SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

SLD icing flight test campaigns results including atmosphere characterization

FINAL DISSEMINATION EVENT OF SENS4ICE PROJECT

Aurélien Bourdon (CNRS), Daniel Martins da Silva (Embraer), Johannes Lucke (DLR)

Directorate General for Research and Innovation, Brussels, Belgium – 29 November 2023

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

SENS4ICE

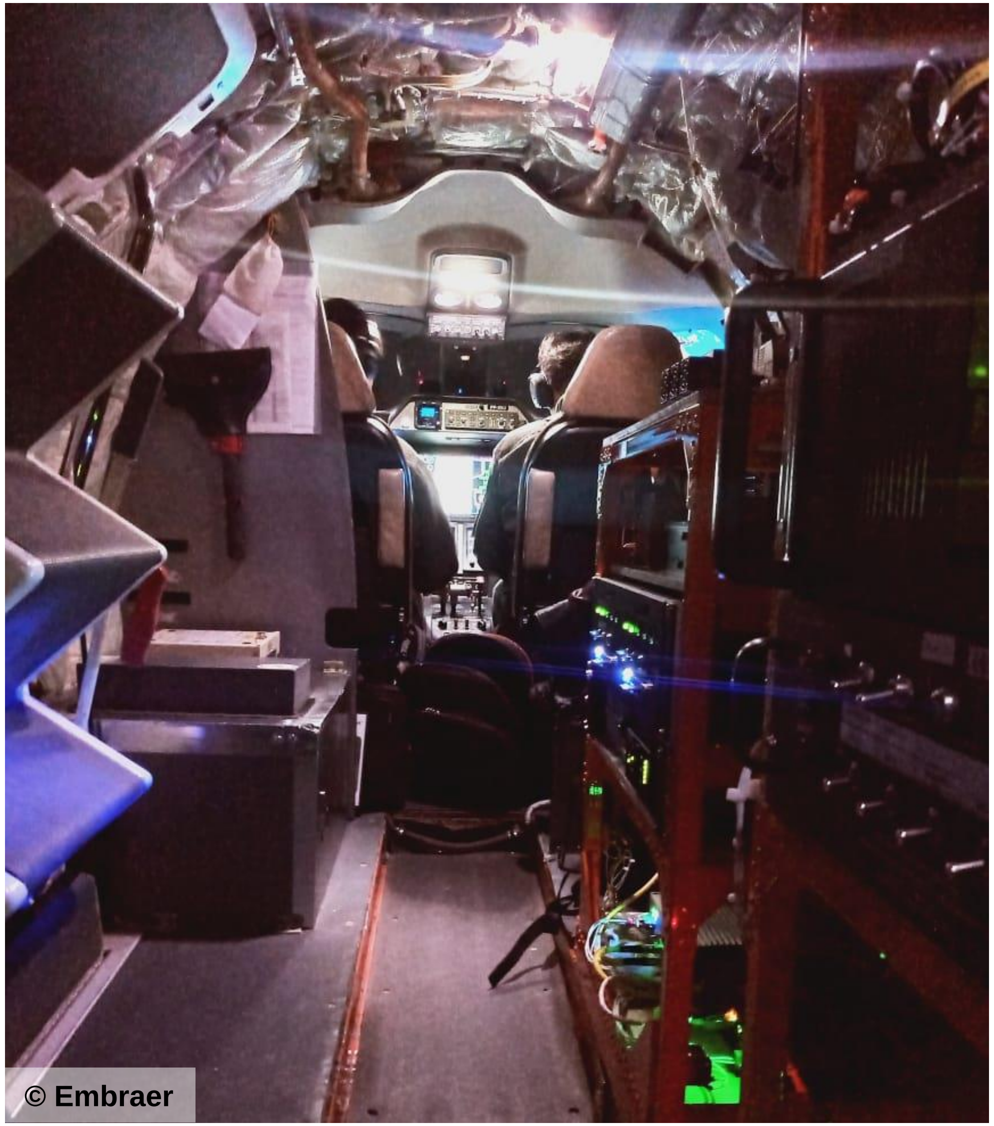
SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

American SLD icing flight test campaign

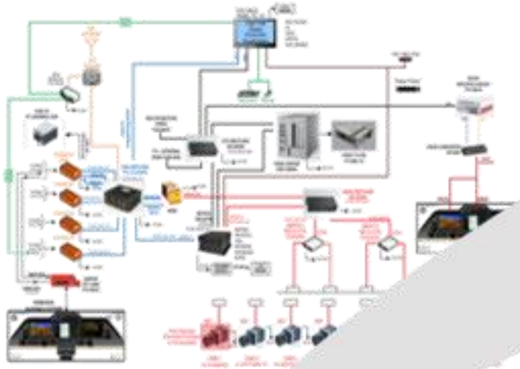
Daniel Martins da Silva (Embraer)

US SLD icing FT campaign: Phenom 300

- Experimental Phenom 300
- Twin turbofan aircraft
- Most delivered aircraft in its category
- More than 2 million flight hours
  - Robust in-service history
- Operated by EMBRAER

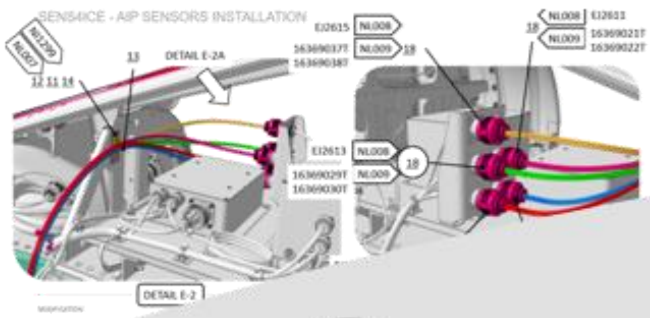


US SLD icing FT campaign: preparation, installation & tests



2019
✓Defining requirements for sensor development and integration.

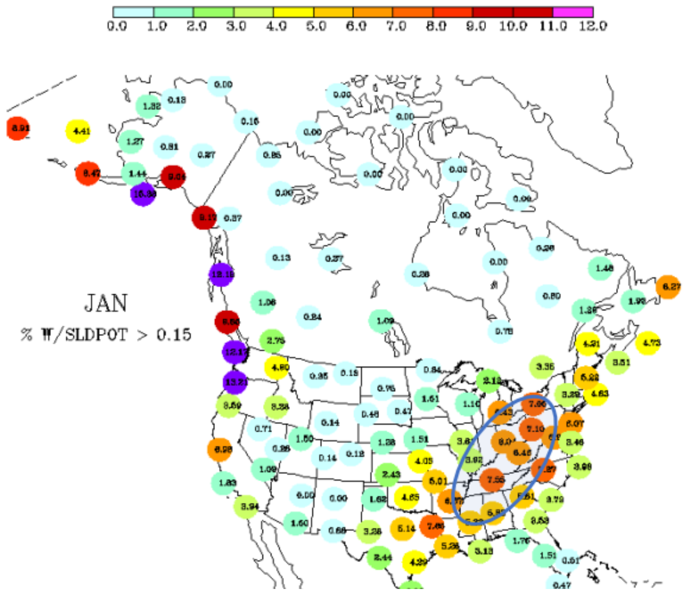
2021
✓Selection of sensors for in-flight demonstration.
✓Defining communication architecture and data acquisition.
✓Approval and validation of mechanical and electrical interfaces.



2022
✓Modification of the prototype and integration of tested systems.
✓Integration tests, EMI/EMC, verification flight.
✓Release of the aircraft for a test campaign in natural ice.

2023
✓Flight test demonstration on natural ice.

US campaign: when & where to fly?

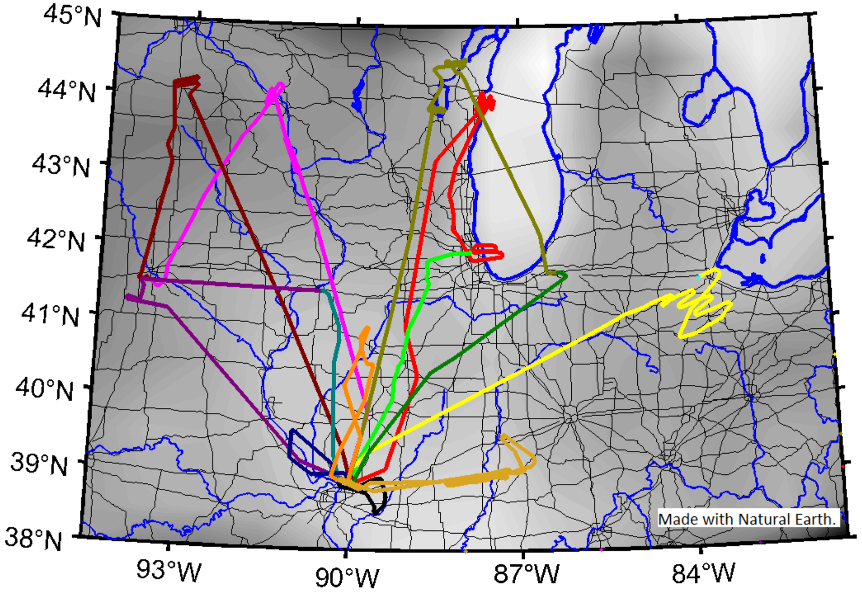


Climatology and Meteorological studies were performed to find the best period and location in US (in-site support of Ben Bernstein):

⇒ February-March as the best suitable months

⇒ Operation Base @ Alton, IL

- Flat terrain
- Good alternate airports
- Flexibility to move N/S/E/W
- Considerable amount of weather data



⇒ Safety requirements for Flights Tests such as

- Limited exposure time for detection purposes
- The higher LWC, the shorter the exposure time

US campaign payload: direct & indirect sensors

SENS4ICE ice detection technologies tested with EMBRAER's Phenom 300

- **SRP** – Short Range Particulate (HONEYWELL)
- **AIP** - Atmospheric Icing Patches (AEROTEX)
- **IDS** - Ice Differentiator Sensor (COLLINS)
- **PFIDS** - Primary in-Flight Ice Detection Sensor (SAFRAN)
- **HIDS** - Hybrid Ice Detection System (SAFRAN)
- **IIDS** - Indirect Ice Detection System (DLR)

Phenom 300 with test sensors and reference instruments

US campaign: The flights

Flight #	Date	Objective
1474-1	22/02/2023	Shakedown
1475-1	23/02/2023	Appendix O
1475-2	23/02/2023	Appendix C
1476-1	25/02/2023	Appendix O
1476-2	25/02/2023	Appendix C
1477-1	01/03/2023	Appendix O
1477-2	01/03/2023	Appendix O
1478-1	06/03/2023	Appendix C
1478-2	06/03/2023	Dry Air
1479-1	08/03/2023	Appendix O
1479-2	08/03/2023	Return to Base
1480-1	08/03/2023	Troubleshoot
1481-1	09/03/2023	Appendix C
1482-1	10/03/2023	Appendix O
1482-2	10/03/2023	Appendix C

15 flights

25 flight hours

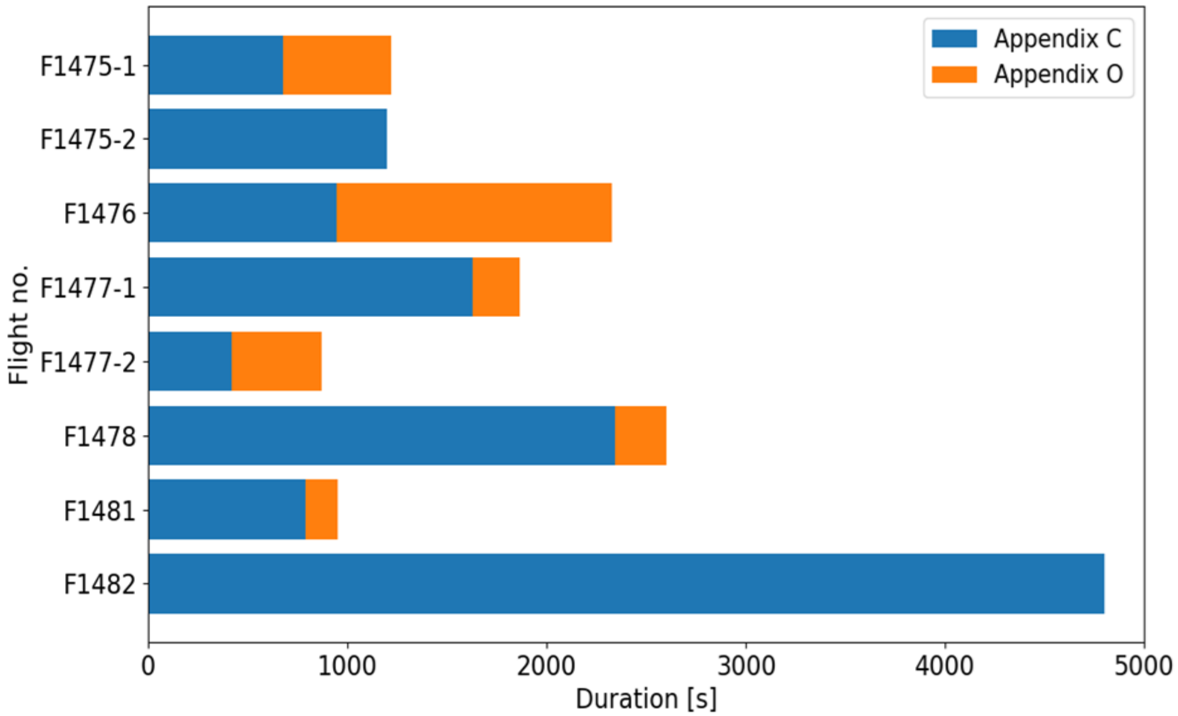
4.3 hours in icing conditions

1.2 hour in SLD environment*

Embraer investment: €1.8M

FLIGHT TEST CAMPAIGN

SUMMARY



Microphysics data analysis DLR Institute of Atmospheric Physics

SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

European SLD icing flight test campaign

Aurelien Bourdon (SAFIRE)

European SLD icing FT campaign: which aircraft?

- Bi-turbo propelled ATR 42 modified as flying lab
- Operated by Safire, the French Facility for airborne research (CNRS/Météo-France/CNES)
- French CoA

European campaign: when & where to fly?

Climatology and Meteorological studies were performed to find the best period and location in Europe (with support of external partners DWD, Météo-France, Ben Bernstein):

⇒ April as the best suitable month

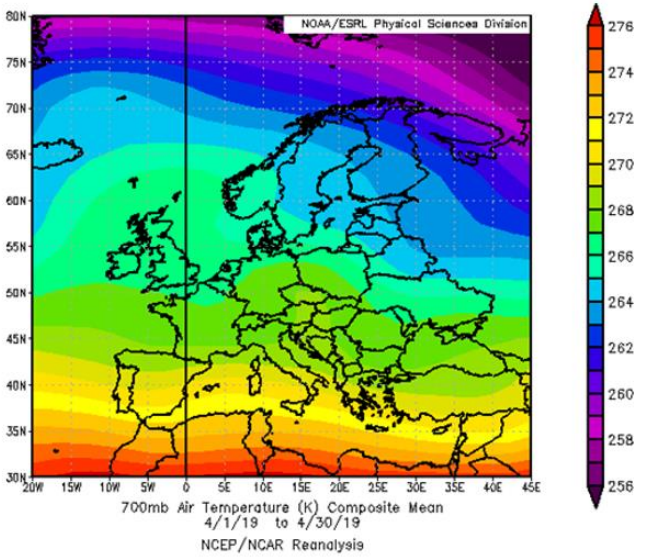
⇒ Best option: flights from Toulouse (France)

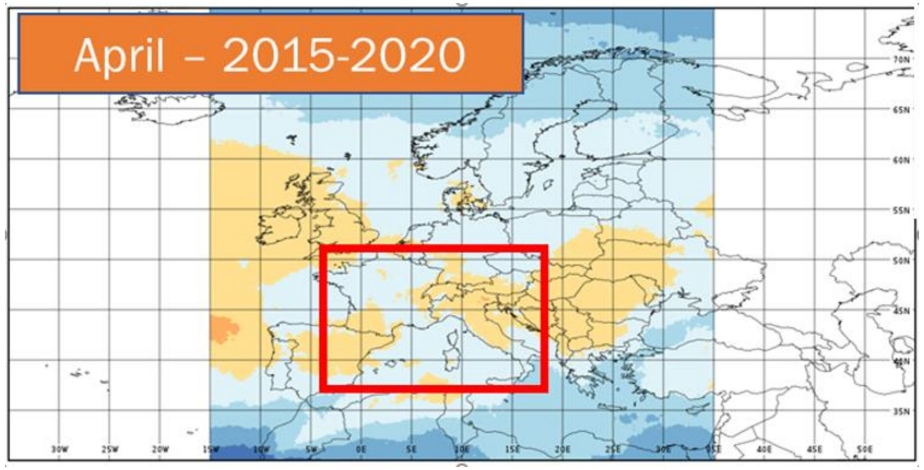
- Reasonable costs
- ATC/airspace flexibility aspects

⇒ Safety requirements for Flights Tests such as

- To fly higher than 8000ft AGL
- Below air t° > 0°C to de-ice the aircraft

Flights re-scheduled to April 2023 (Covid-19 crisis impact)





European SLD icing FT campaign: preparation, installation & tests

Definition of all aspects linked to Flight Tests execution

- Aircraft configuration definition
- Aircraft certification with SENS4ICE payload
- Estimated icing encounters & exposure time into ice conditions
- What-if scenario & Go/No-go criteria
- Roles of participants before and during flight and on-ground

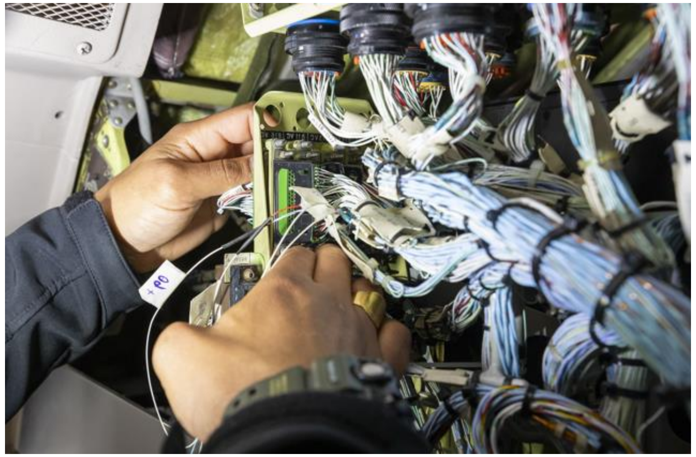
ATR and payload installation

Execution of ground tests on SAFIRE ATR 42

- (EMI/EMC, Inter-Intra systems…)

Execution of “Pre Campaigns” flights:

- Flights in March 2023 (Functional check flights, debugging, calibration of acquisition process,…)



European campaign payload: direct & indirect sensors

SENS4ICE ice detection technologies tested with SAFIRE ATR 42

- **FOD** - Fiber Optic Detector (INTA)
- **AMPERA** - Atmospheric Measurement of Potential and ElectRic field on Aircraft (ONERA)
- **LILD** - Local Ice Layer Detector (DLR)
- **CM2D** - Cloud Multi-Detection Device (DLR)
- **HIDS** - Hybrid Ice Detection System (Safran)
- **IIDS** - Indirect Ice Detection System (DLR)

SAFIRE ATR 42 with test sensors and reference instruments

European campaign: Reference Instruments for Icing Atmosphere Characterisation

Various sensors (from CNRS/SAFIRE & DLR) to characterise the atmosphere, such as

Nevzorov Probe

DLR and SAFIRE instruments underwing with ice accretion on the unheated parts while inside supercooled liquid clouds

European campaign: The flights

April 2023

From Toulouse Francazal or Toulouse Blagnac Airport

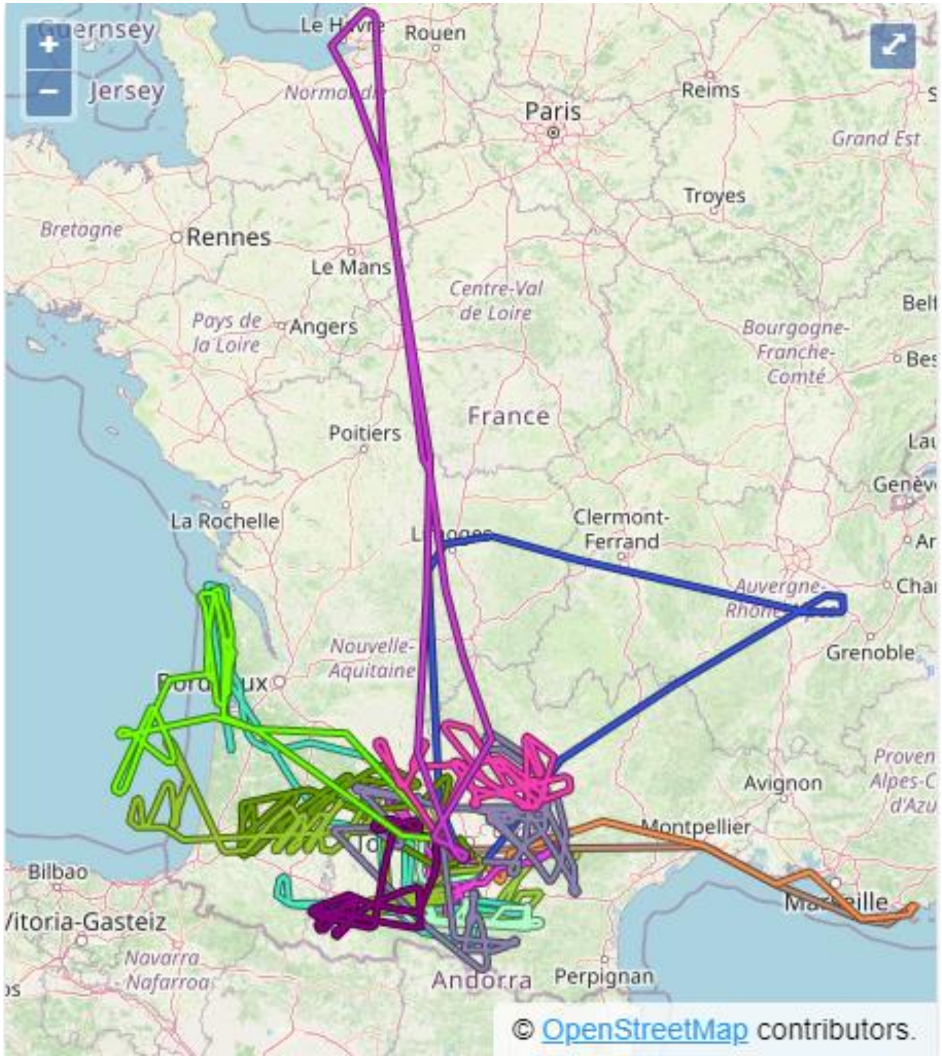
15 flights with a total of **about 50 flight hours** successfully conducted

Targeting natural liquid water icing conditions and in particular SLD conditions

Access to Data from CNRS/Safire sensors and probes (atmosphere characterization) is public :

https://safireplus.aeris-data.fr/data-access

(link is available from SENS4ICE website and LinkedIn profile)



Airborne data was obtained using the aircraft managed by Safire, the French facility for airborne research, an infrastructure of the French National Center for Scientific Research (CNRS), Météo-France and the French National Center for Space Studies (CNES). Distributed data are processed by SAFIRE.

Map Data From OpenStreetMap https://www.openstreetmap.org/copyright/en licensed under the Open Database License

SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Atmosphere characterization for the SENS4ICE flight campaigns

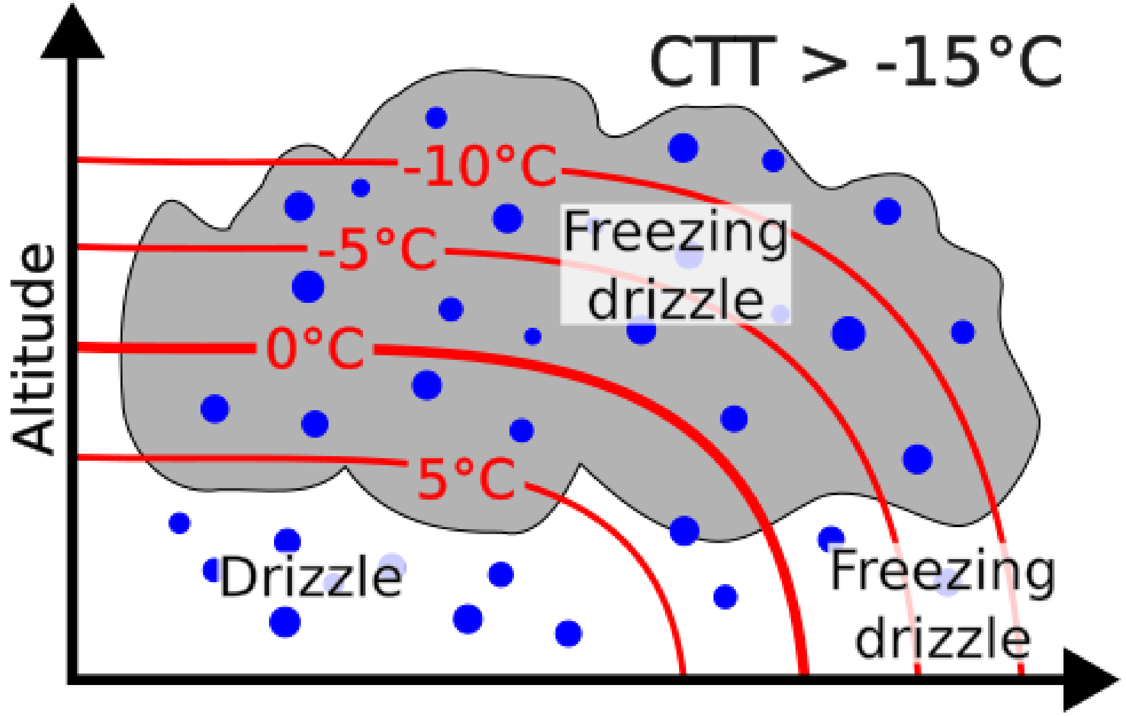
Johannes Lucke (DLR)

Part 1: Formation of SLD conditions and Appendix O envelopes

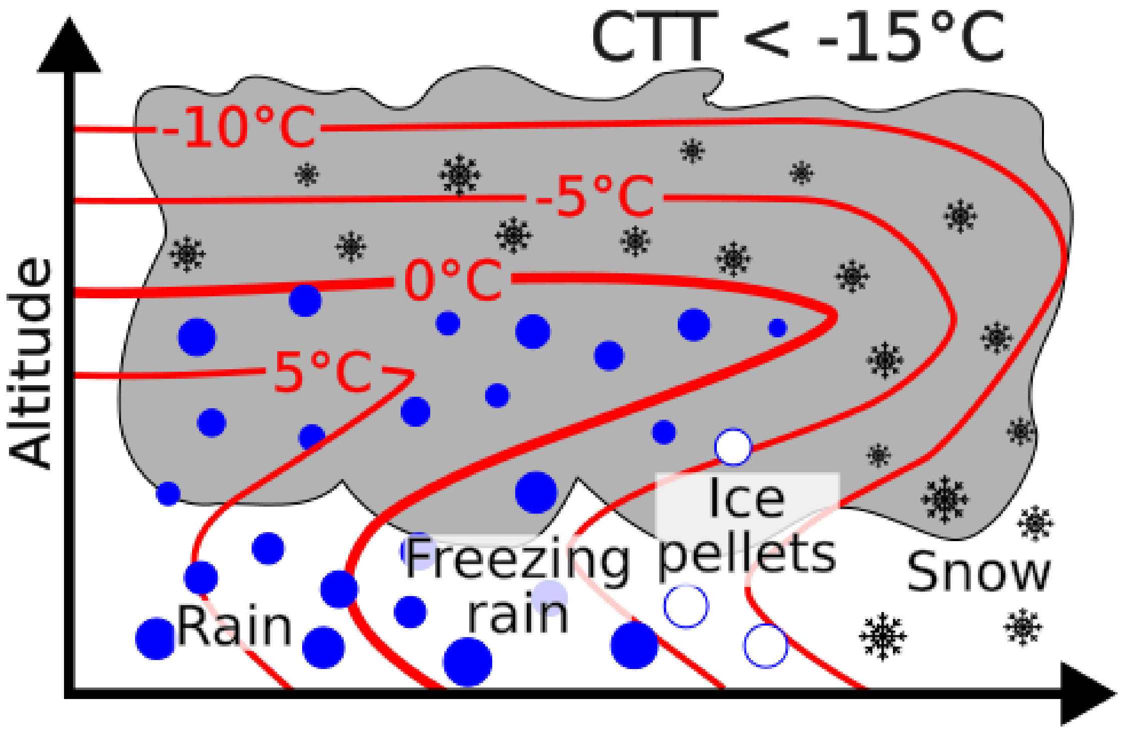
Formation of SLD icing conditions

Two types of SLD conditions are differentiated:

1. Freezing Drizzle (FZDZ)

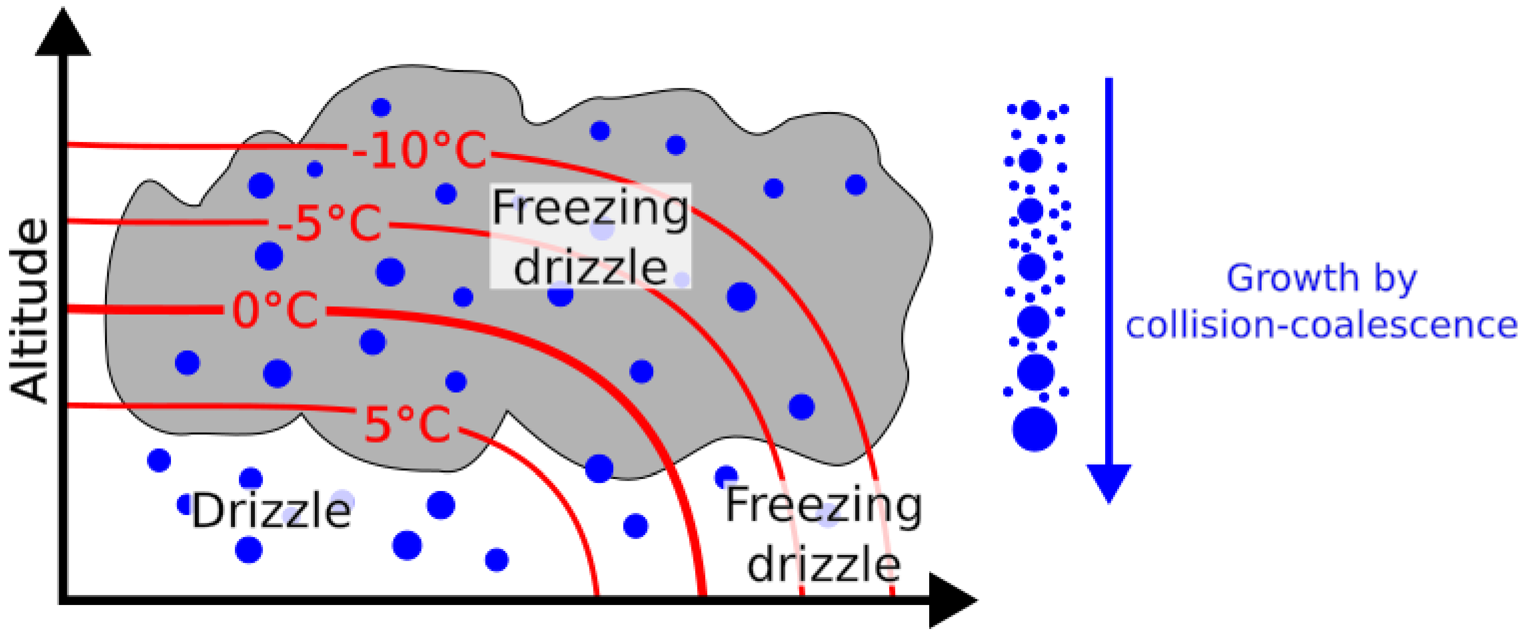


2. Freezing Rain (FZRA)



Not targeted and not encountered

Freezing Drizzle



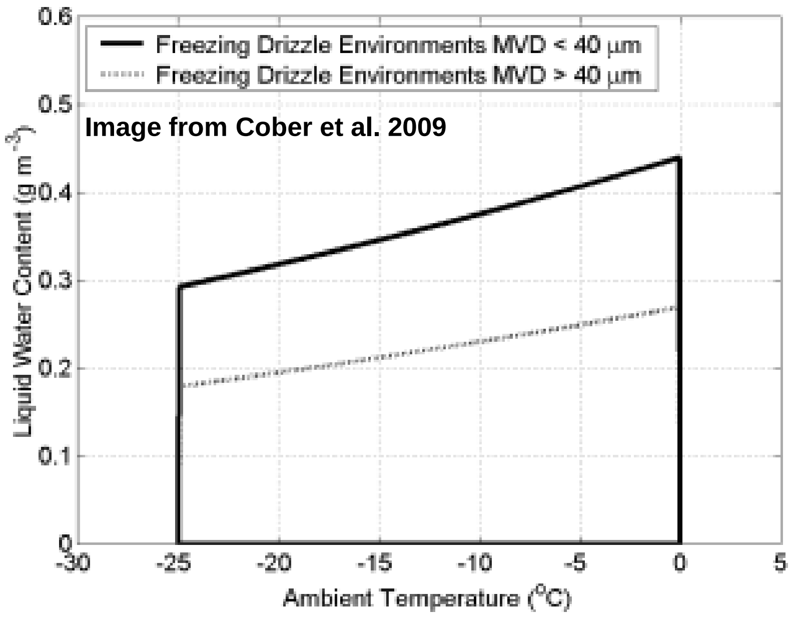
- Drizzle drops sediment and collect other drops in the process (collision-coalescence).

→ Maximum drop diameters tend to increase towards lower altitude.

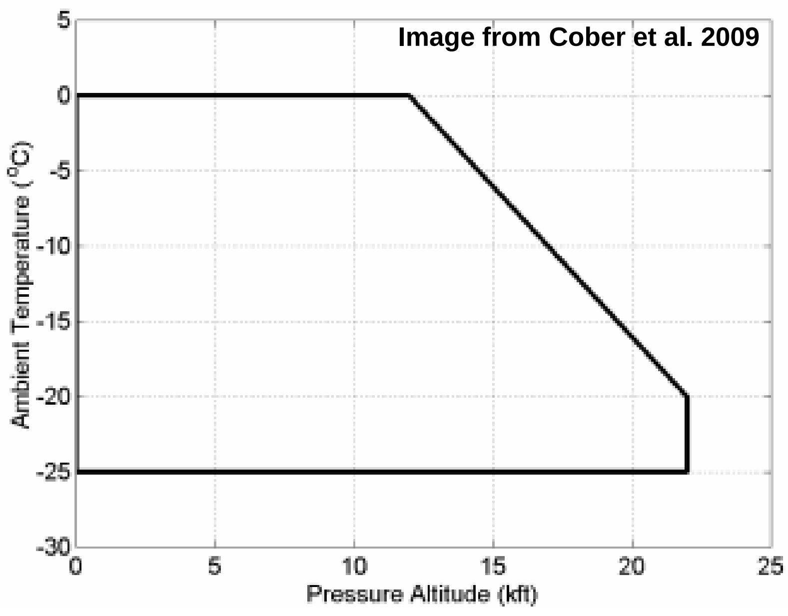
- Appendix O conditions encountered depend on sampling strategy.

Envelopes for Freezing Drizzle in Appendix O

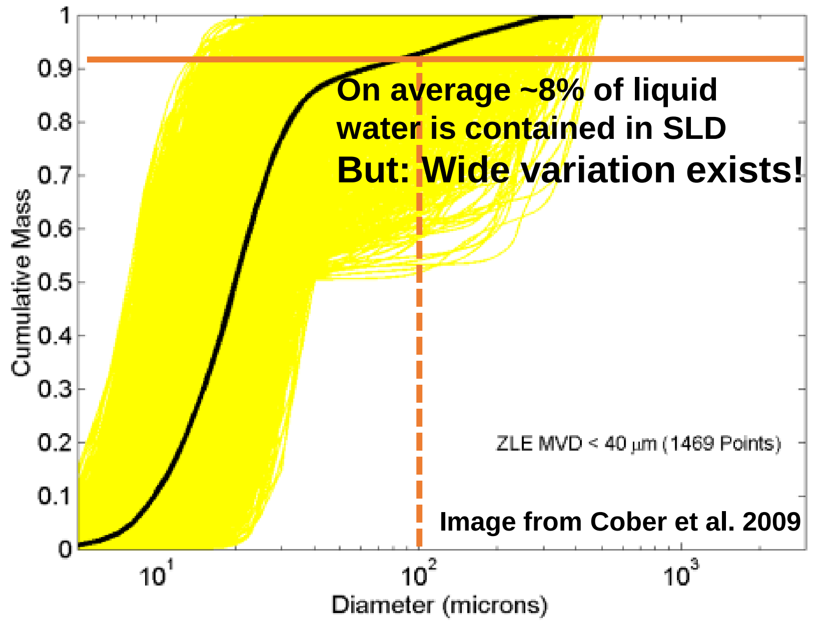
- The certification envelopes for FZDZ are functions of LWC, temperature and pressure.
- Furthermore, differences in the droplet size distribution occur.



LWC max: 0.42 g/m³
Temperature min: -25 °C



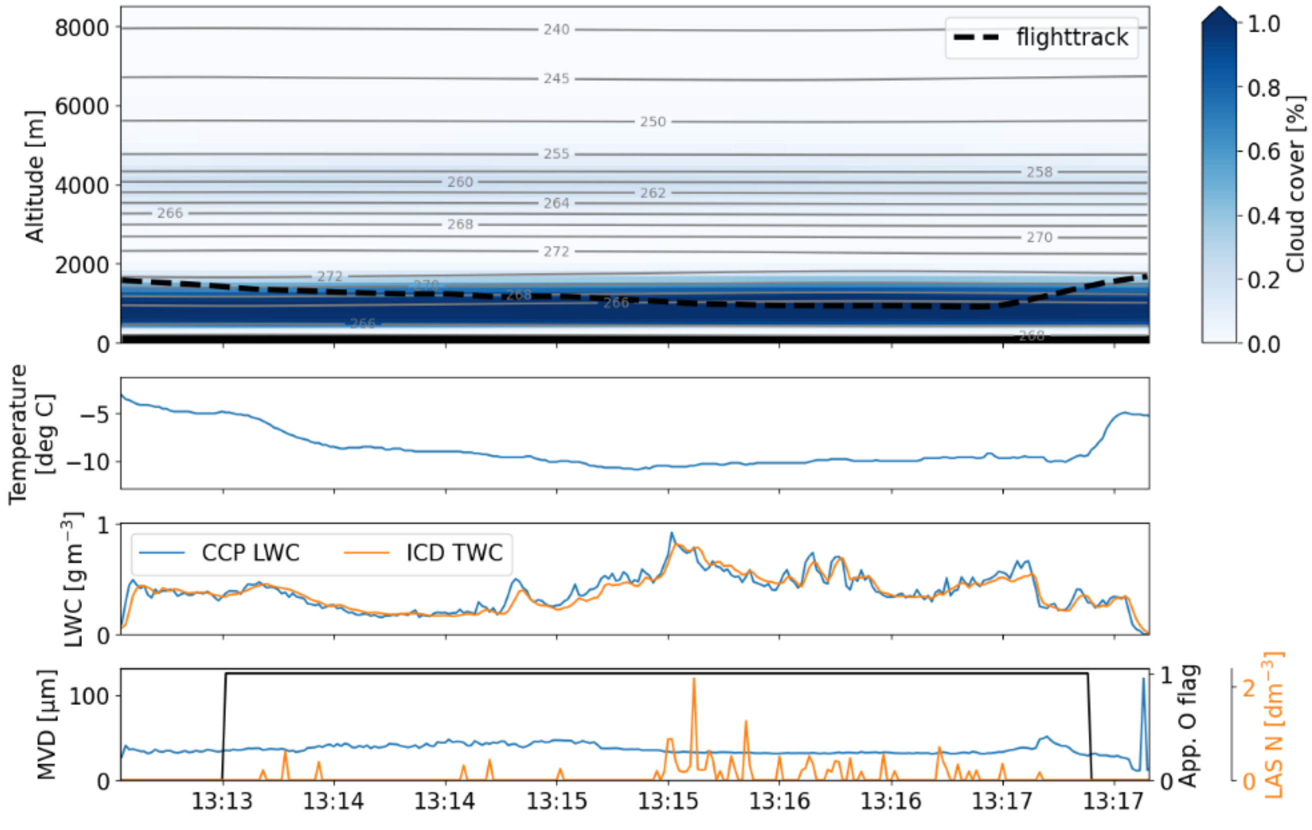
Pressure altitude max: 22000 ft, 6700 m



SLD LWC influences severity of an icing encounter!

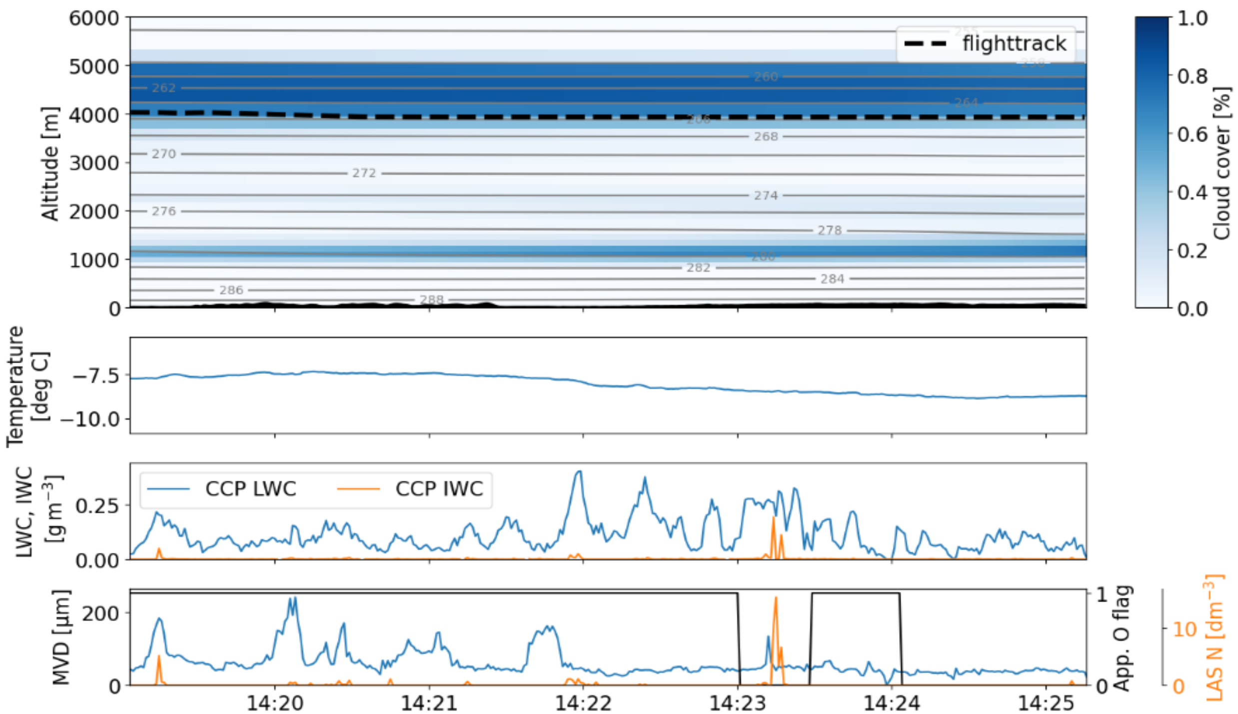
Part 2: Observations during the SENS4ICE campaigns

US campaign: Example of an Appendix O encounter



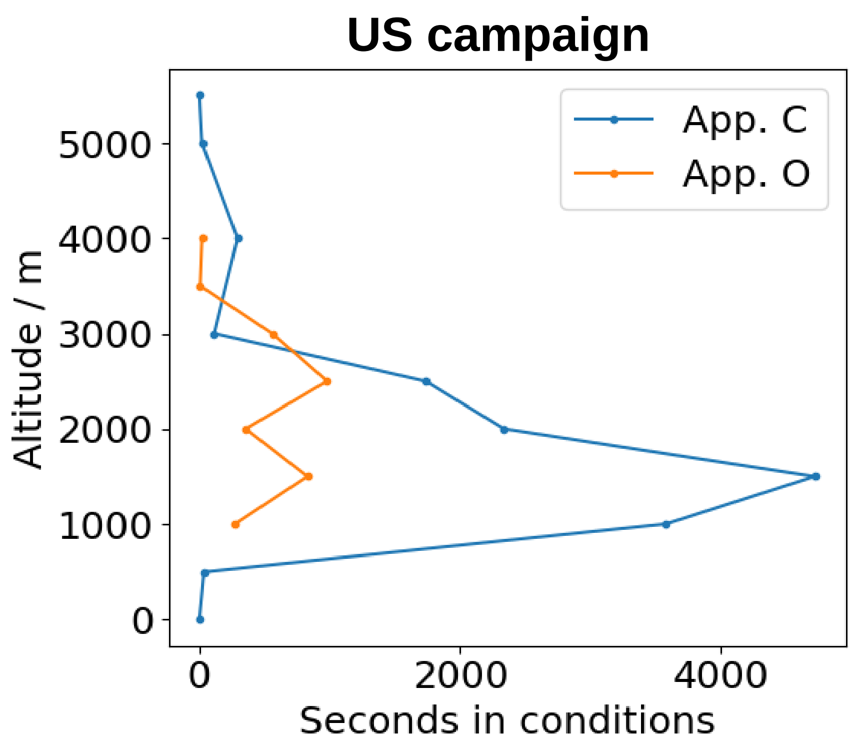
- Clouds most often occurred as closed stratus decks.
- Appendix O was encountered above a stable layer.
- Typically the cloud was approached from the top.

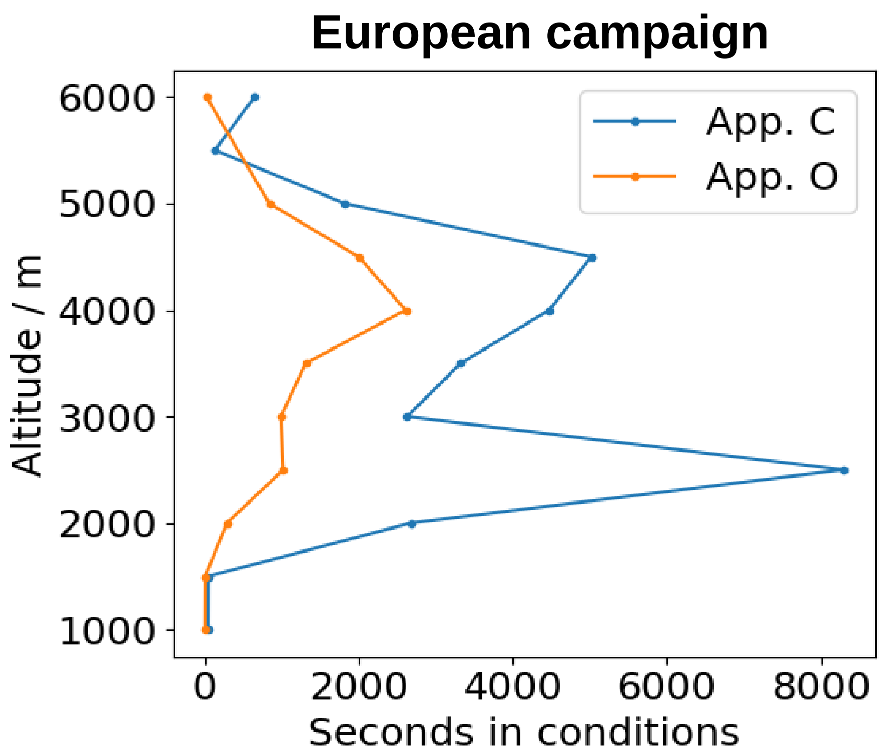
European campaign: Example of an Appendix O encounter



- Cloud consisted of multiple layers, which were not separately resolved in the ERA5 cloud cover data.
- Clouds were thinner and patchier, large variation of LWC existed within the clouds.

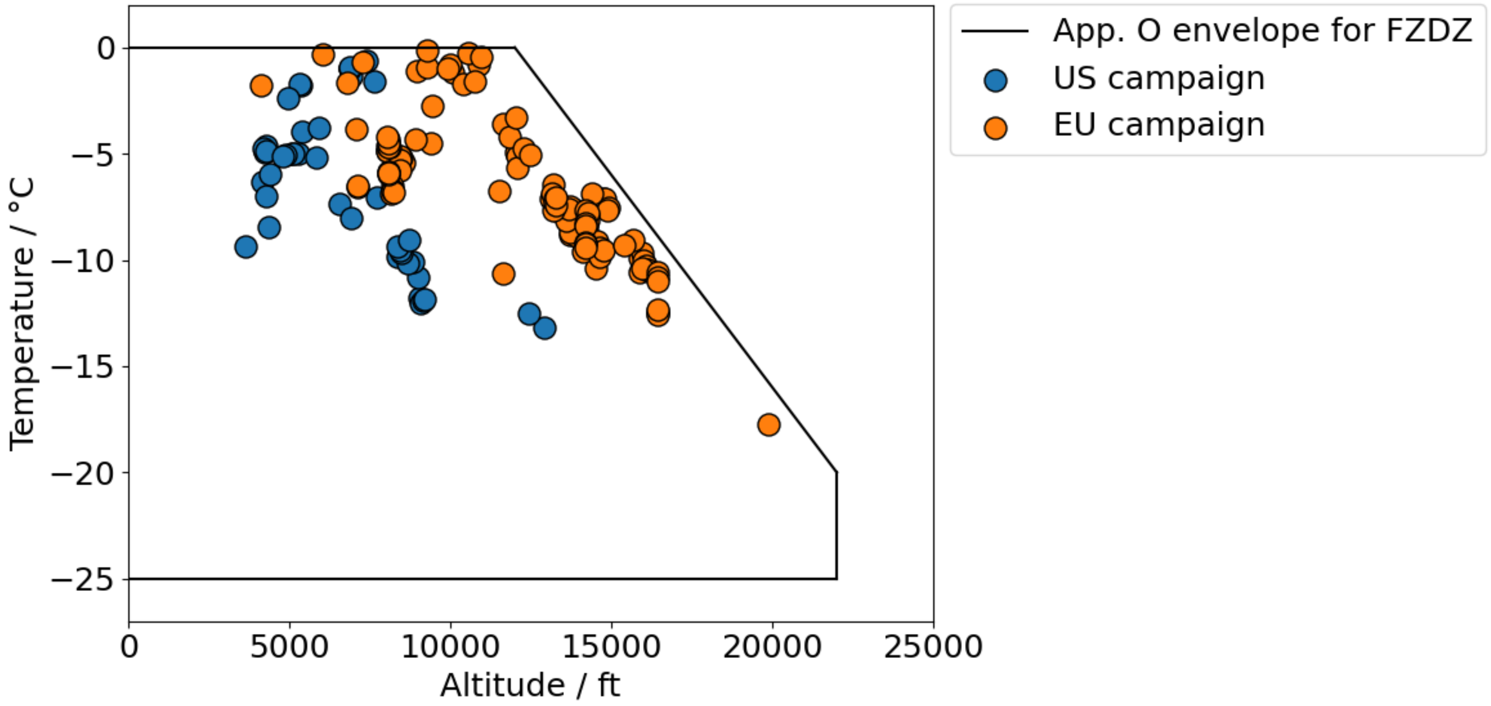
Altitude of icing conditions





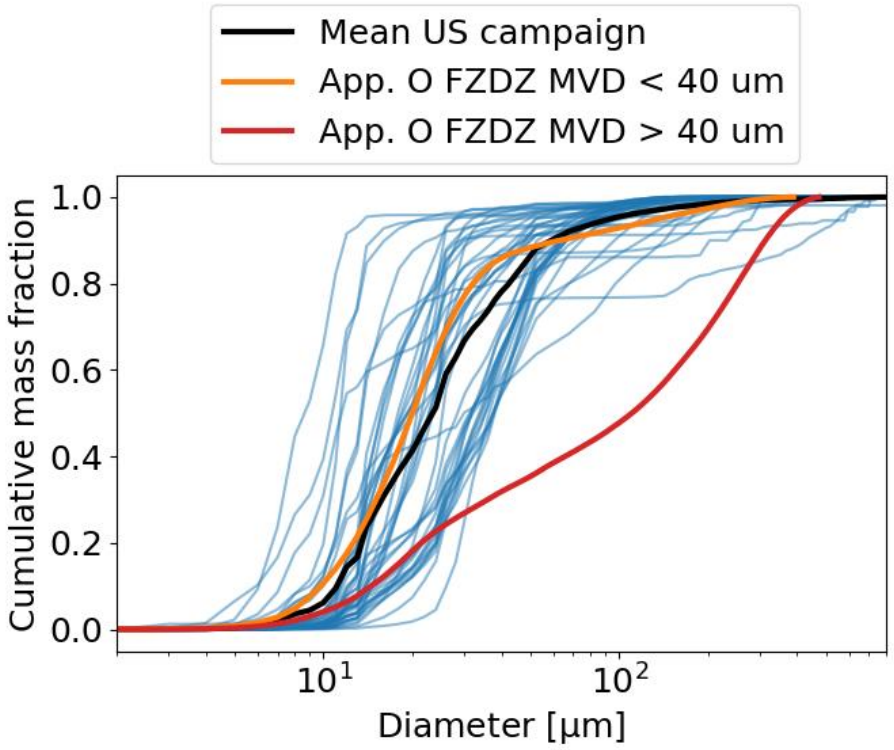
- US campaign: Icing conditions mostly between 1000 and 3000 m.
- European campaign: Significant portion of icing conditions between 3500 – 5000 m.
- Most Appendix O conditions during the EU campaign between 3500 – 5000 m.
- Different altitudes are reflect the different seasons during which the campaigns occurred.

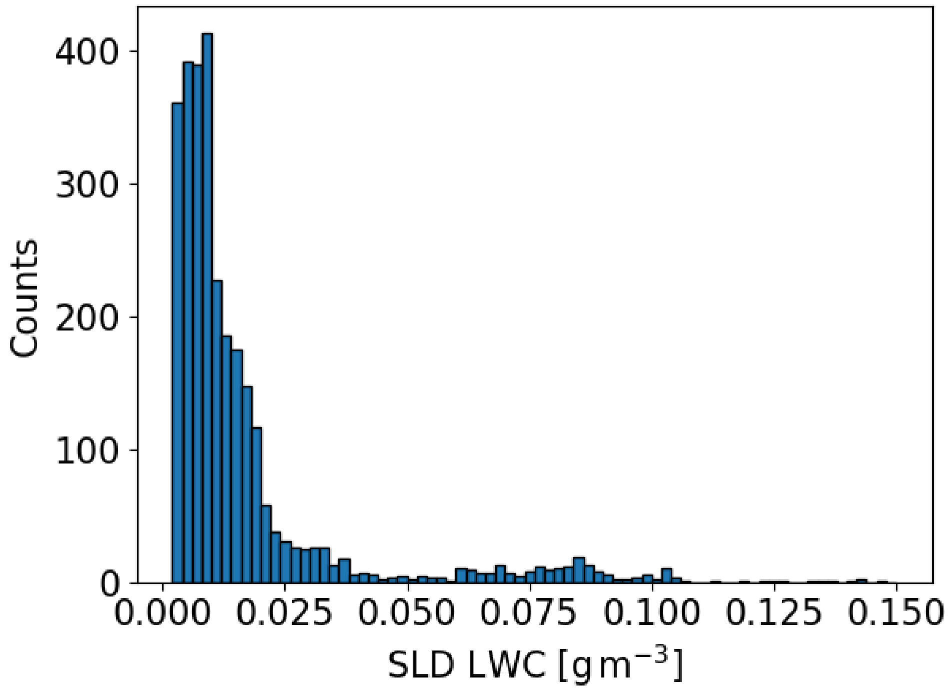
Altitude and Temperature of Freezing Drizzle conditions during the SENS4ICE flight campaigns



- FZDZ encounters of SENS4ICE fall well within the App. O altitude–temperature envelope.
- Temperature range of FZDZ conditions similar during US and European campaign.

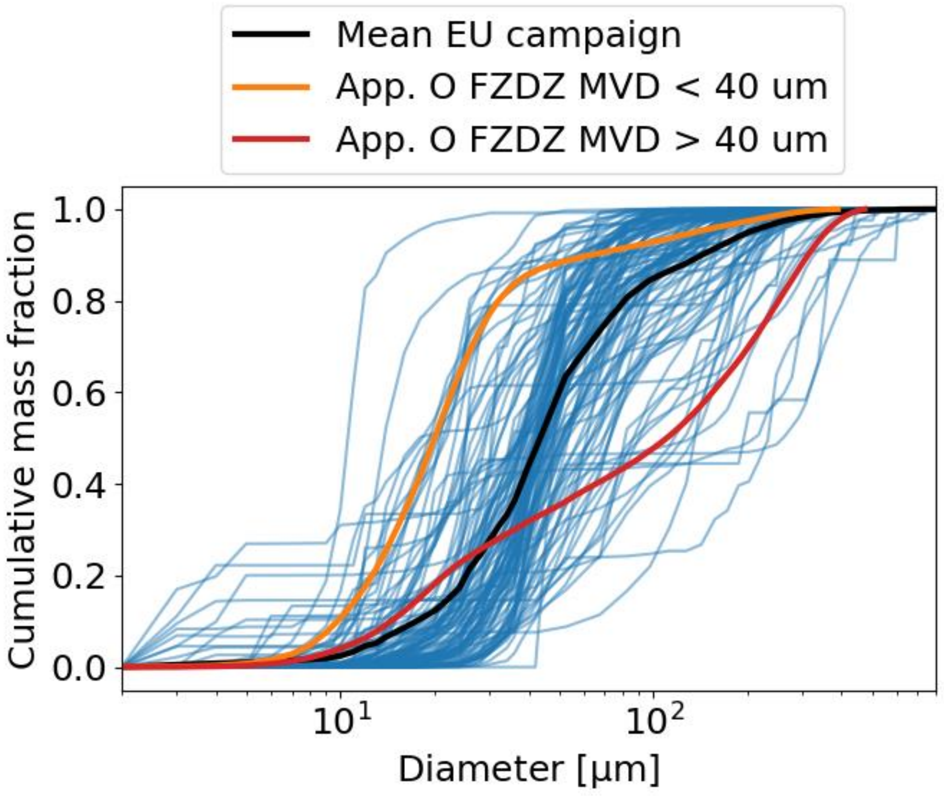
US campaign: Characteristics of Appendix O conditions

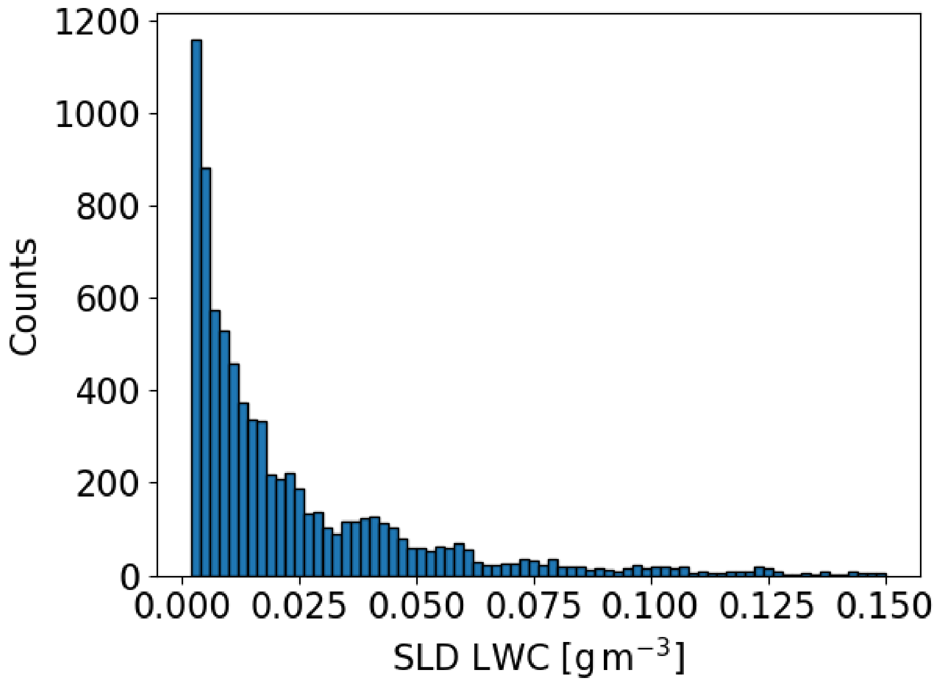




- Average size distribution (MVD = 25 µm) in close agreement with the average distribution for FZDZ MVD < 40 µm from Appendix O → also bimodal distribution.
- Sampling close to cloud top → low MVD.
- LWC in SLD reached up to 0.1 g/m³, but mostly below 0.04 g/m³.

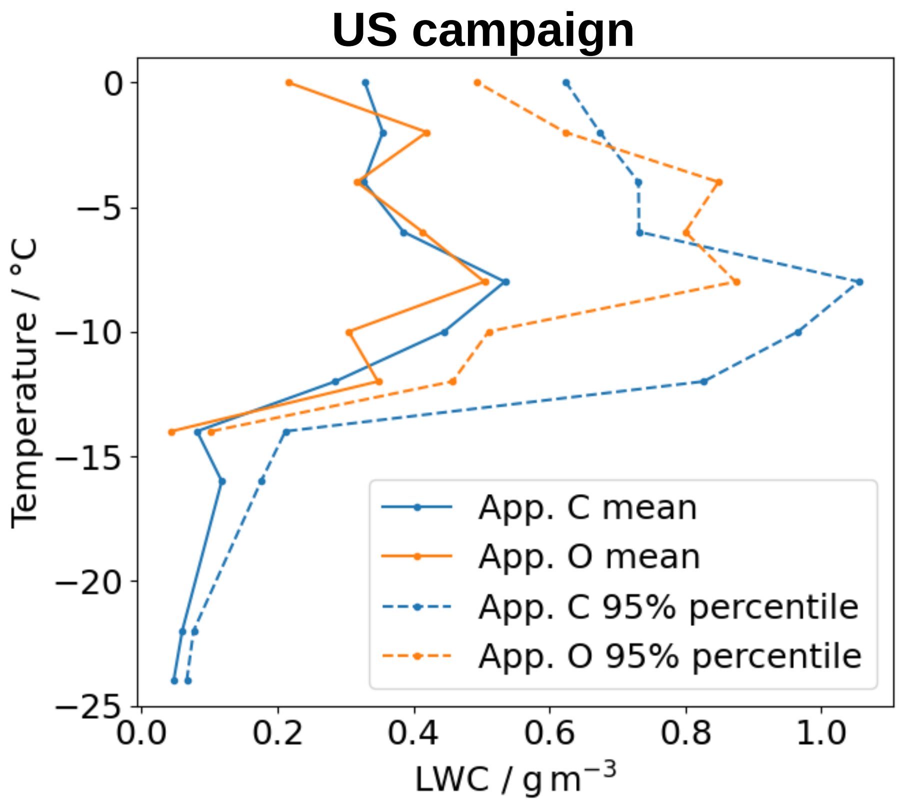
European campaign: Characteristics of Appendix O conditions

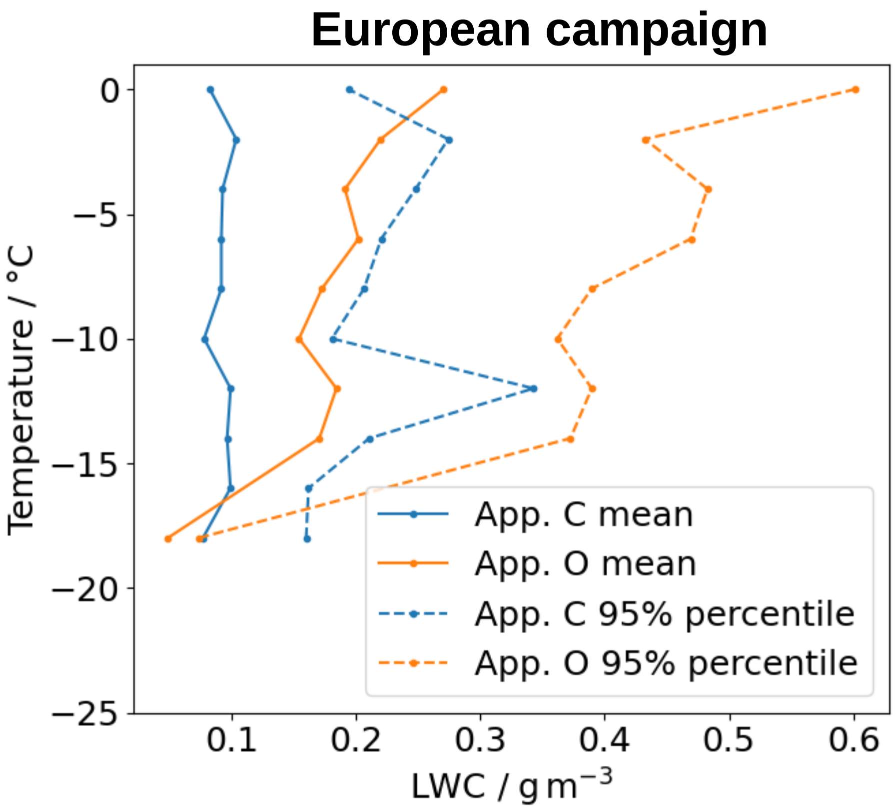




- Average size distribution is monomodal (MVD = 43 μm), unlike the averages from Appendix O.
- On average almost 50% of LWC in droplets larger than 40 μm. → Important for severity.
- LWC in SLDs relatively often between 0.025 and 0.06 g/m³.

LWC of icing conditions

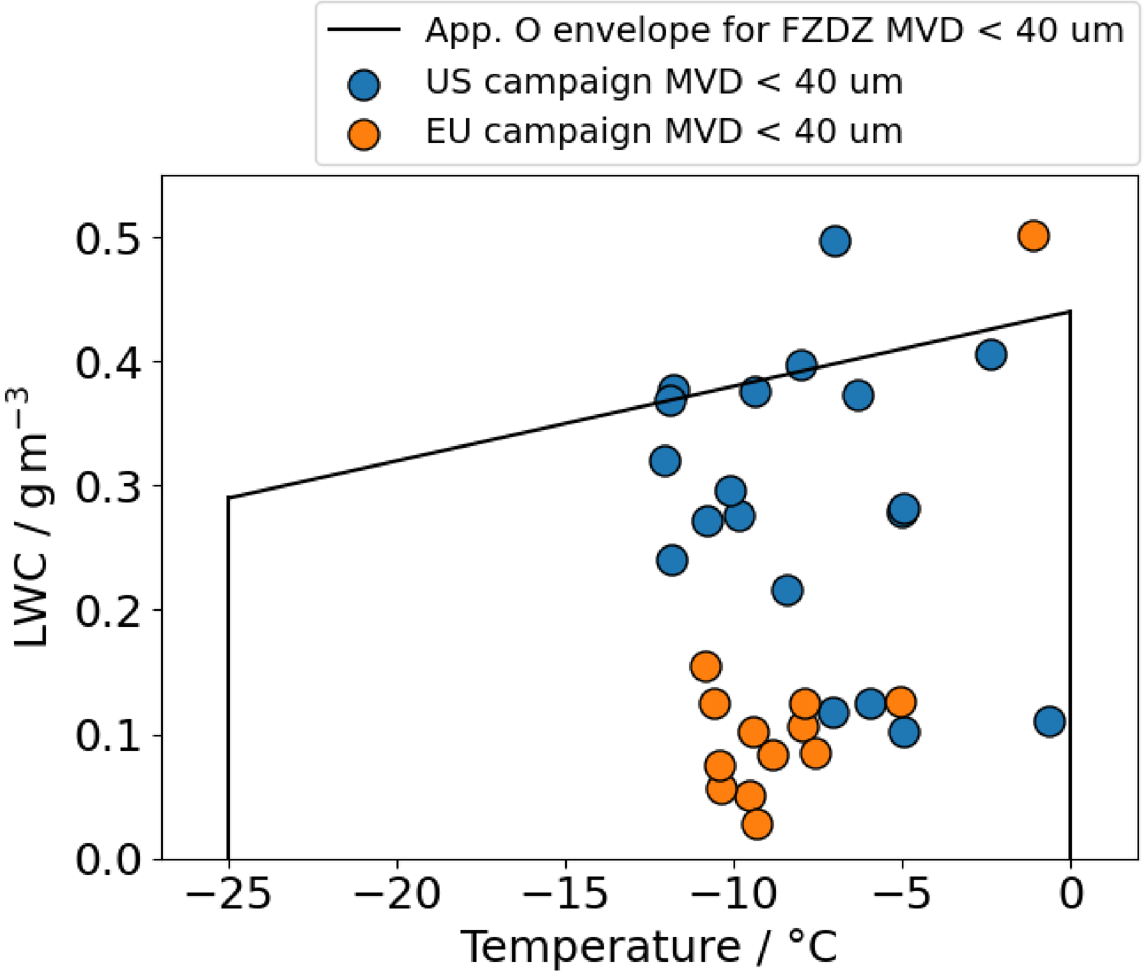




- LWCs were higher during the US campaign.
- US campaign: LWCs in Appendix C and O conditions are similar.
- European campaign: LWCs in Appendix O significantly higher than in Appendix C.

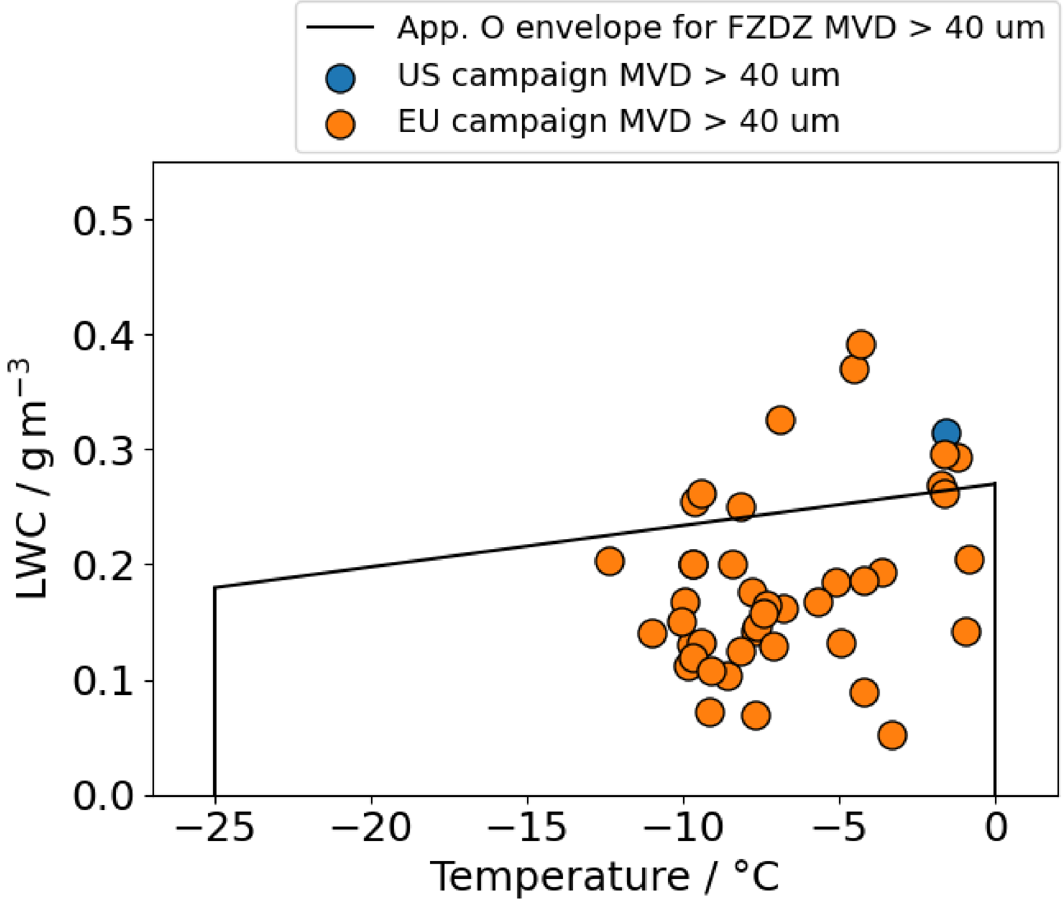
Comparison to the LWC envelopes of Appendix O Case: Freezing Drizzle MVD < 40 µm

- Many LWC observations at the upper limit of the envelope.
- Two LWC measurements exceed the envelope limit significantly.
- Shorter sampling distance of LWC values was accounted for with a scaling factor.
- Only encounters exceeding 30 s were used for this plot.

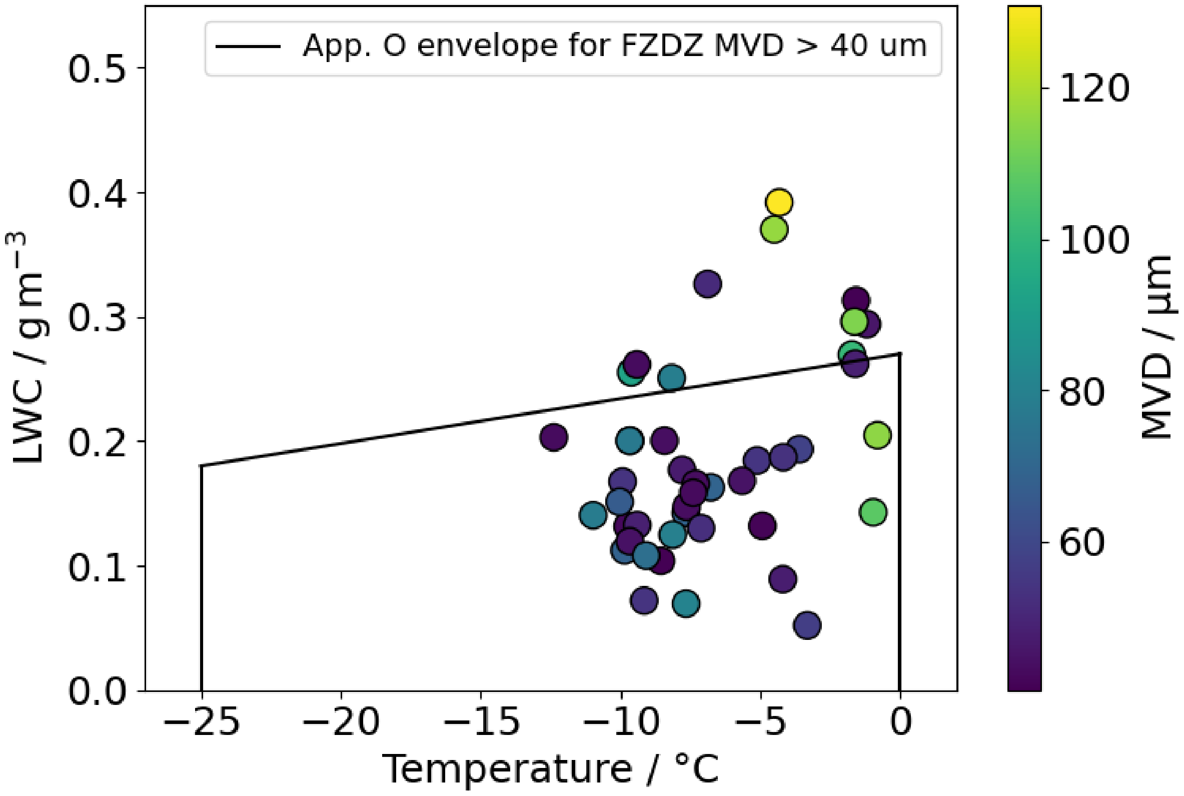


Comparison to the LWC envelopes of Appendix O
Case: Freezing Drizzle MVD > 40 µm

- The European campaign encountered many cases of FZDZ MVD > 40 µm.
- Again, multiple values exceed the envelope limits.
- But: Are the observed MVDs significantly larger than 40 µm?



Comparison to the LWC envelopes of Appendix O
Case: Freezing Drizzle MVD > 40 µm



Several of the encounters that exceed the envelopes have MVDs significantly larger than 40 µm.

Part 3: Implications from the SENS4ICE campaigns and suggestions for future work

1. Conclusions from SENS4ICE atmosphere characterization

1. Appendix O conditions during the **US campaign** were in most cases representative of the FZDZ MVD < 40 µm regime.

    → Two encounters exceeded Appendix O envelopes.

    → Not many conditions with FZDZ MVD > 40 µm were encountered during the US campaign.

    Future work, but enhanced safety precautions required.

2. Appendix O conditions during the **European campaign** often had MVDs larger 40 µm.

    → These conditions were unimodal, atypical for Appendix O conditions.

    → Several of these Appendix O conditions exceeded the LWC specified in the envelopes.
    Are summer/spring conditions at higher altitudes sufficiently represented in Appendix O envelopes ? Further research needed!

    → Formation (through high supersaturations or through collision coalescence) of large drops and improved presentation of freezing processes needs further research

2. Freezing Rain (FZRA)

- The SENS4ICE campaigns did not attempt to measure freezing rain conditions.
- Flight testing in FZRA is very challenging due to the low altitude at which FZRA occurs.
- The low altitude requires even more safety precautions than the measurement of freezing drizzle.
- Improved forecasting and nowcasting tools can also decrease risk of freezing rain.

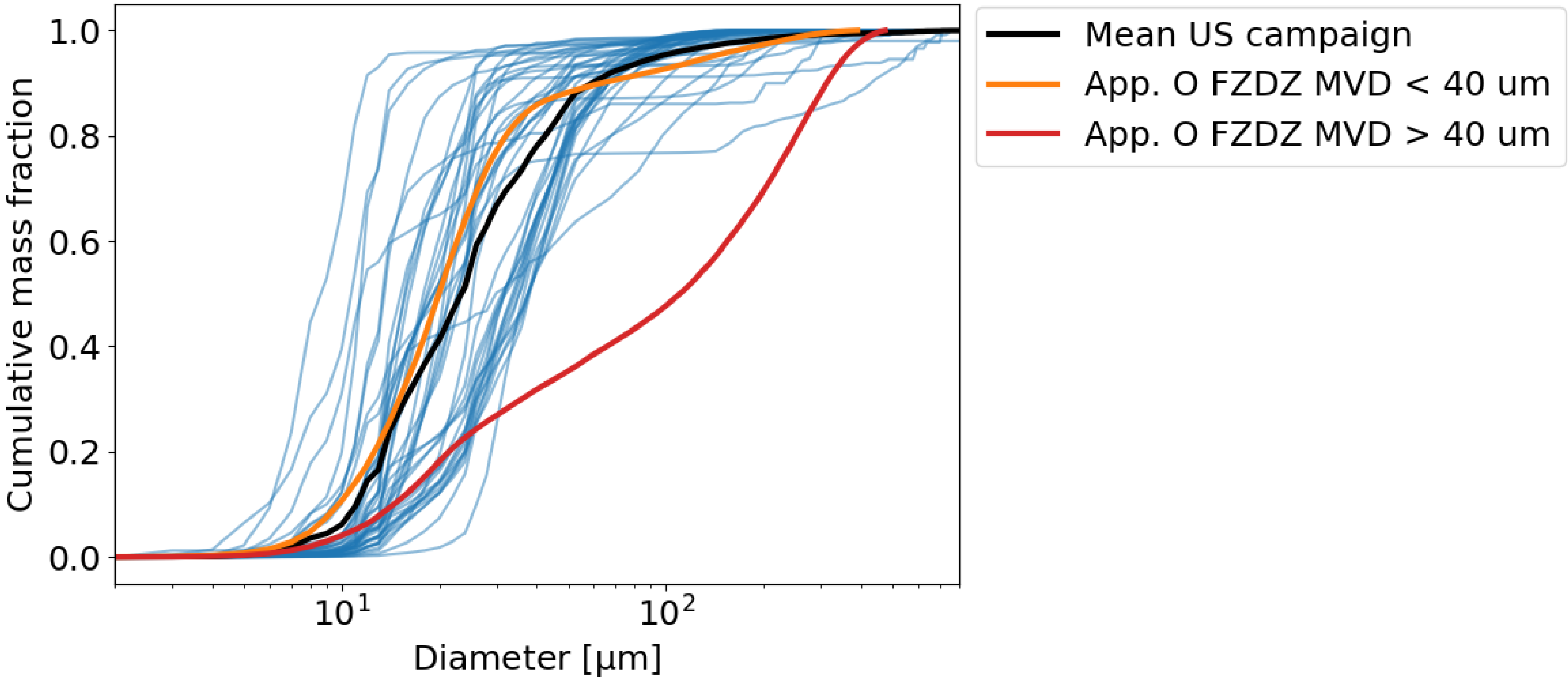
→ **Further research needed!**

- Glaciated cloud conditions above the supercooled liquid cloud layer initiate „seeding“

→ Forecast of Appendix O conditions requires knowledge on all cloud layers

→ Improved forecasts and nowcasting on ice clouds needed

3. Certification for Appendix O

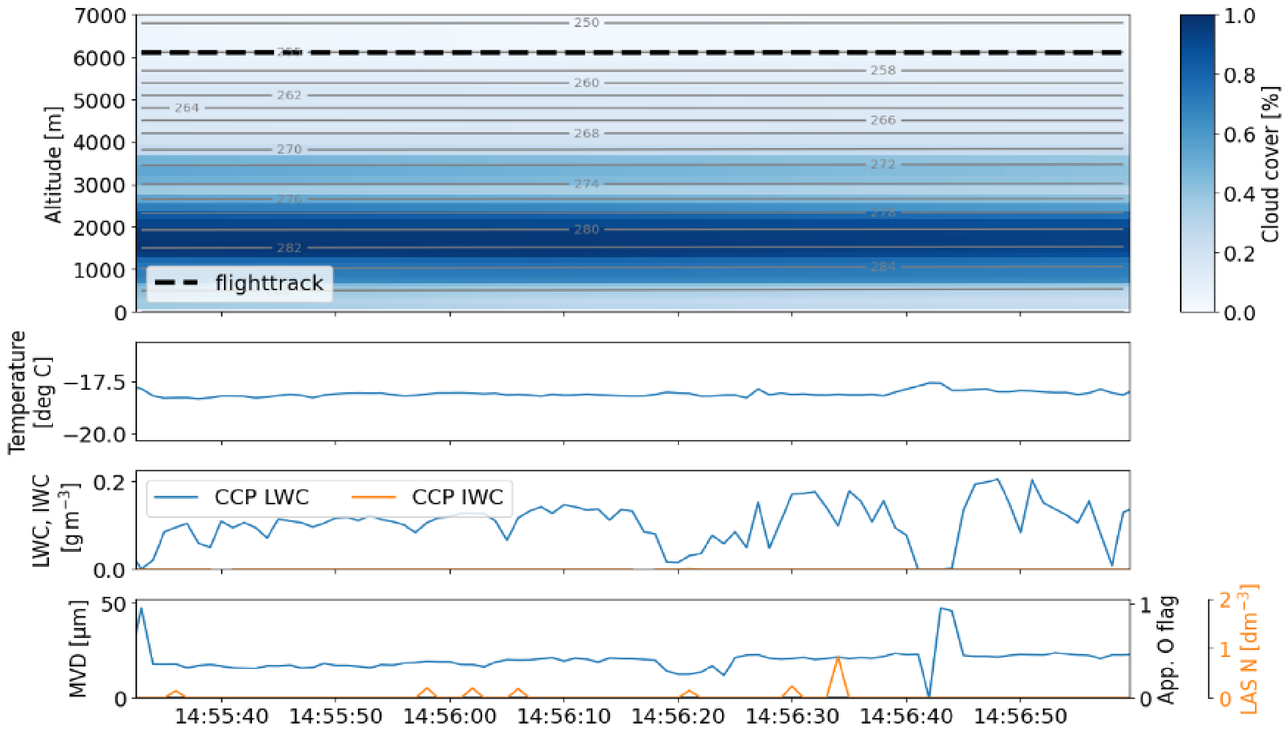


- There is currently no established procedure for certification for Appendix O.
- While for aircraft Appendix O conditions with many large drops are likely the most severe, sensors may have more difficulties detecting few large drops.

→ Adequate procedures for certification need to be established.

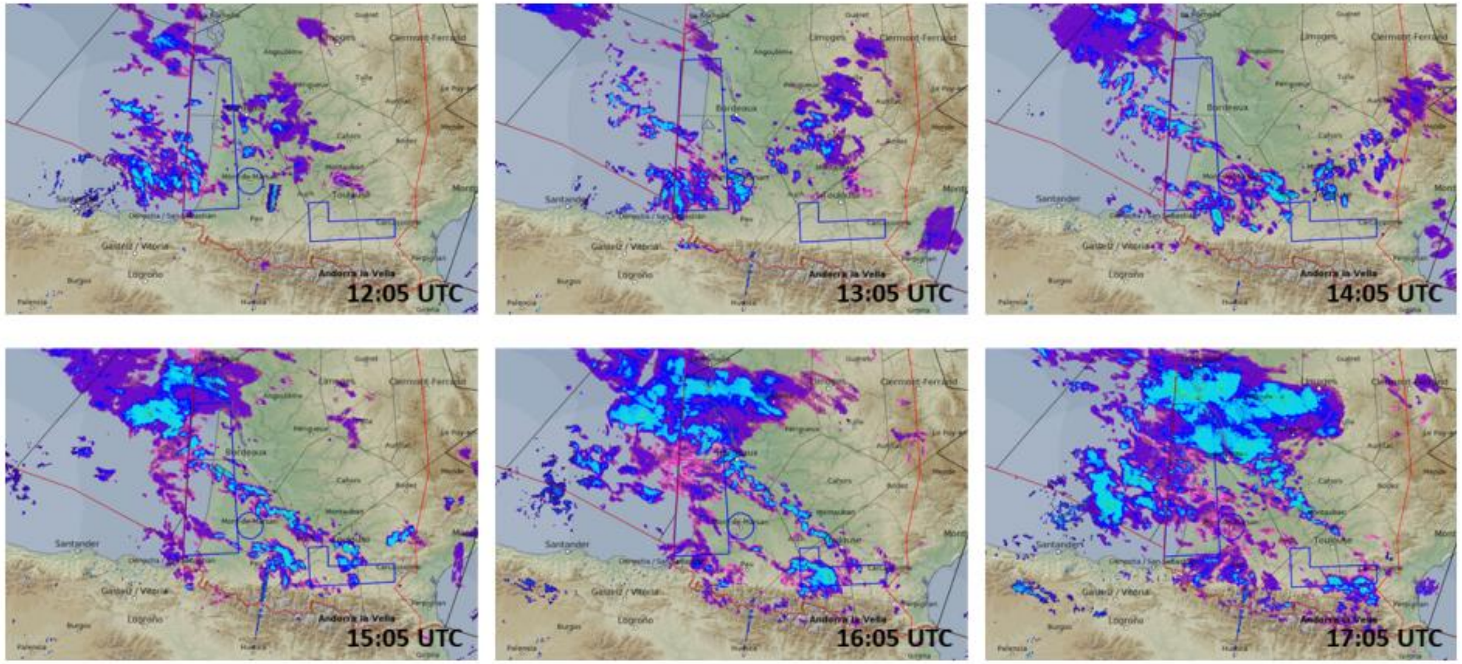
4. Improve icing prediction with new cloud schemes in weather models

- Forecast of Appendix O and C requires knowledge on cloud phase and droplet size
- → currently not represented in icing forecasts
- New cloud schemes (two moment schemes) need to be implemented into forecast products to differentiate between Appendix C and O
- → Current gap of icing forecast!



- SENS4ICE data can help validate results of models.
- Further airborne cloud microphysical measurements needed to calibrate and validate forecasts with new cloud schemes.
- Mid-level clouds were found to be insufficiently represented in ERA5 reanalysis data.

5. Improving radar retrieval for detection of Appendix O conditions



- Many Appendix O encounters were detected in the remnants of the clouds with low radar reflectivity
- Improvement of radar retrieval for detection and differentiation of Appendix O and C conditions needed

6. Challenges of flying in icing conditions

It is a significant challenge to fly in Appendix O conditions, which requires an interdisciplinary team with experts from many areas, among others:

- Meteorology, Weather forecast and nowcast
- Aircraft certification
- Aircraft operation including knowledge on necessary safety precautions
- Sensor technology and evaluation of in-situ measurement

→ A large collaborative effort is needed!

Visit our website www.sens4ice-project.eu
and Linkedin #sens4iceproject