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# Characterizing and Modeling Wind Power Forecast Errors from Operational Systems for Use in Wind Integration Planning Studies

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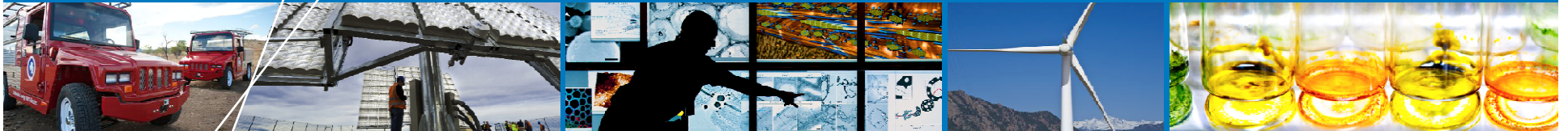
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# Characterizing and Modeling Wind Power Forecast Errors from Operational Systems for use in Wind Integration Planning Studies

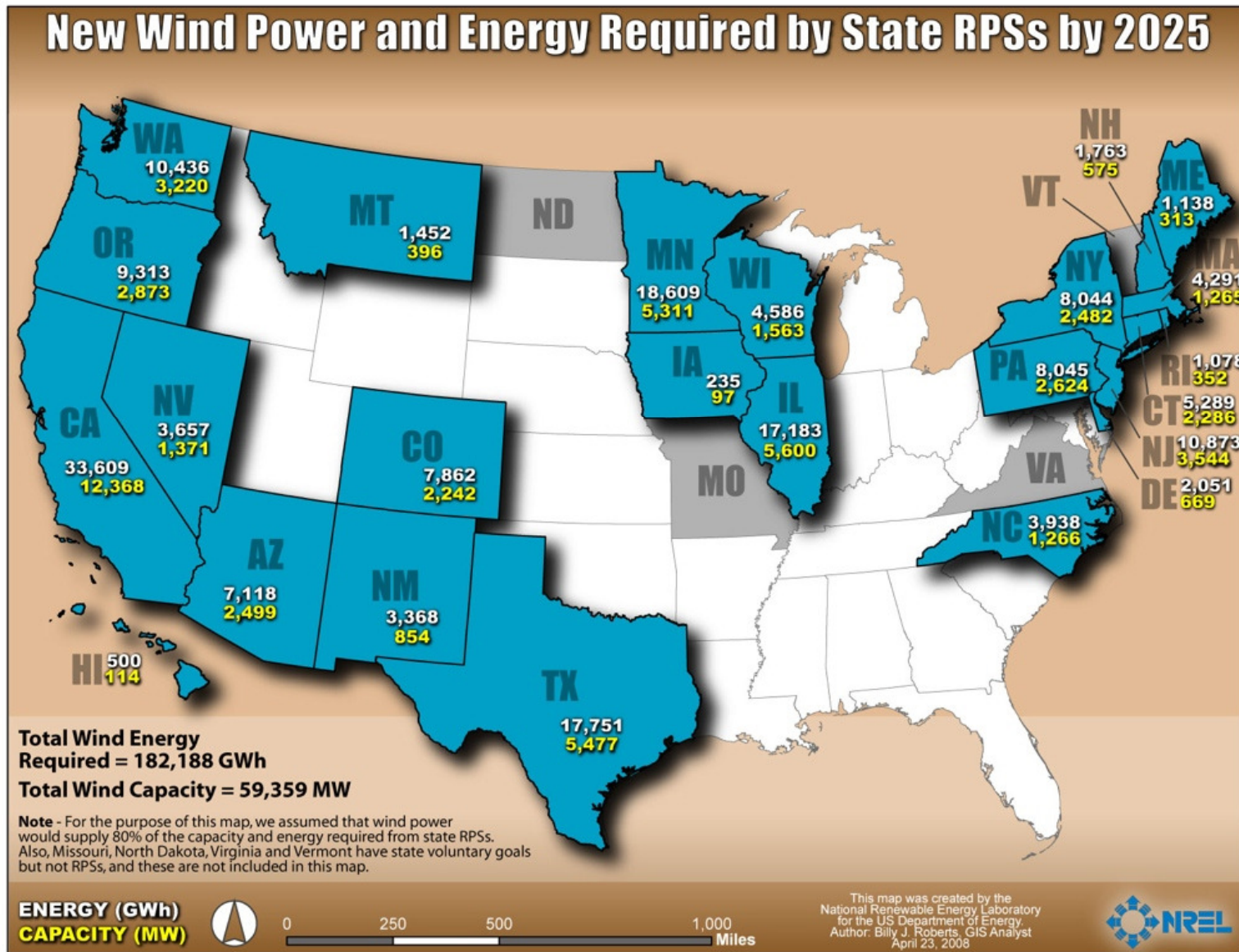


## Modeling, Simulation, and Optimization for the 21<sup>st</sup> Century Electric Power Grid

**Bri-Mathias Hodge**

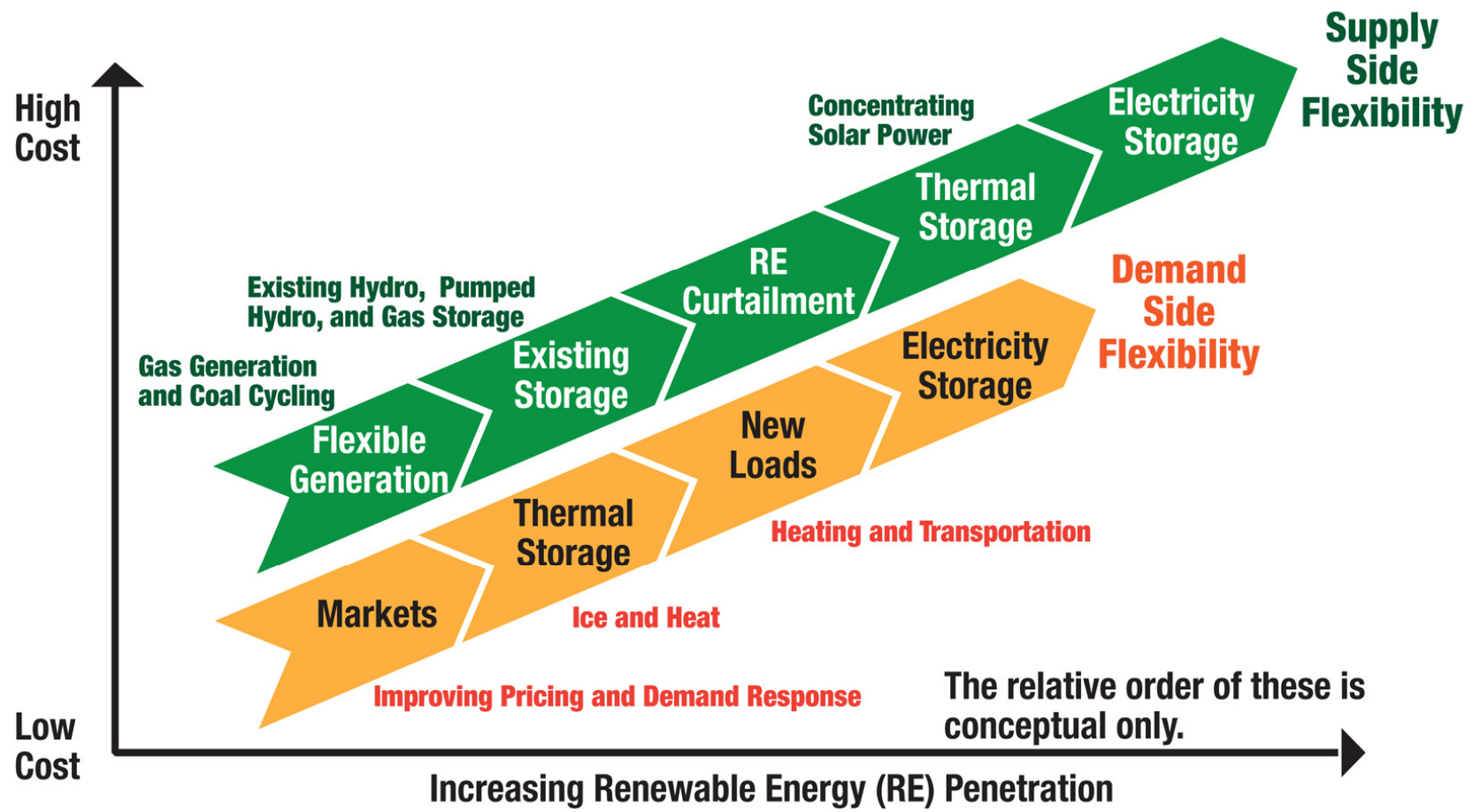
**October 23, 2012**

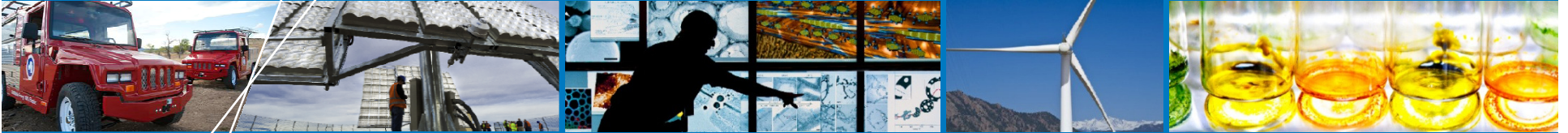
# Renewable Energy Portfolio Standards



# Renewable Generation Integration Background

## Flexibility Supply Curve

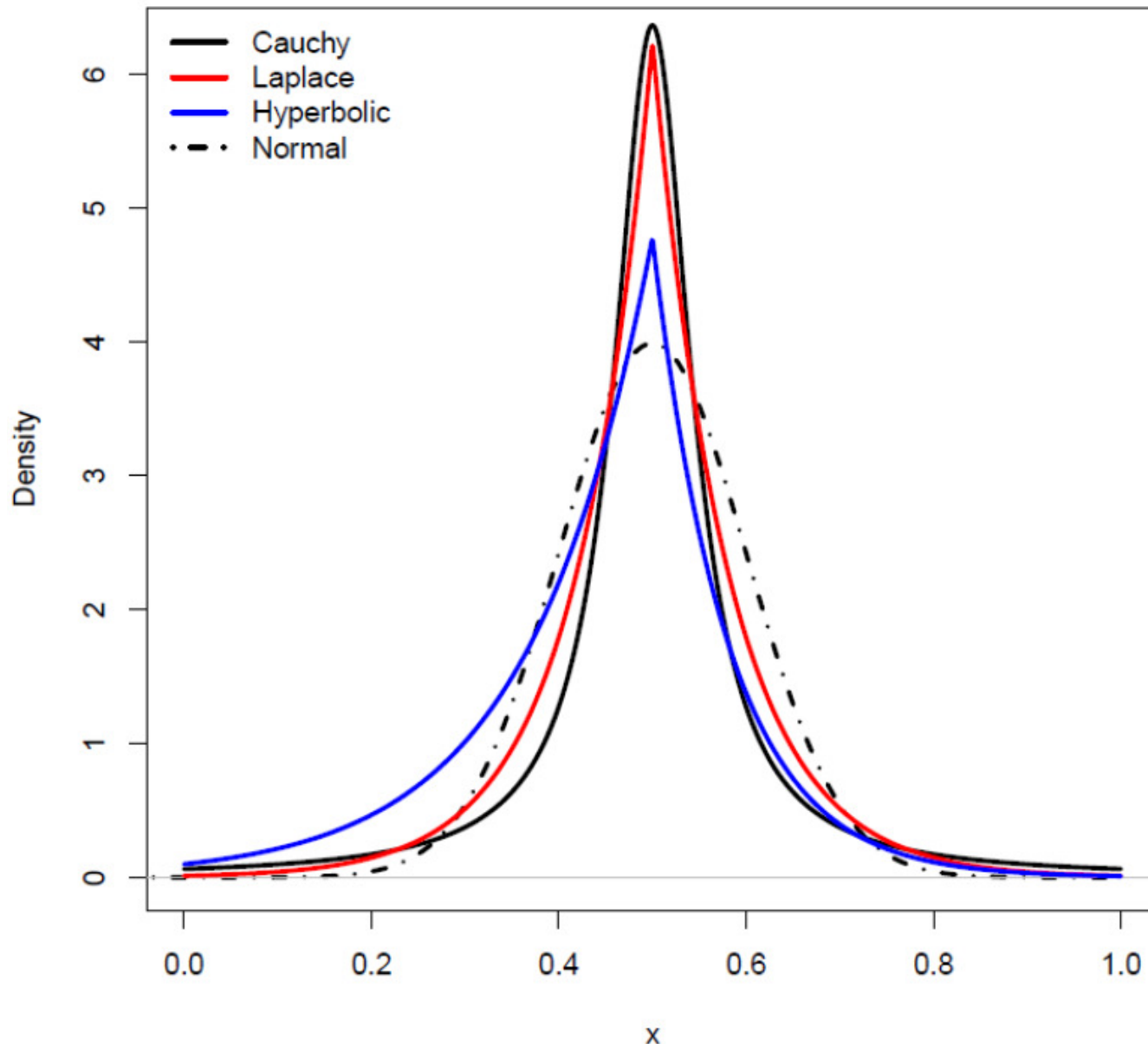




# Forecast Error Characterization and Modeling



# Statistical Background



- Skewness – 3<sup>rd</sup> Statistical Moment

$$\gamma = E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right]$$

- Kurtosis – 4<sup>th</sup> Statistical Moment

$$K = \frac{E(\varepsilon^4)}{\sigma^4}$$

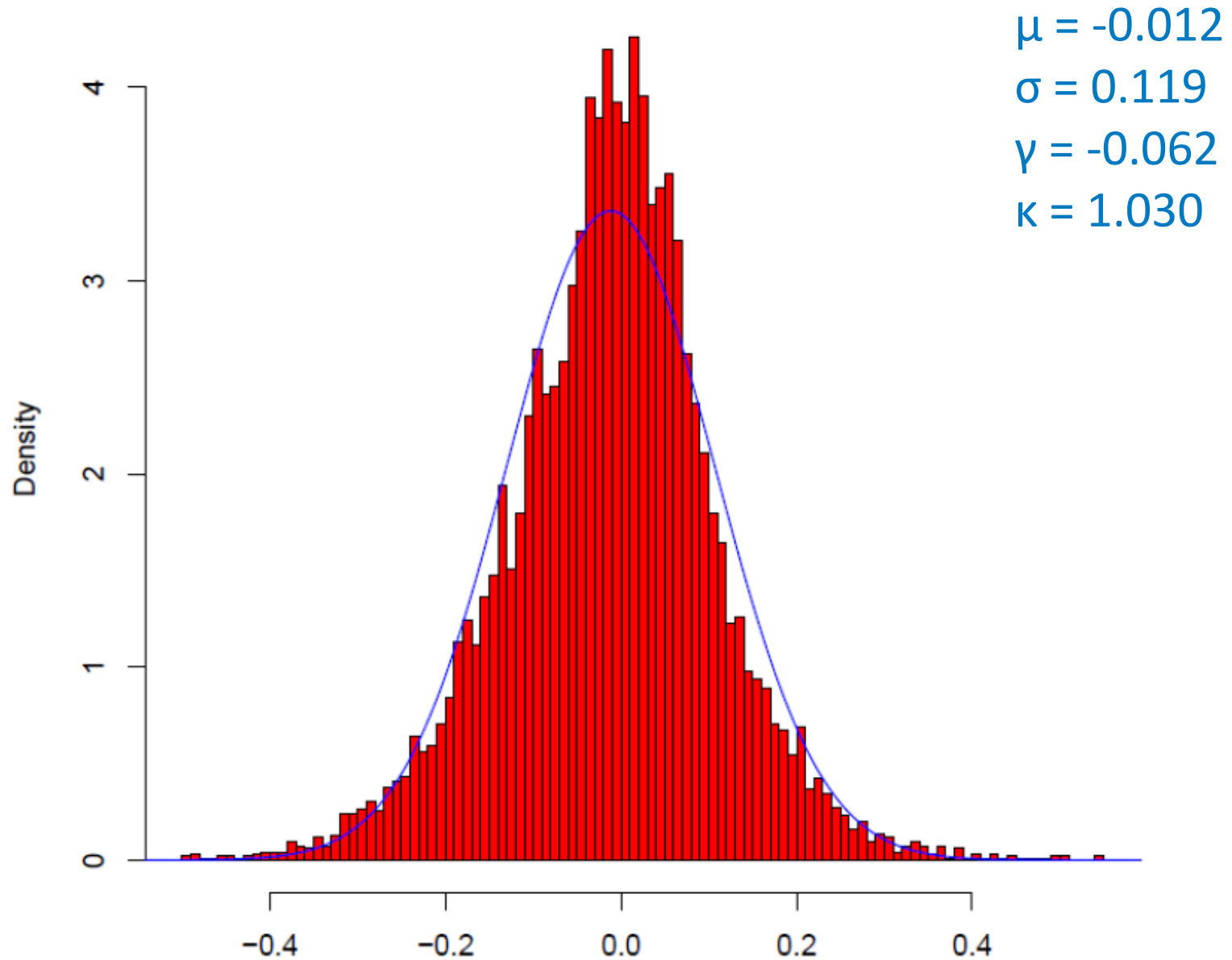
# Data Utilized

Pix 19096

- **ERCOT data**
  - Day-ahead forecasts
  - Hourly power output
  - 13 months of data
  - Forecasts made at 16:00 the day prior
  - ~ 9,000 MW wind capacity
- **CAISO data**
  - Day-ahead forecasts
  - Hourly power output
  - 12 months of data
  - ~ 940 MW wind capacity
- **Xcel Energy data**
  - Forecasts produced every 15 minutes for the next 72 hours
  - Hourly power output
  - 3 months of data
  - Single wind plant ~ 300 MW capacity

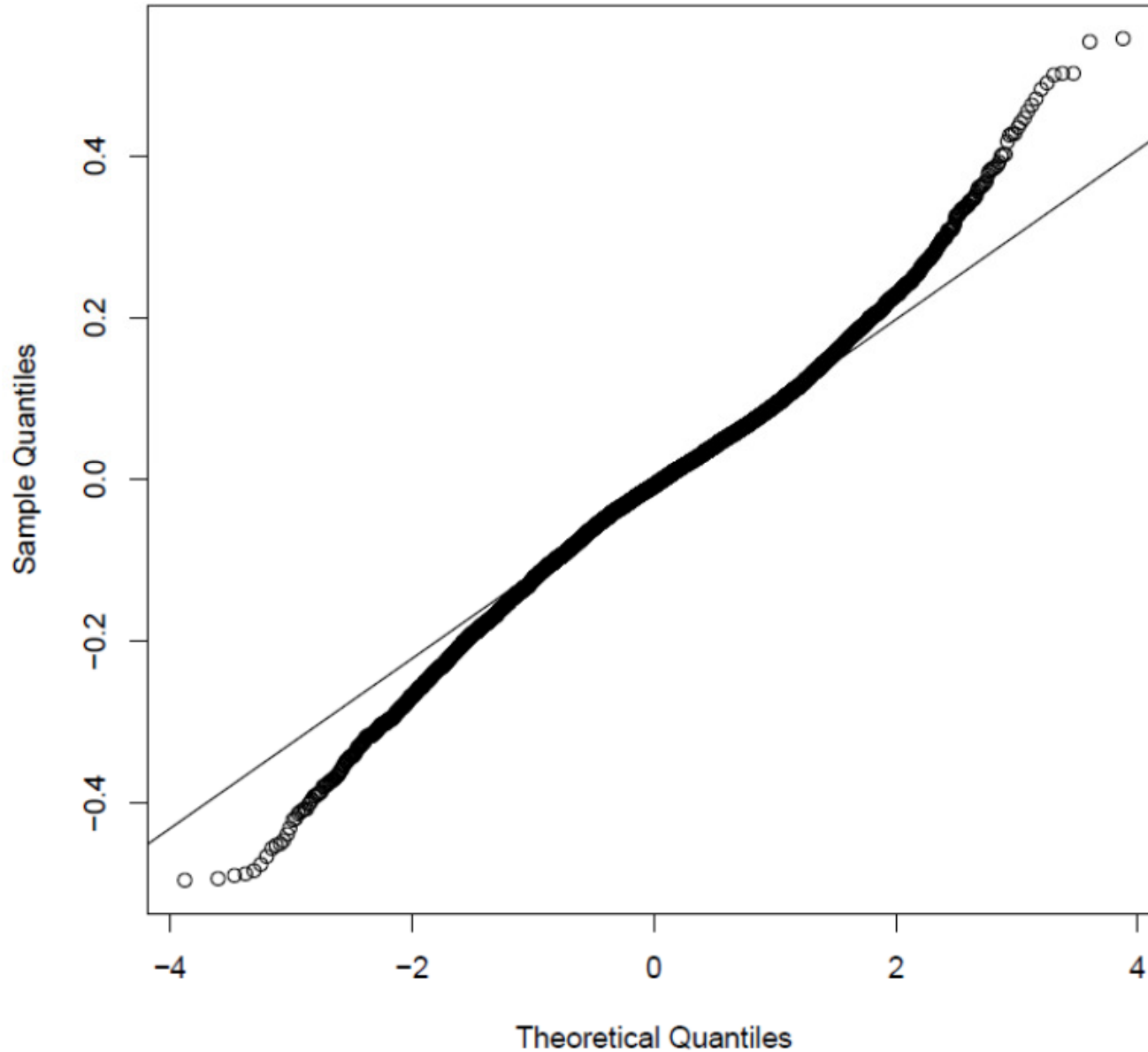


# ERCOT Day-Ahead Histogram



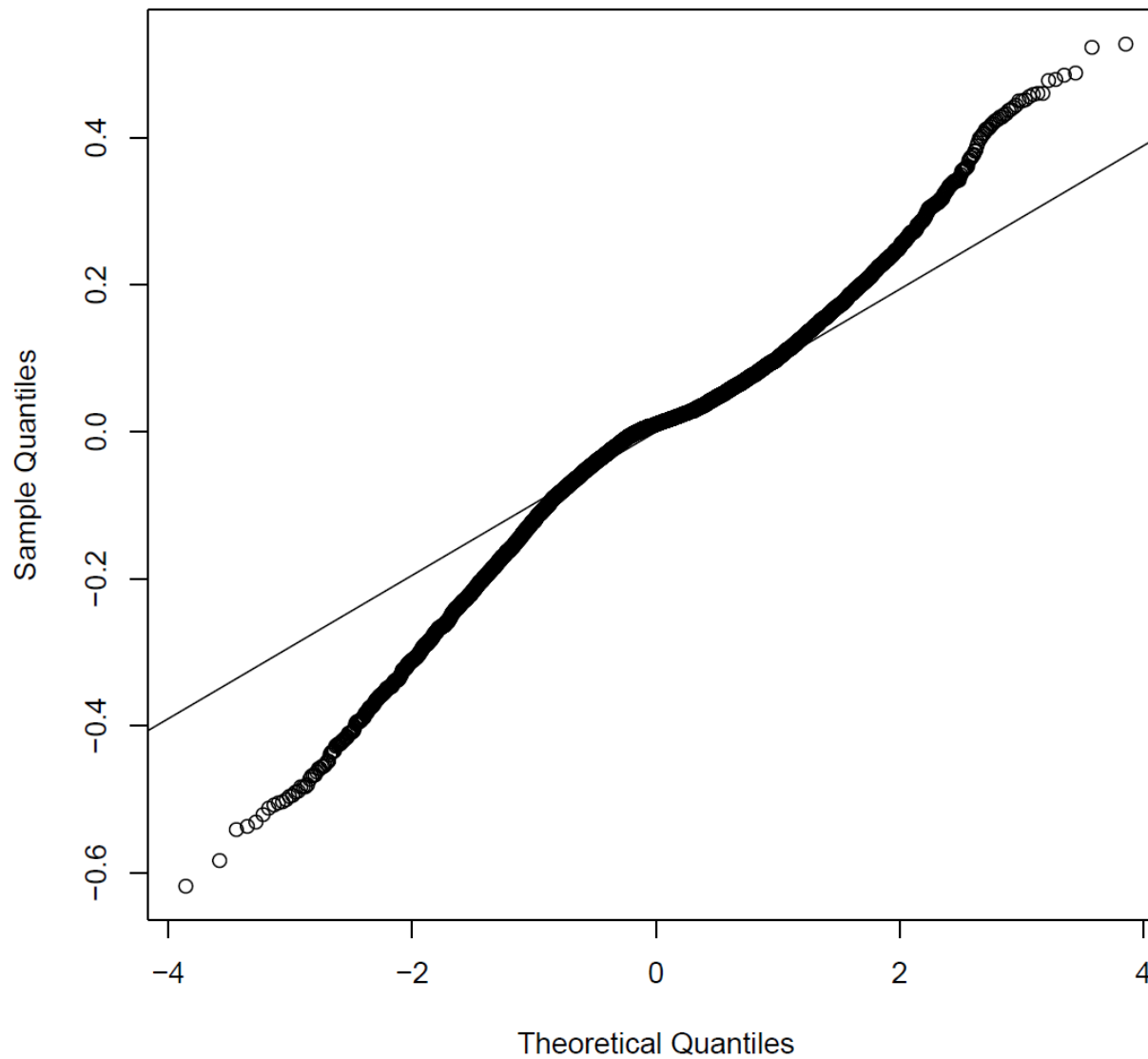


# ERCOT Day-Ahead Normal Q-Q Plot

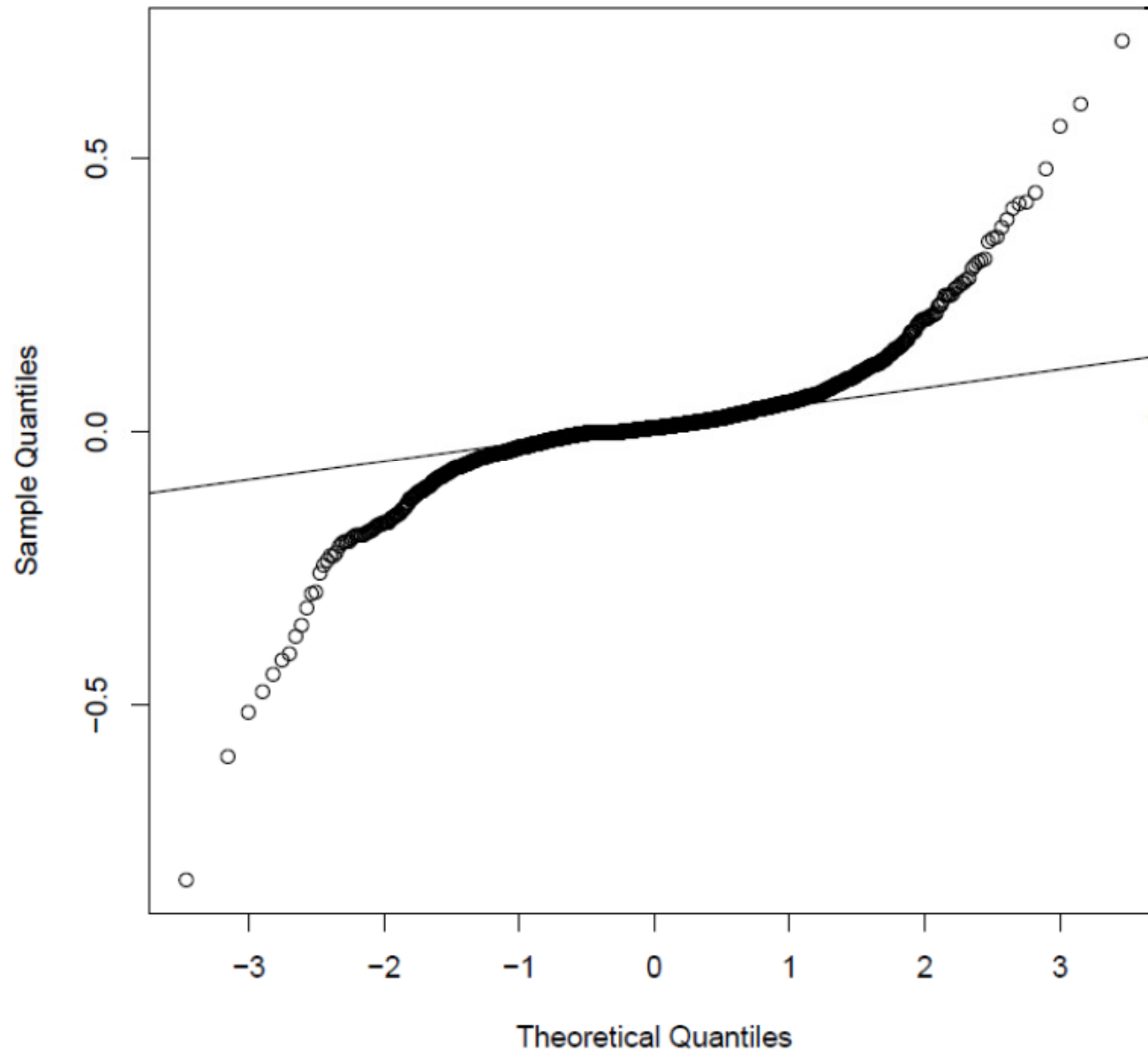


# CAISO Day-Ahead Normal Q-Q Plot

Normal Q-Q Plot

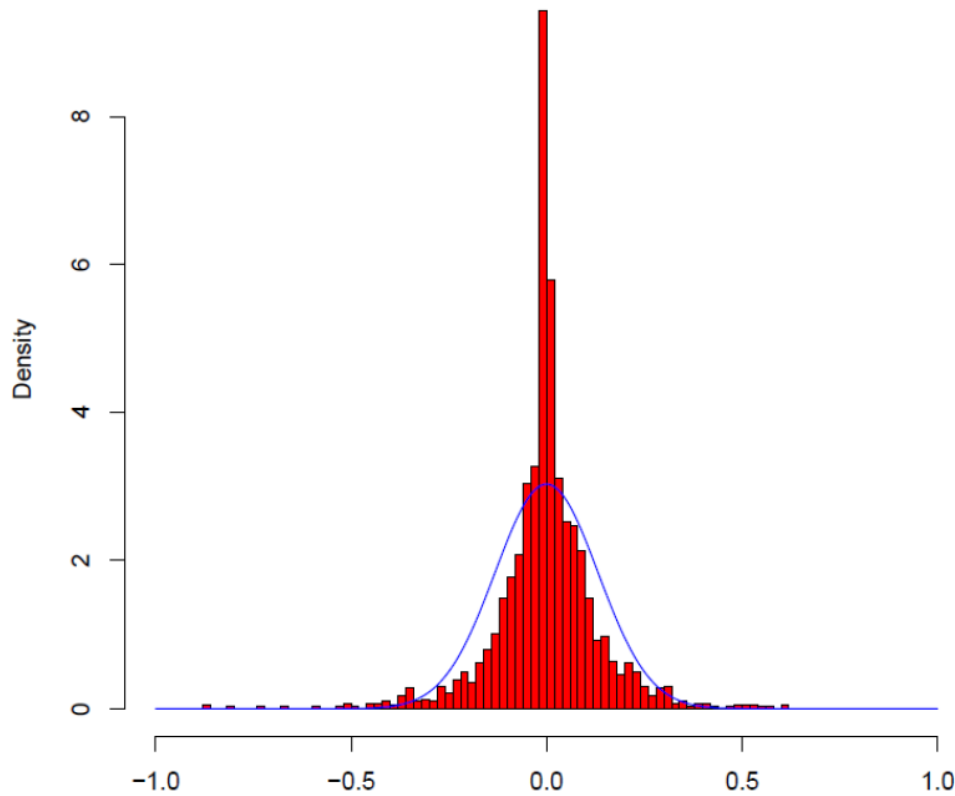


# Xcel Plant 1-Hour Normal Q-Q Plot



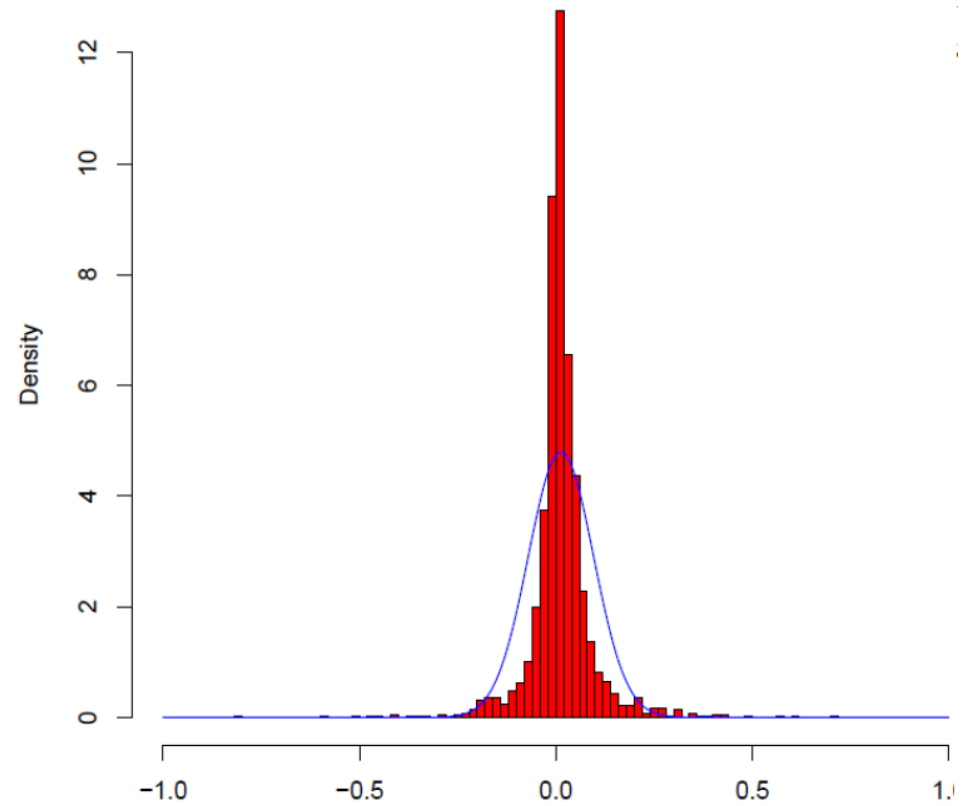
# Xcel Hour-Ahead Persistence Comparison

Persistence Model



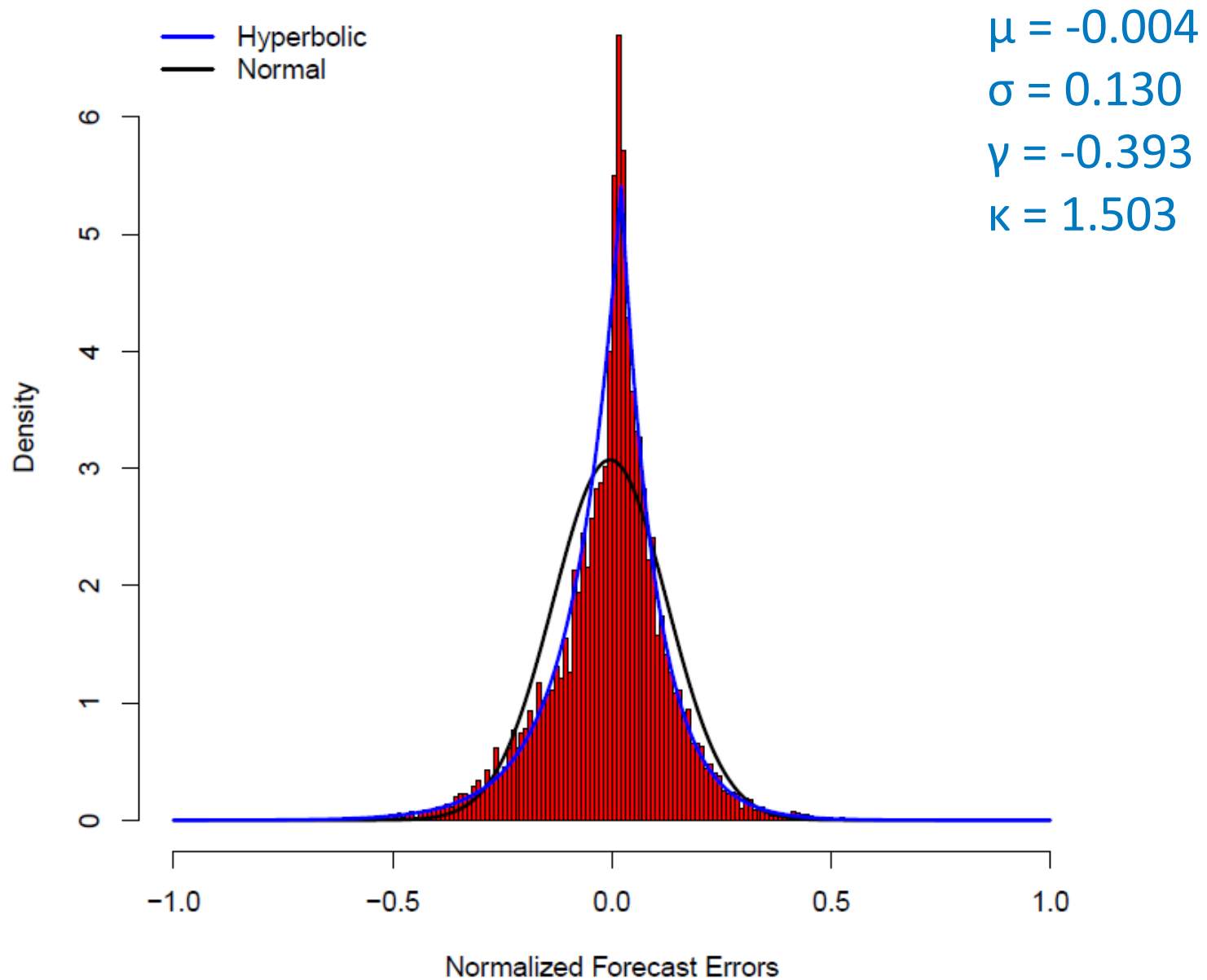
$$\gamma = -0.51; \kappa = 5.97$$

Operational Model



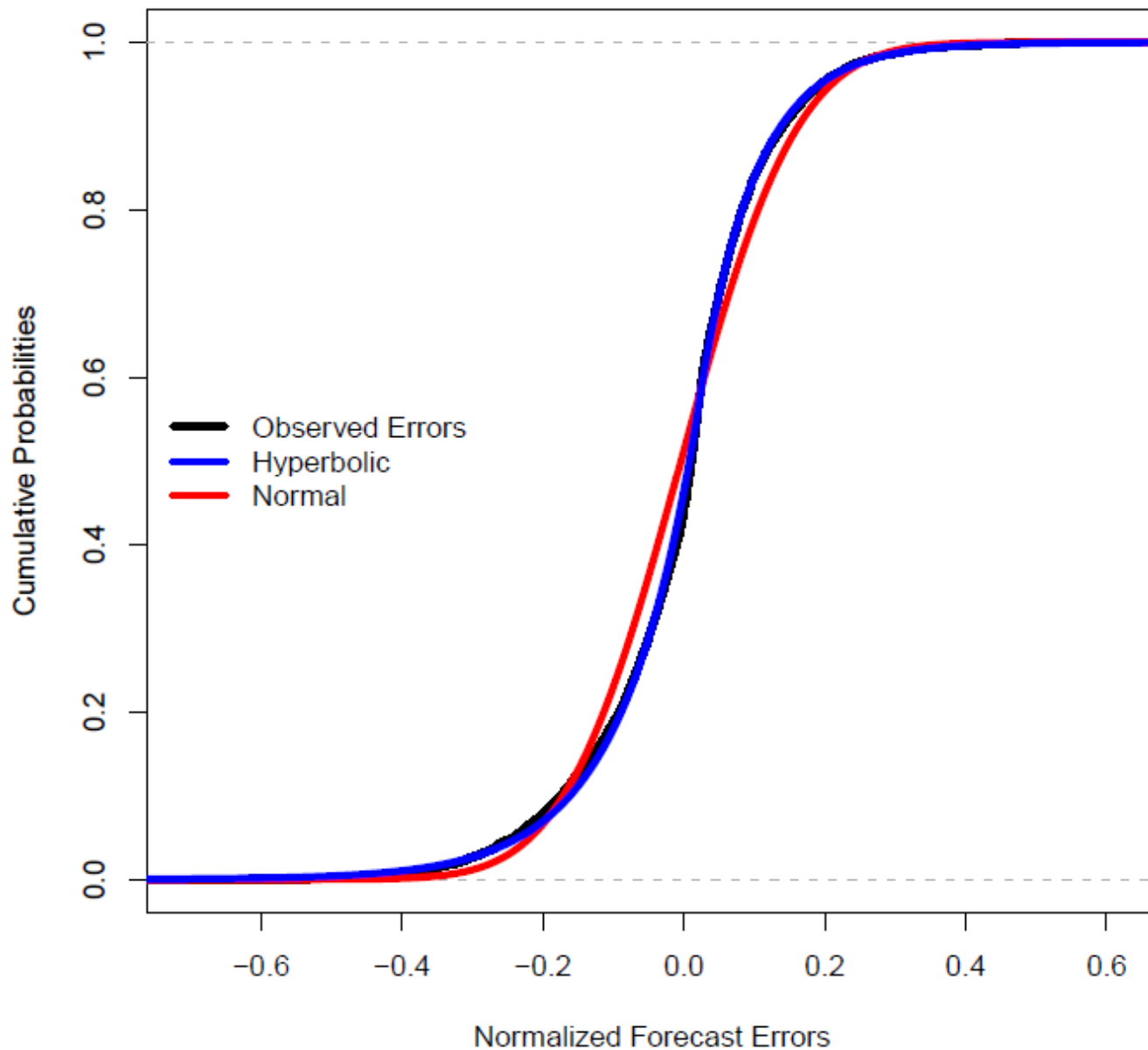
$$\gamma = -0.01; \kappa = 17.62$$

# Modeling CAISO Day-Ahead Wind Forecasting Errors

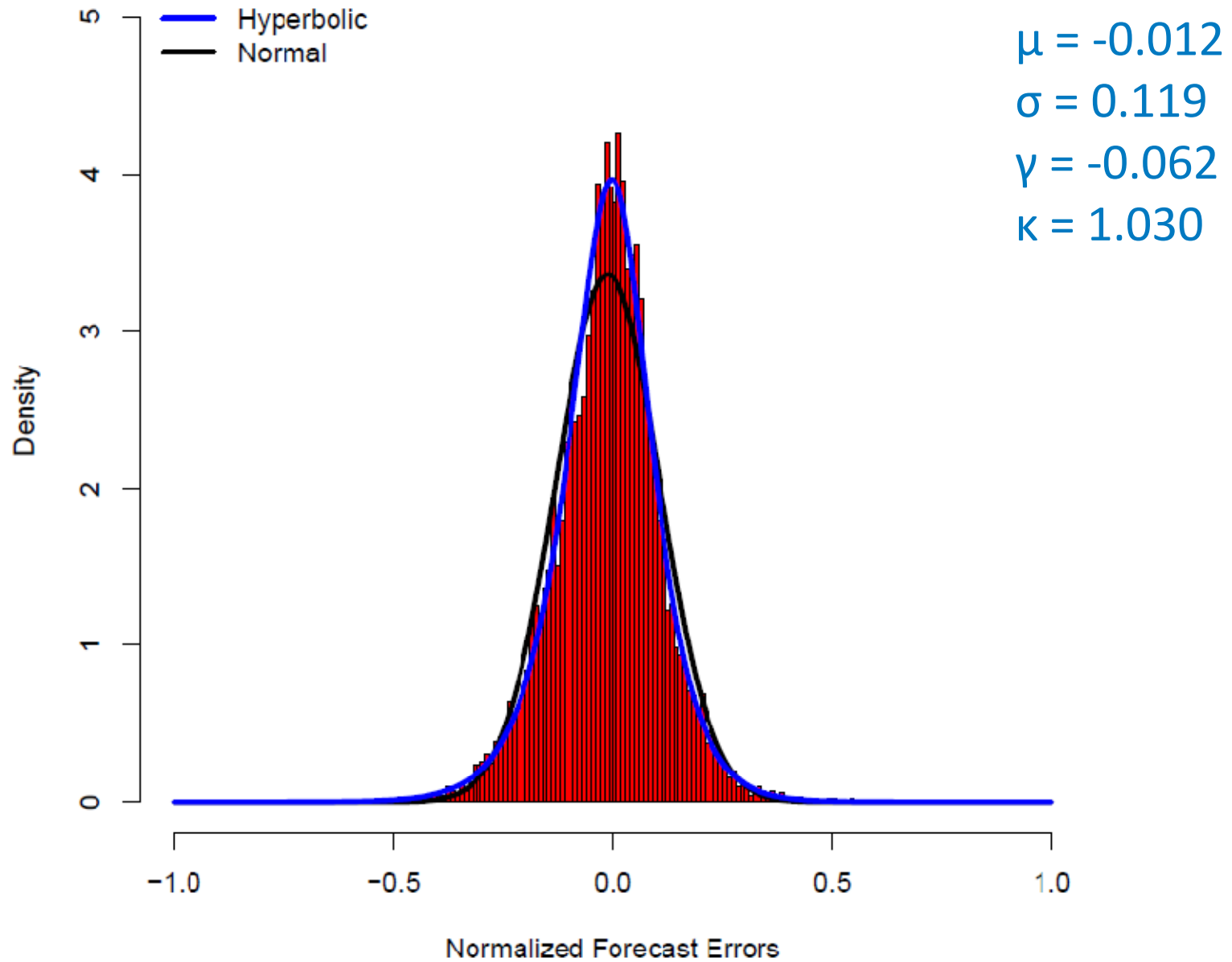




# Cumulative Distribution Plot of CAISO Wind Errors

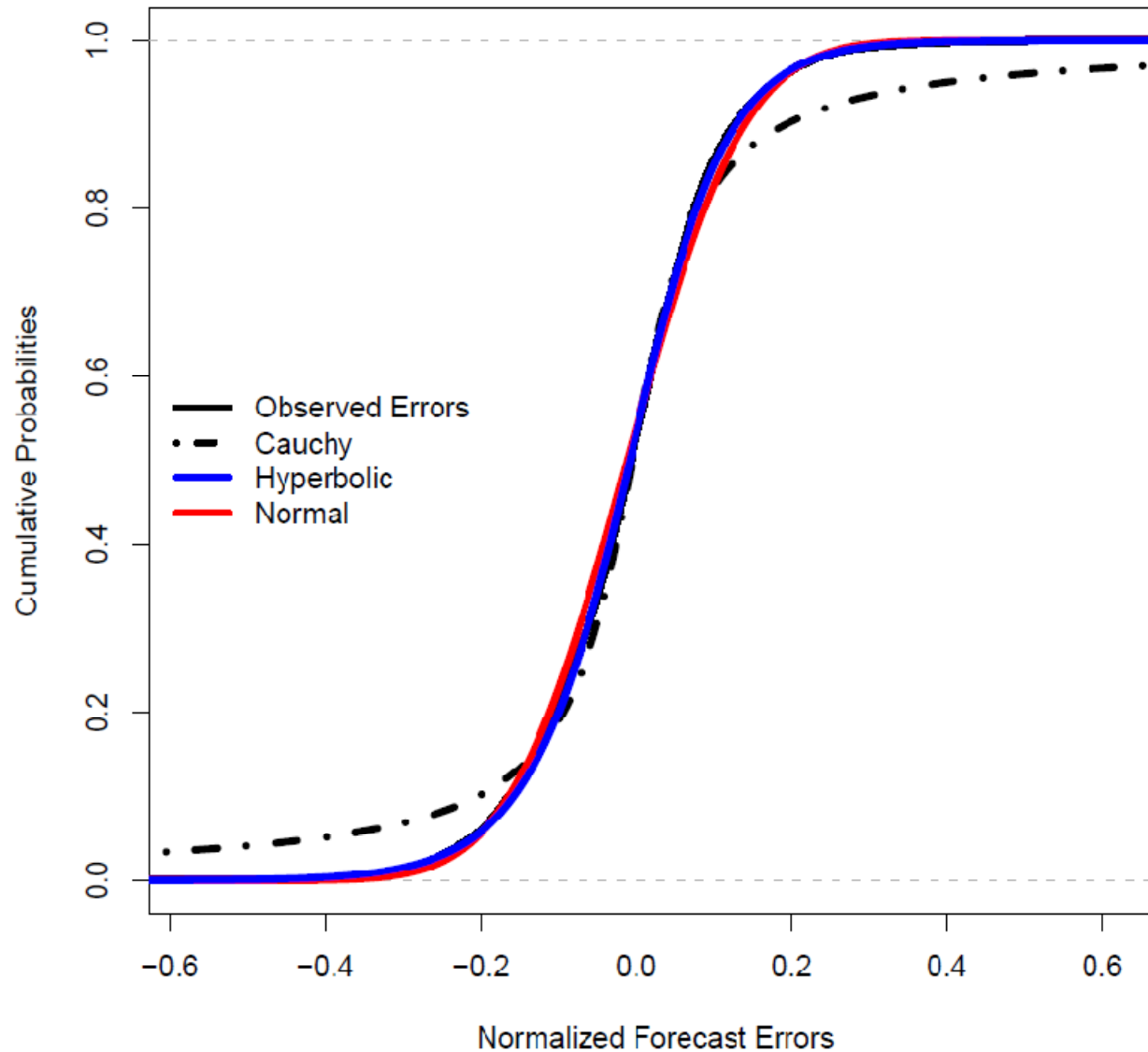


# Modeling ERCOT Wind Forecast Errors



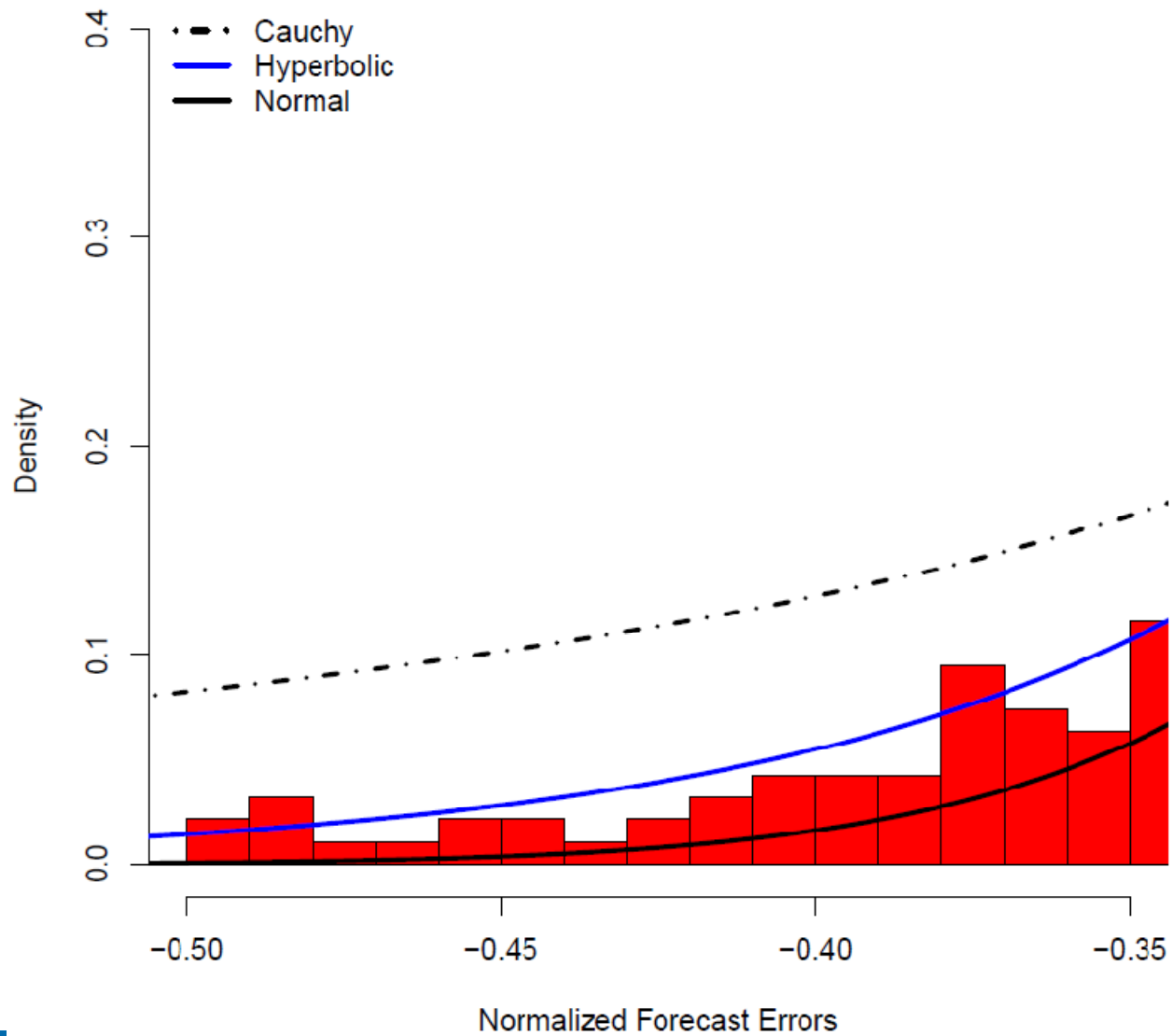
# ERCOT Day-Ahead Distribution

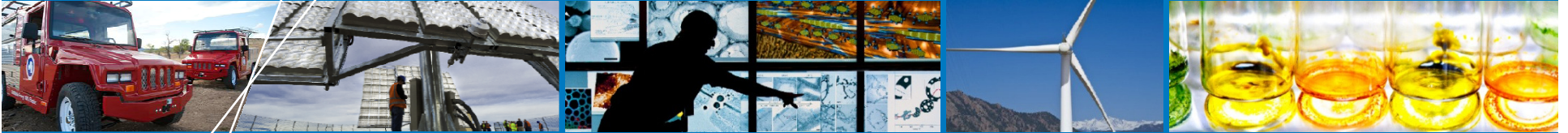
Cumulative Distribution Plot



# ERCOT Day-Ahead Distribution

ERCOT Day-Ahead Forecast Errors

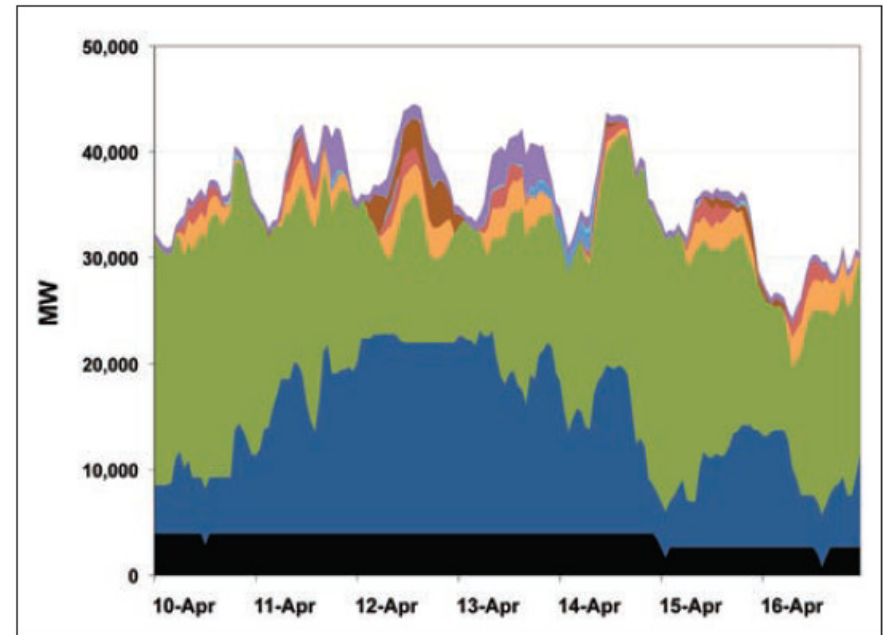
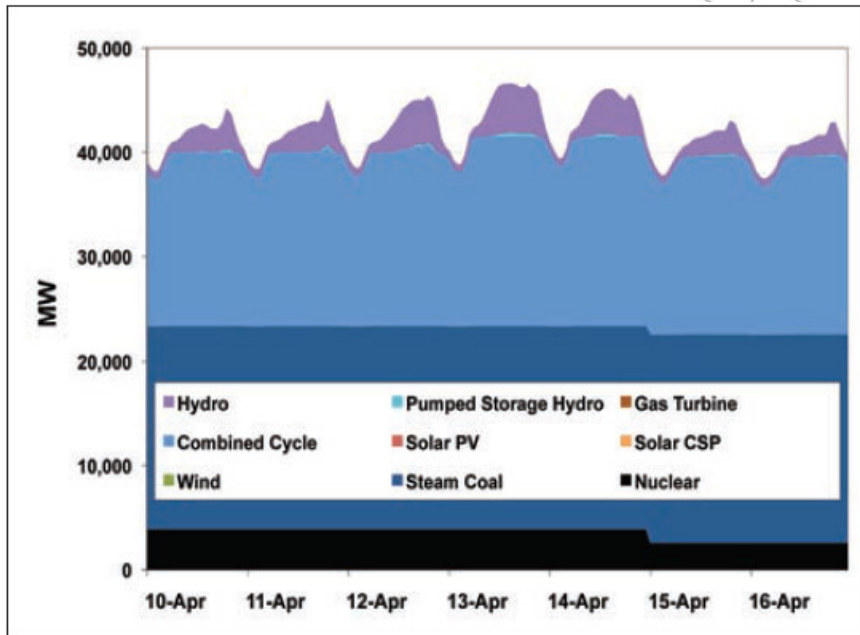
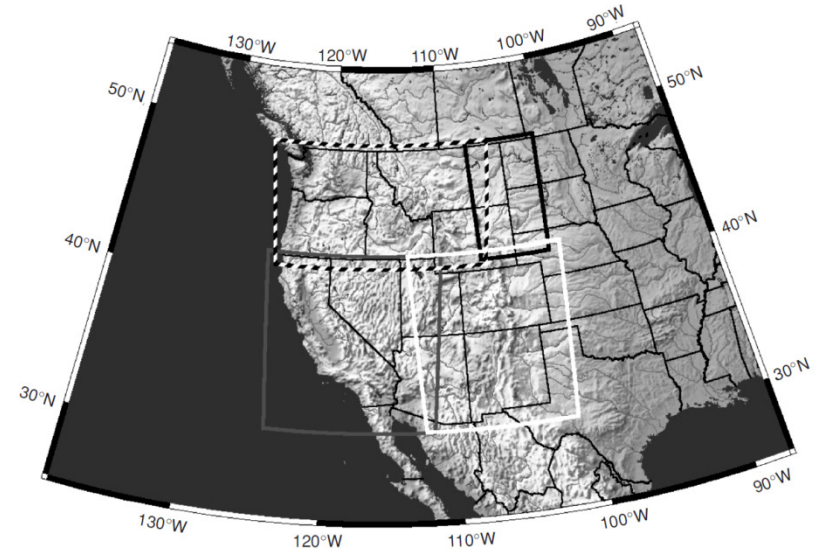
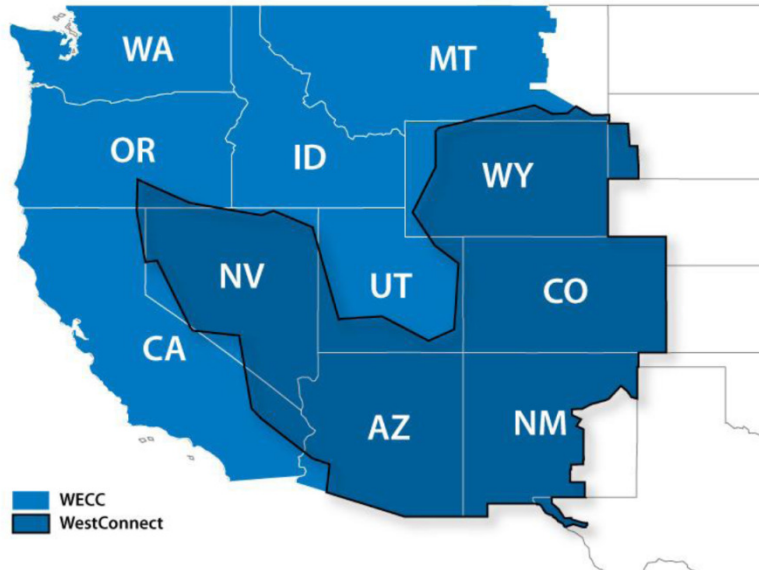




# Application to the WWSIS 2

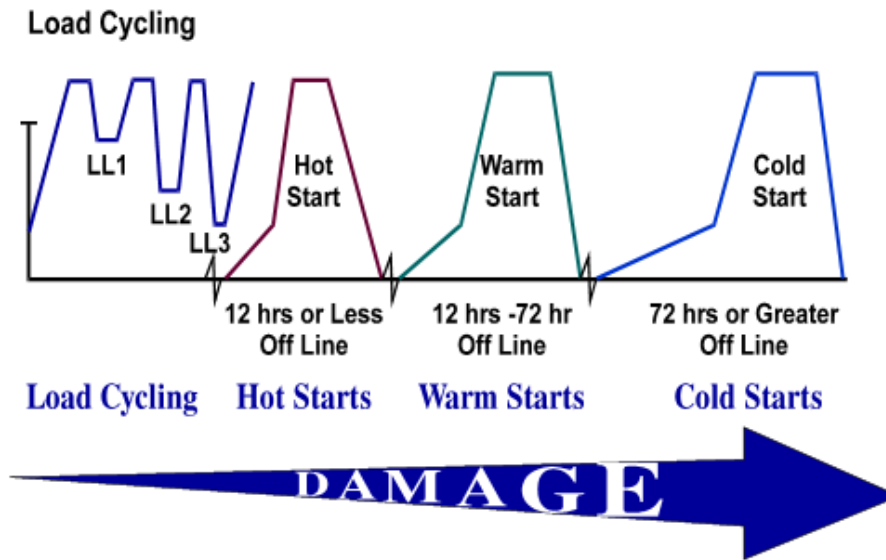


# Western Wind and Solar Integration Study



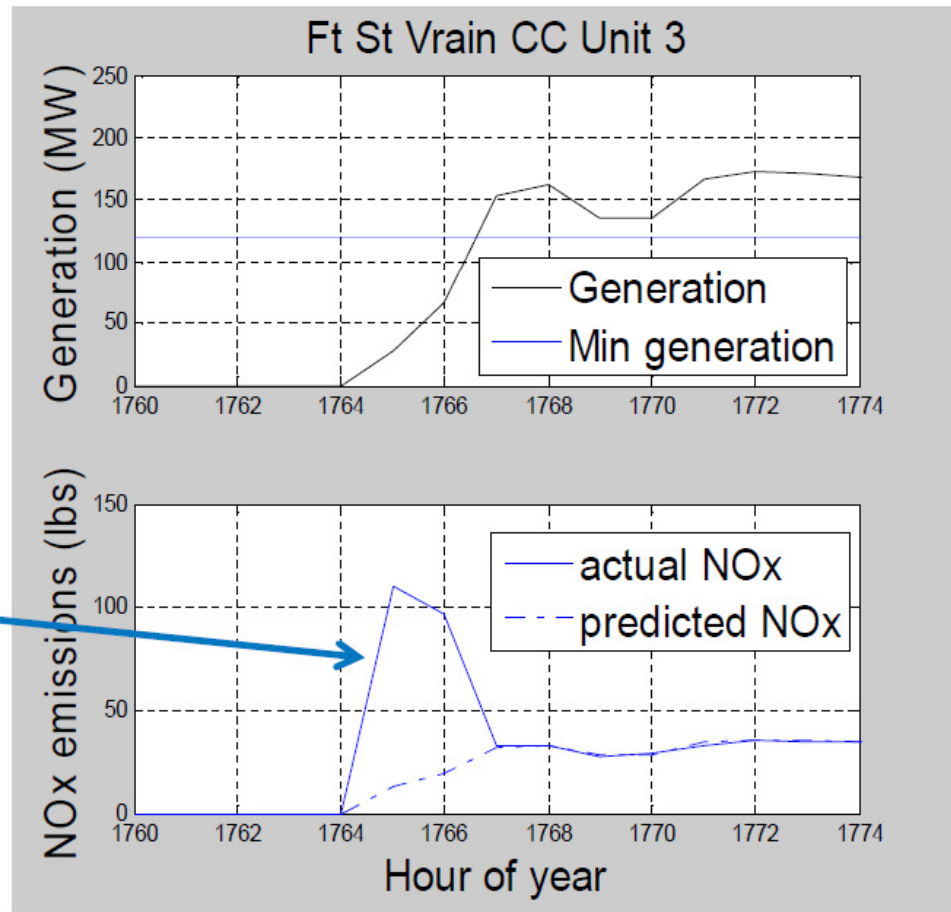
# WWSIS Phase 2

## Thermal Unit Cycling



Additional start-up emissions

## Emissions Analysis



Source: Steve Lefton, Intertek APTECH, with permission.

# Production Cost Modeling – Balancing Areas

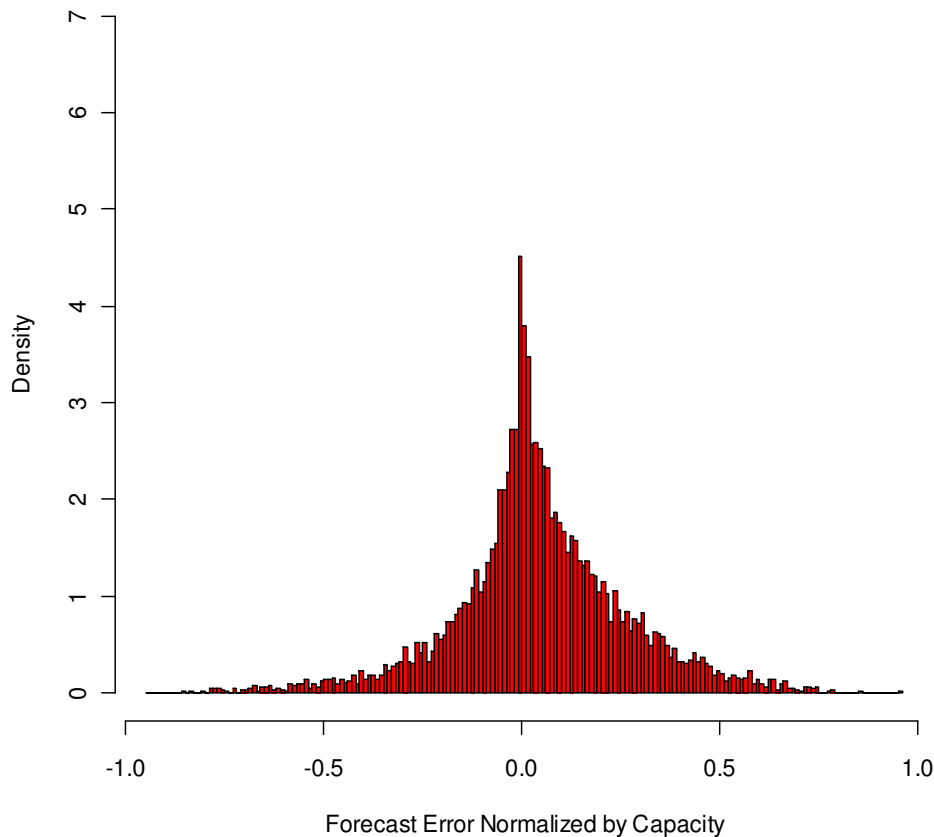


# Comparison of Operational and WWSIS Forecasts - CAISO

WWSIS 1 CAISO errors - 960 MW

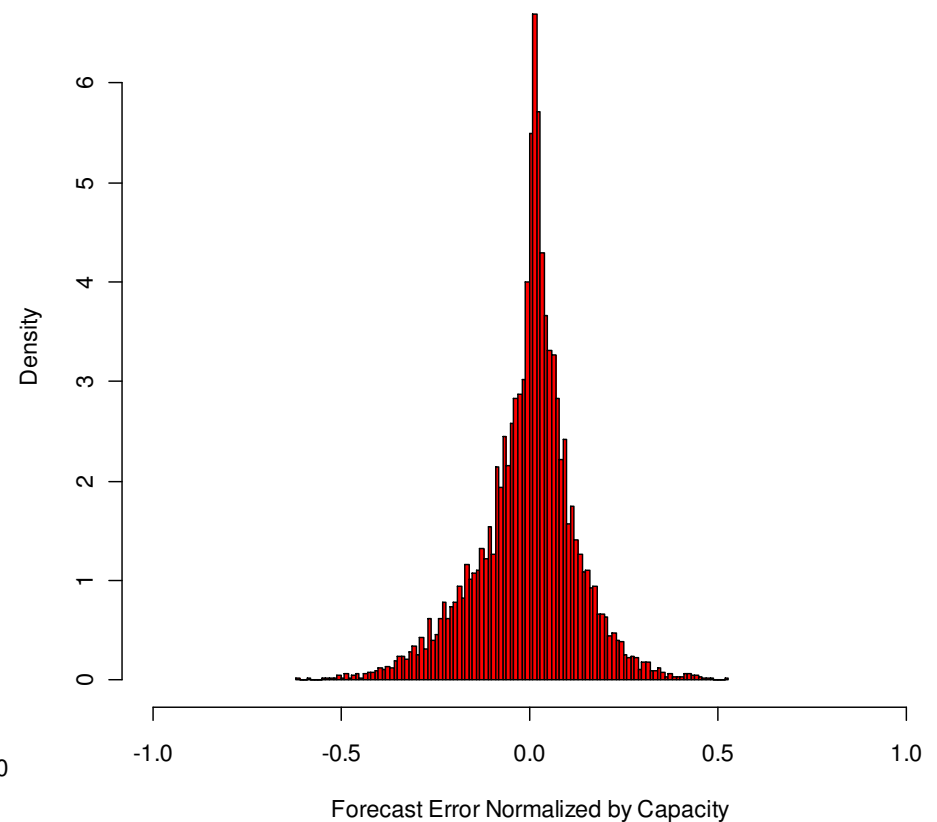
Operational CAISO errors - ~ 950 MW

Histogram of WWSIS Forecast Errors for CAISO



Mean = 0.044; Standard deviation = 0.222  
Skewness = -0.061; Kurtosis = 1.680

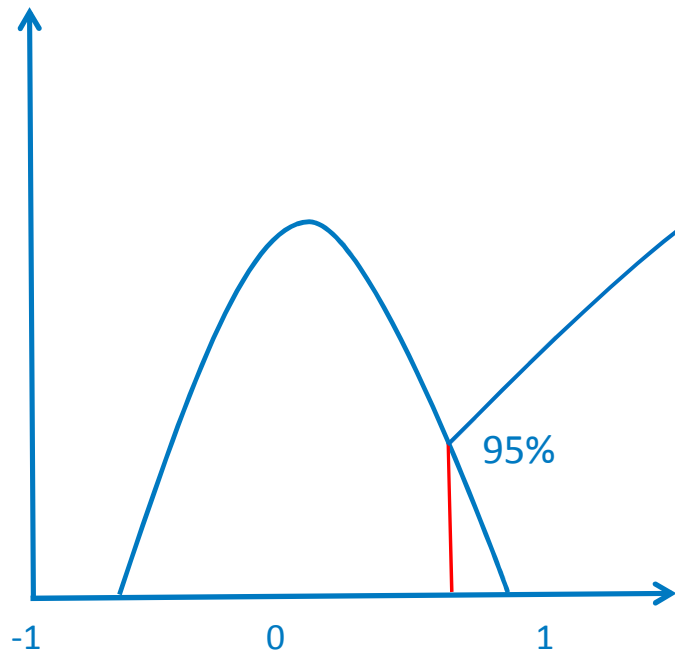
Histogram of Actual Forecast Errors from CAISO



Mean = -0.004; Standard deviation = 0.130  
Skewness = -0.393; Kurtosis = 1.503

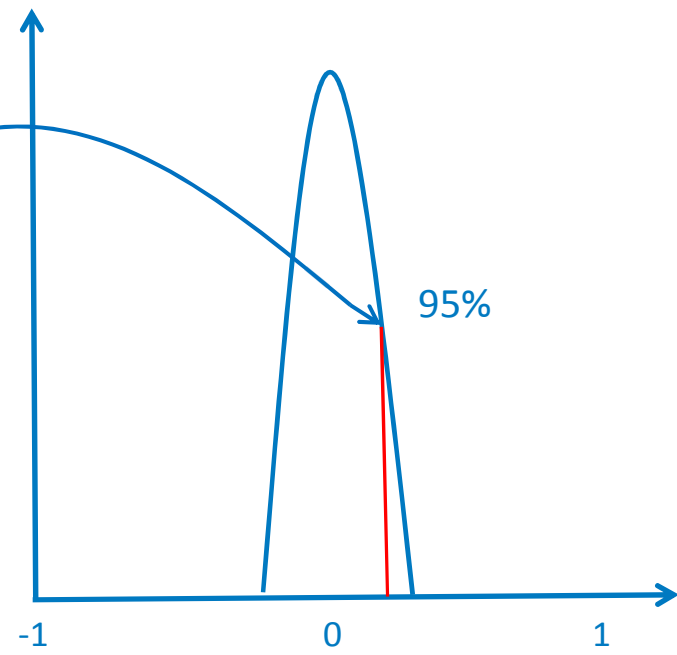
# Mapping Forecast Errors

WWSIS Forecast Errors



Normalized Forecast Error

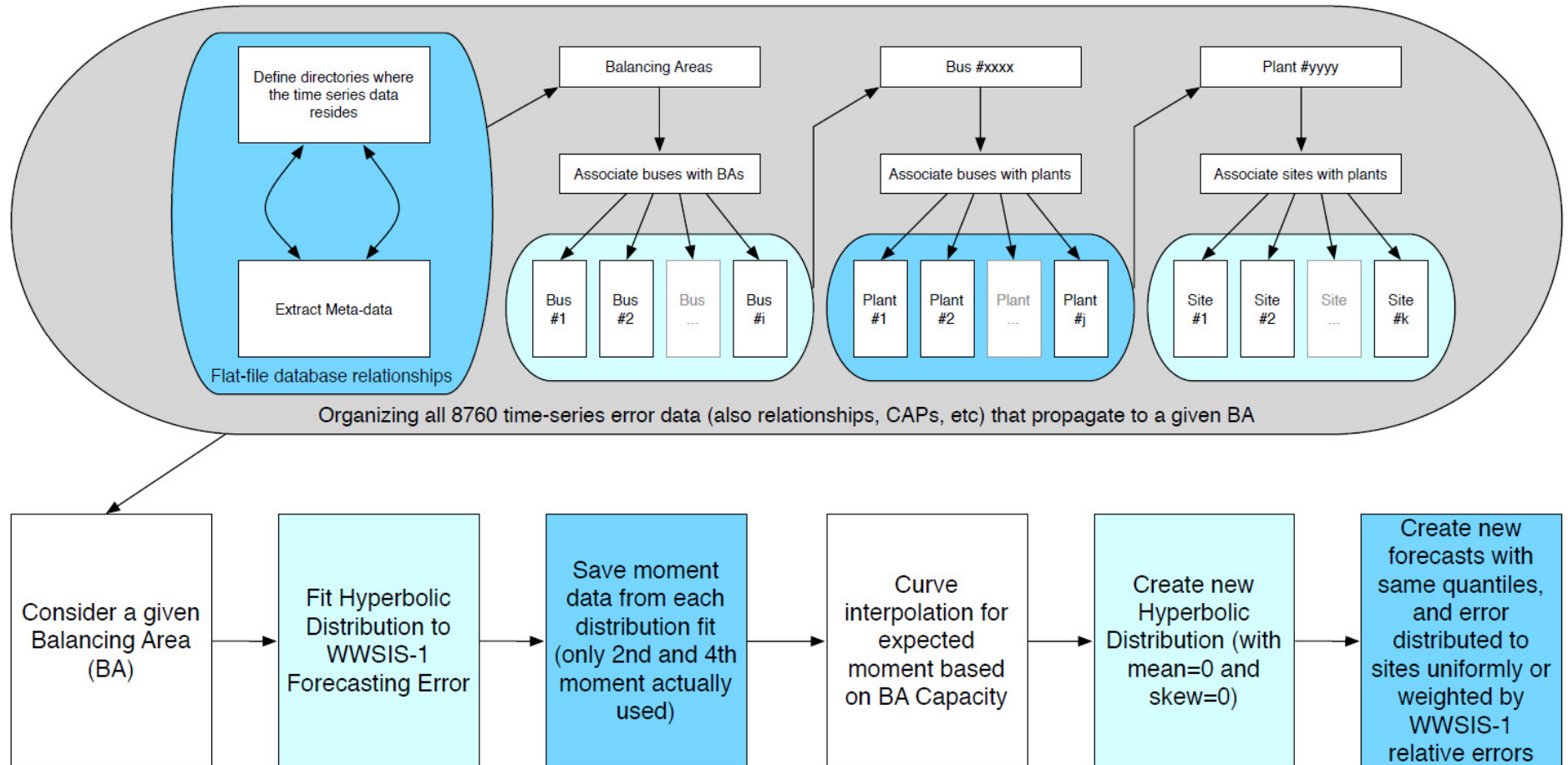
Model Production Forecast Errors



Normalized Forecast Error



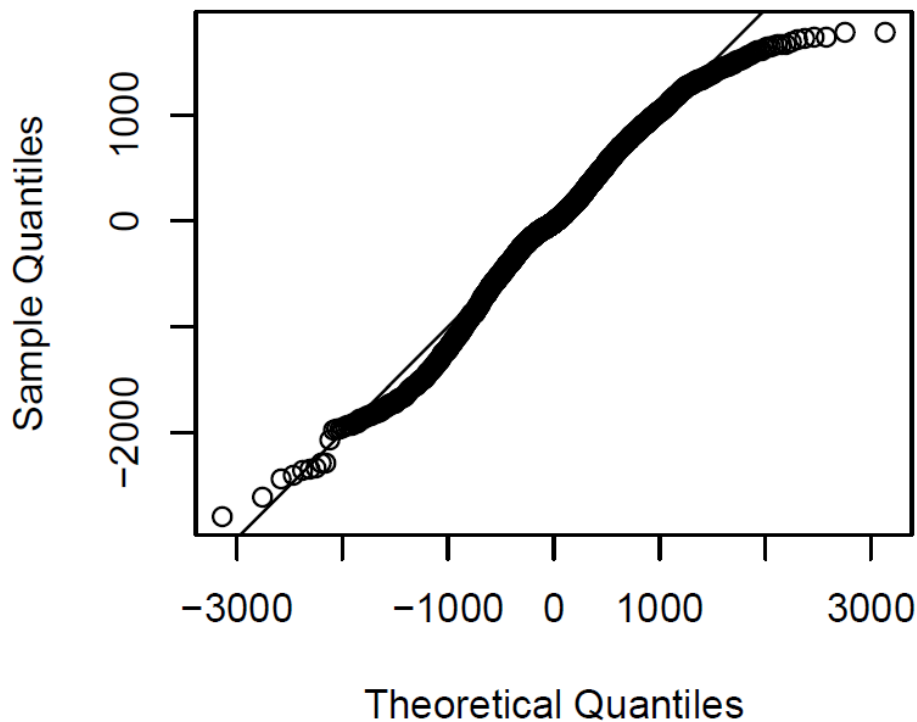
# Overview of Forecast Error Correction Procedure



# Forecast Error Correction Procedure Results

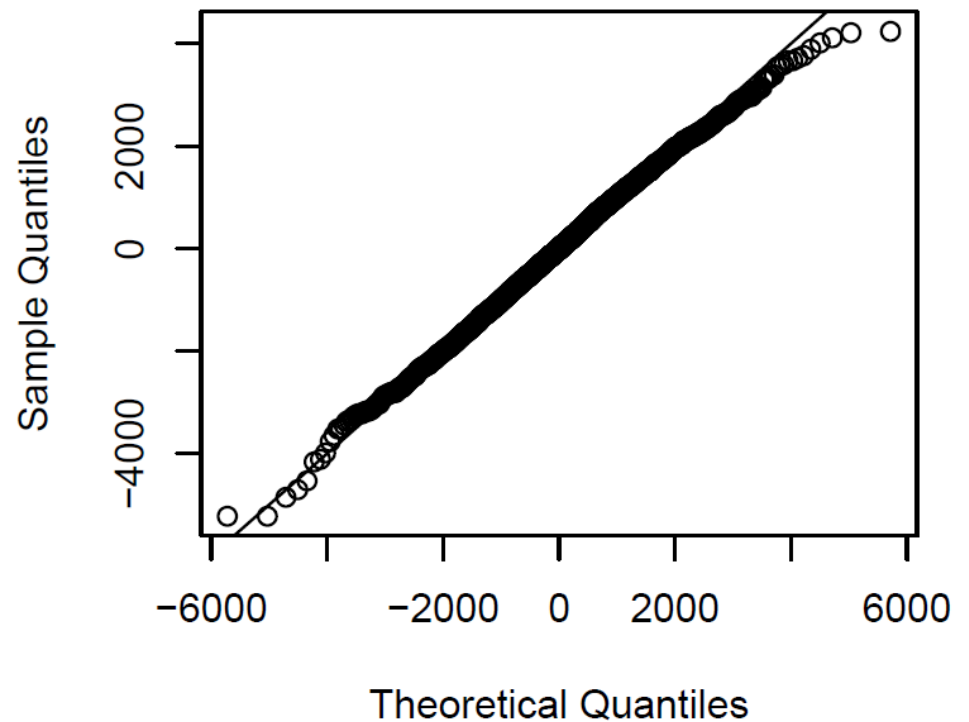
## Original Forecasts

Q-Q plot of Measured Error versus Theoretical values



## Updated Forecasts

Q-Q plot of Measured Error versus Theoretical values



# Acknowledgements



- Anthony Florita
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- Debra Lew
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- Greg Brinkman

PIX 11188

- David Maggio – ERCOT
- James Blatchford - CAISO
- Keith Parks – Xcel Energy

PIX 14961



# Questions?

PIX 17731



PIX 16105

