SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Overview of SENS4ICE project: SENSors and certifiable hybrid architectures FOR safer aviation in ICing Environment

Final Public Workshop of ICE GENESIS

Carsten Schwarz (DLR)

Toulouse, France – 07 December 2023

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

SENS4ICE Project Overview

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- JAN 2019 - DEC 2023 (extended, originally DEC 2022)
- 17 Consortium partners including coordinator DLR
- Budget:
  - total estimated eligible costs 8.7 M EUR
  - max. EU contribution 6.6 M EUR
  - project effort in person-months approx. 800 PM
- https://www.sens4ice-project.eu
- #sens4iceproject on LinkedIn

DLR
LEONARDO AIRCRAFT
ATR PROPELLING THE NEXT CONNECTION
AeroTex UK LLP
ONERA THE FRENCH AEROSPACE LAB
CIRA Centro Italiano Ricerche Aerospaziali
Technische Universität Braunschweig
Collins Aerospace
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SAFRAN
Honeywell | THE FUTURE IS WHAT WE MAKE IT
EMBRAER
Collins Aerospace
Honeywell THE POWER OF CONNECTED
INTA
National Research Council Canada
Conseil national de recherches Canada

SENS4ICE Goal/ Impact

Safire ATR 42: image DLR with Safire permission

Problem

- Detect icing conditions
- Including SLD (supercooled large droplets) / App. O (CS-25 / 14 CFR Part 25) icing
- Detection very challenging

Solution

- 10 direct detection technologies
- Hybrid approach – fusion of input data: sensor(s) and indirect detection

Benefits

- Operational benefits:
    - activate anti-/de-icing
    - avoid/ leave icing conditions
- Certification process benefits – flights in App. O/ SLD icing
    - safety risk due to severe and unknown aircraft icing
    - online evaluation of safety margins during flight tests/ certification flights

SENS4ICE Timeline / Summary / Achievements

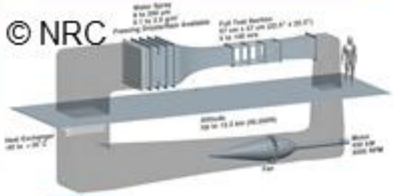
Upgrade icing wind tunnels for App. O

Develop sensors/ technologies for App. O detection

© Collins

Icing wind tunnel testing

© NRC



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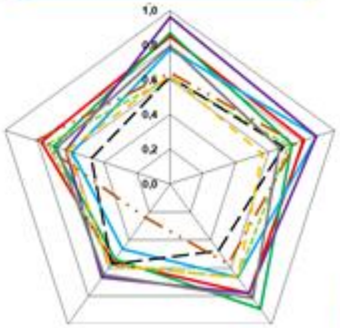
Sensor technology evaluation and selection



Hybrid ice detection

Indirect ice detection

Remote ice detection

Flight test preparation

Flight testing

FEB/MAR 2023

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Flight test analysis/ techno-logy evalua-tion

Commu-nication, Dissem-ination, Exploi-tation

2019 - 2020 | **2021** | **2022** | **2023**

8.7 M EUR including 6.6 M EUR EU contribution

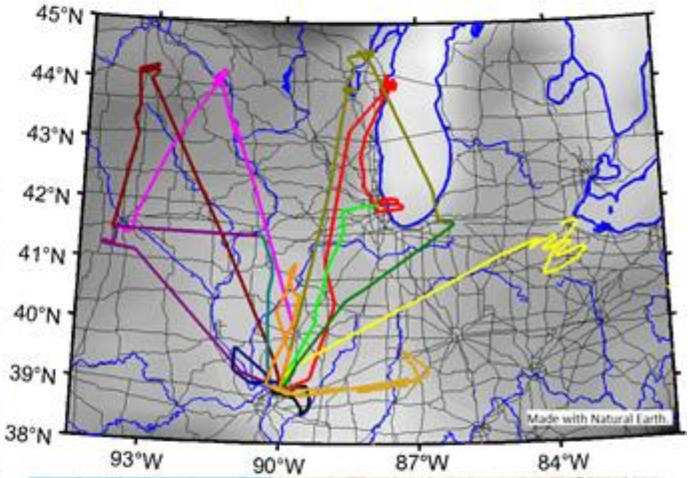
SENS4ICE sensor technologies overview, sensor types and principles

Developer	Sensor	Sensor Type	Sensor Principle
AeroTex	AIP - Atmospheric Icing Patch	Atmospheric	Isothermal with inertial separation at different sensors along aircraft
Collins	IDS - Ice Detection System	Atmospheric	Thermal response to heat impulse
DLR	LILD - Local Ice Layer Detector	Accretion	Ultrasonic wave attenuation / phase change
Honeywell	SRP - Short Range Particulate	Atmospheric	Collecting backscattered light from particles
INTA	FOD - Fiber Optic Detector	Accretion	Latent heat measured with fiber optic
ONERA	AHDEL - Atmospheric Hydrometeor Detector based on Electrostatics	Atmospheric	Particle charging and subsequent measurement of the charge
ONERA	AMPERA - Atmospheric Measurement of Potential and ElectRic field on Aircraft	Atmospheric	Measurement of aircraft electric potential
SAFRAN	AOD - Appendix O Discriminator	Atmospheric	Shadowgraphy
SAFRAN	PFIDS - Primary in-Flight Icing Detection System	Accretion	Optical reflection from accretion
DLR	CM2D - Cloud Multi-Detection Device [BCPD - Backscatter Cloud Probe with Polarization Detection]	Atmospheric	Single particle optical backscatter
DLR	CM2D - Cloud Multi-Detection Device [Nevzorov]	Atmospheric	Isothermal measurement of water content

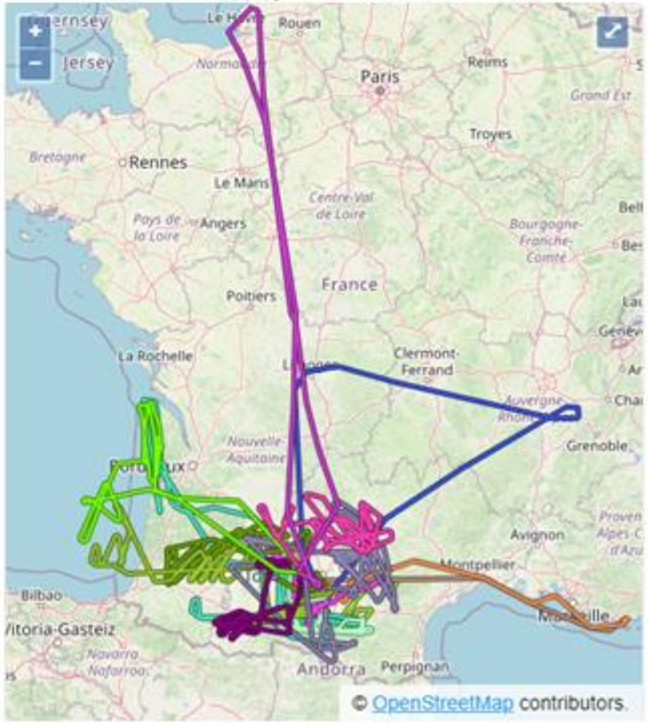
SENS4ICE Flight Campaigns

- Total flight test time: 75h in natural icing conditions
- North America
  - February/March 2023
  - Embraer Phenom 300 operated by Embraer
  - **15 flights** with a total of **25 flight hours** (including ferry and check flights) successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions
  - 260+ min in App C and 50 min in App O
- Europe
  - April 2023
  - French ATR 42 environmental research aircraft of Safire
  - **15 flights** with a total of **about 50 flight hours** successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions
  - 610+ min App C and 150+ min App O

Embraer Phenom 300



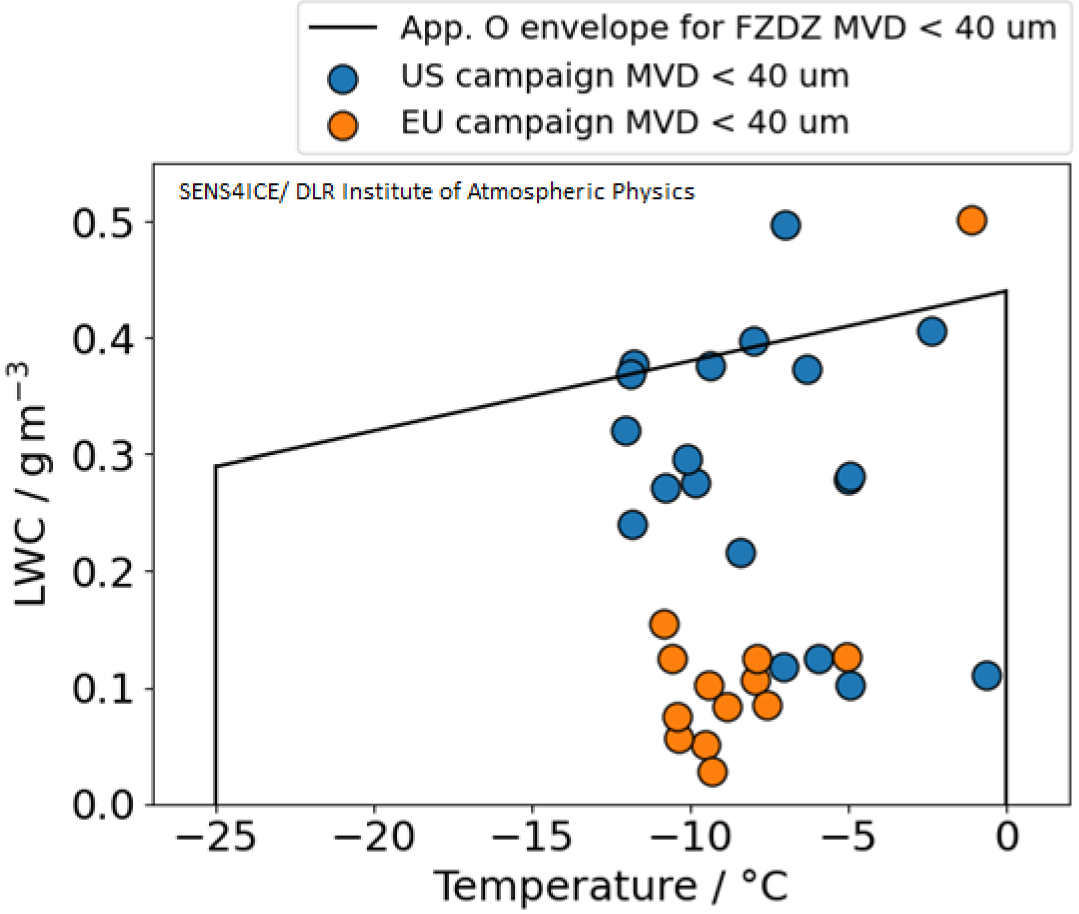
SAFIRE ATR 42

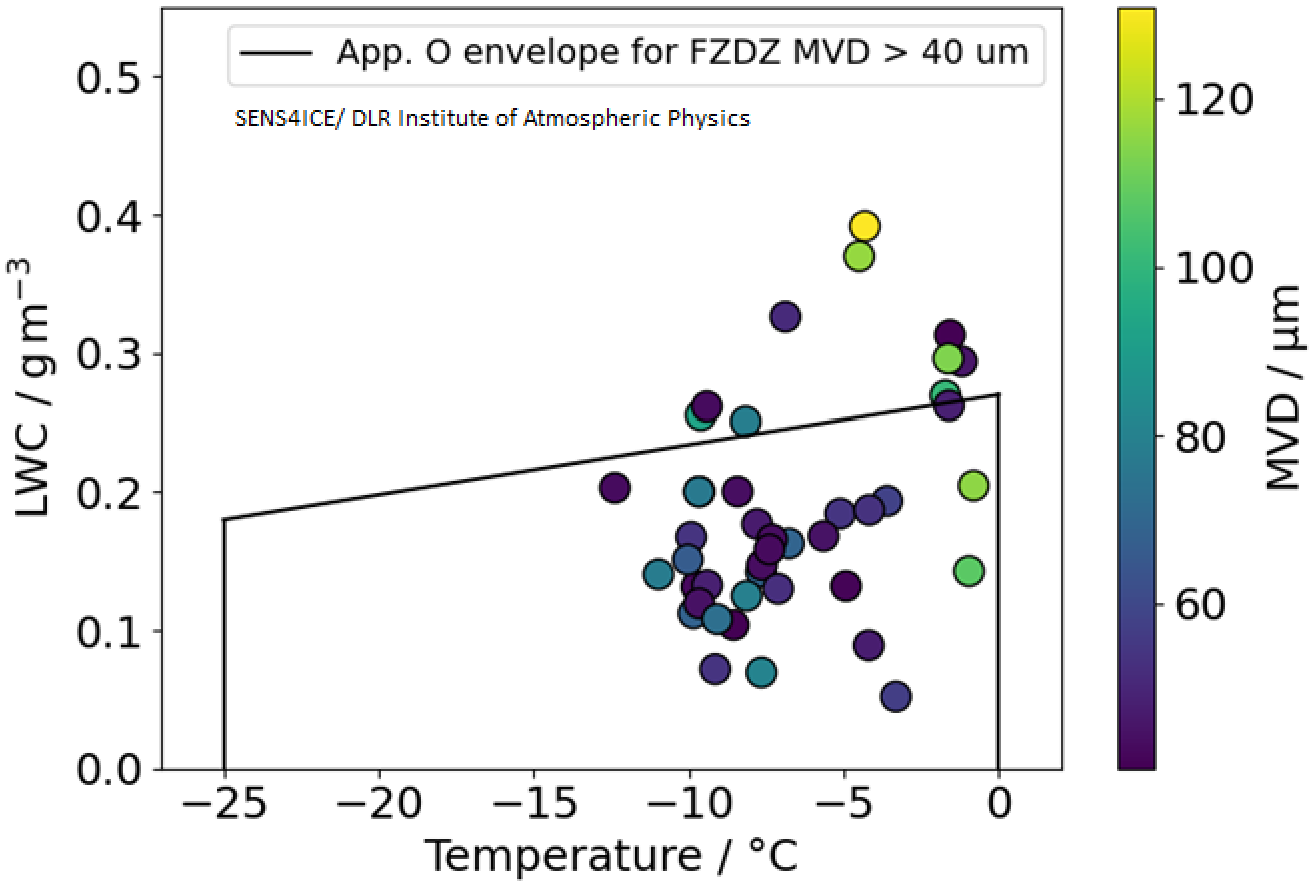


SAFIRE atmospheric reference data publicly available
https://safireplus.aeris-data.fr/data-access

SENS4ICE Flight Campaigns: **Comparison with App O LWC Envelopes**

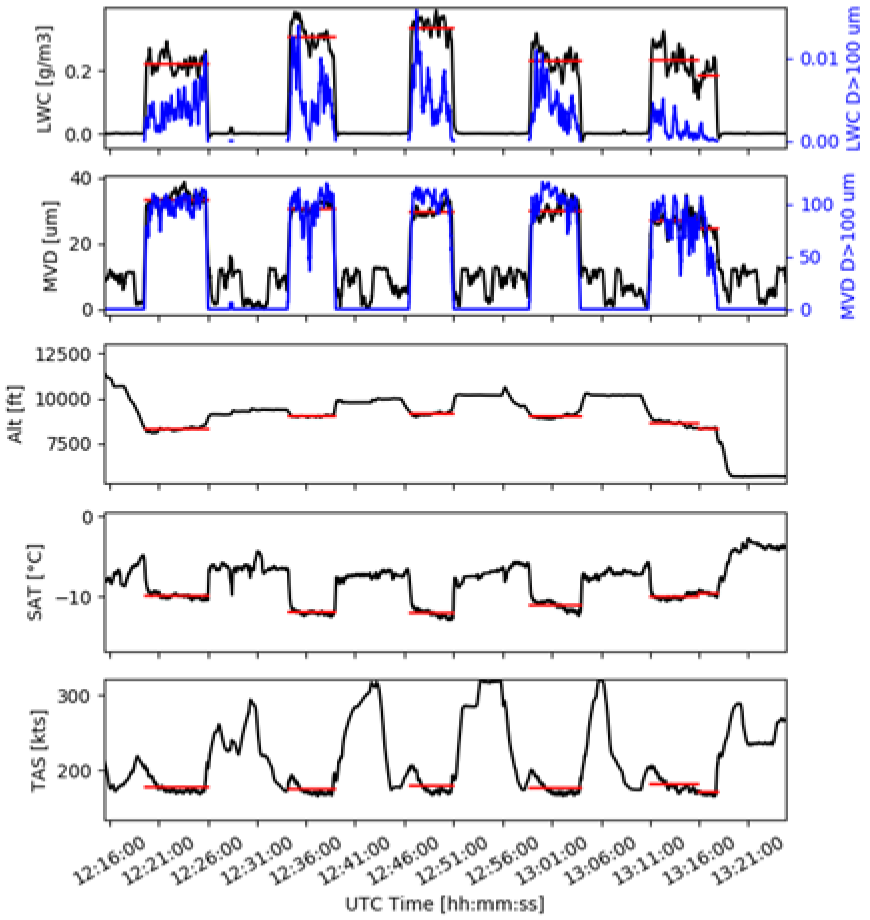
- Shorter sampling distance of LWC values accounted for with scaling factor
- Only encounters exceeding 30 s used for this analysis
- Several encounters exceeding MVD 40+ envelope with MVDs significantly larger than 40 µm



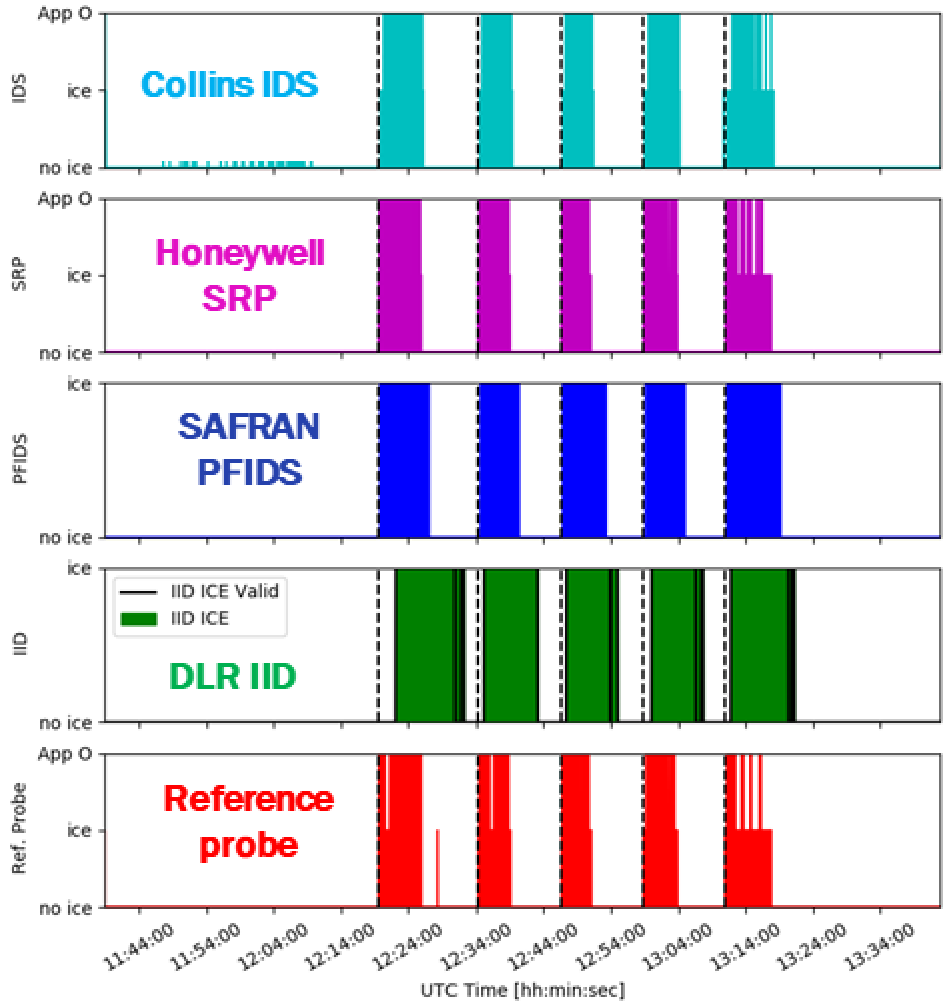


North America Flight Campaign Results

Flight 1476 – Direct and Indirect Ice detection in **App O conditions**



Reference probes and A/C data

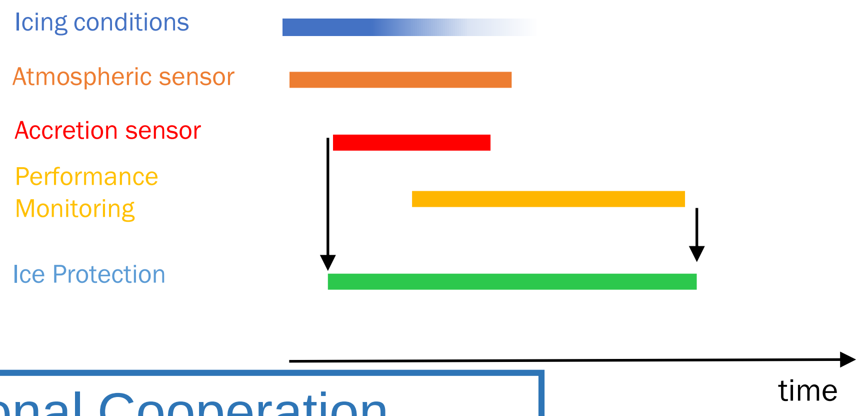


Hybrid ice detection data analysis by SAFRAN

EU Project SENS4ICE - Results

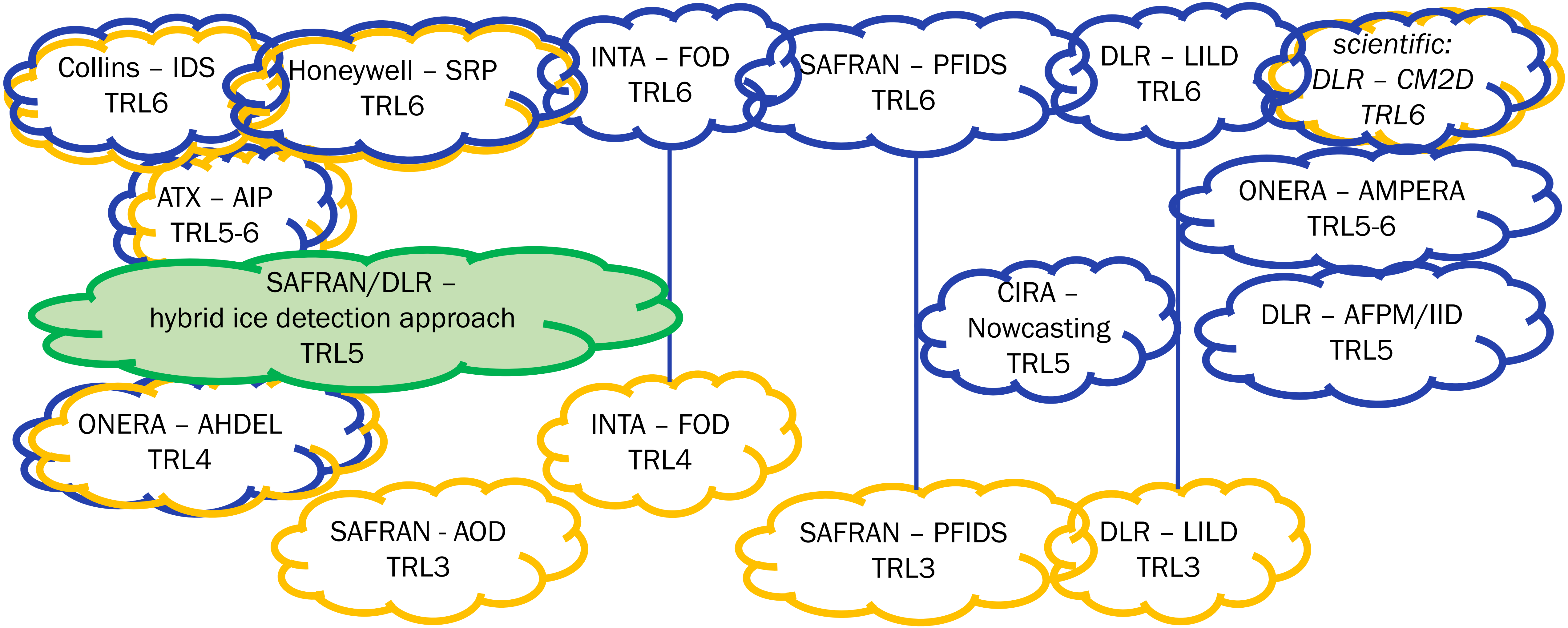
SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- **Direct, indirect and remote ice detection technologies particularly for SLD** (Supercooled Large Droplets) icing developed, considerably matured and successfully demonstrated in IWT (icing wind tunnel) and natural icing conditions in flight campaigns
- Intense and significant coverage of **relevant icing conditions** achieved for IWT (icing wind tunnels) and flight campaigns including valuable SLD encounters
  → while certification envelope is multi-dimensional and much larger
- **Broad and promising technology application** for different purposes/vehicles
  → many innovative technologies low size/ low weight/ low power or even a software solution (indirect detection)
- Game changer **hybrid solution** for challenging task of SLD detection
  - combining dissimilar technologies into a hybrid solution combining both direct and indirect technologies > TRL5 reached
  - successfully tested/demonstrated in two flight campaigns
  - benefits of quick warnings and continuous ice accretion and flight performance monitoring
  - IPS efficiency optimisation



- Excellent Fruitful International Cooperation
- Outstanding Communication and Dissemination

SENS4ICE – Technology readiness levels TRL reached
App O detection and App O discrimination



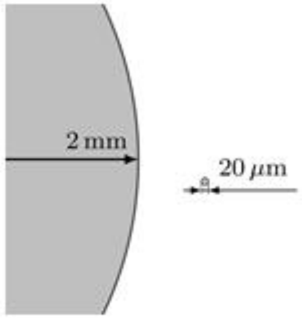
- Exploitation: patents for most technologies filed/ underway, relationships with supply/OEM industry established

SENS4ICE Challenge/Outcome

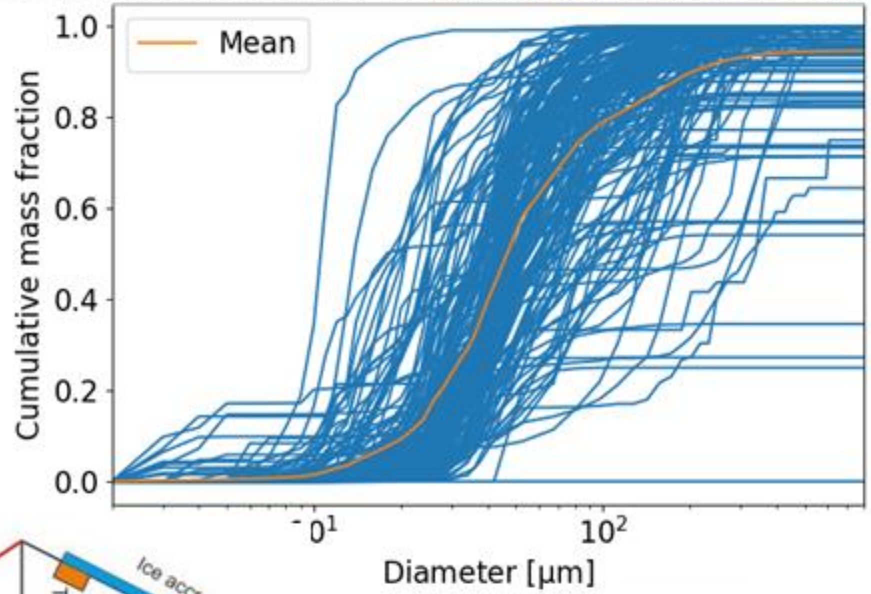
- Detect icing conditions – challenge: SLD

Solution/Innovation

- 8 direct detection technologies matured & flight test demonstrated
- Hybrid approach – fusion of input data: sensor(s) and indirect detection

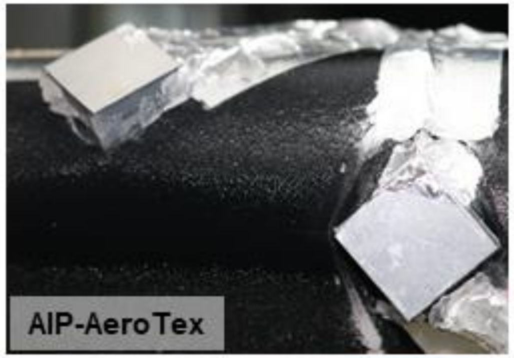


SENS4ICE Flight Campaign Europe - Droplet diameter distribution
Microphysics data analysis - DLR Institute of Atmospheric Physics

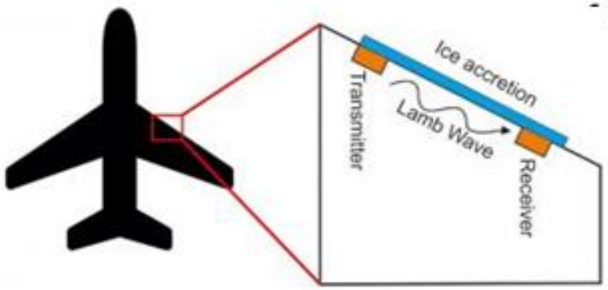


PFIDS-Safran

HIDS-Safran/ IIDS-DLR



AIP-AeroTex

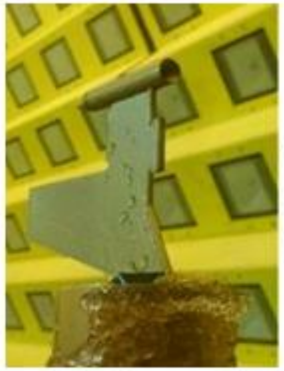


LILD-DLR

AMPERA-ONERA

IDS-Collins

SRP-Honeywell



CM2D-DLR

FOD-INTA

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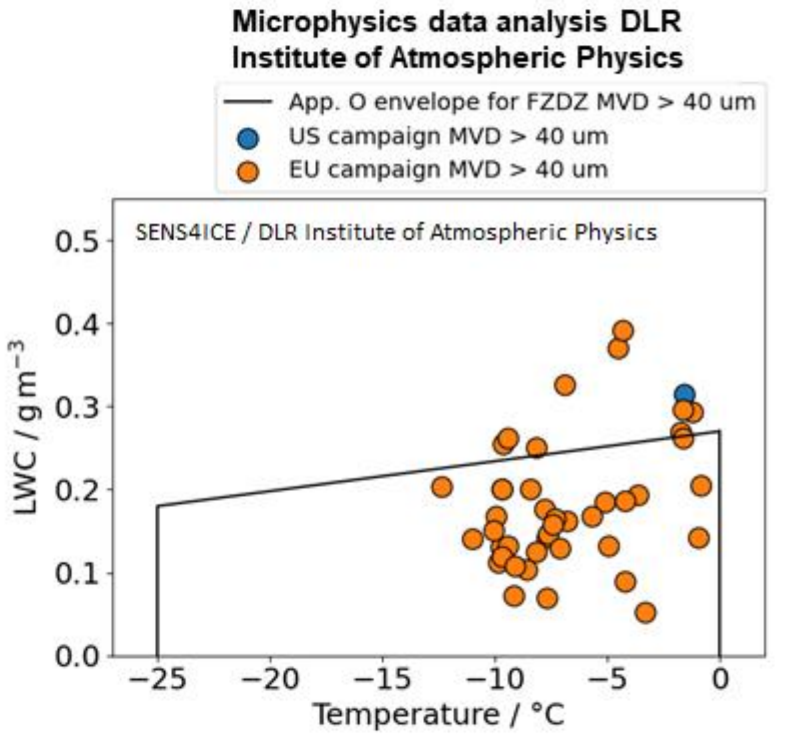
Conclusion & Outlook - Research Gaps

- further research/ development/ testing in enhanced icing wind tunnels and in natural icing conditions in flight required covering the full range of App O, specifically freezing rain, for maturing icing detection and discrimination technologies and identifying path for certification

- dedicated research and development for smart ice protection technologies with high efficiency required e.g. for greener aviation high aspect ratio aircraft and small/ low speed/ low altitude/ unmanned vehicles



- Improve understanding of icing effects on aircraft for rare and safety/certification relevant icing conditions (Appendix O/ SLD) to enable certification and safe operations for new aircraft/vehicle designs

SENS4ICE – Conclusion & Outlook

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- Particularly for App O/ SLD improve physical understanding, forecasting/nowcasting capabilities: Extensive data collection with enhanced icing wind tunnels and in natural icing conditions in flight required as sufficient data is not available today specifically freezing rain
- Enhancing aviation icing safety including for rare SLD conditions may involve revolutionary hybrid approach including novel detection technologies – challenge detecting few large droplets/ low liquid water content
  - further research/ development/ testing of detection technologies in enhanced icing wind tunnels and in natural icing conditions in flight required covering the full range of App O, specifically freezing rain
  - develop robust and reliable discrimination of safety relevant icing conditions (e.g. freezing drizzle/rain)
  - no clear path for certification requirements for sensor technologies (including software algorithms)
- Enhancing aviation icing safety including for rare SLD conditions for conventional aircraft and also make it possible for future unconventional vehicles like UAV, UAM, more/all electric vehicles due to low size/weight/power solutions
  - dedicated research and development required e.g. for small/ low speed/ low altitude vehicles and atmospheric conditions, including efficient and smart IPS
- Safe aircraft operation in icing conditions related not solely to atmospheric icing conditions but ice formation on airframe and degradation of flight characteristics
  - SENS4ICE showed impact of SLD icing in App. O must always be considered by effect on aircraft (relevant for certification) and not only detection of icing conditions.
  - changes for view on certification path/ definition acceptable means of compliance (AMC/MoC) particularly for new aircraft designs.

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If not acknowledged, images courtesy of the consortium partners.

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