



June 20-22, 2023
Vienna, Austria

International Conference on Icing

of Aircraft, Engines,
and Structures

sae.org/icing





SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Overview on the meteorological conditions during the SENS4ICE airborne test campaigns

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International Conference on Icing of Aircraft, Engines, and Structures – SAE

June 20 - 22, 2023, Vienna, Austria

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



And al. :

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FOR SAFER AVIATION IN ICING ENVIRONMENT

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The SENS4ICE team



Overview and Outline

- Two airborne measurement campaigns.
- Similar, but different places / aircrafts / seasons / probabilities to observe icing...
- All partners involved for a same target : Capture App. O & (some) App. C conditions
- A lot of preparation for planning, flight strategies, forecast briefing (EU dry-run organized one year before the campaign), exchange of know-how...
- All hands on deck during the campaigns
- Big effort to prepare data and to present first preliminary results (<2 months after EU campaign)

Plan

- 1) Weather Forecasting tools combined with research aircraft capacities**
- 2) Example cases**
- 3) Preliminary summary of observed conditions during US and EU campaigns**





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**Weather Forecasting tools combined with
research aircraft capacities**

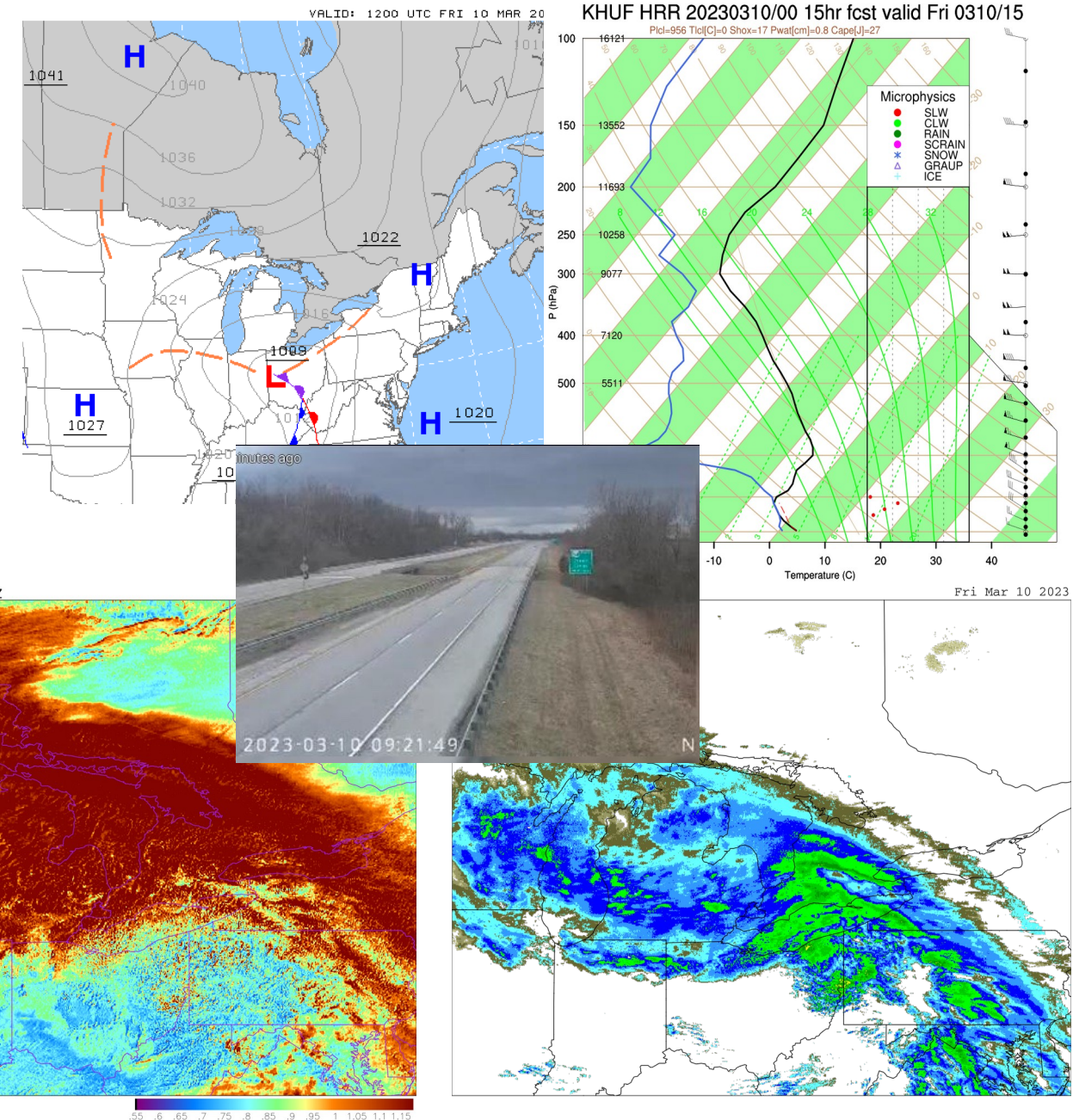
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Tools Used In the U.S. Campaign

- Synoptic Weather Patterns
- Models: NAM, HRRR
 - T, RH, microphysics - Maps, forecast profiles
- Satellite: GOES-16
 - IR, VIS, Near-IR (CH5), SW-IR (CH6)
 - Combinations: CH6/5, CH7-14, Night Microphysics
- Radar: NEXRAD & mosaics
 - Maps of reflectivity
- Surface Observations
- Pilot Reports
- Balloon-borne soundings
- Webcams

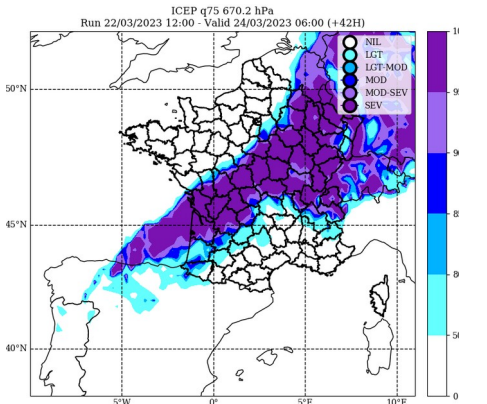
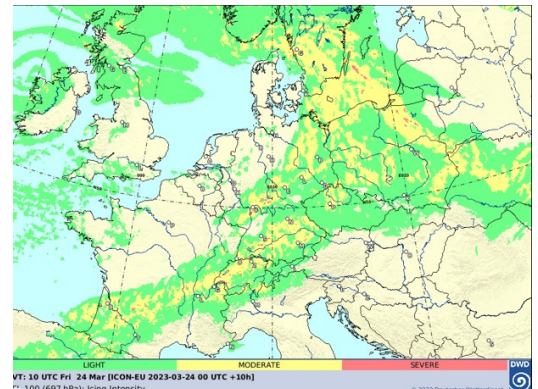
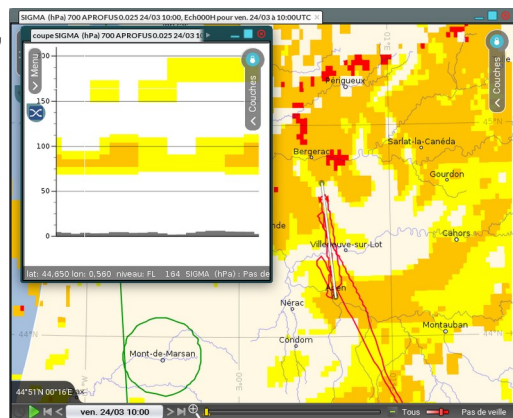
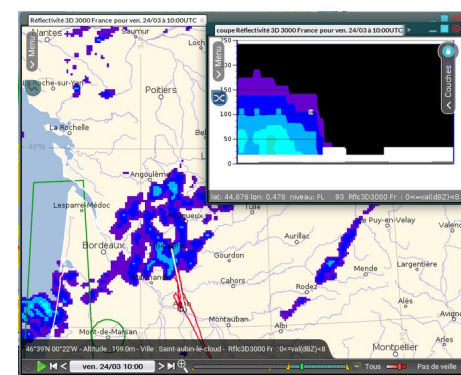
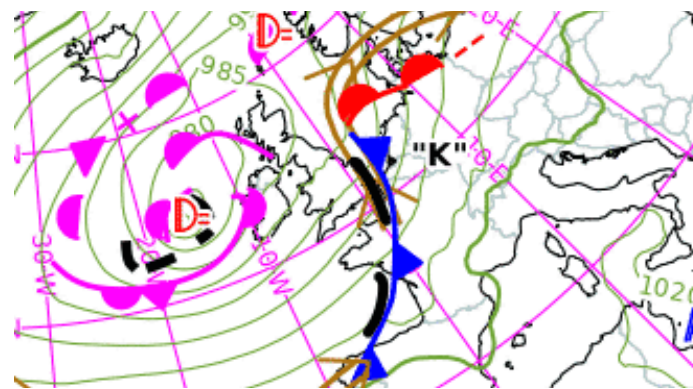
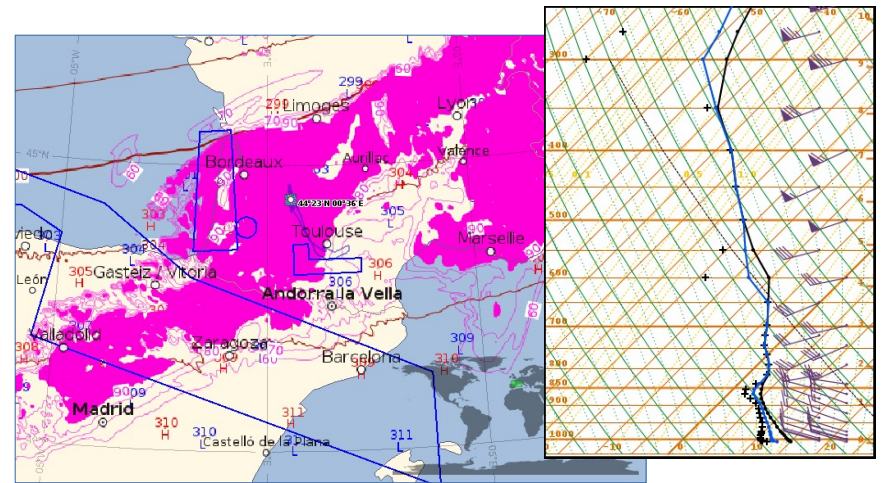
Examples from 10 Mar event



Tools from the European Campaign

- Models: ARPEGE (MF), AROME (MF), IFS (ECMWF)
 - T, RH, microphysics maps, forecast soundings
 - Ensembles (PEARP, EPS)
 - Synoptic charts
- Satellite: Meteosat-10 (MSG-3, MSG-4 in maintenance)
 - IR, VIS, Day-Night Microphysics, Cloud Top Pressure, Icing clouds
- Radar: ARAMIS, OPERA
 - Maps of reflectivity, cross section
- Icing dedicated products :
 - ADWICE (DWD), CIRA satellite, SIGMA, ICEP
- PIREPs
- Soundings

Examples are from 24 Mar



Role of the weather forecaster

2-5 days before a possible flight

- Probability of icing clouds in a temperature range from 0°C to -20°C in areas **where A/C can fly**

1 day before



- Confirmation / adjustment of the previous forecast
- Have icing conditions improved or worsened compared to previous forecasts?
- Has the timing changed?
- Chances for SLD?
- Support the team to generate a flight plan

D-Day

- Last observation (Satellite,..): GO / NO GO
- During the flight: flight guidance

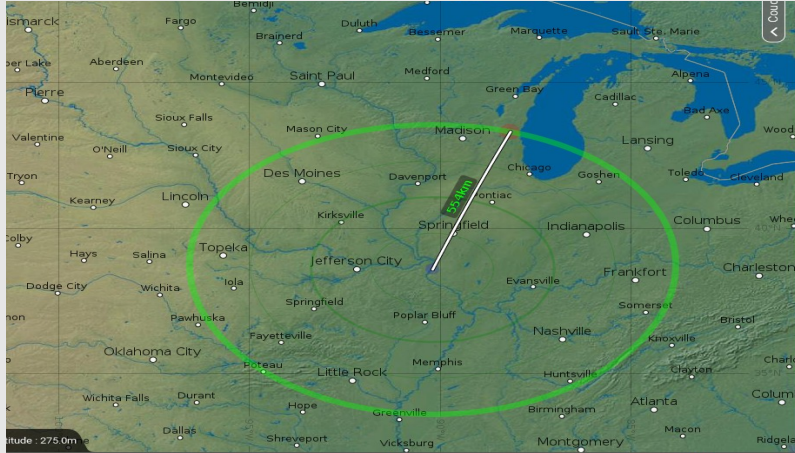
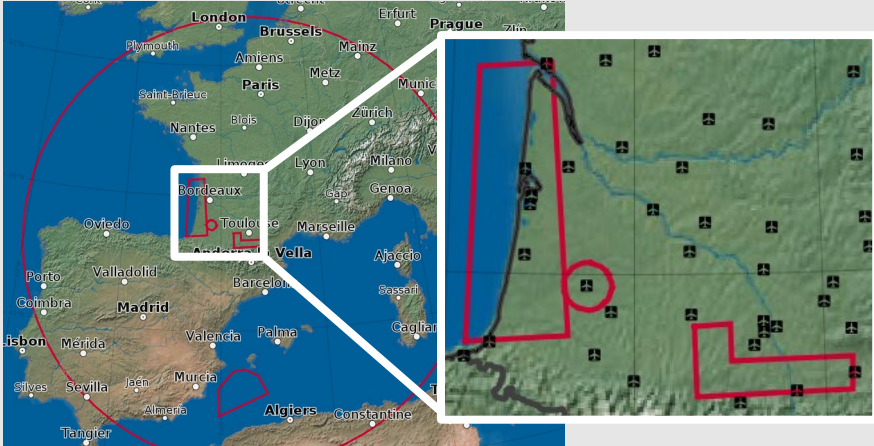


Aircrafts to probe icing conditions

	US Campaign	EUR Campaign
Aircraft	 <p>@Embraer</p> <p>Embraer Phenom 300</p>	 <p>@SAFIRE</p> <p>ATR 42</p>
Location	Alton / St. Louis Regional Airport (KALN)	Francazal airport (LFBF)
Capabilities	<p>Max Alt. : FL 450 Heated leading edges</p>	<p>Max Alt : FL 200 Deicing boots</p>
Project rules / limitation	<p>Short encounters: ~3-min (equiv. time) Sample during aeronautical day</p>	<p>If severe conditions forecasted: T>0°C SFC-8000 ft., Duration of encounters : 30s max. Flight during aeronautical day</p>
Max. flight time	4 h (instrumented)	5h



Areas, constraints and prior notice

	US Campaign	EUR Campaign
Period	Winter 2023 (End of Feb, begin of Mar)	Spring 2023 (April)
Area and ATC		
Prior notice	<p>300 nm radius preferred Could extend with remote landing All public airspace</p> <p>None required</p>	<p>3 CER* in France Airways within a radius of 500 nm</p> <p>CER : limited availability: D+1 (before 12h), Friday for Monday Airways : 2-4H (D+1 if refuel)</p>





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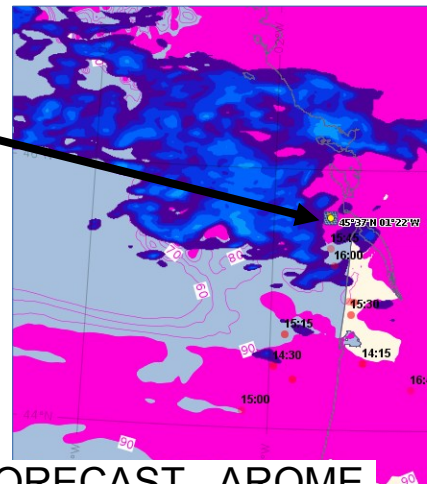
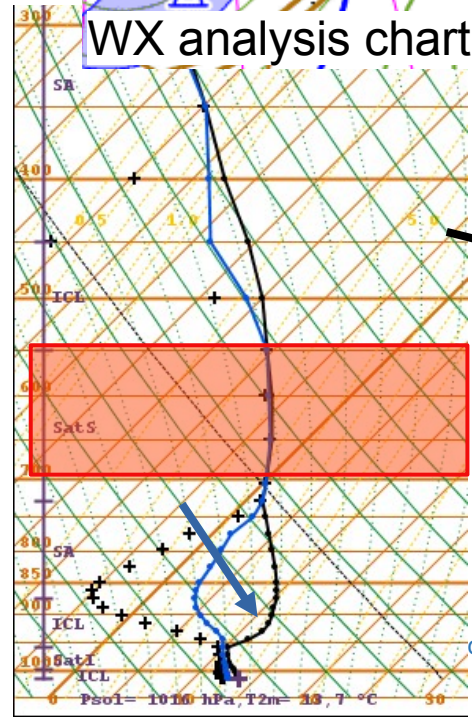
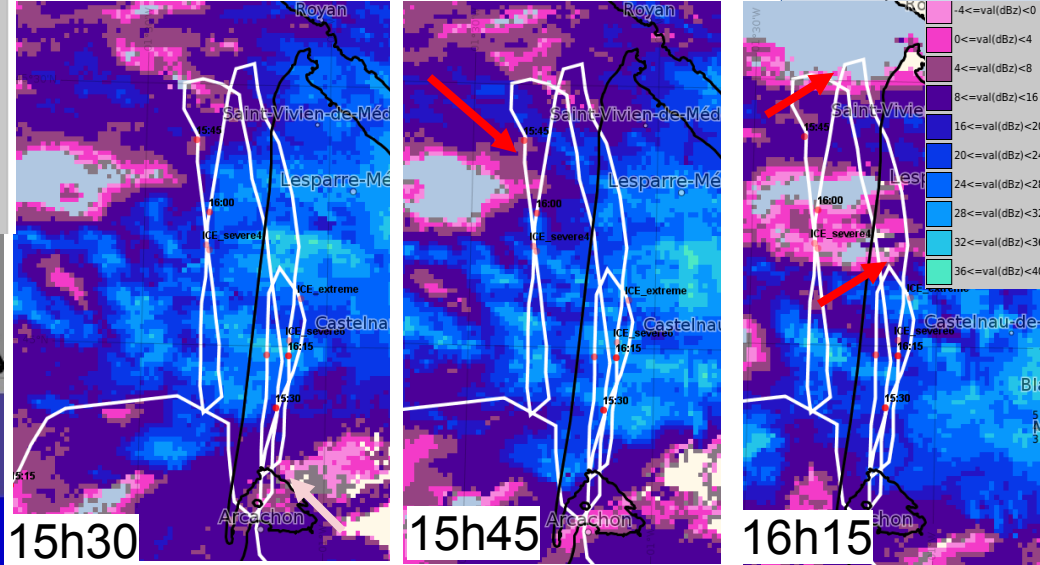
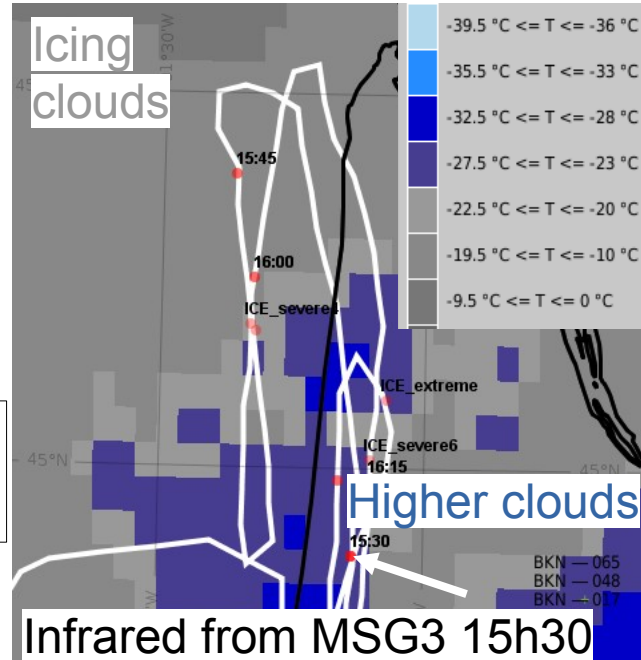
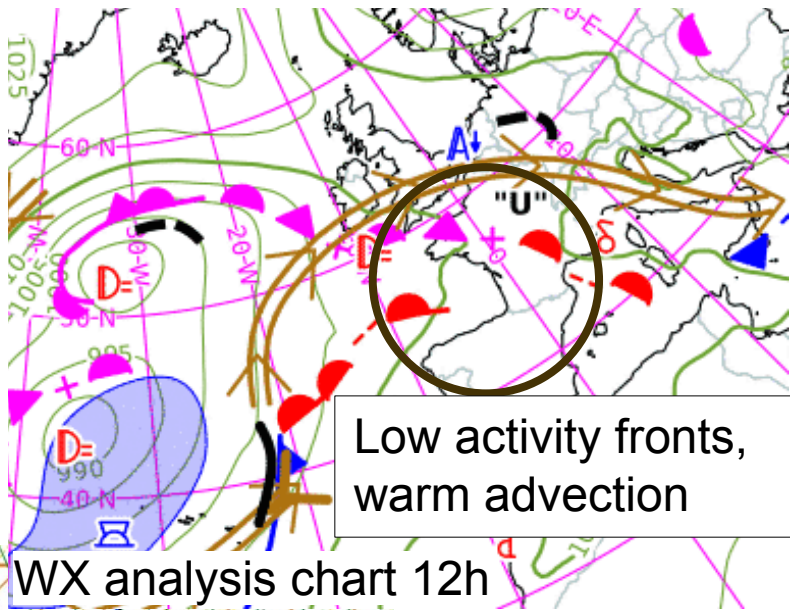
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Example cases

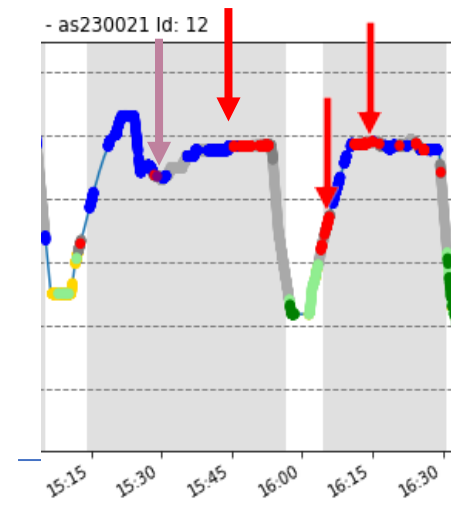
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EU Campaign - Flight #as230021 – 26 April

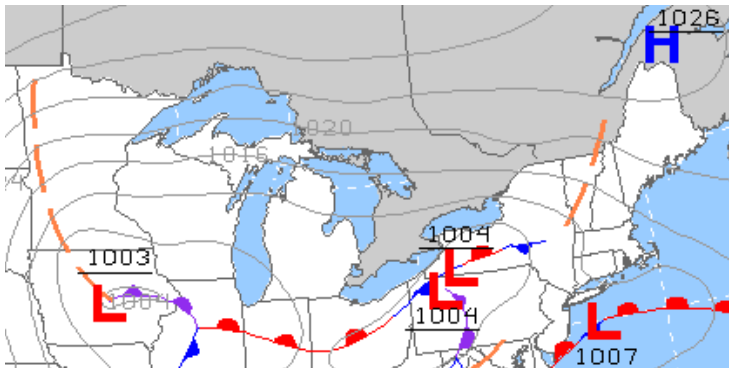


- N-S track pattern with vertical profiles for deicing
- A/C probed in the wake of higher clouds associated to rainfall => clean air
- **Inconsistent icing conditions, due to fine-scale weather pattern** (not well forecasted by models)
- **SLW/SLD** often at top of the clouds (-10°C), in radar reflectivity holes (warm rain process)
- **Ice crystals** in the strongest radar echoes
- **Rain/drizzle** in positive temp. layer

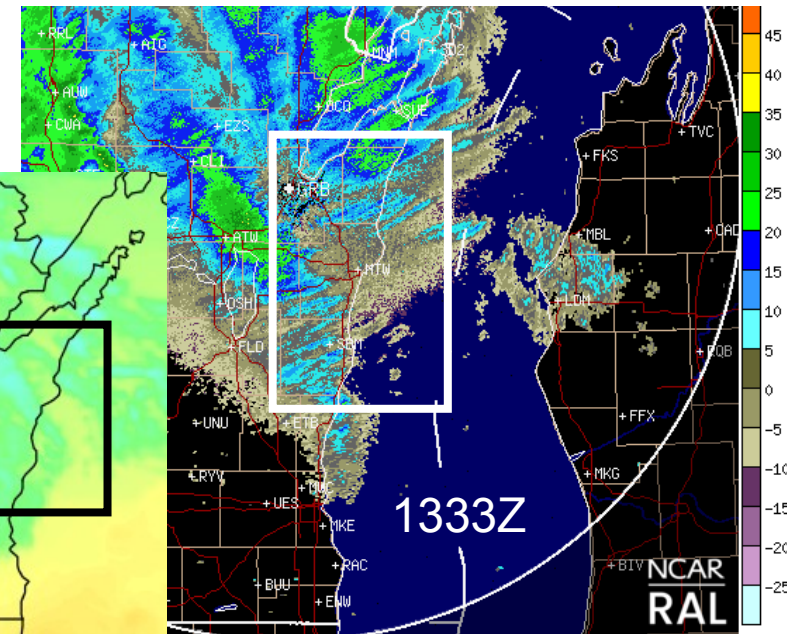
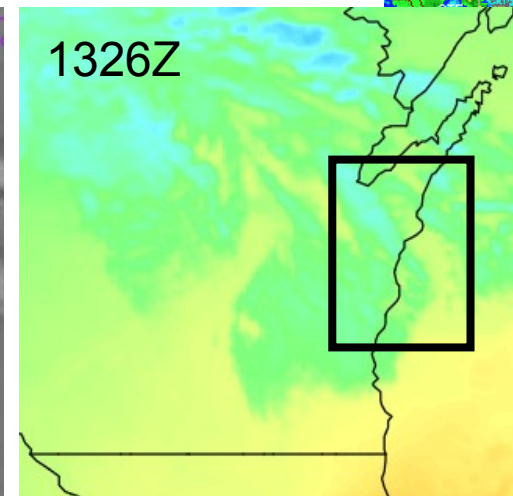
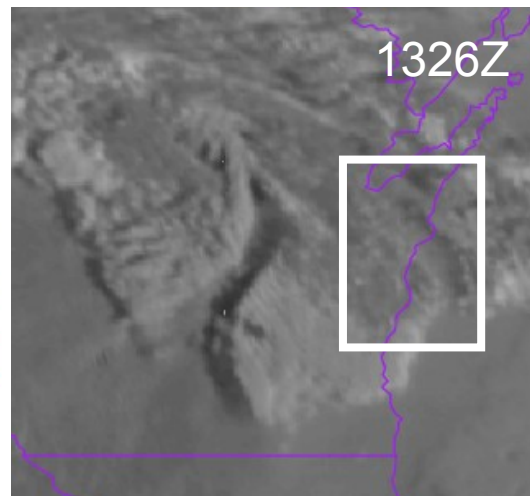
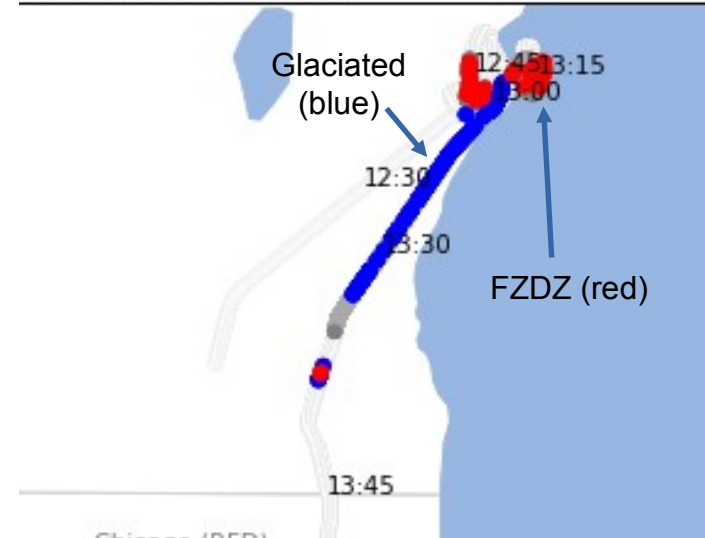
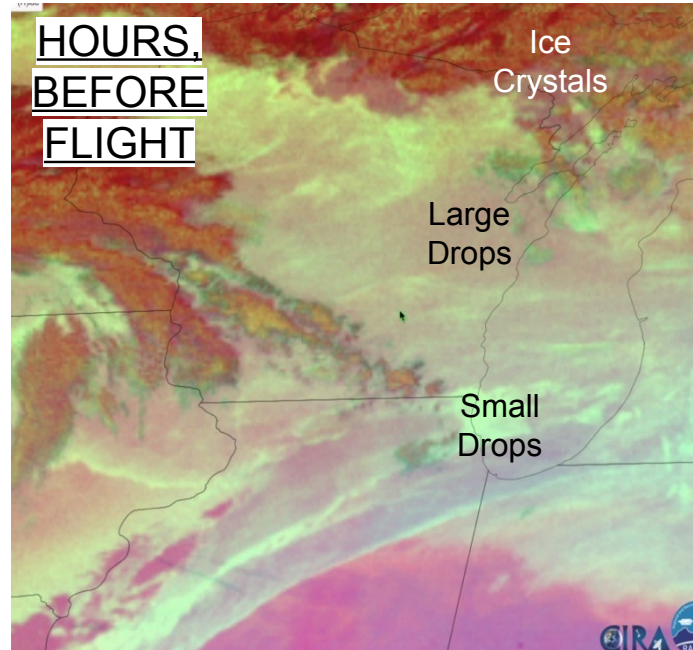
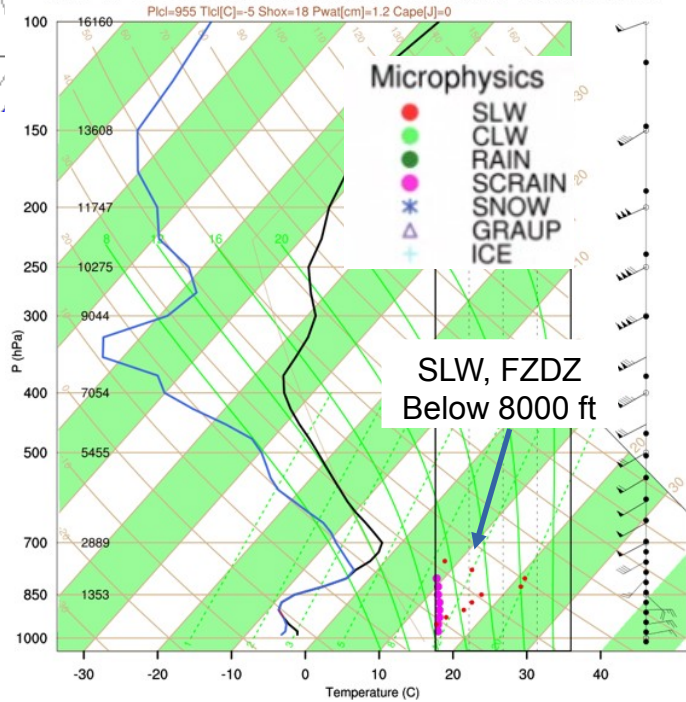


US Campaign - Flight #1475 - Wisconsin FZDZ

F1475-1 - 2023-02-23



KMTW HRR 20230223/06 06hr fcst valid Thu 0223/12





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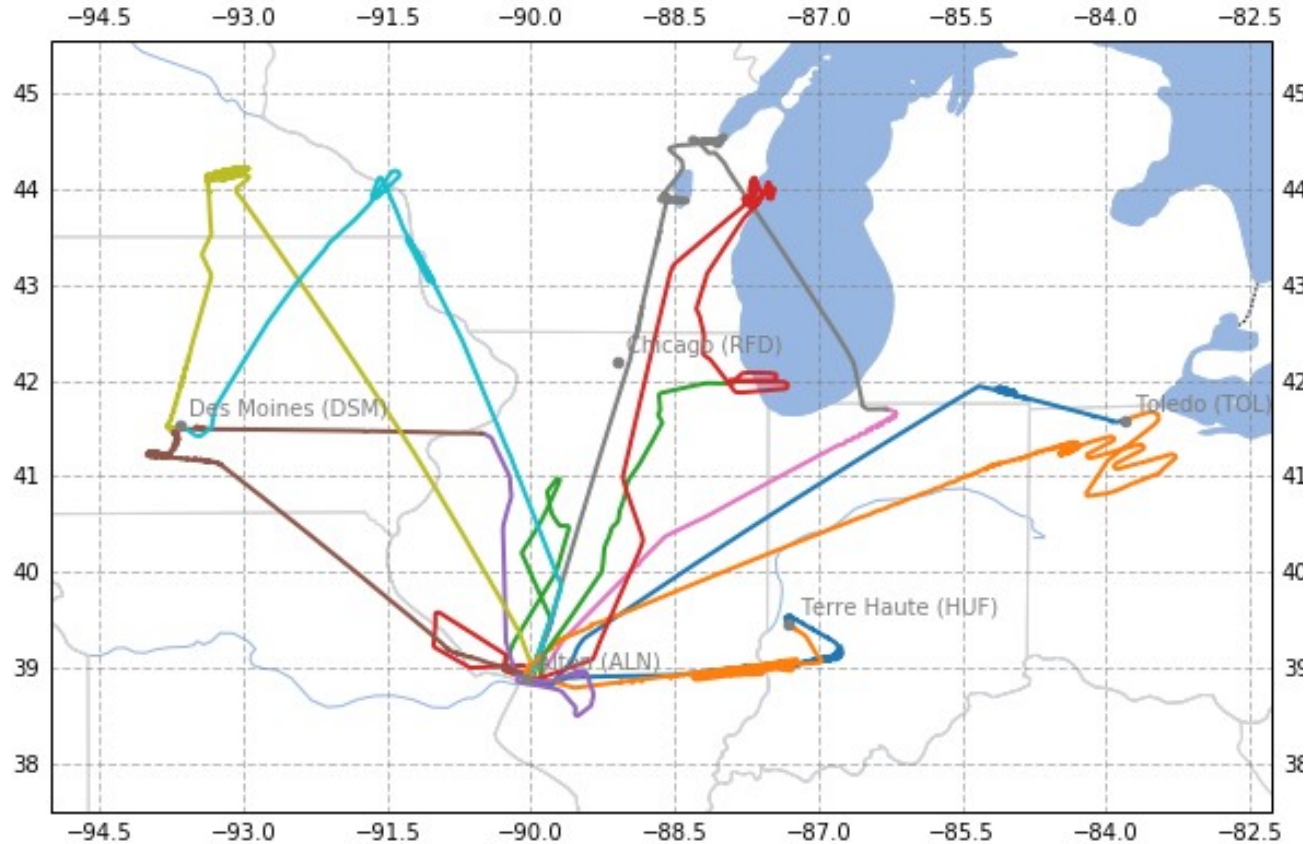
SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
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Preliminary summary of observed conditions during US and EU campaigns

This project has received funding from European Union's Horizon 2020
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Overview of the US Campaign



Ground tracks from Flightradar24

Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

- **15 flights** conducted (including ferry and check flights).
- **25 flight hours**, targeting natural icing conditions. SLD, in particular.
- **55 encounters*** of **2-7 min duration**
- **Total of ~4h** in icing conditions

* From Embraer reports



Data used for evaluation and Classification of icing and SLD encounters



DATA provided by Johannes Lucke and Tina Jurkat-Witschas (DLR), Lyle Lilly and Dan Bouley (SEA) and the EMB and SAFIRE team
EVALUATION : Johannes Lucke, Deniz Menekay and Simon Kirschler

- **LWC** : from SEA Ice Crystal Detector (ICD; US) / from CCP and Nevzorov (EU),
 - Droplets distribution and Ice Crystals detection:
 - **Dmax** : CCP Volume diameter, 99th percentile
 - **N Crystals**: CCP Number Concentration of aspherical particles with area above 0,0225mm²
 - 15s for US / 30s for EU rolling mean (different TAS)
 - Phase: CIP measurements to differentiate
- Number of particles tends to be underestimated
=> Preliminary results, future works !
- Jurkat-Witschas T. et al., SAE, 2023
 - Lucke et al., SAE, 2023

Icing:

- LWC > 0.025 g/m³
- Ambient temperature (SAT) <0°C

SLD:

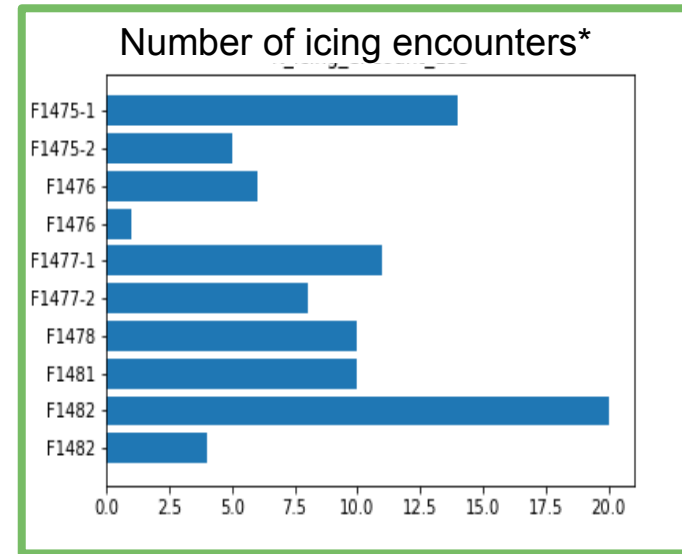
- LWC > 0.025 g/m³
- Large ice crystal < 1/L (Cober & Isaac 2012).
- **VD99 30s > 100 micrometer.**
- SLD concentration >10x ice particle concentration
- SLD concentration > 0.1/L
- The Nevzorov LWC > 60% Nevzorov 8mm cone TWC measurement
- Ambient temperature (SAT) <0°C

Classification of icing condition

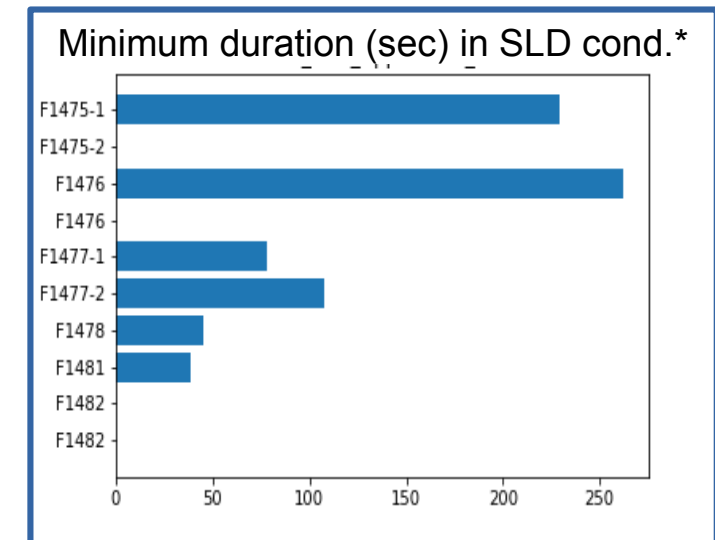
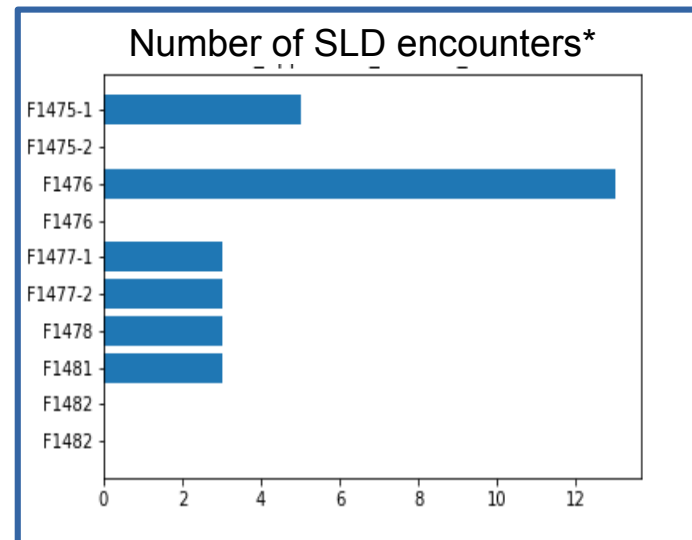


Overview of measurements for the US Campaign

Flight	DAY	DURATION (hours)	HOURS
F1475-1	20230223	2,8	11:43-14:29
F1475-2	20230223	1,2	17:18-18:33
F1476	20230225	2,1	11:38-13:43
F1476	20230225	1,7	15:54-17:33
F1477-1	20230301	2,2	11:38-13:48
F1477-2	20230301	1,6	16:56-18:34
F1478	20230306	2,5	11:46-14:18
F1481	20230309	1,2	12:01-13:13
F1482	20230310	2,3	12:08-14:24
F1482	20230310	1	16:39-17:40



*minimum duration of 15s



Characterize in-Situ measurements for the US Campaign

Supercooled Liquid Phase	Positive Temperature	Mixed Phase	Glaciated	Clear
LWC > 0.01 g/m ³ SAT < 0°C LAS < 1 / L	LWC > 0.01 g/m ³ SAT > 0°C LAS < 1 / L	LWC > 0.01 g/m ³ SAT < 0°C LAS > 1 / L	LWC < 0.01 g/m ³ SAT < 0°C LAS > 1 / L	LWC < 0.01 g/m ³ LAS < 1 / L
Small Drops (SM DP Icing) Dmax<100um	Small Drops (SM DP POS) Dmax<100um	(MIXED)	(Glac)	(Clear)
Freezing Drizzle (FZDZ) Dmax<500um	Drizzle (DZ) Dmax<500um			
Freezing Rain (FZRA) Dmax>500um	Rain (RA) Dmax>500um			

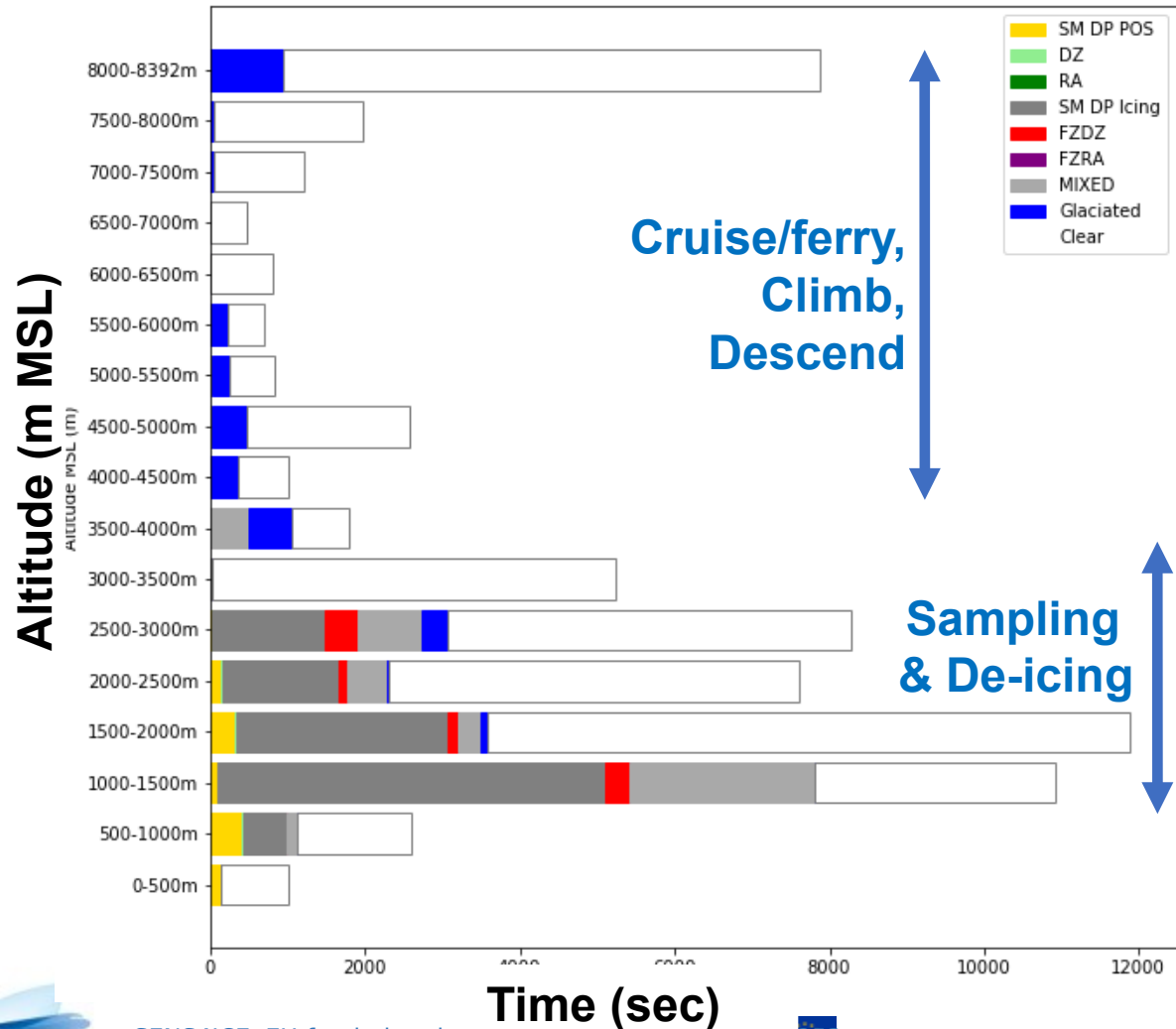
LAS : Large ASpherical ice particles

Adapted from Bernstein et al. (2021), AMS, Overview of NRC Convair-580
In-situ Flight Observations Made During ICICLE
And using data analysed from DLR

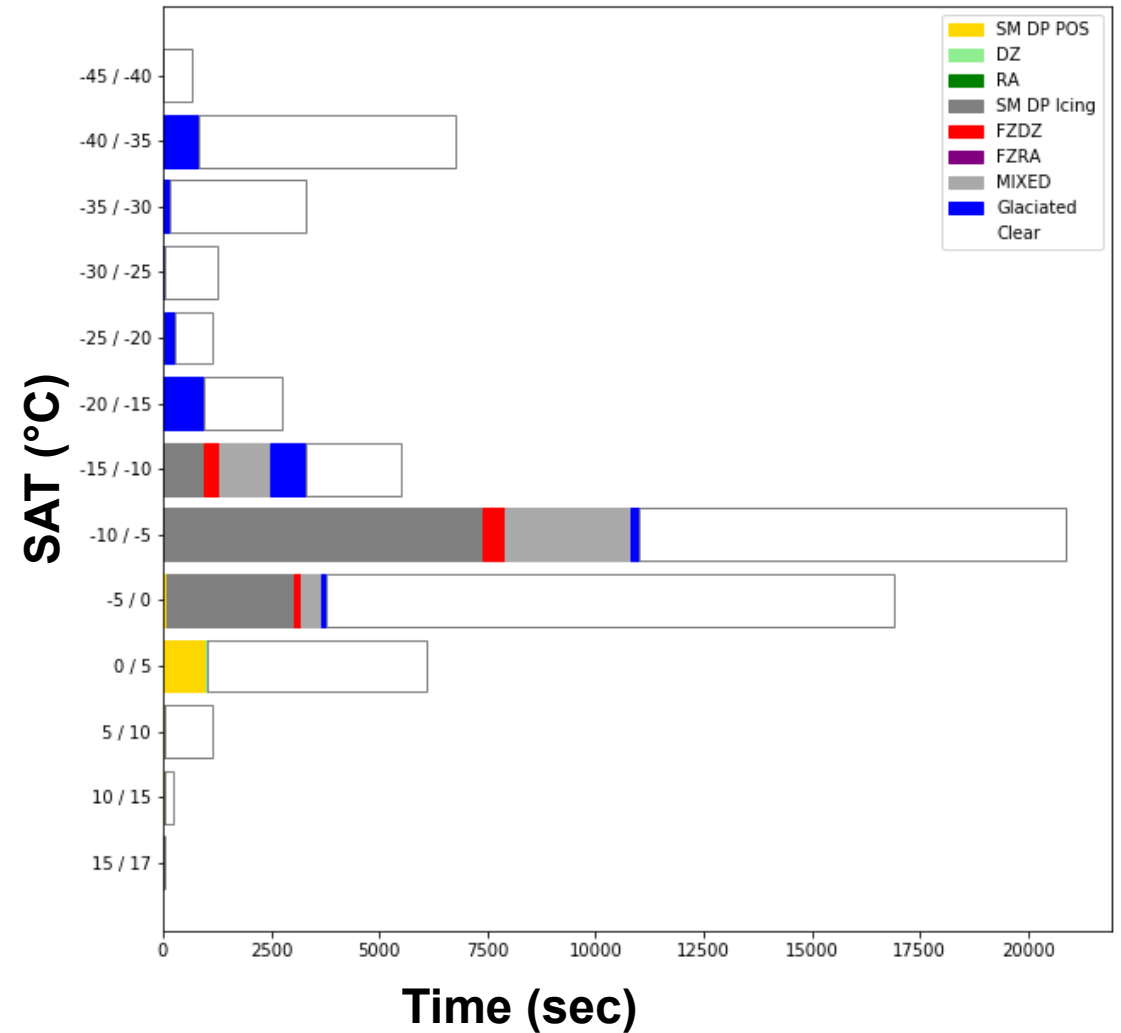


Characterize in-Situ measurements for the US Campaign

Icing / non icing vs. Altitude



Icing / non icing vs. Temperature



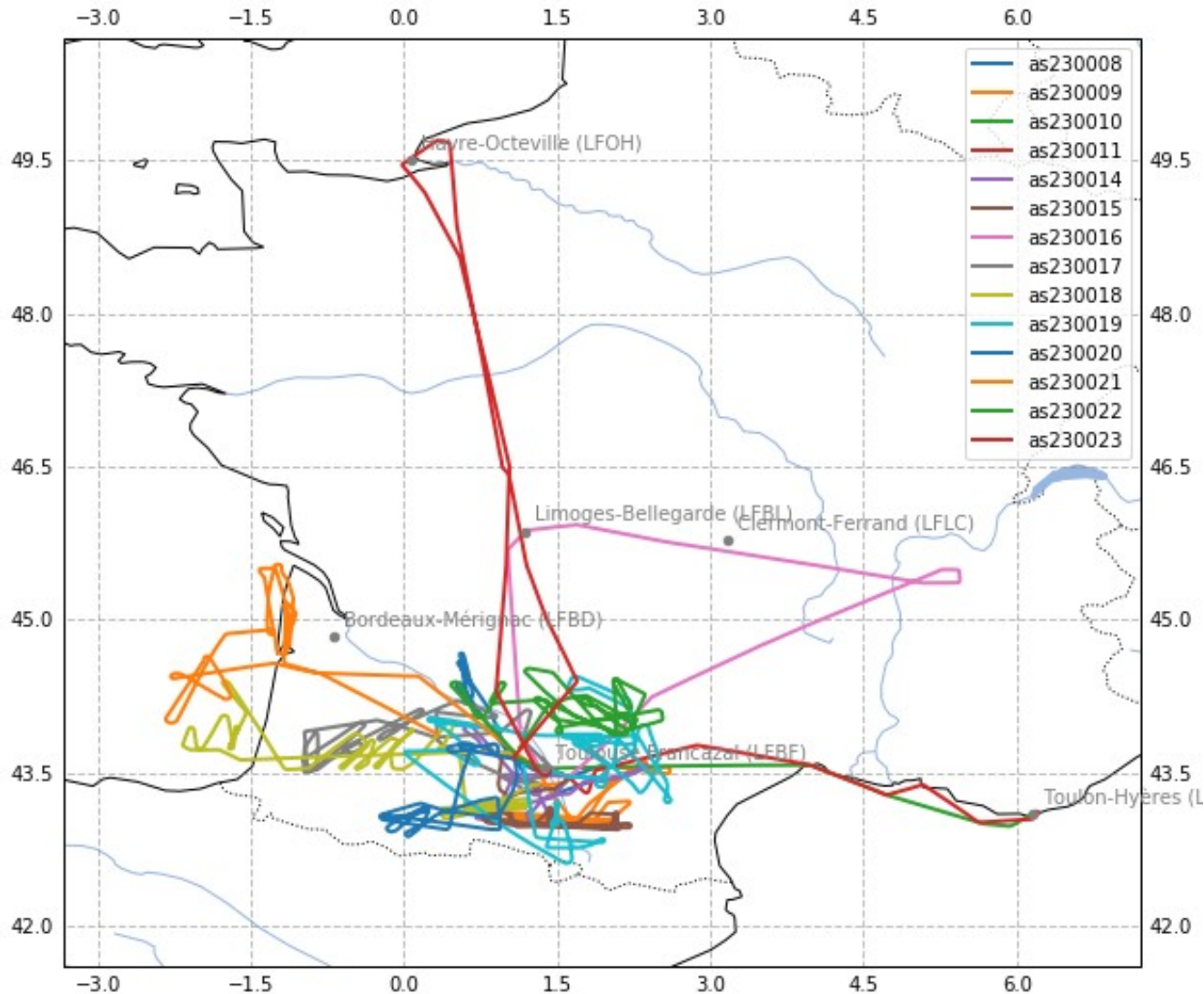
Conditions Flight by Flight (US)

Flightnum	ID	SM DP POS	DZ	RA	SM DP Icing	FZDZ	FZRA	MIXED	Glac	Clear	Unknown	All
F1475-1	1	0,52 %	0,04 %	0,00 %	0,69 %	0,18 %	0,00 %	0,20 %	0,96 %	11,19 %	0,00 %	14,87 %
F1475-2	2	0,08 %	0,00 %	0,00 %	1,52 %	0,00 %	0,00 %	0,36 %	0,00 %	4,77 %	0,00 %	6,72 %
F1476	3	0,03 %	0,00 %	0,00 %	1,01 %	0,65 %	0,00 %	0,33 %	0,00 %	8,30 %	0,27 %	11,19 %
F1476	4	0,01 %	0,00 %	0,00 %	1,00 %	0,00 %	0,00 %	0,00 %	0,00 %	7,94 %	0,00 %	8,95 %
F1477-1	5	0,15 %	0,00 %	0,00 %	1,97 %	0,09 %	0,00 %	0,70 %	0,50 %	7,95 %	0,02 %	11,61 %
F1477-2	6	0,01 %	0,00 %	0,00 %	0,89 %	0,38 %	0,00 %	0,03 %	0,00 %	7,36 %	0,00 %	8,79 %
F1478	7	0,04 %	0,00 %	0,00 %	3,50 %	0,14 %	0,00 %	0,30 %	2,82 %	6,68 %	0,00 %	13,60 %
F1481	8	0,75 %	0,03 %	0,00 %	1,16 %	0,05 %	0,01 %	0,10 %	0,73 %	3,51 %	0,00 %	6,54 %
F1482	9	0,04 %	0,00 %	0,00 %	3,20 %	0,00 %	0,00 %	2,24 %	0,01 %	6,43 %	0,00 %	12,21 %
F1482	10	0,01 %	0,00 %	0,00 %	1,92 %	0,00 %	0,00 %	0,06 %	0,00 %	3,53 %	0,00 %	5,51 %
All		1,63 %	0,08 %	0,00 %	16,85 %	1,50 %	0,01 %	4,32 %	5,01 %	67,66 %	0,29 %	100,00 %

*Percentage of each condition across ALL measurements data
Ferry flights & cruise time are included.*



Overview of the European Campaign



- **51.5** total flight hours (including EMI test, calibration and test flight)
- **15 measurement flights** were operated (12 in CER)
- Icing conditions encountered during almost all flights
- Some SLD conditions were detected.
- Flight Data from SAFIRE

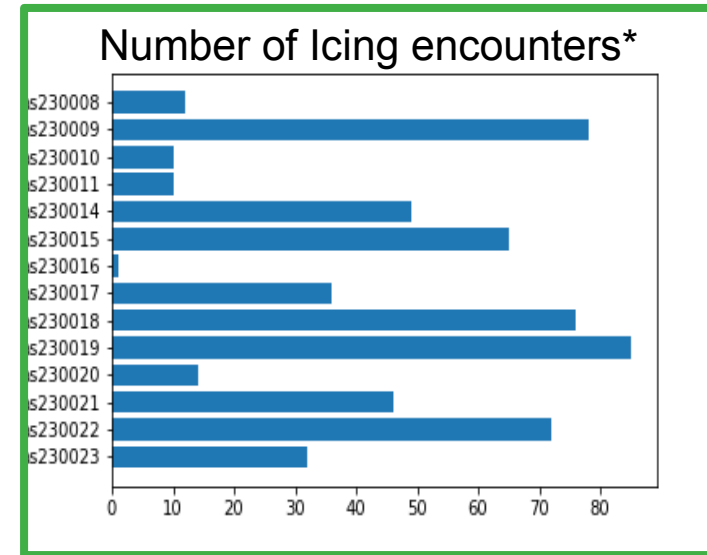
Airborne data obtained using the aircraft managed by Safire, the French facility for airborne research, an infrastructure of the French National Center for Scientific Research (CNRS), Météo-France and the French National Center for Space Studies (CNES). Distributed data are processed by SAFIRE.

Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

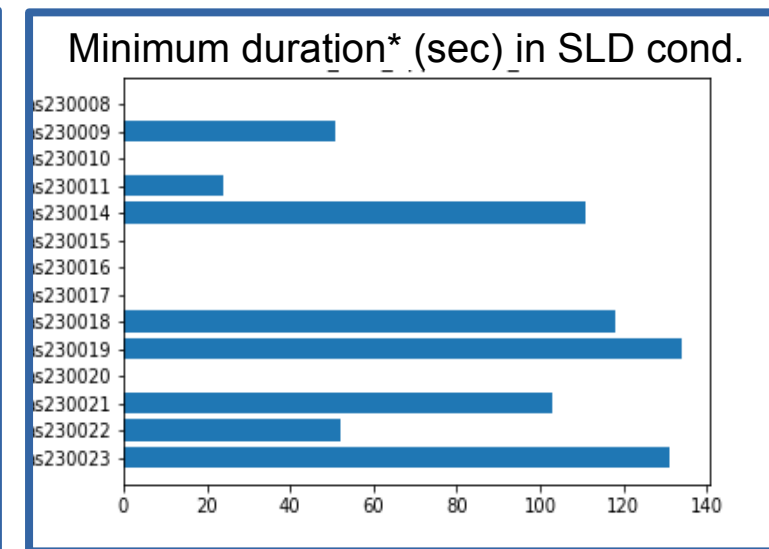
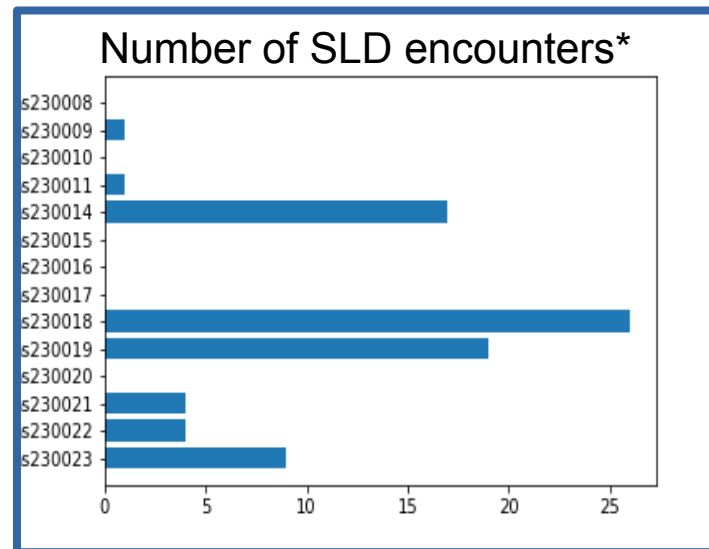


Overview of the European Campaign

Flight	DAY	DURATION	HOURS
as230008	20230324	1,6	09:29-11:04
as230009	20230403	3,5	06:08-09:38
as230010	20230404	1,2	11:38-12:53
as230011	20230404	1,3	13:11-14:29
as230014	20230415	2,3	06:03-08:20
as230015	20230418	3,1	13:56-17:02
as230016	20230420	2,6	10:41-13:15
as230017	20230422	2,8	06:02-08:52
as230018	20230424	4,3	12:22-16:41
as230019	20230425	4,8	11:04-15:52
as230020	20230426	2,4	06:30-08:53
as230021	20230426	3,3	13:34-16:54
as230022	20230427	3,3	06:33-09:51
as230023	20230427	3,5	12:08-15:40

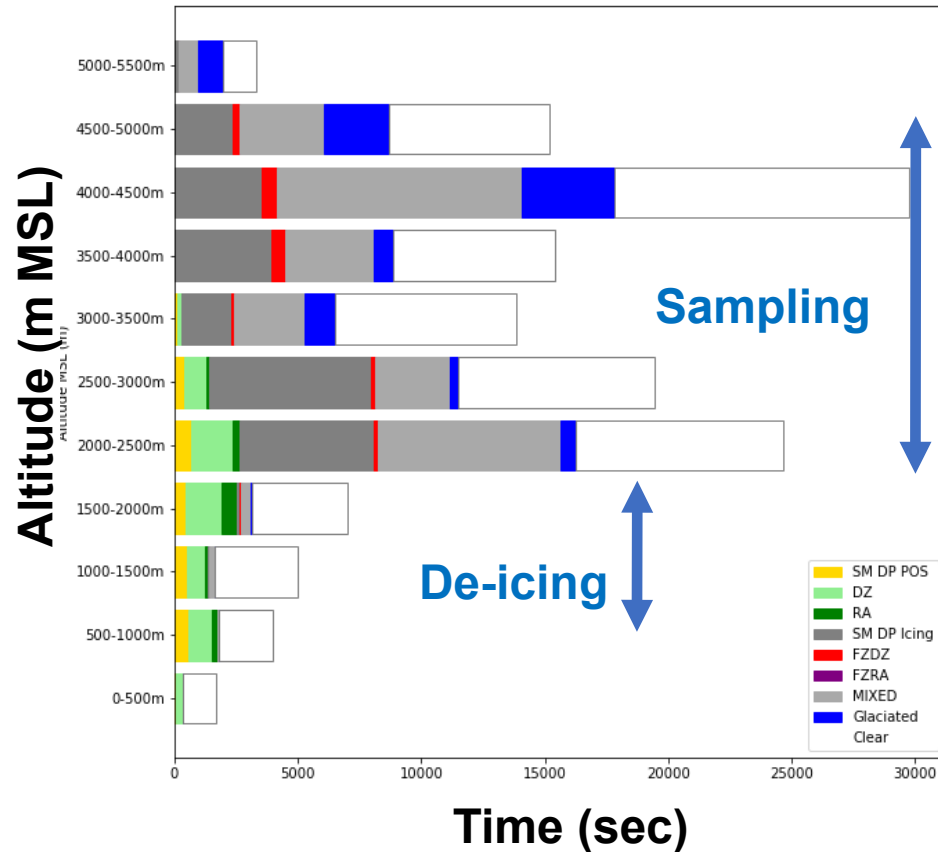


*minimum duration of 15s

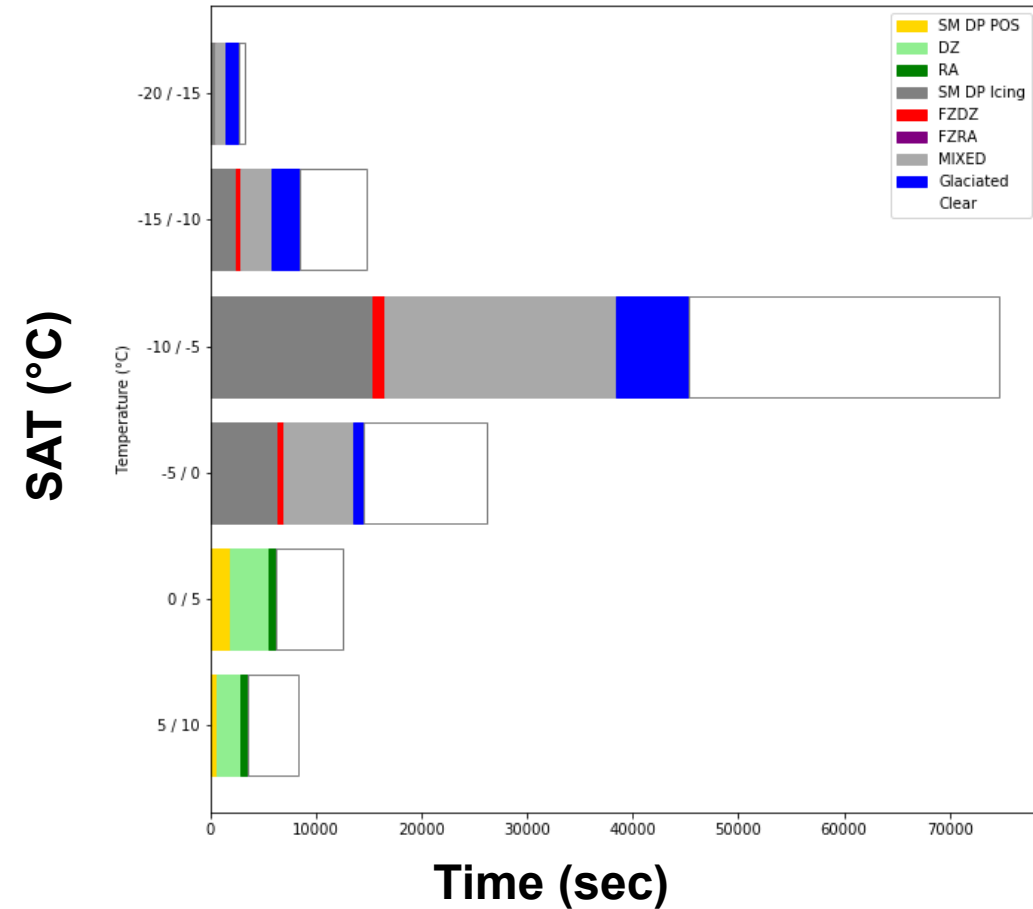


Characterize in-Situ measurements for the EU Campaign

Icing / non icing vs. Altitude



Icing / non icing vs. Temperature



- => Large droplets sometimes appear in medium levels (FL080-160) in spring
- => Clouds with drizzle/rain below were probed when A/C deiced



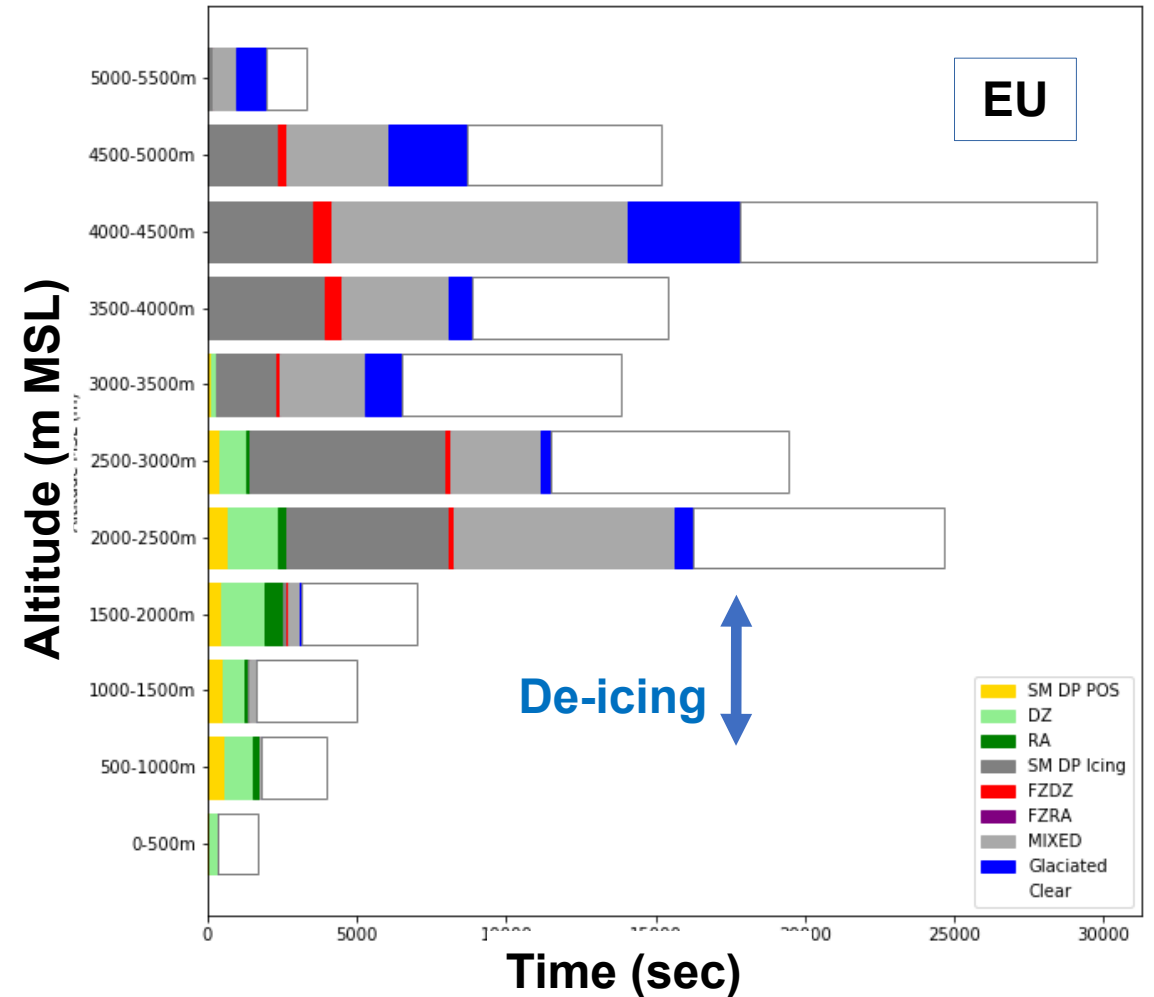
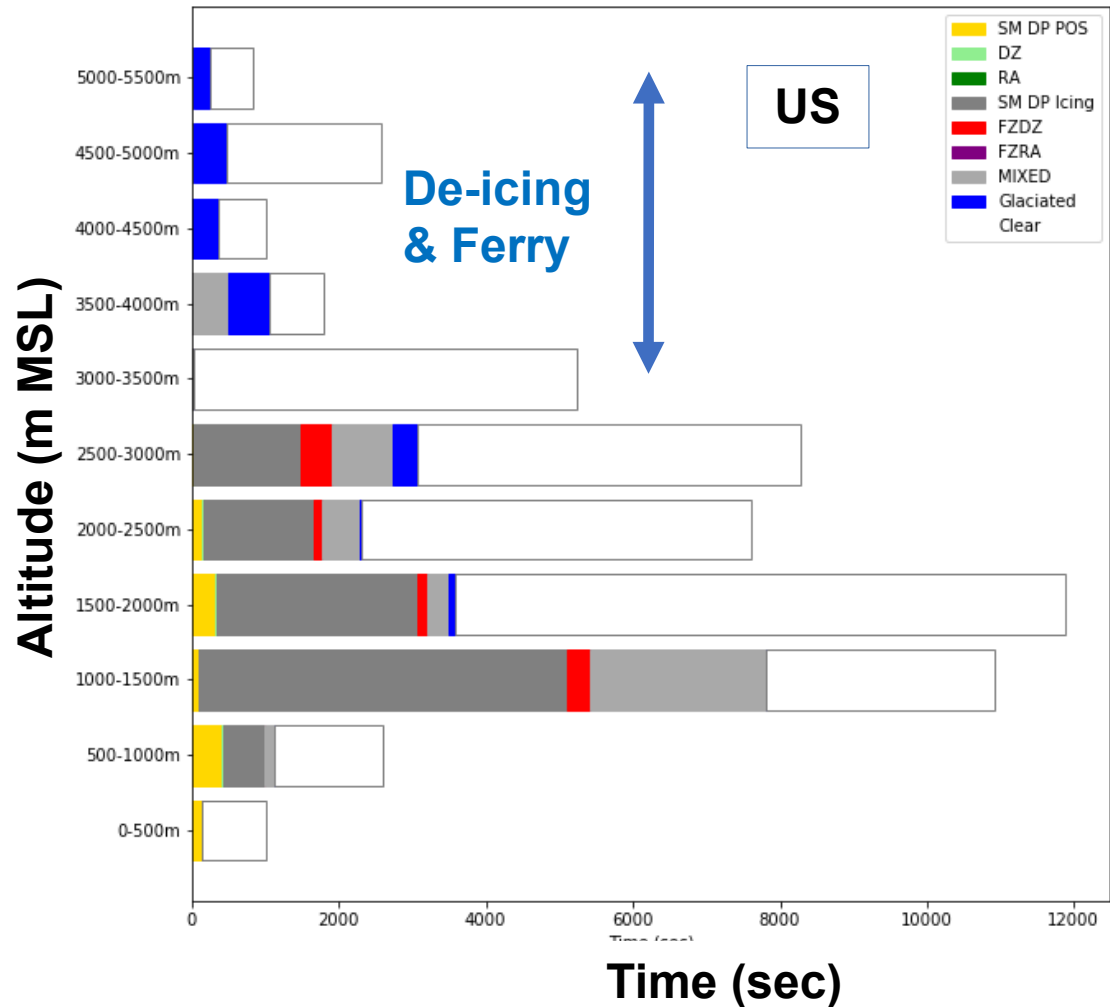
Conditions flight by flight (EU)

Flightnum	ID	SM DP POS	DZ	RA	SM DP Icing	FZDZ	FZRA	MIXED	Glac	Clear	Unknown	All
as230008	1	0,05 %	0,00 %	0,00 %	0,95 %	0,00 %	0,00 %	0,27 %	0,27 %	2,39 %	0,00 %	3,92 %
as230009	2	0,09 %	0,00 %	0,00 %	2,98 %	0,00 %	0,00 %	2,75 %	0,28 %	2,63 %	0,00 %	8,73 %
as230010	3	0,03 %	0,03 %	0,03 %	0,27 %	0,00 %	0,00 %	0,36 %	0,01 %	2,31 %	0,07 %	3,11 %
as230011	4	0,04 %	0,04 %	0,02 %	0,14 %	0,00 %	0,00 %	0,66 %	0,07 %	2,23 %	0,05 %	3,25 %
as230014	5	0,14 %	0,46 %	0,03 %	0,53 %	0,07 %	0,00 %	2,50 %	0,18 %	1,76 %	0,02 %	5,69 %
as230015	6	0,04 %	0,00 %	0,00 %	4,18 %	0,01 %	0,00 %	0,10 %	0,00 %	3,42 %	0,00 %	7,75 %
as230016	7	0,01 %	0,00 %	0,00 %	0,29 %	0,00 %	0,00 %	0,16 %	0,66 %	5,27 %	0,02 %	6,41 %
as230017	8	0,41 %	0,23 %	0,12 %	2,15 %	0,00 %	0,00 %	1,05 %	0,05 %	3,01 %	0,03 %	7,06 %
as230018	9	0,21 %	0,84 %	0,13 %	1,45 %	0,65 %	0,00 %	2,91 %	0,44 %	3,84 %	0,32 %	10,79 %
as230019	10	0,16 %	1,50 %	0,22 %	1,38 %	0,25 %	0,00 %	3,60 %	1,68 %	2,94 %	0,25 %	12,00 %
as230020	11	0,23 %	0,21 %	0,00 %	0,88 %	0,00 %	0,00 %	0,07 %	0,43 %	4,08 %	0,02 %	5,93 %
as230021	12	0,30 %	0,29 %	0,07 %	0,86 %	0,19 %	0,00 %	2,59 %	2,04 %	1,82 %	0,14 %	8,31 %
as230022	13	0,14 %	0,26 %	0,11 %	0,43 %	0,03 %	0,00 %	3,38 %	1,45 %	2,26 %	0,15 %	8,21 %
as230023	14	0,03 %	0,37 %	0,22 %	0,50 %	0,10 %	0,00 %	2,14 %	0,68 %	4,73 %	0,07 %	8,84 %
All		1,88 %	4,23 %	0,96 %	16,98 %	1,32 %	0,00 %	22,54 %	8,25 %	42,68 %	1,15 %	100,00 %

Percentage of each condition across measurements data
(take off and landing are suppressed)
Some ferry phase are included.



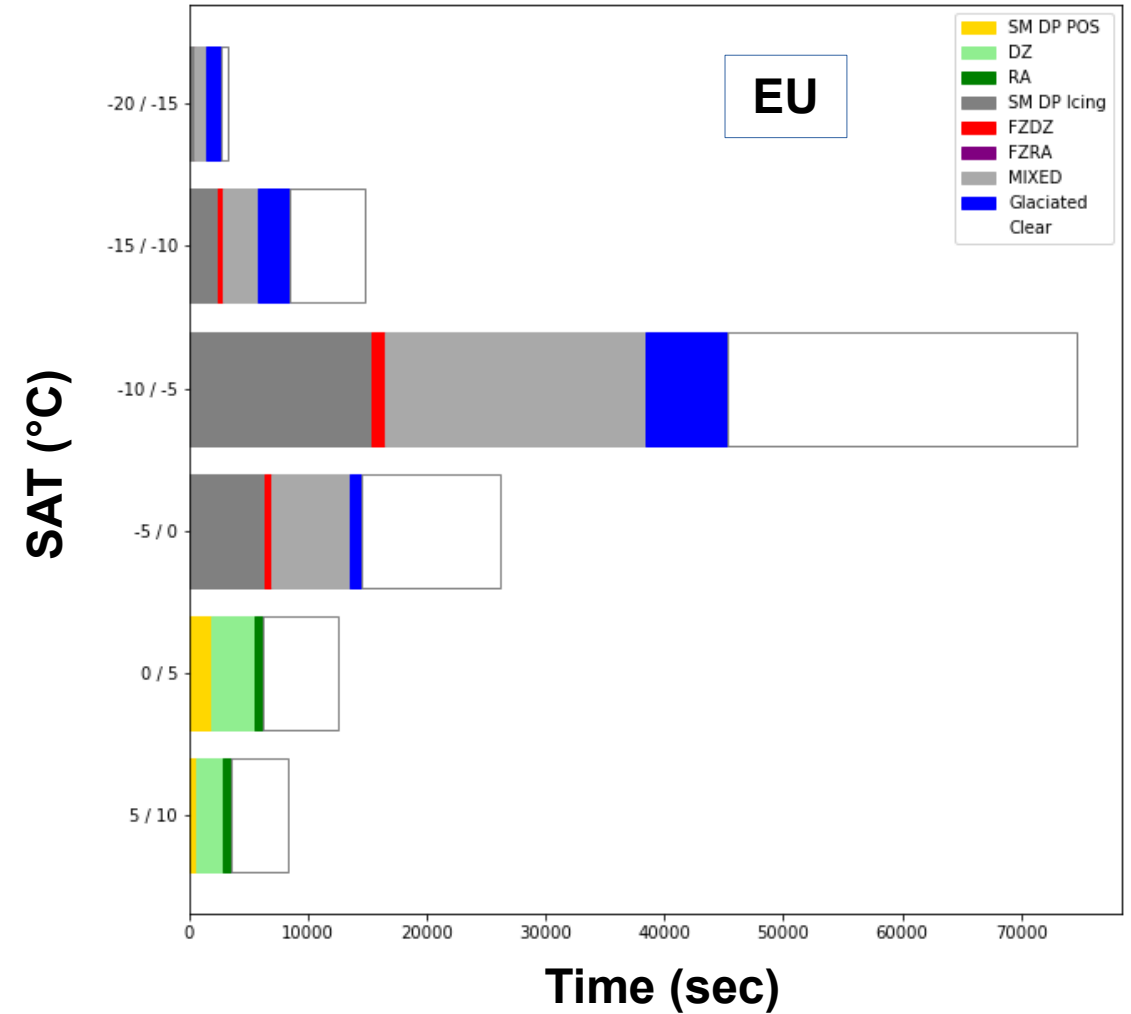
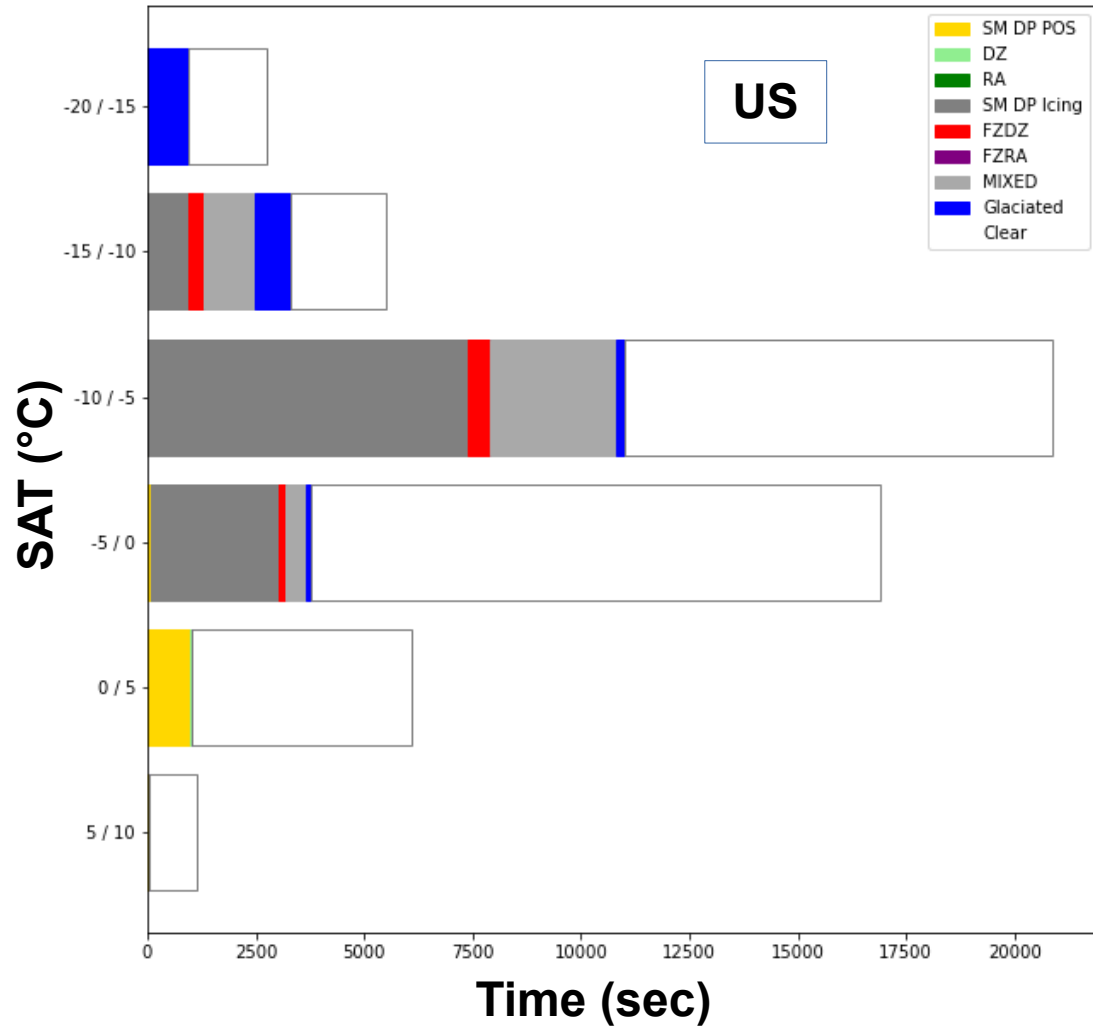
Comparison between the two campaigns



=> EU campaign altitudes ~ 1000m to 2000m higher because of the season & safety requirements
 => More $T > 0^{\circ}\text{C}$ rain/drizzle drops probe during EU camp., due to deicing beneath icing clouds



Comparison between the two campaigns



=>The results are quite similar, despite differences in season and location



Overall results

- How were they similar?
 - Icing and SLD conditions were found many times in both campaigns.
 - Almost all flights sampled icing. Frequency enhanced by flight guidance
 - **Both were very successful !**
- How were they different?
 - Different plane, different season/location => different de-icing strategies
- How was this season's icing frequency compared to climatology and expectations?
 - US: Seemed normal.
 - Typical patterns for this time of the year.
 - Good storm track, lots of frontal systems, nice variety of conditions.
 - Best for SLD early in the morning, as usual. Still some events later in the day.
 - Europe: Seemed above normal
 - At the end of the campaign, good west-north-westerly flow, allowing warm advection in SW of France.
 - Significant icing at mid levels (FL100-180) is not unusual at this time of year



The planets must be aligned :-)

Recipe for success :

Aircrafts

+

Instrument Operators

+

Forcasters

+

NATURE ! Which provided icing layers !



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