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October 26, 2011

PJM RENEWABLE INTEGRATION STUDY WIND & SOLAR DATA DEVELOPMENT

FINAL PRESENTATION

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AWS Truepower Project Goals

Develop synthetic power output profiles and power forecasts for theoretical wind and solar generating facilities.

- Modeled Numerical Weather Prediction data from the (Eastern Wind Integration and Transmission Study[1] (EWITS) was used as input.
- Theoretical wind and solar power plants within the PJM interconnection region were obtained with objective site selection process.
- Wind power output for onshore and offshore sites was computed using a composite of current industry standard power curves.
- Solar power output for centralized and distributed scale sites is based on current technology types and commercially available PV modules.
- Four-hour, six-hour, and next-day wind and solar power forecasts were developed using state-of-art synthetic forecasting tools.
- All results have been validated against several observed measurements.

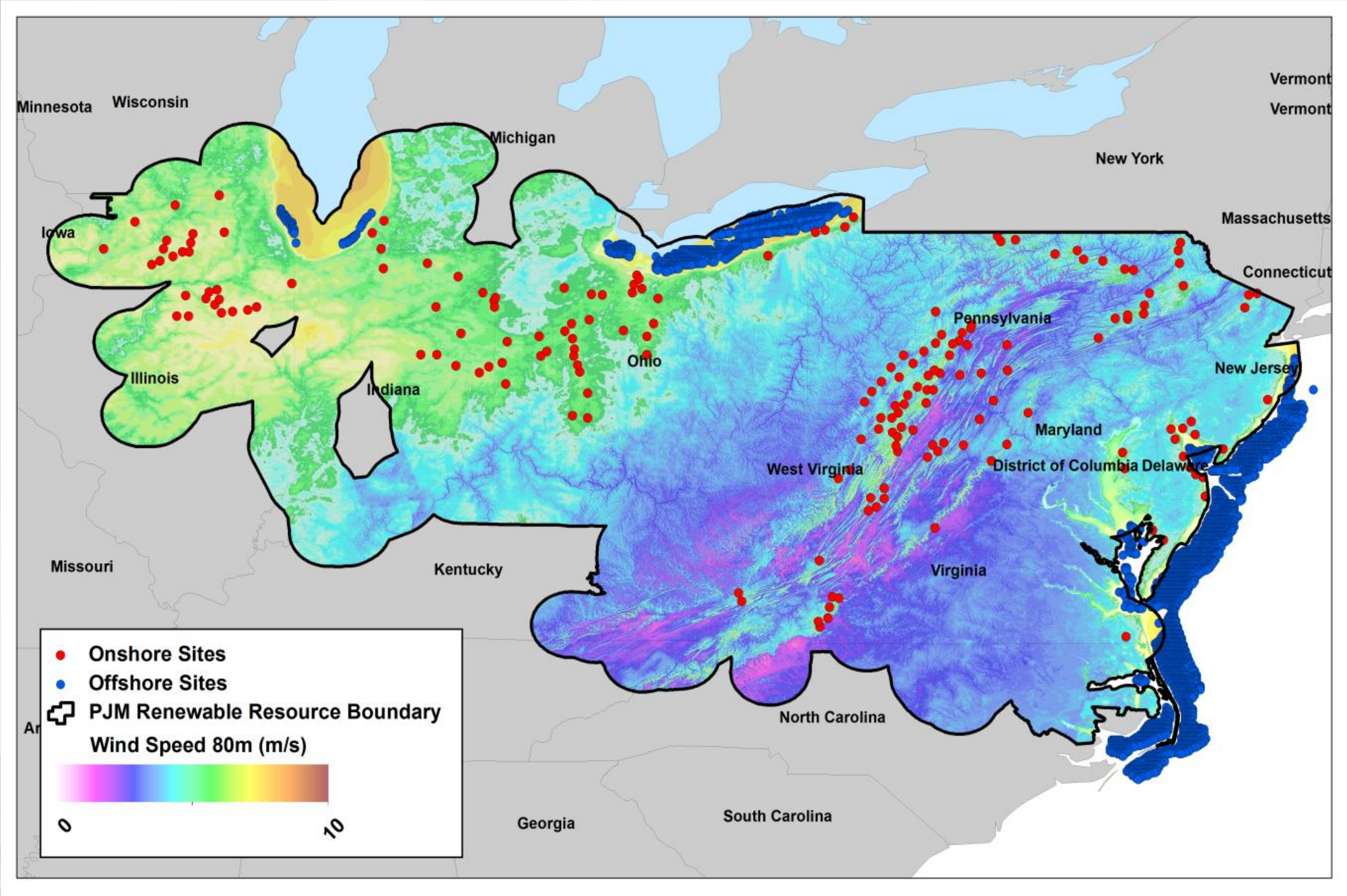
[1] http://www.nrel.gov/wind/systemsintegration/ewits.html

Wind Study Assumptions

- Hypothetical wind farm locations and wind simulations from EWITS study are within PJM Renewable Resource Boundary
- Onshore and Offshore wind sites avoid exclusion (no build) areas
- PJM queue sites modeled at EWITS location with queue capacity
- Convert wind to 10 minute power output using updated composite turbine power curve
- Simulate wind power forecast for each hypothetical wind farm

Wind Study Map – Onshore & Offshore

PJM Renewable Resource Boundary and hypothetical wind sites



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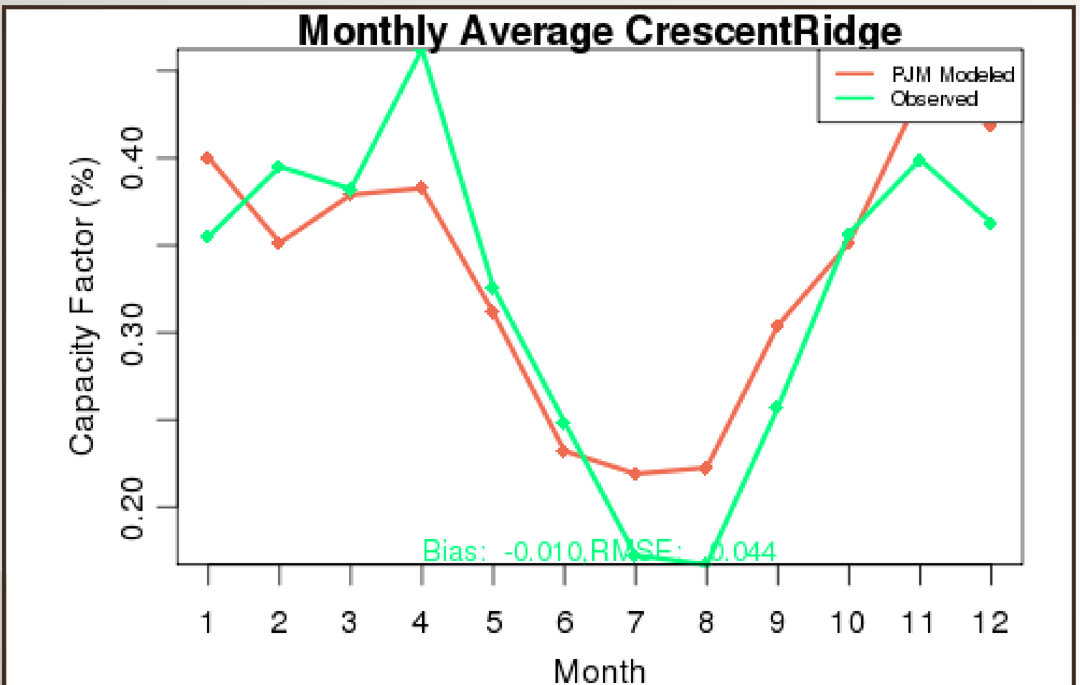
Wind Study Data Summary

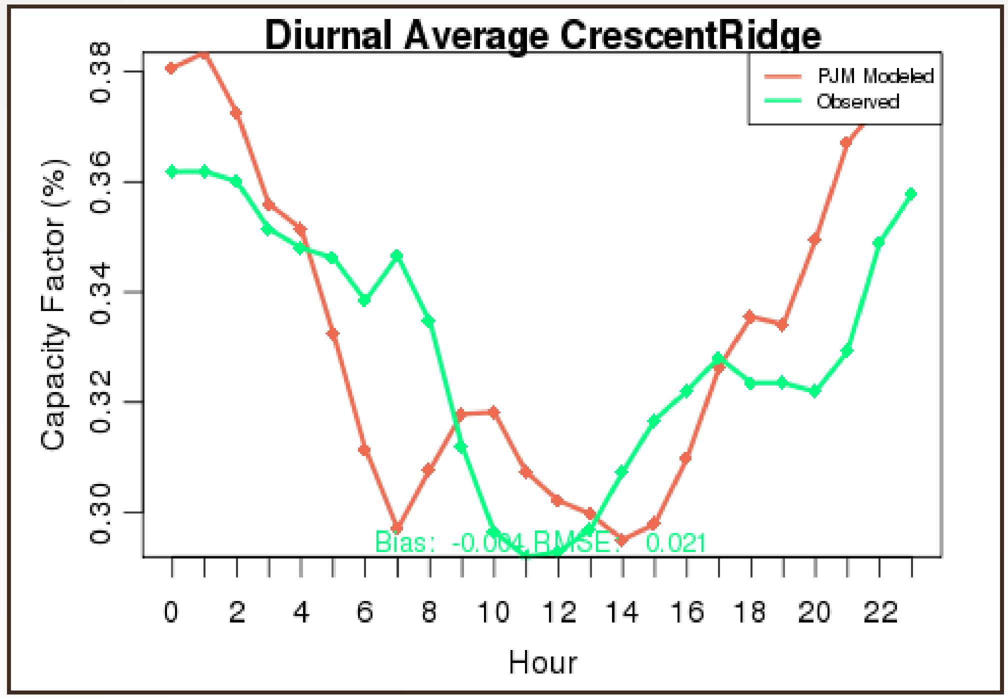
State by state table summary of hypothetical wind farm capacity

	Onshore		Offshore		Queue		Total	
State	**Count**	**GW**	**Count**	**GW**	**Count**	**GW**	**Count**	**GW**
DE	7	1.02	111	2.22	1	0.45	119	3.69
IA	1	0.30	33	0.66	0	0.00	34	0.96
IL	63	35.45	3	0.06	71	12.58	137	48.10
IN	58	29.78	-	-	34	7.31	92	37.09
KY	6	1.49	-	-	1	0.06	7	1.55
MD	9	1.11	354	7.08	8	0.72	371	8.91
MI	14	5.96	18	0.36	6	1.17	38	7.49
NJ	8	1.33	657	13.14	4	0.39	669	14.86
NC	4	0.48	1385	27.70	0	0.00	1389	28.18
OH	34	17.45	606	12.12	42	7.41	682	36.97
PA	56	6.99	123	2.46	67	8.92	246	18.36
TN	1	0.10	-	-	0	0.00	1	0.10
VA	16	2.10	979	19.58	6	0.48	1001	22.16
WI	7	2.20	-	-	0	0.00	7	2.20
WV	18	2.38	-	-	14	1.50	32	3.87
Total	**302**	**108.12**	**4269**	**85.38**	**254**	**40.99**	**4825**	**234.49**

Wind Data Validation – Power Output

- Eight wind power plants were simulated using actual turbine layouts, power curves, and plant size[2]
- Good agreement between simulated and actual power plant profiles
- Total bias between stations of approx. 4.7%





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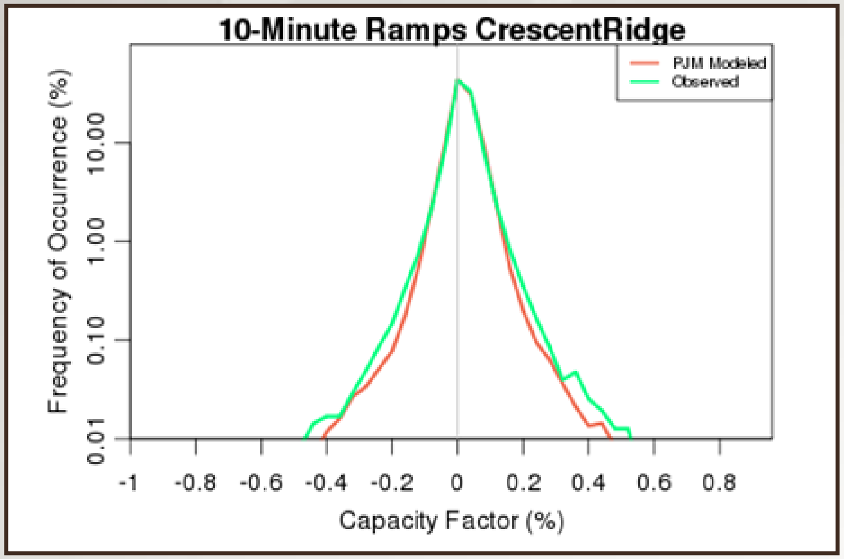
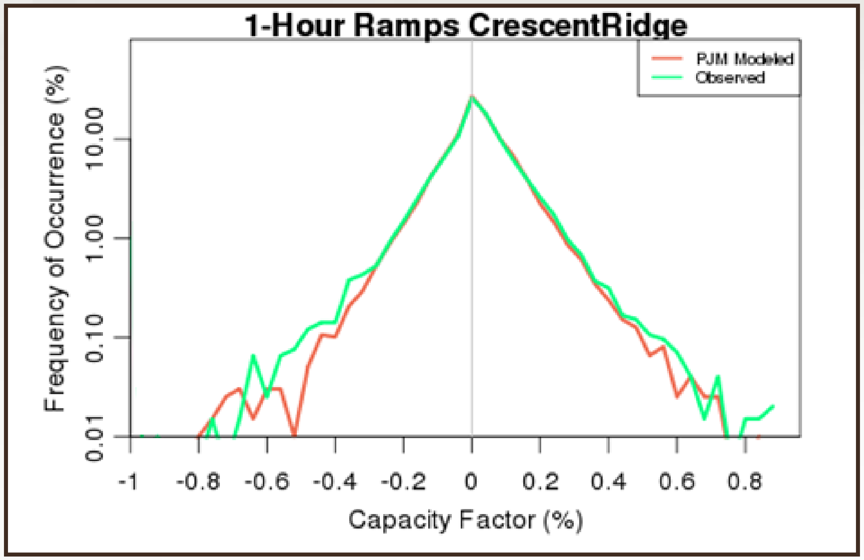
[2] Observations (2009-2011) do not coincide with delivered datasets (2004-2006).

Wind Data Validation – Power Output

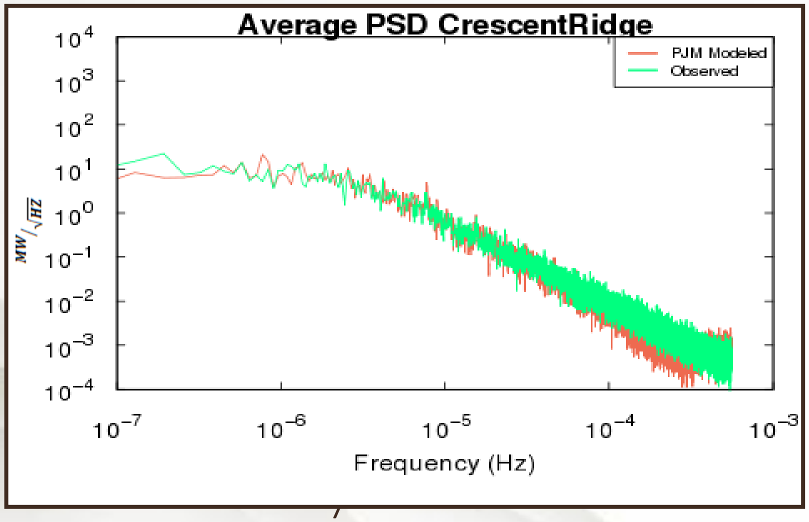
- Modeled versus observed wind power ramp frequency
- Power spectral density





PJM Modeled

Observed



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Wind Data Validation – Forecasts

- Synthetic forecasts compare well against actual forecasts across all stations

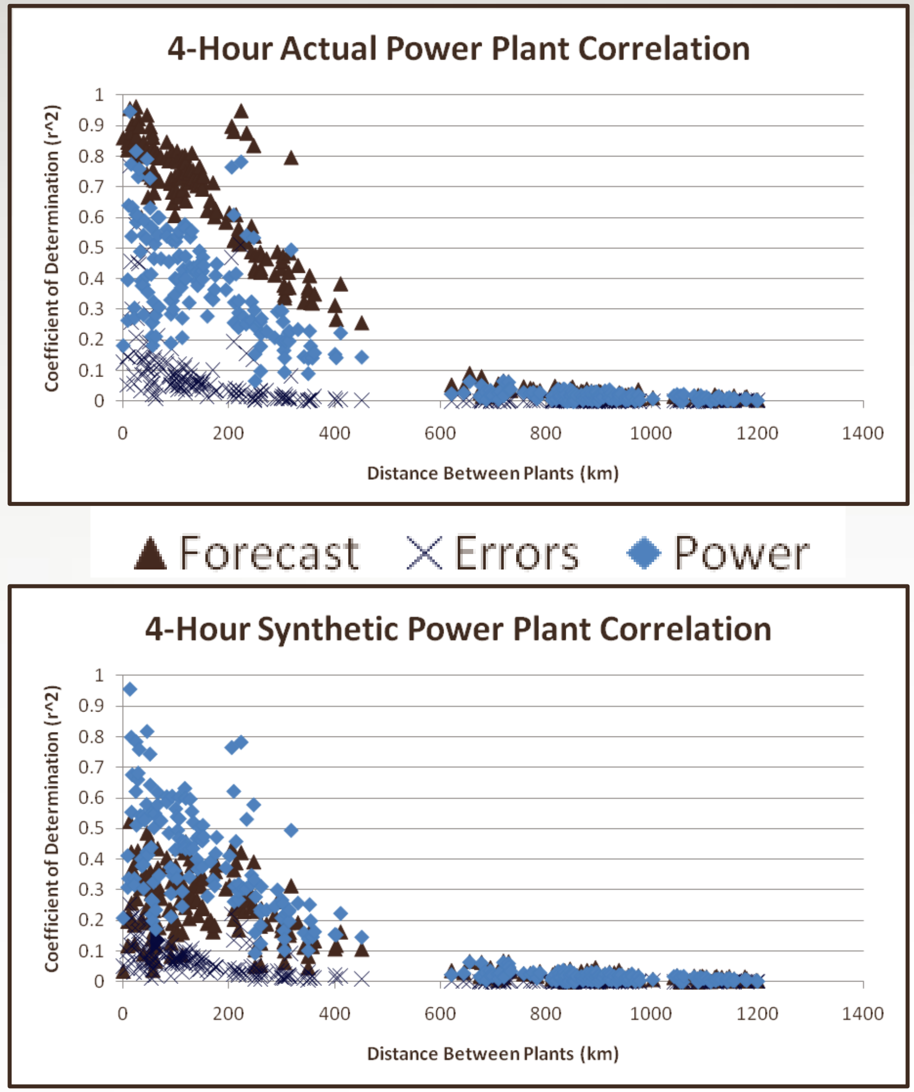
Next Day Forecast	Correlation (r^2)		RMS Forecast Error (CF)		MA Forecast Error (CF)	
	Actual	SynFcst	Actual	Synfcst	Actual	Synfcst
Mean	**0.770**	**0.739**	**0.193**	**0.196**	**0.133**	**0.144**
Min	0.681	0.636	0.148	0.149	0.099	0.106
Max	0.826	0.813	0.234	0.238	0.167	0.180
Standard deviation	0.042	0.050	0.023	0.025	0.017	0.020

- Autocorrelation of forecasts are similar for both actual and synthetic

Time Shift (h)	Observed	PJM	Synfcst	PJM Error	Synfcst Error
0	1	1	1	1	1
1	0.944	0.980	0.959	0.890	0.921
2	0.875	0.946	0.924	0.769	0.842
3	0.814	0.906	0.888	0.674	0.772
4	0.756	0.863	0.852	0.600	0.706
5	0.700	0.820	0.817	0.536	0.644
6	0.647	0.776	0.784	0.484	0.589
7	0.598	0.733	0.751	0.437	0.535
8	0.552	0.691	0.719	0.399	0.487

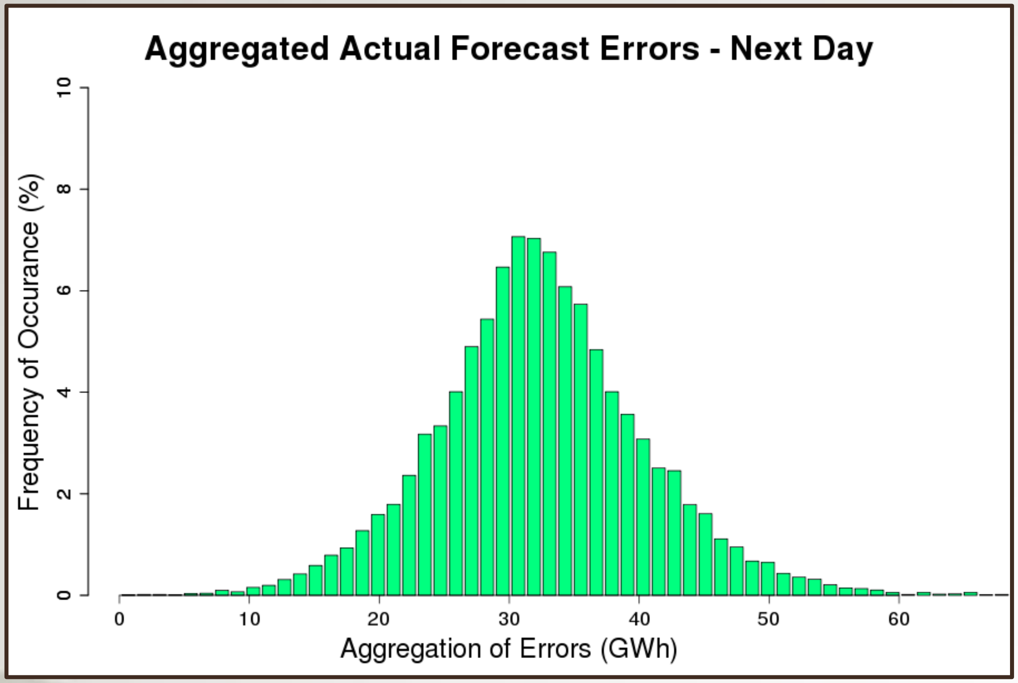
Wind Data Validation – Forecasts

- Synthetic forecasts tend to be less correlated in space than actual forecasts
- The errors correlate very similarly in space
- Gives confidence in the synthetic forecast's ability to predict system wide power generation with correct spatial distribution

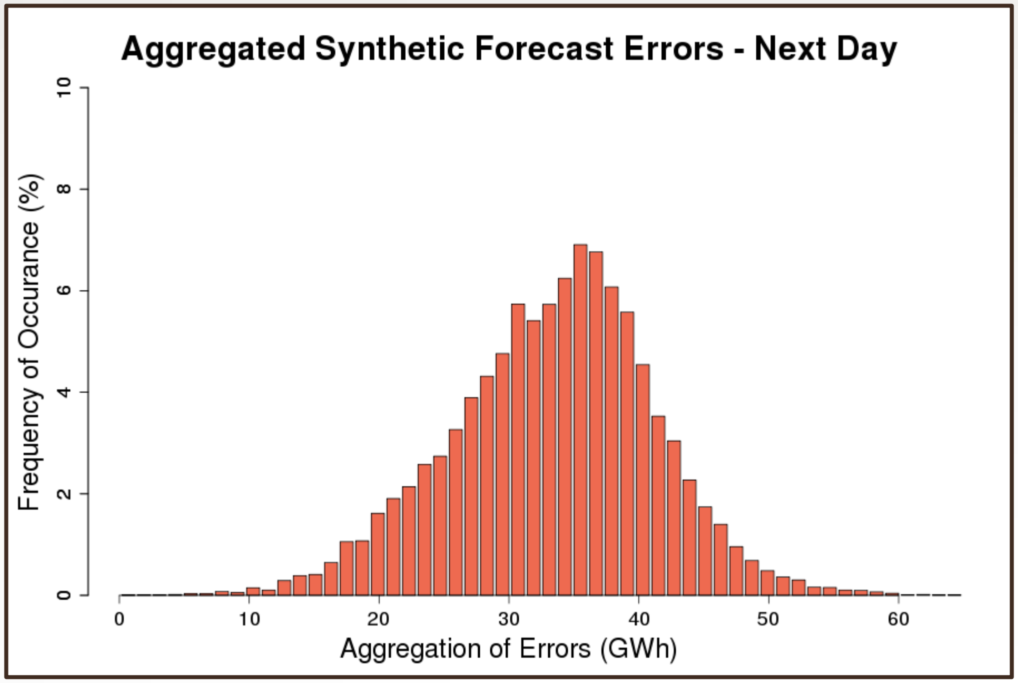


Wind Data Validation – Forecasts

Actual Forecast



Synthetic Forecast



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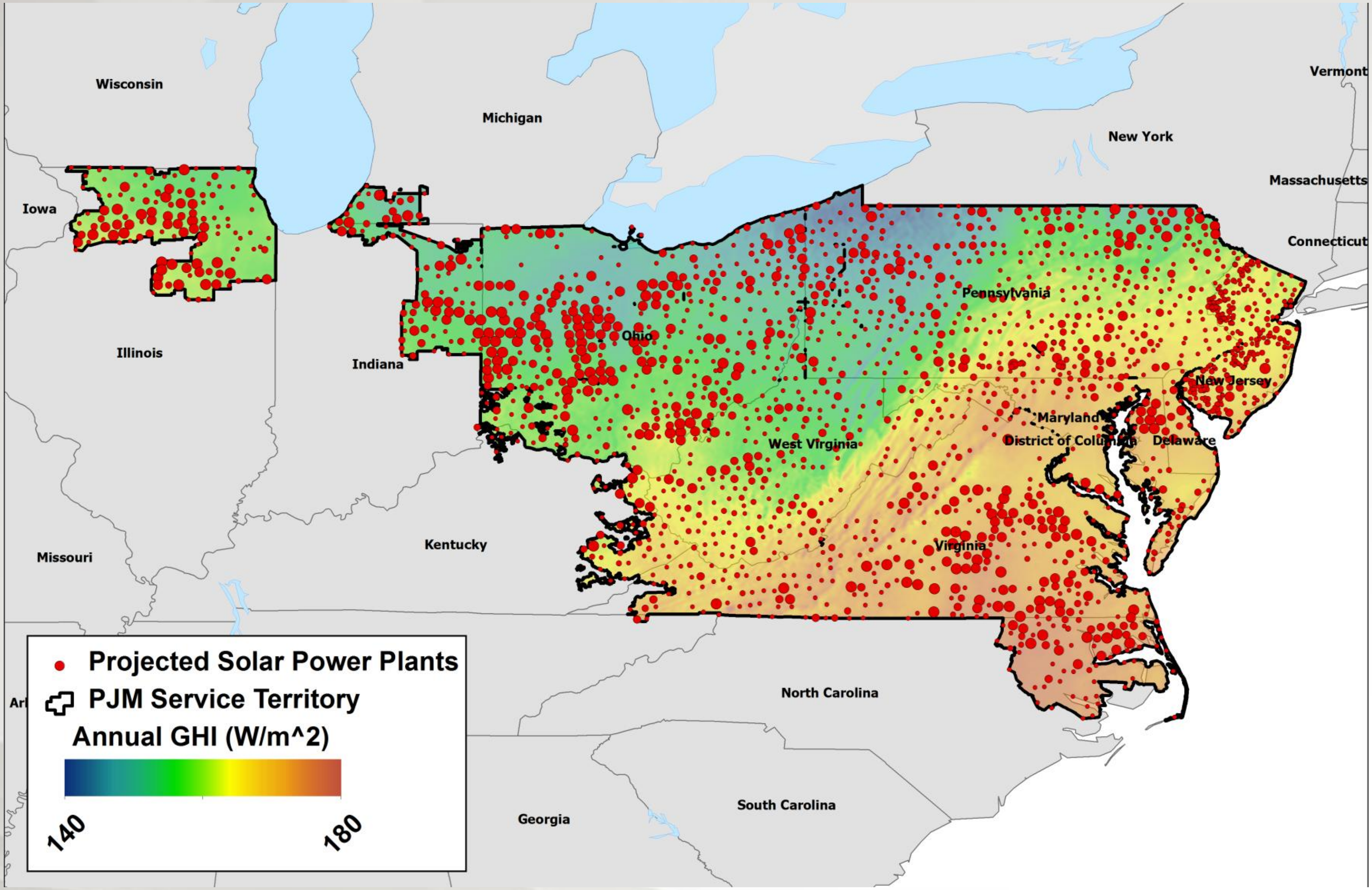
Solar Study Assumptions - Centralized

- Assumptions used to create the hypothetical solar utility sites
  - Sites screened by capacity factor
  - Gross power density of 45 MW/km^2
  - Sites range in capacity from 1-100 MW
  - Minimum 10-25 km separation between sites
- Queue sites modeled at planned capacity and location
- Exclusions similar to wind sites
- Irradiance simulations from EWITS study
- Convert irradiance to 10-minute power output using composite fixed thin film solar PV panels tilted to latitude and single axis tracking mono-crystalline PV panels tilted to latitude
- Simulate solar power forecast for each hypothetical solar facility

Solar Study Map – Centralized

PJM Service Territory and hypothetical centralized solar sites



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Solar Study – Centralized Data Summary

State by state table summary of hypothetical centralized solar site capacity

State	Plants in Queue	Queue Capacity	Projected Plants	Projected Capacity	Total Plants
Delaware	1	0.01	15	0.47	16
District of Columbia	0	0.00	0	0.00	0
Illinois	4	0.05	123	5.78	127
Indiana	0	0.00	68	2.82	68
Kentucky	0	0.00	50	1.41	50
Maryland	9	0.12	73	2.27	82
Michigan	0	0.00	22	0.99	22
North Carolina	4	0.07	70	2.54	74
New Jersey	265	2.67	49	1.09	314
Ohio	14	0.22	364	18.45	378
Pennsylvania	47	0.76	409	11.76	456
Tennessee	0	0.00	2	0.08	2
Virginia	10	0.19	300	11.51	310
West Virginia	0	0.00	200	4.63	200
Total	**354**	**4.08**	**1745**	**63.81**	**2099**

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Solar Study Assumptions - Distributed

- Assumptions used to create the hypothetical distributed (rooftop) solar data
  - Commercial – NLCD Classification: high-intensity; fixed panels tilted to latitude and south facing
  - Residential – NLCD Classification: medium-intensity; fixed, mix of tilt and azimuths
- Queue sites modeled at planned capacity and location
- Hypothetical solar facility locations require new analysis
  - Commercial distributed (250-1000 kW)
  - Residential distributed (1-10 kW)
- Irradiance simulations from EWITS study
- Convert irradiance to 10-minute power output using composite solar technology efficiencies
  - Commercial: fixed panel mono-crystalline PV tilted to latitude
  - Residential: fixed panel mono-crystalline PV mixed azimuth and tilt
- Simulate distributed solar power forecast for each city included in study

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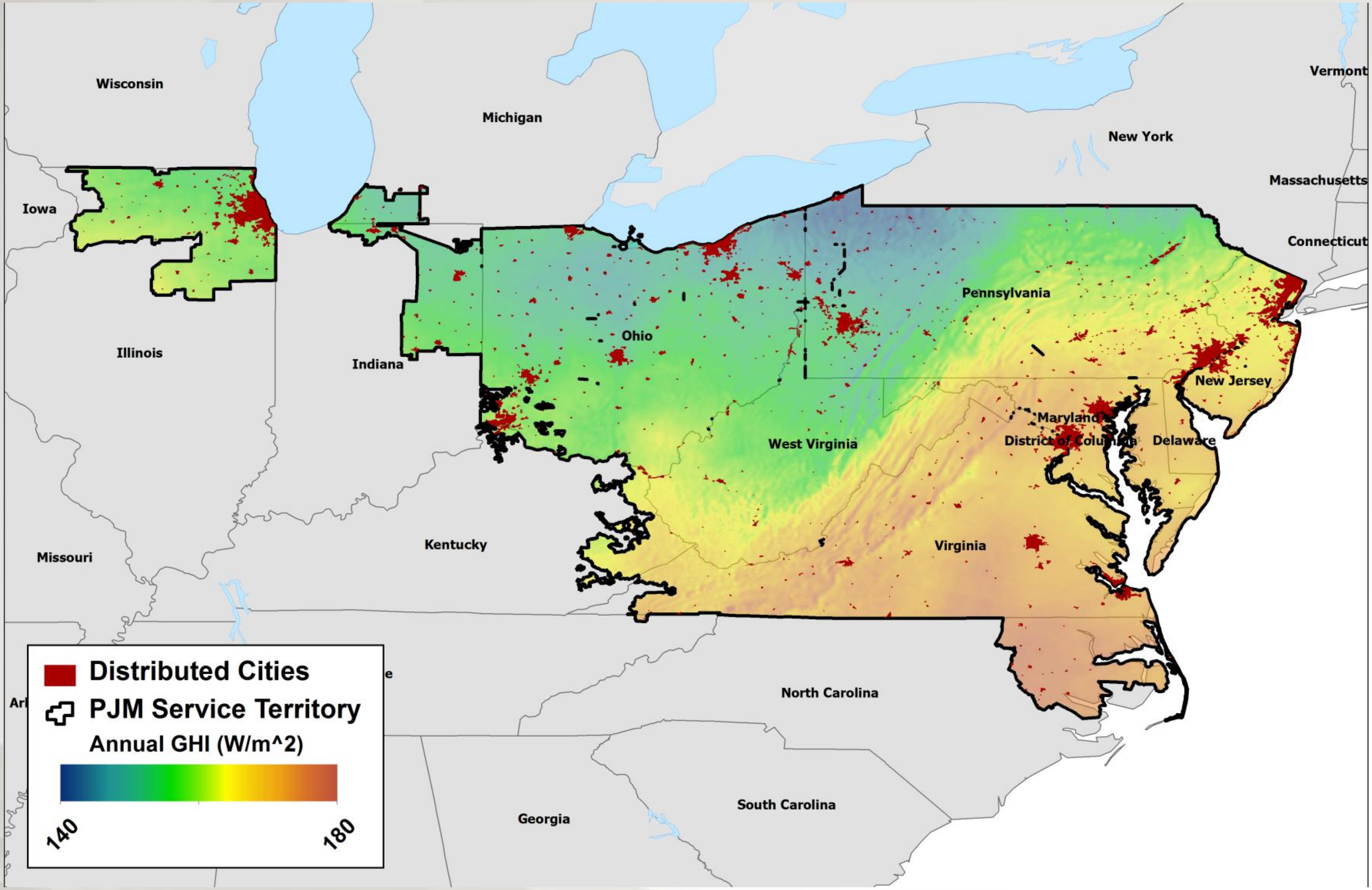
Solar Study – Distributed

Map of PJM Service Territory and cities with distributed solar



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Solar Study – Distributed

State by state table summary of hypothetical distributed solar site capacity

State	#	Residential		Commercial		Rooftop	Total
	Cities	GW	%	GW	%	Target (70%)	GW
Delaware	8	0.23	39%	0.36	61%	0.36	0.59
District of Columbia	1	0.30	16%	1.58	84%	0.03	1.89
Illinois	91	1.61	16%	8.47	84%	1.27	10.08
Indiana	27	0.12	13%	0.86	87%	0.00	0.98
Kentucky	6	0.03	18%	0.16	82%	0.00	0.19
Maryland	44	0.90	26%	2.58	74%	1.12	3.48
Michigan	17	0.02	15%	0.11	85%	0.00	0.13
North Carolina	24	0.04	22%	0.16	78%	0.01	0.20
New Jersey	99	4.06	31%	8.98	69%	3.54	13.04
Ohio	201	1.39	18%	6.38	82%	0.66	7.77
Pennsylvania	285	1.22	13%	8.44	87%	0.64	9.66
Tennessee	2	0.00	19%	0.00	81%	0.00	0.00
Virginia	91	0.42	13%	2.73	87%	0.00	3.16
West Virginia	52	0.10	15%	0.56	85%	0.00	0.67
Total	**948**	**10.47**	**20%**	**41.38**	**80%**	**7.64**	**51.85**

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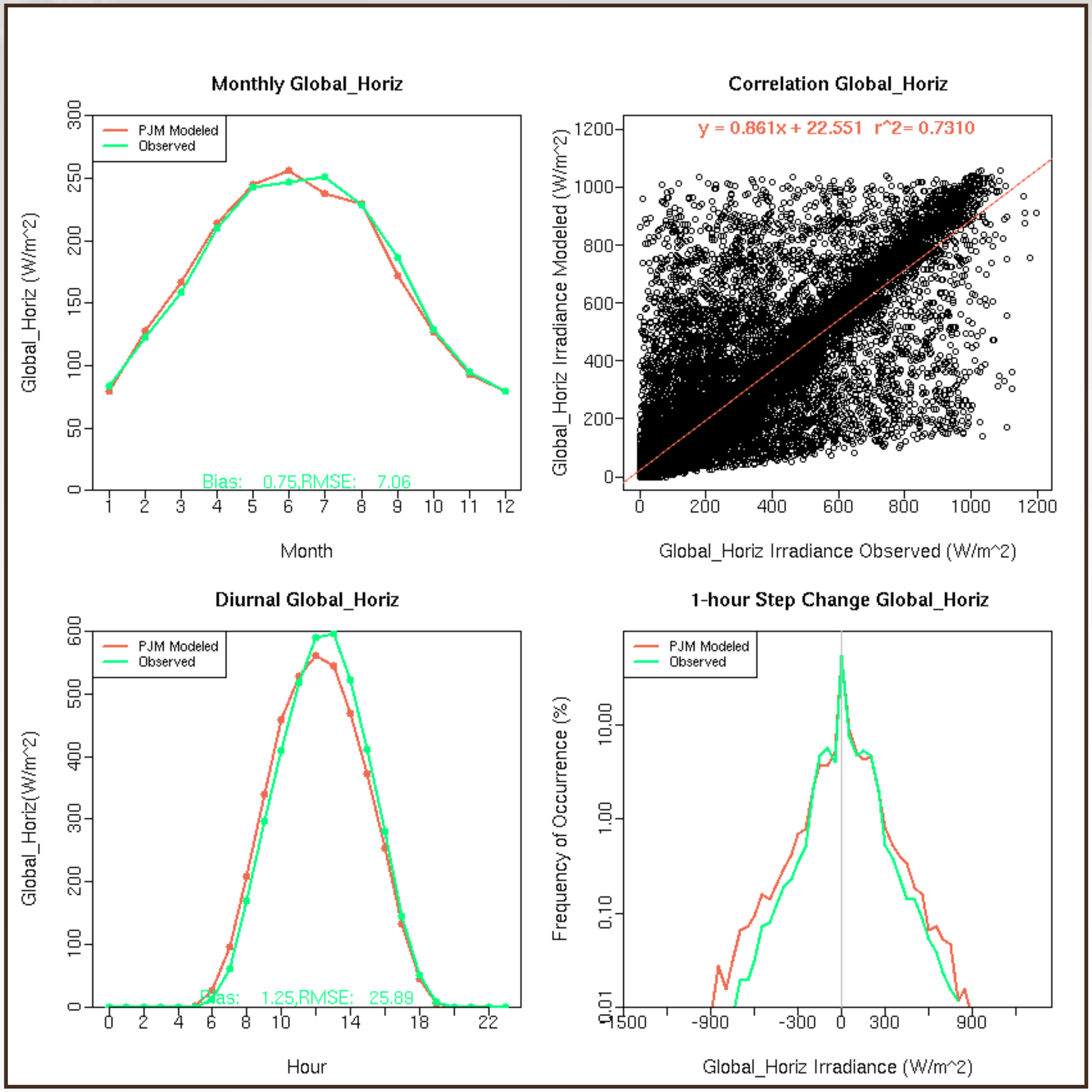
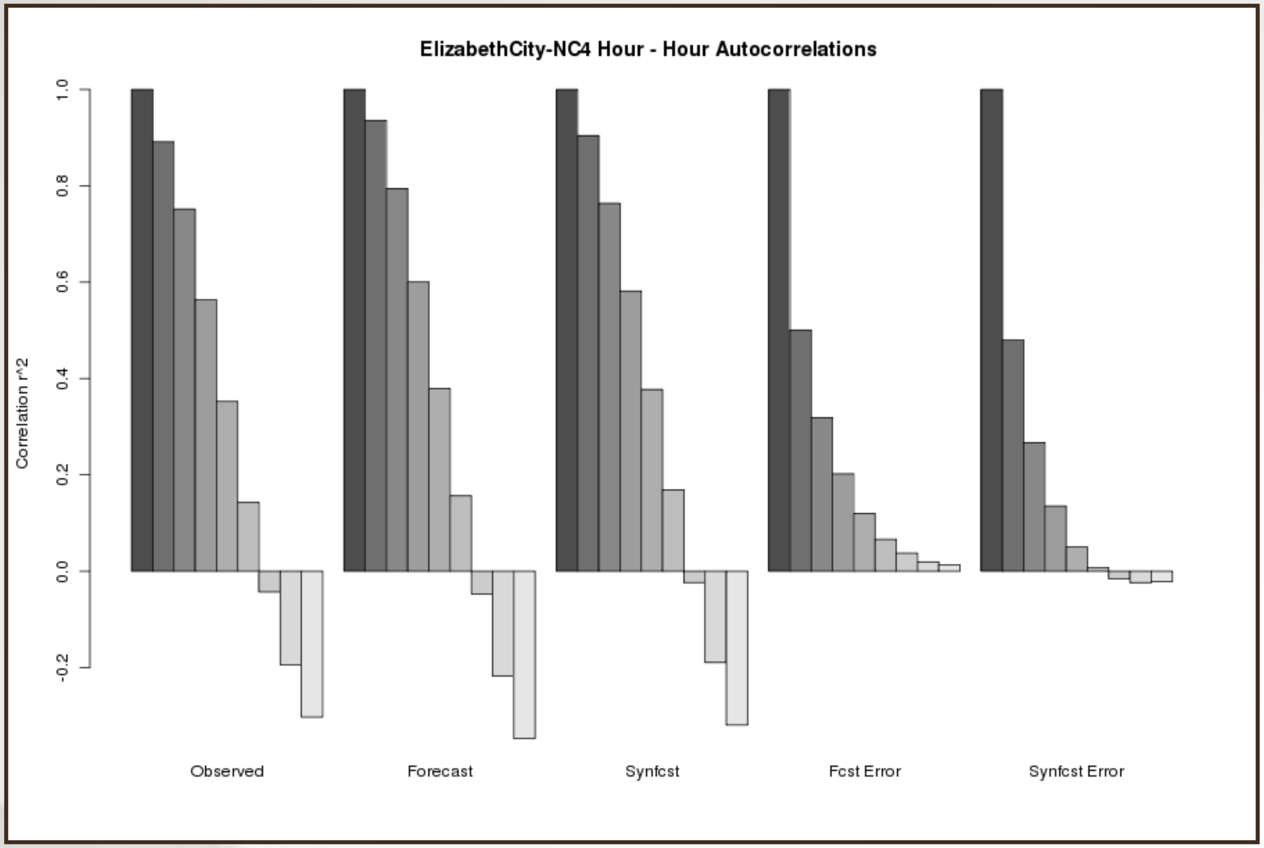
Solar Data Validation – Power Output

- Modeled Global Horizontal Irradiance contains almost no bias compared to measurement stations in the PJM region
- Ramp distribution matches well; modeled is slightly more variable



Solar Data Validation – Forecasts

- Autocorrelation of synthetic forecast very similar actual forecast
- Solar irradiance displays anti-correlation for time lags of greater than six hour



Autocorrelation of observed, forecast, and errors

Solar Data Validation – Forecasts

- Similar trend to the wind power forecasts
- Synthetic forecasts are slightly less correlated in space than actual forecasts
- The correlation of errors match very well compared to the actual
- Correlations are much less dependent on distance as compared to wind