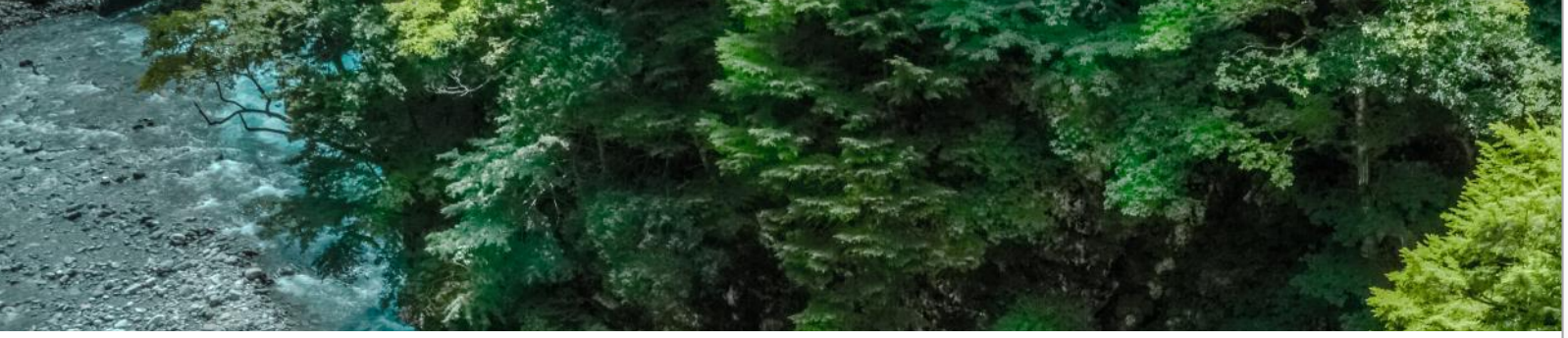
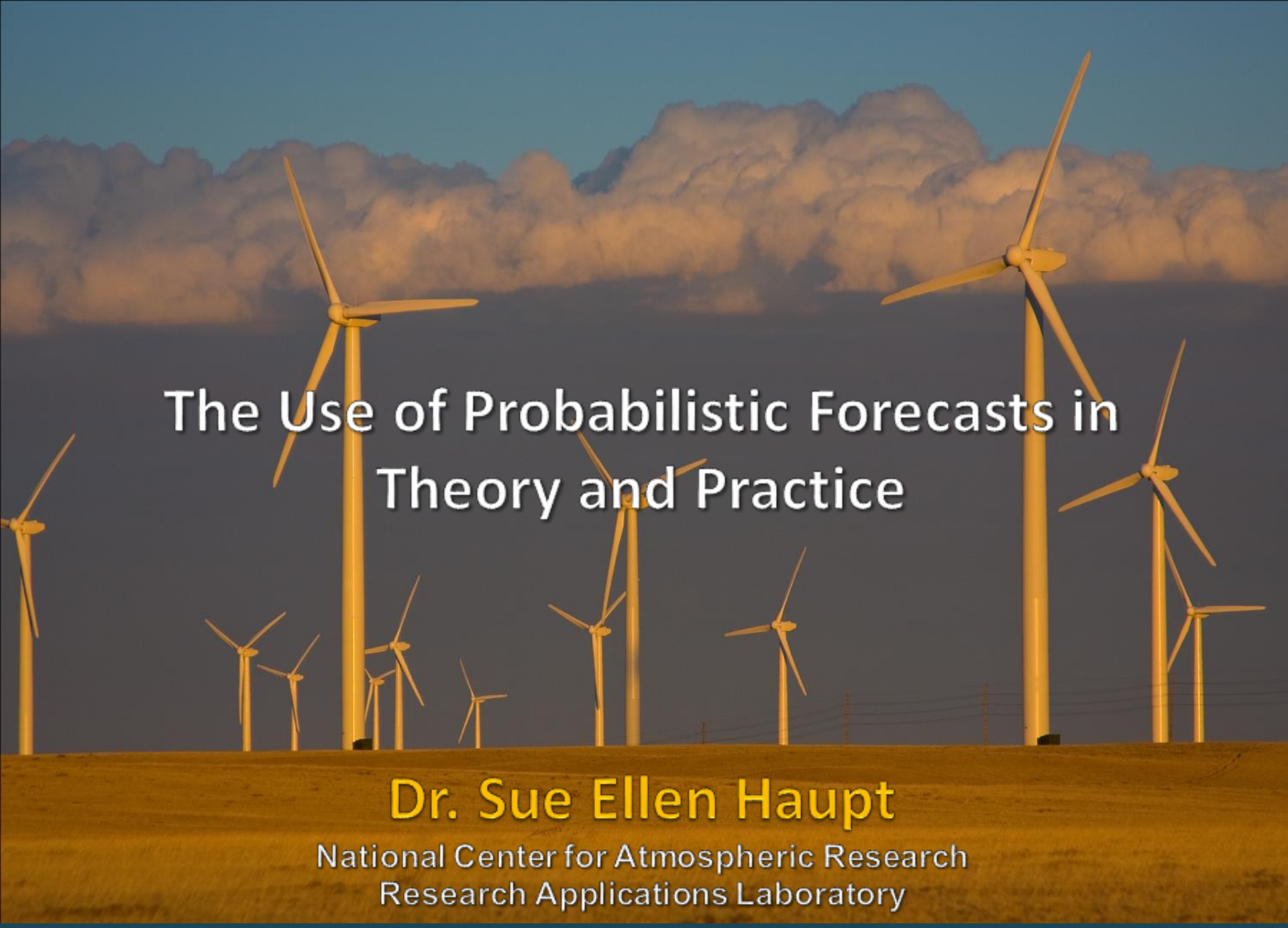


# The Use of Probabilistic Forecasts in Theory and Practice

**Dr. Sue Ellen Haupt**, National Center for Atmospheric Research
**Timothy Miller**, Southwest Power Pool
**Dr. Pengwei Du**, ERCOT

October 22, 2019

ESIG
ENERGY SYSTEMS INTEGRATION GROUP



# The Use of Probabilistic Forecasts in Theory and Practice


Dr. Sue Ellen Haupt

National Center for Atmospheric Research
Research Applications Laboratory

# A Team Effort

## The Use of Probabilistic Forecasts

### Applying Them in Theory and Practice

By Sue Ellen Haupt, Mayte Garcia Casado, Michael Davidson, Jan Dobschinski, Pengwei Du, Matthias Lange, Timothy Miller, Corinna Möhrlen, Amber Motley, Rui Pestana, and John Zack

By Sue Ellen Haupt, Mayte Garcia Casado, Michael Davidson, Jan Dobschinski, Pengwei Du, Matthias Lange, Timothy Miller, Corinna Möhrlen, Amber Motley, Rui Pestana, and John Zack

MUCH OF THE ELECTRIC SYSTEM IS WEATHER dependent; thus, our ability to forecast the weather contributes to its efficient and economical operation. Climatological forecasts of meteorological variables are used for long-term planning, capturing changing frequencies of extreme events, such as cold and hot periods, and identifying suitable locations for deploying new resources. Planning for fuel delivery and maintenance relies on subseasonal to seasonal forecasts. On shorter timescales of days, the weather affects both energy demand and supply. Electrical load depends critically on weather because so much electricity is used for heating and cooling. As more renewable energy is deployed, it becomes increasingly important to understand how these energy sources vary with atmospheric conditions; thus, predictions are necessary for planning unit commitments. On the scales of minutes to hours, short-term nowcasts aid in the real-time grid integration of these variable energy resources (VERs).

Meteorologists use the dynamical equations of fluid motion to forecast the weather by numerically integrating those equations forward in time in numerical weather prediction (NWP) models. The weather is both variable and

Digital Object Identifier 10.1109/MPE.2019.2932639
Date of publication: xxxxxx



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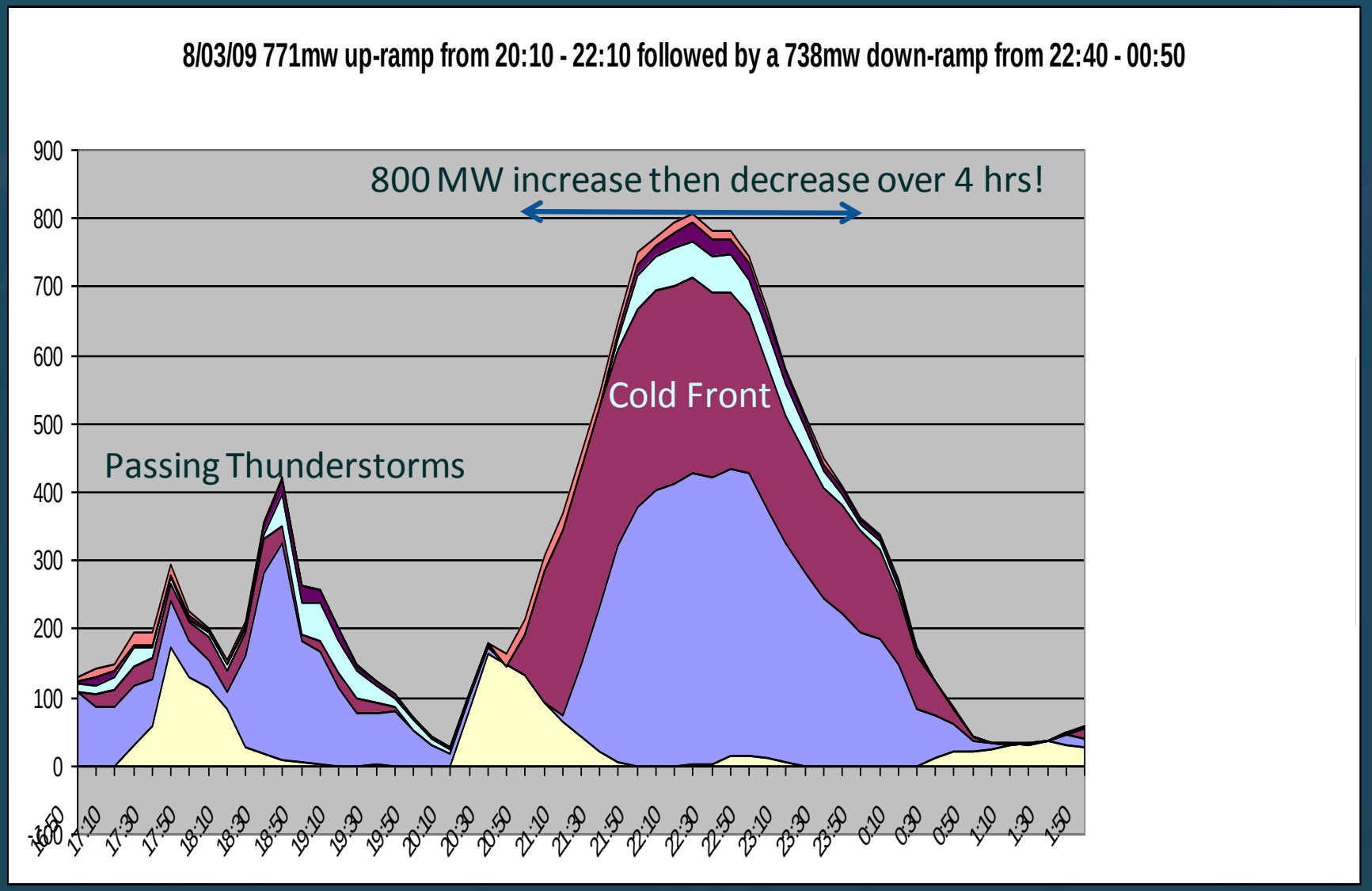
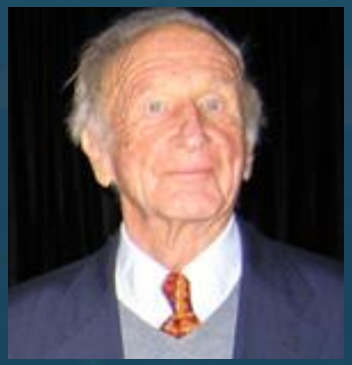
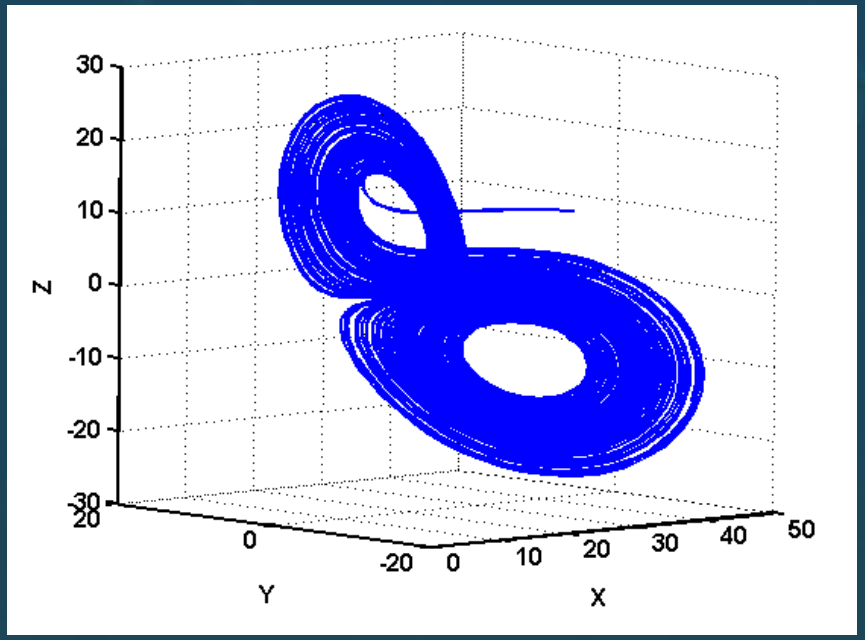
# We wish to predict specific events



# Why is Atmospheric Flow Subject to Uncertainy?



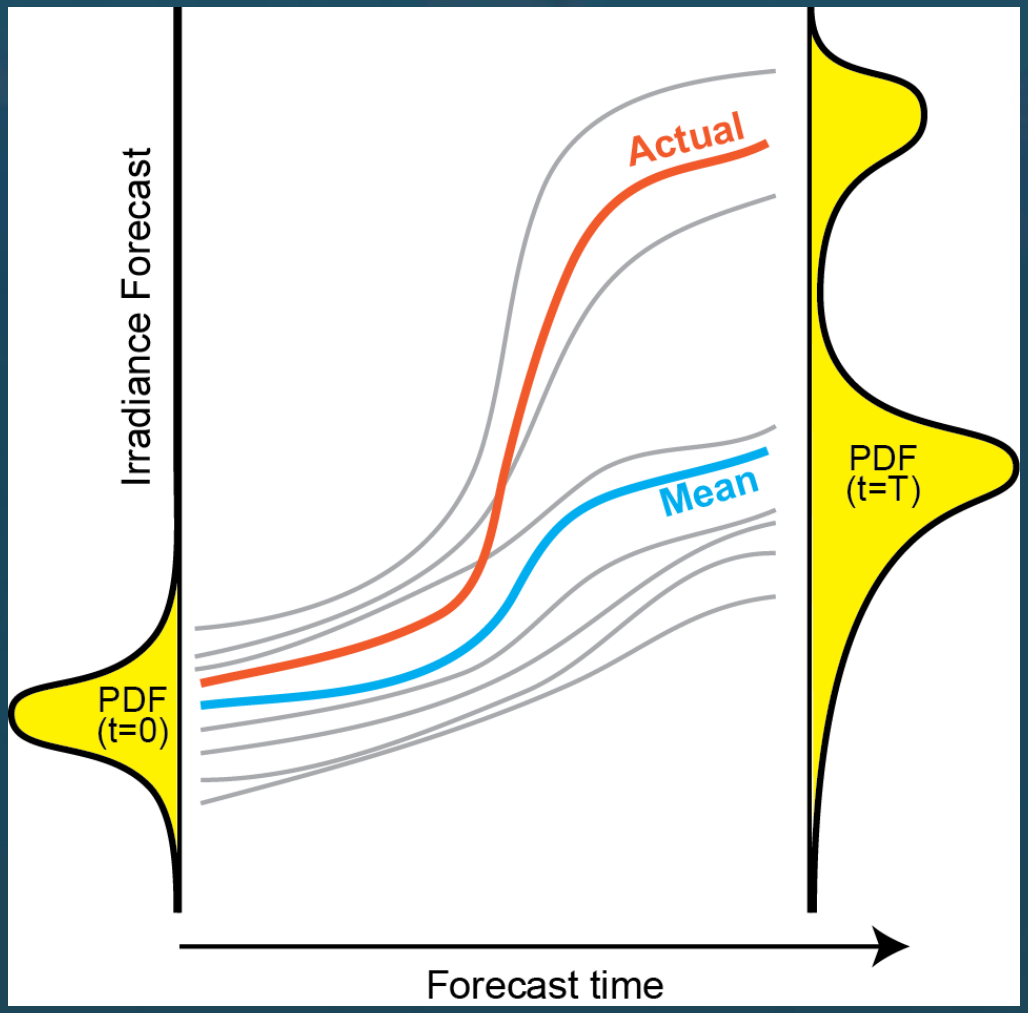
Ed Lorenz



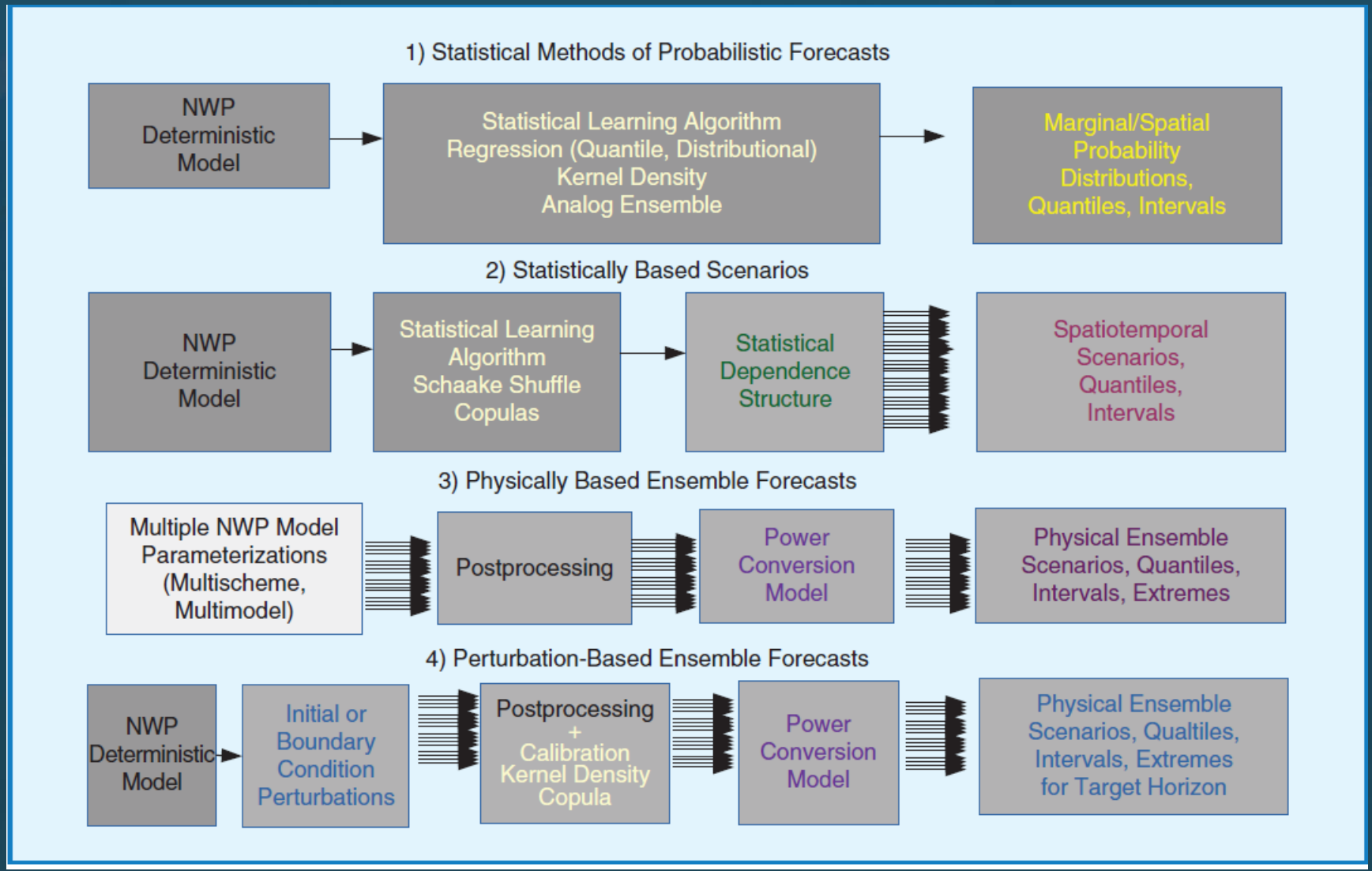

- Nonlinearity
- Sensitivity to initial conditions
- Chaos ⇒ There are limits to predictability
- Think in terms of attractors & manifolds
- Requires probabilistic forecasts

# Ensembles & Uncertainty Quantification

- Account for uncertainties due to imperfect initial conditions and model formulation
- Produce more accurate predictions than any single model realization
- Provide flow-dependent uncertainty estimates



# Different Methods of Making Probabilistic Forecasts



# Ensemble vs. Statististic (one case)

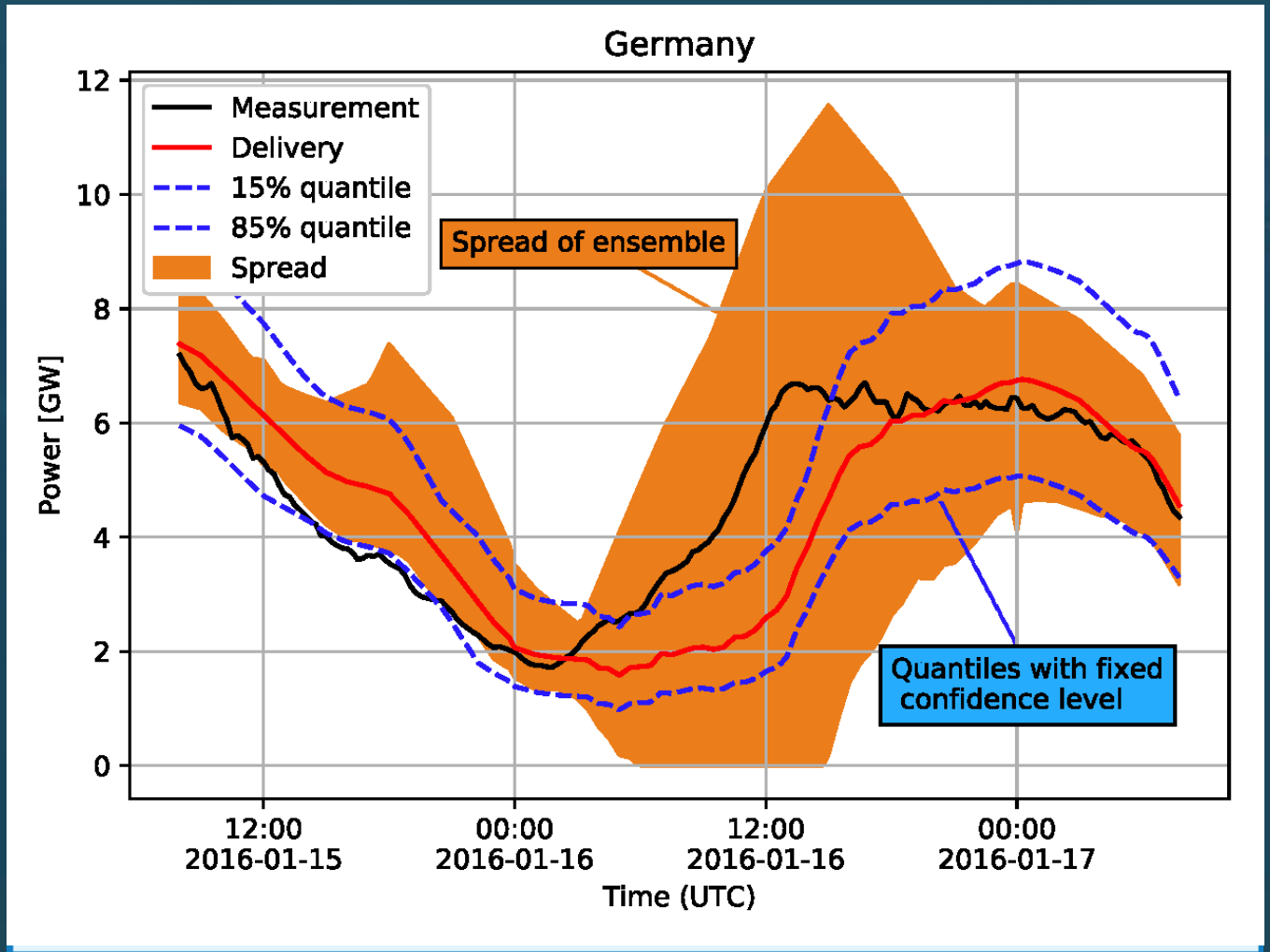


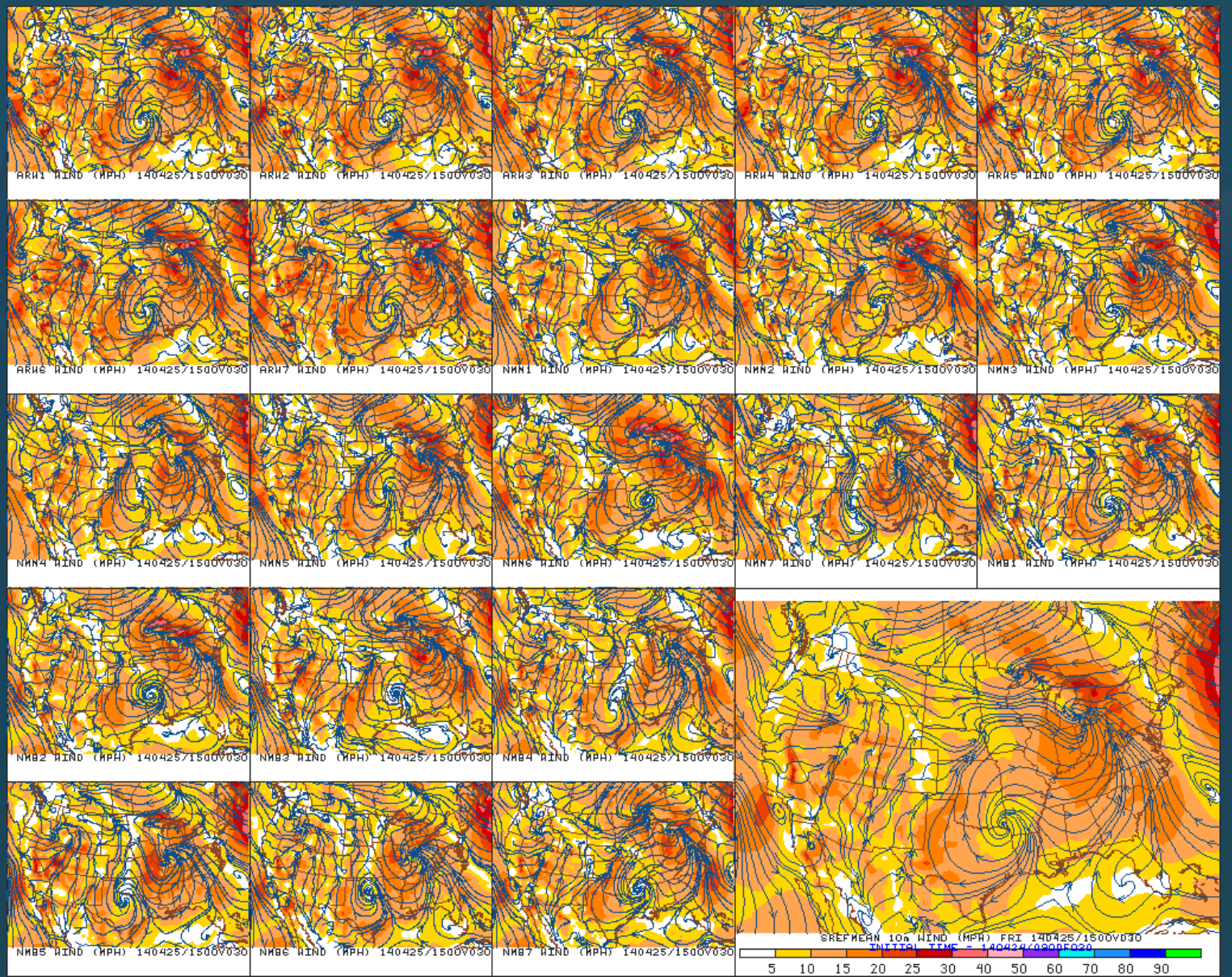

**figure 2.** A comparison of uncertainty information between a statistical approach based on a single NWP (blue dashed lines) and spread (deviation) of multiple NWP forecasts (orange shading). (Source: Energy & meteo systems.)

# Short Range Ensemble Forecast System

## 30 hr forecast

10 m Wind

500 mb Height



# How do we determine a Good Match?

- Since probabilistic, need to evaluate based on large number of forecasts

## The Brier Score

- Mean square error of a probability forecast

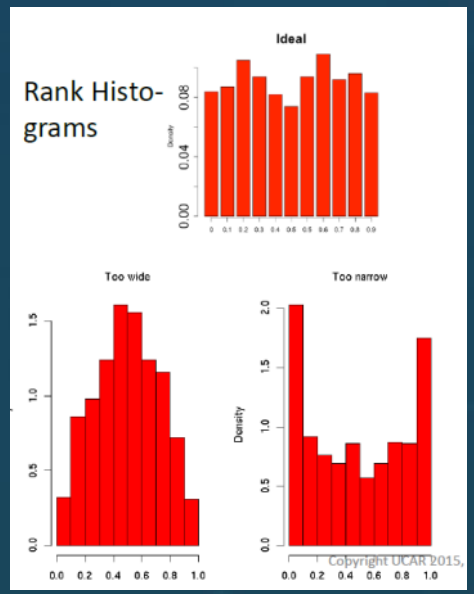
$$BS = \frac{1}{n}\sum_{i=1}^{n}(f_i - x_i)^2$$

where $n$ is the number of forecasts

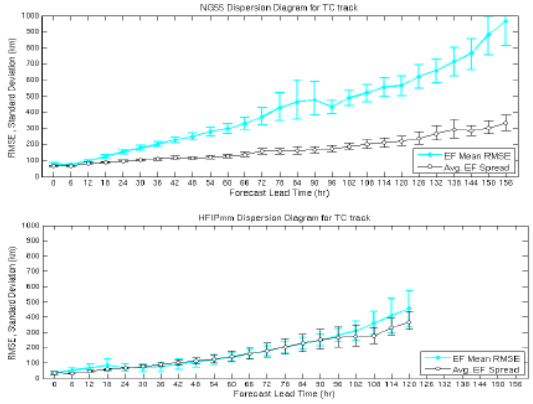
$f_i$ is the forecast prob on occasion $i$

$x_i$ is the observation (0 or 1) on occasion $i$

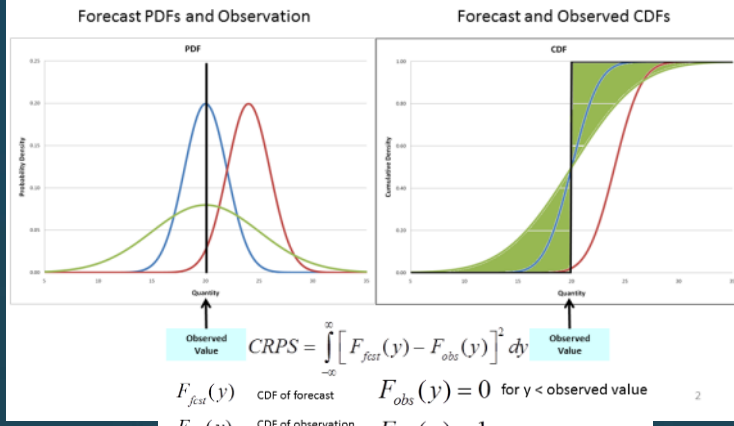
- Weights larger errors more than smaller ones


## Spread-skill




## Continuous Ranked Probability Score

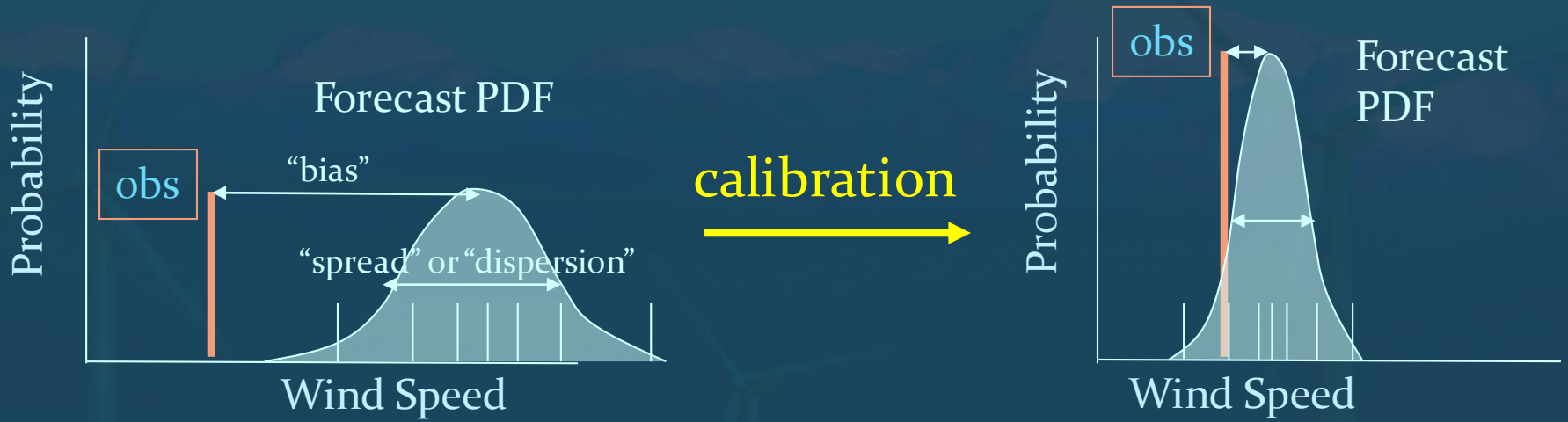



$$BS = \frac{1}{n}\sum_{i=1}^{I} N_i(f_i - \bar{x}_i)^2 - \frac{1}{n}\sum_{i=1}^{I} N_i(\bar{x}_i - \bar{x})^2 + \bar{x}(1-\bar{x})$$

Reliability — Resolution — Uncertainty

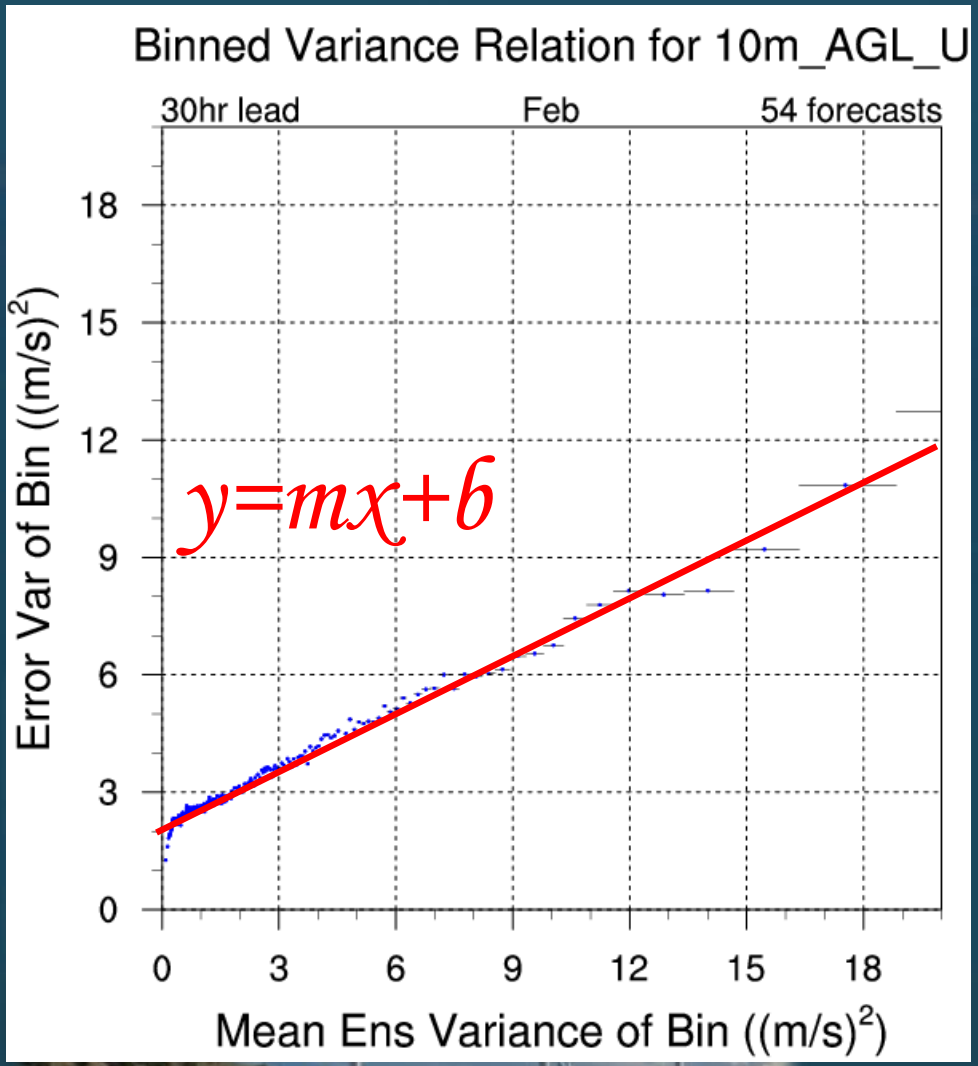
Frequency matches actual — Distinguish different events — Variability of Observations

# How do we improve the Match?




- Centered (the right answer)
- Sharp (narrow range)
- Reliable (quantile predicted matches quantile observed averaged over time)

# Example Calibration




Linear Variance Calibration

Kolczynski et al. (2009, MWR)).

## Example Calibration Techniques

- Linear Variance Calibration
- Ensemble Kalman Filter
- Quantile Regression
- Bayesian Model Averaging
- Kernal Density Methods
- Analogue Method
- Many others, including logistic regression, nonhomogeneous Gaussian regression, EMOS, ….

# Using Probabilistic Forecasts

## Topics in Paper

- Used as Input for Grid Security Calculations (German TSOs)
- Used to Fine-Tune Unit Commitment (SPP) – Tim Miller
- Capturing Extreme Conditions (ERCOT) – Pengwei Du
- Forecasting for Extreme Events, such as High-speed Shutdown Risk (Ireland)
- TSO Use (Red Electrica – Spain)

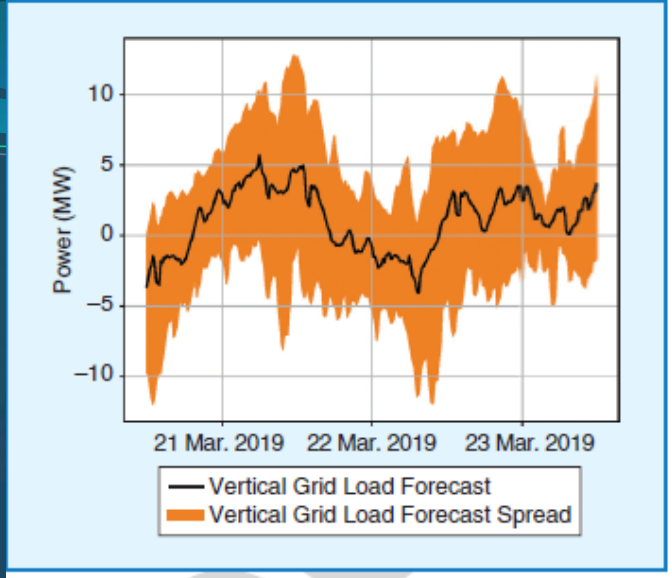



**figure 3.** A forecast of vertical grid load (solid black line) for one substation between TSO and DSO grids with upper and lower bands indicating uncertainty. Negative values refer to transport to the lower-voltage grid; positive values represent transport to the higher-voltage grid. *<AU: Please*

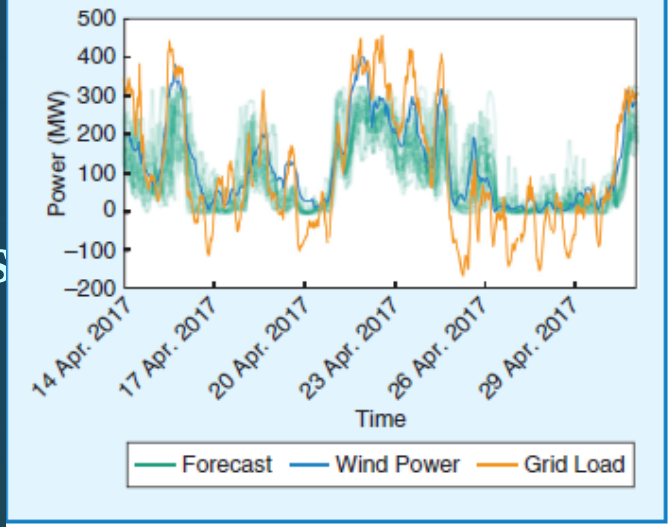
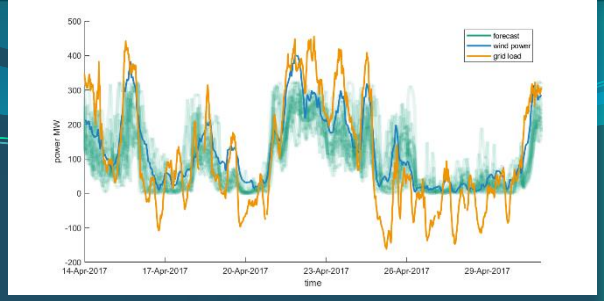



**figure 4.** An example of a load flow measurement at a transformer between extra-high and high voltage levels. The blue and green curves show, respectively, deterministic and scenario-based forecasts of the wind-power share at this transformer.

# Summary




- The atmosphere is inherently Chaotic
- Ensemble prediction embraces and quantifies the uncertainty, producing
  - Better mean forecasts
  - Estimates of uncertainty
- The ensemble should be calibrated
- Research is showing
  - Better ways of creating ensembles
  - Better ways of blending ensemble information via postprocessing
- Such probabilistic forecasts can enhance decision-making

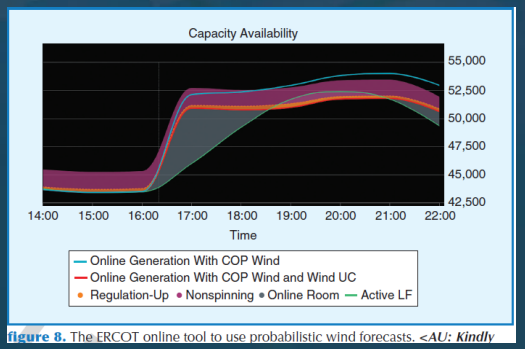



**figure 8.** The ERCOT online tool to use probabilistic wind forecasts. *<AU: Kindly*

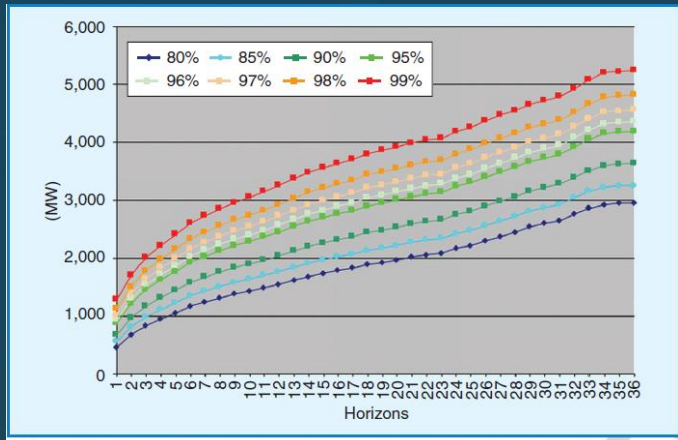



**figure 12.** A graph from the REE system of probabilistic reserves at different time horizons and different confidence intervals. *<AU: Please note that the raw image file*

SPP Southwest Power Pool

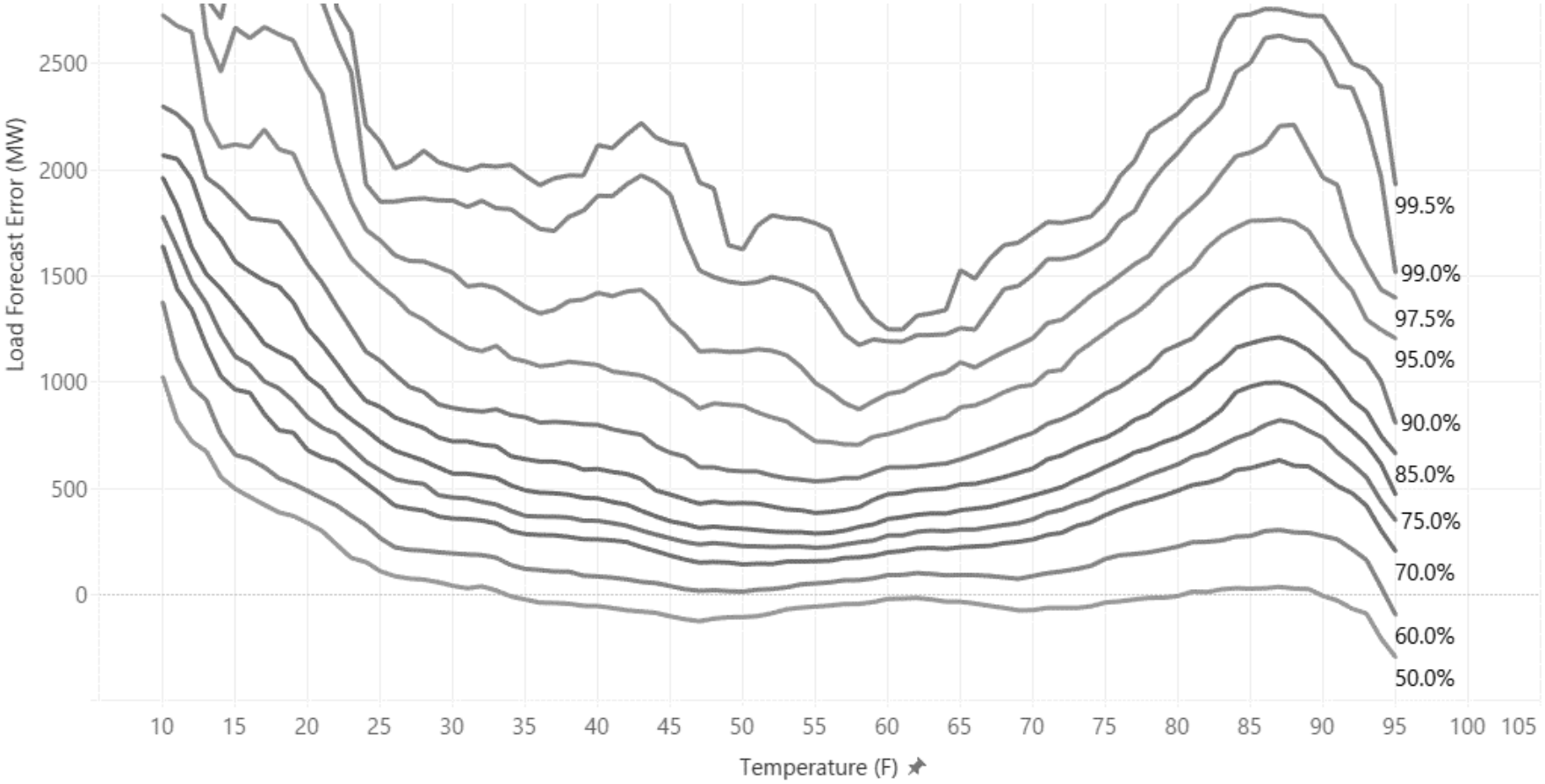
# MAINTAINING AWARENESS OF UNCERTAINTY

## OCTOBER 2019 ESIG WEBINAR

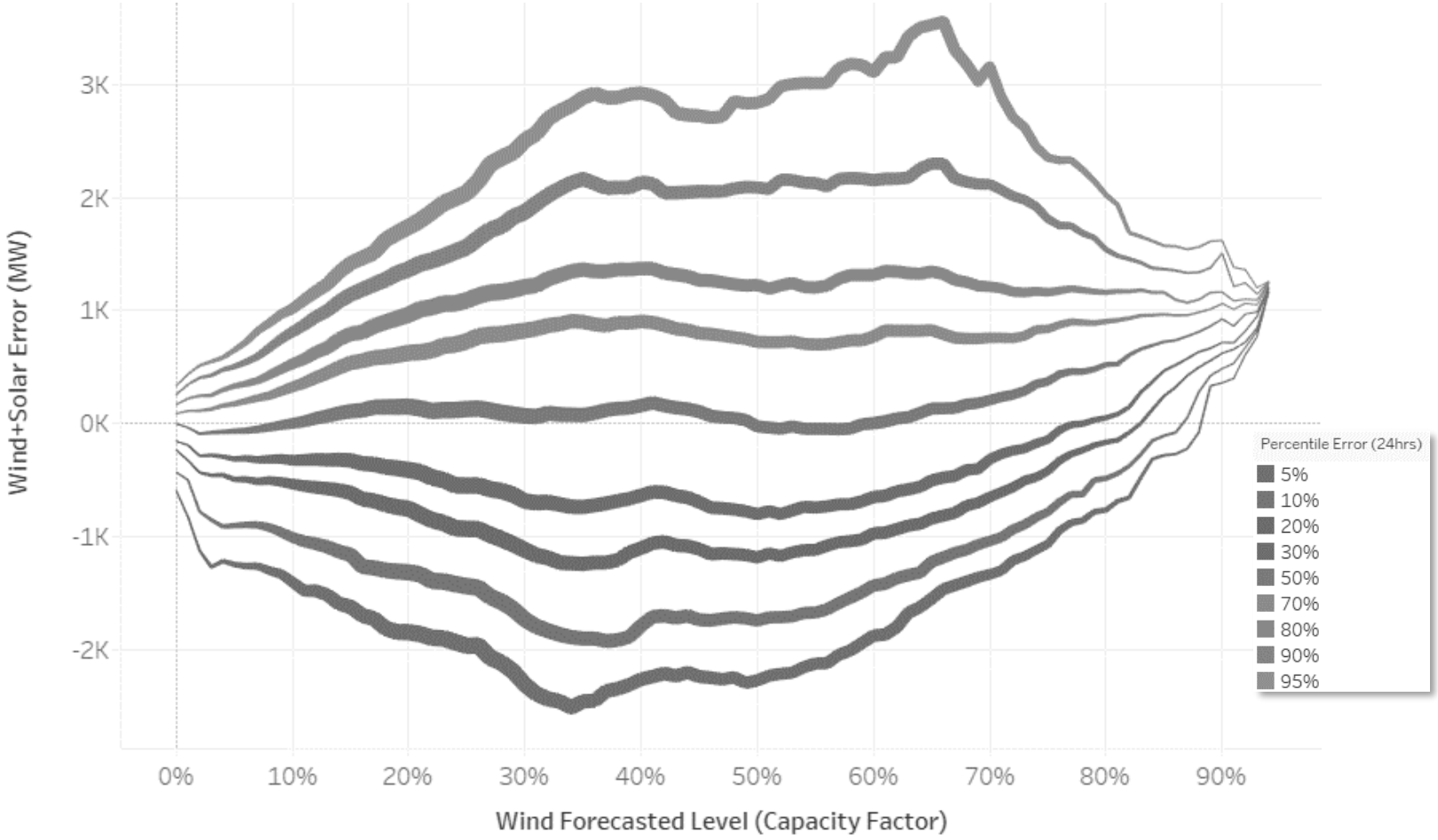
# SPP'S FOCUS

- Ensure adequate capacity in real-time to manage longer-term uncertainties
  - Load forecasts
  - Variable resource forecasts
  - Resource capacity plans

# LOAD FORECAST ERROR



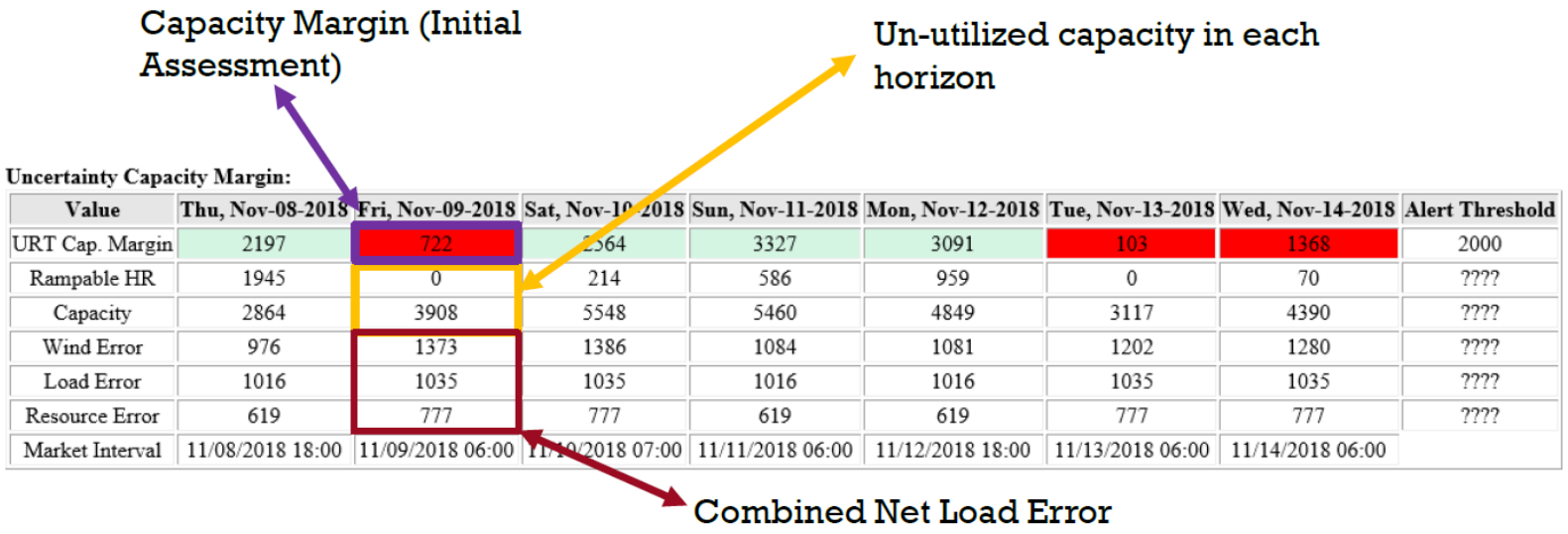
# WIND & SOLAR FORECAST ERROR



# EXAMPLE HIGH RISK SCENARIO REPORT

- 1, 4, & 8 Hour Horizons (assessing potential errors and available resources over each horizon)
- Flags potential capacity deficiencies over the next 7 days triggering further investigation
- URT Capacity Margin = Available Capacity + RampableHeadroom – Wind Error – Load Error – Resource Error

# EXAMPLE HIGH RISK SCENARIO REPORT




**Uncertainty Capacity Margin:**

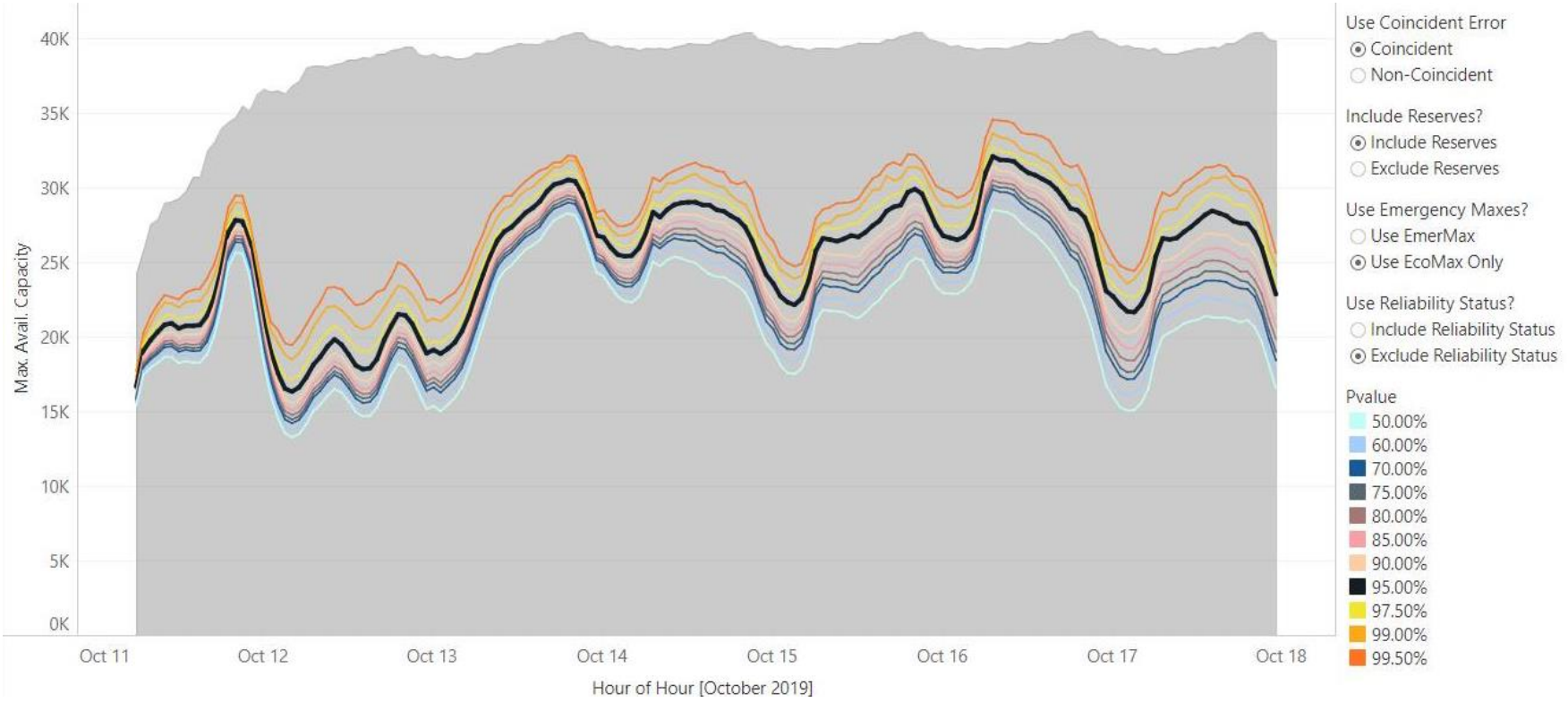
| Value | Thu, Nov-08-2018 | Fri, Nov-09-2018 | Sat, Nov-10-2018 | Sun, Nov-11-2018 | Mon, Nov-12-2018 | Tue, Nov-13-2018 | Wed, Nov-14-2018 | Alert Threshold |
|---|---|---|---|---|---|---|---|---|
| URT Cap. Margin | 2197 | 722 | 2564 | 3327 | 3091 | 103 | 1368 | 2000 |
| Rampable HR | 1945 | 0 | 214 | 586 | 959 | 0 | 70 | ???? |
| Capacity | 2864 | 3908 | 5548 | 5460 | 4849 | 3117 | 4390 | ???? |
| Wind Error | 976 | 1373 | 1386 | 1084 | 1081 | 1202 | 1280 | ???? |
| Load Error | 1016 | 1035 | 1035 | 1016 | 1016 | 1035 | 1035 | ???? |
| Resource Error | 619 | 777 | 777 | 619 | 619 | 777 | 777 | ???? |
| Market Interval | 11/08/2018 18:00 | 11/09/2018 06:00 | 11/10/2018 07:00 | 11/11/2018 06:00 | 11/12/2018 18:00 | 11/13/2018 06:00 | 11/14/2018 06:00 | |

# UNCERTAINTY CAPACITY MARGIN

High
Severe

| Day of Hour | Hour of Hour | Pvalue 50.00% | 60.00% | 70.00% | 75.00% | 80.00% | 85.00% | 90.00% | 95.00% | 97.50% | 99.00% | 99.50% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| October 11, 2019 | 6 | 8,856 | 8,659 | 8,456 | 8,338 | 8,216 | 8,063 | 7,872 | 7,567 | 7,248 | 6,899 | 6,554 |
| | 7 | 8,344 | 8,075 | 7,834 | 7,701 | 7,565 | 7,375 | 7,127 | 6,741 | 6,347 | 5,917 | 5,557 |
| | 8 | 9,625 | 9,342 | 9,064 | 8,916 | 8,748 | 8,538 | 8,272 | 7,775 | 7,314 | 6,744 | 6,183 |
| | 9 | 9,628 | 9,331 | 9,014 | 8,861 | 8,664 | 8,452 | 8,113 | 7,555 | 7,029 | 6,157 | 5,734 |
| | 10 | 10,337 | 9,990 | 9,681 | 9,494 | 9,294 | 9,060 | 8,735 | 8,176 | 7,576 | 6,691 | 6,184 |
| | 11 | 10,425 | 10,042 | 9,710 | 9,527 | 9,312 | 9,076 | 8,733 | 8,155 | 7,564 | 6,837 | 6,409 |
| | 12 | 11,042 | 10,618 | 10,277 | 10,086 | 9,872 | 9,617 | 9,265 | 8,720 | 8,146 | 7,318 | 6,784 |
| | 13 | 11,376 | 10,978 | 10,621 | 10,430 | 10,216 | 9,941 | 9,573 | 9,004 | 8,406 | 7,410 | 6,779 |
| | 14 | 12,425 | 12,022 | 11,656 | 11,465 | 11,233 | 10,943 | 10,540 | 9,956 | 9,403 | 8,305 | 7,553 |
| | 15 | 12,453 | 12,032 | 11,649 | 11,441 | 11,203 | 10,954 | 10,549 | 9,943 | 9,315 | 8,344 | 7,514 |
| | 16 | 13,598 | 13,158 | 12,754 | 12,538 | 12,285 | 12,018 | 11,617 | 11,005 | 10,401 | 9,404 | 8,519 |
| | 17 | 13,021 | 12,563 | 12,152 | 11,905 | 11,646 | 11,368 | 10,982 | 10,412 | 9,923 | 8,972 | 8,193 |
| | 18 | 12,011 | 11,565 | 11,142 | 10,892 | 10,654 | 10,389 | 9,970 | 9,461 | 8,960 | 8,413 | 7,671 |
| | 19 | 9,741 | 9,366 | 8,992 | 8,769 | 8,527 | 8,290 | 7,969 | 7,392 | 6,928 | 6,259 | 5,730 |
| | 20 | 9,042 | 8,686 | 8,318 | 8,114 | 7,897 | 7,664 | 7,323 | 6,846 | 6,341 | 5,671 | 5,195 |
| | 21 | 9,922 | 9,543 | 9,177 | 8,977 | 8,757 | 8,515 | 8,224 | 7,757 | 7,222 | 6,496 | 6,060 |
| | 22 | 11,133 | 10,732 | 10,318 | 10,139 | 9,894 | 9,625 | 9,335 | 8,843 | 8,364 | 7,655 | 7,362 |
| | 23 | 15,075 | 14,602 | 14,137 | 13,925 | 13,671 | 13,370 | 13,046 | 12,459 | 11,967 | 11,249 | 10,896 |

# CAPACITY VS. UNCERTAINTY



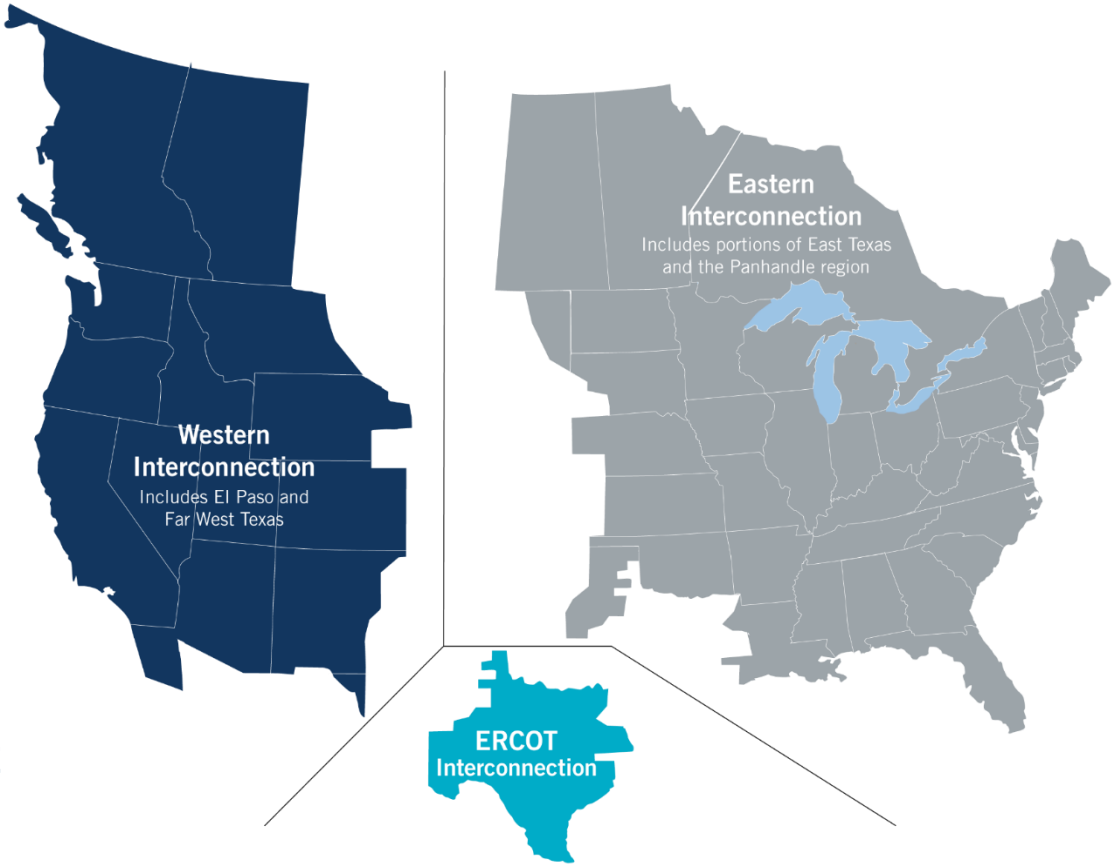
# INTEGRATE PROBABILISTIC INFORMATION INTO GRID OPERATIONS

Pengwei Du
ERCOT
10/22/2019

# What is ERCOT?

The Texas Legislature restructured the Texas electric market in 1999 and assigned ERCOT four primary responsibilities:

- **System Reliability**
- **Competitive Wholesale Market**
- **Open Access to Transmission**
- **Competitive Retail Market**




ERCOT is a nonprofit organization and regulated by the Public Utility Commission of Texas, with oversight by the Texas Legislature.

ERCOT is not a market participant and does not own generation or transmission/distribution wires.

# Current Records

**Peak Demand Record: 74,666 megawatts (MW)***

- August 12, 2019, 4-5 p.m.

**Weekend Peak Demand Record: 71,915 MW***

- Sunday, August 11, 2019, 5-6 p.m.

**Winter Peak Demand Record: 65,915 MW**

- Jan. 17, 2018, 7-8 a.m.

**Wind Generation Records (instantaneous)**

- Output: 19,672 MW
  - Jan. 21, 2019, 7:19 p.m.
- Penetration (load served): 56.16%
  - January 19, 2019, 3:10 a.m.
  - Total MW Served by Wind = 17,406 MW

**Recent Monthly Peak Demand Records**

**2019**

- March: 60,756 MW (March 5, 7-8 a.m.)
- August: 74,666 MW (Aug. 12, 4-5 p.m.)*
- September: 68,817 MW (Sept. 6, 4-5 p.m.)*

**2018**

- January: 65,915 MW (Jan. 17, 7-8 a.m.)
- May: 67,265 MW (May 29, 4-5 p.m.)
- June: 69,123 MW (June 27, 4-5 p.m.)
- July: 73,473 MW (July 19, 4-5 p.m.)
- November: 56,317 MW (Nov. 14, 7-8 a.m.)

**2017**

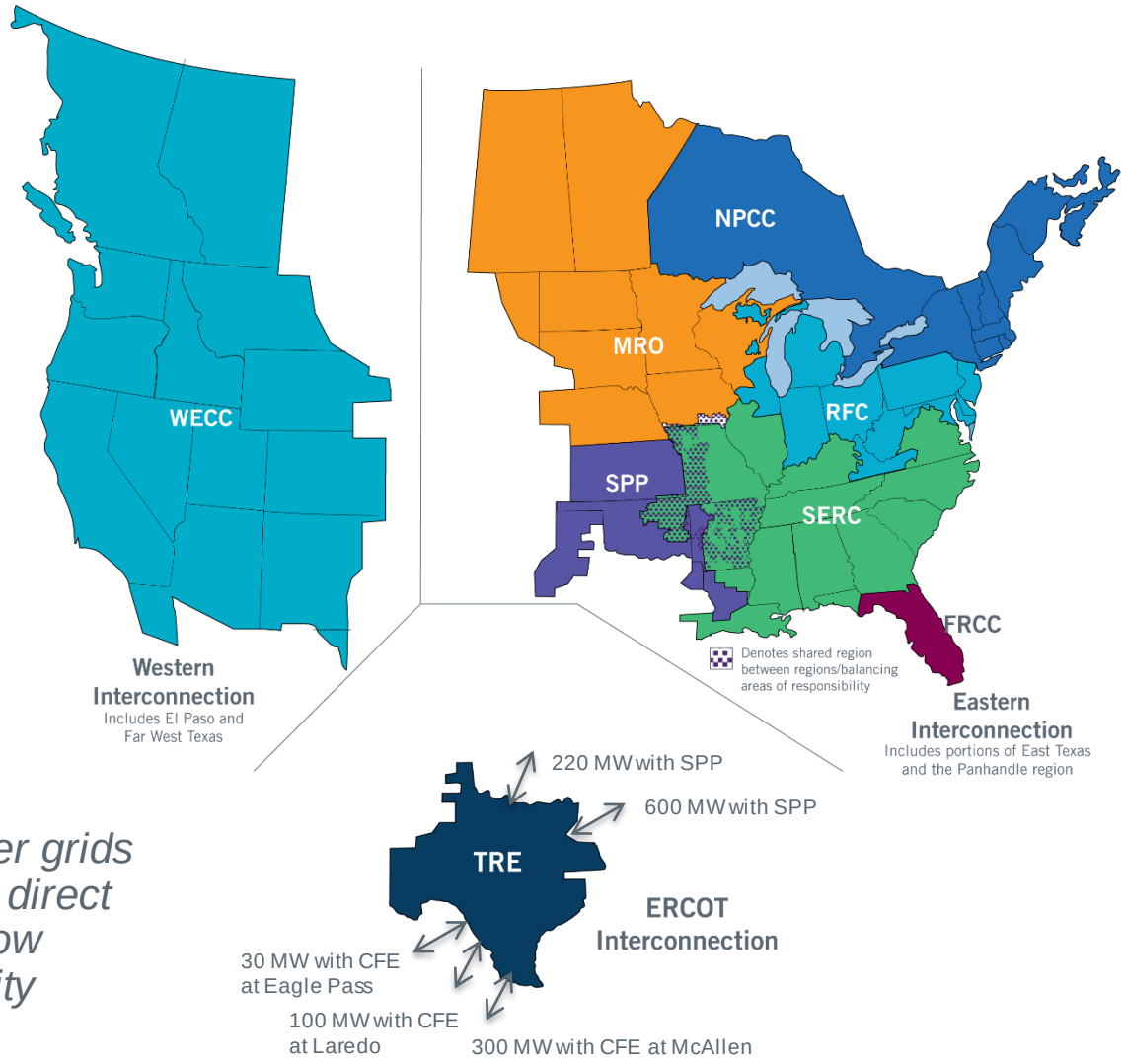
- April: 53,486 MW (April 28, 4-5 p.m.)
- October: 62,333 MW (Oct. 9, 4-5 p.m.)

**New records are preliminary, subject to change in final settlement*

# The ERCOT Region

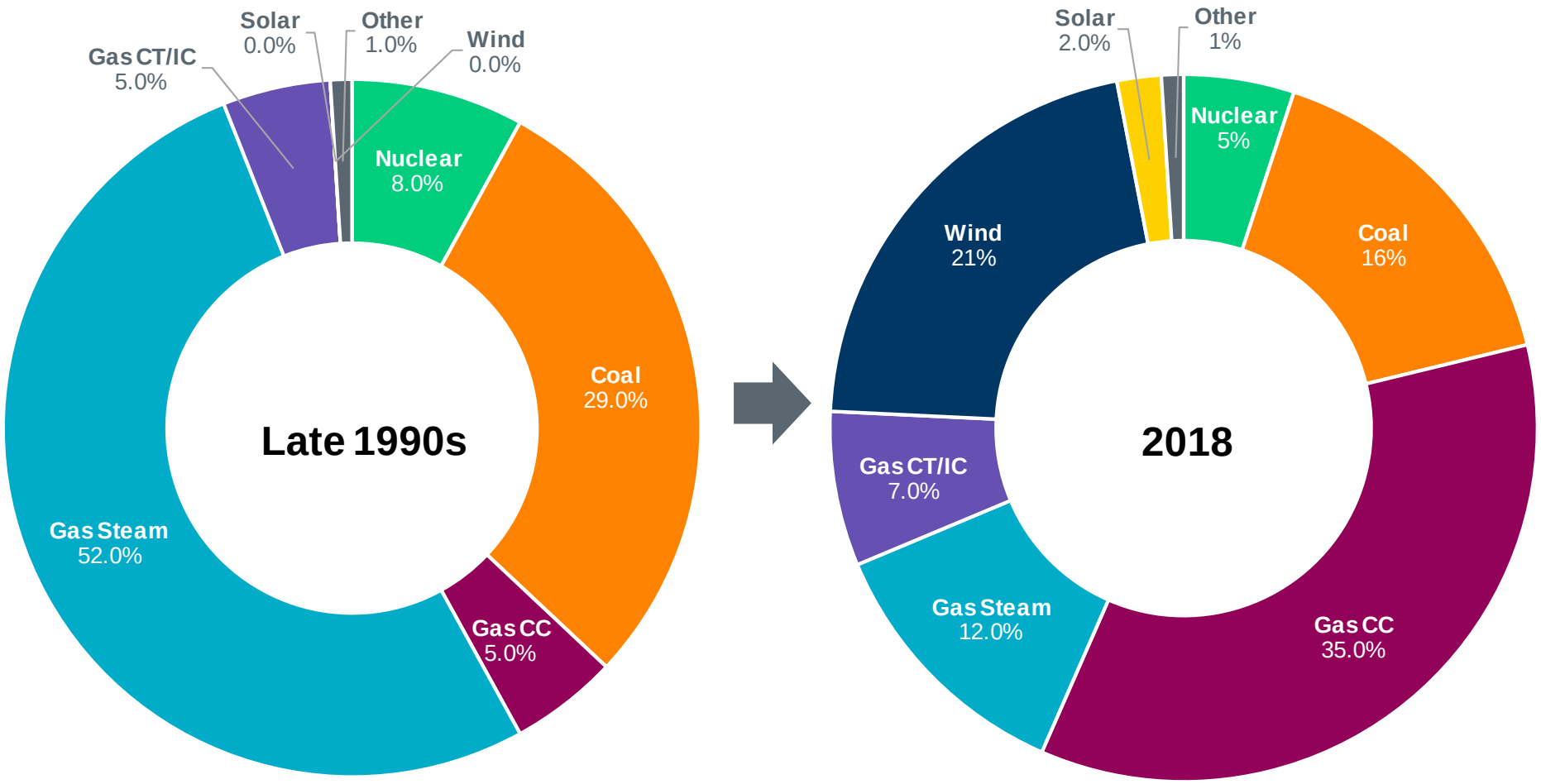
**The interconnected electrical system serving most of Texas, with limited external connections**

- 90% of Texas electric load; 75% of Texas land
- More than 46,500 miles of transmission lines
- 600+ generation units

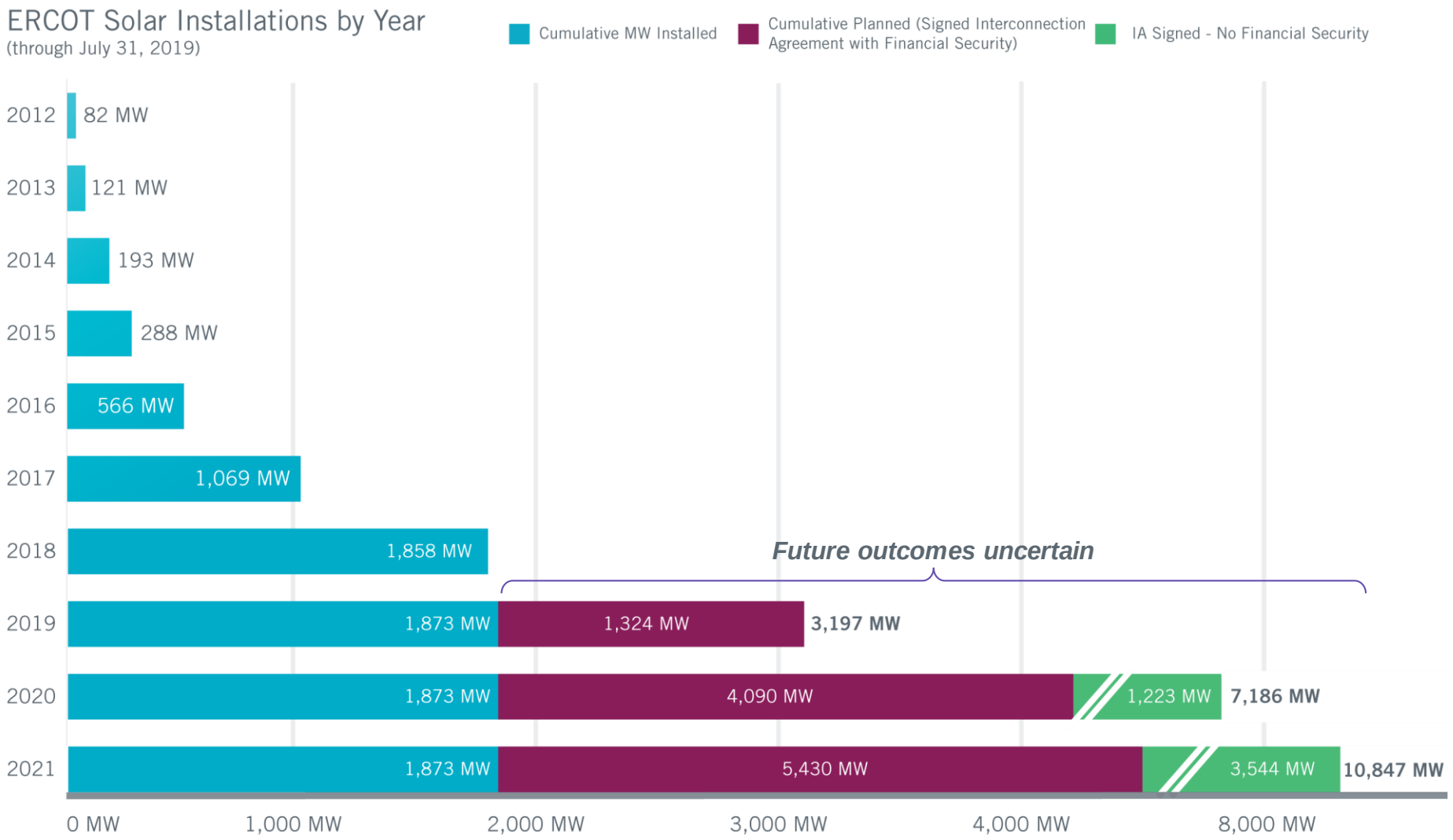



*ERCOT connections to other grids are limited to ~1250 MW of direct current (DC) ties, which allow control over flow of electricity*

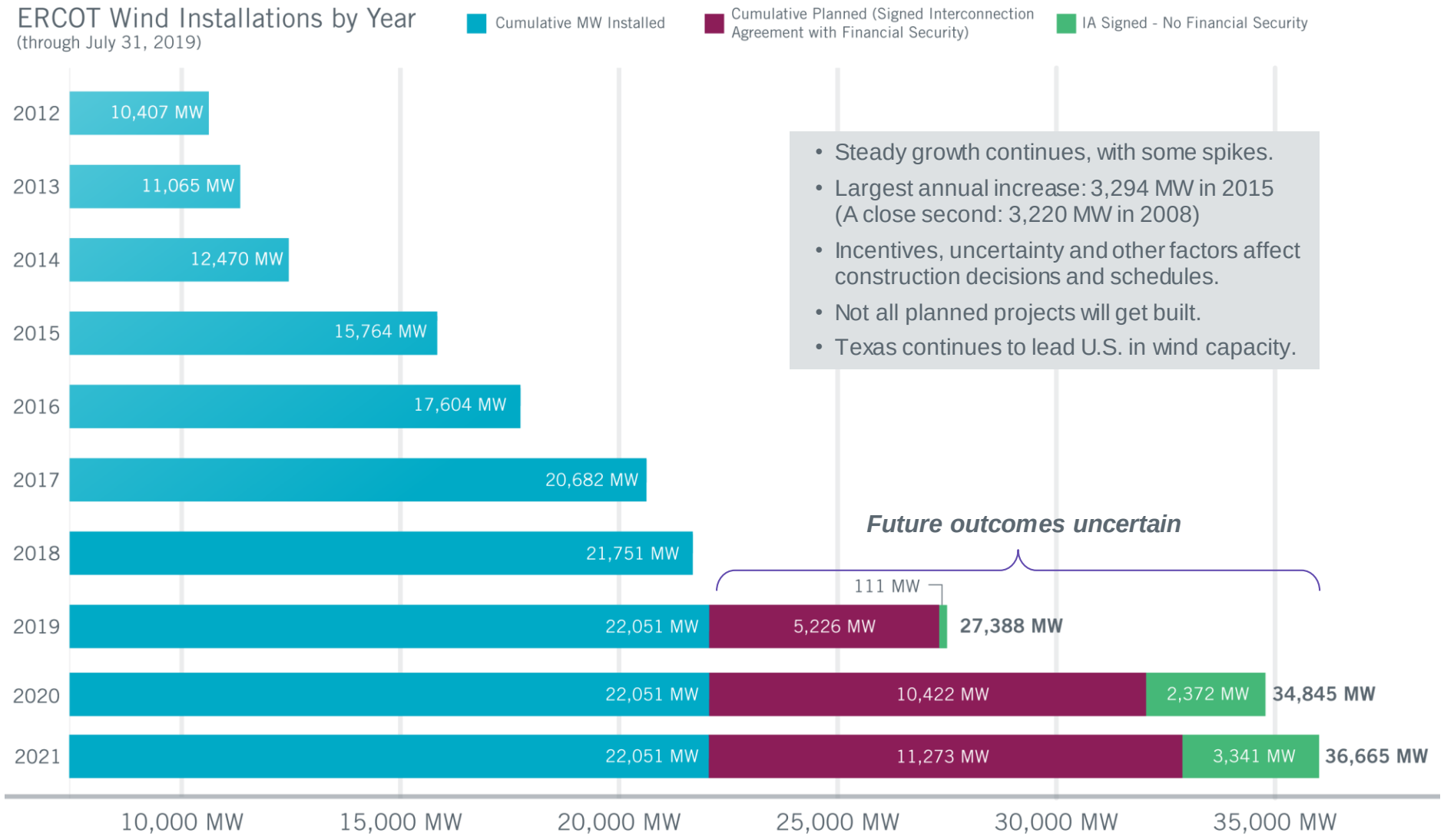
# Changing Resource Capacity Mix



# Utility Scale Solar Generation Capacity – July 2019



# Wind Generation Capacity – July 2019




- Steady growth continues, with some spikes.
- Largest annual increase: 3,294 MW in 2015 (A close second: 3,220 MW in 2008)
- Incentives, uncertainty and other factors affect construction decisions and schedules.
- Not all planned projects will get built.
- Texas continues to lead U.S. in wind capacity.

# Wind Forecasting at ERCOT

## Wind Generation Resource (WGR)

- **Asset Registration Information**
- **Outage/De-rate Schedule**
- **Real Time Telemetry**

## Wind Forecast Service

- **Two Forecast Service Providers** each provide:
- **Hourly Forecast for each WGR** for each hour of next week, updated hourly
- **Intra-hour Forecast** for next 2-hr, at 5-min resolution, updated every 15-min
- Extreme Event Forecasts and Probabilistic Forecasts, used for risk assessment

energy & meteo systems

UL

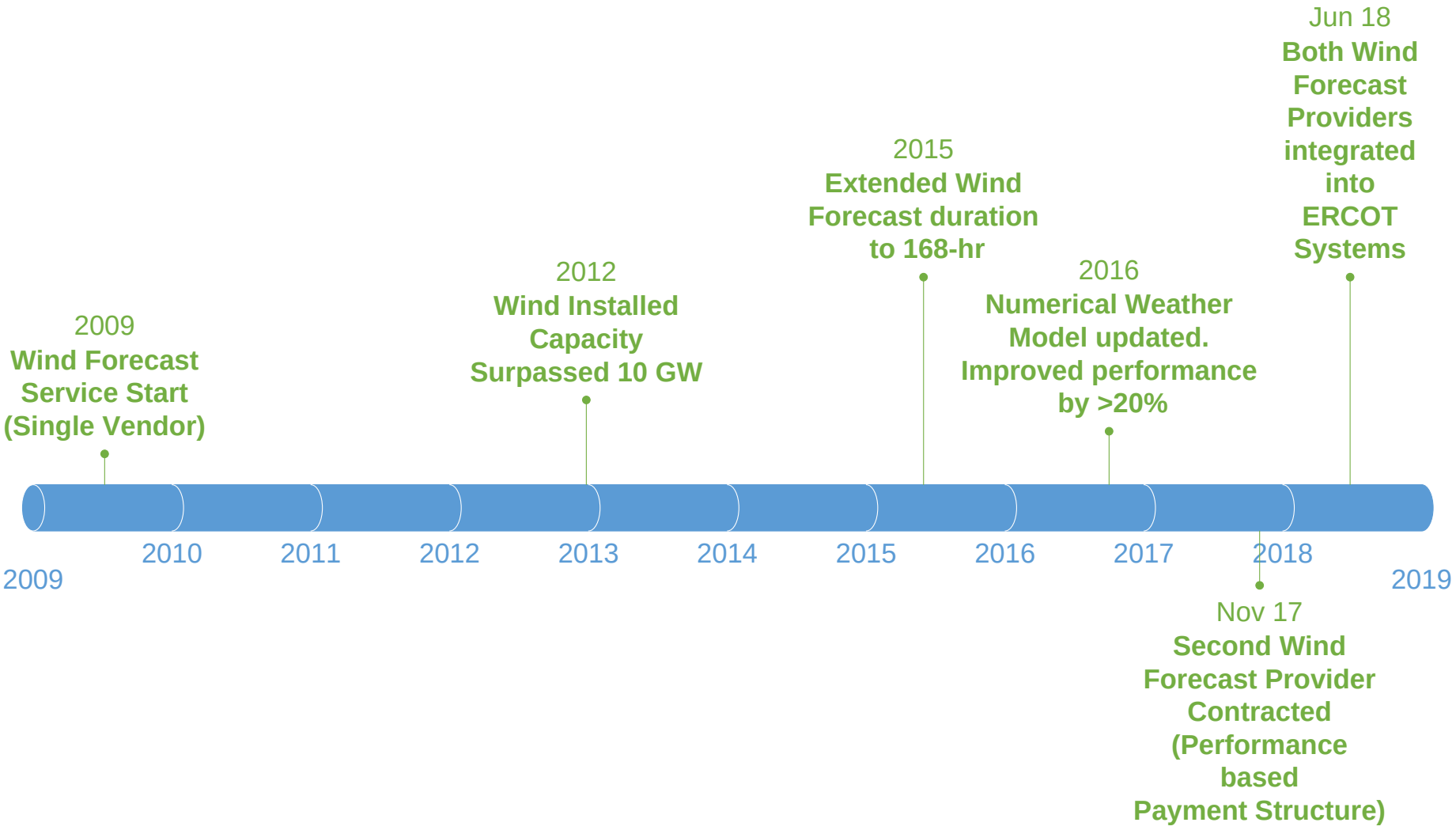
## ERCOT Systems

- ERCOT Control Room can select "active forecast" for every hour and every 5-min.
- **Hourly Forecast** Used in all Look Ahead Studies (ex. Outage Coordination, Reliability Unit Commitment, Next Day Study)
- **Intra-hour Forecast** To be used in Real Time Dispatch
- Extreme Event Forecasts and Probabilistic Forecasts, used for risk assessment

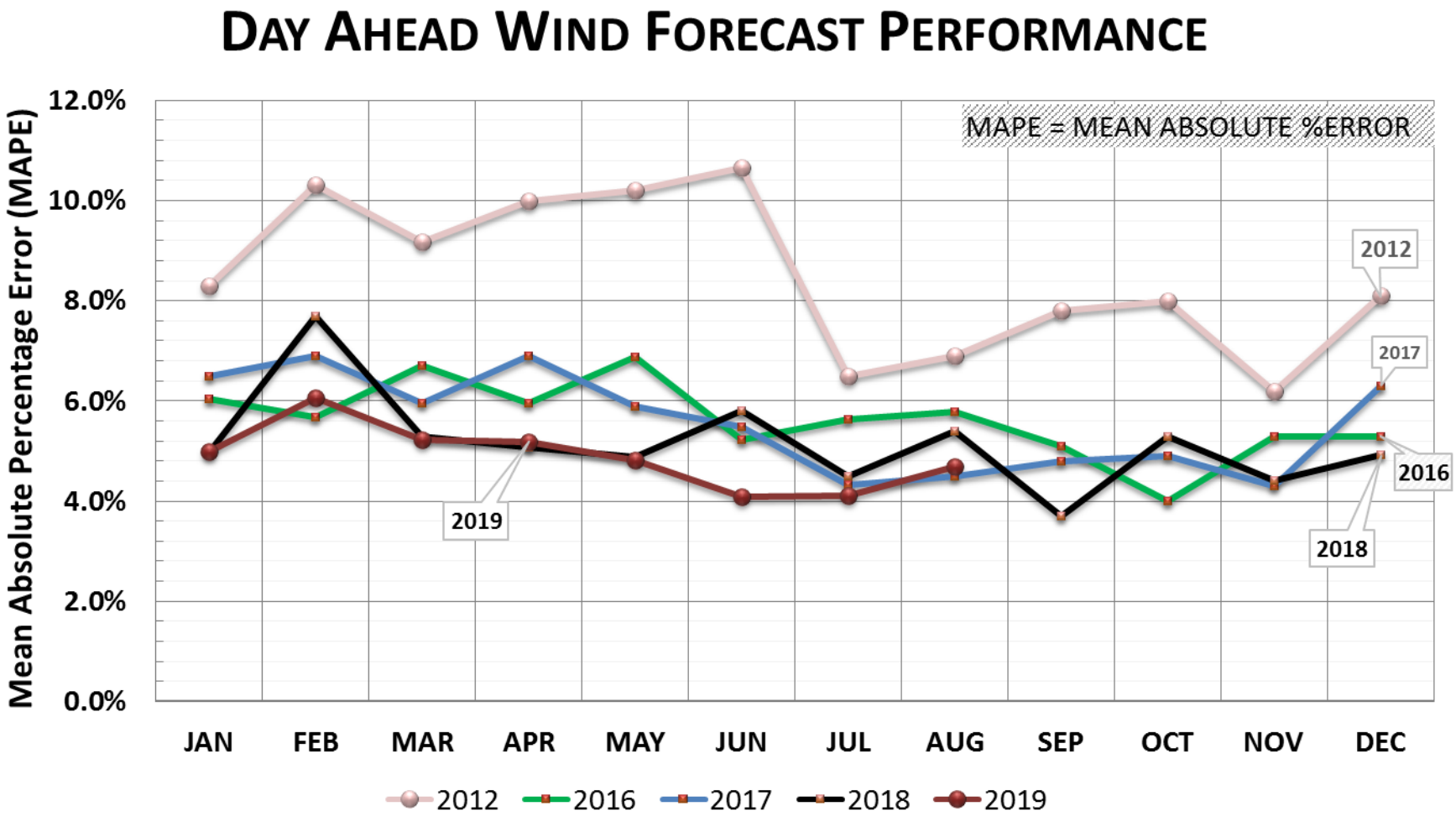
* WGR Operators can reduce the Current Operating Plan (COP) High Sustained Limit (HSL) to reflect operating condition changes.

ercot

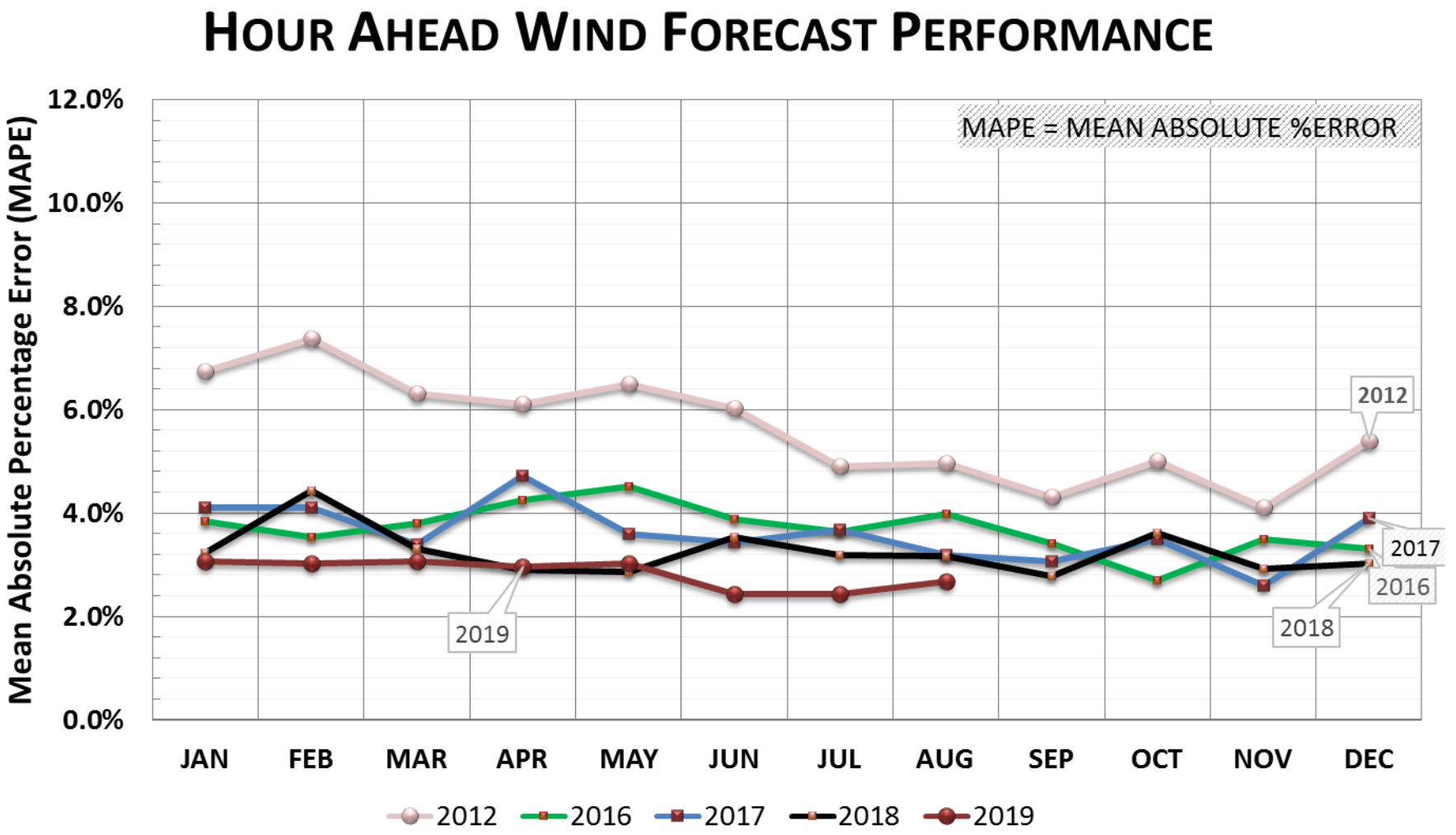
# Timelines of Wind Forecast



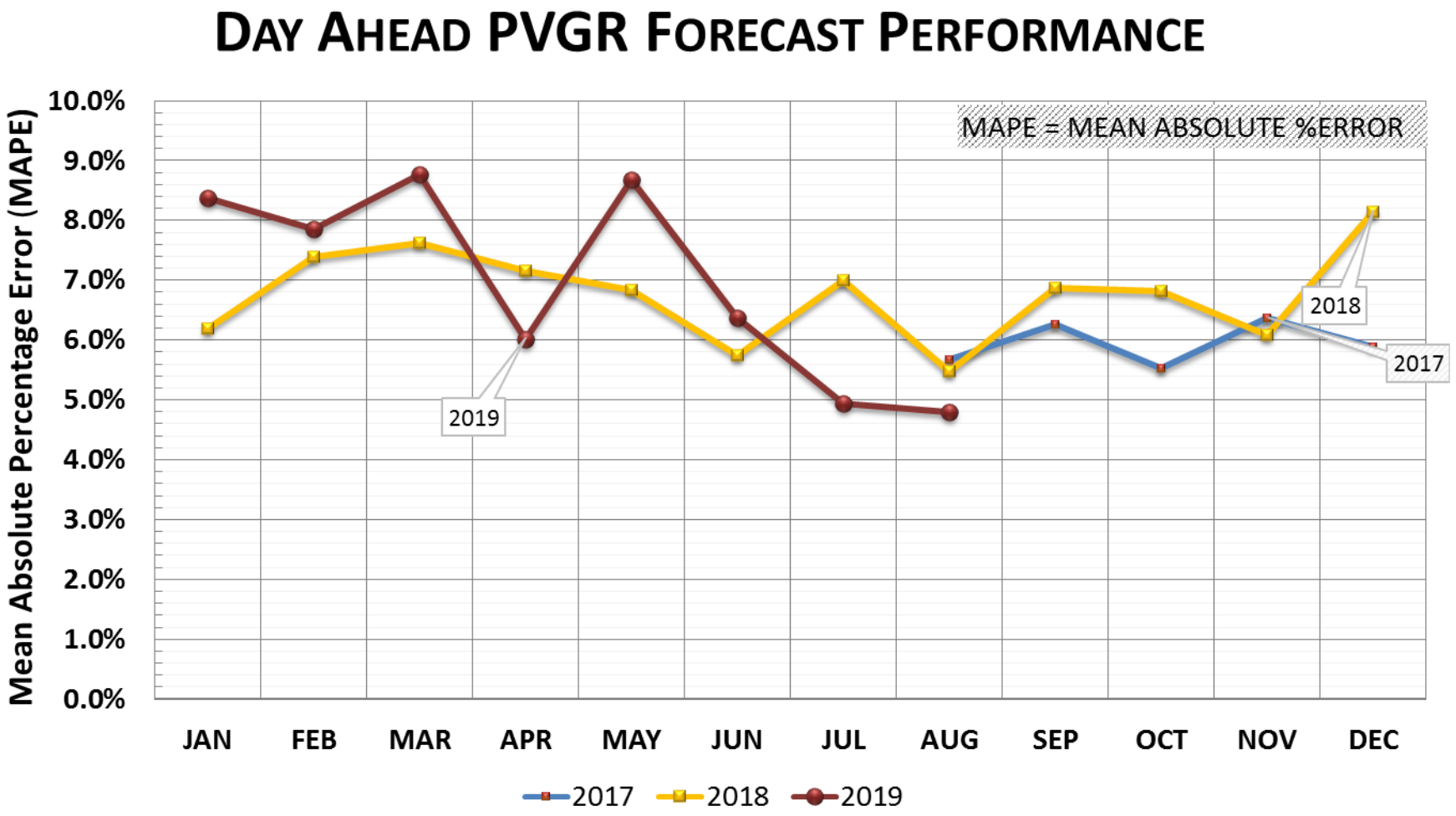
# Wind Forecast Errors (Day-Ahead)



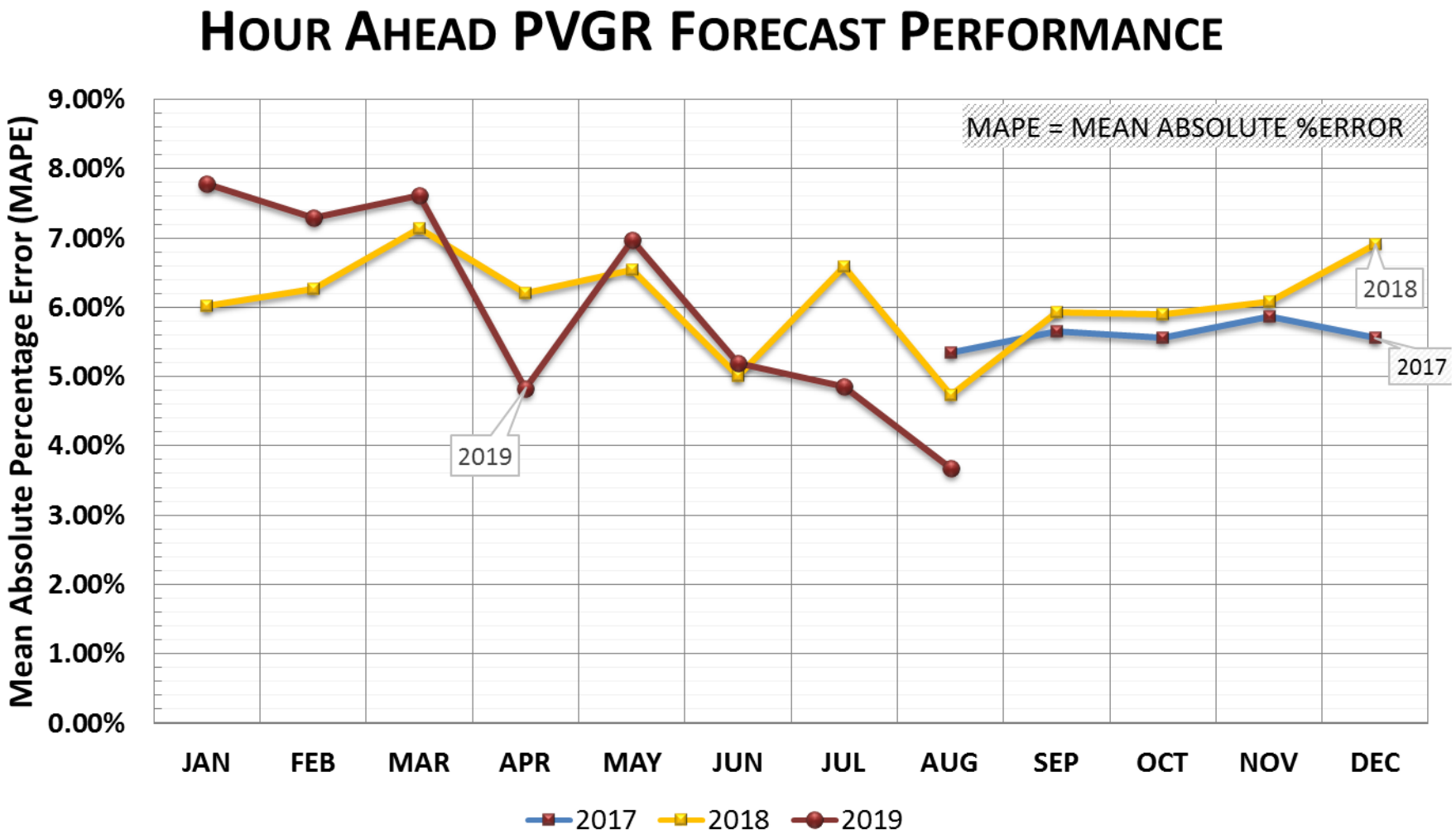
# Wind Forecast Errors (Hour-Ahead)



# PVGR Forecast Errors (Day-Ahead)

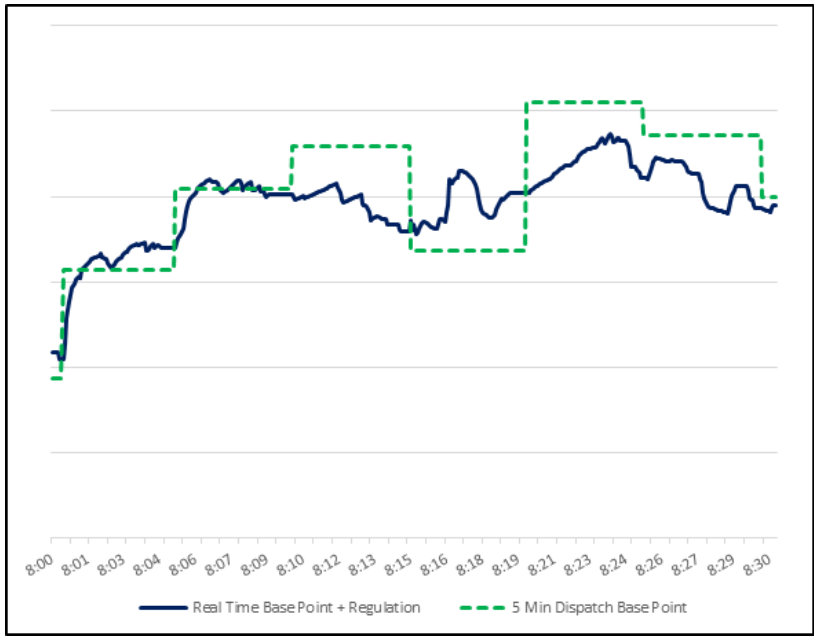


# PVGR Forecast Errors (Hour-Ahead)



# Ancillary Services – Regulation Service

- SCED sends dispatch instruction every 5 minutes.
- LFC sends Regulation signals to generation resources every 4 second service to move up or down to maintain frequency at nominal.



# Ancillary Services – Non-Spinning Reserve Service (NSRS)

- Non-spinning Reserve Service
  - 30 minute product that can be provided by unloaded capacity, offline Generators, and Load Resources
  - Wind power and load forecast error is one of the inputs used for calculating the requirement for this service
  - The net forecast error uncertainty that NSRS will be used to mitigate will depend on the risk of net load ramp.
  - During higher net load ramp risk hours, we procure NSRS to cover up to 95$^{th}$ percentile of net forecast uncertainty.
  - During low net load ramp risk hours, we may only procure NSRS to cover 70$^{th}$ percentile of net forecast uncertainty.

# Integrating and Managing Renewables

- With increasing integration of renewables, large variations in renewable generation are possible to occur more frequently.

- It is essential to monitor and identify durations when large variations in renewable generation are expected and take actions that preposition the rest of ERCOT's generation fleet in order to maintain reliable grid operations.

  – Adding a new desk in the Control Room to provide increased situational awareness to renewables [2016]
    - Created displays to identify incorrect information telemetered for renewables and mitigate these.
    - Developed capability to monitor inertia and sufficiency of procured Responsive Reserve requirements in Real Time and Day Ahead.
    - Built tools for assessing adequacy of available generation capacity and Non Spin reserves for serving variability expected in net load near Real Time.

# Capacity Availability Tool

Capacity Availablity Tool (CAT)

Show Actuals: ☑ Use Available Gen: ☑ Use STWPF: ☑ Use LF UC: ☑

Wind: 1h - 3h Percentile: 95 4h - 6h Percentile: 95 Load: 1h - 3h Percentile: 68 4h - 6h Percentile: 68 REFRESH

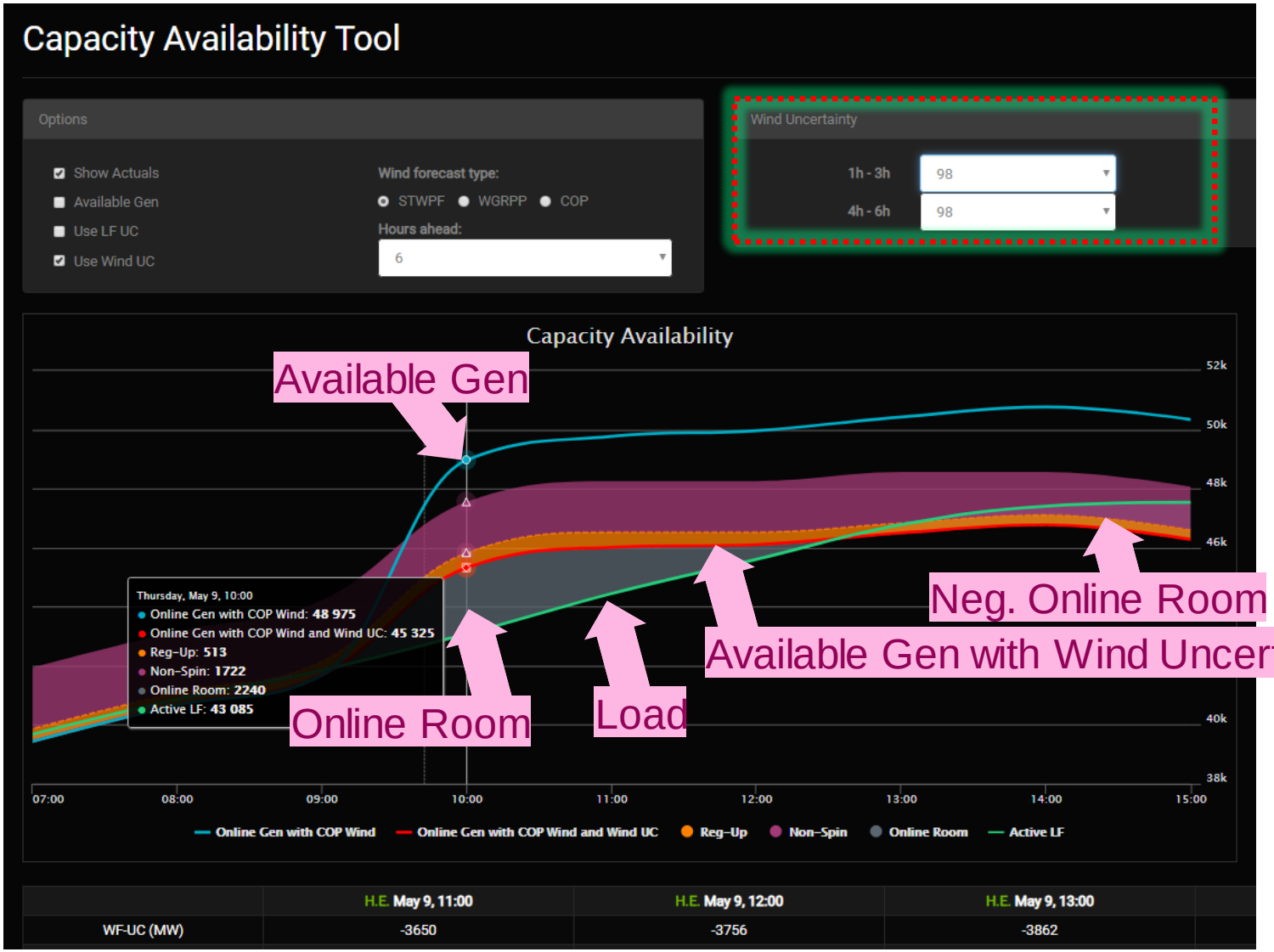
Display 1 | Display 2 | Display 3

Chart

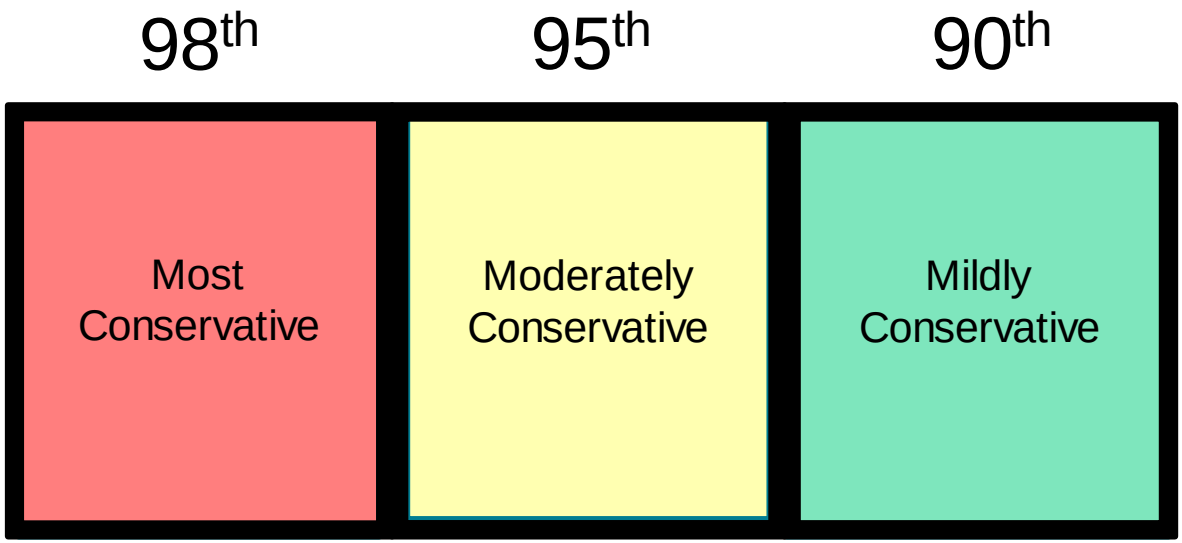
IOHR: 50 Items

| ID | Time | DC Tie Sched | Reg Up | Non Spin | Active LF | Active LF with Actual | Load UC (%) | Load UC (MW) | Active LF with LF UC | COP Wind | Wind Forecast | Actual Wind | Wind UC (%) | Wind UC (MW) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H-2 | 5/9/2019 8:00:00 AM | -264 | 439 | 2065 | 39489 | 39681.31 | 0 | 0 | 39681.31 | 8544.399 | 8270.698 | 8137.776 | 0 | 0.00 |
| H-1 | 5/9/2019 9:00:00 AM | -214 | 440.1 | 2065 | 40131 | 40865.68 | 0 | 0 | 40865.68 | 8426.8 | 8319.798 | 8749.08 | 0 | 0.00 |
| H00 | 5/9/2019 10:00:00 AM | -164 | 479 | 2065 | 41516 | 41702.14 | 0 | 0 | 41702.14 | 8751.199 | 8662.103 | 8621.324 | 0 | 0.00 |
| H01 | 5/9/2019 11:00:00 AM | 11 | 513 | 1722 | 43085 | 43085 | 0.0226 | 973.721 | 44058.72 | 8651.302 | 8782.401 | | -0.1378544 | -3,566.78 |
| H02 | 5/9/2019 12:00:00 PM | 111 | 515 | 1722 | 44445 | 44445 | 0.0269 | 1195.571 | 45640.57 | 8814.997 | 8950.598 | | -0.1262395 | -3,266.26 |
| H03 | 5/9/2019 1:00:00 PM | 84 | 431 | 1722 | 45607 | 45607 | 0.0312 | 1422.938 | 47029.94 | 8867.4 | 9004.102 | | -0.1146247 | -2,965.75 |
| H04 | 5/9/2019 2:00:00 PM | 86 | 338.9 | 1722 | 46782 | 46782 | 0.03386667 | 1584.35 | 48366.35 | 8992.9 | 9130.299 | | -0.1276528 | -3,302.83 |
| H05 | 5/9/2019 3:00:00 PM | 89 | 341.9 | 1453 | 47410 | 47410 | 0.03653333 | 1732.045 | 49142.05 | 9115.804 | 9252.304 | | -0.1406809 | -3,639.91 |
| H06 | 5/9/2019 4:00:00 PM | 63 | 331 | 1453 | 47542 | 47542 | 0.0392 | 1863.646 | 49405.64 | 9124.101 | 9261.802 | | -0.153709 | -3,976.99 |

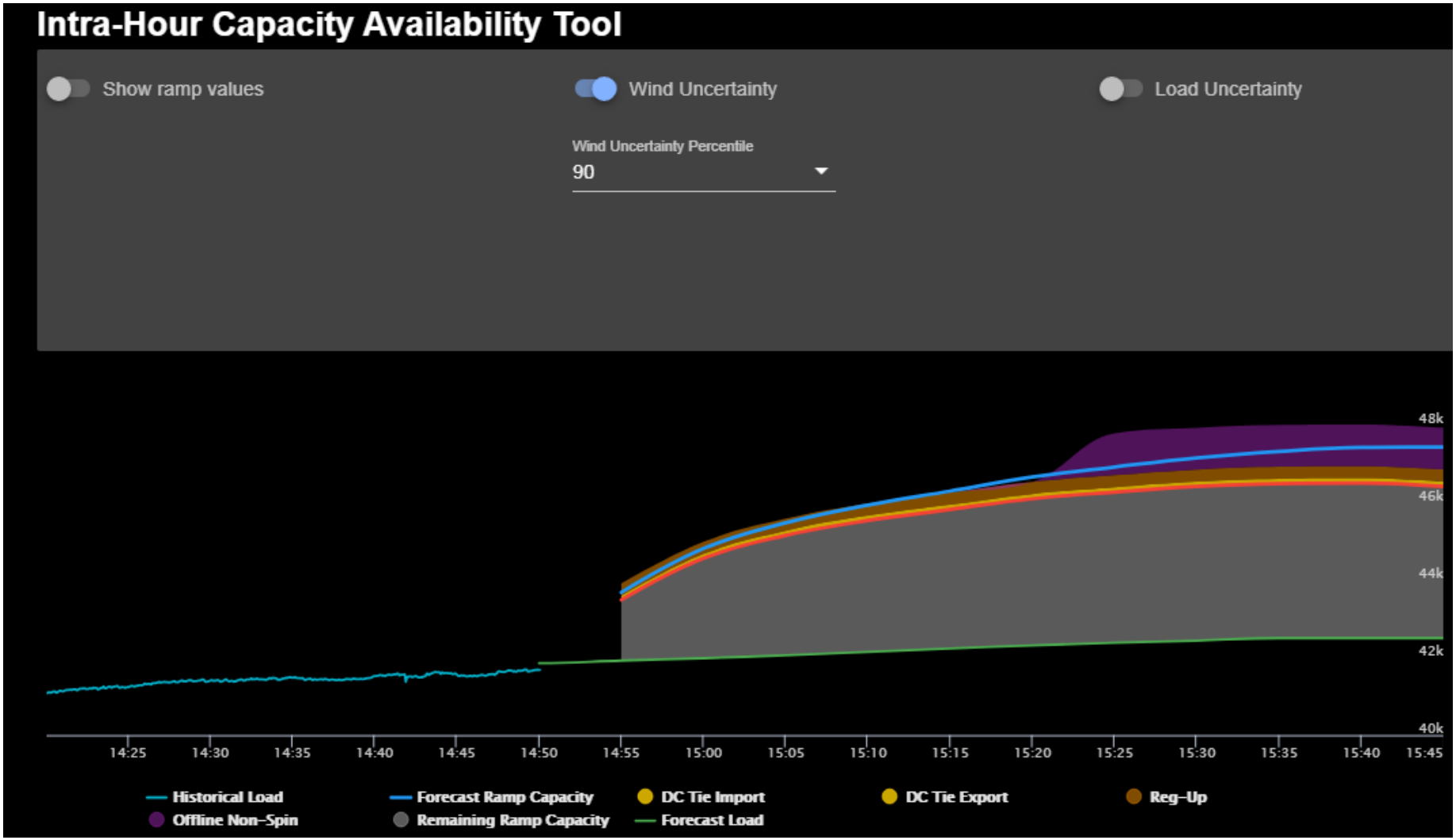
# Capacity Availability Tool



# Percentile

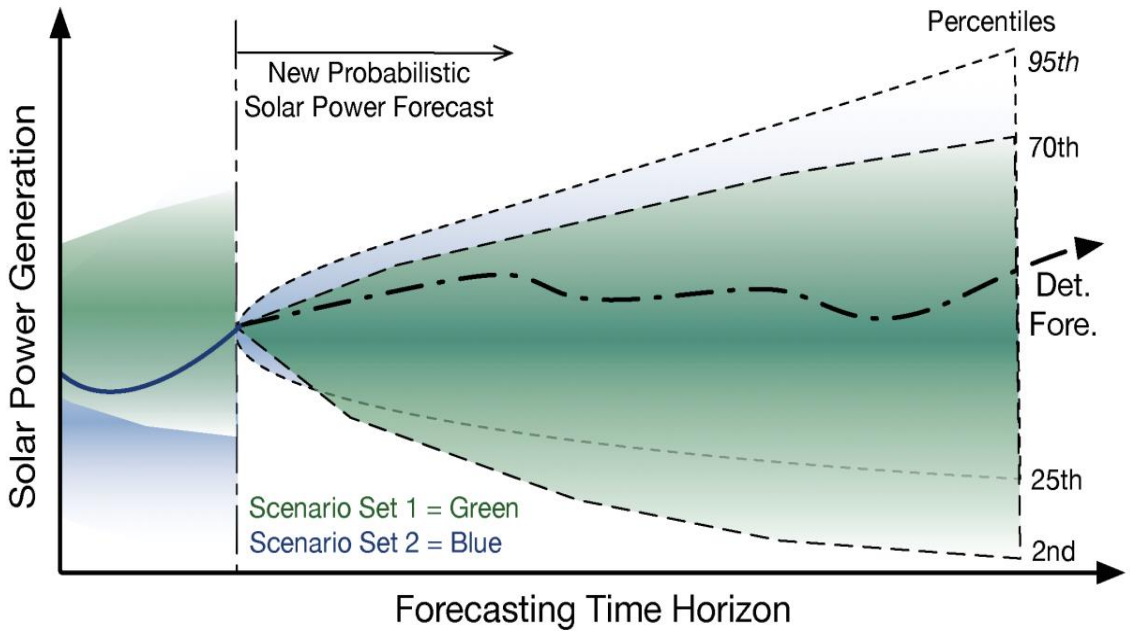

98th
95th
90th
Most Conservative
Moderately Conservative
Mildly Conservative

# Operational Tool to Monitor Ramp for Next 1-hour



# Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)

- SUMMER-GO will bring probabilistic solar forecasts into ERCOT's real-time operation environment through automated reserve and dispatch tools that increase economic efficiency and improve system reliability.
- ERCOT is partnering with NREL, UT Dallas and Maxar for this 3-year project (2018-2020) funded by the Department of Energy



ESIG

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