

HOW EFFICIENT IS YOUR BLADE HEATING?



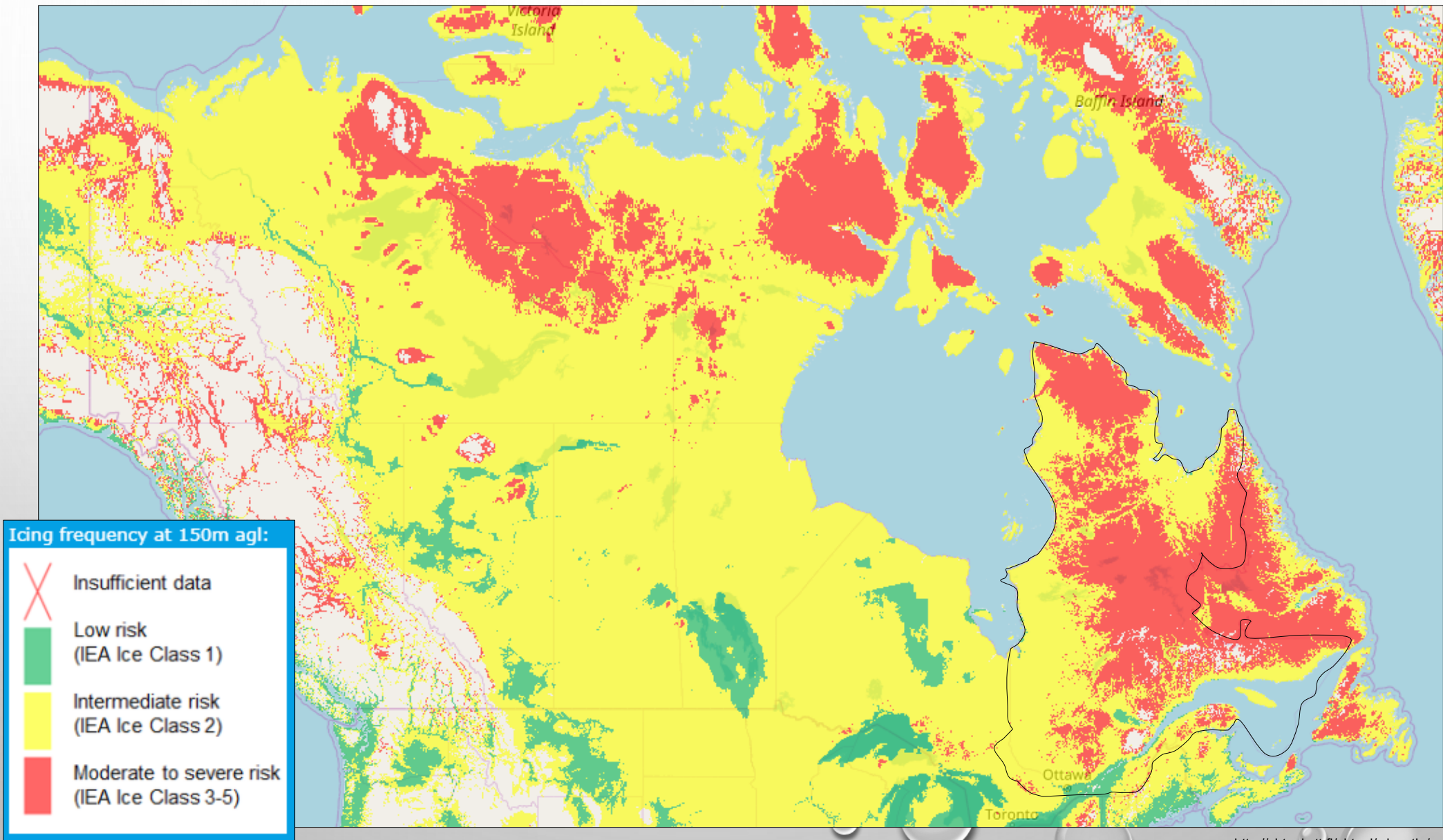
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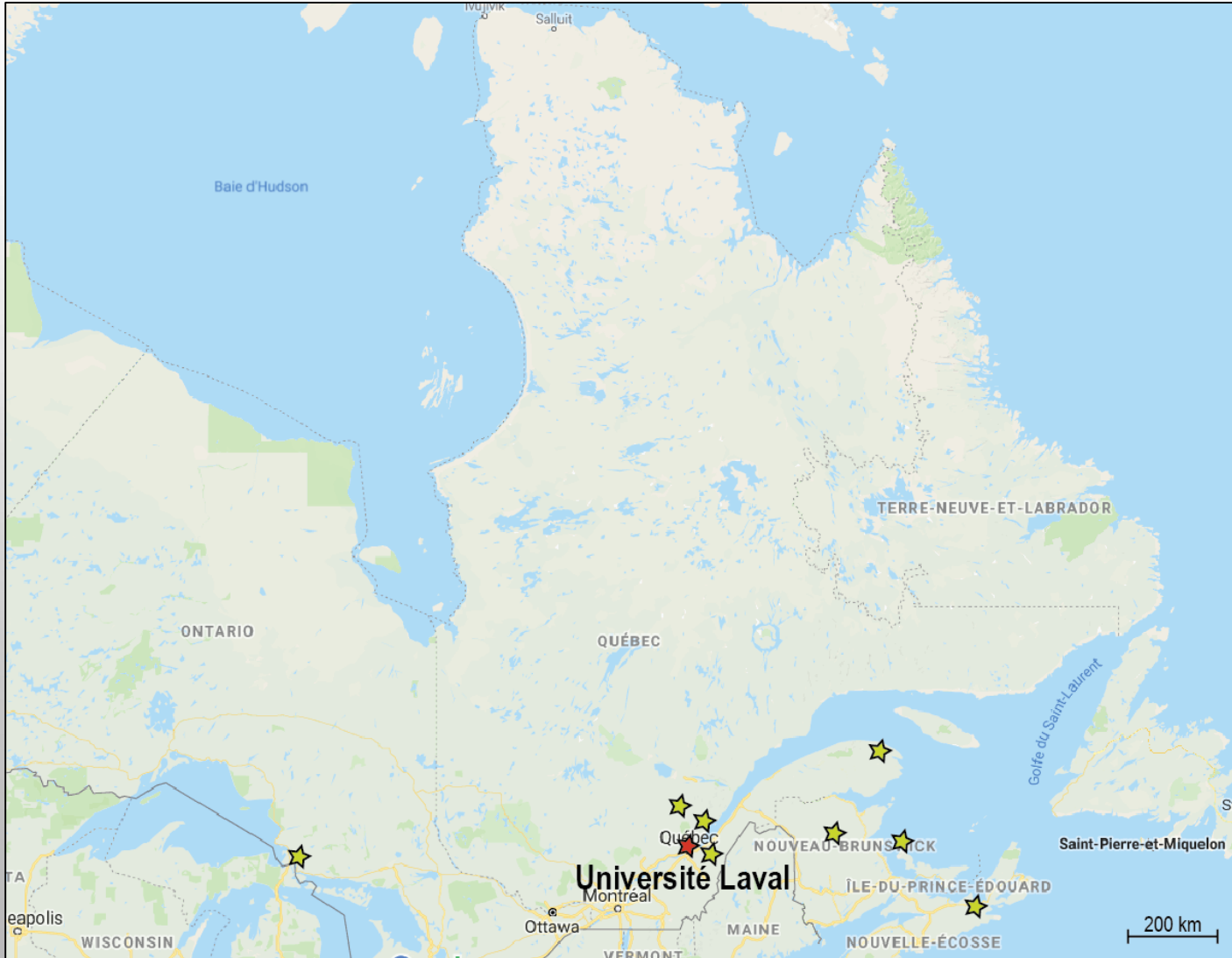
Not enough heat to prevent accumulation nor to remove ice.

- Wind speed too important.
- Temperature too low.

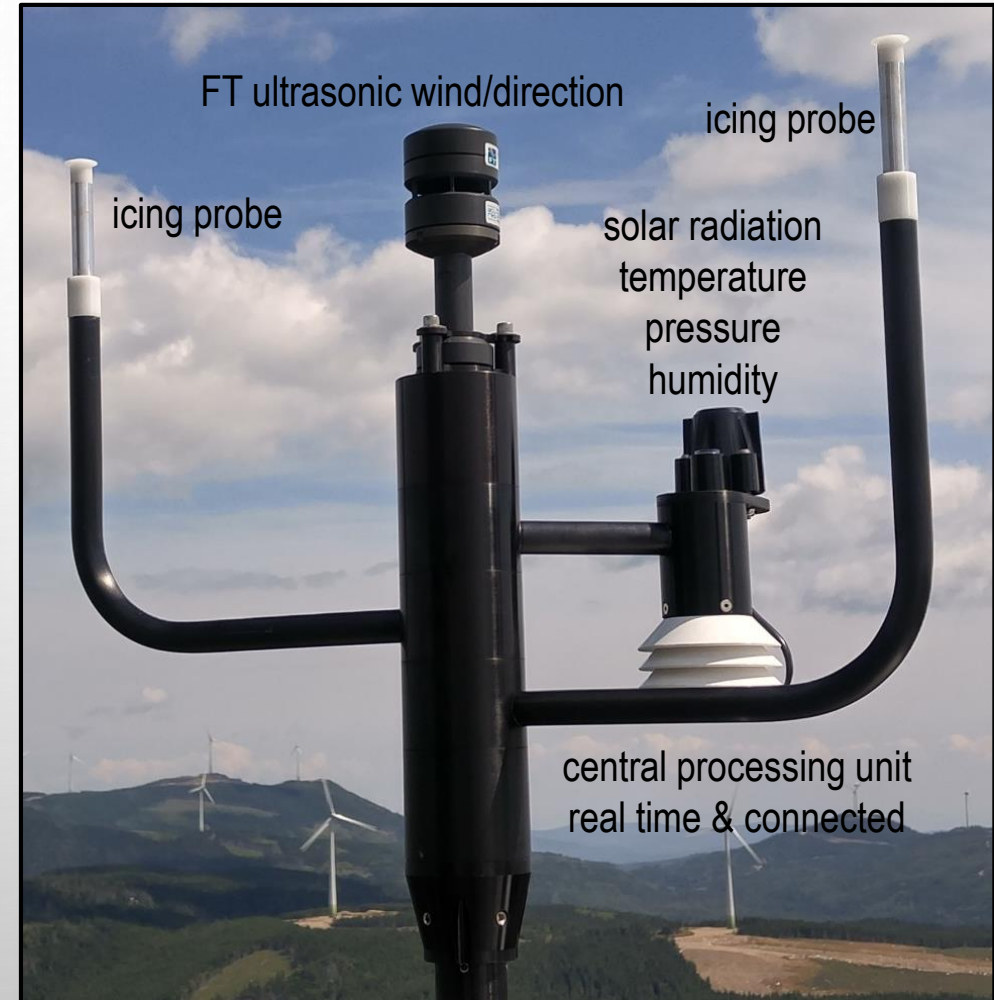


source: <http://virtual.vtt.fi/virtual/wiceatla/>

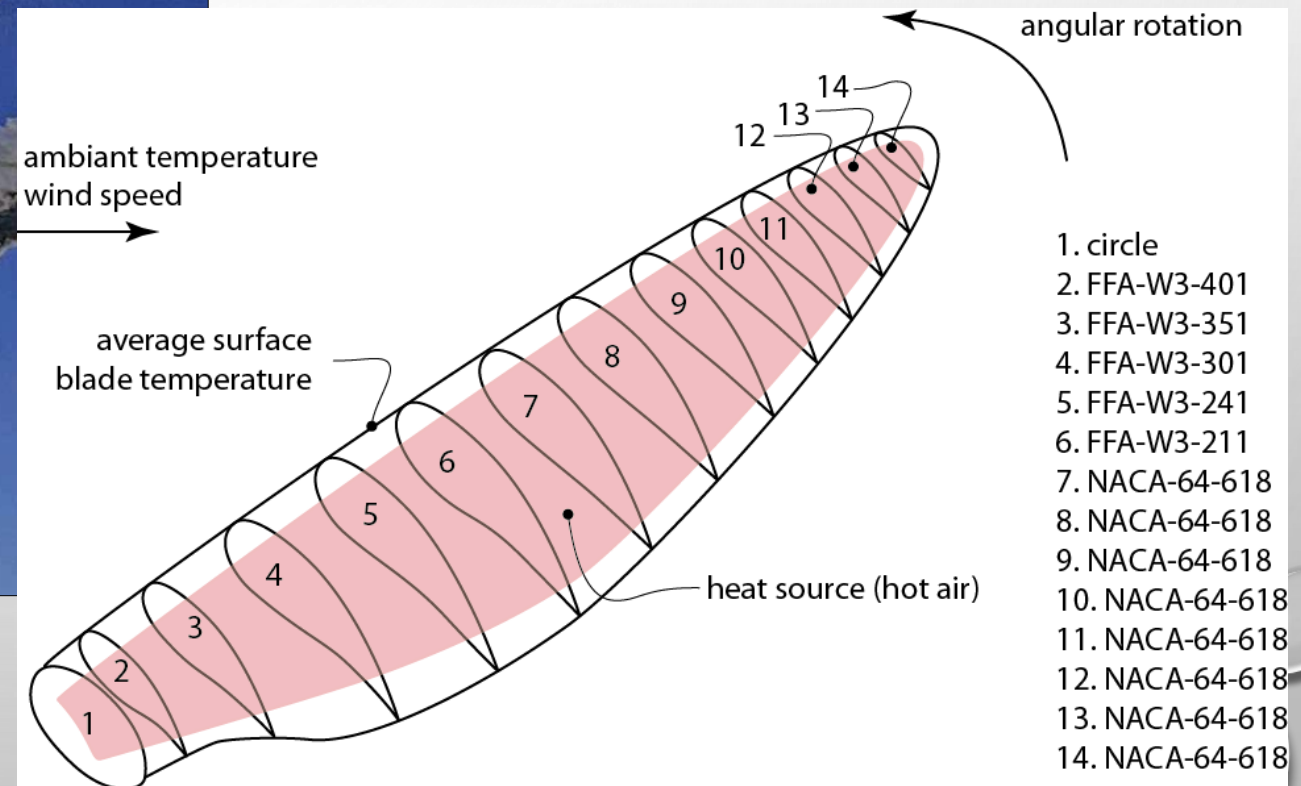
MY RESEARCH INTERESTS



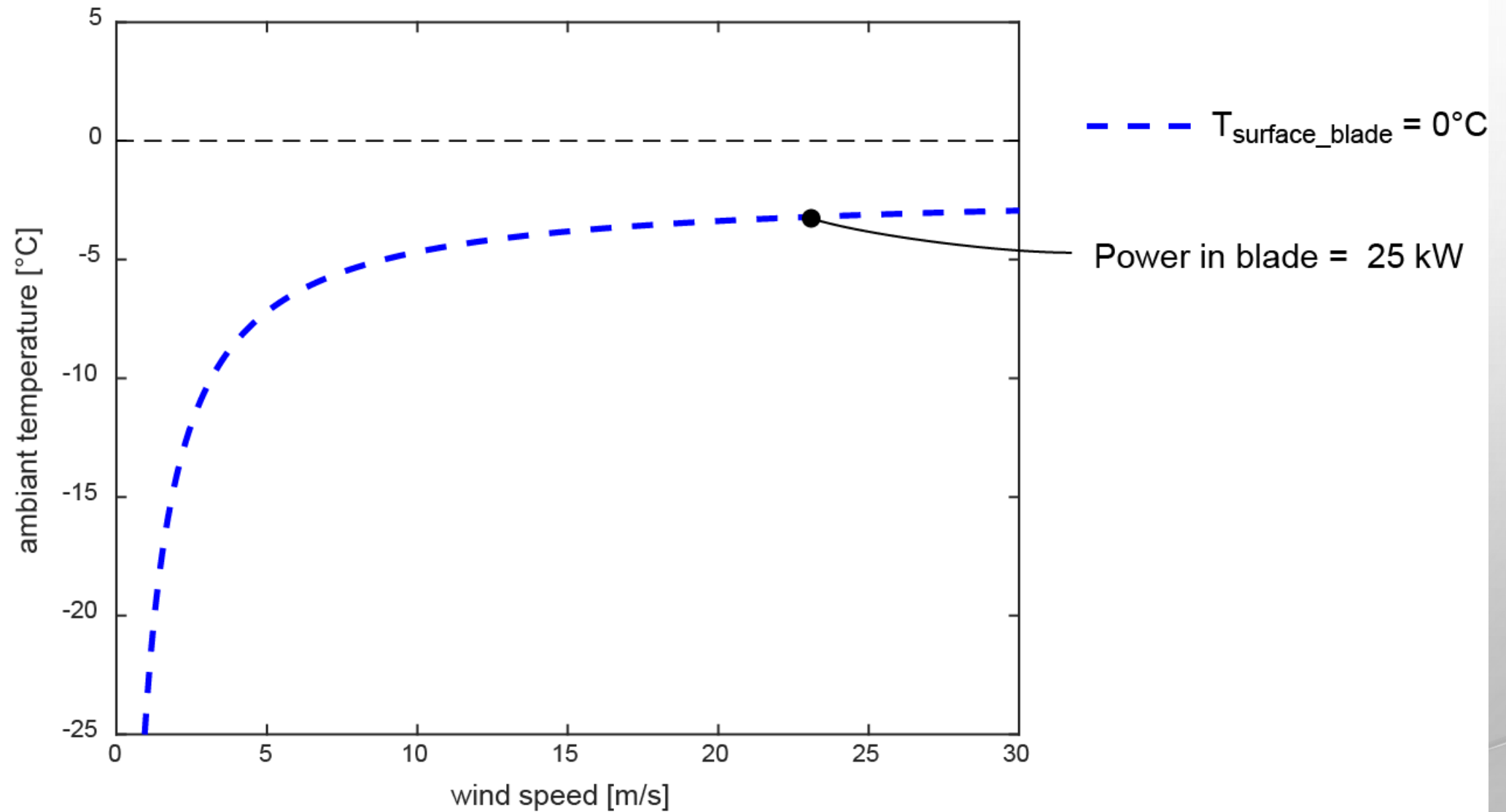
Meteorological Conditions Monitoring Station (MCMS)



THROWBACK TO WINTERWIND 2018



THROWBACK TO WINTERWIND 2018



UNDISCLOSED INDUSTRIAL PARTNER...

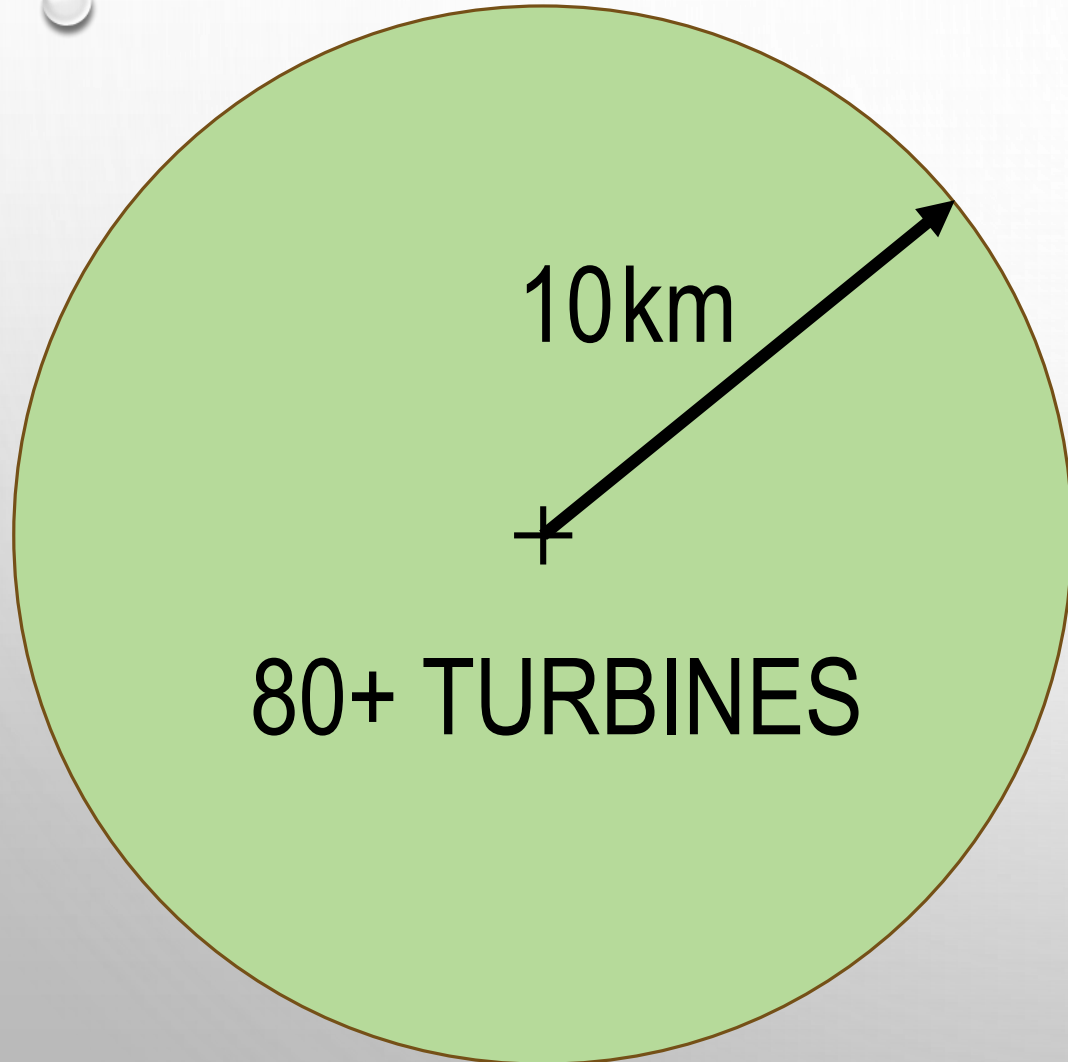
"What is going on?"

"Where is my money?"

"Icing losses... why? I have heated turbines!"

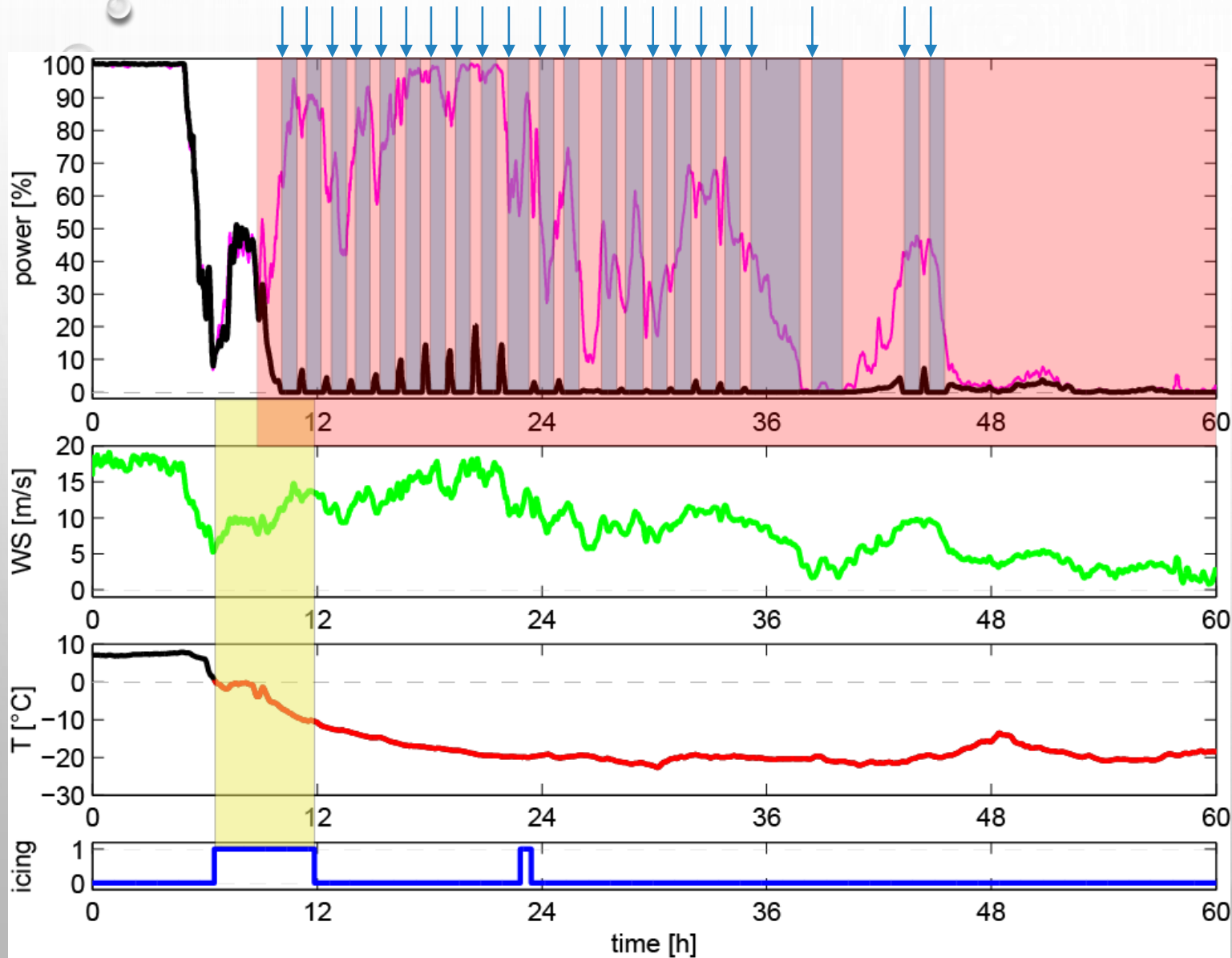
"What should I expect from the Ice Protection Systems?"

WHERE AND WHEN



- Undisclosed location
- Confidential operator
- Hot air blade heating
- 2 years of data (2016-03 to 2018-03)

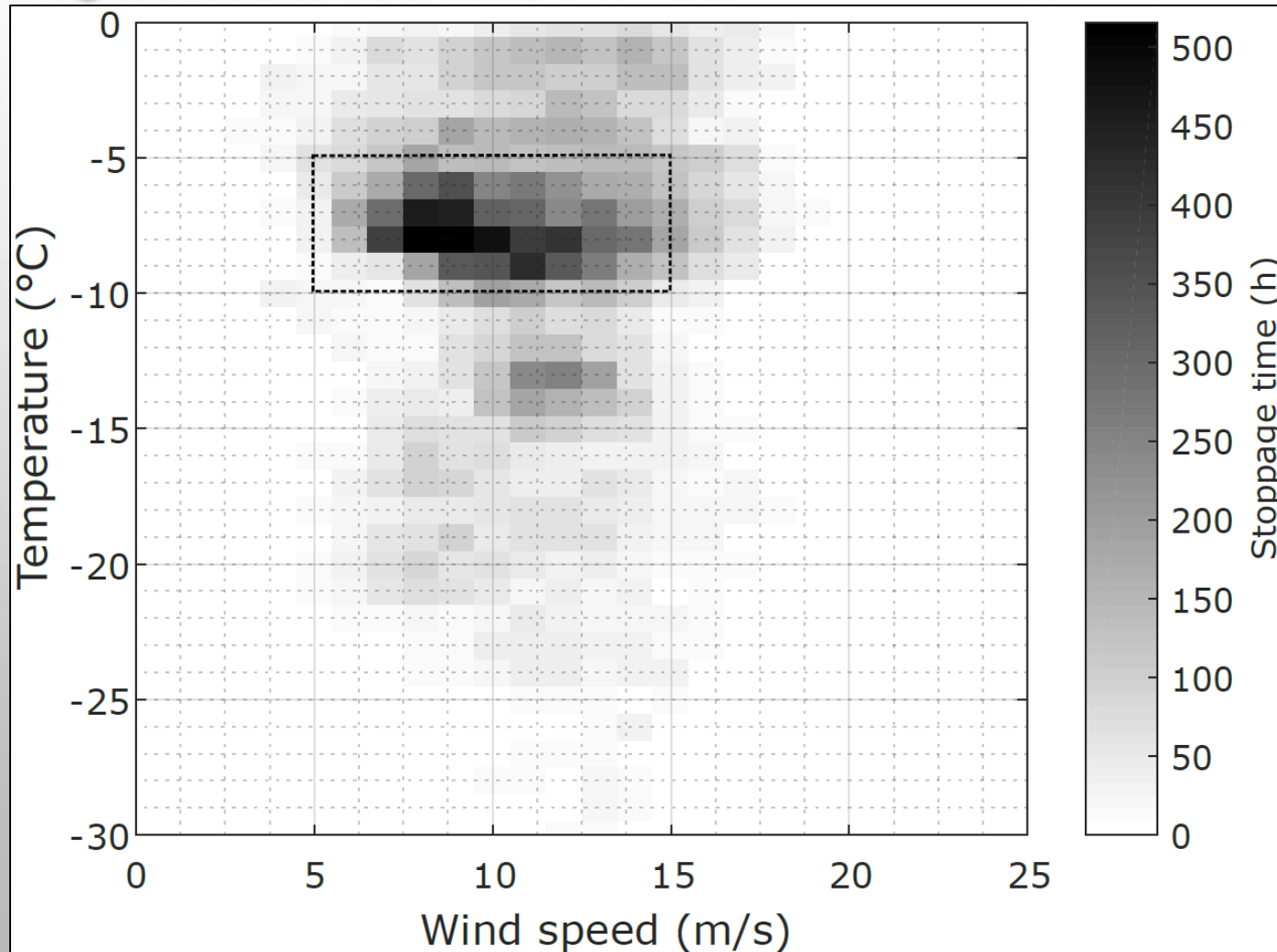
TYPICAL ICING EPISODE



22 events within this episode.
1 event = 1 turbine stoppage
For each event:

- mean temperature
- mean wind speed
- duration

STATISTICAL ANALYSIS

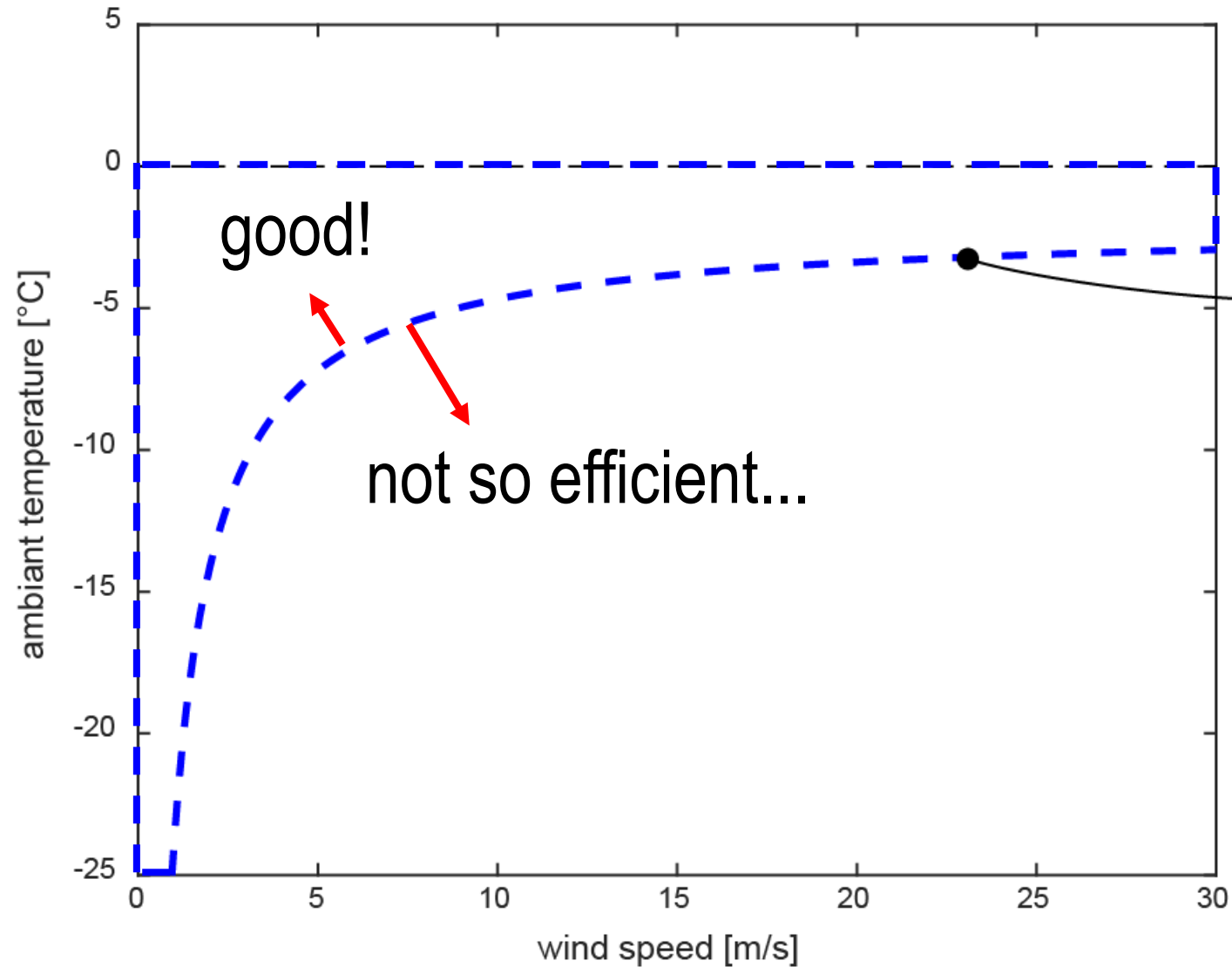


turbine stoppages = 12521
total downtime = 27 185h

hypothetical:

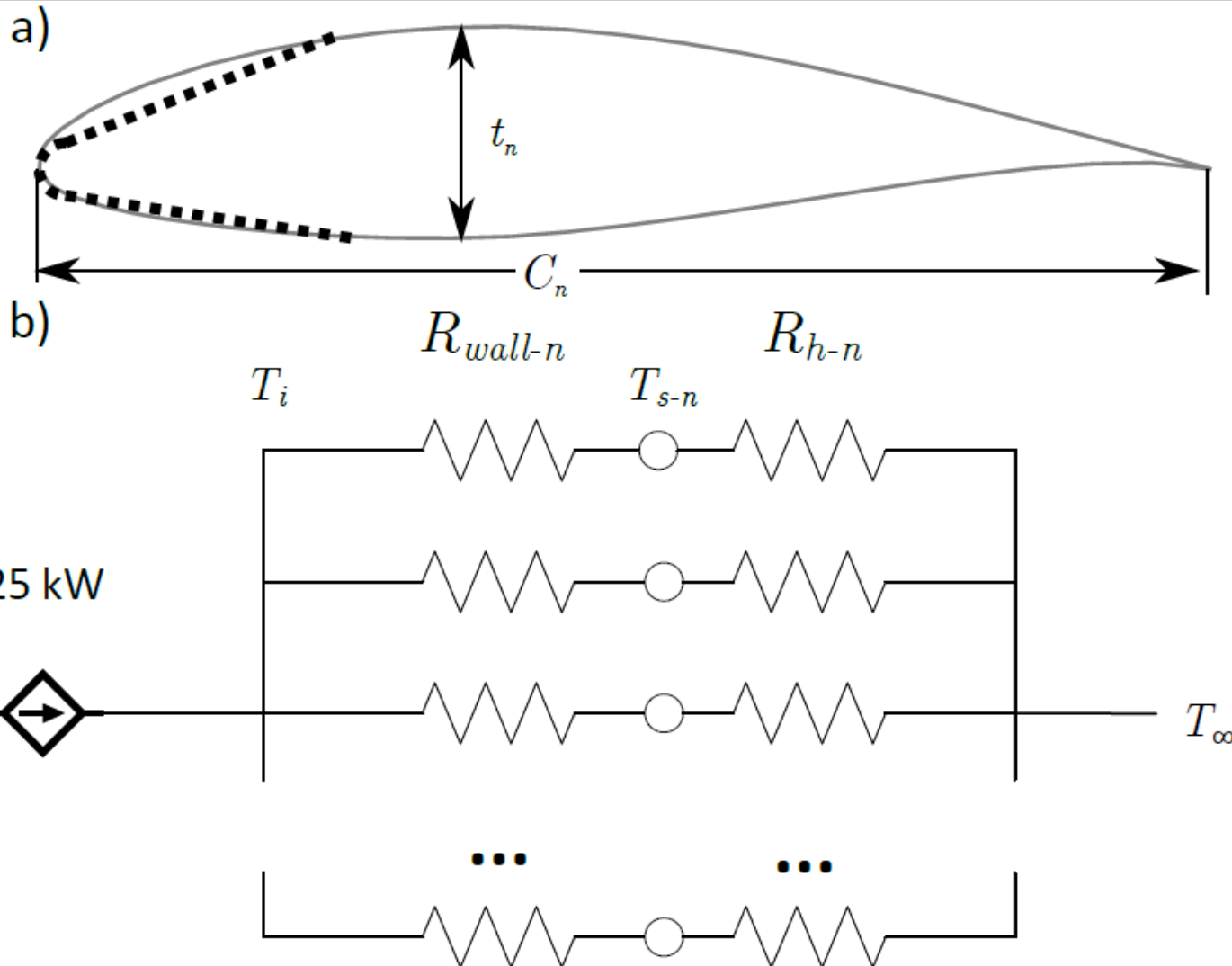
for 3MW turbines with $C_p=0.3$
@6.6c€/kWh (0.10\$CAD/kWh)
loss = 1.6M€ (2.5M\$CAD)

IPS PERFORMANCE ENVELOPE CONCEPT



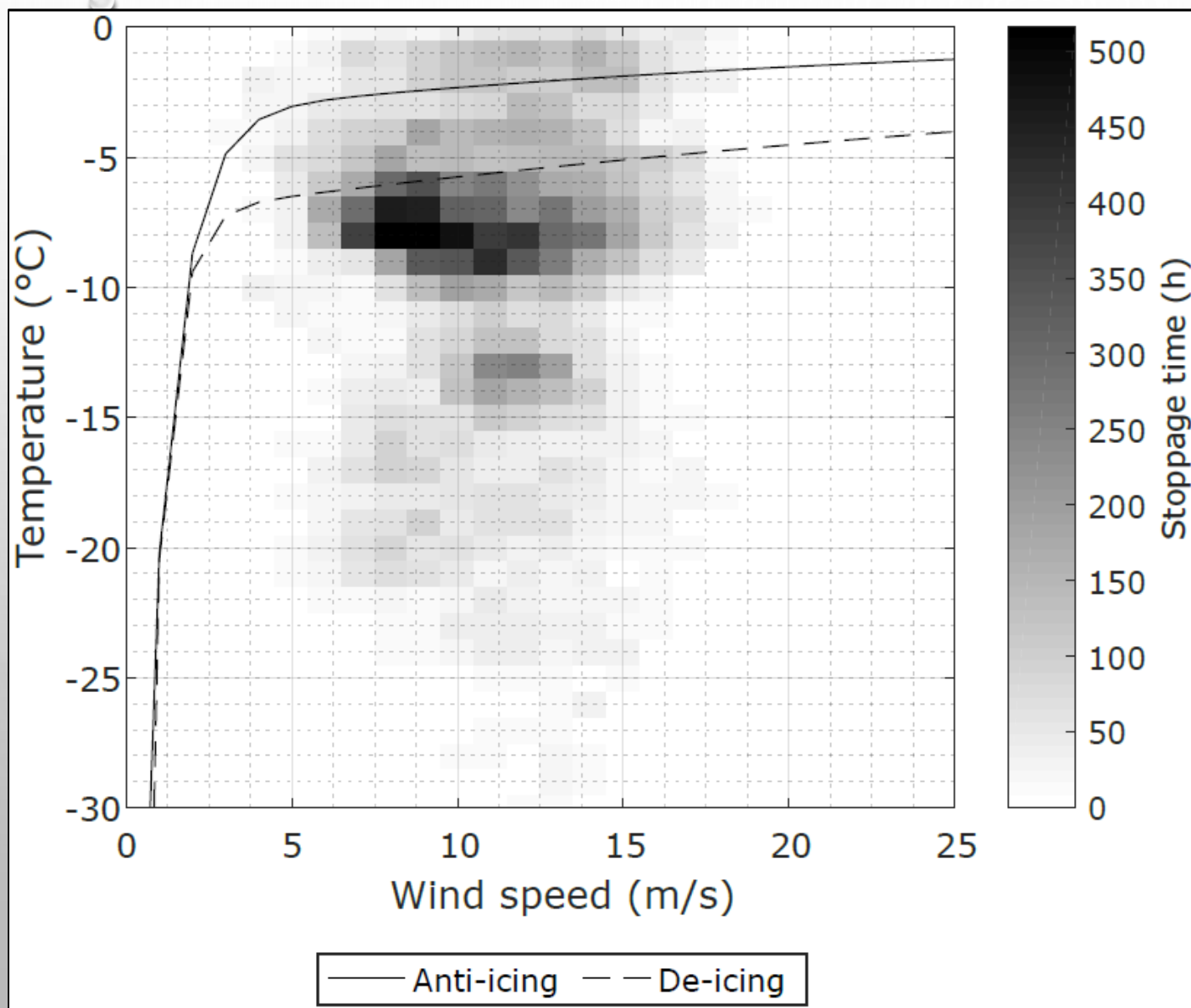
IPS performance envelope boundary

BLADE HEATING MODEL



- Based on a simple 1D blade heating model;
- Blade broken into 14 sections of different profiles;
- Does not take into account LWC;
- Accounts for rotation rate (higher convection at the tip);
- Thermal resistance approach.

IPS PERFORMANCE ENVELOPE



- Simple model;
- Fairly accurate;
- Easy to use (2 parameters)
 - wind speed
 - air temperature
- Can explain why;
- Should be provided by the turbine manufacturer.

CONCLUSION AND PERSPECTIVES

- The "IPS performance envelope" should be made available.
- Developers and operators: "Ask for it!"
- Wind turbine manufacturers: "Be proud of your product and share your IPS performance envelope!"





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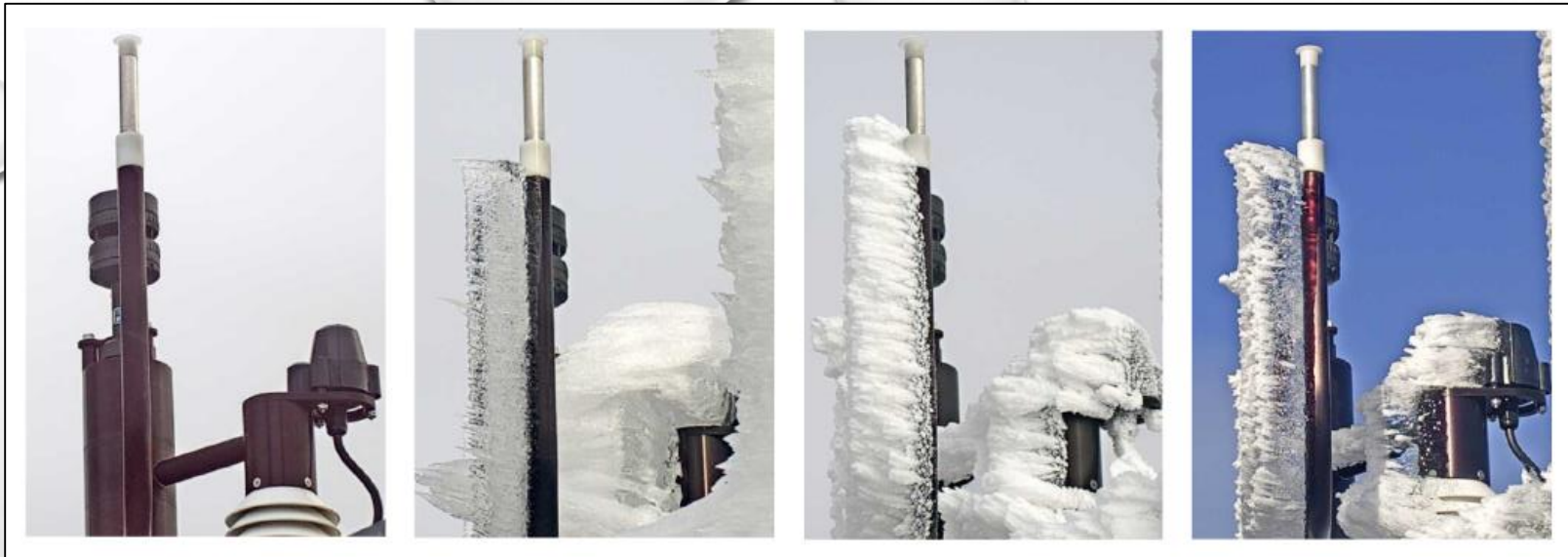
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G1V 0A6

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MERCI
THANK YOU
TACK

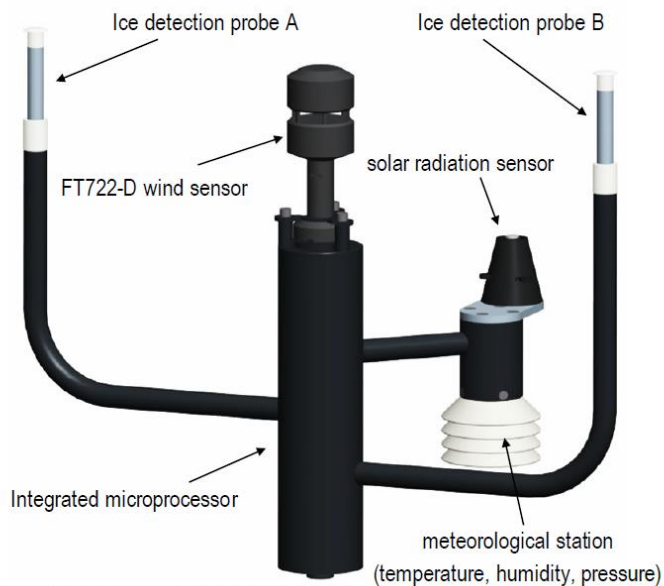
Meteorological Conditions Monitoring Station (MCMS)



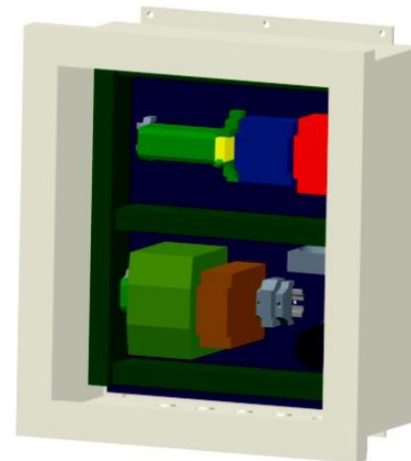
Measurements

Wind speed	0 to 50 m/s	± 0.5 m/s (0 to 15 m/s) ± 4 % (>15 m/s)
Wind direction	0 to 360°	± 4 °
Temperature	-40 to 60 °C	± 0.1 °C (-18°C to 30°C) ± 0.5 °C (else)
Relative humidity	0 to 100 %	± 3 % RH
Barometric pressure	30 to 110 kPa	± 0.1 kPa
Solar radiation	0 to 1800 W/m ²	± 5 %
Liquid water content ²	Typ. 0 to 1 g/m ³	
Icing severity ²	Typ. 0 to 10 g/(sm ²)	
Ice accumulation ²	mm	
Icing type ²	glaze, soft rime, hard rime	
Precipitation	on/off	
Meteorological icing	on/off	
Instrumental icing	on/off	

MCMS (nacelle or mast)



Electrical box (in the nacelle or on the met mast)



ETL Certified *Intertek*

24 VDC, 10 A
surge protected

digital communication
surge protected

115/230 VAC

Ethernet