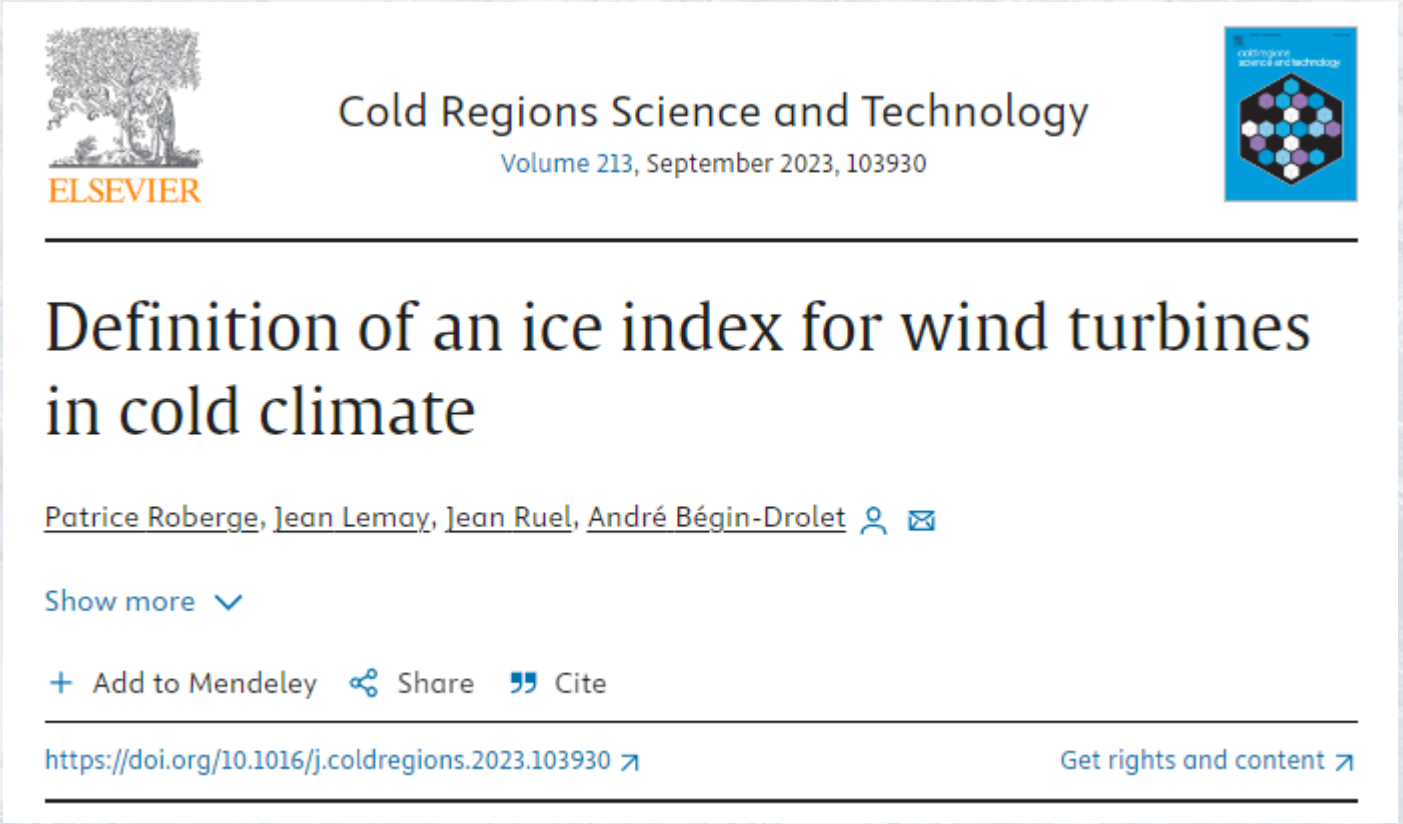
Navigating Icy Waters: Decoding Wind Turbine Success with the Ice Index

Winterwind 2024 – 2024-03-18

Patrice Roberge, Ph.D.
Icetek, Québec, Canada

Context

- Full paper with details
- DOI: https://doi.org/10.1016/j.coldregions.2023.103930
- This presentation is based on research made at Université Laval



ELSEVIER

Cold Regions Science and Technology

Volume 213, September 2023, 103930

Definition of an ice index for wind turbines in cold climate

Patrice Roberge, Jean Lemay, Jean Ruel, André Bégin-Drolet

Show more

+ Add to Mendeley Share Cite

https://doi.org/10.1016/j.coldregions.2023.103930

Get rights and content

Context

- Titanic, From Southampton to New-York
- Best pilot = shortest travel time?
- Other factors? Icebergs, temperature, Wind?
- Two ships?
- How to benchmark?

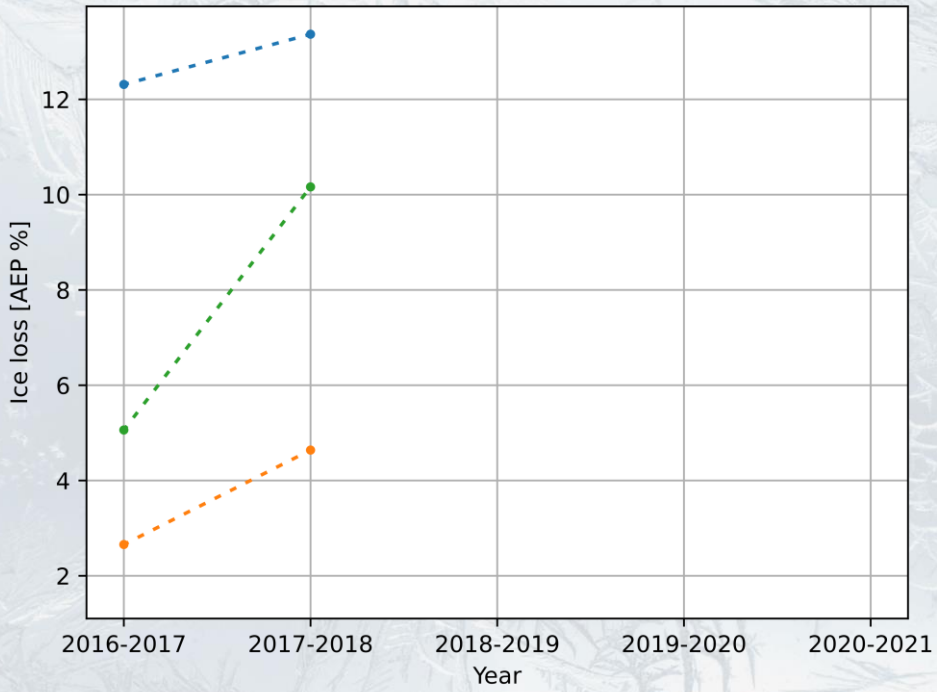
Context

- Performance based only on icing losses
- How do we get a reference?
- Two ships : two technologies
- Benchmark on icing frequency

Example

- Significant icing losses (3-15% AEP losses)
- Trending in the wrong direction

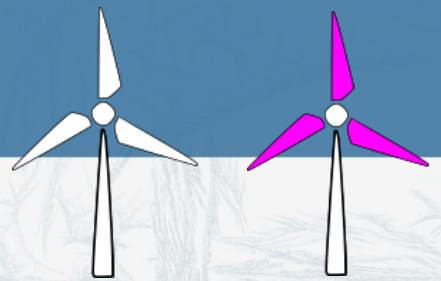
Seasonal variability (same wind farm)



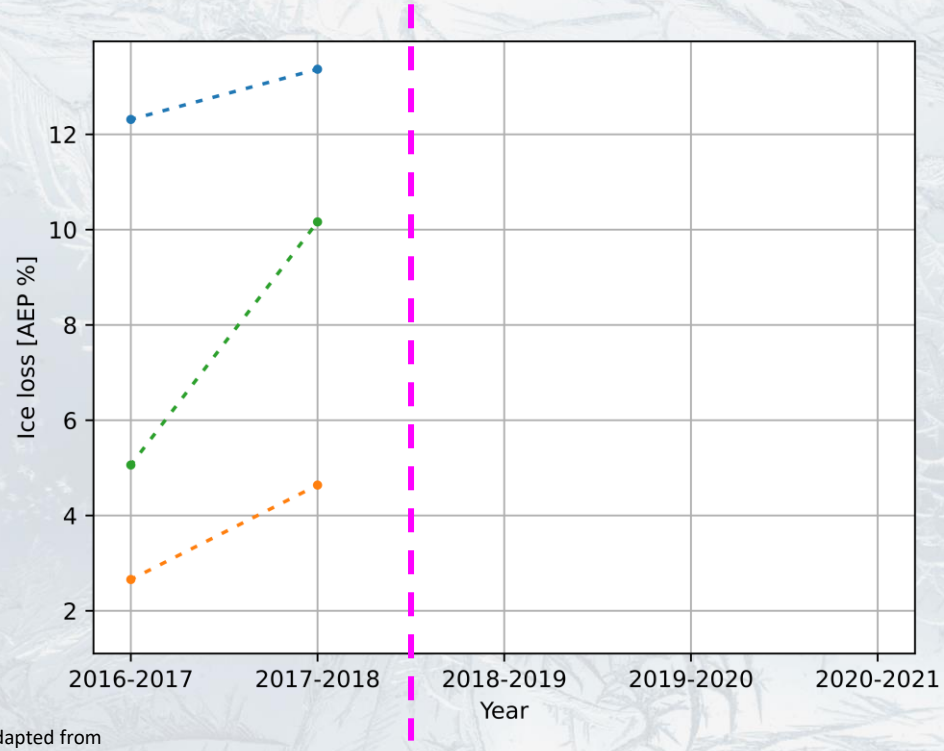
Adapted from
Christophersen, A. L., Beltoft, D. & Zagar M. (2022). Validation of ice-affected plant energy assessment at a large OEM. Winterwind 2022, Skellefte˚a, Sweden 19-21 April 2022

Example

- Significant icing losses (3-15% AEP losses)
- Trending in the wrong direction
- Winterwind 2018, pink blades!



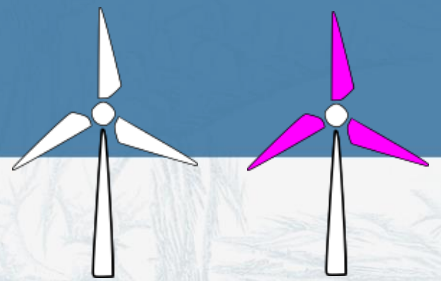
Seasonal variability (same wind farm)



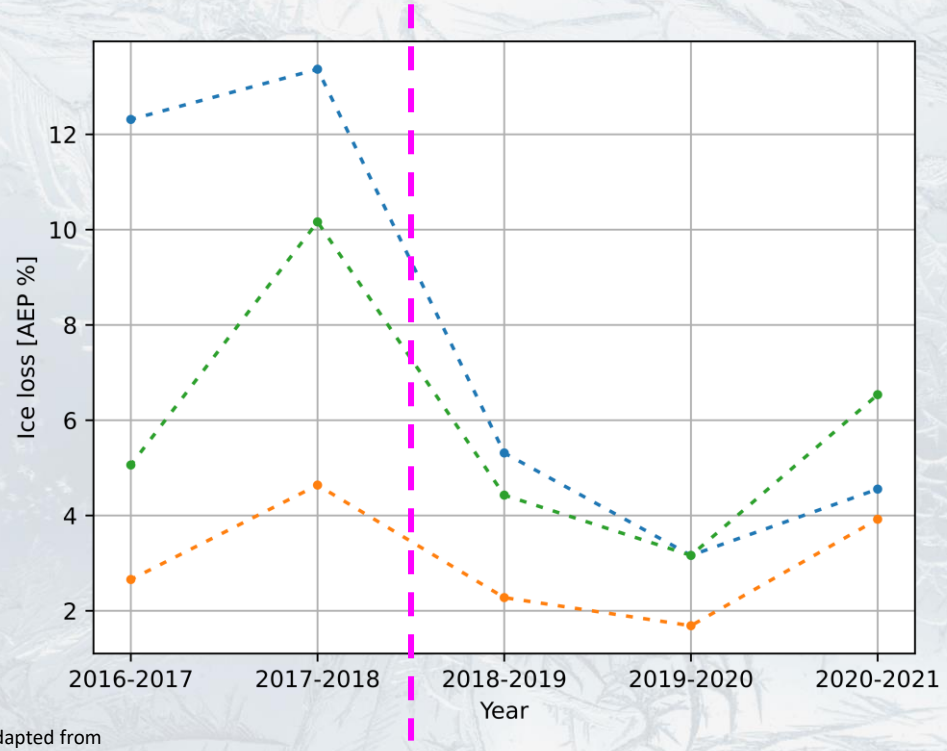
Adapted from
Christophersen, A. L., Beltoft, D. & Zagar M. (2022). Validation of ice-affected plant energy assessment at a large OEM. Winterwind 2022, Skellefte˚a, Sweden 19-21 April 2022

Example

- Significant icing losses (3-15% AEP losses)
- Trending in the wrong direction
- Winterwind 2018, pink blades!
- Reduction of losses, pink blades work!
- Not quite true…



Seasonal variability (same wind farm)



Adapted from
Christophersen, A. L., Beltoft, D. & Zagar M. (2022). Validation of ice-affected plant energy assessment at a large OEM. Winterwind 2022, Skellefte˚a, Sweden 19-21 April 2022

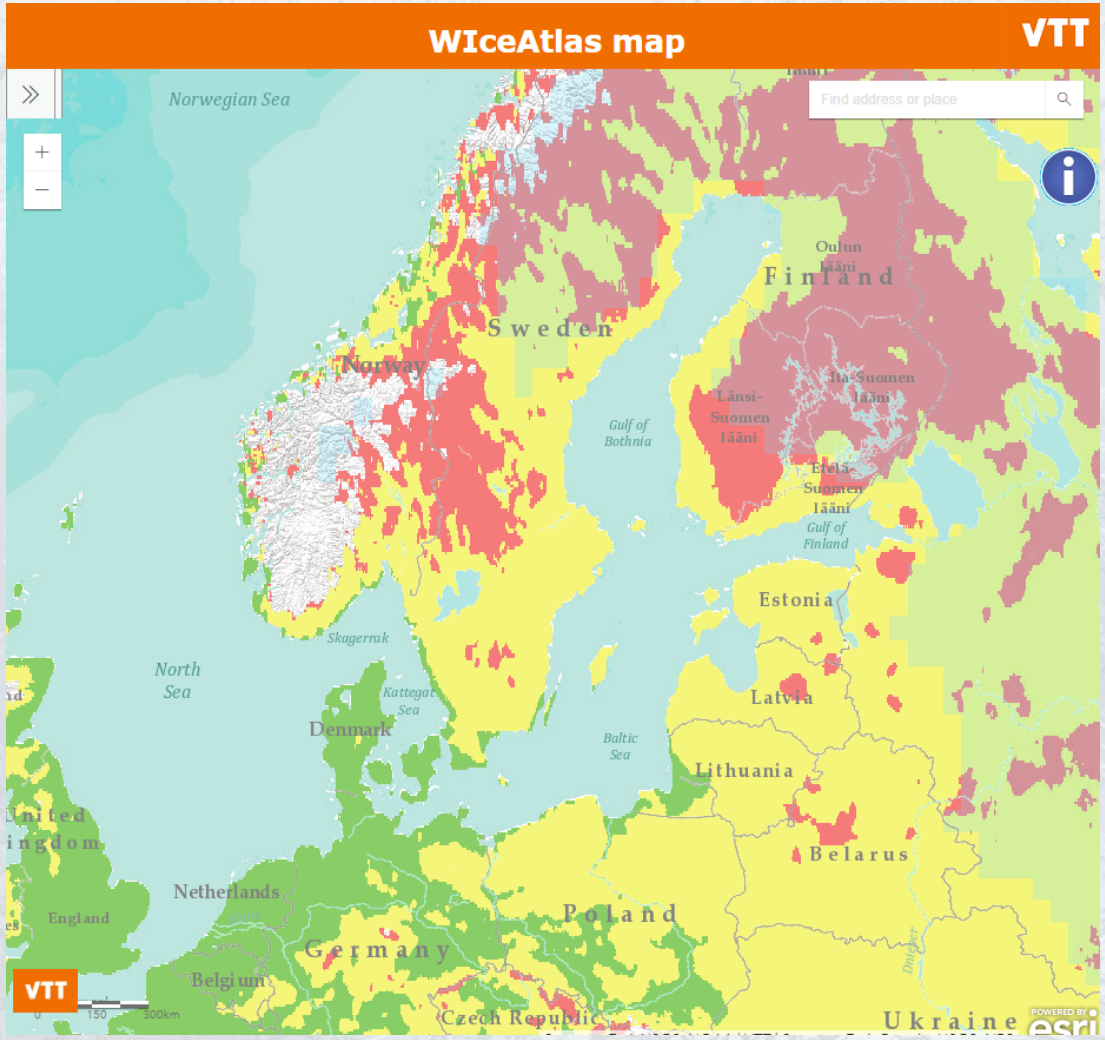
Challenge

- Reference it with the **Ice Index**
- Why?
  Inter-annual variation of icing
  5x > wind variations[1]
- Impact of icing solutions lost in variations of other factors

1-Wind Power Icing Atlas (WIceAtlas) & icing map of the world
Winterwind 2015, Piteå Sweden, Simo Rissanen, Ville Lehtomäki

The Ice Index

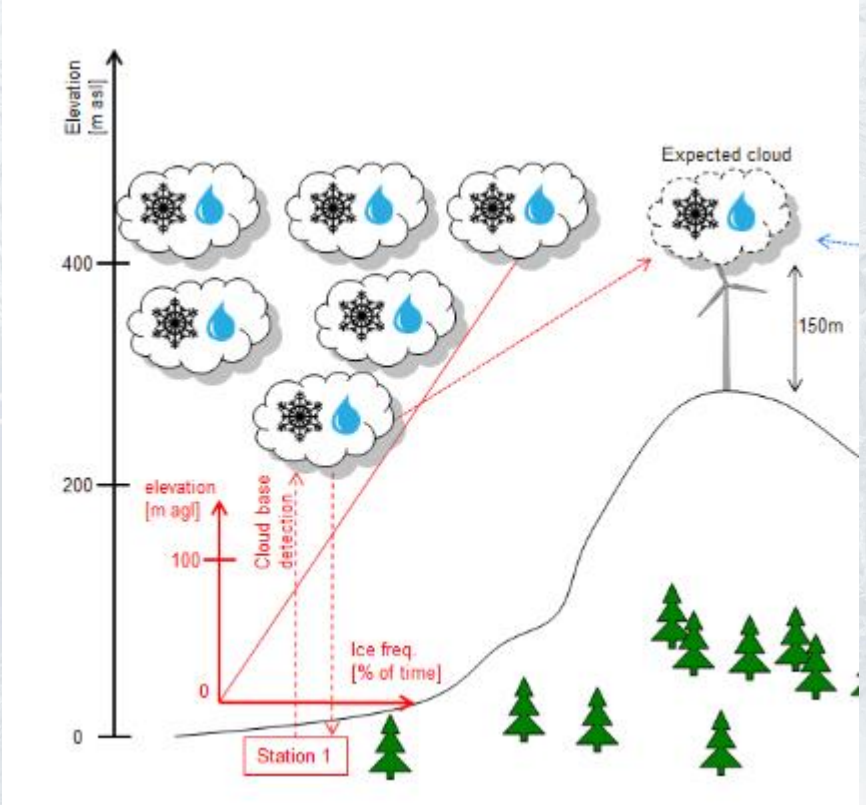
- Adapt the methodology from WIceAtlas icing map
- From long term, to yearly, to monthly values
- Benchmark!



Credit VTT, https://projectsites.vtt.fi/sites/wiceatlas/www.vtt.fi/sites/wiceatlas/methodology.html

The Ice Index

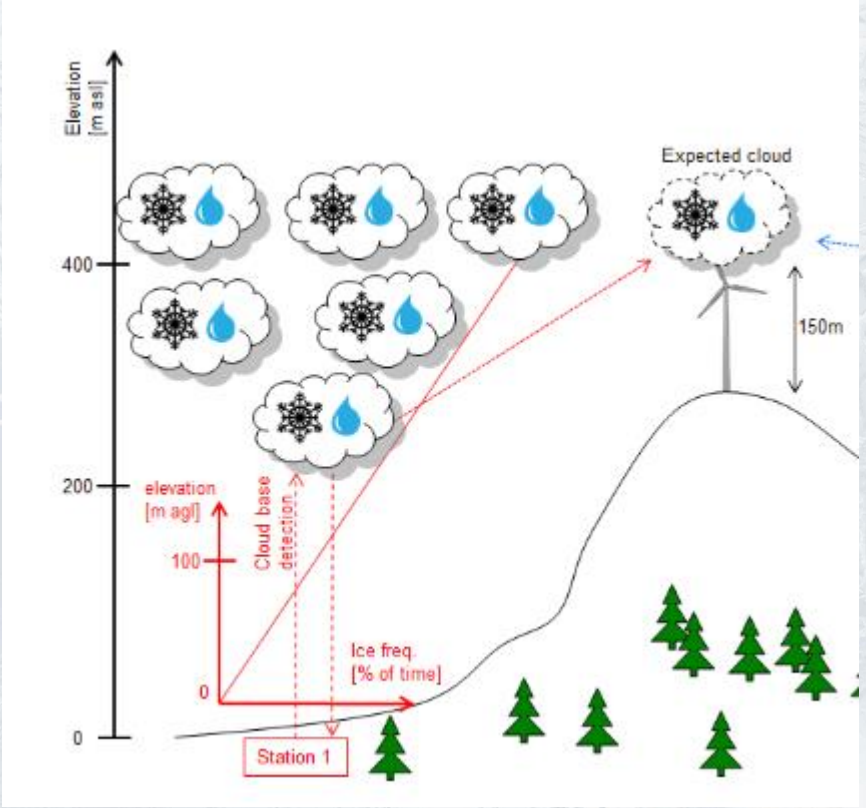
- Cloud base height (CBH) from met. Station
- On average OK indicator
- CBH below turbine height + Temperature below 0ºC
- Ice fraction (IF) = Fraction of the time when both criteria are met



Credit VTT, https://projectsites.vtt.fi/sites/wiceatlas/www.vtt.fi/sites/wiceatlas/methodology.html

The ice index

- Cloud base height (CBH) from met. Station
- On average OK indicator
- CBH below turbine height + Temperature below 0ºC
- Ice fraction (IF) = Fraction of the time when both criteria are met



Credit VTT, https://projectsites.vtt.fi/sites/wiceatlas/www.vtt.fi/sites/wiceatlas/methodology.html

The Ice Index

Definition of yearly index

$$Index = \frac{IF\ Current\ year\ value}{IF\ Historical\ year\ average}$$

$$II_Y = \frac{IF_Y}{\overline{IF_Y}}$$

The Ice Index

Definition of yearly index

$$Index = \frac{IF\ Current\ year\ value}{IF\ Historical\ year\ average}$$

$$II_Y = \frac{IF_Y}{\overline{IF_Y}}$$

Example:

Current year value = 3.2%

Yearly average = 2.8%

Index = 1.14

$$II_Y = \frac{3.2}{2.8} = 1.14$$

The ice index

Definition of monthly index

$$Index = \frac{IF\ Current\ month\ value}{IF\ Historical\ year\ average} \times Scaling\ factor$$

$$Scaling\ factor = \%\ of\ the\ year\ when\ T<0ºC\ (historical)$$

$$II_m = \frac{IF_m}{\overline{IF_Y}} Sf$$

The ice index

Definition of monthly index

$$Index = \frac{IF\ Current\ month\ value}{IF\ Historical\ year\ average} \times Scaling\ factor$$

$$II_m = \frac{IF_m}{IF_Y} Sf$$

Scaling factor = % of the year when T<0ºC (historical)

Example:

Ice fraction this month = 10.6%
Scaling factor = 0.3
Yearly average = 2.8%
Index = 1.14

$$II_m = \frac{10.6}{2.8} 0.3 = 1.14$$

The Ice Index

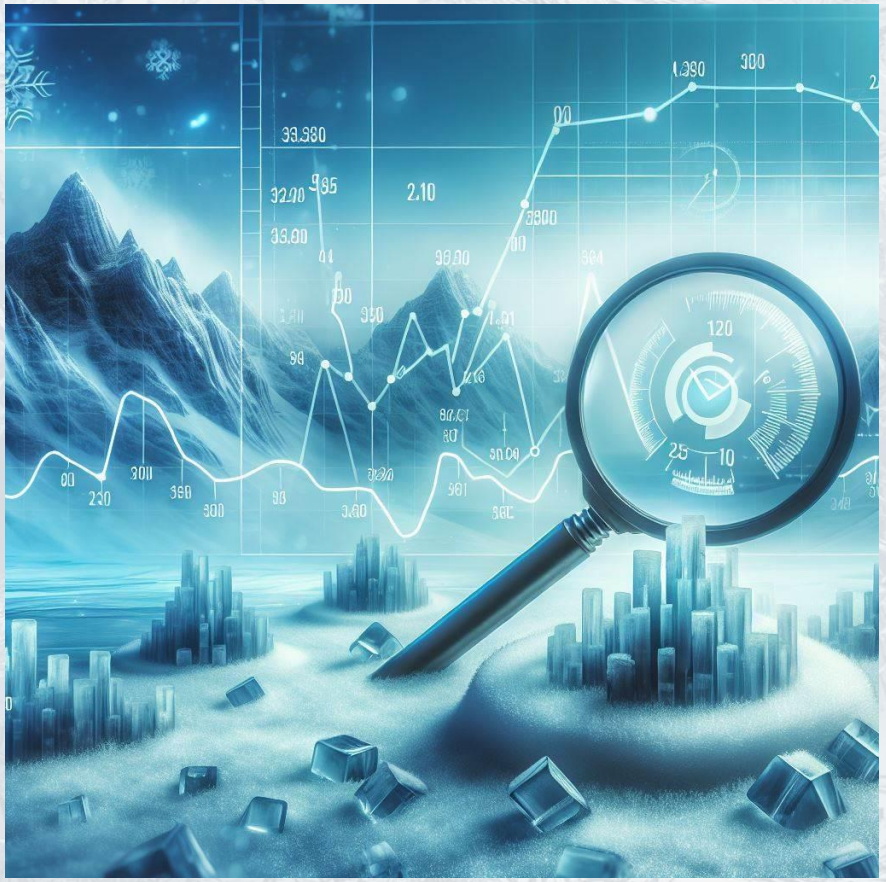
How to interpret?

1 = average icing conditions

>1 = Icing more frequent

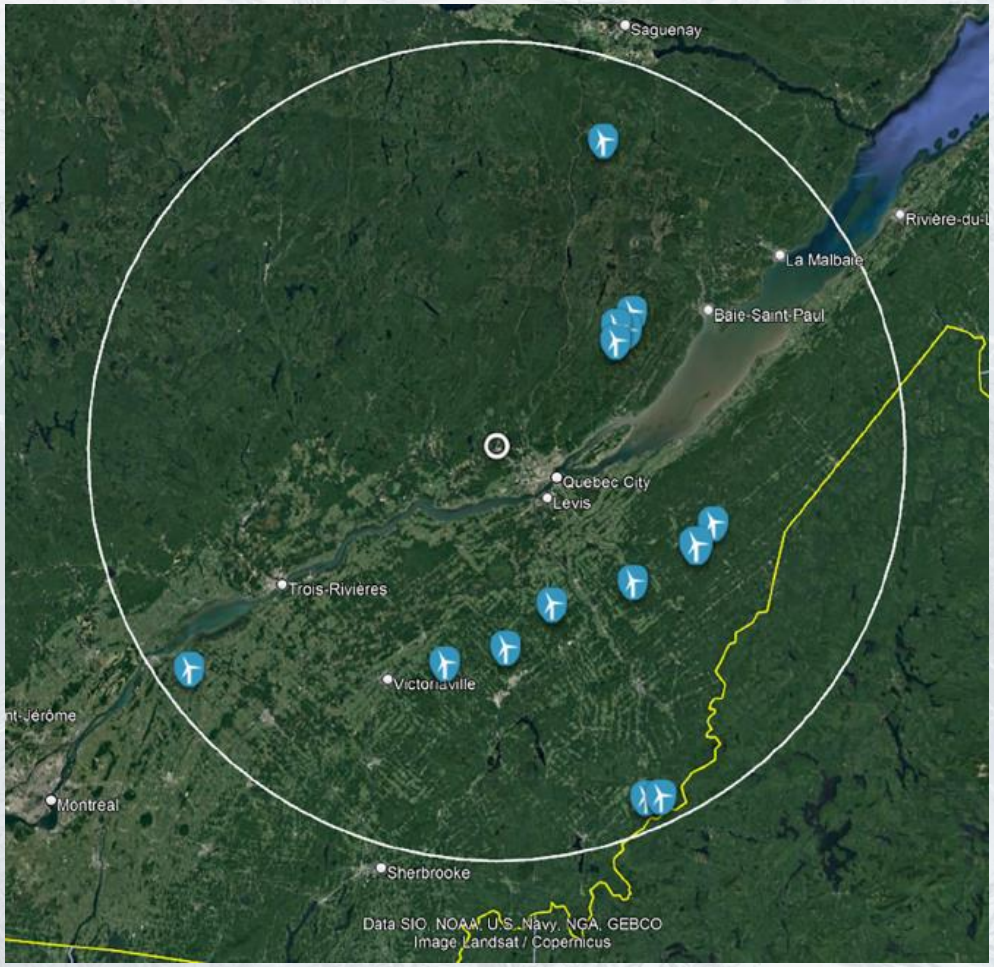
<1 = Icing less frequent

For monthly values = relative to a typical winter month



Validation

- Data: 6 out of 14 wind farms, 160 km radius
- 22 years of reference data from meteorological station
- IC-1 ice sensors on site



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.

Validation

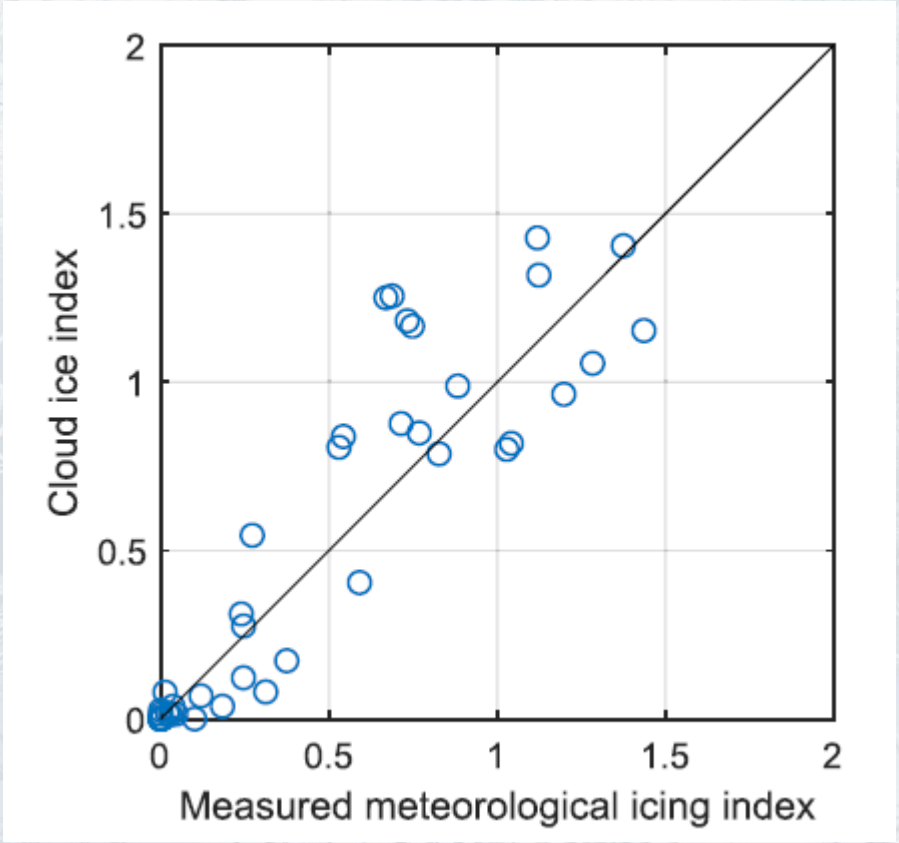
- Reference : IC-1 field data
- Icing frequency measured *in-situ*

- 4 years of data
- Each dot = one month
- Ice index (CBH) vs. IC-1 sensor

Validation

- 4 years of data
- Each dot = one month
- Ice index (CBH) vs. IC-1 sensor

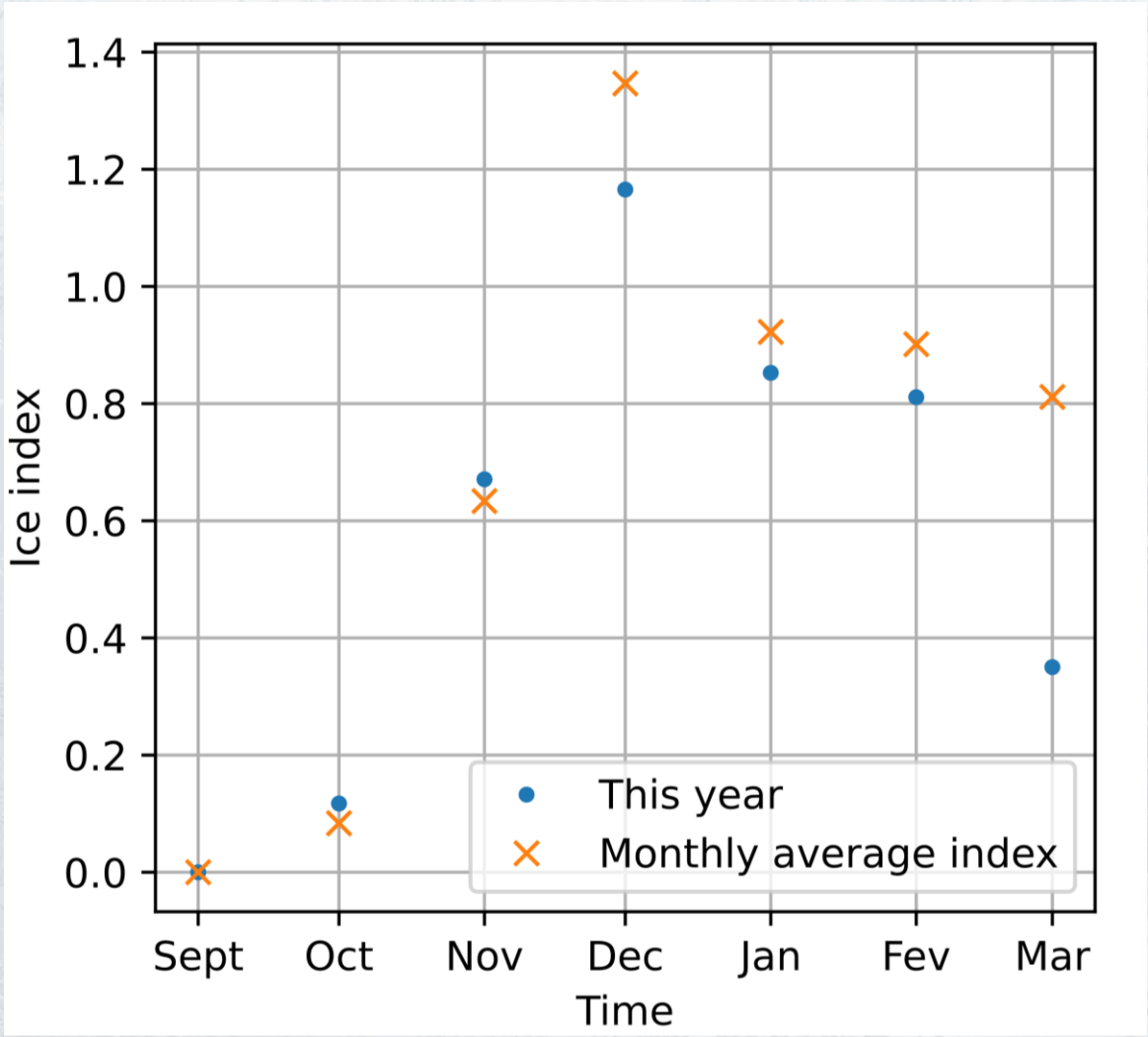
- Optimal = 1:1 line
- $R^2 = 0.84$
- Not as accurate as field results but OK



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.

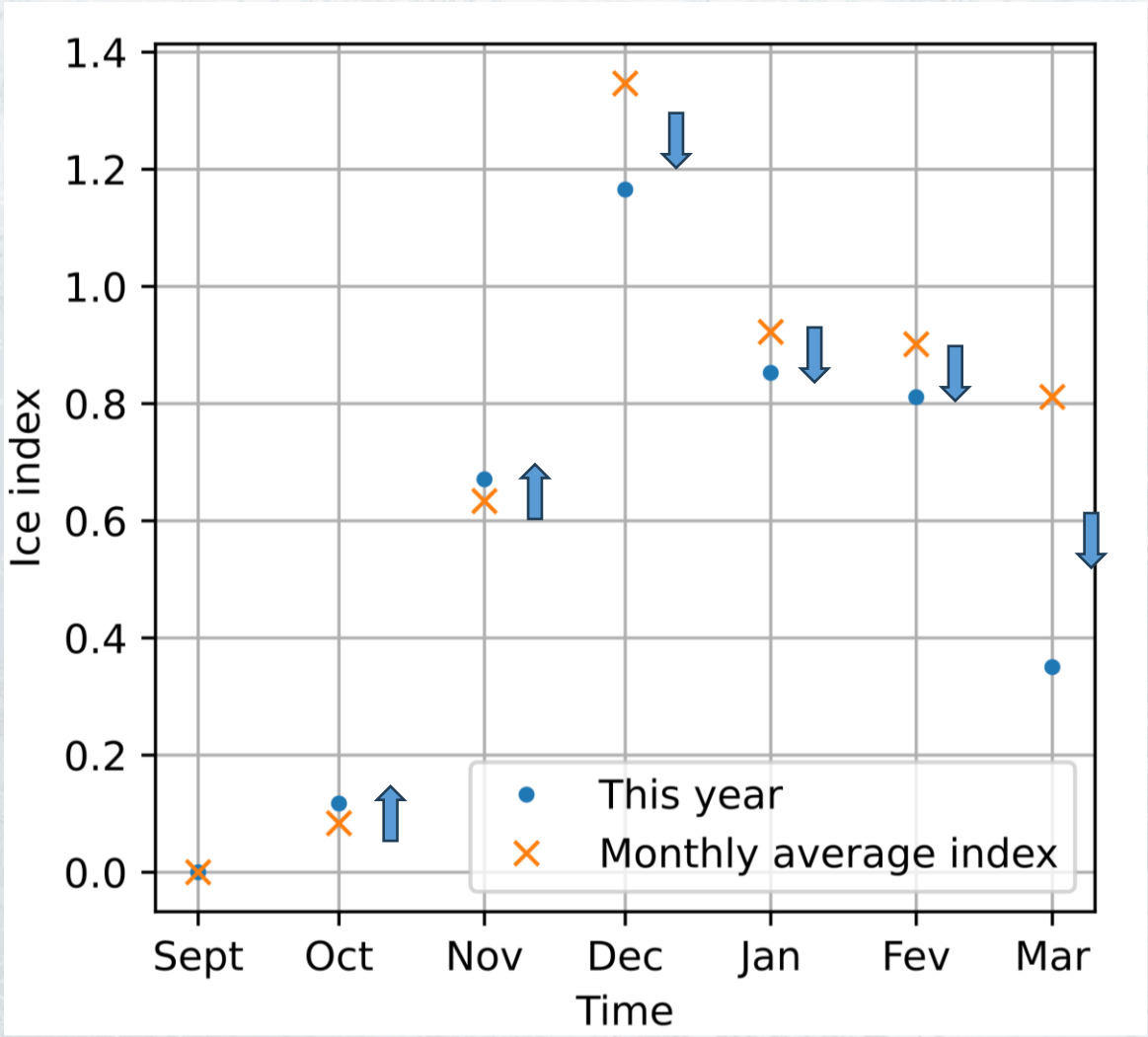
Ice Index in Quebec this winter

- Computed for a wind farm at 600m
- Started the winter with more frequent icing
- El Nino storms, warm temperatures slowed down icing



Ice index in Quebec this winter

- Computed for a wind farm at 600m
- Started the winter with more frequent icing
- El Nino storms, warm temperatures slowed down icing



Conclusion and perspectives

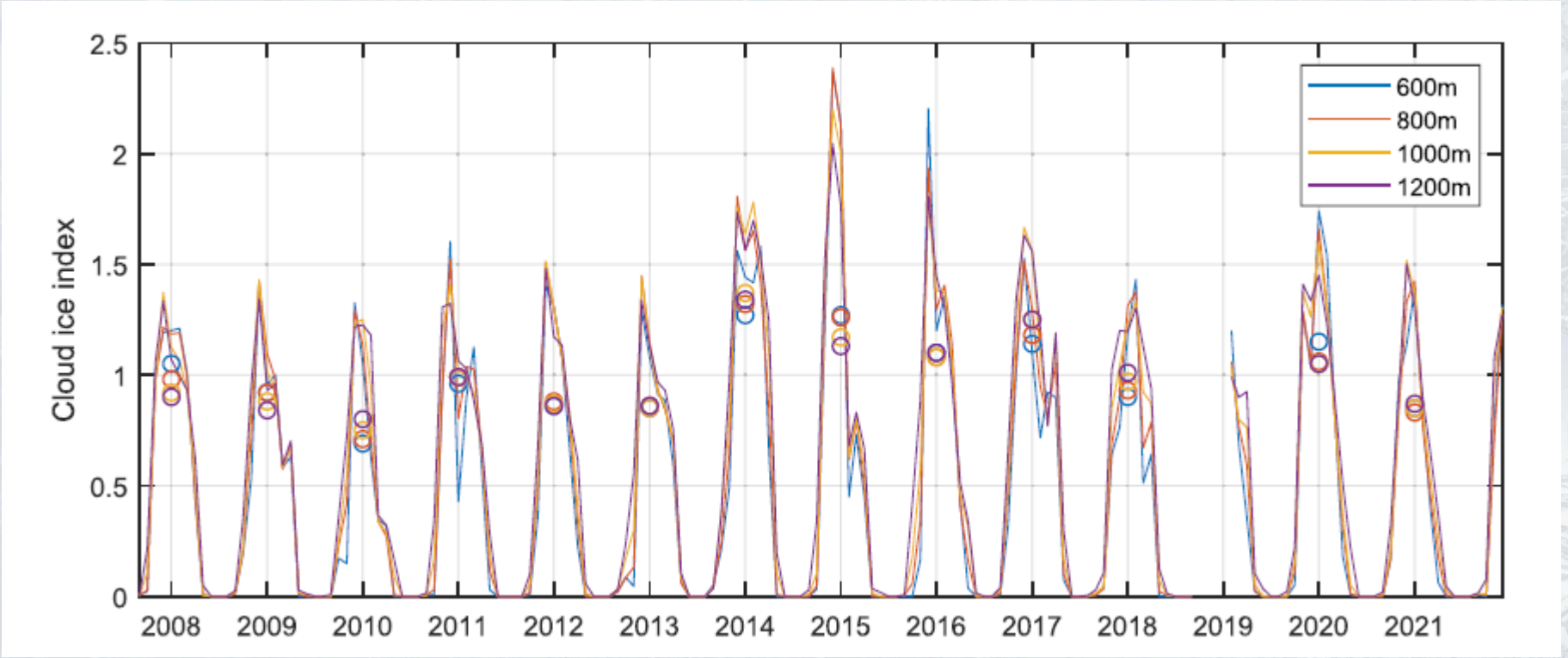
- Publishing Ice Index monthly / yearly basis for Canada
- Reliability of the data is an issue without a sensor
- Do you have ideas on how to improve?

- 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.

- Contact : Patrice.roberge@icetek.ca

Ice index in Quebec in the past 10 years

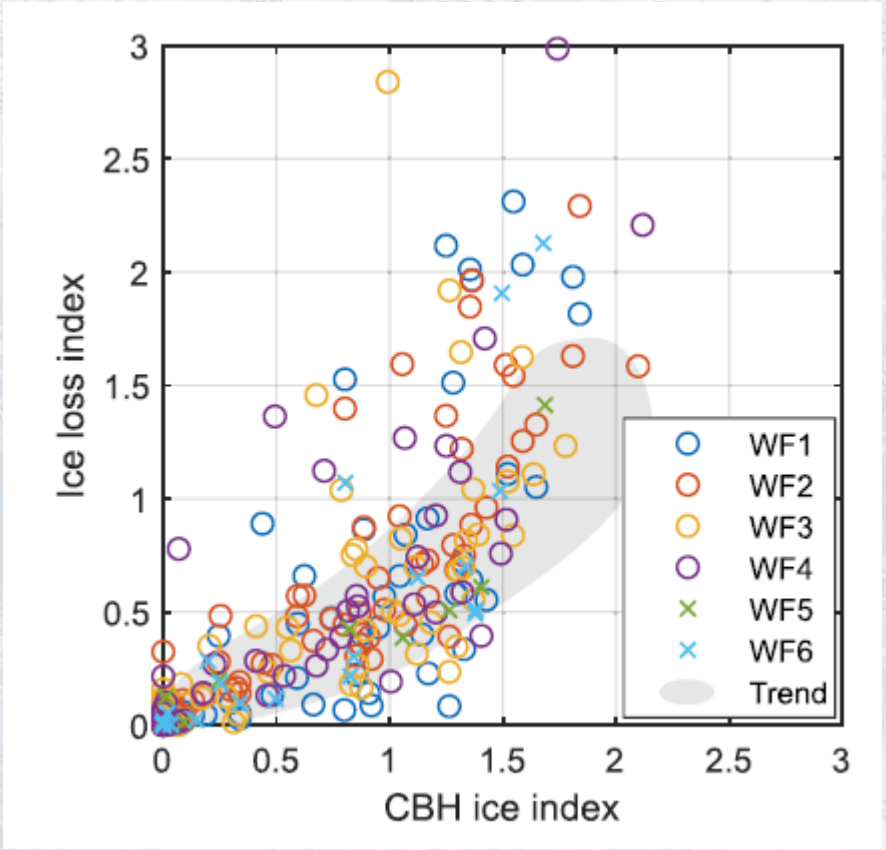
- Impact of altitude
- Some winters are shorter or more intense



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.

Validation

- Monthly ice index
- Data from CBH vs. SCADA icing losses (individual tubines)
- 6 wind farms, 1-4 years
- Lots of noise
- Circles = No IPS
- Crosses = IPS
- Lots of other factors
- Most of the points are in the main trend



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.

Ice index in Quebec this winter

Observations on the field

- Low icing losses on heated turbines
- High icing losses on farms without heated turbines
- Most of storms came with temperatures between -5ºC and 0ºC