SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Meteorological conditions and microphysical properties that lead to aircraft icing as observed during the SENS4ICE campaigns

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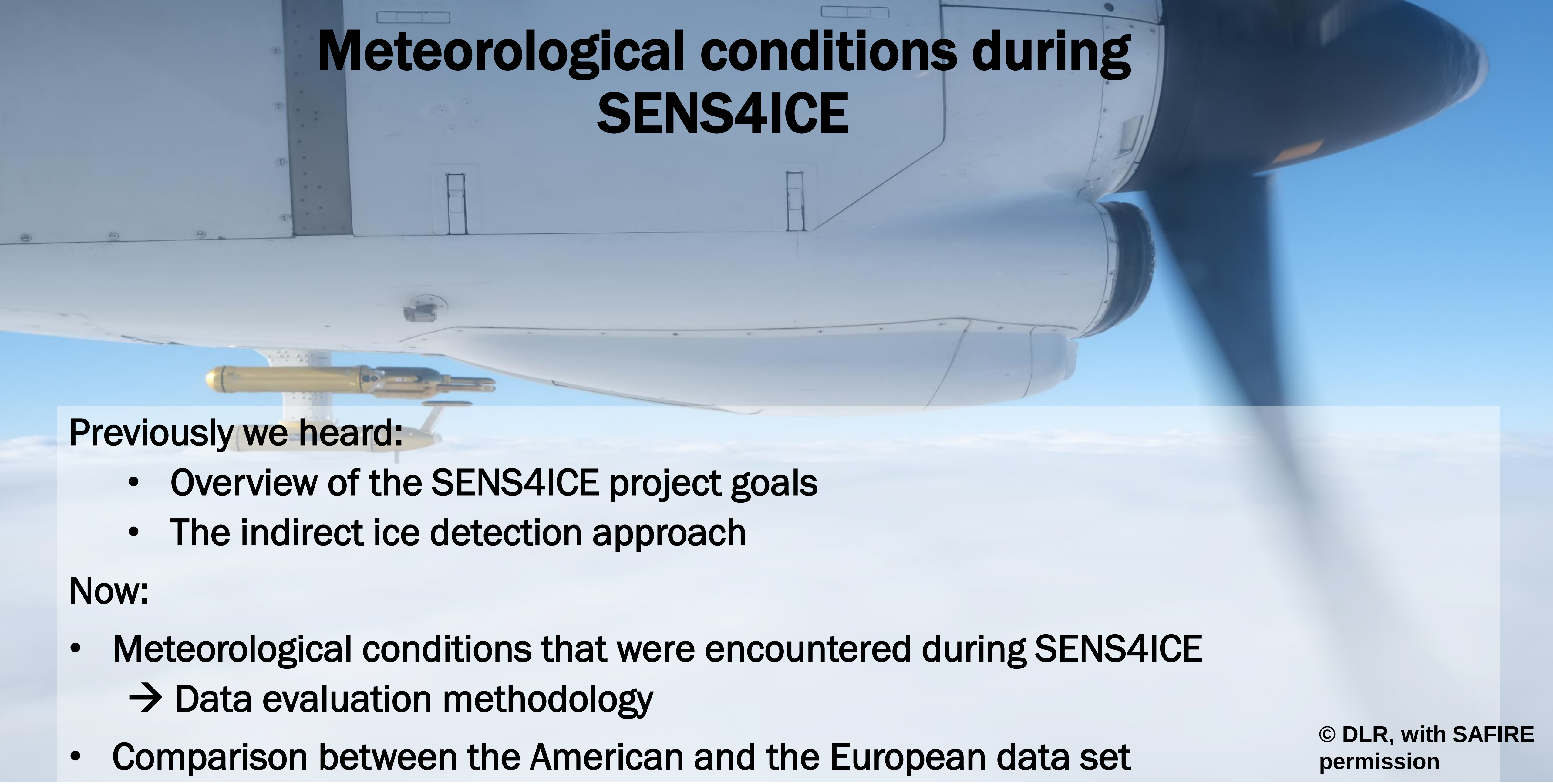
Meteorological conditions during SENS4ICE



Previously we heard:

- Overview of the SENS4ICE project goals
- The indirect ice detection approach

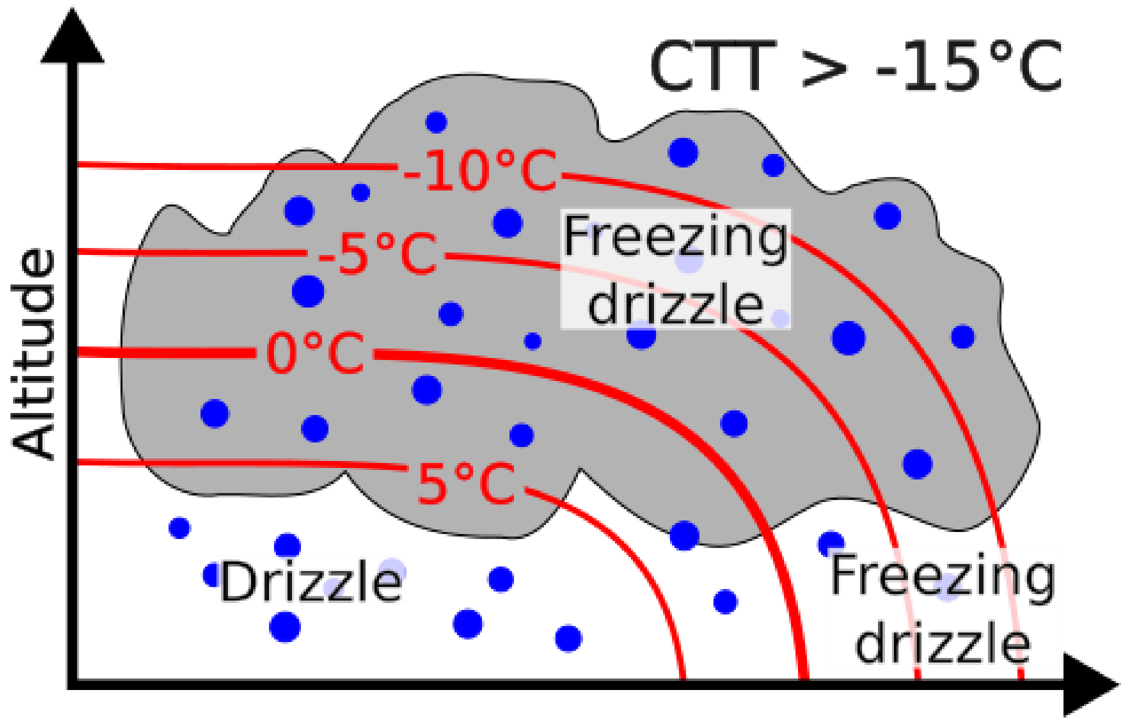
Now:

- Meteorological conditions that were encountered during SENS4ICE
  → Data evaluation methodology
- Comparison between the American and the European data set

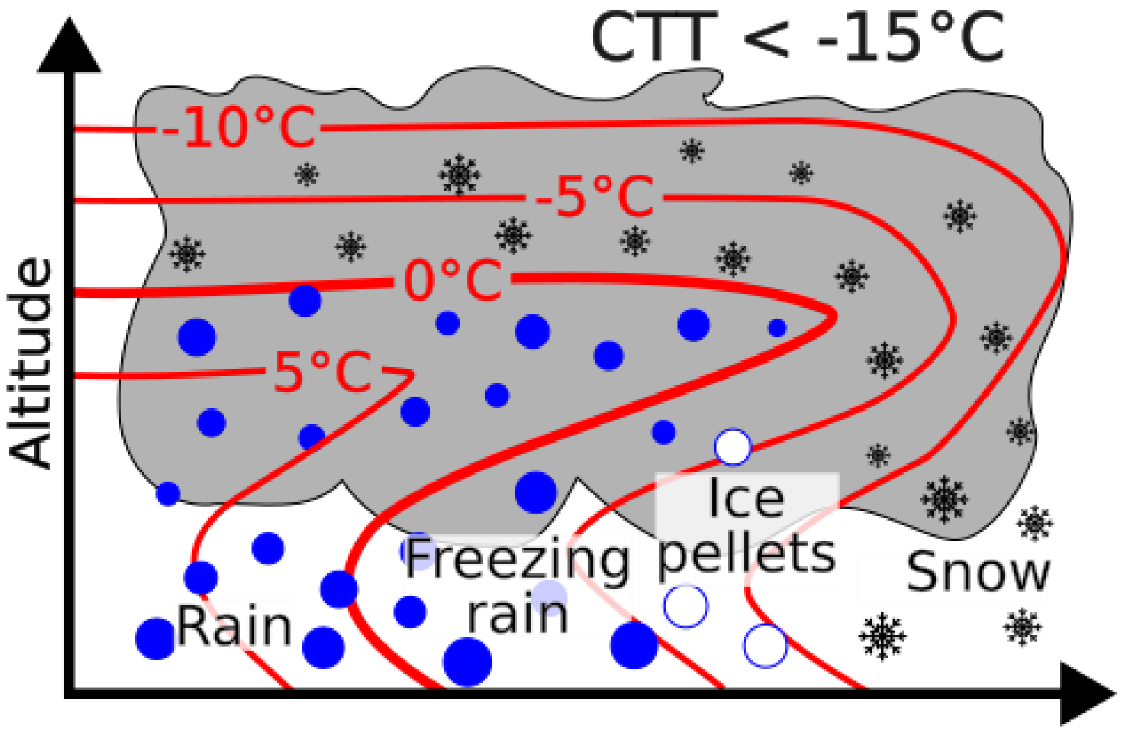
Formation of SLD icing conditions

Two types of SLD conditions are differentiated:

1. Freezing Drizzle (FZDZ)



2. Freezing Rain (FZRA)



Freezing Drizzle and Freezing Rain

Freezing Drizzle:

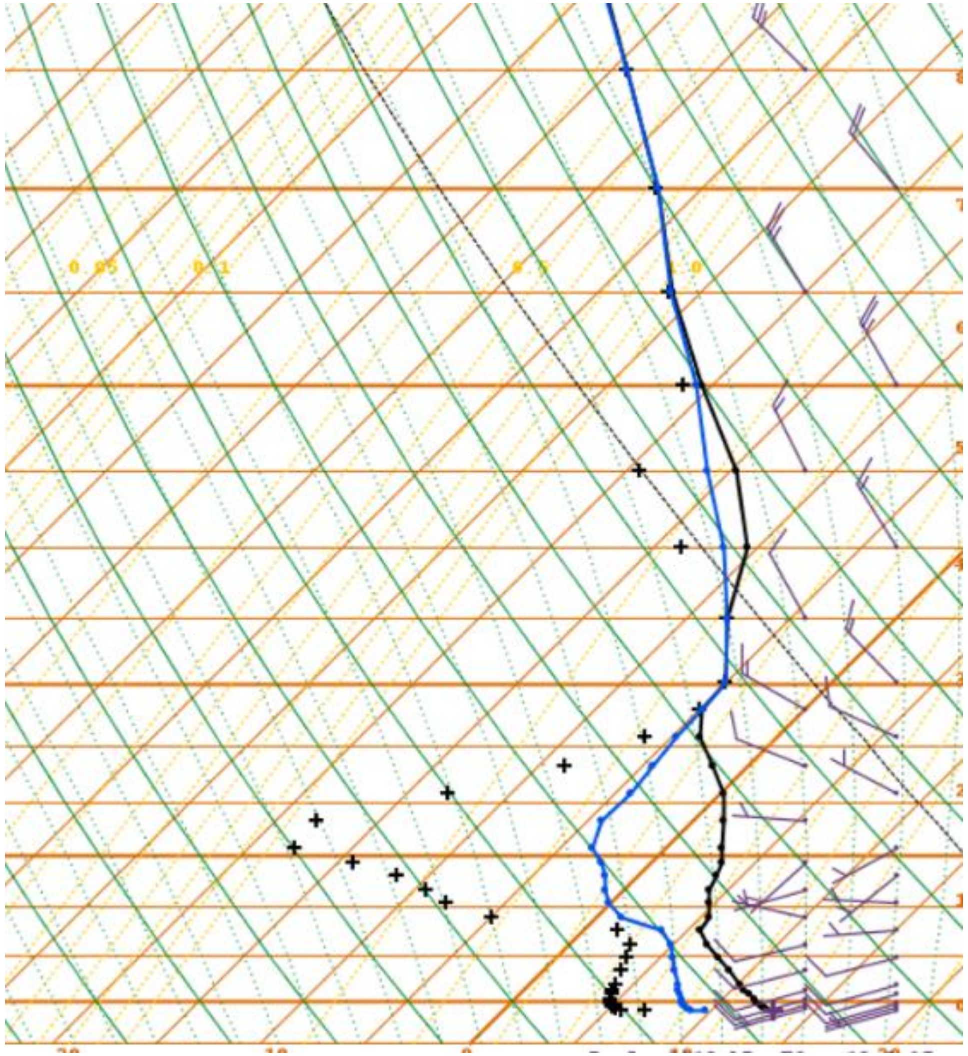
- Drop diameters between 100 – 500 µm
- Low CCN and INP concentrations

  → Often above stable layer

Freezing Rain:

- Drop diameters larger than 500
- Occurs at very low altitudes

  →not targeted during SENS4ICE



Freezing Drizzle distributions

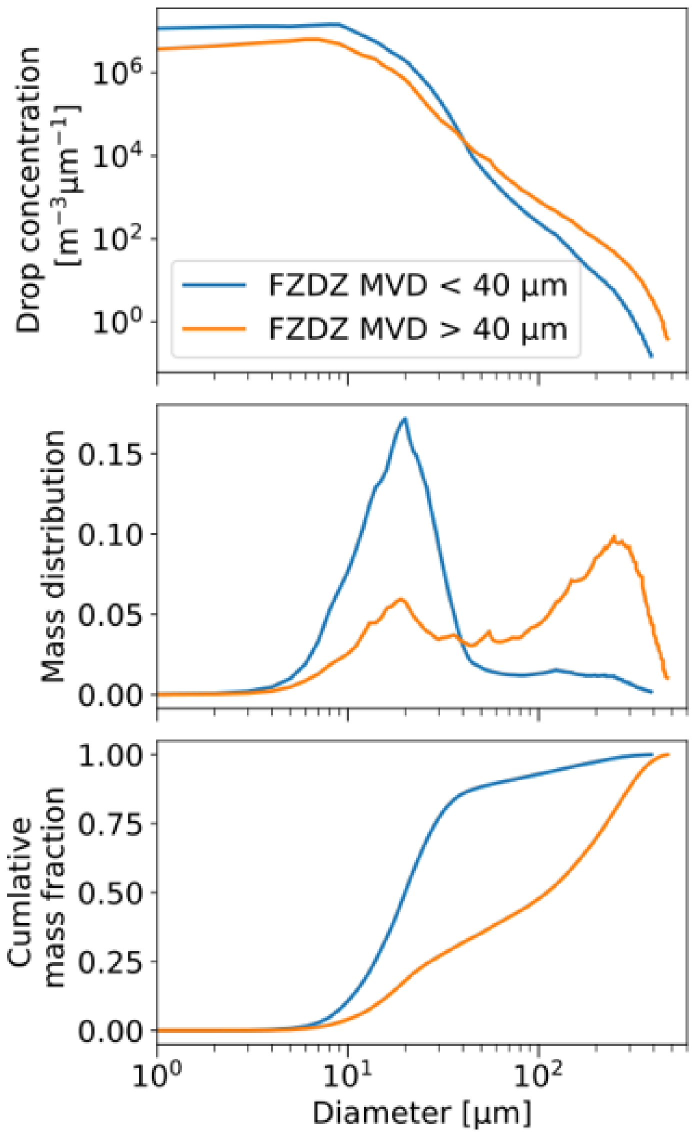
Three types of distributions

- Size distributions

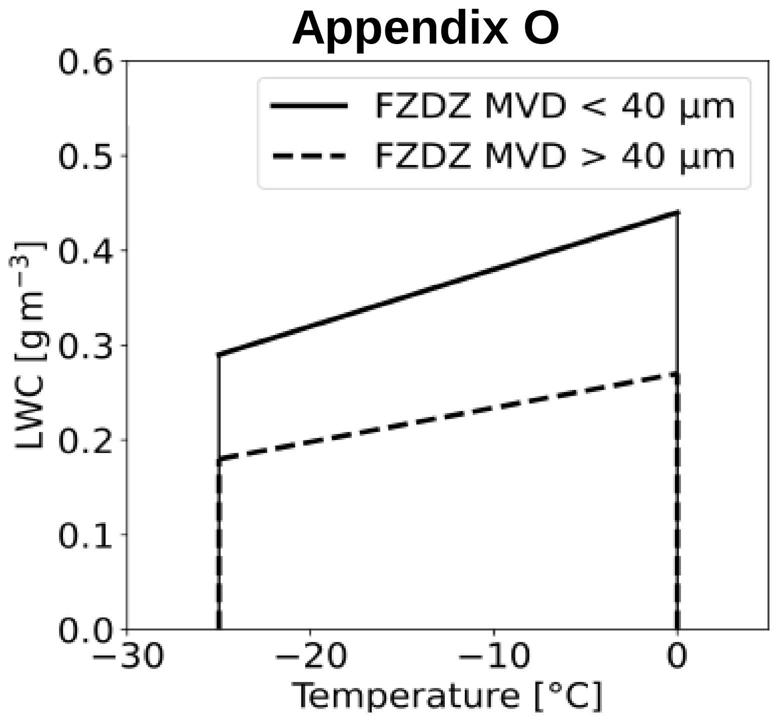
- Mass distributions

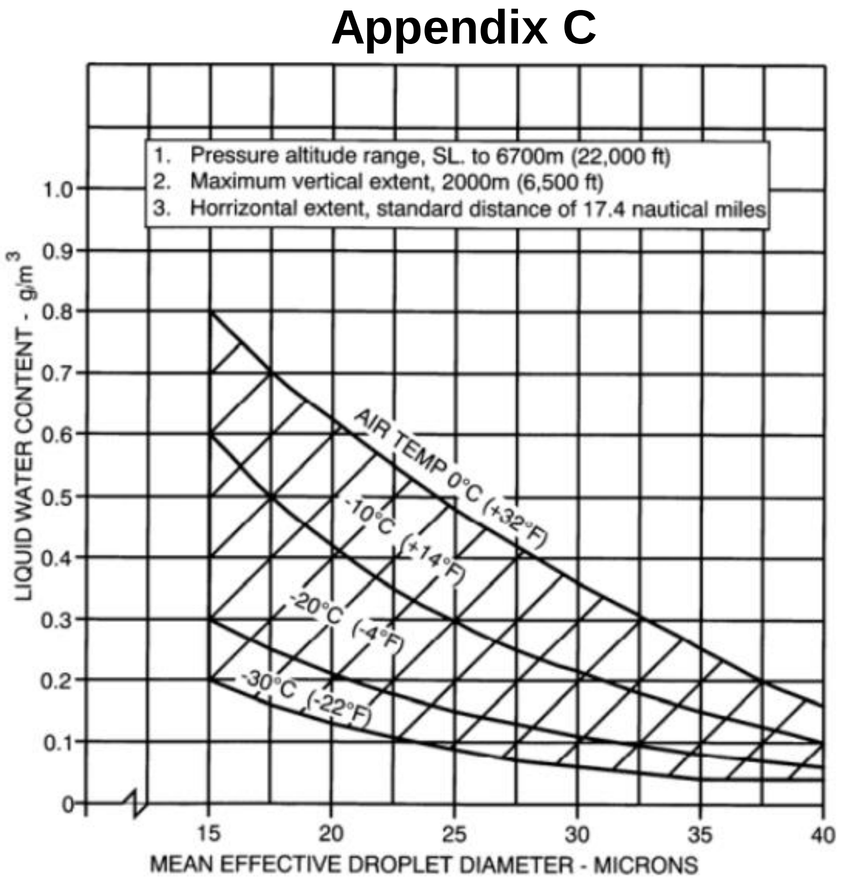
- Cumulative mass distributions

→ **FZDZ conditions are often bimodal**



Design envelopes for FZDZ





- Rulemakings for flight in FZDZ are in Appendix O to part 25 of European and American aviation regulations.

  → FZDZ conditions are called Appendix O conditons.

- Maximum LWCs are defined in envelopes → Used to certify aircraft

SENS4ICE flight campaigns

American flight campaign:

- Embraer Phenom-300
- 25 flight hours
- February – March 2023
- Based out of Alton, Illinois

European flight campaign:

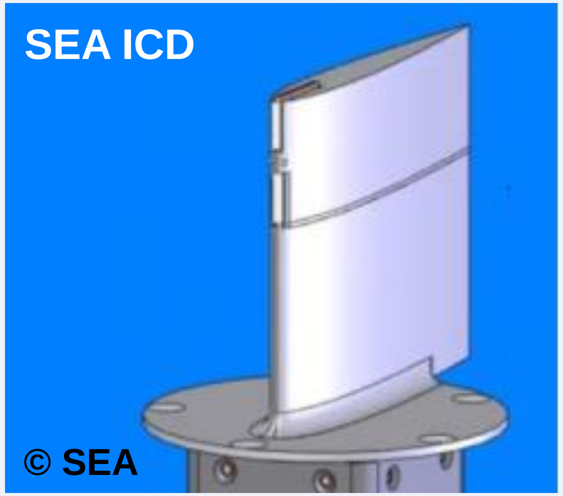
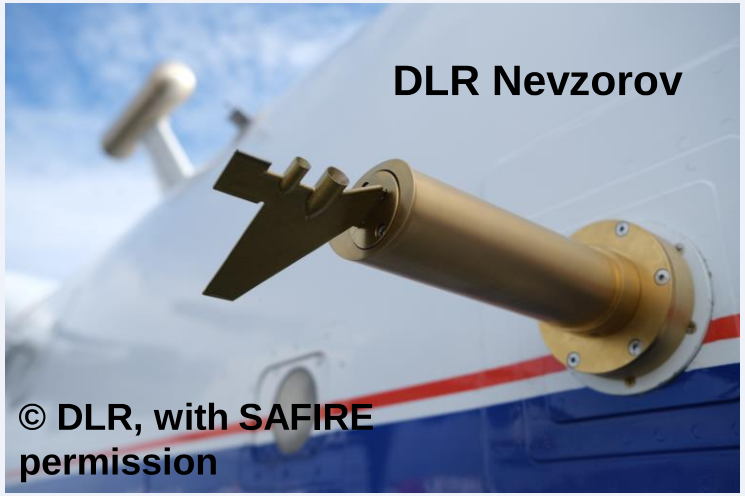
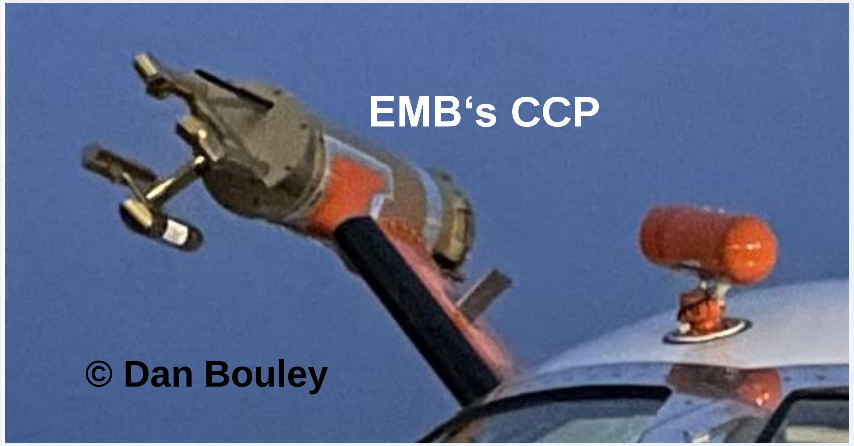
- SAFIRE ATR-42
- 50 flight hours
- April 2023
- Based out of Toulouse, France

Reference instrumentation

- Both research aircraft were equipped with established airborne instruments

  → **Reference instrumentation**

- DLR characterizes the icing atmosphere from these measurements
- Data set needed by the sensor developers to verify measurements

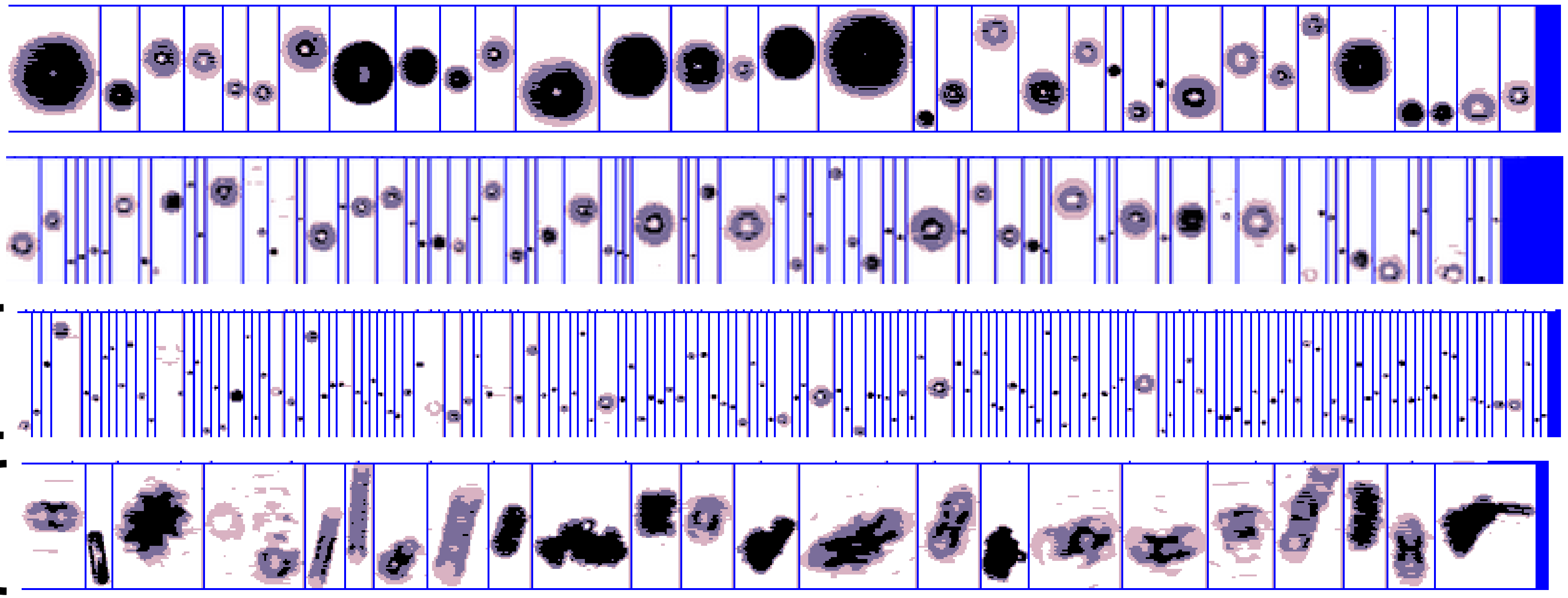
	Phenom-300	SAFIRE-ATR 42
Hotwire instruments: LWC		
Optical instruments: Particle size distributions		
Other instruments carried:		SAFIRE-CDP, SAFIRE-CIP, SAFIRE-UHSAS, SAFIRE-Robust, SAFIRE-GERBER, DLR-PIP, DLR-BCPD, DLR-HSI

Data evaluation

Optical array probe measurements from the CIP are used to differentiate particles

We sort into 3 categories:

1. SLD
2. Small droplets
3. Ice crystals



Challenges in recognizing SLD in images

Out of focus particles:

- Many of the imaged particles are not perfectly in focus.
- Trade off: Removal of out of focus images reduces statistics, but may be necessary to avoid false detections.
- Accurately detecting only SLDs is challenging

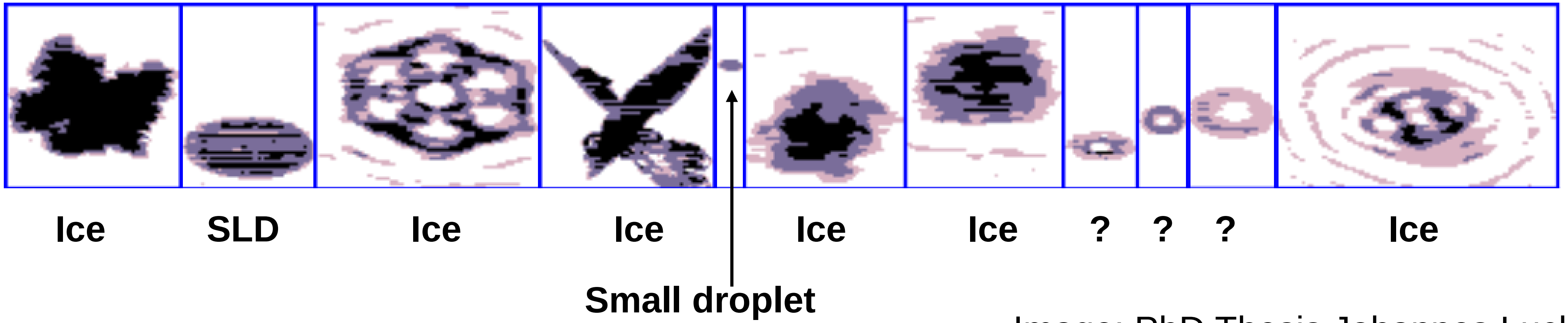


Image: PhD Thesis Johannes Lucke

Challenges of LWC measurements

- SLD sensors splash on the LWC instruments.
- Ice and Liquid water needs to be differentiated.

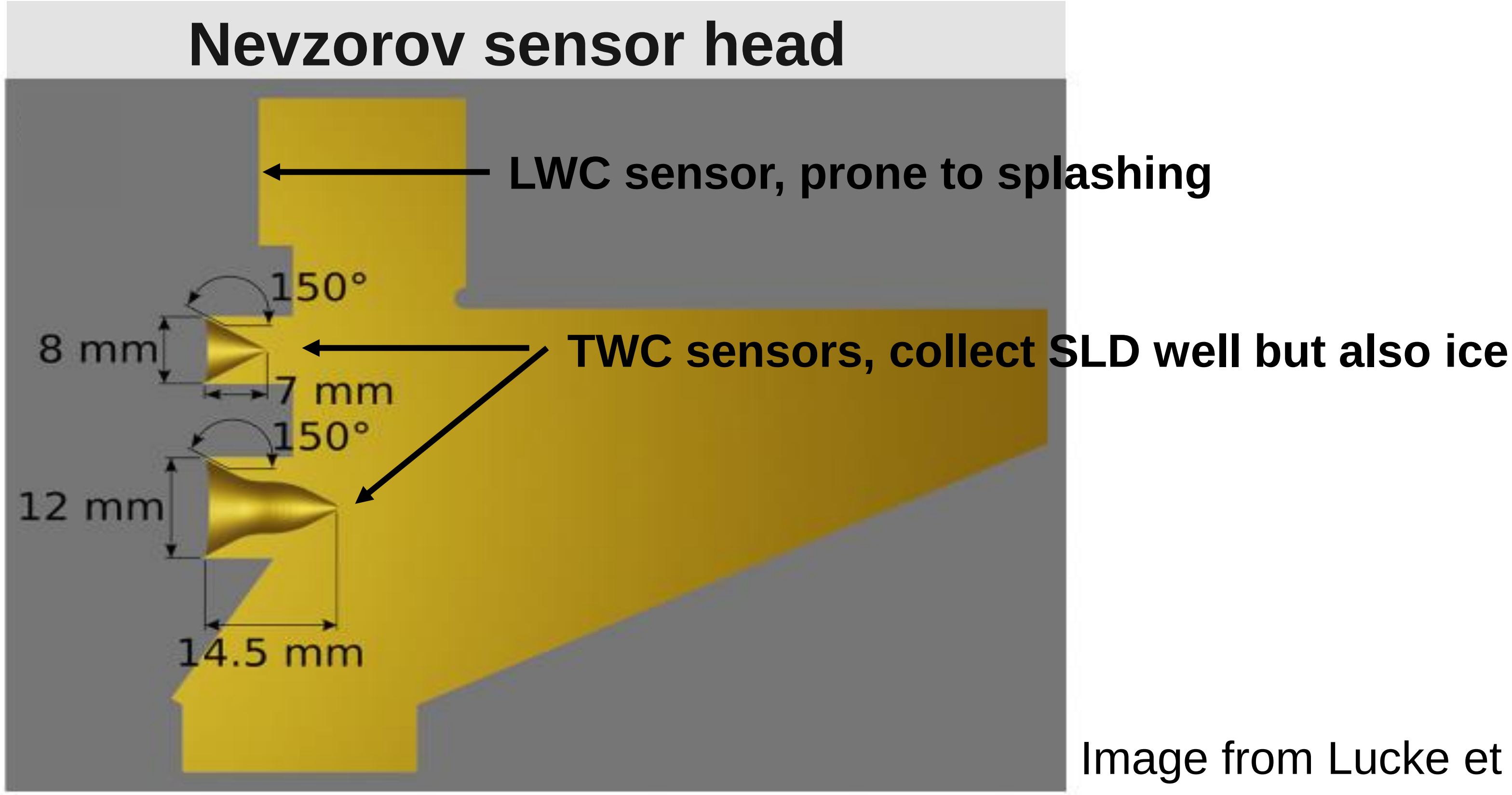
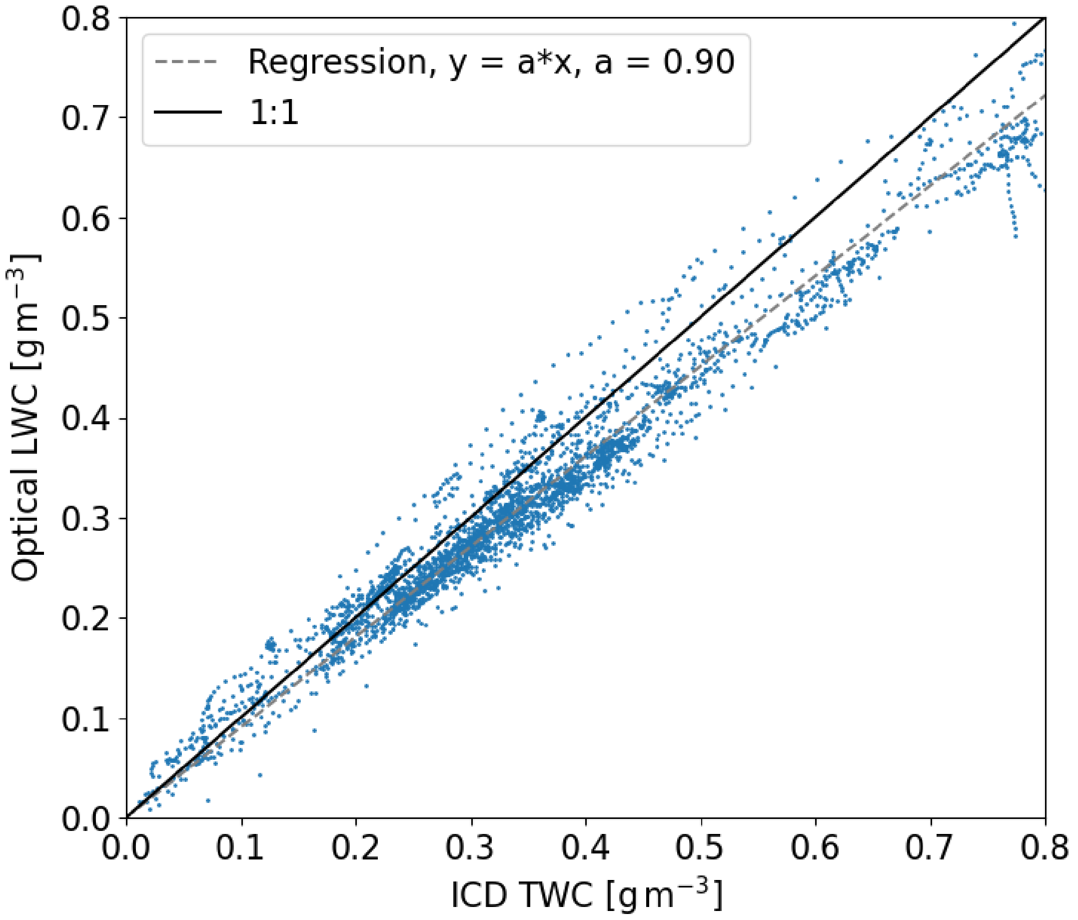


Image from Lucke et al. 2022

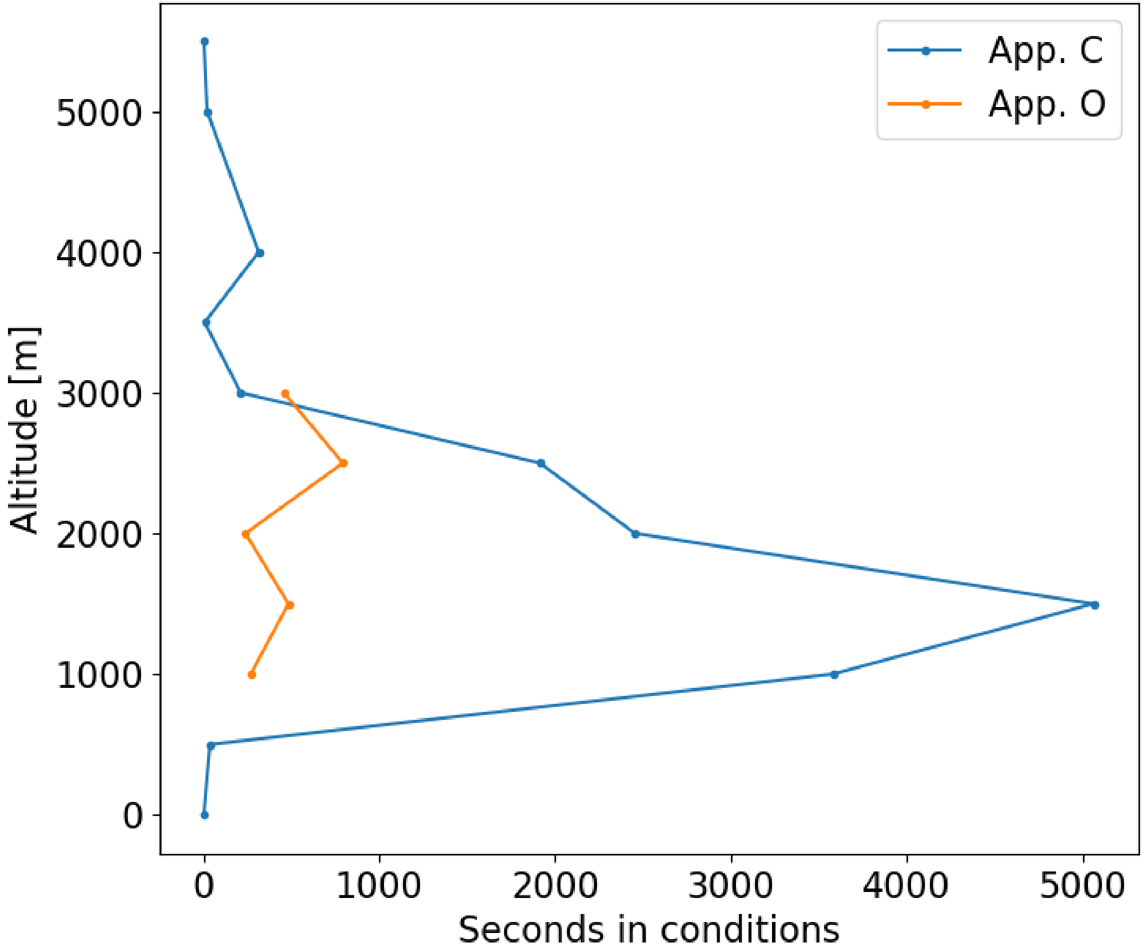
Consistency of data



- LWC can be derived from two data sources
  → LWC instruments
  → Optical instruments (Large uncertainty!)
- Good agreement between optical LWC and hotwire TWC

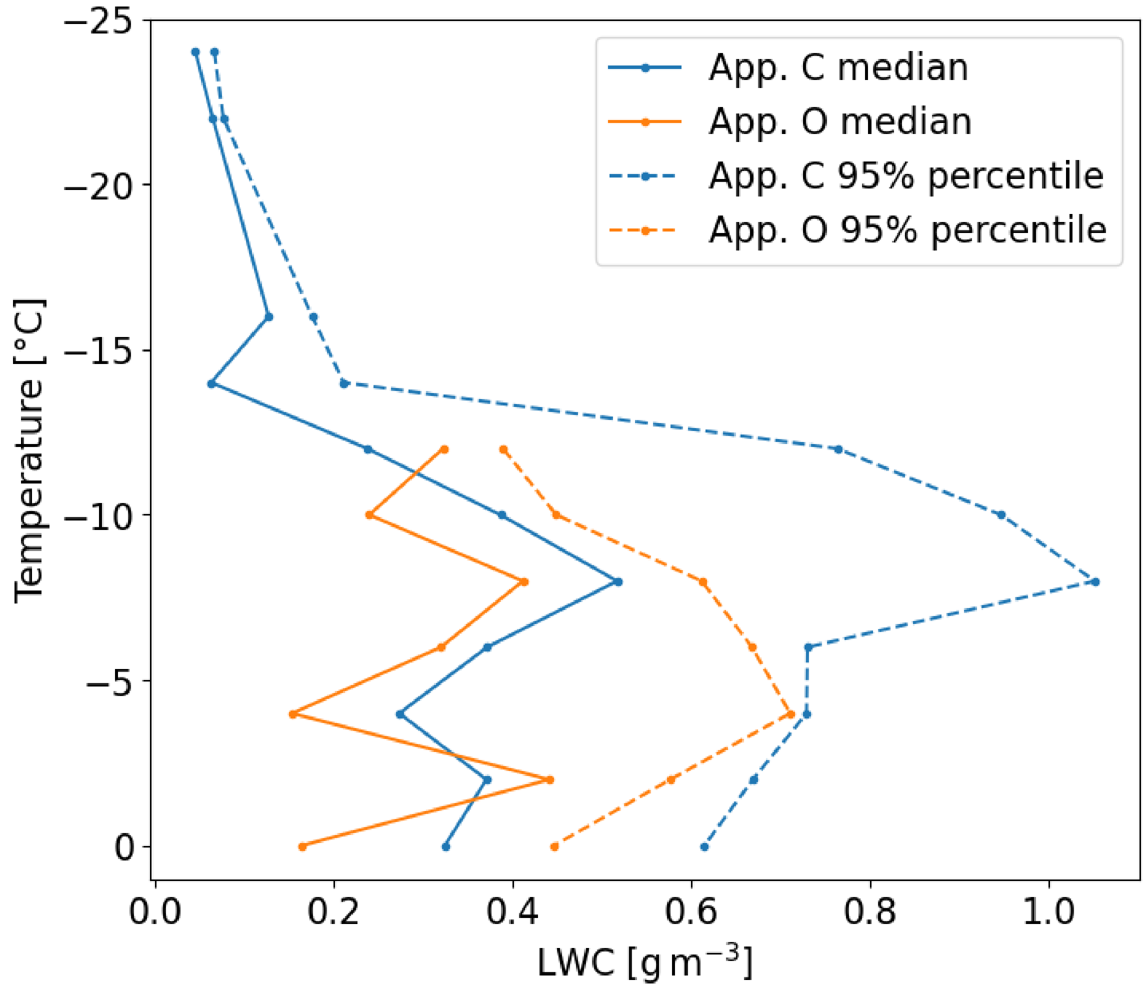
  → Sorting works accurately.
- Data evaluation strategy is appropriate

Altitude of icing conditions during the US campaign



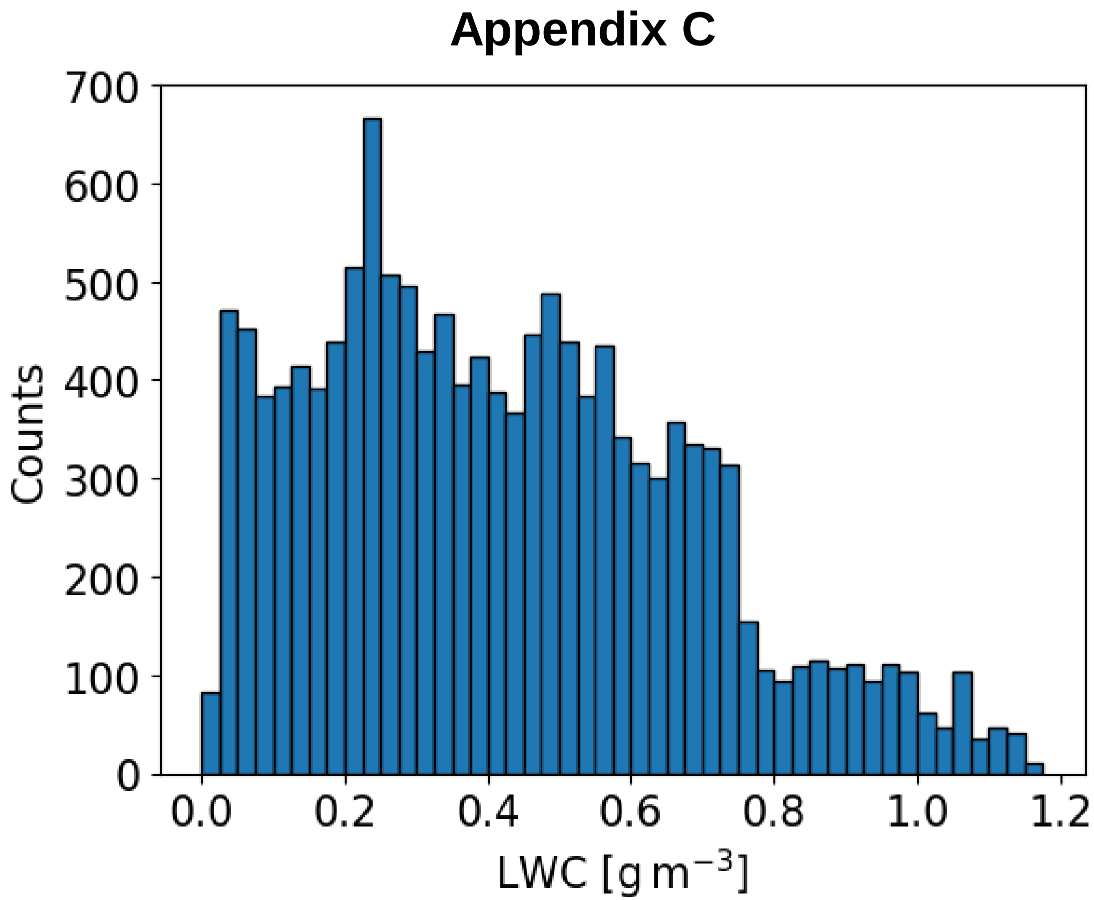
- Icing conditions were encountered between 500 and 3000 m, with a maximum around 1500 m
- Appendix O conditions were encountered between 1000 and 3000 m

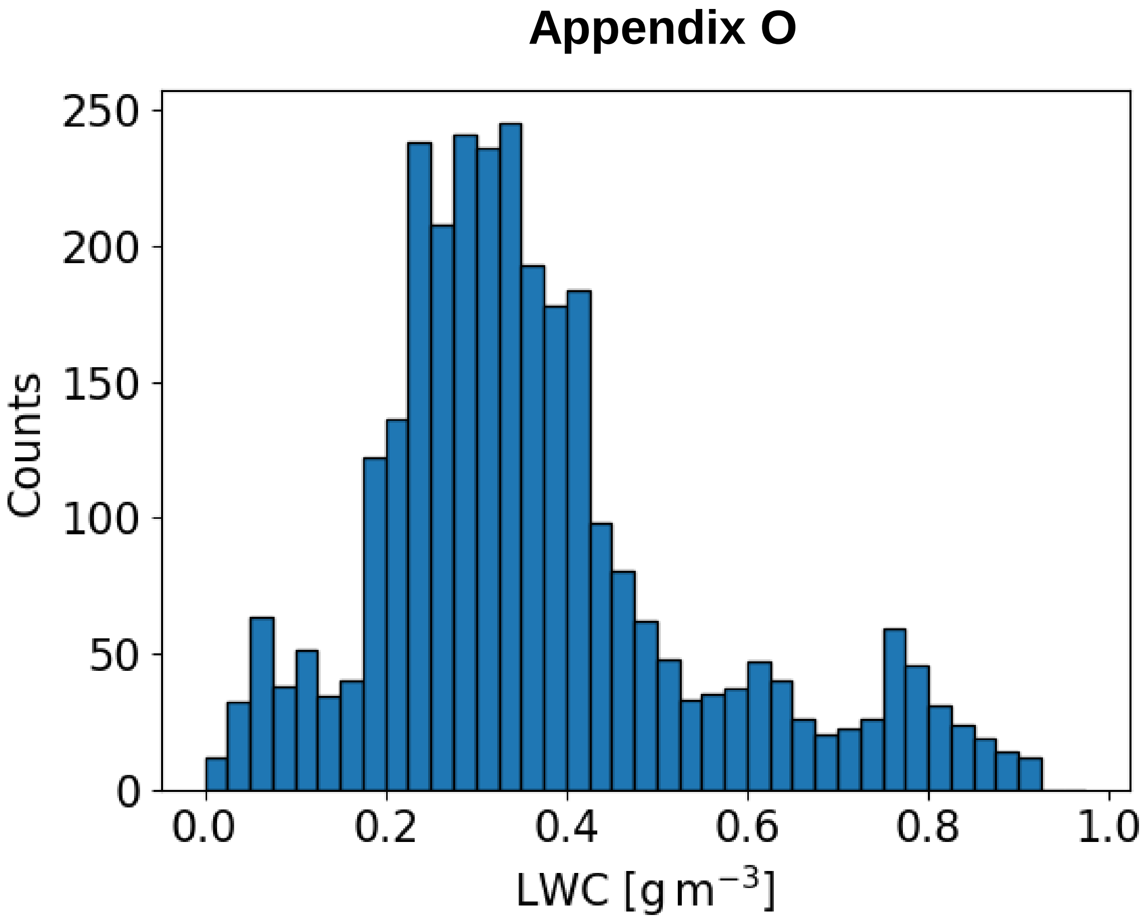
Temperature distribution of Appendix C and O conditions



- Appendix O conditions were encountered from -12°C upwards.
- The median liquid water content in Appendix C conditions decreases sharply at around -13°C.
- Appendix C LWCs are larger than Appendix O LWCs

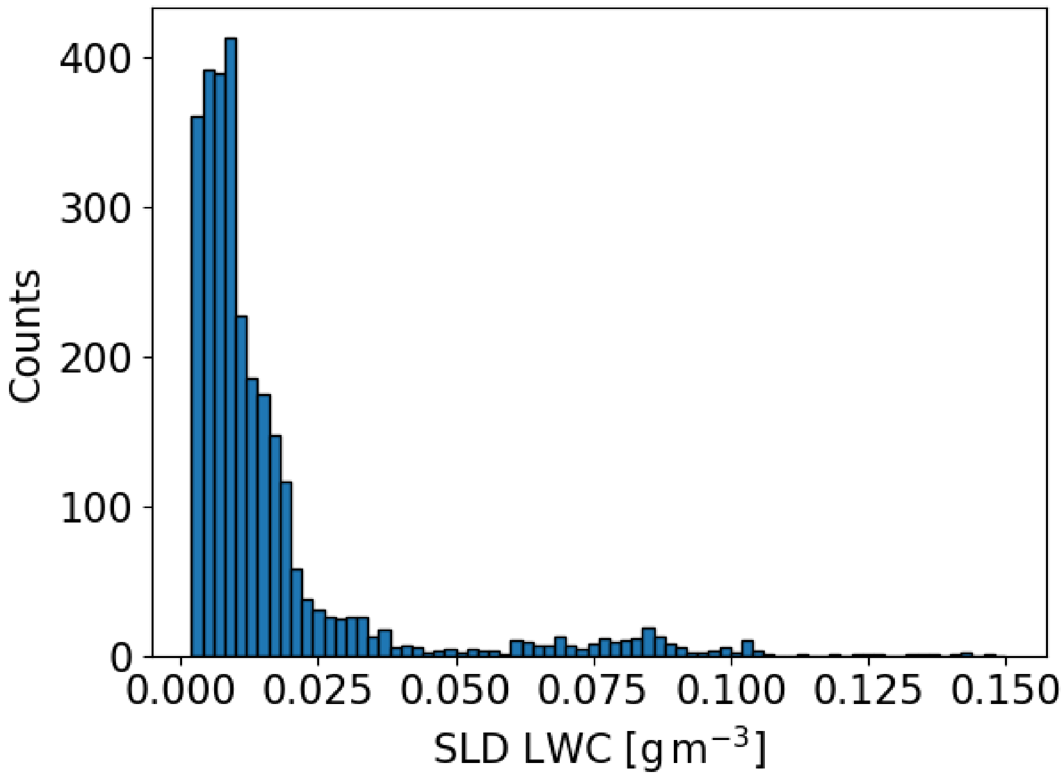
LWC distribution of Appendix C and O conditions

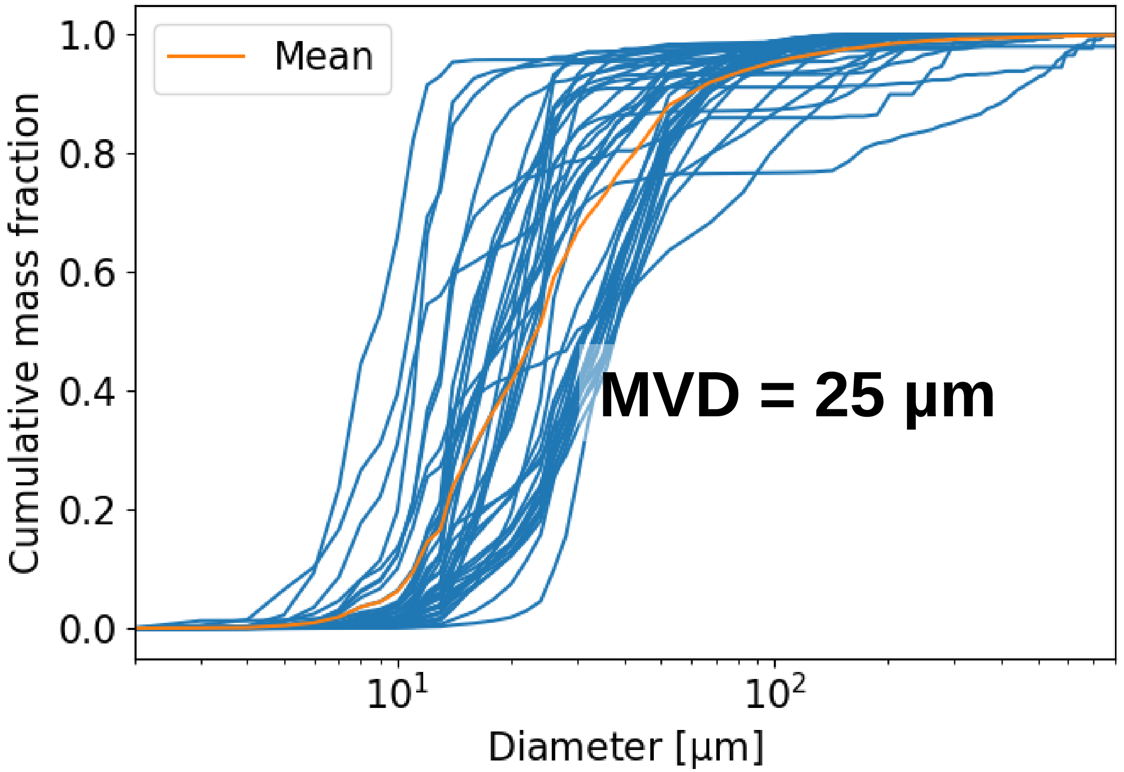




- Appendix C conditions frequently reached LWCs of 0.8 g/m³
- Appendix O conditions peaked around 0.3 g/m³, but in few cases reached up to 0.9 g/m³

Characteristics of Appendix O conditions during the US campaign





- LWC in SLD reached up to approximately 0.1 g/m³
- Low overall percentage of LWC in SLD

Altitude of icing conditions during the EU campaign

Predicted altitude of icing conditions in April

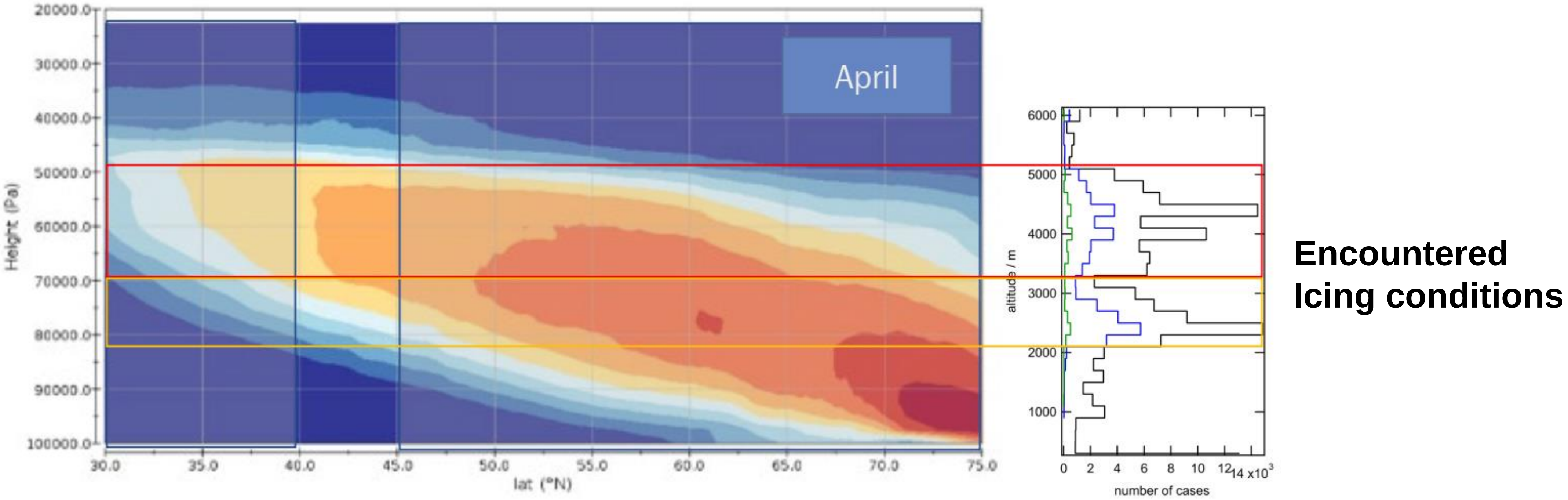
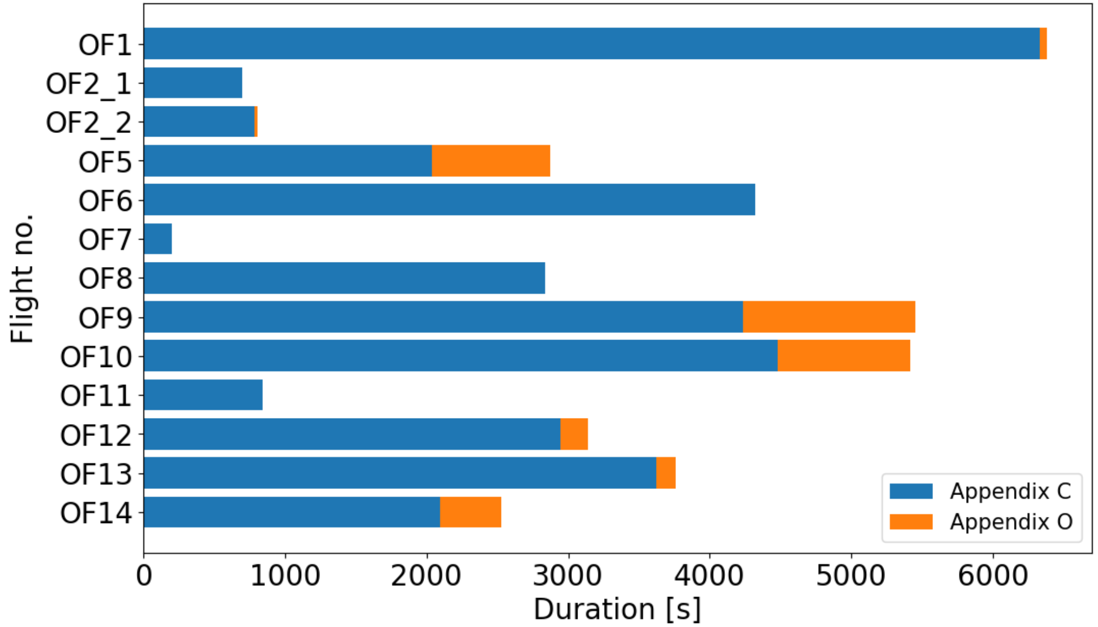


Image from Jurkat-Witschas et al. 2023

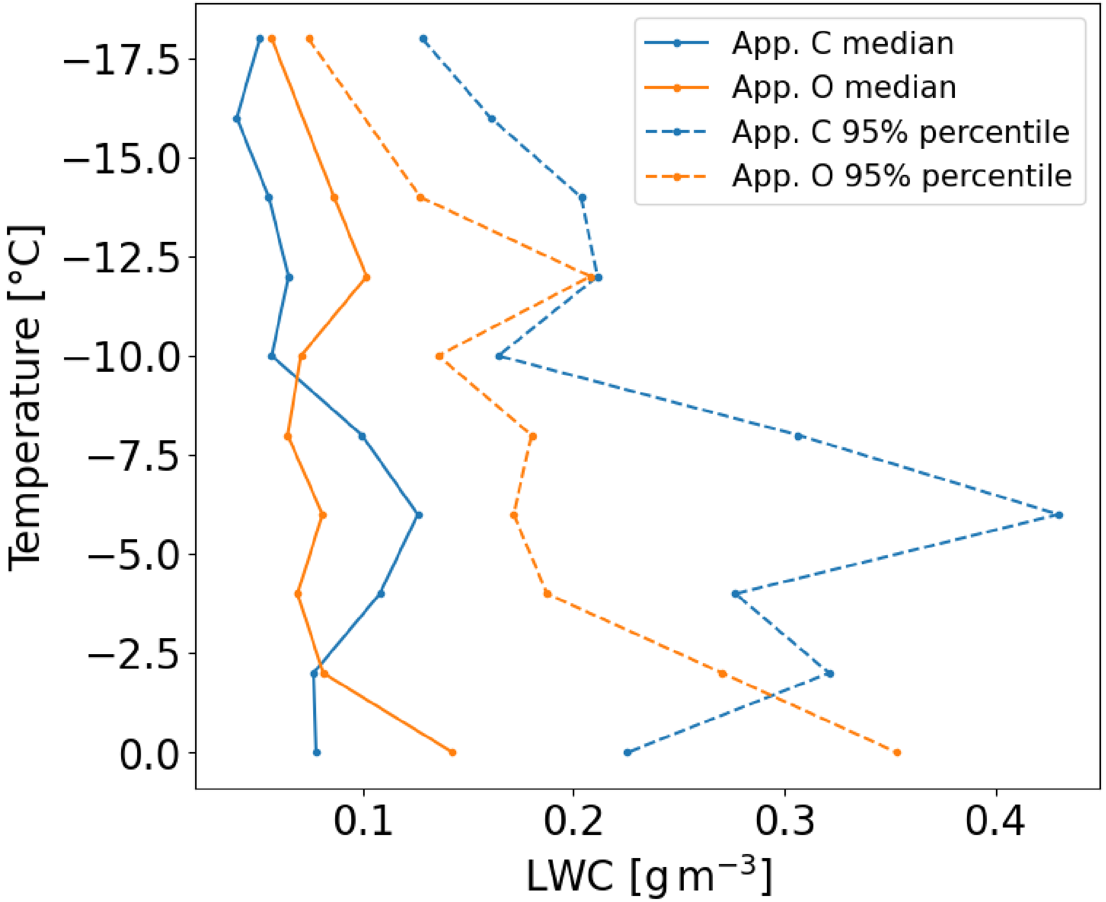
- Atypical season (chosen due to safety considerations)
- Icing conditions encountered at higher altitude than during the American campaign.

Icing conditions encountered during the SENS4ICE campaign



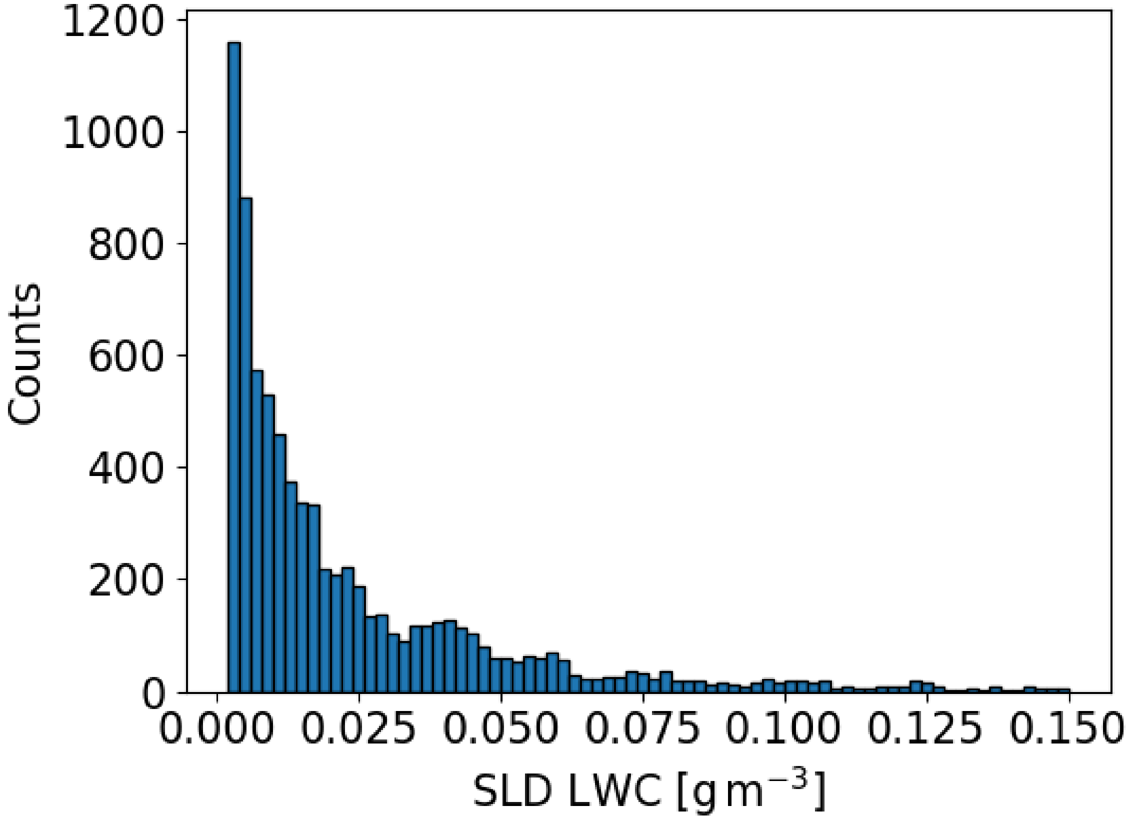
- Many Appendix C conditions encountered
- Appendix C conditions were often mixed-phase clouds with a significant amount of number particles.

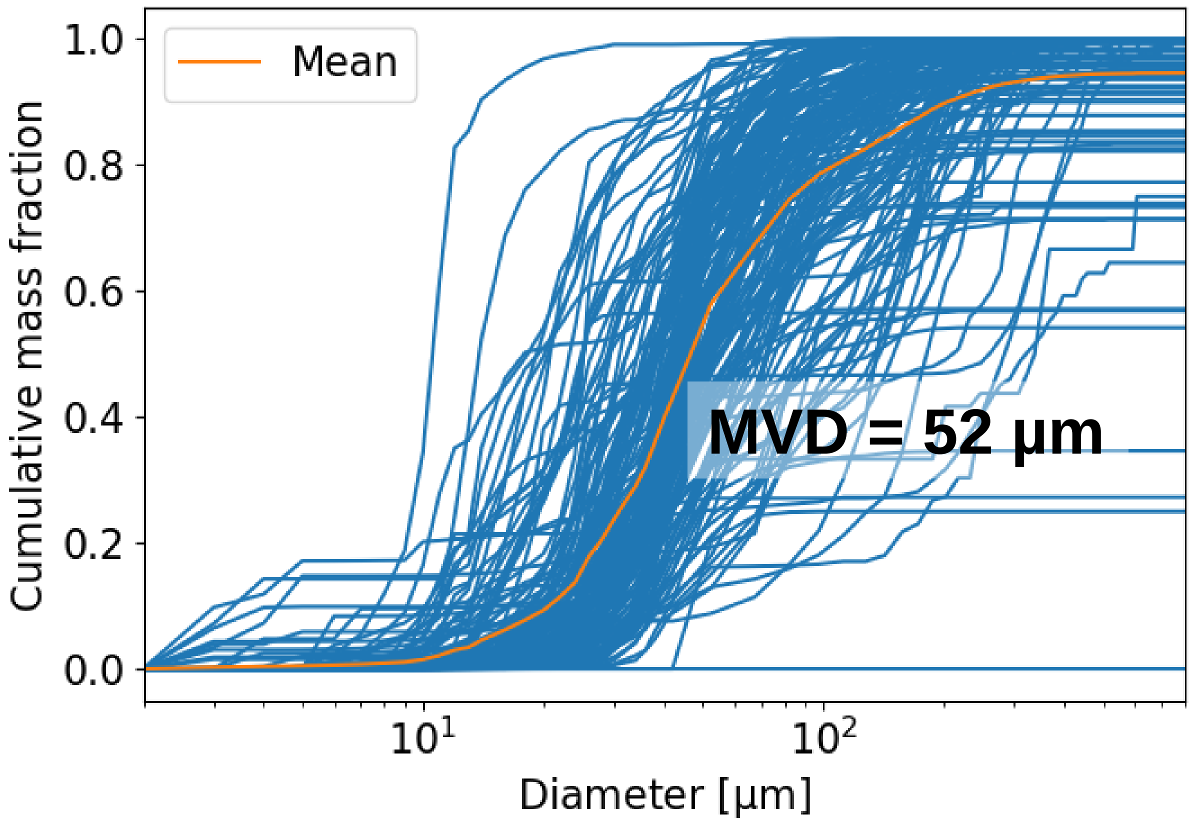
Observations EU flight campaign



- Lower overall LWCs than during the American campaign
- Clouds were patchier, encounters were shorter
- Low LWC beyond -15°C, as in the US campaign.

Characteristics of Appendix O conditions during the EU campaign





- LWC in SLDs relatively often between 0.025 and 0.06 g/m³
- High overall percentage of LWC in SLD

Conclusions (1)

- Icing conditions from two flight campaigns were evaluated.
- The data evaluation procedure of the optical instruments was confirmed by comparison to LWC measurements of a hotwire probe.
- Beyond -15°C the LWC observed in icing conditions (both Appendix C and Appendix O) decreases markedly.
- Appendix O conditions were encountered also in the spring season at relatively high altitudes.

Conclusions (2)

Observations from the American and the European campaing differ:

Parameter	Observation
Altitude of icing conditions	Higher during the European campaign
LWC	Higher during the American campaign
SLD LWC	Higher during the European campaign
Appendix O MVD	Higher during the European campaign

Imprint

Topic:	Meteorological conditions and microphysical properties that lead to aircraft icing as observed during the SENS4ICE campaigns
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