SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

An aviation support tool for satellite remote detection of in-flight icing

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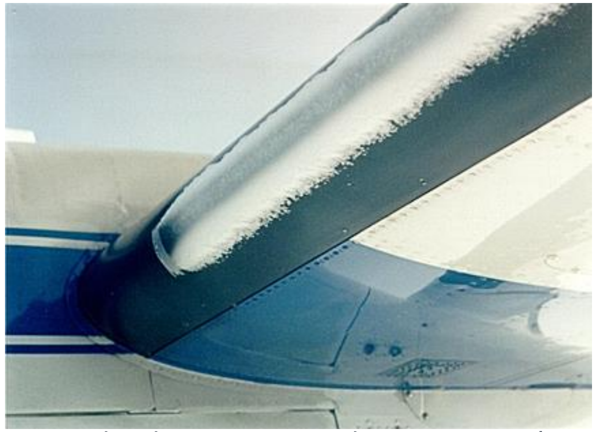
Introduction

In-flight icing, i.e. the accretion of ice on airplane's surfaces during flight, is caused by supercooled water droplets that freeze instantly when they impact the airframe and it represents a critical meteorological risk to aviation as it affects aircraft performance, stability and controllability. Therefore, the remote detection of weather conditions leading to in-flight icing is a goal of great interest to the scientific community.



Credit: Thomas P. Ratvasky, U.S. National Aeronautics and Space Administration

The Meteorology Laboratory of CIRA is working on the goal to characterize in-flight icing using **satellite** data since 2017. A first algorithm for in-flight icing **detection** has been developed in collaboration with Meteorological Service of Italian Air Force (ITAF) and with the support of the internal experimental knowledge on icing thanks to the CIRA Icing Wind Tunnel facility. This product has been implemented into ITAF operational chain and is usable in meteorological surveillance functions for aviation safety.

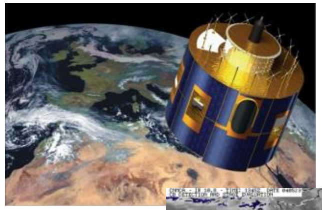
Currently, in the framework of the H2020 EU project **SENS4ICE** (SENSors and certifiable hybrid architectures for safer aviation in ICing Environment), a further maturation of the previously developed algorithm has been achieved, in order to consider also **Supercooled Large Drop** (**SLD**) Icing Conditions.

Icing detection tool: input

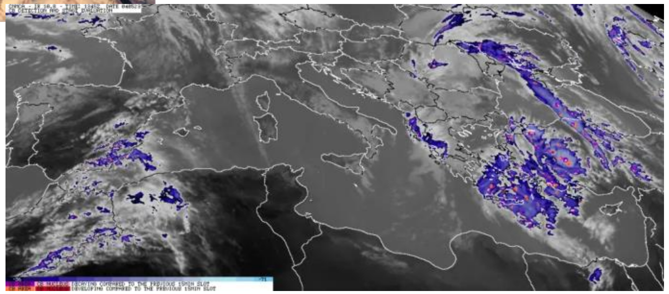
The algorithm relies on knowledge or inference from satellite data of the main meteorological factors determining icing condition: ***Temperature*, *Droplet size* and *Cloud type***.

ALGORITHM INPUT:

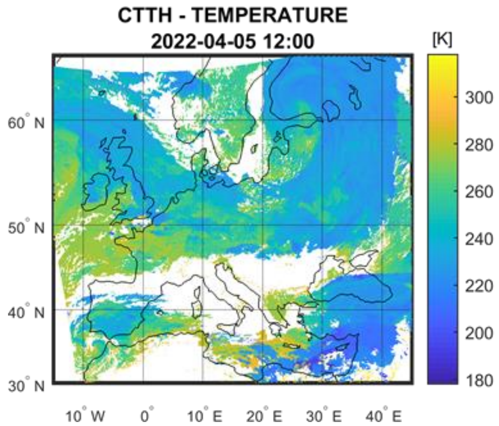
- satellite products, based on Meteosat Second Generation (MSG) data:
  - **NEFODINA** and **NEFODINA2** products, provided by ITAF, to detect convective areas;
  - Cloud Top Temperature and height (GEO-**CTTH**), NWCSAF product, to evaluate cloud properties;
  - Optimal Cloud Analysis (**OCA**) product, distributed by EUMETSAT, to retrieve cloud microphysical properties (effective radius).
- A set of experimental curves, representing the **icing reference certification rules** (**Appendix C** and **Appendix O** of FAA 14 CFR Part 25 / EASA CS-25), defining the interrelationship between icing-related cloud variables.



EUMETSAT



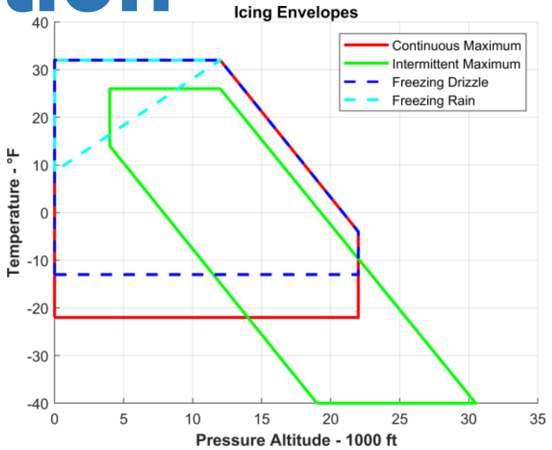
www.meteoam.it



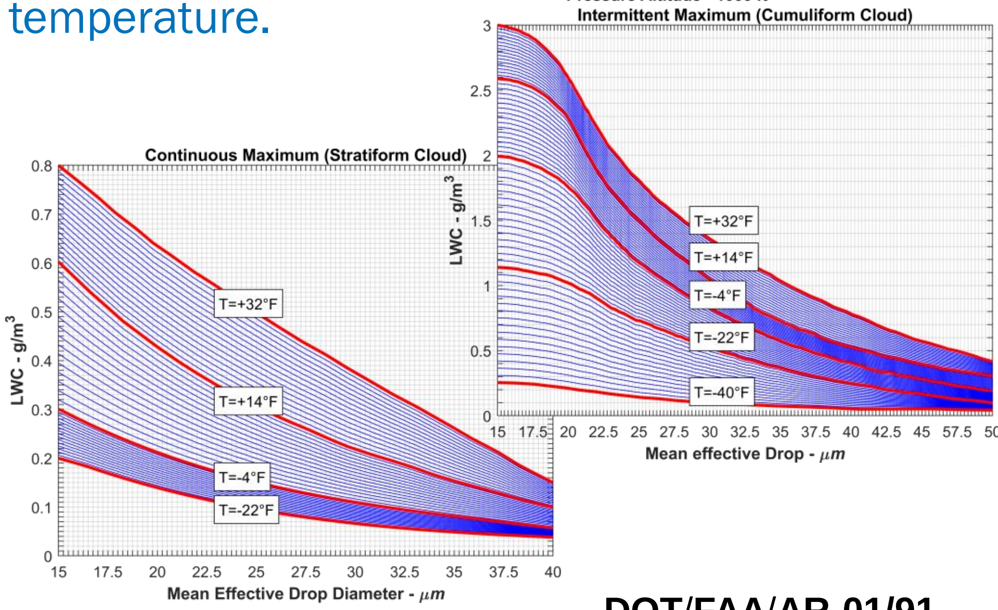
Icing detection tool: algorithm description

Zollo and Bucchignani, 2023

- Cumuliform clouds and stratiform clouds are processed separately by the algorithm.
- Temperature and pressure **vertical profiles are estimated** using the **standard atmosphere approximation** starting from the satellite values available only at the cloud top.
- The algorithm verifies if temperature and pressure altitude fall within the specific ranges defined by the limiting icing envelope in terms of altitude and temperature.



- In case of **App. C**, the curves defining the atmospheric icing conditions, which describe the interrelationship between LWC, mean effective diameters (MED) and temperature, are used to retrieve the values of LWC, then used to classify the severity of the icing phenomenon.
- In the case of stratiform clouds, further checks are performed in order to evaluate the possible presence of **App. O** conditions, on the base of the Mean Effective Drop Diameter retrieved from satellite: possible SLD condition is assumed if MED>40 µm.



DOT/FAA/AR-01/91

Supercooled Water Content (g/m^3)	Intensity
0.1-0.6	Light
0.6-1.2	Moderate
>1.2	Severe

Icing detection tool: altitudes estimate

Temperature vertical profiles are estimated using the **standard atmosphere approximation**, starting from the temperature at the cloud top.

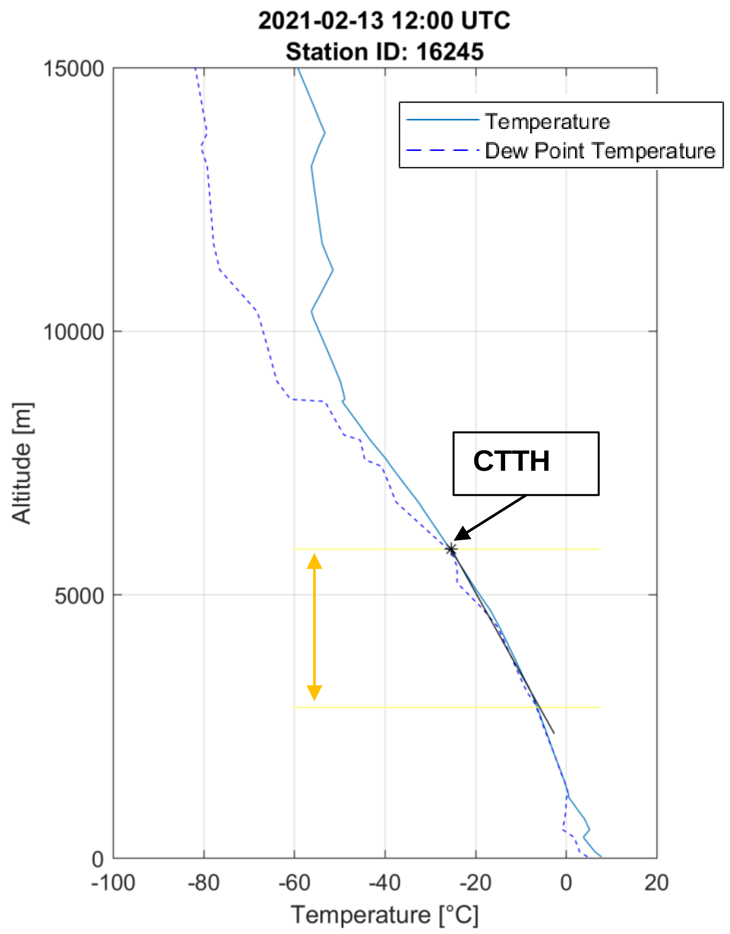
Due to the limitations of this approach, two alternatives have been investigated:

- temperature profiles retrieved from **satellite** through Radio Occultation;
- temperature profiles obtained from Numerical Weather Prediction (**NWP**) models.

But…

- satellite retrieved profiles from radio occultation are discontinuous in time and space;
- the use of temperature profiles obtained from NWP would imply a very strong increase in the computational times and costs of the algorithm.

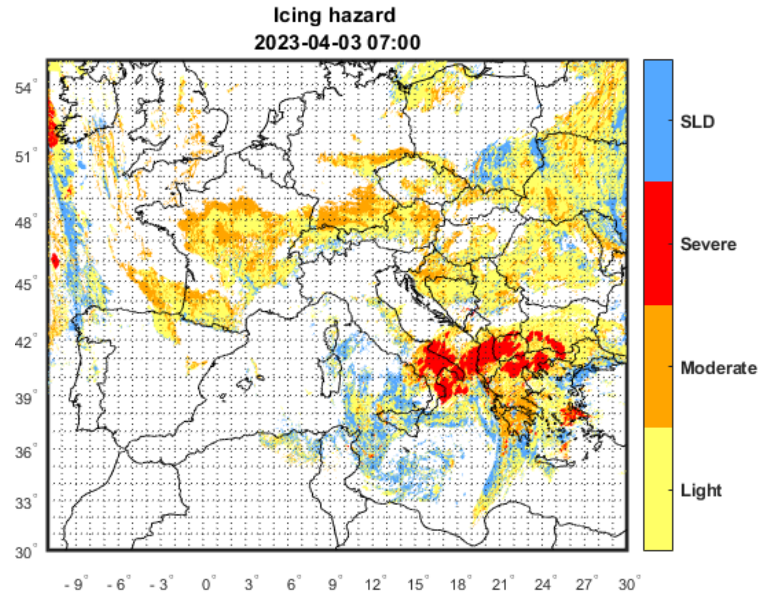
Furthermore, a preliminary comparison with respect to soundings data, has shown that, in terms of mean bias, the difference between the temperature profiles estimated using the standard atmosphere approximation and NWP profiles is not very significant. For these reasons, at this stage, the usage of NWP data was not preferred.

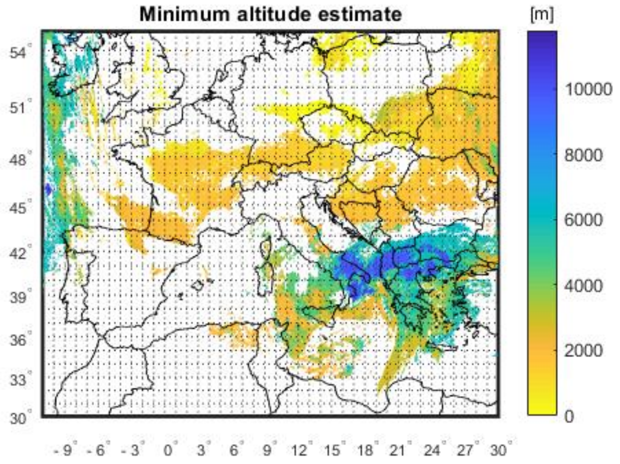


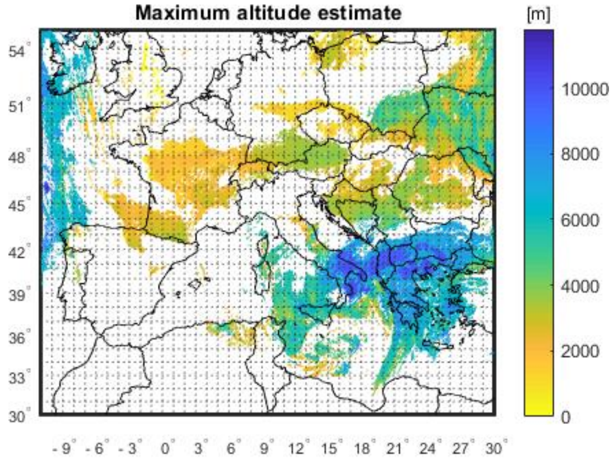
https://weather.uwyo.edu/upperair/sounding.html

Icing detection tool: output

- The output of the tool shows the areas potentially affected by in flight icing hazard, giving an estimate of the severity of the phenomenon (light, moderate, severe) with indication of possible SLD conditions.
- An estimate of the minimum and maximum altitudes affected by the icing hazard is also available for each pixel of the map.
- The spatial and temporal resolutions are respectively of about 3 km and 15 minutes.
- As for the evaluation of algorithm results:
  - a complete validation is a challenging task, due to the lack of suitable observations;
  - PIREPs (pilot reports) represent the only dataset for direct in-situ icing observation, but these data are difficult to be found and collected;
  - it is even more difficult to find observations on the presence of SLD.







Icing detection tool: preliminary validation

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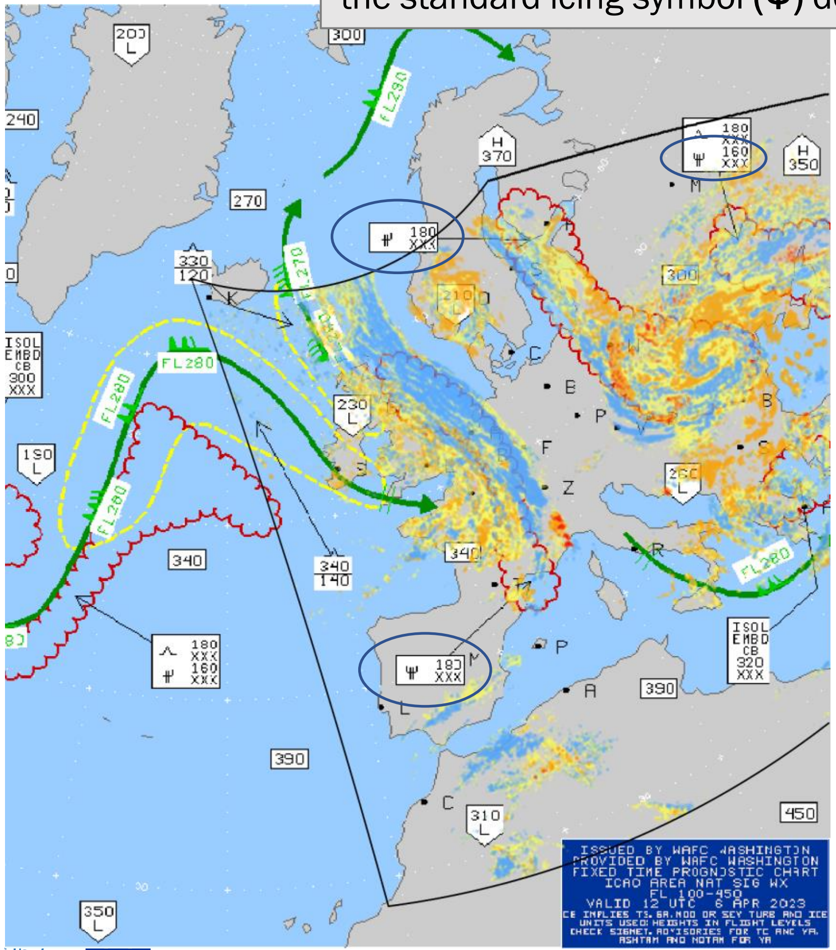
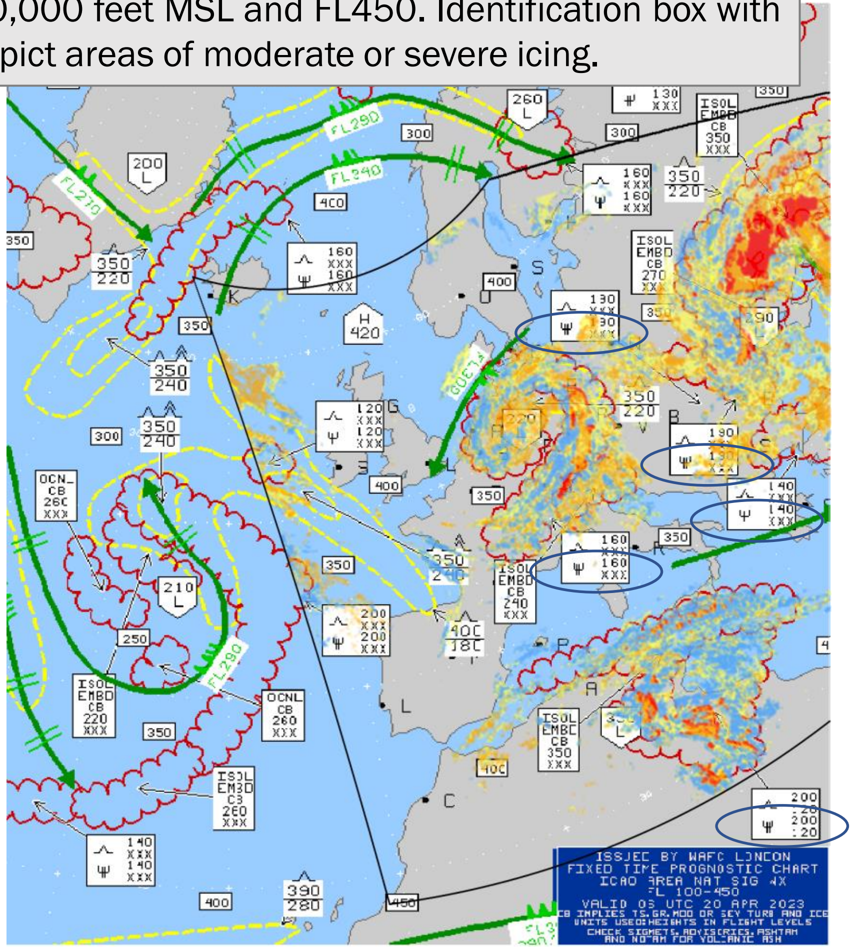
A qualitative comparison with Mid-Level Significant Weather (SIGWX) Chart has shown a quite good agreement in definition of regions affected by icing conditions.

The Mid-Level Significant Weather (SIGWX) Chart provides a forecast of significant weather phenomena between 10,000 feet MSL and FL450. Identification box with the standard icing symbol (Ψ) depict areas of moderate or severe icing.

Such a comparison has been carried out for several hundreds of dates (starting from September 2020) with a general tendency of good agreement and a minority of cases with poor accordance.





Some examples of overlapping of the algorithm results on SIGWX charts.

https://www.aviationweather.gov/

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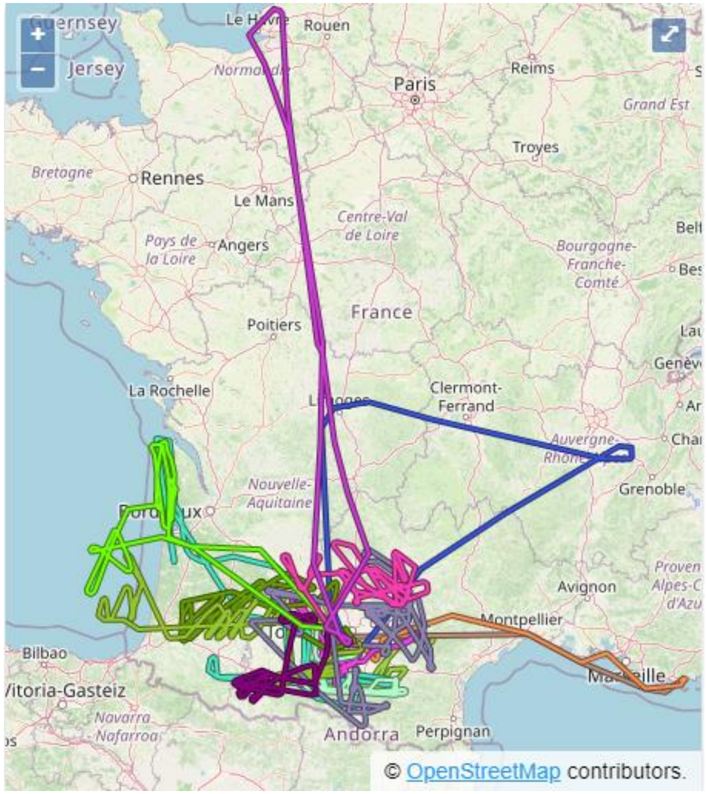
SENS4ICE Flight Campaign Europe

- This tool has been used during the **SENS4ICE flight campaign** held in April 2023.
- During the flight test campaign, information on the remote detection of icing conditions has been provided in the pre-flight phase and updated in near-real time.
- Considering the challenge of validating such a kind of product, the SENS4ICE flight campaign represents an important chance to evaluate the performance of the tool in environmental icing conditions.
- **15 flights** with a total of **about 50 flight hours** successfully conducted using the French ATR 42 environmental research aircraft of Safire, targeting natural liquid water icing conditions and in particular SLD conditions.
- The analysis of post-flight data is ongoing.



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

Flight data

- Microphysical cloud parameters were measured in-situ with scientific airborne instruments of DLR and SAFIRE (*Jurkat-Witschas et al. 2023, Lucke et al 2022, Lucke et al. 2023*).
- DLR evaluated the measurements for the presence of icing conditions in general and Appendix O icing.
- An **Icing Flag** indicates the presence of icing conditions. The flag is raised once the LWC exceeds 0.025 g/m³.
- An **Appendix O Flag** indicates the presence of Appendix O conditions. At least 1% of the total cloud water content needs to be contained in SLD in order for an icing condition to be identified as Appendix O.

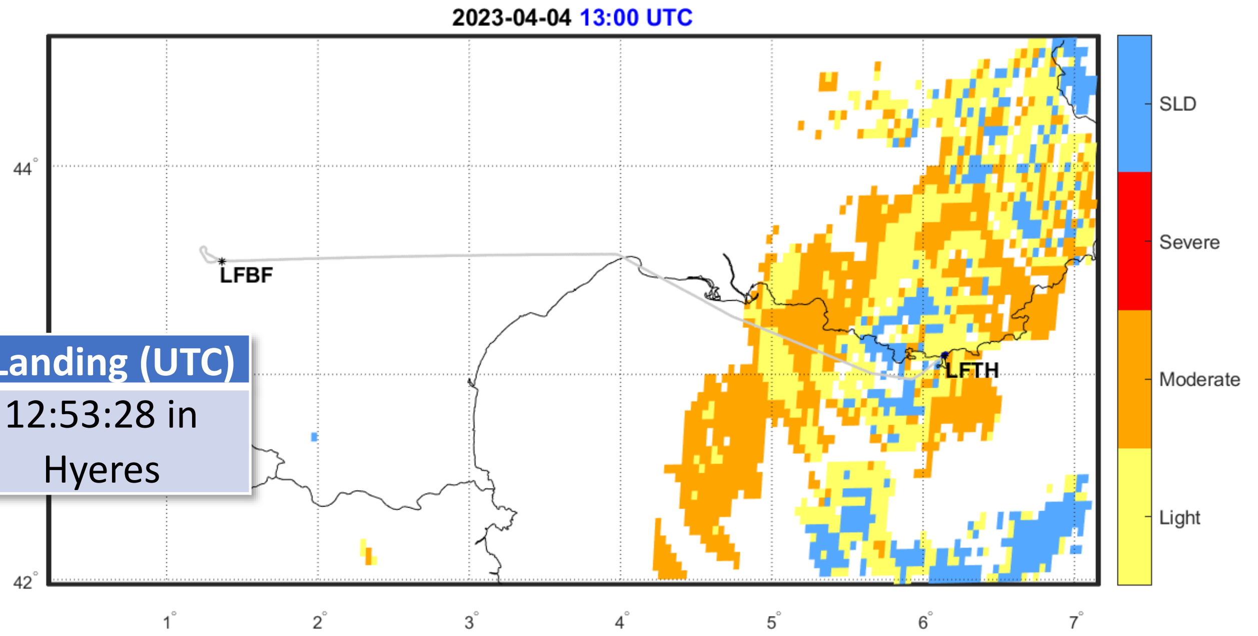
Nevzorov probe for the measurement of LWC and TWC

Particle sizing instrumentation

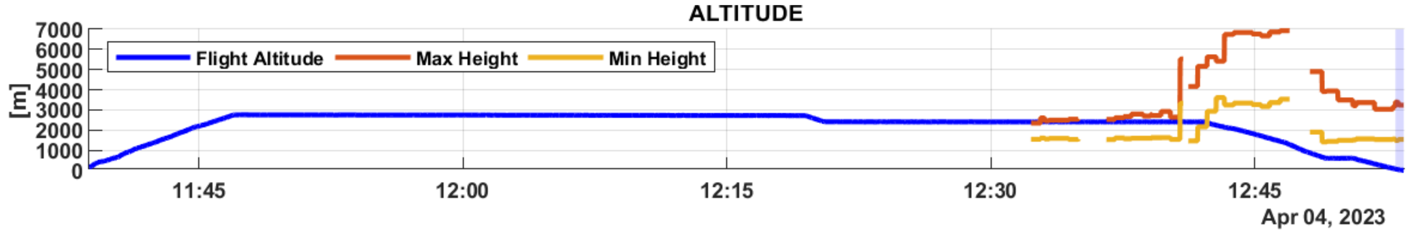
Example of comparison with flight data (1)

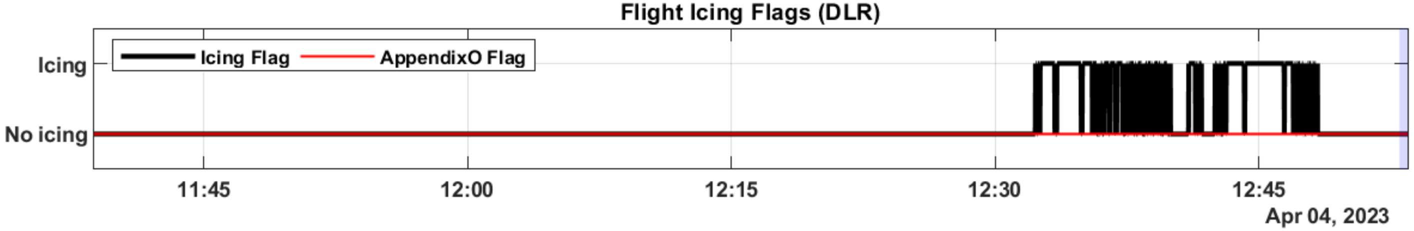
SENS4ICE Flight No	Safire Flight ID	Date	Takeoff (UTC)	Landing (UTC)
2	as230010	2023-04-04	11:38:45 in Francazal	12:53:28 in Hyeres

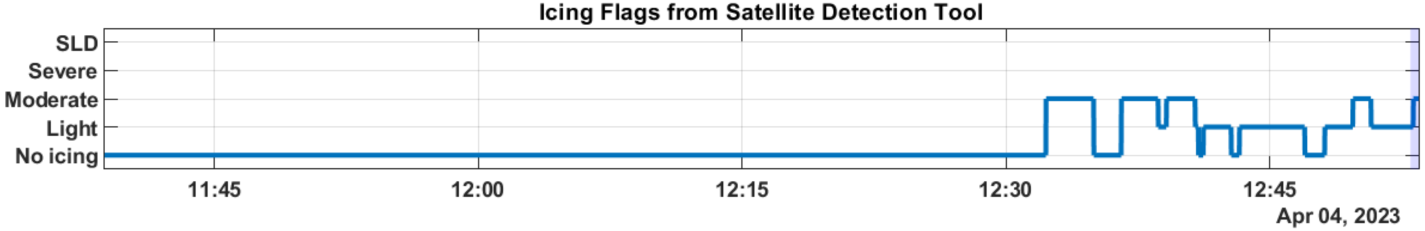
Flight through airways.



- For the comparison with flight data, an updated satellite image has been considered every 15 minutes (satellite temporal resolution).
- The nearest point to the position of the aircraft has been considered from the satellite image.





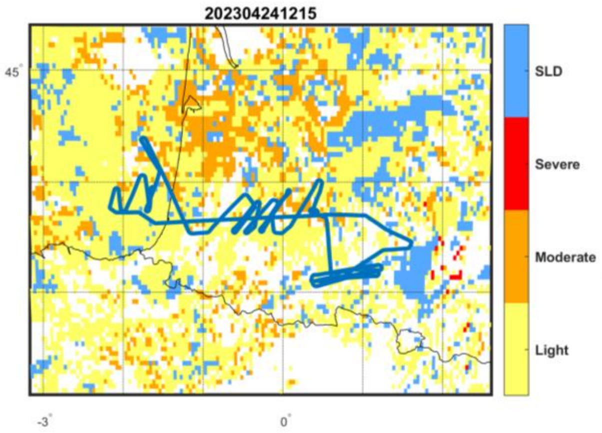


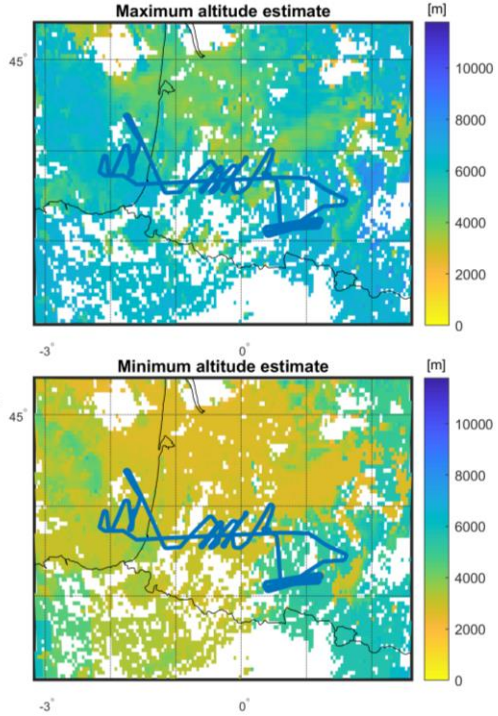
SENS4ICE, EU-funded project, Grant Agreement No 824253

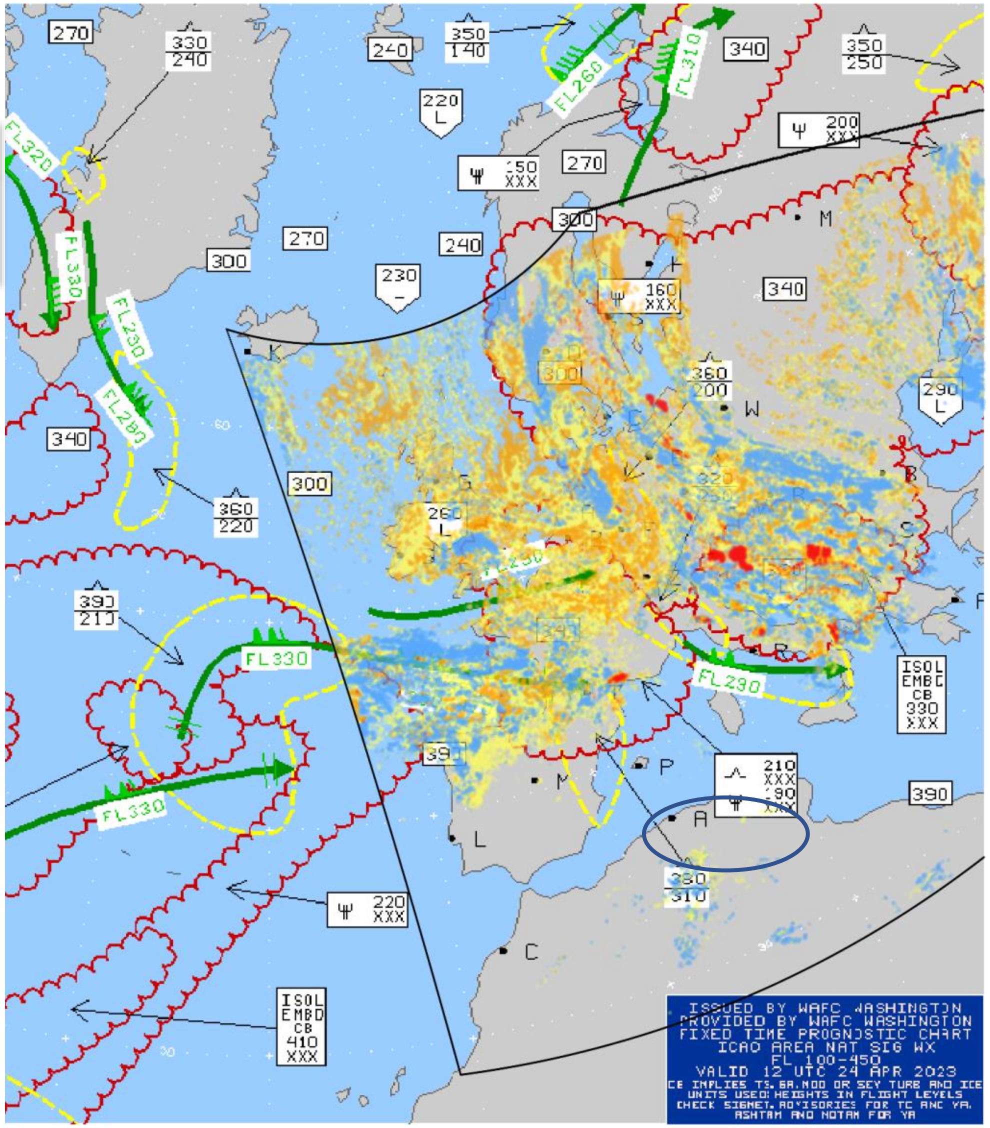
Example of comparison with flight data (2)

SENS4ICE Flight No	Safire Flight ID	Date	Takeoff (UTC)	Landing (UTC)
10	as230018	2023-04-24	12:22:37 in Francazal	16:52:22 in Francazal

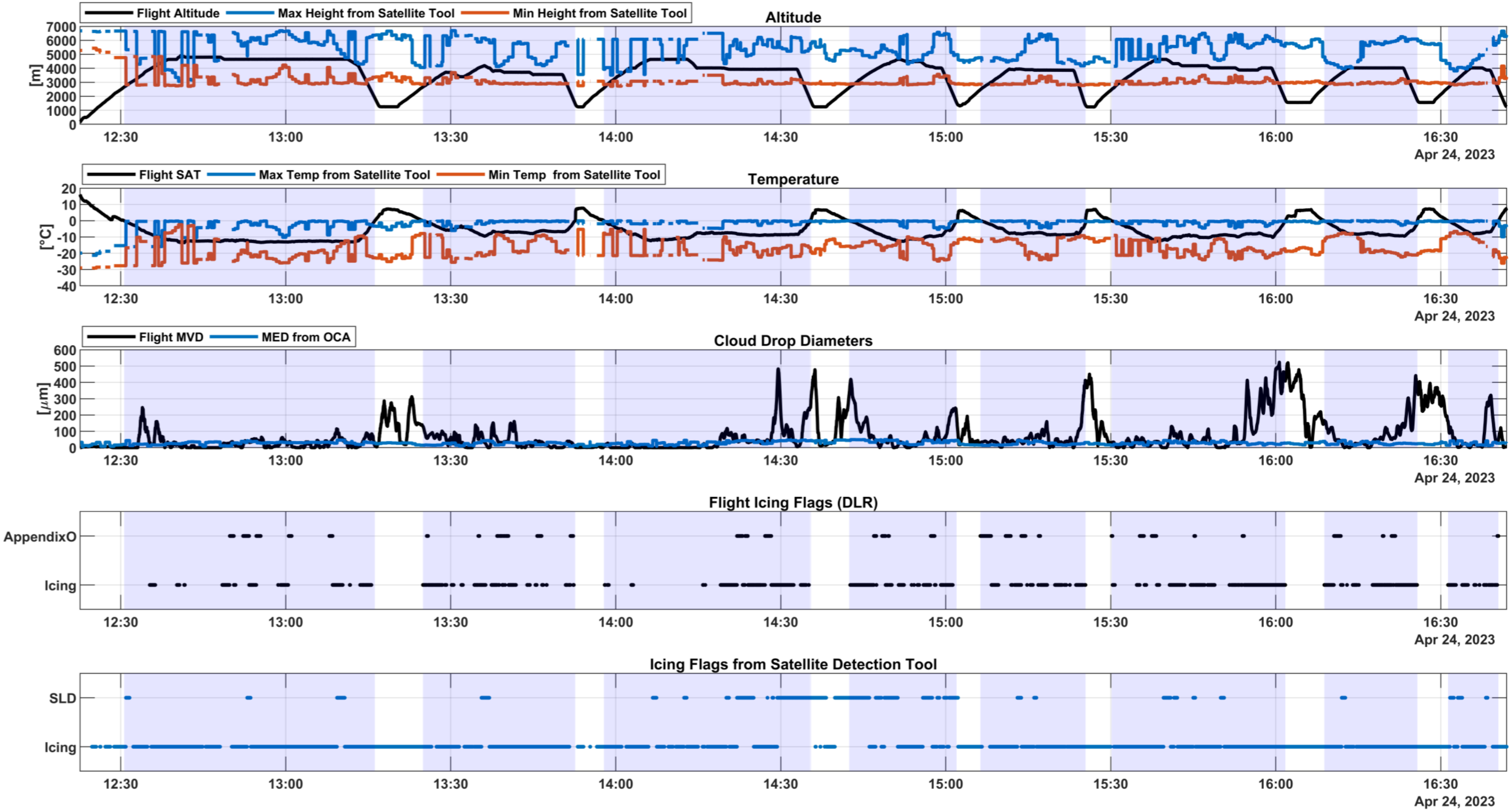
Flight in specific areas with dedicated ATC used for testing purposes.







Example of comparison with flight data
Preliminary results



Conclusions and future work

- The early detection of regions affected by icing conditions is a challenging and desirable goal in order to increase aviation safety. In this framework, CIRA developed a tool based on satellite data for the remote detection of in-flight icing.

- The tool relies on satellite data, to remotely infer the properties of clouds, and a set of experimental curves and envelopes, as provided by aircraft certification specifications (FAA / EASA), defining the atmospheric icing conditions.

- This presentation has provided a preliminary analysis of the performance of the implemented tool.

- Preliminary results regarding the evaluation of the tools in relevant icing conditions using the data of the SENS4ICE flight campaign are promising.

- Further investigations are ongoing with the aim to verify the level of probability of detection and false alarm rate of the tool. The results of this validation activity will be used to identify the strengths and weaknesses of the tool and the needed steps for its future maturation and exploitation.

- Further improvements can be expected in the near future thanks to innovative satellite products with enhanced cloud retrieval techniques.

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Thank you

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