SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Icing detection technologies evaluation
Remote ice detection

FINAL DISSEMINATION EVENT OF SENS4ICE PROJECT

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

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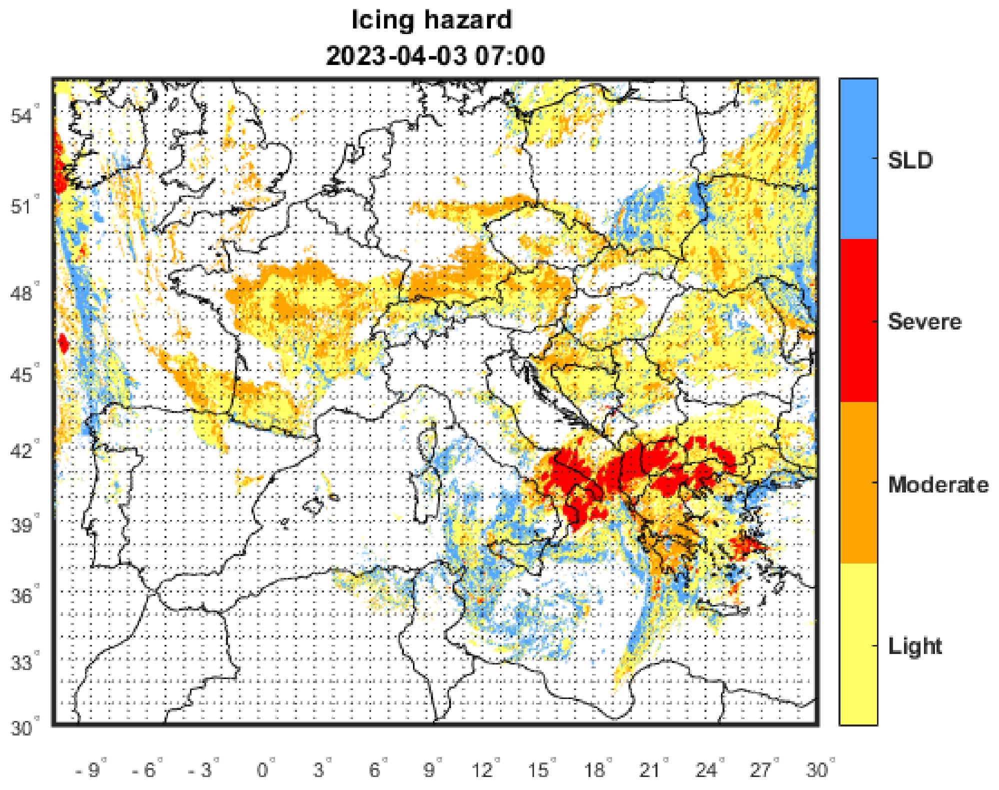
Introduction

- One of the objectives of SENS4ICE project is to increase pilot awareness of icing threats through the development of a remote detection technology.
- The Meteorology Laboratory of CIRA addressed this task.
- CIRA has developed a first algorithm for in-flight icing **detection** 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 in 2017. This product has then been implemented into ITAF operational chain and is usable in meteorological surveillance functions for aviation safety.
- 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.

Remote detection tool for icing conditions: overview

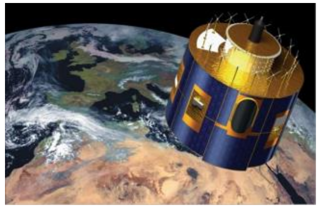
- Remote Detection based on satellite data
- The tool relies on satellite data to retrieve information about the main meteorological factors determining icing condition (Temperature, Droplet size and Cloud type)
- Output of the tool: visualization of areas affected by in flight icing hazard with indication of possible SLD conditions, along with an estimate of the minimum and maximum altitudes affected.
- TRL2 at project start; now: TRL5
- Testing through European Flight Test Campaign



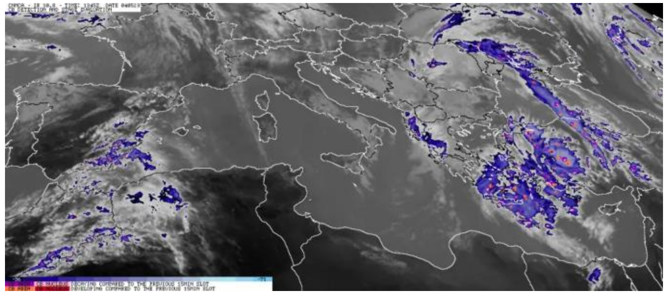
Remote detection tool for icing conditions: input

ALGORITHM INPUT:

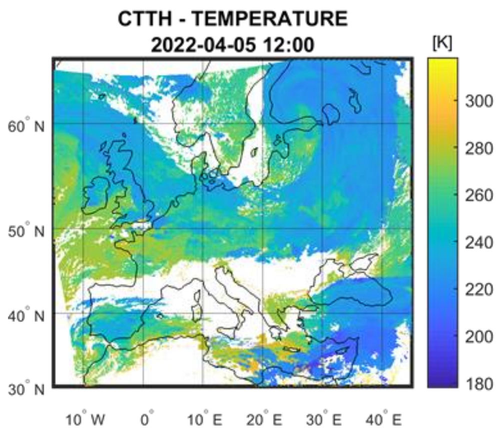
- satellite products, based on Meteosat Second Generation (MSG) data:
  - **NEFODINA** and **NEFODINA2** products, provided by ITAF, to detect convective areas;
  - Cloud Top Temperature and height (GEO-**CTTH**), NWCSAF product, to evaluate cloud properties;
  - Optimal Cloud Analysis (**OCA**) product, 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.



Credit: EUMETSAT

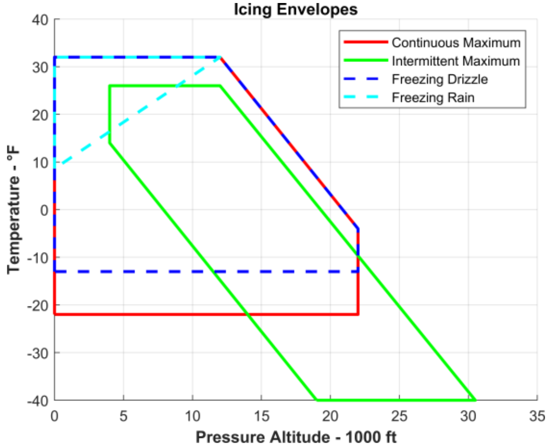


www.meteoam.it

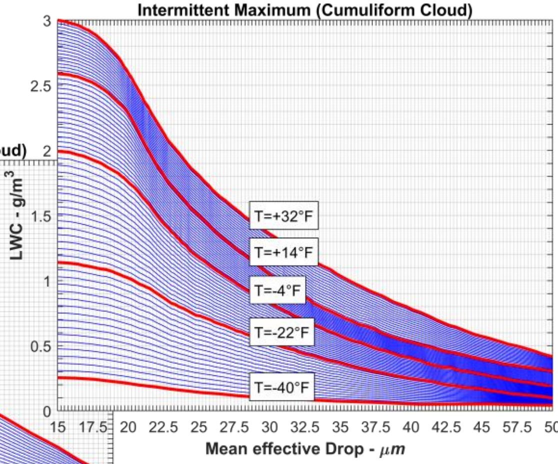


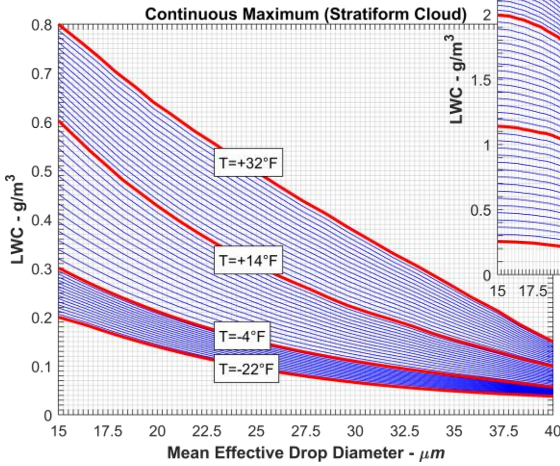
Algorithm description

- 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

Zollo and Bucchignani, 2023

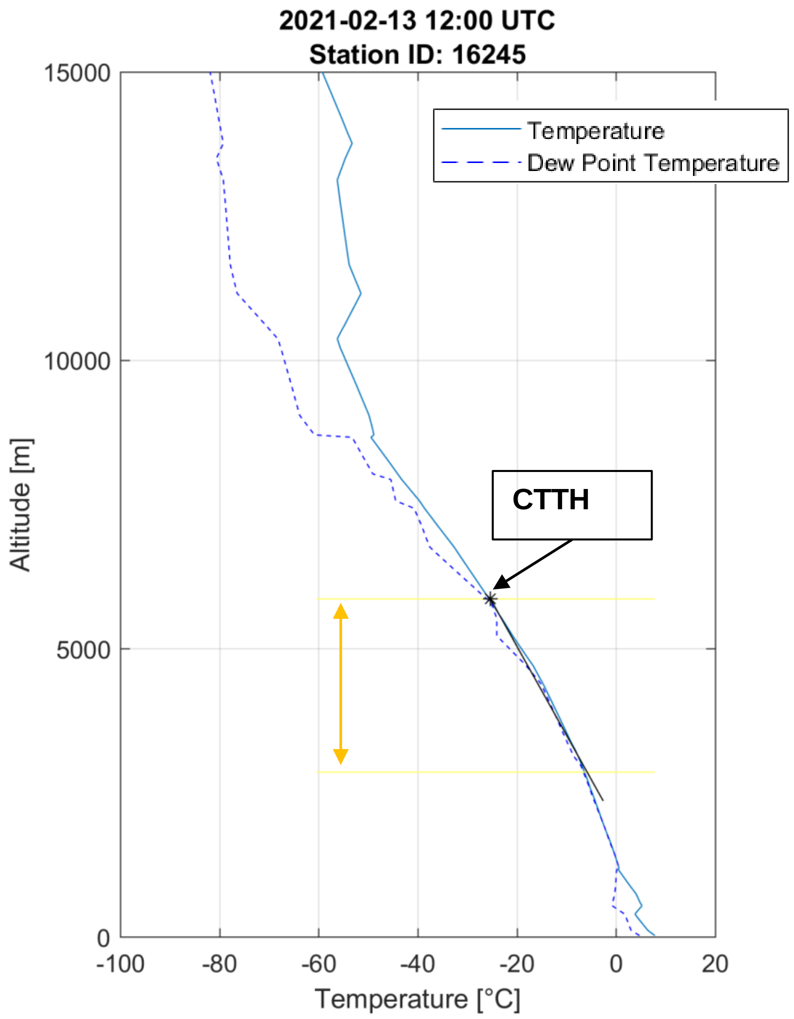
Altitudes estimate

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 (discontinuous in time and space);
- temperature profiles obtained from Numerical Weather Prediction (**NWP**) models (strong computational increase).

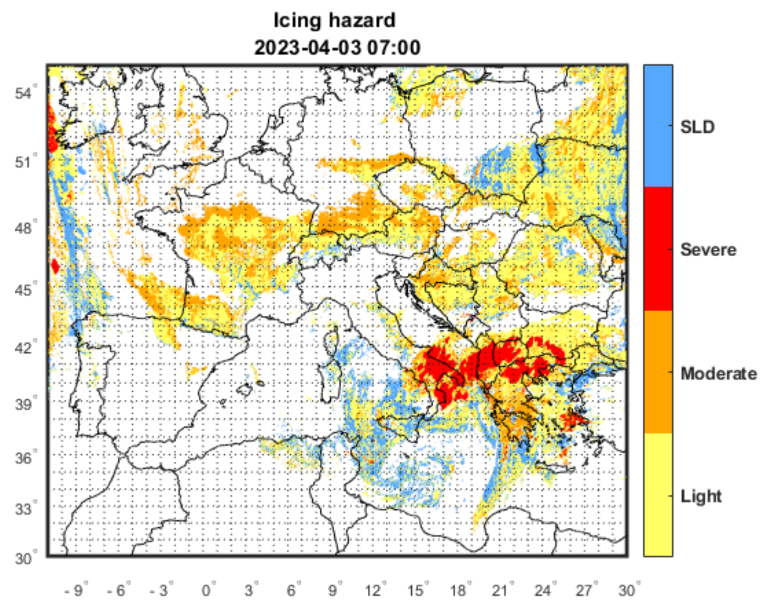
A preliminary comparison with respect to soundings data has shown that, in terms of mean bias, the difference between the temperature profiles estimated using the standard atmosphere approximation and NWP profiles is not very significant. For these reasons, at this stage, the usage of NWP data was not preferred, but the combination of multiple data sources in the algorithm could be an important way forward for a further enhancement of the tool.

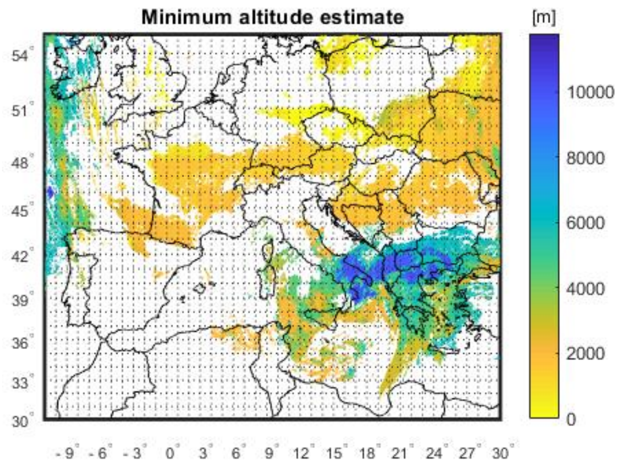


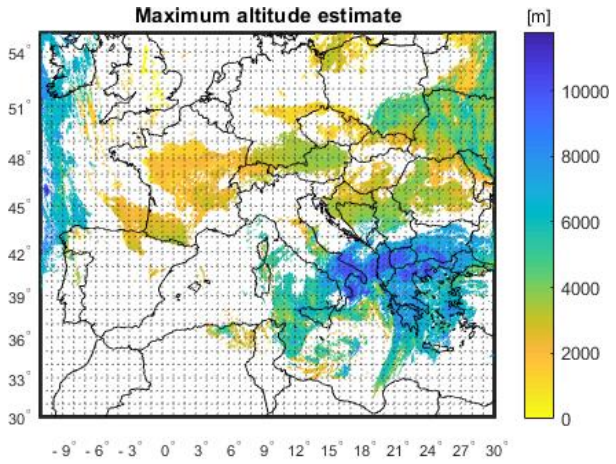
https://weather.uwyo.edu/upperair/sounding.html

Remote detection tool for icing conditions: 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.







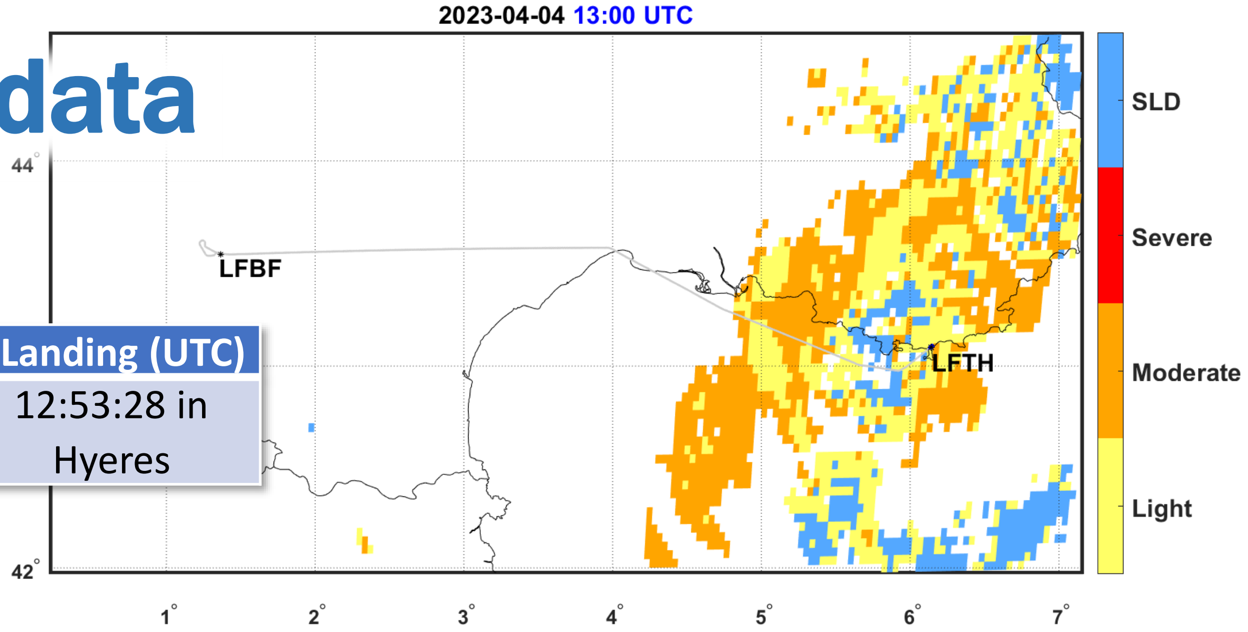
SENS4ICE Flight Campaign Europe

- This tool has been used during the SENS4ICE flight campaign held in April 2023: 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 flight campaign represents an important chance to evaluate the performance of the tool in environmental icing conditions.
- 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

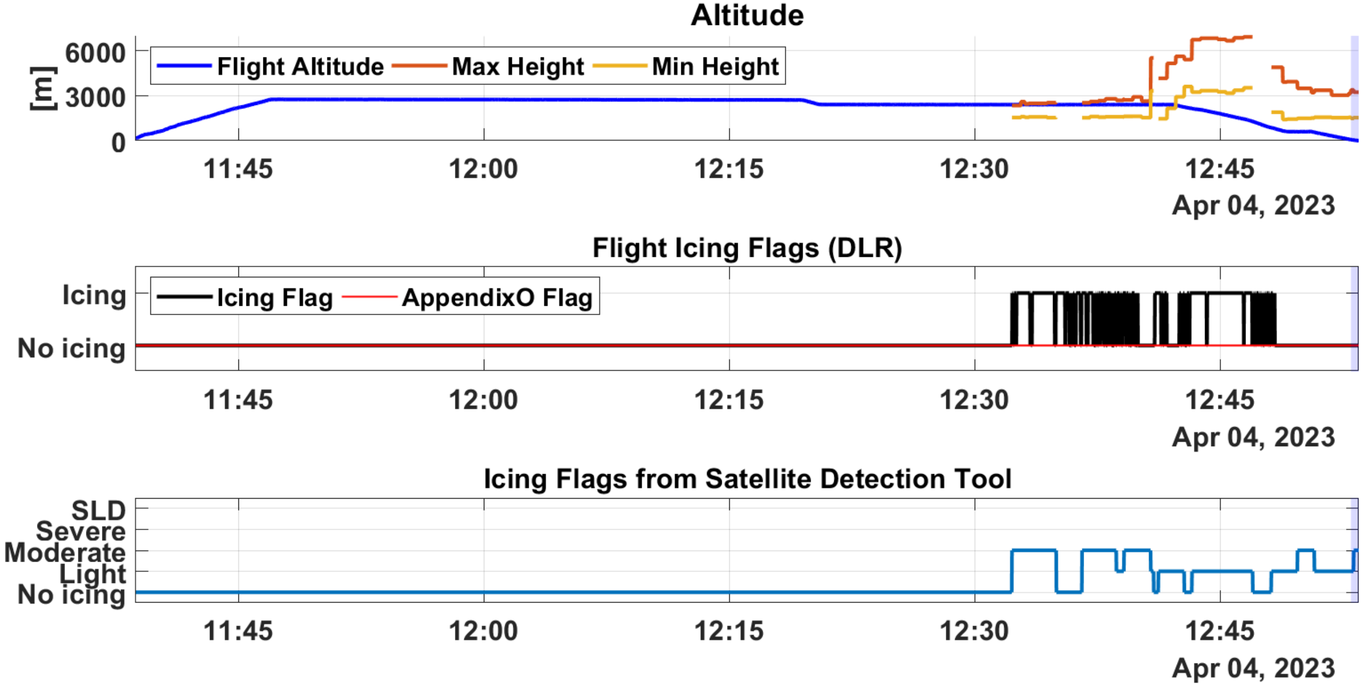
Comparison with flight data



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.

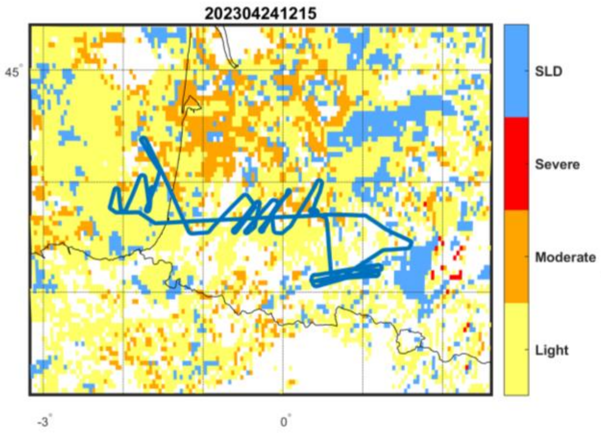
- For the comparison with flight data, an updated satellite image has been considered every 15 minutes (satellite temporal resolution).
- The nearest point to the position of the aircraft has been considered from the satellite image.

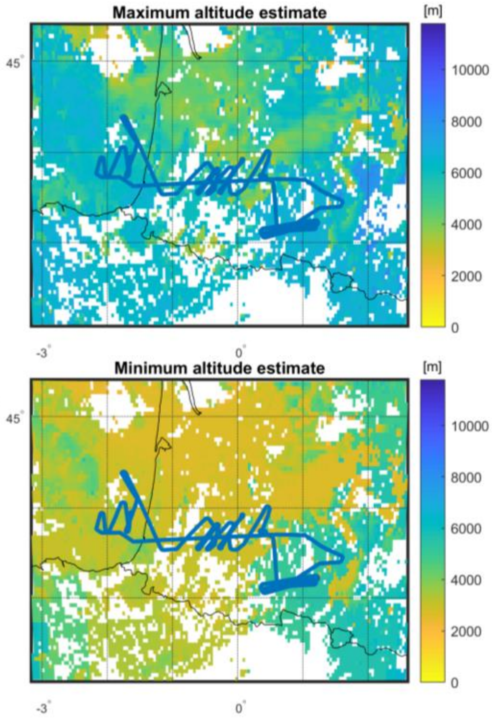


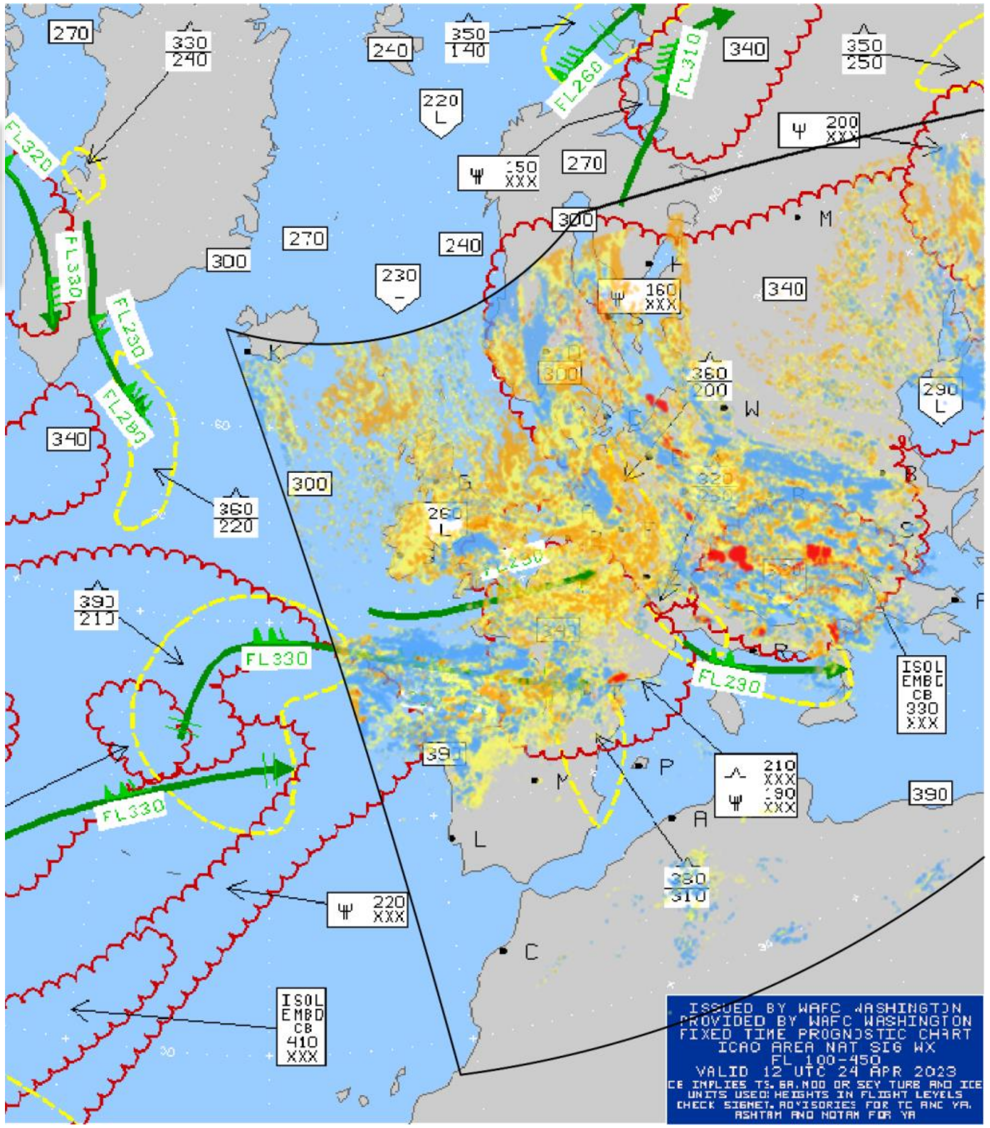
Comparison with flight data

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.

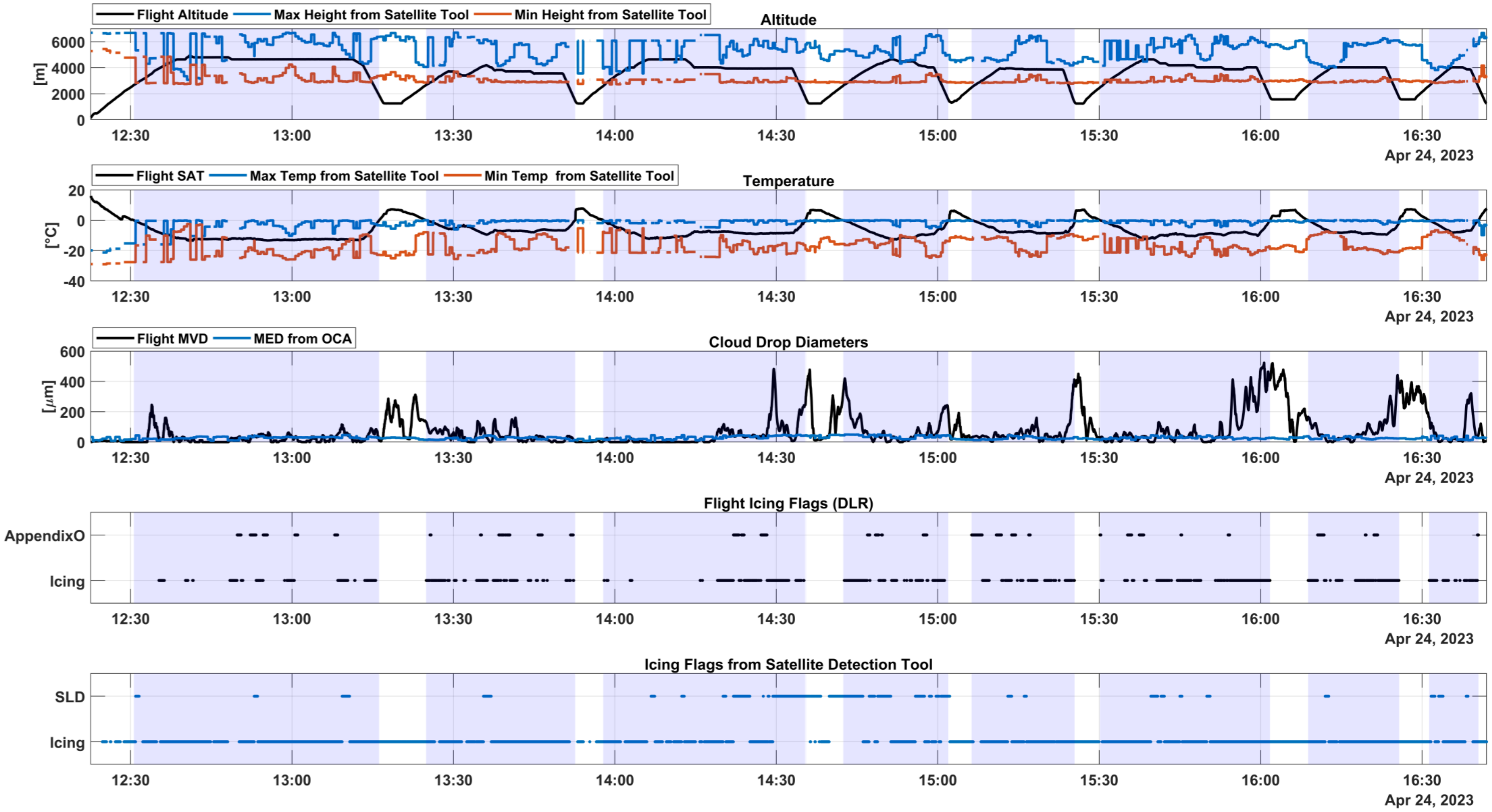






https://www.aviationweather.gov/

Comparison with flight data



Conclusions and Outlook

- The early detection of regions affected by icing conditions is a challenging and desirable goal in order to increase aviation safety. In the framework of SENS4ICE project, 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.
- The first results regarding the evaluation of the tools in relevant icing conditions using the data of the SENS4ICE flight campaign are promising, suggesting that this satellite-based approach can be exploited for applications supporting aviation meteorology.
- Further investigations are still ongoing with the aim of performing a fully detailed validation to identify the needed steps for its future maturation and exploitation.
- The main drawback of the used satellite data is that meteorological parameters are sensed only at the top of the cloud. Therefore further research is needed to find a way forward, e.g. by combining different types of data or by using the new generation satellite products, expected in the near future, with enhanced cloud retrieval techniques.

References

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