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Manager of Atmospheric Modeling

# Integration of WindSim's Forecasting Module into an Existing Multi-Asset Forecasting Framework

4 DECEMBER 2014
2014 WINDSIM AMERICAS USER'S MEETING
ORLANDO, FLORIDA

Pattern

Pattern Energy Group Inc.

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# PATTERN METEOROLOGICAL HIGH PERFORMANCE COMPUTING CENTER (MHPCC)

- Pattern's own private cluster, in operation since 2007, features 48 HP computing blades with up to dual six-core chips, for 448 computational cores for data processing, a 35 terabyte storage system, and Infiniband interconnections for lightning quick data transfer and execution.
- State of the art Mesoscale Numerical Weather Prediction (NWP) model customized for wind applications:
  - Community-wide, open source development; and primary forecast model by National Weather Service (NWS) and research institutions worldwide.
  - Preferred model of choice by resource assessment companies within the wind industry (e.g., DNV GL, 3Tier, etc.)
- Initialized with the NCEP/NCAR Global Reanalysis (2.5°) for pre-construction modeling and Global Forecast System (GFS) and North American Mesoscale (NAM) models for forecasting applications.

# MHPCC HISTORY & FORECASTING APPLICATIONS

**Pattern's Santa Isabel, Puerto Rico (left) and El Arrayán, Chile (right) sites were original MHPCC generated prospects now in operation.**

- 25 TB of data generated simulating more than 140 different project areas for wind development.
- Generate twice-daily automated forecasts of wind speed, density, wind direction and empirically-derived farm power for all in-operation and in-construction assets.

# WINDSIM FORECASTING INTEGRATION

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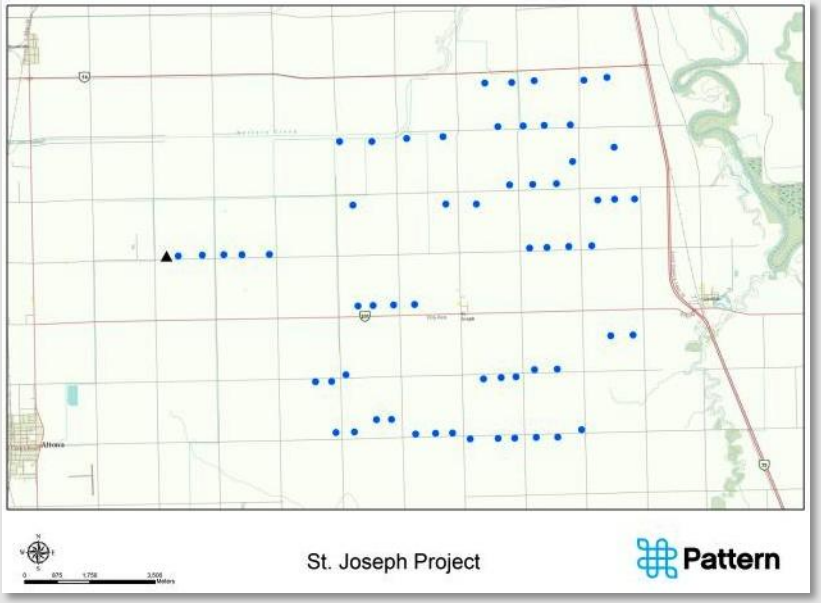
# BENEFIT OF WINDSIM'S FORECASTING MODULE

- MHPCC forecasts use mesoscale modeled point directly from 1-km spatial resolution grid.
- Despite this high-resolution, model error and bias is common and repeatable:
  - Noted some low biases during specific seasons and wind flow patterns at certain assets;
  - Execution time of even higher-resolution grid not-cost effective and can lead to compounding error.
- WindSim module with neural-network corrected training can account for known biases in the mesoscale modeled data.
- Execution time is 5-10 minutes (depending on park size and forecast length); substantially less than a full higher-resolution NWP simulation.
- How do we harness the benefit from higher-resolution wind flow modeling?

# TESTING METHODOLOGY

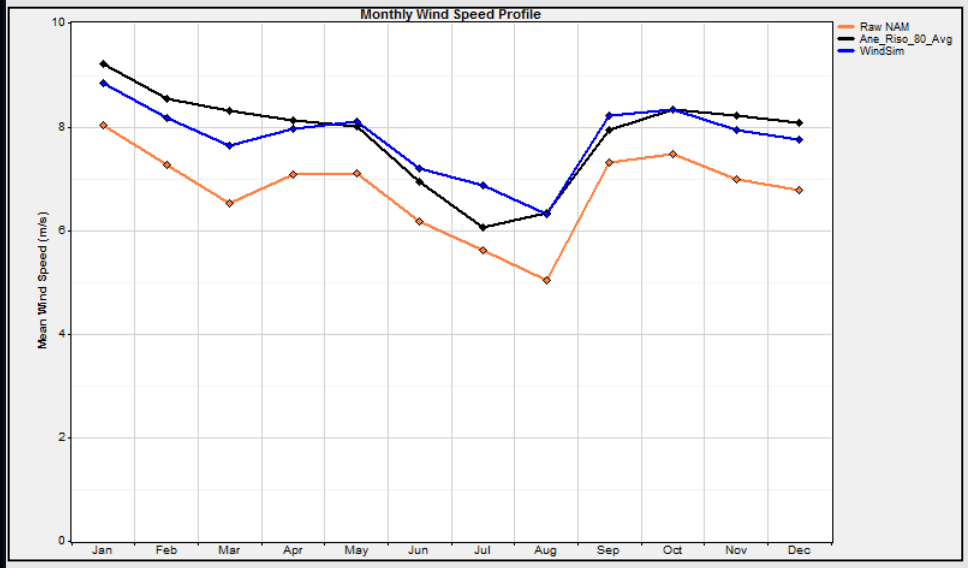
- Forecast data: historical 2-day running forecasts from the 00 UTC NAM raw model cycles for the past 18 months at three assets with varying terrain complexity and flow. Forecasts from the 36-48 hour time wind utilized in the process.
- Observed data: permanent met tower at hub height for the concurrent time period.
  - Mesoscale modeled point typically very close to permanent tower.
  - Algorithm to correct for waked wind sectors undertaken.
- Use WindSim NN correction on “forecast” and “observed” for (1) entire data set and (2) broken into seasons..

# ST. JOSEPH WIND

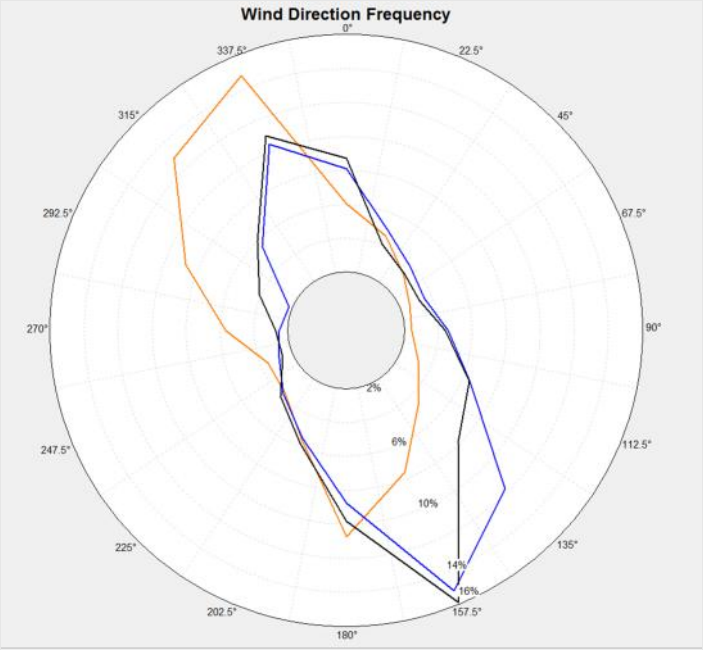



- 138 MW project using SWT-2.3-101 turbines located in flat farm land in Southern Manitoba.
- Considered simple terrain and simple flow complexity.

# ST. JOSEPH VALIDATION

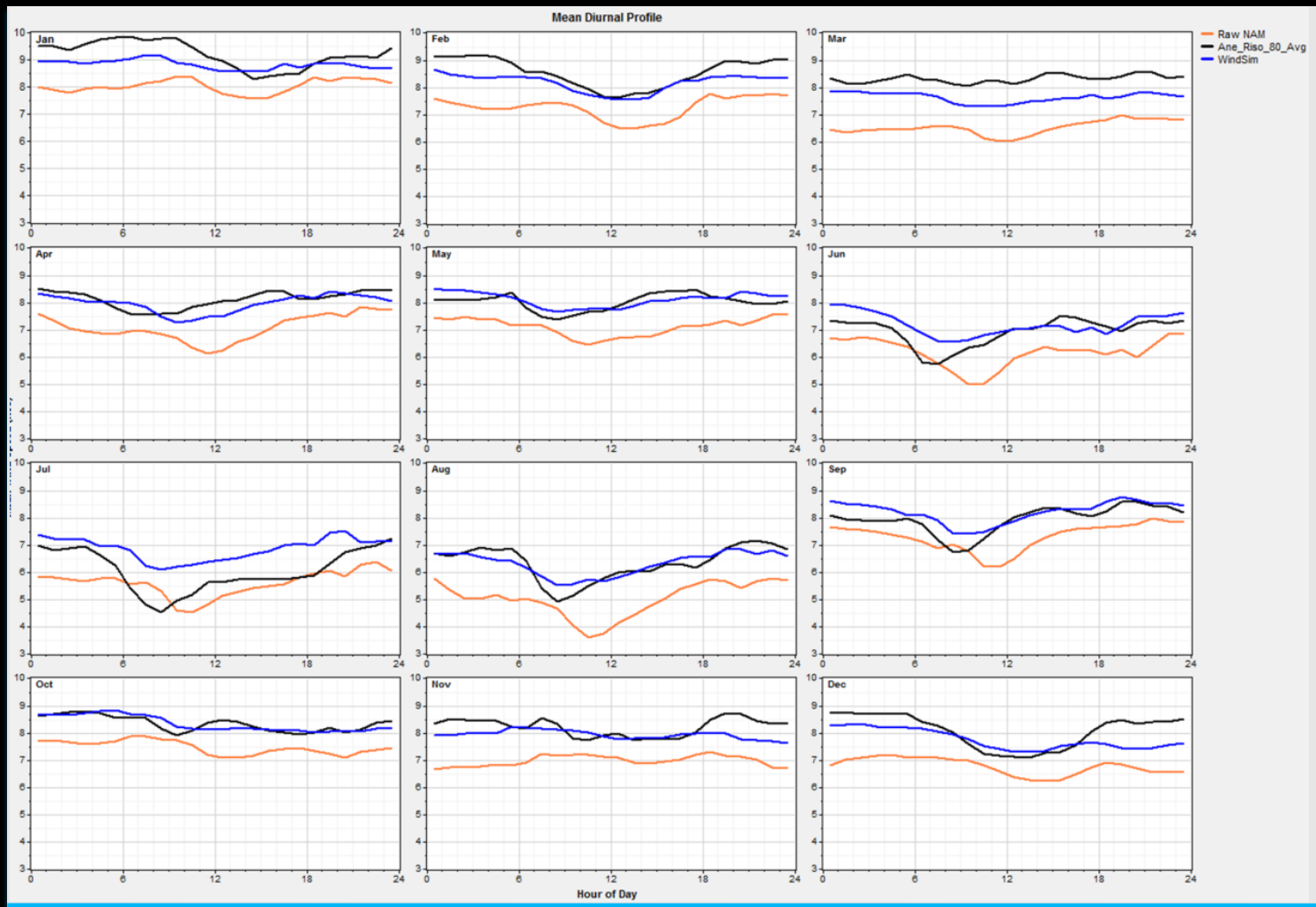



KEY
**Black**: Obs **Orange**: NAM **Blue**: WS




- Noticable low bias in NAM throughout most of the months of the year, particularly in Summer and early fall. WindSim corrected very close to actuals on a monthly average time-scale.
- Large improvement in the wind direction measurements using WindSim at this site.

# ST. JOSEPH DIURNAL/MONTHLIES

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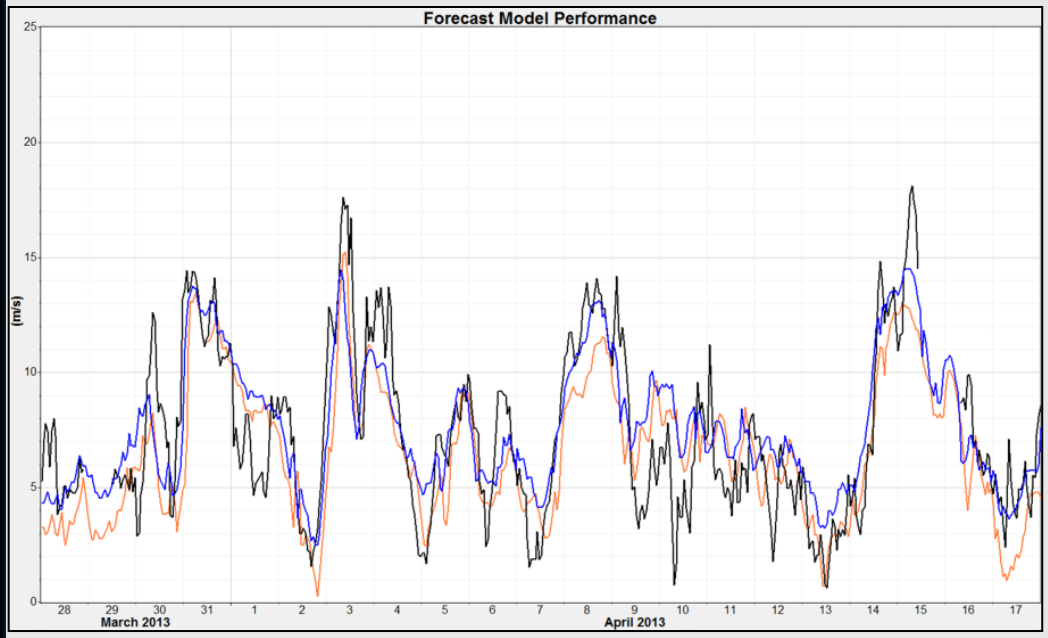
# ST. JOSEPH ERROR ANALYSIS




| SJW | | | |
|---|---|---|---|
| Relative (%) | Raw NAM | WS | Improvement |
| MBE | -12.29% | -0.01% | 12.3% |
| MAE | 28.25% | 23.95% | 4.3% |
| RMSE | 36.70% | 31.20% | 5.5% |

KEY
**Black**: Obs **Orange**: NAM **Blue**: WS

| Absolute (m/s) | Raw NAM | WS | Improvement |
|---|---|---|---|
| MBE | -0.97 | 0.00 | 0.97 |
| MAE | 2.24 | 1.89 | 0.34 |
| RMSE | 2.91 | 2.47 | 0.44 |

- WindSim corrected wind speeds lower all error measures 4-12%, with a noticeable improvement in the mean bias error.
- Already very good forecast improved quite a bit; higher MAE due to large number of frontal passages and associated ramps.

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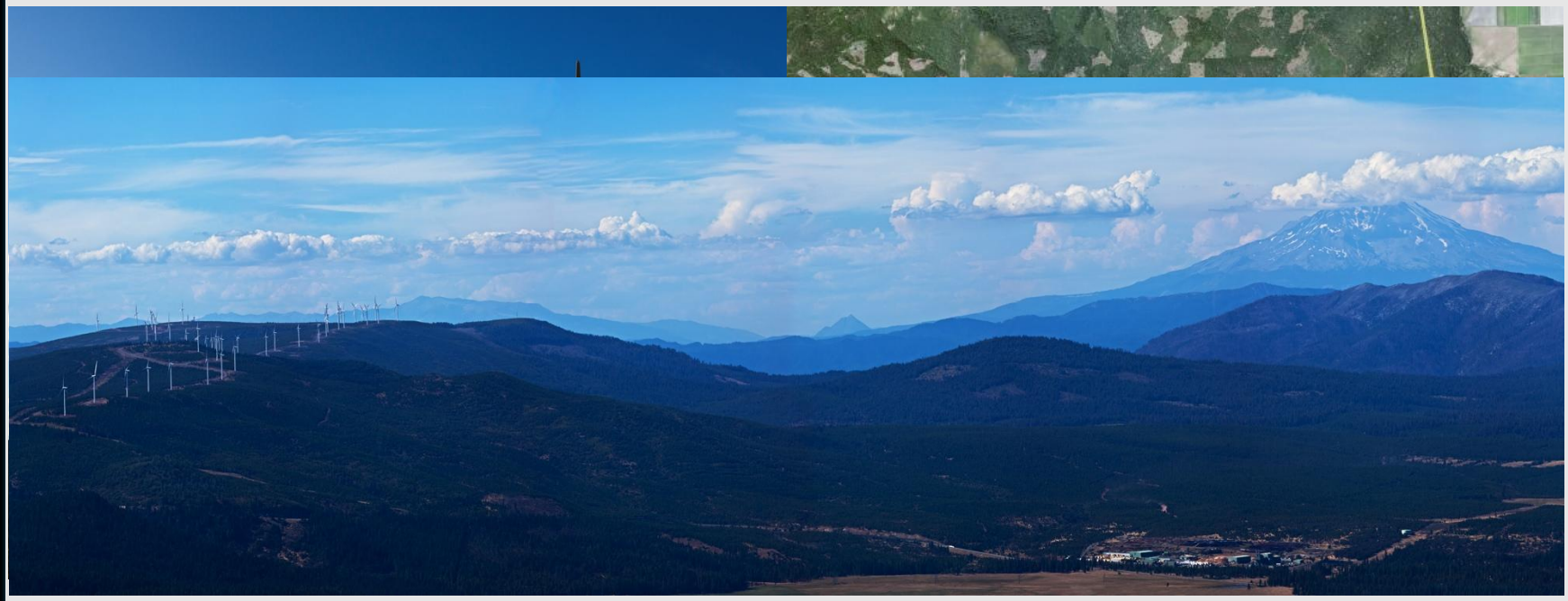
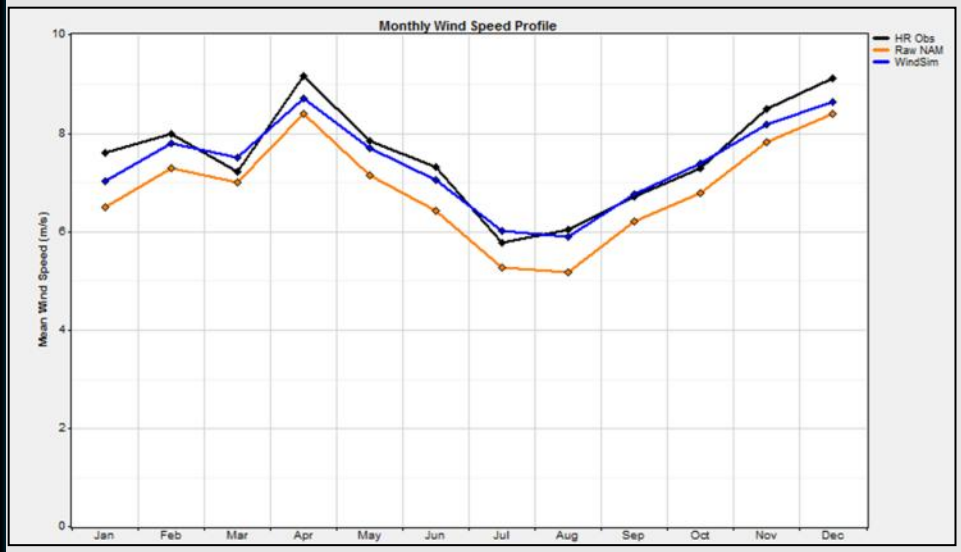
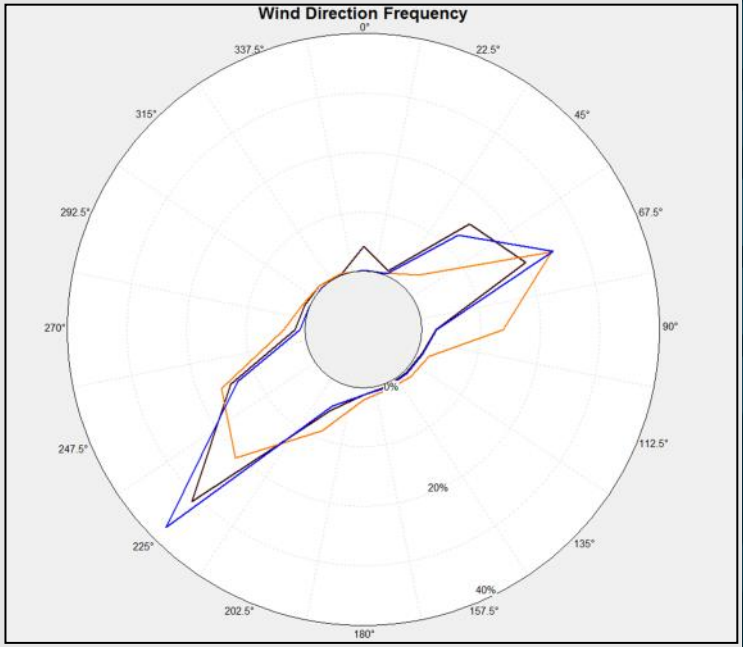
# HATCHET RIDGE



- 101 MW project using SWT-2.3-93 machines located on isolated ridge line in Northern California.
- Driven heavily by synoptic flow in winter/fall, but a very noticeable summertime diurnal pattern.
- Considered moderate terrain and high flow complexity.

# HATCHET RIDGE VALIDATION




KEY
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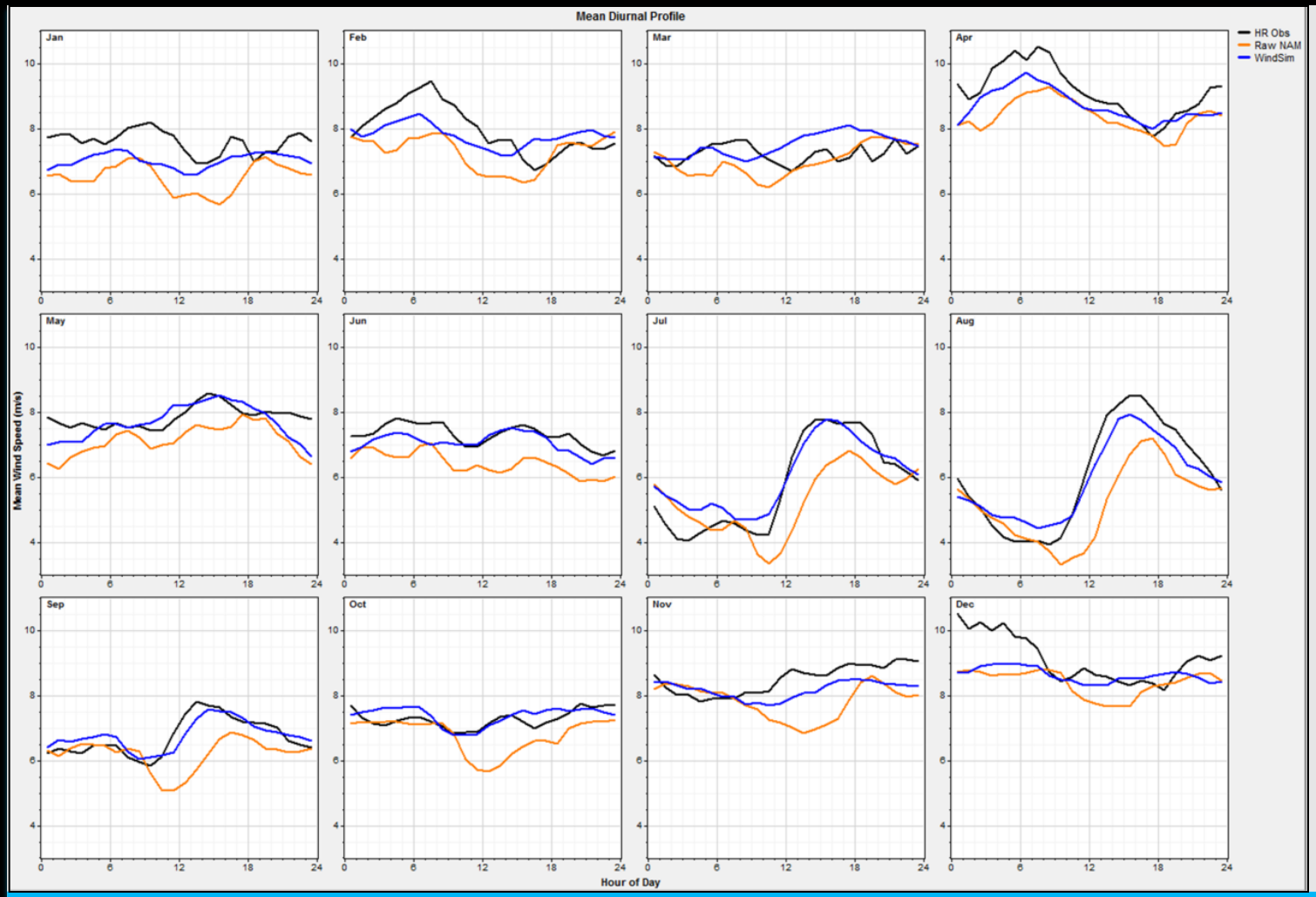
- Another noticeable low bias throughout most of the months of the year, particularly in Summer and early fall. WindSim corrected very close to actuals on a monthly average time-scale.
- Large improvement in the wind direction measurements using WindSim at this site.

# HATCHET RIDGE DIURNAL/MONTHLIES




KEY
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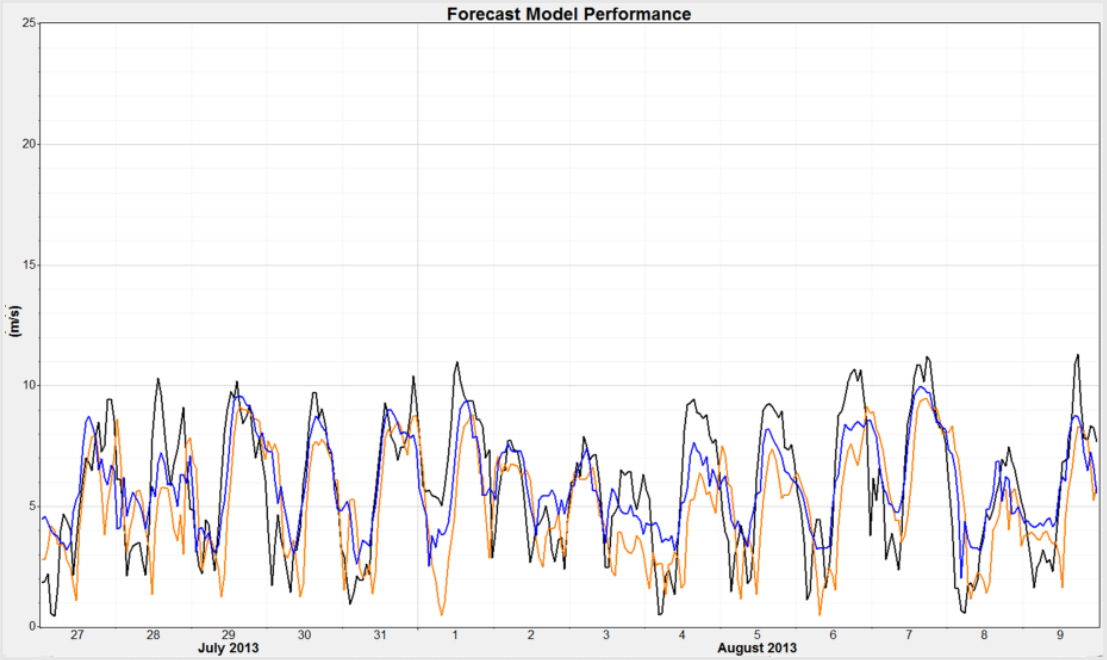
**Blue**: WS

Pattern

# HATCHET RIDGE ERROR ANALYSIS




| HRW | | | |
|---|---|---|---|
| Relative (%) | Raw NAM | WS | Improvement |
| MBE | -6.73% | 0.41% | 7.1% |
| MAE | 29.77% | 25.25% | 4.5% |
| RMSE | 39.03% | 33.64% | 5.4% |

KEY
**Black**: Obs **Orange**: NAM **Blue**: WS

| Absolute (m/s) | Raw NAM | WS | Improvement |
|---|---|---|---|
| MBE | -0.50 | -0.07 | 0.43 |
| MAE | 2.21 | 0.30 | 1.91 |
| RMSE | 2.90 | 0.39 | 2.51 |

- WindSim corrected wind speeds lower all error measures 4-7%, with a noticeable improvement again in the summer-time conditions.
- Less improvement noted in strongly synoptically-forced events.

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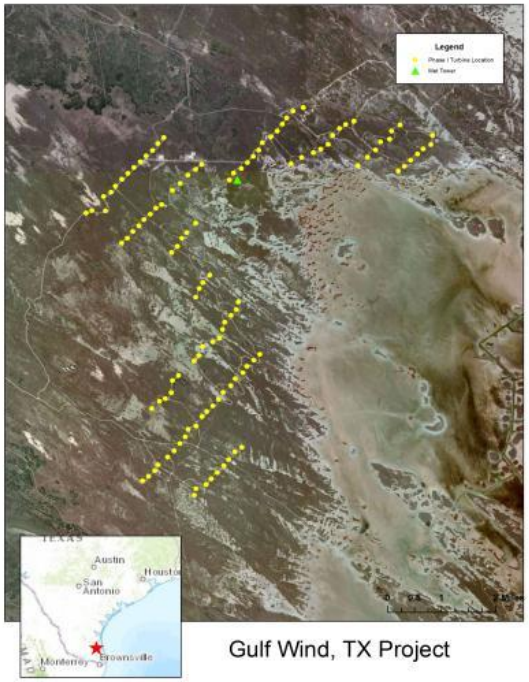
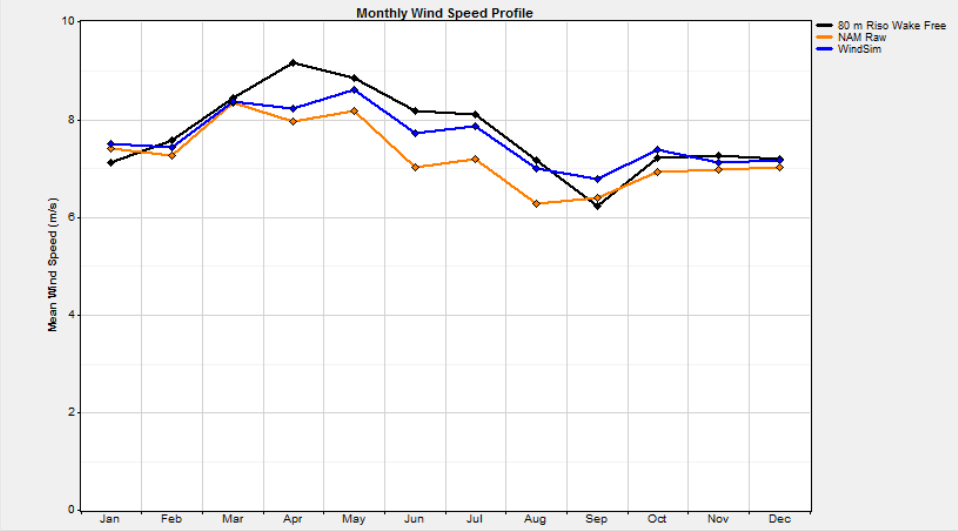
# GULF WIND

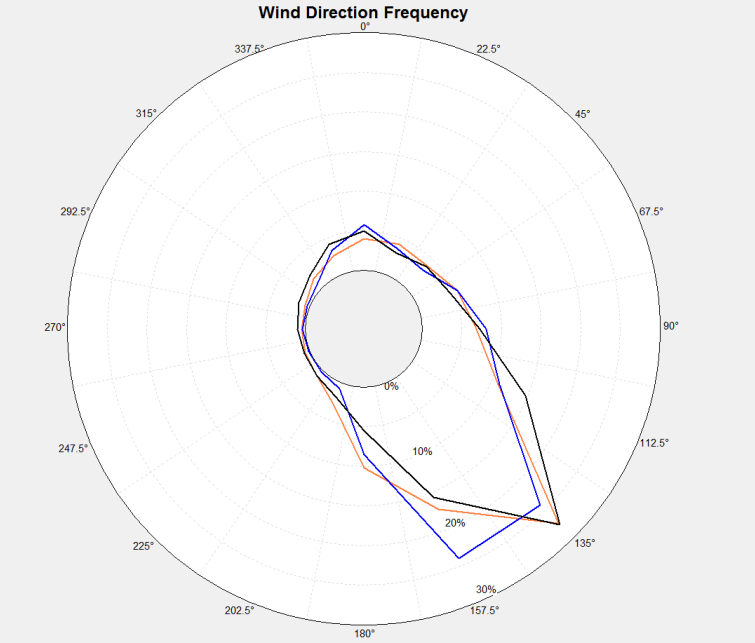



Gulf Wind, TX Project

- 283 MW project using MWT-2.4-95 located on lower south Texas coast near Gulf of Mexico.
- Strong diurnal wind speed profile from sea breeze & influence from pressure systems in the Southern Plains.
- Considered simple terrain with moderate flow complexity.

# GULF WIND VALIDATION

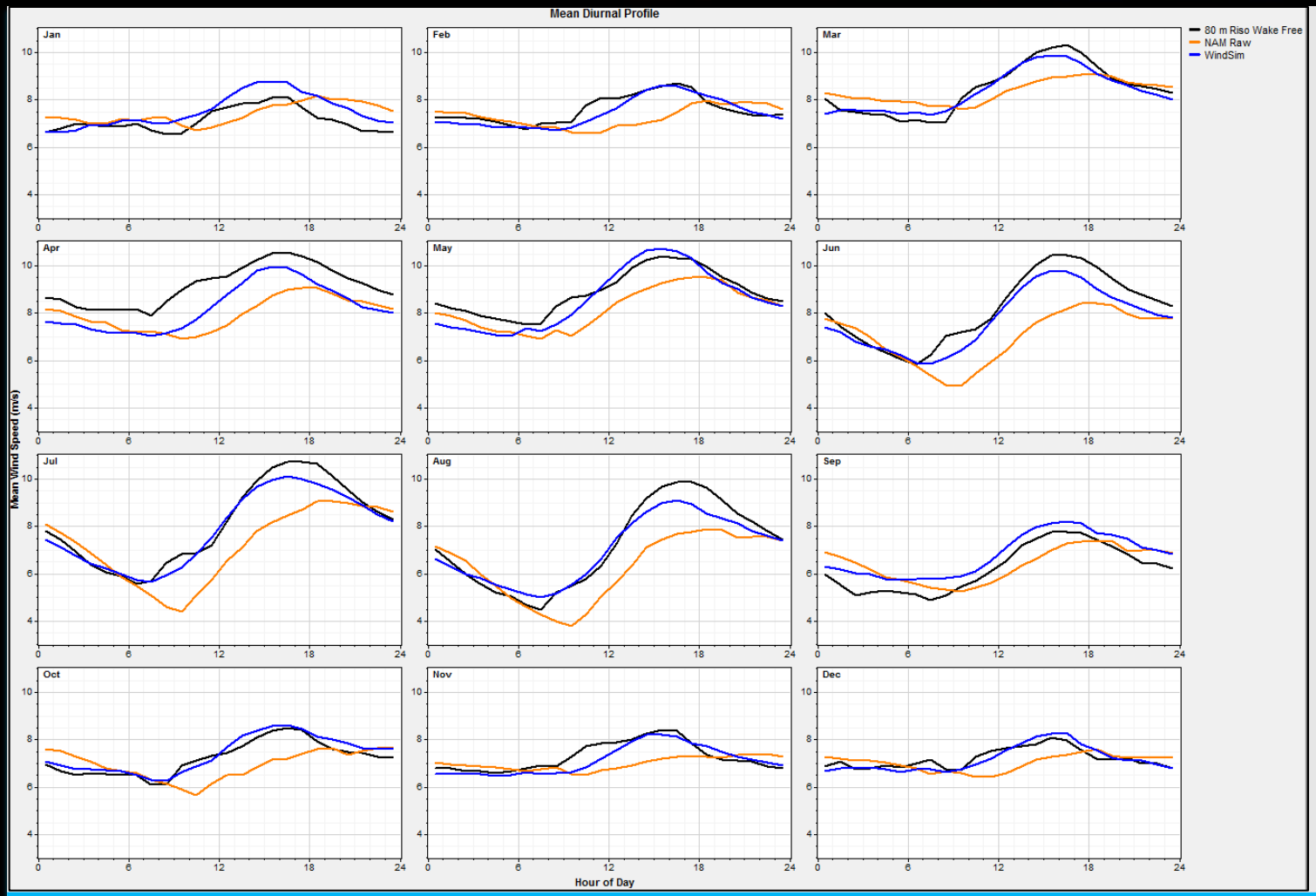



KEY
**Black**: Obs **Orange**: NAM **Blue**: WS

- Notable low bias in Raw NAM (Orange) forecast, particularly in Spring and Summer months. WindSim corrected does a much better job even on the monthly average scale.
- All do relatively well with wind direction frequency.

# GULF WIND DIURNAL/MONTHLIES




KEY
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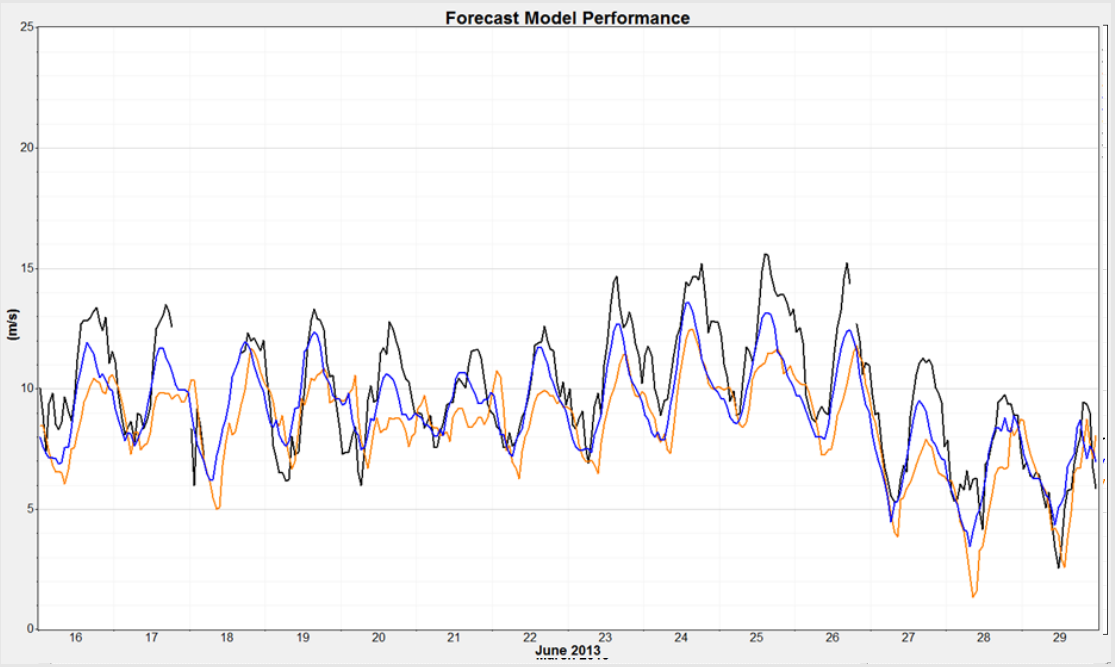
**Blue**: WS

Pattern

# GULF WIND ERROR ANALYSIS




| PGW | | | |
|---|---|---|---|
| Relative (%) | Raw NAM | WS | Improvement |
| MBE | -4.93% | -0.95% | 4.0% |
| MAE | 24.02% | 19.08% | 4.9% |
| RMSE | 31.38% | 25.12% | 6.3% |

KEY
**Black**: Obs **Orange**: NAM **Blue**: WS

| MAE (%) | Raw NAM | WS | Improvement |
|---|---|---|---|
| ***Non-Seasonal*** | | | |
| Winter | 23.78 | 19.47 | 4.31 |
| Spring | 22.03 | 17.32 | 4.71 |
| **Summer** | **23.05** | **17.39** | **5.66** |
| Fall | 27.94 | 22.63 | 5.31 |

- WindSim corrected wind speeds lower by all error measures 4-6%, particularly in the summer months, where error improves 5% during a critical high-energy and high-price period.
- Despite improvement, room for even better prediction may lie in breaking neural network correction by season rather than using the entire training period (more later).

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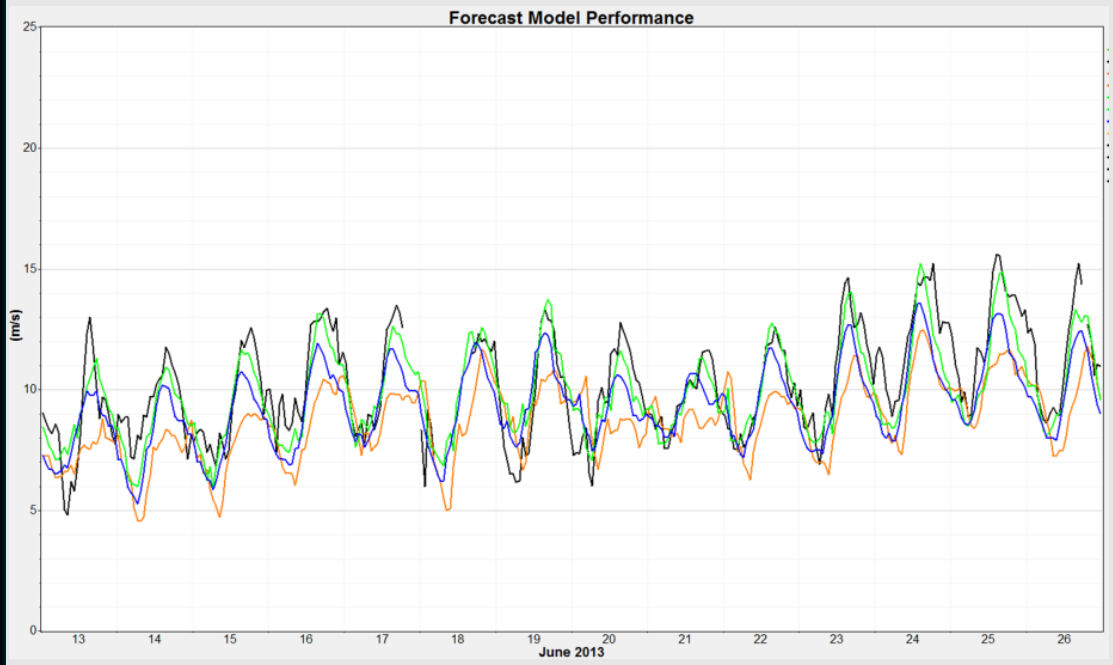
# GULF WIND SEASONAL CORRECTION




**PGW**

| Relative (%) | Raw NAM | WS | Improvement |
|---|---|---|---|
| MBE | -4.93% | -0.95% | 4.0% |
| MAE | 24.02% | 19.08% | 4.9% |
| RMSE | 31.38% | 25.12% | 6.3% |

**PGWS**

| Relative (%) | Raw NAM | WS | Improvement |
|---|---|---|---|
| MBE | -4.93% | -1.42% | 3.5% |
| MAE | 24.02% | 17.77% | 6.3% |
| RMSE | 31.38% | 23.67% | 7.7% |

| Relative (%) | Improvement |
|---|---|
| MAE | -0.5% |
| MBE | 1.3% |
| RMSE | 1.5% |

KEY
**Black**: Obs **Orange**: NAM **Blue**: WS **Green**: Seasonal WS

- By doing the NN correction by season, the training improved most error statistics. Interestingly, MAE dropped some (perhaps due to the mix of seasonal influences in Apr-Jun).
- MAE has improved more than 7% from the original raw mesoscale forecasts.

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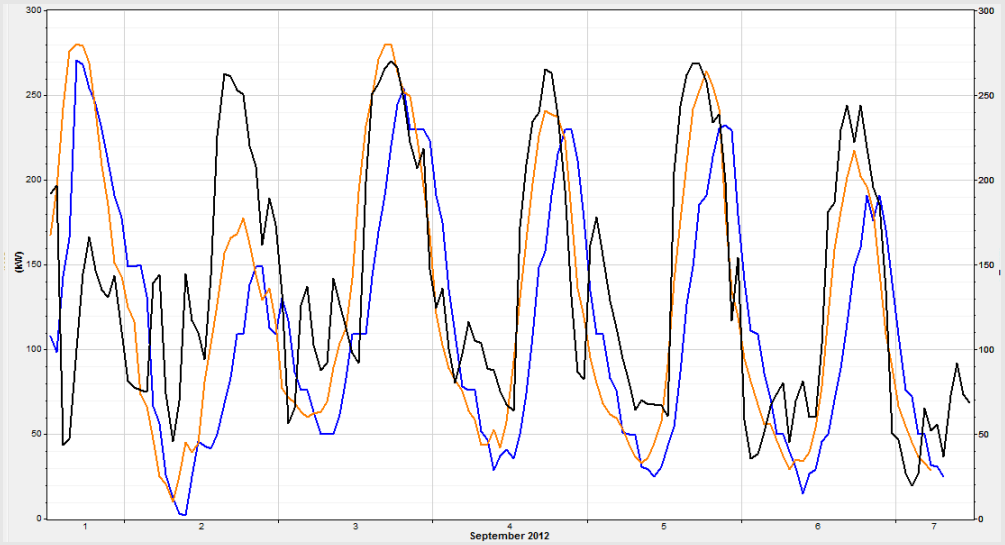
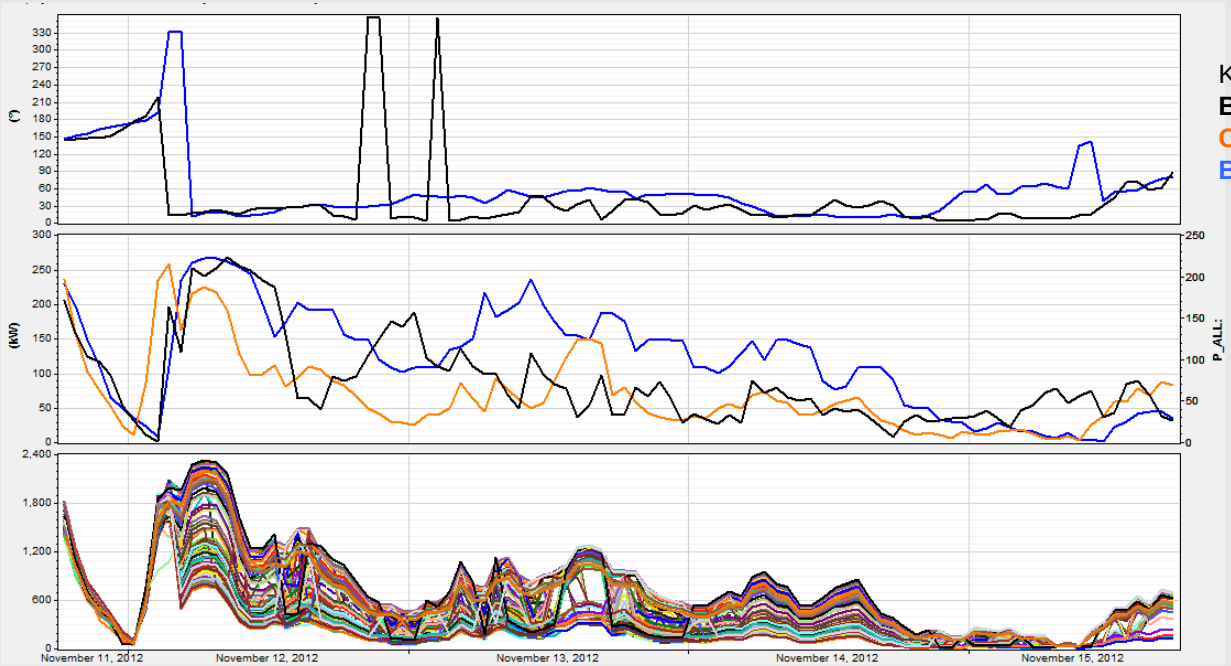
# GULF WIND POWER ERROR




| Base Mesoscale | | |
|---|---|---|
| **Power** | | |
| MBE | (9,501.44) | -3.4% |
| MAE | 48,186.97 | 17.2% |
| RMSE | 64,936.27 | 23.2% |
| | | |
| Full Correction WS | | |
| **Power** | | |
| MBE | (8,882.69) | -3.2% |
| MAE | 38,774.64 | 13.8% |
| RMSE | 54,400.00 | 19.4% |

- Using the raw NAM forecast hit with the empirical power curve and the WindSim Forecast module power with dynamic wake and neural network correction to the wind data, we see a noticeable improvement in power prediction across all seasons.
- Using the WindSim power forecasting module leads to a 4-6% improvement in MAE, particularly in the summer months.
- The 13.8% MAE achieved is on a 36-48 hour forecast, in line with current industry standards.

# GULF WIND POWER ERROR IN WAKED SECTOR




KEY
**Black**: Obs
**Orange**: WPFC
**Blue**: WS

| Base Mesoscale | *Waked* | |
|---|---|---|
| **Power** | | |
| MBE | 38,066 | 13.6% |
| MAE | 53,287 | 19.0% |
| RMSE | 71,185 | 25.4% |
| | | |
| Full Correction WS | *Waked* | |
| **Power** | | |
| MBE | (1,970) | -0.7% |
| MAE | 29,267 | 10.5% |
| RMSE | 44,192 | 15.8% |

- MBE drops 13%, from a 13% over prediction to a slight under-prediction in the off-axis sector (15-45 degrees).
- MAE and RMSE drops 10% as well, indicating a better prediction of farm power in the waked sector.

# CONCLUSIONS

- WindSim's neural network corrected forecasting module helped improve our mesoscale forecasting error by different measures by 4-10% at three different sites of varying flow and terrain complexity.
  - Low biases noted in all three sites.
  - Mesoscale model doing quite well with site generally but improved with WindSim Forecasting.
- Promise shown in breaking neural network training by season, particularly for sites with strong seasonally changing wind flow.
  - Coastal site with varying influencing wind pattern aided in breaking by site's known pattern.
- Power error also reduced and WindSim's Forecasting Module's predicted power with dynamic wake able to replicate closely the production patterns observed.
- Biggest improvement is in waked sector with solving dynamically for wakes in off-axis sectors.
- Ability to integrate WindSim Forecasting for multiple tools within operating business.

# THANK YOU

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