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ERCOT Forecasting Overview and Response to QMWG & ERCOT Questions

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Overview

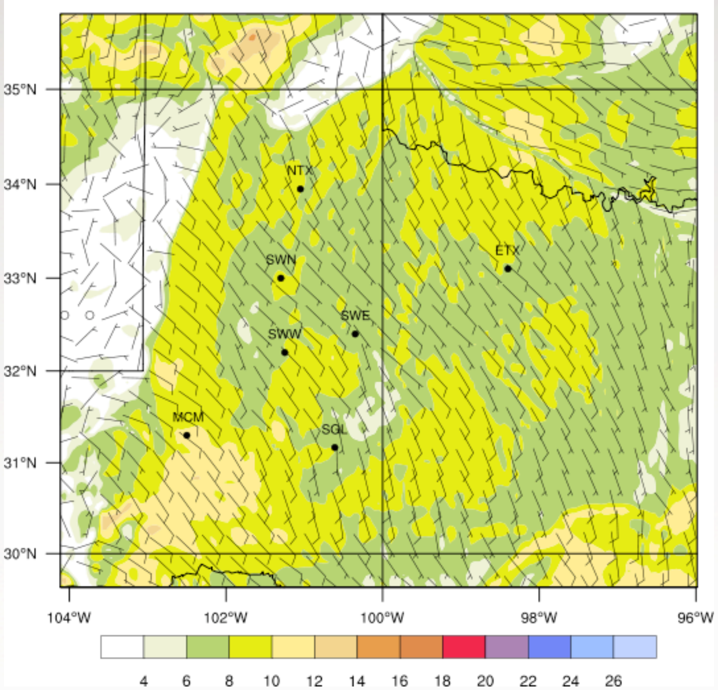
- ERCOT Forecast Review
  - Methods
  - Products
  - Recent Performance
- Response to Questions
- ERCOT-related Forecasting Research

Methods

Physics-based Models

(also known as Numerical Weather Prediction (NWP) Models)

- Differential equations for basic physical principles are solved on a 3-D grid
- Must specify initial values of all model variables for every grid cell for each forecast cycle
- Simulates the evolution of all basic atmospheric variables over a 3-D volume
- Modeling system has internal empirical components – e.g. turbulence sub-model



Roles of NWP Models

- Blends data from a wide variety of sources over a large area to use as forecast input
- Provides a link between current data at any site and the future behavior of the forecast site
- Can make a forecast for a site without having data from the site (does not need training)
- Is not constrained by historical data (can forecast rare or extreme events)

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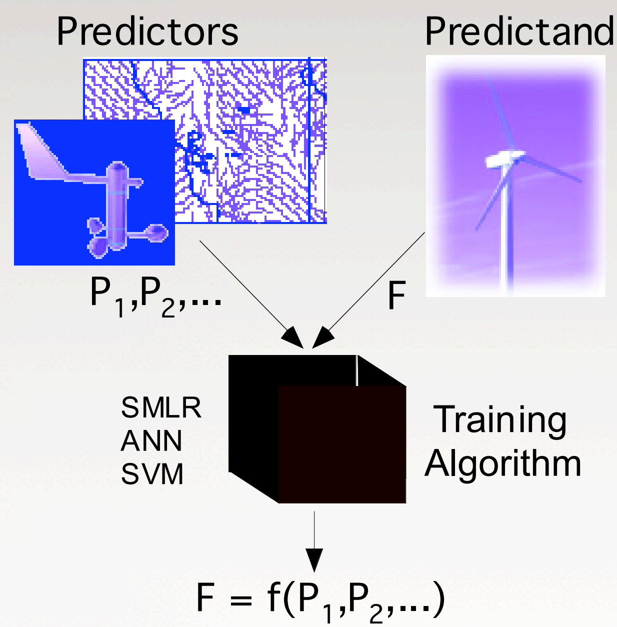
Statistical Models

- Empirical equations are derived from historical predictor and predictand data ("training sample")
- Current predictor data and empirical equations are then used to make forecasts
- Many different model-generating methods available (linear regression, neural networks, support vector regression etc.)



Roles of Statistical Models

- Account for processes on a scale smaller than NWP grid cells (downscaling)
- Correct systematic-errors in the NWP forecasts
- Incorporate additional (onsite and offsite) observational data
  - received after the initialization of most recent NWP model runs
  - not effectively included in NWP simulations

Model Output Statistics (MOS)

Methods

Plant Output Models

- Relationship of met variables to power production for a specific wind plant
- Many possible formulations
  - implicit or explicit
  - statistical or physics-based
  - single or multi-parameter

Roles of Plant Output Models

- Transforms predictions of met variables to power output forecasts
- Estimates impact of facility-scale variations in wind (among turbine sites)
- Accounts for turbine layout effects (e.g. wake effects)
- Considers operational factors (availability, turbine performance etc)

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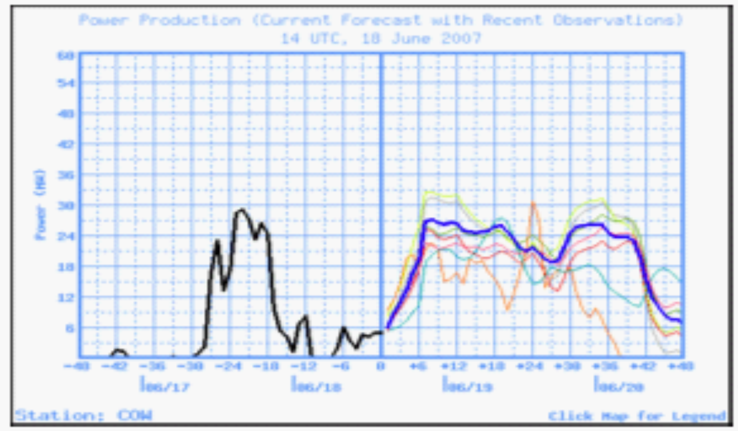
Forecast Ensembles

- Uncertainty present in any forecast method due to
  - Input data
  - Model type
  - Model configuration



- Approach: perturb input data and model parameters within their range of uncertainty and produce a set of forecasts (i.e. an ensemble)

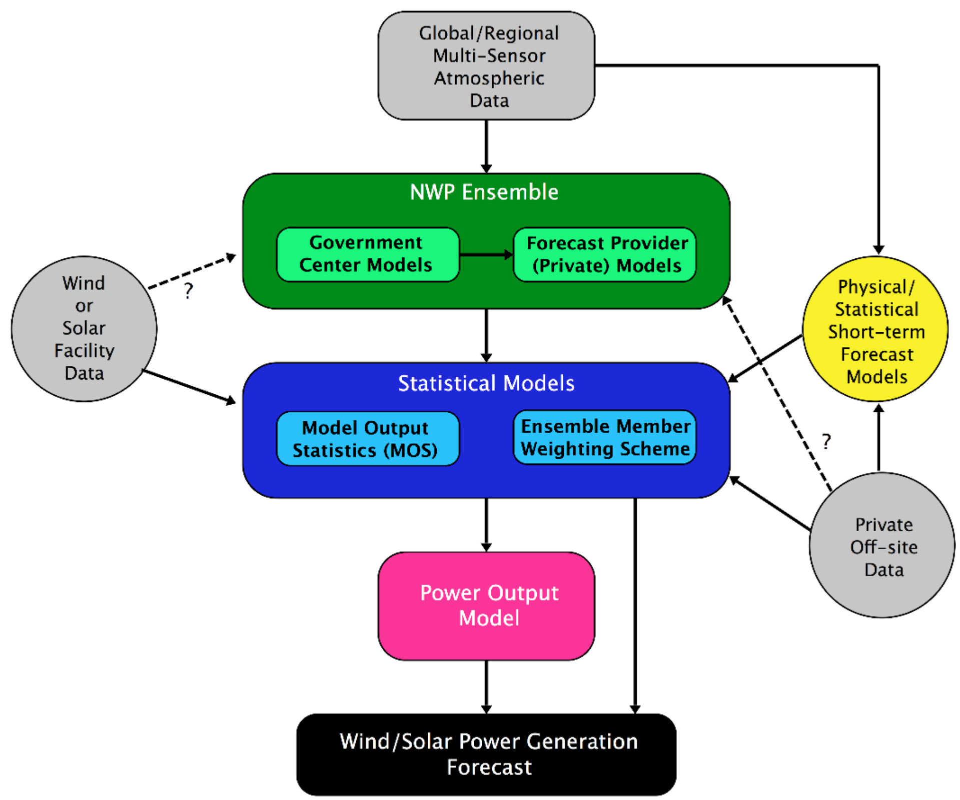
Roles of Ensembles

- Composite of ensemble members is often the best performing forecast
- Statistical weighting of ensemble members is typically used to create a composite
- Ensemble spread provides case-specific measure of forecast uncertainty
- Can be used to estimate structure of forecast probability distribution

Methods

Integrated Forecast System

- Days ahead
  - A statistical composite of an ensemble of statistically adjusted NWP forecasts
- Hours ahead
  - Time series methods
  - Feature detection algorithms
  - Rapid update NWP
  - Ensemble composite of the above
- Minutes Ahead
  - Time series methods
  - Feature detection algorithms with remotely sensed data?



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Methods

Application to ERCOT Forecasts

- **Standard Cycle NWP**
  - Ensemble of runs updated every 6 or 12 hours; run to 60 hours
  - Based on US NWS and Environment Canada (EC) large scale model output
  - Primary tool for look ahead periods > 6 hours
- **Short Cycle NWP (mostly for ELRAS at present)**
  - Currently one run updated every two hours; run to 13 hours
  - Assimilates regional data including WGR met data
- **Multi-predictor Statistical Models**
  - Now trained with raw power (not HSL) with curtailment times removed
  - NWP model output (MOS)
  - Recent trends from onsite data (power and met)
  - Time-lagged off-site predictors
- **Persistence & Climatology**
- **Ensemble**
  - Unweighted average currently in use due to data issues
  - Working towards weighted composite based on historical performance
- **Feature Detection and Tracking (under development)**

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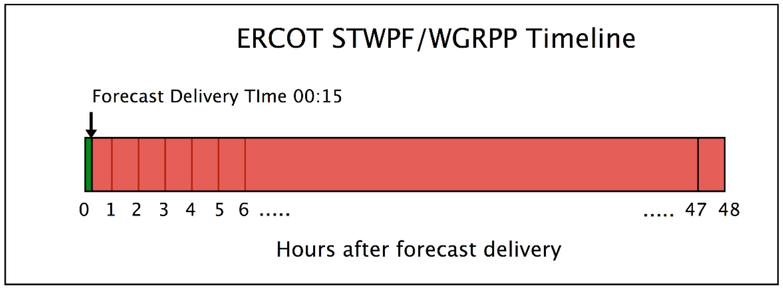
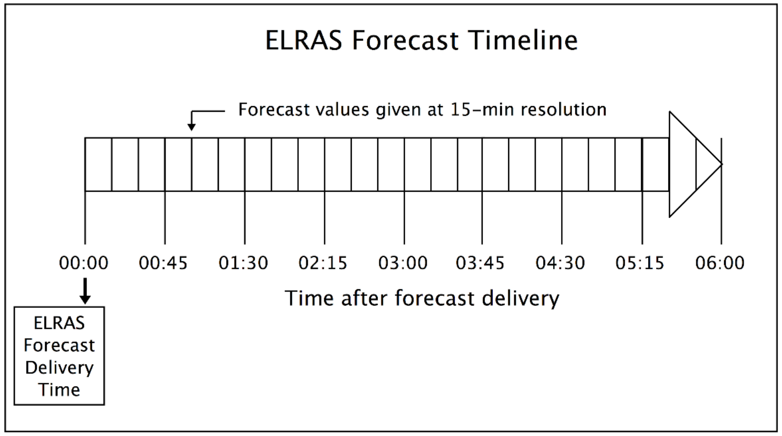
ERCOT Forecast Products

- **Short Term Wind Power Forecast (STWPF)**
  - Delivery: 15 mins after the hour (DT)
  - 0-48 hour forecast
    - first interval begins on the hour (DT-0:15)
  - Average hourly MW
  - 80% POE MW (labeled as WGRPP)
- **ERCOT Large Ramp Alert System (ELRAS)**
  - Delivery: every 15 minutes
  - 0-6 hr forecast
    - first interval begins at time of delivery
  - POE for ramp rate thresholds for 3 time periods beginning at interval
  - List of ramp events with attributes
  - Situational awareness information

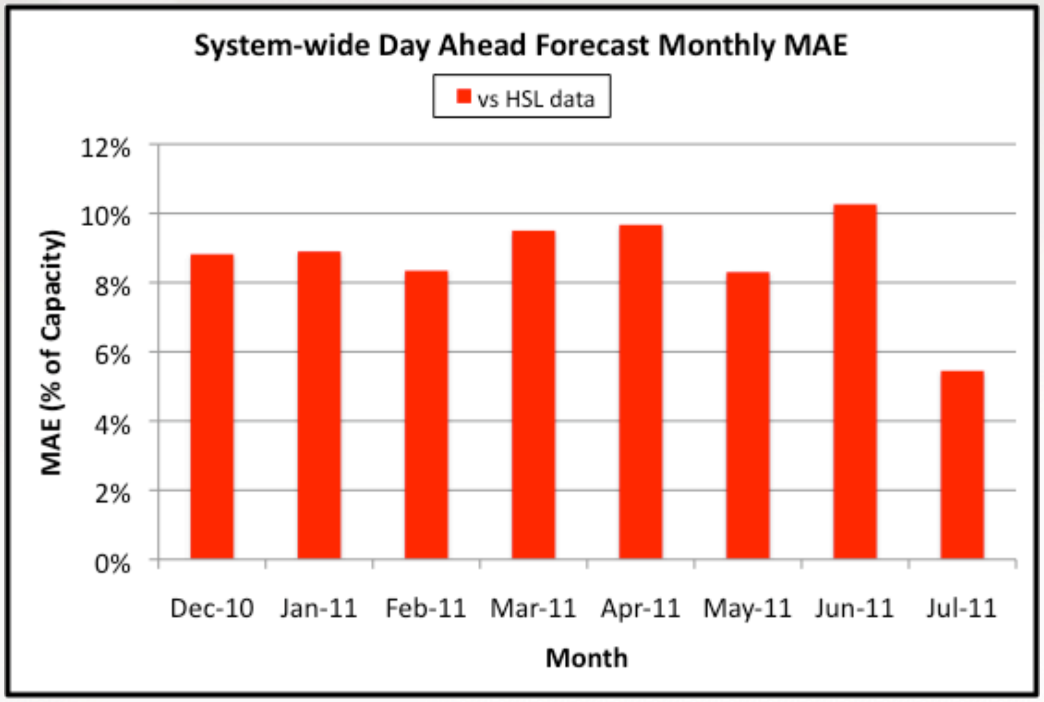




Performance

Recent Day-Ahead Performance

- HSL data used as “actual”
- Forecast delivered at 15:15 Central Time
- Over most recent 8 months the average day ahead MAE for system-wide forecasts was 8.6%
- Monthly MAE ranged from 10.3% to 5.4%
- Data issues remain so actual performance is most likely better than this
  - HSL data anomalies
  - Unreliable availability
  - Questionable met data



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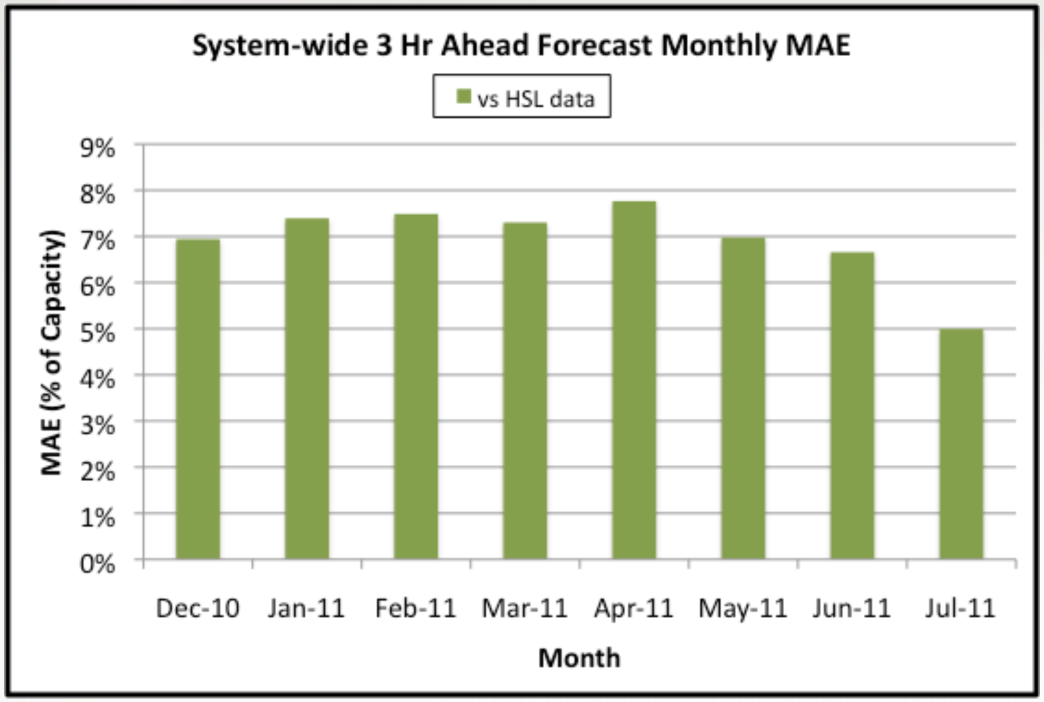
Performance

Recent 3 Hr Ahead Performance

- HSL data used as "actual"
- Forecast delivered at 15 minutes after each hour
- Over most recent 8 months: 6.9% MAE for system-wide forecasts
- Monthly MAE ranged from 7.8% to 5.0%
- Data issues remain so actual performance is most likely better
  - 0-6 hr look ahead is more sensitive to current data issues
  - So more impact than on day ahead forecasts



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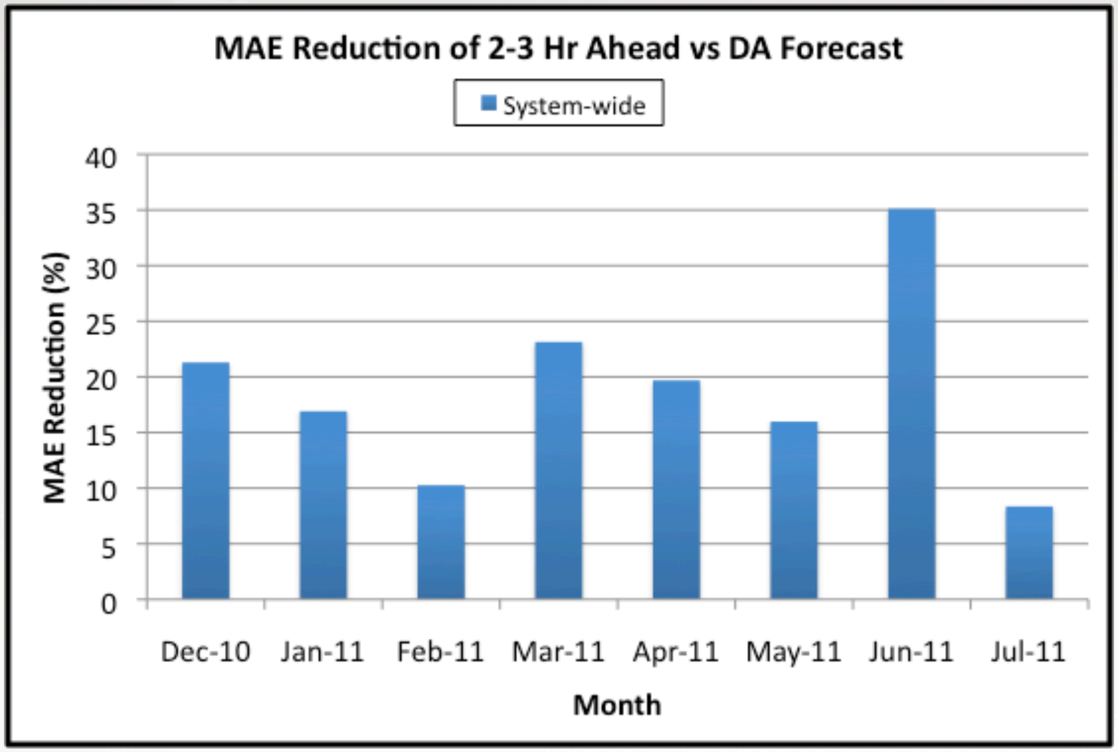
Responses to Questions

Questions

Question #1: Why the Hour-Ahead provides little improvement over the Day-Ahead forecast accuracy?

- Over a large sample of cases, hour ahead forecasts do substantially improve upon day-ahead
- Average MAE reduction of 2-3 hour ahead forecast over day-ahead for the Dec 2010 – July 2011 period is 18.8%



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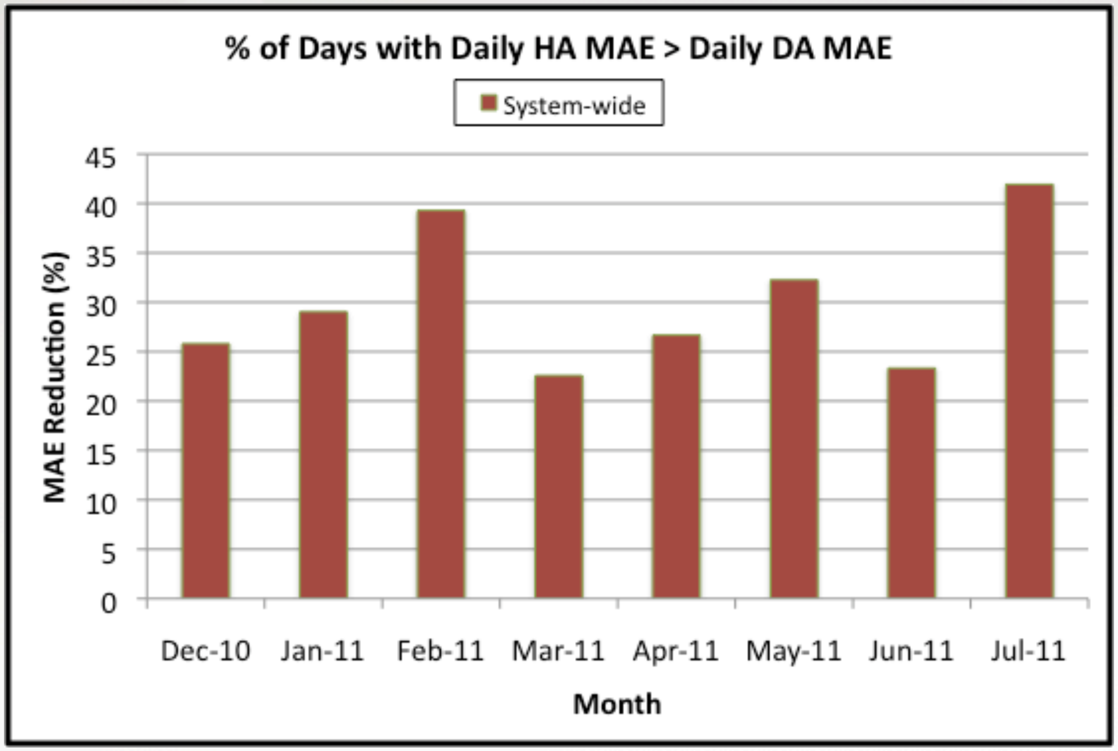
Questions

Question #1: Why the Hour-Ahead provides little improvement over the Day-Ahead forecast accuracy? (CONTINUED)

- However, for a fraction of of days the DA forecast does have a lower MAE
- Average % of monthly days with daily HA MAE > DA MAE for the Dec 2010 – July 2011 period is 30.0%



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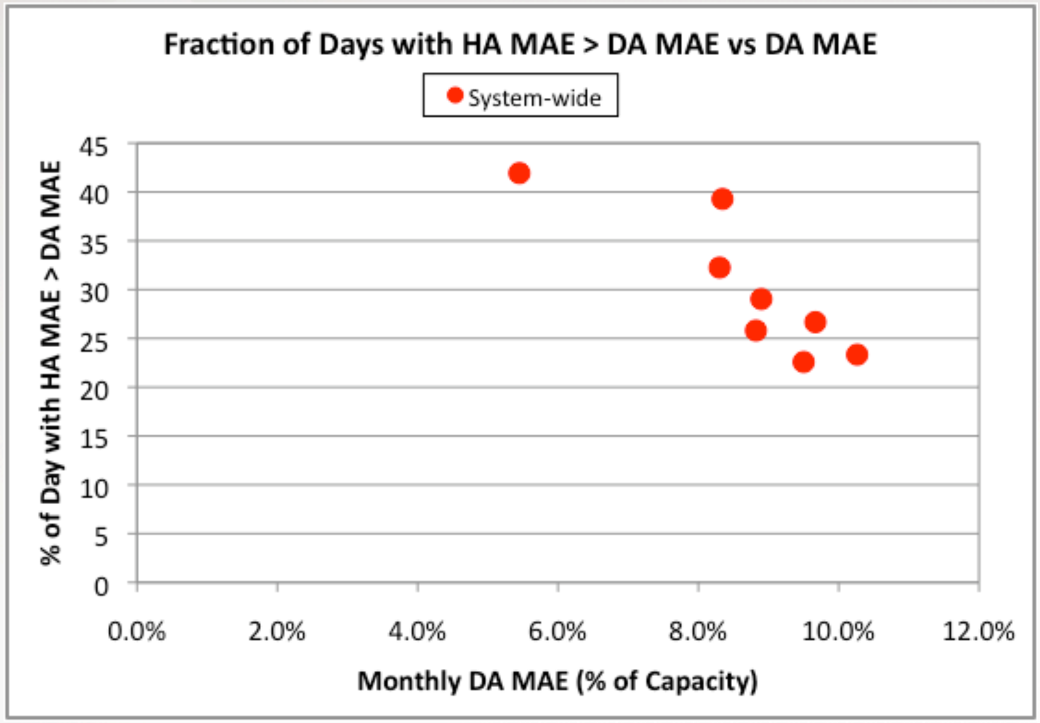
Questions

Question #1: Why the Hour-Ahead provides little improvement over the Day-Ahead forecast accuracy? (CONTINUED)

- The fraction of days for which DA MAE is better than HA MAE is strongly correlated with the DA MAE
- Interpretation: If the DA forecast is very good, it is hard for the HA to improve upon it!
  - DA and HA performance is essentially the same on many of those days but random fluctuations mean DA has slightly lower MAE sometimes



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Question #1: Why the Hour-Ahead provides little improvement over the Day-Ahead forecast accuracy? (CONTINUED)

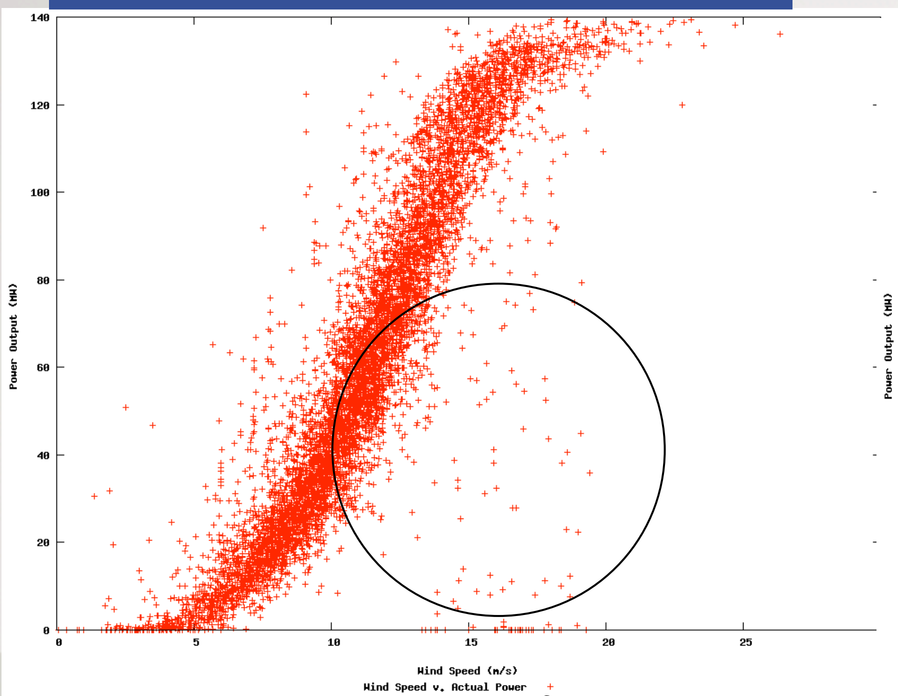
- Hour ahead forecasts are much more sensitive to the availability and quality of data from the WGRs
  - Recent trends in met and power data from the site are important predictors
  - Day ahead forecasts experience less impact since current trends are typically not a useful predictor
- A number of data issues have been encountered that have impacted the hour ahead forecasts
  - Curtailment information not available for use in forecast production
    - Curtailment information currently received 1 to 2 weeks after the forecast day
    - Internal AWST curtailment detection algorithm used in real-time
    - HSL has not been operationally used YET – some issues remain
  - Unreliable availability
  - Inconsistent quality of meteorological data

Questions

ACTUAL POWER AND WIND SPEED RELATIONSHIPS
Example: Good Correlation

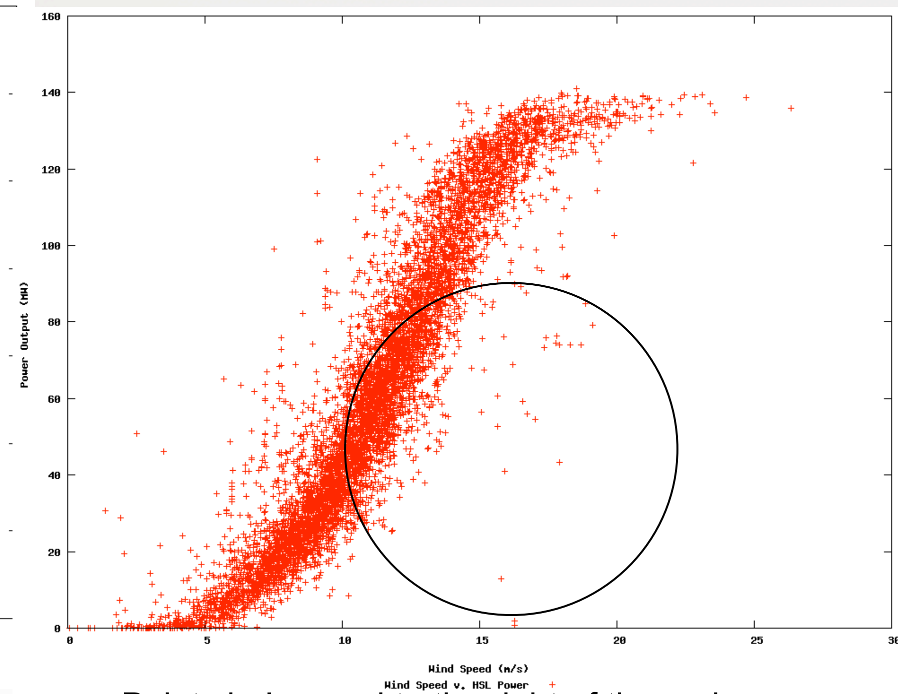
In this case the power and wind speed data enable the specification of a well-defined WGR-scale power curve

Wind speed vs. Raw Power



- Points below and to the right of the main power curve with respect to raw power reflect curtailment and/or reduced availability

Wind Speed vs. HSL



- Points below and to the right of the main power curve with respect to HSL power reflect reduced availability

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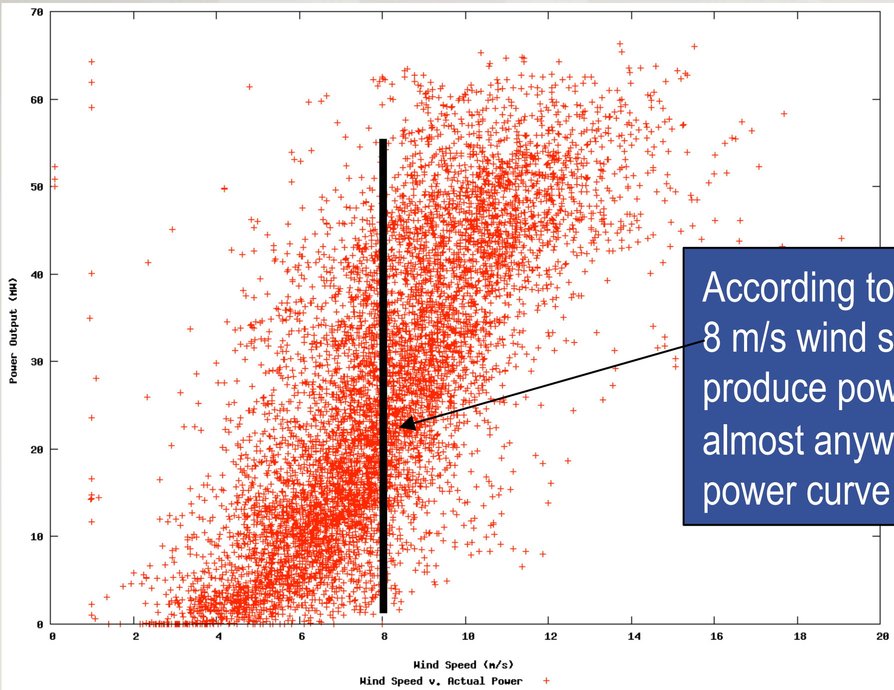
Questions

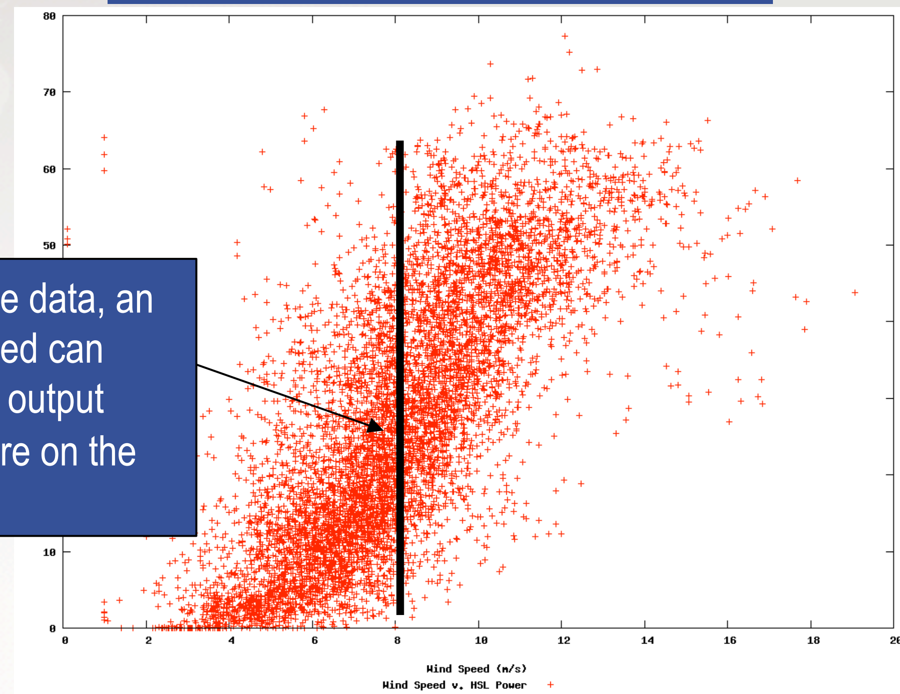
ACTUAL POWER AND WIND SPEED RELATIONSHIPS

Example: Poor Correlation

Wind speed vs. Raw Power



Wind Speed vs. HSL



According to the data, an 8 m/s wind speed can produce power output almost anywhere on the power curve

Possible causes for the high degree of scatter

- Meteorological data updates are too infrequent
- Poorly sited met tower for the WGR or instrumentation issues
- Inconsistent patterns or reliability in curtailment and/or availability reduction data

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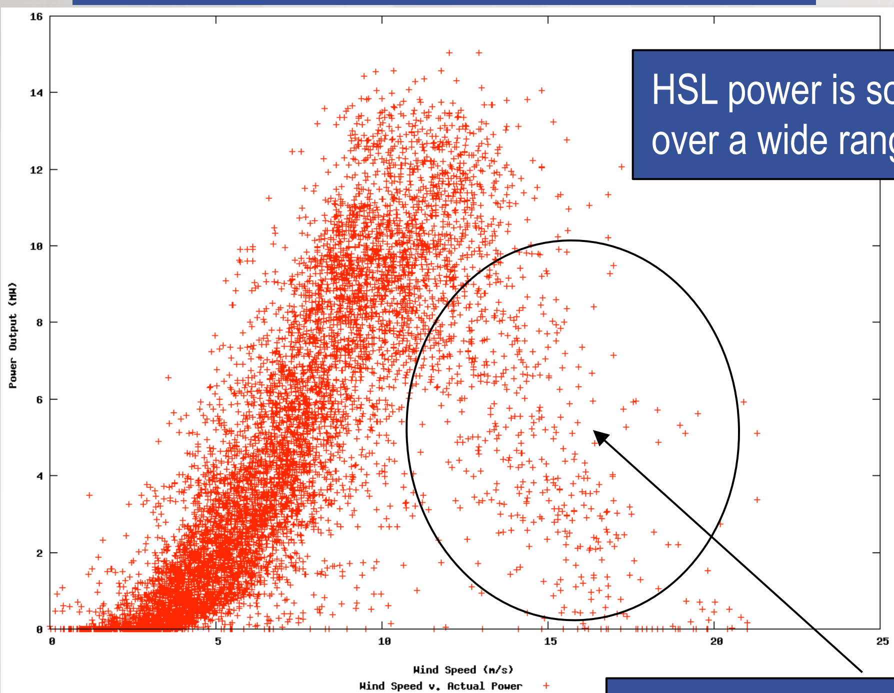
Questions

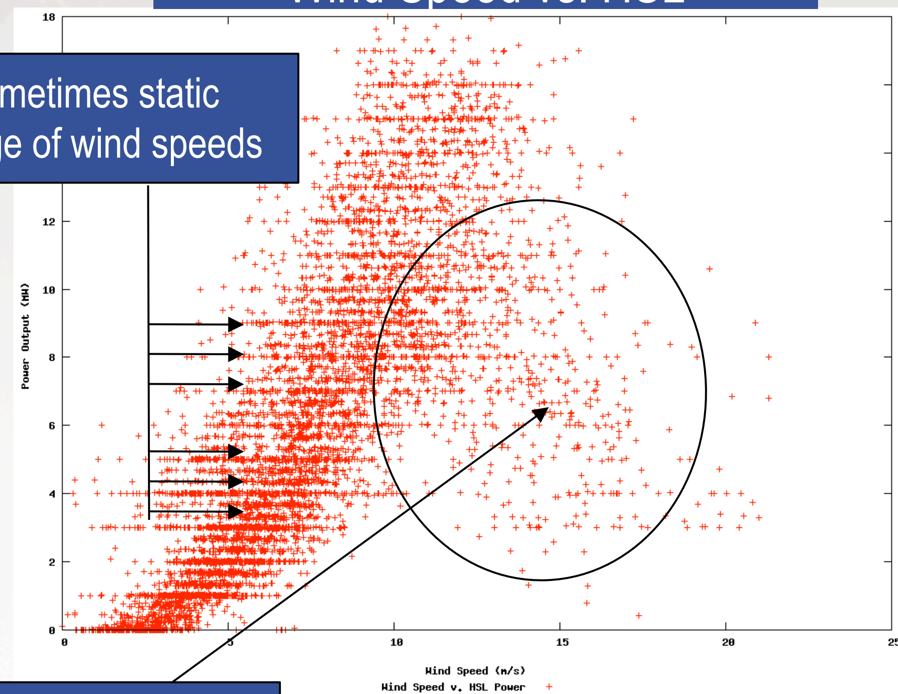
ACTUAL POWER AND WIND SPEED RELATIONSHIPS

Example: Separate data quality issues with raw and HSL power

Wind speed vs. Raw Power



Wind Speed vs. HSL



HSL power is sometimes static over a wide range of wind speeds

Power is significantly reduced at wind speeds that should feature full generation in the absence of curtailment or availability reductions

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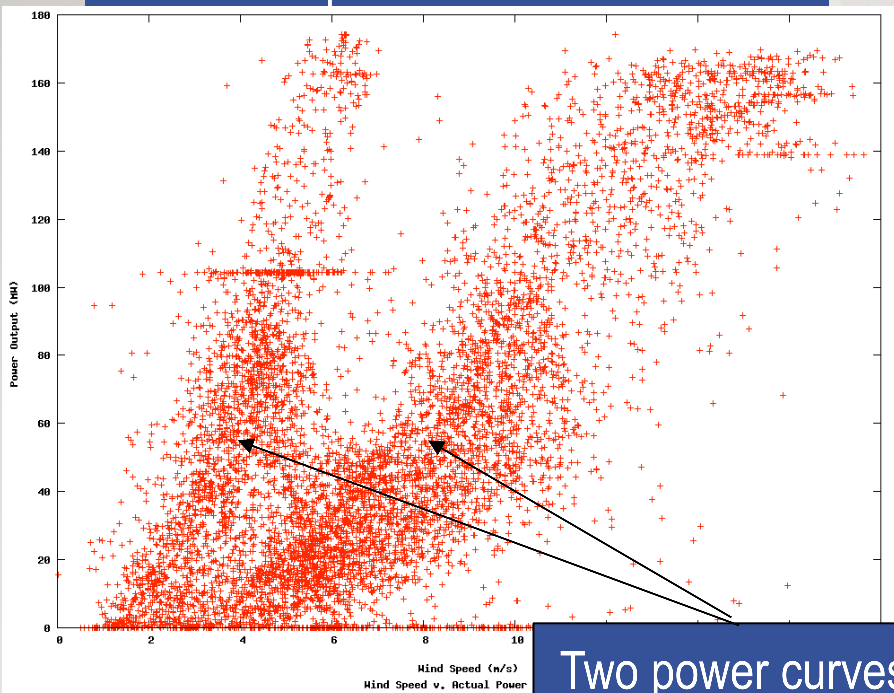
Questions

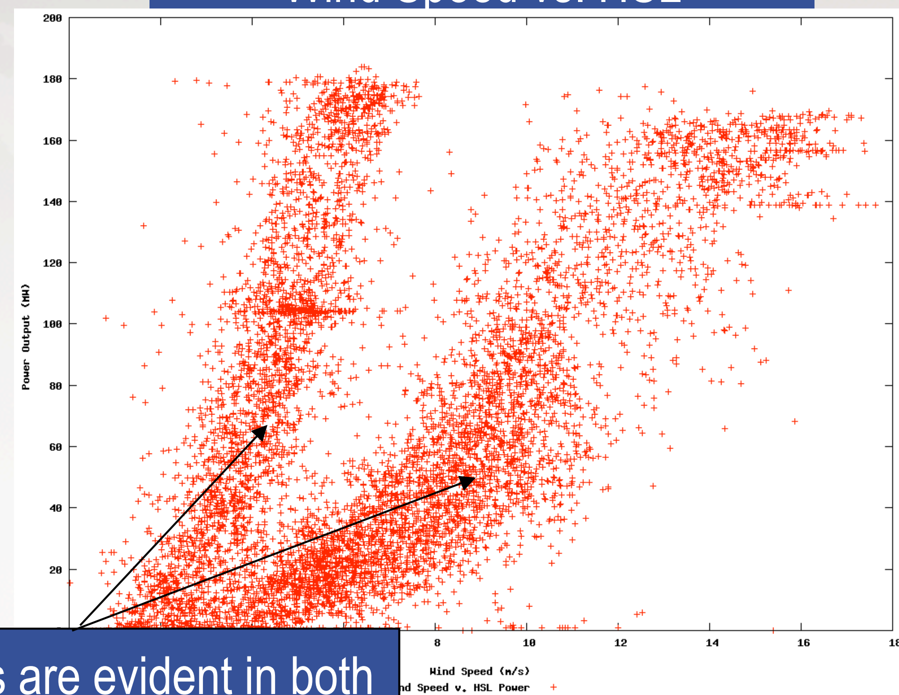
ACTUAL POWER AND WIND SPEED RELATIONSHIPS

Example: Multiple Power Curves

Wind speed vs. Raw Power



Wind Speed vs. HSL



Two power curves are evident in both the raw power and HSL scatter plots

<u>Possible causes for multiple power curves</u>

- Problem with meteorological sensor
- Intermittent errors in unit conversion between m/s and mph
- Met tower is always waked when the wind is blowing from a certain direction

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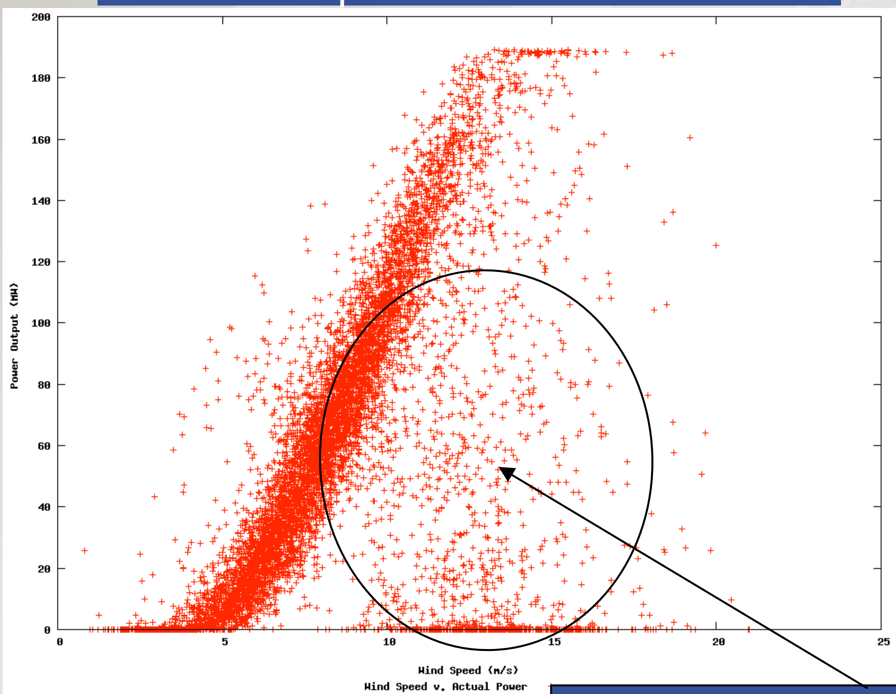
Questions

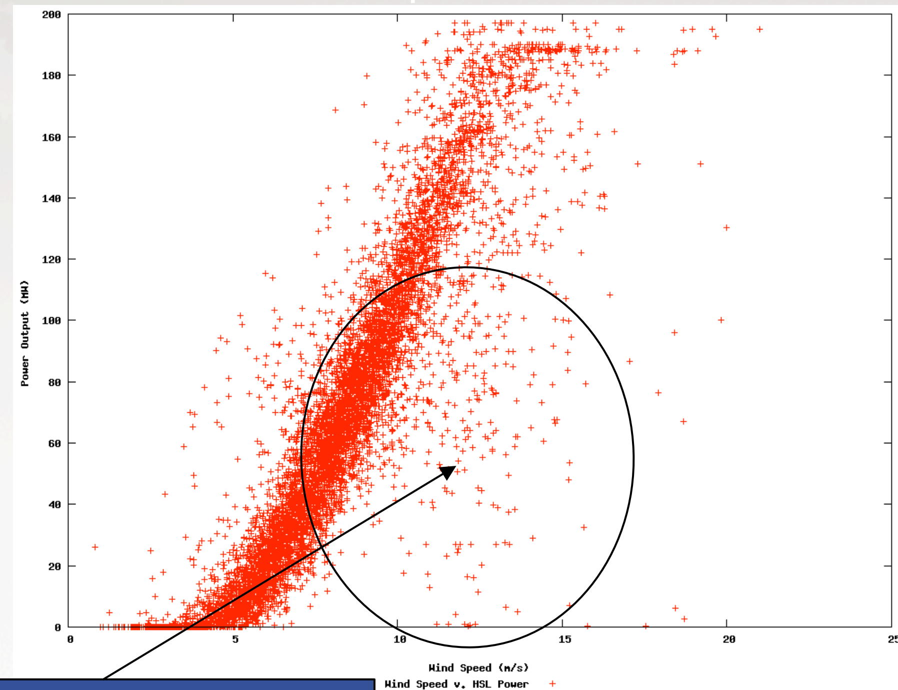
ACTUAL POWER AND WIND SPEED RELATIONSHIPS

Example: Forecast Verification Issues

Wind speed vs. Raw Power



Wind Speed vs. HSL



Scatter plots made with HSL data remove a lot of apparent curtailment, but a significant number of outliers remain

- Forecast verification uses HSL data as best available estimate of uncurtailed power
- If there are remaining issues, the apparent forecast performance is degraded

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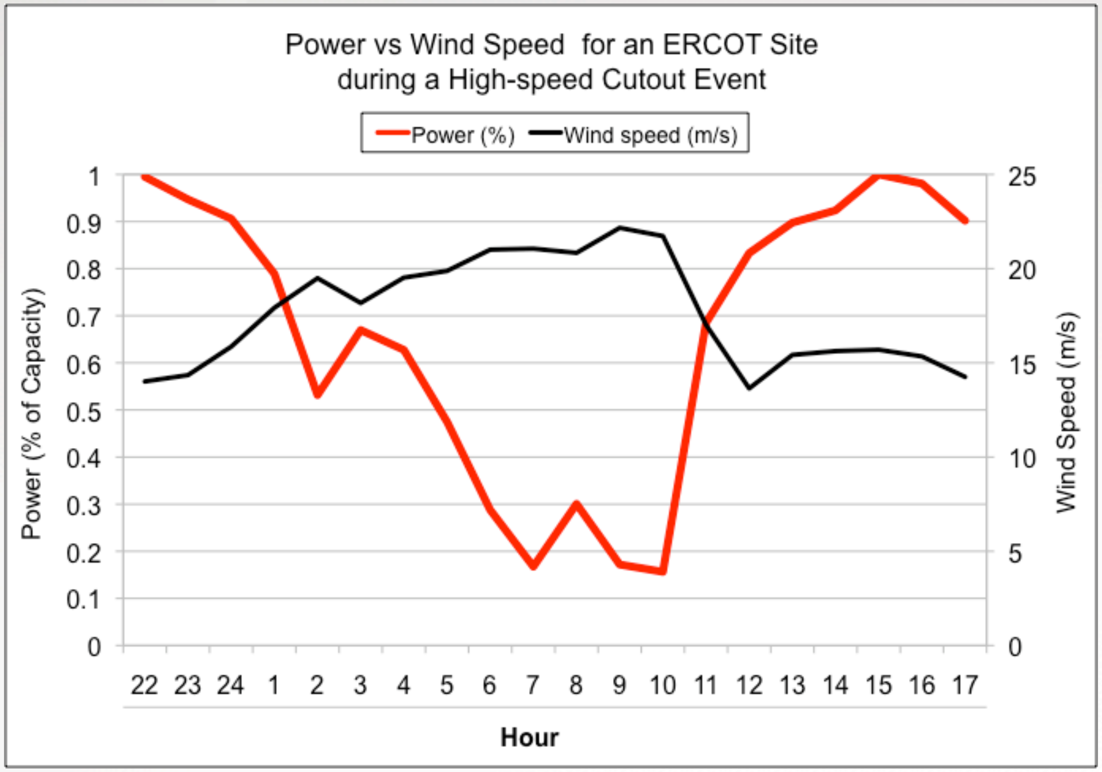
Question #2: What is the value of the met data in the forecast?

- Uses of meteorological data in the forecasting process
  - Recent trends of conditions at the WGR
  - Training the MOS models
  - Training the statistical plant output model
  - Quality control of power production data
  - Input into rapid update NWP
  - Input into feature detection and tracking algorithms
- Value depends on look-ahead period and the situation
  - More value for 0-6 hr look ahead periods
  - More value for critical situations
    - High speed cut-out
    - High and low temperature cut-out
    - Icing
    - Other types of ramp events

Question #2: What is the value of the met data in the forecast? (CONTINUED)

Example: High Speed Cut-out

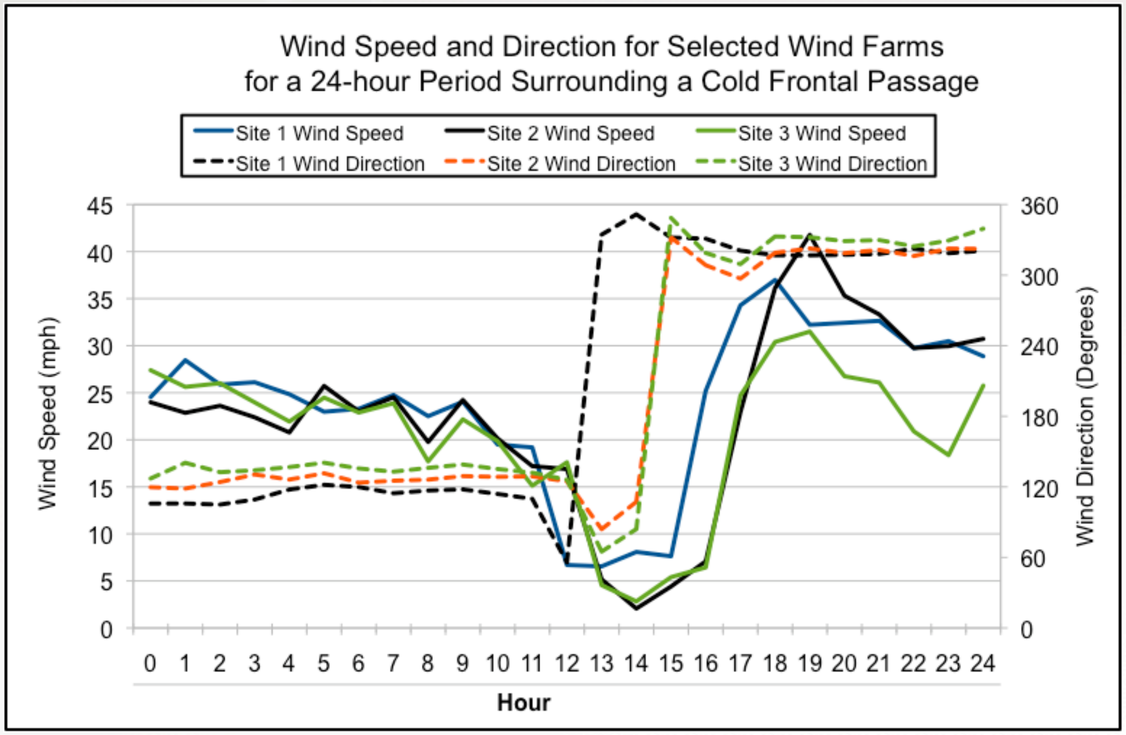
- Example: high speed cut-out
- Cut-out begins as anemometer wind speeds exceed 15 m/s
- Having only power data makes it difficult to anticipate cut-out and return to production



Question #2: What is the value of the met data in the forecast? (CONTINUED)

Example: Feature Detection and Tracking

- Example: Propagation of a Cold Front
- Cold front passes at site 1 about 2 hours before sites 2 and 3
- Can be an important tool for some types of ramp events



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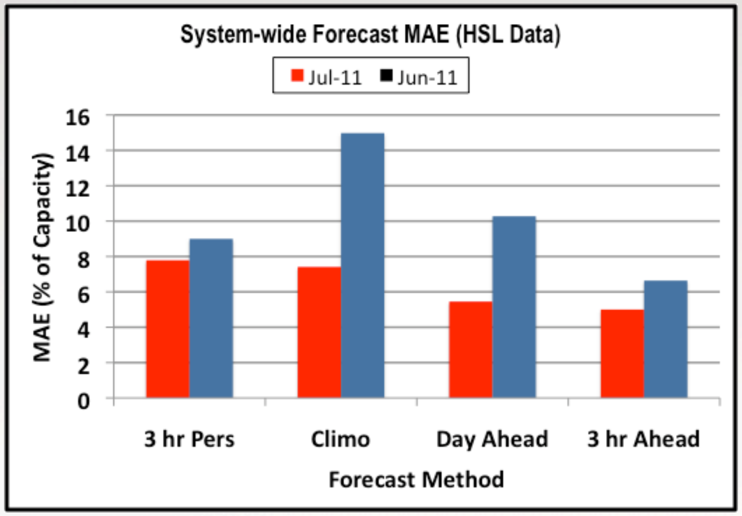
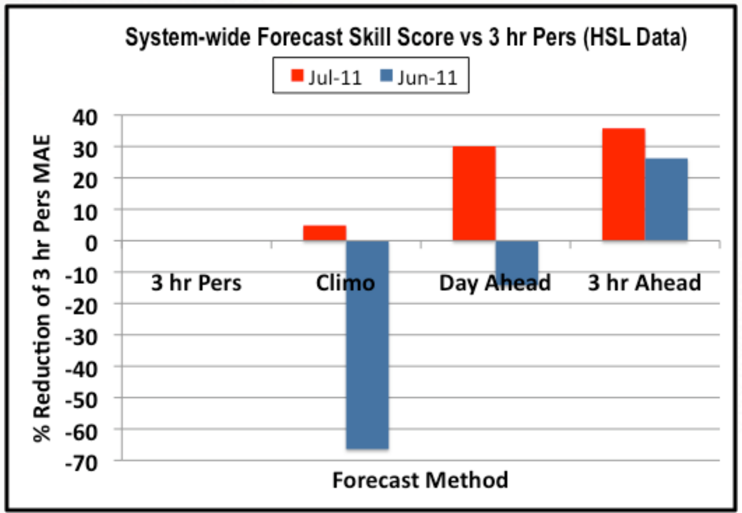
Questions

Question #3: Is there a particular reason why the forecast is doing so well this month (July)?

- High Predictability Regime
  - Lower wind variability
  - Less deviation from climatology
  - Wind variability controlled mostly by larger scale weather systems
  - Lack of thunderstorm activity
  - Less time in steep part of power curve
- Improvements to forecast system
  - Extended use of curtailment data
  - Better QC of met data
- General Conclusion: Forecast system has HIGH SKILL in the prediction of large scale weather systems!





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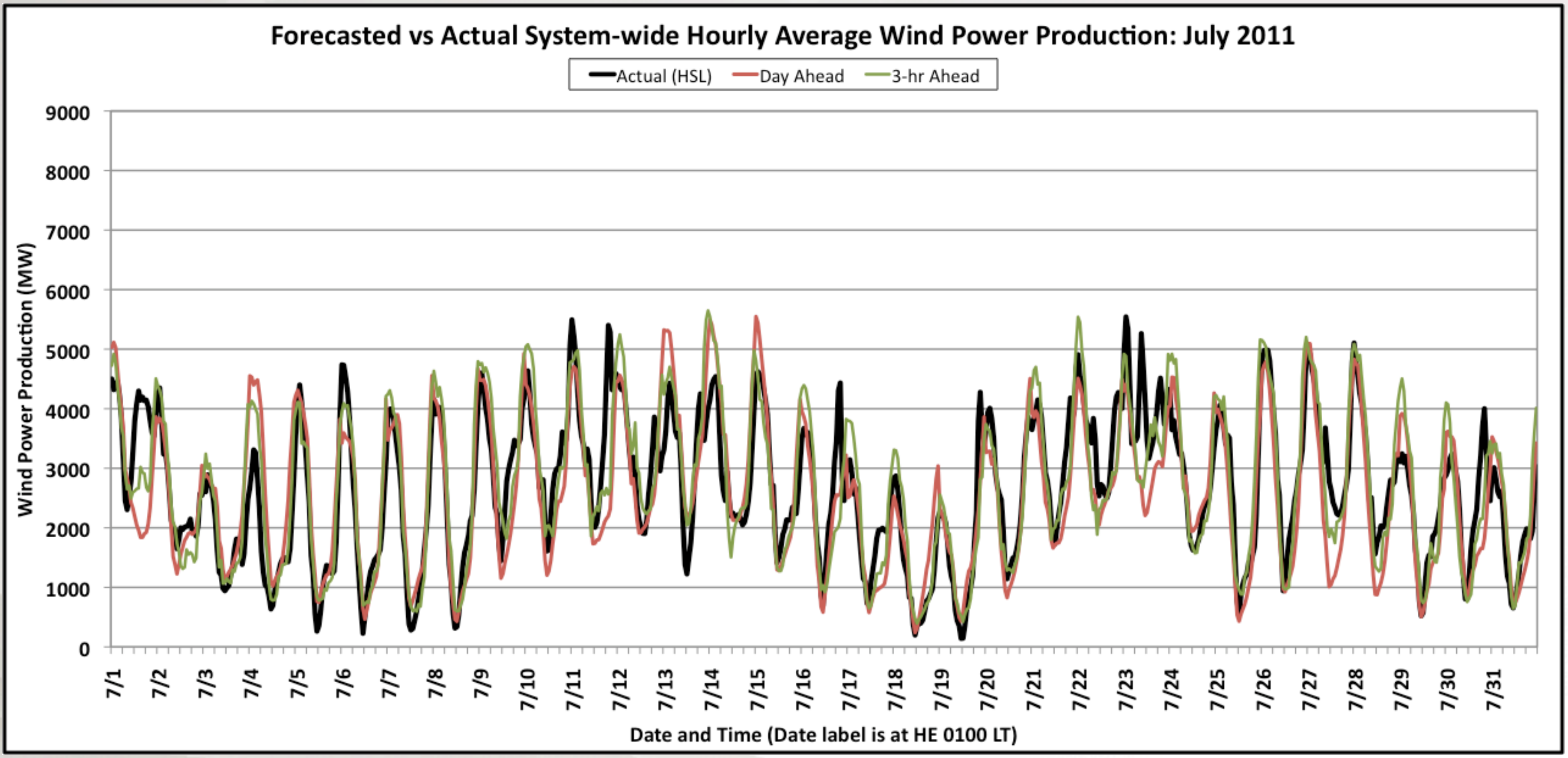
Questions

Question #3: Is there a particular reason why the forecast is doing so well this month (July)? (CONTINUED)

Forecasted and Actual Hourly Wind Power Production for July 2011



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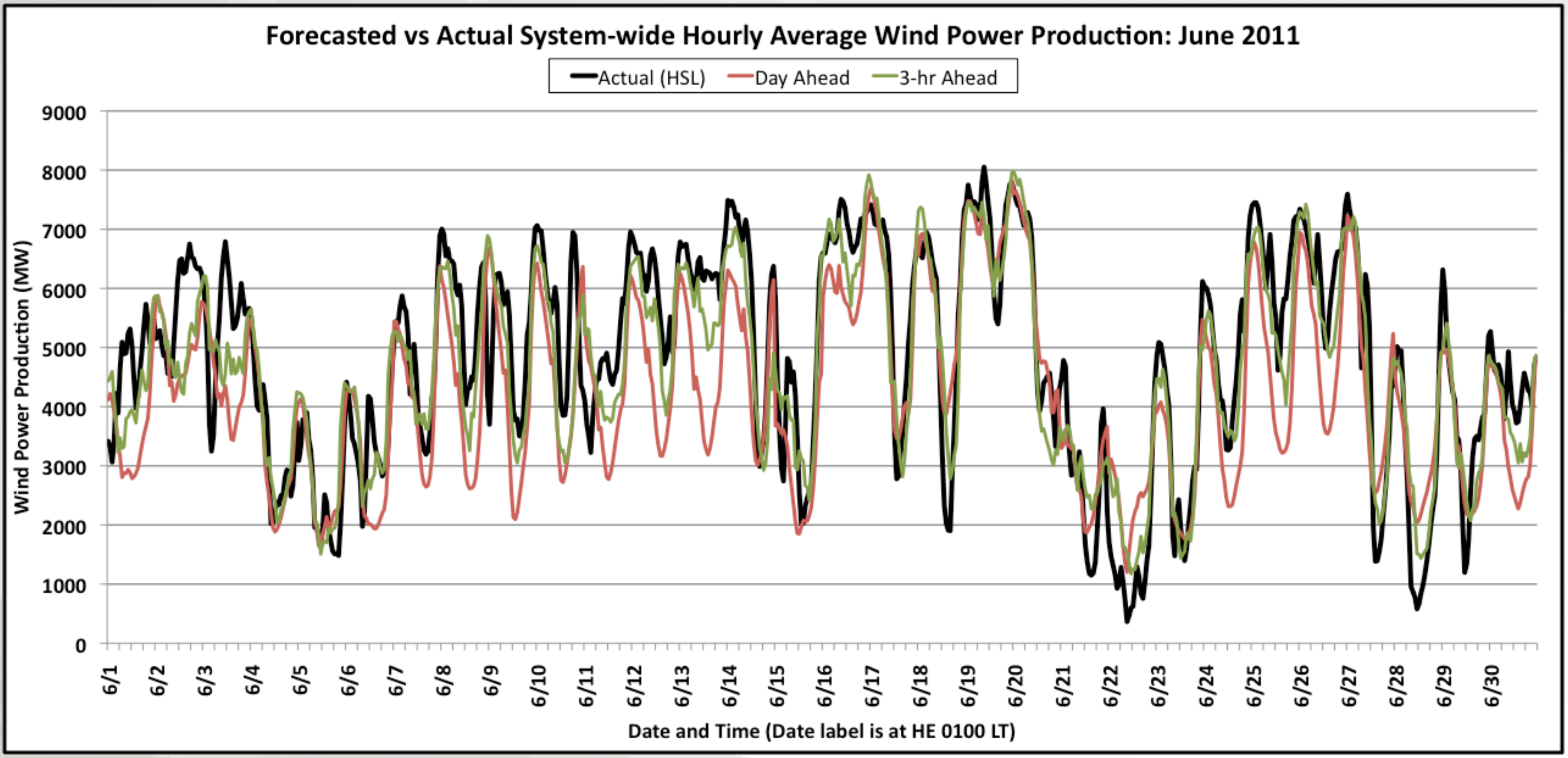
Questions

Question #3: Is there a particular reason why the forecast is doing so well this month (July)? (CONTINUED)

Forecasted and Actual Hourly Wind Power Production for June 2011



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Question #4: How does the frequency with which met data is delivered to AWST affect forecast accuracy? Does accuracy track linearly with frequency?

- Depends on the look-ahead time frame and forecast interval
  - For > 6 hours ahead: training of plant output model
  - For a few hours ahead: determining recent onsite and offsite trends
- Issue: Snap shot vs average values
  - "Snap shots" are noisier – contain small scale fluctuations (e.g. gusts)
  - Need enough "snap shots" to get representative average values
  - Ideally: a significant sample of "snap shots" per forecast interval
- Controlled studies of impact of data frequency on forecast accuracy have not been performed on
- Accuracy does not track linearly with frequency
- 1-minute snap shot values are a good standard

Question #5: What is the explanatory power of each of the four measures collected from wind resources in ERCOT? Can we save time, money & effort by delivering some data less frequently?

- Onsite “Explanatory Power” varies with the situation
  - Wind speed is consistently valuable
  - Wind direction can be important in some situations
    - Certain wind directions depending on turbine layout
  - Temperature can be critical in some situations
    - High and low temperature cut-out
    - Icing ((example: Feb 3, 2011)
  - Pressure is least significant
- Data also used for off-site forecasts (i.e. other WGRs)
- A study of the benefits of each variables has not been performed
- Likely don’t need all the data at high frequency all the time but.....
- 1-minute frequency appears to a good all purpose interval

Question #6: How is turbine availability tracked now?

- Actual Availability
  - Supplied in the near real-time data feed from ERCOT to AWST
  - # of turbines in 3 categories is reported
    - Available, unavailable, and unknown
    - "Unknown" category is a problem for the forecast system
  - Scales power for use in training of statistical models
  - Considered in determining recent trends for hours ahead forecasts
- Forecasted Availability
  - **Currently:** entered in AWST-supplied web site
  - **Soon:** added to near-real-time data stream from ERCOT to AWST
  - Forecasts are adjusted to forecasted availability for each hour
  - No forecast of curtailment is considered
  - Inaccurate availability forecasts contribute to power forecast error

ERCOT-related Forecasting Research

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Research

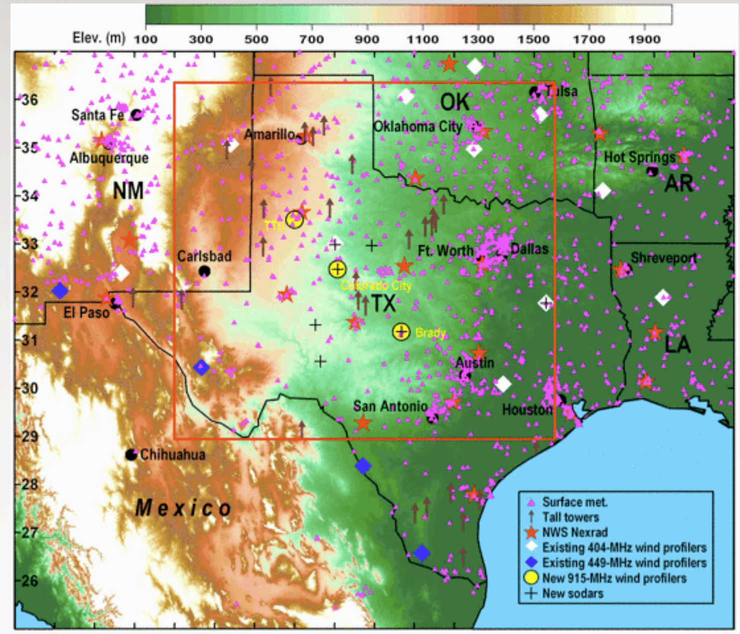
Wind Forecasting Improvement Project (WFIP)

- **Objective: Determine how much 0-6 hr wind power forecasts can be improved through the deployment of a customized sensor network and advanced prediction models**
- **Venue: 2 projects**
  - ERCOT-region (7-member team led by AWST)
  - MISO-region (project led by WindLogics)
  - More info: http://www.esrl.noaa.gov/psd/psd3/wfip/
- **Sponsor: DOE; NOAA contributes their support**
- **Approach:**
  - 2 year project (October 2010 – October 2012)
    - 6 months planning
    - 12 month sensor deployment and forecasting experiment
    - 6 months to analyze results
  - Deployment of customized sensor network (NOAA and private vendors)
  - Application of a suite of advanced prediction models
  - Extensive analysis of meteorological and economic impact

Research

Sensors and Models

- **Sensor Deployment**
  - Enhanced sensor network deployment plan shown at right
  - All sensors were deployed during June and July and are now providing data
  - NOAA, OU and AWST forecast systems are beginning to ingest the data and use it to make real-time experimental forecasts



- **Multiple Advanced Prediction Techniques**
  - NOAA: High Resolution Rapid Refresh (HRRR) – hourly updates on a 3 km grid
  - U of OK: advanced data assimilation and model system on a 2 km grid
  - AWST: 12-member high resolution ensemble forecast system
  - All systems to use data from enhanced sensor network