FabricAir | BorealisWind Ice Protection System

# Triggering ice protection systems with weather forecasts

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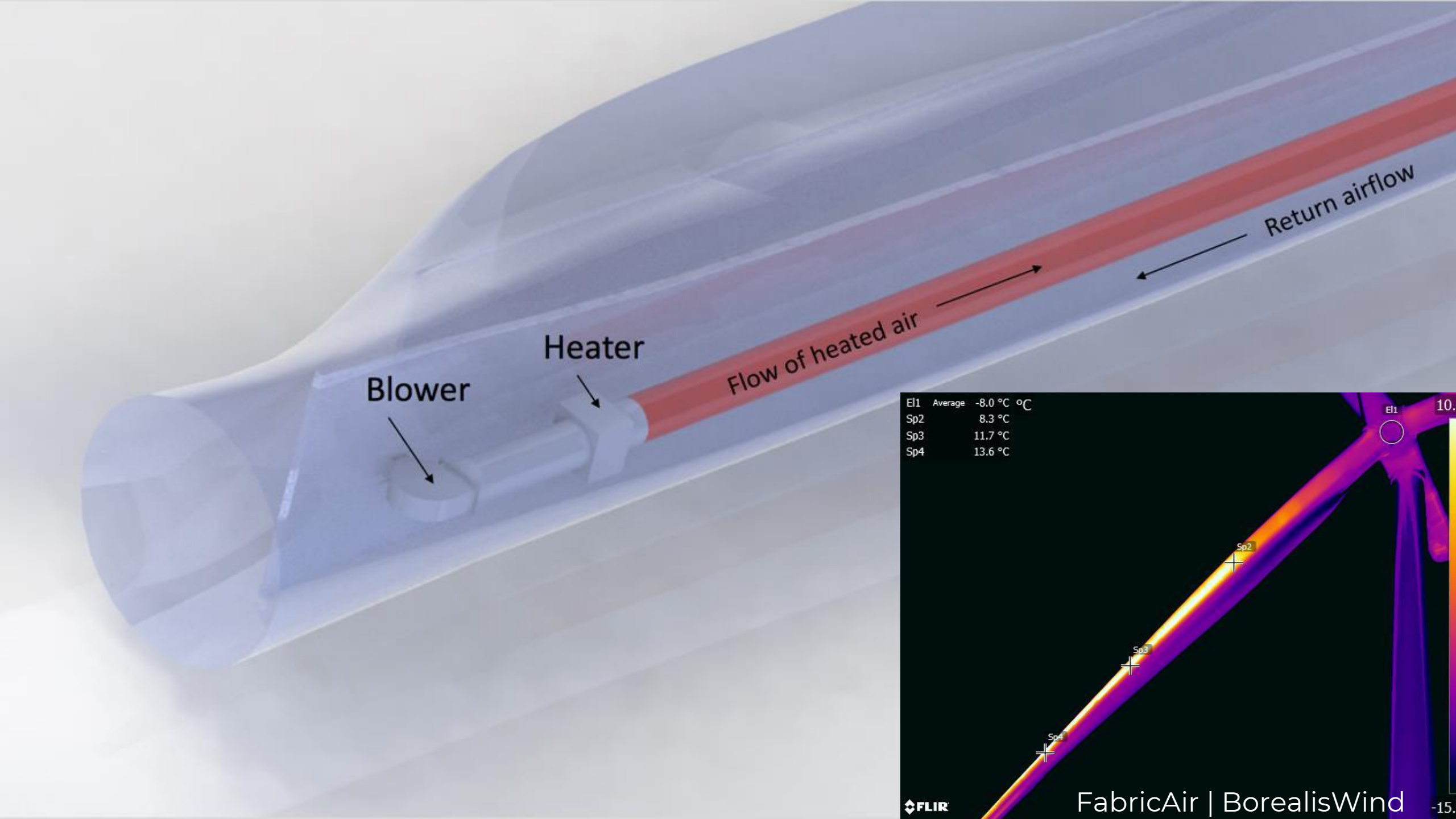
Winterwind
February 2025

## Who are we?

- Started in 2016, now part of FabricAir A/S
- Provide retrofit Ice Protection Systems (IPS)
- 6 winters of operational validation at wind farms in Canada
- 500 MWh energy gain per turbine, 10% AEP increase on average

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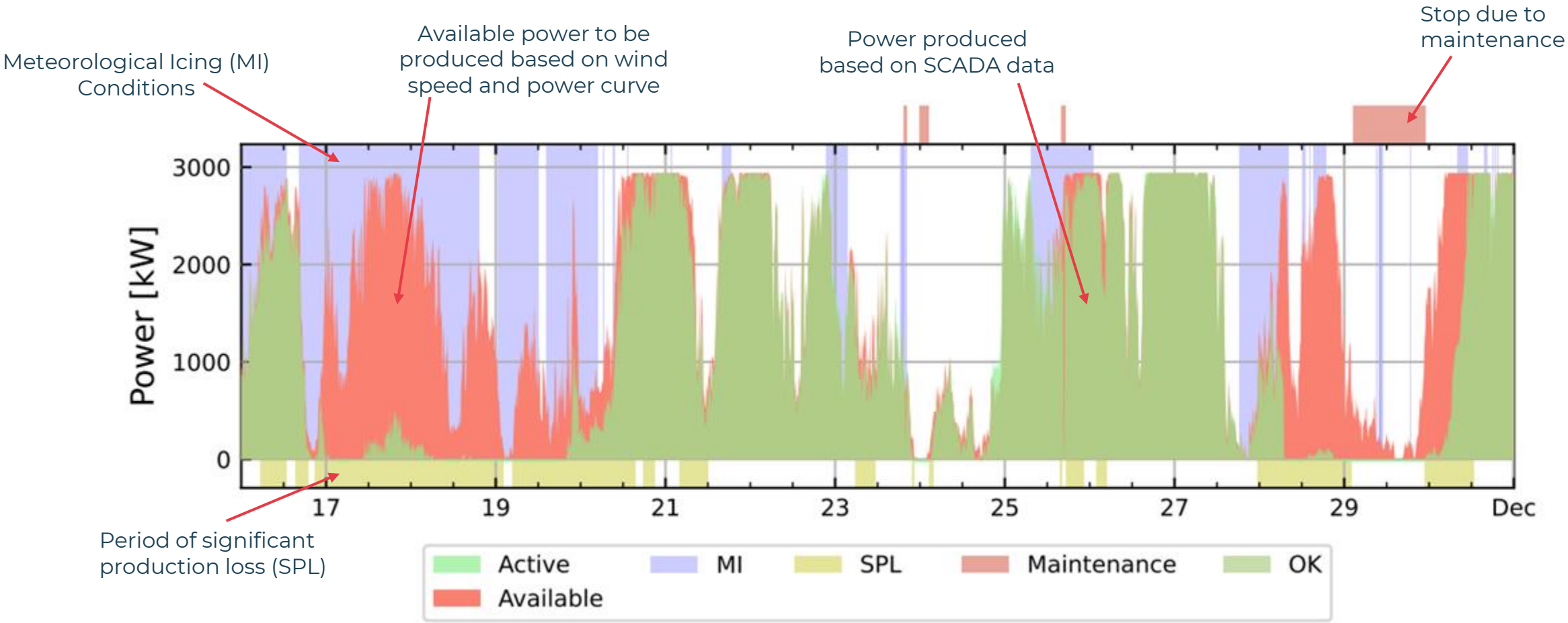
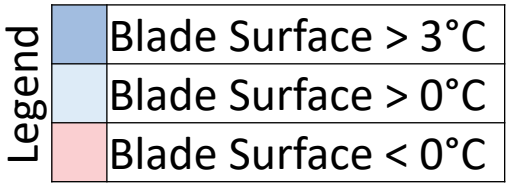
# Introduction – Turbine Performance




Analysis and Graph by Icetek (Icetek.ca)

# Introduction – Operational Envelope




## De-icing:

**Remove/prevent ice accumulation on an idle turbine**

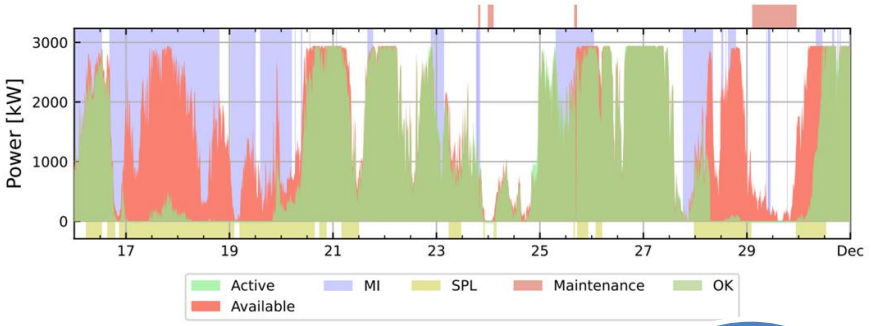
| Blade Surface Temp. | Wind Speed [m/s] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | >24 |
| Wind Temperature °C 0 | | | | | | | | | | | | |
| -2 | | | | | | | | | | | | |
| -4 | | | | | | | | | | | | |
| -6 | | | | | | | | | | | | |
| -8 | | | | | | | | | | | | |
| -10 | | | | | | | | | | | | |
| -12 | | | | | | | | | | | | |
| -14 | | | | | | | | | | | | |
| -16 | | | | | | | | | | | | |
| -18 | | | | | | | | | | | | |
| -20 | | | | | | | | | | | | |

## Anti-icing:

**Remove/prevent ice accumulation on a spinning turbine**

| Blade Surface Temp. | Wind Speed [m/s] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | >24 |
| Wind Temperature °C 0 | | | | | | | | | | | | |
| -2 | | | | | | | | | | | | |
| -4 | | | | | | | | | | | | |
| -6 | | | | | | | | | | | | |
| -8 | | | | | | | | | | | | |
| -10 | | | | | | | | | | | | |
| -12 | | | | | | | | | | | | |
| -14 | | | | | | | | | | | | |
| -16 | | | | | | | | | | | | |
| -18 | | | | | | | | | | | | |
| -20 | | | | | | | | | | | | |

# Key Factors in IPS Performance




| Blade Surface Temp. | Wind Speed [m/s] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | >24 |
| Wind Temperature °C 0 | | | | | | | | | | | | |
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| -8 | | | | | | | | | | | | |
| -10 | | | | | | | | | | | | |
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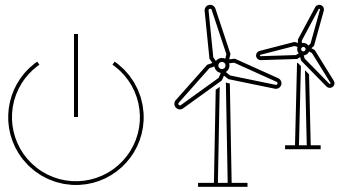
| -20 | | | | | | | | | | | | |



Performance Envelope

System Availability

**% Recovery**

Heated Area Coverage

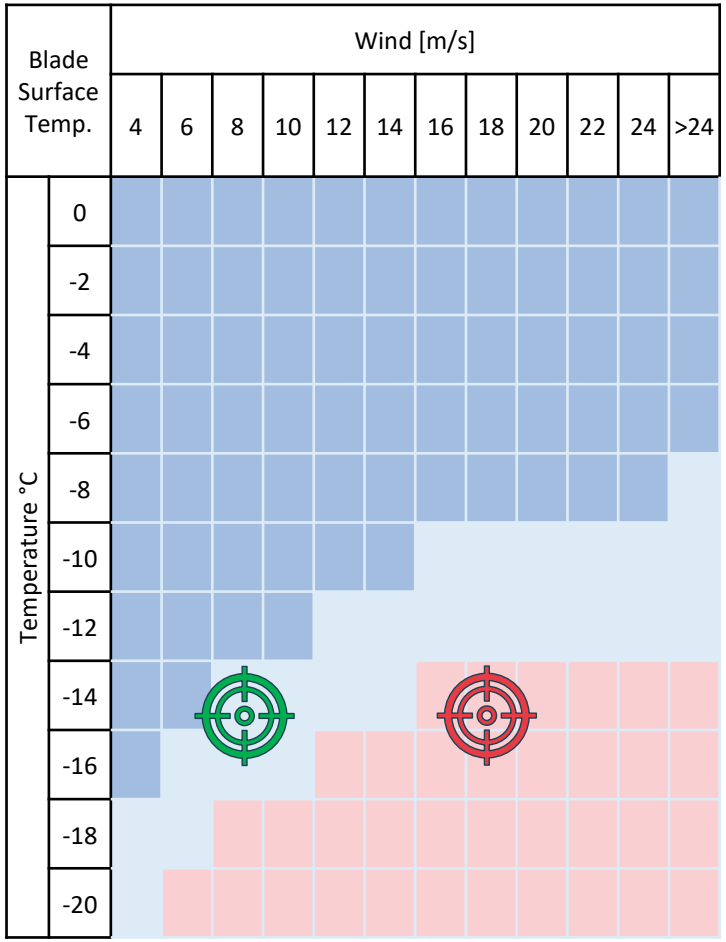
Triggering Methodology

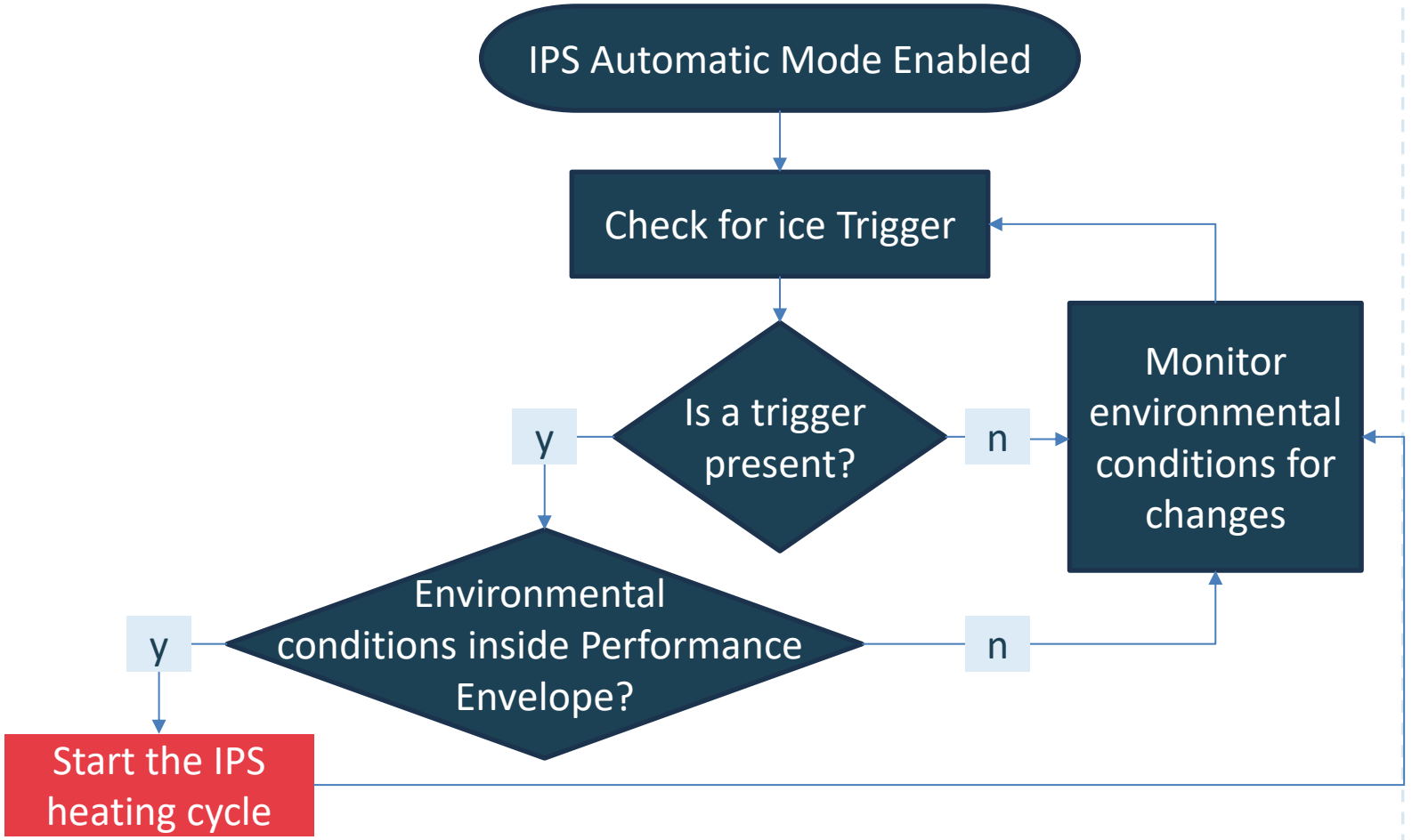

Icetek.ca

# Importance of Effective Triggering

- Specific for anti-icing
- Triggering early enough in the icing event will prevent ice build-up
  - Prevent turbine standstill
  - Avoid reduced-power-curve & yaw-idle modes
- Turning off outside the performance envelope will prevent energy waste
- Managing site wide power consumption

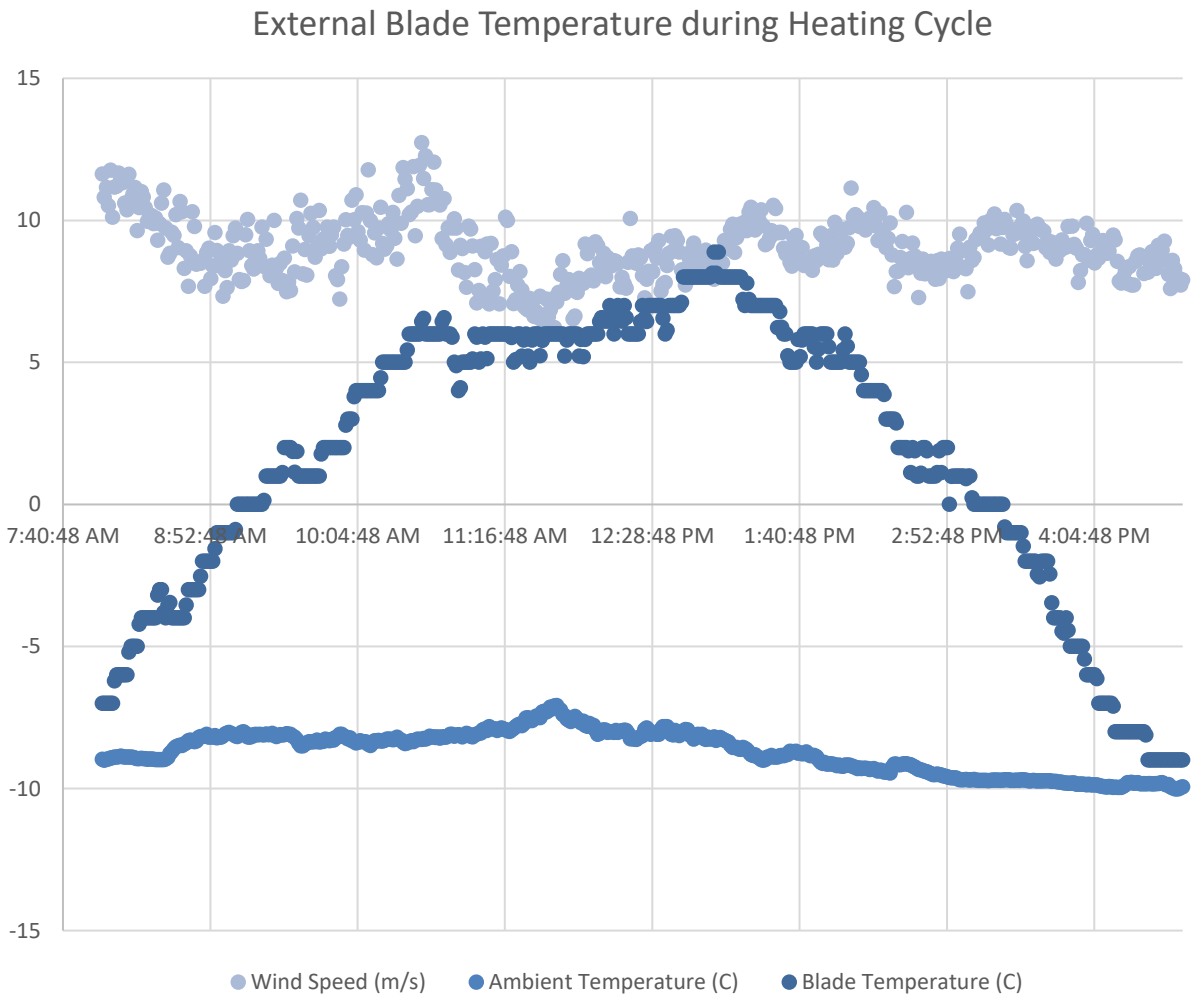
# Importance of Effective Triggering



# Importance of Effective Triggering

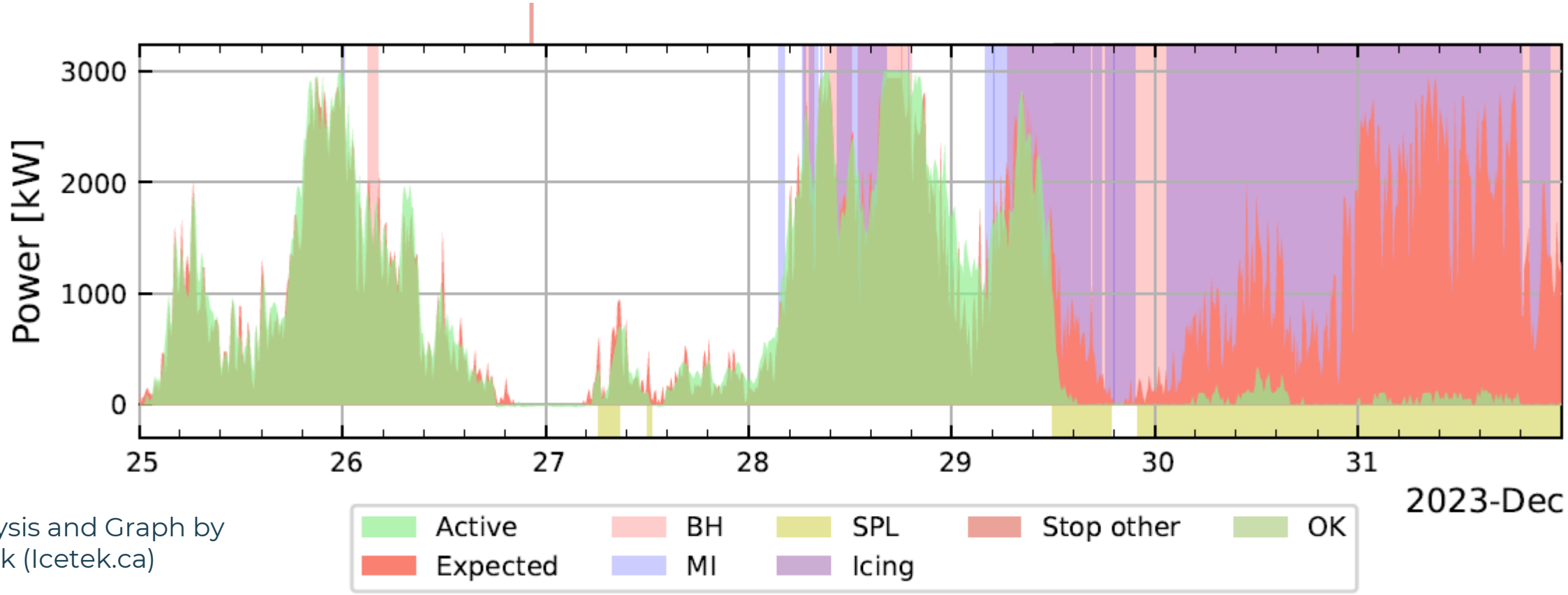
- Time required to reach positive external blade temperature in the given conditions
  - Ambient temperature
  - Wind speed
  - Icing severity
  - Rotor RPM
- Duration of the icing event



# Previous BIPS Triggering Methods

- Turbine operation codes
- Power curve degradation (IEA Wind TCP Task 19)
- Heated vs. unheated anemometers
- Third-party ice detection sensors
- Manual activation

# Examples of Limitations of Traditional Methods




Analysis and Graph by
Icetek (Icetek.ca)

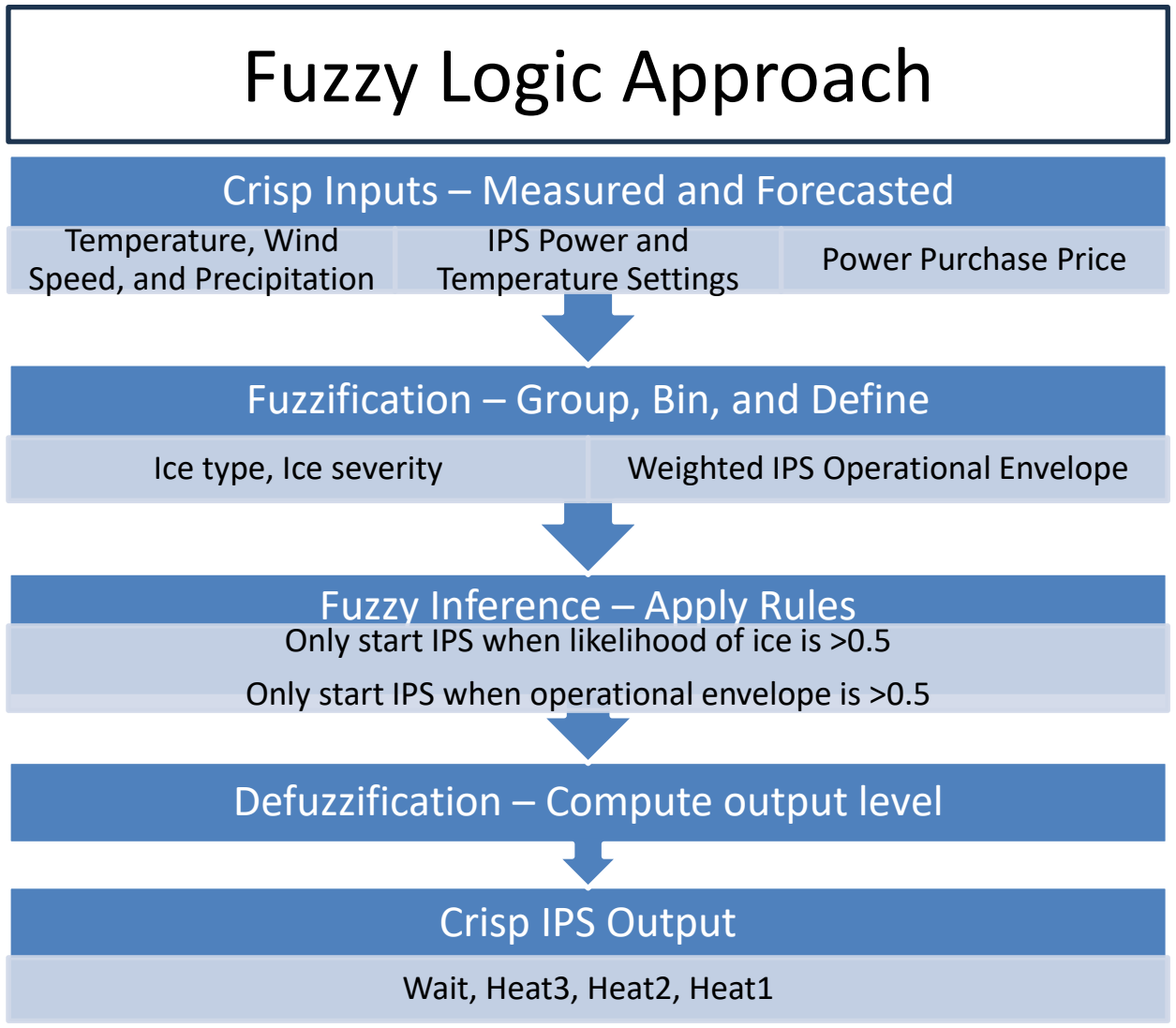
# Introducing Advanced Forecast-Based Trigger

Uses open-source weather forecast data

Leverages fuzzy logic for smarter decisions

# How the Forecast-Based Trigger Works

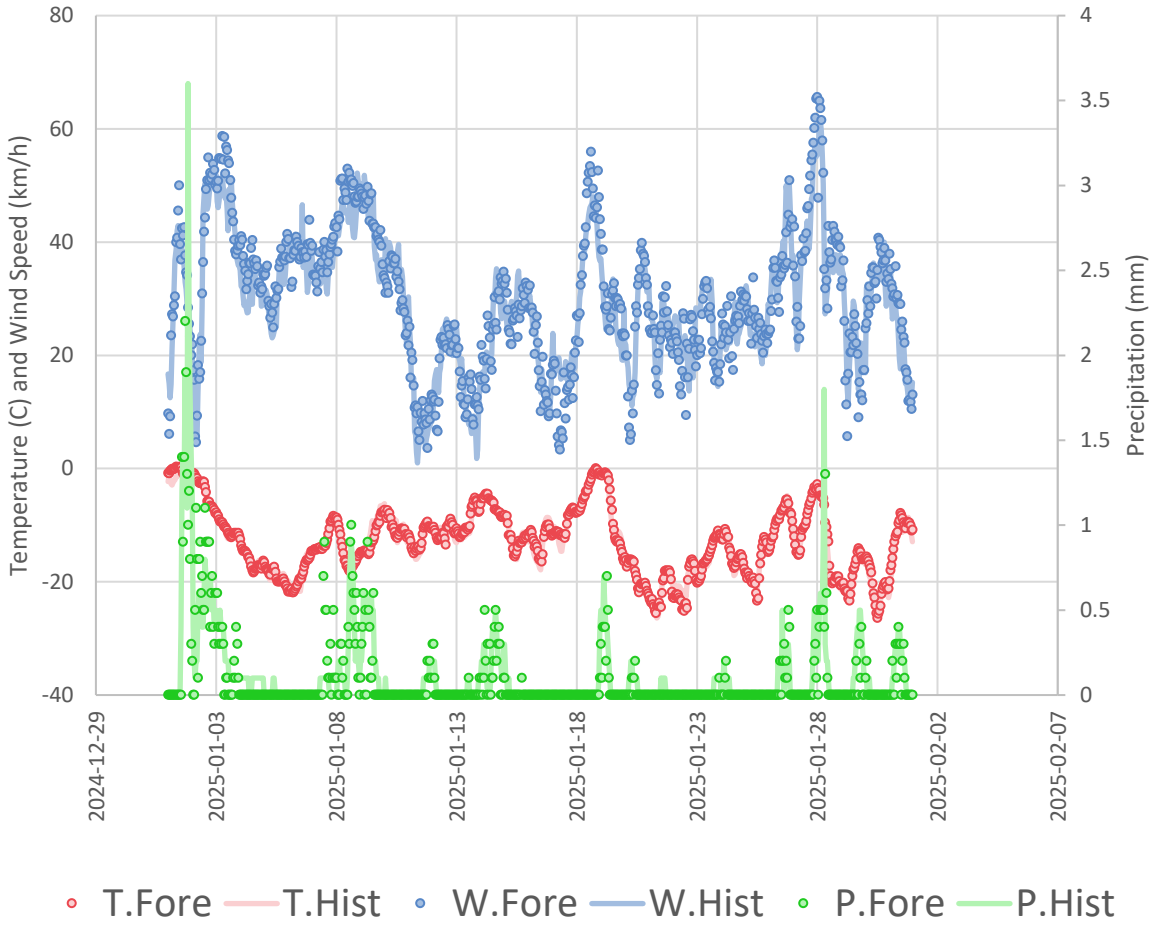
- Monitors weather forecasts based on turbine coordinates
- Use fuzzy logic to allow forecasting data to interact with IPS data
- Predicts icing events based on weather that is likely to cause icing
- Optimizes IPS activation for energy efficiency
  - Start or end IPS cycle early
  - Heat3 blades, 2 blades, or 1 blade at a time



# Validation & Testing Plan

1. Use three anonymized test sites in North America
2. Gather data during Q4-2024
    a) Forecasted data from open sources
    b) Measured data from Iceteck, Eologix, Borealis sensors and Turbine sensors.
    c) Compare Forecasted vs Measured to determine accuracy and reliability of forecasted data
3. Build fuzzy logic and trigger conditions based on Q4-2024 data
    a) Compare Forecasted vs. Iceteck triggers to determine expected efficacy of forecasted triggers
4. Test fuzzy logic triggering during Q1-2025 on a sample of turbines from the test sites
    a) Compare test turbines vs control turbines to validate the:
        i. Increase in reclaimed power from predicted triggering
        ii. Reduction in waste power from operating outside of the IPS Operational Envelope

# Validation & Testing Plan –Forecasted Accuracy




- Line is historical, and dots were forecasted
- Forecasts were made from 13 open sources with a 7 day average outlook
- Correlation for January 2025 from forecast to historical measurements:
  - Windspeed 0.93 – Very Strong
  - Temperature 0.98 – Very Strong
  - Precipitation 0.74 - Strong

# Fuzzification of the Operational Envelope

| Legend | |
|---|---|
| | Blade Surface > 3°C |
| | Blade Surface > 0°C |
| | Blade Surface < 0°C |

## De-icing:

**Remove/prevent ice accumulation on an idle turbine**

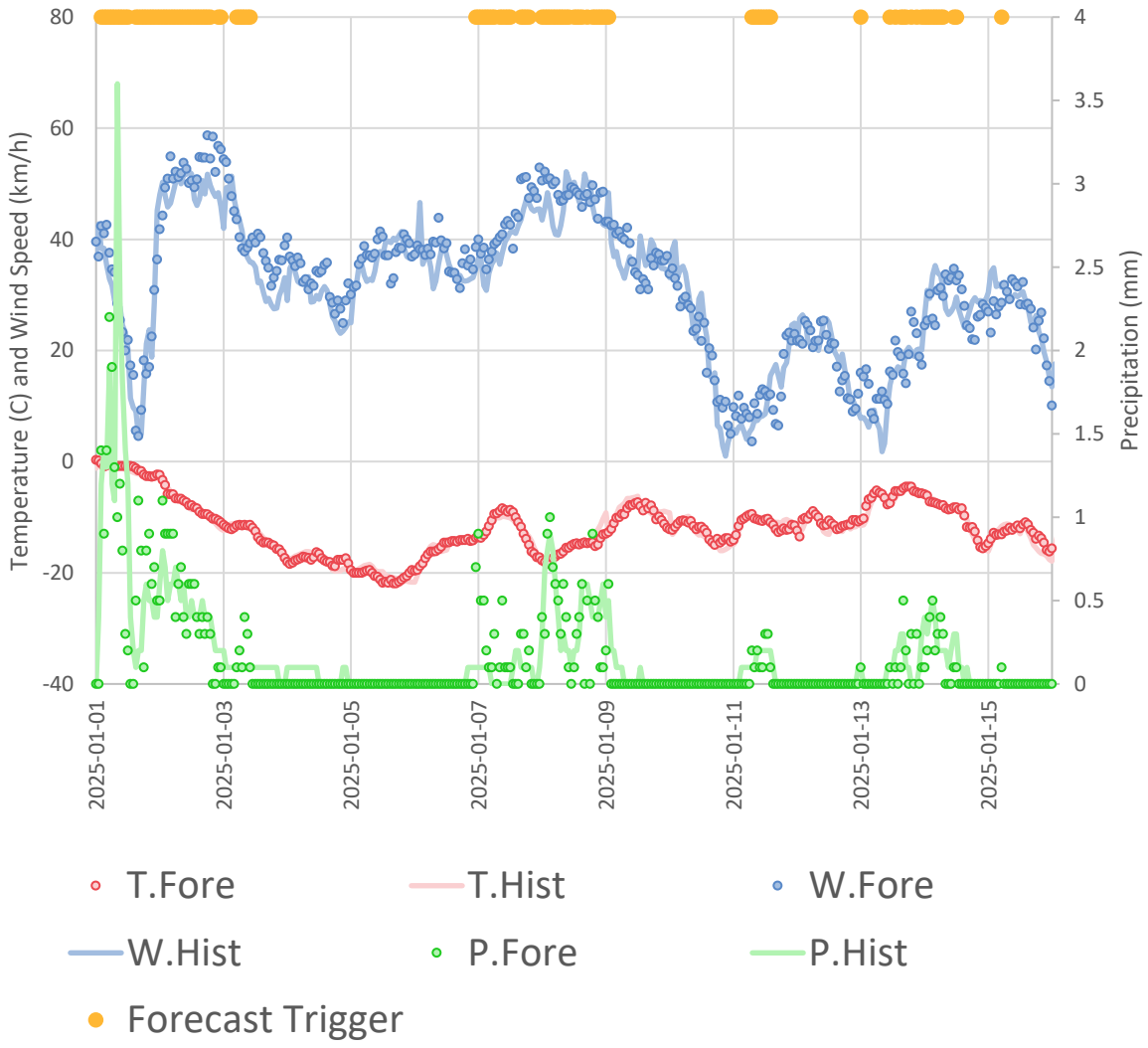
| Blade Surface Temp. | Wind Speed [m/s] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind Temperature °C | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | >24 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| -2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| -4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | .9 | .9 | .9 |
| -6 | 1 | 1 | 1 | 1 | .9 | .9 | .9 | .9 | .9 | .9 | .8 | .8 |
| -8 | 1 | 1 | .9 | .9 | .9 | .8 | .8 | .8 | .8 | .8 | .8 | .5 |
| -10 | .9 | .9 | .9 | .8 | .8 | .8 | .7 | .7 | .7 | .7 | .7 | .7 |
| -12 | .9 | .8 | .8 | .8 | .7 | .7 | .7 | .7 | .7 | .7 | .7 | .7 |
| -14 | .8 | .8 | .7 | .7 | .7 | .7 | .3 | .3 | .3 | .3 | .3 | .3 |
| -16 | .8 | .7 | .7 | .7 | .3 | .3 | .3 | .1 | .1 | .1 | .1 | .1 |
| -18 | .7 | .7 | .3 | .3 | .3 | .1 | .1 | .1 | 0 | 0 | 0 | 0 |
| -20 | .7 | .3 | .1 | .1 | .1 | .1 | 0 | 0 | 0 | 0 | 0 | 0 |

## Anti-icing:

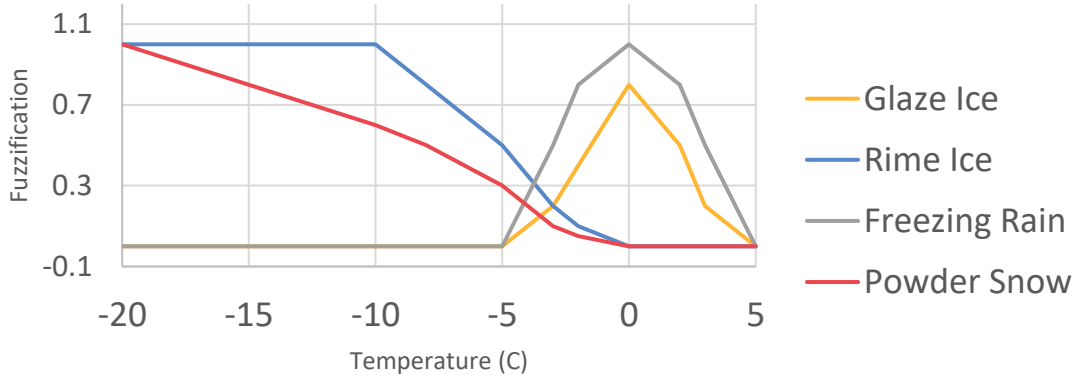
**Remove/prevent ice accumulation on a spinning turbine**

| Blade Surface Temp. | Wind Speed [m/s] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind Temperature °C | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | >24 |
| 0 | .9 | .9 | .9 | .9 | .9 | .9 | .9 | .8 | .8 | .8 | .8 | .8 |
| -2 | .9 | .8 | .8 | .8 | .8 | .8 | .8 | .8 | .7 | .7 | .7 | .7 |
| -4 | .8 | .8 | .7 | .7 | .7 | .7 | .7 | .7 | .7 | .7 | .7 | .7 |
| -6 | .8 | .7 | .7 | .7 | .7 | .7 | .7 | .7 | .3 | .3 | .3 | .3 |
| -8 | .7 | .7 | .3 | .3 | .3 | .3 | .3 | .3 | .3 | .1 | .1 | .1 |
| -10 | .7 | .3 | .3 | .1 | .1 | .1 | .1 | .1 | .1 | .1 | 0 | 0 |
| -12 | .3 | .3 | .1 | .1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -14 | .1 | .1 | .1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

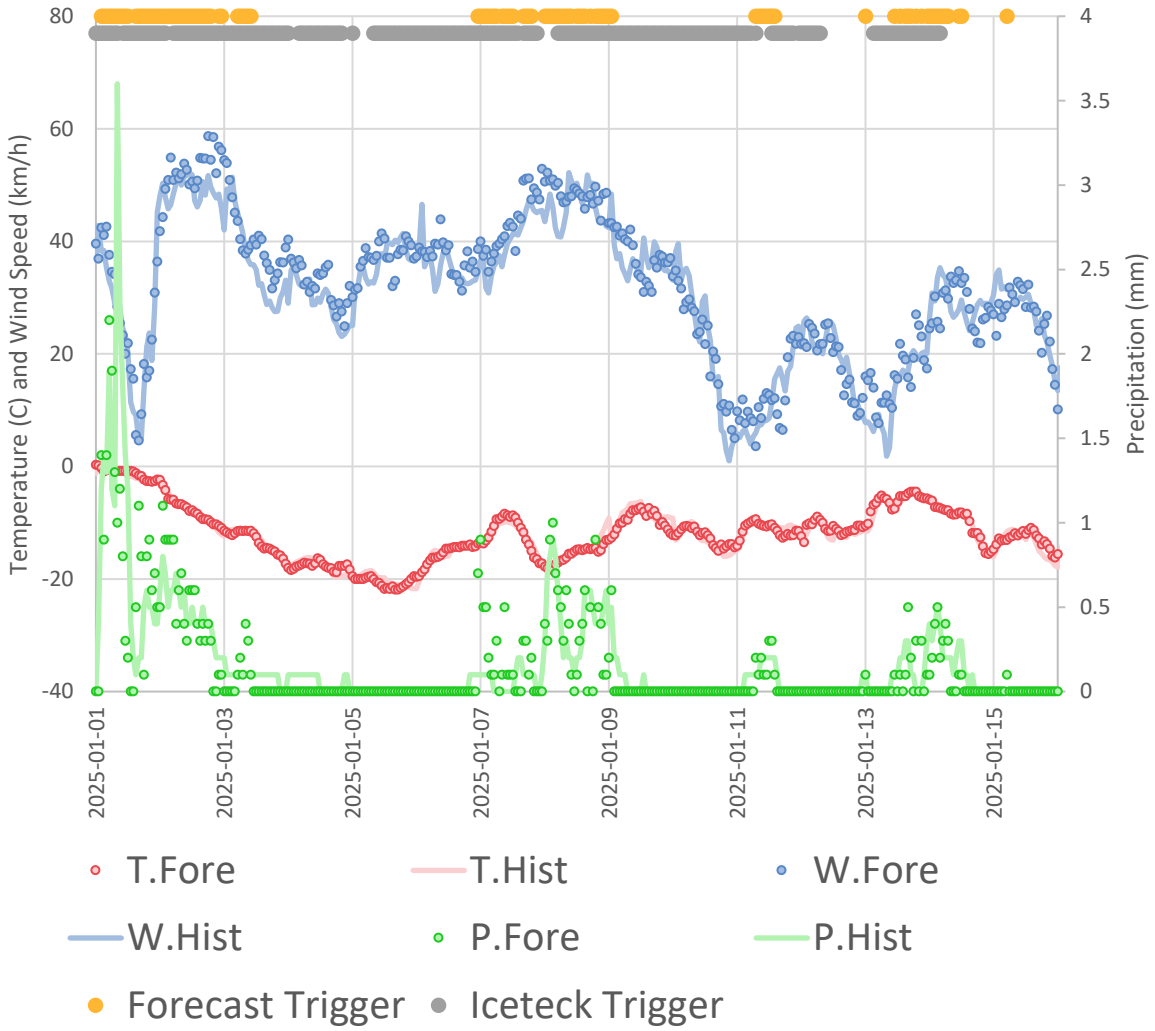
# Validation & Testing Plan




- 2 week period as example
- Forecast trigger using fuzzy logic binning:
  - IPS performance envelope
    - Wind speed
    - Ambient temperature
  - Ice type



# Validation & Testing Plan

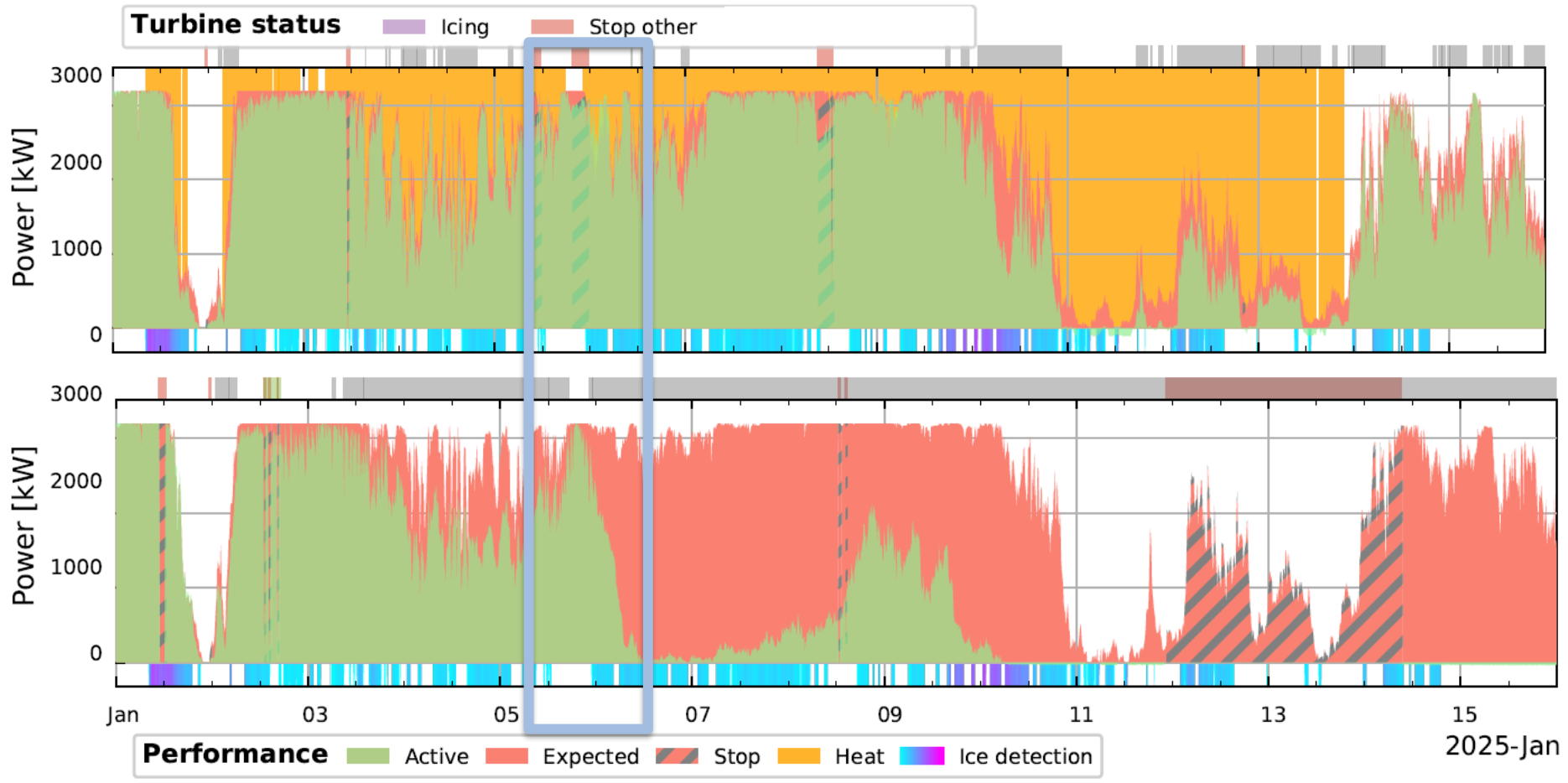



- Compare our Forecast Trigger to the measured Iceteck Trigger
- Hourly basis comparison:
  - Matching 59%
  - Missed triggers 33%
  - False triggers 8%

# Example Event

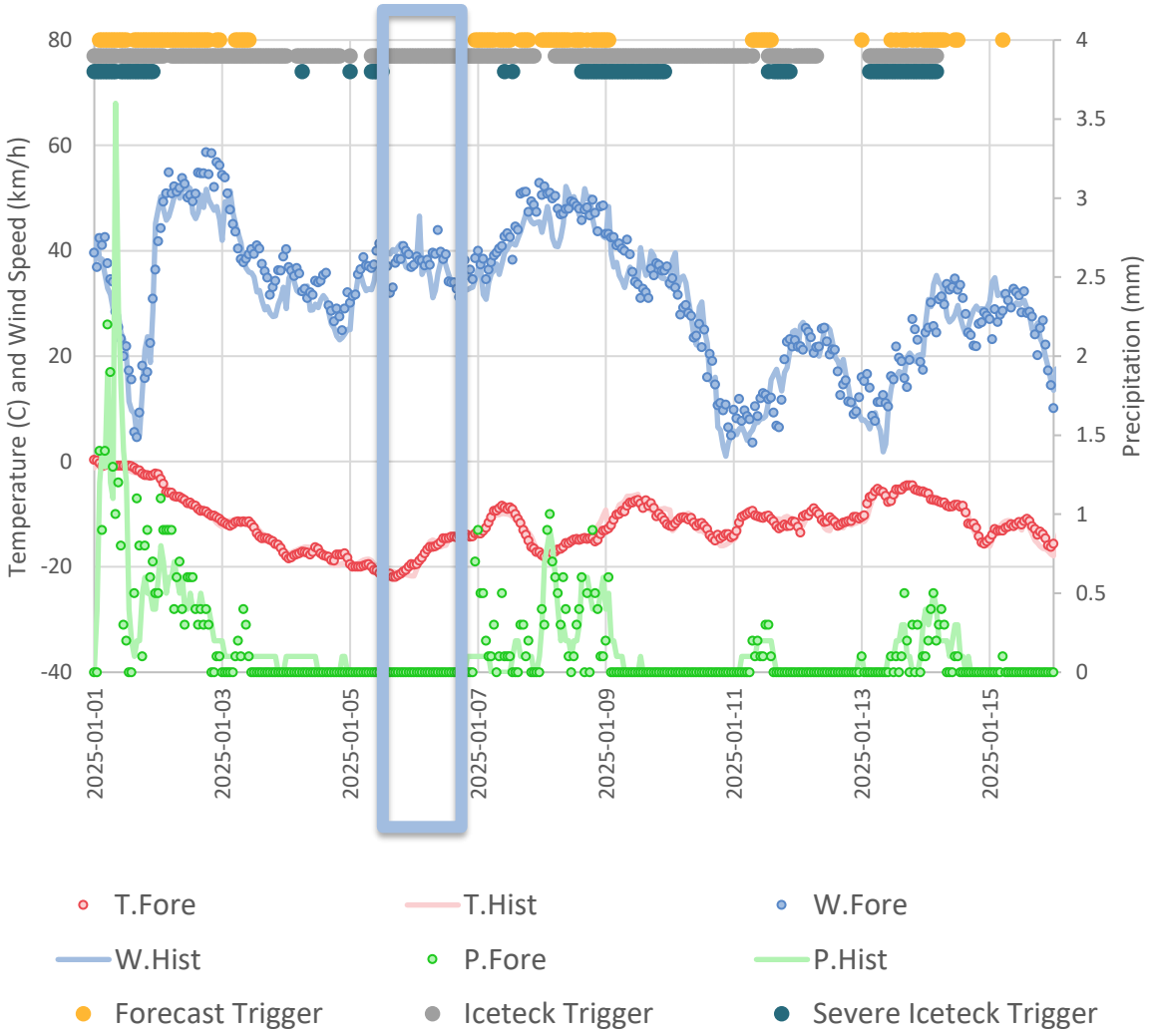
Turbine with BIPS

Reference Turbine




Analysis and Graph by Icetek (Icetek.ca)

# Future Developments - Parameterization

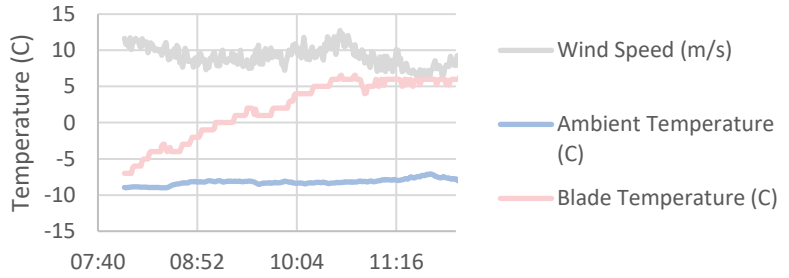



- Identify <u>what</u> the Forecast Trigger is good at predicting
- Filter Iceteck measured Ice severity >0.3
- Hourly basis comparison:
  - Matching 74%
  - Missed triggers 10%
  - False triggers 16%

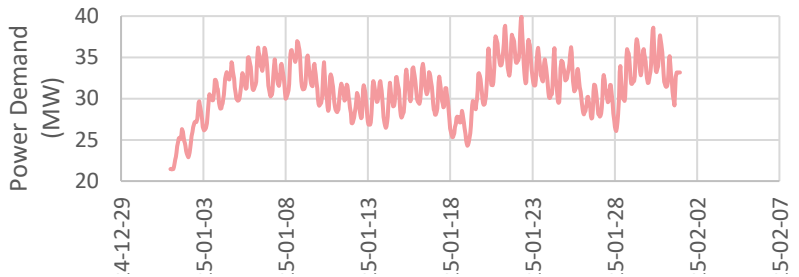
# Future Developments

- Integrating forecasting into BIPS performance framework
- Addressing cyber security risks
- Enhancing decision-making with:

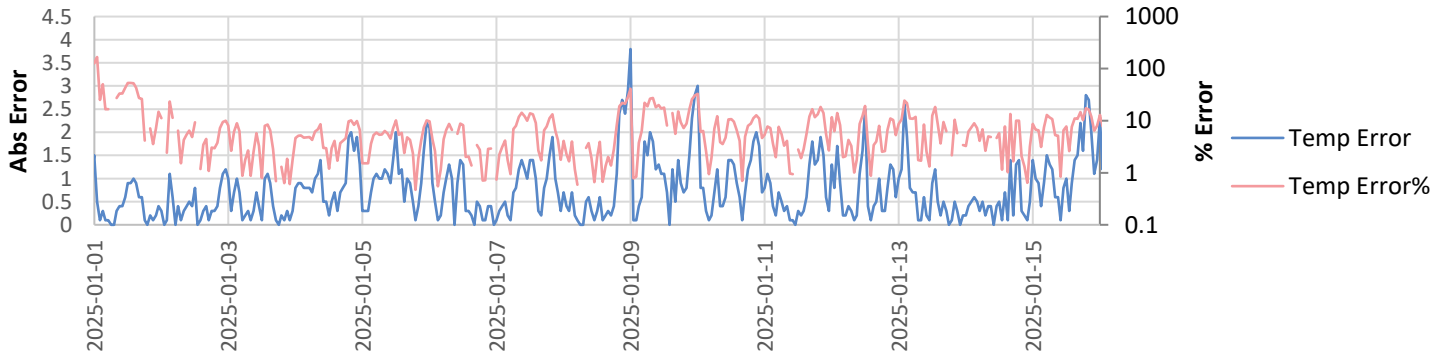
**Include the Time to Reach Steady State Blade Temperatures**




**Include Power Price Forecasting**




**Forecast Confidence in Fuzzy Logic based on Real-Time Comparison to Live Measured values**



# Summary & Key Takeaways

- Effective IPS triggering is key to performance
- Forecast-based activation offers major advantages
  - Proactive heating to prevent ice & production loss
  - Optimizing energy use when needed
  - Could consider adding power price data to enhance decision making

FabricAir | BorealisWind Ice Protection System

# Summary & Key Takeaways

- Effective IPS triggering is key to strong performance
- Forecast-based activation offers major advantages
  - Proactive heating to prevent ice & production loss
  - Optimizing energy use when needed
- Decision making can be improved by adding power purchase price, confidence intervals, and more physical phenomenon specific to the IPS design or customer's preferred operational strategies

Daniela Roeper & Dylan Baxter
FabricAir, Canada
Winterwind, February 2025