WIND DATA REPORT

Chester, MA

March 2007 – May 2007

Prepared for

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by

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NOTICE AND ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

All the work presented in this Wind Data Report including installation and decommissioning of the meteorological tower and instrumentation, and the data analysis and reporting was performed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

Wind monitoring equipment was first installed in Chester, MA on April 14 2006, with data collection starting from that day through the present. Five anemometers, three vanes, a temperature sensor, and a data logger are mounted on a 40 m monitoring tower.

Data collection percentages during the three month period of March 2007 through May 2007 were good: the raw data recovery rate was 100%, and after quality assurance the percentage of good data was 97.65%. The average wind speed during the three months was 4.67 m/s at 39 m height (10.45 mph at 128 ft.)*. Turbulence intensity for this time period was an average of 0.25. The prevailing wind was from the Northwest.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by RERL and the Massachusetts Technology Collaborative (MTC). This document is found through the RERL website:

http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1 - Station Location

The monitoring tower is located on South Globble Mountain, on a cleared area on the east slope that extends down to the East-South-East. The wind monitoring equipment is mounted on a 40m NRG tubular steel tower, anchored with guy lines at four directions. Site coordinates are 42º 17' 23.0 North, 72º 59' 52.3 West per the WSG84 standard (the World Geodetic System 1984, an international standard for absolute localization with earthly coordinates). See the figure below for a map of the tower location, which is at the red cross in the middle square.
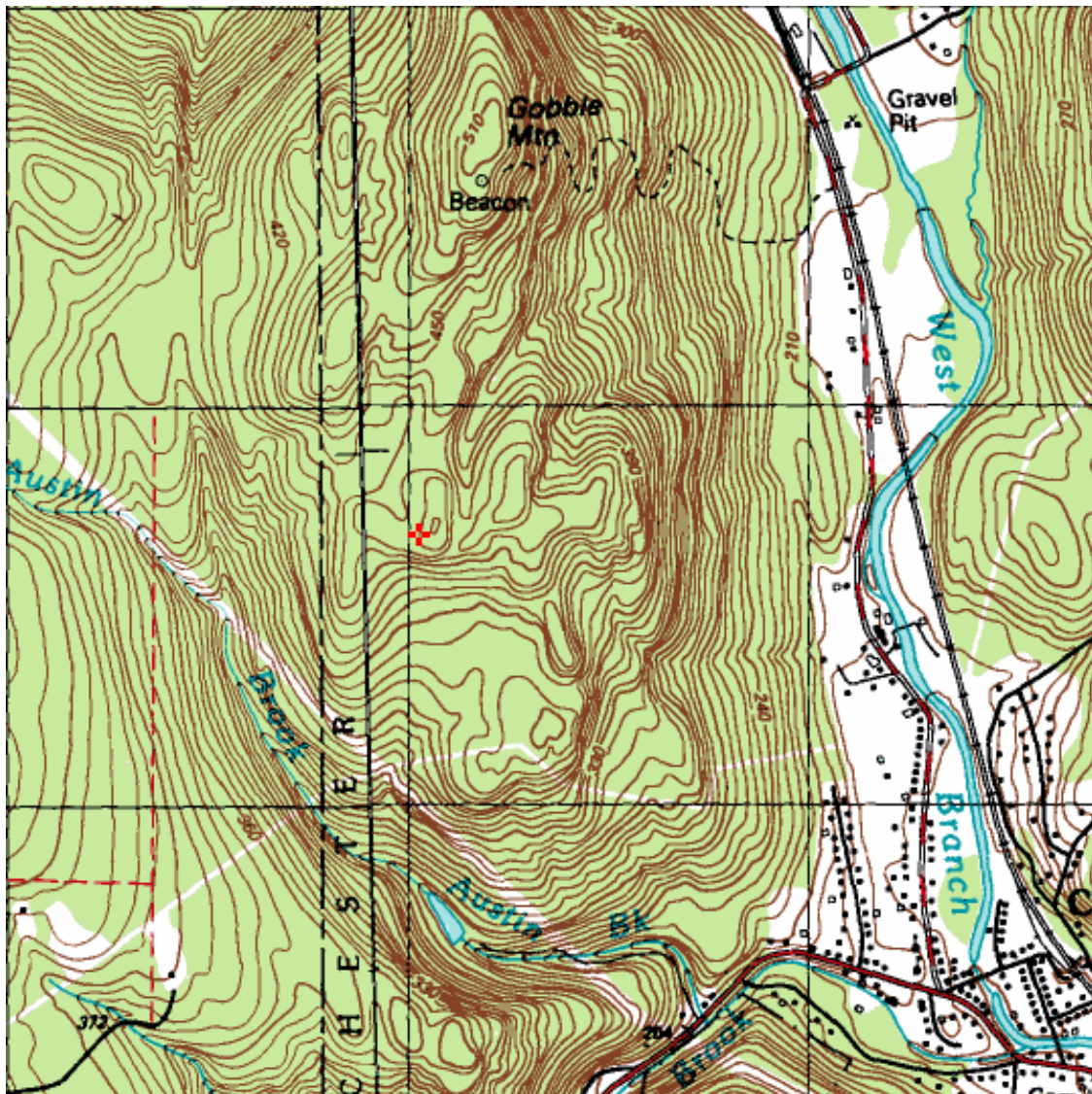
Figure 1 - Map of Chester wind tower site

SECTION 2 - Instrumentation and Equipment

A 40m NRG tower holds five NRG anemometers on three booms: one at 25.6 m, two at 30 m, and two at 39 m. Each anemometer is 43" or further away from the tower, and 5" above its boom. Also, there are two NRG 200P Wind Vanes at 39 m, and one at 30 m.

The installed equipment comprises:

- Symphonie data logger

- NRG 110S Temperature Sensor

- Five #40 anemometers, standard calibration (slope 0.765 m/s, offset 0.350 m/s)

- Three #200P wind direction vanes

- Medium booms for vanes, 39" from tower mast

- Long side booms for anemometers, 54" from tower mast

- Lightning rod and grounding cable

SECTION 3- Data Summary

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

Table 1. Wind Speed and Direction Data Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Height Units	39 m [m/s]	39 m [m/s]	39 m [m/s]	30 m [m/s]	30 m [m/s]	30 m [m/s]	25 m [m/s]	25 m [m/s]	25 m [m/s]
Mar 2007	5.29	16	315	4.69	14	315	4.12	12.1	315
Apr 2007	4.5	16.4	315	4	14.3	315	3.71	12.5	315
May 2007	4.21	11.4	315	3.66	9.5	315	3.24	8.3	315
Mar - May 2007	**4.67**	**16.4**	**315, NW**	**4.12**	**14.3**	**315, NW**	**3.69**	**12.5**	**315, NW**

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when a larger amount of data are missing, the percent of the available data that are used to determine the data statistics is noted.

No measurement of wind speed or direction can be perfectly accurate. Wind speed measurement errors occur due to anemometer manufacturing variability, anemometer calibration errors, the response of anemometers to turbulence and vertical air flow and due to air flows caused by the anemometer mounting system. Every effort is made to reduce the sources of these errors. Nevertheless, the values reported in this report have an expected uncertainty of about ± 2% or ± 0.2 m/s, whichever is greater. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included in Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed at the highest measurement height is between 9.5 and 10.5 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α, have been determined. They can be used in the following formula to estimate the average wind speed, $U(z)$, at height z, when the average wind speed, $U(z_r)$, at height z_r is known:

$$U(z)=U(z_r)\left(\frac{z}{z_r}\right)^\alpha$$

The change in wind speed with height is a very complicated relationship related to atmospheric conditions, wind speed, wind direction, time of day and time of year. This formula will not always provide the correct answer at any given site. Nevertheless the calculated shear coefficient, based on measurements at two heights, can be used to characterize the degree of increase in wind speed with height at a site.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{low} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right)\bigg/\log\left(\frac{z_{high}}{z_{low}}\right)$$

Table 2. Shear and Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, α
Height Units	39 m [-]	30 m [-]	25 m [-]	Between 50 m and 40 m [-]
Mar 2007	0.25	0.28	0.32	0.17
Apr 2007	0.25	0.28	0.31	0.15
May 2007	0.25	0.28	0.31	0.19
Mar - May 2007	**0.25**	**0.28**	**0.31**	**0.17**

SECTION 4- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed.

- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over the year.

- Diurnal – A plot of the average wind speed for each hour of the day.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed. Turbulence Intensity is calculated as the standard deviation of the wind speed divided by the wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine.

- Wind Rose – A plot, by compass direction showing the percentage of time that the wind comes from a given direction and the average wind speed in that direction.

With regards to the Chester site, the following observations are noted:

- Time Series, Figure 2: wind speeds seldom exceeded 10m/s at the Chester site during the spring months. Periods of icing (0 m/s wind speed) are also seen.

- Wind Speed Distribution, Figure 3: we can see in Figure 3 that wind speeds are mostly between 4 and 5 m/s during the spring months. A higher than typical first bar (0-1 m/s) is present, likely due to prolonged periods of icing.

- Monthly Average, Figure 4: we show the average for 12 months, May 2006 through May 2007.

- Diurnal, Figure 5: we can see in Figure 5 a clear trend of higher wind speeds during daylight hours.

- Turbulence Intensity, Figure 6: we can see that turbulence numbers roughly cluster between 0.2 and 0.3 for most wind speeds.

- Wind Rose, Figure 7: a northwesterly wind direction bias is clear, possibly due to a channeling effect of the local terrain.

Data for the wind speed histograms, monthly and diurnal average plots, and wind roses are included in APPENDIX B.

Wind Speed Time Series
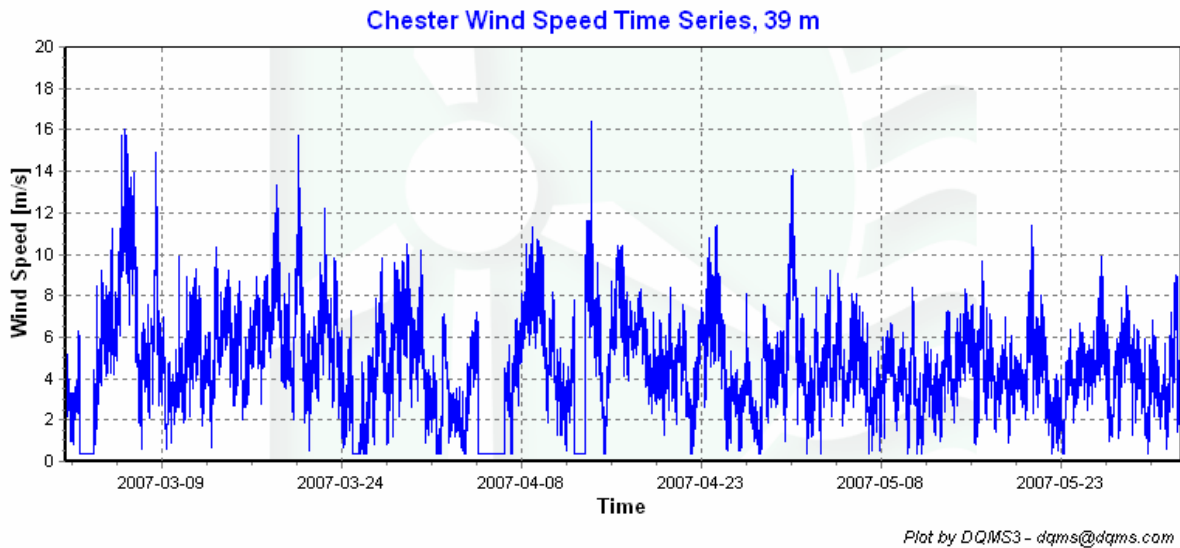
Figure 2 - Chester wind speed time series, March 2007 – May 2007

Wind Speed Distributions
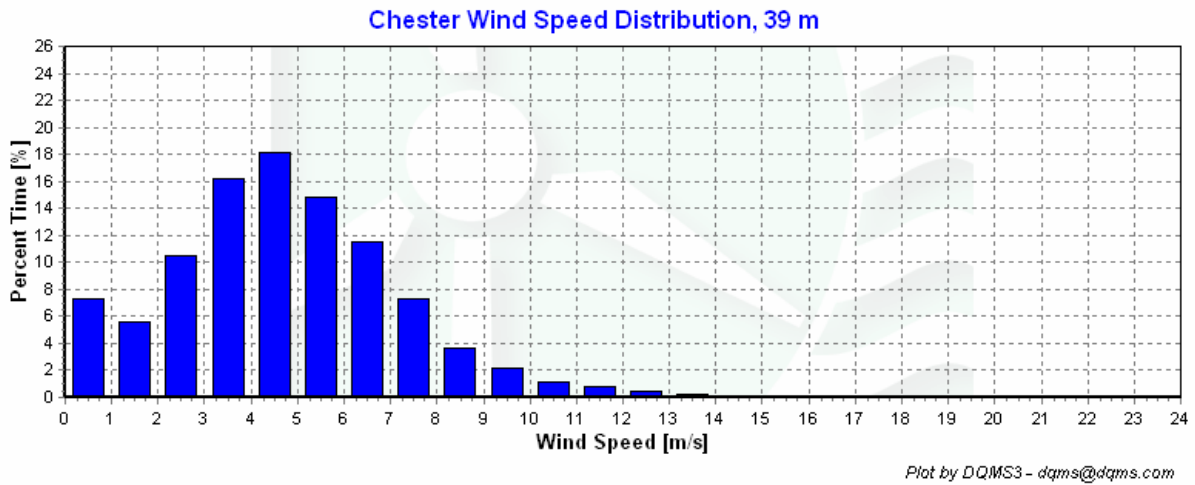
Figure 3 - Chester wind speed distribution, March 2007 – May 2007

Monthly Average Wind Speeds

Figure 4 - Chester monthly average wind speed, May 2006 – May 2007

Diurnal Average Wind Speeds

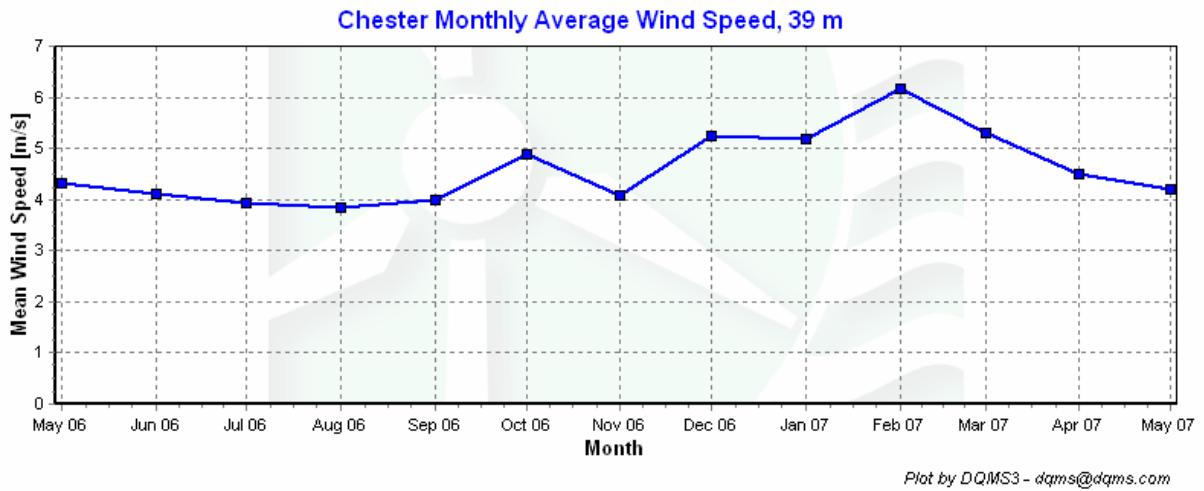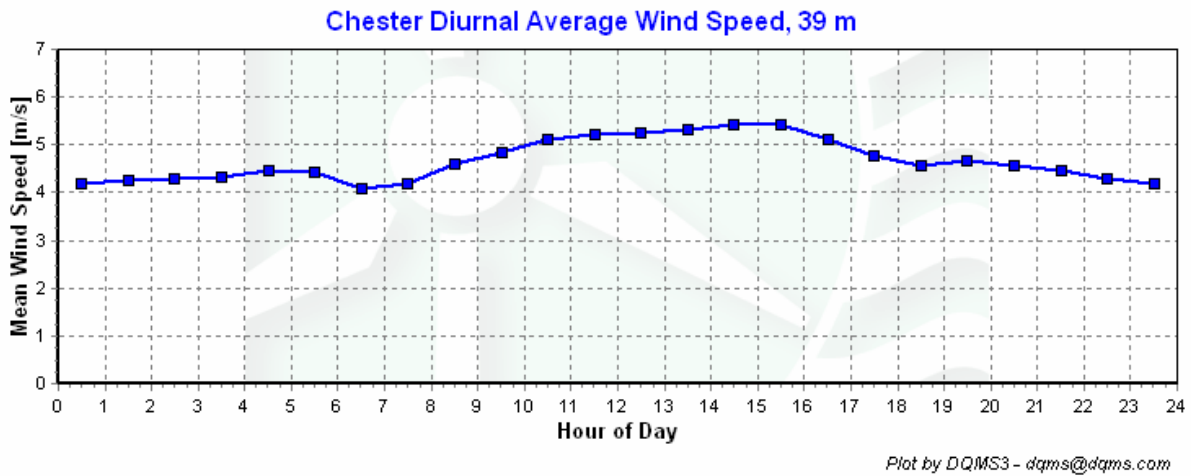**Figure 5 - Chester diurnal average wind speed, March 2007 – May 2007**
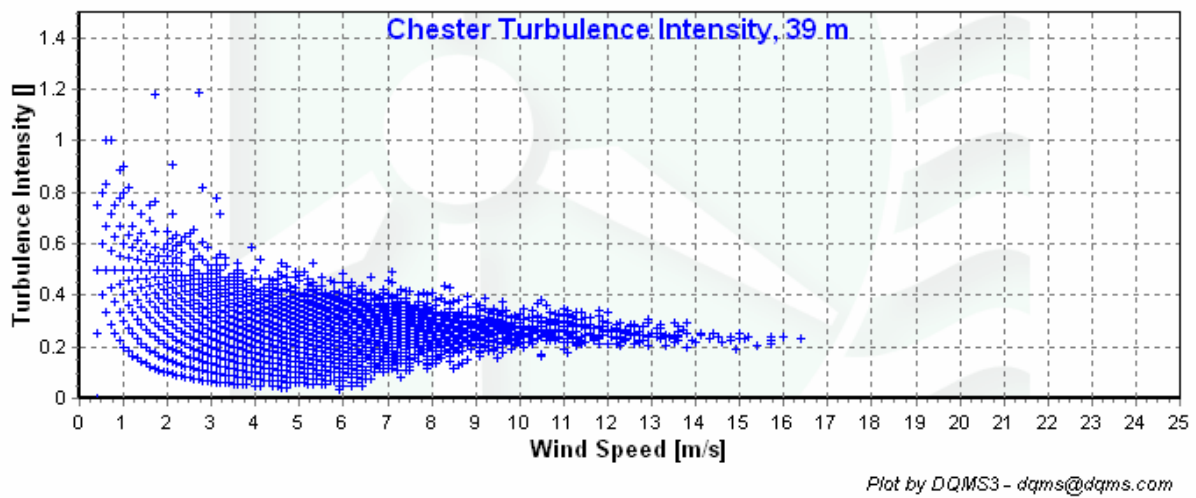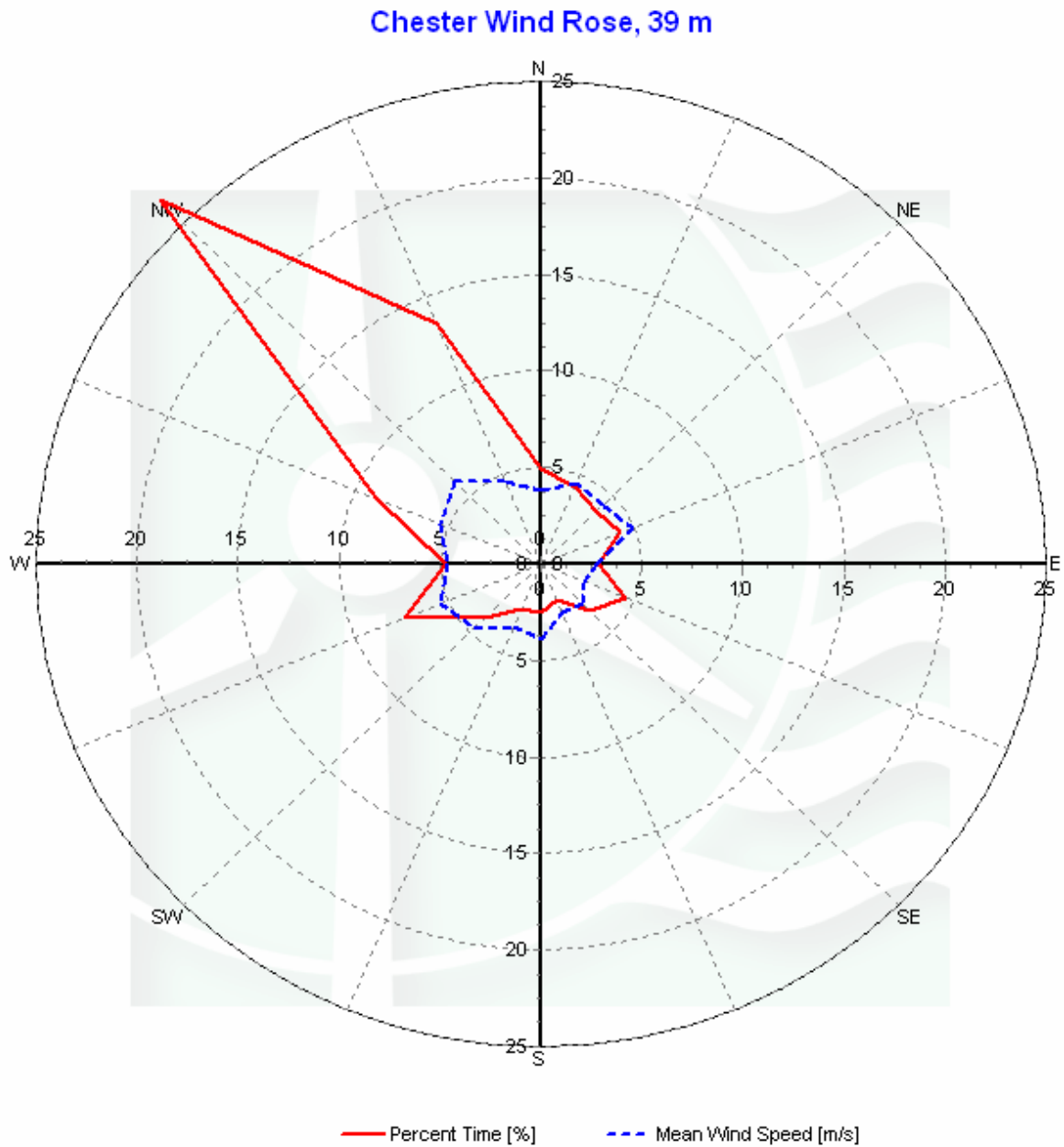
Turbulence Intensities

Figure 6 - Chester turbulence intensity, March 2007 – May 2007

Wind Roses

Figure 7 - Chester wind rose, March 2007 – May 2007

SECTION 5 - Significant Meteorological Events

The months of March 2007 through May 2007 were uneventful meteorologically

SECTION 6 - Data Collection and Maintenance

During the period of March 1st 2007 through May 31 2007, no maintenance events occurred.

SECTION 7 - Data Recovery and Validation

All raw wind data are subjected to a series of tests and filters to weed out data that are faulty or corrupted. Definitions of these quality assurance (QA) controls are given below under Test Definitions and Sensor Statistics. These control filters were designed to automate the quality control process and used many of the previous hand-worked data sets made at UMass to affect a suitable emulation. The gross percentage of data recovered (ratio of the number of raw data points received to data points expected) and net percentage (ratio of raw data points which passed all QA control tests to data points expected) are shown below.

| Gross Data Recovered [%] | 100 |
| Net Data Recovered [%] | 97.649 |

Test Definitions

All raw data were subjected to a series of validation tests, as described below. The sensors tested and the parameters specific to each sensor are given in the Sensor Performance Report which is included in APPENDIX A. Data which were flagged as invalid were not included in the statistics presented in this report.

MinMax Test: All sensors are expected to report data values within a range specified by the sensor and logger manufacturers. If a value falls outside this range, it is flagged as invalid. A data value from the sensor listed in Test Field 1 (TF1) is flagged if it is less than Factor 1 (F1) or greater than Factor 2. This test has been applied to the following sensors (as applicable): wind speed, wind speed standard deviation, wind direction, temperature, and solar insolation.

$$F1 > TF1 > F2$$

MinMaxT Test: This is a MinMax test for wind direction standard deviation with different ranges applied for high and low wind speeds. A wind direction standard deviation data value (TF1) is flagged either if it is less than Factor 1, if the wind speed (TF2) is less than Factor 4 and the wind direction standard deviation is greater than

Factor 2, or if the wind speed is greater than or equal to Factor 4 and the wind direction standard deviation is greater than Factor 3.

$$(TF1 < F1)$$
$$\text{or } (TF2 < F4 \text{ and } TF1 > F2)$$
$$\text{or } (TF2 \geq F4 \text{ and } TF1 > F3)$$

Icing Test: An icing event occurs when ice collects on a sensor and degrades its performance.   Icing events are characterized by the simultaneous measurements of near-zero standard deviation of wind direction, non-zero wind speed, and near- or below-freezing temperatures. Wind speed, wind speed standard deviation, wind direction, and wind direction standard deviation data values are flagged if the wind direction standard deviation (CF1) is less than or equal to Factor 1 (F1), the wind speed (TF1) is greater than Factor 2 (F2), and the temperature (CF2) is less than Factor 3 (F3). To exit an icing event, the wind direction standard deviation must be greater than Factor 4.

$$CF1 \leq F1 \text{ and } TF1 > F2 \text{ and } CF2 < F3$$

CompareSensors Test: Where primary and redundant sensors are used, it is possible to determine when one of the sensors is not performing properly. For anemometers, poor performance is characterized by low data values. Therefore, if one sensor of the pair reports values significantly below the other, the low values are flagged. At low wind speeds (Test Fields 1 and 2 less than or equal to Factor 3) wind speed data are flagged if the absolute difference between the two wind speeds is greater than Factor 1. At high wind speeds (Test Fields 1 or 2 greater than Factor 3) wind speed data are flagged if the absolute value of the ratio of the two wind speeds is greater is greater than Factor 2.

$$[\ TF1 \leq F3 \text{ and } TF2 \leq F3 \text{ and } abs(TF1 - TF2) > F1 \ ]$$
$$\text{or } [\ (TF1 > F3 \text{ or } TF2 > F3) \text{ and } (abs(1 - TF1 / TF2) > F2 \text{ or } abs(1 - TF2 / TF1) > F2) \ ]$$

Sensor Statistics

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

Expected Data Points: the total number of sample intervals between the start and end dates (inclusive).

Actual Data Points: the total number of data points recorded between the start and end dates.

% Data Recovered: the ratio of actual and expected data points (this is the *gross data recovered percentage*).

Hours Out of Range: total number of hours for which data were flagged according to MinMax and MinMaxT tests. These tests flag data which fall outside of an expected range.

Hours of Icing: total number of hours for which data were flagged according to Icing tests. This test uses the standard deviation of wind direction, air temperature, and wind speed to determine when sensor icing has occurred.

Hours of Fault: total number of hours for which data were flagged according to CompareSensors tests. These tests compare two sensors (e.g. primary and redundant anemometers installed at the same height) and flag data points where one sensor differs significantly from the other.

% Data Good: the filter results are subtracted from the gross data recovery percentage to yield the *net data recovered percentage*.

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1										
2	Etmp2DEGC					MinMax	-30	60		
3	EtmpSD2DEGC					MinMax	-30	60		
4	Etmpmax2DEGC					MinMax	-30	60		
5	Etmpmin2DEGC					MinMax	-30	60		
10	Anem39aMS					MinMax	0	90		
11	Anem39bMS					MinMax	0	90		
12	Anem30aMS					MinMax	0	90		
13	Anem30bMS					MinMax	0	90		
14	Anem25MS					MinMax	0	90		
20	AnemSD39aMS					MinMax	0	4	0	0
21	AnemSD39bMS					MinMax	0	4	0	0
22	AnemSD30aMS					MinMax	0	4	0	0
23	AnemSD30bMS					MinMax	0	4	0	0
24	AnemS250MS					MinMax	0	4	0	0
30	Vane39DEG					MinMax	0	359.9		
31	Vane30DEG					MinMax	0	359.9		
32	Vane25DEG					MinMax	0	359.9		
50	Turb39zNONE					MinMax	0	2		
51	Turb30zNONE					MinMax	0	2		
52	Turb25zNONE					MinMax	0	2		
60	Wshr0zNONE					MinMax	-100	100		
200	VaneSD39DEG	Anem39yMS				MinMaxT	0	100	100	10
201	VaneSD30DEG	Anem30yMS				MinMaxT	0	100	100	10
202	VaneSD25DEG	Anem25MS				MinMaxT	0	100	100	10
301	Anem39aMS	AnemSD39aMS	Vane39DEG	VaneSD39DEG	Etmp2DEGC	Icing	0.5	1	2	2
302	Anem39bMS	AnemSD39bMS	Vane39DEG	VaneSD39DEG	Etmp2DEGC	Icing	0.5	1	2	2
303	Anem30aMS	AnemSD30aMS	Vane30DEG	VaneSD30DEG	Etmp2DEGC	Icing	0.5	1	2	2
304	Anem30bMS	AnemSD30bMS	Vane30DEG	VaneSD30DEG	Etmp2DEGC	Icing	0.5	1	2	2
305	Anem25MS	AnemSD25MS	Vane25DEG	VaneSD25DEG	Etmp2DEGC	Icing	0.5	1	2	2
400	Anem39aMS	Anem39bMS				CompareSensors	1	0.35	3	0
401	Anem30aMS	Anem30bMS				CompareSensors	1	0.35	3	0
500	Amax39aMS					MinMax	0	90		
501	Amin39aMS					MinMax	0	90		
502	Amax39bMS					MinMax	0	90		
503	Amin39bMS					MinMax	0	90		
504	Amax30aMS					MinMax	0	90		

Continued: Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
505	Amin30aMS					MinMax	0	90		
506	Amax30bMS					MinMax	0	90		
507	Amin30bMS					MinMax	0	90		
508	Amax25MS					MinMax	0	90		
509	Amin25MS					MinMax	0	90		
510	Vmax39DEG					MinMax	0	359.9		
511	Vmin39DEG					MinMax	0	359.9		
512	Vmax30DEG					MinMax	0	359.9		
513	Vmin30DEG					MinMax	0	359.9		
514	Vmax25DEG					MinMax	0	359.9		
515	Vmin25DEG					MinMax	0	359.9		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Etmp2DEGC	13249	13249	100	0	0	0	100
EtmpSD2DEGC	13249	13249	100	0	0	0	100
Anem39aMS	13249	13249	100	1.667	65	0.833	96.943
AnemSD39aMS	13249	13249	100	1.667	65	0.833	96.943
Anem39bMS	13249	13249	100	1.833	65	7.833	96.619
AnemSD39bMS	13249	13249	100	1.833	65	7.833	96.619
Anem30aMS	13249	13249	100	1.333	59.333	0.667	97.222
AnemSD30aMS	13249	13249	100	1.333	59.333	0.667	97.222
Anem30bMS	13249	13249	100	1.5	59.333	20.5	96.317
AnemSD30bMS	13249	13249	100	1.5	59.333	20.5	96.317
Anem25MS	13249	13249	100	0.5	52	0	97.622
AnemSD25MS	13249	13249	100	0.5	52	0	97.622
Vane39DEG	13249	13249	100	1	65	0	97.011
VaneSD39DEG	13249	13249	100	1	65	0	97.011
Vane30DEG	13249	13249	100	1.333	59.333	0	97.253
VaneSD30DEG	13249	13249	100	1.333	59.333	0	97.253
Vane25DEG	13249	13249	100	1.833	52	0	97.562
VaneSD25DEG	13249	13249	100	1.833	52	0	97.562
Total	264980	264980	100	24.833	954	59.667	97.649

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	March - May 2007 [%]
0.5	7.35
1.5	5.54
2.5	10.5
3.5	16.21
4.5	18.14
5.5	14.87
6.5	11.5
7.5	7.33
8.5	3.65
9.5	2.19
10.5	1.11
11.5	0.75
12.5	0.45
13.5	0.26
14.5	0.08
15.5	0.07
16.5	0.02
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Date	39m Mean 10 min [m/s]
2006 May	4.32
June	4.12
July	3.94
August	3.84
September	4
October	4.88

Continued: Monthly Average Wind Speed Data

Date	39m Mean10 min [m/s]
November	4.1
March	5.25
January 2007	5.2
February	6.19
March	5.29
April	4.5
May	4.21
Spring: March - May 2007	4.60

Diurnal Average Wind Speed Data

Hour of Day	March - May 2007 Mean Wind Speed [m/s]
0	4.2
1	4.27
2	4.29
3	4.32
4	4.46
5	4.43
6	4.09
7	4.2
8	4.61
9	4.82
10	5.11
11	5.23
12	5.26
13	5.31
14	5.41
15	5.41
16	5.12
17	4.76
18	4.58
19	4.66
20	4.57
21	4.45
22	4.3
23	4.18

Wind Rose Data

Direction	March - May 2007	
	Percent Time [%]	**Mean Wind Speed [m/s]**
N	4.94	3.81
NNE	4.36	4.54
NE	3.84	4.29
ENE	4.26	4.91
E	2.82	2.72
ESE	4.5	2.34
SE	3.36	2.95
SSE	2.01	2.7
S	2.47	3.91
SSW	2.51	3.47
SW	3.9	4.7
WSW	7.29	5.43
W	4.7	4.61
WNW	8.89	5.44
NW	26.69	6.01
NNW	13.47	4.63