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Wind Power Production and Ramp Forecasting Research Update

ESIG 2019 Meteorology & Market Design for Grid Services Workshop
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CanmetENERGY
Leadership in ecoInnovation

Canada

Presentation Outline

- Background / motivation
- Forecasting R&D goals
- Methodology & performance:
  1. Short-term wind power production forecast
  2. Ramping forecast
  3. Ice accumulation forecast
- Conclusions and next steps

CanmetENERGY-Ottawa

CanmetENERGY-Ottawa leads the development of energy S&T solutions for the environmental and economic benefit of Canadians

Personnel:

- 179 Term and Full-time
- Visiting Scientists
- Co-op Students

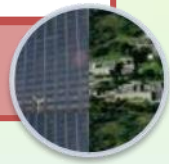
Pilot-scale Facilities:

- To accelerate the advancement of clean energy technologies from the initial research stage through to demonstrations

CanmetENERGY laboratories across Canada

- Buildings & Communities
- Clean Fossil Fuels
- Industrial Processes
- Renewables (wind, marine, solar thermal, bioenergy)
- Transportation

Ottawa



- Oil sands & heavy oil

Devon

- Buildings
- Industrial process integration
- Smart grids
- Solar PV
- RETScreen International

Varennes

- Minerals and metals

Hamilton

Wind Energy R&D at CanmetENERGY-Ottawa

Current areas of engagement:

- Grid integration of utility-scale wind and solar
- Wind power forecasting
- Renewable energy analysis for remote communities
- Offshore wind resource and constraint assessment
- Advancing Canadian wind models

Advanced Wind Forecasting: Motivation

- Environment and Climate Change Canada (ECCC) produces national meteorological forecasts every 6 hours, but no existing mechanism to convert these into a format applicable to wind energy applications
- Responding to specific interest from utilities in:
  - Forecasting large wind speed ramps affecting system economics and stability
  - Predicting effect of icing on power production

Problem statement:
How can we better leverage existing ECCC meteorological forecasts to better assist utilities and system operators?

Project goals

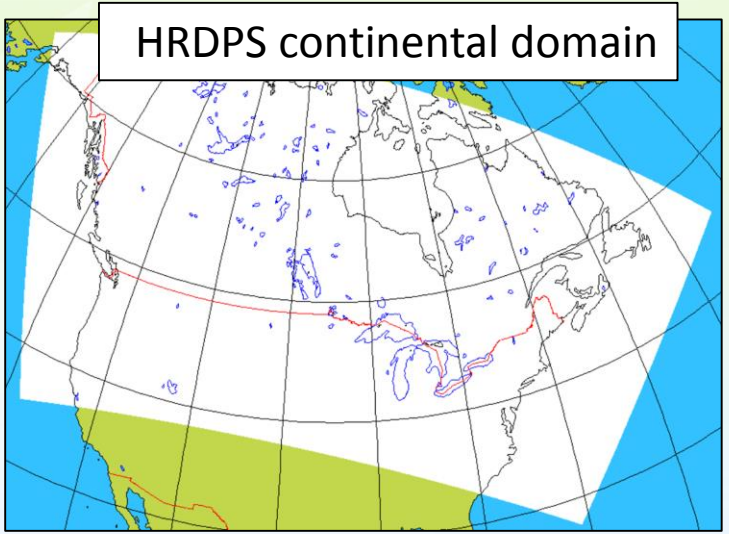
Short-term wind forecast	Evaluate and improve short-term wind forecasts based on the ECCC wind forecast model
Ramp forecast	Develop and test a wind ramp forecasting algorithm
Icing forecast	Develop and implement icing forecasting methods using ECCC forecasting model
Wind forecasting software package	Produce a comprehensive wind forecasting package that combines short-term and ramp forecasting elements

Project team

CanmetENERGY — Natural Resources Canada	Project sponsor / national wind R&D co-ordinator
UNB EST. 1785 UNIVERSITY OF NEW BRUNSWICK — Emera & NB Power Research Centre for Smart Grid Technologies — Emera — Énergie NB Power	Short-term wind power and ramping forecast
NERGICA — Renewable Energy Research and Innovation	Icing forecast and power loss model
Environment and Climate Change Canada / Environnement et Changement climatique Canada	Provision of meteorological forecasts
Wind Energy Institute of Canada / Institut de l'énergie éolienne du Canada	Battery storage coupling and forecast validation

ECCC Wind Speed Forecasts

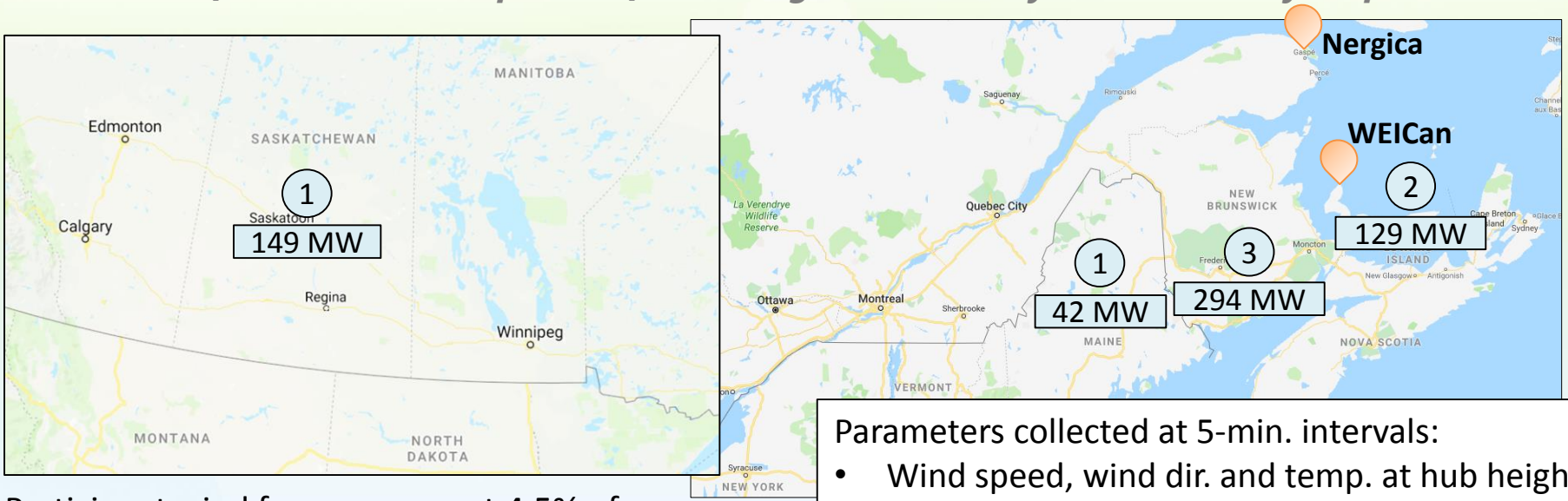
- Forecast data obtained from the High Resolution Deterministic Prediction System (HRDPS), derived from one version of the Global Environmental Multiscale (GEM) model used to generate medium range weather forecasts
- Infrastructure investment of $500M over 10 years
- Forecasts generated at 2.5 km horizontal grid spacing every six hours for 48-hr period at 1 hr resolution
- Project specifications:
  - Forecasts at 30 min. intervals for first 24 hours, 1 hour intervals for second 24 hours
  - Atmospheric parameters extracted from 0 to 300 m at 10 m intervals
  - 2.5km grid points interpolated to GPS coordinates at specific locations



Meteorological Service of Canada (MSC) Data Server: http://dd.weather.gc.ca/

Wind Farm Telemetry Data

Seven wind farms selected to provide forecasting and telemetry data over 2-4 year period



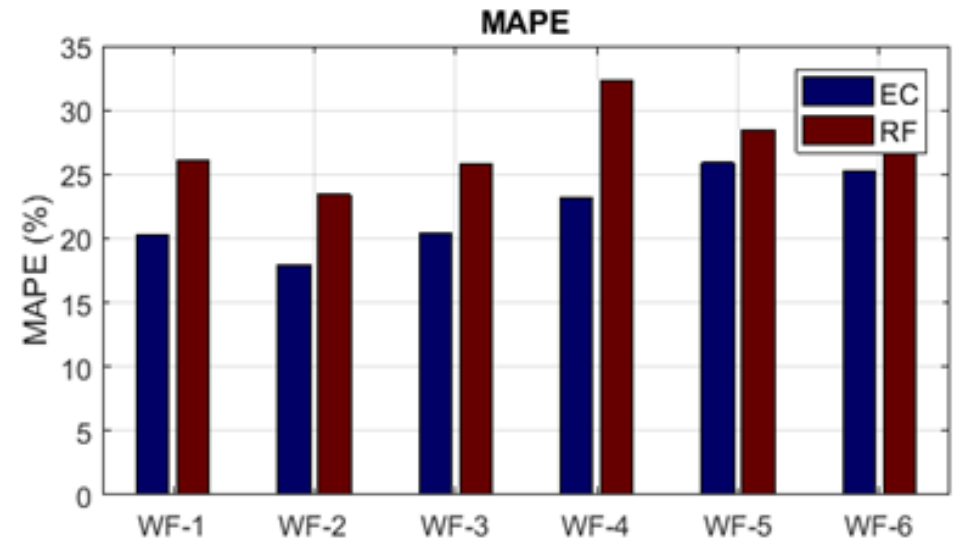
Participant wind farms represent 4.5% of Canada's total installed wind energy capacity of 12,796 MW as of Aug. 2018

Parameters collected at 5-min. intervals:

- Wind speed, wind dir. and temp. at hub height
- Generated wind power
- Available capacity

Assessment of ECCC Wind Forecasting Model

ECCC wind speed forecasts compared to observational data and reference forecast (RF) over 32-month period (June 2015 to Feb. 2018)



- ECCC wind speed forecast slightly improved over reference
- Some differences across time horizons, wind speed bins
- Both show wind speed error of 20-30% compared to telemetry data

Mean Absolute Percentage Error (MAPE) $= \frac{100}{N}\sum_{i=1}^{N}\frac{|e_i|}{|y_i|}$ where e_i represents the forecast error at a discrete time i

Note: Content for this slide provided by UNB

Power Curve Modelling

Characterizing the relationship between wind speed and wind farm power production

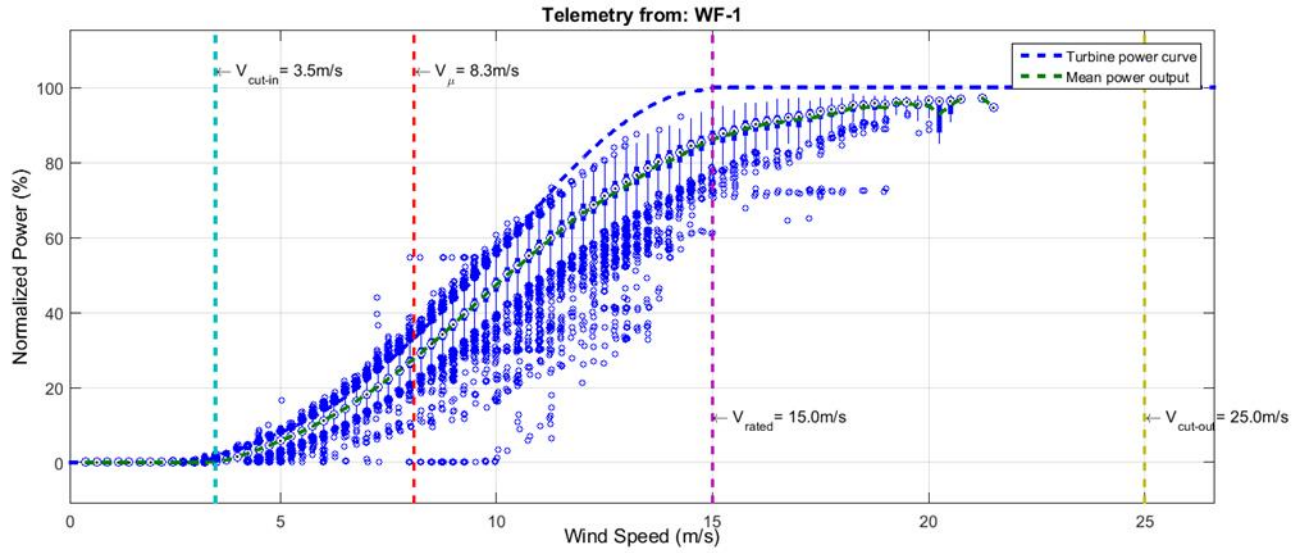
Four models investigated:

<u>Parametric models</u>

- Polynomial curve fitting
- Cumulative distribution function (CDF)

<u>Machine learning models</u>

- Multiple layer perceptron (MLP)
- Non-linear auto-regressive exogenous (NARX) neural network



Comparison between manufacturer's power curve and power curve extracted from three years of telemetry data (aggregated over wind farm)

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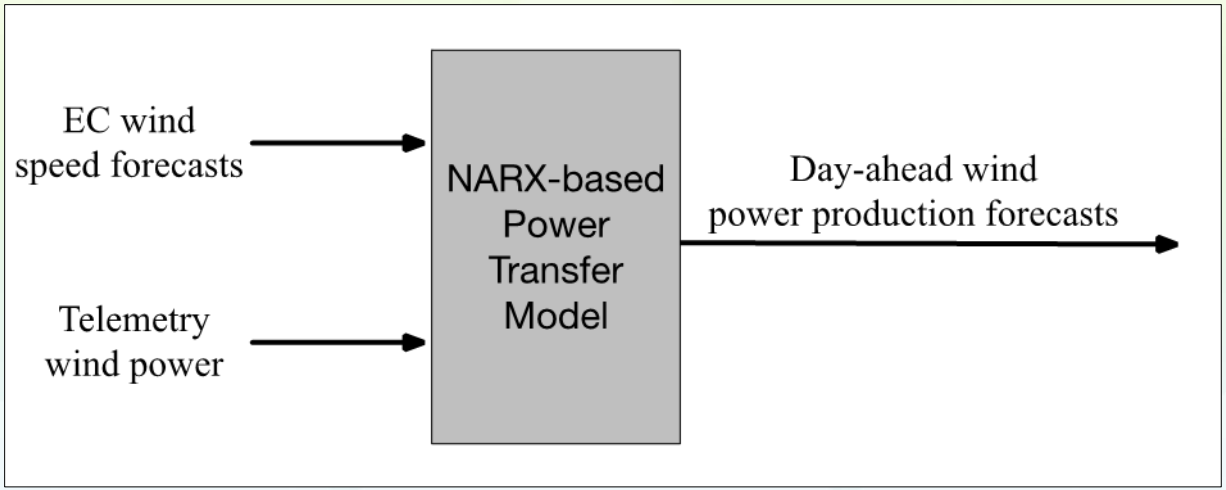
Methodology: Day-ahead Forecast

NARX-based neural network model converts wind speed forecasts into wind power production



NARX-based power curve modelling approach provided the lowest error values and narrowest error dispersion of the methods attempted

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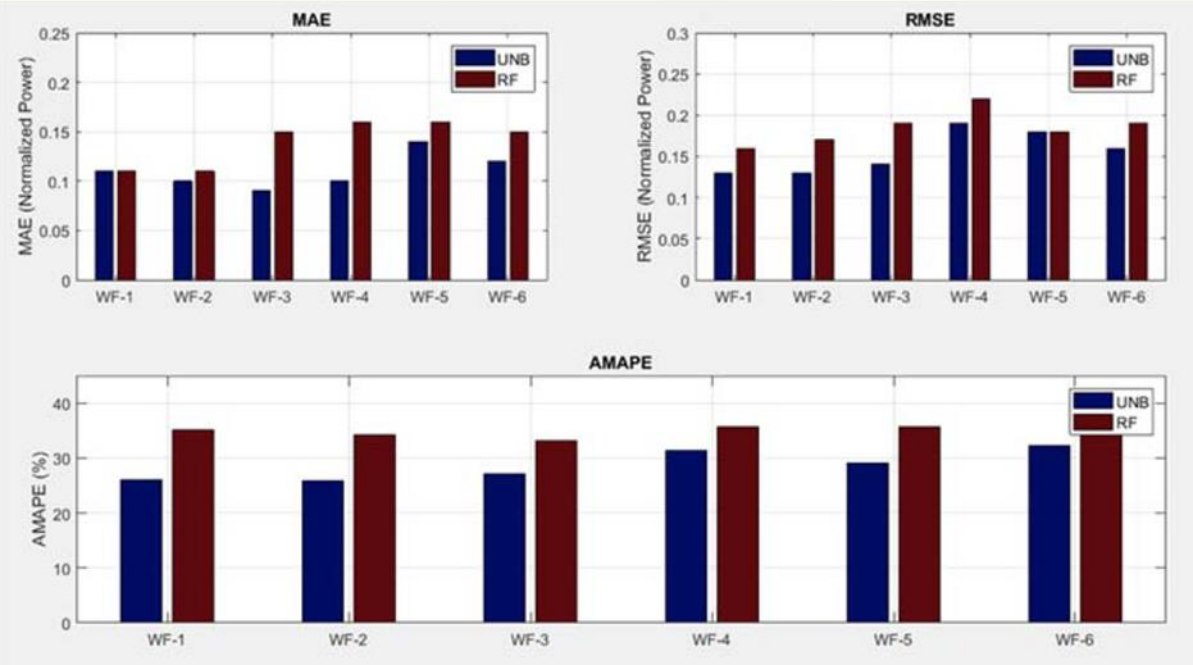
Performance: Day-ahead Forecast

Assessment of day-ahead wind power production forecast (Jan. 1, 2018 – Dec. 31, 2018)



Average error:

UNB: 28.65%

RF: 34.79%

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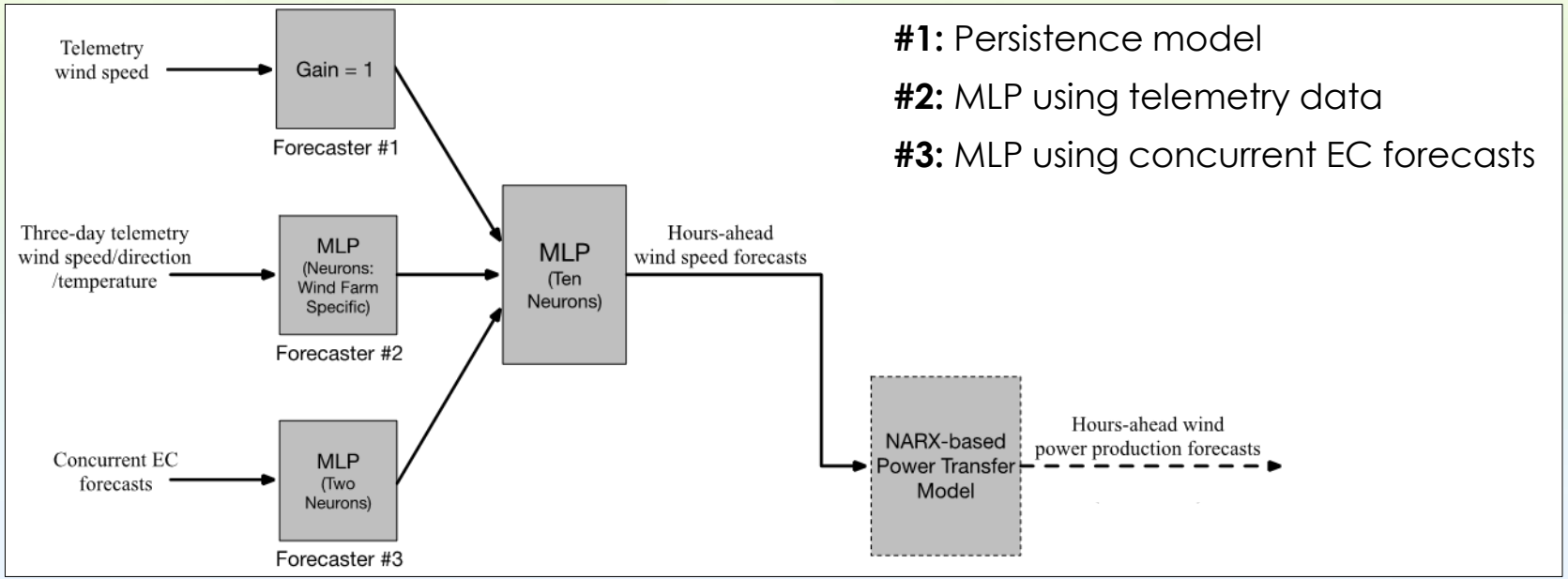
Methodology: Hours-ahead Forecast

Three independent forecasts combined into NARX-based power transfer model to provide hours-ahead wind power production forecasts (30 min. to 6.5 hrs at 5-min time steps)



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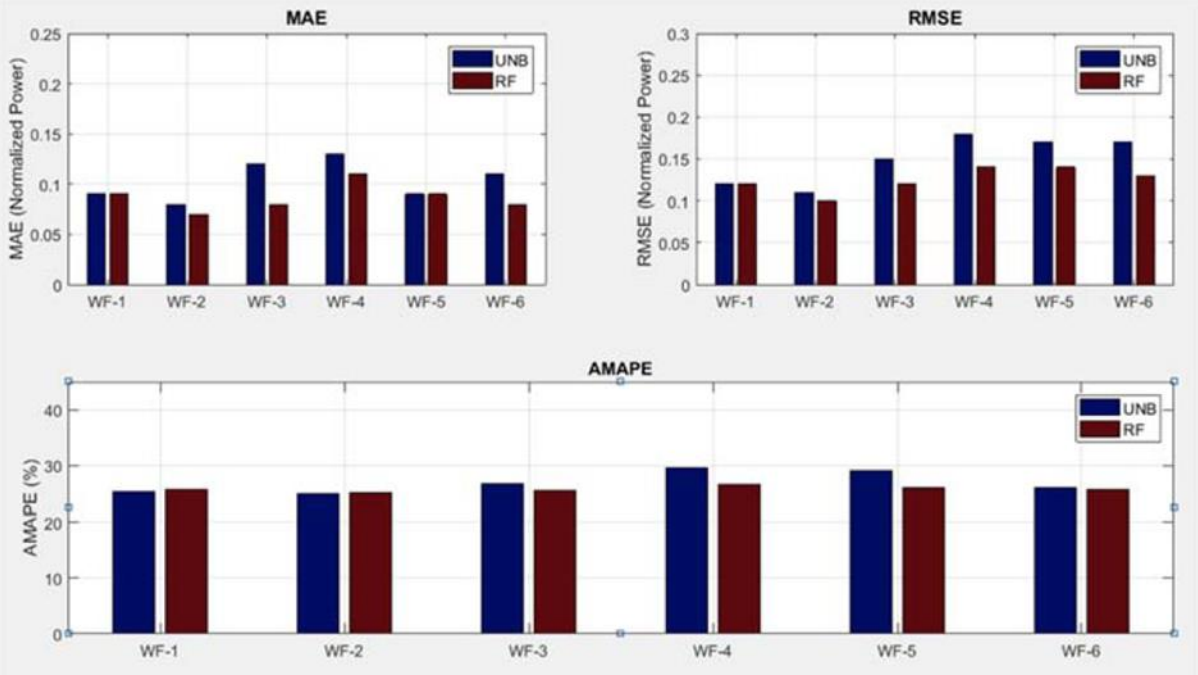
Performance: Hours-ahead Forecast

Assessment of hours-ahead wind power production forecast (Jan. 1, 2018 – Dec. 31, 2018)



Average error:

UNB: 26.96%

RF: 25.81%

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Wind Ramp Forecasting

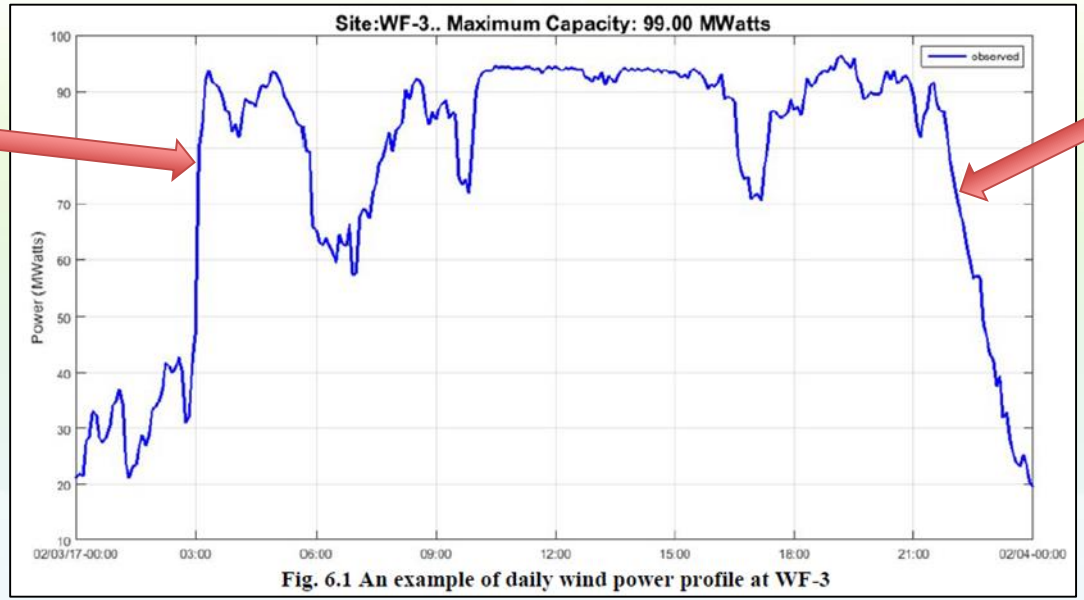

Fig. 6.1 An example of daily wind power profile at WF-3

Both up and down ramps require compensation from other sources of generation to maintain electricity supply/demand balance

Note: Content for this slide provided by UNB

Ramp Definition

- No single definition of ramp event
- Commonly defined based on:
  - ramp magnitude only
  - ramp magnitude and duration
  - ramp rate of change
- Two methods of ramp identification tested:
  - DSI: Definition-Based Sign Indicator
  - SDA: Swinging Door Algorithm
- Ultimately UNB team produced a novel method of ramp detection based on similarity search method

In this work, a ramp is defined as a change in wind farm power capacity of greater or equal to 50% over a four hour period

$$|P(t+\Delta t) - P(t)| \geq \lambda \cdot P_{capacity}$$

where $\lambda = 50\%$ and $\Delta t = 4$ (hour)

magnitude duration

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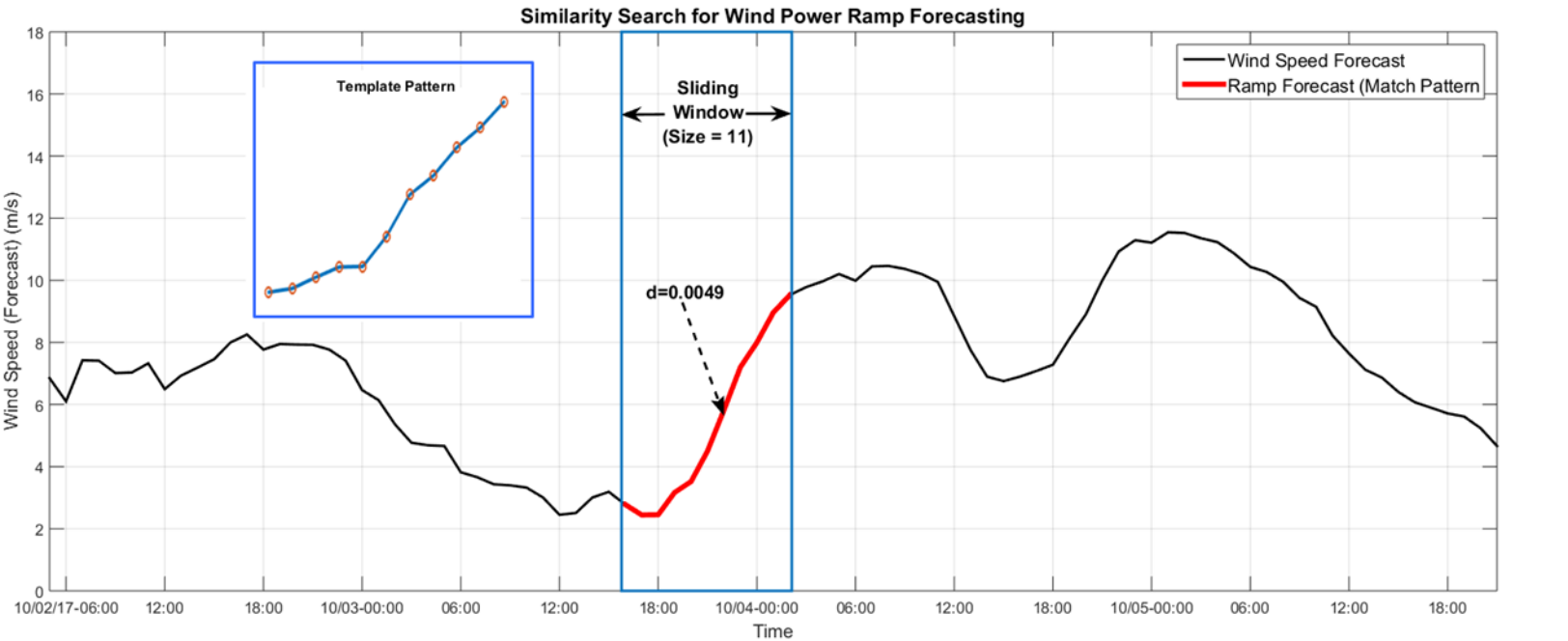
Wind Power Ramp Forecasting

Wind power ramp event forecasting algorithm developed from ECCC wind speed forecasts



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Ramp Forecasting Performance

Results Jan. 1, 2018 – Dec. 31, 2018

Wind Farm	Ramp Event	TOL	ACC	Hit		Timing Effective		Mag. Error	False Alarm	Miss
WF-1	101	45%	61.39%	62	40.00%	73	72.28%	11	82	28
WF-2	218	50%	69.72%	152	37.16%	175	80.28%	23	234	43
WF-3	403	60%	64.02%	258	40.82%	286	70.97%	28	346	117
WF-4	459	70%	65.58%	301	46.31%	360	78.43%	59	290	99
WF-5	437	60%	61.56%	269	39.27%	341	78.03%	72	344	96
WF-6	418	65%	68.90%	288	43.05%	316	75.60%	28	353	102

- Accuracy (ACC) is the percentage of actual ramp events successfully reported by the model
- An identification is deemed “Hit” if the ramp event identification test satisfies criteria for ramp amplitude of 80%-120% of actual *and* timing error within ± 1 hour

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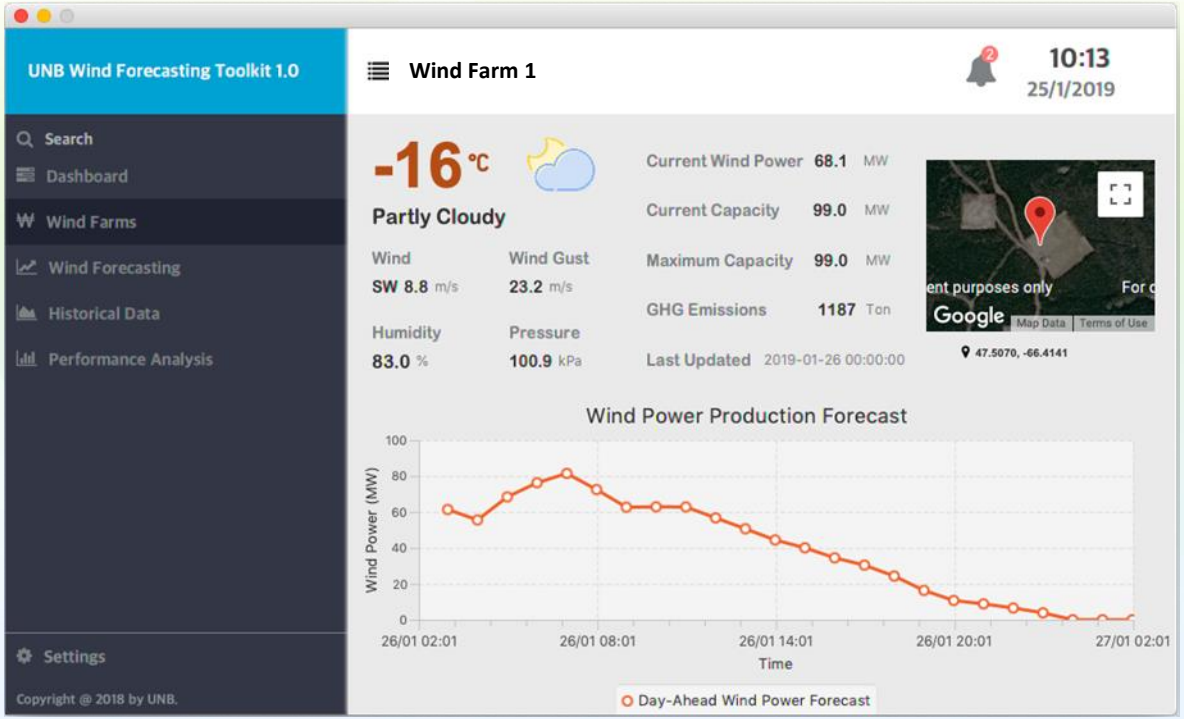
Forecasting Package

OVERVIEW

UNB wind forecast package provides wind forecasts including day-ahead and hours-ahead wind power production forecast and ramp event forecast



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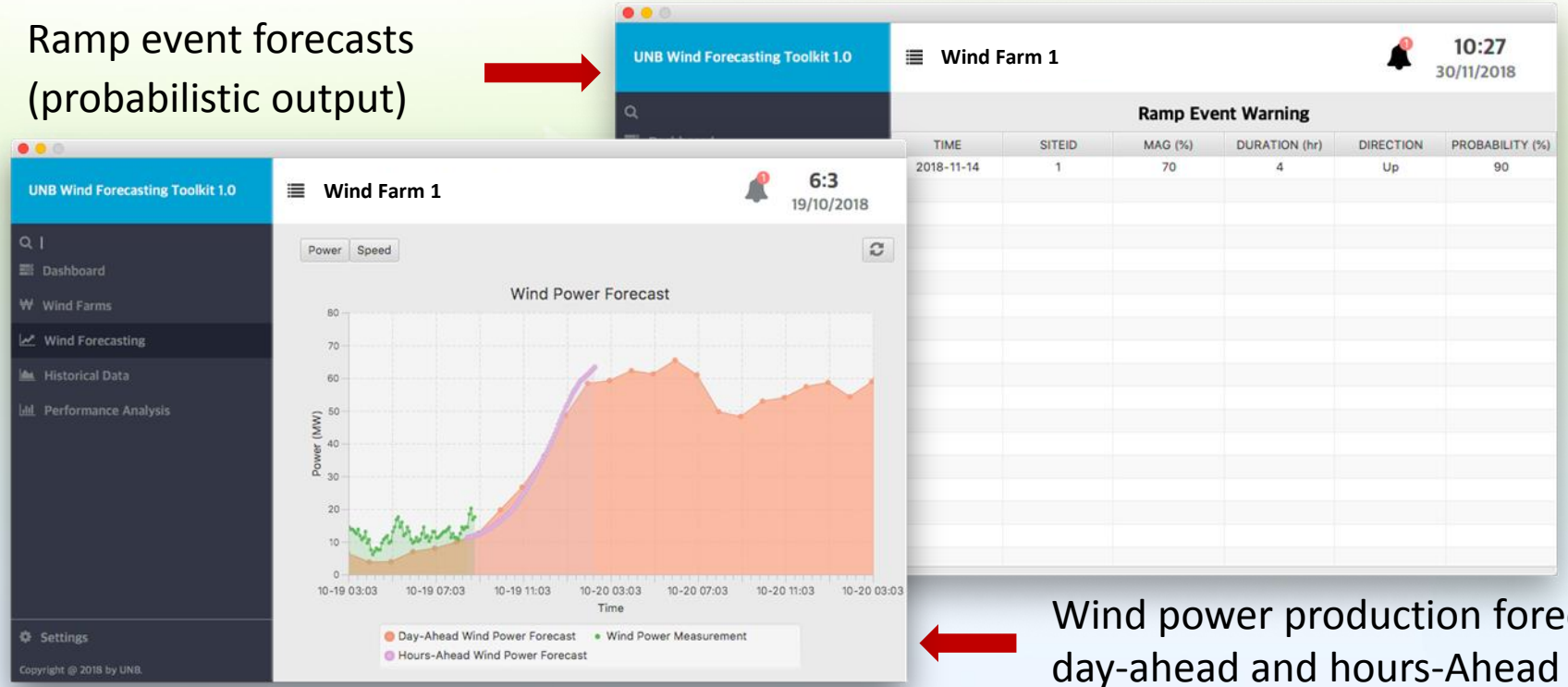
Forecasting Package

Ramp event forecasts (probabilistic output)



Wind power production forecasts: day-ahead and hours-Ahead

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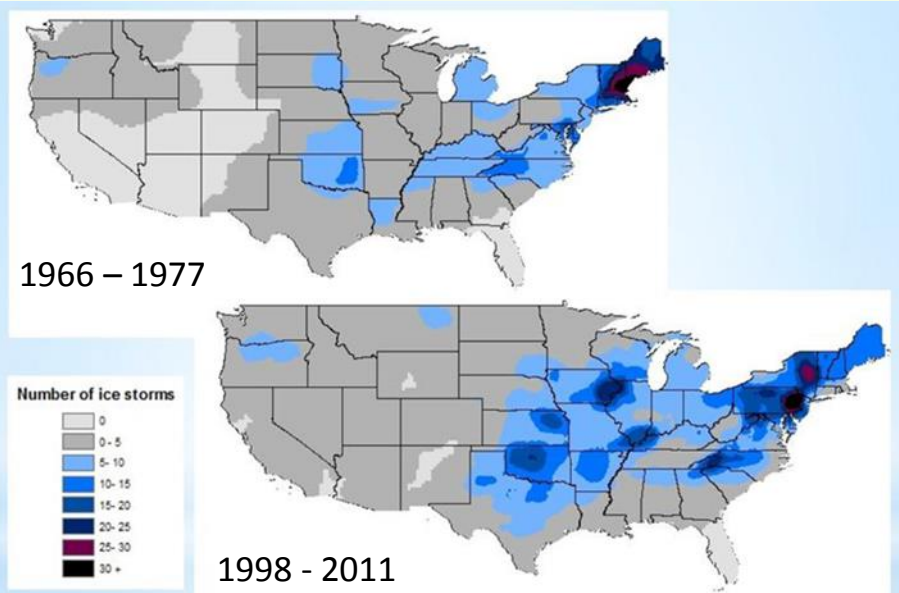
Forecasting Icing Events: Motivation

Number of documented ice storms across U.S.



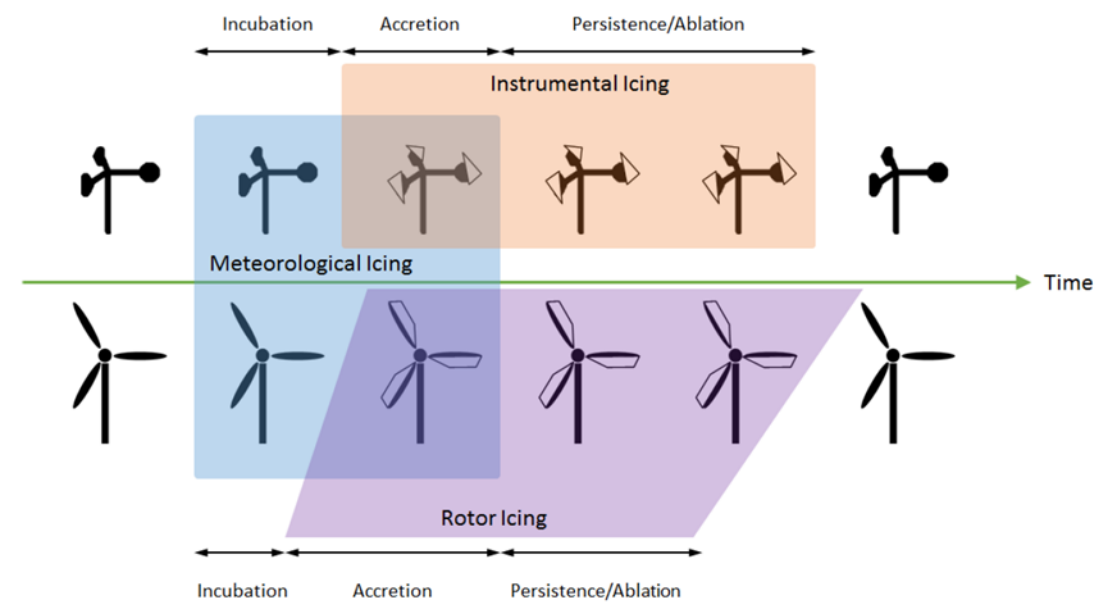
- Icing event frequency and location is changing
- Applications beyond wind energy: transmission, transportation etc.

Source: Kovacik, C., and K. Kloesel, 2014: Changes in Ice Storm Frequency Across the United States. Southern Climate Impacts Planning Program, 21 pp.

Note: Content for this slide provided by Nergica

Ice Forecasting Model Development

Icing events characterized by phase and location of occurrence



Note: Content for this slide provided by Nergica

Ice Forecasting Model Development

Ice forecasting model developed by Nergica using input ECCC forecasts

- Measurement & instrumentation
  - Wind speed, temperature
  - Icing detectors (Combitech, Goodrich)
  - Cameras on wind turbine nacelles
- Input ECCC forecasts
  - Operational weather forecast (48 hrs, updated every 6 hrs)
  - Adjusted to turbine location and altitude
  - Time resolution: 30 min.
- Validation over two winter periods
  - 2017-12-20 to 2018-04-30
  - 2018-11-27 to 2019-03-31

Research conducted at Nergica's test site (Gaspé, Québec)

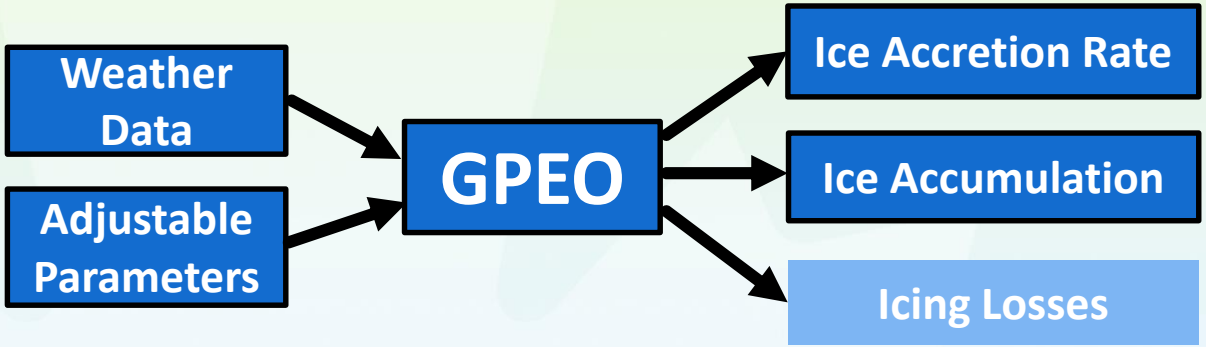
Note: Content for this slide provided by Nergica

The Ice and Energy Loss Model (GPEO)

GPEO model translates atmospheric conditions into operational icing forecast

Model elements

1. Ice accretion
   - Freezing rain, in-cloud icing, wet snow
2. Ice ablation
   - Simplified ice fall model
   - Ice melting
3. Total ice accumulation
4. Filtering
5. Ice losses
   - Transfer function



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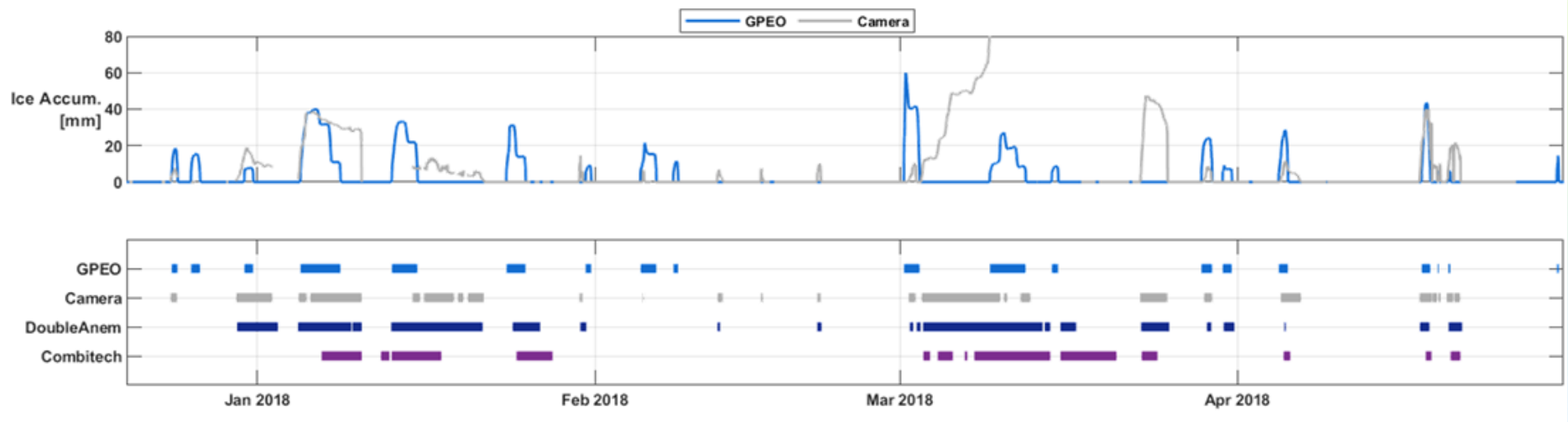
GPEO Model Assessment

Modeled ice accumulation and event length vs. instrumental observations



- Analysis shows some consensus on icing event detection but differences in event duration

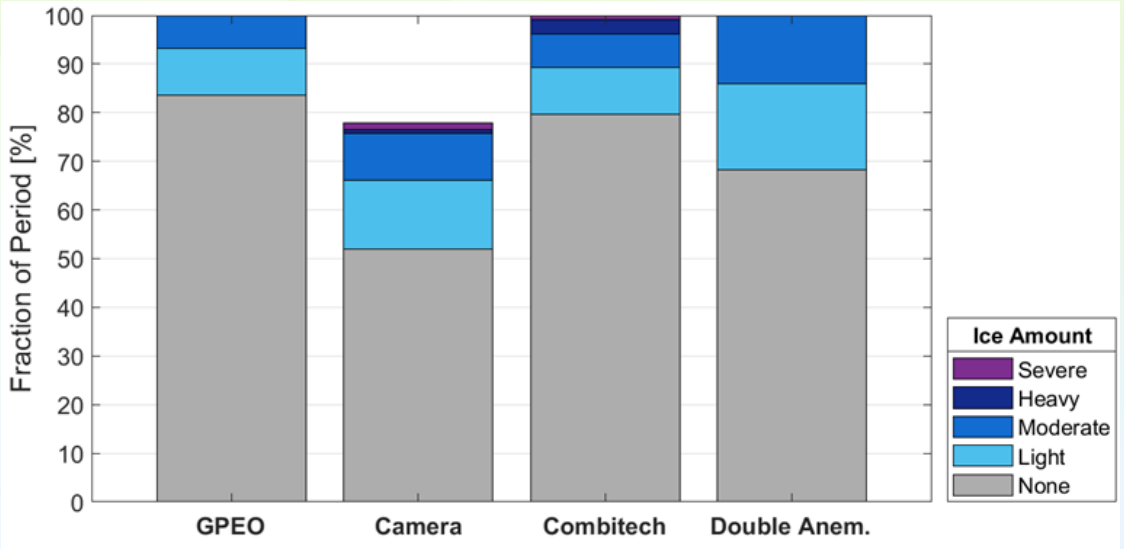
Note: Content for this slide provided by Nergica

GPEO Model Assessment

Overall insights:

- Good results on annual basis
- Accretion well modelled, when inputs are accurate
- Melting rate too high
- Next steps:
  - Further validation against observation data
  - Refinement of ice shedding and melting models
  - Predict wind turbine power loss

Ice severity: Winter 2017-2018



Note: Content for this slide provided by Nergica

Conclusions and Next Steps

- Short-term and ramping wind power forecasting models developed by UNB, leveraging the ECCC wind speed forecasts as model inputs
- Comprehensive forecasting package developed that includes day-ahead and hours-ahead wind power production forecasting, ramp event forecasting and performance assessment for historical data
- Package currently being tested at Nergica and WEICan, with further testing in utility settings intended
- Ice forecasting model developed by Nergica, with power loss prediction component and further refinement and validation underway

Acknowledgements

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Thank you!

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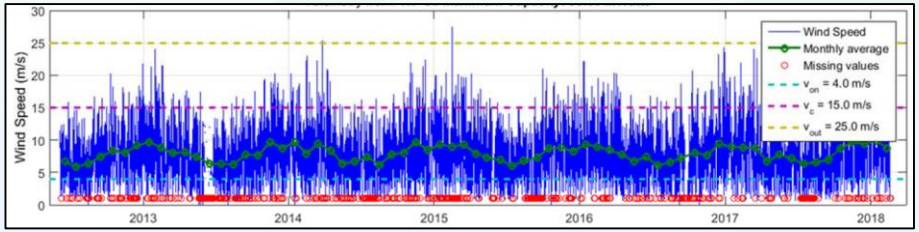
Appendix

Wind Farm Telemetry Data

Wind speed, direction and temperature at hub height at 5-minute intervals

Weather Variable	Unit	Frequency
Wind Speed @ hub height	Meters per second (m/s)	Every 5 minutes
Wind direction @ hub height	Degrees (0° to 360°)	Every 5 minutes
Temperature @ hub height	Degrees (Celsius)	Every 5 minutes
Generated wind power	Megawatts (MW)	Every 5 minutes
Available capacity	Megawatts (MW)	Every 5 minutes
Number of turbines	Cardinal number	Once or upon change
Turbine types	Model identification	Once or upon change
Turbine rated power for each turbine	Megawatts (MW)	Once or upon change
Turbine cut-in, rated and cut-out speeds	Meters per second (m/s)	Once or upon change

Quality assessment procedure to exclude erroneous samples



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Forecasting Model Assessment

Global Statistical Metrics

e_i represents the forecast error at a discrete time i

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(e_i)$$

$$\text{Root Mean Square Error (RMSE)} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(e_i)^2}$$

$$\text{Mean Average Error (MAE)} = \frac{1}{N}\sum_{i=1}^{N}|e_i|$$

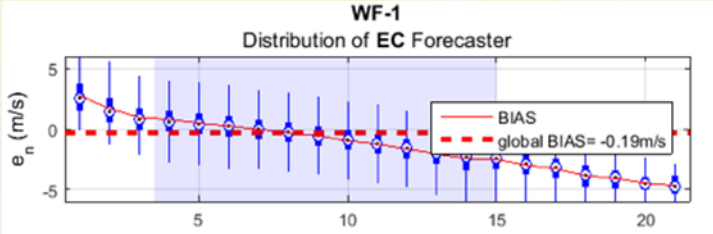
$$\text{Mean Absolute Percentage Error (MAPE)} = \frac{100}{N}\sum_{i=1}^{N}\frac{|e_i|}{|y_i|}$$

Note: Content for this slide provided by UNB

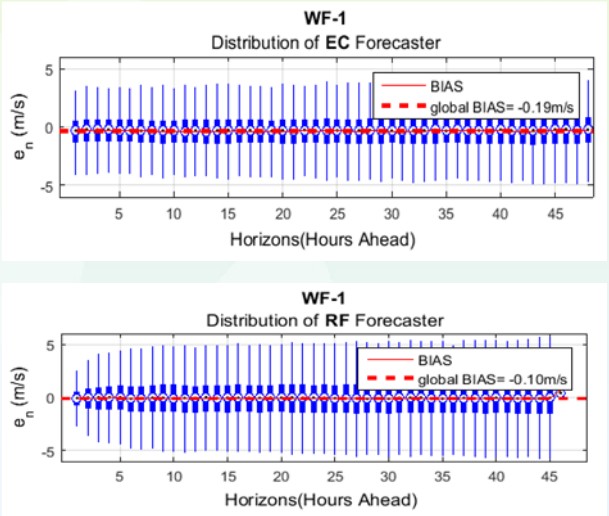
Assessment of ECCC Wind Forecasting Model

ECCC wind speed forecasts compared to observational data and reference forecast (RF) over 32-month period (June 2015 to Feb. 2018)

Error distribution by wind speed



Error distribution by forecast horizon



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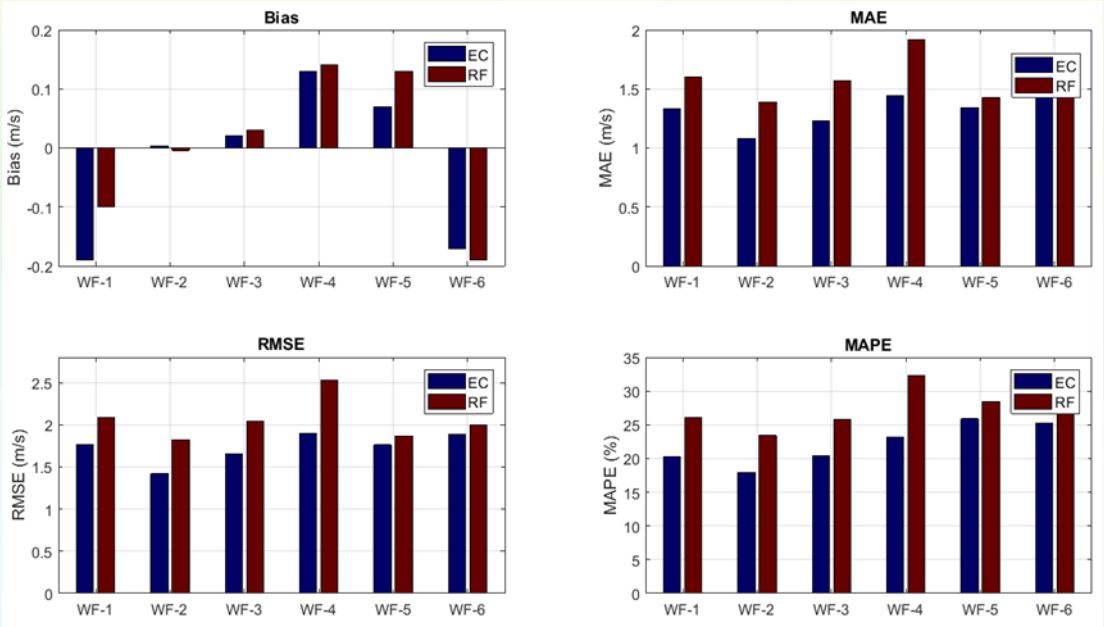


Both ECCC and RF wind speed forecasts show average error of 20-30% compared to telemetry data

Note: Content for this slide provided by UNB

Reference Forecast

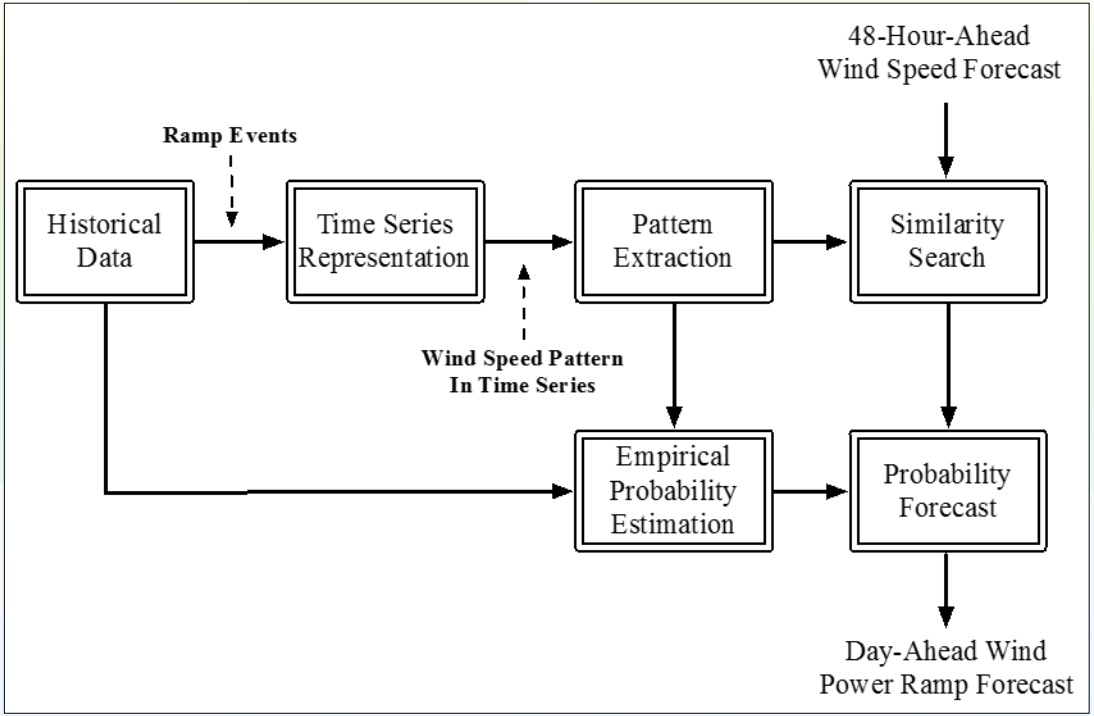
Reference commercial forecast used for comparison & model development

Comparison between ECCC and Reference forecasts

	EC forecasts	RF forecasts
Look ahead time	48 hours ahead	45 hours ahead
Time resolution	1 hour since 2014	15 minutes
Delay	6 hours ahead	Unknown
Update hours	4 times/day (00,06, 12,18)	5 times/day (05,11,15,17,23)
Forecasts at wind farm locations	No, only EC high resolution (2.5km) grid points. Interpolation needed	Yes
Forecasts at hub heights	No	Yes

Note: Content for this slide provided by UNB

Wind Power Ramp Forecasting Algorithm



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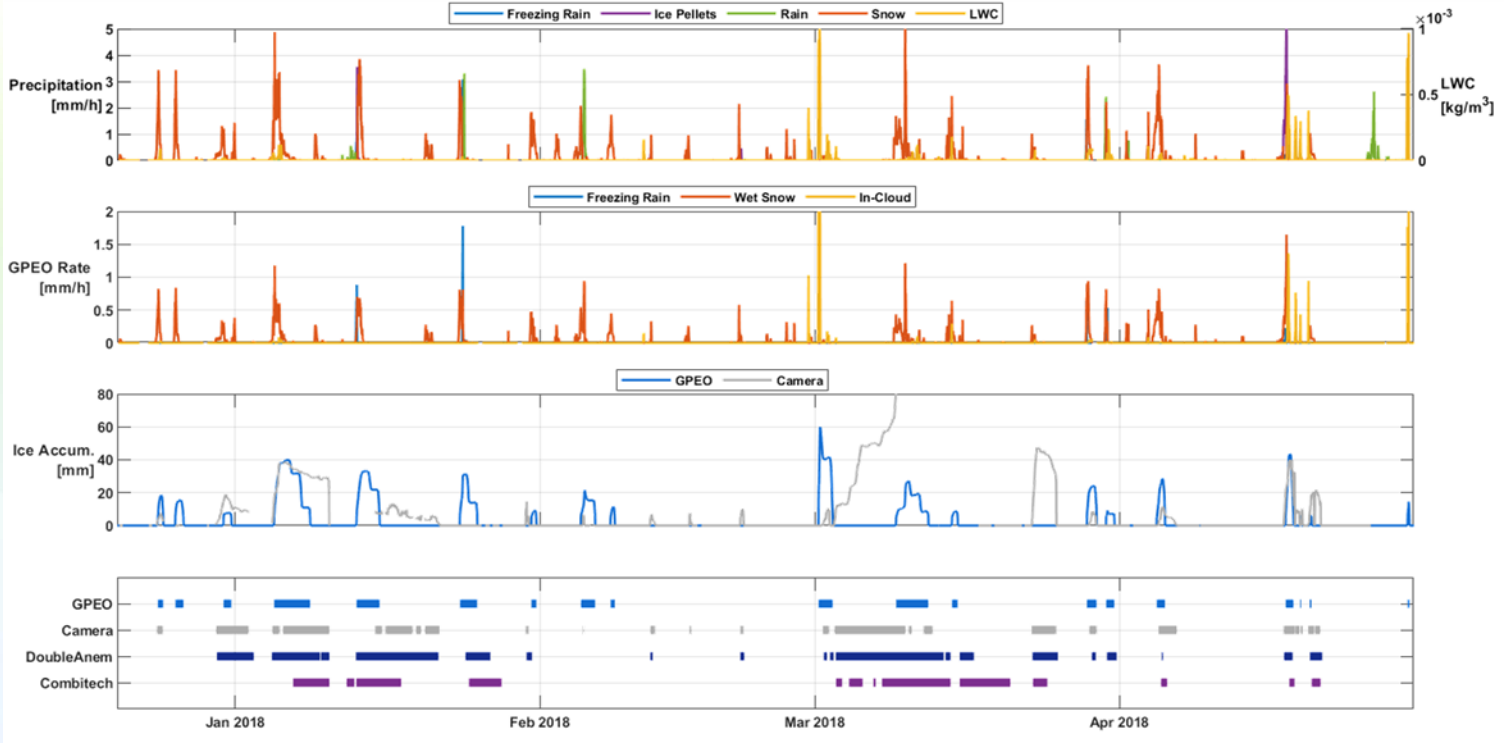
GPEO Model Assessment

Precipitation rates from ECCC forecast

Modeled ice accretion rate (mm/h)

Modeled ice accumulation (mm)

Modeled predictions vs. observations



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