WIND DATA REPORT

Narragansett School District
Templeton, Massachusetts

December 1, 2005 - February 28, 2006

Prepared for

Massachusetts Technology Collaborative
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by

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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.

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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 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 first such report for Narragansett.

The season covered by this report is December 2005 – February 2006 (winter quarter). However, since the tower was not erected until January 19th, 2006, this report contains only one calendar month of data for the winter quarter time period (i.e. February). Statistics for the available dataset (Jan 19—Feb 28) are presented in this report, though care is advised when comparing with statistics from other sites that may possess an entire winter quarter's worth of data. The mean recorded wind speed for this quarter was 5.71 m/s (12.77 mph)[1] and the prevailing wind direction was from the West. 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 92.8%. Although approximately 7.2% of the data failed the quality assurance tests (primarily due to sensor icing), the results are still acceptable for the purpose of gaining an understanding of the wind resources in Templeton, Massachusetts.

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.

[1] 1m/s=2.237 mph

SECTION 1 - Station Location

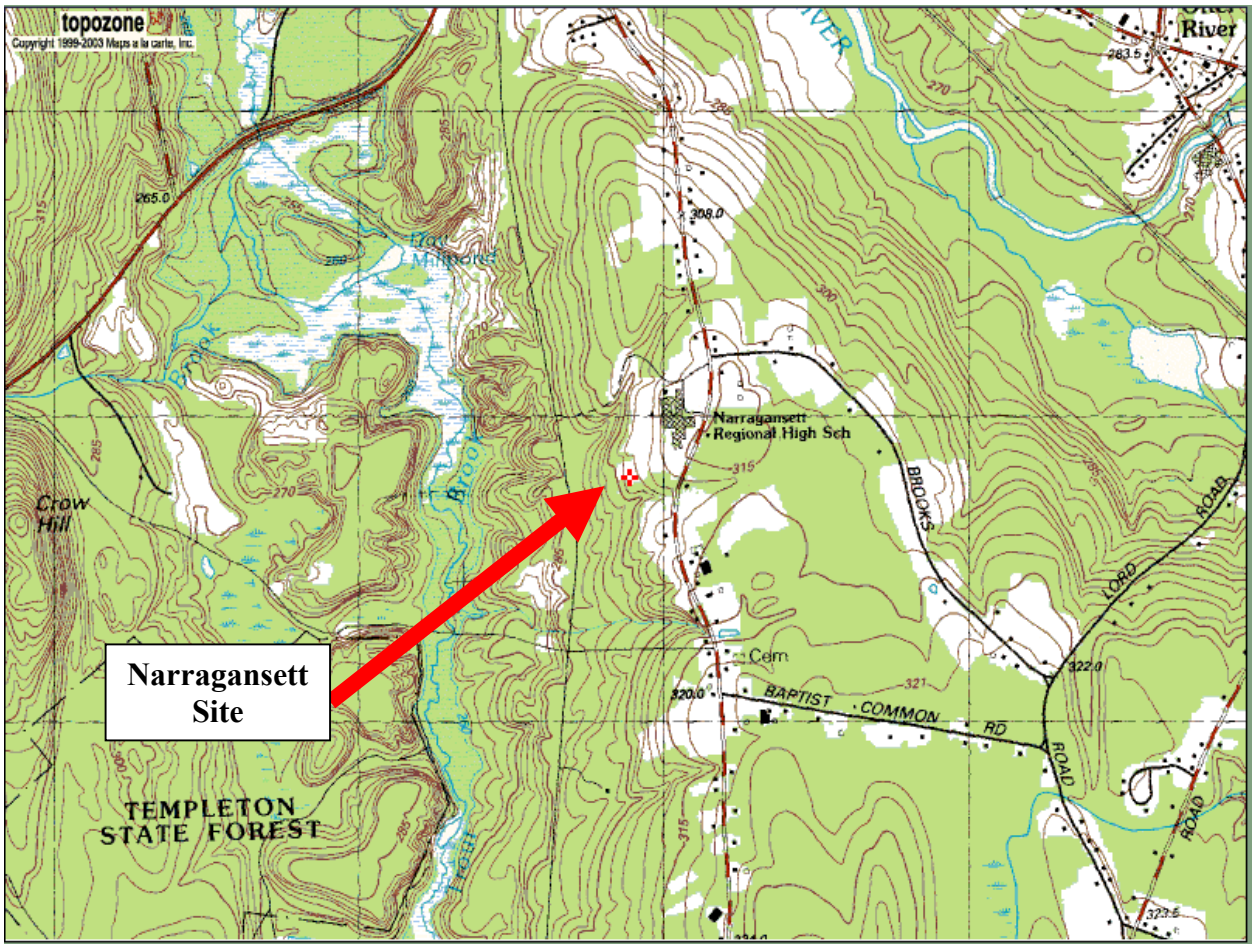

Figure 1 Topographic Map Showing Narragansett Site Location--Source Topozone.com

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.

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 is 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:

- Some icing events (esp. January 30th through February 2nd).
- No maintenance operations were needed or performed.

Given that the tower was installed on January 19th, 2006, only February has a full month of data to report for this quarter consisting of December, January, and February.

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]**	**39 m, [ ]**	**20 m, [ ]**	**50m--38m [ ]**
Dec 2005	--	--	--	--	--	--	--	--	--	--	--	--	---
Jan 2006	--	--	--	--	--	--	--	--	--	--	--	--	--
Feb 2006	5.71	16.5	0.22	W	4.99	14.7	0.25	W	3.09	10.2	0.37	W	0.51
Dec '05 – Feb '06	**5.31**	**16.5**	**0.22**	**WNW**	**4.63**	**14.7**	**0.26**	**WNW**	**2.79**	**10.2**	**0.4**	**W**	**0.56**

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 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

In December 2005, January 2006 and February 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 [%]	100%
Net Data Recovered [%]	92.861%

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 1 quarter (3 months). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time for all data starting on January 19th, 2006 through February 28th, 2006 in Figure 3. The data do not represent the entire winter quarter because the tower was not erected until January 19th, 2006. This plot presents data at 50 meters. Immediately obvious is sensor icing at the end of January.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. Figure 4 shows that the wind speeds ranged between 4 and 5 m/s (8.9 and 11.2 mph) approximately 16% of the time. This plot presents data at 50 meters and is drawn from the entire dataset.

- 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 and represents only data from February 2006. The monthly average wind speed data is limited because the tower was not erected until February January 19th, 2006.

- Diurnal – A plot of the average wind speed for each hour of the day. Figure 6 shows that the hourly average varied between 4 and 7 m/s (8.9 and 15.7 mph), with the highest average speeds in the afternoon. Again, the data does not represent the entire winter quarter because the tower was not erected until January 19th, 2006. This plot presents data at 50 meters and is drawn from the entire dataset.

- 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. In general, turbulence intensities range from 0.1 to 0.4; for Narragansett, the average turbulence intensity was 0.22. 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 dataset.

- 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. Figure 8 shows the prevailing direction from the west. The wind blew from the West 17.83% of the time with a mean wind speed of 6.1 m/s (13.6 mph). This plot presents data at 50 meters and is drawn from the entire dataset.

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

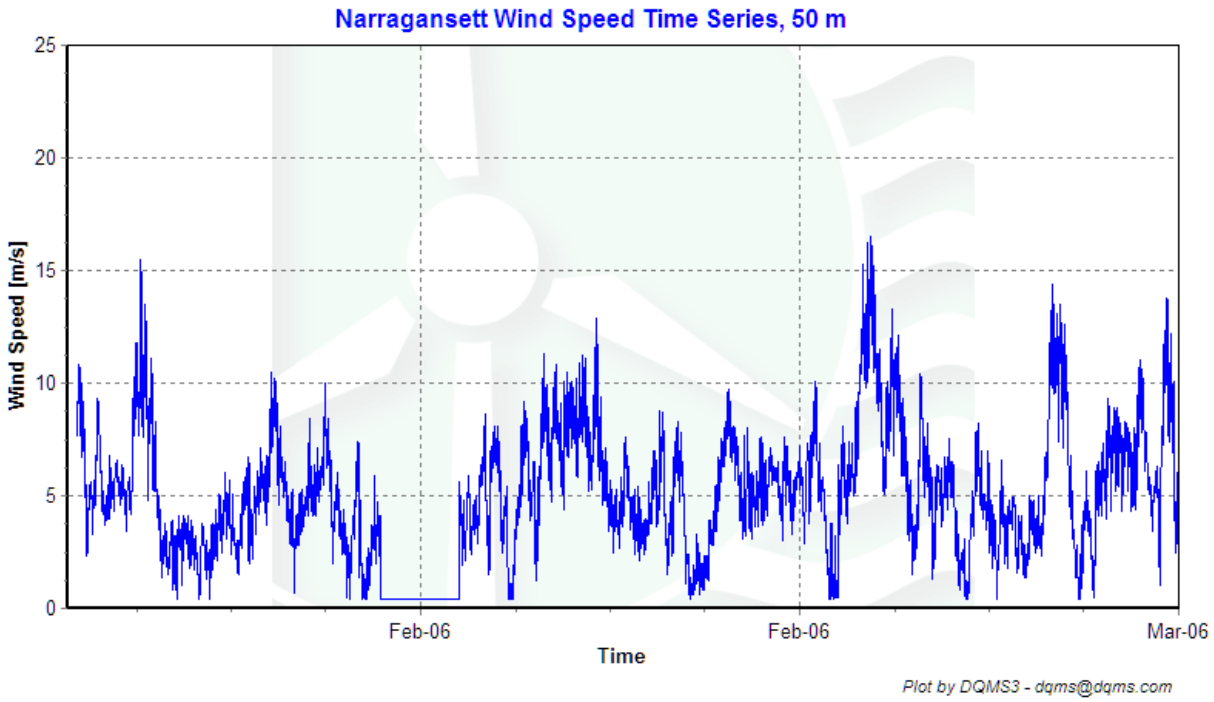

Figure 3 – Wind Speed Time Series, Jan 19, 2006 through Feb 28, 2006

Wind Speed Distributions

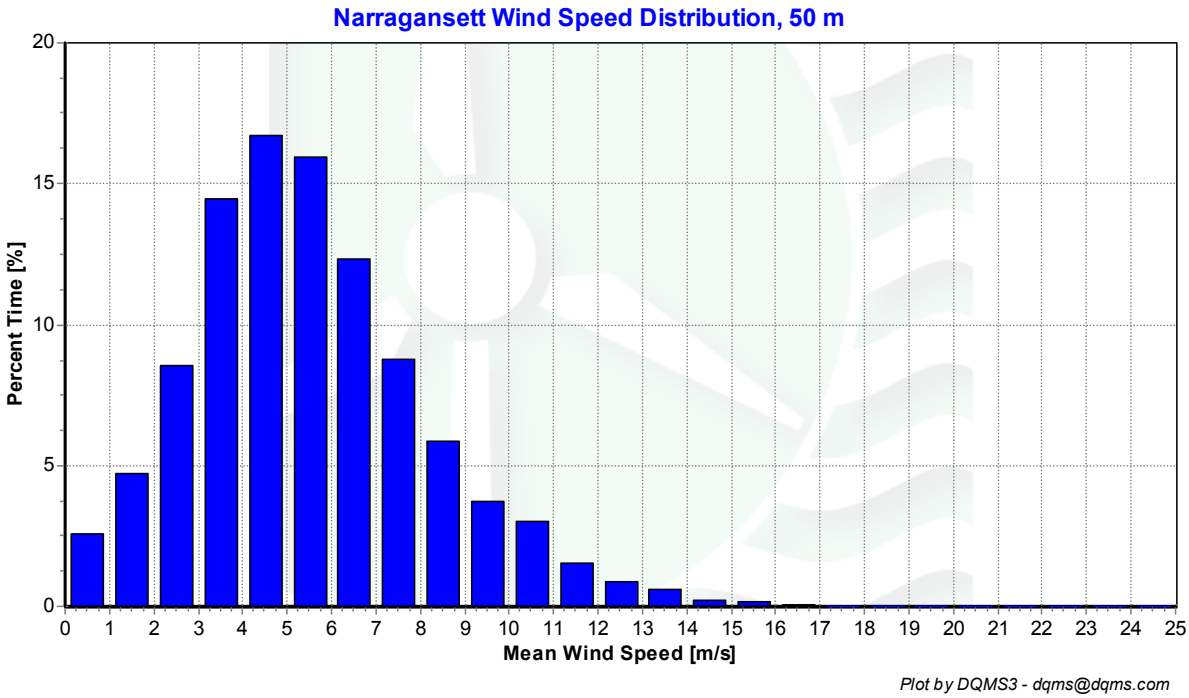

Figure 4 – Wind Speed Distribution, Jan 19, 2006 through Feb 28, 2006

Monthly Average Wind Speeds

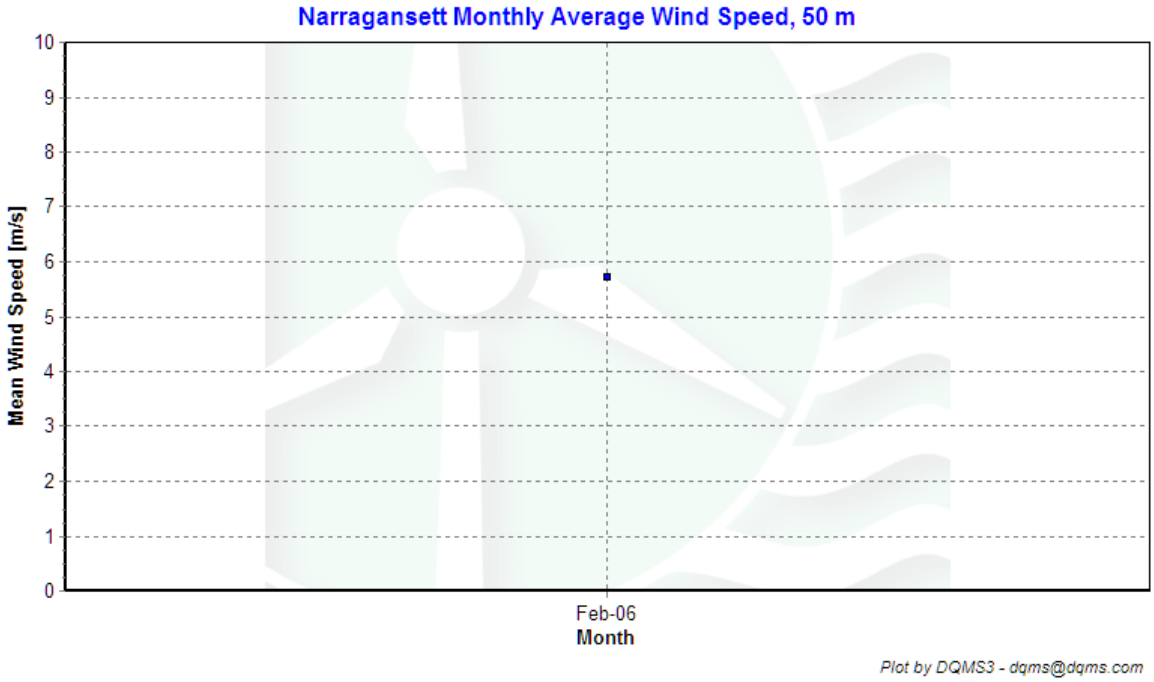

Figure 5 – Monthly Average Wind Speed, Feb 2006

Diurnal Average Wind Speeds

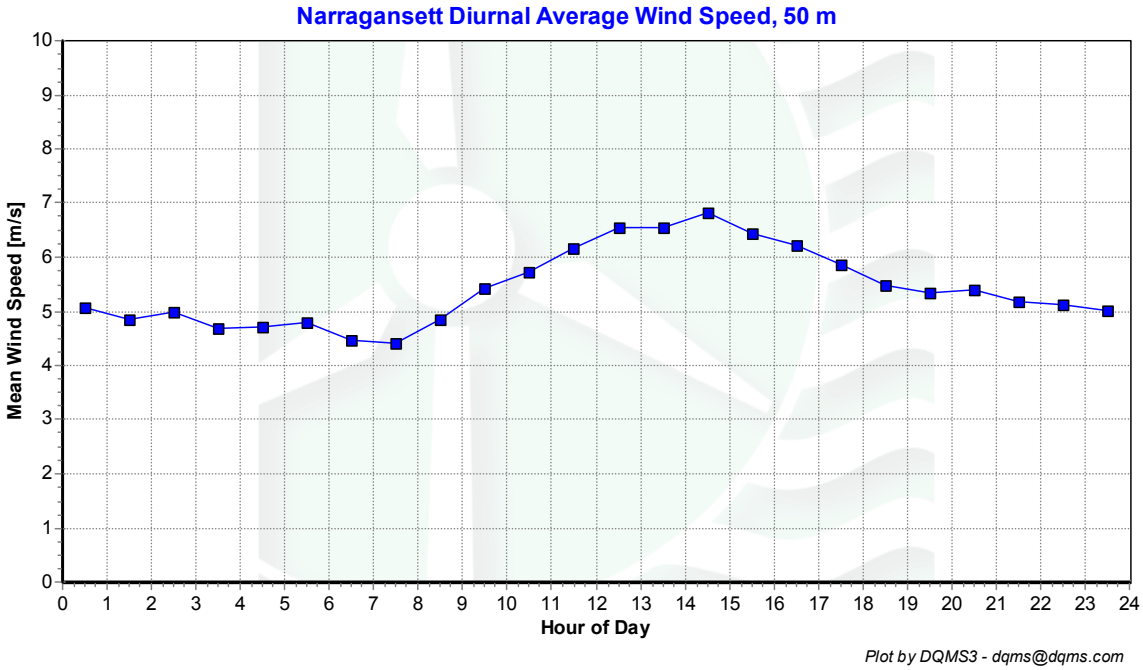

Figure 6 – Diurnal Average Wind Speed, Jan 19, 2006 through Feb 28, 2006

Turbulence Intensities

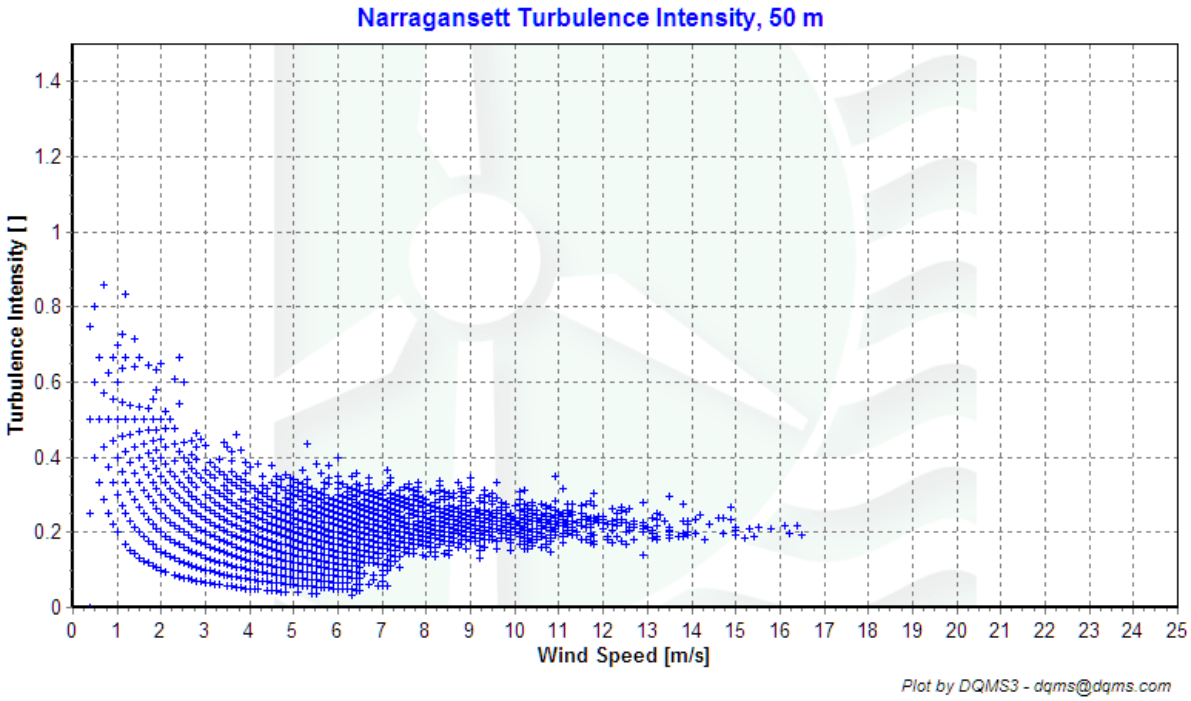

Figure 7 – Turbulence Intensity, Jan 19, 2006 through Feb 28, 2006

Wind Roses

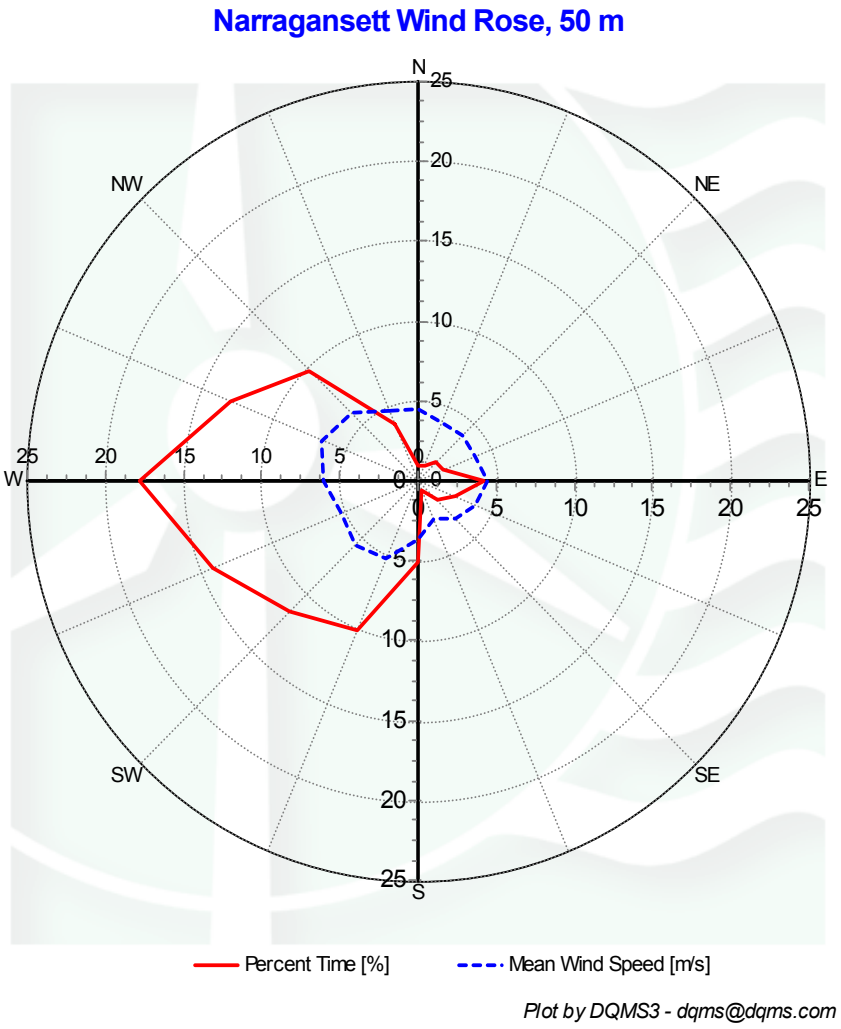

Figure 8 – Wind Rose, Jan 19, 2006 through Feb 28, 2006

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert	0	0	0
2	Etmp2aDEGC						MinMax	-30	60	0
3	Etmx2aDEGC						MinMax	-30	60	0
4	Etmn2aDEGC						MinMax	-30	60	0
5	EtmpSD2aDEGC						MinMax	-30	60	0
10	Anem50aMS						MinMax	0	90	0
11	Anem50bMS						MinMax	0	90	0
12	Anem38aMS						MinMax	0	90	0
13	Anem38bMS						MinMax	0	90	0
14	Anem20aMS						MinMax	0	90	0
15	Anem50yMS						MinMax	0	90	0
16	Anem38yMS						MinMax	0	90	0
20	AnemSD50aMS						MinMax	0	4	0
21	AnemSD50bMS						MinMax	0	4	0
22	AnemSD38aMS						MinMax	0	4	0
23	AnemSD38bMS						MinMax	0	4	0
24	AnemSD20aMS						MinMax	0	4	0
25	AnemSD50yMS						MinMax	0	4	0
26	AnemSD38yMS						MinMax	0	4	0
30	Vane50aDEG						MinMax	0	359.9	0
31	Vane38aDEG						MinMax	0	359.9	0
32	Vane20aDEG						MinMax	0	359.9	0
50	Turb50zNONE						MinMax	0	2	0
51	Turb38zNONE						MinMax	0	2	0
60	Wshr0zNONE						MinMax	-100	100	0
70	Pwrd50zWMS						MinMax	0	5000	0
71	Pwrd38zWMS						MinMax	0	5000	0
200	VaneSD50aDEG	Anem50yMS					MinMaxT	0	100	100
201	VaneSD38aDEG	Anem38yMS					MinMaxT	0	100	100
202	VaneSD20aDEG	Anem20aMS					MinMax	0	100	100
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC		Icing	0.5	1	2
400	Anem50aMS	Anem50bMS					CompareSensors	1	0.25	3
401	Anem38aMS	Anem38bMS					CompareSensors	1	0.25	3
500	Amax50aMS						MinMax	0	90	0
501	Amax50bMS						MinMax	0	90	0

502	Amax38aMS						MinMax	0	90	0
503	Amax38bMS						MinMax	0	90	0
504	Amax20aMS						MinMax	0	90	0
510	Amin50aMS						MinMax	0	90	0
511	Amin50bMS						MinMax	0	90	0
512	Amin38aMS						MinMax	0	90	0
513	Amin38bMS						MinMax	0	90	0
514	Amin20aMS						MinMax	0	90	0
520	Vmax50aDEG						MinMax	0	359.9	0
521	Vmax38aDEG						MinMax	0	359.9	0
522	Vmax20aDEG						MinMax	0	359.9	0
530	Vmin50aDEG						MinMax	0	359.9	0
531	Vmin38aDEG						MinMax	0	359.9	0
532	Vmin20aDEG						MinMax	0	359.9	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	5833	5833	100	0	86.5	0.5	91.051
AnemSD50ams	5833	5833	100	0	86.5	0.5	91.051
Anem50bms	5833	5833	100	0	86.5	0	91.102
AnemSD50bms	5833	5833	100	0	86.5	0	91.102
Anem38aMS	5833	5833	100	0	90.333	0.167	90.691
AnemSD38aMS	5833	5833	100	0	90.333	0.167	90.691
Anem38bMS	5833	5833	100	0.333	87.5	5.333	90.417
AnemSD38bMS	5833	5833	100	0.333	87.5	5.333	90.417
Anem20aMS	5833	5833	100	0	44.833	0	95.388
AnemSD20aMS	5833	5833	100	0	44.833	0	95.388
Vane50aDEG	5833	5833	100	0.5	86.5	0	91.051
VaneSD50aDEG	5833	5833	100	0.5	86.5	0	91.051
Vane38aDEG	5833	5833	100	0.167	90.333	0	90.691
VaneSD38aDEG	5833	5833	100	0.167	90.333	0	90.691
Vane20aDEG	5833	5833	100	0.333	44.833	0	95.354
VaneSD20aDEG	5833	5833	100	0.333	44.833	0	95.354
Etmp2aDEGC	5833	5833	100	0	0	0	100
EtmpSD2aDEGC	5833	5833	100	0	0	0	100
Total	**104994**	**104994**	**100**	**2.667**	**1234.667**	**12**	**92.861**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	2.57
1.5	4.74
2.5	8.54
3.5	14.44
4.5	16.73
5.5	15.92
6.5	12.31
7.5	8.79
8.5	5.84
9.5	3.73
10.5	3
11.5	1.52
12.5	0.86
13.5	0.58
14.5	0.21
15.5	0.15
16.5	0.07
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	5.5

Table 2 - Wind Speed Averages, 50m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.07
1.5	4.85
2.5	4.99
3.5	4.69
4.5	4.72
5.5	4.81
6.5	4.46
7.5	4.41
8.5	4.86
9.5	5.41
10.5	5.73
11.5	6.17
12.5	6.54
13.5	6.54
14.5	6.81
15.5	6.44
16.5	6.22
17.5	5.87
18.5	5.47
19.5	5.33
20.5	5.4
21.5	5.18
22.5	5.12
23.5	5.03

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%], 50 m	Mean Wind Speed [m/s], 50 m
N	0.9	4.54
NNE	1.09	3.92
NE	1.69	4.03
ENE	1.76	3.91
E	4.25	4.41
ESE	2.59	3.96
SE	1.74	3.42
SSE	0.64	2.58
S	5.06	3.71
SSW	10.14	5.29
SW	11.57	5.7
WSW	14.15	5.32
W	17.83	6.1
WNW	13.01	6.64
NW	9.78	5.98
NNW	3.81	4.72

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