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SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Measurements of Appendix O conditions in IWT using scientific airborne instrumentation

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Virtual

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The Sens4Ice project

Sens4Ice project

The Sens4Ice project aims to develop systems capable of detecting Appendix O conditions for commercial aviation.

Such systems consist of **two** parts:

Direct system

- Detects SLD or ice accretion.

Coupled with

Indirect system

- Analyses aircraft performance to assess if ice accretion occurs.

The ability of the **direct sensors** to detect Appendix O is initially assessed during **wind tunnel testing.**

Sens4Ice timeline

Reference probes are used to measure atmospheric conditions

DLR provides reference instrumentation

Reference measurement results facilitate selection process

Upgrade wind tunnels to produce Appendix O

Develop sensors for detection of Appendix O

Wind tunnel testing

Gate 2: Selection of the most promising designs for flight testing

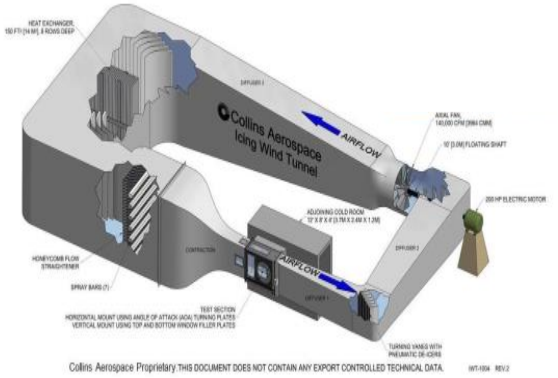
Flight testing

2019 - 2020

2021

2023

Sens4Ice wind tunnels#



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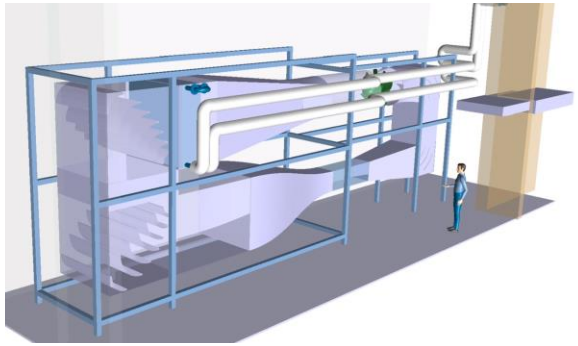

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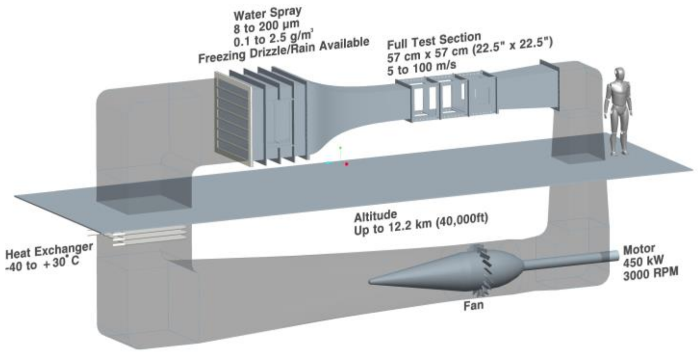

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Goodrich Icing Windtunnel (Collins Aerospace)

Airspeed*: 40 – 85 m/s
Temperature*: 0 – -30°C
Cross Section: 56 x 112 cm²

Instrumentation for Appendix C:
PDI, Icing Blade

Instrumentation for SLD:
PDI, SEA probe

TU Braunschweig Icing Windtunnel

Airspeed*: 40 m/s
Temperature*: 0 – -20°C
Cross Section: 50 x 50 cm²

Instrumentation for Appendix C:
PDI, rotating cylinder

Instrumentation for Appendix O:
PDI, no dedicated LWC instrument

NRC Altitude Icing Windtunnel

Airspeed*: 40 -100 m/s
Temperature*: -5 – -20°C
Cross Section: 57 x 57 cm²

Instrumentation for Appendix C:
Malvern, rotating cylinder

Instrumentation for Appendix O:
Malvern, rotating cylinders

#The TSAGI SENS4ICE IWT facilities have not been involved in the SENS4ICE 2020/2021 reference measurement activities.
*Airspeeds and temperatures listed are those used for Sens4Ice, not the maximum conditions.

Strategy for Sens4Ice wind tunnel measurements

- DLR reference measurements in three wind tunnels

  →This gives us comparable measurements!

- For Appendix C we compare reference measurements with tunnel in-house measurements. → Cross-check for our reference measurements

- No established calibration methods for Appendix O exist.

  →We can compare the reference measurements to tunnel in-house instrumentation used to measure Appendix O.

  →We gain new knowledge about the measurement of Appendix O conditions.

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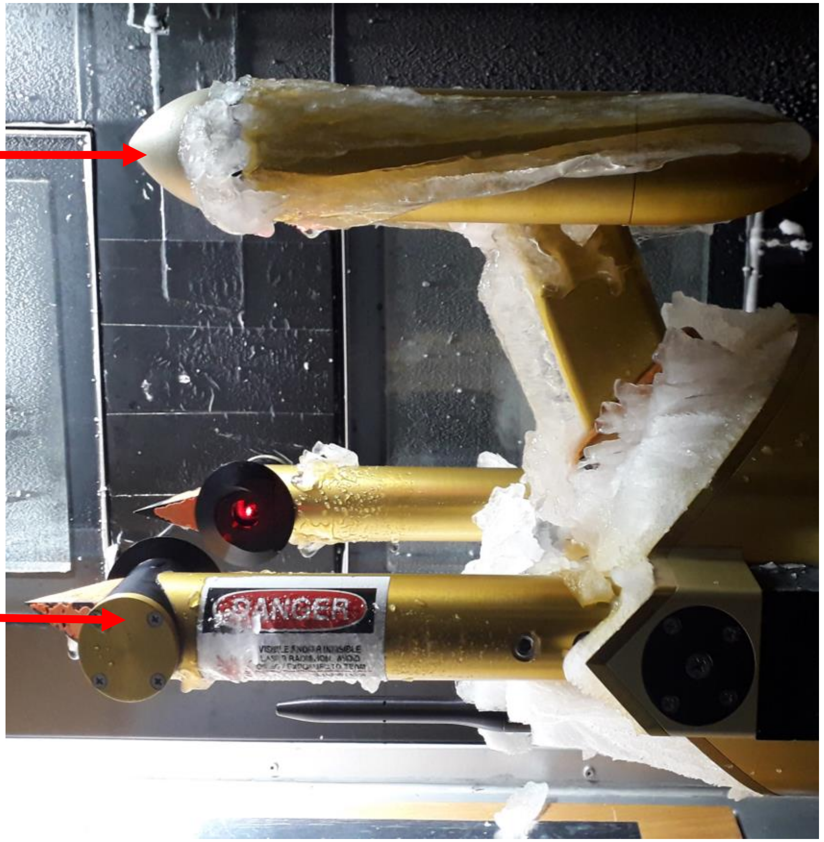
DLR Reference Instrumentation

DLR Reference instrumentation

Cloud Combination Probe (CCP)

CDP

CIP



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- CDP: Scattering probe for particle size measurements from 2 – 50 µm
- CIP: Optical array probe for particle size measurements from 15 – 950 µm
- Flight proven instrument, described in Weigel et al. 2016[1], Braga et al 2017a & b[2]
- OAP data processing with SODA software by Aaron Bansemer[3]

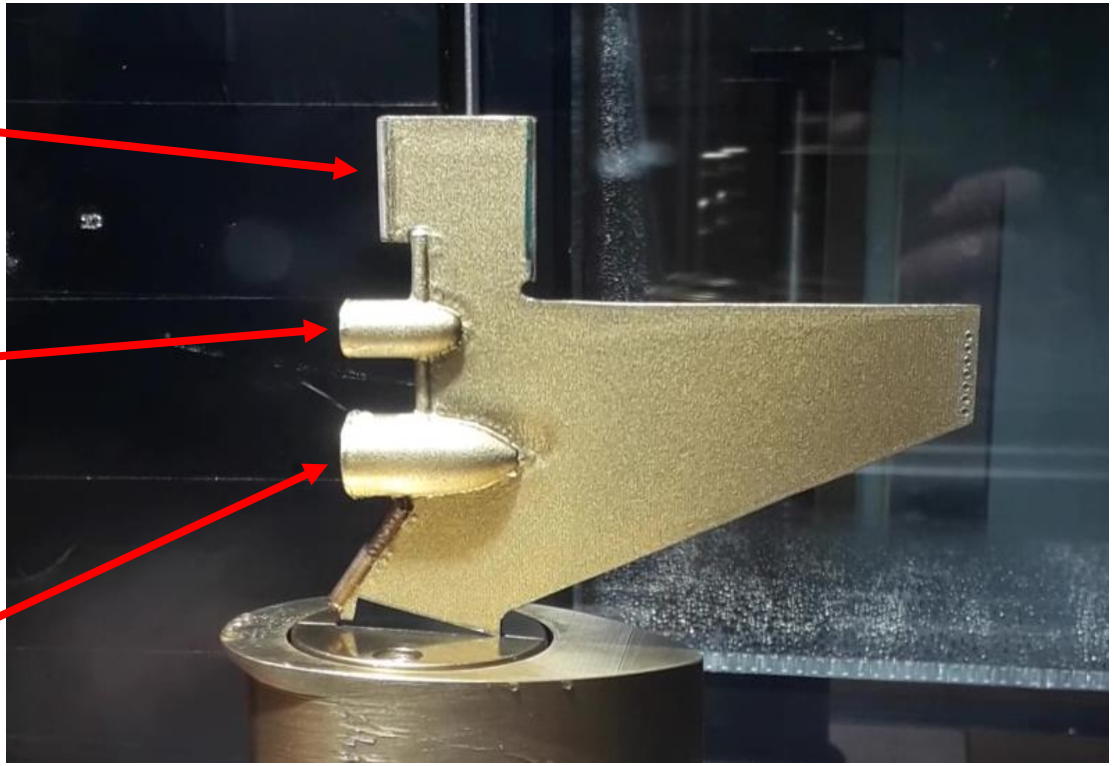
[1] Weigel et al. 2016, Atmos. Meas. Tech., [2]Braga et al 2017a & b, Atmos. Chem. Phys. , [3] https://github.com/NCAR/soda2_hiwc

Measuring the LWC with the Nevzorov probe

LWC sensor:
- Collects small droplets well
- Large droplets splash

8 mm TWC sensor:
- Lower collection efficiency for small droplets than LWC sensor
- Suitable for large droplets

12 mm TWC sensor:
- Very low collection efficiency for small droplets
- Yet to be characterized



The Nevzorov probe has been described in various publication, among others in: Korolev et al. (1998), Strapp et al. (2003), Isaac et al. (2006), Schwarzenboeck et al. (2009), Korolev et al. (2013).

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Challenges measuring SLD

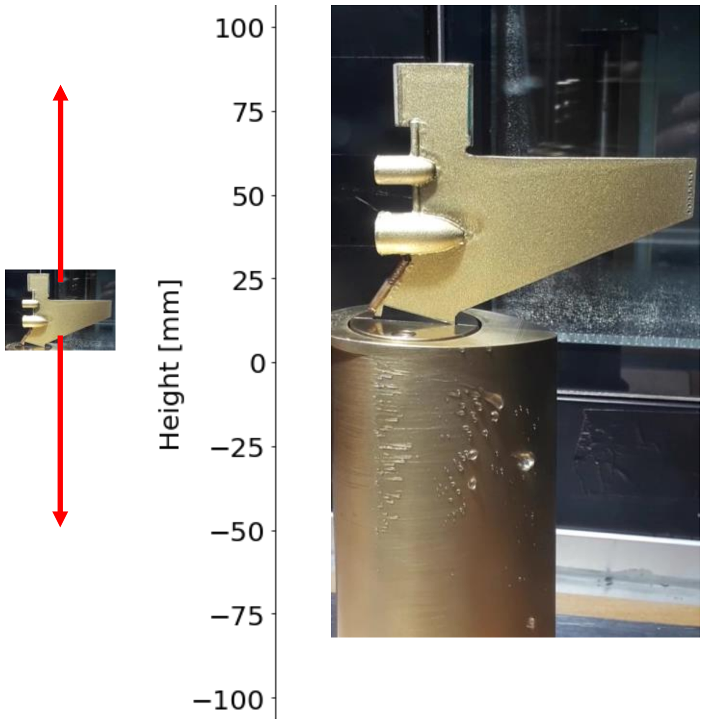
Challenges of measuring SLD

Where should we measure SLD?

Challenge: Find homogenous spray distribution

- Large droplet spray bars located at the top
- Small tunnel cross section, large separation of measurement volumes
- Lower airspeeds than in flight
- Solution: perform traverse measurements

Large droplet measurements at different heights at TUBS



Challenges of measuring SLD

The same challenge exists for the CCP, the CIP and CDP sample volumes are separated by 13.5 cm.

- The CIP measures large droplets, hence we positioned it where we expect to see the large droplets.
- The CDP measures small droplets, therefore we can position it where no large droplets are present.

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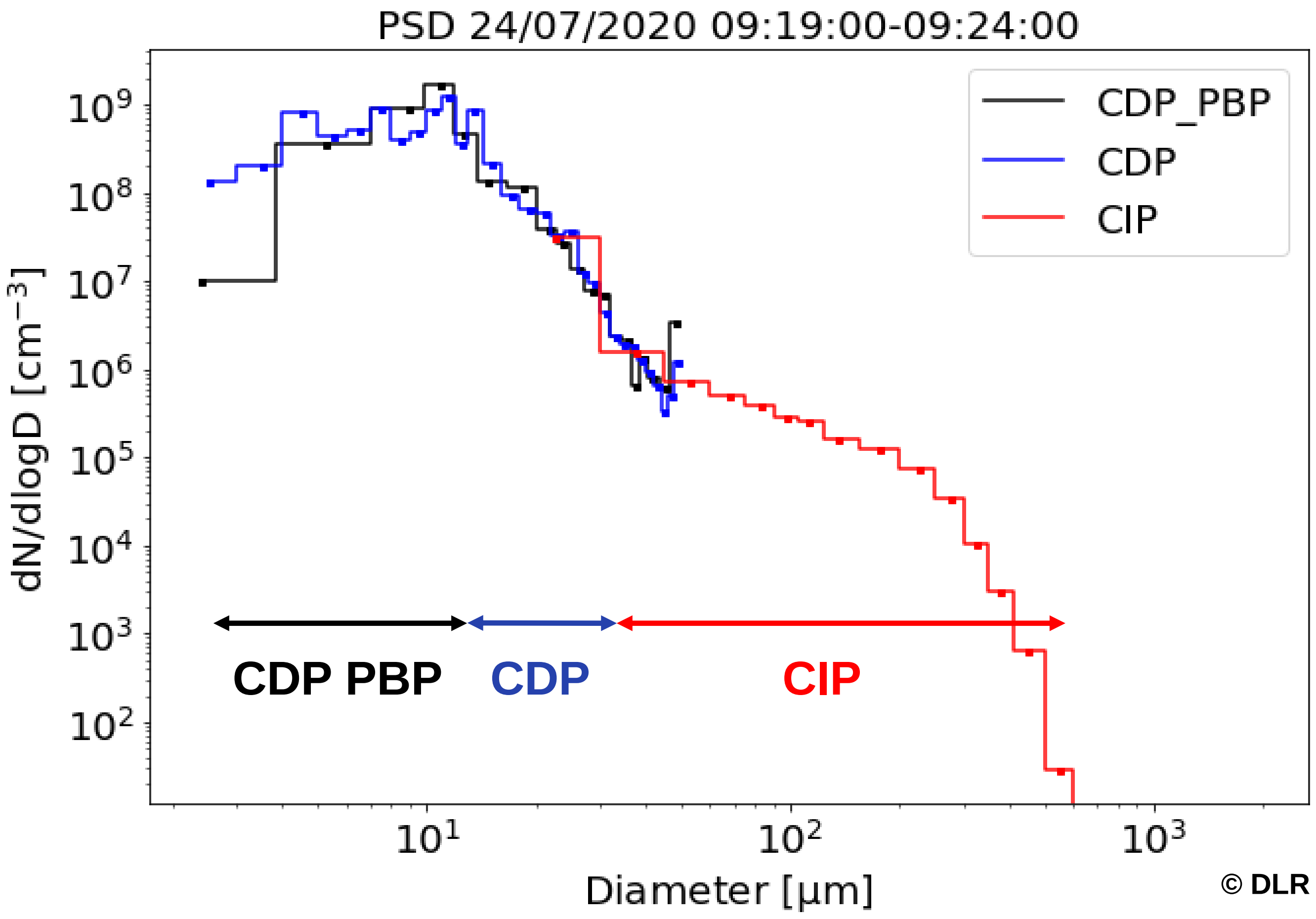
Data analysis

Combining size distributions

- Three data sources used for PSD
- In-depth calibration
  - PBP analysis
  - DOF analysis
  - Interarrival time analysis
  - Analysis of overlap regions



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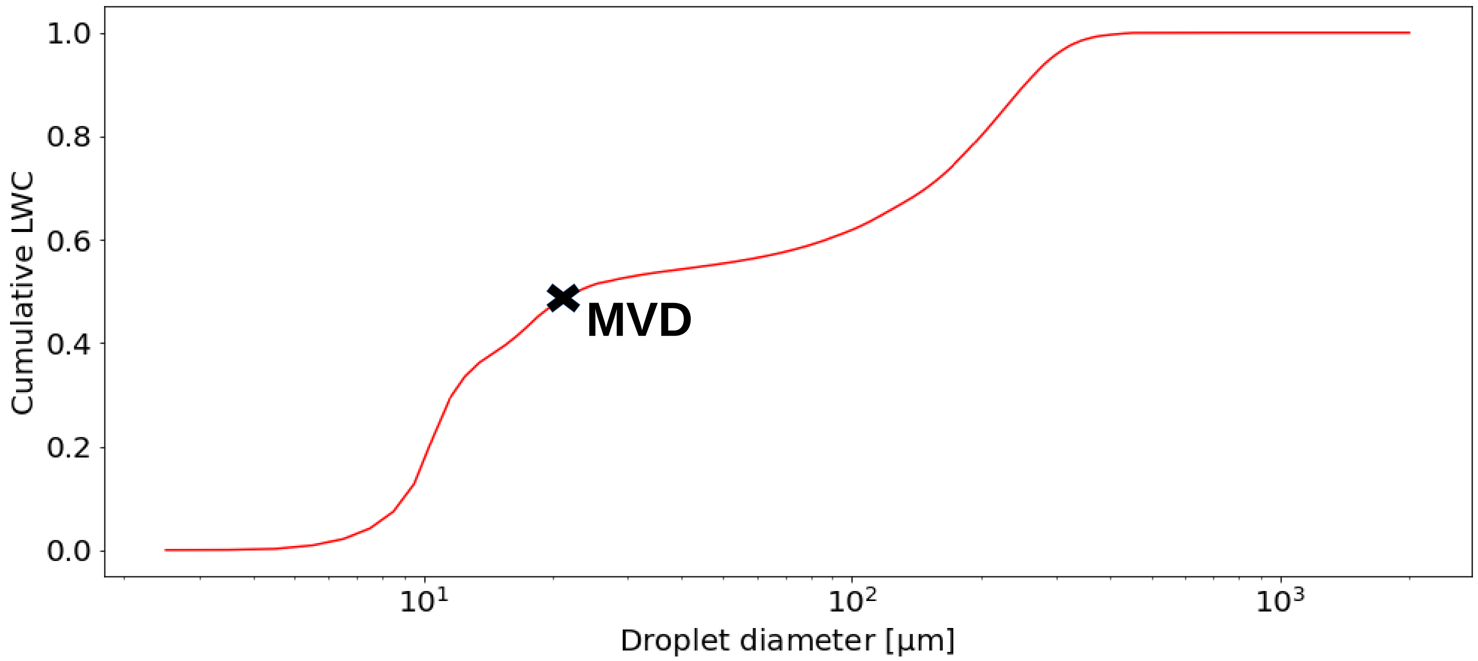
Results

Size distribution from TUBS

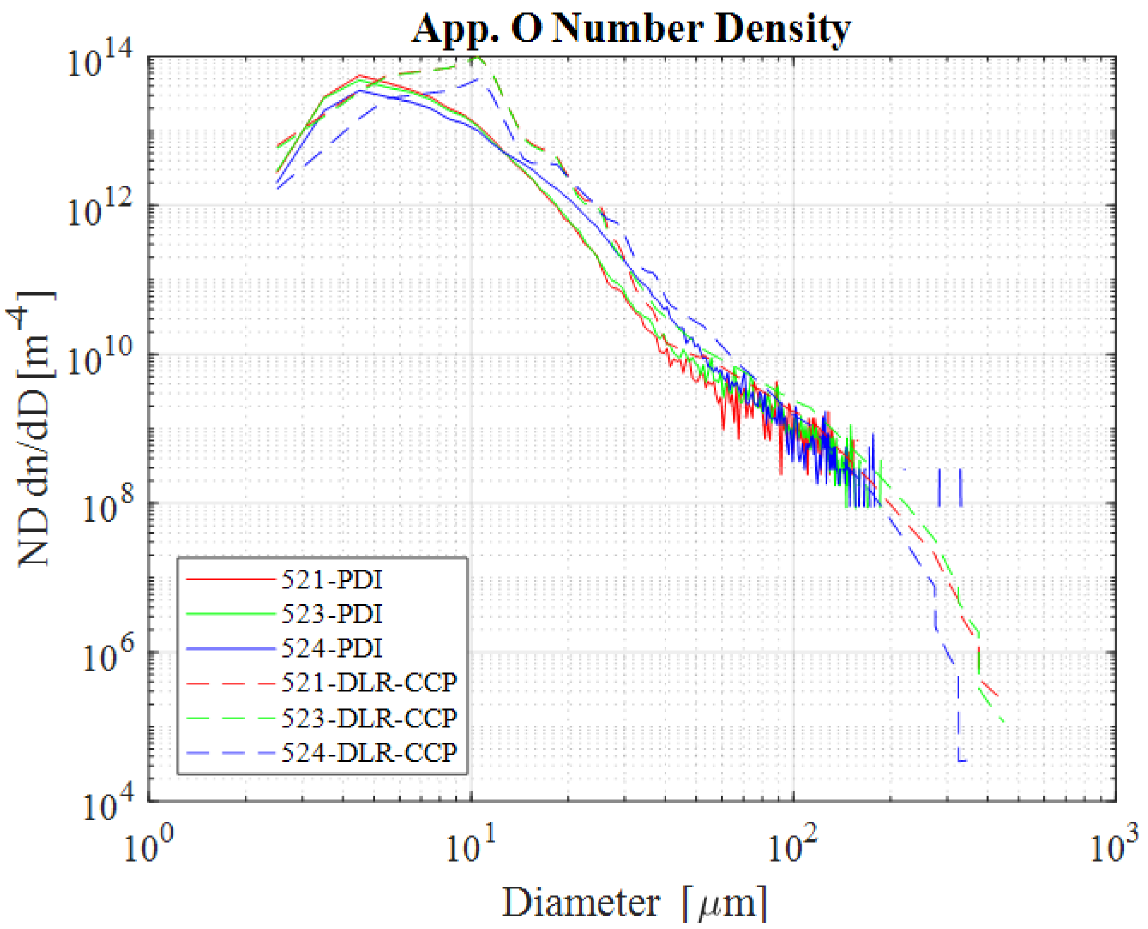
- We interpolate the size distribution to 1 µm resolution (as described in Cober and Isaac 2012[4]).



MVD falls between the two modes → It is very sensitive to small uncertainties in the LWC of one mode

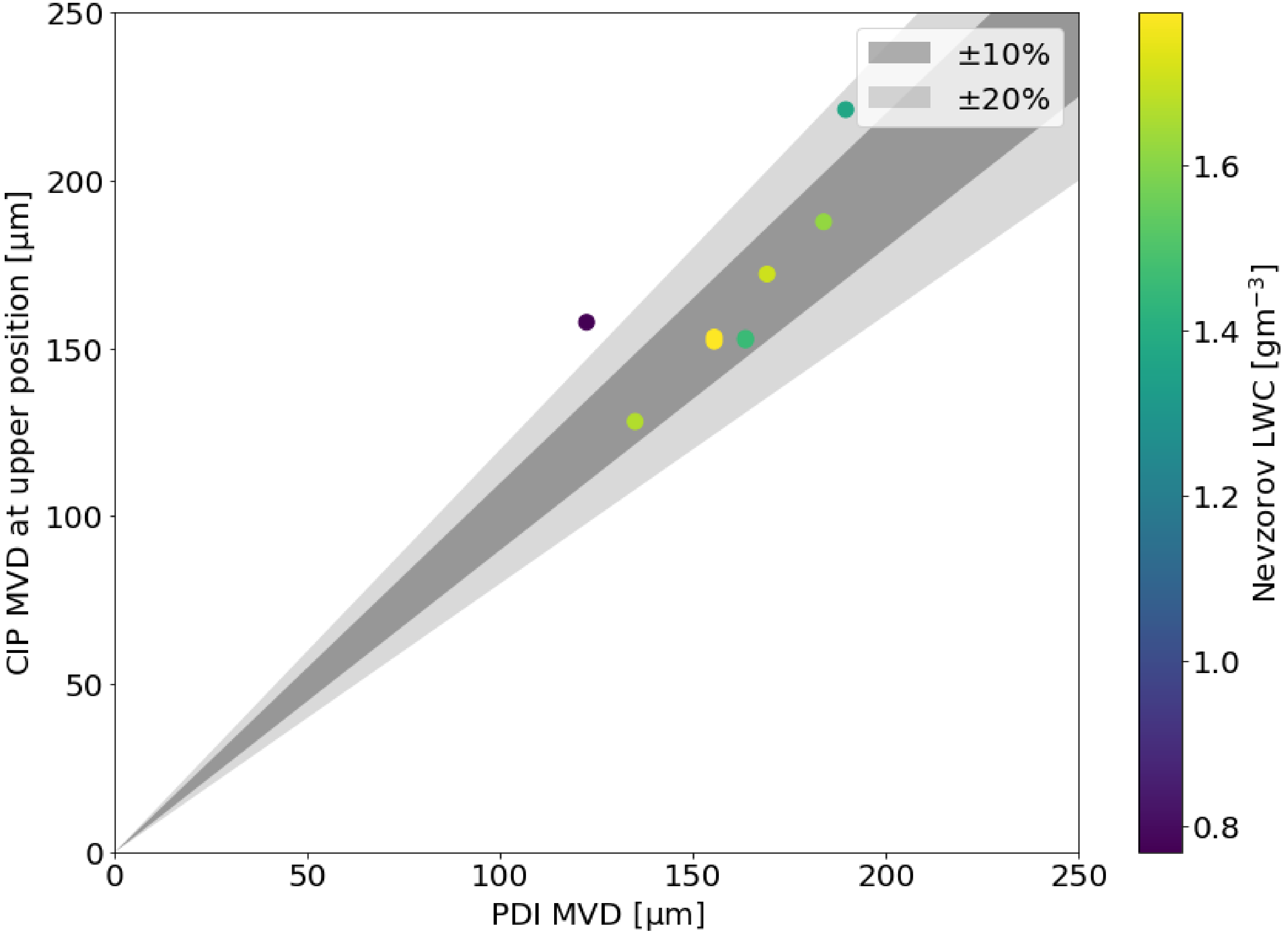
[4] Cober and Isaac 2012, Journal of Applied Meteorology and Climatology

Comparison of CCP and PDI measurements at TUBS



- We compared CCP and PDI measurements.
- The shapes of the distributions agree well.
- CCP measures higher number concentration over most of the spectrum.
- Peaks of CCP and PDI differ.
- We are currently investigating the issue.

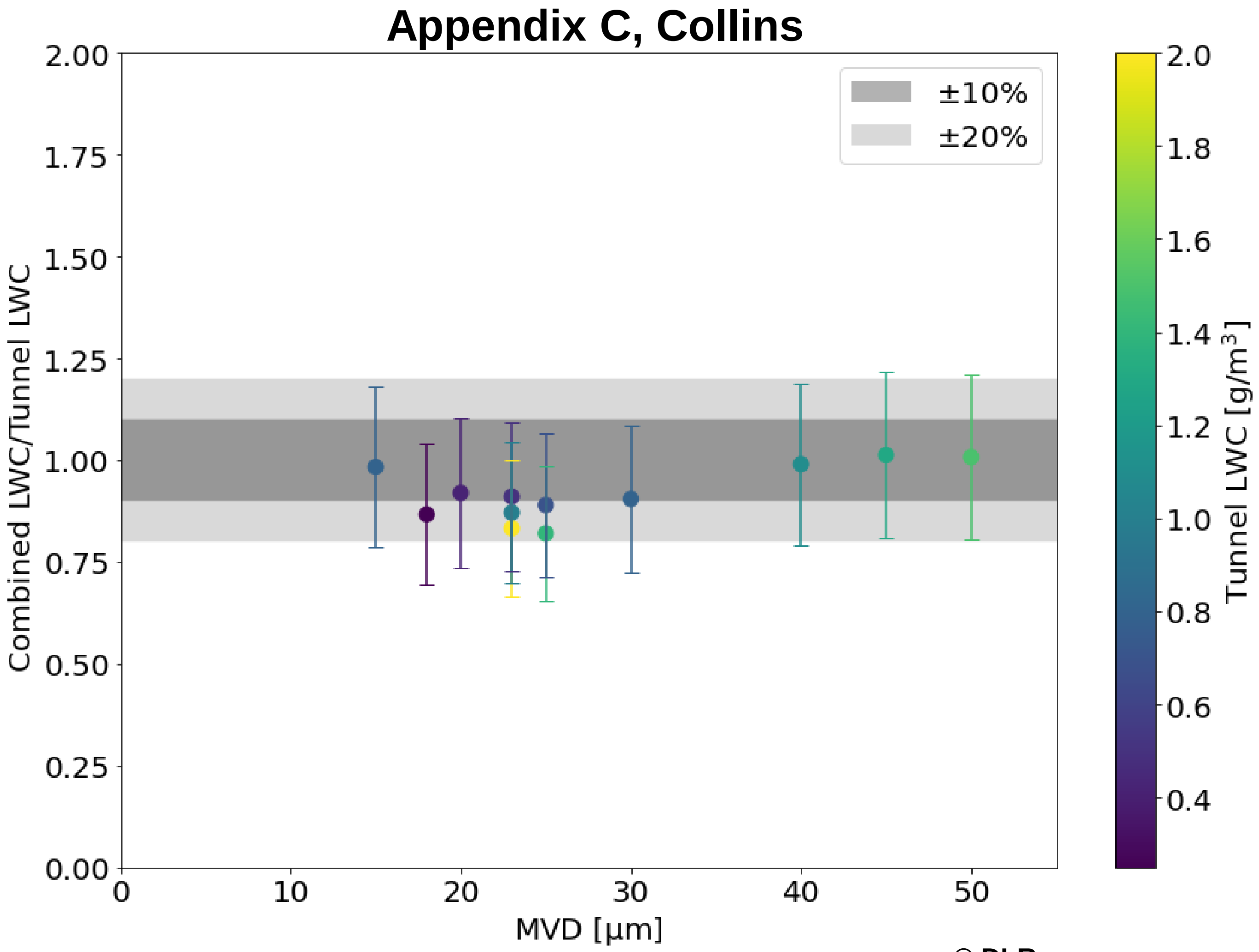
Comparison of CIP and PDI measurements at Collins



Contributors to the above figure: Matthew Hamman, Andrew Taylor, Galdemir Botura (all Collins Aerospace), Daniel Martins da Silva, Rogerio Pereira de Lima (both Embraer)

- PDI and CCP measure very similar MVDs for most test points.
- The size range between 50 and 150 µm is relatively difficult to measure with OAP probes due to changes in the depth of field.
- The agreement supports our calibration of the CIP.

Nevzorov data for Appendix C at 67 m/s



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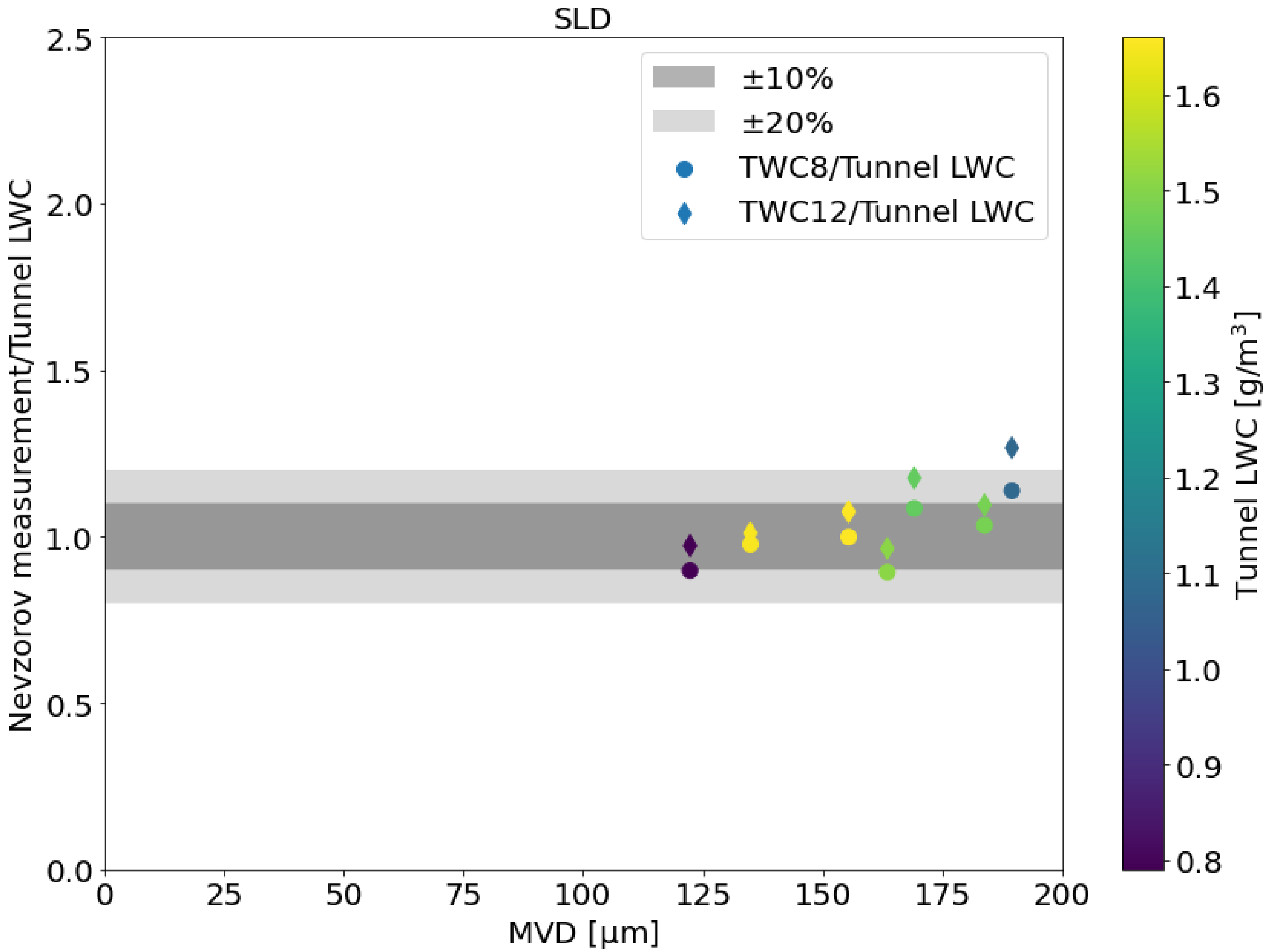
- Very good agreement between Nevzorov and tunnel data (Icing blade).
- Error bars based on:
- +-10% wind tunnel reproducibility
- +-10% Nevzorov measurement accuracy

Nevzorov measurements in SLD conditions

- All SLD measurements at 76 m/s.
- Nevzorov shows generally good agreement with SEA probe (Tunnel LWC).
- For MVDs > 180 um , SEA probe and Nevzorov measurements agree within a range of +20%.



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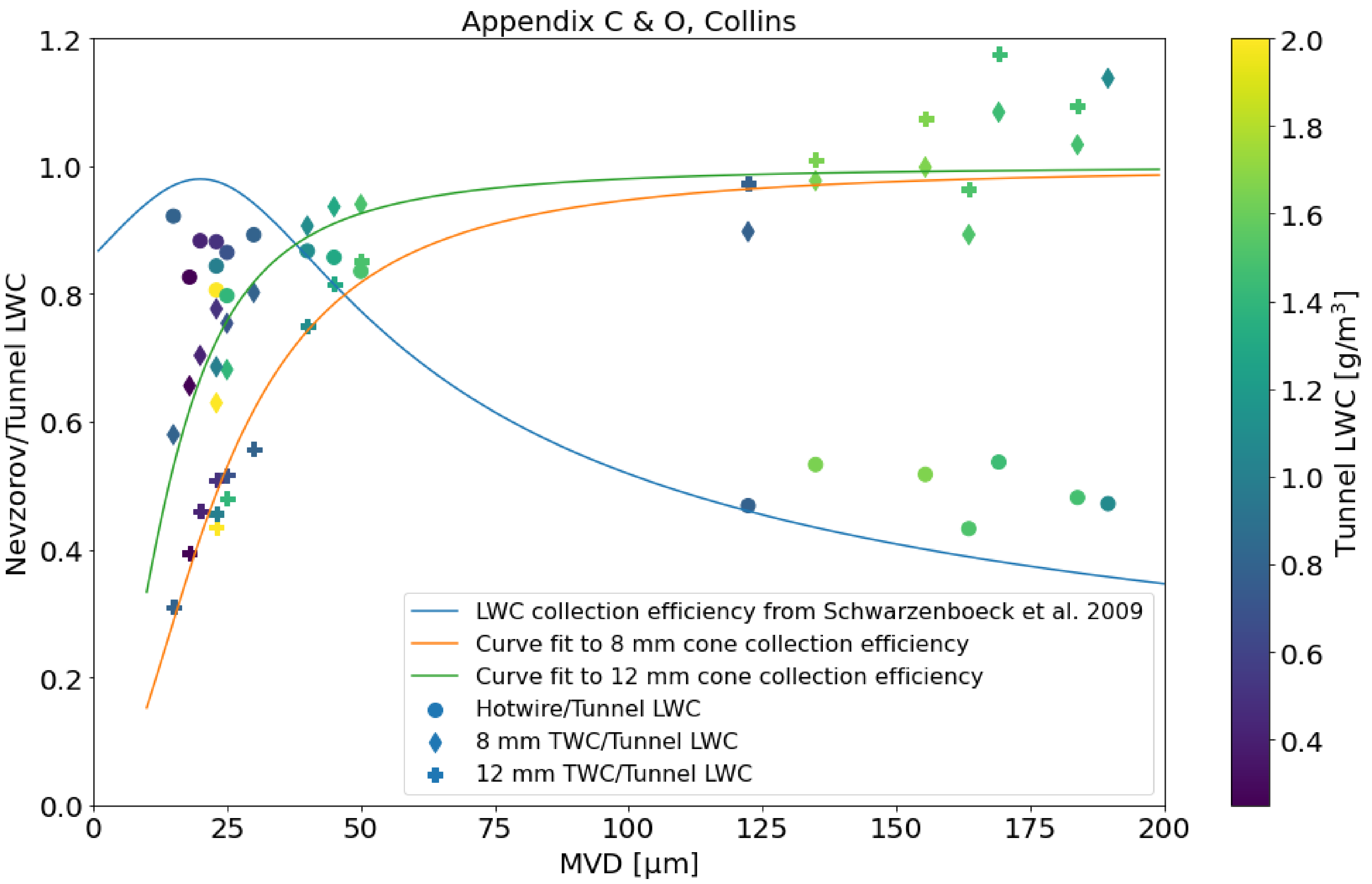

We determine the LWC with the suitable sensor:

- Small MVDs: Hotwire
- Medium MVDs: 8 mm cone
- Large MVDs: 12 mm cone
- Bimodal distributions: Very wide distribution, ideally use collection efficiency of only one sensor.

We derive the MVD and the size distribution from the CCP.

Conclusion

- A large data set of SLD conditions in three wind tunnels has been acquired during SENS4ICE wind tunnel testing (despite Covid-19 situation).
- Very good cooperation and discussions with wind tunnel operators have been established.
- LWC values from Nevzorov and SEA probe agree well in SLD conditions.
- MVD values from CCP and PDI agree well in SLD conditions.
- The comparison of size distributions from reference and in-house measurements is ongoing: Small differences in the size distribution may significantly affect the MVD.
- The work performed within the project will increase our understanding of the measurement of SLD conditions in IWT and during atmospheric airborne experiments.

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