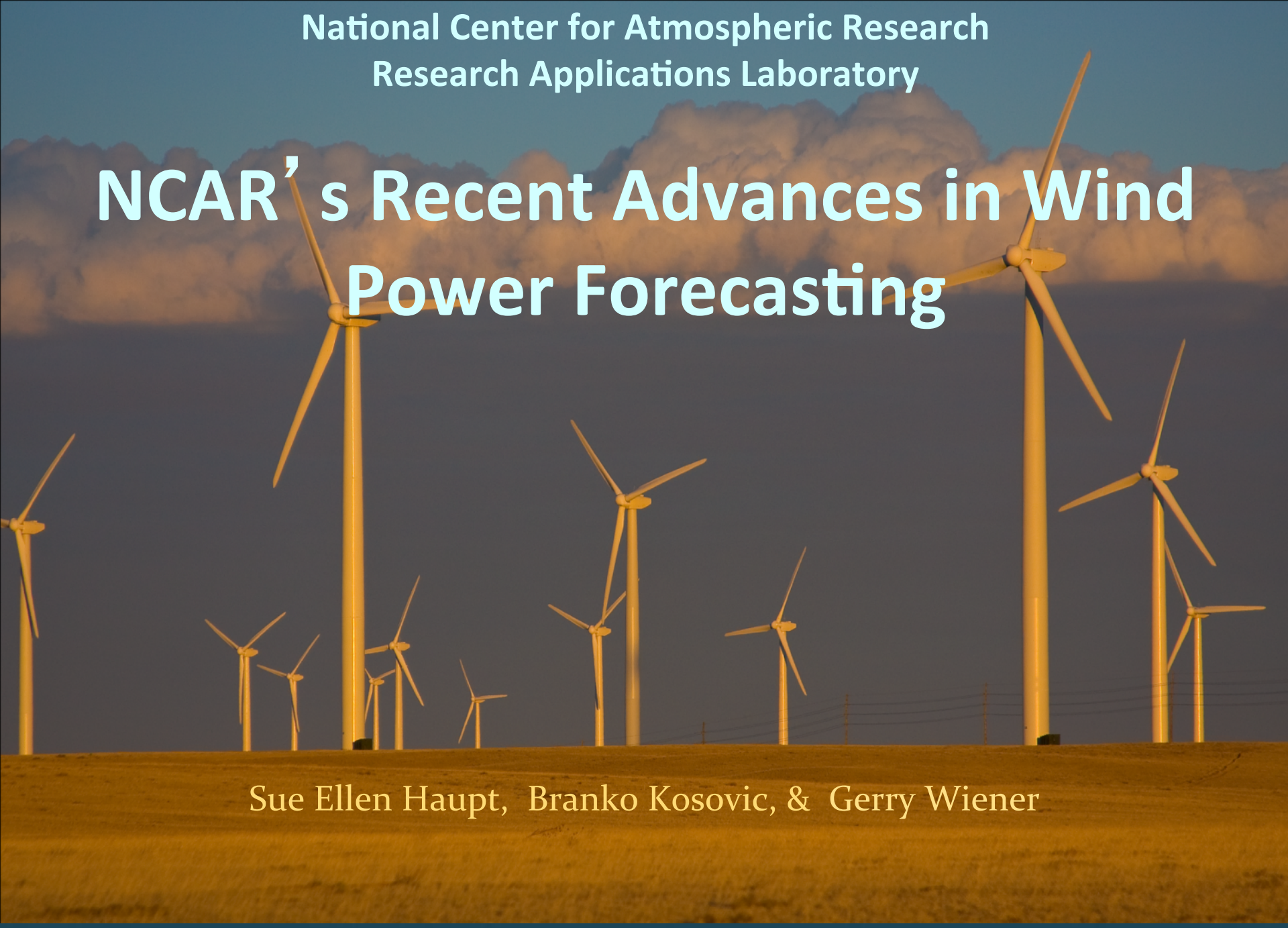
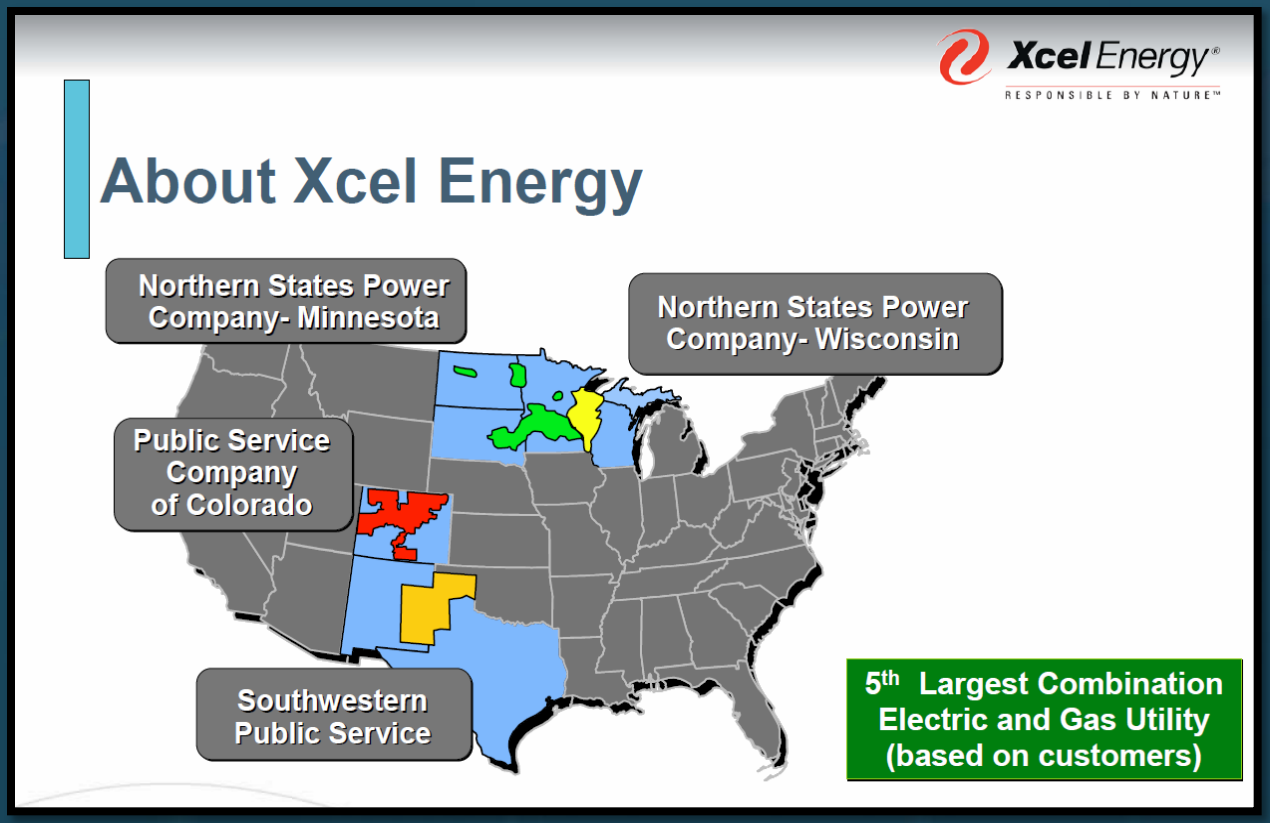
National Center for Atmospheric Research
Research Applications Laboratory

NCAR's Recent Advances in Wind Power Forecasting



Sue Ellen Haupt, Branko Kosovic, & Gerry Wiener

Xcel Energy Service Areas



5736 MW (wind)
(highest in continental US)

Moving toward 40%

Obtain up to 60% of energy from wind at some times

Provides good geographical diversity for research and testing

Wind Power Forecasting Necessary for Effective Grid Integration

- Day Ahead forecasting – Energy trading and planning
- Short-term forecasting – Grid integration and stabilization

Thus, an effective forecasting system should target both

Cedar Creek Wind Farm, Northeast Colorado
Photo by Carlye Calvin, UCAR

Variable Energy Forecasting System

Natl Center Data
HRR, NAM, GFS, RAP
GEM (Canada), ECMWF

WRF RTFDDA System

Ensemble System

Solar Energy Forecast

Supplemental Wind Farm Data
Met towers
Wind profiler
Surface Stations

Wind Farm Data
Nacelle wind speed
Generator power
Node power
Availability

Dynamic, Integrated Forecast System (DICast®)

VDRAS
(nowcasting)

Expert System
(nowcasting)

Extreme Weather Events

CSV Data

Statistical Verification

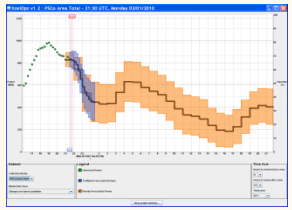
Wind to Energy Conversion Subsystem

Probabilistic and Analog Forecast

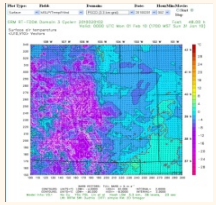
Potential Power Forecasting

Data Mining for Load Estimation

Operator GUI



Meteorologist GUI



WRF Model Output

DICast Integrator System

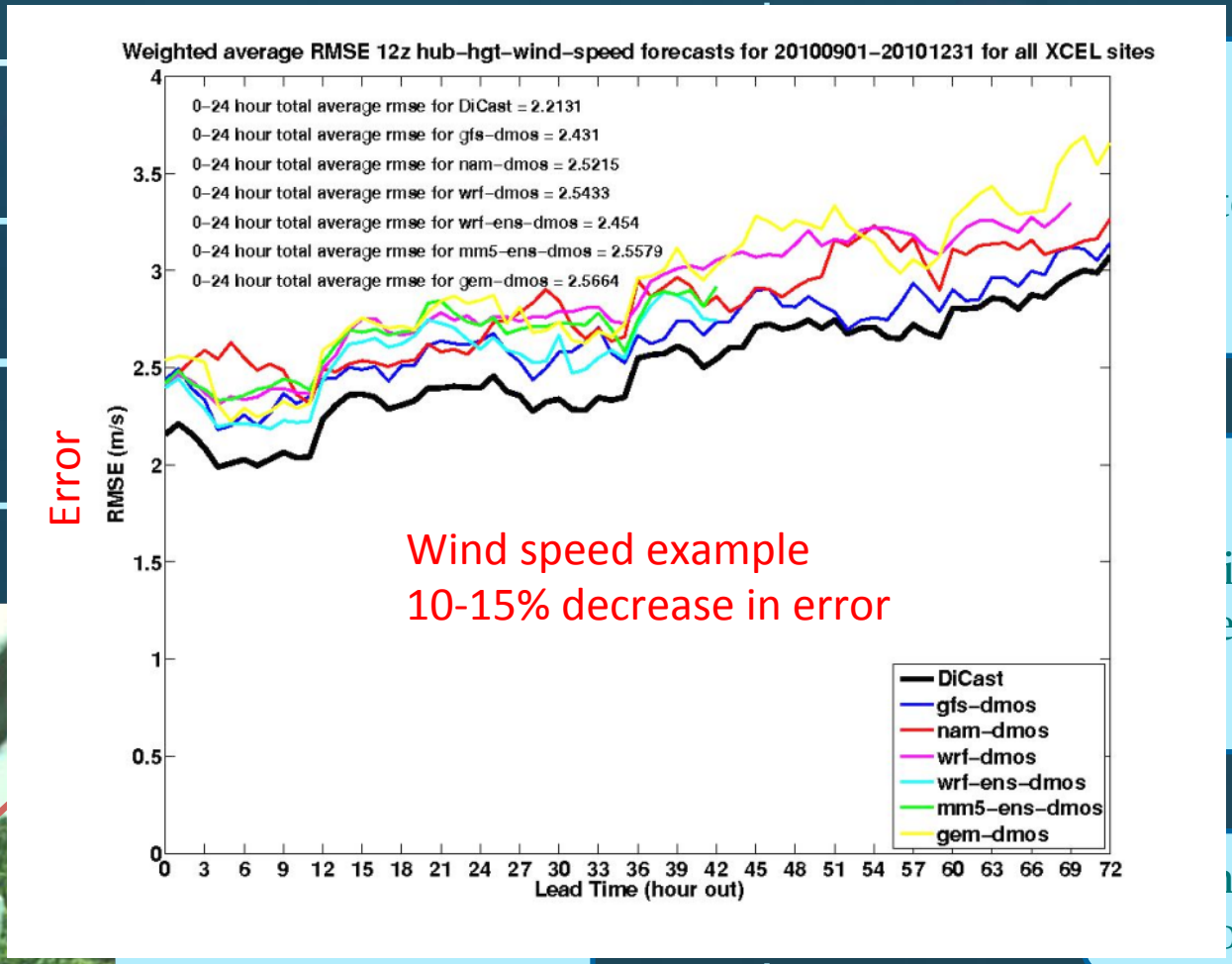
Dynamic Integrated foreCast System

Nacelle Winds

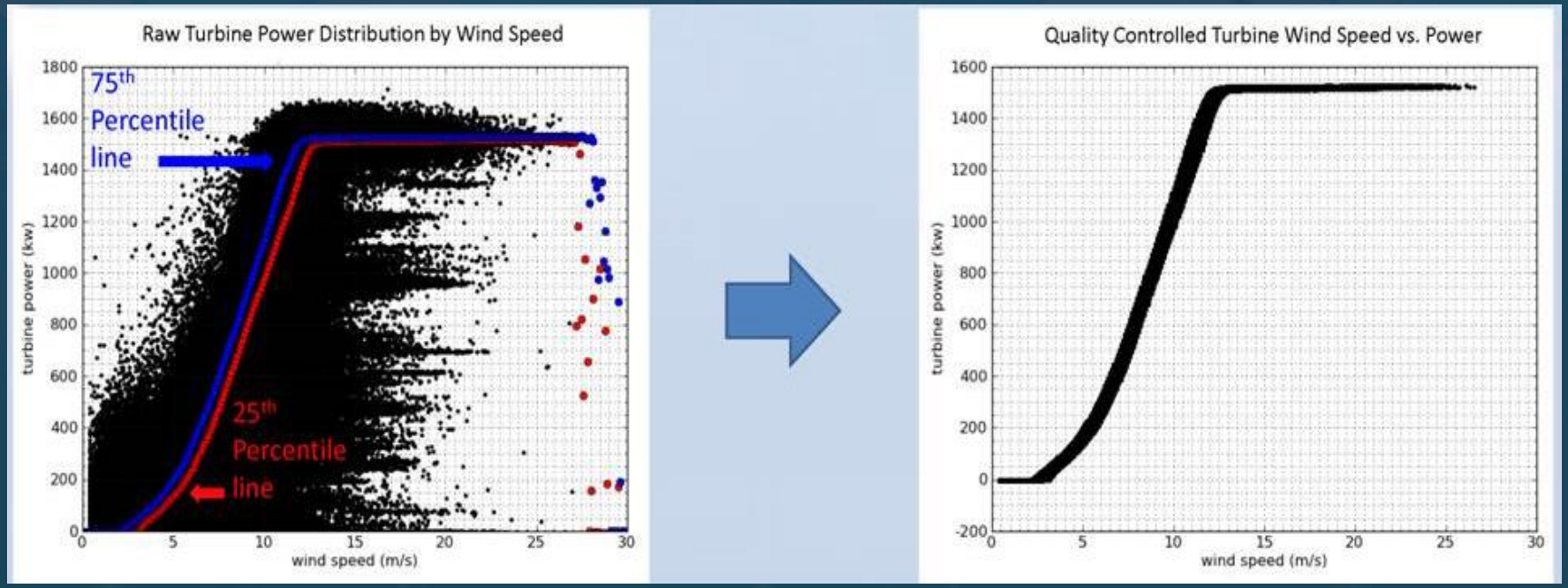
egrator

ine Power ediction

d Power orecast



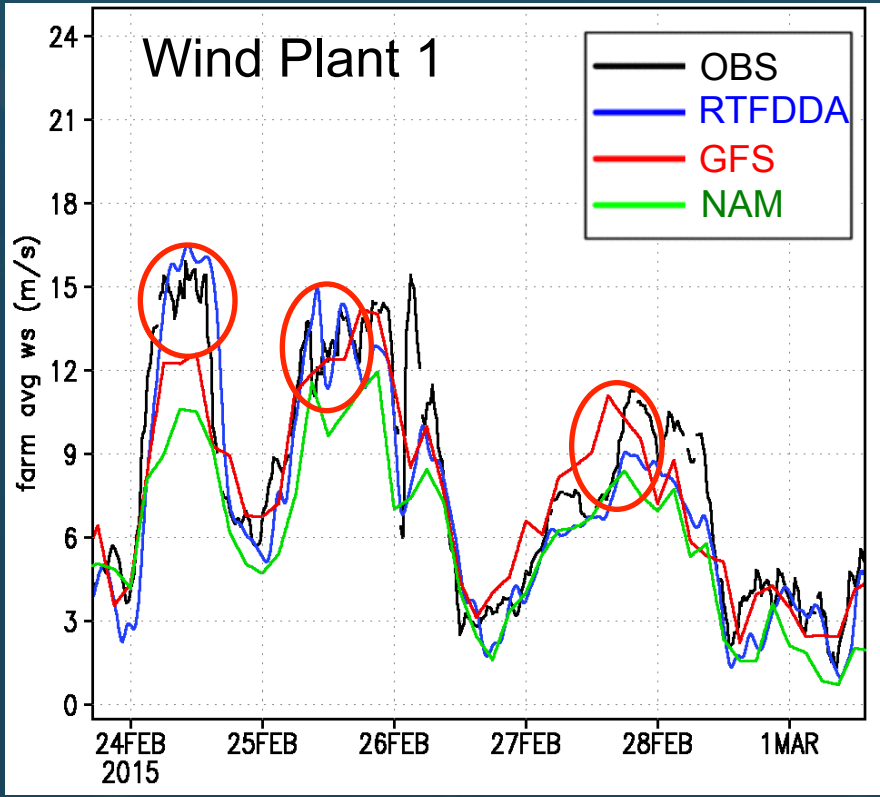
Customized Power Conversion Curves

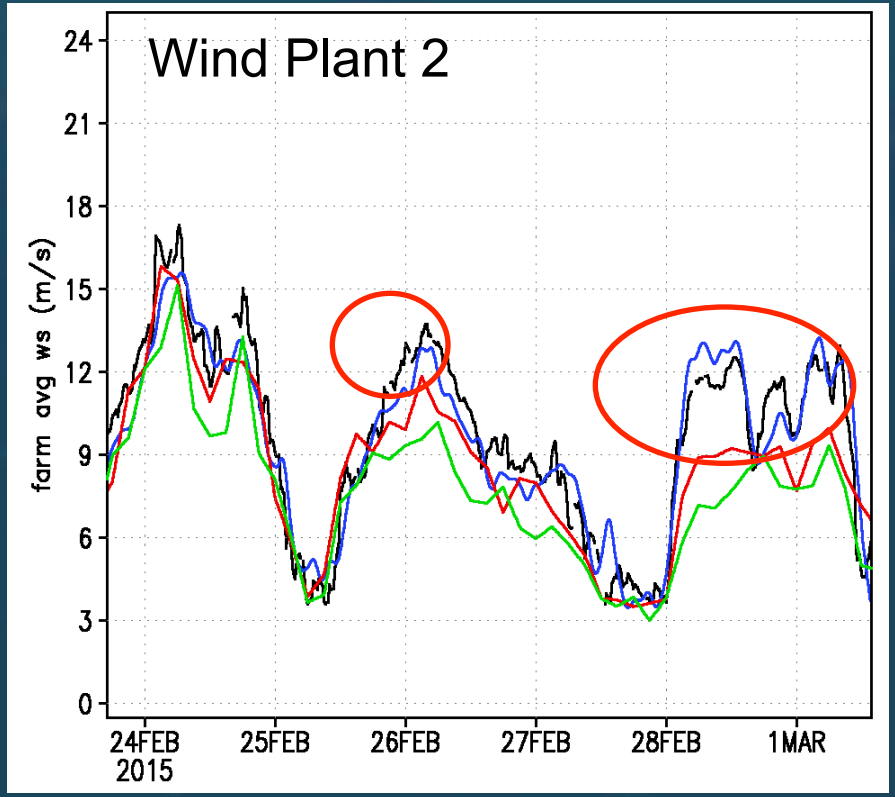


Observation-based power curves represent the site better than manufacturers' power curves

Gerry Wiener

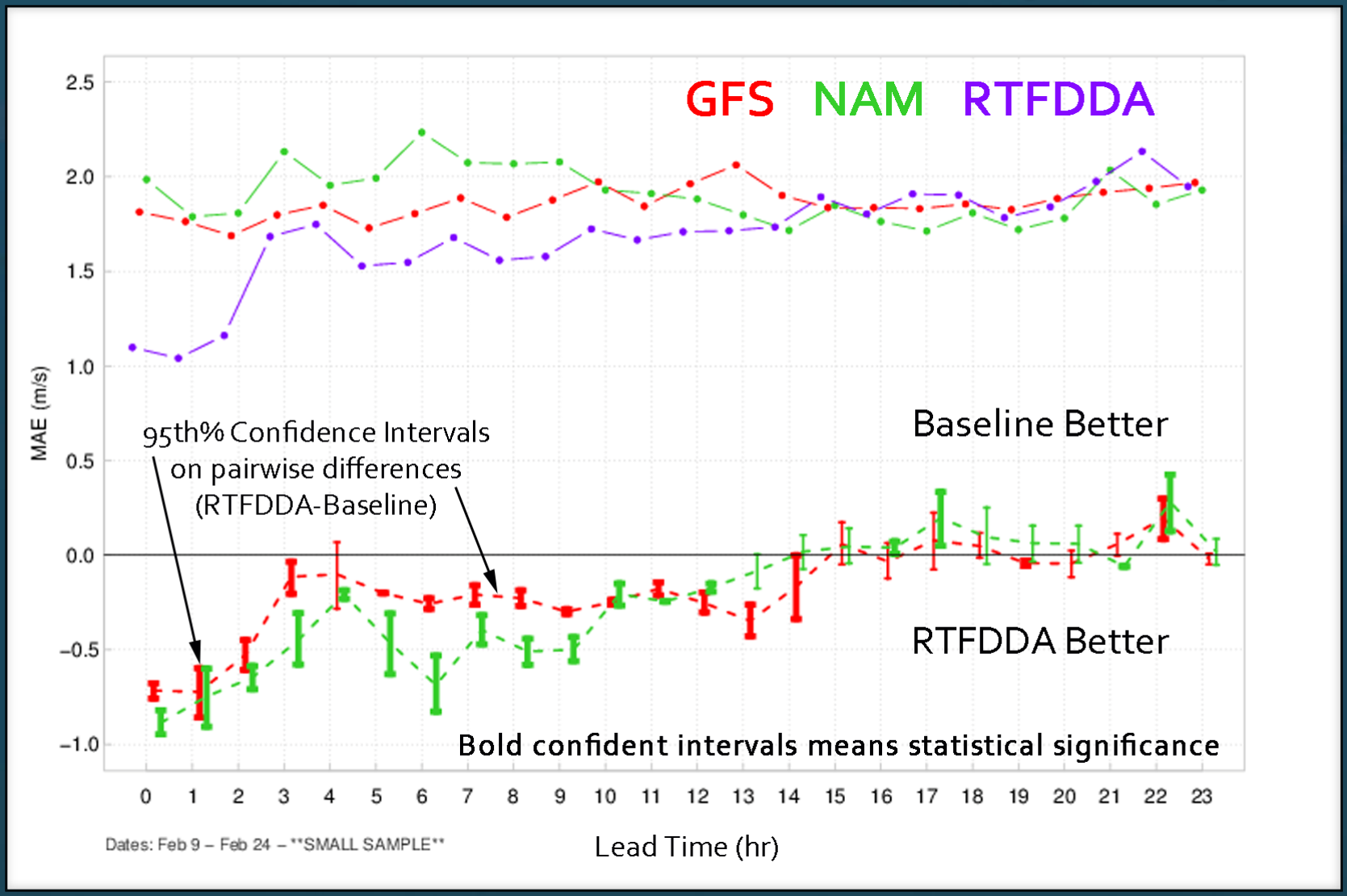
WRF-Real Time 4D Data Assimilation (RTFDDA) Assimilates Wind Farm Data





- WRF RTFDDA exhibits exceptional capability for forecasting wind ramps in term of their timing, rates and magnitudes.
- Rapid cycling (hourly) WRF RTFDDA is recommended where 0 - 6h ahead wind ramp prediction is critical.

WRF- RTFDDA Improves Short Term Forecasts (0-9h)



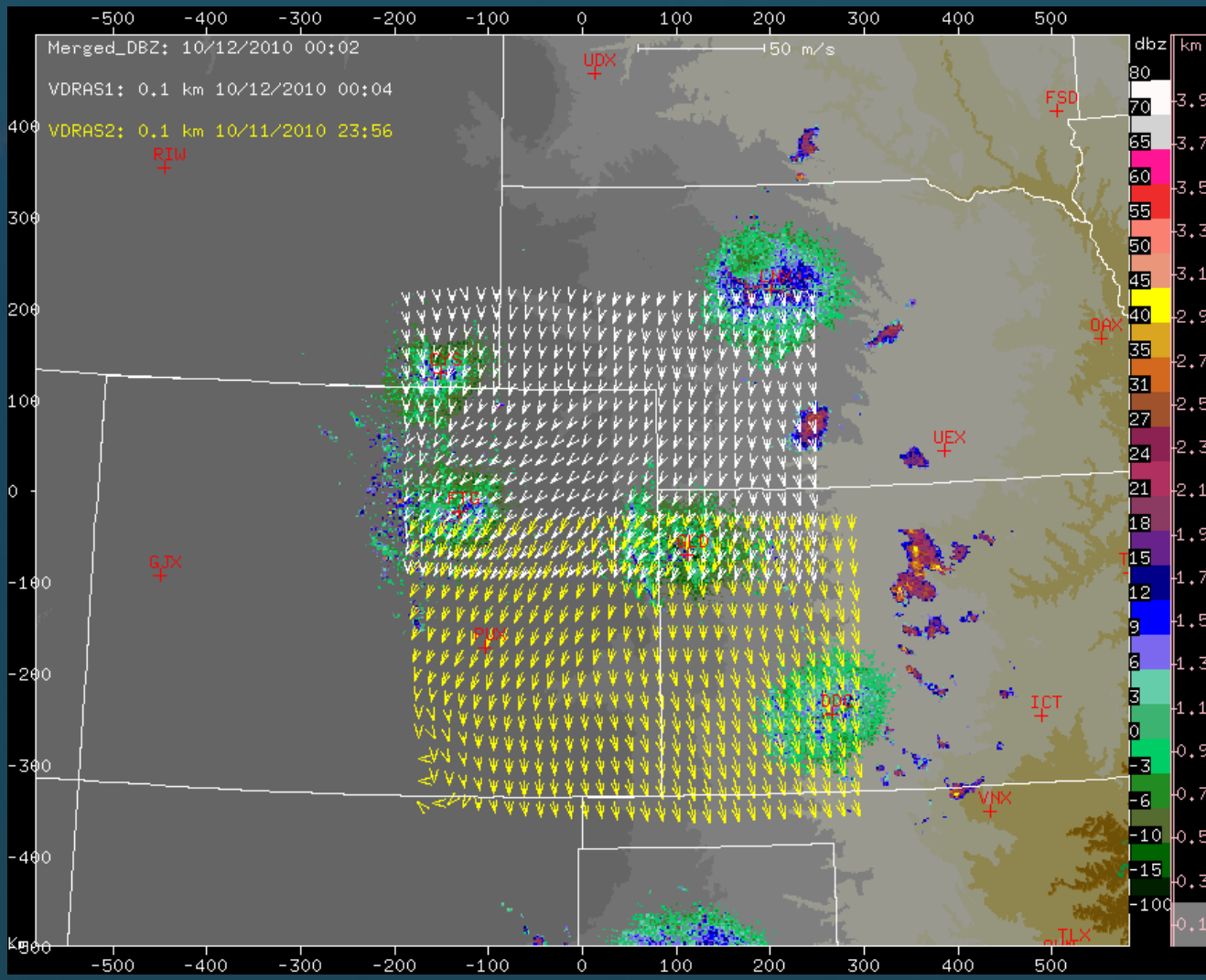
Wind Energy Ramp Event Nowcasting

VDRAS

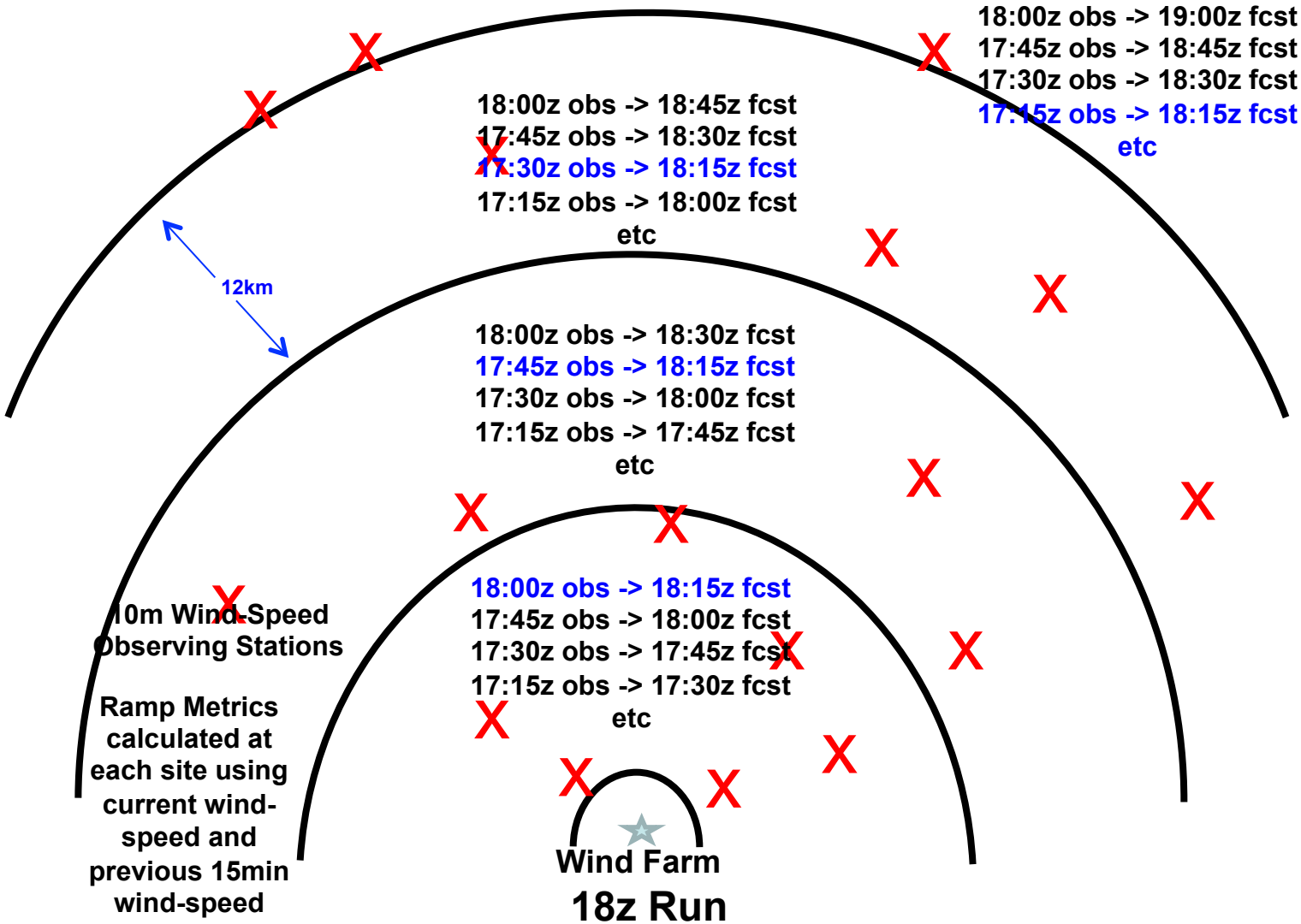
Variational
Doppler Radar
Analysis System

+

Expert System
(obs-based)

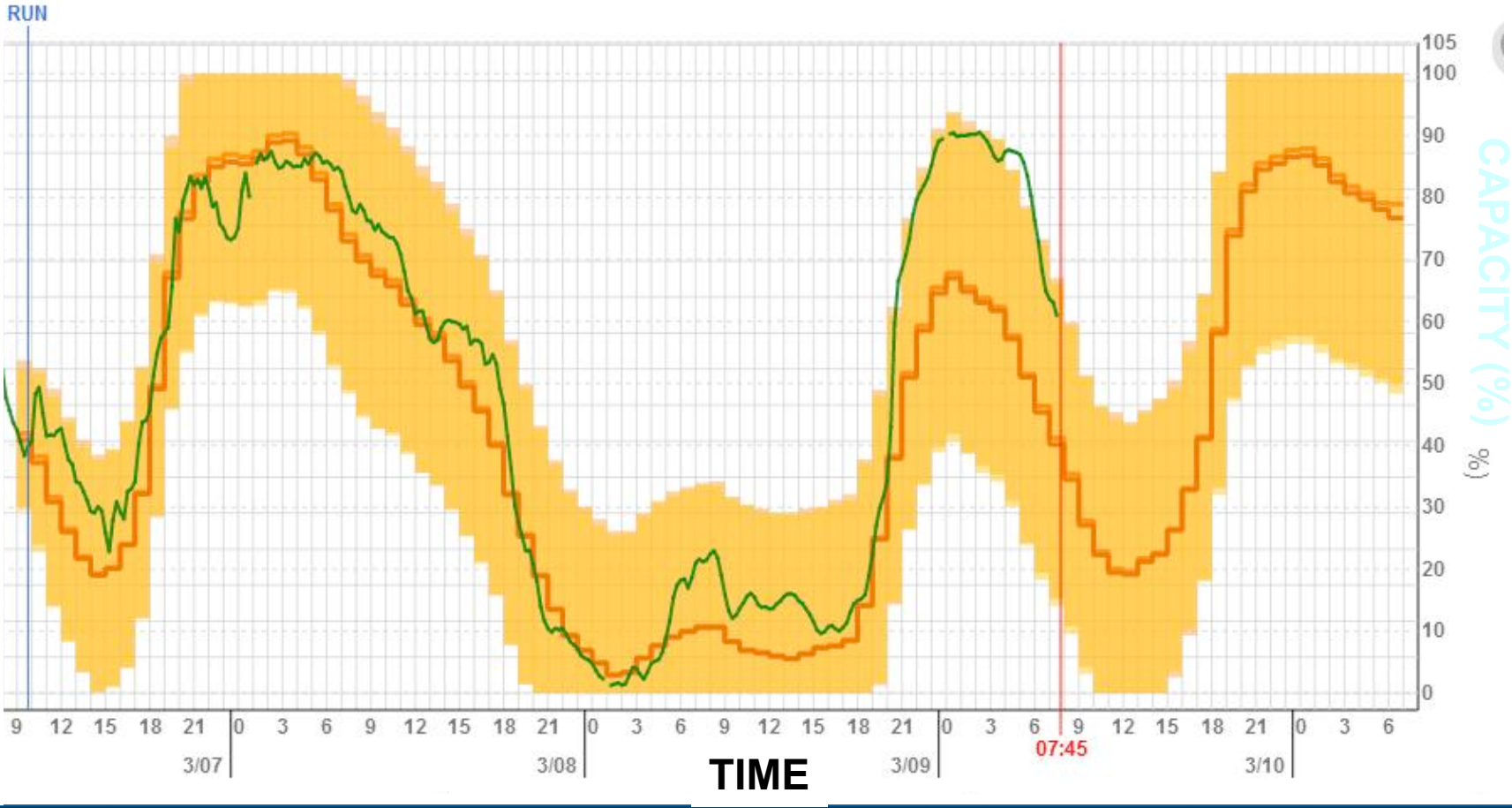


Observation-based Ramp Forecasting

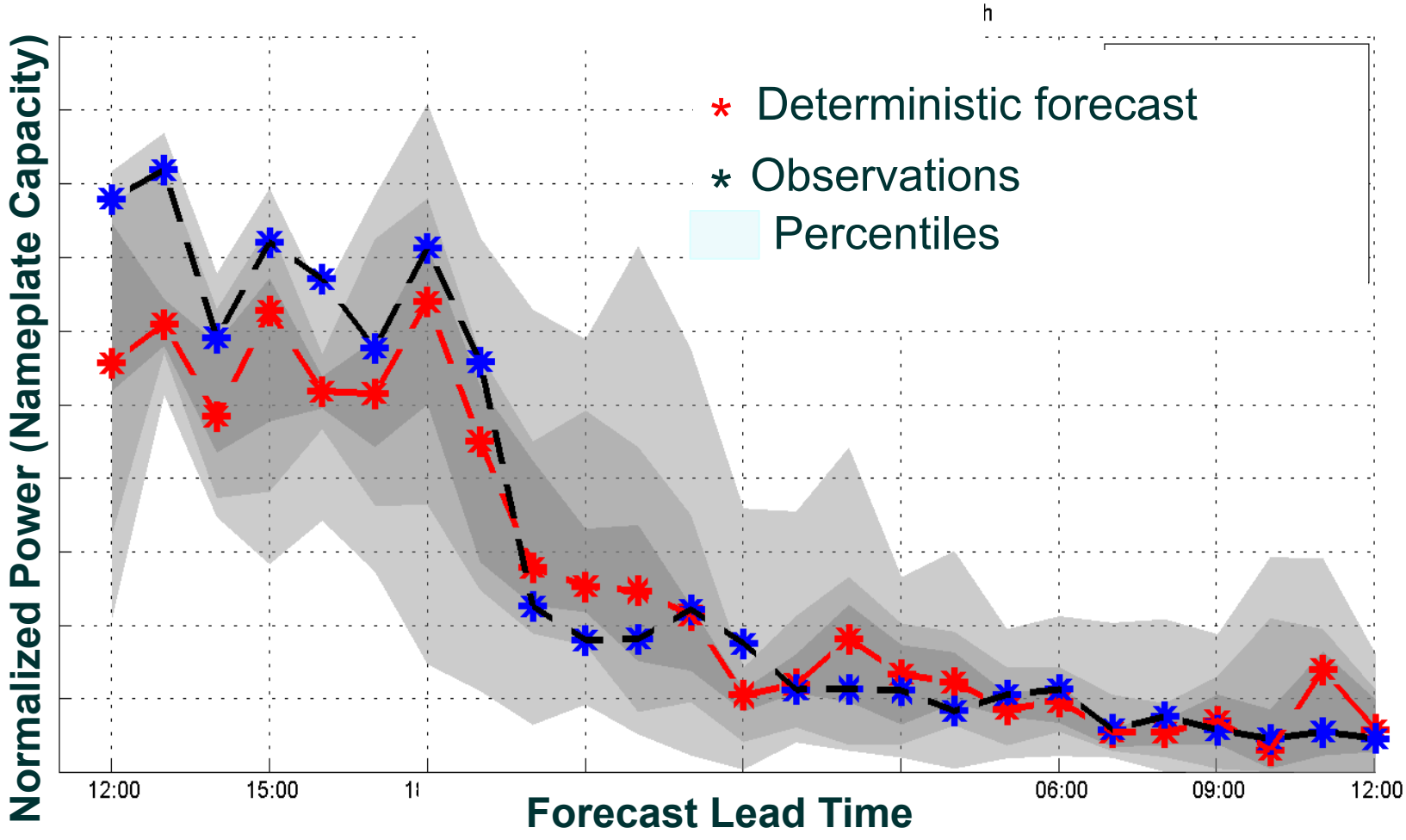


DICast System Blends Output from Several Numerical Weather Prediction Models

Public Service of Southwestern Public Service Company
Total Power, 03/08 Ramp



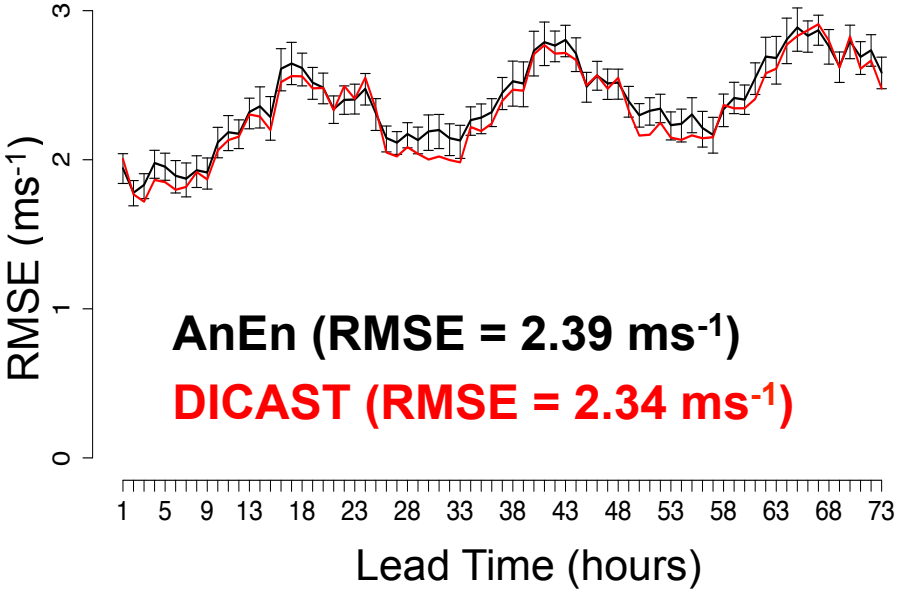
Probabilistic Power Prediction With Analog Ensemble Method



Probabilistic Forecasting Using Analog Approach Compares Well with Deterministic DICast

Training (188-223 days) | Optimization (18 days) | Test (35 days)

Test (35 days)



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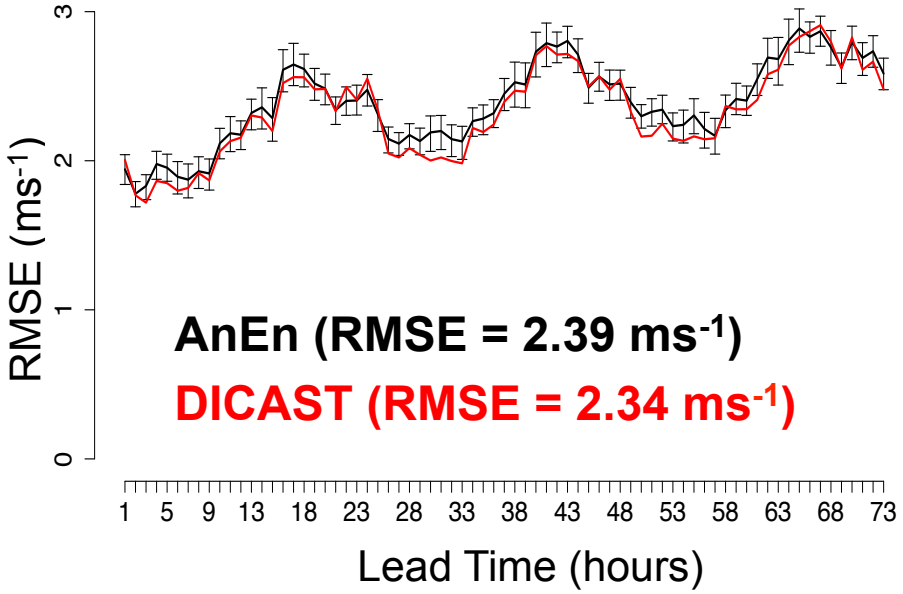
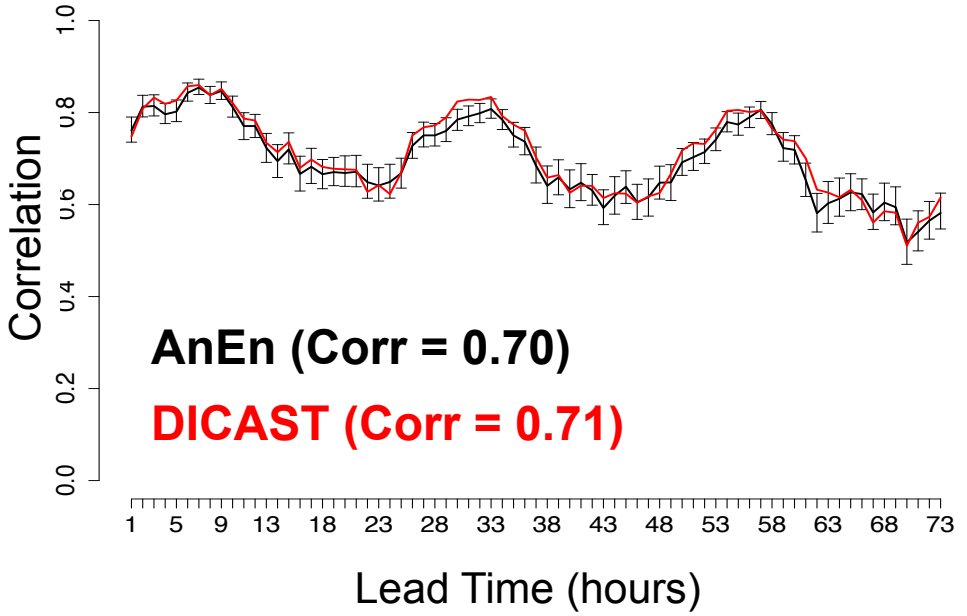


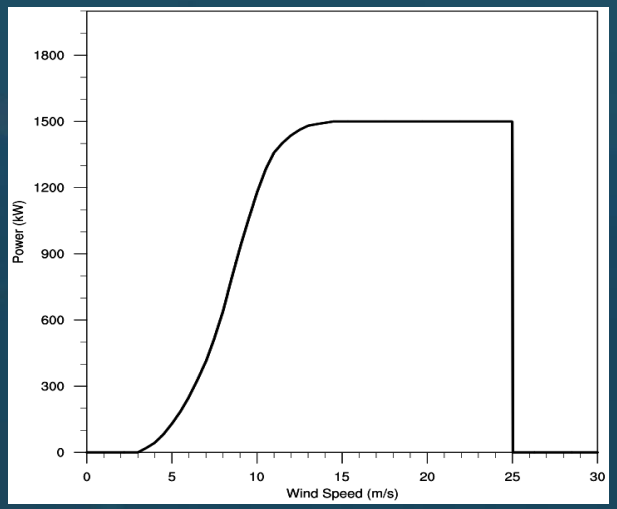


Icing Forecasting System ExWx Provides Categorical Forecast of Icing

- Predicting wind turbine icing is critical for power trading on open market and short term load balancing.
- In order to successfully develop a robust wind turbine icing forecasting system, a truth dataset must be developed.
- Limited documentation of icing events and monitoring equipment make identifying icing after the fact difficult.
- Plus, there is a “Big Data” problem.

Datasets For Icing Forecast

Power Data



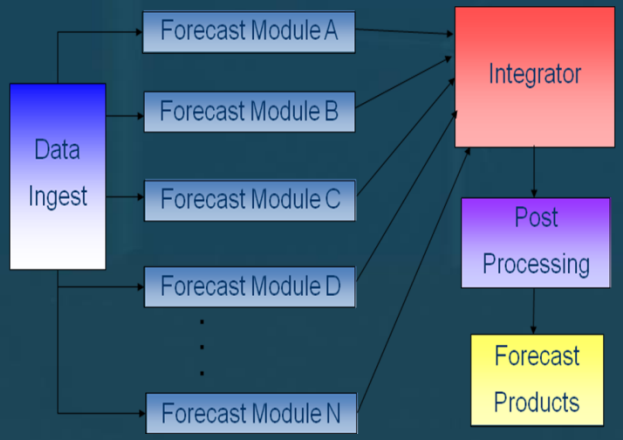
PRIMARY

Sensor Data

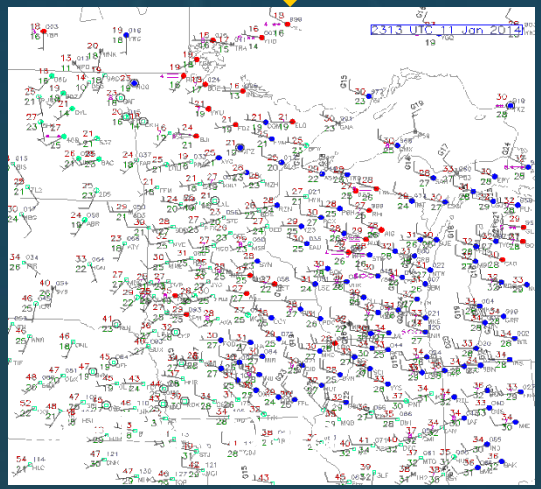
http://www.newavionics.com/Images/9734_410x359.jpg

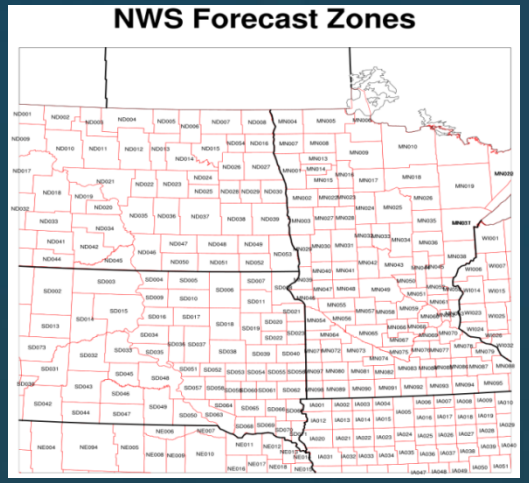
SECONDARY

DICast Data

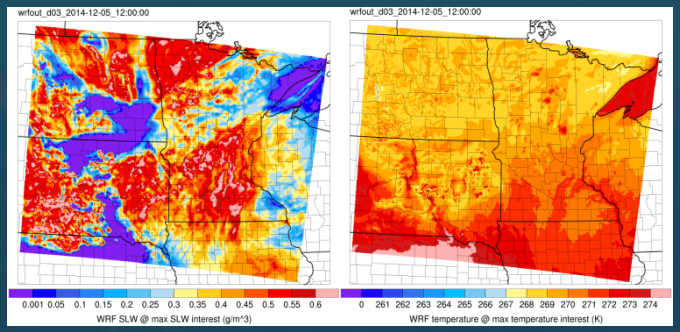


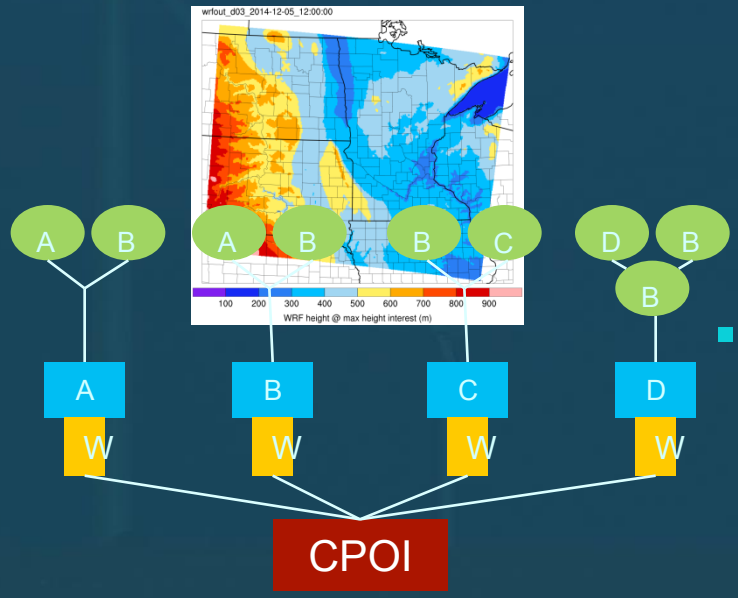
NWS Data





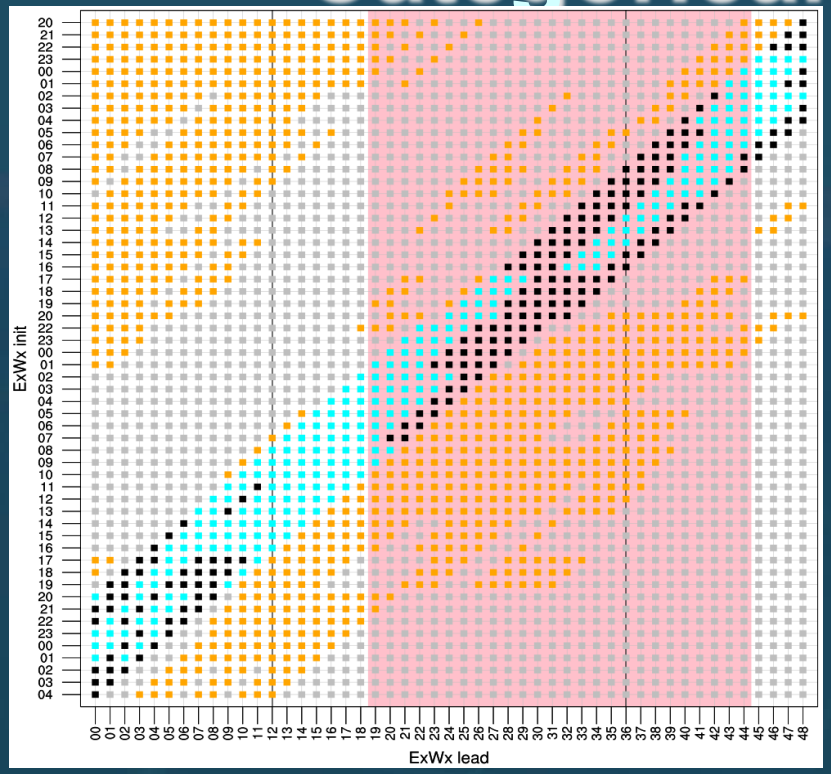
ExWx Uses WRF-RTFDDA and DICast Blended NWP Output to Compute Icing Potential





- **WRF icing potential**
  - Evaluates all WRF model levels < 1km
  - Combines model level height, model predicted supercooled liquid water, and temperature at each level using fuzzy logic maps (configurable)
  - Final potential at each WRF grid point is the maximum of the icing potential at each level < 1km
- **DICast icing potential**
  - Conditional probability of icing (CPOI) deterministic forecast from DICast
  - Combines five NWP model solutions
  - Typically one site per farm, more in some cases

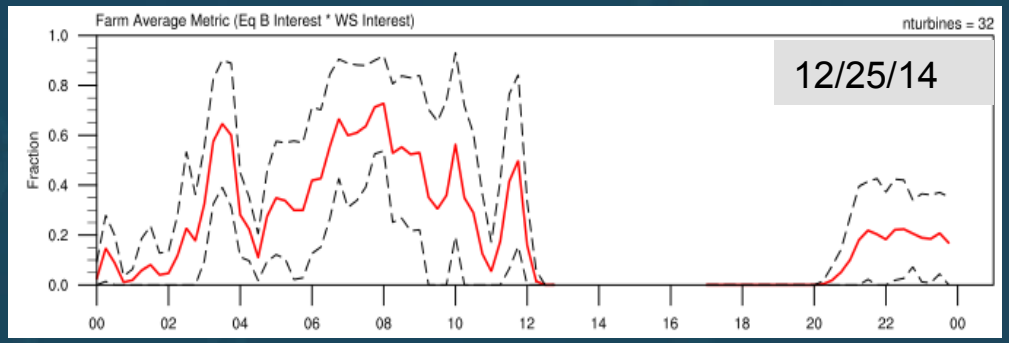
Icing Forecasting System Provides Categorical Icing Forecast

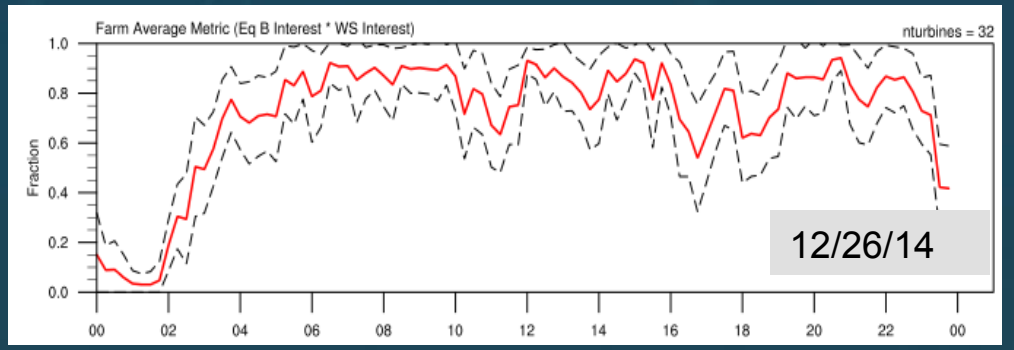


ExWx icing potential forecasts for all ExWx runs affecting the event window (8 hours centered on 00Z)

- Icing potential < 0.5 inside window
- Icing potential > 0.5 inside window
- Icing potential > 0.5 outside window
- Icing potential < 0.5 outside window

- Note no missing data-wherever DICast was missing the WRF is used exclusively (and vice-versa)
- Threshold of 0.5 is configurable based on experience of operators
- Event well forecast by ExWx!!!





Wind Power Forecasts → Savings for Ratepayers

Forecast MAE		Percentage Improvement	Savings
2009	2014*		
16.83%	10.10%	40%	$49,000,000

Also: saved > 267,343 tons CO2 (2014)

Drake Bartlett, Xcel

CO-Labs - Governor's Award 2014 for Sustainability

Summary

- NCAR's comprehensive variable power forecasting system integrates recent advances in forecasting at a range of time scales including
  - Ramp forecasts
  - Probabilistic forecasting
  - Forecasting of extreme events
- Day-ahead forecasting system provides significant savings for ratepayers.
- Effectiveness of a forecasting system for efficient integration of variable generation depends on the quality and quantity of data.
- More data (amount, frequency) is better, however,…
  First data from existing sources should be:
  - Standardized
  - Quality controlled
  - Delivered in timely manner, and
  - Archived for future use (e.g., training for machine learning algorithms).


Thank You !
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Marcia Politovich
Daniel Adrianson
Paul Prestopnik
Jenny Sun
Seth Linden
Julia Pearson
Tara Jensen
…