GLOBAL INSIGHTS ON WIND TURBINE ICING:

OPERATIONAL ENVELOPES AND ICE PROTECTION SYSTEM EFFICIENCY ACROSS DIVERSE CLIMATES

Winterwind, February 3rd, 2025

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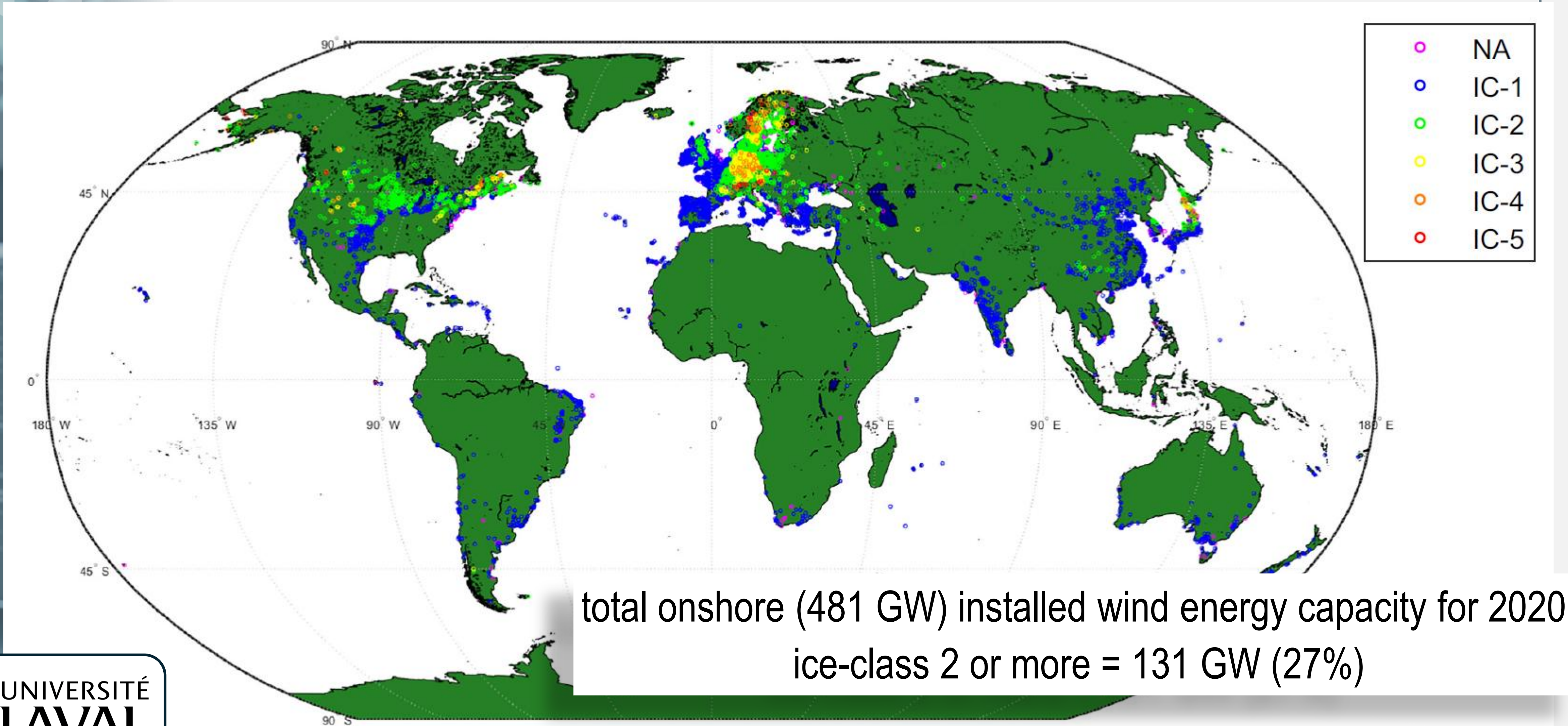
WIND TURBINES ICING



total onshore (481 GW) installed wind energy capacity for 2020:
ice-class 2 or more = 131 GW (27%)

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Roberge, P.; Baxter, D.; Ruel, J.; Roeper, D.; Lemay, J.; & Bégin-Drolet, A. (2022). *Towards standards in the analysis of wind turbines operating in cold climate. Part B: Methodology for evaluating wind turbine alternative operational strategies.* Cold Regions Science and Technology, 196, 103494. doi:10.1016/j.coldregions.2022.103494

WIND TURBINES ICING

- Worldwide challenges of operators/manufacturers:

Turbine performance

Safety (ice throw)

Structural loads

Maintenance delays

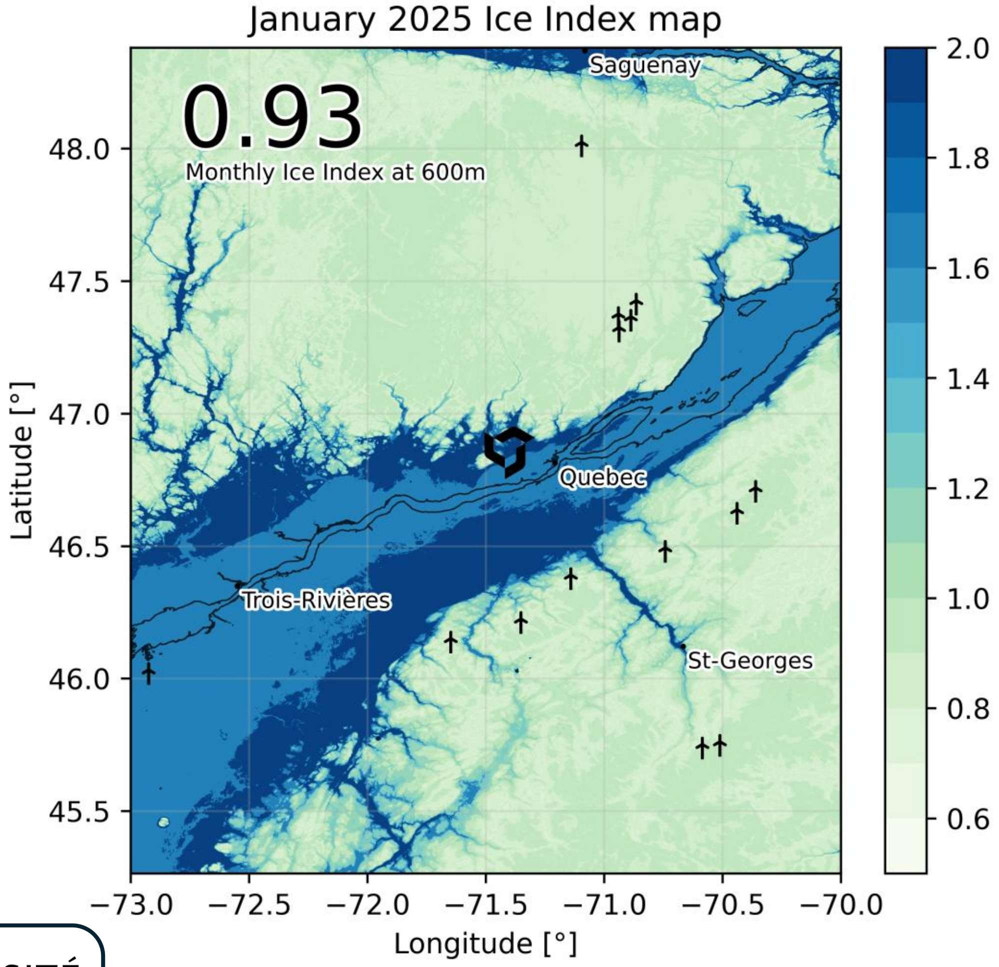
Consumption surcharge

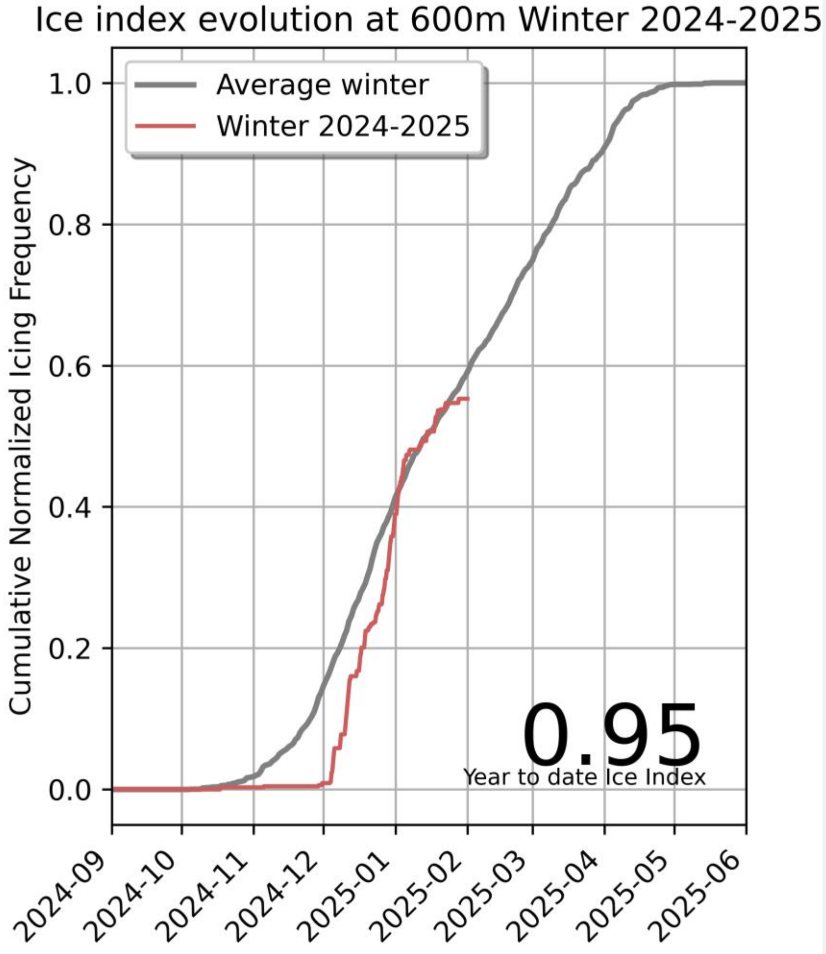
- Critical importance to **measure** and **take action** to minimize the impact of icing

TAKING ACTION

- Accurate determination of icing losses
  - Financial models
  - Budgets
  - Assets management
  - Ice index

TAKING ACTION





Roberge, P.; Lemay, J.; Ruel, J. & Bégin-Drolet, A. (2023). Definition of an ice index for wind turbines in cold climate. Cold Regions Science and Technology. 103930. https://doi.org/10.1016/j.coldregions.2023.103930

TAKING ACTION

- Accurate determination of icing losses
  - Financial models
  - Budgets
  - Assets management
- Monitor icing conditions (LWC, ice thickness)
  - Preemptive stop (early stopping)
  - Pro-active heating / improved heating trigger

TAKING ACTION

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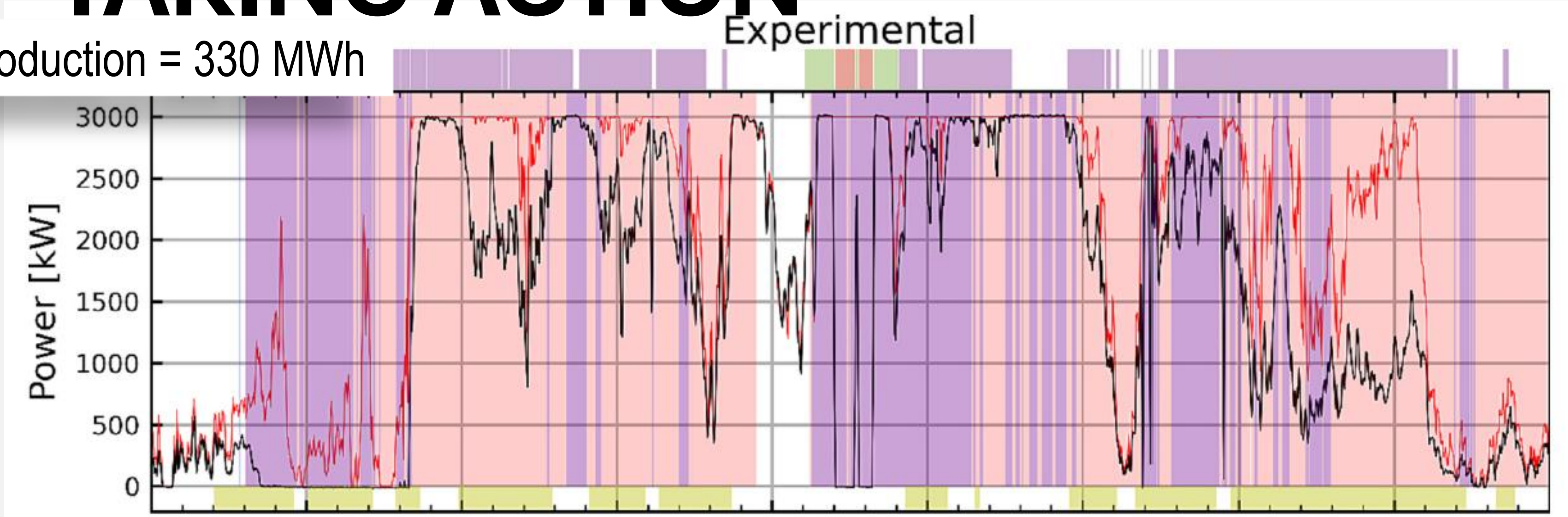
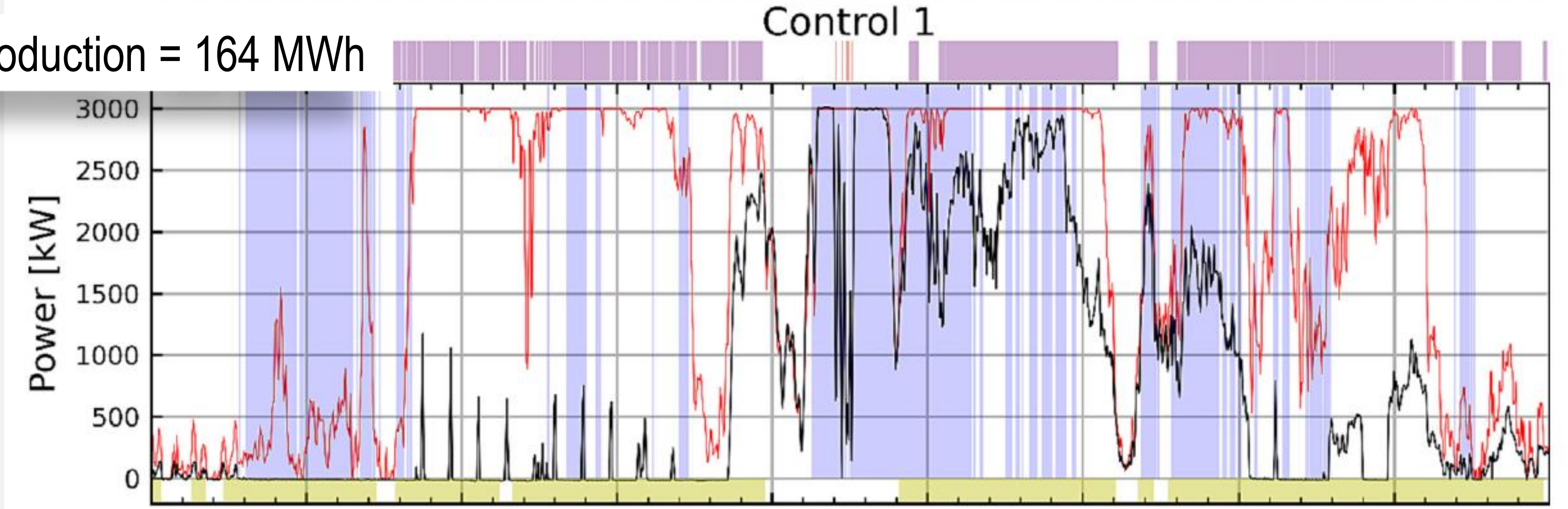
- Intelligent heating
  - Based on ice sensor (+ power curve)
  - Taking into account operationnal enveloppes
  - Including foreseeable scenarios (weather forecast)

TAKING ACTION

Efficiency = 79%, production = 330 MWh



Efficiency = 42%, production = 164 MWh



Roberge, P.; Lemay, J.; Ruel, J. & Bégin-Drolet, A. (2023) Understanding ice accretion on wind turbines with field data. Cold Regions Science and Technology, 210, 103853. https://doi.org/10.1016/j.coldregions.2023.103853

TAKING ACTION

- Safety concerns
  - Ice throw warnings
  - Inability to access roads due to danger
  - Protection of key maintenance labor
  - Decisions for site managers
  - Informed « Job Safety Analysis (JSA) »
  - Protection of civilians
  - Protection of nearby assets (vehicle, buildings)
  - Direct turbine damage (nacelle, instruments, stairs)

TAKING ACTION

- Monitor turbine health
  - Blade/Tower load sensors (*e.g.* Eleven-i CMS sensors)
  - Increase oscillations
  - SCADA systems still not fully adapted
  - Blade heating system (health checks)

TAKING ACTION

- Maintenance impacts
  - Can workers go do their jobs?
  - Can jobs be better planned?

TAKING ACTION

- Energy consumption management
    - Reduce unnecessary heating
    - Management under low wind or park-wide stoppages

MONITOR ICING CONDITION

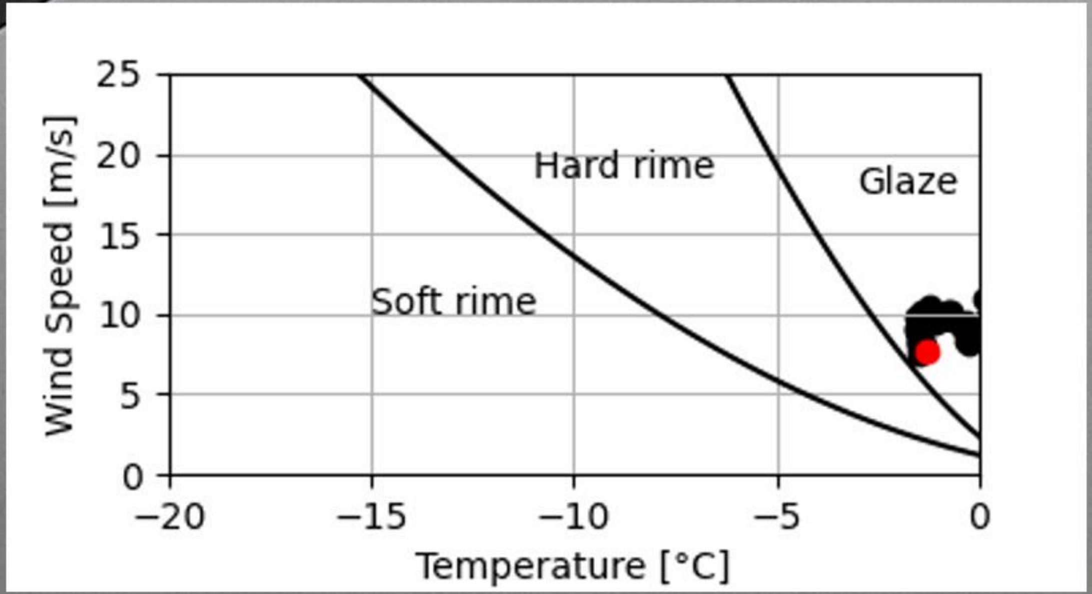
- Measure liquid water content
- Models to yield ice accumulation
- Blade heating trigger before ice accumulation
- Coupled with camera for visual cues

IC-1 by Icetek

Bégin-Drolet, A.; Ruel, J. & Lemay, J. (2017). METHOD AND APPARATUS FOR DETERMINING AN ICING CONDITION STATUS OF AN ENVIRONMENT. US Patent 9,846,261. Filed 2013-05-13. Granted 2017-12-19


IC-1 installed

Location: Eastern Canada
Date: November 23rd, 2024



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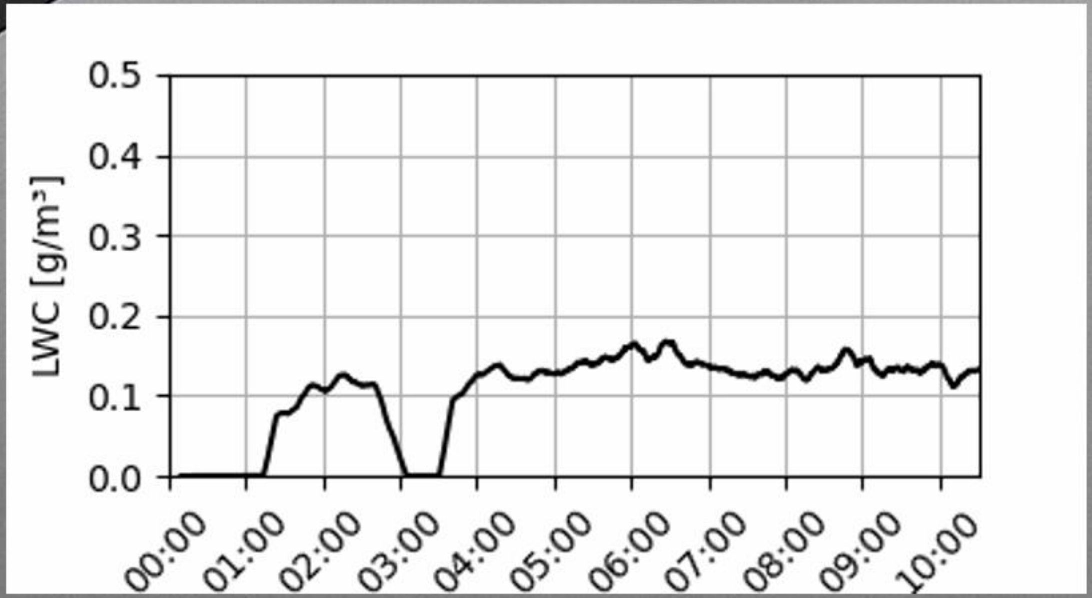

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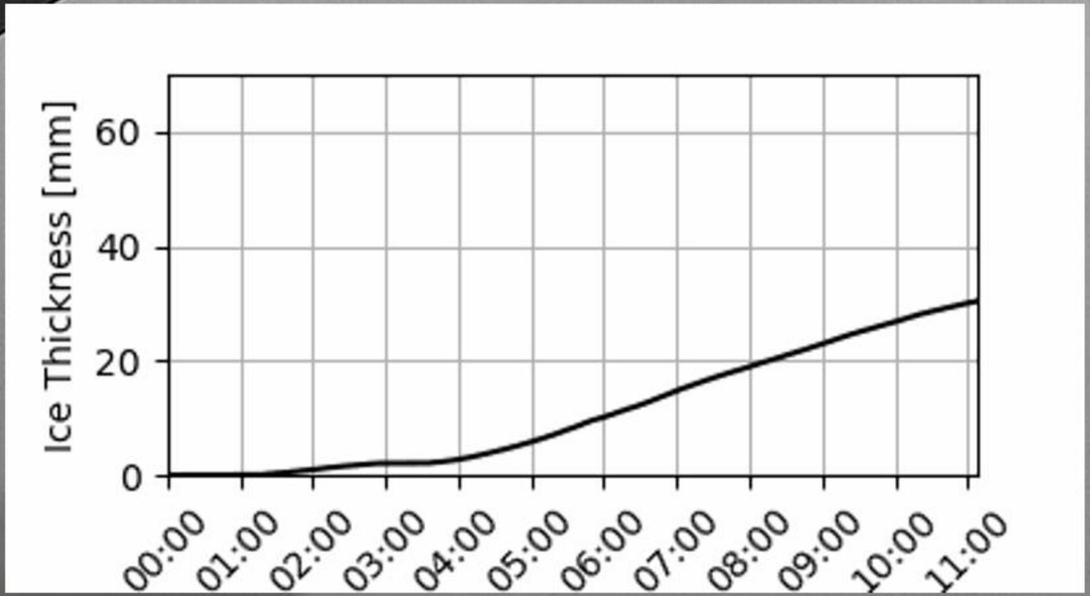
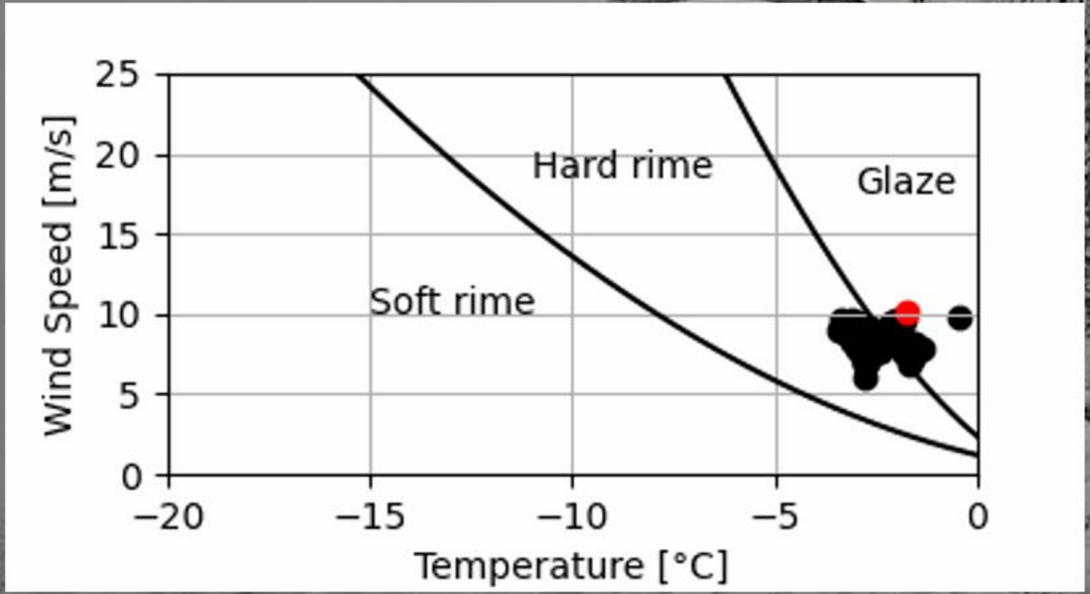


Location: Eastern USA
Date: December 27th, 2024



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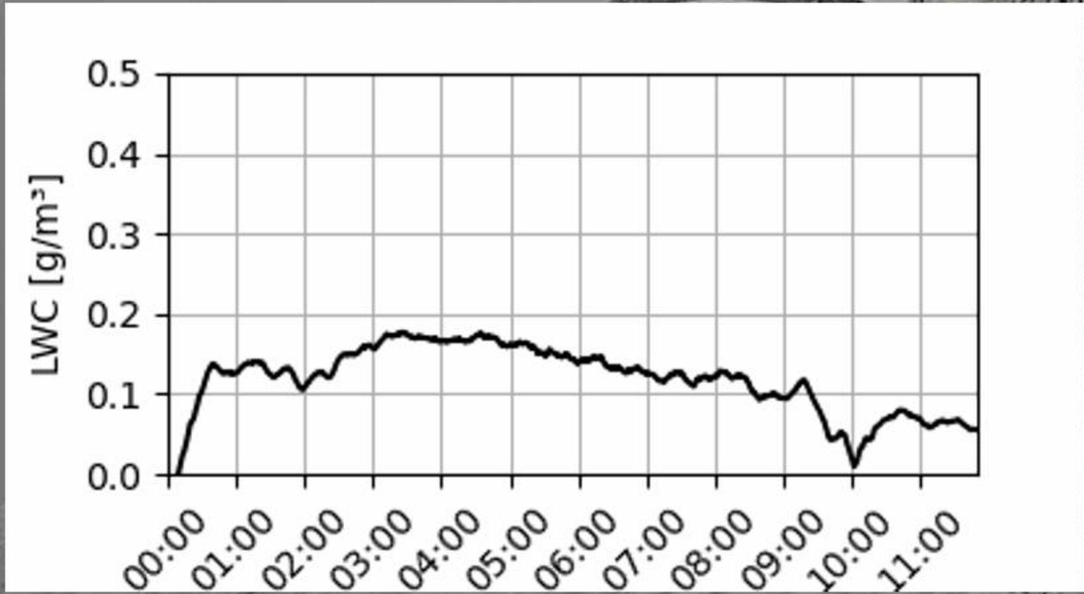

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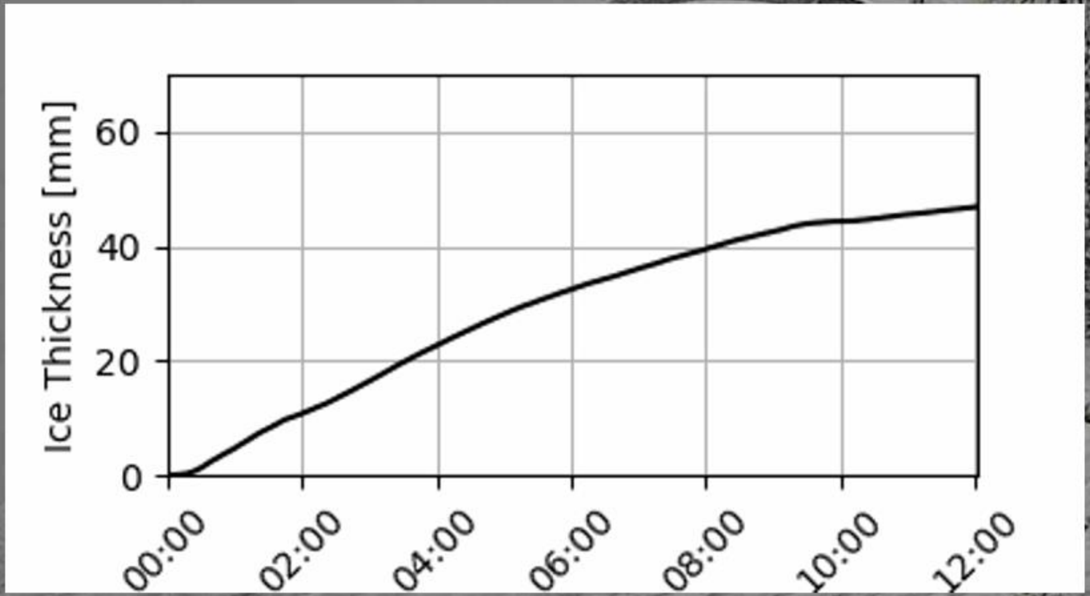
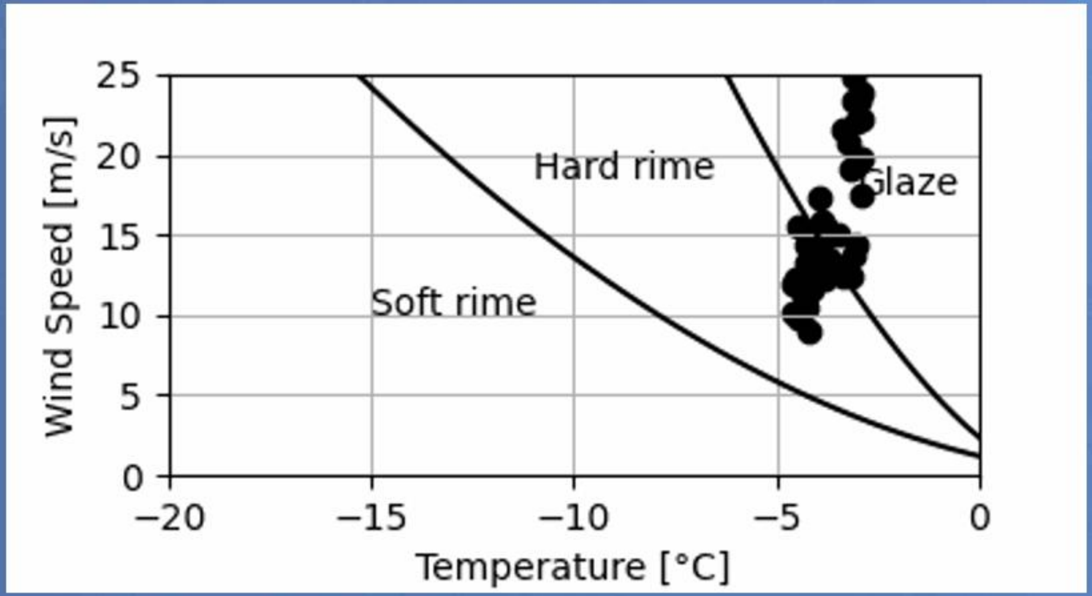


Location: Norway

Date: December 16th, 2024



In collaboration with

NORDEX

Location: Norway
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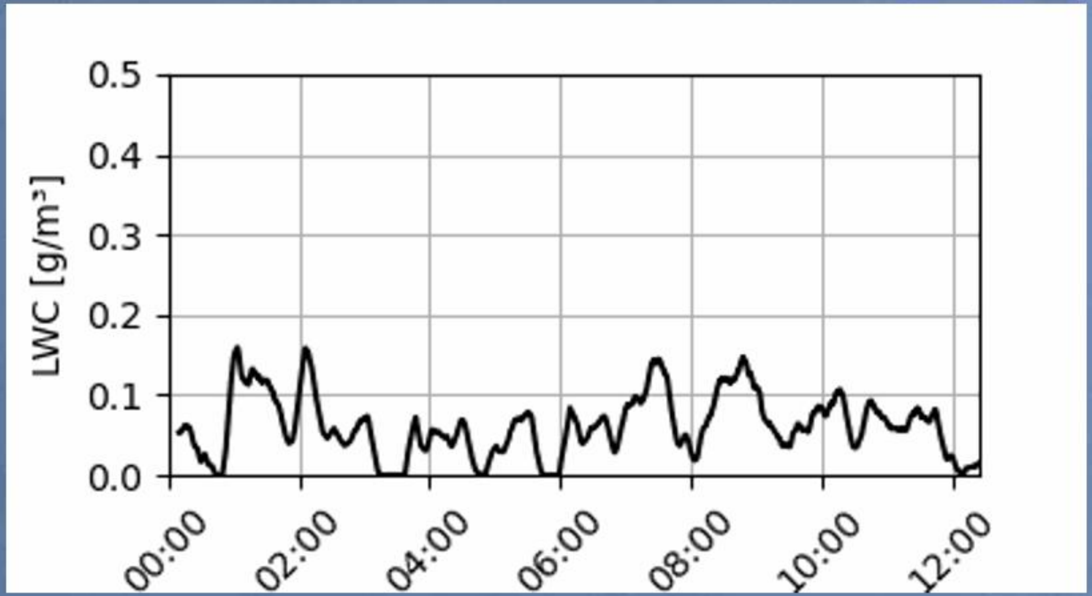

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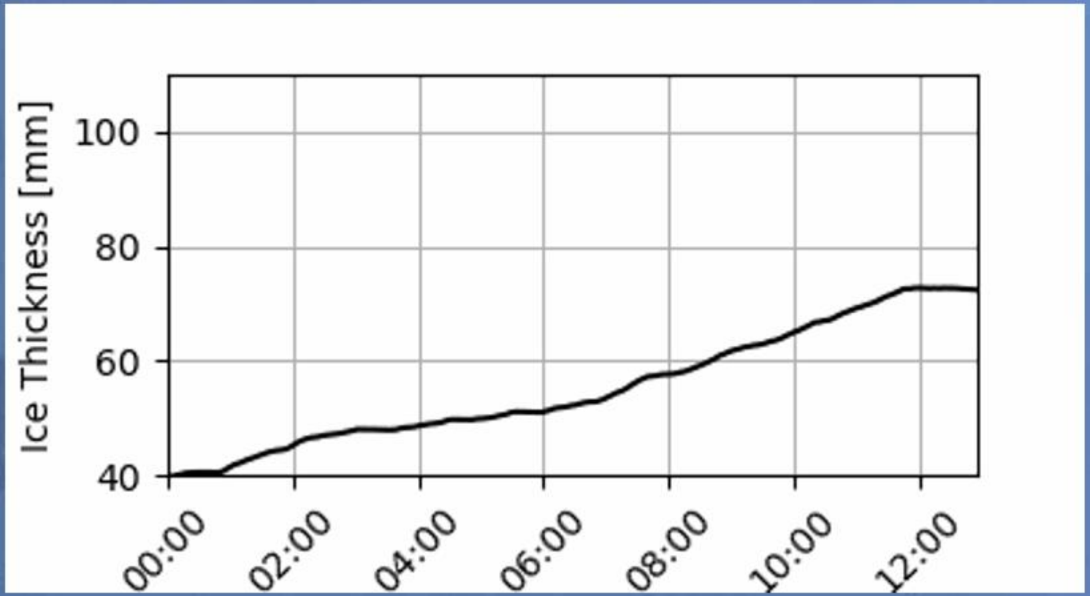
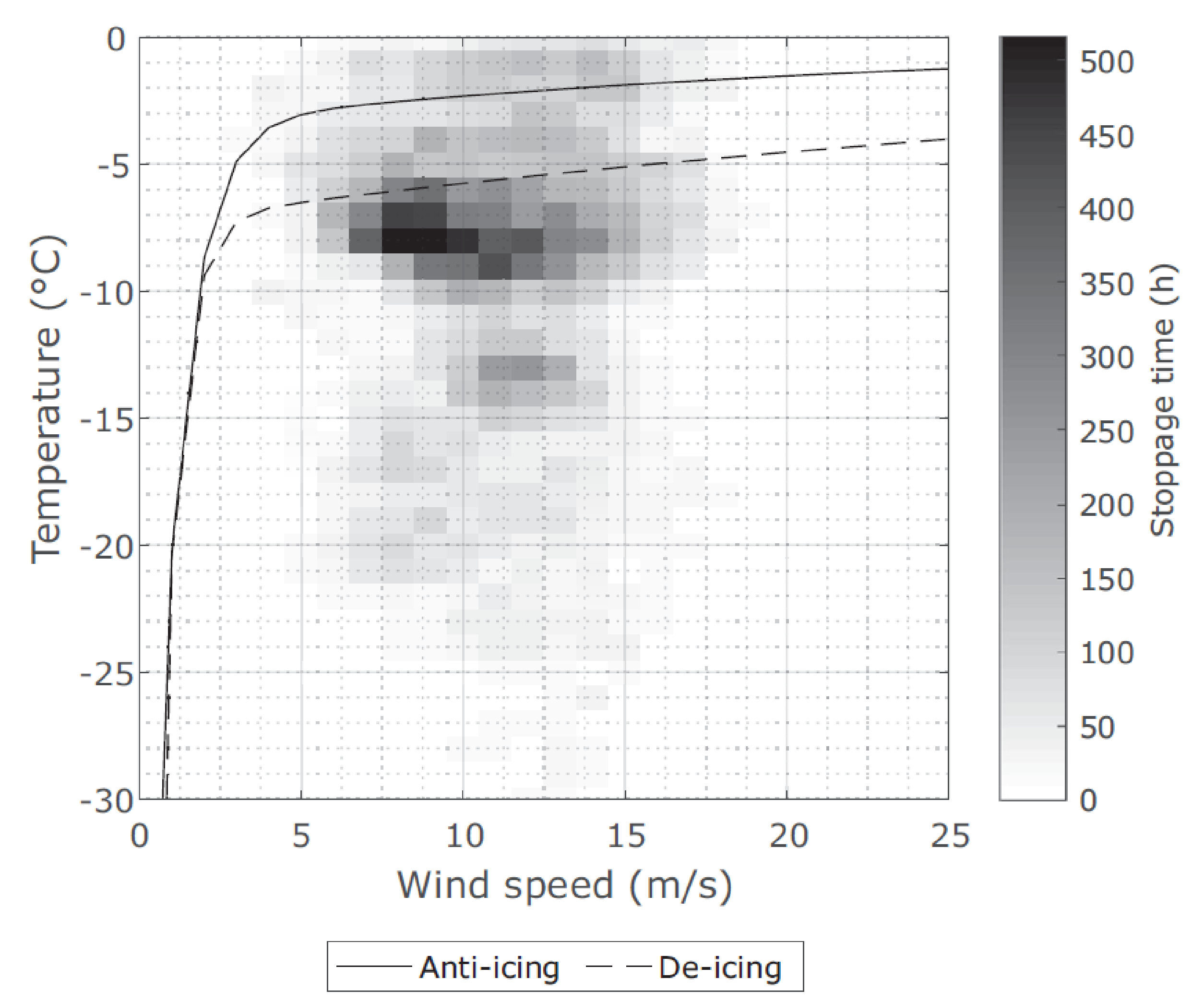


In collaboration with

OPERATIONAL ENVELOPPE

- When are blade heating systems efficient ?
  - Blade surface temperature above 0˚C
- Modeled using
  - Blade geometry and properties
  - Heating source and power
- Heating efficiency becomes function of
  - Wind
  - Ambient temperature
  - LWC

OPERATIONAL ENVELOPPE



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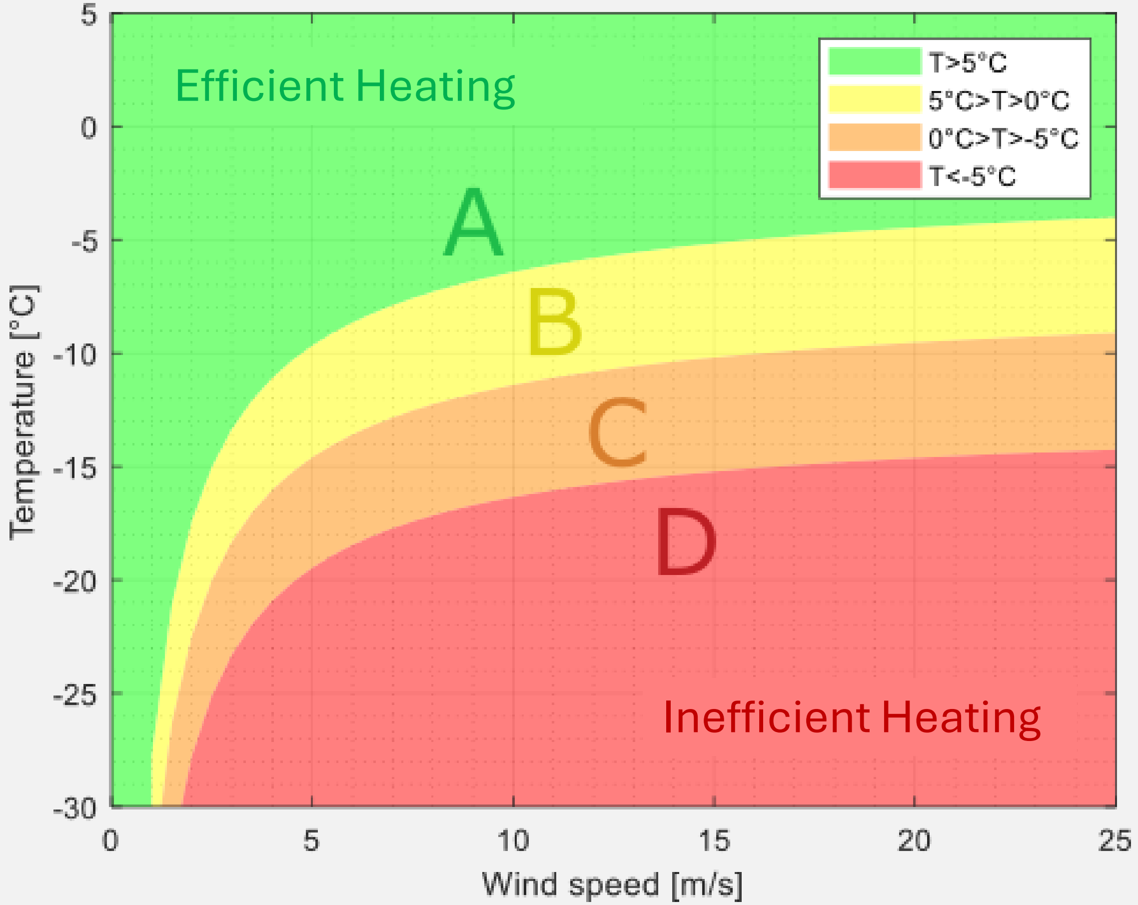
OPERATIONAL ENVELOPPE

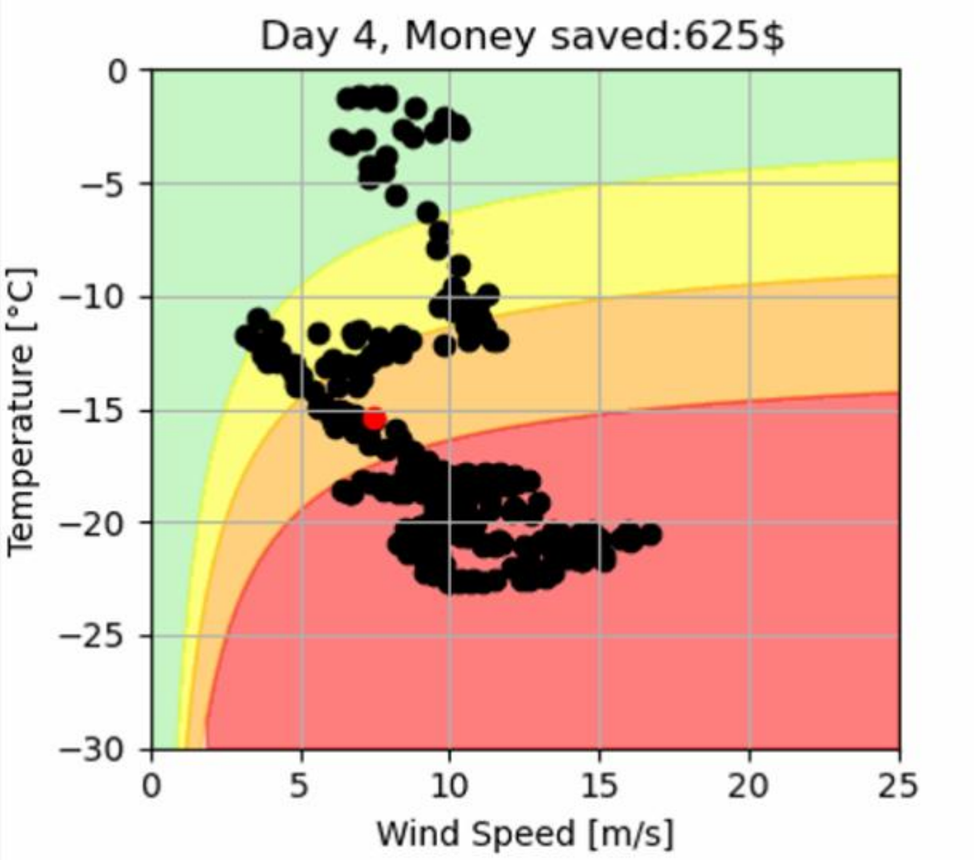
Included into blade heating strategy

Limits heating costs



OPERATIONAL ENVELOPPE

- Direct gain
  - ↓ Heating cost
- Indirect gain
  - ↓ Peak consumption
  - ↓ Wear and tear
- LWC in play



100 kW of heating power, 100$/MWh

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Thank you!

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