FabricAir

BorealisWind
Ice Protection System

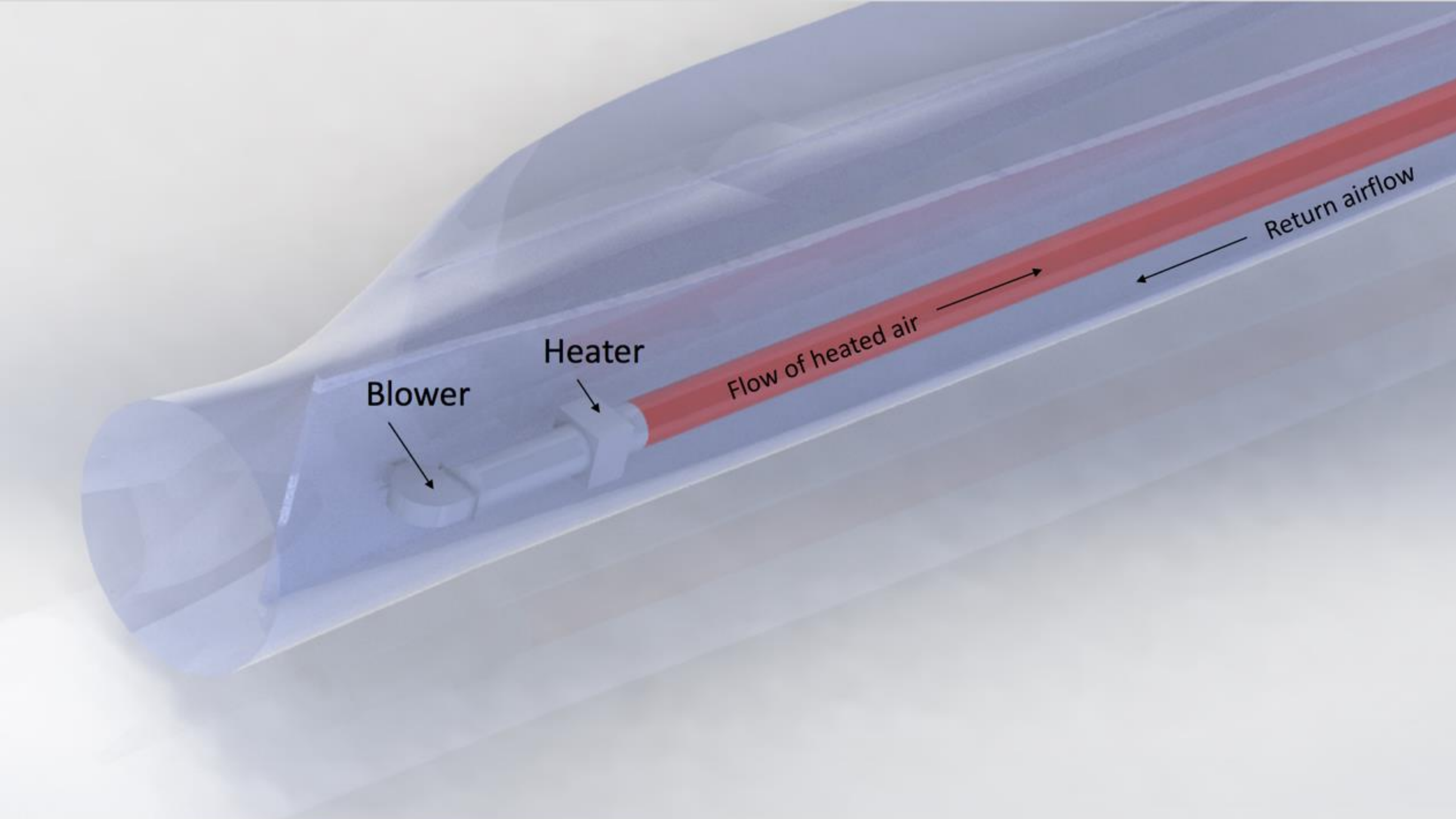
Scan for web site

Strategies to Optimize ROI of an Ice Protection System

Dylan Baxter P.Eng, March 2024

Who are we?

- Provide aftermarket and OEM Ice Protection Systems (IPS) for all turbine makes/models
- 5 wind farms retrofitted in Canada
- 5 winters of validated operation
- 500 MWh energy gain per turbine
- 10% AEP increase on average

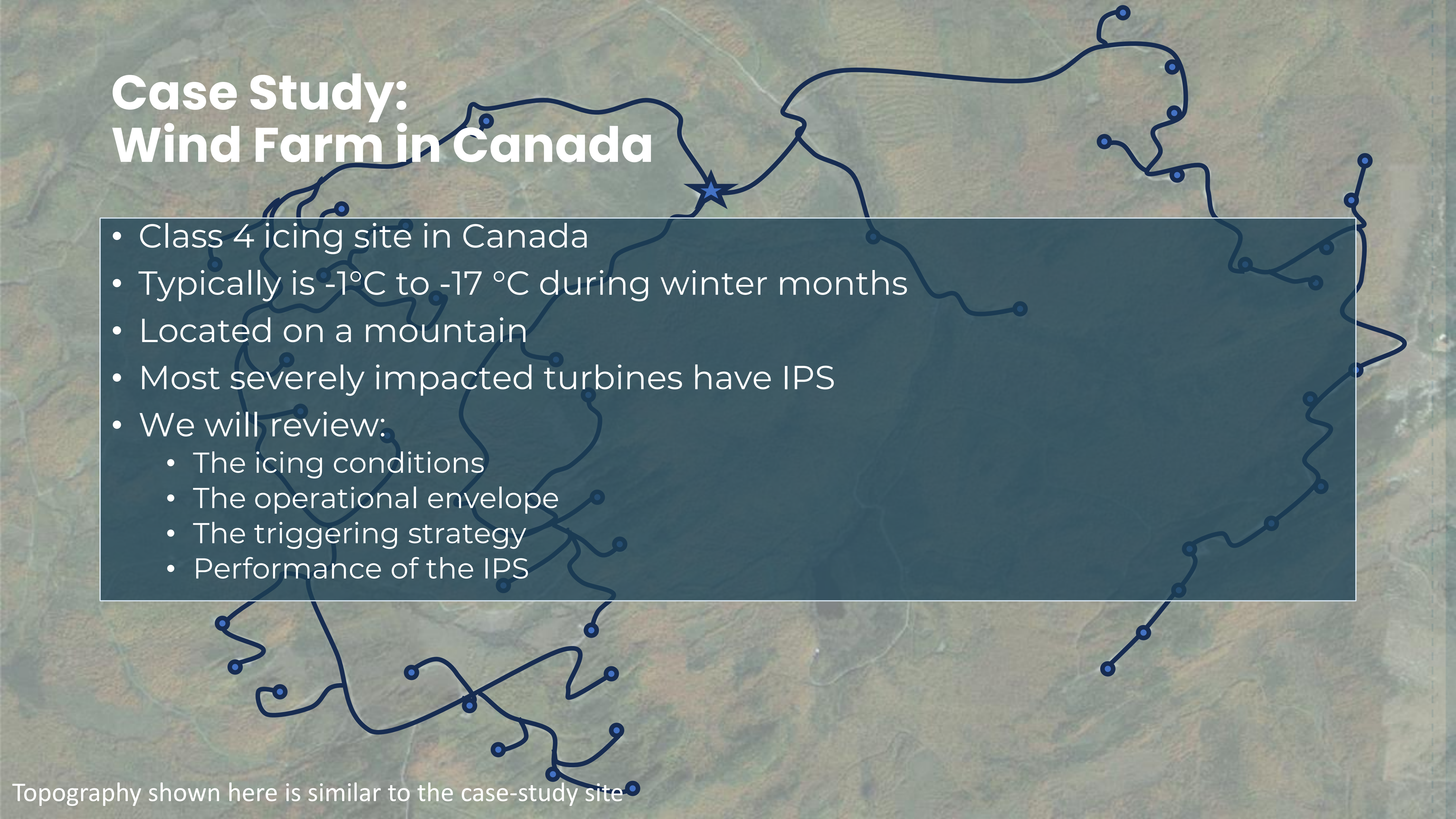

Heater
Blower
Flow of heated air
Return airflow

Infrared Photo of a Blade Equipped with a BorealisWind Ice Protection System

Ambient Wind Temperature	-7 °C
Wind Speed	6 m/s
Blade Internal Temperature	32 °C
Blade External Temperature	11 °C

Case Study:
Wind Farm in Canada

- Class 4 icing site in Canada
- Typically is -1°C to -17 °C during winter months
- Located on a mountain
- Most severely impacted turbines have IPS
- We will review:
    - The icing conditions
    - The operational envelope
    - The triggering strategy
    - Performance of the IPS



Topography shown here is similar to the case-study site

Icing Conditions

610 hours of icing per year

~50% of icing time

~75% of icing time

Abnormally frequent icing below -8C

Temperature (°C)	Annual Icing (hours)	Wind Speed [m/s]											
		4	6	8	10	12	14	16	18	20	22	24	>24
	0	22	38	39	29	19	11	5	2	1	0	0	0
	-2	16	25	26	19	13	7	3	2	0	0	0	0
	-4	11	21	22	16	11	8	2	1	0	0	0	0
	-6	8	18	17	14	8	4	2	1	0	0	-	-
	-8	7	13	13	10	7	3	1	1	0	0	0	-
	-10	5	10	10	7	5	2	1	0	0	0	-	-
	-12	3	7	7	6	4	1	1	0	0	-	-	-
	-14	2	4	5	4	2	1	0	0	0	0	0	-
	-16	1	3	3	2	1	1	0	0	-	-	-	-
	-18	1	2	2	1	1	0	0	0	0	-	-	-
	-20	1	2	3	2	1	1	0	0	-	-	-	-

Thermodynamic Model - High Level

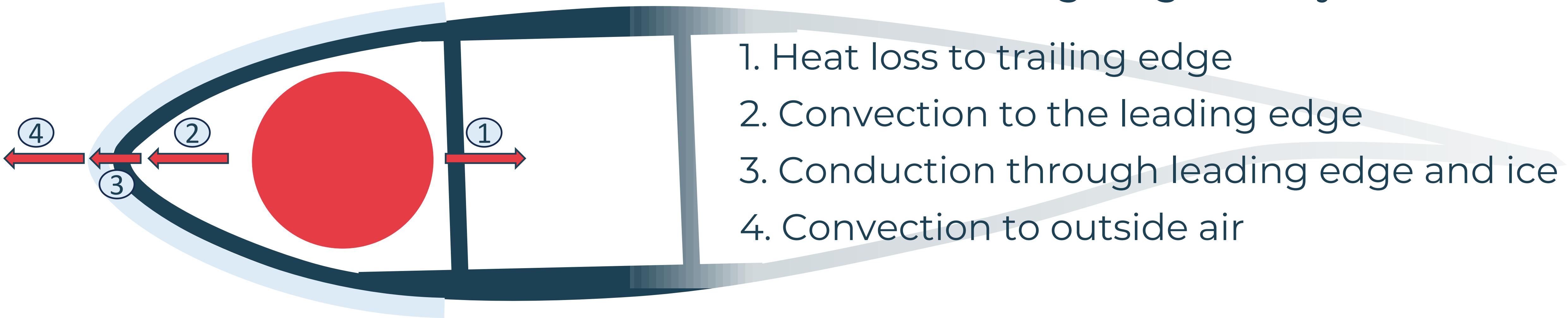
Assumptions:

- Ice Type: Rime
- Liquid Water Content = 0 g/m^3
- Ambient Temperature = [-20, 0] °C
- Wind = [4, 24] m/s

Design Parameters per Blade:

- Duct Length: 45 m
- Heater Power: 30 kW
- Airflow: 7000 m^3/h
- Temperature Limit: Tg – 20 °C

Calculate heat transfer inside the Leading-Edge Cavity



1. Heat loss to trailing edge
2. Convection to the leading edge
3. Conduction through leading edge and ice
4. Convection to outside air

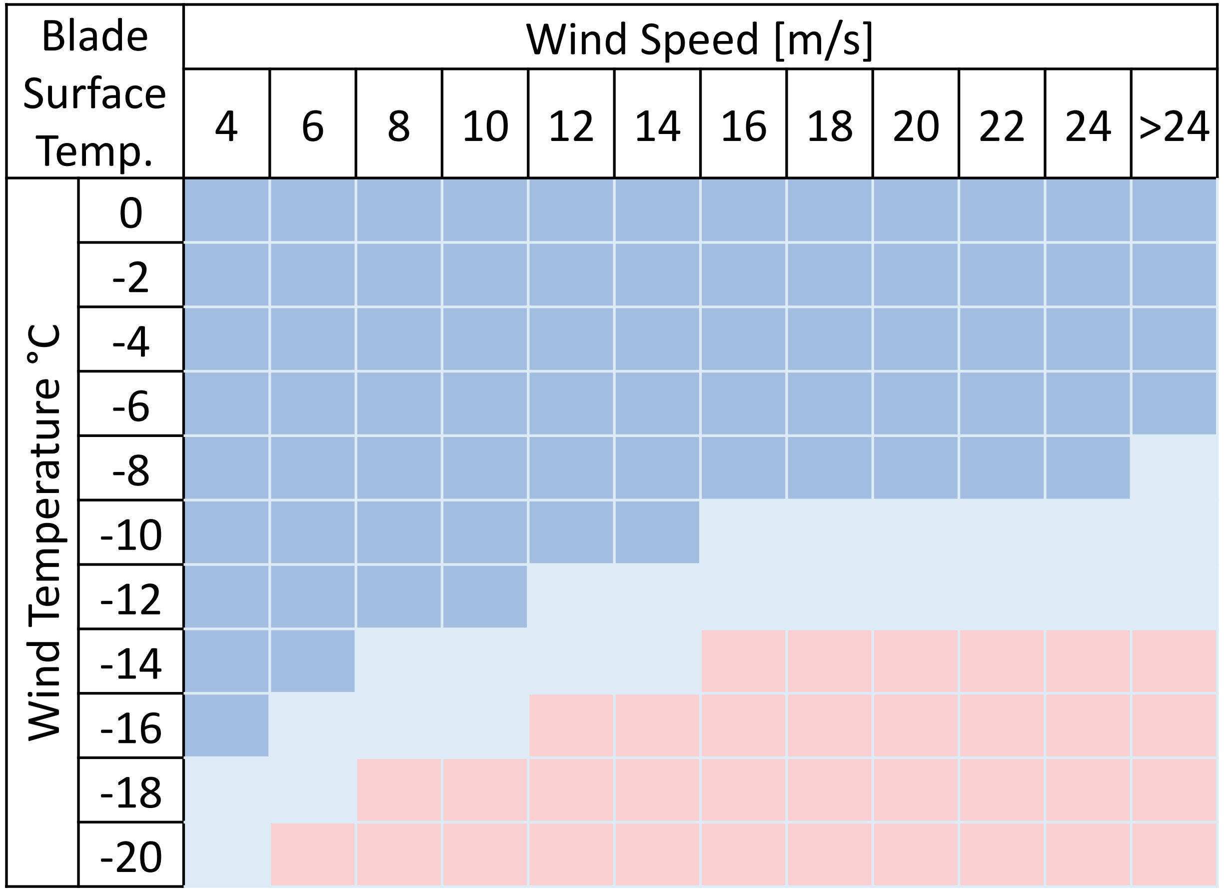
Operational Envelope

Legend

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

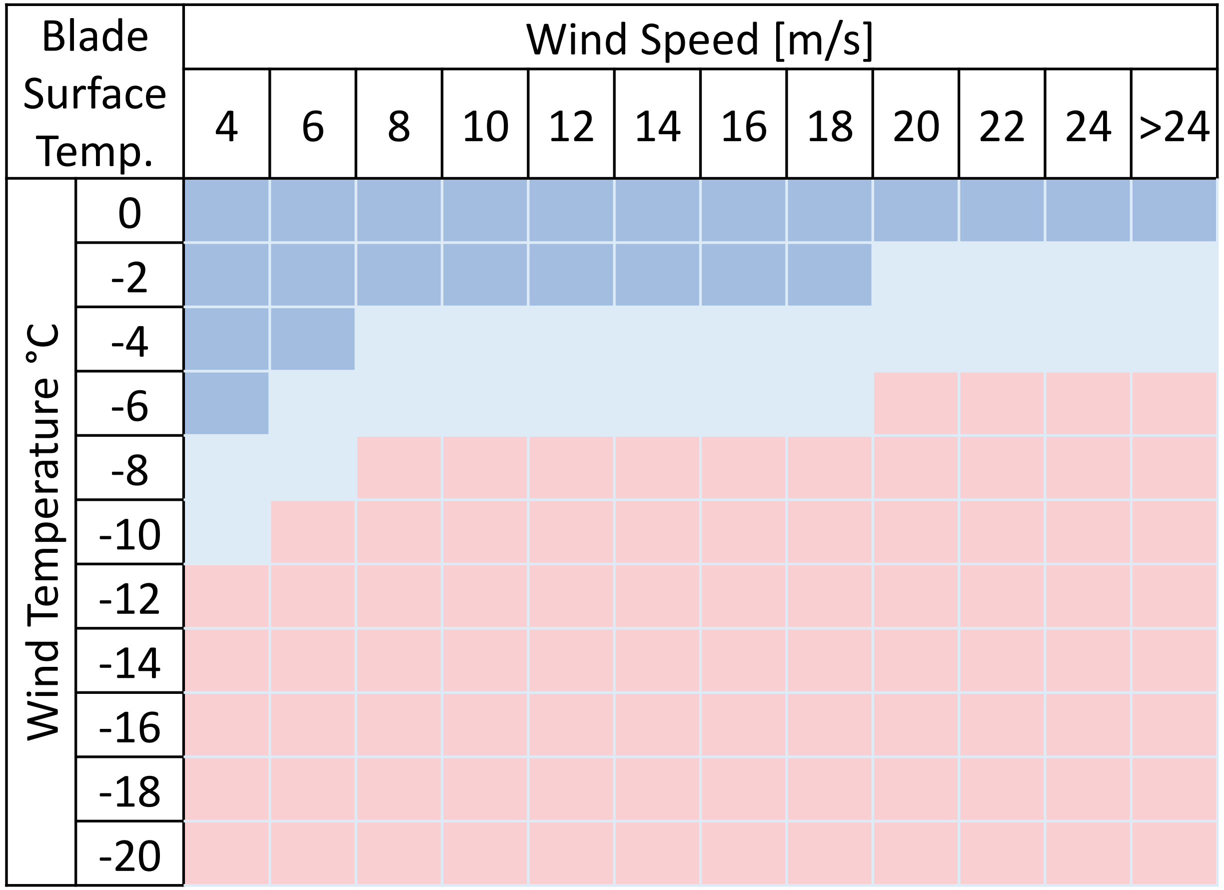
De-icing:

Remove/prevent ice accumulation on an idle turbine



Anti-icing:

Remove/prevent ice accumulation on a spinning turbine



Operational Envelope

Legend	
(dark blue)	Blade Surface > 3°C
(light blue)	Blade Surface > 0°C
(pink)	Blade Surface < 0°C

De-icing:

98% of icing hours covered

Annual Icing (hours)		Wind Speed [m/s]											
		4	6	8	10	12	14	16	18	20	22	24	>24
Wind Temperature °C	0	22	38	39	29	19	11	5	2	1	0	0	0
	-2	16	25	26	19	13	7	3	2	0	0	0	0
	-4	11	21	22	16	11	8	2	1	0	0	0	0
	-6	8	18	17	14	8	4	2	1	0	0	-	-
	-8	7	13	13	10	7	3	1	1	0	0	0	-
	-10	5	10	10	7	5	2	1	0	0	0	-	-
	-12	3	7	7	6	4	1	1	0	0	-	-	-
	-14	2	4	5	4	2	1	0	0	0	0	0	-
	-16	1	3	3	2	1	1	0	0	-	-	-	-
	-18	1	2	2	1	1	0	0	0	0	-	-	-
	-20	1	2	3	2	1	1	0	0	-	-	-	-

Anti-icing:

77% of icing hours covered

Annual Icing (hours)		Wind Speed [m/s]											
		4	6	8	10	12	14	16	18	20	22	24	>24
Wind Temperature °C	0	22	38	39	29	19	11	5	2	1	0	0	0
	-2	16	25	26	19	13	7	3	2	0	0	0	0
	-4	11	21	22	16	11	8	2	1	0	0	0	0
	-6	8	18	17	14	8	4	2	1	0	0	-	-
	-8	7	13	13	10	7	3	1	1	0	0	0	-
	-10	5	10	10	7	5	2	1	0	0	0	-	-
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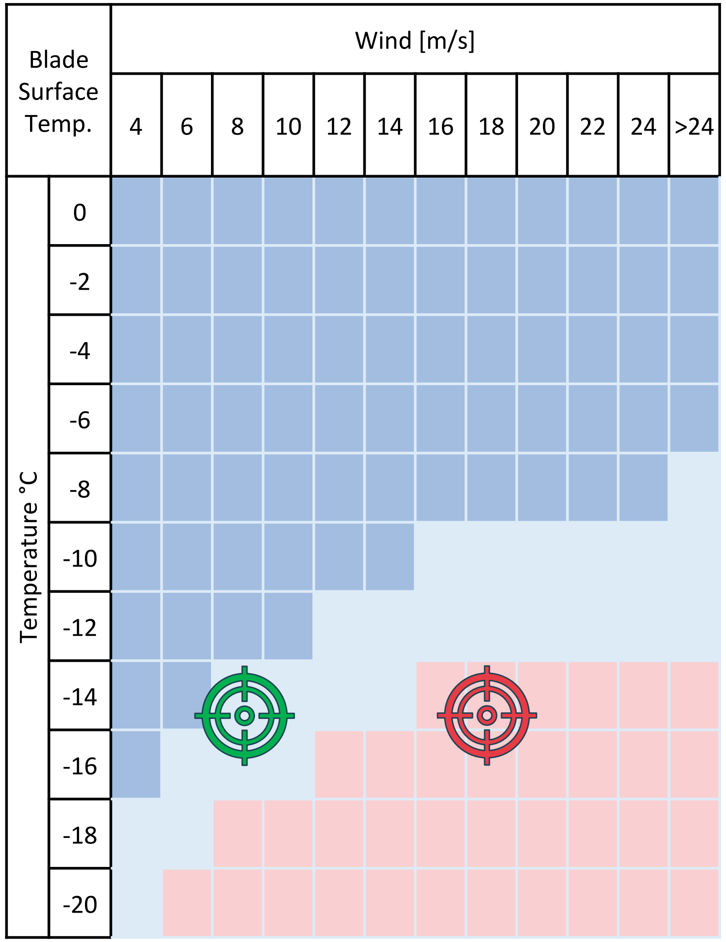
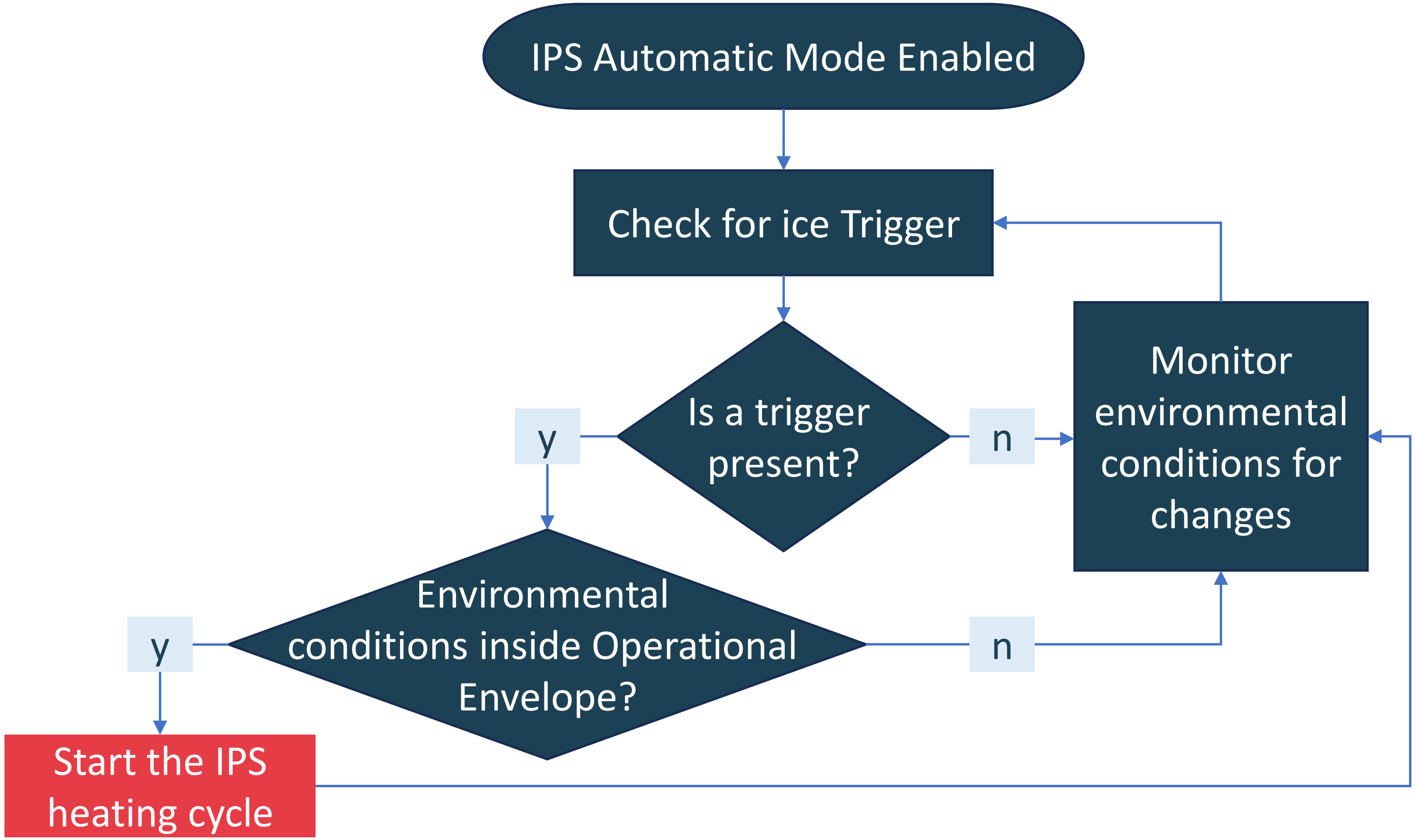
	-14	2	4	5	4	2	1	0	0	0	0	0	-
	-16	1	3	3	2	1	1	0	0	-	-	-	-
	-18	1	2	2	1	1	0	0	0	0	-	-	-
	-20	1	2	3	2	1	1	0	0	-	-	-	-

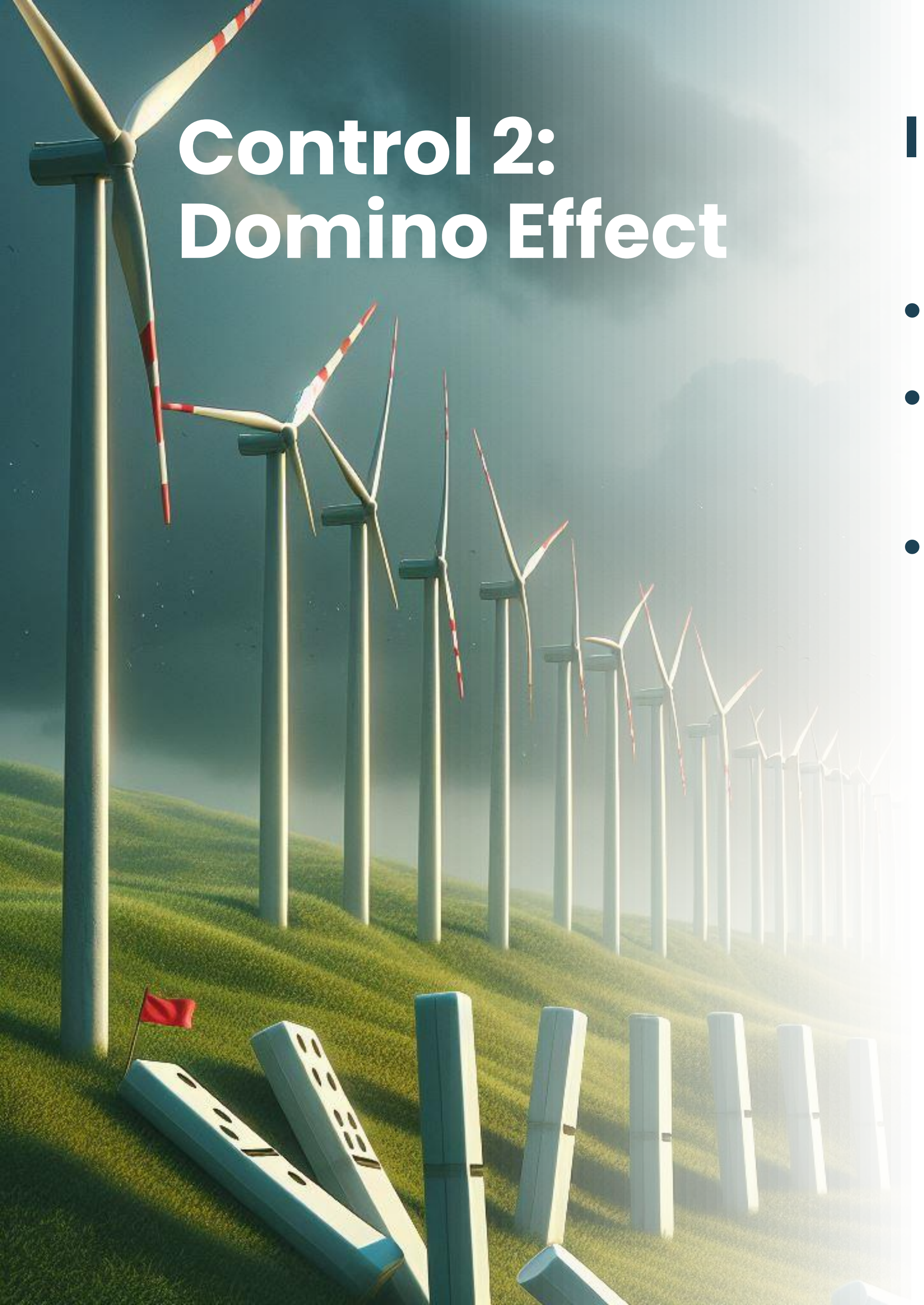
Ice Detection Methods in Timeline

Beginning	1	Fog, snow, rain humidity	Public forecasted icing conditions
	2	Icing event starts	IC-1 detects start of icing event (icetek.ca)
	3	Ice begins to form on the blade	Eologix detects ice on the blade (eologix-ping.com)
	4	Turbine performance starts to decrease	
During	5		Turbine error code: reduced performance
	6		Turbine error code: vibrations, or weight-imbalance
	7	Turbine stops in icing error	
	8	Turbine is not accessible for maintenance	
End	9	Icing event ends	IC-1 detects end of icing event (icetek.ca)
	10	Temperatures increase	
	11	Ice sheds from turbine and anemometer	Turbine error codes clear
	12	Regular operation resumes	

Control 1: Operational Envelope







Control 2: Domino Effect

Important for Low Wind Events!

- IPS are most effective during low wind
- But running an IPS can be expensive if site-wide production is below 0 MWh
- It is important to consider which turbines should be heated first:
  - Which turbine is most likely to recover first?
  - Which turbine will produce the most power after ice is shed?
  - Once the most likely turbine to succeed is de-iced, power the IPS of the next most likely to succeed
  - Repeat the process until all turbines have recovered

Create a priority list of IPS equipped turbines

Control 3: Self-Organizing Priority

Topography is similar to case-study

Control 3:
Self-Organizing Priority

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Control 3: Self-Organizing Priority

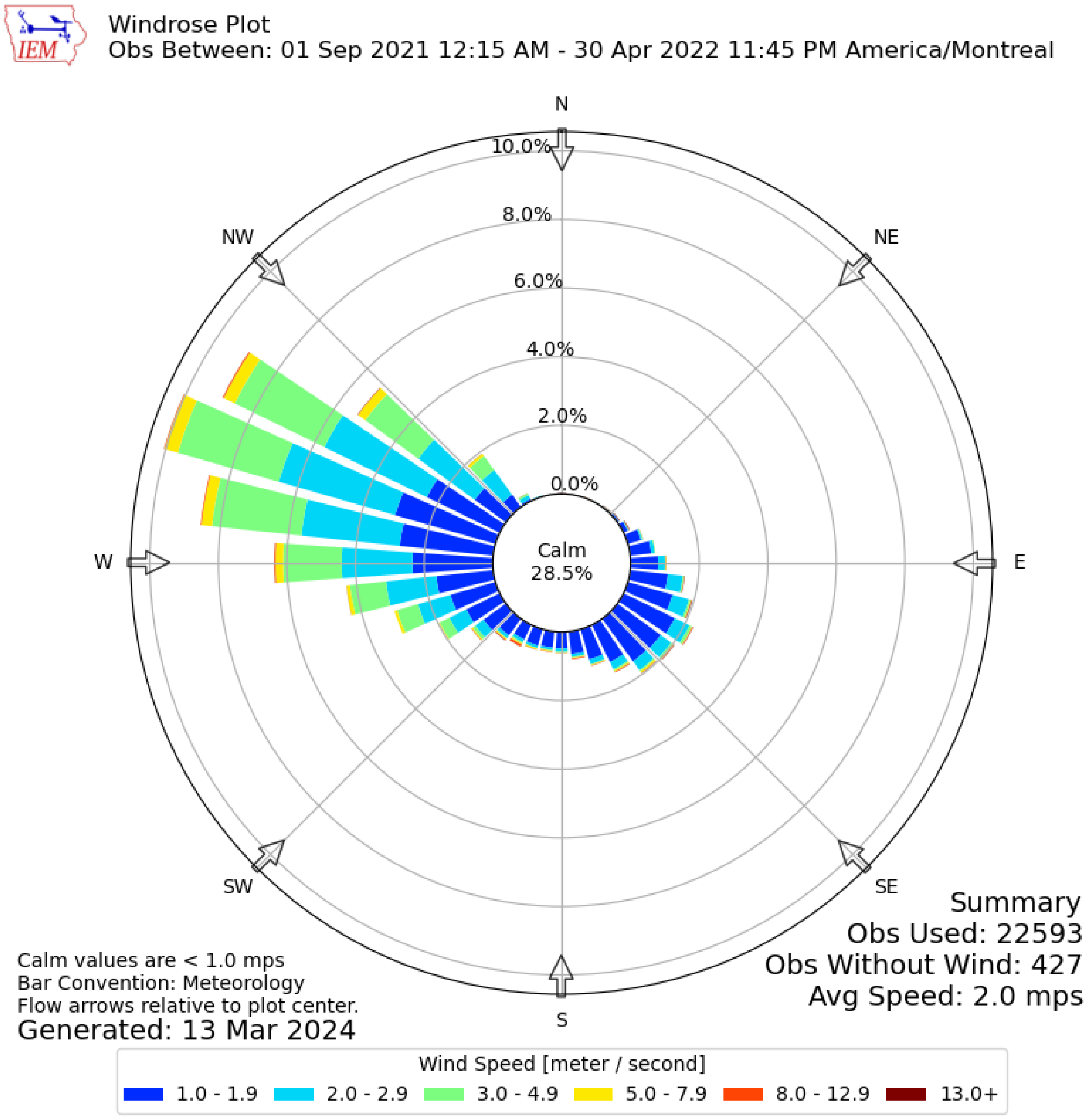
Create a static list considering:

- Constants - elevation, rated power
- History - past turbine performance

Update the list considering:

- Turbine signals - maintenance codes
- Environment - wind direction, speed

Constantly monitor the changing conditions and adjust the Priority List



ref: Iowa Environmental Mesonet

Control X:
Other Conditions to Consider

Forecasted weather conditions

- Its important to consider if the near and distant forecasted conditions are improving or worsening when deciding to heat or not to heat
- Inform whether to follow or ignore the typical “low site production” protocols

Price of Power

- When power prices surge or fall it could present an important opportunity to recovered lost energy production

Case Study: IPS Performance

Bold shows icing losses for turbines with IPS

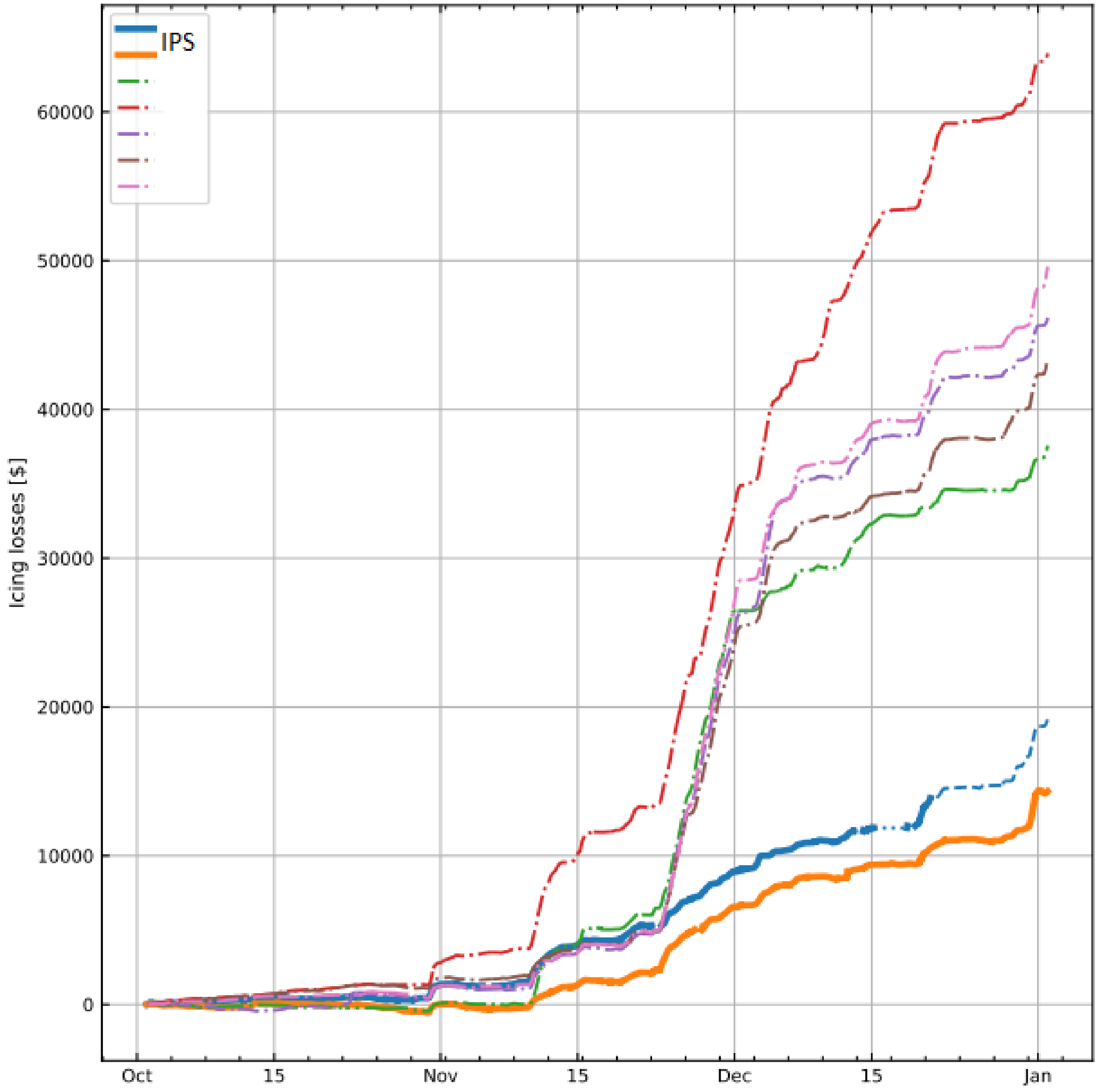
Dotted shows icing losses for control turbines

- Turbine with IPS is dotted when IPS is not available

This winter as of Jan 2024:

- 96% Availability
- $90,600 CAD / 61,500€ recovered from two turbines with IPS

Data analyzed and graphed by Icetek (icetek.ca)



FabricAir

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Ice Protection System

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