



# Linking Icing Estimates to Operational Losses

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CanWEA



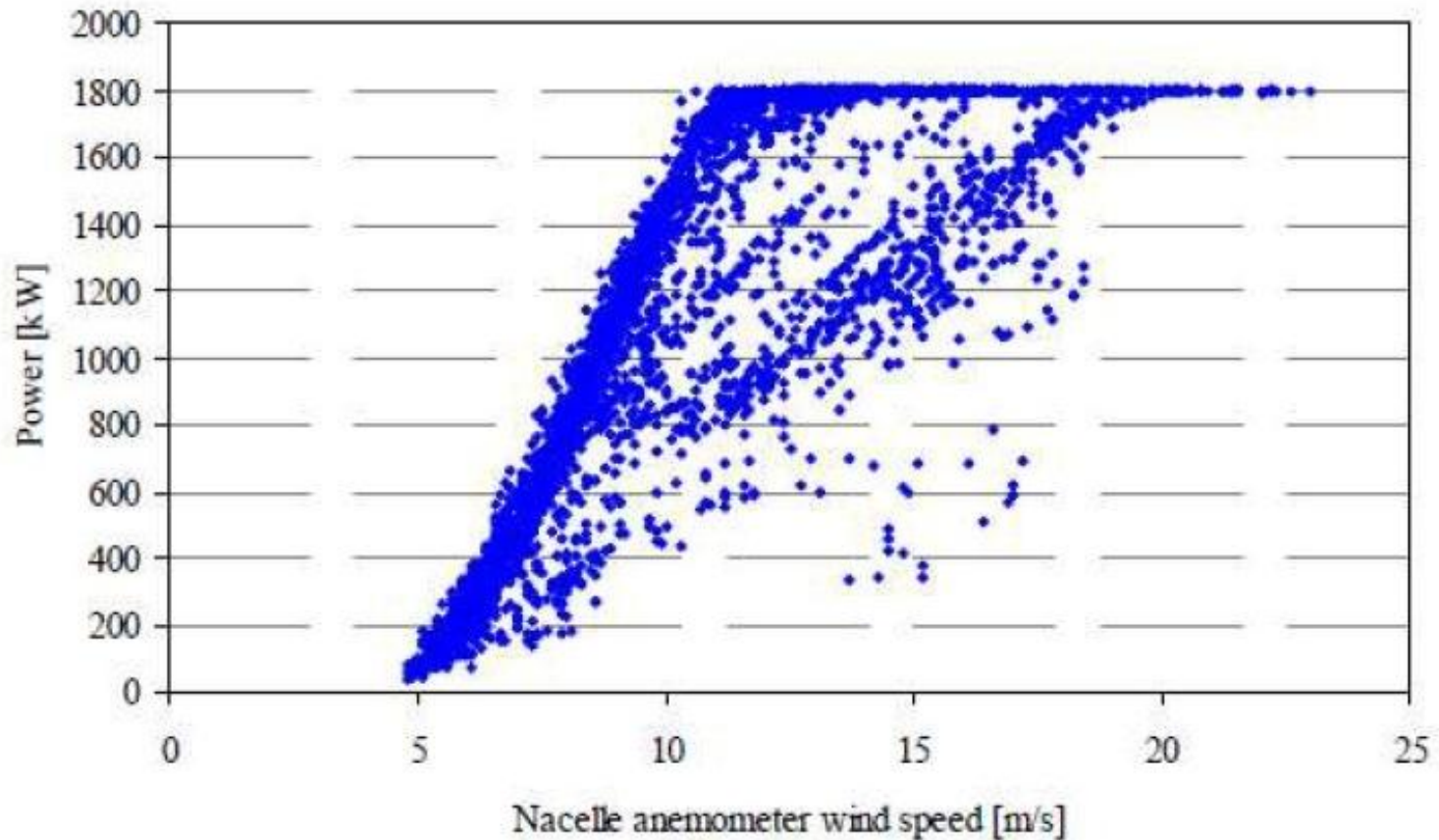
# *Icing Estimates and Operational Losses*

- Effects and impact of icing
- Meteorology of icing
- Climatological estimates
- On-site met tower estimates
- Operational icing losses
- Project planning and mitigation

# Effects and Impacts of Icing

- Reduced quality of wind measurements
- Performance degradation
- Turbine shutdown during severe icing
- Mechanical effects on turbine operation

# BAD NEWS: Performance degradation due to icing



J.F. Corbett, GL Garrad Hassan, 2010: *Predicting Icing Losses*, VindKraft Cold Climates Workshop

# VERY BAD NEWS: Turbine shutdown due to icing



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Northern [REDACTED] wind  
turbines frozen solid

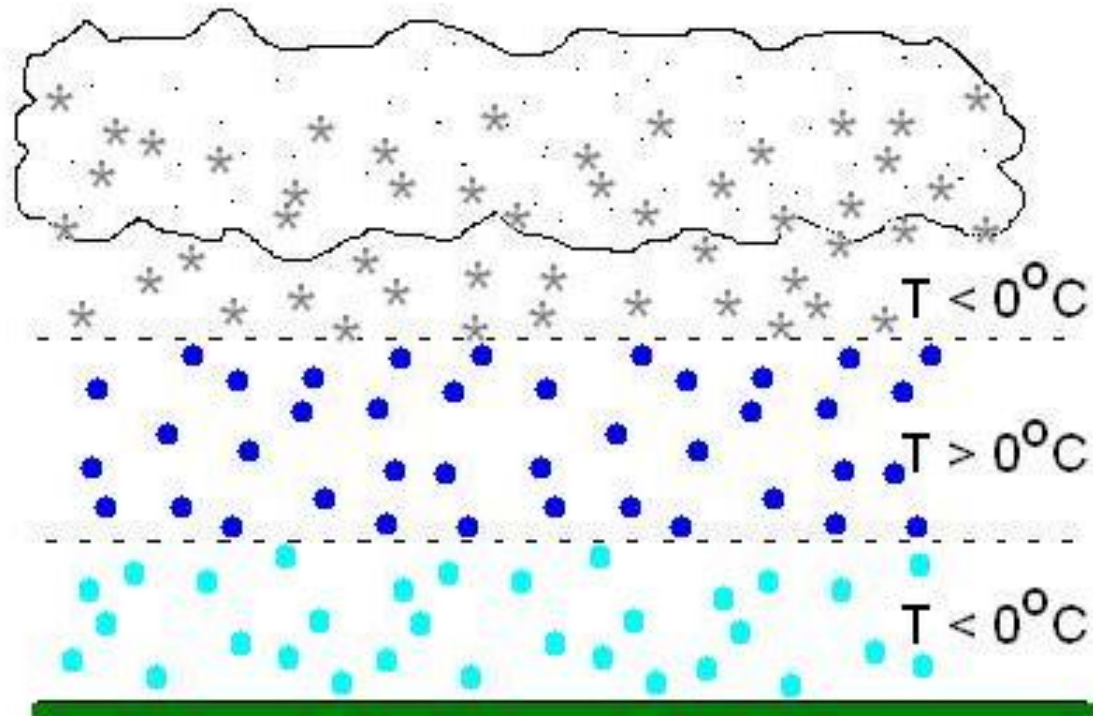
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Greg Weston, *Telegraph-Journal* · Feb. 15, 2011

# Meteorology of Icing

- Icing conditions: **COLD** and **WET**
- Glaze
  - Freezing precipitation
  - Raindrops freeze on colder surface
- Rime (in-cloud icing)
  - Supercooled cloud or fog
  - Cloud droplets freeze on any surface

## Glaze (freezing precipitation)



Snow at cloud level ( $T < 0^{\circ}\text{C}$ )

Falling snow melts ( $T > 0^{\circ}\text{C}$ )

Rain freezes on contact with surface ( $T < 0^{\circ}\text{C}$ )

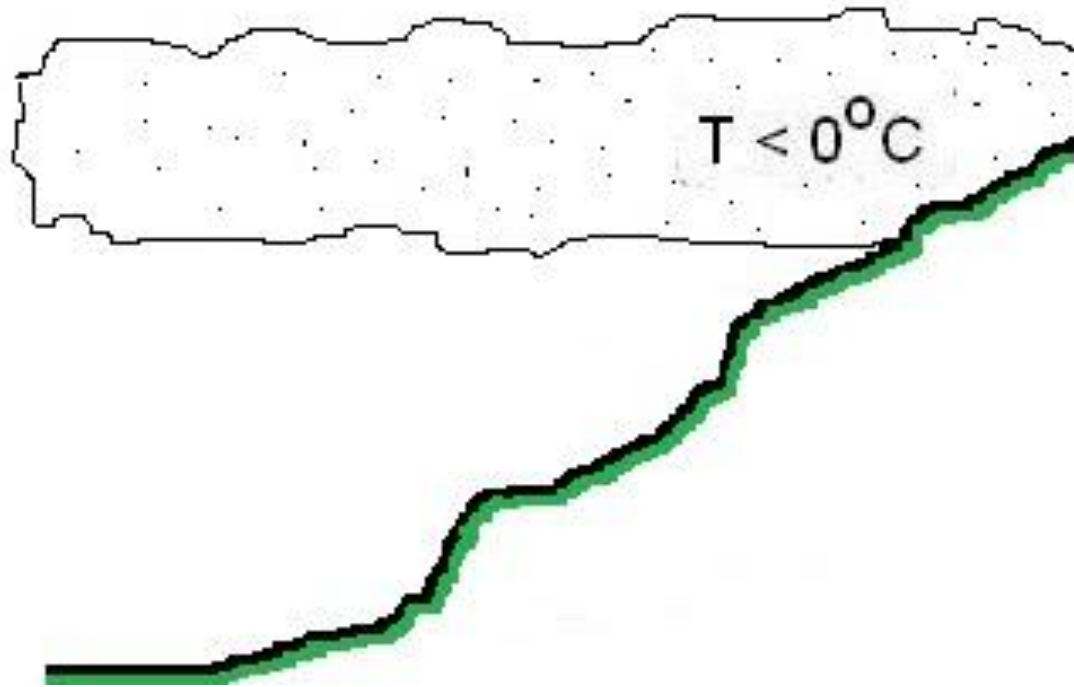
## Rime (in-cloud icing)



Cloud at surface ( $T < 0^{\circ}\text{C}$ )  
Supercooled cloud droplets  
Freeze on contact with surface



# Effect of Elevation

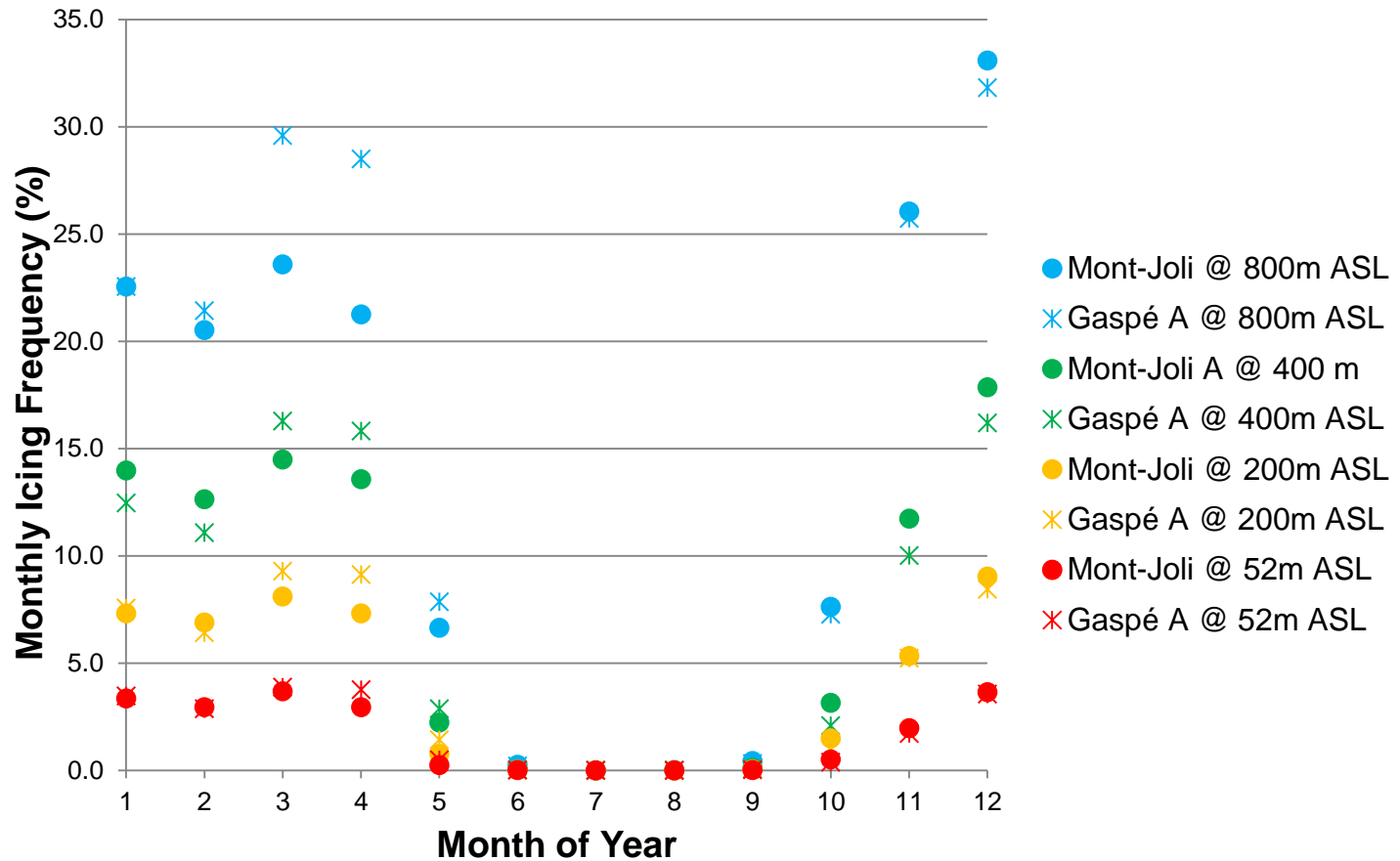


Temperature decrease with elevation  
Colder air holds less water vapour  
Rime more frequent at higher elevations

# Climatological Icing Estimates

- Reference station observations
- Adjustments for changes in elevation
  - Temperature decreases with elevation
  - Cloud base lower at higher elevation
- Apply tests for ‘icing conditions’
  - Freezing precipitation observed or likely
  - Cloud base < turbine height,  $-15^{\circ} < T < 0^{\circ}\text{C}$

# Icing Frequency vs. Elevation



Climatological icing estimates using two reference stations

# On-Site Met Tower Icing Estimates

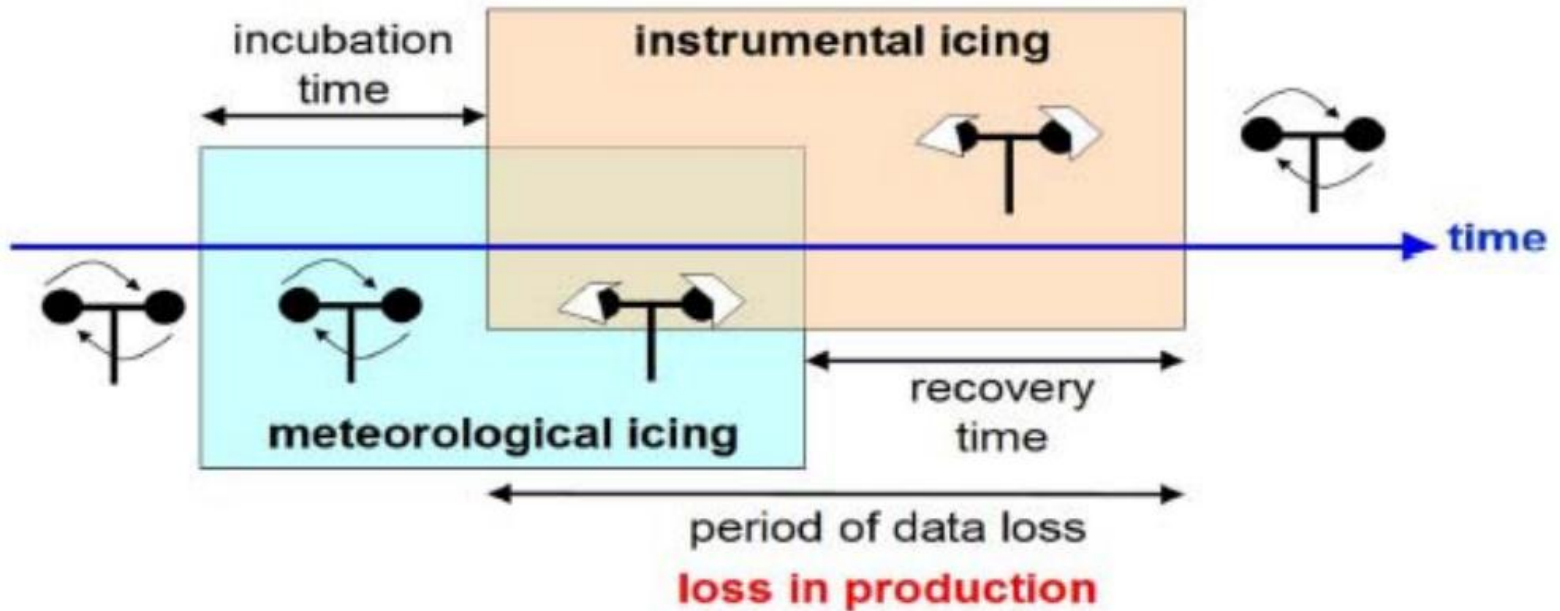
## ➤ Deluxe vs. Discount sensors

- Ice Detectors: Thousands of dollars
- Wind vane: Hundreds of dollars

## ➤ Indirect ice detection

- Wind vane (wind direction 'flat-lined')
- Anemometer (zero wind speed)
- Temperature (near or below freezing)

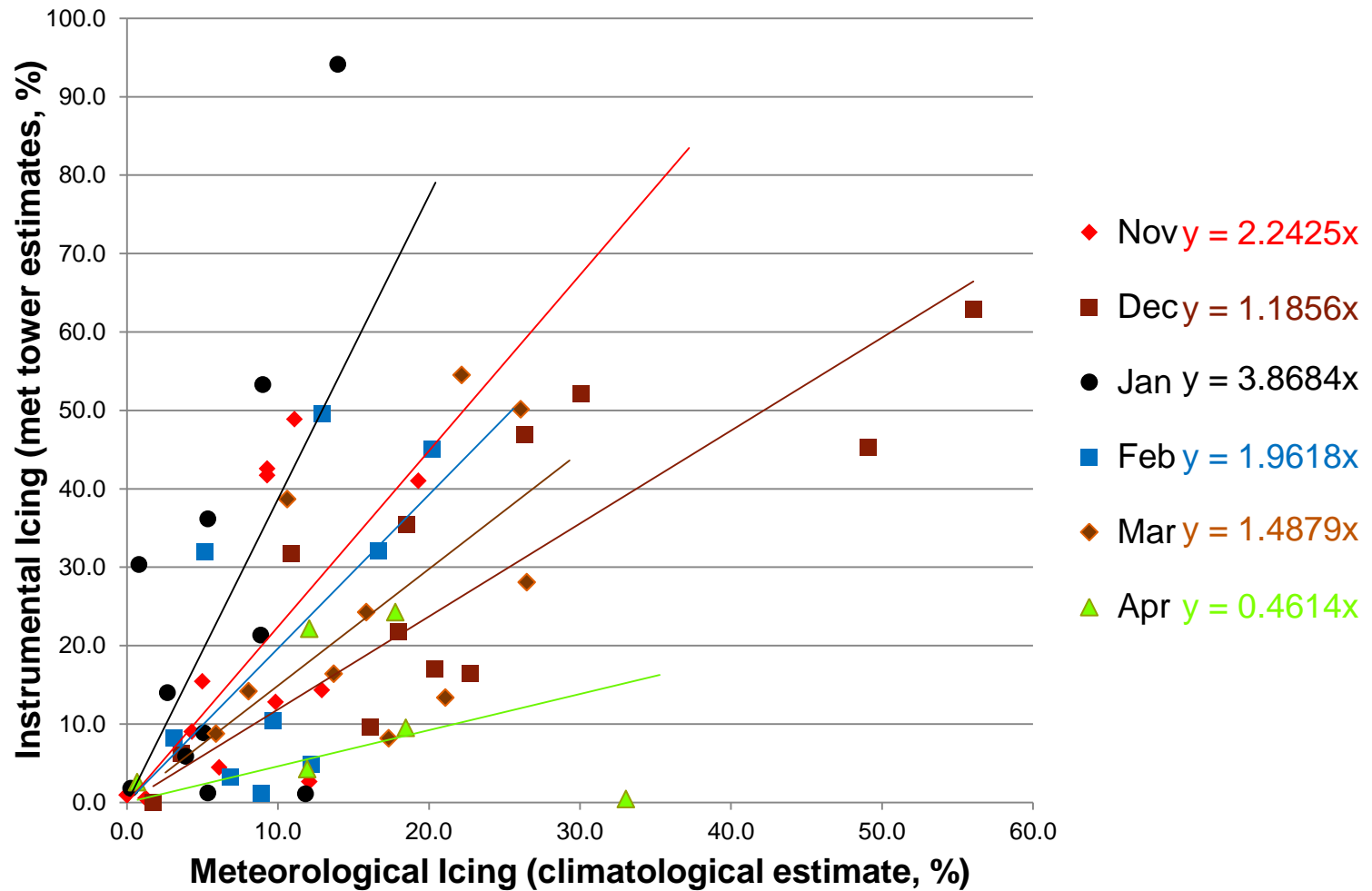
# Meteorological vs. Instrumental Icing



**Performance Index** = Instrumental Icing / Meteorological Icing

R. Cattin, 2012: *Icing of Wind Turbines: Vindforsk projects, a survey of the development and research needs*, Elforsk report 12:13.

# Performance Index by Month of Year



# Operational Icing Losses: Test Case

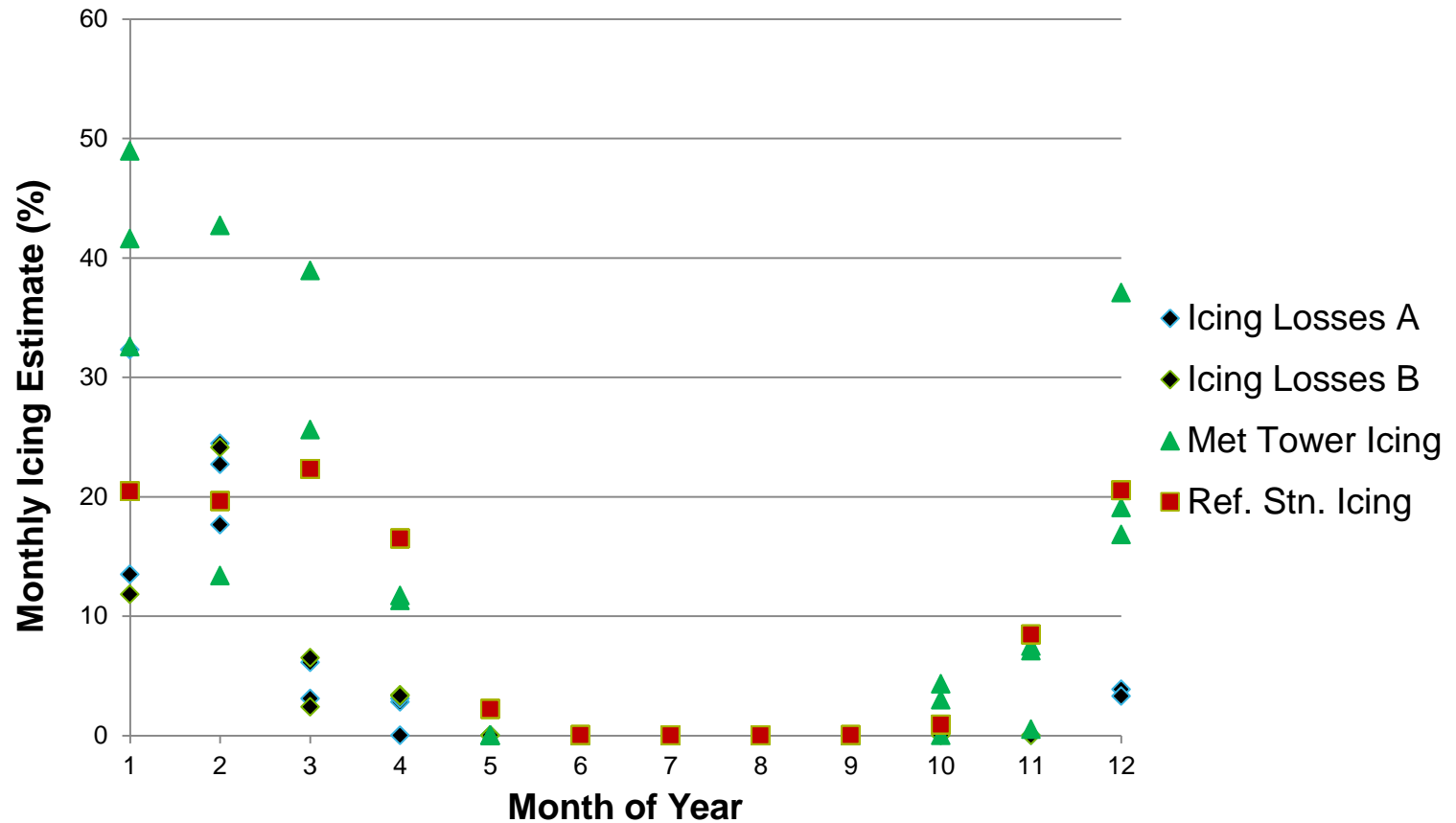
## ➤ Operational wind farm

- Located in Eastern Canada
- Significant icing losses

## ➤ Icing loss estimates

- Losses due to icing, noted by operator
- On-site met towers for several years
- Reference station (30 km away)

# Icing Losses: Test Case

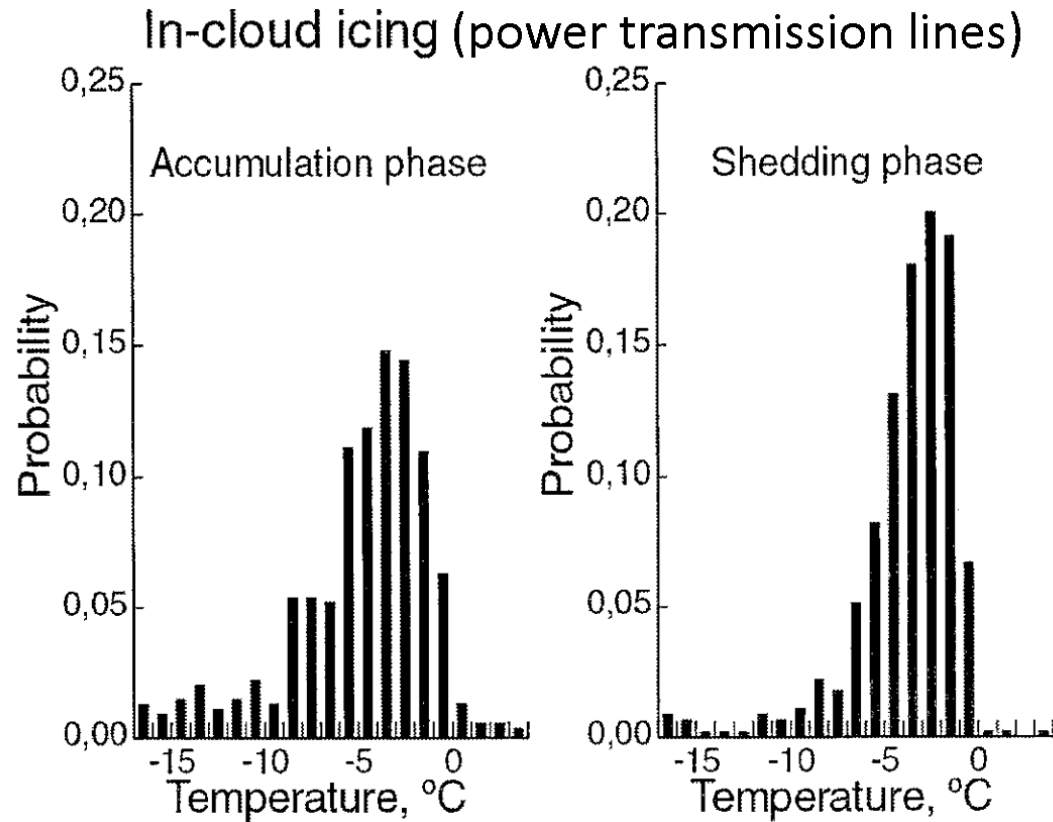




# Persistence of Ice and Temperature

- Less melting in coldest months
- Ice adhesion stronger at low temperatures
- Greatest impact of icing in coldest months
  - More frequent formation of ice
  - Less frequent melting or ice shedding

# Persistence of Ice and Temperature



K. Savadjiev and M. Farzaneh, 2001: *Study of icing rate and related meteorological parameter distributions during atmospheric icing events*, Proceeding of the Eleventh International Offshore and Polar Engineering Conference

# Project Planning and Mitigation

- Site selection
  - Anticipate icing severity
- Turbine selection
  - Cost-benefit analysis of anti-icing features
- Mitigation
  - Selective shutdown during severe icing
- Monitoring
  - Evaluation of mitigation procedures

# Work in Progress: Monitoring of Icing Conditions

