

WIND DATA REPORT

Nantucket, MA

September 1st 2005 to November 30th 2005.

Prepared for

Massachusetts Technology Collaborative
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NOTICE AND ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

NOTICE AND ACKNOWLEDGEMENTS	1
Table of Contents	2
Table of Figures	2
Executive Summary	3
SECTION 1 - Station Location.....	4
SECTION 2 - Instrumentation and Equipment.....	4
SECTION 3 - Data Collection and Maintenance.....	5
SECTION 4 - Significant Meteorological Events	6
SECTION 5 - Data Recovery and Validation.....	6
Test Definitions.....	6
Sensor Statistics	7
SECTION 6 - Data Summary	8
SECTION 7 - Graphs.....	10
Wind Speed Time Series.....	10
Wind Speed Distributions	10
Monthly Average Wind Speeds	11
Diurnal Average Wind Speeds.....	11
Turbulence Intensities.....	12
Wind Rose.....	13
APPENDIX A – Sensor Performance Report.....	14
Test Definitions.....	14
Sensor Statistics	15
APPENDIX B - Plot Data.....	16
Wind Speed Distribution Data	16
Monthly Average Wind Speed Data	16
Diurnal Average Wind Speed Data.....	17
Wind Rose Data	18

TABLE OF FIGURES

Figure 1 - Nantucket Site Location.....	4
Figure 2 - Wind Speed Time Series, September 1, 2005 - November 30, 2005.....	10
Figure 3 - Wind Speed Distribution, September 1, 2005 - November 30, 2005.	10
Figure 4 - Monthly average wind speeds, August 1, 2005 – November 30, 2005.	11
Figure 5 - Diurnal Wind Speed, September 1, 2005 - November 30, 2005.....	11
Figure 6 - Turbulence Intensity vs. Wind Speed, September 1, 2005 - November 30, 2005.....	12
Figure 7 - Wind Rose, September 1, 2005 - November 30, 2005.....	13

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.

This report covers wind data measured at a radio tower in Nantucket, MA, which was 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).

The season covered by this report is September 1, 2005 – November 30, 2005. The quarterly mean recorded wind speed was 9.6 m/s (18.2 mph) and the prevailing direction was from the southwest. 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 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:

No data were missing (i.e. the logger reported values for every 10-minute timestamp). No maintenance work was done in this quarter.

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
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, []
05-Sep	7.7	20.5	SSW	0.09	7.0	18.5	SSW	0.11	6.7	17.5	SSW
05-Oct	10.2	26.4	E	0.10	9.4	23.8	ENE	0.12	9.0	23.0	ENE
05-Nov	10.8	24.6	SW	0.08	9.7	21.9	SSW	0.10	9.1	20.6	SW
Sep-Nov 05	9.6	26.4	SW	0.09	8.7	23.8	SSW	0.11	8.3	23.0	SSW

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 $\pm 2\%$ or ± 0.2 m/s.

SECTION 4 - Significant Meteorological Events

There were no extreme meteorological events in the two months covered by this report. The highest wind speeds in the 3 months are less than 27 m/s as shown by the time series graph.

Source: <http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms>

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 [%]	100.0
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.

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

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).

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

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.

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

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. The following graphs are included:

- Time Series – 10-minute average wind speeds at a height of 99 m are plotted against time. 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 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 - November 2005. 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 hourly average varied between 8.95 and 10.2 m/s (20.0 and 22.8 mph), with the highest average speeds at night. 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 0.1. In the graph (below), the turbulence intensity flattens out between 4 and 5 m/s (8.9 and 11.2 mph). 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. Wind blew from this direction 9.6% of the time with a mean wind speed of 10.7 m/s (23.9 mph). The wind rose plot is shown in Figure 6.

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

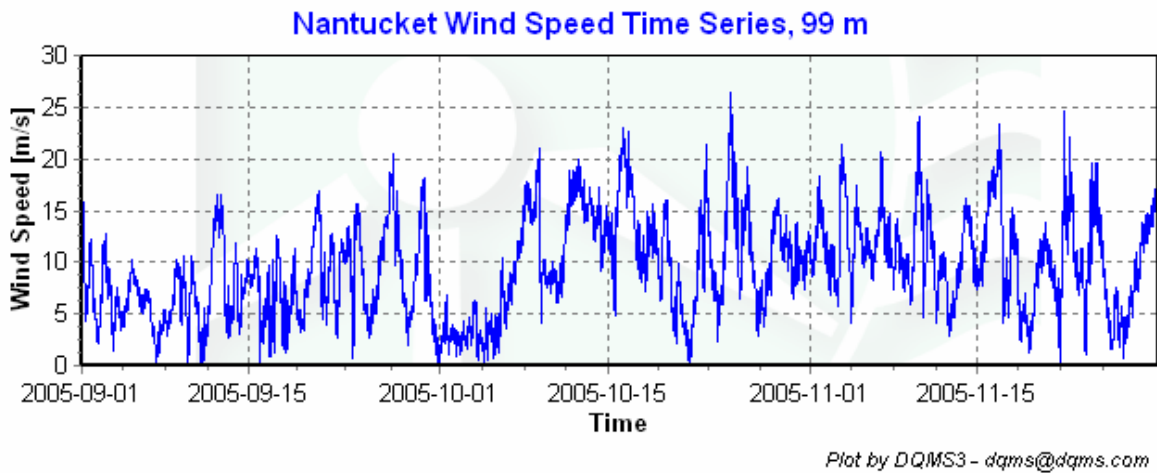


Figure 2 - Wind Speed Time Series, September 1, 2005 - November 30, 2005.

Wind Speed Distributions

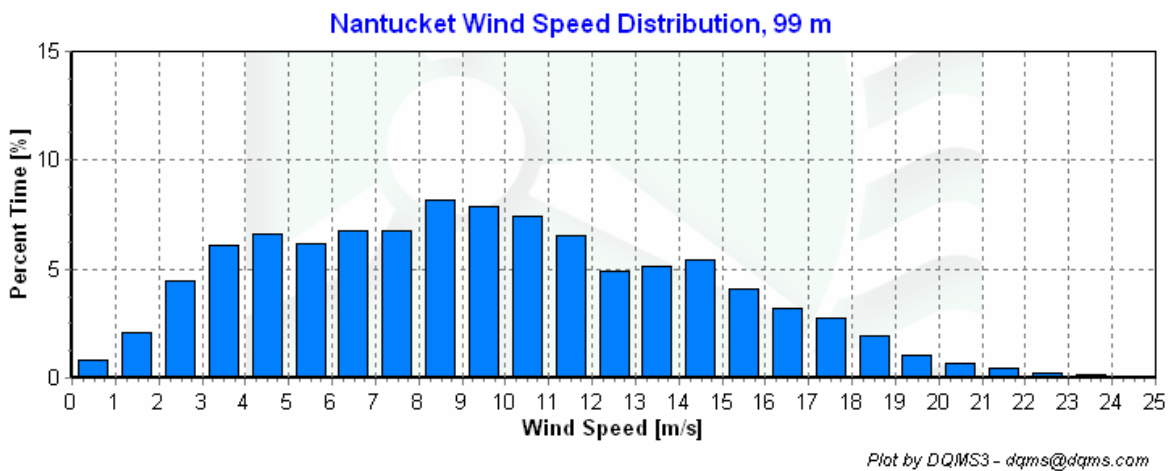


Figure 3 - Wind Speed Distribution, September 1, 2005 - November 30, 2005.

Monthly Average Wind Speeds

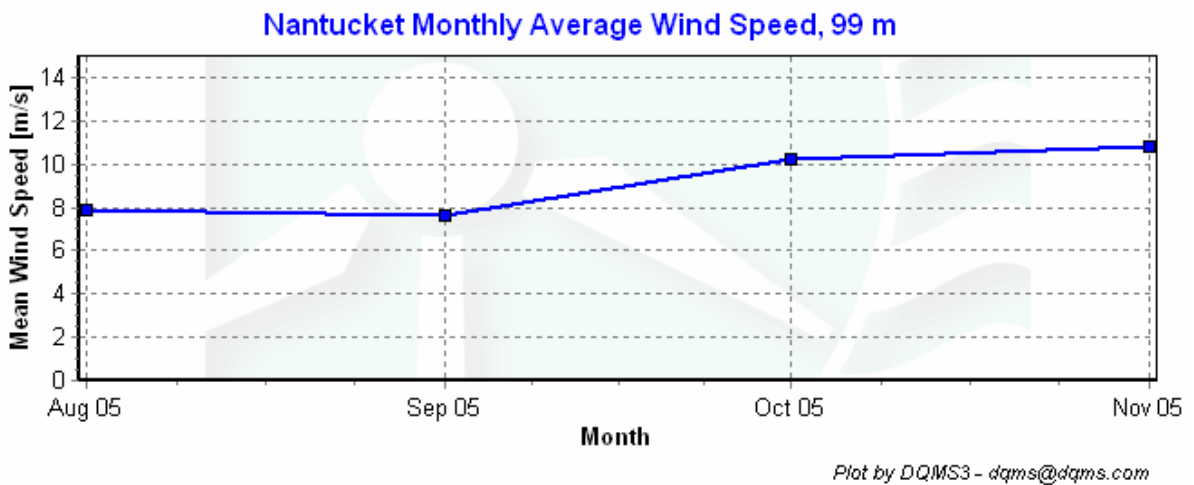


Figure 4 - Monthly average wind speeds, August 1, 2005 – November 30, 2005.

Diurnal Average Wind Speeds

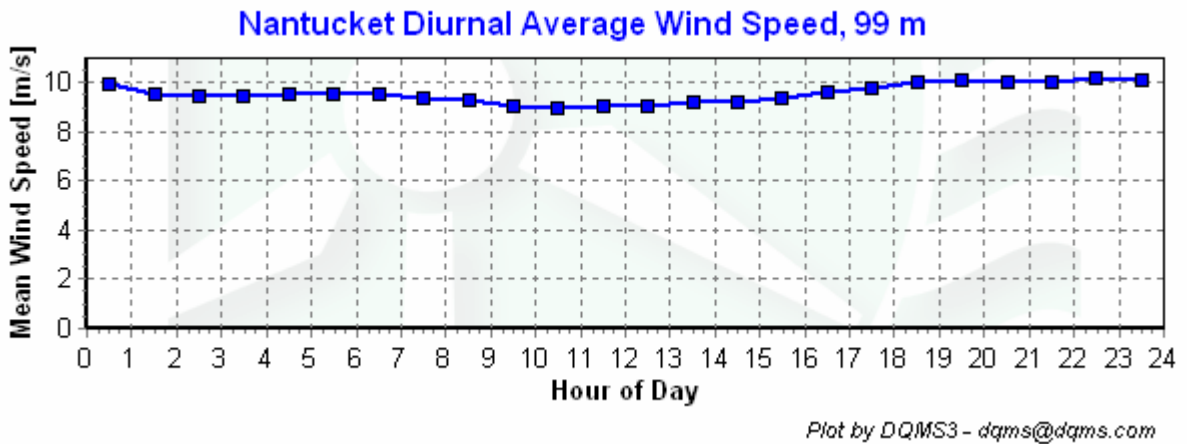


Figure 5 - Diurnal Wind Speed, September 1, 2005 - November 30, 2005.

Turbulence Intensities

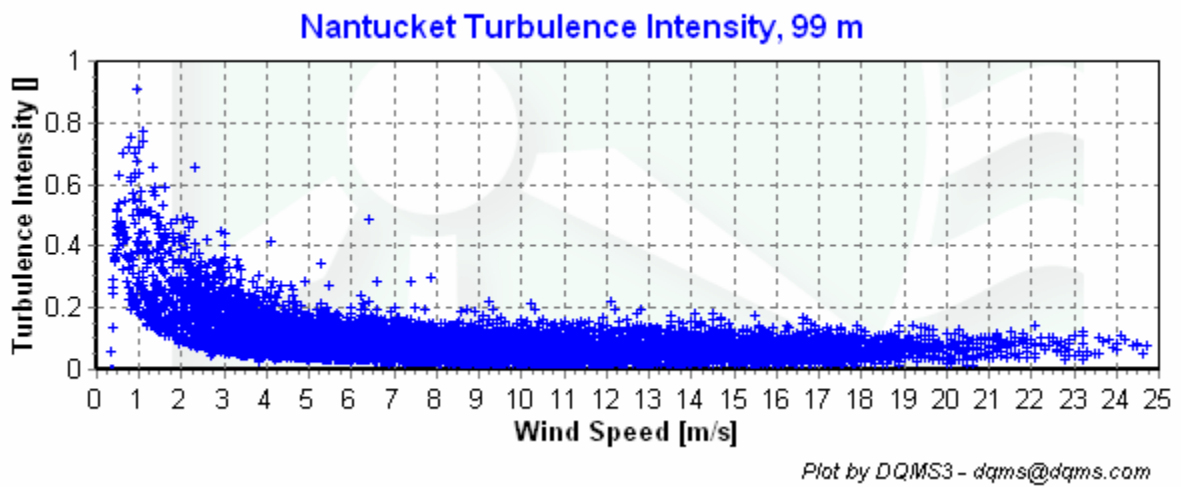
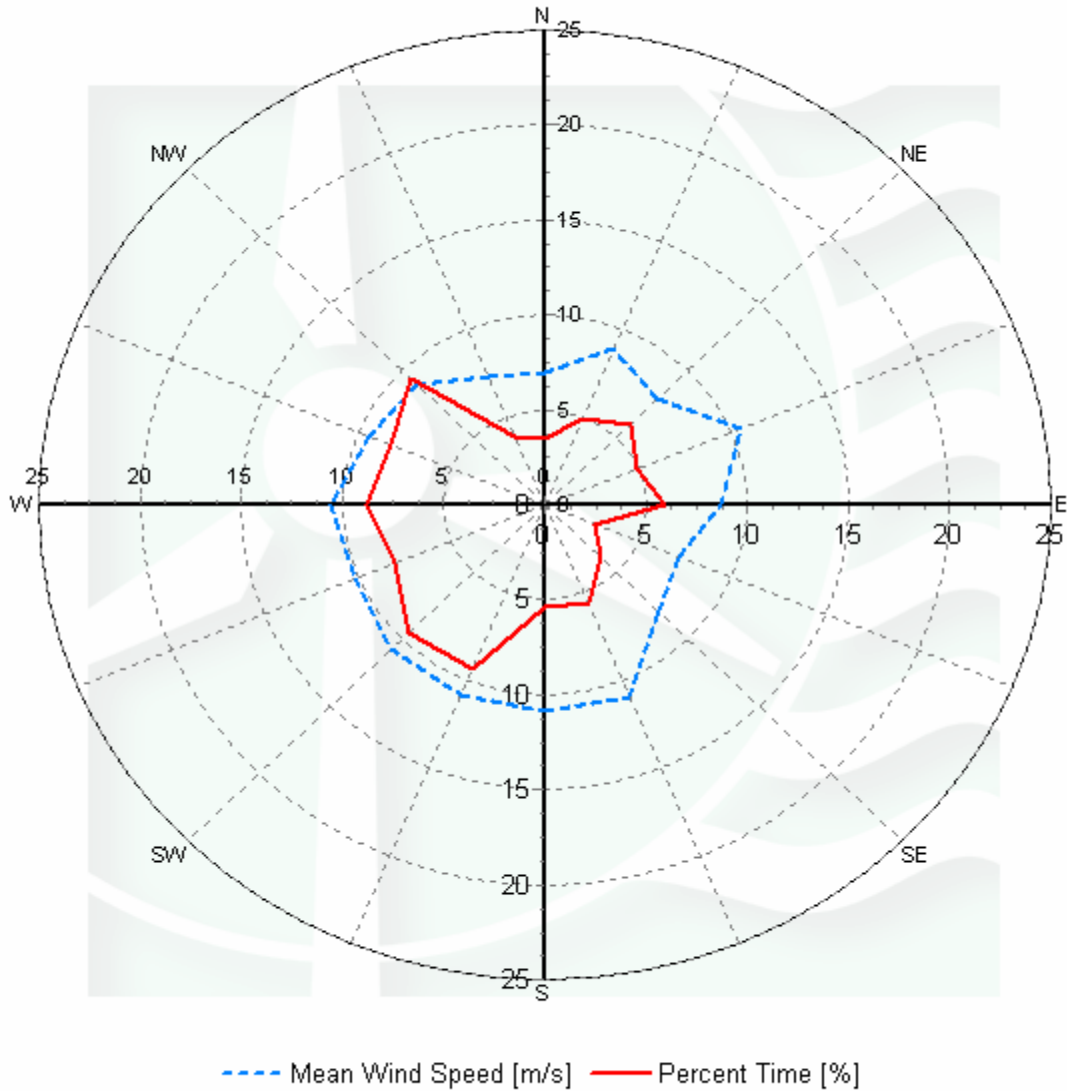


Figure 6 - Turbulence Intensity vs. Wind Speed, September 1, 2005 - November 30, 2005.

Wind Rose

Nantucket Wind Rose, 99 m



Plot by DQMS3 - dqms@dqms.com

Figure 7 - Wind Rose, September 1, 2005 - November 30, 2005.

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	13104	13104	100	0	5.667	99.741
AnemSD99ams	13104	13104	100	0	5.667	99.741
Anem99bms	13104	13104	100	0	0.333	99.985
AnemSD99bms	13104	13104	100	0	0.333	99.985
Anem68ams	13104	13104	100	0	36.333	98.336
AnemSD68ams	13104	13104	100	0	36.333	98.336
Anem68bms	13104	13104	100	0	3	99.863
AnemSD68bms	13104	13104	100	0	3	99.863
Anem58ams	13104	13104	100	0	1	99.954
AnemSD58ams	13104	13104	100	0	1	99.954
Anem58bms	13104	13104	100	0	0	100
AnemSD58bms	13104	13104	100	0	0	100
Vane99aDEG	13104	13104	100	0.167	0	99.992
VaneSD99aDEG	13104	13104	100	0.167	0	99.992
Vane68aDEG	13104	13104	100	0	0	100
VaneSD68aDEG	13104	13104	100	0	0	100
Vane58aDEG	13104	13104	100	0.167	0	99.992
VaneSD58aDEG	13104	13104	100	0.167	0	99.992
Total	235872	235872	100	0.667	92.667	99.763

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.84
1.5	2.05
2.5	4.44
3.5	6.11
4.5	6.59
5.5	6.14
6.5	6.72
7.5	6.79
8.5	8.18
9.5	7.9
10.5	7.42
11.5	6.57
12.5	4.94
13.5	5.15
14.5	5.44
15.5	4.07
16.5	3.2
17.5	2.76
18.5	1.95
19.5	1.08
20.5	0.7
21.5	0.46
22.5	0.24
23.5	0.14
24.5	0.09

Table 1 - Wind Speed Distribution, September 1, 2005 - November 30, 2005.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Aug-05	7.9
Sep-05	7.7
Oct-05	10.2
Nov-05	10.8

Table 2 - Wind Speed Averages, 50m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	9.91
1.5	9.56
2.5	9.45
3.5	9.42
4.5	9.54
5.5	9.56
6.5	9.56
7.5	9.4
8.5	9.32
9.5	9.08
10.5	8.95
11.5	9.04
12.5	9.06
13.5	9.19
14.5	9.24
15.5	9.34
16.5	9.62
17.5	9.81
18.5	10.03
19.5	10.12
20.5	10.01
21.5	10.04
22.5	10.18
23.5	10.11

Table 3 - Diurnal Average Wind Speeds, September 1, 2005 - November 30, 2005.

Wind Rose Data

Direction	Percent Time [%], 50 m	Mean Wind Speed [m/s], 50 m
N	3.53	6.97
NNE	4.92	8.89
NE	5.95	7.88
ENE	4.87	10.5
E	5.93	8.74
ESE	2.71	7.12
SE	3.85	7.97
SSE	5.56	10.93
S	5.41	10.91
SSW	9.33	10.9
SW	9.55	10.7
WSW	8.07	10.18
W	8.78	10.58
WNW	8.23	9.36
NW	9.37	8.91
NNW	3.94	7.35

**Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction,
September 1, 2005 - November 30, 2005.**