

MIT Bates Linear Accelerator Center Wind Energy Resource Assessment Project

Preliminary Analysis Report

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Wind Energy Projects in Action (WEPA)
Massachusetts Institute of Technology

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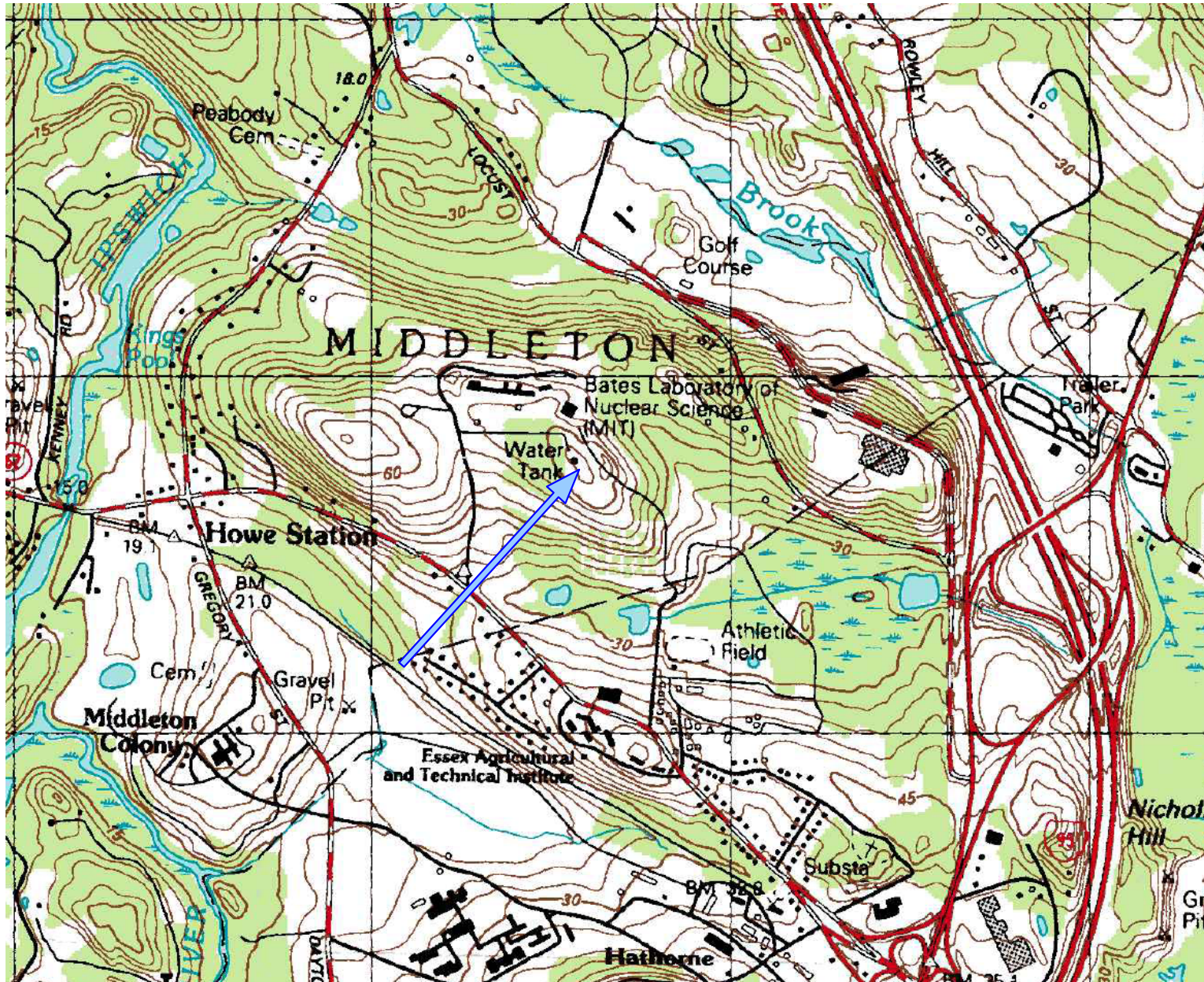
Bates Google Earth visualization
<http://www.youtube.com/watch?v=cnqsUIGZgHc>

Bates Water Tower Site

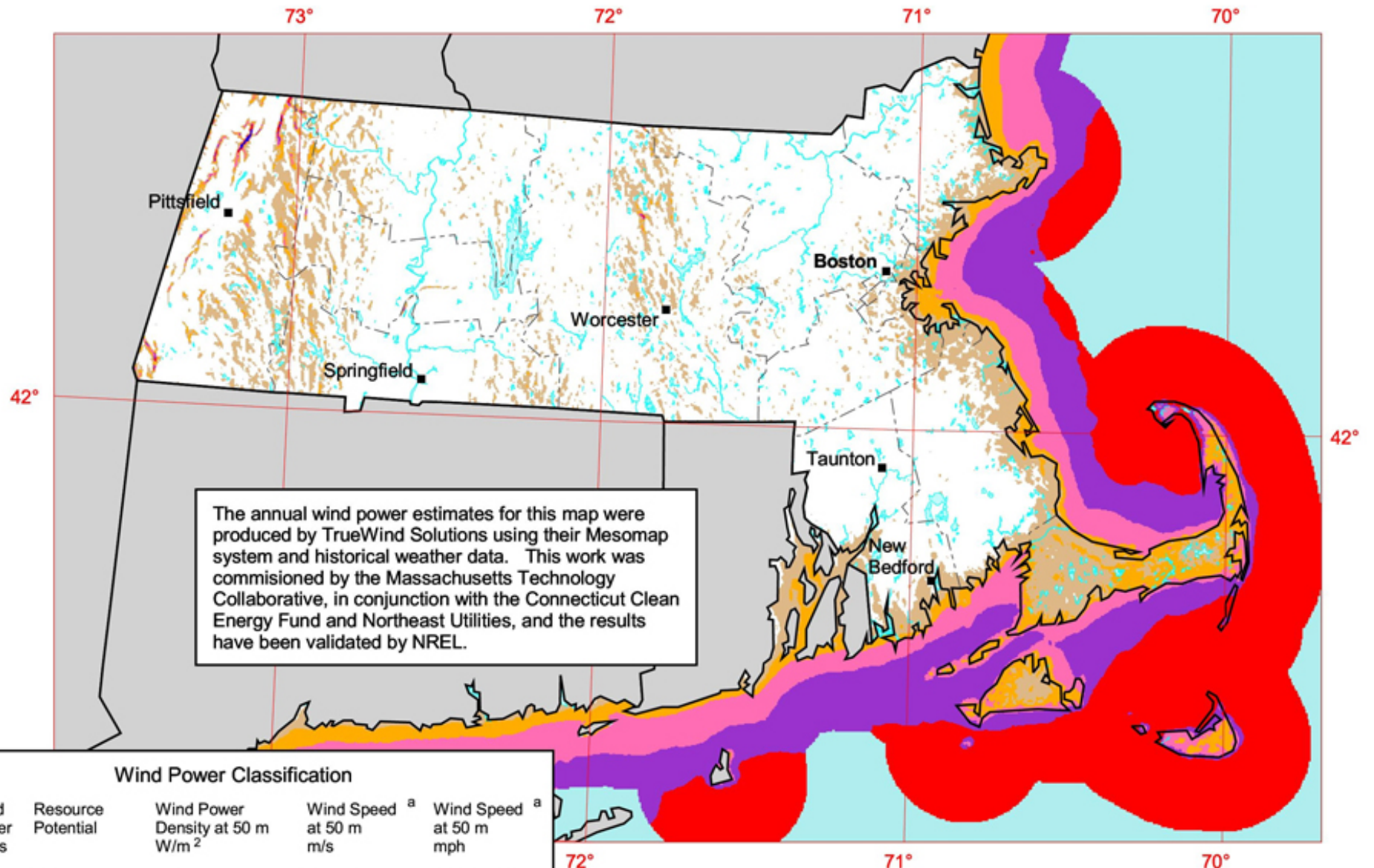


- Elevation: 64 ± 1 m above mean sea level
- Coordinates $+42^{\circ} 35' 47.90''$, $-70^{\circ} 58' 42.66''$
(Latitude 42.596638, Longitude -70.978518)

Bates Water Tower Site



Massachusetts - 50 m Wind Power

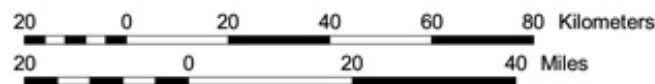


The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. This work was commissioned by the Massachusetts Technology Collaborative, in conjunction with the Connecticut Clean Energy Fund and Northeast Utilities, and the results have been validated by NREL.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ²	Wind Speed ^a at 50 m m/s	Wind Speed ^a at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

^a Wind speeds are based on a Weibull k value of 2.0




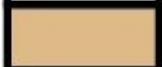

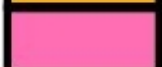



U.S. Department of Energy
National Renewable Energy Laboratory



Wind Power Density

$$WPD \equiv \frac{P}{A} = \frac{1}{2} \rho U^3$$

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	1 Poor	0 - 200	0.0 - 6.0	0.0 - 13.4
	2 Marginal	200 - 300	6.0 - 6.8	13.4 - 15.2
	3 Fair	300 - 400	6.8 - 7.5	15.2 - 16.8
	4 Good	400 - 500	7.5 - 8.1	16.8 - 18.1
	5 Excellent	500 - 600	8.1 - 8.6	18.1 - 19.3
	6 Outstanding	600 - 800	8.6 - 9.5	19.3 - 21.3
	7 Superb	> 800	> 9.5	> 21.3

^a Wind speeds are based on a Weibull k of 2.4 at 500 m elevation.

Fundamental Equation of Wind Power

– Wind Power depends on:

- amount of air (volume)
- speed of air (velocity)
- mass of air (density)

flowing through the area of interest (flux)

– **Kinetic Energy** (mass, velocity):

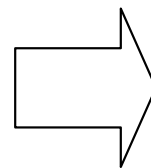
- $KE = \frac{1}{2} \cdot m \cdot U^2$

– **Power** is KE per unit time:

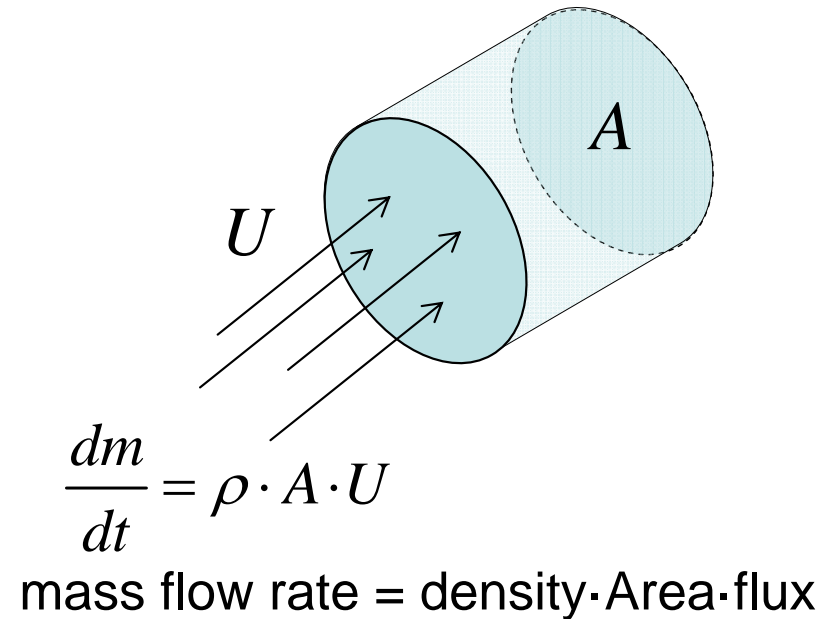
- $P = \frac{1}{2} \cdot \frac{dm}{dt} \cdot U^2$

– Thus:

- $P = \frac{1}{2} \cdot \rho \cdot A \cdot U^3$



- Power ~ cube of velocity
- Power ~ air density
- Power ~ rotor area ~ square of radius



Meteorological Tower

- NRG Systems 34m tower

	Sensor 1	Sensor 2	Sensor 3	Sensor 4
• Serial Number	1021	1022	1016	1023
• Monitoring Height	34m	34.2m	20m	20.2m
• Primary / Redundant	20cm	20cm	20cm	20cm
• Mounting Orientation Degrees - Magnetic	268	124	268	124
• Boom Length	1.5m	1.5m	1.5m	1.5m
• Mount Above Boom				
• Calibrated by:	Otech	Otech	Otech	Otech
– Calibration Date	10/16/09	10/16/09	10/16/09	10/16/09
– Slope (mph/Hz)	0.759	0.758	0.757	0.759
– Offset (mph)	0.34	0.38	0.38	0.38
• Logger Terminal #	Ch 1	Ch 2	Ch 3	Ch 13
Comments:				

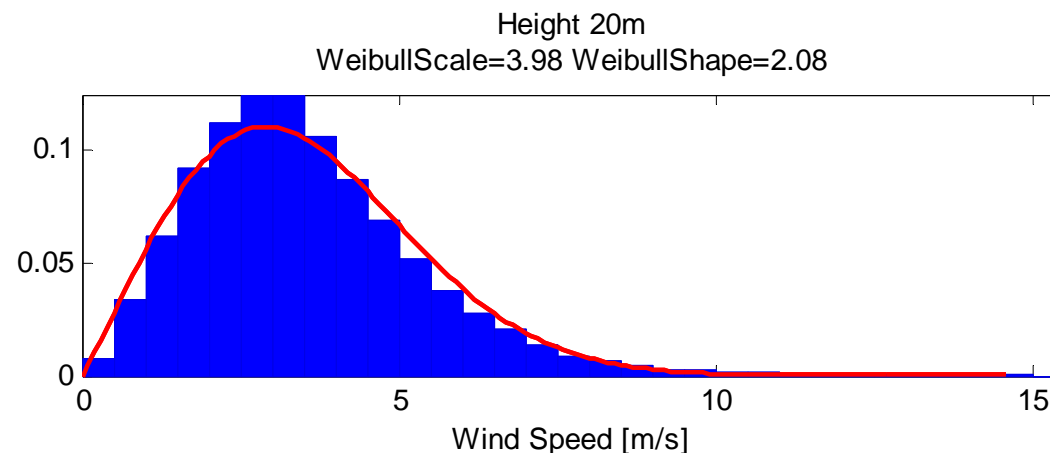
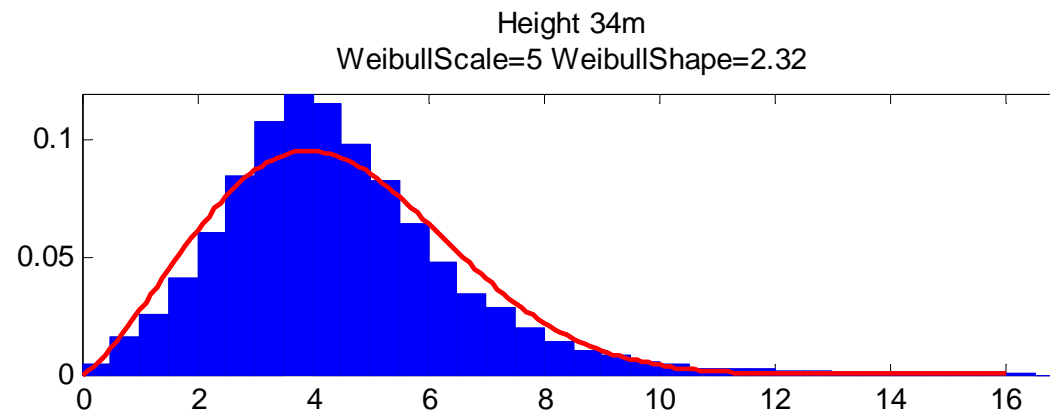
	Sensor 1	Sensor 2
• Monitoring Height	33m	19m
• Mounting Orientation Degrees - Magnetic	178	178
• Boom Length	1.5m	1.5m
• Mount Above Boom	20cm	20cm
• Deadband Orientation (°)	-2	-2
• Logger Terminal #	Ch 7	Ch 8
Comments:		



Wind Resource Assessment

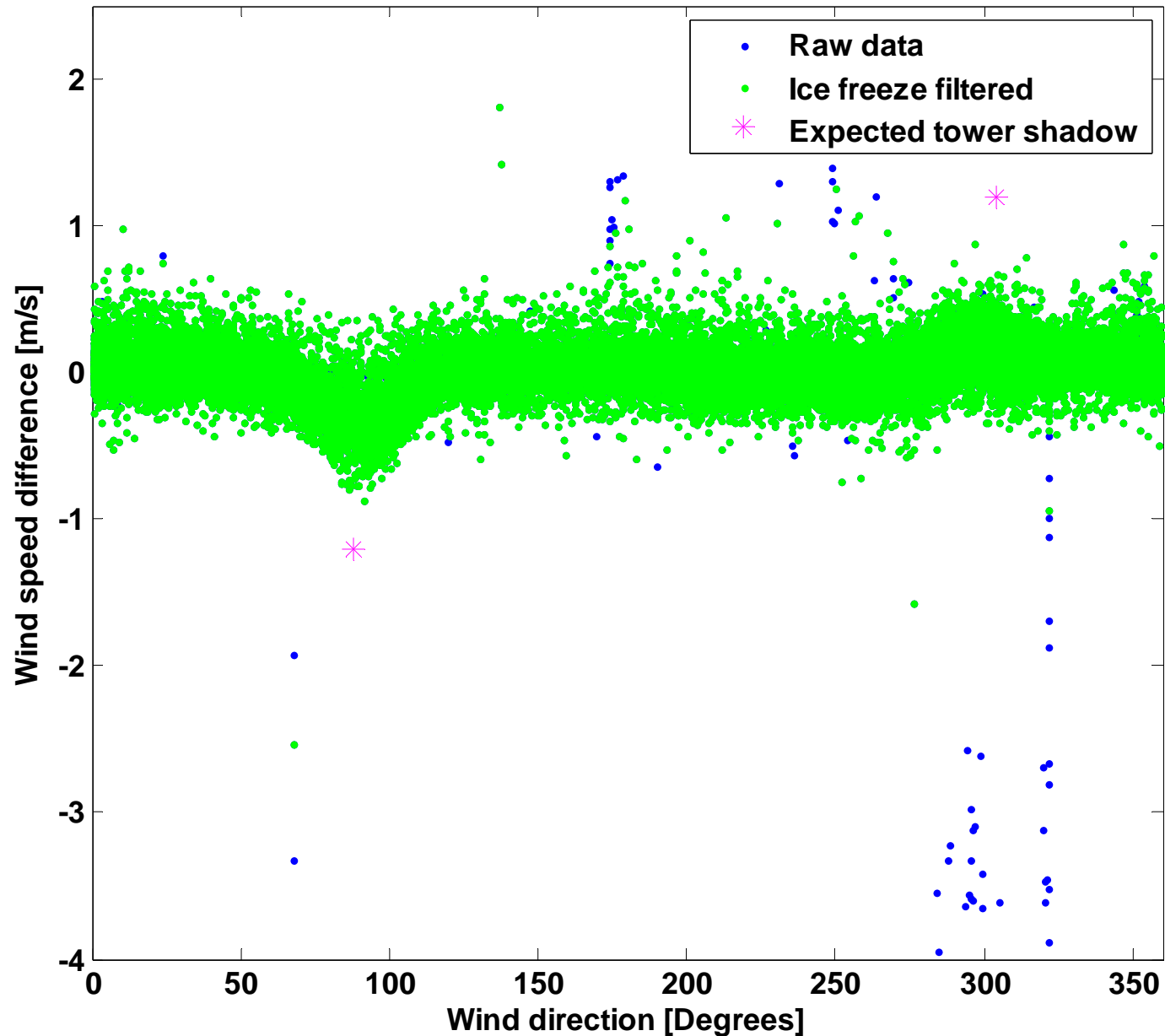
Data collection

- 1 year: November 3 2010 - November 7 2011
- Two heights: 20 and 34 meters above the ground
- Data filtering: icing and tower shadow
- Data recovery rate 98.9%.



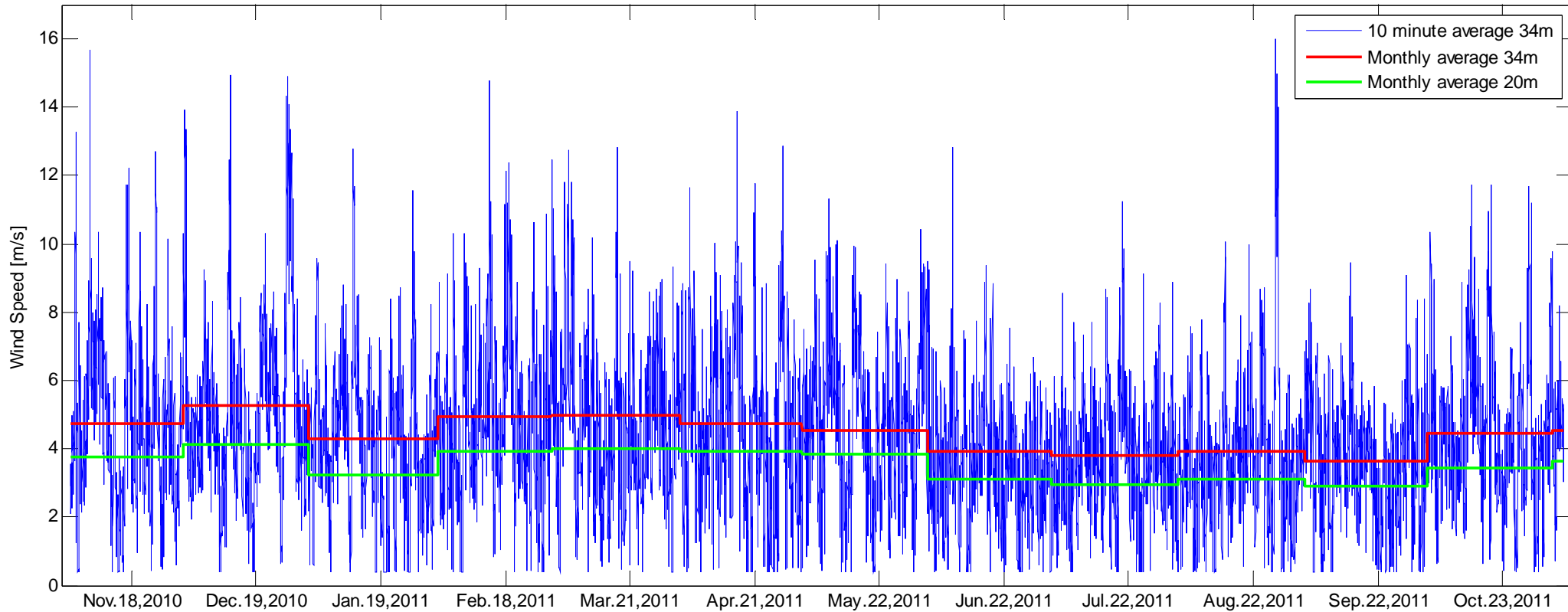
Tower Shadow and Data Filtering

- Difference between two anemometers mounted at different angles



Wind Resource Analysis

Measured Wind Speed



	Mean Wind 34m	Weibull Scale 34m	Weibull Shape 34m	Mean WPD 34m	Mean Wind 20m	Weibull Scale 20m	Weibull Shape 20m	Mean WPD 20m
1 year	4.43	5.00	2.32	92	3.52	3.98	2.08	52

Wind Resource Analysis

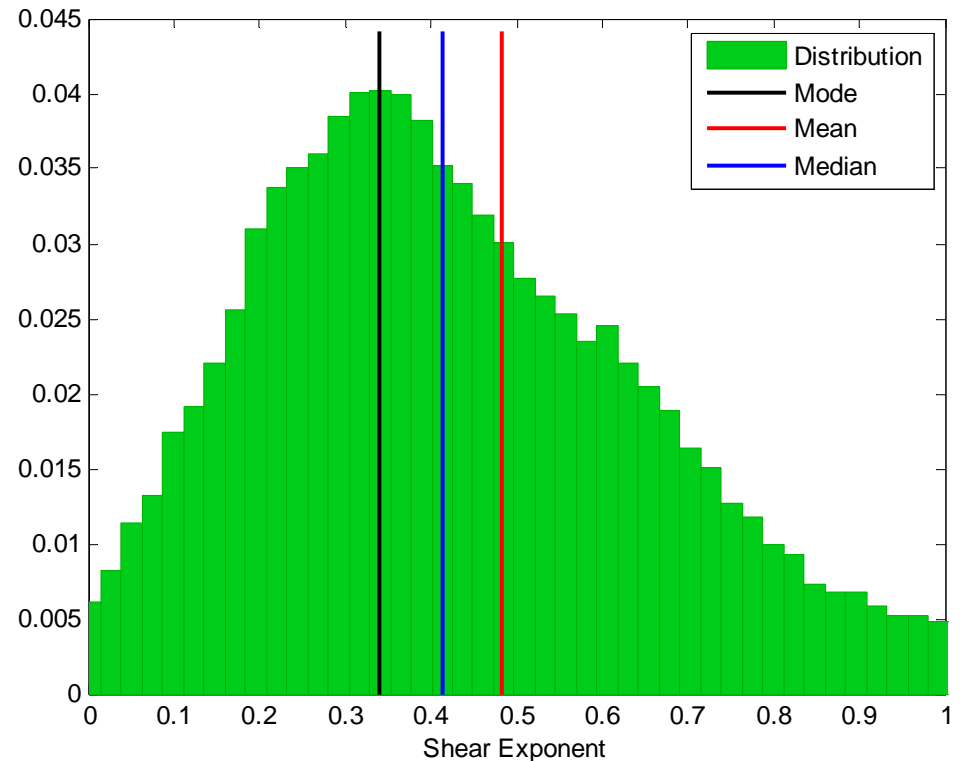
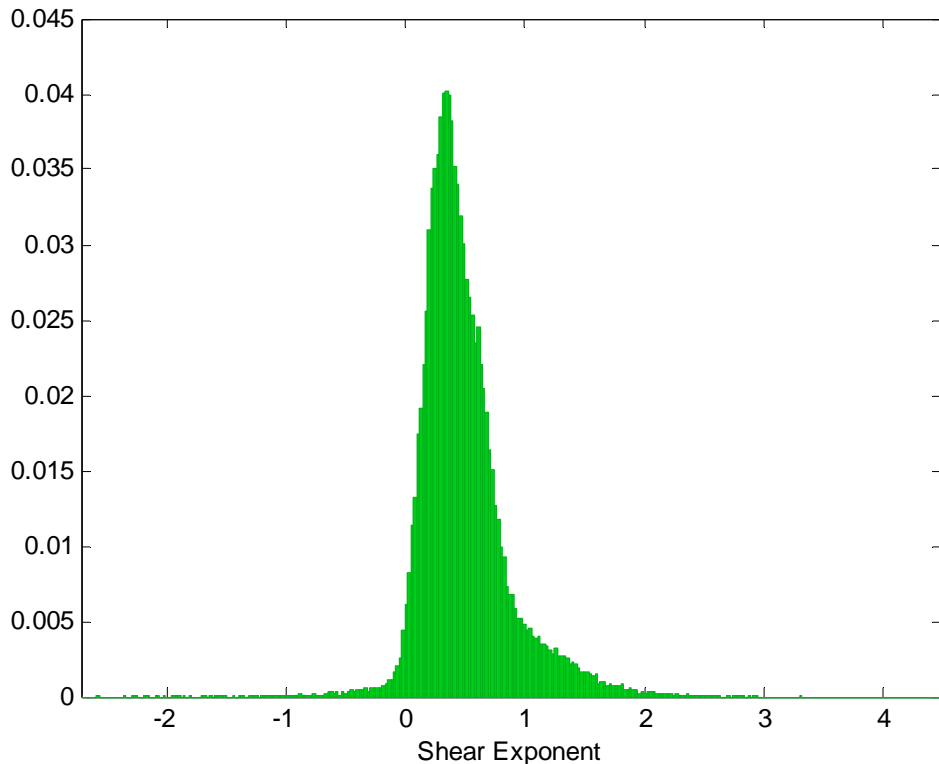
Measured Wind Speed

	Mean Wind 34m	Weibull Scale 34m	Weibull Shape 34m	Mean WPD 34m	Mean Wind 20m	Weibull Scale 20m	Weibull Shape 20m	Mean WPD 20m
Nov 2010	4.72	5.32	2.40	107	3.75	4.24	2.20	59
Dec 2010	5.28	5.97	2.26	167	4.13	4.68	1.93	96
Jan 2011	4.29	4.84	2.37	85	3.23	3.65	2.11	41
Feb 2011	4.94	5.56	2.58	120	3.92	4.42	2.49	62
Mar 2011	4.96	5.59	2.65	119	4.01	4.53	2.35	69
Apr 2011	4.74	5.34	2.16	116	3.90	4.41	2.02	70
May 2011	4.55	5.12	2.62	88	3.83	4.32	2.46	55
Jun 2011	3.93	4.42	2.57	56	3.10	3.50	2.25	31
Jul 2011	3.80	4.26	2.76	47	2.93	3.32	2.27	26
Aug 2011	3.92	4.43	2.02	75	3.10	3.50	1.80	44
Sep 2011	3.64	4.09	2.76	42	2.92	3.29	2.45	24
Oct 2011	4.46	5.04	2.37	90	3.44	3.89	2.04	48
1 year	4.43	5.00	2.32	92	3.52	3.98	2.08	52

Wind Shear Estimation

$$U(h) = U_0 \left(\frac{h}{h_0} \right)^\alpha$$

- **Shear:** increase of horizontal velocity with height
- Power law fit to vertical wind profile
- Wind Shear Exponent
- Matching WPD at 2 measurement heights



Extrapolated Wind Power Density

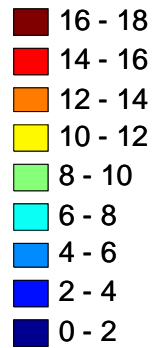
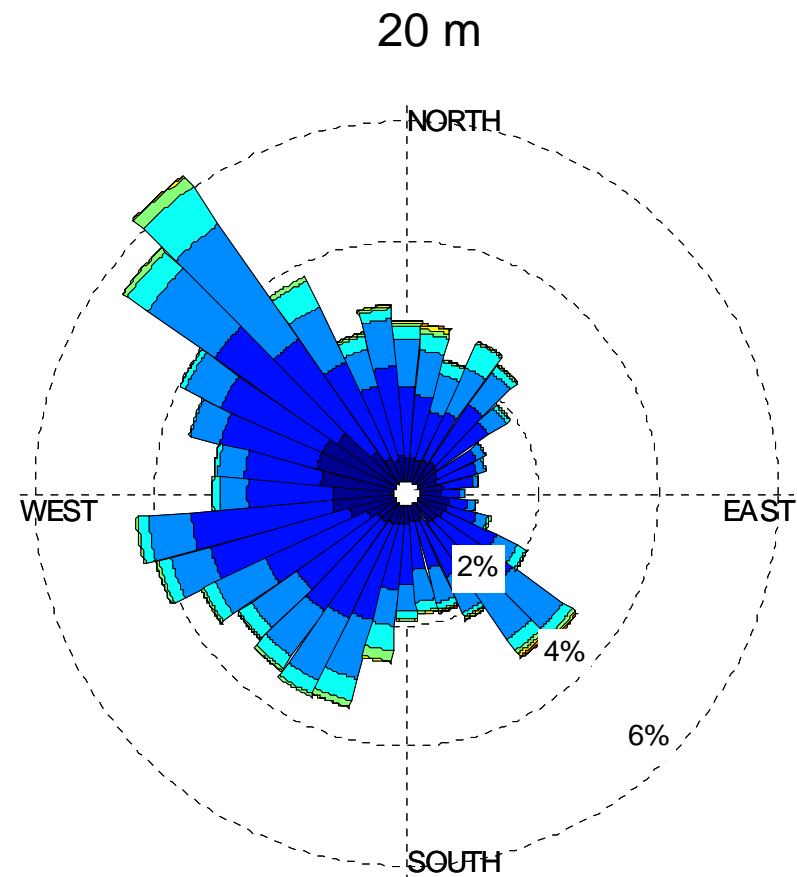
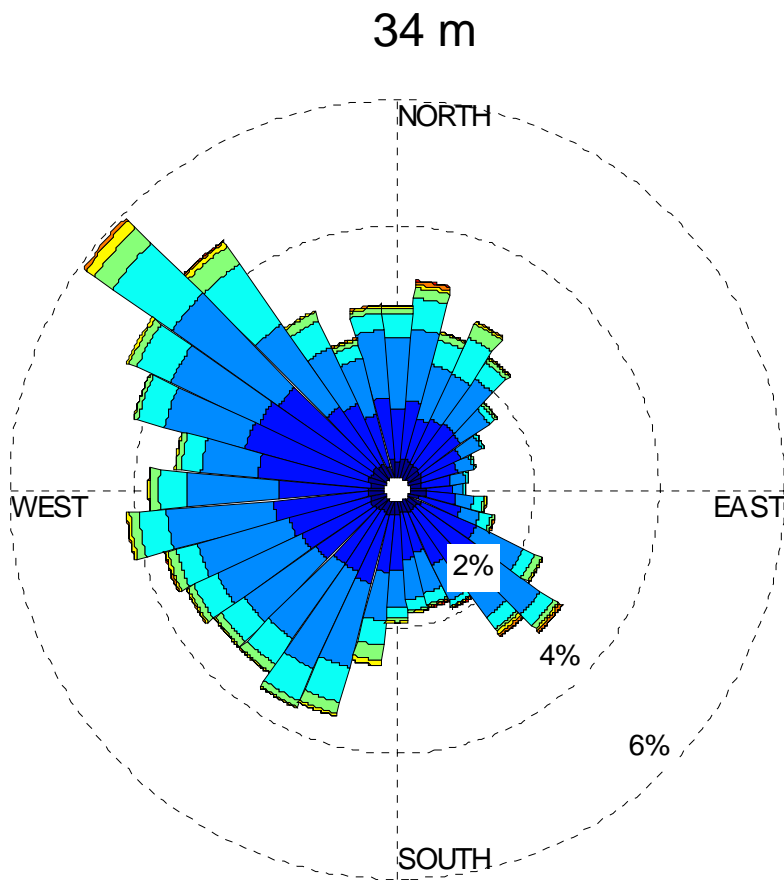
$$WPD = \frac{1}{2} \rho U^3$$

- Sensitivity to wind shear
- Uncertainty due to vertical extrapolation

Elevation	20m	34m	50m	80m	100m
Shear=0.36	52.0	92.0	139	230	293
Shear=0.34	53.6	92.0	136	219	274
Shear=1/7	73.4	92.0	108	132	145
Upper bound	51.7	92.0	152	489	3647
Lower bound	92.15	91.99	91.81	91.48	91.26

Directional Wind Distribution

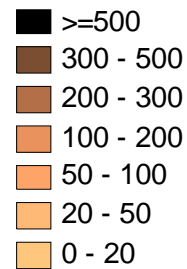
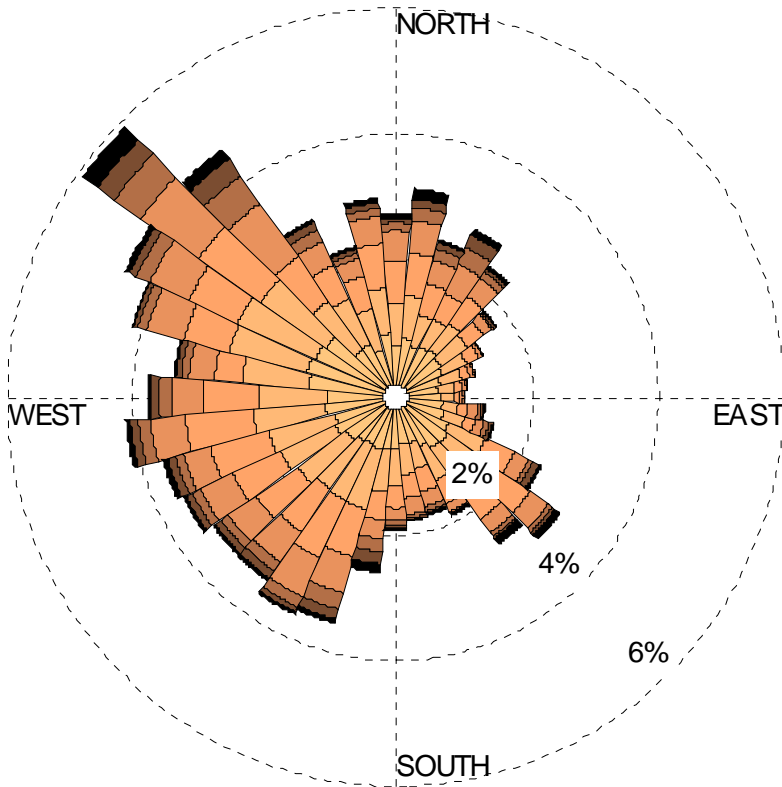
- Wind rose



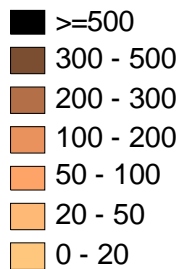
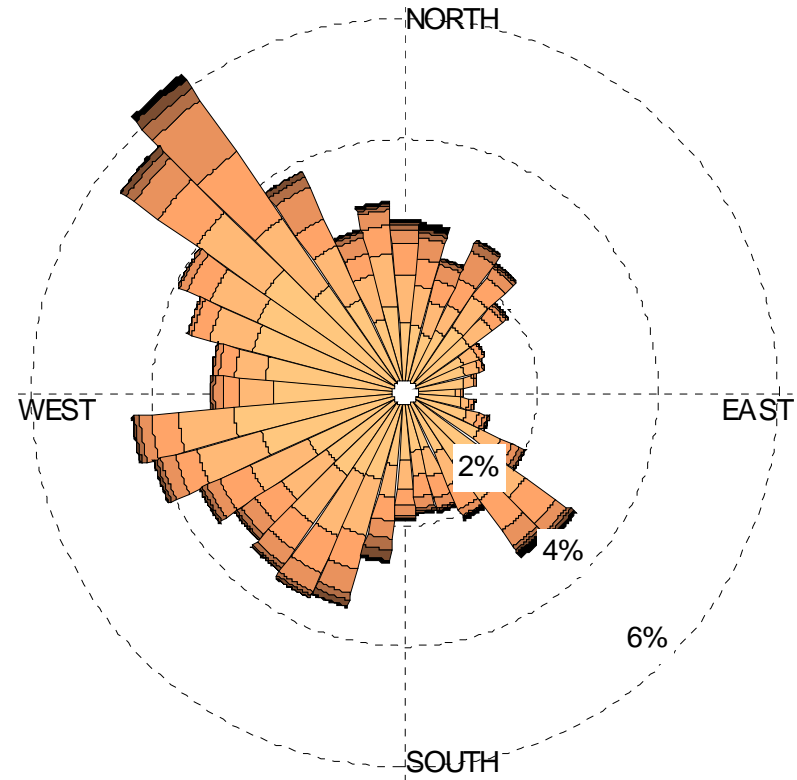
Directional WPD Distribution

- Energy rose

34 m



20 m



Turbine Power Estimates

	Skystream 3.7	Polaris 20	Northern Power 100	Aeronautica 29-225	Polaris 500
Manufacturer	Southwest Windpower	Polaris America	Northern Power Systems	Aeronautica Windpower	Polaris America
Rated Power [kW]	2.4	20	100	225	500
Hub Height [m]	20	36.6	37	50	50
Rotor Diameter [m]	3.7	10	21	29	50
Cutin / Cutout Speeds [m/s]	3.5 / 25	2.5 / 25	3.5 / 25	4 / 25	2.5 / 25
Rated Wind Speed [m/s]	13	10	14.5	15	12
Approximate Cost [\$]	20,000	140,000	450,000	1,300,000	1,800,000

Shear Estimate		Skystream 3.7	Polaris 20	Northern Power 100	Aeronautica 29-225	Polaris 500
Shear=0.36	Annual Energy Production [kWh]	1,103	17,980	102,700	243,200	786,750
	Annual Capacity Factor [%]	5.24	10.26	11.71	12.33	17.95
Shear=1/7	Annual Energy Production [kWh]	1,103	16,960	97,320	184,500	634,000
	Annual Capacity Factor [%]	5.24	9.67	11.10	9.36	14.46

Summary

- MIT Bates Linear Accelerator Center Wind Energy Resource Assessment Project
- NRG 34m meteorological tower at Bates Water Tower Site
- 1 year of data: November 3 2010 - November 7 2011
- Wind power class 1 - “Poor” resource potential
- Uncertainty in vertical extrapolation
- Preliminary understanding of prevailing winds
- Selected turbines power estimates

Low wind site may benefit from the newer low wind turbine technology.

Questions