Communicating Uncertainty in Actionable Ways

Matt Cote
Director of Forecasting, UL Solutions
16 June 2026

Agenda

- Introduction to UL solutions
- Background info on renewable energy forecasting uncertainty
- Probability of Exceedance (POE) forecast usage example
- Using individual ensemble member forecasts
- High speed cutout event example
- Turbine icing event example
- Final Comments

Intro to renewable energy forecasting services at UL Solutions

1 UL Solutions specializes in providing renewable energy forecasts to **independent system operators (ISOs), utilities** and **balancing authorities** in the Americas.

2 Over **25 years** of experience in wind and solar forecasting

3 Services include deterministic, probabilistic and extreme event forecasts with automated direct data exchanges and hosted visualization software.

4 Provider of renewable energy forecasting services for more than **3,300** centralized wind and solar facilities, and nearly **600,000** individual rooftop photovoltaic (PV) installations

5 Delivering forecasts for over **+220 GW** of centralized and distributed wind and solar generation capacity around the world

6 Provider of data simulation services to help grid operators plan for future renewable generation scenarios

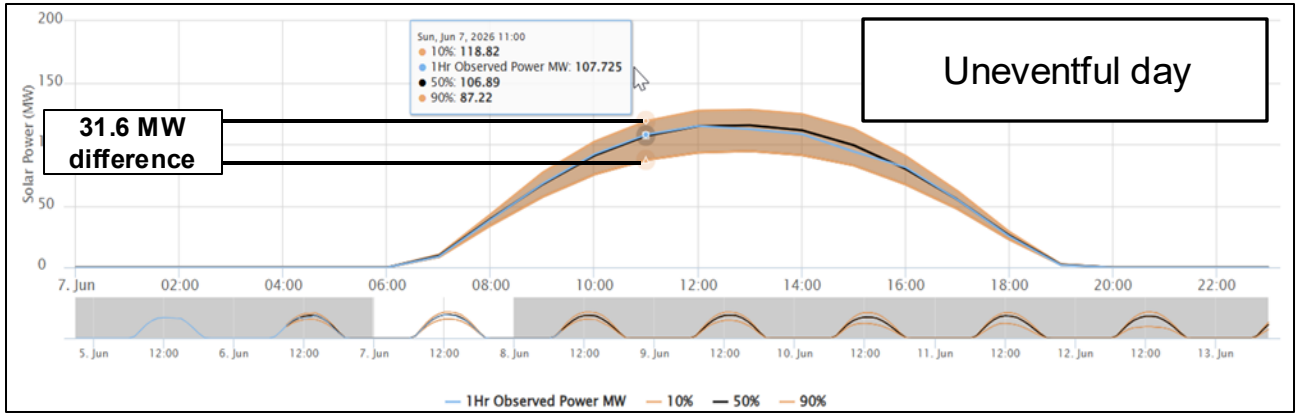
For more information: https://www.UL.com/software/renewable-energy-forecasting-energy-integration

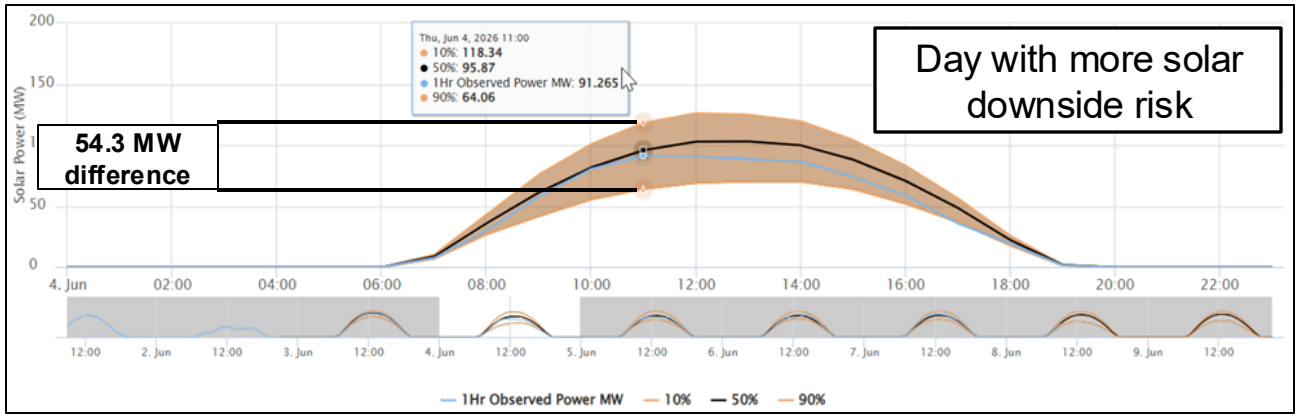
Methods of presenting renewable forecast uncertainty

- **Considering *only* weather forecast uncertainty (e.g., wind, cloud cover, etc.)**
  - Probability of exceedance (POE) forecasts – single, pair, or many
  - Scenario-based / ensemble member forecasts
- **Also considering discrete events or hazards specific to renewables (ramps, cutouts, ice/snow buildup, avian curtailments, wind stow, wildfire smoke, etc.)**
  - Include some/all in POE or ensemble member forecasts (**Important:** Do you know if your POE forecast includes some/all of these impacts?)
  - Probability of event onset
  - Probability of reduced generation due to the triggering event
  - Magnitude / timing ranges of impacts
  - Alerts identifying the risks and essential parameters of the risks
- **Before event** – forecast should predict possible onset of event, evolution of the event, *and* its possible end (if in the forecast range)
- **During event (esp. for icing and snow events)** – forecast should identify that an event is *in progress*, as well as its magnitude of impact, its evolution through the remainder of the event, *and* its possible end (if in forecast range)

Solar POE forecast on two types of days

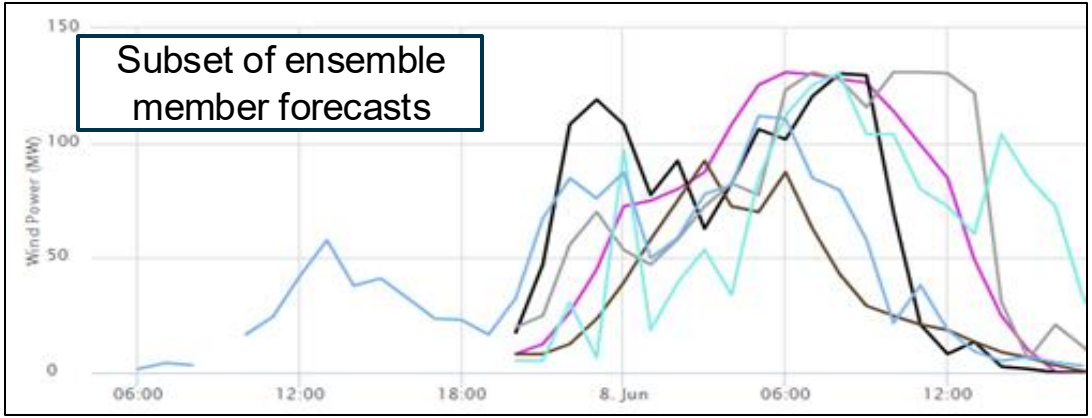
- Common application: Feed confidence band width into downstream algorithms to help quantify uncertainty/risk for the day
- On their own, POE forecasts provide no context for the sources of potential uncertainty (e.g., weather model discrepancies, ramp possibilities, high variability)
- Actuals are *expected* to sometimes fall outside of POE bounds, with frequency depending on the POE levels chosen

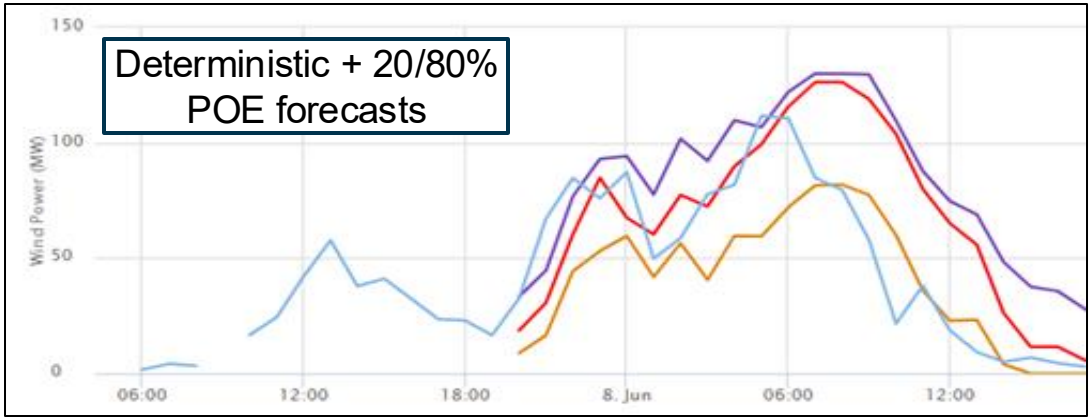




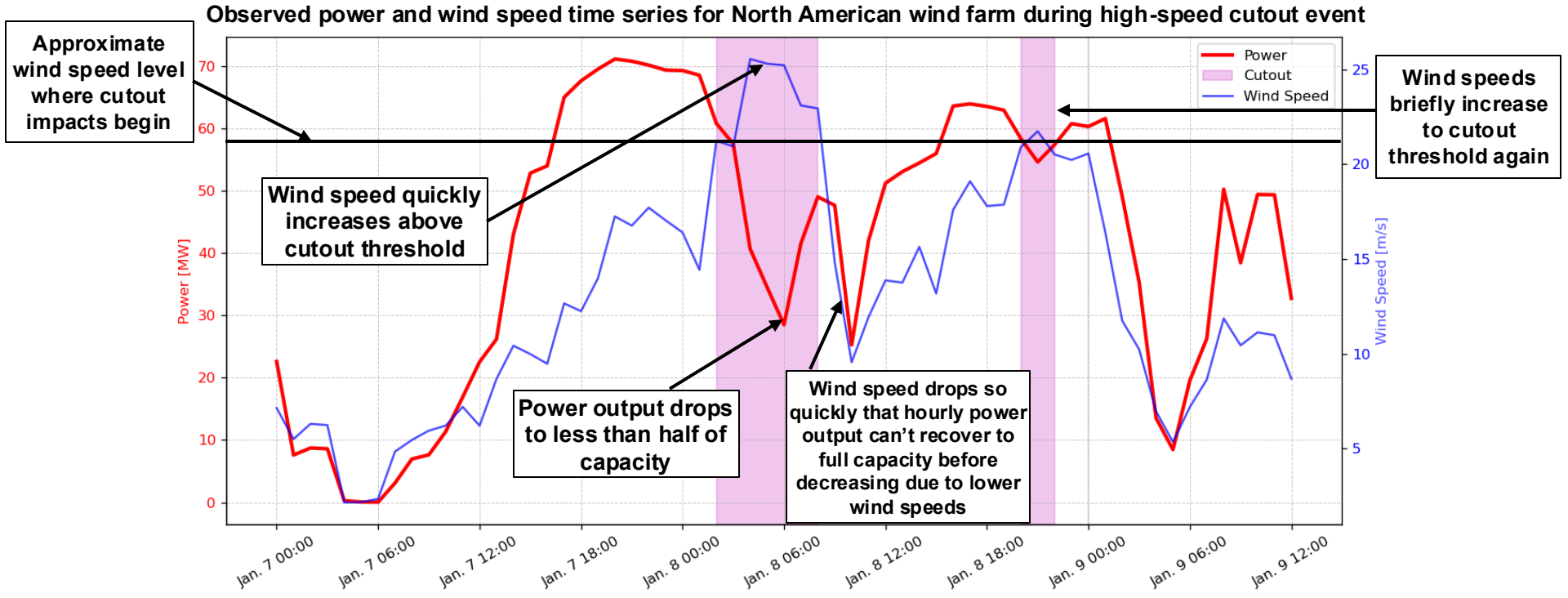
Ensemble member / scenario forecasts vs. POE forecasts for wind ramp events

- Individual model forecasts can depict scenarios of how an event may unfold, but gives no indication to the likelihood of any particular scenario
- Can indicate edge case risk not captured by POE bands
- Can be fed into downstream algorithms just like POEs to assess uncertainty and risk
- Tend to be useful for meteorologists and energy traders who are able to effectively interpret and apply the information, but the displays can get overwhelming quickly when too many lines are plotted

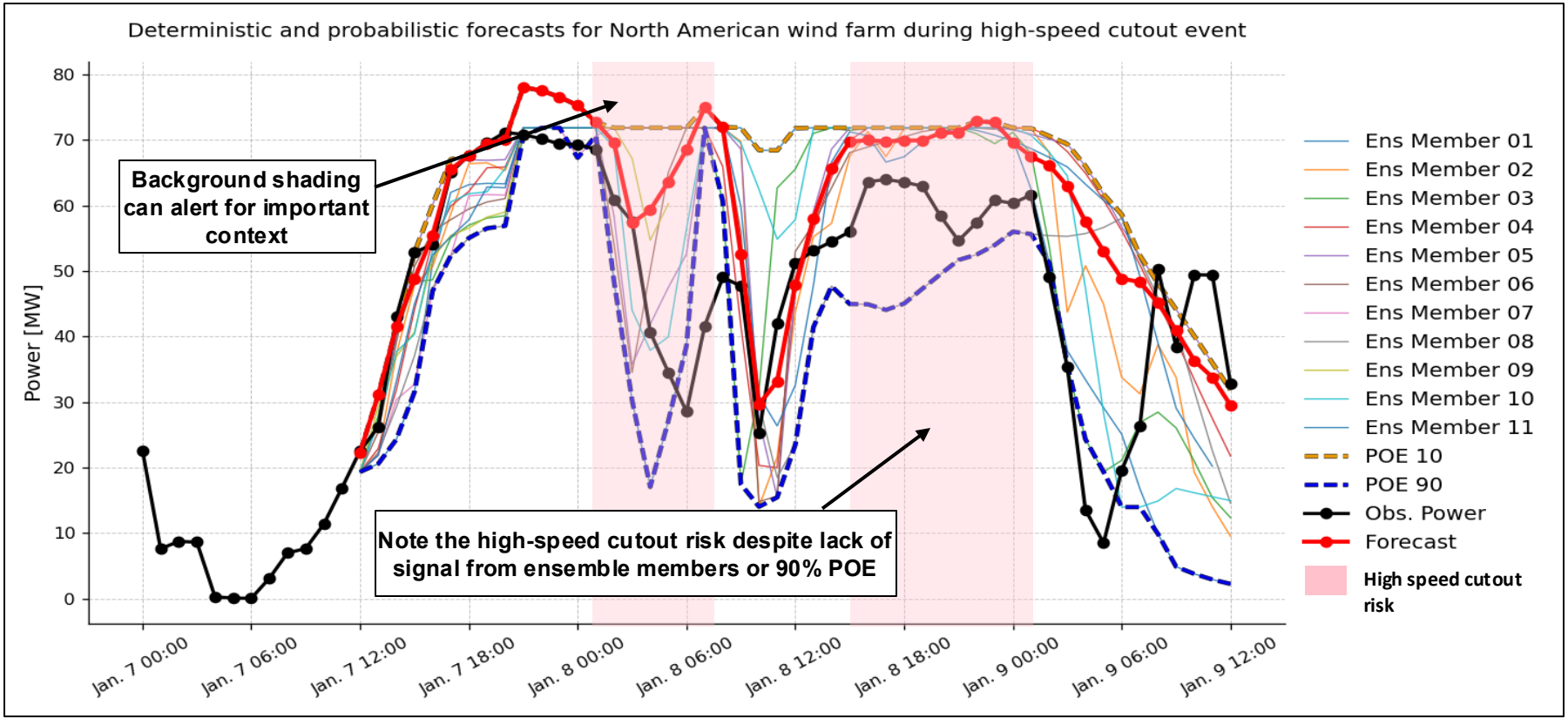




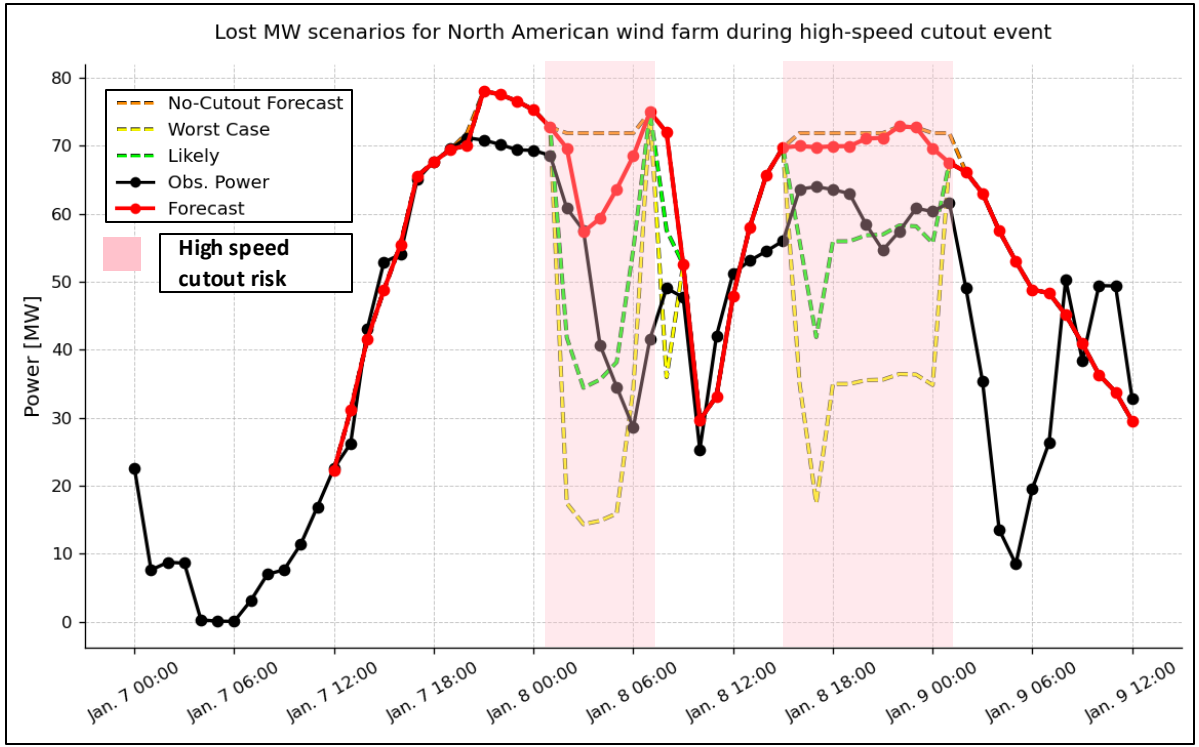
High-speed cutout event



High-speed cutout event



High-speed cutout event

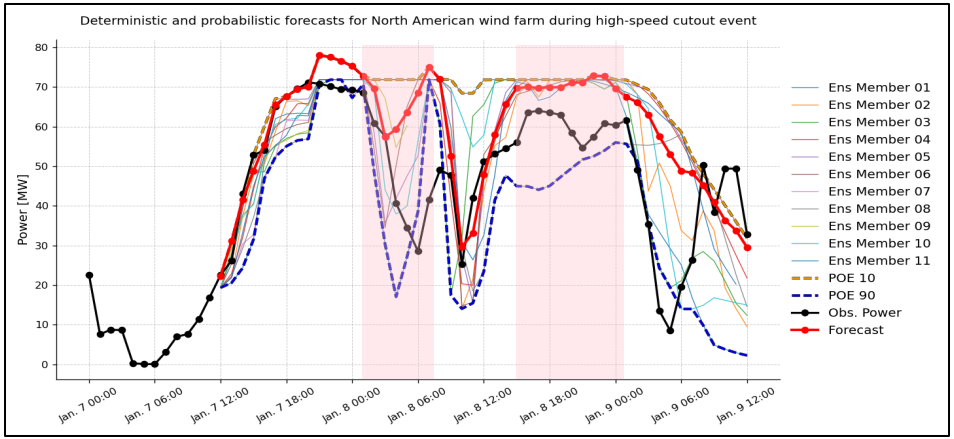


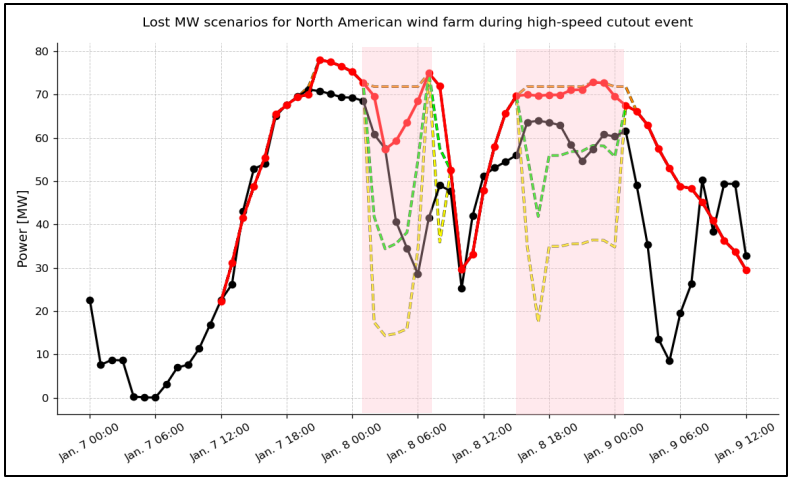
- Additional concept: Scenarios depicting risk of MW losses
  - "No cutout" scenario
  - "Likely" scenario
  - "Worst case" scenario
- Signal for risk of lost MW due to cutout does appear for the 2nd event, contrary to the POE and ensemble member forecasts
- Important to pair with a "non-event" scenario, so users now what to expect if the event does not occur

High-speed cutout event

- Additional concept: Variability index
- POEs don't inherently communicate variability, just uncertainty
- Goal with variability index is to concisely indicate to users how variable the renewable generation is expected to be on a particular day relative to historical norms
- Indices based on historical norms can also be used for uncertainty (e.g., confidence band width)

Variability Index





High-speed cutout event

Putting it all together

POE forecasts (inclusive of event-driven MW losses)

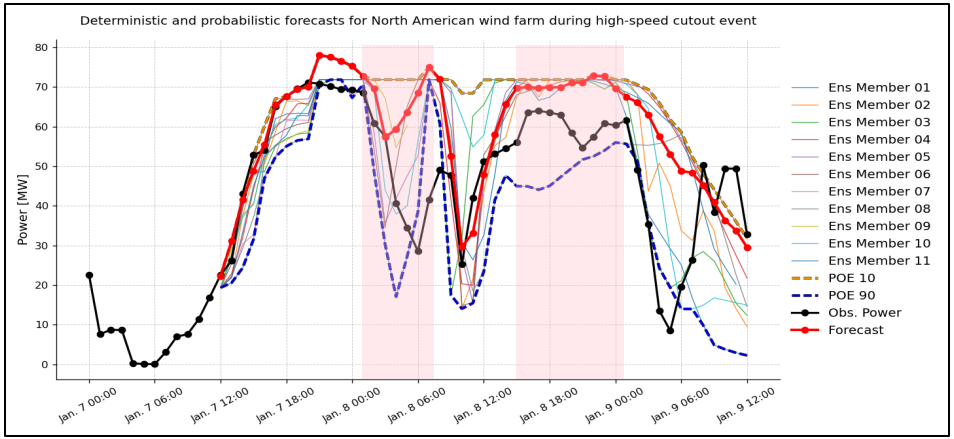
Event-based scenario forecasts

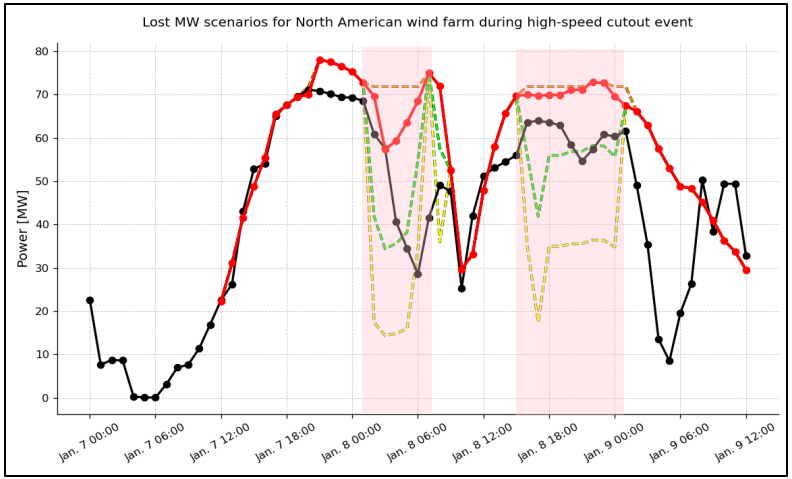
Event-based probabilistic shading/alerts

Individual ensemble member forecasts (as an on/off toggle or separate chart for certain users)

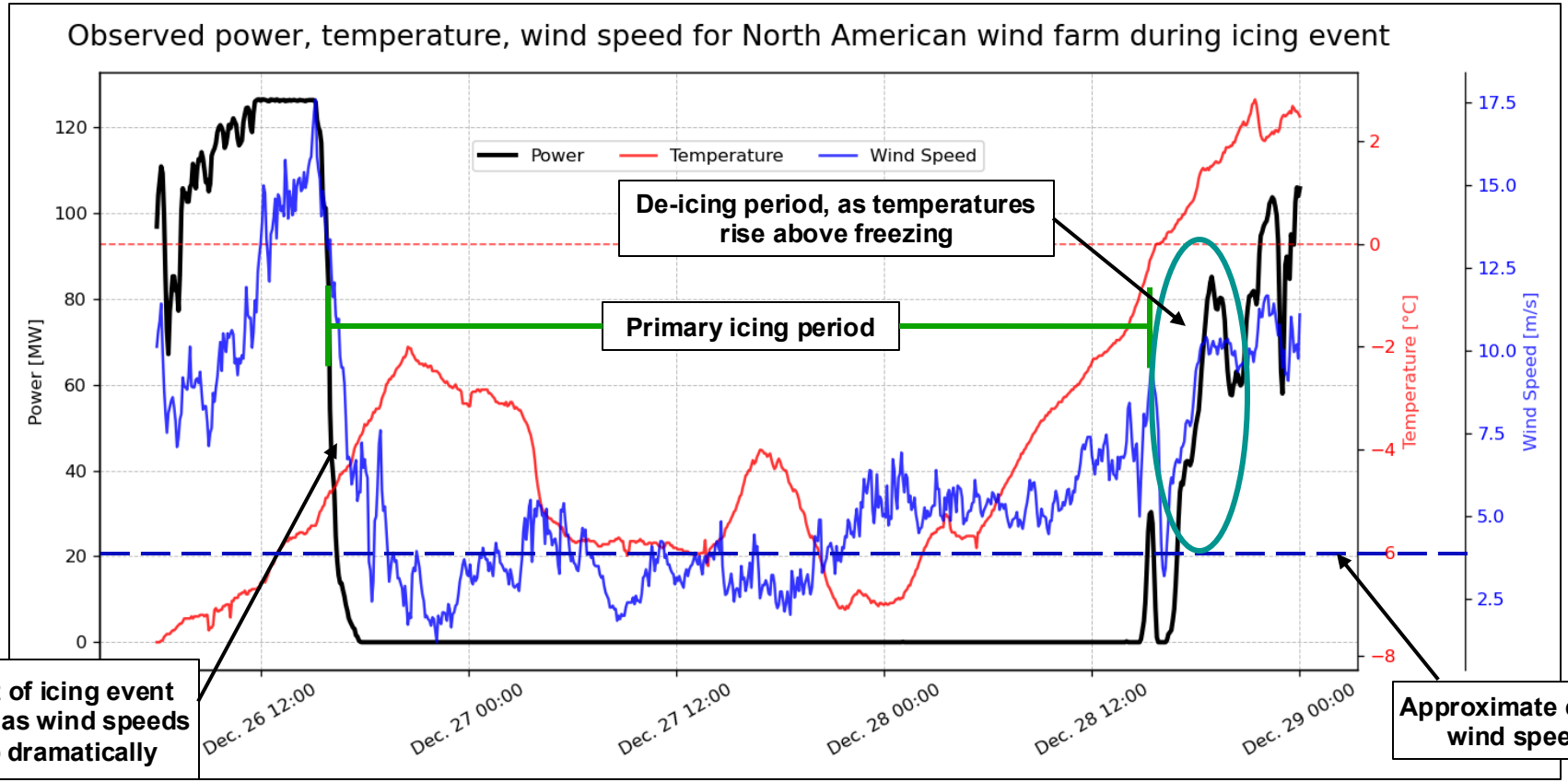
- ✓ Valuable forecast context
- ✓ Historical perspective
- ✓ Explainable risk assessment
- ✓ Actionable insights

Variability Index

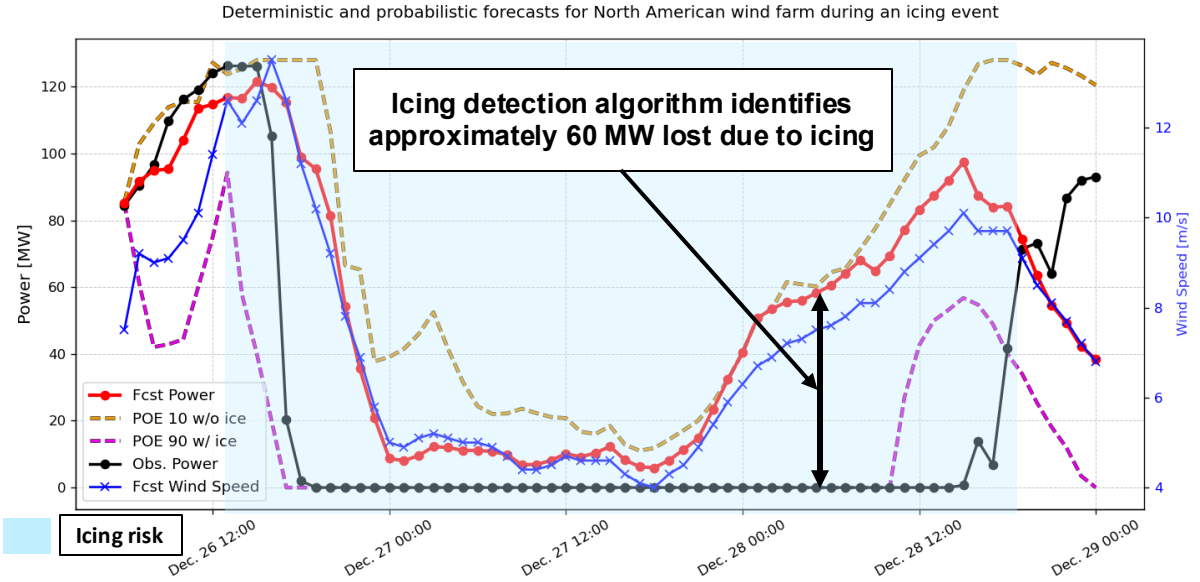




Turbine icing event



Turbine icing event



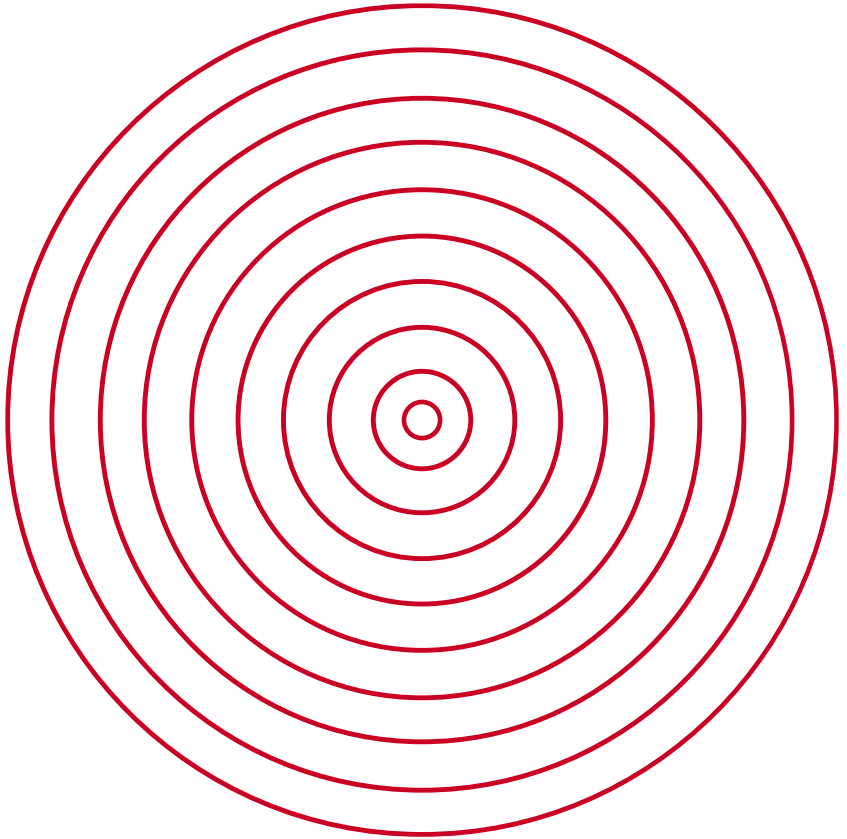
- During a turbine icing event, it's important to recognize *that* icing is reducing generation, by approximately how much, and *communicating that fact to the users*
- Key problem becomes predicting the evolution of wind generation due to **de-icing**, in addition to normal wind forecast uncertainty

- Ensemble member forecasts primarily using wind speed are not particularly helpful, since wind power output may not be well correlated with wind speed during the event
- Ensemble member forecasts predicting important de-icing factors (temperature, irradiance, wind speed, precipitation, etc.) are *more* important during these periods
- Effective forecast representation composed of POE forecasts (inclusive of turbine icing impacts), event-based scenario (e.g., "no ice") forecasts, and background alert shading to highlight the likely period of reduced generation

Final Comments

- There are a lot of input data sources used in renewable energy forecasting that can be consolidated and presented in different ways to capture uncertainty, variability, and risk due to high impact events
  - Exact forecast products and displays for each application should be determined through consultation with your forecasting providers
- Equally important with receiving the uncertainty information associated with high impact events is how best to use that information. Details in this area are best left for a separate talk, but some possibilities include:
  - Entering outages/de-rates that can be automatically applied to forecast data
  - Subscribing to a forecast override service that allows users to change the incoming forecast data on-demand due to rapidly changing conditions in real time
  - Developing user playbooks and providing training
  - Developing and applying automated algorithms that ingest and use data on the type(s) of expected high-impact events and the forecast uncertainty data associated with them

Questions?



Matt Cote
Director of Forecasting
Matthew.Cote@UL.com

UL.com/Solutions