WIND DATA REPORT

Narragansett School District
Templeton, Massachusetts

June 1, 2006 - August 31, 2006

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

William L.W. Henson
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

October 16, 2006

Report template version 2.0

Renewable **E**nergy **R**esearch **L**aboratory
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.ceere.org/rerl • (413) 545-4359 • rerl@ecs.umass.edu

NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Renewable Energy Research Laboratory (RERL) 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), pursuant to work order number 05-1. 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.

TABLE OF CONTENTS

Notice and Acknowledgements 1
Table of Contents 2
Table of Figures 3
Executive Summary 4
SECTION 1 - Station Location 5
SECTION 2 - Instrumentation and Equipment 6
SECTION 3 - Data Collection and Maintenance 7
SECTION 4 - Significant Meteorological Events 8
SECTION 5 - Data Recovery and Validation 8
  Test Definitions 9
  Sensor Statistics 10
SECTION 6 - Data Summary 10
SECTION 7 - Graphs 12
  Wind Speed Time Series 12
  Wind Speed Distributions 13
  Monthly Average Wind Speeds 13
  Diurnal Average Wind Speeds 14
  Turbulence Intensities 14
  Wind Roses 15
APPENDIX A - Sensor Performance Report 16
  Test Definitions 16
  Sensor Statistics 17
APPENDIX B - Plot Data 18
  Wind Speed Distribution Data 18
  Monthly Average Wind Speed Data 18
  Diurnal Average Wind Speed Data 19
  Wind Rose Data 20

TABLE OF FIGURES

Figure 1 – Topographic Map Showing Narragansett Site Location--Source Topozone.com..... 5
Figure 2 – Preparation to Raise Met-tower at Narragansett Site 6
Figure 3 – Wind Speed Time Series, June 1, 2006 through August 31, 2006..... 12
Figure 4 – Wind Speed Distribution, June 1, 2006 through August 31, 2006..... 13
Figure 5 – Monthly Average Wind Speed, February 2006 through August 2006..... 13
Figure 6 – Diurnal Average Wind Speed, June 1, 2006 through August 31, 2006 14
Figure 7 – Turbulence Intensity, June 1, 2006 through August 31, 2006..... 14
Figure 8 – Wind Rose, June 1, 2006 through August 31, 2006..... 15

EXECUTIVE SUMMARY

All the work presented in this Wind Data Report including installation and commissioning 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 meteorological tower installed at Narragansett Regional High School in the town of Templeton, MA. Installed on January 19th, 2006, the wind monitoring station has been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 50 m (164.1 ft) and 38 m (124.7 ft), and an additional anemometer and vane are mounted at 20 m (65.6 ft). Reports are made on a quarterly basis; and this report is the third such report for Narragansett.

The season covered by this report is June 2006 – August 2006 (summer quarter). Due to a high percentage of missing data (25.03%), results for this quarter cannot be determined. The cause of the missing data is unknown. A further explanation regarding the missing data is given in the main body of this report.

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

SECTION 1 - Station Location

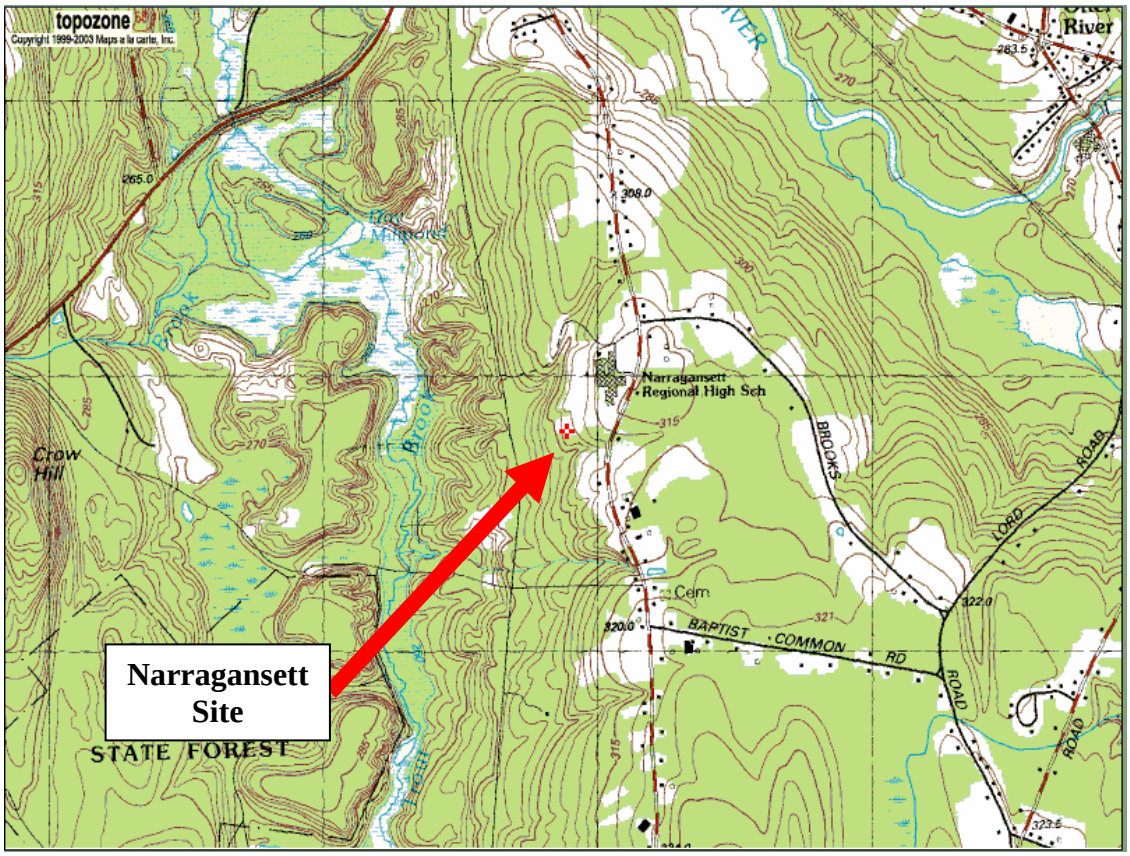

Figure 1 – Topographic Map Showing Narragansett Site Location--Source Topozone.com

The Narragansett site is located near the Narragansett Regional High School in Templeton, MA. Latitude and Longitude are 42° 35.17'N and 72° 4.60'W, respectively, using the NAD 27 datum. Figure 1 marks the site location on a topographic map.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) SecondWind tower. All other monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- Electrical enclosure box
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50 m (164.1 ft), two at 38 m (124.7 ft) and one at a height of 20 m (65.6 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 50 m (164.1), 38 m (124.7 ft) and 20 m (65.6 ft) each.
- 5 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 – Preparation to Raise Met-tower at Narragansett Site

The data from the Symphonie logger are mailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These data 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 quality assurance (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:

- Data for the last 4 days of the past quarter and the first 24 days of this quarter are missing—the exact cause is unknown. Data is collected on site-dedicated data cards. Typically on a monthly or bi-monthly basis, cards are swapped by volunteers and sent to the RERL for processing. When a card is received at the RERL, data are extracted and the card is cleared for turn-around. Records indicate that although all data-cards have been accounted for, the missing data was never received.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Wind Shear Coefficient
Height units	**50 m, [m/s]**	**50 m, [m/s]**	**50 m, [ ]**	**50 m, [ ]**	**39 m, [m/s]**	**39 m, [m/s]**	**39 m, [ ]**	**39 m, [ ]**	**20 m, [m/s]**	**20 m, [m/s]**	**20 m, [ ]**	**20 m, [ ]**	**50m--39m [ ]**
June 2006	--	--	--	--	--	--	--	--	--	--	--	--	--
July 2006	3.89	10.5	0.22	SSW	3.32	9.3	0.26	SSW	1.99	6.7	0.39	SSW	0.69
Aug 2006	3.6	10.2	0.23	NNW	3.04	9.1	0.27	SSW	1.68	5.7	0.41	SSW	0.77
June'06 – Aug'06	--	--	--	--	--	--	--	--	--	--	--	--	--

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—in this case from the anemometry located at 50 m and 38 m. 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 August 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

In June 2006, July 2006 and August 2006 there were no major meteorological events that would have caused notable fluctuations in wind speed measurements.

Source: http://www.erh.noaa.gov/box/MonthlyClimate2.shtml

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 [%]	75.002%
Net Data Recovered [%]	74.970%

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. Care should be exercised in interpreting all quarterly summary graphs (i.e. quarterly wind speed distribution, quarterly diurnal distribution, and quarterly wind rose) for the summer quarter, due to the quantity of missing data. The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time for all data starting on June 1st, 2006 through August 31st, 2006 in Figure 3. This plot presents data at 50 meters. Immediately obvious is the missing data in the month of June.

- Wind Speed Distribution – 75% of quarterly data available. This plot presents data at 50 meters. Figure 4 shows that wind speeds ranged from 3 m/s to 4 m/s (6.71 mph to 8.95 mph) approximately 21 percent of the time over the quarter.

- Monthly Average Wind Speeds – This plot shows the trends in the mean monthly wind speed at a height of 50 m. This graph shows the trends in the wind speed over the year. The monthly average wind speed plot is shown in Figure 5. Averages cannot be calculated for either May or June due to the missing data.

- Diurnal – 75% of quarterly data available. This plot presents data at 50 meters. Figure 6 shows that the average wind speeds ranged from approximately 3 m/s (6.71 mph) during the morning hours to 4.75 m/s (10.63 mph) during the afternoon hours during the quarter.

- Turbulence Intensity – 75% of quarterly data available. 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. In general, turbulence intensities range from 0.1 to 0.4; for Narragansett, the average turbulence intensity was 0.23. In Figure 7, the turbulence intensity flattens out between 7 and 8 m/s (15.7 and 17.9 mph). This plot presents data at 50 meters and is drawn from the entire quarterly dataset.

- Wind Rose – 75% of quarterly data available. This plot presents data at 50 meters. Figure 8 shows that the wind blew from the SSW approximately 15 percent of the time and averaged about 4.75 m/s (10.63 mph) from this direction during the quarter.

SECTION 7- Graphs

Data for the wind speed histograms, monthly and diurnal average plots, and wind roses are included in APPENDIX B. Care should be exercised in interpreting all quarterly summary data (i.e. quarterly wind speed distribution, quarterly diurnal distribution, and quarterly wind rose) for the summer quarter, due to the quantity of missing data.

Wind Speed Time Series

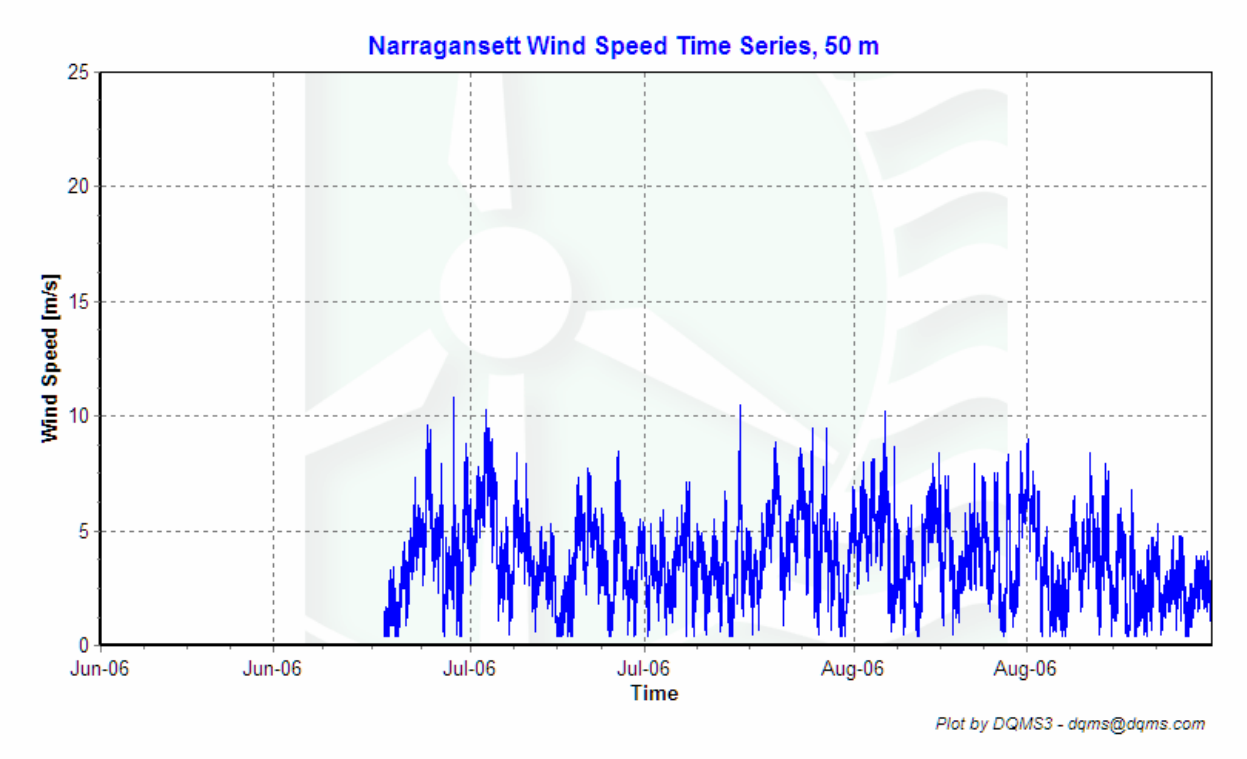

Figure 3 – Wind Speed Time Series, June 1, 2006 through August 31, 2006

Wind Speed Distributions

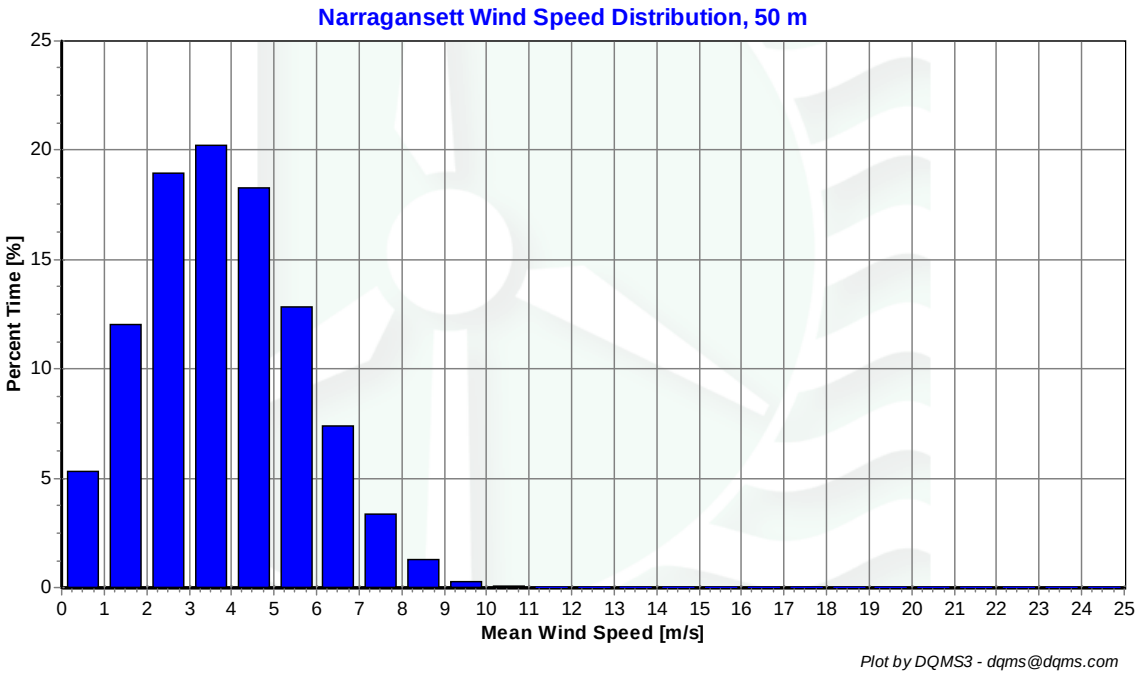

Figure 4 – Wind Speed Distribution, June 1, 2006 through August 31, 2006

Monthly Average Wind Speeds

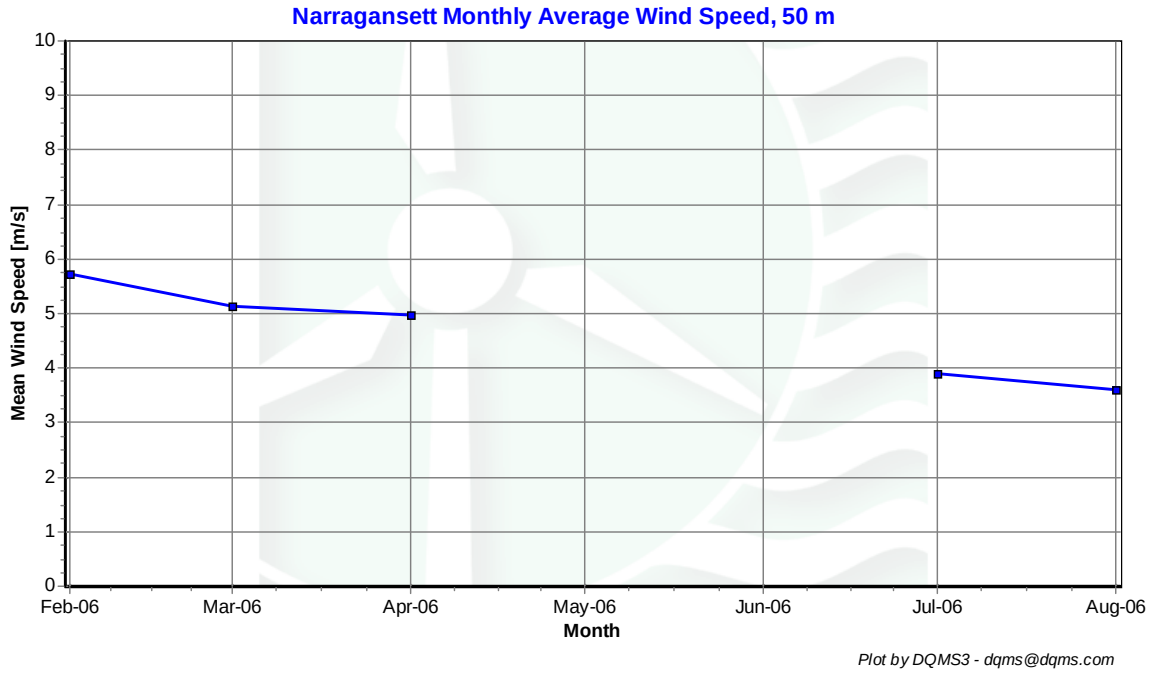

Figure 5 – Monthly Average Wind Speed, February 2006 through August 2006

Diurnal Average Wind Speeds

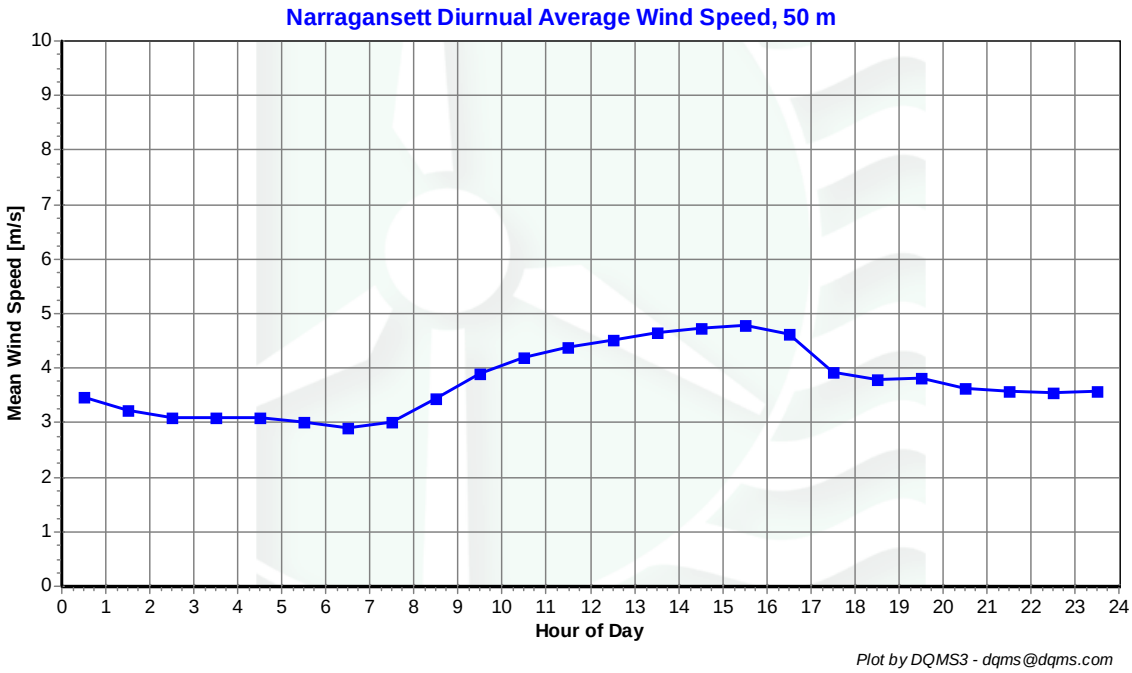

Figure 6 – Diurnal Average Wind Speed, June 1, 2006 through August 31, 2006

Turbulence Intensities

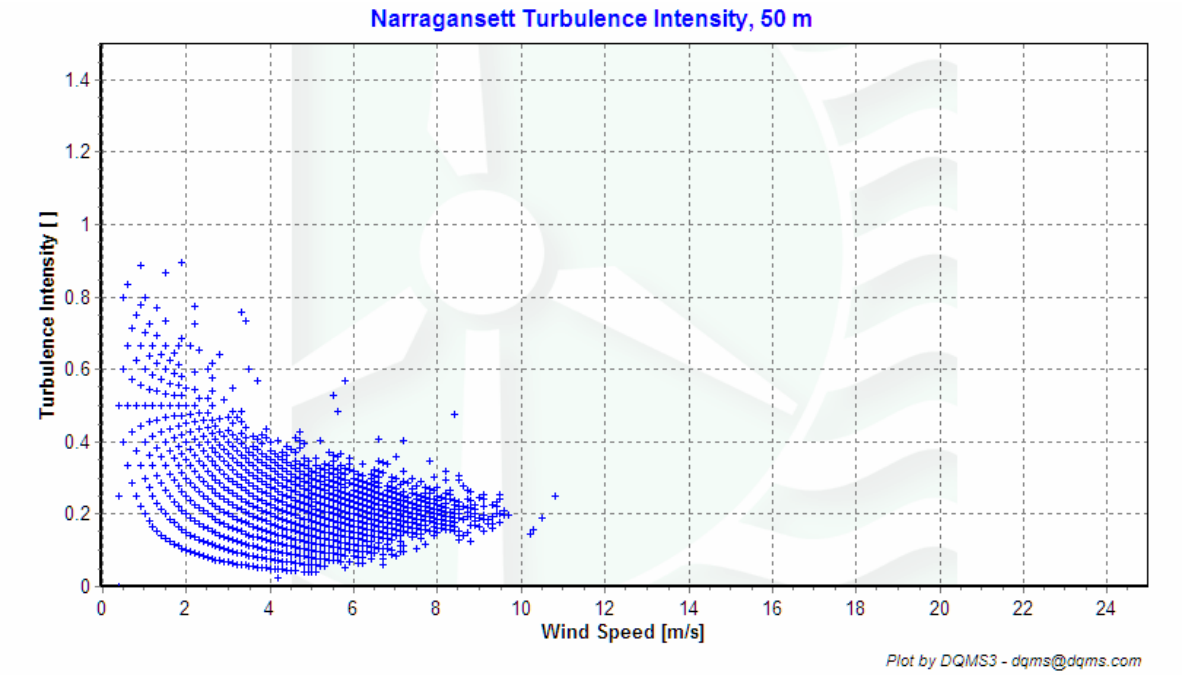

Figure 7 – Turbulence Intensity, June 1, 2006 through August 31, 2006

Wind Roses

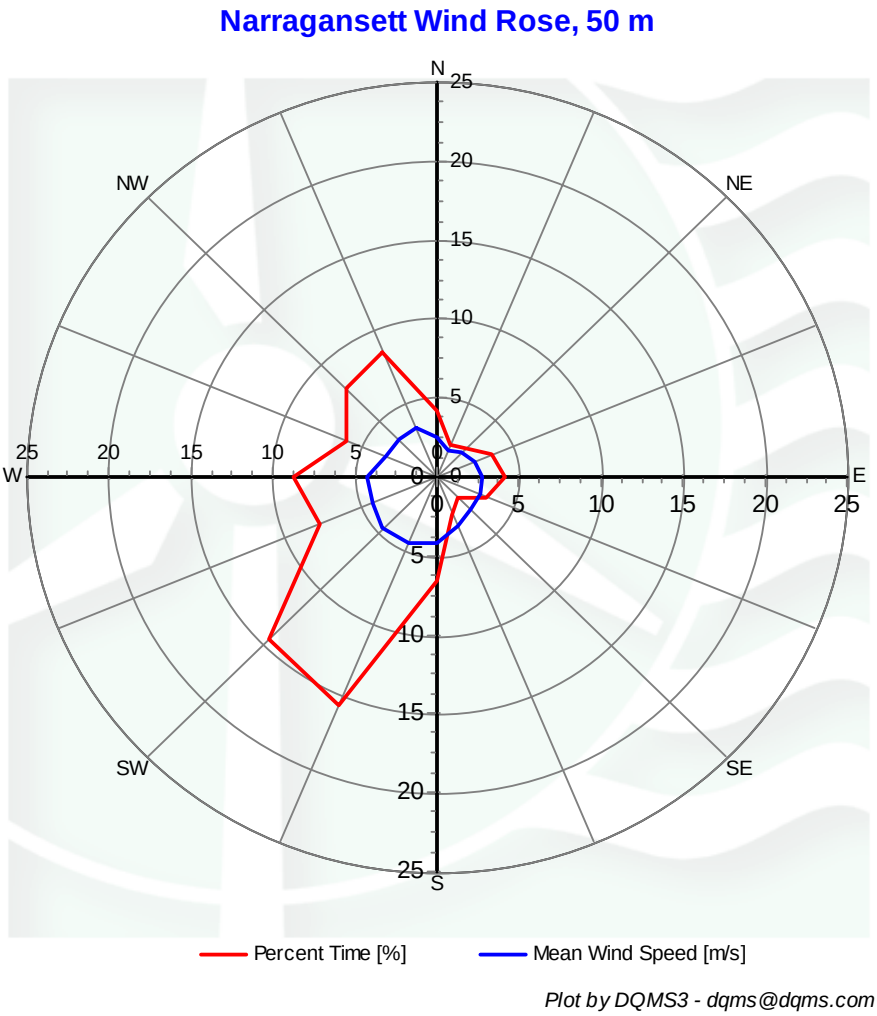

Figure 8 – Wind Rose, June 1, 2006 through August 31, 2006

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert	0	0	0	0
2	Etmp2aDEGC						MinMax	-30	60	0	0
3	Etmx2aDEGC						MinMax	-30	60	0	0
4	Etmn2aDEGC						MinMax	-30	60	0	0
5	EtmpSD2aDEGC						MinMax	-30	60	0	0
10	Anem50aMS						MinMax	0	90	0	0
11	Anem50bMS						MinMax	0	90	0	0
12	Anem38aMS						MinMax	0	90	0	0
13	Anem38bMS						MinMax	0	90	0	0
14	Anem20aMS						MinMax	0	90	0	0
20	AnemSD50aMS						MinMax	0	4	0	0
21	AnemSD50bMS						MinMax	0	4	0	0
22	AnemSD38aMS						MinMax	0	4	0	0
23	AnemSD38bMS						MinMax	0	4	0	0
24	AnemSD20aMS						MinMax	0	4	0	0
30	Vane50aDEG						MinMax	0	359.9	0	0
31	Vane38aDEG						MinMax	0	359.9	0	0
32	Vane20aDEG						MinMax	0	359.9	0	0
50	Turb50zNONE						MinMax	0	2	0	0
51	Turb38zNONE						MinMax	0	2	0	0
52	Turb20ZNONE						MinMax	0	2	0	0
60	Wshr0zNONE						MinMax	-100	100	0	0
200	VaneSD50aDEG	Anem50yMS					MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS					MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS					MinMax	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
400	Anem50aMS	Anem50bMS					CompareSensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS					CompareSensors	1	0.25	3	0
500	Amax50aMS						MinMax	0	90	0	0
501	Amax50bMS						MinMax	0	90	0	0
502	Amax38aMS						MinMax	0	90	0	0
503	Amax38bMS						MinMax	0	90	0	0
504	Amax20aMS						MinMax	0	90	0	0
510	Amin50aMS						MinMax	0	90	0	0
511	Amin50bMS						MinMax	0	90	0	0

512	Amin38aMS						MinMax	0	90	0	0
513	Amin38bMS						MinMax	0	90	0	0
514	Amin20aMS						MinMax	0	90	0	0
520	Vmax50aDEG						MinMax	0	359.9	0	0
521	Vmax38aDEG						MinMax	0	359.9	0	0
522	Vmax20aDEG						MinMax	0	359.9	0	0
530	Vmin50aDEG						MinMax	0	359.9	0	0
531	Vmin38aDEG						MinMax	0	359.9	0	0
532	Vmin20aDEG						MinMax	0	359.9	0	0

Sensor Statistics

Sensors	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50ams	13249	9937	75.002	0	0	0	75.002
AnemSD50ams	13249	9937	75.002	0	0	0	75.002
Anem50bms	13249	9937	75.002	0	0	0.5	74.979
AnemSD50bms	13249	9937	75.002	0	0	0.5	74.979
Anem38aMS	13249	9937	75.002	0	0	0.5	74.979
AnemSD38aMS	13249	9937	75.002	0	0	0.5	74.979
Anem38bMS	13249	9937	75.002	0	0	2.333	74.896
AnemSD38bMS	13249	9937	75.002	0	0	2.333	74.896
Anem20aMS	13249	9937	75.002	0	0	0	75.002
AnemSD20aMS	13249	9937	75.002	0	0	0	75.002
Vane50aDEG	13249	9937	75.002	0.5	0	0	74.979
VaneSD50aDEG	13249	9937	75.002	0.5	0	0	74.979
Vane38aDEG	13249	9937	75.002	0.333	0	0	74.987
VaneSD38aDEG	13249	9937	75.002	0.333	0	0	74.987
Vane20aDEG	13249	9937	75.002	1.833	0	0	74.919
VaneSD20aDEG	13249	9937	75.002	1.833	0	0	74.919
Etmp2aDEGC	13249	9937	75.002	0.5	0	0	74.979
EtmpSD2aDEGC	13249	9937	75.002	0	0	0	75.002
Total	**238482**	**178866**	**75.002**	**5.833**	**0**	**6.667**	**74.97**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	5.31
1.5	12.01
2.5	18.94
3.5	20.23
4.5	18.3
5.5	12.81
6.5	7.4
7.5	3.36
8.5	1.31
9.5	0.3
10.5	0.04
11.5	0
12.5	0
13.5	0
14.5	0
15.5	0
16.5	0
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Feb-06	5.71
March-06	5.12
April-06	4.96
May-06	--
June-06	--
July-06	3.89
Aug-06	3.6

Table 2 - Wind Speed Averages, 50m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	3.47
1.5	3.24
2.5	3.09
3.5	3.08
4.5	3.08
5.5	3.01
6.5	2.89
7.5	3.01
8.5	3.43
9.5	3.89
10.5	4.18
11.5	4.37
12.5	4.51
13.5	4.66
14.5	4.73
15.5	4.78
16.5	4.62
17.5	3.94
18.5	3.8
19.5	3.81
20.5	3.64
21.5	3.56
22.5	3.56
23.5	3.57

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%], 50 m	Mean Wind Speed [m/s], 50 m
N	4.14	2.52
NNE	2.16	1.87
NE	2.54	2.17
ENE	3.6	2.52
E	4.19	2.76
ESE	3.29	2.87
SE	1.8	2.89
SSE	2.55	3.42
S	6.53	4.13
SSW	15.68	4.49
SW	14.54	4.65
WSW	7.77	4.22
W	8.79	4.25
WNW	5.95	3.42
NW	7.88	3.3
NNW	8.59	3.4

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction