WIND DATA REPORT

Nantucket, MA

July 22nd 2005 to August 31st 2006

Prepared for

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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 preformed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at a radio tower in Nantucket, MA. Sensors were installed on July 21, 2005. Two anemometers and one wind vane are mounted at 99 m (324.8 ft), 68 m (223.1 ft), and 58 m (190.3 ft).

This final report presents data for the entire duration of the wind monitoring campaign at Nantucket. The data covers the period from July 22, 2005 until October 3, 2006. Because of seasonal variations in the wind speed, wind data is typically reported in integer year intervals. Thus, while there are approximately 13 total months of data, all the yearly summary statistic provided, and all graphs except for the time series graph and monthly average graph, are from the period of September 1, 2005 until August 31, 2006, which covers exactly one year.

During the period of September 1, 2005 to August 31, 2006, the mean recorded wind speed at 99 meters was 9.7 m/s (21.7 mph *) and the prevailing wind direction at 99 m was SW. The gross data recovery percentage (the actual percentage of expected data received) was 99.9 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.8%.

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 Nantucket station is located at the town of Nantucket landfill. The tower base is located at 41.281° N, -70.169° W (WGS84) (Figure 1). The elevation at the station is approximately 3 m above sea level. The red cross indicates the approximate location of the tower.

Figure 1 - Nantucket Site Location

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 142.6 m (467.8 ft) radio tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- 9300 Data Logger (Removed 8/10/2005)
- Symphonie Data Logger (Installed on 8/10/2005)
- 6 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 99 m (324.8 ft), two at 68 m (223.1 ft) and two at 58 m (190.3 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 99 m (324.8 ft), 68 m (223.1 ft) and 58 m (190.3 ft).

- 6 – Sensor booms, 12’ length
- Lightning rod and grounding cable

The data from the Symphonie logger is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These are then combined into 10-minute averages, and along with the standard deviation for those 10-minute periods, are put into a binary file. These binary files are converted to ASCII text files using the NRG software BaseStation®. These text files are then imported into a database software program where they are subjected to QA tests prior to using the data.

SECTION 3- Data Collection and Maintenance

The following maintenance/equipment problems occurred during the report period, and the following corrective actions taken:

The logger was switched on August 10, 2005.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity	Wind Shear Coefficient
Heights, units	**99 m, [m/s]**	**99 m, [m/s]**	**99 m, [ ]**	**99 m, [ ]**	**68 m, [m/s]**	**68 m, [m/s]**	**68 m, [ ]**	**68 m, [ ]**	**58 m, [m/s]**	**58 m, [m/s]**	**58 m, [ ]**	**58 m, [ ]**	**99m, 68 m, [ ]**
05-Aug	7.9	19.4	SW	0.09	7.1	17.0	SW	0.11	6.6	15.5	SW	0.12	0.23
05-Sep	7.7	20.5	SSW	0.09	7.0	18.5	SSW	0.11	6.7	17.5	SSW	0.11	0.18
05-Oct	10.2	26.4	E	0.10	9.4	23.8	ENE	0.12	9.0	23.0	ENE	0.12	0.16
05-Nov	10.8	24.6	SW	0.08	9.7	21.9	SSW	0.10	9.1	20.6	SW	0.11	0.26
05-Dec	10.1	32.1	WNW	0.08	9.4	30.5	WNW	0.10	9.0	29.0	WNW	0.11	0.17
06-Jan	11.1	28.4	W	0.08	10.1	25.5	W	0.10	9.5	23.9	W	0.11	0.22
06-Feb	10.9	26.0	NW	0.09	10.1	24.7	NW	0.11	9.6	23.9	NW	0.12	0.17
06-Mar	9.3	25.0	NW	0.08	8.6	21.6	NW	0.10	8.1	19.9	NW	0.11	0.20
06-Apr	10.0	26.1	E	0.09	9.0	22.6	N	0.11	8.6	21.6	E	0.11	0.26
06-May	9.9	23.7	SW	0.09	8.7	22.4	SW	0.12	8.3	21.3	SW	0.12	0.31
06-Jun	9.9	21.2	SW	0.07	8.7	18.8	SW	0.10	8.1	18.1	SW	0.11	0.31
06-Jul	9.2	22.1	SW	0.08	8.0	20.2	SSW	0.10	7.4	19.1	SSW	0.11	0.31
06-Aug	7.5	17.7	SW	0.09	6.7	15.1	WSW	0.11	6.4	14.3	WSW	0.12	0.22
06-Sep	7.7	18.7	SW	0.09	7.1	16.2	SW	0.11	6.9	15.2	SW	0.11	0.19
Sep 06 – Aug 06	**9.7**	**32.1**	**SW**	**0.09**	**8.8**	**30.5**	**SW**	**0.11**	**8.3**	**29.0**	**SW**	**0.11**	**0.23**

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 can be perfectly accurate. 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.

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 may not 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.

SECTION 4- Significant Meteorological Events

There were no extreme metrological events in the three months covered by this report. The highest wind speeds in the 3 months are less than 21 m/s as shown by the time series graph.

SECTION 5 - 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 [%]	99.9
Net Data Recovered [%]	99.8

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 (F4).

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

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

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*.

SECTION 6 - Data Summary

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from September 1, 2005 until August 31, 2006. The following graphs are included:

- Time Series – 10-minute average wind speeds at a height of 99 m are plotted against time for the period of July 22, 2005 until October 3, 2006. The wind speed time series is shown in Figure 2.

- Wind Speed Distribution –A histogram plot giving the percentage of time that the wind is at a given wind speed at a height of 99 m. The wind blows most often between 8 m/s and 9 m/s, for approximately 8% of the time. The wind speed distribution is shown in Figure 3.

- Monthly Average – This graph shows the trends in the mean monthly wind speed at a height of 99 m from August 2005 - September 2006. This graph shows the trends in the wind speed over the year. To date, January has been the windiest month, with a mean wind speed of 11.1 m/s. The monthly average wind speed plot is shown in Figure 4.

- Diurnal –A plot of the average wind speed for each hour of the day at a height of 99 m. The wind speed was lowest between 9 am and 10 am, with a mean speed of 9.2 m/s. The wind speed was highest between 10 pm and 11 pm, with a mean speed on 10.1 m/s. The diurnal variation plot is shown in Figure 5.

- Turbulence Intensity –A plot of turbulence intensity as a function of wind speed at a height of 99 m. 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. In general, turbulence intensities range from 0.1 to 0.4; for Nantucket, the average turbulence intensity was 0.09 at a height of 99 m. The turbulence intensity plot is shown in Figure 6.

- 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 at a height of 99 m. This wind rose shows the prevailing direction from the southwest. The wind rose plot is shown in Figure 7.

SECTION 7- Graphs

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

Wind Speed Time Series

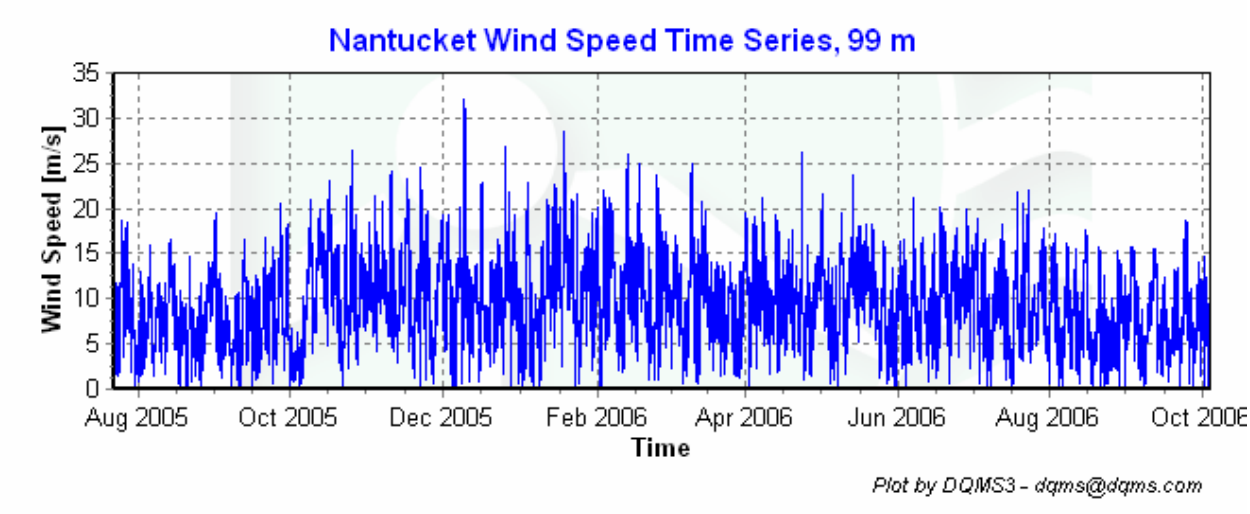

Figure 2 - Wind Speed Time Series, July 22, 2005 - October 3, 2006.

Wind Speed Distributions

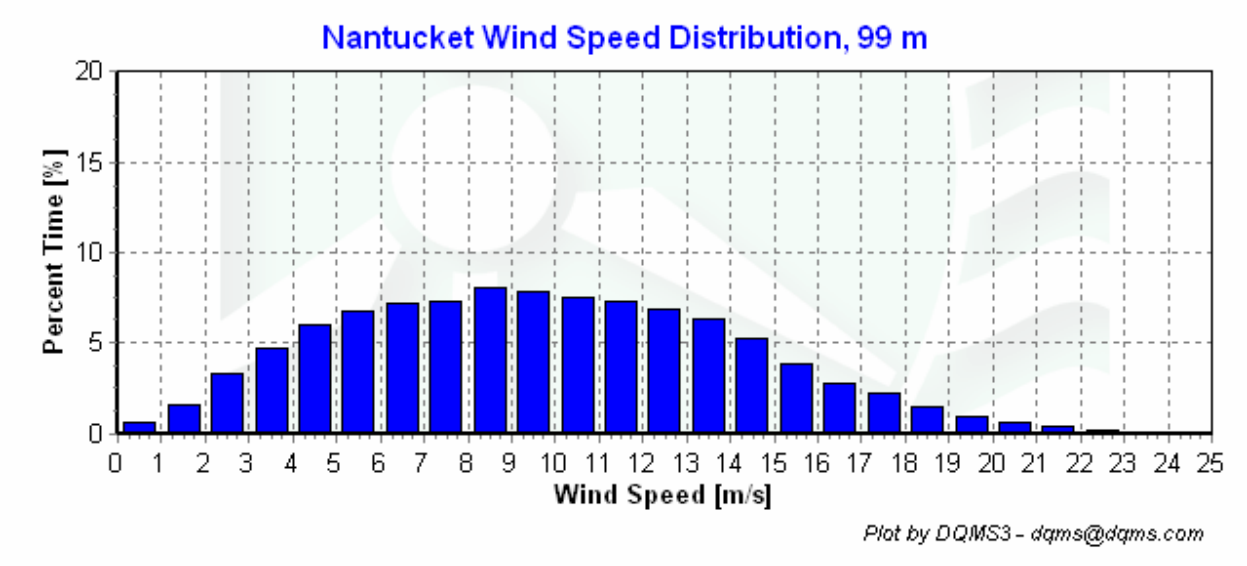

Figure 3 - Wind Speed Distribution, September 1, 2005 - August 31, 2006.

Monthly Average Wind Speeds

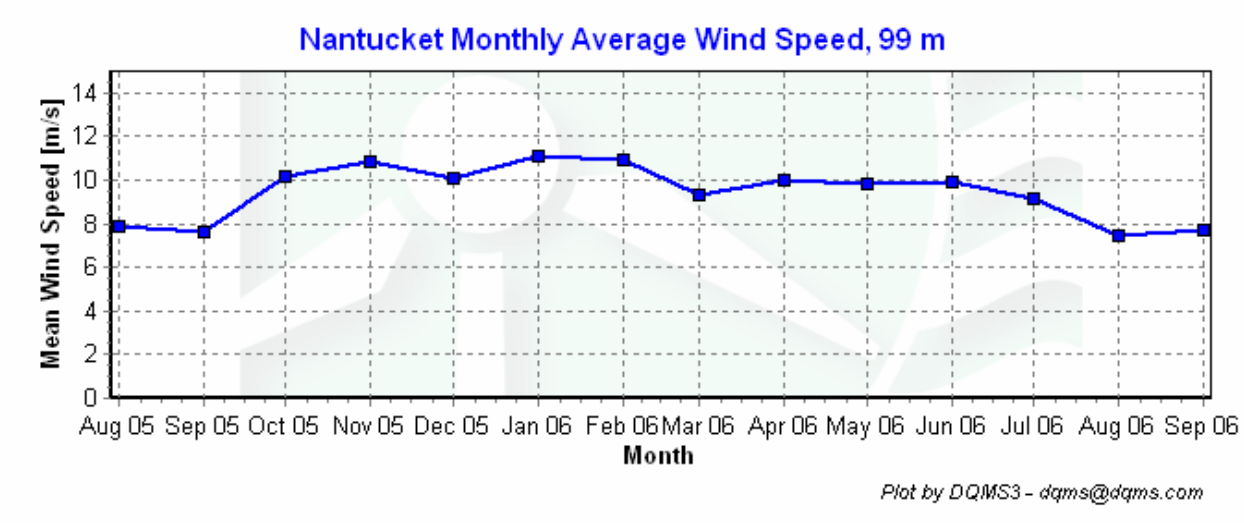

Figure 4 - Monthly Average Wind Speeds, August, 2005 - September, 2006.

Diurnal Average Wind Speeds

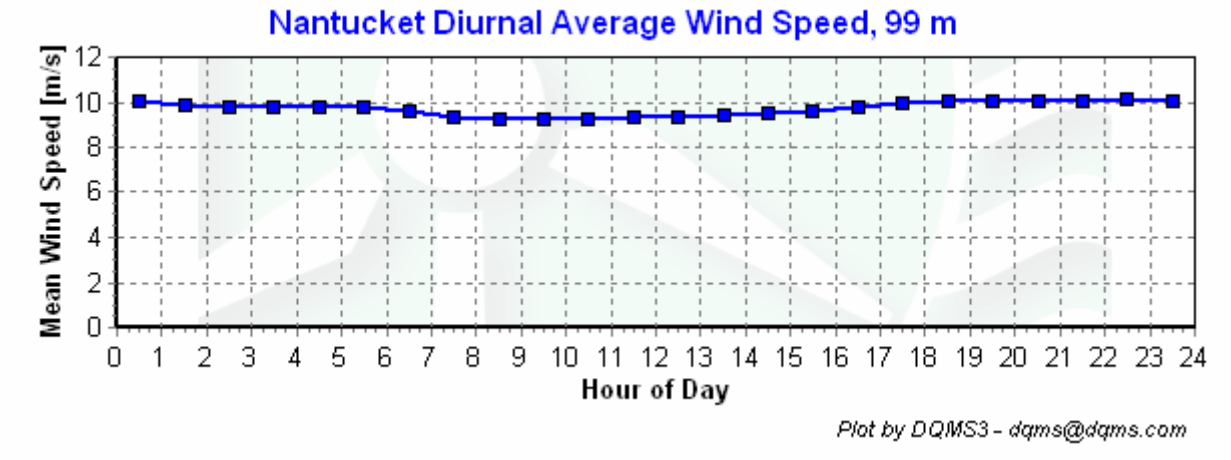

Figure 5 - Diurnal Wind Speed, September 1, 2005 - August 31, 2006.

Turbulence Intensities

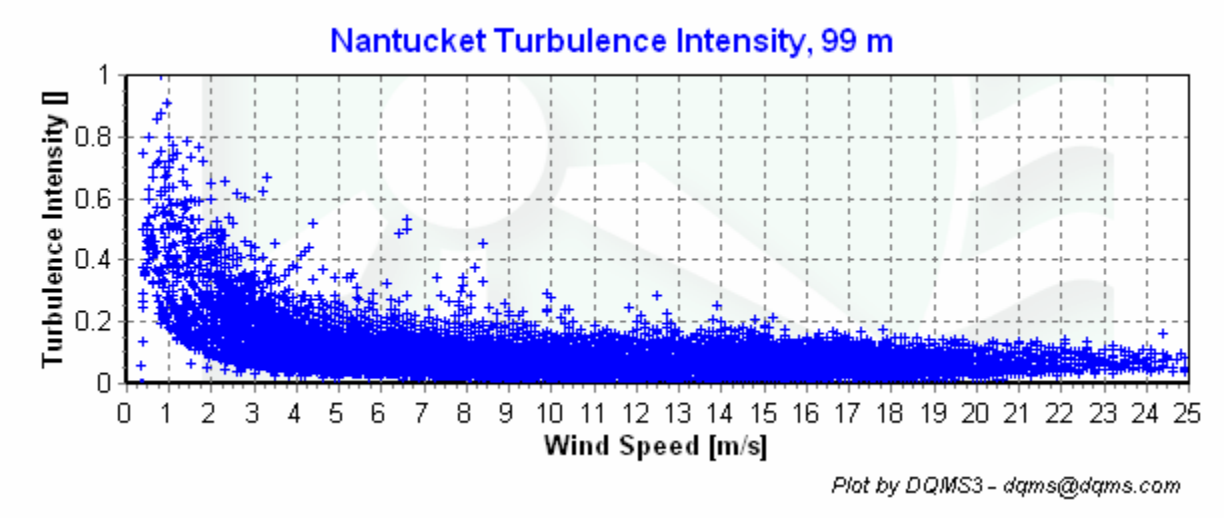

Figure 6 - Turbulence Intensity vs. Wind Speed, September 1, 2005 - August 31, 2006.

Wind Rose

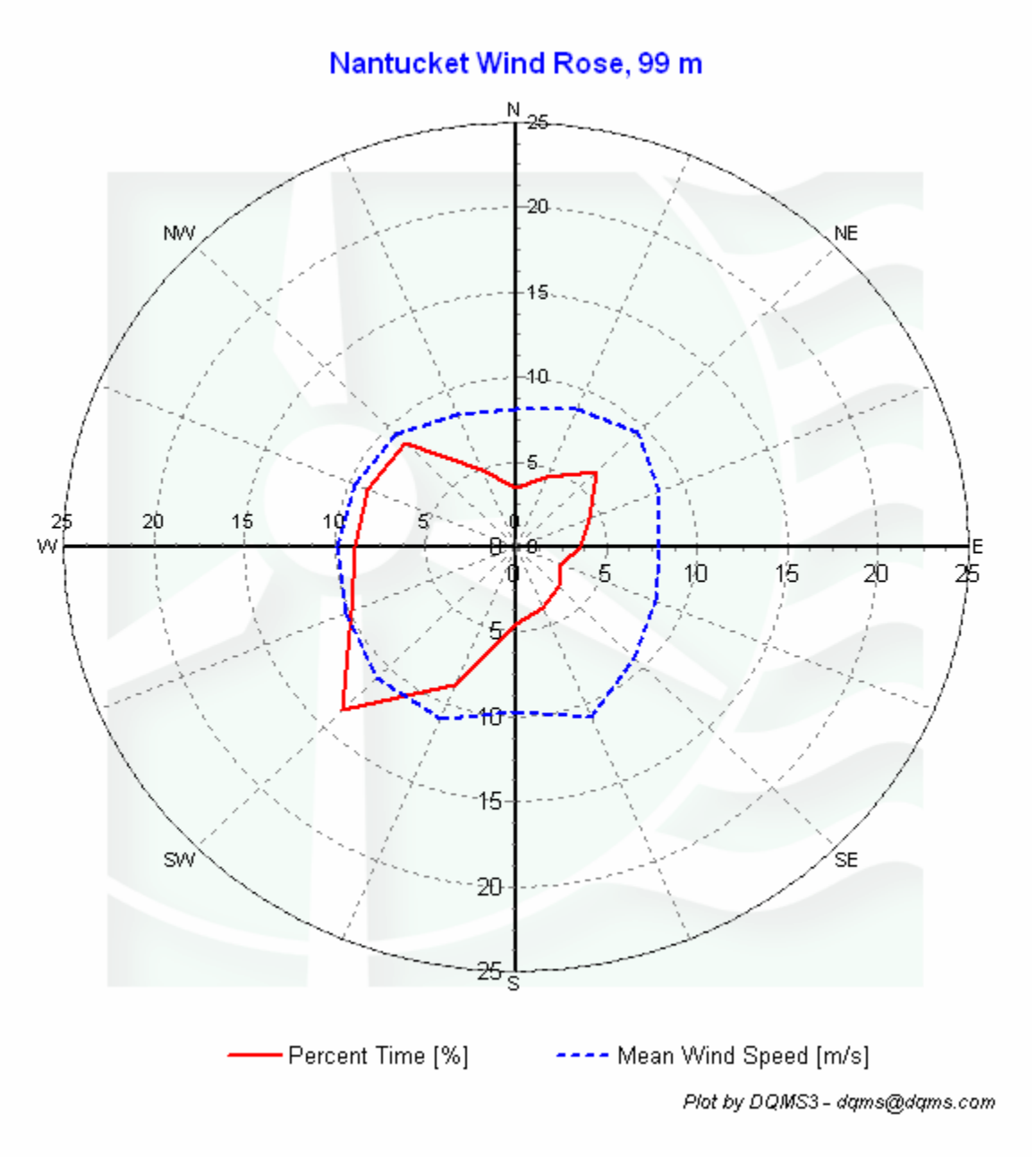

Figure 7 - Wind Rose, September 1, 2005 - August 31, 2006.

APPENDIX A – Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert				
10	Anem99ams						MinMax	0	90	0	0
11	Anem99bms						MinMax	0	90	0	0
12	Anem68ams						MinMax	0	90	0	0
13	Anem68bms						MinMax	0	90	0	0
14	Anem58ams						MinMax	0	90	0	0
15	Anem58bms						MinMax	0	90	0	0
16	Anem99yms						MinMax	0	90	0	0
17	Anem68yms						MinMax	0	90	0	0
18	Anem58yms						MinMax	0	90	0	0
20	AnemSD99ams						MinMax	0	4	0	0
21	AnemSD99bms						MinMax	0	4	0	0
22	AnemSD68ams						MinMax	0	4	0	0
23	AnemSD68bms						MinMax	0	4	0	0
24	AnemSD58ams						MinMax	0	4	0	0
25	AnemSD58bms						MinMax	0	4	0	0
26	AnemSD99yms						MinMax	0	4	0	0
27	AnemSD68yms						MinMax	0	4	0	0
28	AnemSD58yms						MinMax	0	4	0	0
30	Vane99aDEG						MinMax	0	359.9	0	0
31	Vane68aDEG						MinMax	0	359.9	0	0
32	Vane58aDEG						MinMax	0	359.9	0	0
50	Turb99zNONE						MinMax	0	2	0	0
51	Turb68zNONE						MinMax	0	2	0	0
52	Turb58zNONE						MinMax	0	2	0	0
60	Wshr0zNONE						MinMax	-100	100	0	0
200	VaneSD99aDEG	Anem99yms					MinMaxT	0	100	100	10
201	VaneSD68aDEG	Anem68yms					MinMaxT	0	100	100	10
202	VaneSD58aDEG	Anem58yms					MinMaxT	0	100	100	10
400	Anem99ams	Anem99bms					CompareSensors	1	0.25	3	0
401	Anem68ams	Anem68bms					CompareSensors	1	0.25	3	0
402	Anem58ams	Anem58bms					CompareSensors	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Fault	% Data Good
Anem99ams	52560	52554	99.989	0.167	21	99.747
AnemSD99ams	52560	52554	99.989	0.167	21	99.747
Anem99bms	52560	52554	99.989	0.167	4.833	99.932
AnemSD99bms	52560	52554	99.989	0.167	4.833	99.932
Vane99aDEG	52560	52554	99.989	1	0	99.977
VaneSD99aDEG	52560	52554	99.989	1	0	99.977
Anem68ams	52560	52554	99.989	0.167	132.167	98.478
AnemSD68ams	52560	52554	99.989	0.167	132.167	98.478
Anem68bms	52560	52554	99.989	0.5	5.167	99.924
AnemSD68bms	52560	52554	99.989	0.5	5.167	99.924
Vane68aDEG	52560	52554	99.989	0.5	0	99.983
VaneSD68aDEG	52560	52554	99.989	0.5	0	99.983
Anem58ams	52560	52554	99.989	0.5	4	99.937
AnemSD58ams	52560	52554	99.989	0.5	4	99.937
Anem58bms	52560	52554	99.989	0.5	2.5	99.954
AnemSD58bms	52560	52554	99.989	0.5	2.5	99.954
Vane58aDEG	52560	52554	99.989	0.5	0	99.983
VaneSD58aDEG	52560	52554	99.989	0.5	0	99.983
Total	**946080**	**945972**	**99.989**	**8**	**339.333**	**99.768**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.68
1.5	1.66
2.5	3.35
3.5	4.69
4.5	6.06
5.5	6.79
6.5	7.24
7.5	7.34
8.5	8.07
9.5	7.89
10.5	7.51
11.5	7.35
12.5	6.85
13.5	6.32
14.5	5.25
15.5	3.89
16.5	2.83
17.5	2.3
18.5	1.46
19.5	0.94
20.5	0.64
21.5	0.4
22.5	0.21
23.5	0.14
24.5	0.09

Table 1 - Wind Speed Distribution, 99 m, September 1, 2005 - August 31, 2006.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Aug-05	7.85
Sep-05	7.66
Oct-05	10.19
Nov-05	10.82
Dec-05	10.09
Jan-06	11.13

Feb-06	10.92
Mar-06	9.33
Apr-06	9.97
May-06	9.87
Jun-06	9.94
Jul-06	9.16
Aug-06	7.45
Sep-06	7.71

Table 2 - Wind Speed Averages, 99 m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	10.02
1.5	9.87
2.5	9.79
3.5	9.78
4.5	9.76
5.5	9.76
6.5	9.56
7.5	9.31
8.5	9.27
9.5	9.21
10.5	9.25
11.5	9.29
12.5	9.35
13.5	9.38
14.5	9.51
15.5	9.62
16.5	9.78
17.5	9.98
18.5	10.04
19.5	10.07
20.5	10.02
21.5	10.06
22.5	10.12
23.5	10.04

Table 3 - Diurnal Average Wind Speeds, 99 m, September 1, 2005 - August 31, 2006.

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	3.43	8.13
NNE	4.47	8.8
NE	6.24	9.49
ENE	4.41	8.58
E	3.55	7.95
ESE	2.64	8.37
SE	3.32	9.23
SSE	3.86	10.79
S	4.57	9.72
SSW	8.81	10.96
SW	13.55	10.84
WSW	9.82	10.13
W	8.91	9.93
WNW	8.84	9.65
NW	8.69	9.36
NNW	4.91	8.39

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, 99 m, September 1, 2005 - August 31, 2006.