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Advances in wind power forecasting and power loss mitigation for cold climate operation

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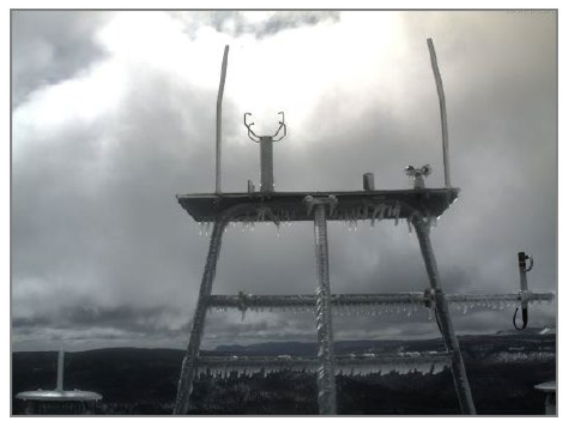
Background and objectives

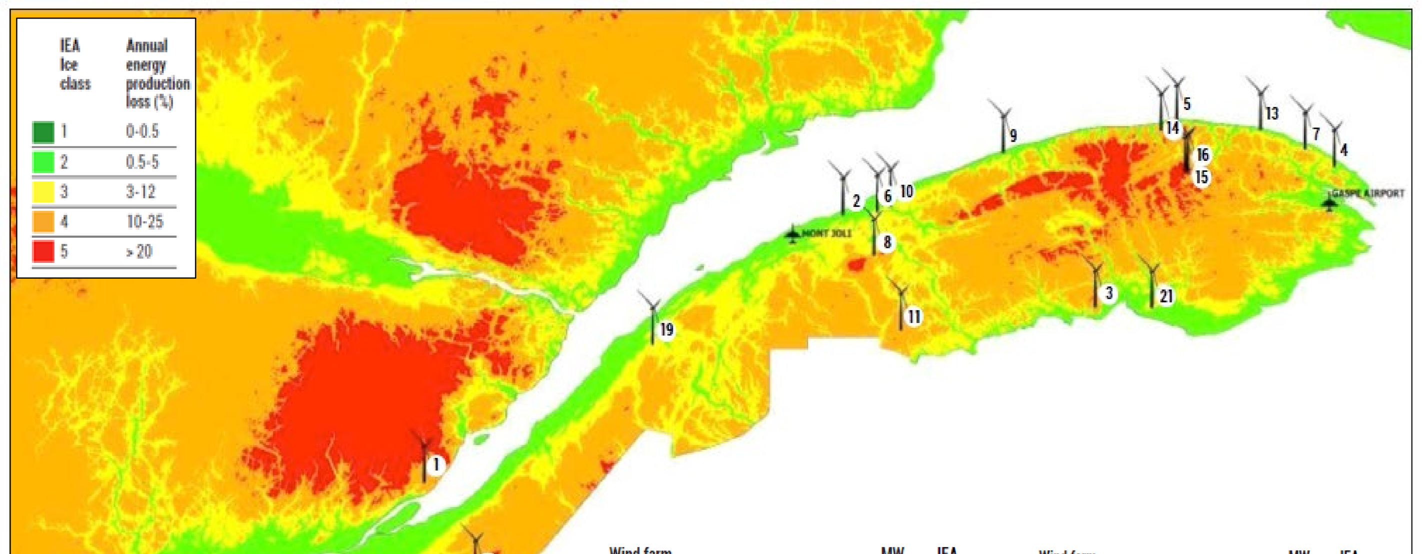
Wind energy's contributions as a reliable source of clean energy continue to grow, both in North America and globally. In Canada, wind energy installed capacity increased by 20% annually from 2008 to 2018 and is one of the lowest cost sources of new generating capacity in the country. Cold climate operation however continues to be challenging: ice that accumulates on the wind turbine rotor from freezing precipitation (glaze) or by supercooled water droplets formed in clouds (rime) changes the shape and surface roughness of the airfoil profiles, affecting the aerodynamic efficiency of the turbine and reducing power production [1, 2]. Production is further impacted if site safety is affected by the risk of ice throw or if turbine shutdowns are triggered. Ice accumulation can also increase vibrations and fatigue of wind turbine components [3].

Example of rime observed at Rivière-au-Renard, Dec. 2014



Example of glaze observed at Rivière-au-Renard, May 2015

Gaps remain in translating advances in atmospheric science into products that can be readily applied by utilities, system operators and the wind energy industry. In 2016, NRCan initiated a multi-year collaborative research program on advanced wind power forecasting with the University of New Brunswick (UNB), Environment and Climate Change Canada (ECCC) and Nergica. Major elements of the program include short-term wind power forecasting, ramp forecasting and icing forecasting, with the common goal being to adapt Canadian meteorological forecasts to provide improved value for wind energy applications. The overall research goal is to provide operational icing forecasts to Canadian utilities, representing a supplementary tool to assist in the operation of a power system with increasing amounts of variable renewable generation.

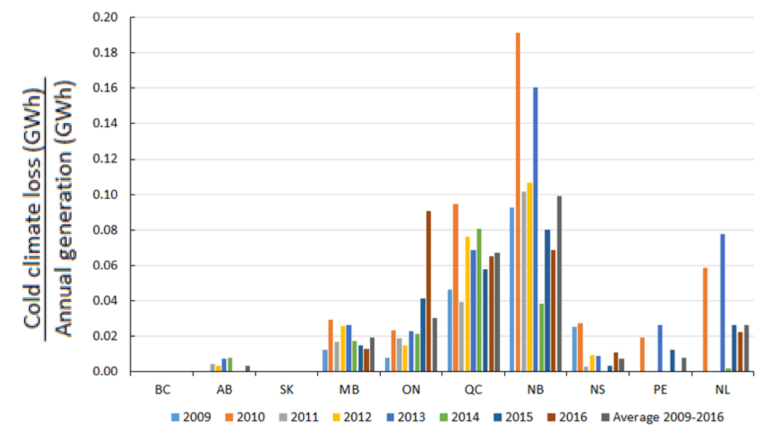


	Wind farm	MW	IEA Ice class
1	Seigneurie de Beaupré	272	4
2	Baie-des-Sables	110	2
3	Carleton	110	4
4	Site de recherche de Nergica	4	3
5	Gros-Morne – Sainte-Madeleine	212	2
6	Jardin d'Éole	128	3
7	Anse-à-Valleau	101	4
8	Lac Alfred	300	3
9	Le Nordais (Cap-Chat)	57	2
10	Le Nordais	42	2
11	Le Plateau I	139	4
12	Massif du Sud	150	5
13	Montagne Sèche	59	2
14	Mont-Louis	101	4
15	Mont Copper	54	4
16	Mont Miller	54	5
17	Montérégie	101	2
18	Saint-Robert-Bellarmin	80	4
19	Viger-Denonville	25	3
20	Parc éolien des Moulins	136	4
21	New Richmond – Saint-Alphonse – Caplan	68	3
22	De l'Érable	100	4

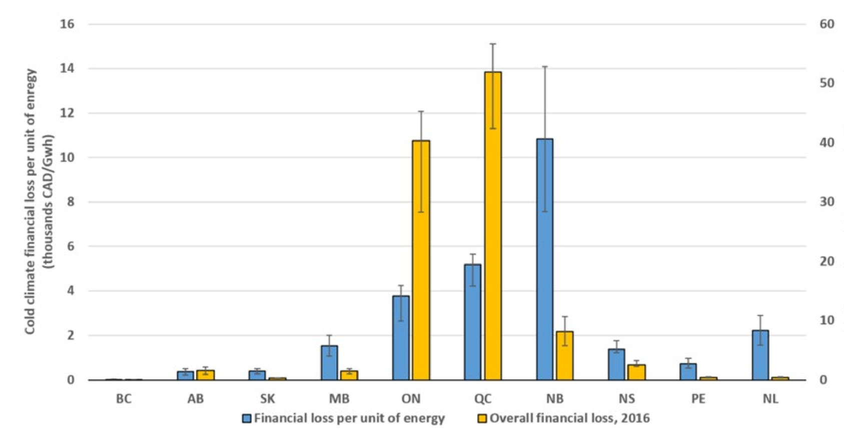
Wind Farms Installed in Icing Climates in Quebec (Nergica, adapted from VTT [4])

Estimation of cold climate – induced losses

NRCan conducted a study 89 Canadian wind farms over 2009-2016 to examine the effect of cold climate on Canadian wind farm performance in terms of energy losses, financial losses and avoidable greenhouse gas (GHG) emissions. The study used monthly wind farm production data obtained through the Wind Power Production Incentive (WPPI) and EcoEnergy for Renewable Power (EcoERP) federal incentive programs.



Cold climate losses by province and by year

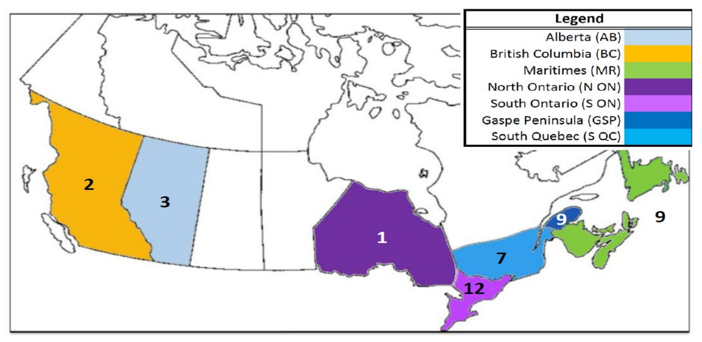


Financial losses due to cold climate, by province

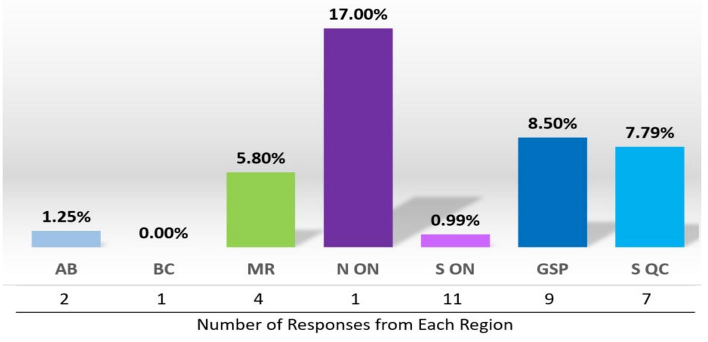
Actual wind farm electricity generation was compared to the expected generation based on turbine power curves and local wind resource data. Losses from the summer (May - Oct) and winter (Nov - Apr) periods were compared, and the net difference between them was taken to represent the combined losses incurred from blade icing, cold temperature shutdown, limited access and any other winter impacts. Losses from the study group were extrapolated to the national level in proportion to overall provincial wind energy generation. New Brunswick showed the highest financial loss, at CAD $10,830 / GWh of electricity generation, while Quebec had the highest absolute loss at CAD $51.9M / year. The total national financial loss due to cold climate was estimated to be CAD $107M / year.

Survey of cold climate operations

The Cold Climate Challenges for Wind Power Projects in Canada Survey was conducted in 2017 by the University of Calgary to gain insights on cold climate challenges for project developers and operators, including regional differences in wind turbine icing, site safety accessibility impacts, and observed cold climate induced losses at commercial wind project sites. 43 wind power projects from across Canada participated in the survey, representing 13 unique operating companies and 3,540 MW of installed capacity, roughly 30% of Canada's total wind power capacity at the end of 2017. AEP losses were generally in line with the results of the wind energy production.



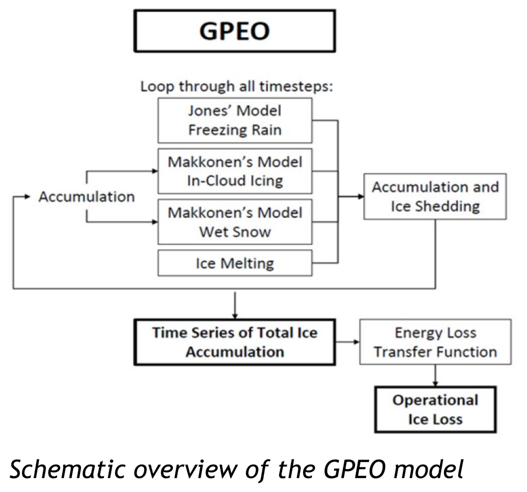
Survey responses by region



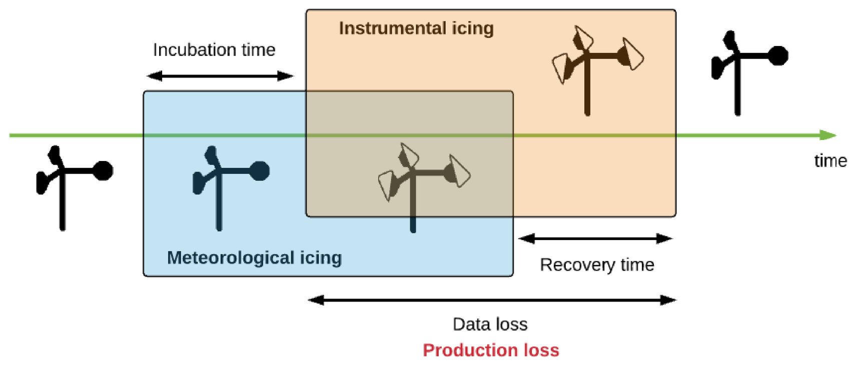
Average AEP losses due to cold climate by region

Developing an operational icing forecast

Modeling ice thickness on rotating blades is complicated by the number of parameters involved and the non-linear rates of ice accumulation and shedding. Nergica has developed a transfer function to produce energy loss forecasts from observation data – this model is known as GPEO, for "Modèle de Givre et de Pertes Énergétiques Opérationnelles" (Icing and Production Loss Model [5]).



Schematic overview of the GPEO model

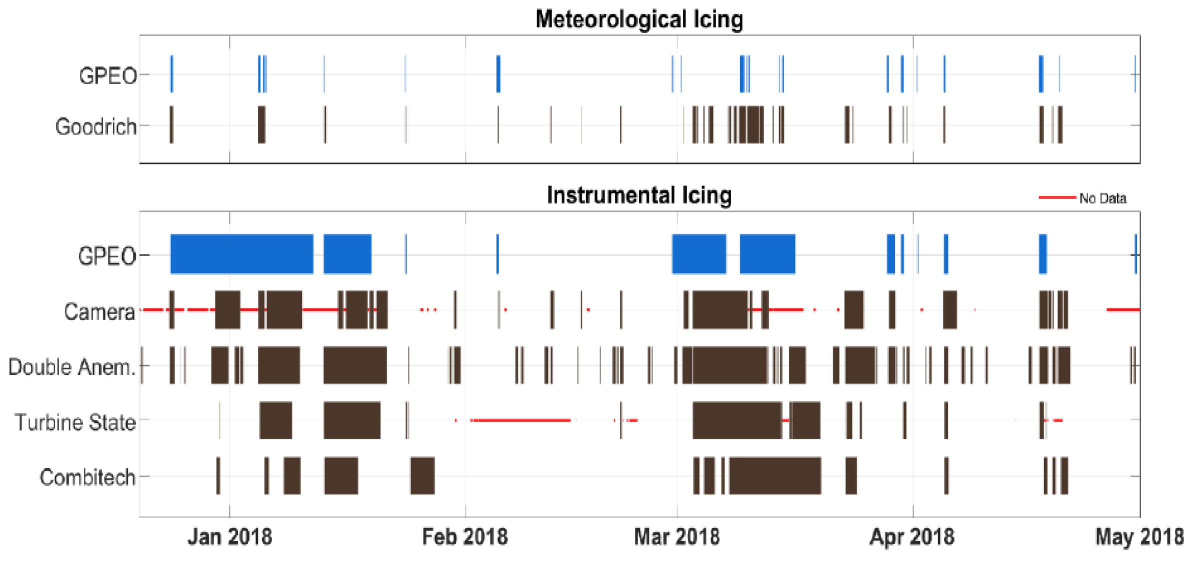


Different stages of ice formation (adapted from Baring-Gould [6])

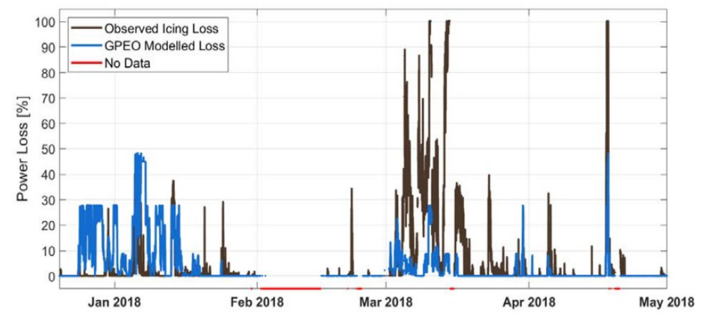
Inputs to the GPEO model are obtained through specialized Environment and Climate Change Canada (ECCC) forecasts, and model outputs include ice accretion rates, total ice accumulation, and ice-related energy losses.

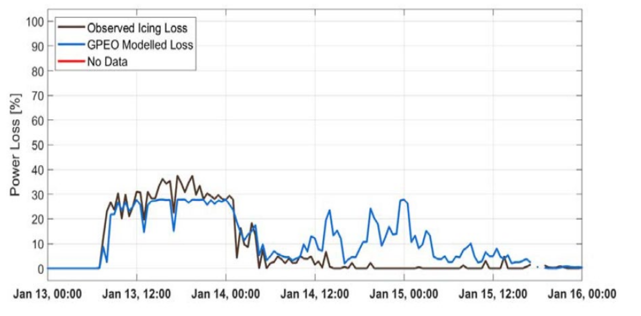
Icing forecast model validation

GPEO's modeled ice accumulation estimates were compared to other ice detection methods including a Goodrich meteorological ice detector, nacelle-mounted ice monitoring cameras, double anemometry (heated and unheated) and a Combitech instrumental ice detector. GPEO successfully identified most meteorological icing periods, but appeared to be less accurate at modelling instrumental icing periods. Each of the sensors measures different parameters related to icing, in different locations (e.g. met mast vs. wind turbine) underscoring the difficulty in establishing a single reference signal for icing to measure GPEO performance against. The accuracy of the GPEO icing forecast is also highly dependent on the accuracy of the ECCC input forecasts. Several icing events that were not well captured by GPEO could be attributed to an absence of icing conditions (e.g. precipitations or clouds) in the meteorological forecasts.



Meteorological and instrumental ice signals obtained from Nergica's experimental wind farm and test site, Jan-May 2018.





Time series comparison of icing induced energy loss from turbine measurements and from GPEO model. Left: Four month period from January to May 2018. Right: Three day period from January 13-15, 2018.

Discussion and conclusions

Two independent studies were conducted and contrasted to better understand the scale and magnitude of cold climate impacts and challenges at Canadian wind farms, in terms of lost revenue for wind farm owners, and lost energy to the grid representing avoidable GHG emissions.

Utilities and system operators face uncertainty around the timing and magnitude of icing events, and the resulting wind farm power loss, and may need to hold additional reserves in their system to account for such events. As the penetration of wind and other renewables increases, an accurate method for forecast icing events is critical, allowing system operators to avoid unnecessarily holding additional reserves or curtailing entire wind farms in advance of a potential icing event.

Nergica is working to further develop the transfer functions between icing accumulation and energy loss, and will conduct additional on-site validation with wind farm operational and observation data. NRCan aims to provide operational icing forecasts to Canadian utilities, and will support validation and testing of the model within actual utility settings.

References:

[1] Wallenius T and Lehtomaki V 2016 Overview of cold climate wind energy: challenges, solutions, and future needs WIREs Energy and Environment 5 126-135

[2] Dierer S et al., 2011. Wind turbines in icing conditions: performance and prediction Adv. in Sci. and Res. 6 245–250

[3] Gantasala S, Luneno J-C and Aidanpaa J-O 2016 Influence of Icing on the Model Behaviour of Wind Turbine Blades Energies 9 862

[4] V. Lehtomäki, S. Rissanen and M. Waham-Gagnon. "Low temperature & icing map for Québec", 8th Quebec Wind Energy Conference, 2014.

[5] C. Arbez C, Clément M, Godreau C, Swytink-Binnema N, Tete K. and Wadham-Gagnon M 2016, Development and Validation of an Ice Prediction Model for Wind Farms, TechnoCentre éolien, Gaspé

[6] I. Baring-Gould et al., "IEA Wind Recommended Practice 13: Wind Energy in Cold Climates", IEA Wind, Technical report, 2011.

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