June 20-22, 2023
Vienna, Austria

SAE INTERNATIONAL

International Conference on Icing

of Aircraft, Engines, and Structures

sae.org/icing

SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

In-flight icing condition detection using an on-board sensor measuring the aircraft electrostatic potential

Rafael Sousa Martins, Aurélie Bouchard, Magalie Buguet, Patrice Blanchet and Philippe Lalande
ONERA – The French Aerospace Lab

SAE International Conference on Icing (Vienna - Austria) – June 20-22, 2023

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

Outline

- Context and objectives
- AMPERA system description
- Adaptation and preparation for icing detection purposes
- Preliminary flight test results
- Conclusion and perspectives

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- EU H2020 SENS4ICE Project (DLR coordination)
  - New technologies for severe in-flight icing detection: 17 partners, different and innovating approaches and technologies
  - Objectives: Increase the **flight safety** in icing conditions, especially for the SLD conditions
  - For direct icing detector, sensors with different physical principles
    - Thermal (heat transfer/temperature)
    - Optical (laser/imaging)
    - Mechanical (wave propagation)
    - Electrical

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ONERA approach : AMPERA (Atmospheric Measurement of Potential and Electric field of Aircraft)

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sample a local area

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overall estimation of aircraft exposure condition

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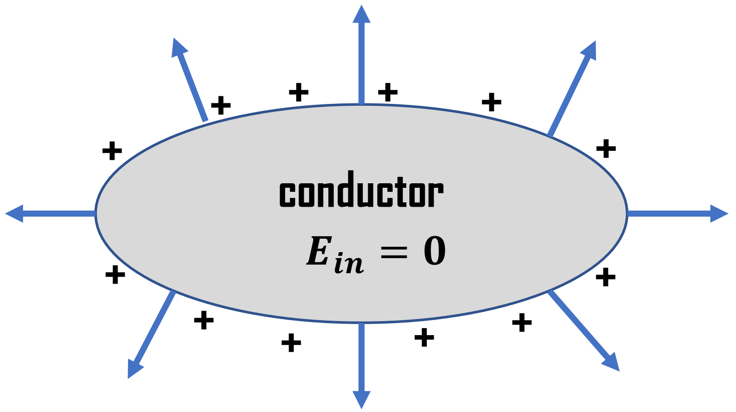
AMPERA system description

- Electric field mill (EFM) network → Multi locally measurement of the surface electric field
- Principle



Normal electrostatic field in a charged conductor

$$E_N = \frac{q}{S\epsilon_0} = \frac{\sigma}{\epsilon_0} \quad [V.m^{-1}]$$

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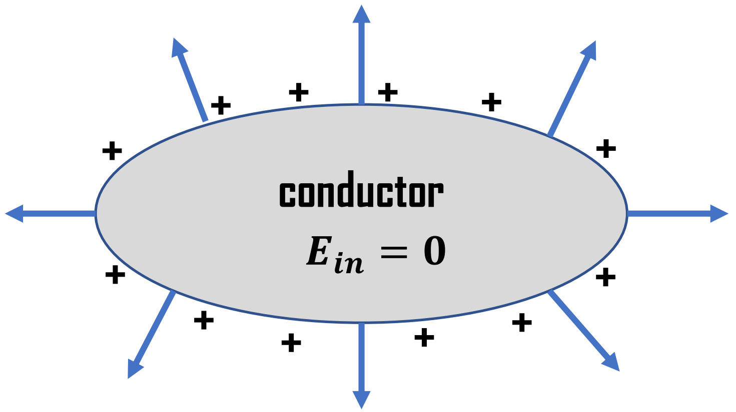

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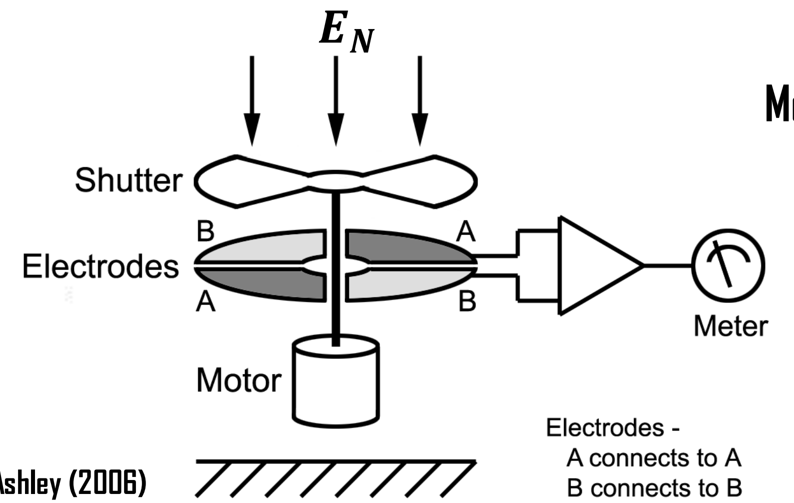
- EFM description



Lynn Ashley (2006)

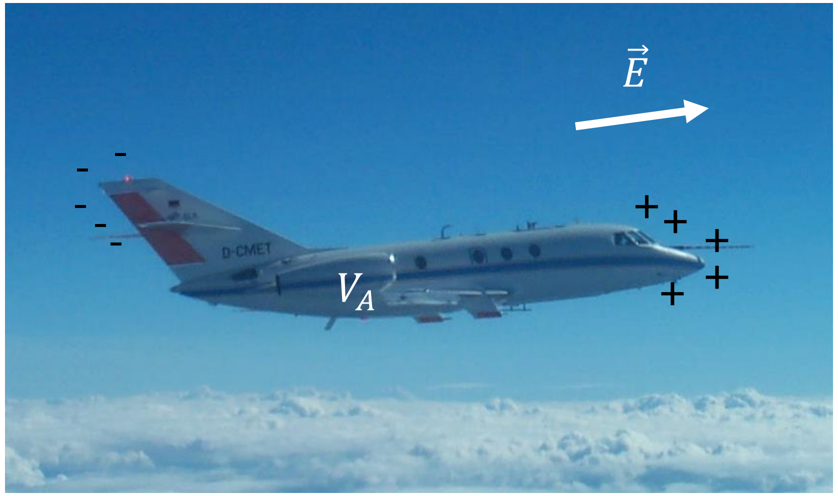
Modulated measurement of electric current in sensing electrode

$$i(t) = \epsilon_0 E_N \frac{dS(t)}{dt} \quad [A]$$

The normal electrostatic field is directly determined

AMPERA system description

- Application of EFM in-flight : network for locally electrostatic field measurement (sampling @10 Hz)



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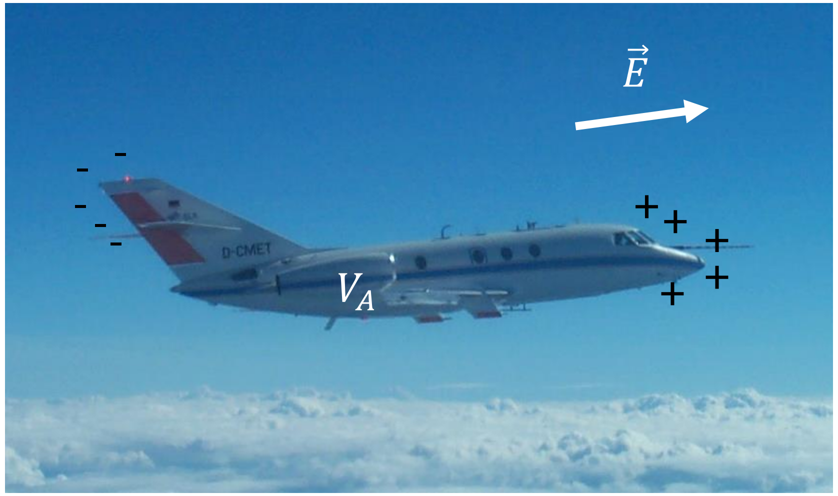


- Normal surface electrostatic field (EFM measurement) is a linear combination of $\vec{E}$ and V_A:

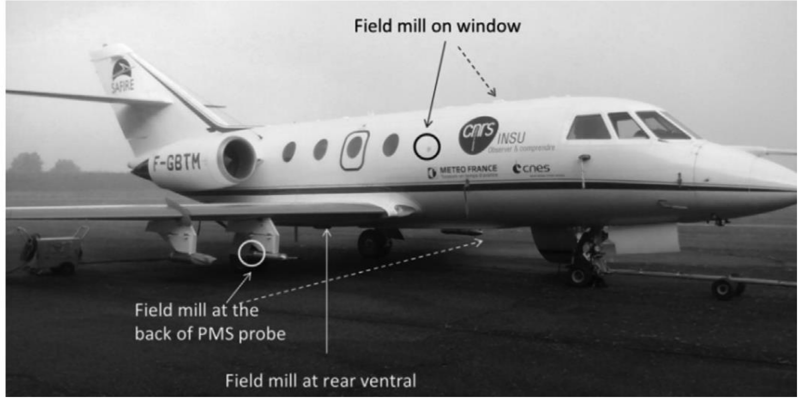
$$\boldsymbol{E_{EFM} = \alpha \times E_X + \beta \times E_Y + \gamma \times E_Z + \lambda \times V_A}$$

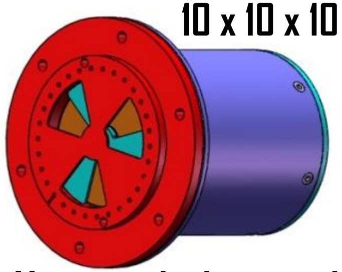
$$\begin{bmatrix} E_x \\ E_y \\ E_z \\ V_a \end{bmatrix} = A^T (A.A^T)^{-1} \begin{bmatrix} E_{EFM1} \\ \vdots \\ E_{EFMn} \end{bmatrix}$$

Ex, Ey, Ez → Ambient electric field
V_A → Aircraft electric potential

AMPERA system description

- AMPERA system utilisation in flight campaign → Thunderstorm and lightning characterization
  - Flight test in many aircraft platforms: Transall C160; Airbus A340 and Dassault Falcon 20





10 x 10 x 10 cm^3

Aluminum body grounded to the fuselage

Flush installation

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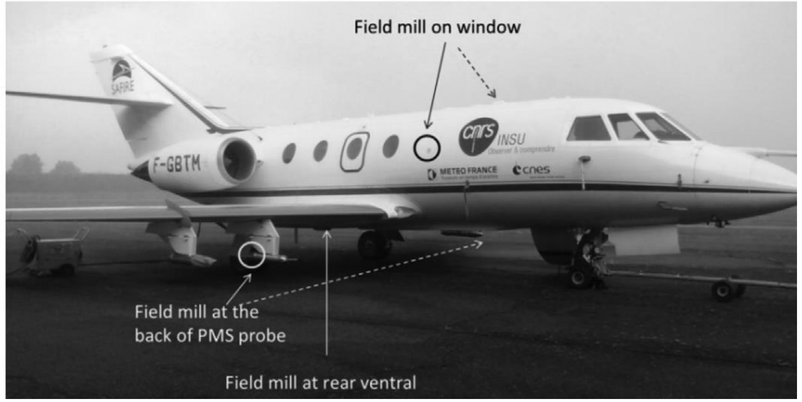

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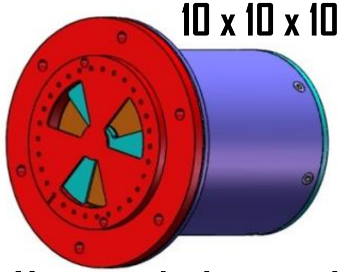


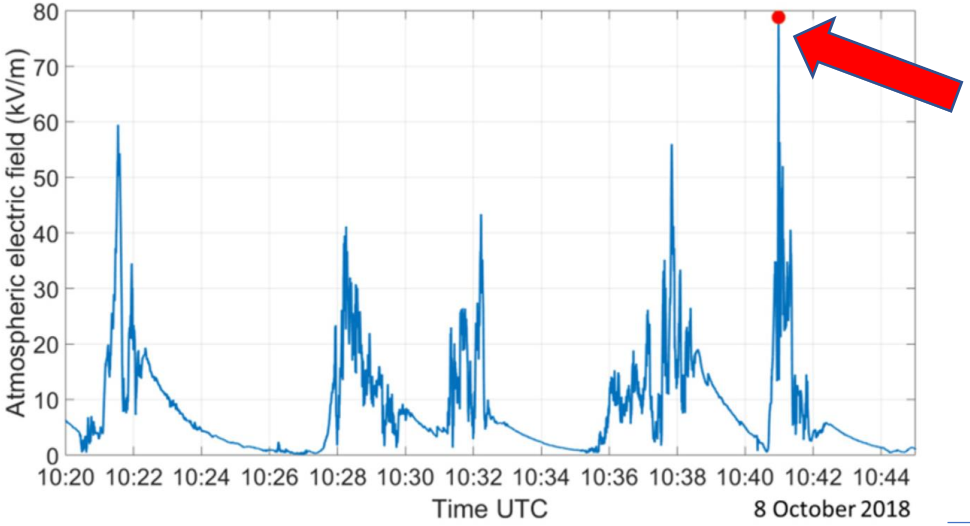
Aluminum body grounded to the fuselage

Flush installation

- Some results: Atmospheric electric field during a in-flight lightning event

EXAEDRE project (https://www.hymex.org/exaedre/)

Buguet et al. (2021) Atmosphere, 12, 1645



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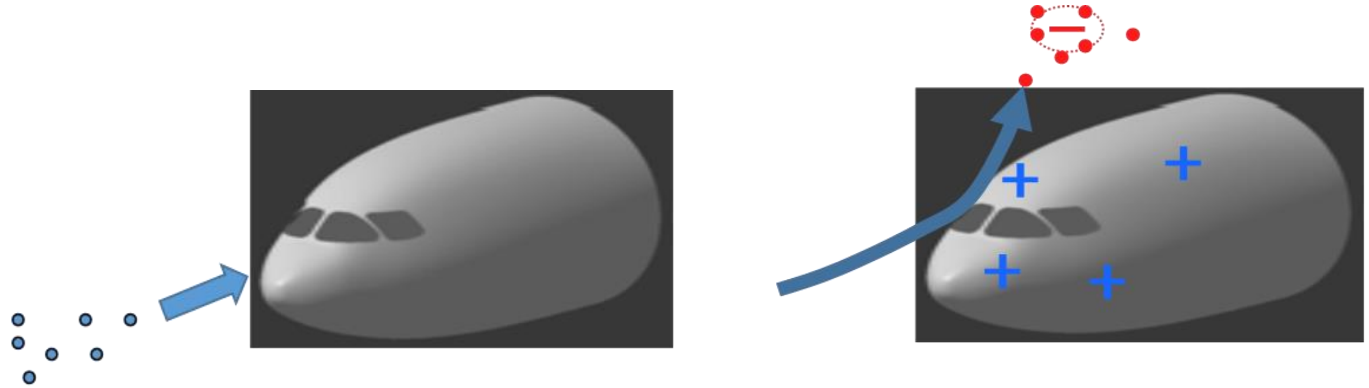
AMPERA utilisation for icing detection

- Principle of triboelectric charging: water droplet or ice crystal impact



overall net charge of all particles impacting the aircraft

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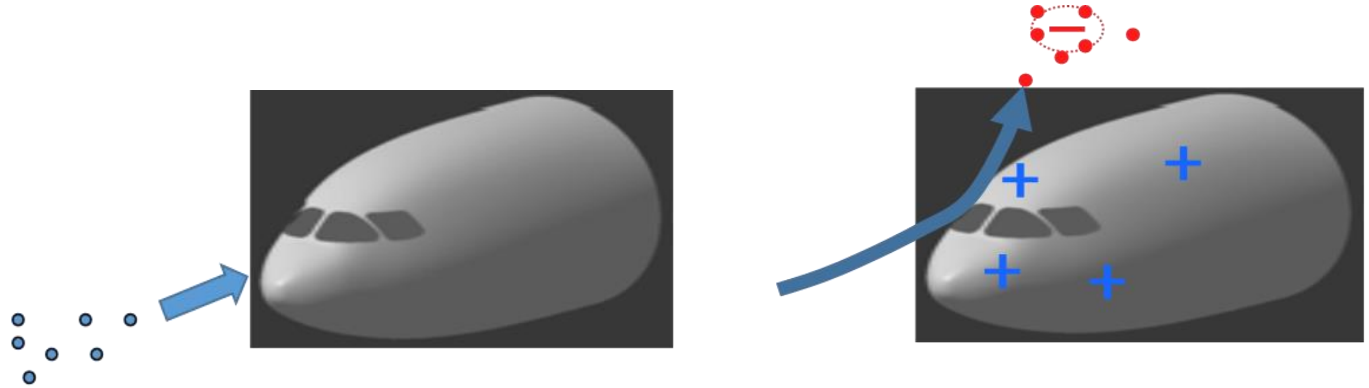
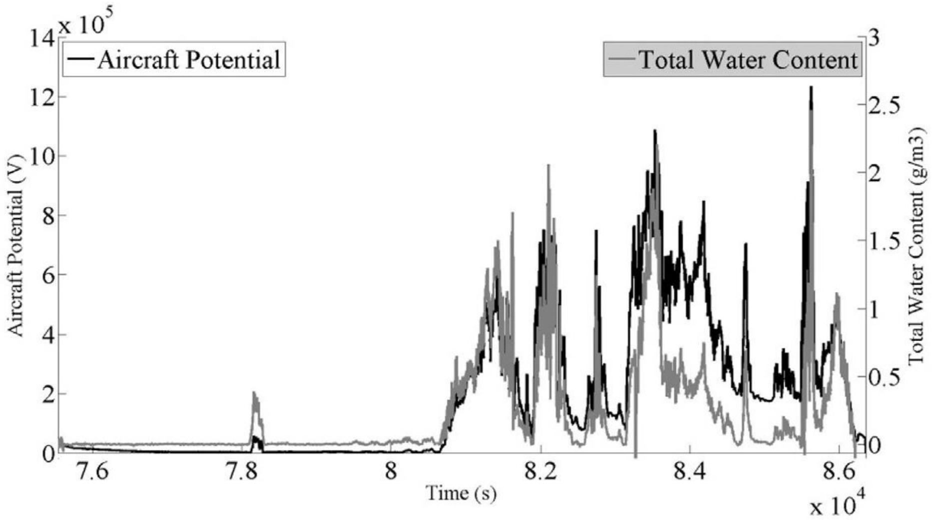


overall net charge of all particles impacting the aircraft

- Icing condition correlation on previous flight test campaign

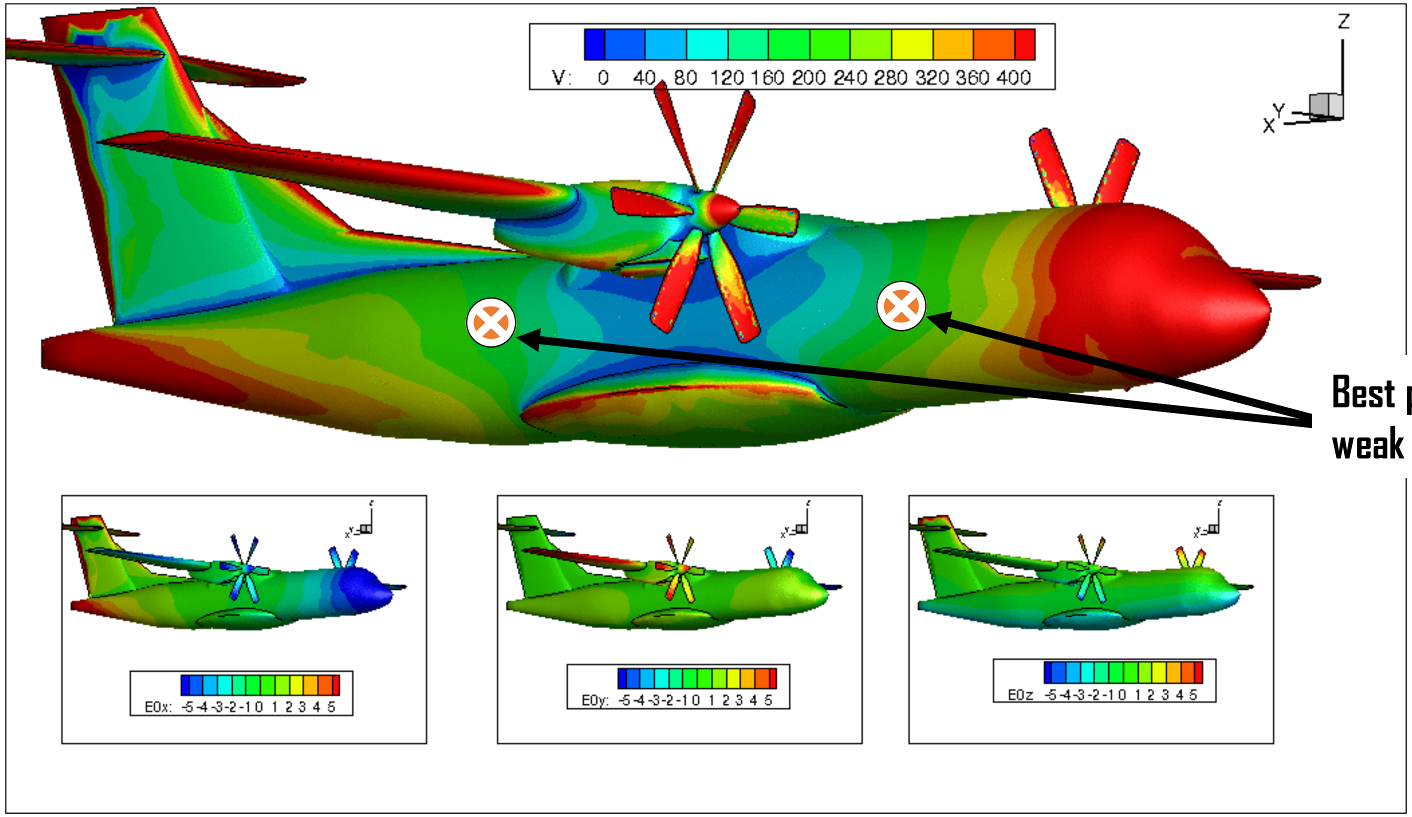


- HAIC-HIWC Project (https://cordis.europa.eu/project/id/314314)
- glaciated high TWC convective cloud
- good agreement between V_A from AMPERA and TWC from IKP2 probe

Bouchard et al. (2020) Atmospheric Research, 237, 104836

AMPERA utilisation for icing detection

- Electrostatic calculation for EFM position on the French ATR 42 environmental research aircraft of Safire

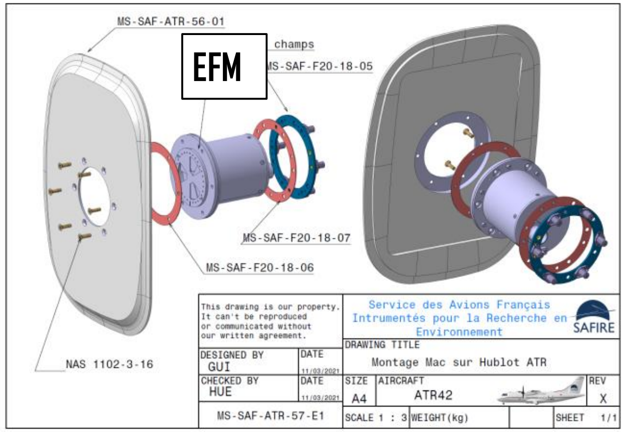


Best positions: moderate V_A but weak E components dependence

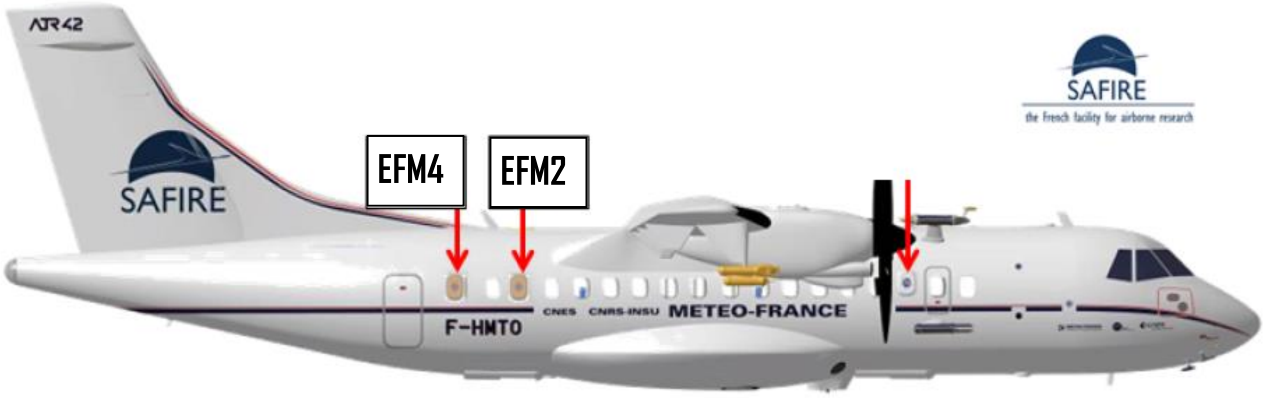
From the electrostatic calculation we can deduce the aircraft capacitance and the normal field coefficients: α, β, γ and λ

AMPERA utilisation for icing detection

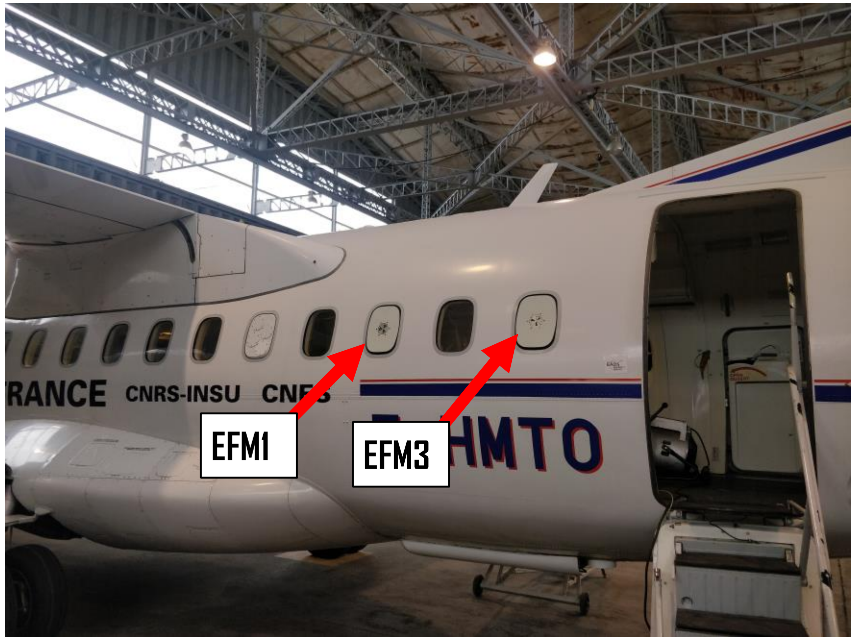
- For Safire ATR42 platform – 4 EFM are installed in rear windows



drawing from Safire



EFM 1 and 3 in the symmetrical opposite windows



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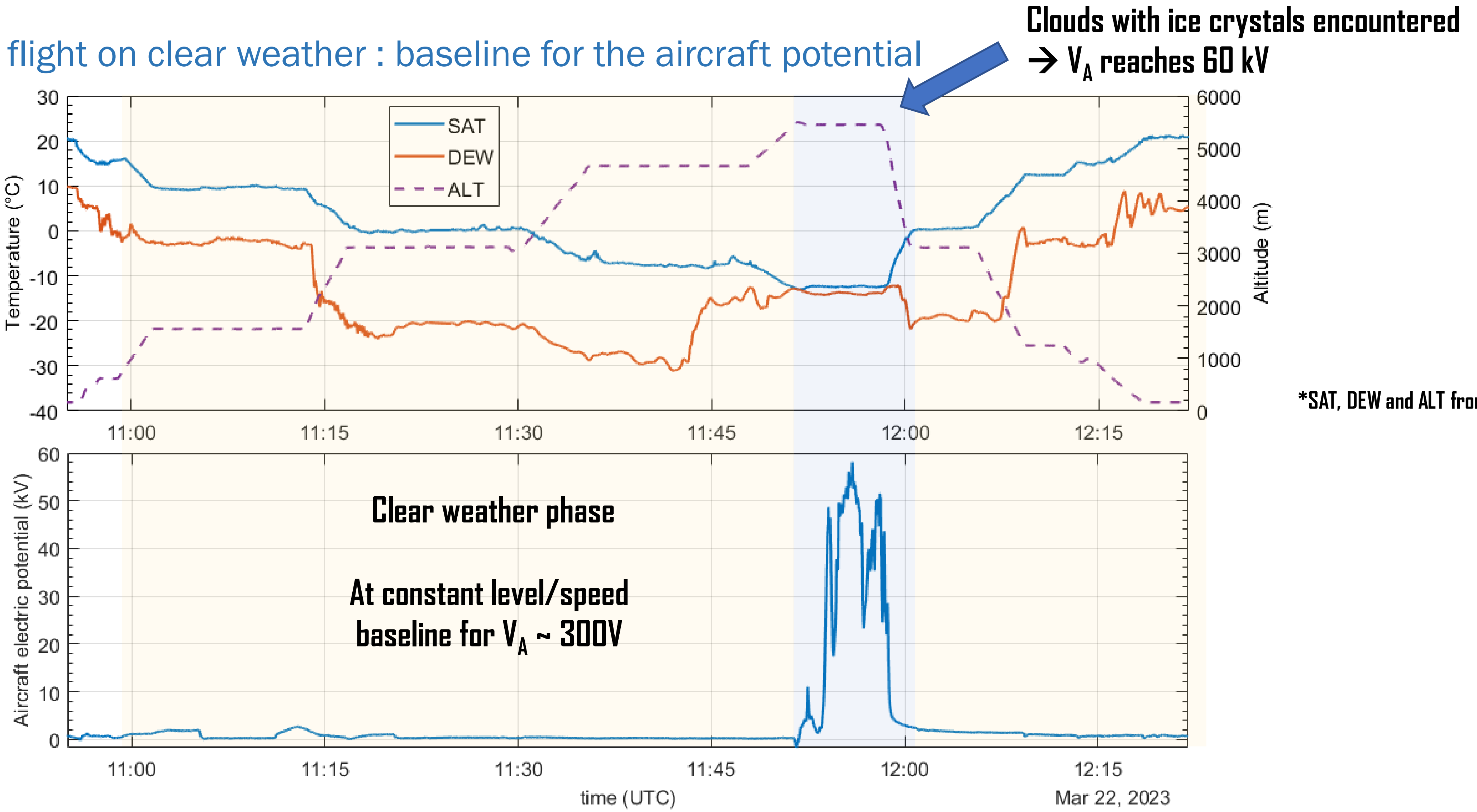
SENS4ICE FT campaign: Calibration flight

- First flight on clear weather : baseline for the aircraft potential

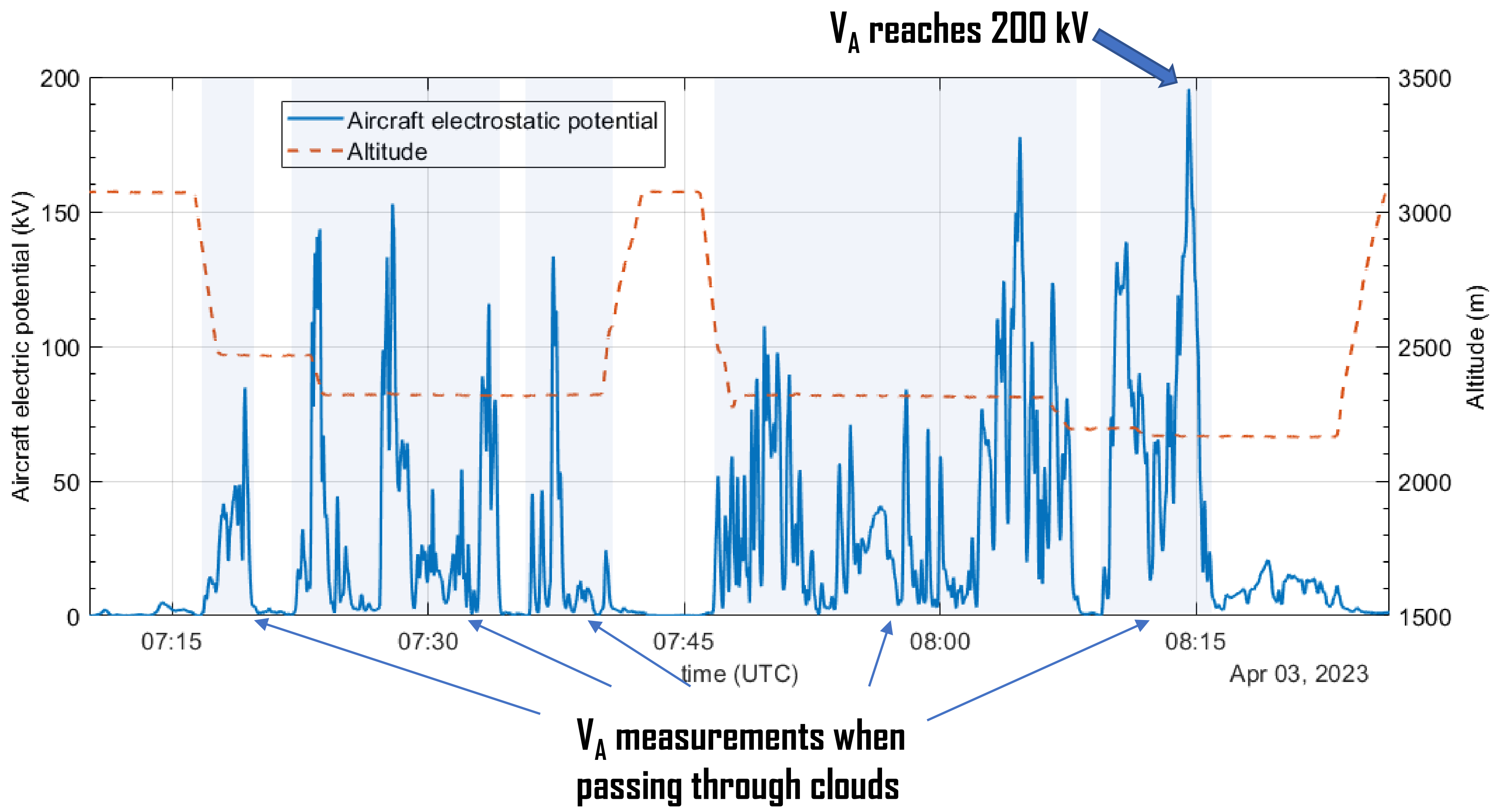


*SAT, DEW and ALT from Safire ATR42

SENS4ICE FT campaign: first results

- Measurement sensibility when crossing a cloud with ice crystals/water droplets

Static temperature during this phase ranging between -8 to -5 °C



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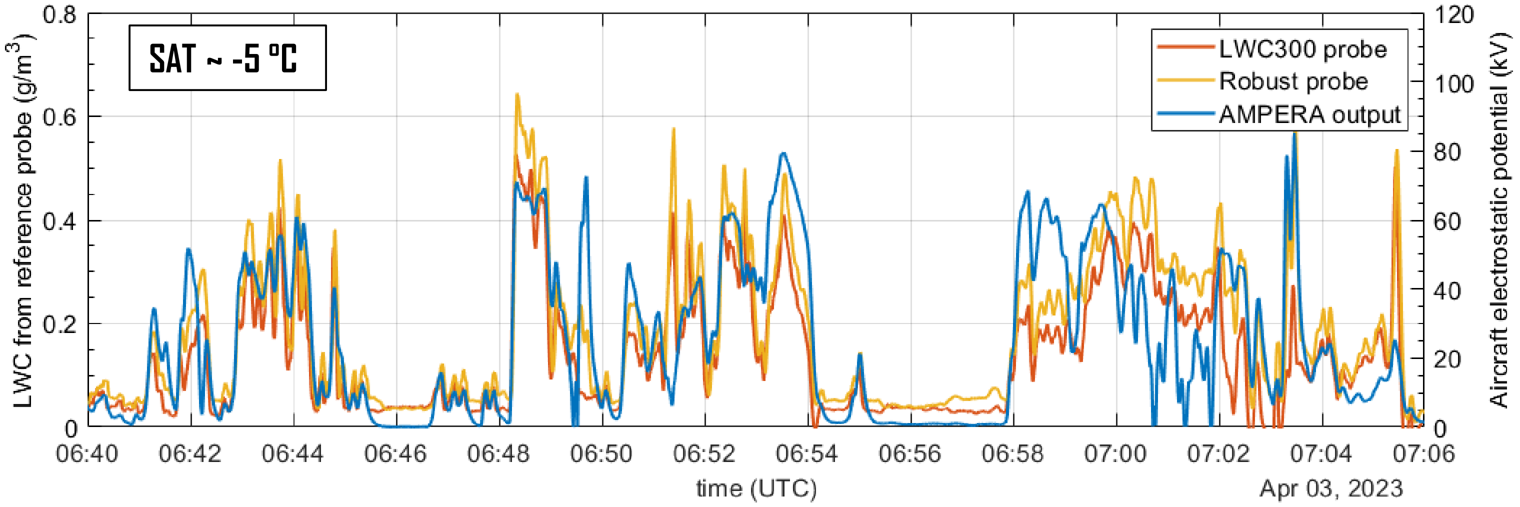
SENS4ICE FT campaign: first results

- AMPERA outputs versus reference probes: example 1



*LWC300 and Robust probe from Safire ATR42

Fair correlation between LWC and Va

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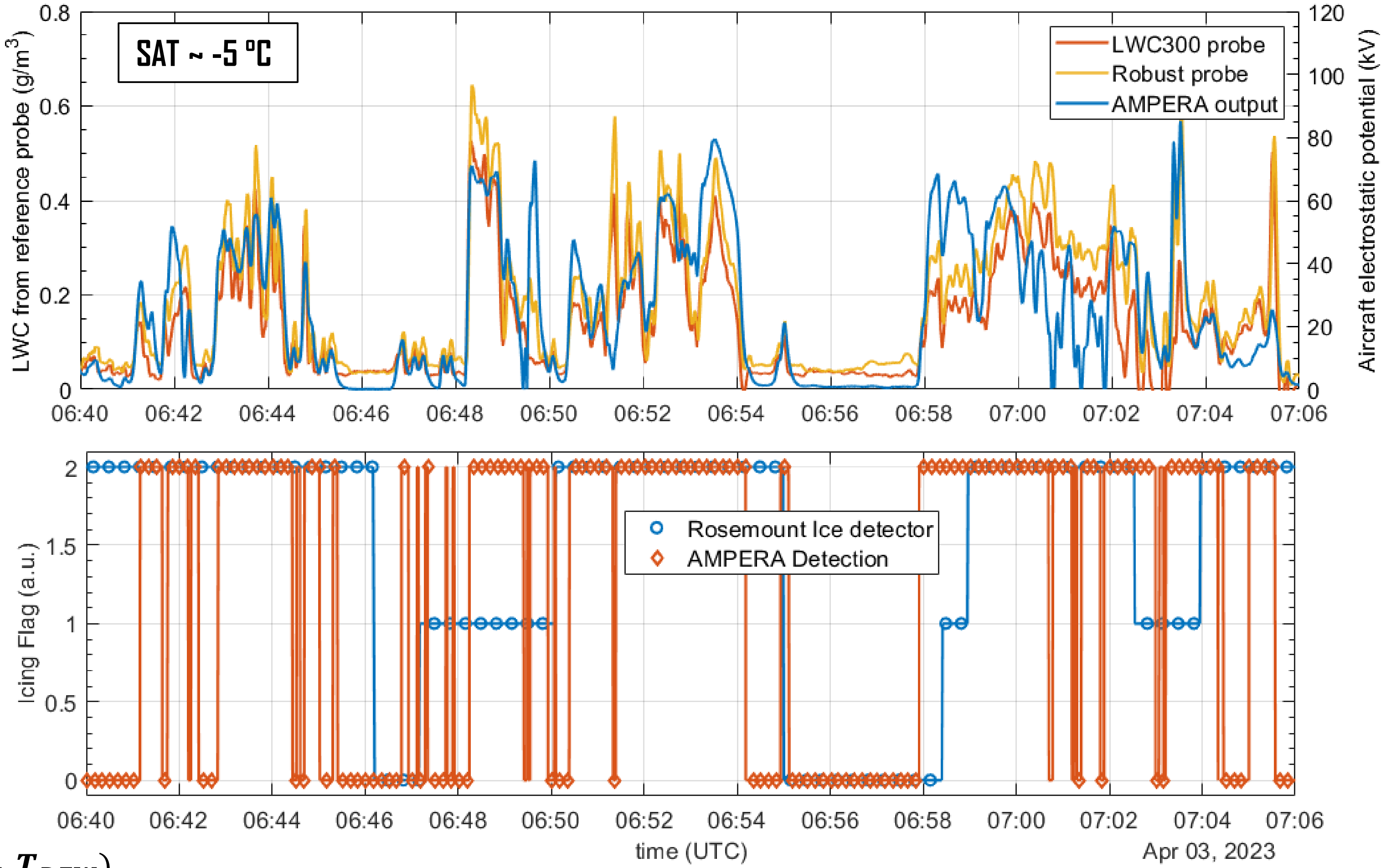

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Good agreement of AMPERA icing Flag (atmospheric condition) versus Aircraft flag (ice accretion)

*Rosemount Ice detector from Safire ATR42

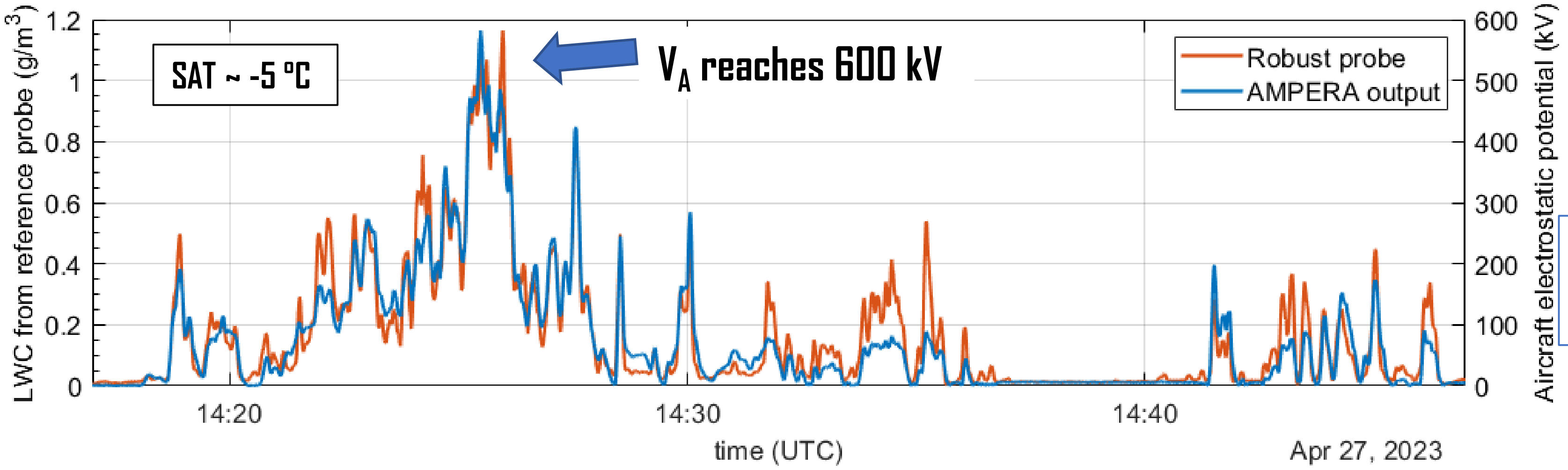
AMPERA Icing detection algorithm:

$$ICE_{Flag} = f(V_A, T_{SAT}, T_{DEW})$$

SENS4ICE FT campaign: first results

- AMPERA outputs versus reference probes: example 2

Flight Level 130
(4000 m)



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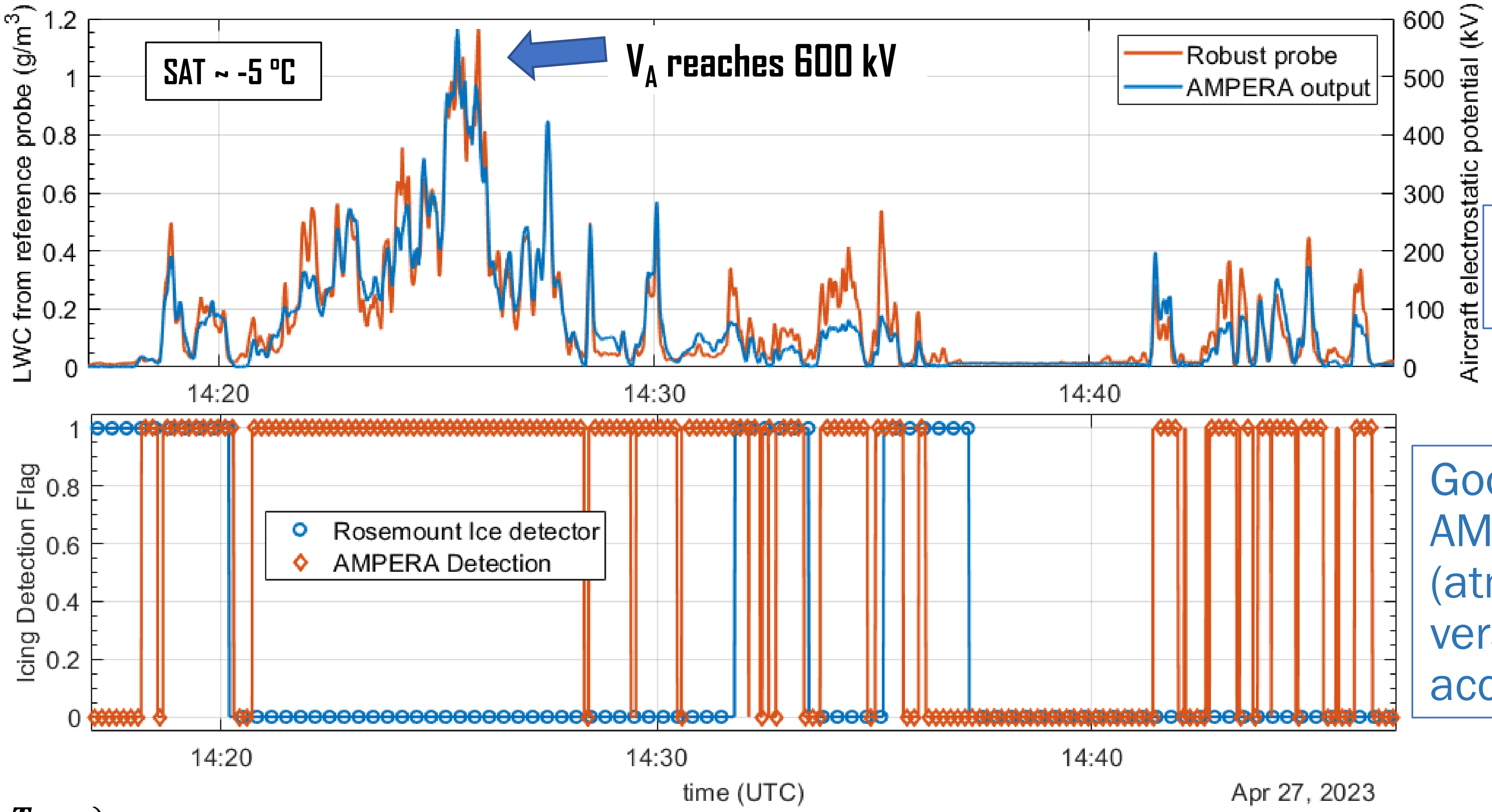

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Conclusion and perspectives

- Conclusion
  - Innovative principle of icing detection
  - Easy integration: anywhere in the aircraft
  - Preliminaries flight test results: robust sensor
  - Quick response taking into account the overall aircraft exposure
  - Comparisons with reference TWC/LWC probes on going
  - Influence of ambient parameters to be determined

- Perspectives
  - Campaign results to be analysed
  - Differentiating aircraft charging by ice crystals and water droplets to be investigated
  - Adapt system to be installed in UAV

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SENS4ICE

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Contact Info

- Thank you

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