WIND DATA REPORT

Mt. Lincoln – Pelham, MA

December 2009 to February 2010

Prepared for

Massachusetts Technology Collaborative
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by

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NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Wind Energy Center (WEC) at the University of Massachusetts, Amherst in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Technology Collaborative (MTC). The opinions expressed in this report do not necessarily reflect those of MTC or the Commonwealth of Massachusetts, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

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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 Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

Wind monitoring equipment was installed at the Mt. Lincoln site in April 2009. The base of the instrumented radio tower is installed 377 meters above sea level. Anemometers and wind direction vanes are installed at 65 and 86 m (213.3 and 282.2 ft) above the tower base. There are three anemometers and a wind vane at both heights. There is a temperature sensor installed near the base of the tower.

This report summarizes the wind data collected during the winter of 2009-2010, between December 2009 and February 2010. The mean recorded wind speed 8.278 m/s (18.52 mph*) at 86 m and the prevailing wind direction was from the northwest. The average wind shear exponent between the two measured heights was 0.268. The average turbulence intensity at 86 m for wind speeds between 10 m/s and 11 m/s was 0.115.

The gross data recovery percentage (the actual percentage of expected data received) was 100% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 96.28%.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by WEC and the Massachusetts Technology Collaborative (MTC). This document is found through the WEC 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 WFCR radio tower is located on Mt. Lincoln in Pelham, Massachusetts. The 100 m (328 ft) radio tower is located at 42° 21' 49.56" North, 72° 25' 22.80" West, approximately 1.25-miles west of Route 202 and 3-miles west of the Quabbin Reservoir. The tower base is 377 m (1,236.9 ft) above sea level. The tower is identified with a yellow box in the center of Figure 1 below.

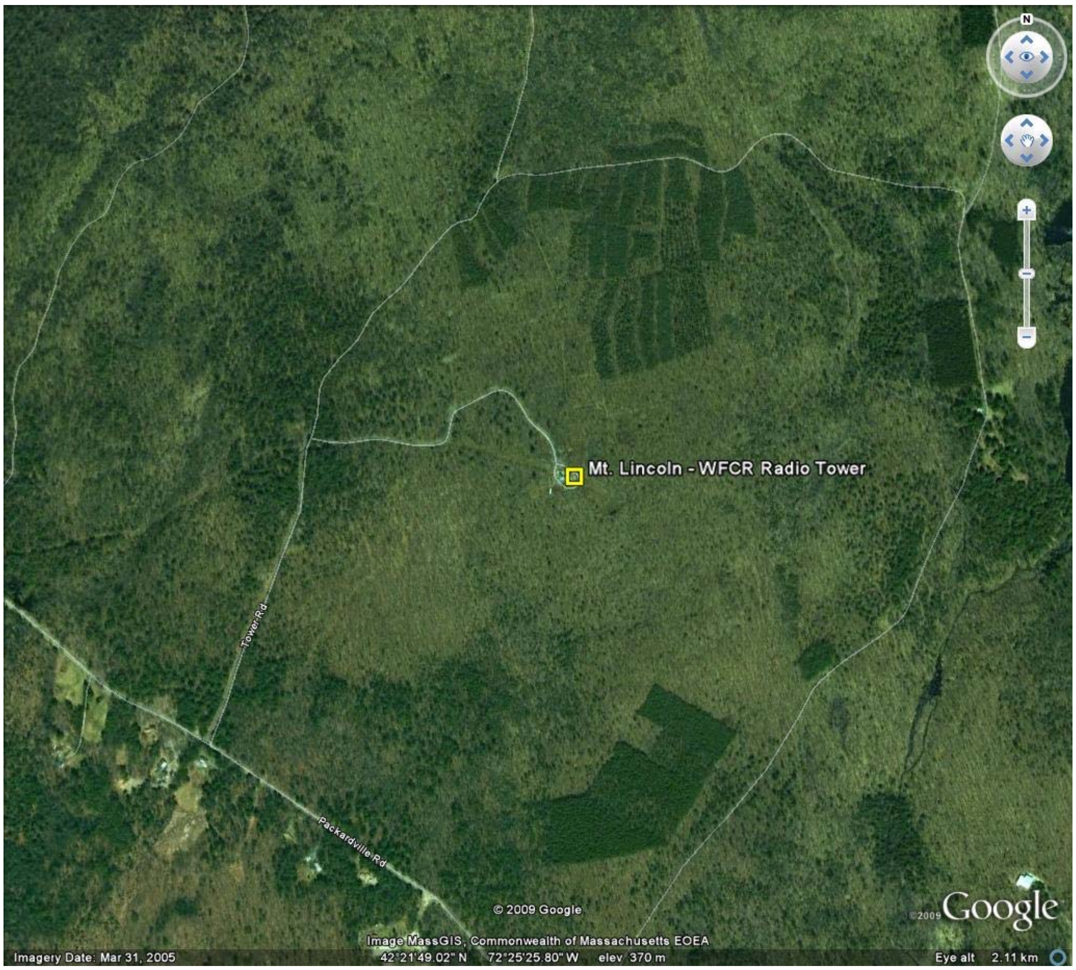

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an existing radio tower, known as the WFCR broadcast tower. WFCR is a 13,000 watt FM station, and the tower consists of a guyed, 3-legged, solid-steel lattice tower that is triangular in cross-section. The wind monitoring equipment comes from NRG systems and consists of the following items:

- NRG Symphonie data logger with internal temperature.
- 6 – NRG #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Three anemometers are located at 65 m (213.3 ft) and three anemometers are located at 86 m (282.2 ft).
- 2 – NRG #200P Wind direction vanes. The vanes are located at 65 m (213.3 ft) and 86 m (282.2 ft).

Data from the Symphonie logger is sent to WEC via a cellular modem once a day. The logger samples wind speed and direction once every two seconds. These samples are combined into 10-minute averages and are put into a binary file along with the maximum, minimum and standard deviation for each 10-minute interval. The binary files are converted to ASCII text files using NRG software. These text files are then imported into a database software program where they are subjected to quality assurance tests prior to data usage.

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.

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 is missing, the percent of the available data that are used to determine the data statistics is noted. For this period, data from all other sensors were well above the acceptable 90% criterion.

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
Height Units	**86 m [m/s]**	**86 m [m/s]**	**86 m [m/s]**	**65 m [m/s]**	**65 m [m/s]**	**65 m [m/s]**
Dec 2009	8.728	20.56	NW	8.091	19.19	NW
Jan 2010	7.735	21.88	NW	7.165	20.75	NW
Feb 2010	8.369	18.96	NW	7.776	18.06	NW
Dec 2009 – Feb 2010	**8.278**	**21.88**	**NW**	**7.679**	**20.75**	**NW**

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 each measurement height is between 10 and 11 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.

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

Table 2. Shear and Turbulence Intensity Data Summary

Date Height Units	Turbulence Intensity at 10 m/s 86 m [-]	Turbulence Intensity at 10 m/s 65 m [-]	Mean Wind Shear Coefficient, α Between 86 m and 65 m [-]
Dec 2009	0.116	0.145	0.198
Jan 2010	0.106	0.132	0.218
Feb 2010	0.122	0.141	0.257
Dec 2009 -Feb 2010	**0.115**	**0.140**	**0.268**

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 Mt. Lincoln site, the following observations are noted:

- Time Series, Figure 2: wind speeds seldom exceeded 20 m/s at the site during the winter months.

- Wind Speed Distribution, Figure 3: we can see in Figure 3 that wind speeds are mostly between 6 and 10 m/s during the winter months

- Monthly Average, Figure 4: we show the monthly averages for 10 months, May 2009 through February 2010.

- Diurnal, Figure 5: we can see in Figure 5 wind speeds that are higher during the evening and early morning hours during winter months.

- Turbulence Intensity, Figure 6: we can see that turbulence numbers are lower than 0.3 for most wind speeds.

- Wind Rose, Figure 7: a northwesterly wind direction bias is shown.

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

Wind Speed Time Series

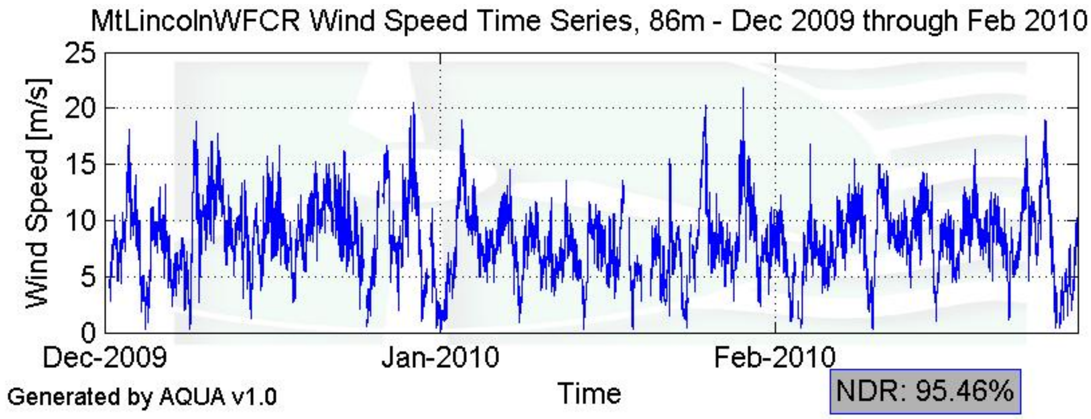

Figure 2 – Wind Speed Time Series, December 1, 2009 – February 28, 2010

Wind Speed Distributions

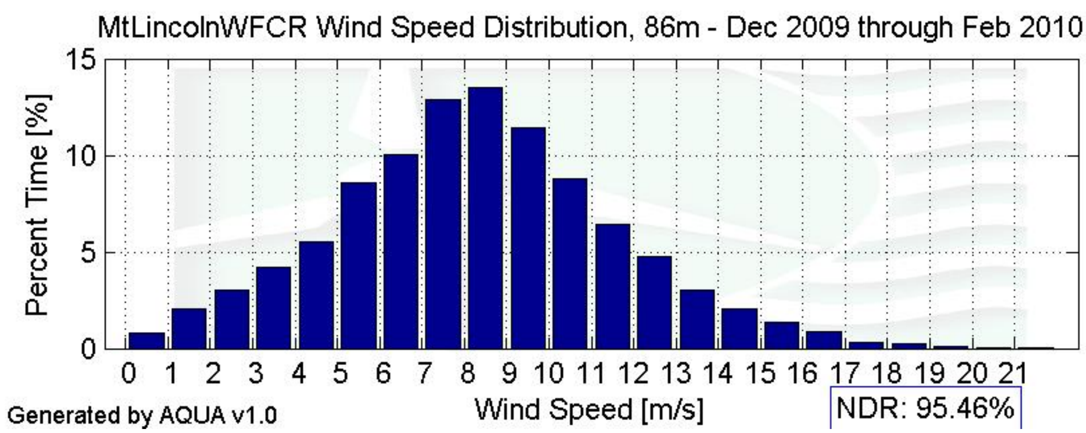

Figure 3 – Wind Speed Distribution, December 1, 2009 – February 28, 2010

Monthly Average Wind Speeds

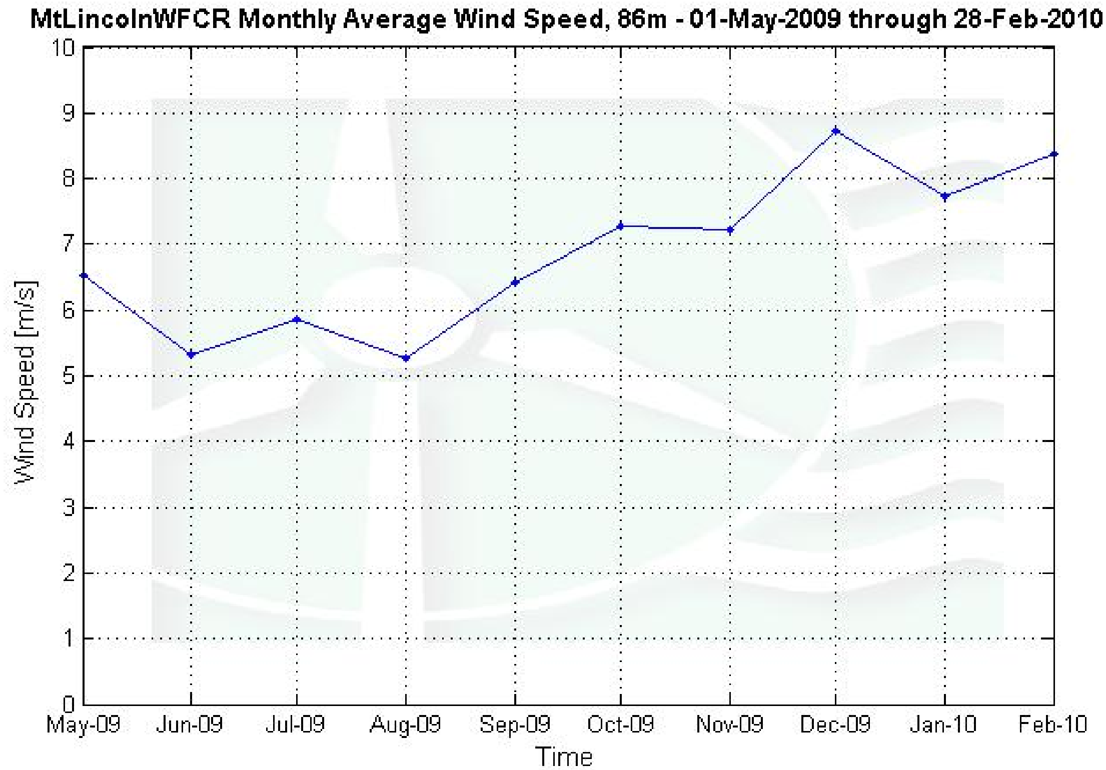

Figure 4 – Monthly Average Wind Speed, May 2009 – February 2010

Diurnal Average Wind Speeds

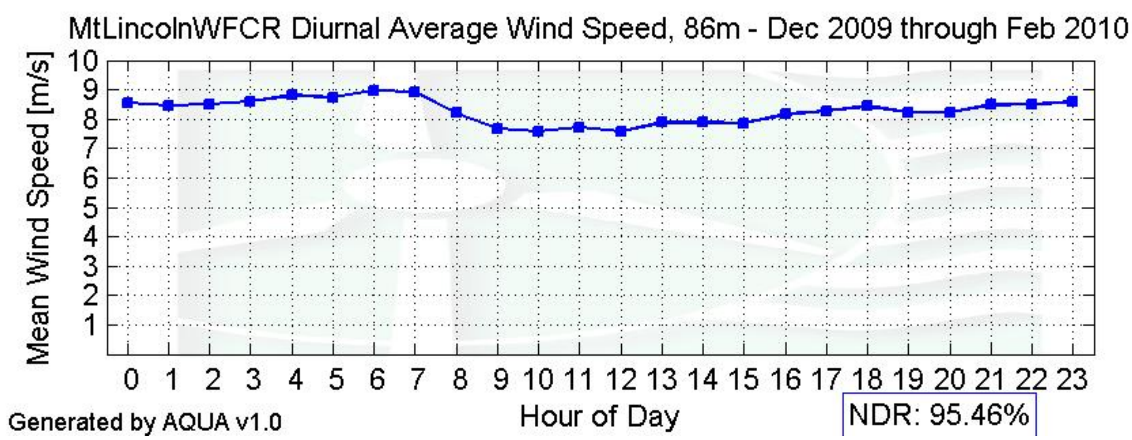

Figure 5 – Diurnal Average Wind Speeds, December 1, 2009 – February 28, 2010

Turbulence Intensities

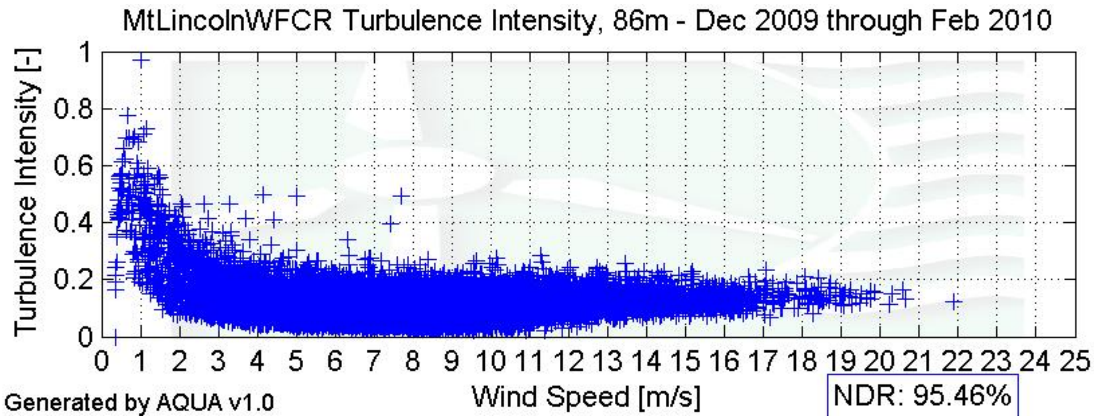

Figure 6 – Turbulence Intensity vs. Wind Speed, December 1, 2009 – February 28, 2010

Wind Rose

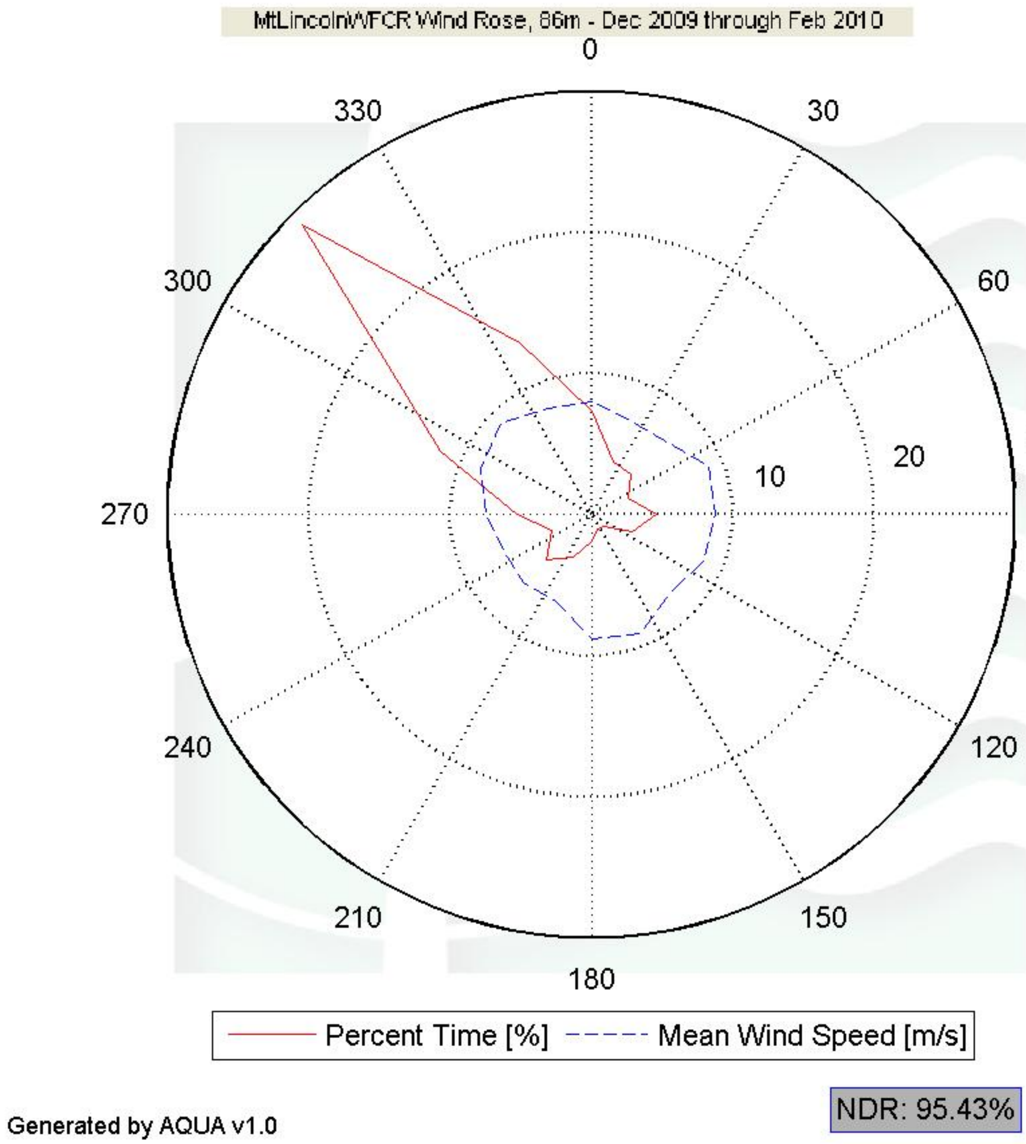

Figure 7 – Wind Rose, December 1, 2009 – February 28, 2010

SECTION 5 - Significant Meteorological Events

There were no extreme metrological events during this data collection period. The highest recorded wind speed was 21.88 m/s (48.95 mph).

SECTION 6 - Data Collection and Maintenance

All sensors and equipment functioned properly throughout the monitoring period. No maintenance was performed during this quarter.

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 [%]	96.28

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

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Temp	12960	12960	100	0	0	0	100
Volt	12960	12960	100	0	0	0	100
Anem65a	12960	12960	100	0.167	68.667	15.333	96.204
Anem65b	12960	12960	100	0.167	69	116.333	91.505
Anem65c	12960	12960	100	0.167	68.333	0	96.829
Vane65	12960	12960	100	0	69.667	0	96.775
Anem86a	12960	12960	100	0.167	98.167	6.167	95.162
Anem86b	12960	12960	100	0.167	98.333	1.167	95.401
Anem86c	12960	12960	100	0.167	98	0	95.455
Vane86	12960	12960	100	0	98.5	0	95.44
Total	129600	129600	100	1	668.667	139	96.277

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	December 2009 - February 2010 [%]
0.5	0.77
1.5	2.05
2.5	3.03
3.5	4.17
4.5	5.51
5.5	8.61
6.5	10.04
7.5	12.86
8.5	13.53
9.5	11.43
10.5	8.78
11.5	6.4
12.5	4.74
13.5	3.06
14.5	2.03
15.5	1.35
16.5	0.89
17.5	0.32
18.5	0.27
19.5	0.12
20.5	0.03
21.5	0.01
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Month	86m Mean 10 min [m/s]
May	6.539
June	5.327
July	5.846
August	5.279
September	6.414
October	7.273
November	7.233
December	8.728
January 2010	7.735
February	8.369
Winter: Dec 2009 – February 2010	**8.278**

Wind Rose Data

Direction	Dec 2009 – February 2010	
	Percent Time [%]	Mean Wind Speed [m/s]
N	7.28	7.97
NNE	4.06	7.15
NE	3.97	7.36
ENE	2.87	8.95
E	4.63	8.81
ESE	3.15	8.61
SE	1.26	7.92
SSE	1.11	9.14
S	1.89	8.87
SSW	3.25	6.7
SW	4.55	6.79
WSW	3.01	6.69
W	5.24	7.48
WNW	11.55	8.54
NW	29	9.08
NNW	13.17	8.14

Diurnal Average Wind Speed Data

Hour of Day	Dec 2009 – Feb 2010 Mean Wind Speed [m/s]
0	8.56
1	8.46
2	8.5
3	8.61
4	8.8
5	8.74
6	8.98
7	8.92
8	8.2
9	7.67
10	7.59
11	7.71
12	7.59
13	7.87
14	7.89
15	7.86
16	8.15
17	8.27
18	8.44
19	8.23
20	8.24
21	8.48
22	8.51
23	8.58