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Enhanced Wind Power Forecasts using New Methods for Predicting Turbine Icing

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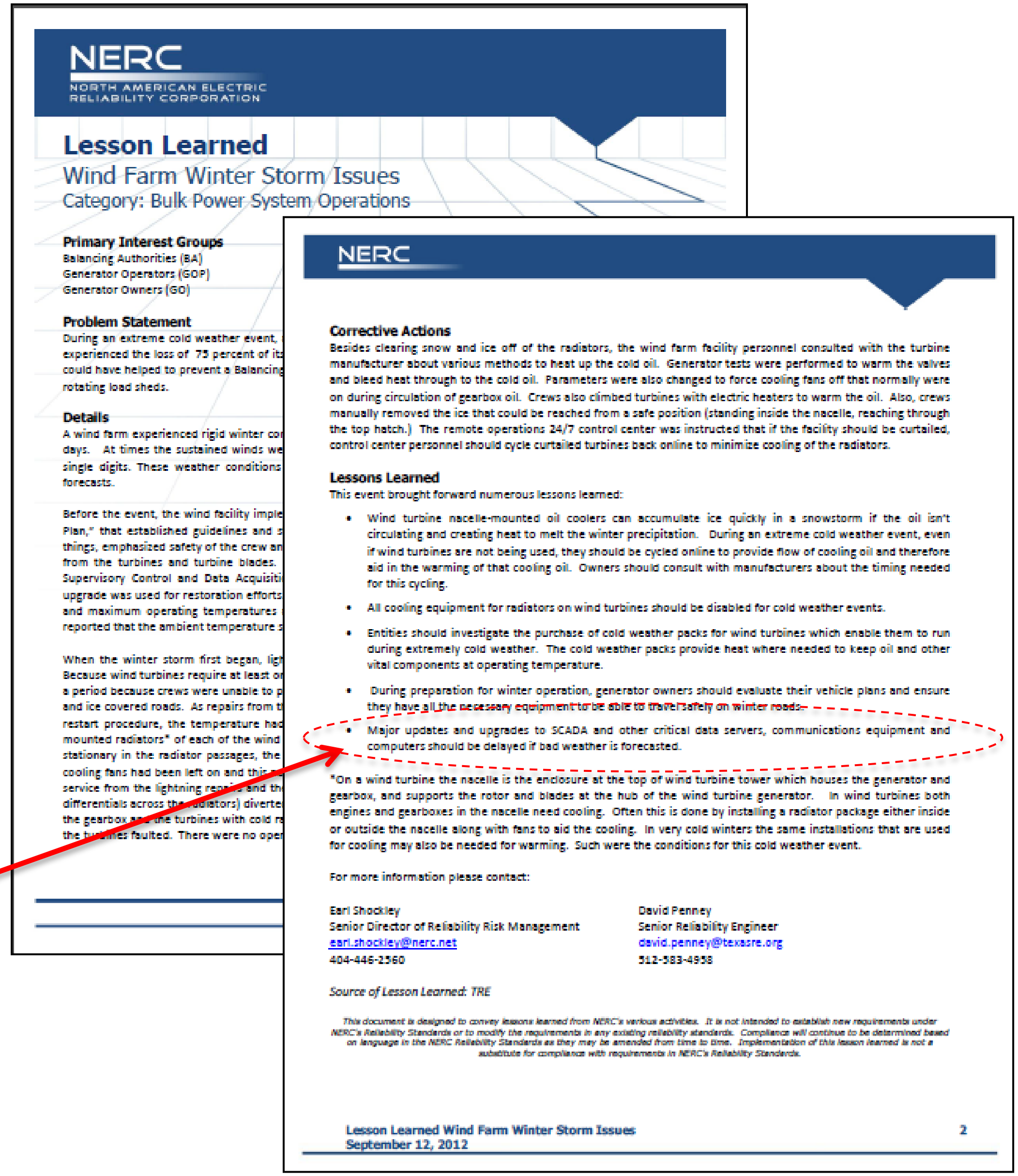
Rotterdam, Netherlands

Background

- *NERC report (Sep, 2012)*
- *Extreme winter storm incident*
- *Loss of 75% of available generation due to turbine faults*
- *Corrective actions and lessons learned*
- *Highlighted the value of "bad weather" fore-casting*



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Lesson Learned

Wind Farm Winter Storm Issues

Category: Bulk Power System Operations

Primary Interest Groups

Balancing Authorities (BA)
Generator Operators (GOP)
Generator Owners (GO)

Problem Statement

During an extreme cold weather event, … experienced the loss of 75 percent of its … could have helped to prevent a Balancing … rotating load sheds.

Details

A wind farm experienced rigid winter co… days. At times the sustained winds we… single digits. These weather conditions … forecasts.

Before the event, the wind facility imple… Plan," that established guidelines and … things, emphasized safety of the crew an… from the turbines and turbine blades. … Supervisory Control and Data Acquisiti… upgrade was used for restoration efforts… and maximum operating temperatures … reported that the ambient temperature …

When the winter storm first began, lig… Because wind turbines require at least o… a period because crews were unable to p… and ice covered roads. As repairs from t… restart procedure, the temperature had … mounted radiators* of each of the wind … stationary in the radiator passages, the … cooling fans had been left on and this … service from the lightning repairs and th… differentials across the radiators) diverte… the gearbox and the turbines with cold r… the turbines faulted. There were no oper…

NERC

Corrective Actions

Besides clearing snow and ice off of the radiators, the wind farm facility personnel consulted with the turbine manufacturer about various methods to heat up the cold oil. Generator tests were performed to warm the valves and bleed heat through to the cold oil. Parameters were also changed to force cooling fans off that normally were on during circulation of gearbox oil. Crews also climbed turbines with electric heaters to warm the oil. Also, crews manually removed the ice that could be reached from a safe position (standing inside the nacelle, reaching through the top hatch.) The remote operations 24/7 control center was instructed that if the facility should be curtailed, control center personnel should cycle curtailed turbines back online to minimize cooling of the radiators.

Lessons Learned

This event brought forward numerous lessons learned:

- Wind turbine nacelle-mounted oil coolers can accumulate ice quickly in a snowstorm if the oil isn't circulating and creating heat to melt the winter precipitation. During an extreme cold weather event, even if wind turbines are not being used, they should be cycled online to provide flow of cooling oil and therefore aid in the warming of that cooling oil. Owners should consult with manufacturers about the timing needed for this cycling.
- All cooling equipment for radiators on wind turbines should be disabled for cold weather events.
- Entities should investigate the purchase of cold weather packs for wind turbines which enable them to run during extremely cold weather. The cold weather packs provide heat where needed to keep oil and other vital components at operating temperature.
- During preparation for winter operation, generator owners should evaluate their vehicle plans and ensure they have all the necessary equipment to be able to travel safely on winter roads.
- Major updates and upgrades to SCADA and other critical data servers, communications equipment and computers should be delayed if bad weather is forecasted.

*On a wind turbine the nacelle is the enclosure at the top of wind turbine tower which houses the generator and gearbox, and supports the rotor and blades at the hub of the wind turbine generator. In wind turbines both engines and gearboxes in the nacelle need cooling. Often this is done by installing a radiator package either inside or outside the nacelle along with fans to aid the cooling. In very cold winters the same installations that are used for cooling may also be needed for warming. Such were the conditions for this cold weather event.

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Source of Lesson Learned: TRE

This document is designed to convey lessons learned from NERC's various activities. It is not intended to establish new requirements under NERC's Reliability Standards or to modify the requirements in any existing reliability standards. Compliance will continue to be determined based on language in the NERC Reliability Standards as they may be amended from time to time. Implementation of this lesson learned is not a substitute for compliance with requirements in NERC's Reliability Standards.

Lesson Learned Wind Farm Winter Storm Issues
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Background

Primary Types of Icing

Riming

- *SCLW transported to surface – freeze instantly*
- *0^o – -20^oC.*
- *asymmetry in crystal shape, formation*
- *may be hard or soft, depending on the size of the SCLW drops*
- *Prefers exposure of structural ridges*

Glazing/ Freezing Rain

- *Depends on a unique stratification of the atmosphere*
- *Often accompanies warm fronts or cold air damming*
- *0^o – -6^oC*
- *Layer on turbine blade and freeze*
- *Very dense, hard to remove relative to rime.*

Background

- Ice accretion may have significant impact on turbine's ability to extract kinetic energy from the wind (air foil drag) (Seifert et al, 1997; Barber et al, 2009; Homola, et al, 2011).

- Existing forecast icing warnings are aviation relevant:

  - Politovich, et al. (2004)
  - Bernstein, et al. (2005)
  - Zhou (2005)

- Makkonen, et al. (2001) outlined basic theory for structural icing prediction (accretion modeling)

- Foder (2001) proposed algorithm for prediction of icing on structures to follow ISO 12494 standard

- VTT of Finland (2009): Recommendations for Wind Energy Projects in Cold Climates: North America, Europe (offshore as well), Scandinavia, and Asia (possibly 60+ GW at risk)

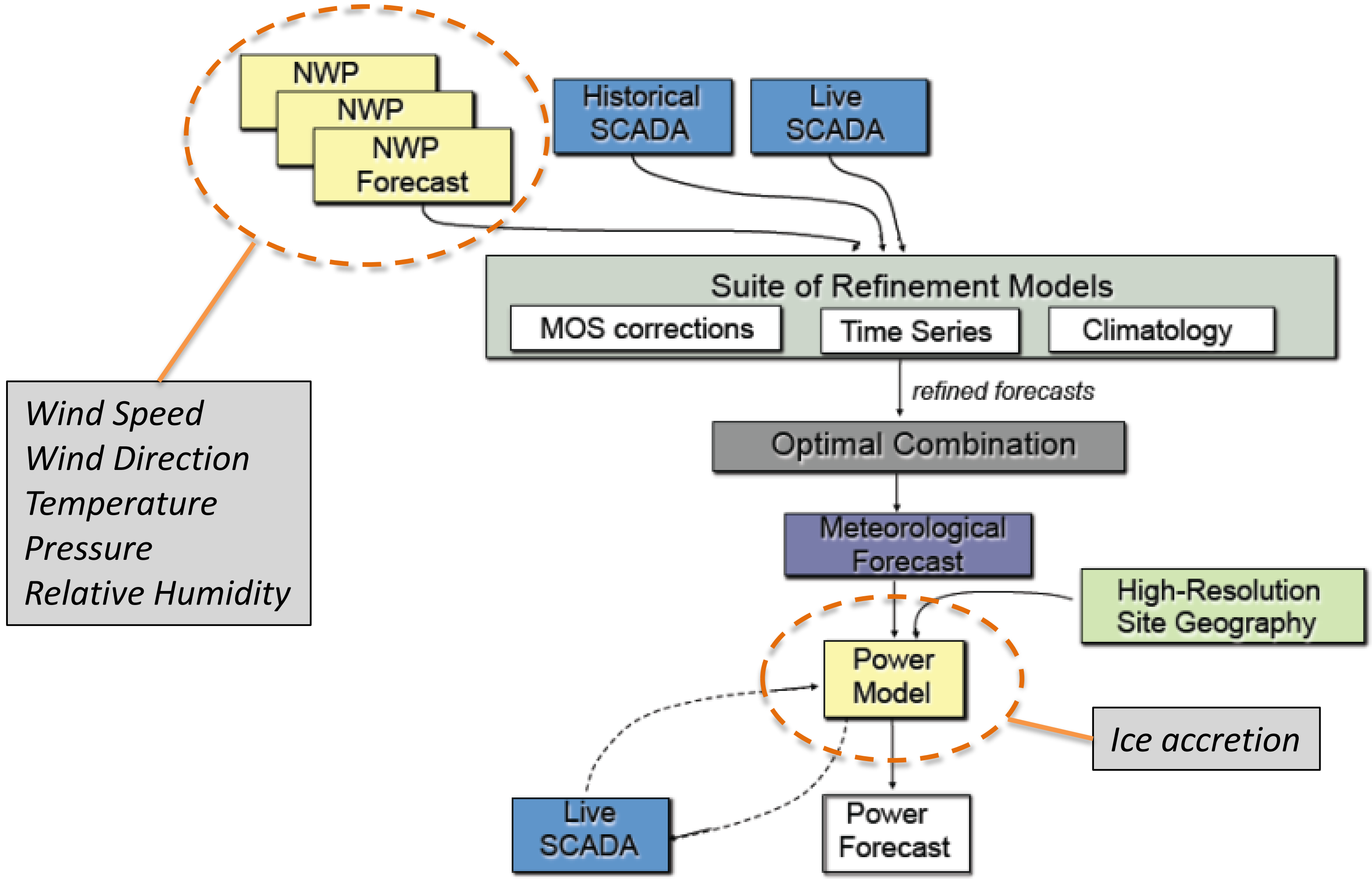
Background

State of the art: Important points and limitations

- *Meteorological icing is NOT the same as instrumental icing but is a necessary condition for instrumental icing (though not sufficient)*
- *Icing prediction is woefully unvalidated – very little reliable observation*
- *NWP generally good with riming and glazing – poor performance with sublimation*
- *No effective MOS correction techniques for icing*
- *Icing prediction highly dependent on cloud microphysics scheme, horizontal resolution (?)*
- *Little to no use of ensemble NWP for icing prediction*

Background

Wind Power Forecasting Process

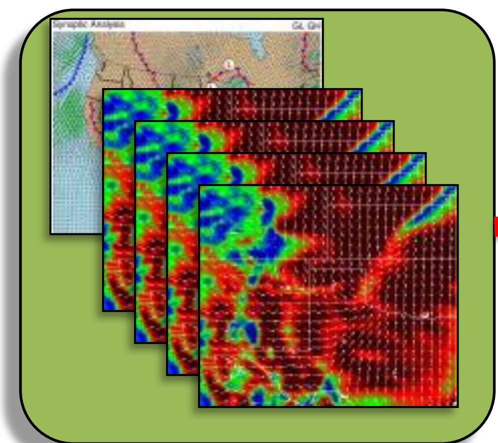


Objectives

- *Develop simple but robust model for predicting icing probability and reduced generation using common variables of various members of an NWP ensemble*
- *Deploy model at multiple sites and assess regional viability, with special emphasis on the similarities and differences between onshore and offshore sites*
- *Demonstrate improvements in accuracy for deterministic forecasts and effectiveness of probabilistic forecasts*

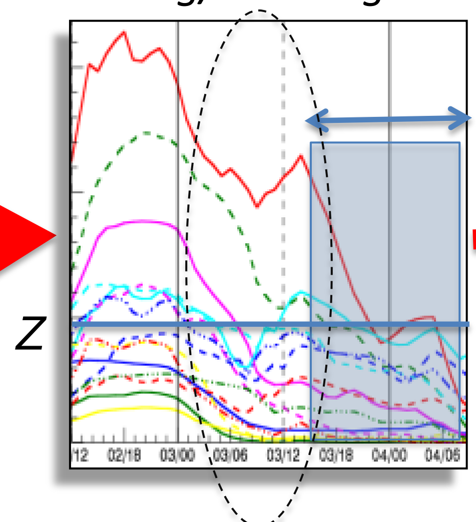
Methods

Ensemble NWP predictions



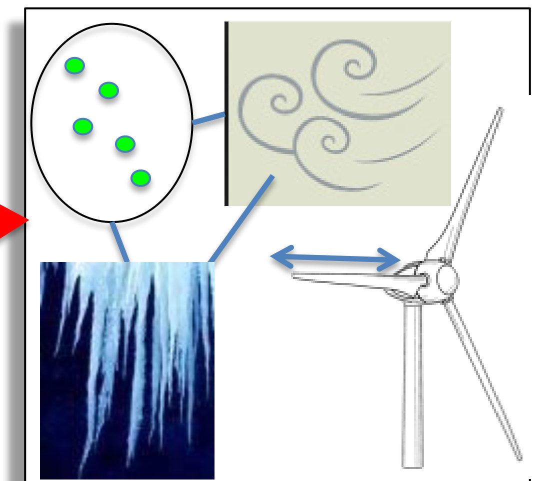
Wind Speed
Wind Direction
Temperature
Pressure
Relative Humidity

Determine Predicted Freezing/Thawing time



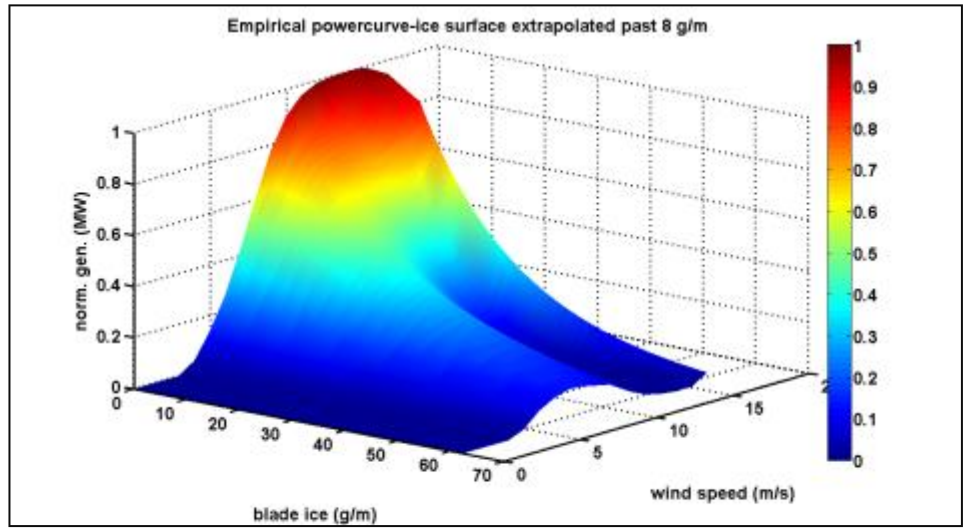
Ensemble Predictions

Accretion Parameterization



Adapted from
Frohboese and Anders (2007)

Methods

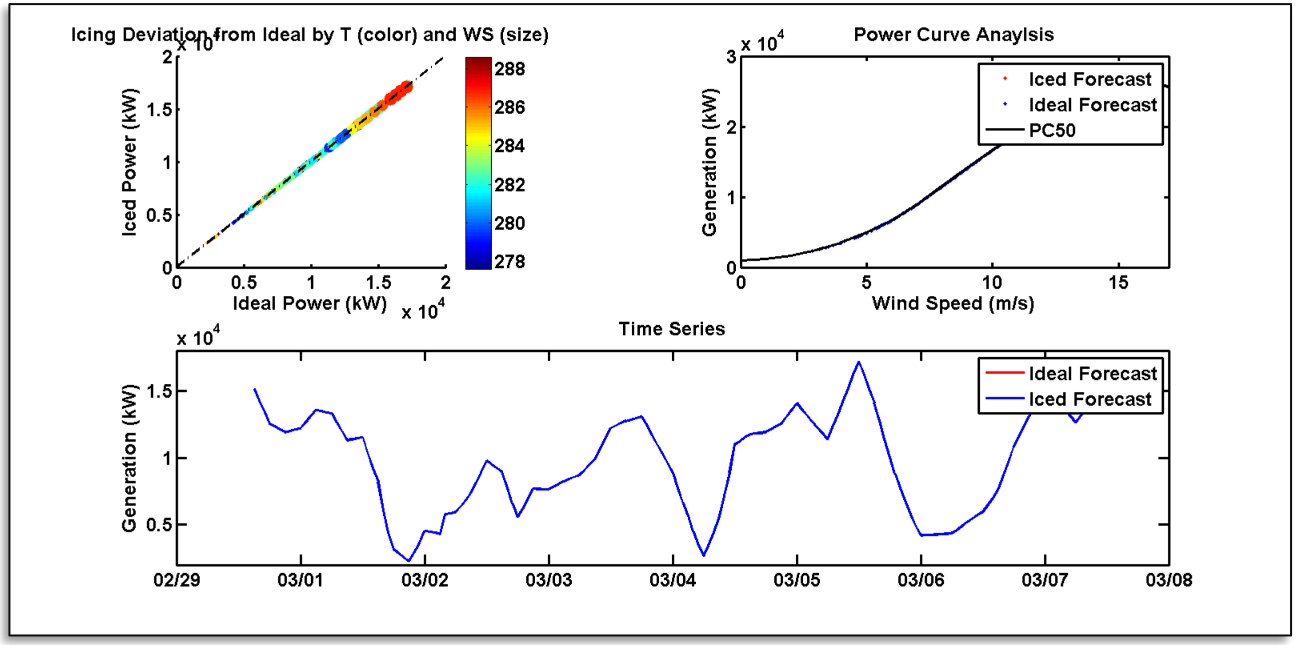


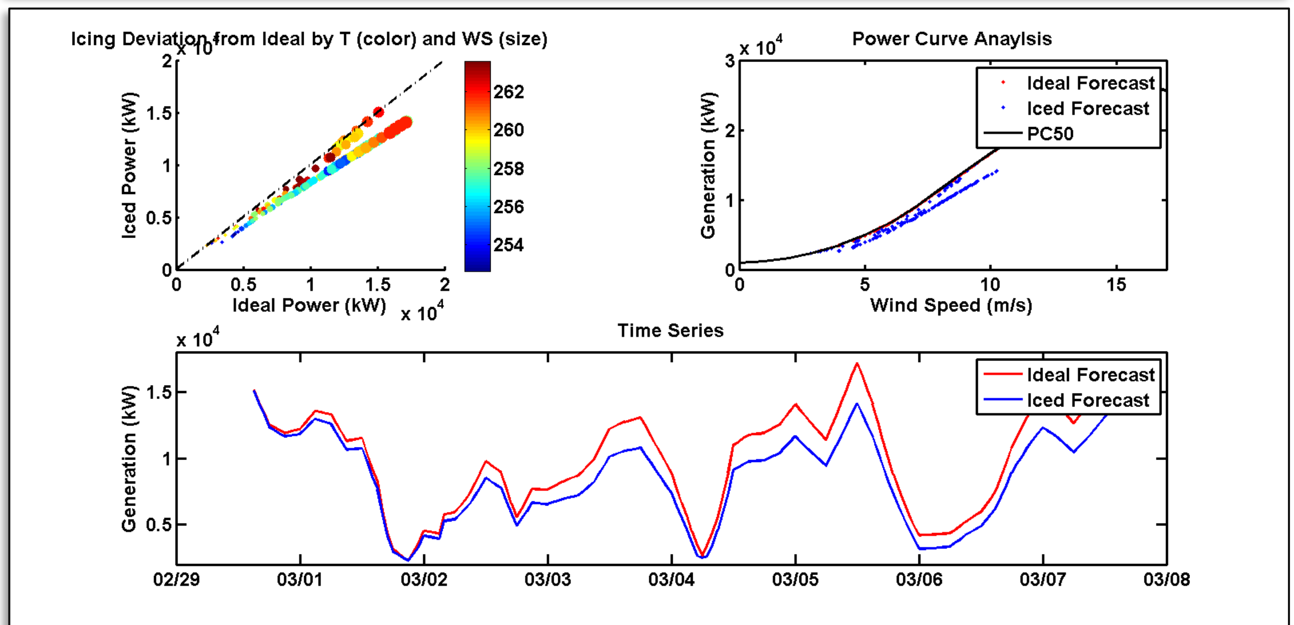
Borrowed from http://www.tuuliatlas.fi/icingatlas/icingatlas_6.html

Borrowed from Finnish Wind Energy Atlas (http://www.windatlas.fi)

Methods

For different levels of ice loading





Methods

Apply Ljundberg & Niemela Model

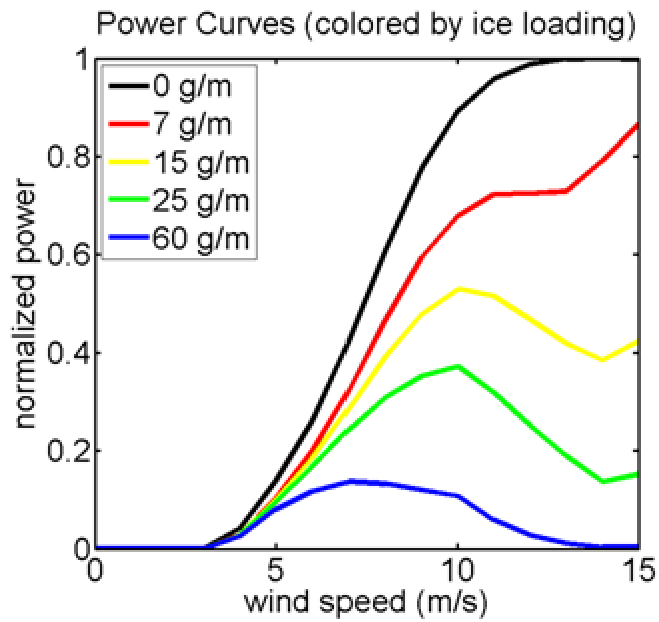
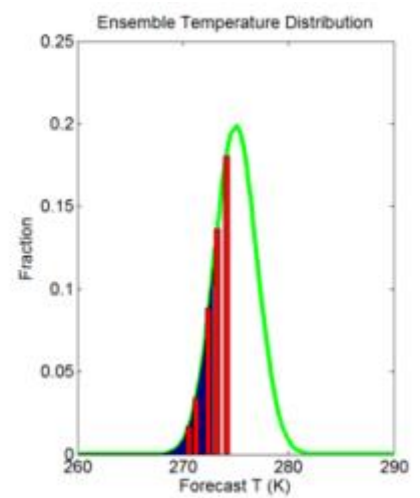
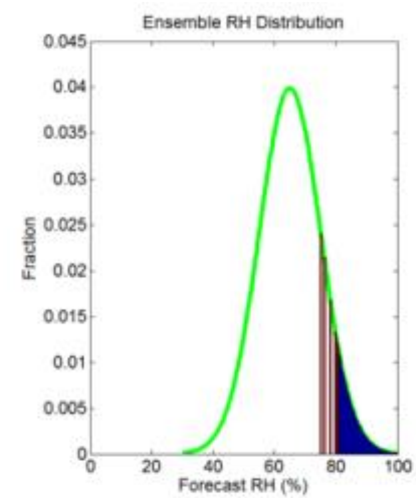


Figure 1: Adapted from Ljungberg, K. and S Niemelä (2011)

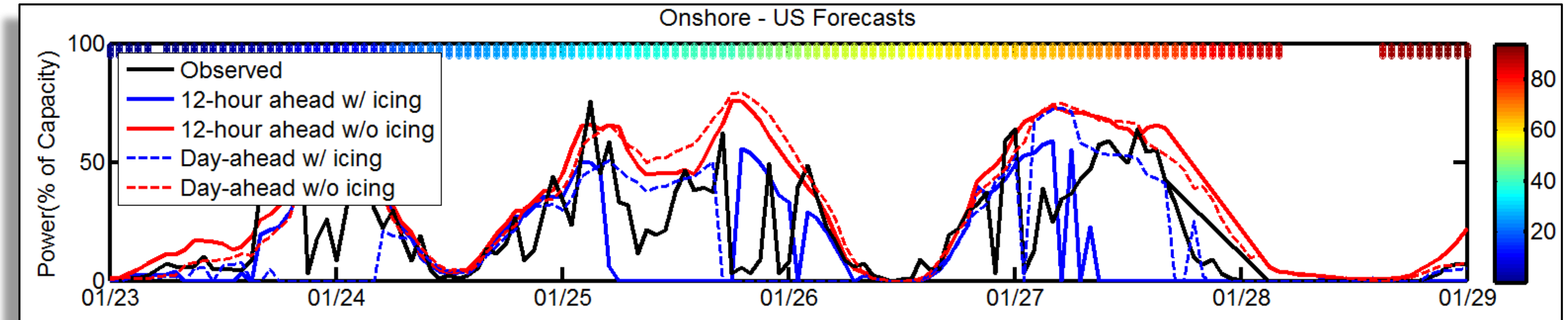
Compose Distributions for Joint Probability Function

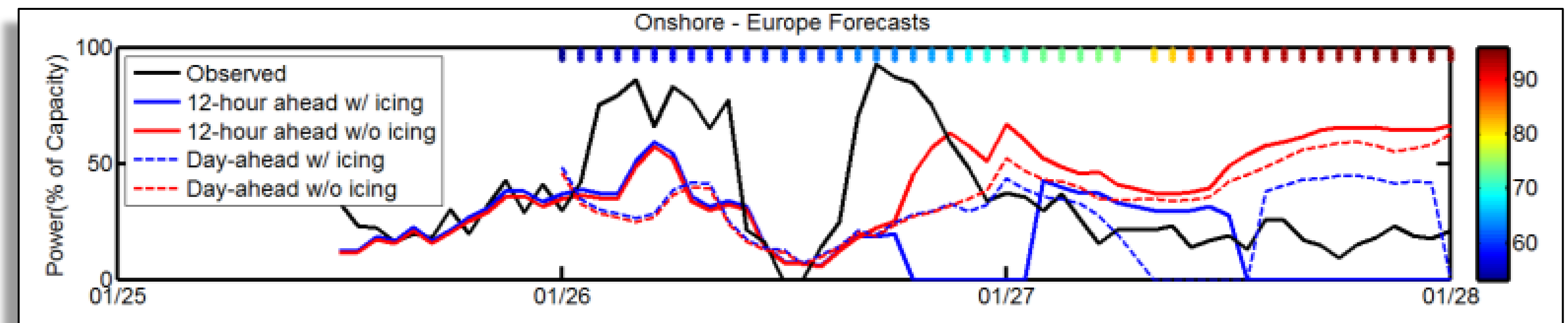




Numerically integrate

Preliminary Validation Results: 2 Onshore Sites





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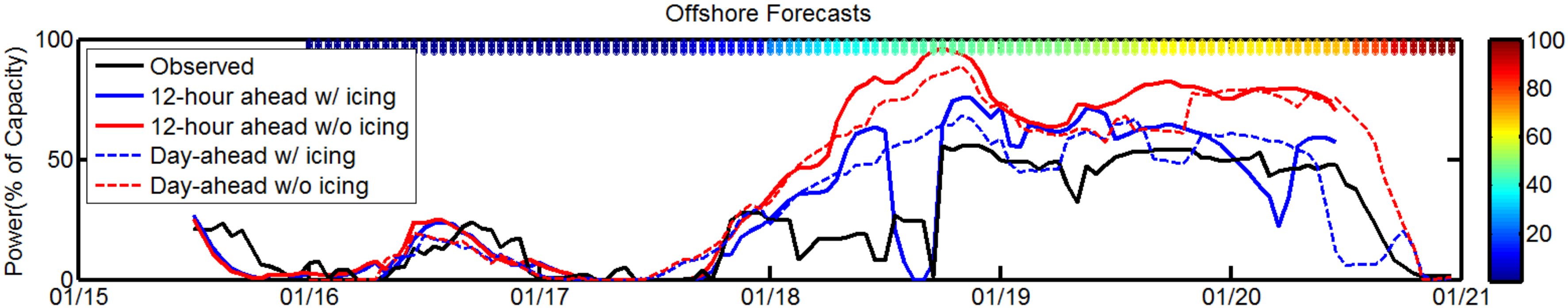
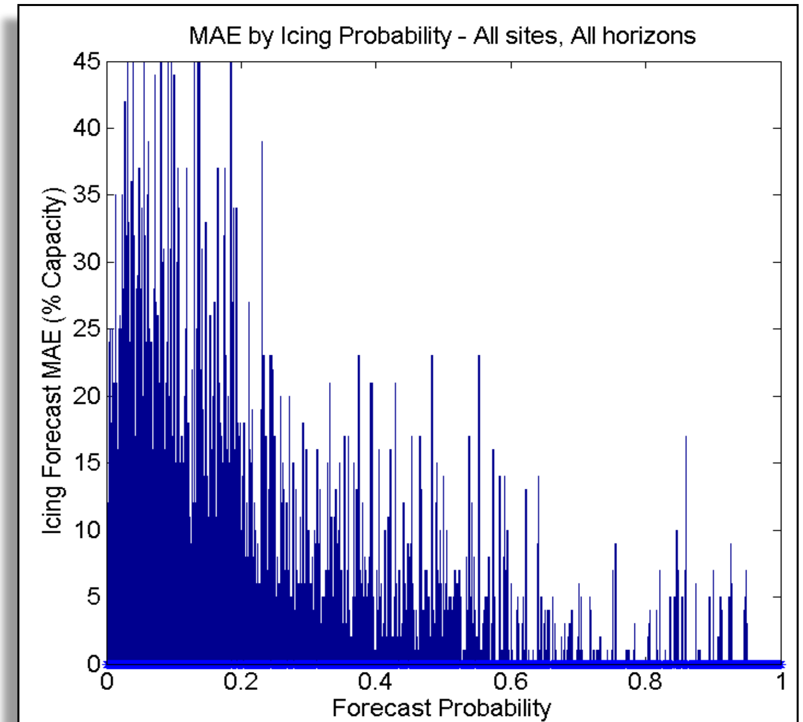
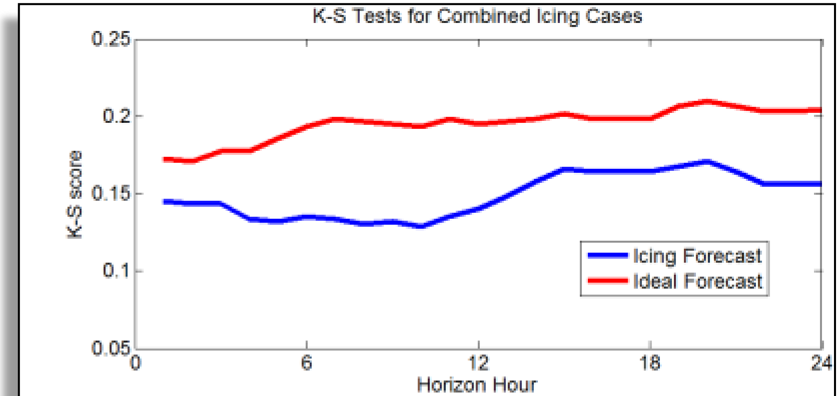
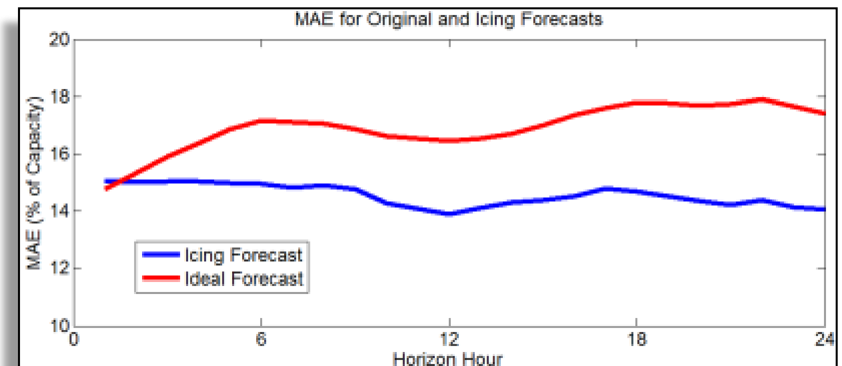
Preliminary Validation Results: Offshore Site



Preliminary Validation Results: Error and Distribution







Summary

- Deterministic icing forecast generated by combining bias-corrected NWP, empirical freeze/thaw time parameterization, and adapted Ljungberg & Niemela model.

- Use of multi-physics, multi-model ensemble NWP allows for prediction of icing probability, using conditional probabilities of forecast ambient conditions.

- Forecast icing model demonstrates reduction in forecast error intra- and inter-day horizons for icing events of varied duration both onshore and offshore.

- Kolmogorov-Smirnov test indicates increased similarity of distributions, at all sites.

- Notable performance variation onshore/offshore – due to more complex meteorology, surface-atmospheric interaction, independent of icing model. Offshore RH, T likely more stable over time and uniform in space – providing increased model fidelity.

Thank You

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