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

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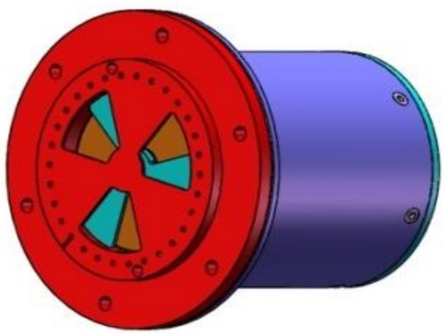
AMPERA – Atmospheric Measurement of Potential and Electric field of Aircraft (ONERA)

- detection type: **atmospheric conditions**
- physical principle: **measurement of aircraft electrical potential and correlation with the overall particles that impact the airframe**
- sensor high-level output description: **LW ICE YES/NO and TWC**
- main sensor specifications: **10x10x10 cm^3/ 0.8 kg / 25 W / per electric field mill**
- TRL at project start: **4** → TRL now: **5-6 (for detecting LW conditions)**
- testing: **flight test on ATR42 platform**



Outline

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

Context and Objectives

- 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

sample a local area

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

overall estimation of aircraft exposure condition

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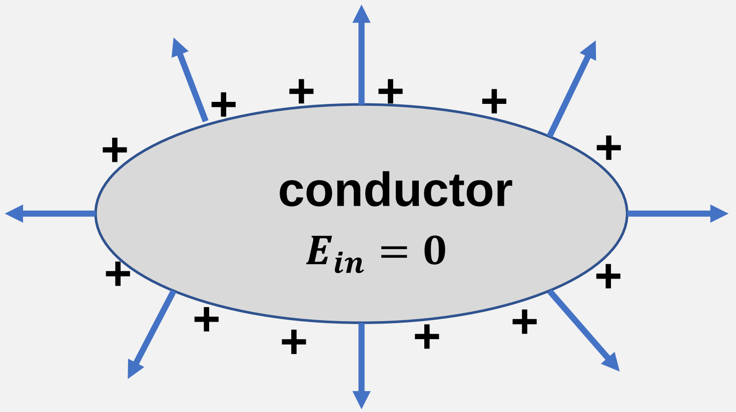
AMPERA system description

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

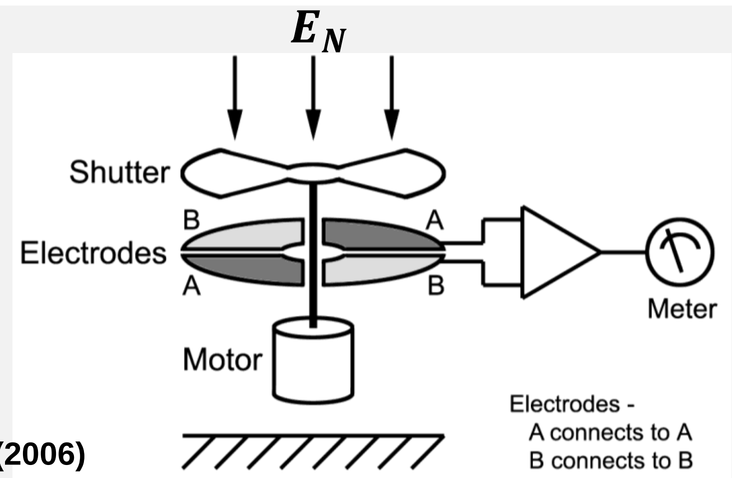
- Principle



Normal electrostatic field in a charged conductor

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

- EFM description



Lynn Ashley (2006)

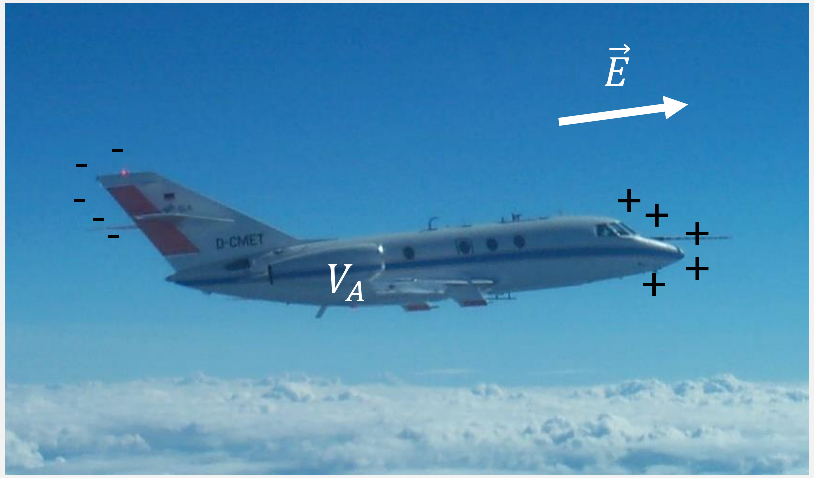
Modulated measurement of electric current in sensing electrode

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

The normal electrostatic field is directly determined

AMPERA system description

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



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

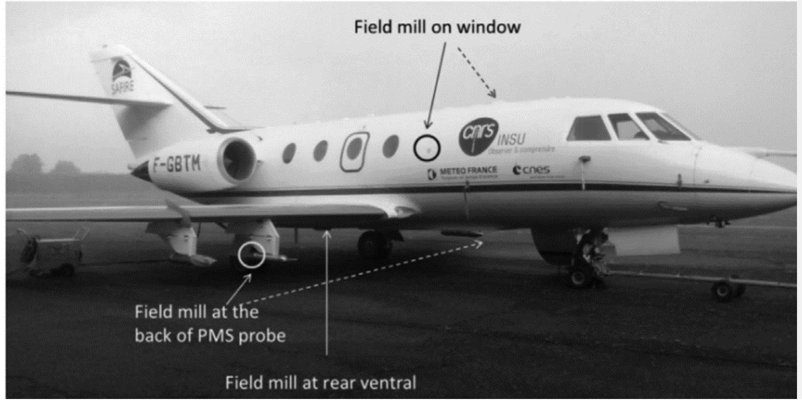
$$\boldsymbol{E_{EFM} = \alpha \times E_X + \beta \times E_Y + \gamma \times E_Z + \lambda \times V_A}$$

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

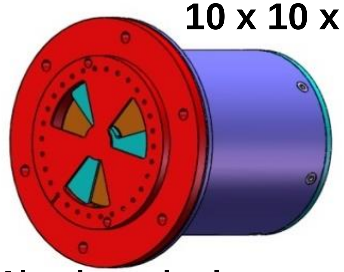
Ex, Ey, Ez → Ambient electric field
V_A → Aircraft electric potential

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



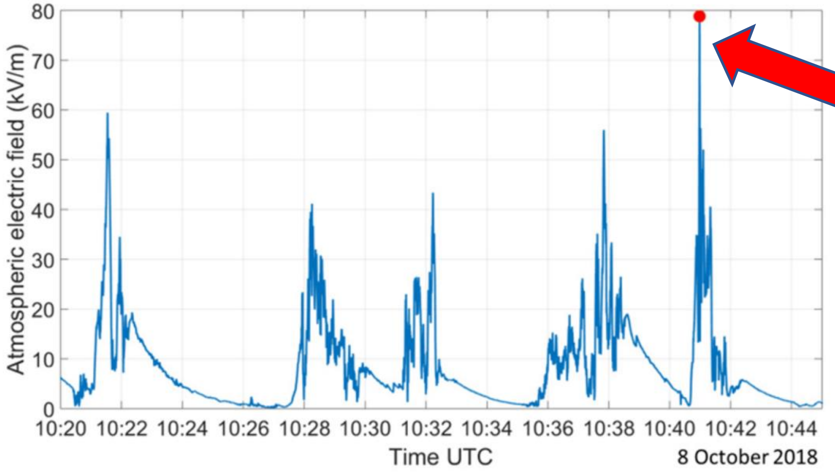
10 x 10 x 10 cm^3



Aluminum body grounded to the fuselage

Flush installation

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



Aircraft lightning strike

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

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

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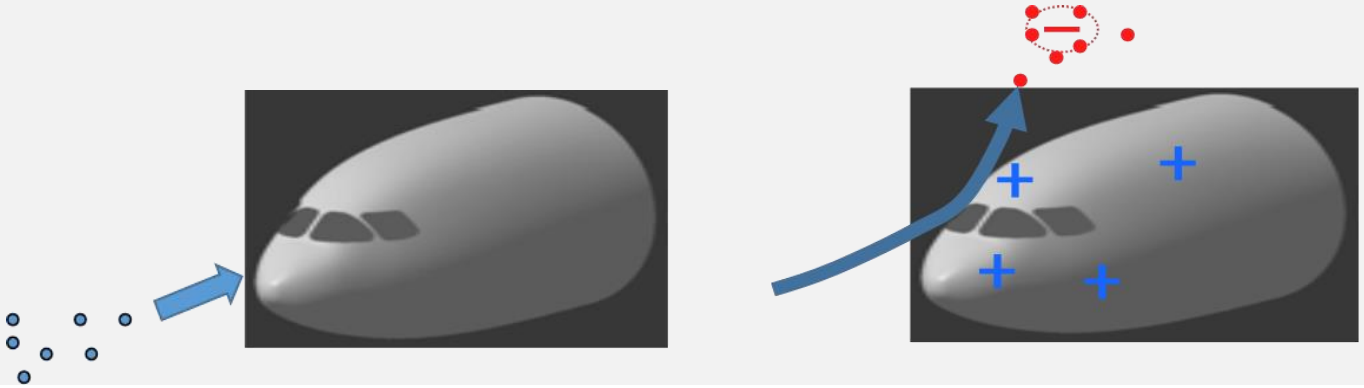
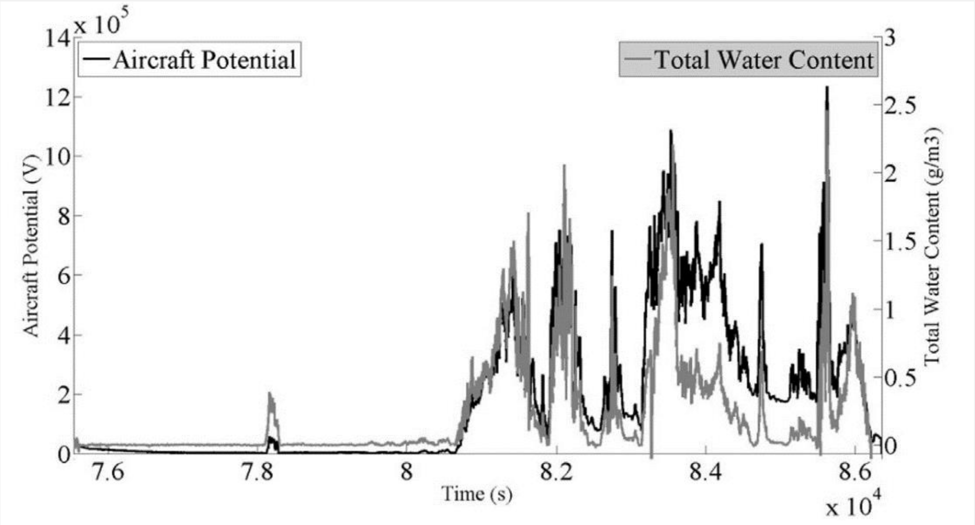
AMPERA utilisation for icing detection

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



overall net charge of all particles impacting the aircraft

- Icing condition correlation on previous flight test campaign

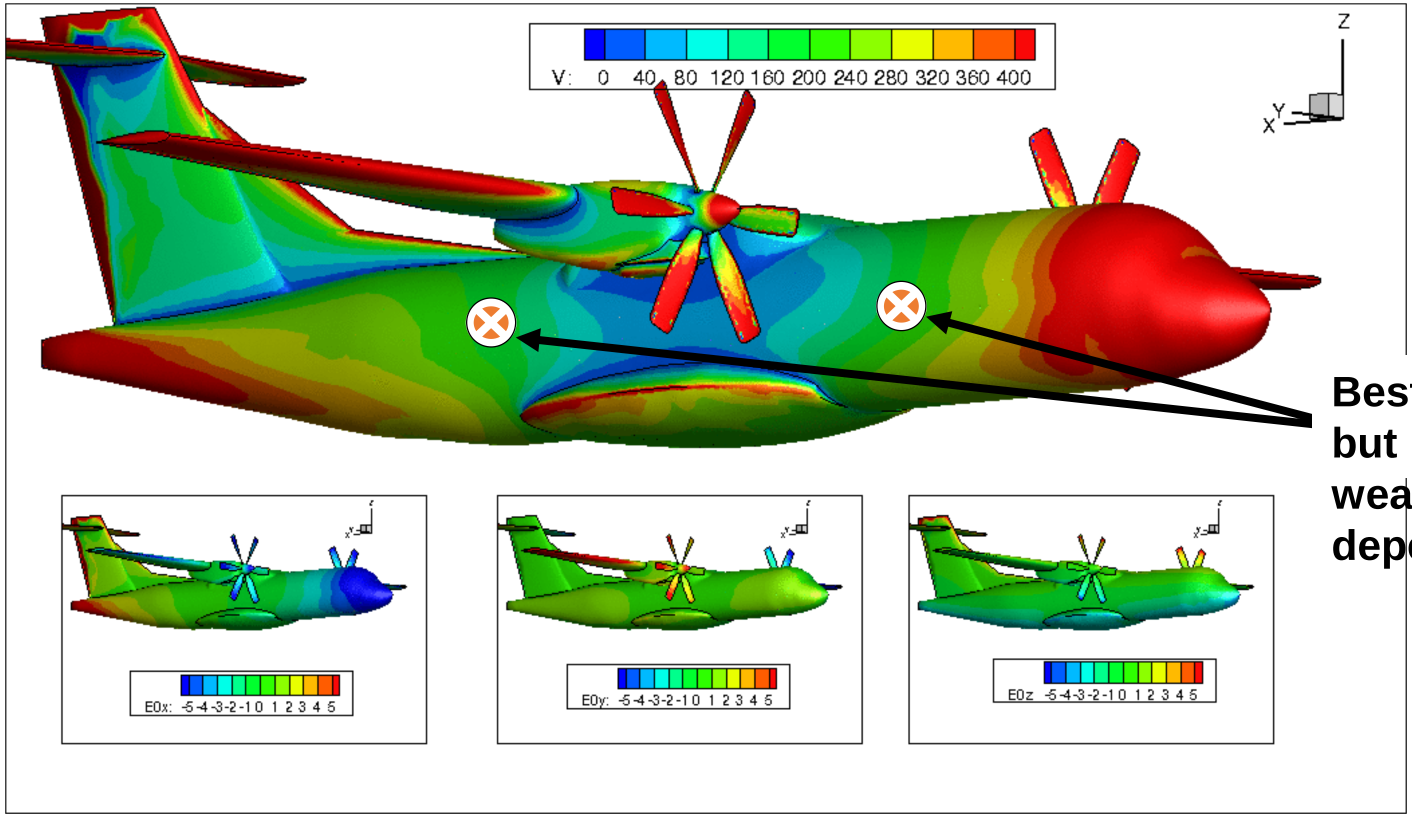


- **HAIC-HIWC Project (https://cordis.europa.eu/project/id/314314)**
- **glaciated high TWC convective cloud**
- **good agreement between V_A from AMPERA and TWC from IKP2 probe**

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

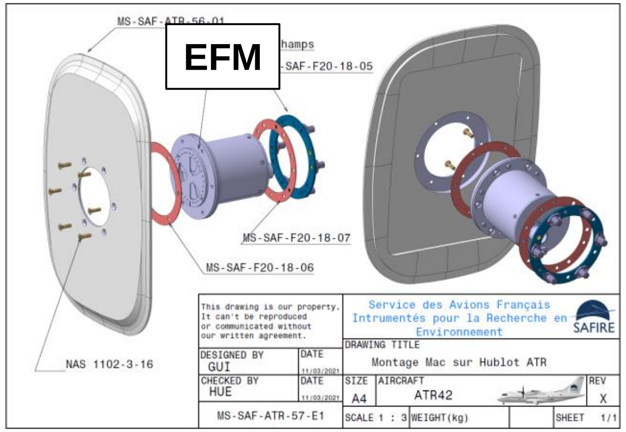


Best positions: moderate V_A but weak E components dependence

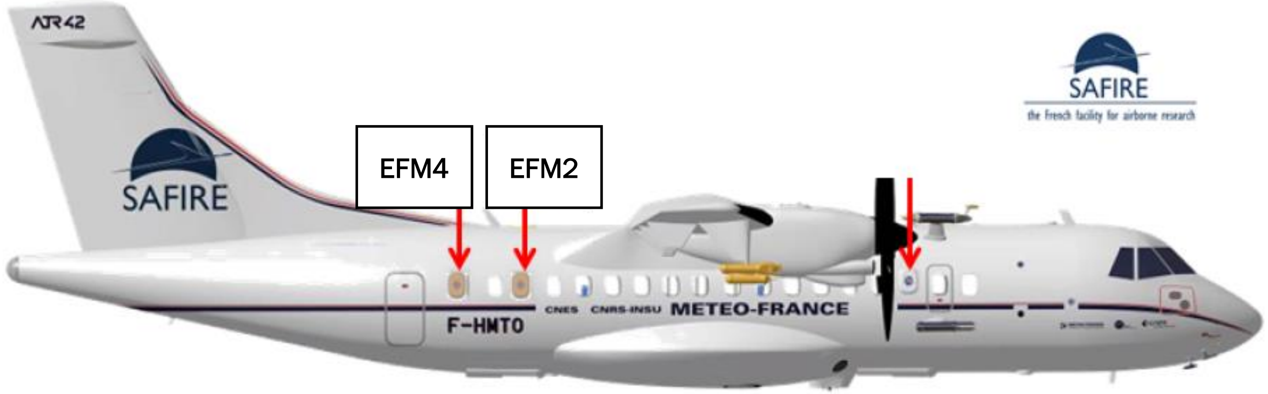
From the electrostatic calculation we can deduce the aircraft capacitance and the normal field coefficients: α, β, γ and λ

AMPERA utilisation for icing detection

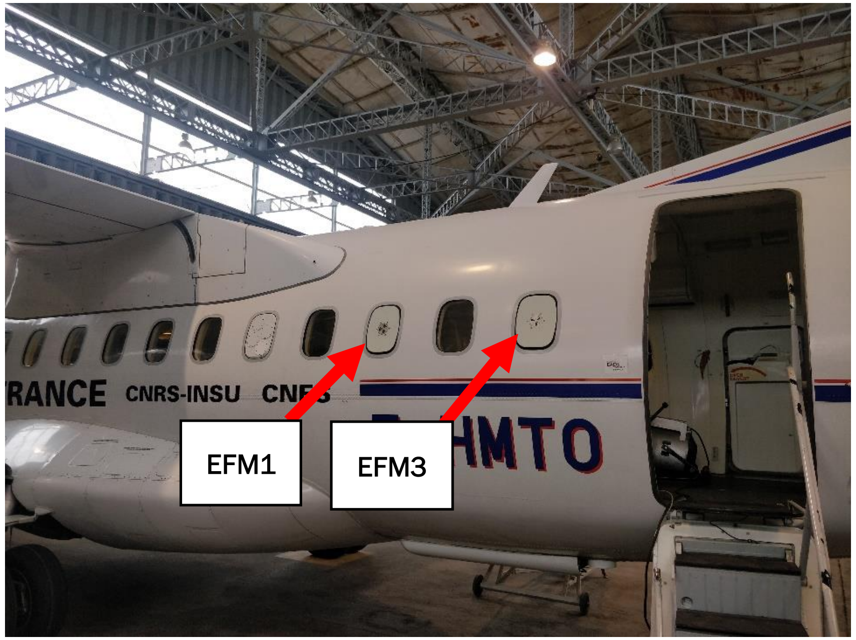
- For Safire ATR42 platform – 4 EFM are installed in rear windows



drawing from Safire



EFM 1 and 3 in the symmetrical opposite windows



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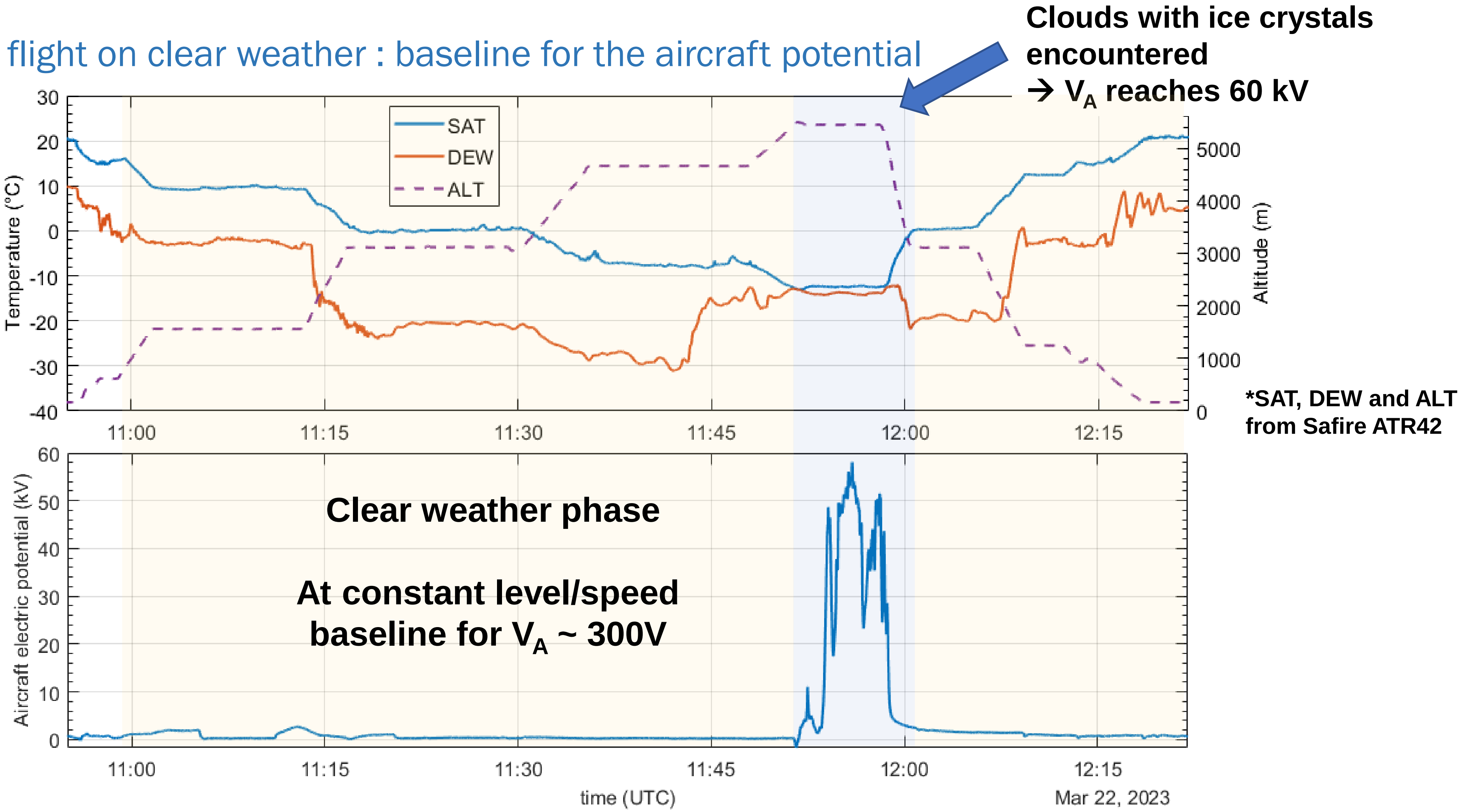
SENS4ICE FT campaign: Calibration flight

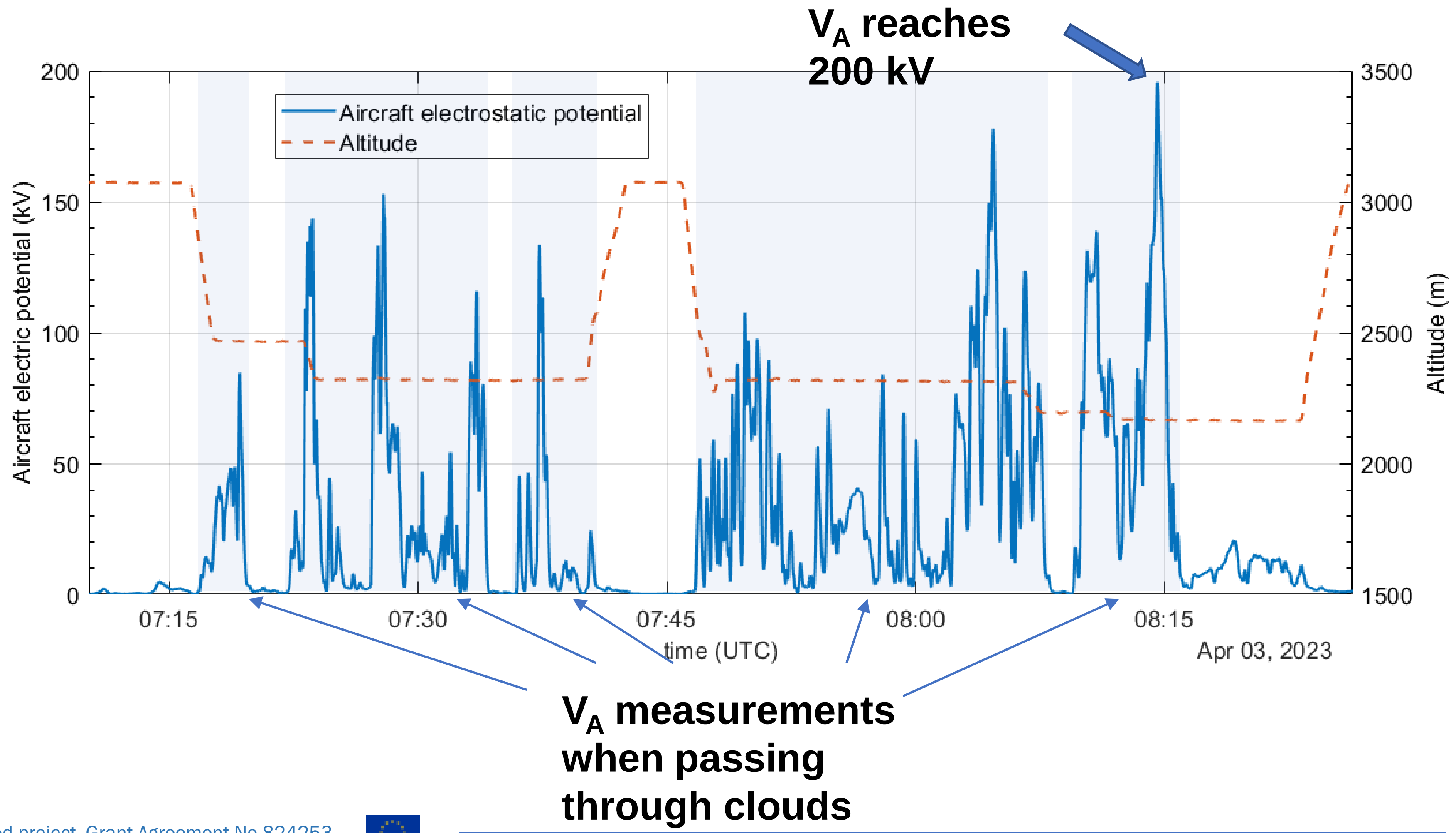
- First flight on clear weather : baseline for the aircraft potential



SENS4ICE FT campaign: first results

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

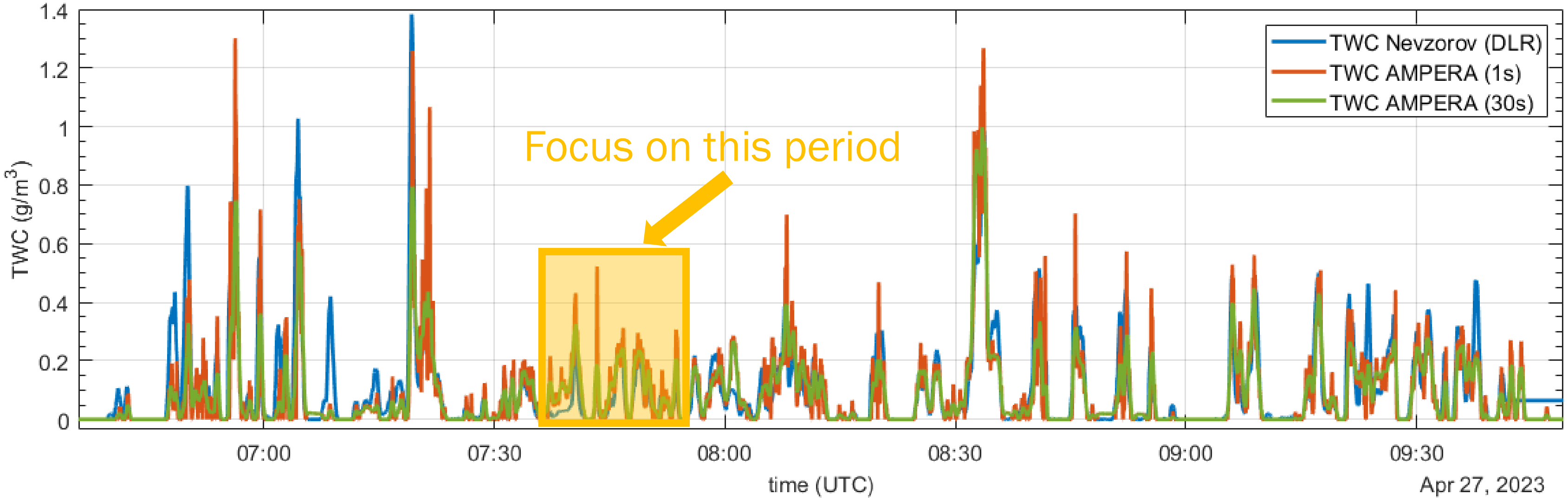
Static temperature during this phase ranging between -8 to -5 °C



***ALT from Safire ATR42**

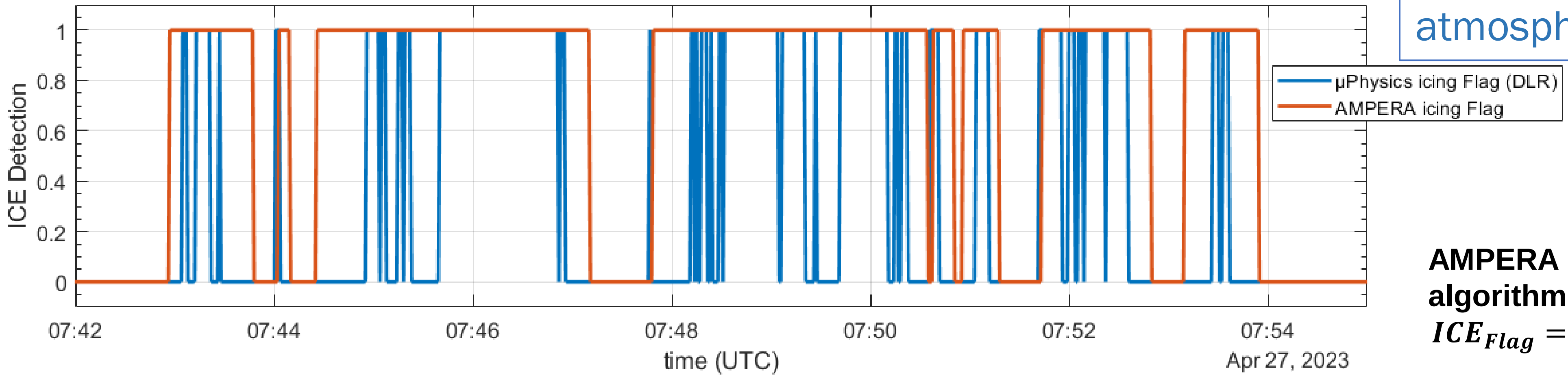
SENS4ICE FT campaign: first results

AMPERA outputs versus reference probes



*Nevzorov probe from DLR team

Good correlation between TWC from reference probe and TWC from AMPERA



Good agreement of µPhysics icing Flag and AMPERA (both atmospheric condition)

AMPERA Icing detection algorithm:

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

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Conclusion and perspectives

Conclusion

- Innovative principle of icing detection
- Easy integration: anywhere in the aircraft
- Preliminary flight test results: robust sensor → good agreement with reference probes
- Quick response taking into account the overall aircraft exposure
- Comparisons with reference probes and influence of ambient parameters ongoing

Perspectives and research gaps

- Complete analysis of all data from last flight campaign → scientific publication
- Need to understand the aircraft triboelectricity process on icing conditions
- Differentiating aircraft charging by ice crystals and water droplets to be investigated → very challenging task!
- More flight data covering the full range of icing conditions would help
- Adapt system to be installed in UAV → reduction of size → new EFM technology

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

If not acknowledged, images courtesy of the consortium partners.

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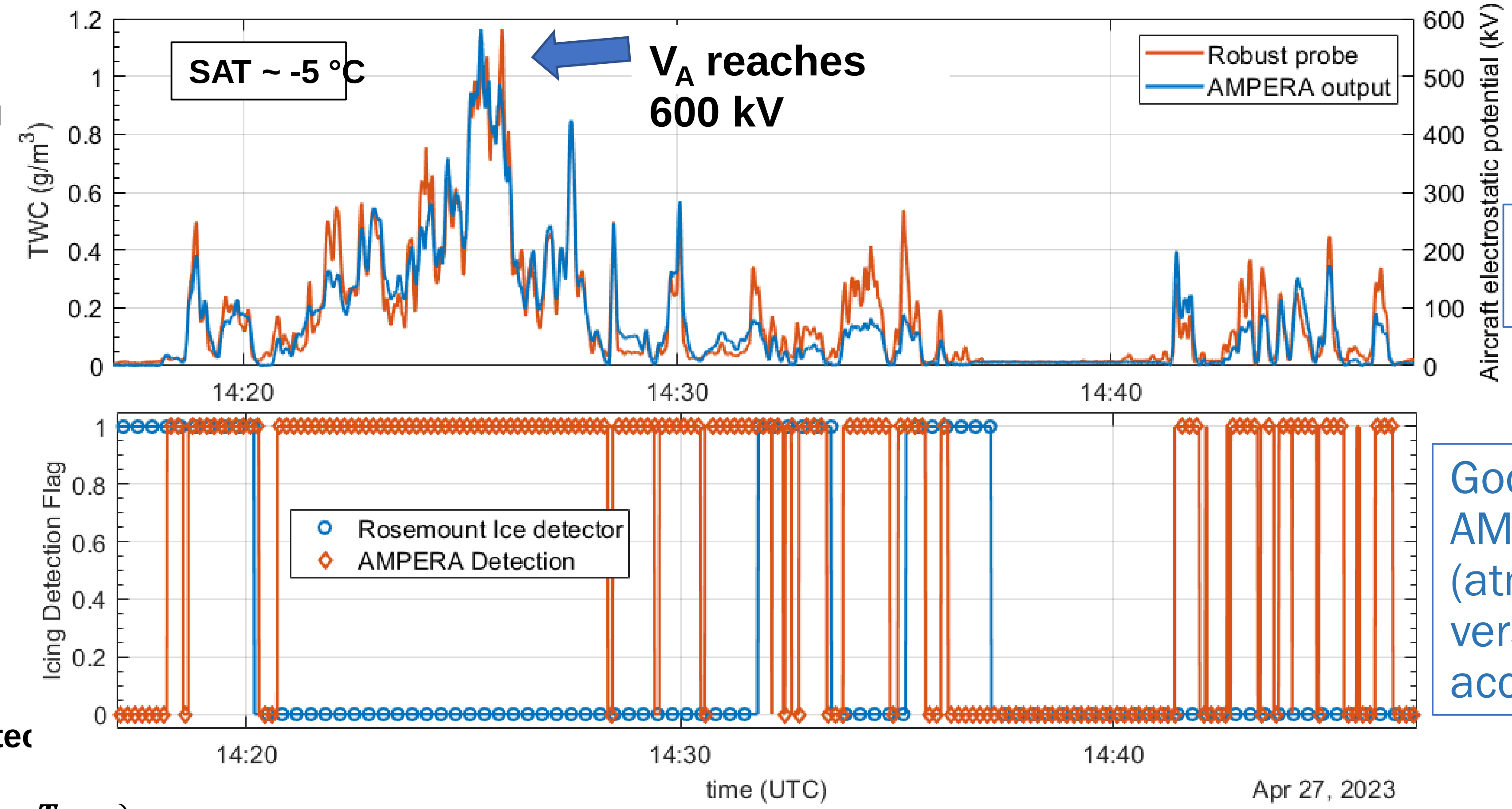
and Linkedin #sens4iceproject

Support slide: SENS4ICE FT campaign

- AMPERA outputs versus reference probes: example 2

*Robust probe from Safire ATI

Flight Level 130
(4000 m)



Good correlation between LWC and Va

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

AMPERA Icing detec algorithm:
$ICE_{Flag} = f(V_A, T_{SAT}, T_{DEW})$

*Rosemount Ice detector from Sa