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In-flight icing: a remote detection tool based on satellite data

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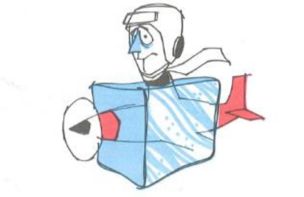
Introduction

Aircraft **in-flight icing** is the accretion of ice on airplane's surfaces during flight and is one of the major weather hazards to aviation. Accreted ice adversely affects flight since it reduces aircraft performance, stability and controllability.



Icing is NOT caused by ICE in clouds. It is caused by ***super-cooled liquid water droplets*** that strike the aircraft and freeze on impact.

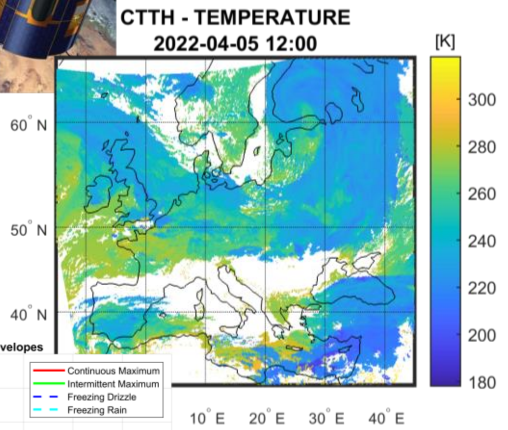
The Meteorological Laboratory of CIRA is working on the goal to characterize in-flight icing using **satellite data** since 2017. A first algorithm for in-flight icing detection has been developed in collaboration with Italian Air Force and with the support of the internal experimental knowledge on icing thanks to the CIRA Icing Wind Tunnel facility.

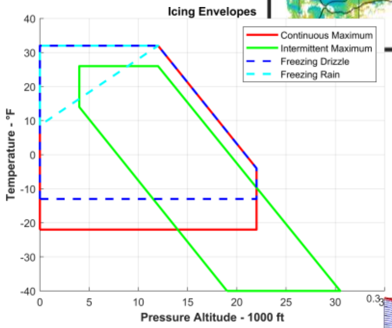
Currently, in the framework of the H2020 EU project SENS4ICE (SENSors and certifiable hybrid architectures for safer aviation in ICing Environment), CIRA is working on an enhancement and a further maturation of the previously developed algorithm in order to take into account also Supercooled Large Drop (SLD) Icing Conditions.

Main meteorological factors determining icing condition are ***Liquid water content (LWC), Temperature, Droplet size*** *and* ***Cloud type***. The developed algorithm for icing detection relies on knowledge or inference of these meteorological factors using satellite data.

Icing detection tool: input and algorithm

- **Input**:
  - satellite products, based on Meteosat Second Generation (**MSG**) data, to detect:
    - convective areas,
    - cloud top temperature and height,
    - cloud microphysical properties such as 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 of LWC, diameter of the cloud droplets, temperature and pressure altitude.

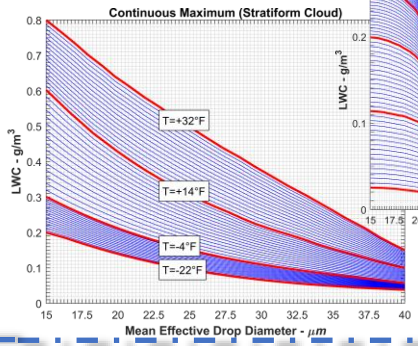


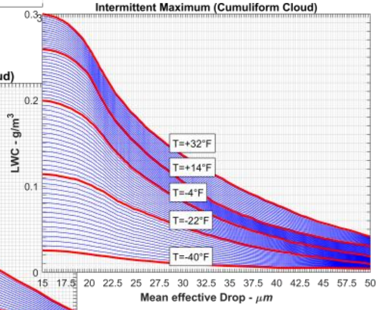


- Cumuliform clouds and stratiform clouds are processed separately by the algorithm.
- The curves defining the atmospheric icing conditions are used to retrieve the values of LWC, then used to classify the severity of the icing phenomenon.

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

Jeck, 2001



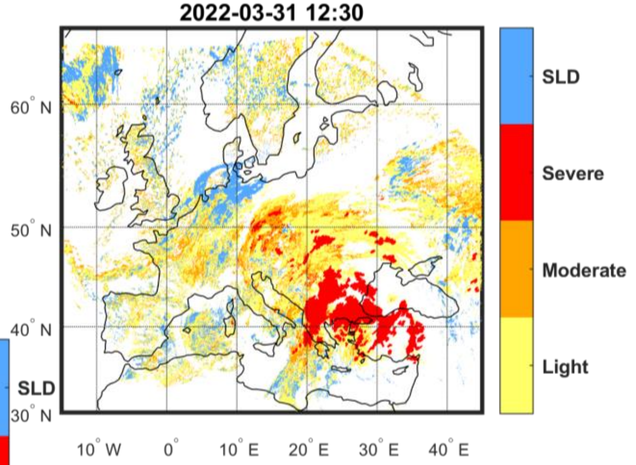


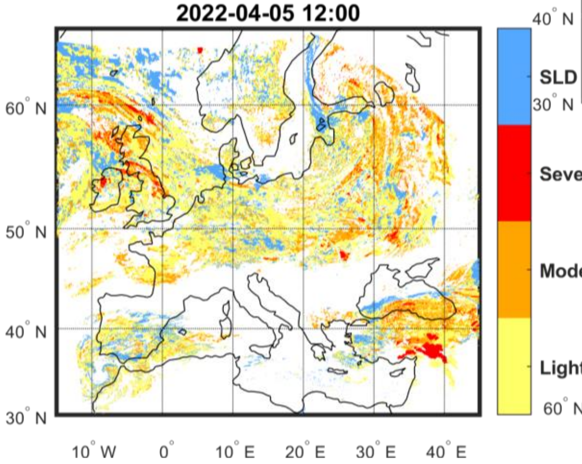
- In the case of stratiform clouds, further checks are performed in order to evaluate the possible presence of SLD conditions, on the base of the Mean Effective Drop Diameter retrieved from satellite.

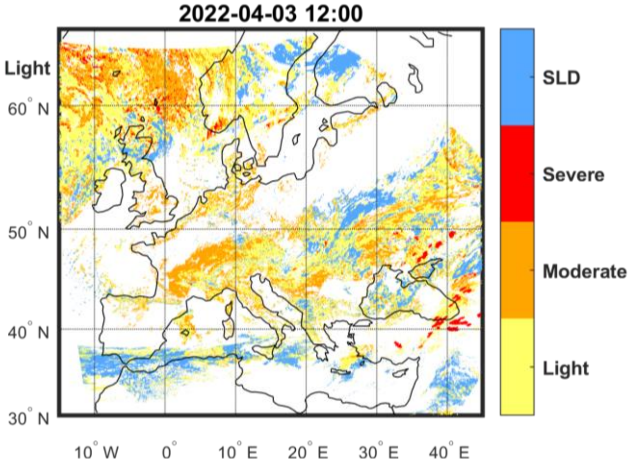
Icing detection tool: output

- This tool is targeted to display the resulting information of the pixel-based analysis of the algorithm as a graphical representation of icing hazard.
- The spatial and temporal resolutions are respectively of about 3 km and 15 minutes.
- An estimate of the minimum and maximum altitudes affected by the icing hazard is also available for each pixel of the map.
- 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.

Examples of output:



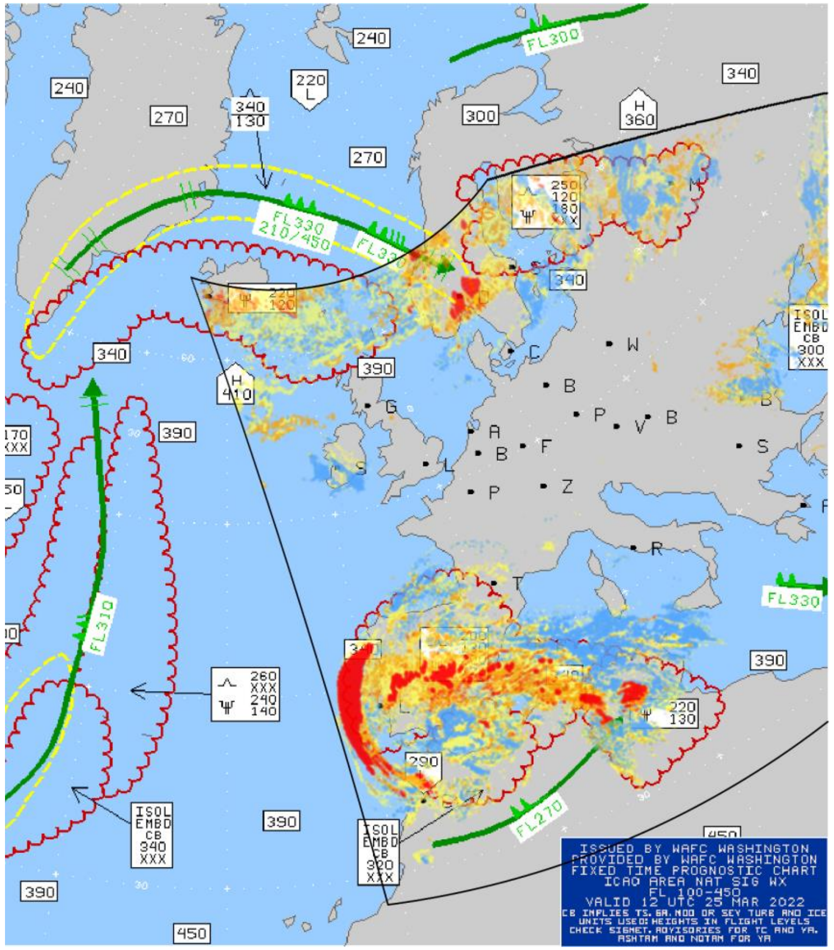


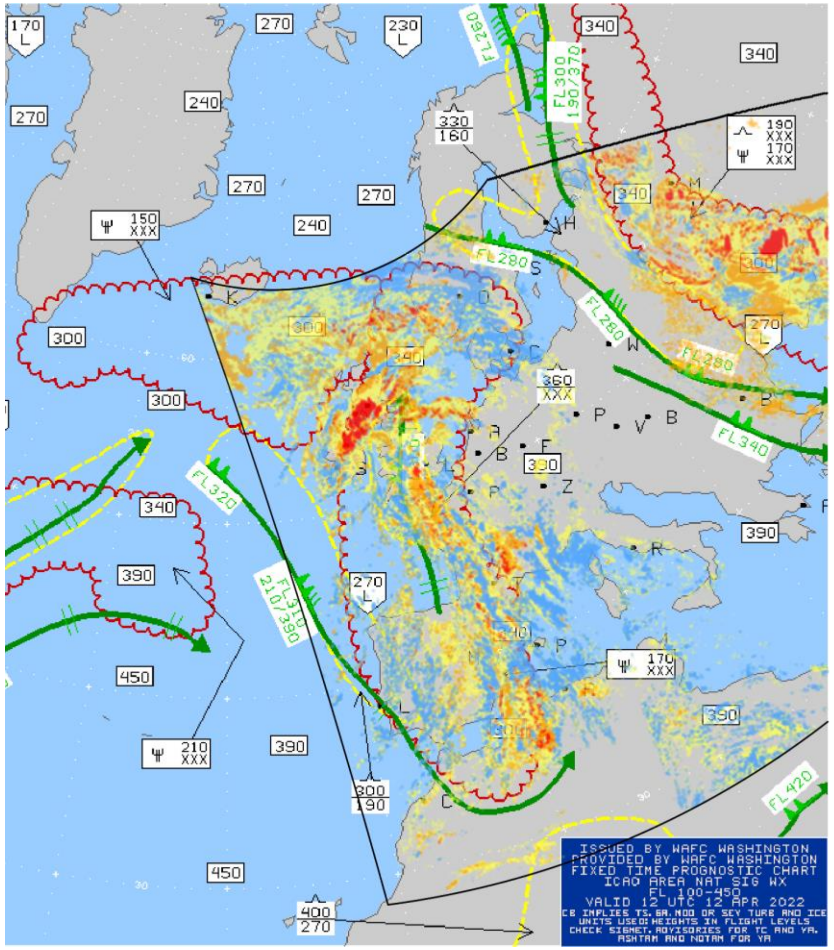


Icing detection tool: preliminary results

A qualitative comparison with Mid-Level Significant Weather (SIGWX) Chart has shown a quite good agreement in definition of regions affected by icing conditions. Further investigations are ongoing using sounding data to better understand the performance of the algorithm.

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

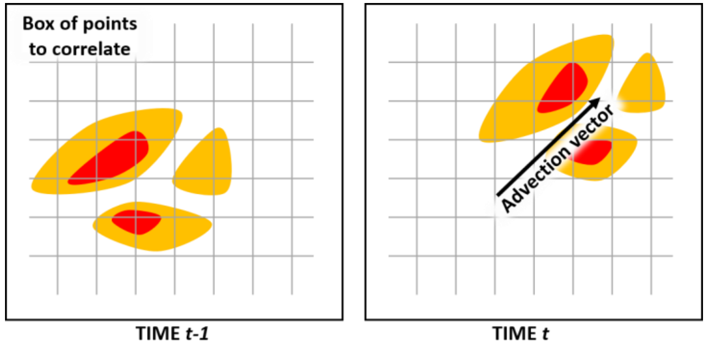




Some examples of overlapping of the algorithm results on SIGWX charts.

Nowcasting tool

The icing detection product has been used as base to develop a nowcasting algorithm based on the extrapolation in time of the current weather conditions detected by satellite data. The idea is to use an estimate of the speed and direction of movement of the current icing conditions, calculated by means of a cross correlation analysis of two consecutive satellite images, to perform a forecast over a short period ahead.



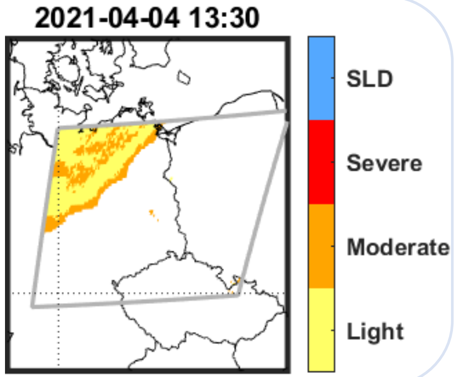
Specifically, a pixel-to-pixel **advection algorithm** based on cross-correlation over sub-areas has been developed.

It was found that the performances vary significantly from day to day: the forecast abilities of nowcasting methods depends on the nature of the event observed.

Slowly changing and quite uniform icing hazard field

⬇

good performance



Rapidly changing and quite scattered icing hazard field

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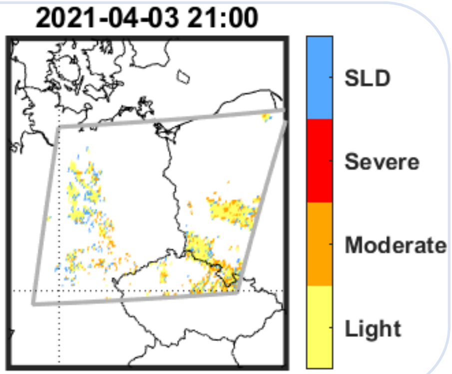
poor performance



Worst results obtained for frames with few icing pixels: cases less crucial (not intense events).

Conclusion 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 product has been utilized as base to develop a nowcasting algorithm based on the extrapolation in time of the current weather condition.

- This presentation has provided a preliminary analysis of the performance of the implemented tools, that show promising results. Further investigations are ongoing.

- These tools will be evaluated in relevant icing conditions in the framework of SENS4ICE flight campaigns, planned in 2023.

Thank you

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