AWS Truewind, LLC

Eastern Wind Integration and Transmission Study

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Outline

AWS Truewind

- Introduction to AWS Truewind
- Scope of Work
- Progress to Date
- Issues and Concerns
- Tasks Remaining

AWS Truewind

Headquarters: Albany, NY

- Mapping
- Energy Assessment
- Project Engineering
- Performance Evaluation
- Forecasting

- Industry Leader & Consultant for 30,000+ MW
- Full spectrum of wind plant design, development and evaluation services
- Project roles in over 50 countries
- Established in 1983; ~100 employees in 4 offices

meteosim Truewind

Scope of Work

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- Test various mesoscale model configurations and choose the best for this study
- Select 600+ GW of wind project sites, both onshore and offshore
- Simulate historical 10-minute winds and plant production at all sites for 2004 to 2006
- Simulate forecasts for the same sites
- Synthesize one-minute data for representative periods

Completed, *in progress*, *future*

Mesoscale Model Validation

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Objective

- Determine the best mesoscale model and model configuration for this study

Approach

- Four configurations of MASS and three configurations of WRF tested

Experiment	Model	Initialization Data, Res	Other
1. MASS/NNGR	MASS 6.8	NNGR, 190 km	
2. MASS/NARR		NARR, 32 km	
3. MASS/NNGR/sfc		NNGR, 190 km	Surface data
4. MASS/NNGR/35 levels		NNGR, 190 km	35 vertical levels
5. WRF/NARR	WRF 2.2.1	NARR, 32 km	
6. WF/NNGR		NNGR, 190 km	
7. WRF/NARR/MYJ		NARR, 32 km	MYJ PBL scheme

MASS = Mesoscale Atmospheric Simulation System, a proprietary numerical weather model
WRF = Weather Research and Forecasting model, the leading community model
NNGR = NCEP/NCAR Global Reanalysis data; NARR = North American Regional Reanalysis

Mesoscale Model Validation

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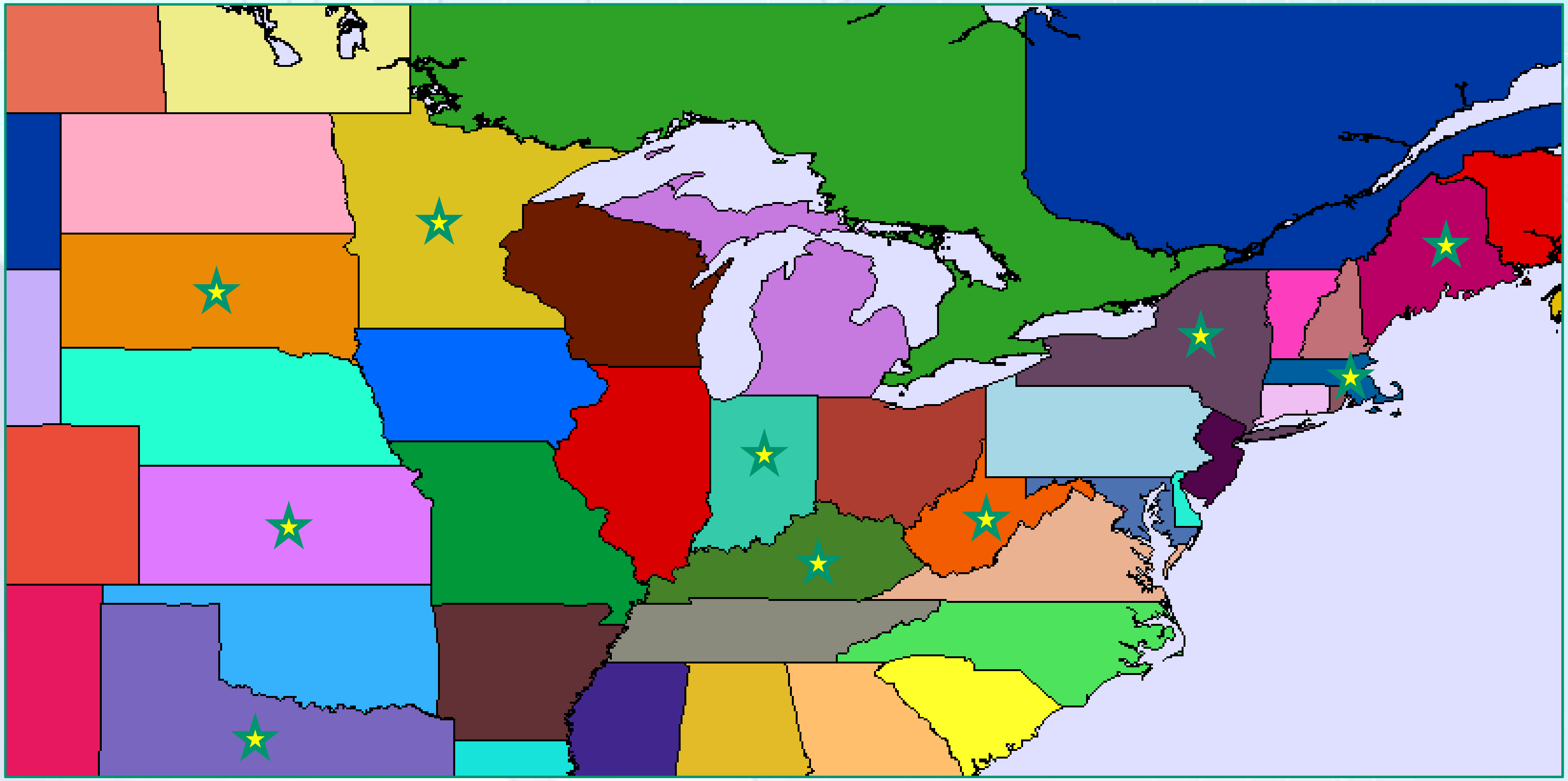
Approach (contd)

- 26 two-week periods of 10-minute simulations were carried out with each model and configuration
- Simulated winds were compared with 80 m data from 10 validation towers
- Mean bias, mean absolute error (MAE), and scaled mean absolute error (SMAE) considered

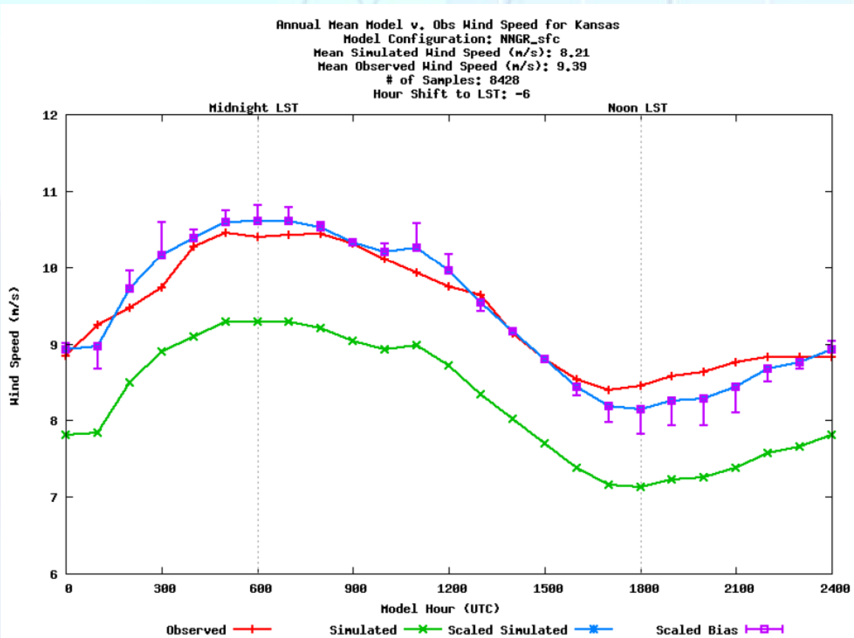
Validation Towers

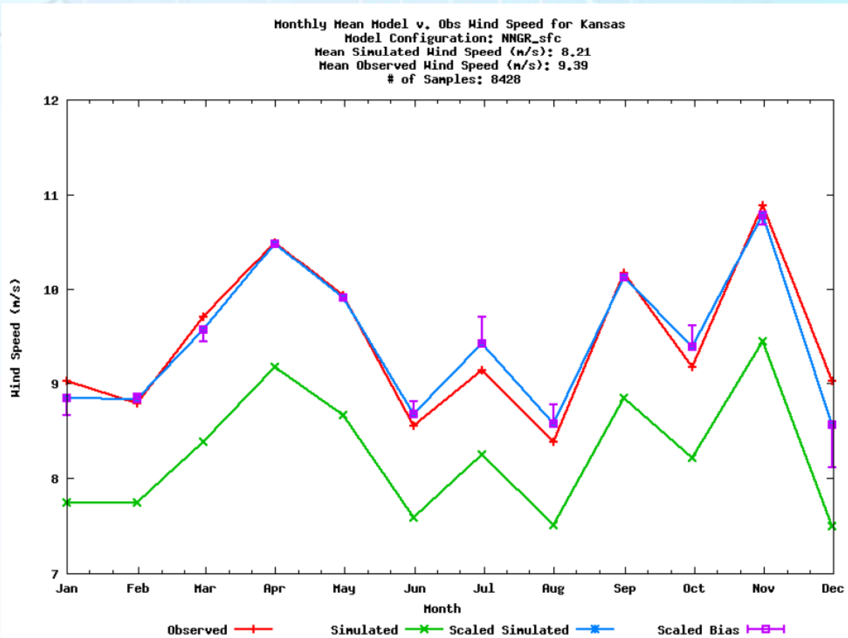


★ *Locations of towers are not exact*

Validation Example

Kansas





Diurnal

Monthly

Validation Example

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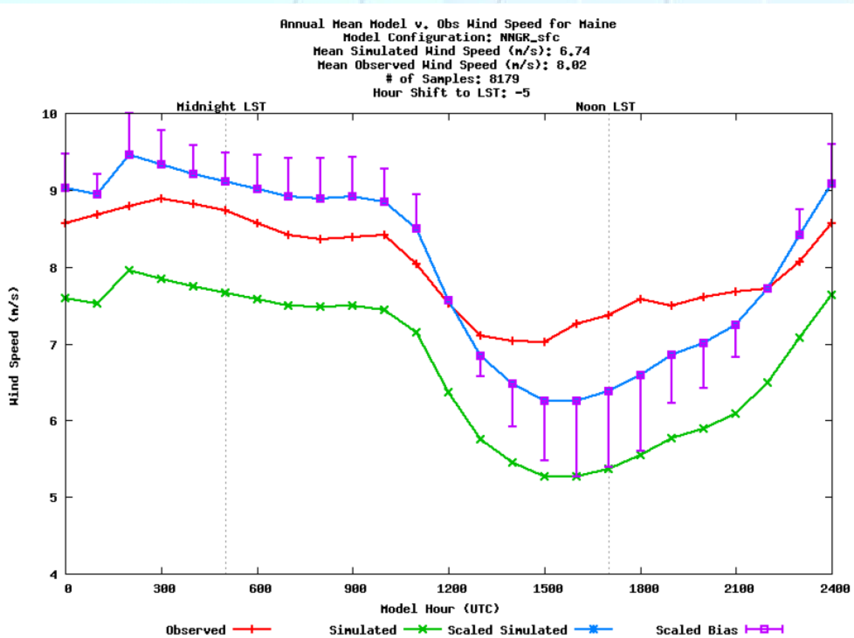
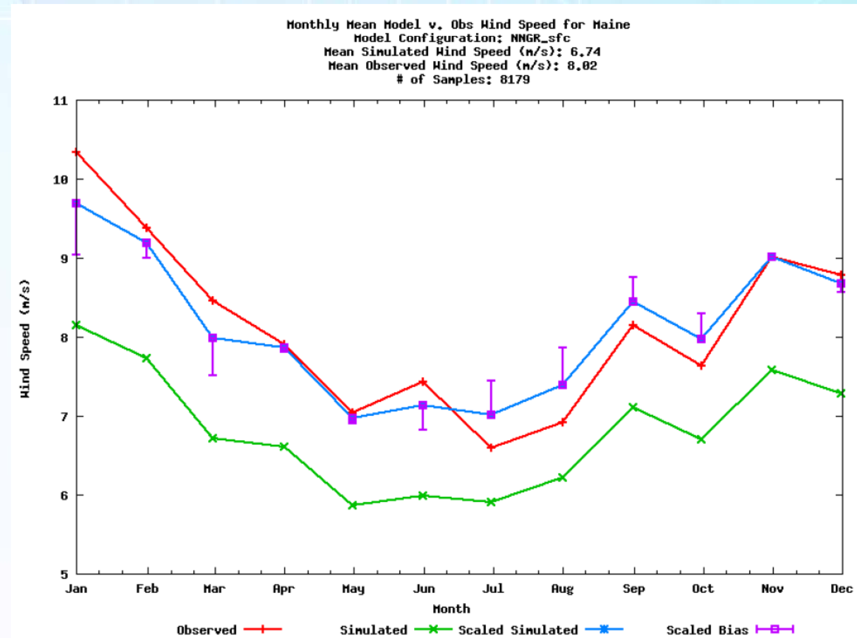
Maine



Diurnal



Monthly

Validation Example

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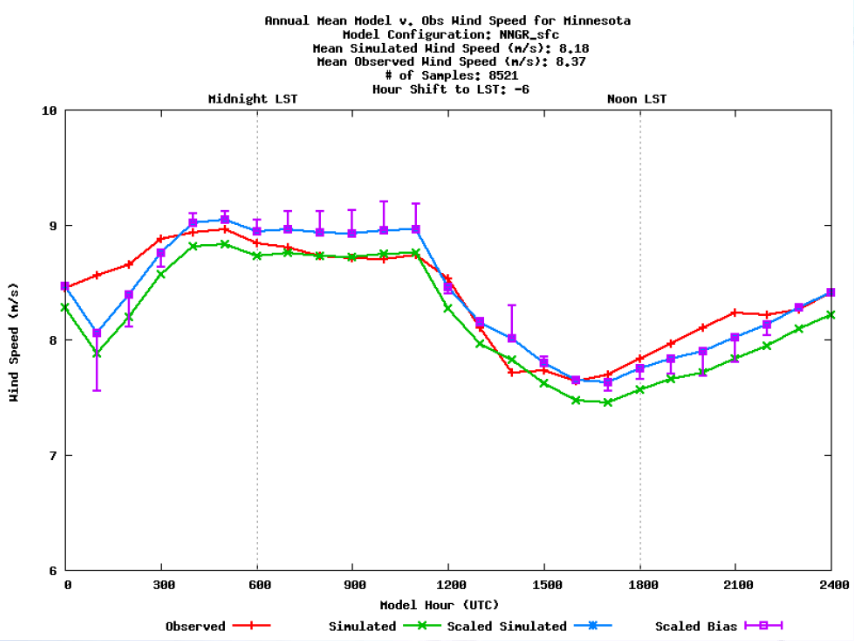
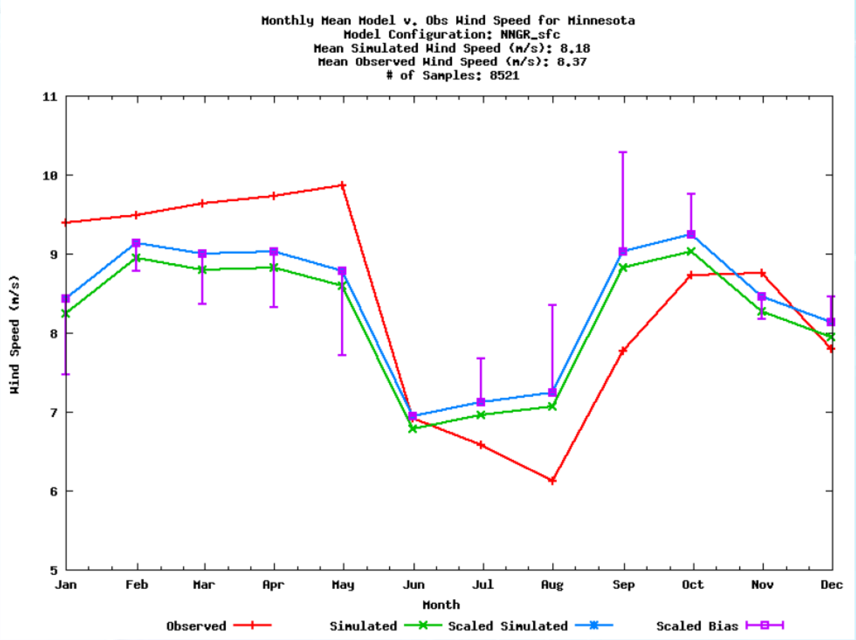
Minnesota

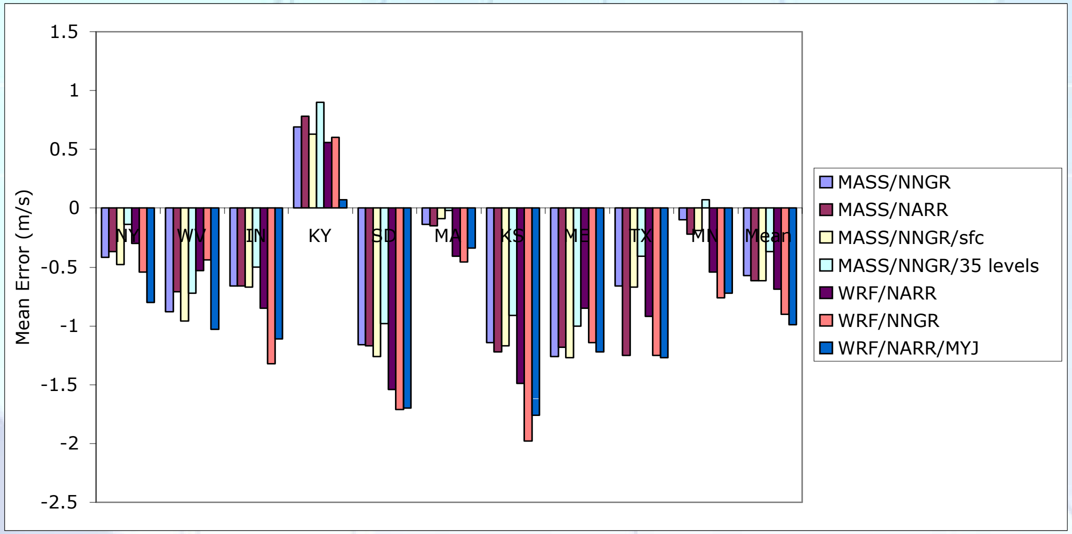


Diurnal

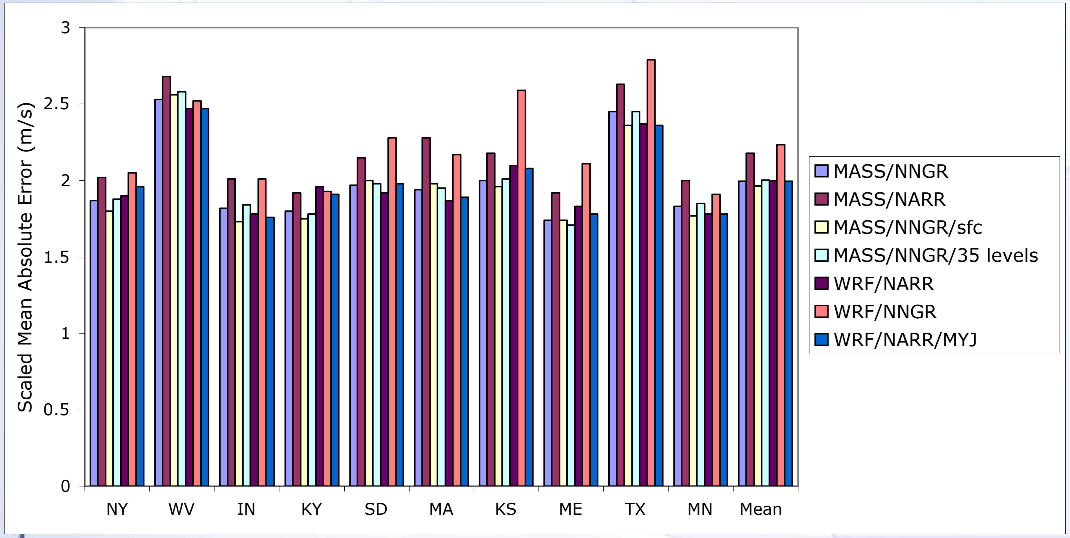


Monthly

Results



Mean bias (m/s)



Mean absolute error (m/s)

By a very small margin, MASS/NNGR/SFC had the lowest overall MAE

Power Conversion Testing

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Objective

- Ensure that the conversion of simulated winds to plant output is realistic

Approach

- Extract mesoscale data for three wind project sites monitored by NREL
- Convert the data to plant output using a combination of deterministic and stochastic methods
- Compare resulting mean capacity factors, average ramp rates, and diurnal/monthly patterns with actual data for 2004
- Adjust method where necessary

Power Conversion Testing

AWS Truewind

Approach

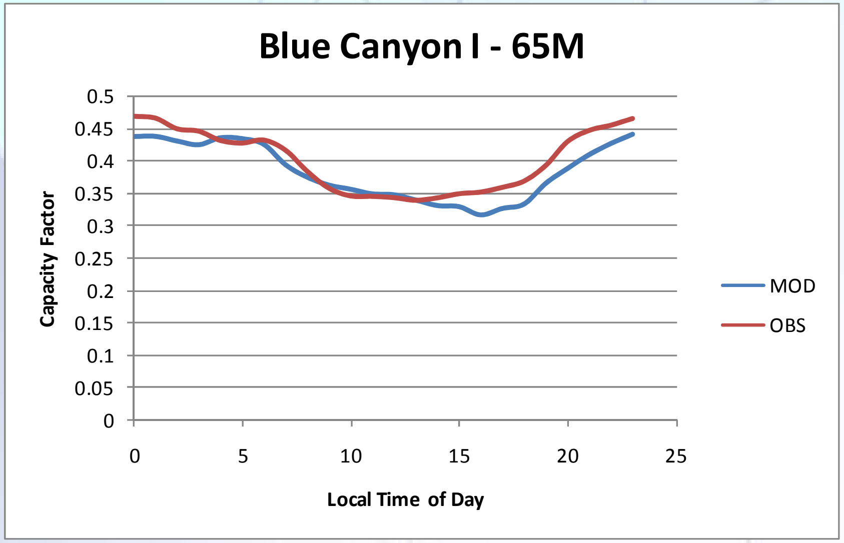
- Power conversion takes into account
  - Turbine power curve for site IEC class
  - Air density, turbulence
  - Wake and non-wake losses
  - Time filtering to replicate the “spatial smoothing” of the output of a real wind plant

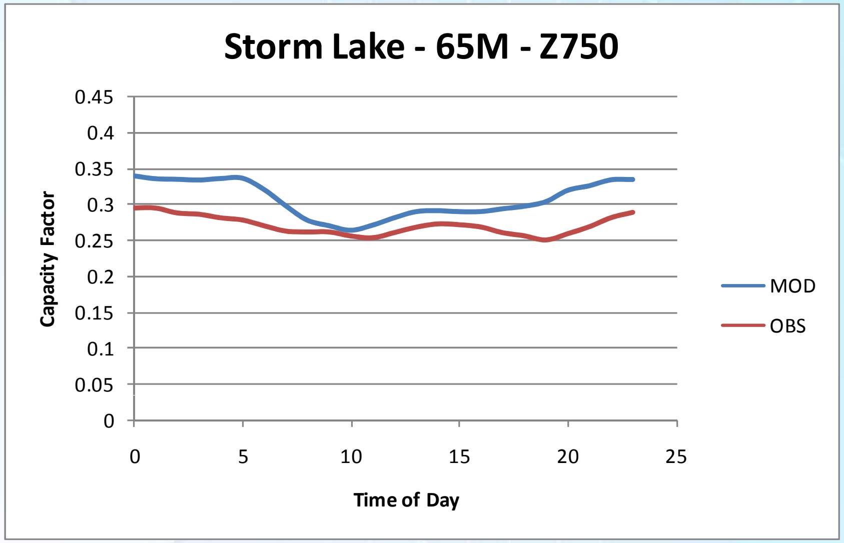
Validation Sites

Plant Name	State	Rated Capacity (MW)	Turbine Type	Hub Height (m)
Blue Canyon I	Oklahoma	74.25	NM72 (1.65MW)	67 m
Lake Benton	Minnesota	103.5	Zond 750	51.2 m
Storm Lake I	Iowa	112.5	Zond 750	63 m

Validation Example

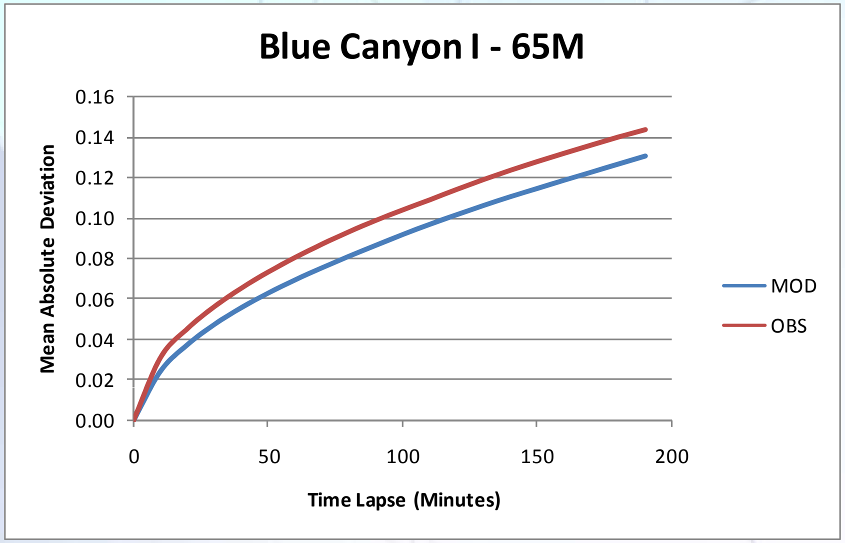
Diurnal Patterns

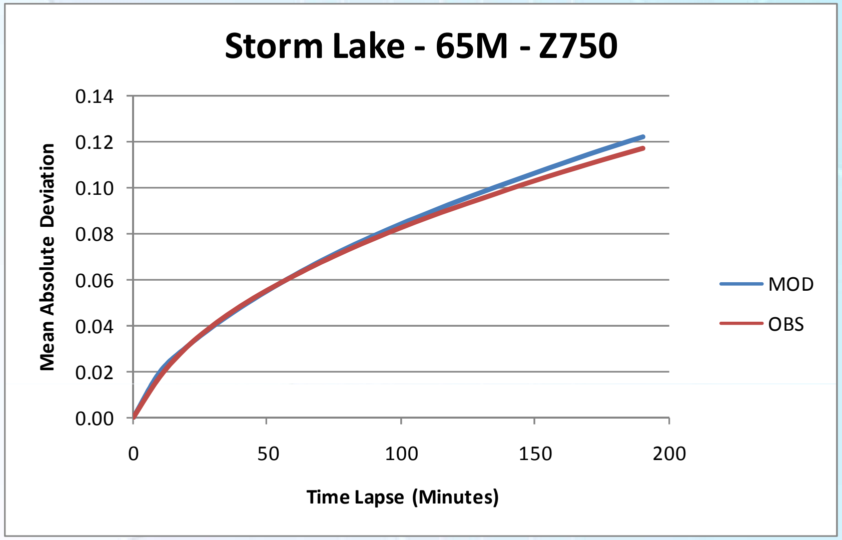




Validation Example

Mean Ramps





Site Selection

Objective

- Select 600+ GW of offshore and onshore wind project sites with acceptable geographic diversity

Approach

- Produce seamless wind speed map of the region
- Convert mean speeds to capacity factors using modeled wind speed distributions, composite IEC Class II power curve, 80 m hub height

Site Screening

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Approach (contd)

- Define exclusions
  - water bodies
  - state and federal parks, other non-public federal lands
  - buffered residential areas
  - buffered airports
  - slopes greater than 20%
- Identify near-contiguous sites meeting these criteria:
  - at least 100 MW
  - locally maximum capacity factor
  - at least 2000 m from neighboring sites
- “Grow” sites until CF decreases or maximum reached; when neighboring sites touch, lower-CF site rejected

The MesoMap Process

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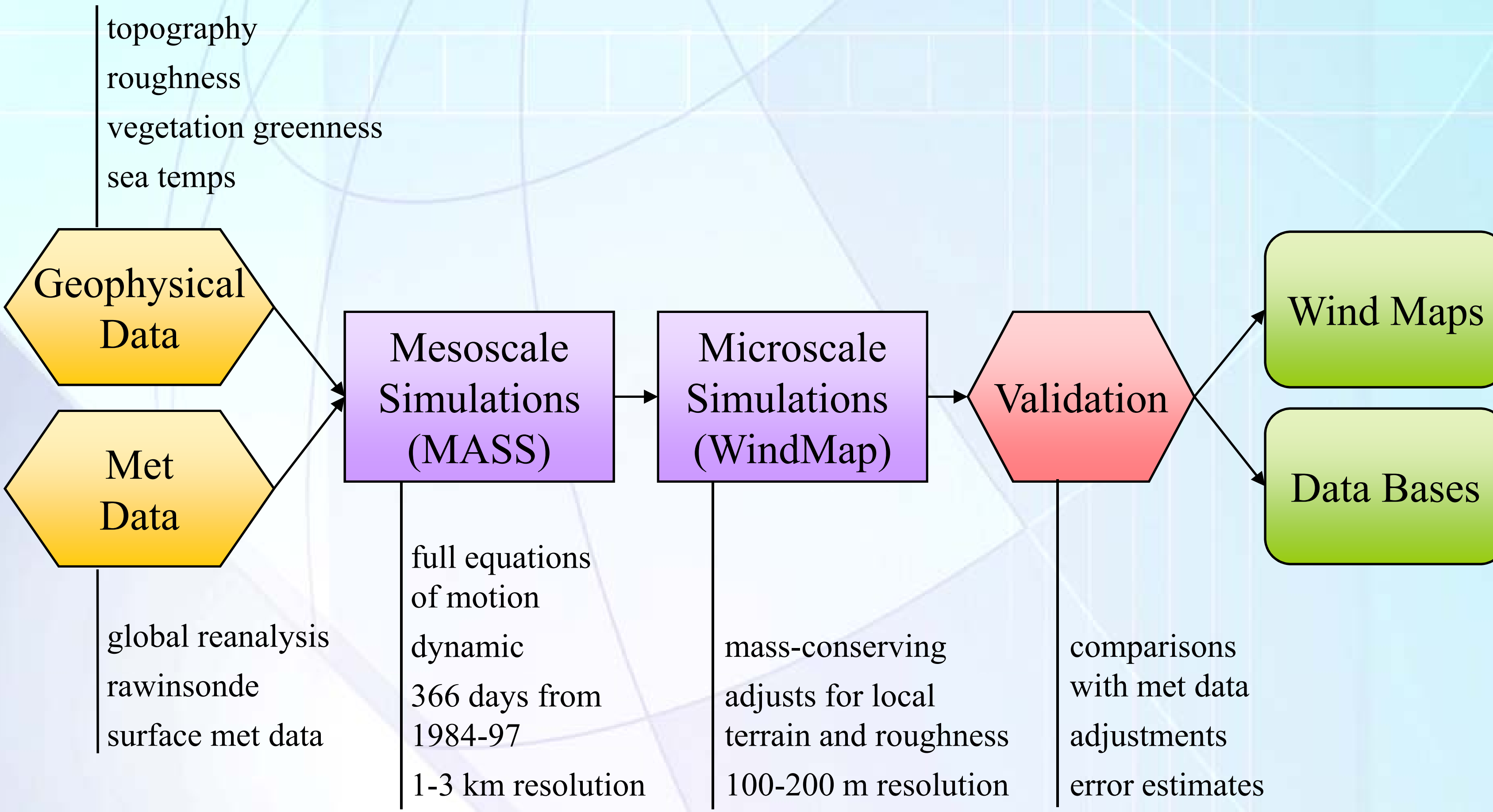
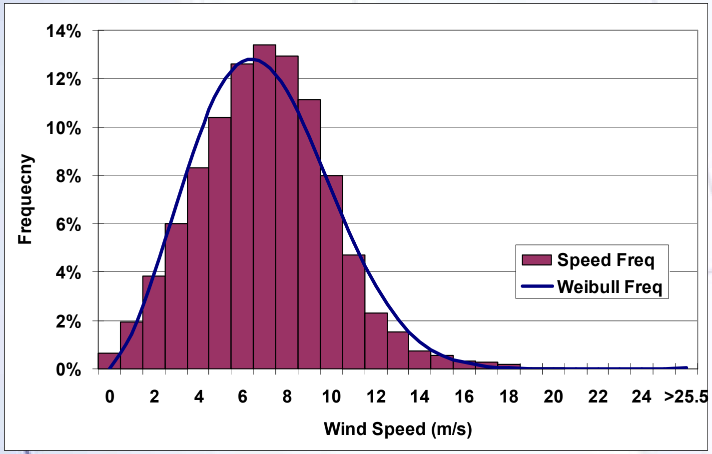
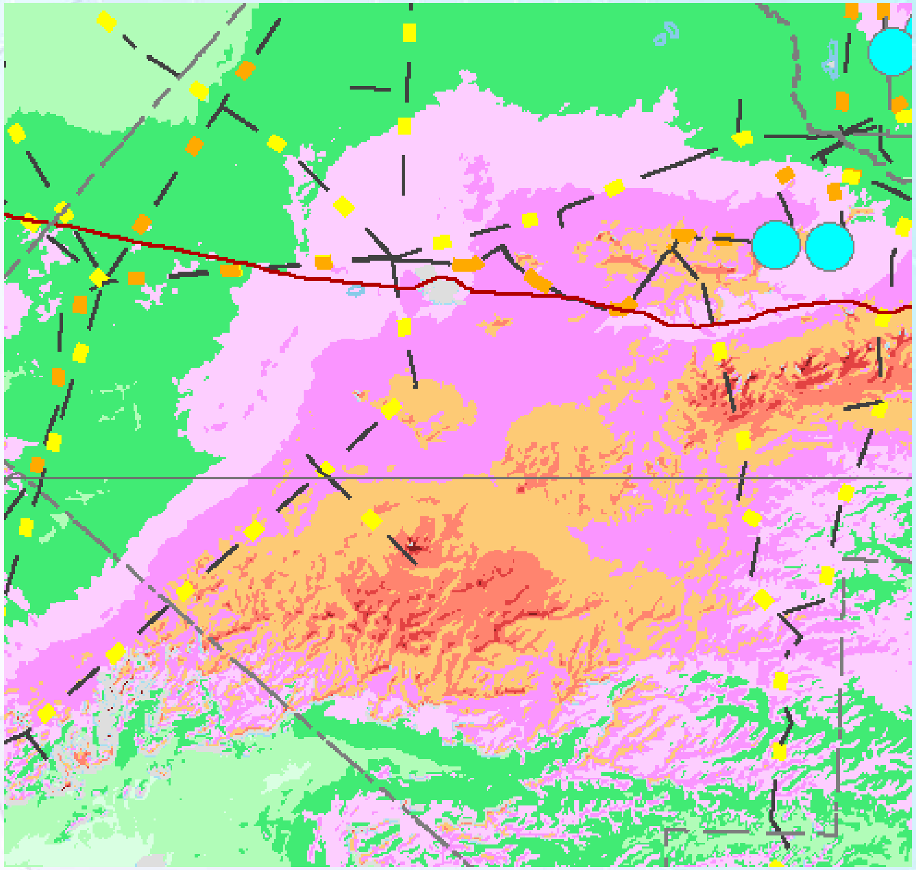


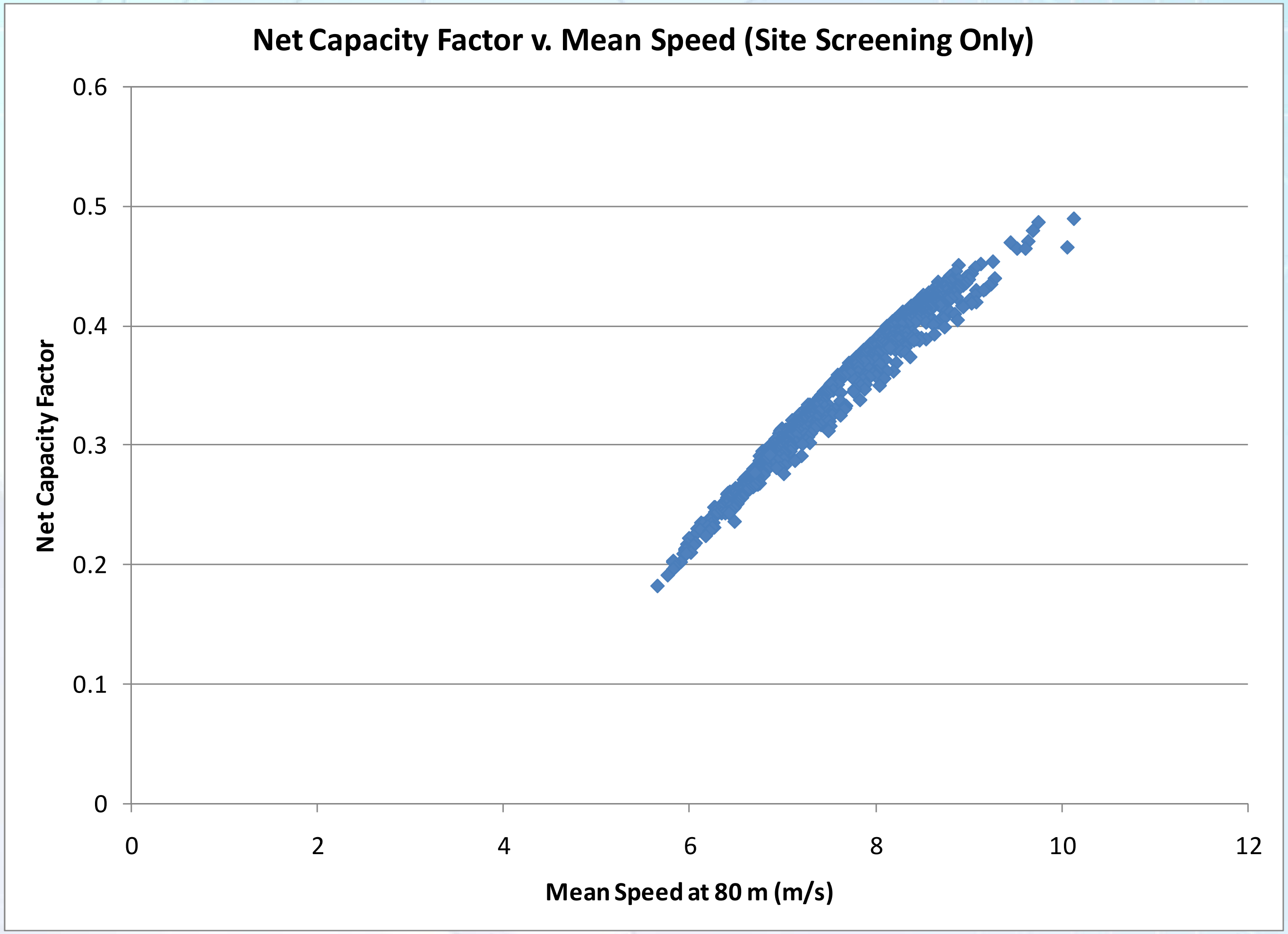
Example Wind Map

- 200 m Resolution
- Validated at 1000+ masts
- ~0.4 m/s error margin
- Proprietary





Speed v. CF



Net Capacity Factor v. Mean Speed (Site Screening Only)
Net Capacity Factor
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Mean Speed at 80 m (m/s)

Site Screening

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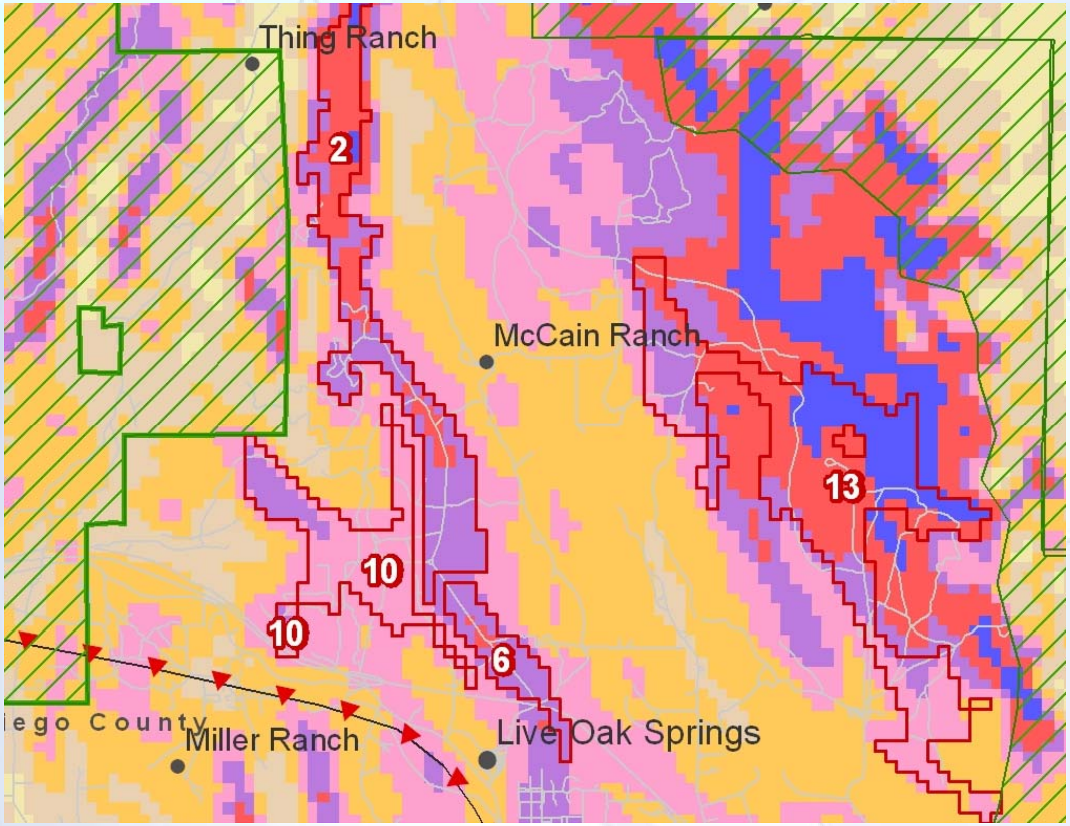
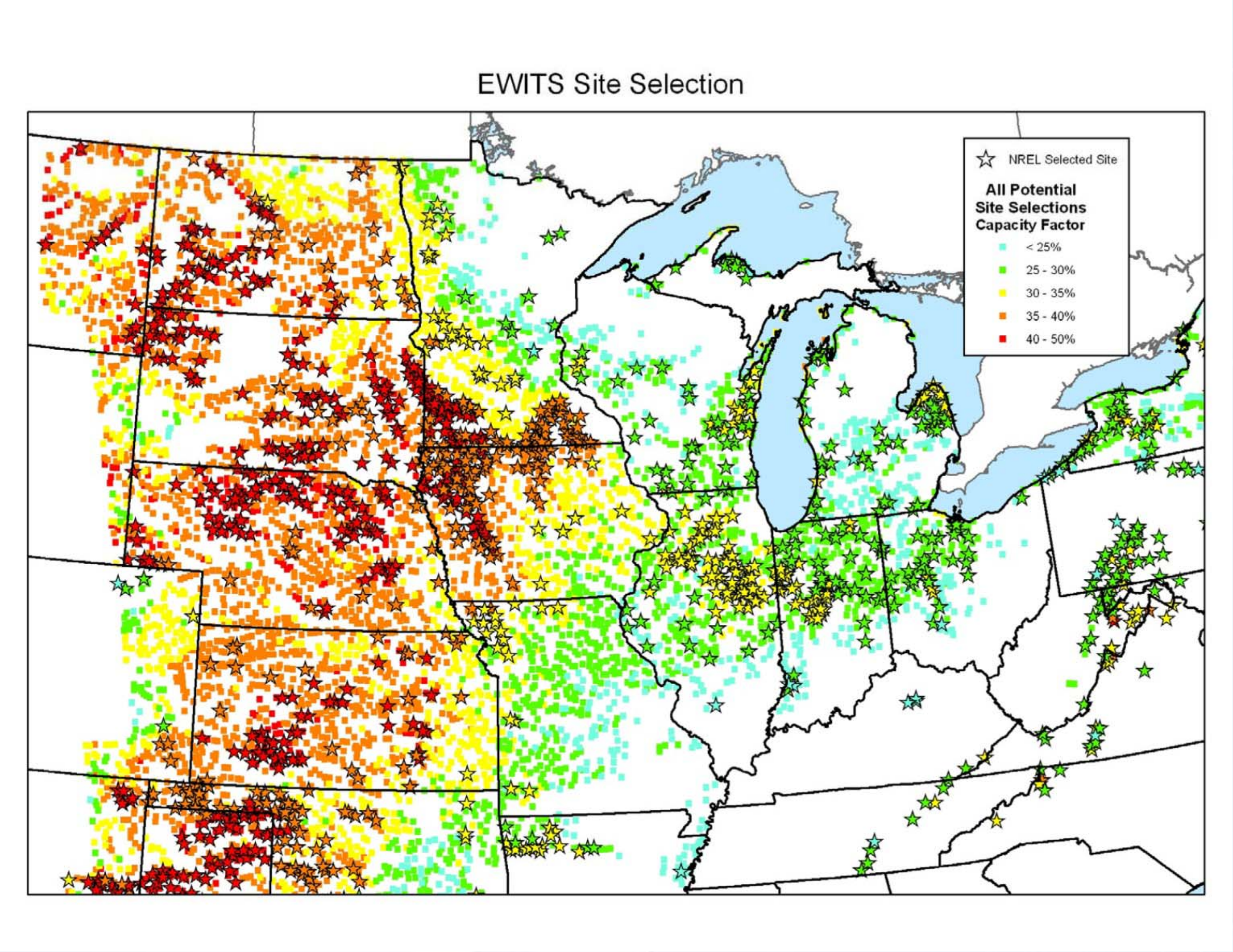


Accounts for:

- Wind speed distribution
- Air density
- Turbine power curve
- Exclusions
- Site rankings

Onshore: All Sites



Onshore: Selected Sites

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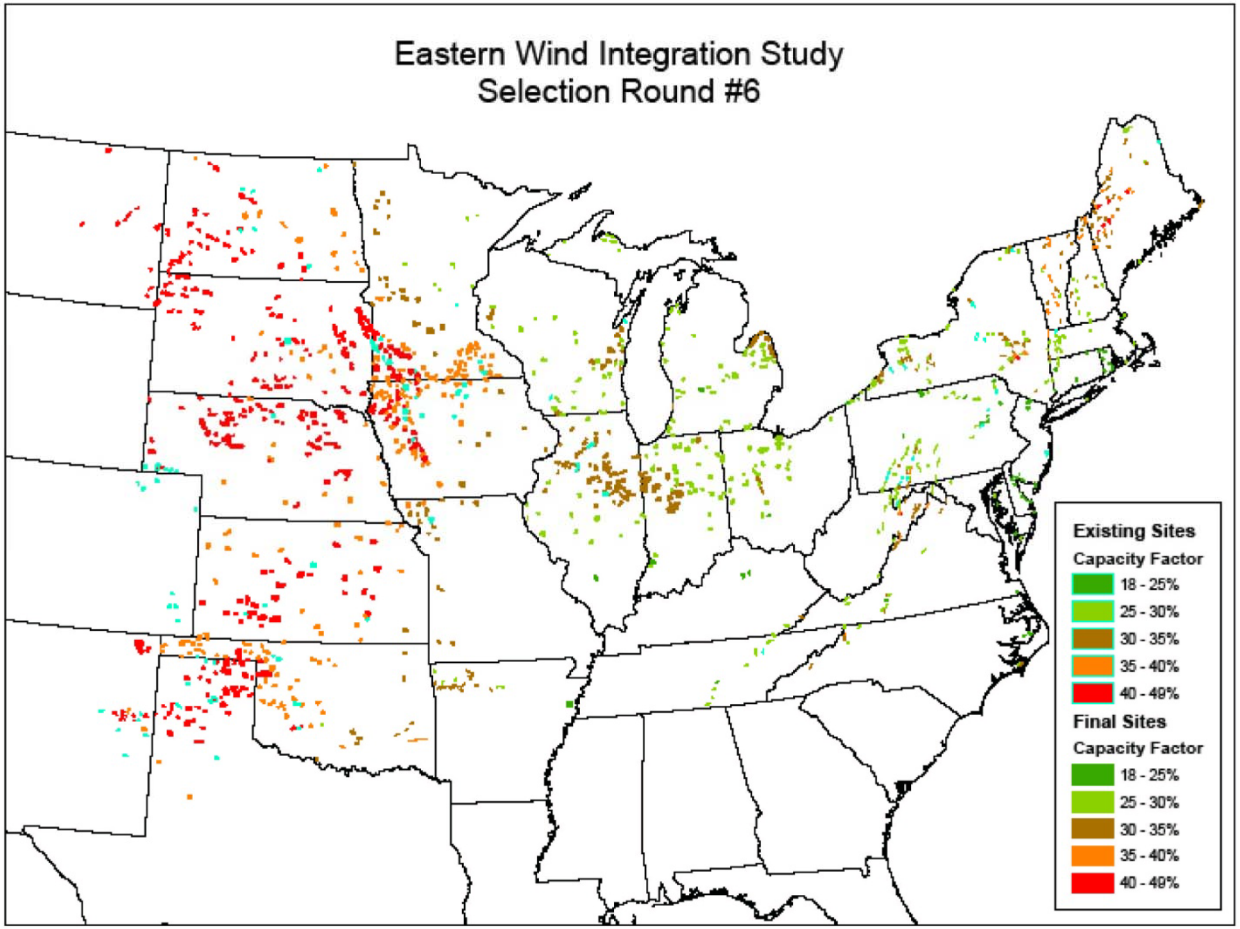
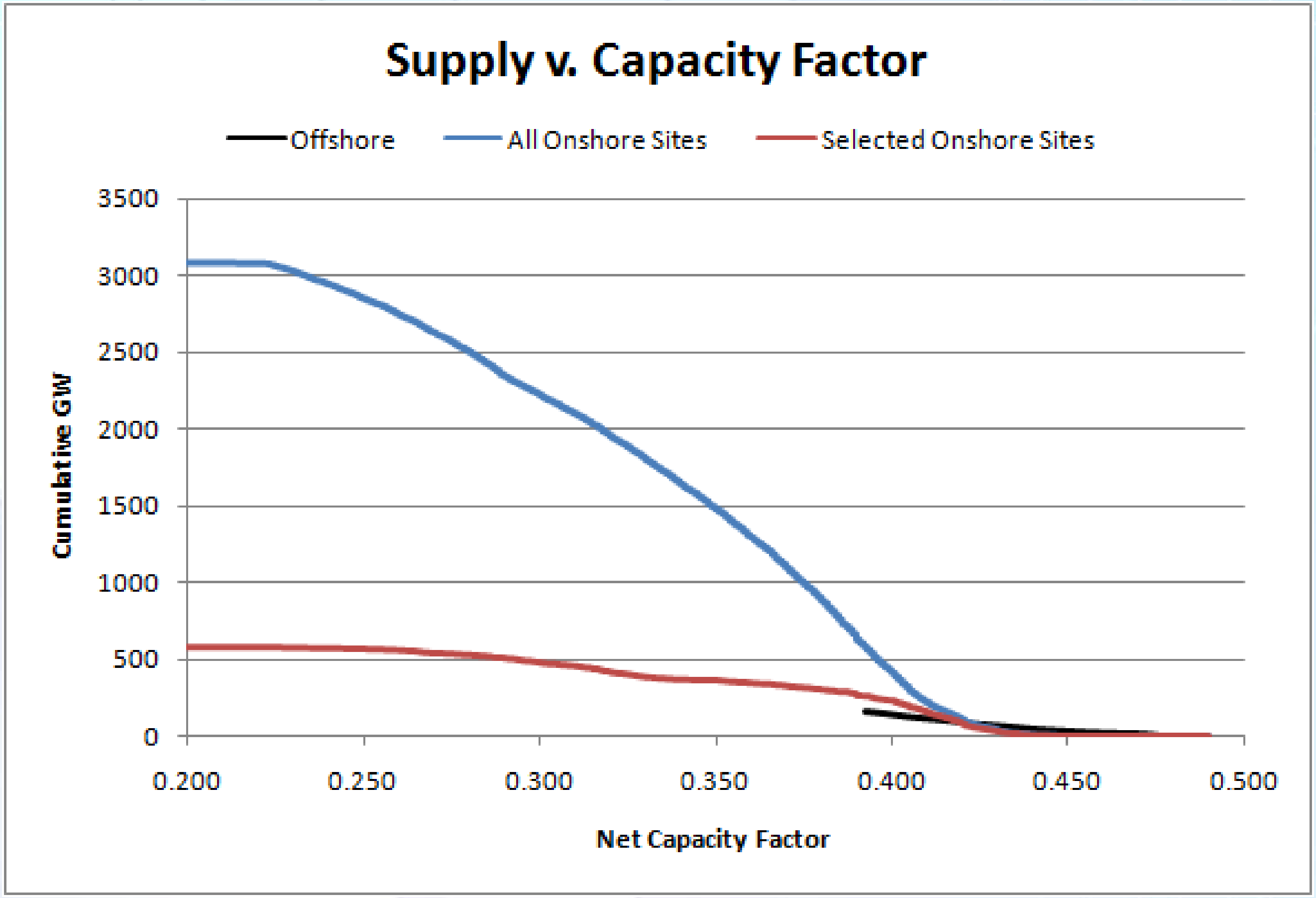


Supply v. CF


Supply v. Capacity Factor
Offshore
All Onshore Sites
Selected Onshore Sites
3500
3000
2500
2000
1500
1000
500
0
Cumulative GW
0.200
0.250
0.300
0.350
0.400
0.450
0.500
Net Capacity Factor

Size Distribution

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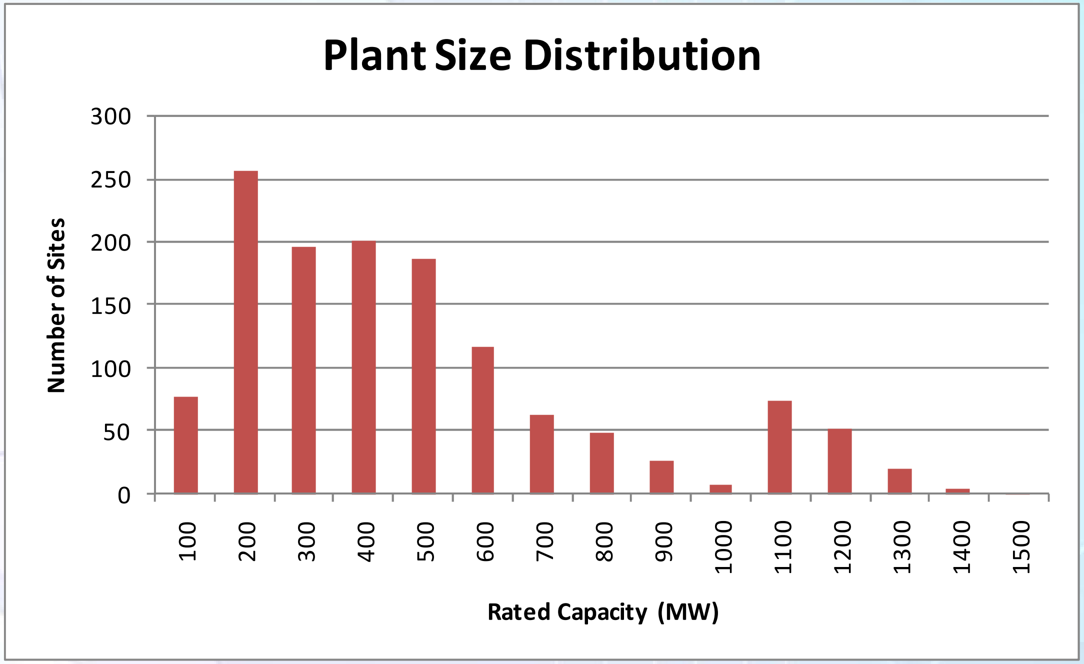
- Maximum onshore plant sizes were normally distributed between 100 MW and 1000 MW
- NREL selected additional "mega" sites (>1000MW)



Site Screening

Offshore Approach

- Consider Great Lakes and Atlantic coastal resources
- Excluded:
  - Water depths >30 m
  - Areas less than 5 miles (8 km) from shore
  - Federal or state protected areas
- Identify 2x2 km cells with net CF>32% (80 m hub height)

Offshore Sites

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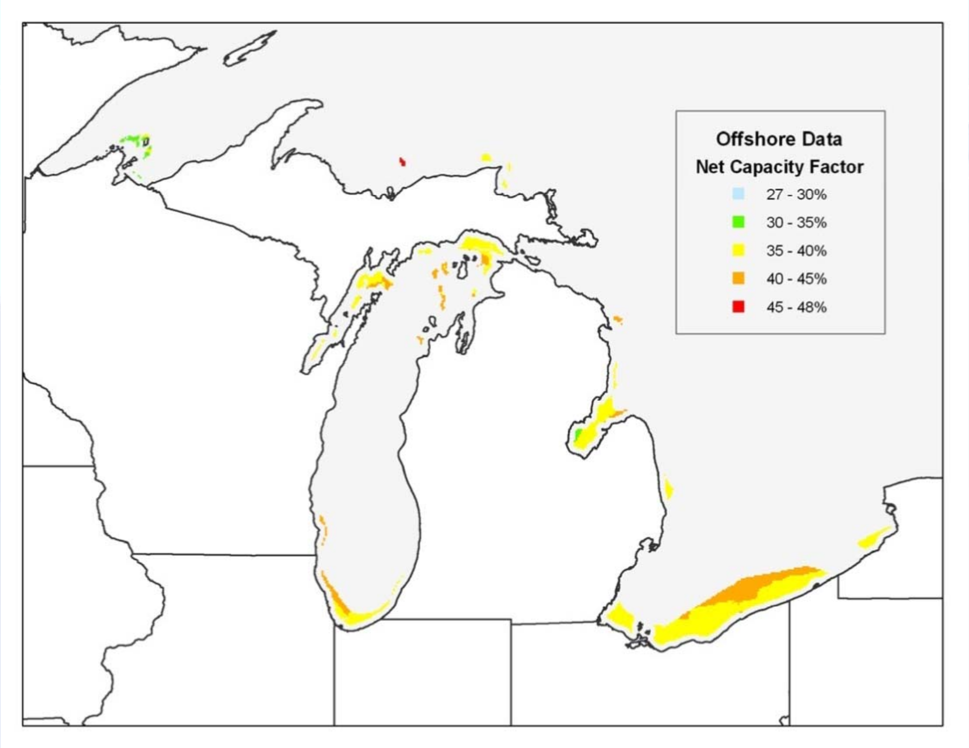

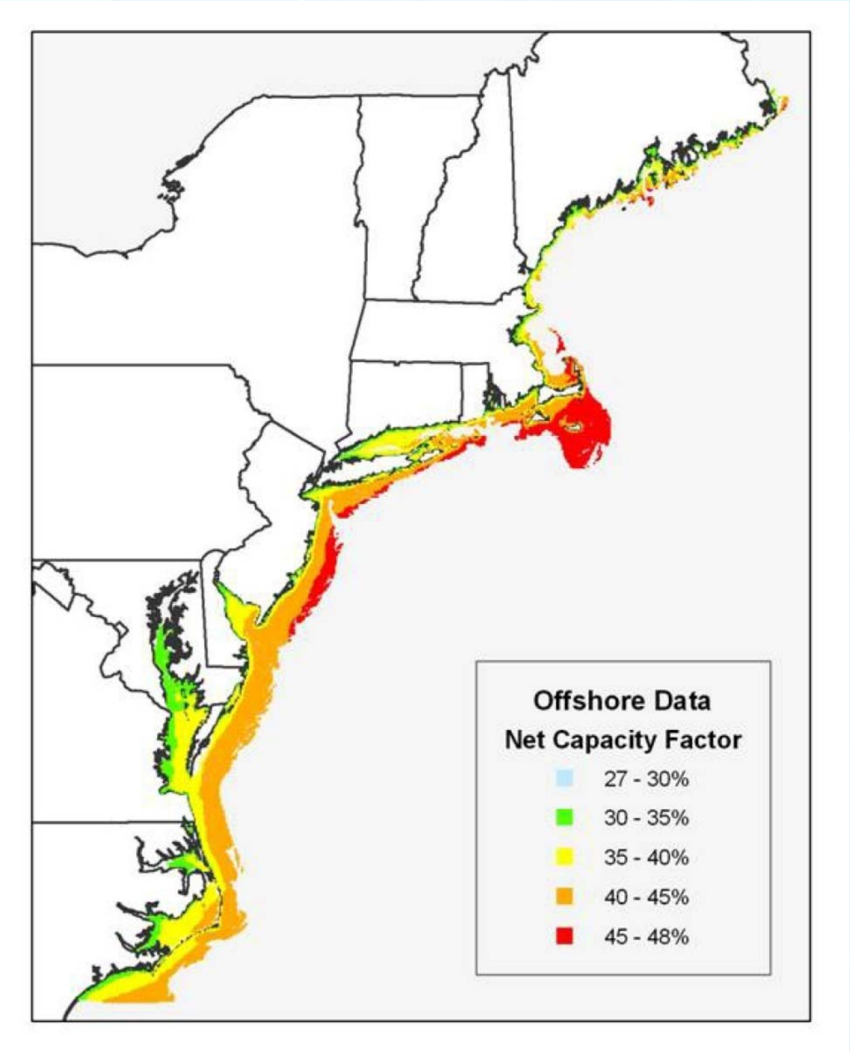

Note: Atlantic offshore sites in this image mistakenly include near-shore sites

Totals

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State	Onshore	Offshore	Total	State	Onshore	Offshore	Total
Arkansas	4.0		4.0	New Hampshire	2.4	44.9	47.3
Colorado	3.8		3.8	New Jersey	1.3	1.3	2.6
Connecticut	0.9	1.7	2.6	New Mexico	10.5		10.5
Delaware	1.0	4.4	5.4	New York	14.9	30.1	45.0
Illinois	42.0	1.3	43.3	North Carolina	2.0	2.0	4.0
Indiana	32.6	9.9	42.5	North Dakota	32.1		32.1
Iowa	52.6		52.6	Ohio	17.4	2.2	19.7
Kansas	46.1		46.1	Oklahoma	40.3		40.3
Kentucky	1.5		1.5	Pennsylvania	7.0	15.8	22.7
Maine	5.9	20.1	26.0	Rhode Island	1.0	29.6	30.6
Maryland	1.1	0.0	1.1	South Dakota	48.5		48.5
Massachusetts	2.2	26.9	29.0	Tennessee	0.9		0.9
Michigan	23.9	10.0	34.0	Texas	31.9		31.9
Minnesota	61.5		61.5	Vermont	2.0		2.0
Missouri	10.1		10.1	Virginia	2.1	5.1	7.2
Montana	5.8		5.8	West Virginia	2.4		2.4
Nebraska	48.5		48.5	Wisconsin	20.5	3.2	23.7
				Total	**580.8**	**208.6**	**789.4**

Offshore totals may change

Main Simulations

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Progress to Date

- 2004 and 2005 mesoscale simulations completed
- 2006 simulations under way, to be completed early September
- Conversion of 2004 data to plant output for onshore sites completed and delivered
- Conversion of 2004 data for offshore and extra MISO sites in progress (this week)

Mesoscale
Numerical Weather Prediction Models

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Solve the physical equations governing the atmosphere on a finite grid, stepping forward in time from an initial state defined by weather data…

Conservation of Momentum (Momentum = mass X velocity)

Rate of change in momentum at a point = Horizontal Transport + Vertical Transport + Pressure Force + Coriolis Force + Gravity + Other Forces

Conservation of Mass (Mass = density X volume)

Rate of change of mass at a point = Horizontal Transport + Vertical Transport + Sources & Sinks

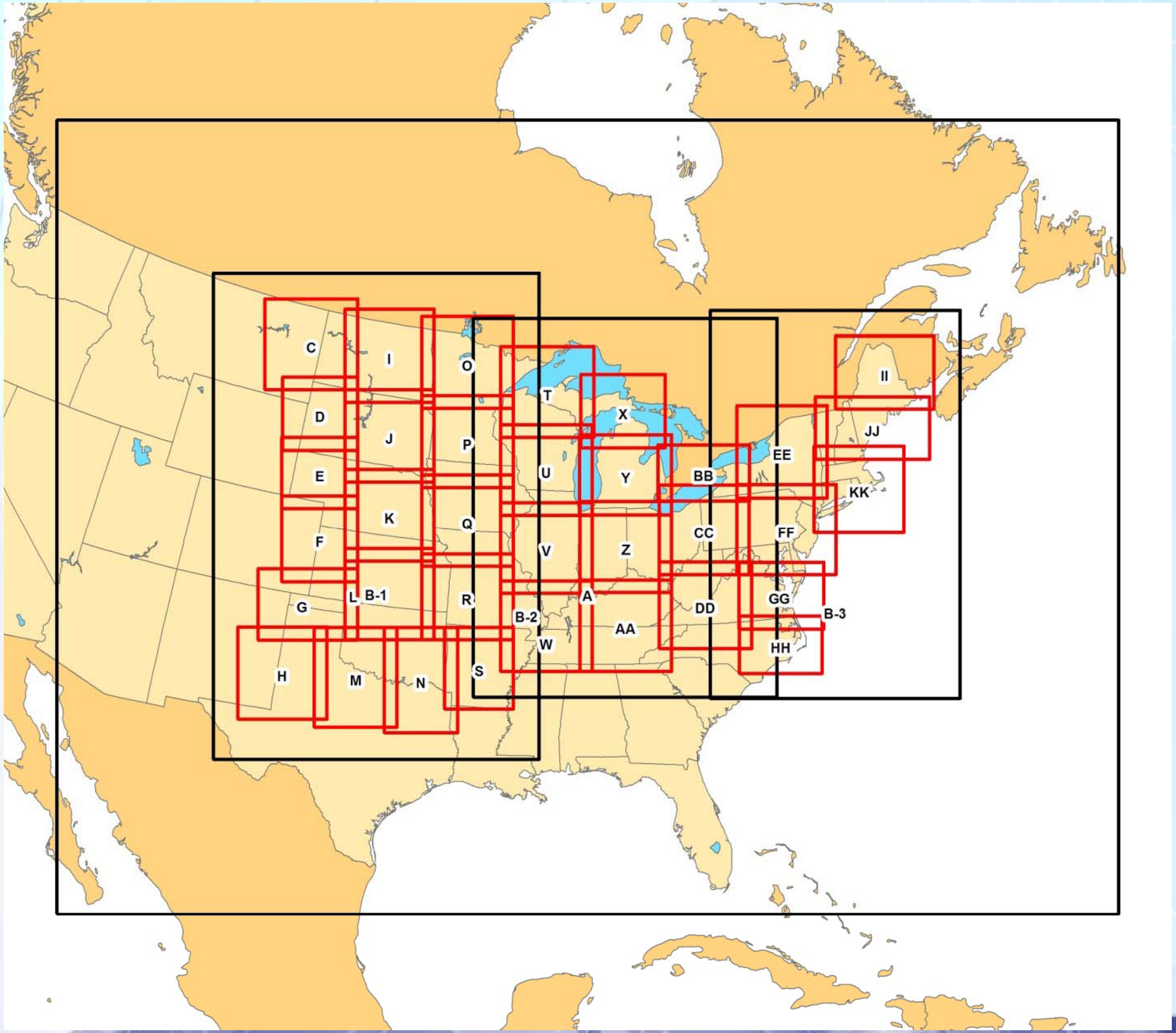
Conservation of Thermodynamic Energy

Rate of change of temperature at a point = Horizontal Transport + Vertical Transport + Expansion & Compression + Sources & Sinks

Equation of State for Moist Air

Pressure = Density X Temperature X (Gas Constant for Moist Air)

Mesoscale Grids

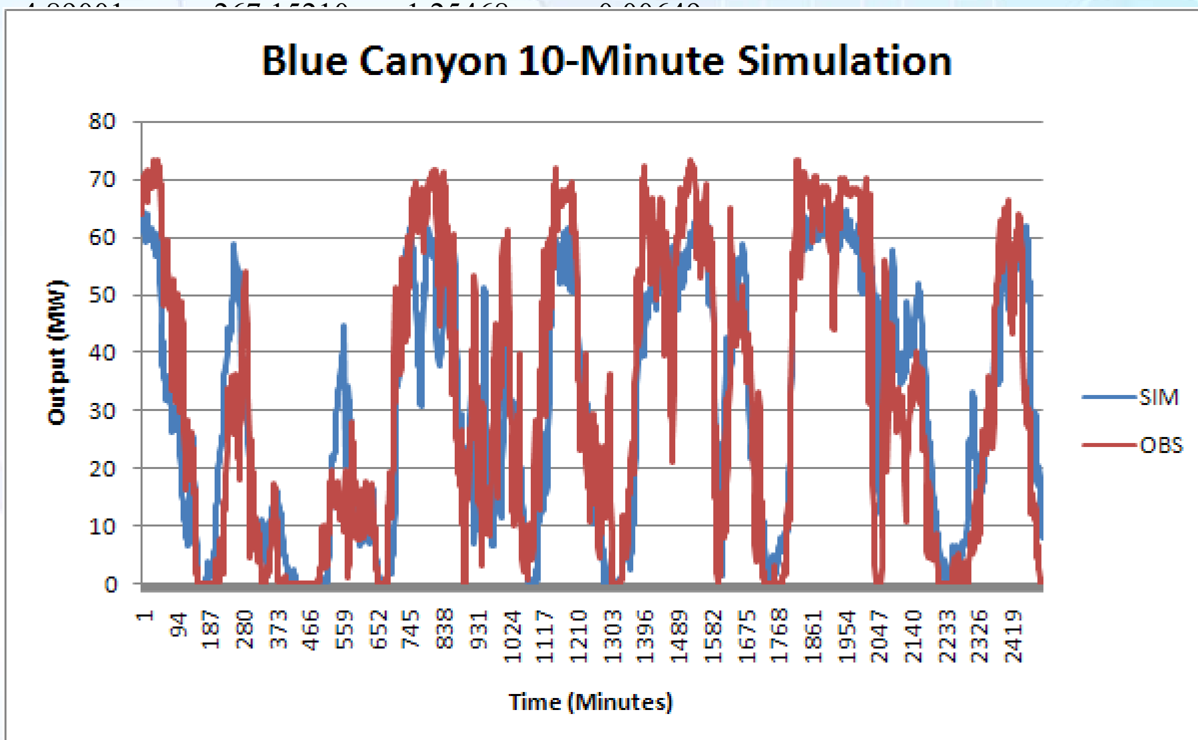


Mesoscale Output/ Power Conversion

47.02225 -68.80990

DATE	TIME	80M SPEED	DIRECTION	DENSITY	TKE
20040101	0010	4.89790	270.09622	1.25625	0.03305
20040101	0020	4.94108	268.34360	1.25527	0.02336
20040101	0030	4.81025	267.33597	1.25509	0.01175
20040101	0040				
20040101	0050				
20040101	0100				
20040101	0110				
20040101	0120				
20040101	0130				
20040101	0140				
20040101	0150				
20040101	0200				
20040101	0210				

….



Simulation Issues

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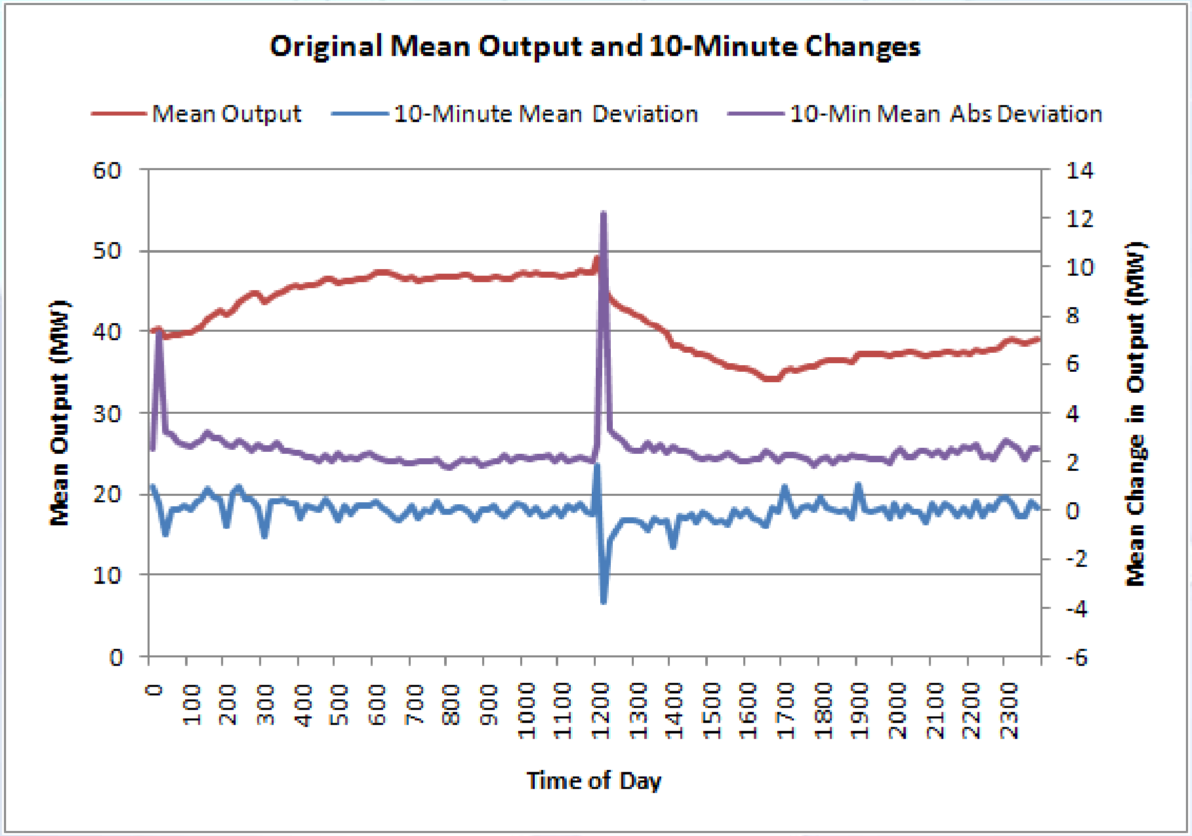
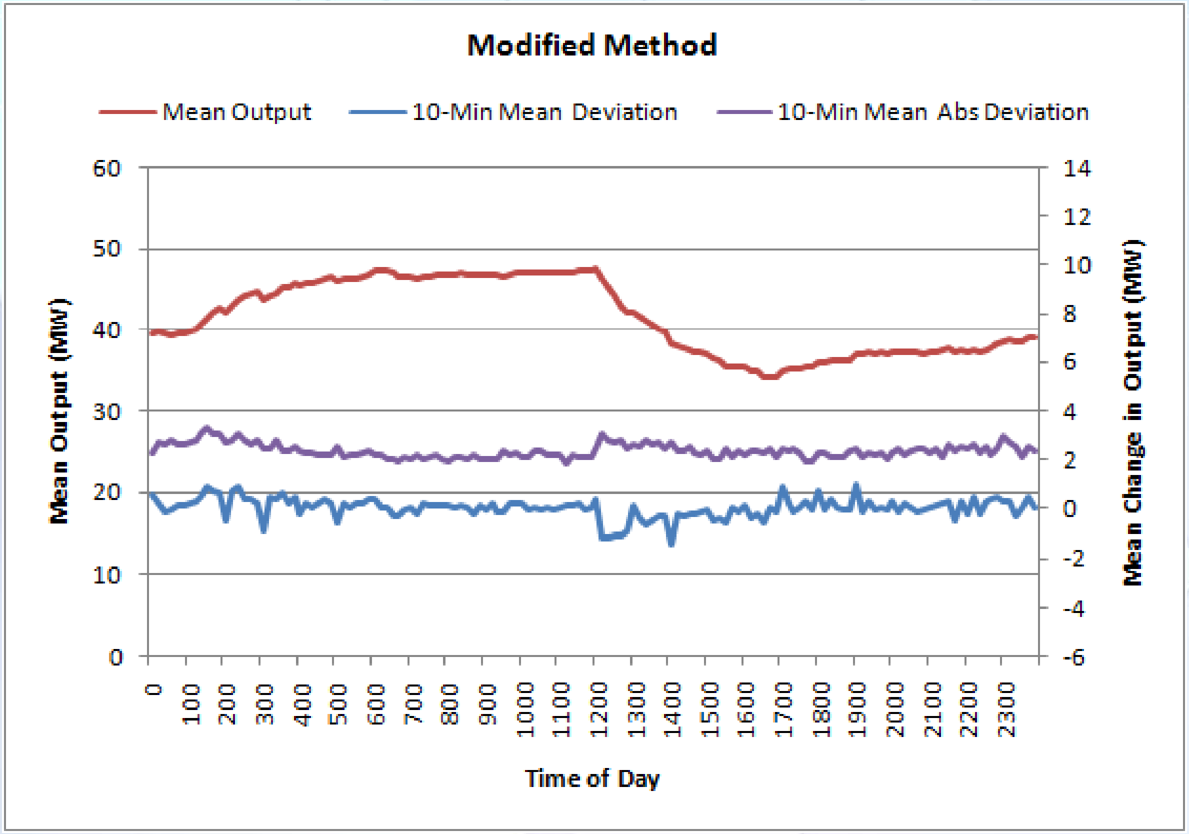
- 2004 runs slowed by cooling, storage problems (solved)
  - 640 networked "cores" generate ~24 KW of heat, require 3 8-ton cooling units
  - 2004+2005 runs take up nearly 50 TB storage
- Occasional run bombs caused by excess energy extended simulations (solved)
- "Large jumps" caused by assimilation of rawinsonde and surface data (fix identified and will be implemented this week)

Data Assimilation Impact



Observations assimilated by the model every 12 hours can abruptly change wind speeds. After-shocks last up to one hour.

Pragmatic Solution



Replace affected data with randomly modulated linear trend. Ten 10-minute records per day are replaced.

Main Tasks Remaining

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- Update onshore and offshore data for 2004 (8/20)
- Complete extraction and conversion for 2005 (8/22)
- Carry out 2006 simulations, extract and convert data to plant output (9/10)
- Synthesize forecasts (October)
- Synthesize one-minute data (October)