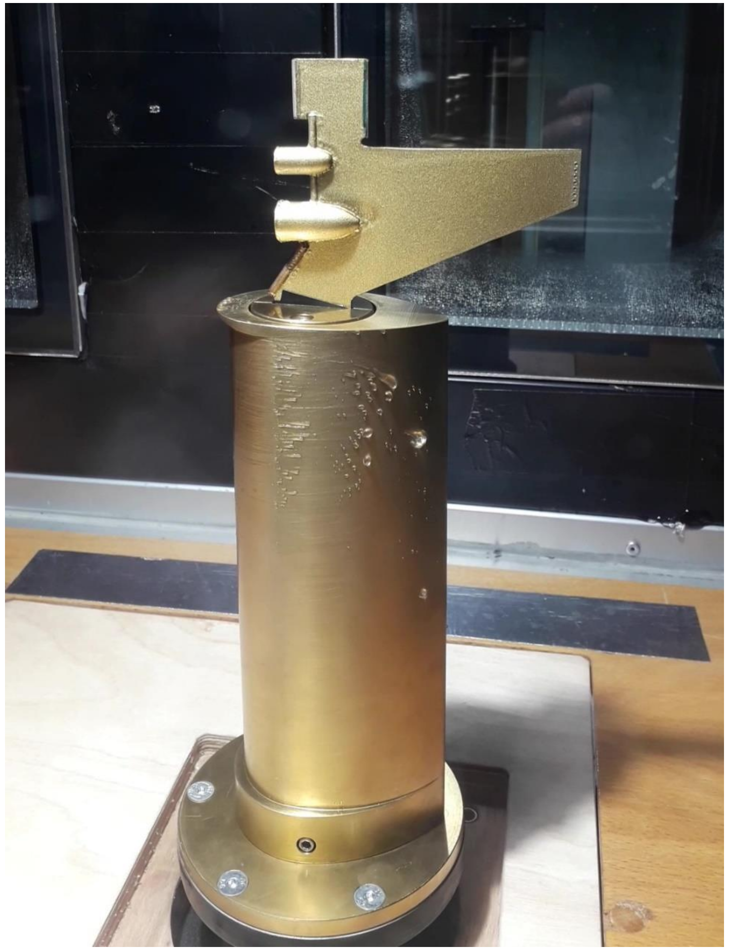
Water impinges on the sensors and reduces their temperature

↓

The sensor draws additional power until the water is evaporated

↓

The LWC is estimated from the power consumption



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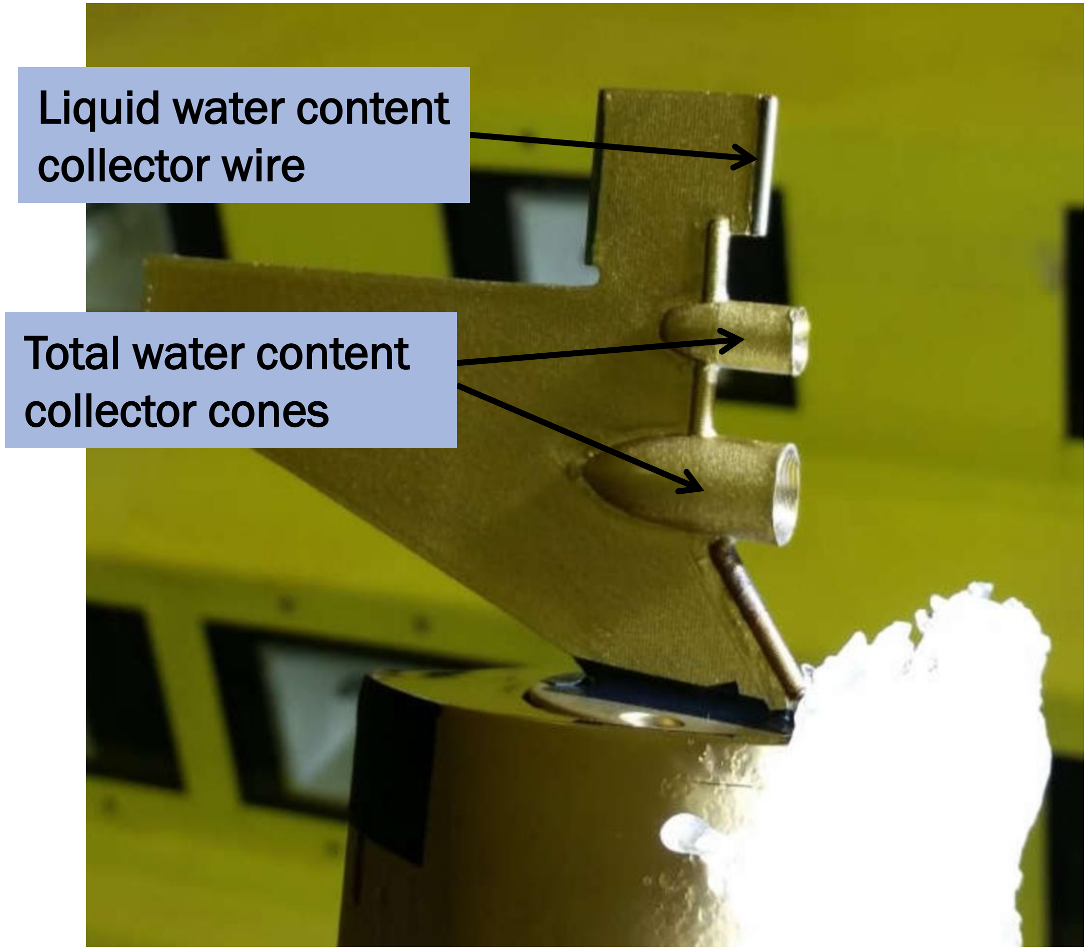
Nevzorov probe sensors: Properties

1. **LWC collector wire**
   - Collects **only** liquid water, no ice!
   - Has the highest collection efficiency for droplets around 20 µm
   - Larger droplets break up on impact and are only **partially** collected
2. **8 mm TWC collector cone**
   - Collects water and ice
   - Only partially collects droplets < 30µm
   - High collection efficiency for droplets > 30 µm
3. **12 mm TWC collector cone**
   - Collects water and ice
   - Poorly characterized until now



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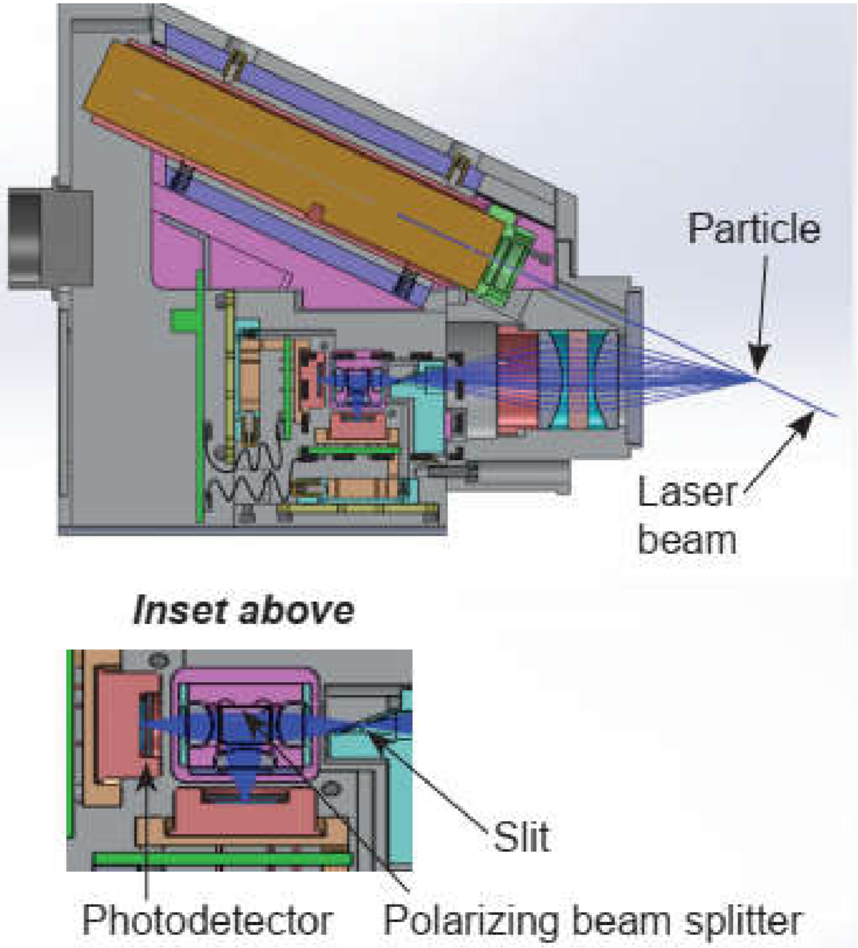
Information taken from: Korolev et al. (1998), Strapp et al (2003), Isaac et al. (2006), Schwarzenboeck et al. (2009), Korolev et al. (2013)

BCPD

- Uses the **intensity** of **backscattered** light to derive droplet sizes
- Similar instrument flew on commercial aircraft during the IAGOS mission [Beswick et al. (2014)]
- Detects droplets up to a size of 50 µm
- Droplet **shape** can be assessed from the **polarization** of the backscattered light

  → **We can distinguish between droplets and ice**
- Characterization of BCPD in the scope of the SENS4ICE project



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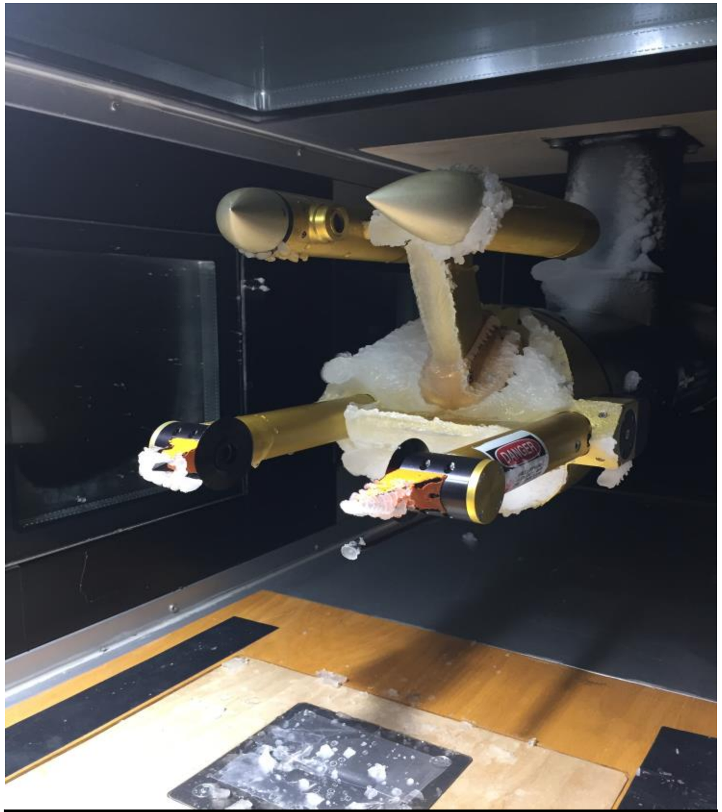
Wind tunnel testing

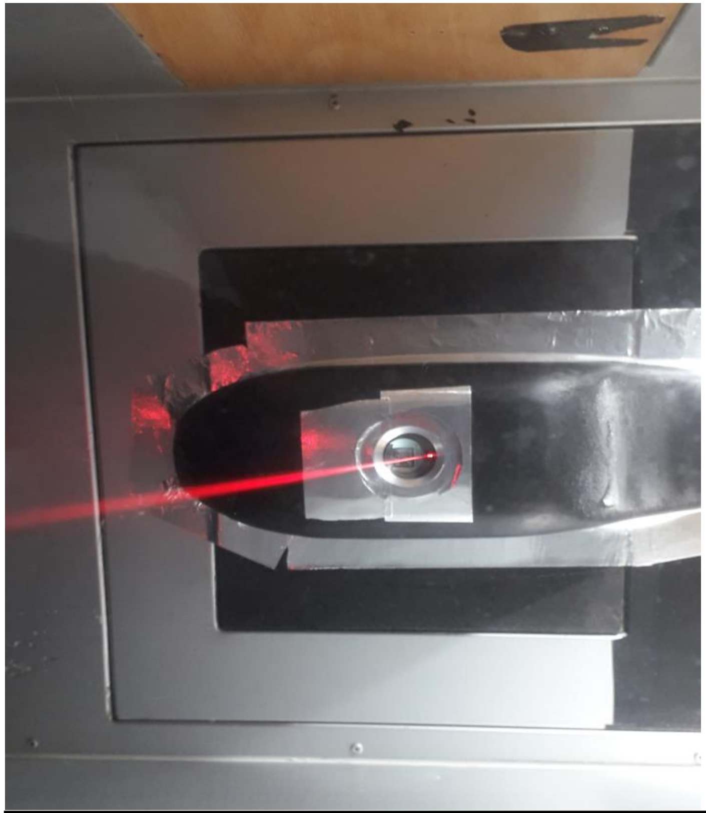
Tests in the TUBS icing wind tunnel

- Wind tunnel testing in Appendix C and O conditions was conducted during three weeks in January and July 2020



CDP size range : 2 – 50 µm
CIP size range: 15 – 950 µm

LWC sensitivity: 0.003 g/m³
Air speed range: 10 – 180 m/s



Size range : 2 – 50 µm

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Goals:

- Collect reference data for SENS4ICE project
- Characterize collection efficiency of 12 mm TWC sensor
- Assess the performance of the BCPD

Reference measurements

The performance of the CM2D is assessed through comparison with other sensors that were tested in the wind tunnel (by TUBS and DLR)

For LWC, measurement data from the following instruments is available:

1. Rotating cylinder
2. Nevzorov probe (LWC and 8 mm TWC collector)
3. Volume flow

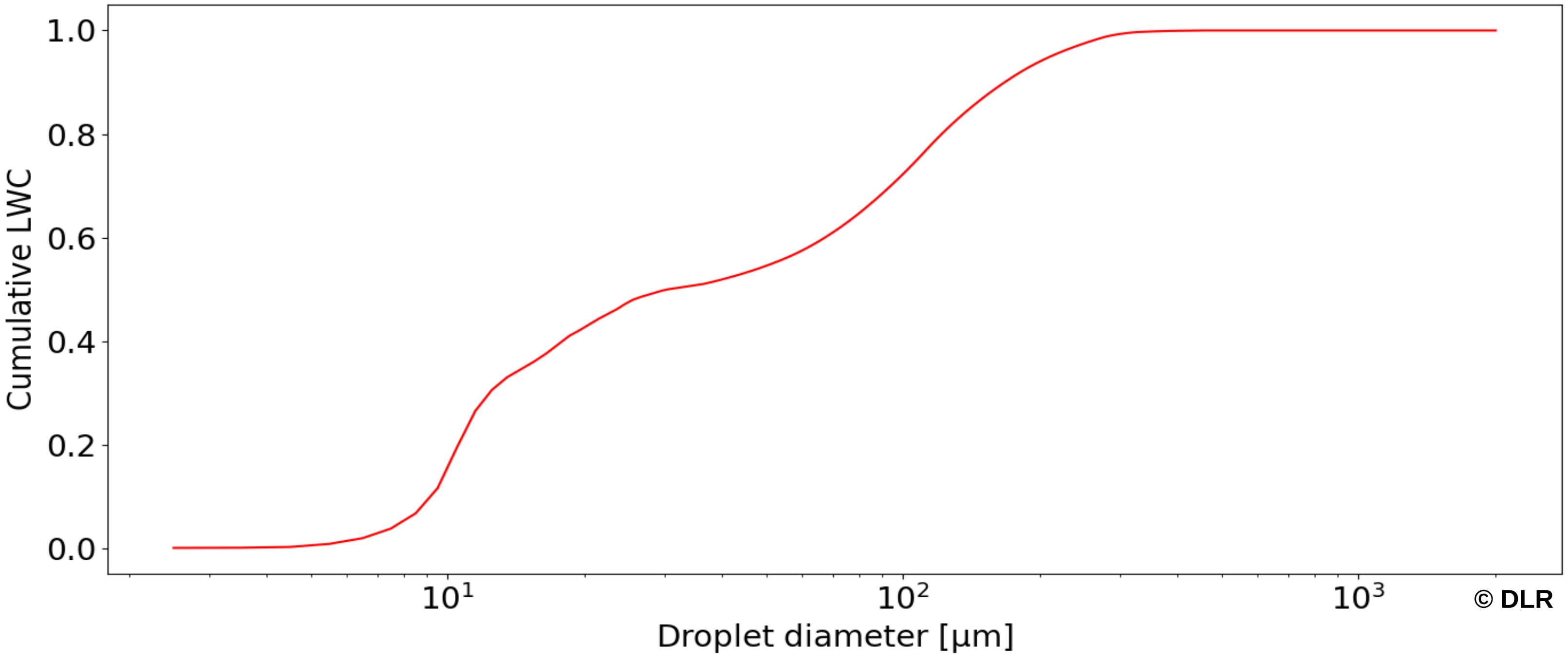
The MVD of each test point is estimated from data of :

1. PDI
2. CCP (CDP & CIP)

Testing conditions

- The instruments were tested in Appendix C and Appendix O conditions
- Temperatures ranged from 0 to -20°C
- An airspeed of 40 m/s was used for all test points

Bimodal size distribution measured in the TUBS wind tunnel with the CCP



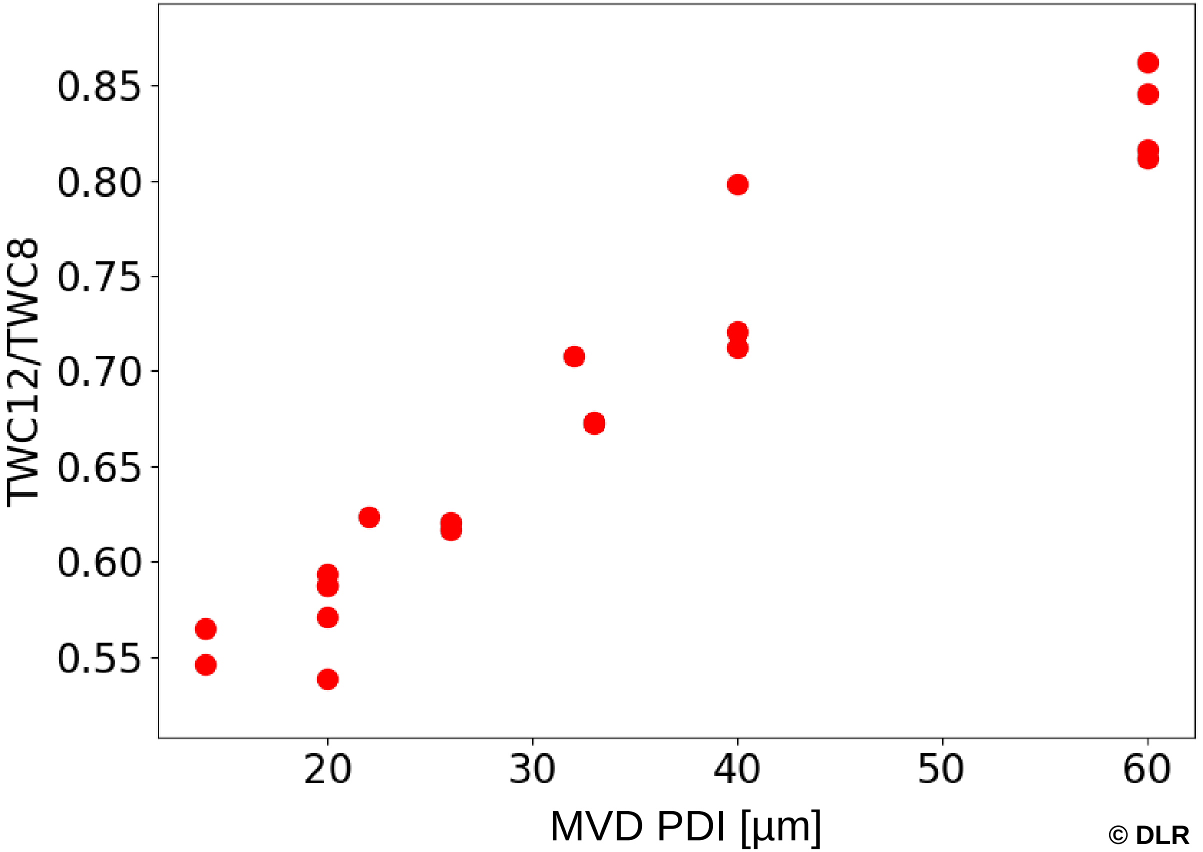
Performance of the 12 mm TWC sensor

- First tests in Appendix C conditions only

- The 12 mm TWC sensor shows a significantly lower response to small droplets than the 8 mm TWC sensor

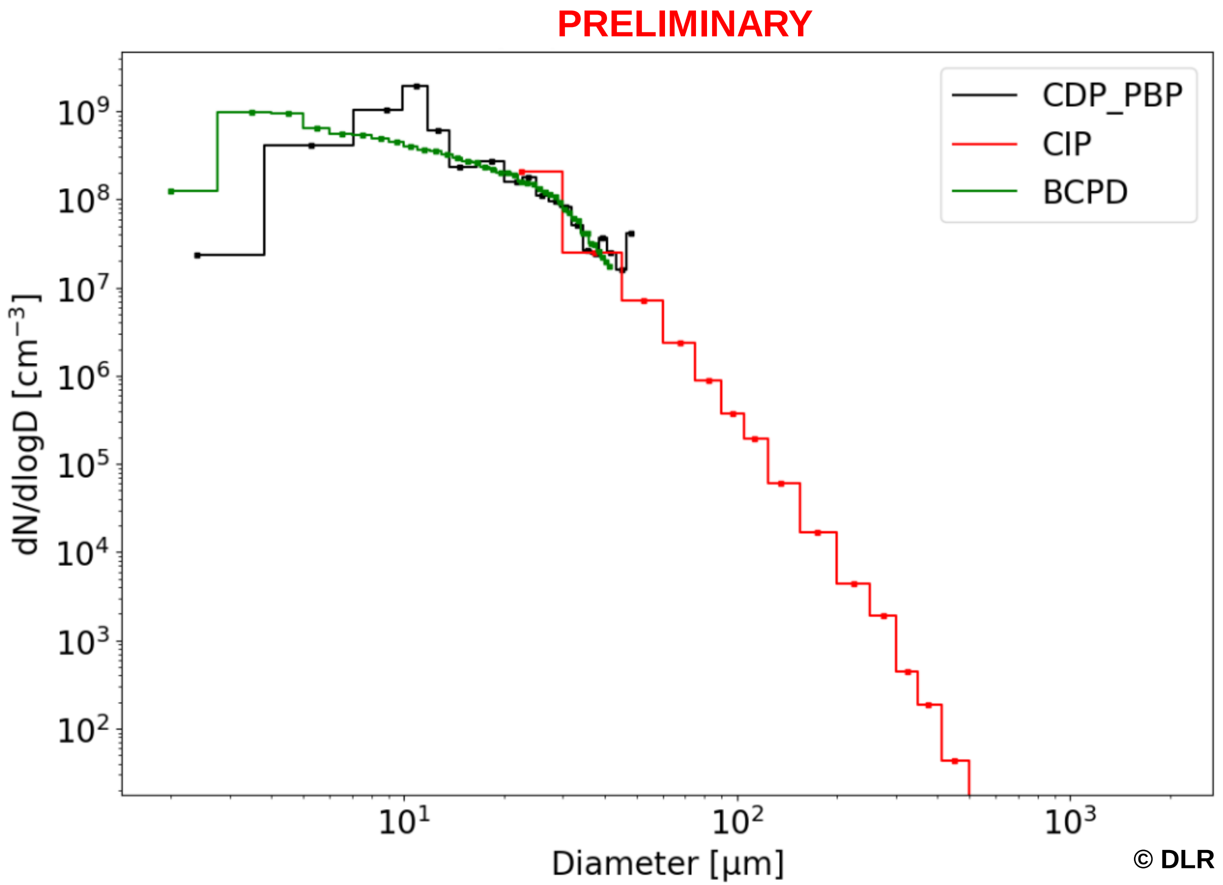
- The 8 mm TWC sensor also does not collect all small drops

→ collection efficiency of 12 mm cone is lower than 0.5 for droplets < 20 µm at an airspeed of 40 m/s



BCPD performance

- The BCPD is a new instrument and has yet to be fully characterized
- First results show that its size distribution and derived MVD agree well with that of the CDP and CIP



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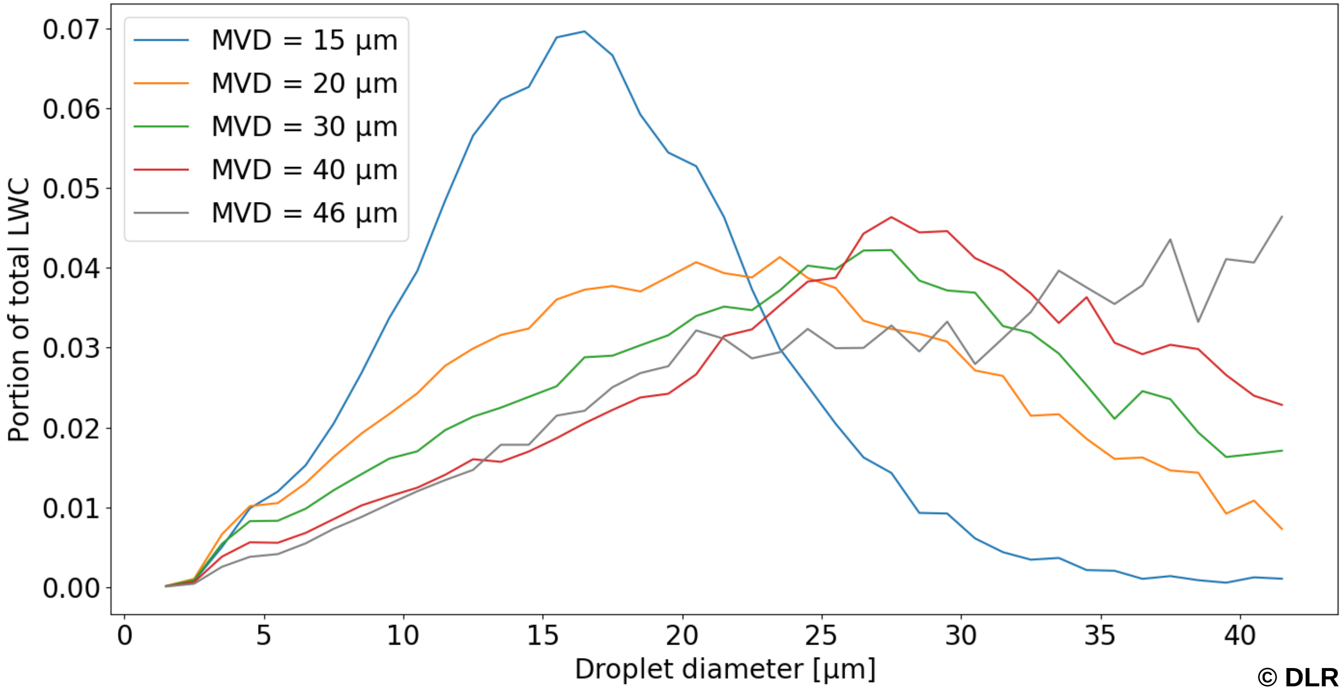
BCPD performance [2]

- For large MVD, only a part of the droplet spectrum is detected by the BCPD
- Hence, the MVD is underestimated
- The true MVD may be estimated by fitting a curve to the known part of the distribution (for unimodal conditions)



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App. O detection strategy of the CM2D

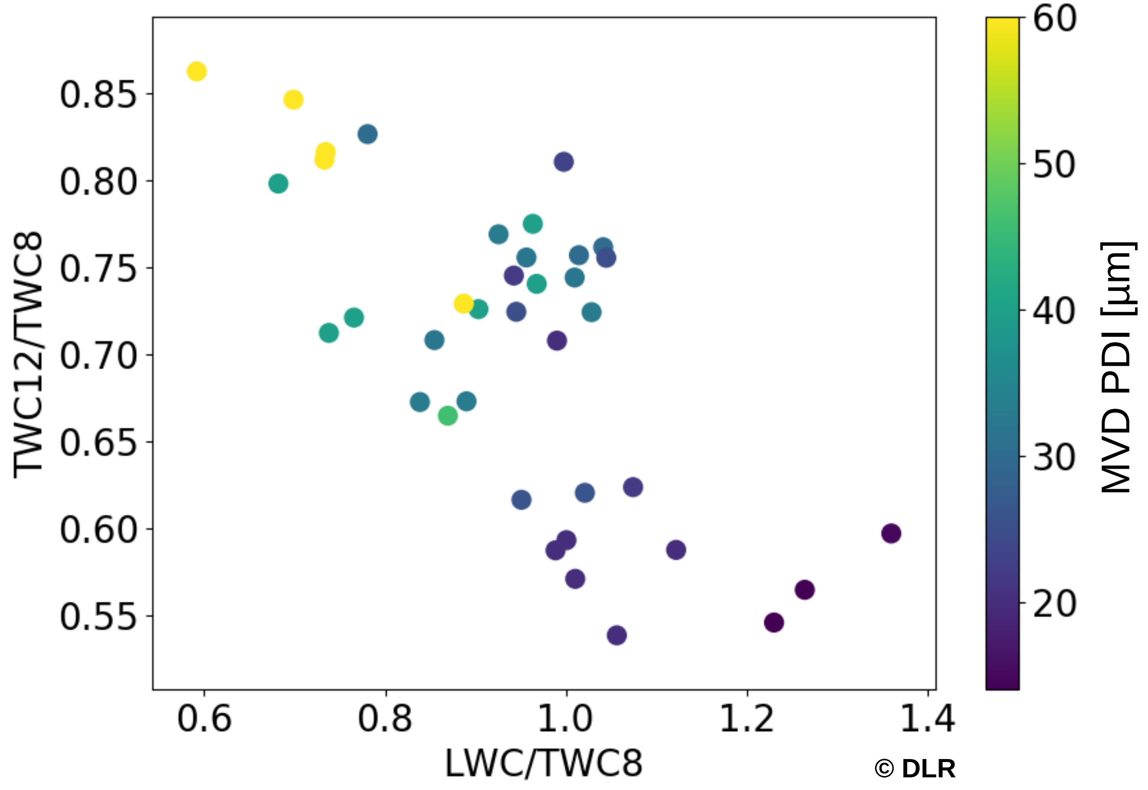
Deriving MVD from Nevzorov sensor ratios

An **increase in droplet MVD** leads to:

1. **A decrease in LWC/TWC8 ratio**

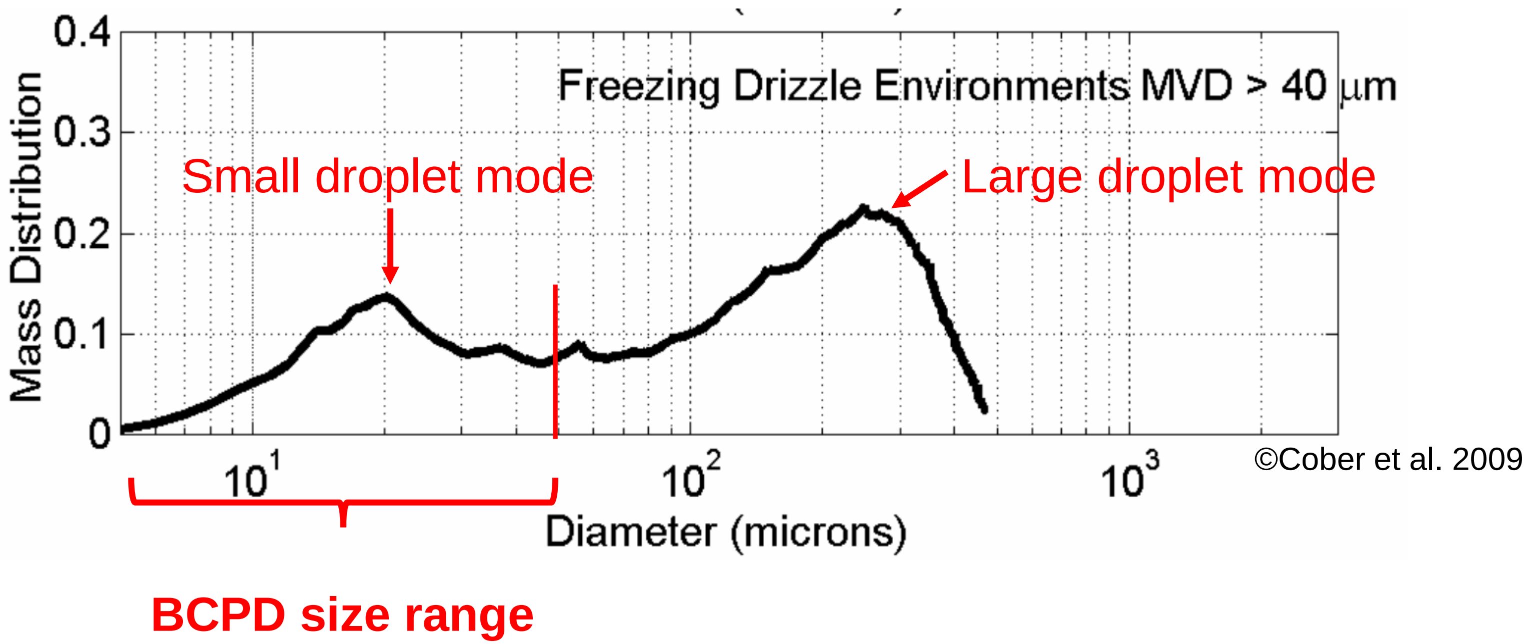
2. **An increase in TWC12/TWC8 ratio**

→ **We obtain an MVD estimate from the sensor ratios**



BCPD MVD

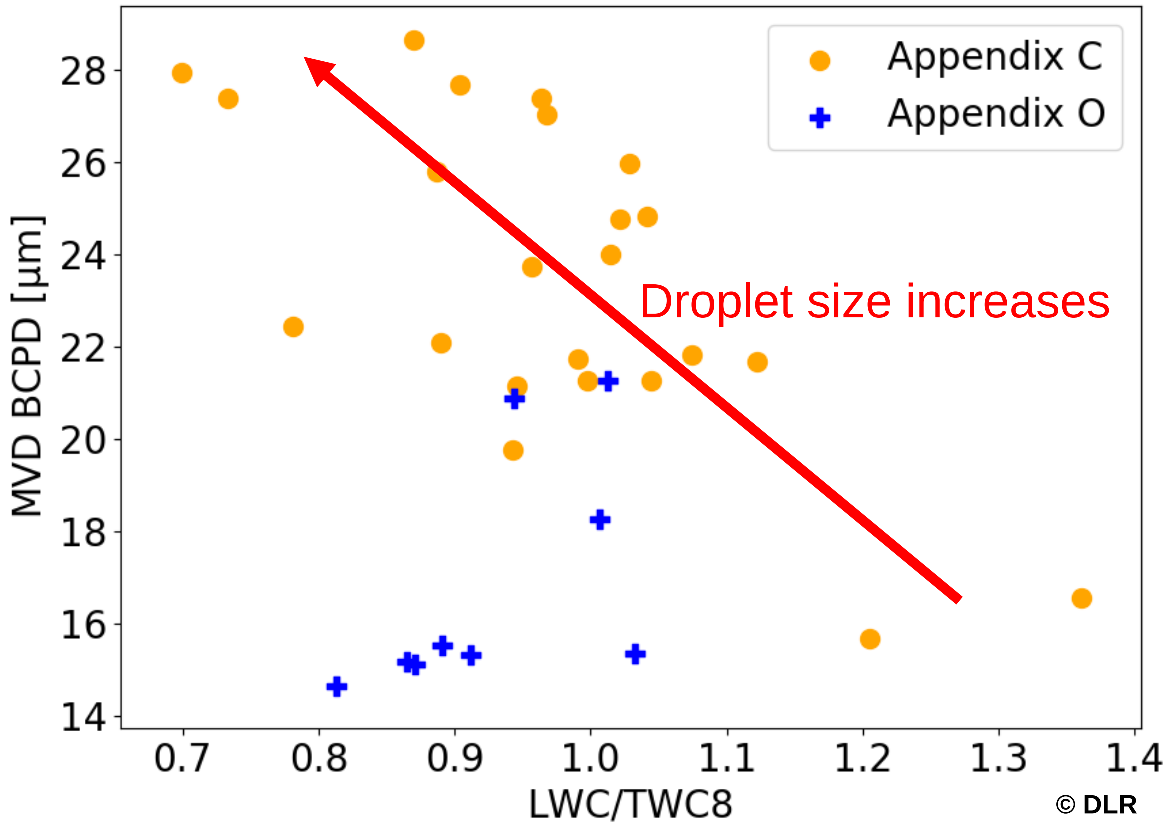
- The BCPD calculates an MVD of the droplets within its **size range**



→ There will be a mismatch between the MVD from BCPD data and the MVD from Nevzorov data!

Detecting Appendix O with Nevzorov and BCPD

- The ratio of LWC to TWC diminishes with increasing MVD (red arrow)
- Appendix O testpoints do not follow the expected LWC/TWC8 to MVD relation
- Instead, they are found in the bottom left of the plot



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Summary and Outlook

Summary

1. Due to differing collection efficiencies, the ratios between the individual Nevzorov sensors can be used to estimate an MVD

2. The BCPD measurements agree well with those of comparable instruments. The MVD computed from the BCPD measurement only represents the small mode of a bimodal distribution

3. Appendix O conditions are differentiated from Appendix C by detecting a mismatch between the MVDs estimated from BCPD and Nevzorov probe measurements

Outlook

Flight testing of the instruments:

- The Nevzorov probe flew as part of the scientific payload of the MOSAiC mission this summer in SLD conditions
  - → First results will be available in the coming months

- The BCPD will fly during the CIRRUS-HL mission on the DLR-HALO aircraft next year
  - → Comparison to underwing probes (CCP, CAS, CAPS) will help to assess the detection efficiency

Further characterization of CM2D behaviour:

- Assessment of false and missed alarm rate from the data gathered at TU Braunschweig
- Tests in other icing wind tunnels in SLD conditions

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 824253.

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