WIND DATA REPORT

Mattapoisett, Massachusetts

March 1, 2005 - May 31, 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 of 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 near the South Shore Marshes Wildlife Management Area in the town of Mattapoisett, MA. Installed on January 20th, 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 49 m (160.8 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 second such report for Mattapoisett.

The season covered by this report is March 2005 – May 2006 (Spring quarter). However, since the data from April 3 until May 1 is missing (due to corruption by the NRG database software), this report contains only two full calendar months of data for the Spring quarter time period (i.e. March and May). Statistics for the available dataset (March 1—May 31) are presented in this report, though care is advised when comparing with statistics from other sites that may possess an entire spring quarter's worth of data. The mean recorded wind speed for this period was 5.67 m/s (12.684 mph)[1] and the prevailing wind direction was from the SSW. The gross data recovery percentage (the actual percentage of expected data received) was 69.65% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 68.65%. These low averages are due to the amount of missing data.

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] 1m/s=2.237 mph

- Station Location

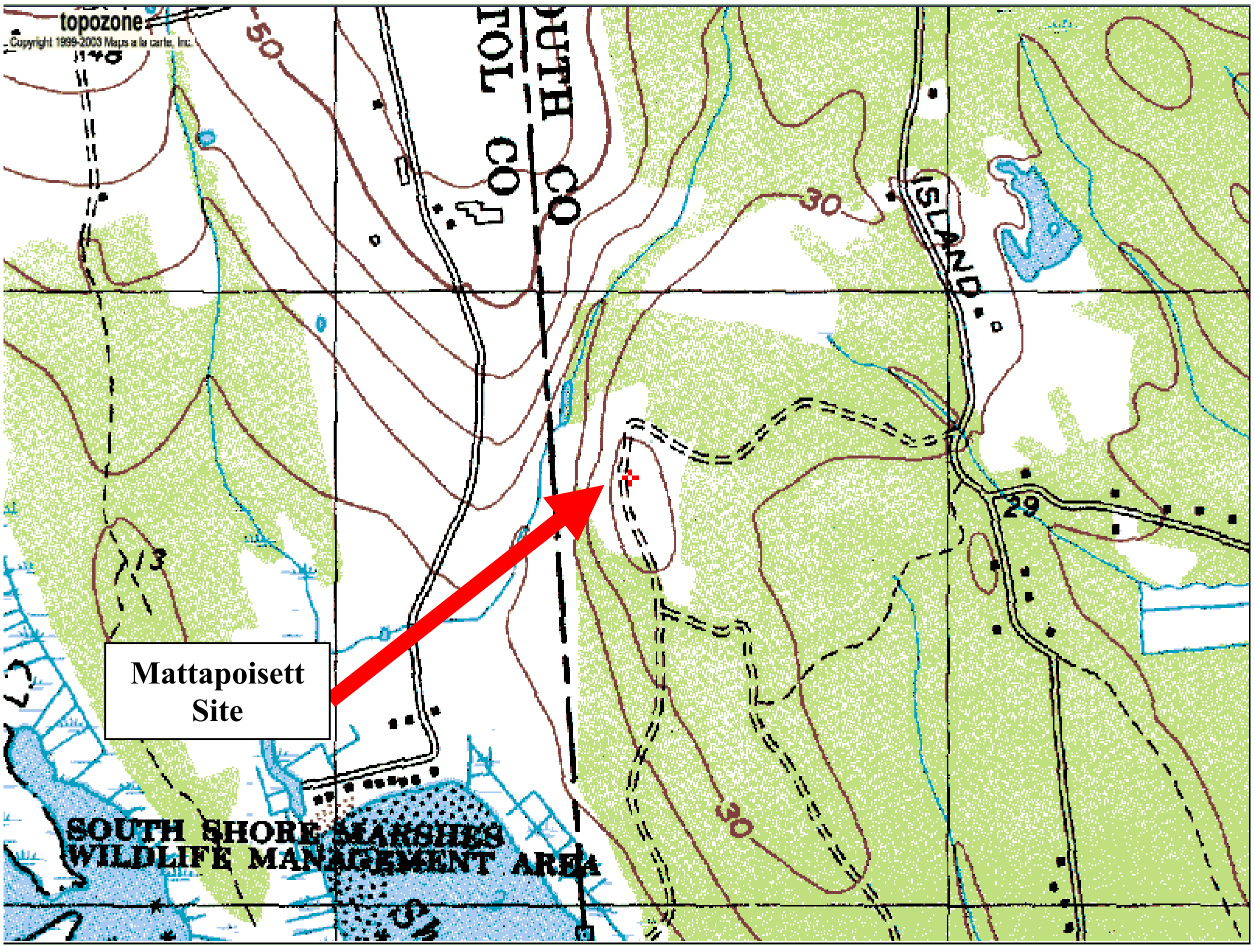

Figure 1 Topographic Map Showing Mattapoisett Site Location--Source Topozone.com

The Mattapoisett site is located near the South Shore Marshes Wildlife Management Area in Mattapoisett, MA. Latitude and Longitude are 41° 38.11'N and 70° 50.55'W, respectively, using the NAD 83 datum.

SECTION 1 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 49 m (164.0 ft) NRG 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 – 0.349 m/s). Two anemometers are located at 49 m (160.8 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 49 m (160.8 ft), 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

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 2 - Data Collection and Maintenance

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

- Some short-duration sensor-icing events.
- Corruption of the main and backup databases due to failure of the NRG software resulting in the loss of data from April 3 until May 1.

Given that the data from April has been irretrievably lost, the quarterly statistics in the report must be treated with care.

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	**49 m, [m/s]**	**49 m, [m/s]**	**49 m, [ ]**	**49 m, [ ]**	**38 m, [m/s]**	**38 m, [m/s]**	**38 m, [ ]**	**38 m, [ ]**	**20 m, [m/s]**	**20 m, [m/s]**	**20 m, [ ]**	**20 m, [ ]**	**49m - 38m []**
March 2006	5.66	15.9	0.17	WNW	5.22	14.7	0.18	WNW	4.07	12	0.25	NW	0.35
April 2006	--	--	--	--	--	--	--	--	--	--	--	--	--
May 2006	5.62	14.1	0.19	SSW	5.06	12.8	0.22	SSW	3.85	9.9	0.3	SSW	0.46
March[2] '06 – May '06	**5.67**	**15.9**	**0.18**	**SSW**	**5.17**	**14.7**	**0.2**	**SSW**	**3.98**	**12**	**0.27**	**SSW**	**0.41**

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. In this case, data from only 68.6% of the Spring quarter (i.e. March and May) exist, so caution is advised when comparing with statistics from complete quarters.

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 49 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

[2] Caution is advised! Statistics represent only 68.6% of Spring quarter.

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 3 - Significant Meteorological Events

The Spring of 2006 had no major meteorological events that would have caused notable fluctuations in wind speed measurements.

Source:
http://www.wunderground.com/history/airport/KEWB/2006/3/1/CustomHistory.html?dayend=31&monthend=5&yearend=2006&req_city=NA&req_state=NA&req_statename=NA

SECTION 4 - 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 [%]	69.645%
Net Data Recovered [%]	68.646%

<u>Test Definitions</u>

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.

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

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 5 - 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 Spring quarter data (i.e. March 1, 2006 to May 31, 2006) in Figure 2. Clearly visible is the missing April data. This plot presents data at 49 meters.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. Figure 3 shows that the wind speeds ranged between 5 and 6 m/s (11.19and 13.42 mph) approximately 15% of the time. This plot presents data at 49 meters and is drawn from the entire Spring quarter dataset, though missing and invalidated data is excluded from the calculation.

- Monthly Average Wind Speeds – This plot shows the trends in the mean monthly wind speed at a height of 49 m. This graph shows the trends in the wind speed over the year. The monthly average wind speed plot is shown in Figure 4 and does not present data from April 2006. As can be seen in the figure, to date, the monthly average wind speed is near 6 m/s (13.42 mph).

- Diurnal – A plot of the average wind speed for each hour of the day. Figure 5 shows that the hourly average varied between 5 and 7 m/s (11.19 and 15.66 mph), with the highest average speeds in the afternoon. This plot presents data at 49 meters and is drawn from the entire Spring quarter dataset, though missing and invalidated data is excluded from the calculation.

- 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 Mattapoisett, the average turbulence intensity for the Spring quarter was 0.18. In Figure 6, the turbulence intensity flattens out between 6 and 7 m/s (13.42 and 15.66 mph). This plot presents data at 49 meters and is drawn from the entire Spring quarter dataset, though missing and invalidated data is excluded from the calculation.

- 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 7 shows the prevailing direction is from the south-southwest. The wind blew from the SSW 13.1% of the time with a mean wind speed of 6.3 m/s (14.09 mph). This plot presents data at 49 meters and is drawn from the entire Spring quarter dataset, though missing and invalidated data is excluded from the calculation.

SECTION 6- Graphs

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

<u>**Wind Speed Time Series**</u>

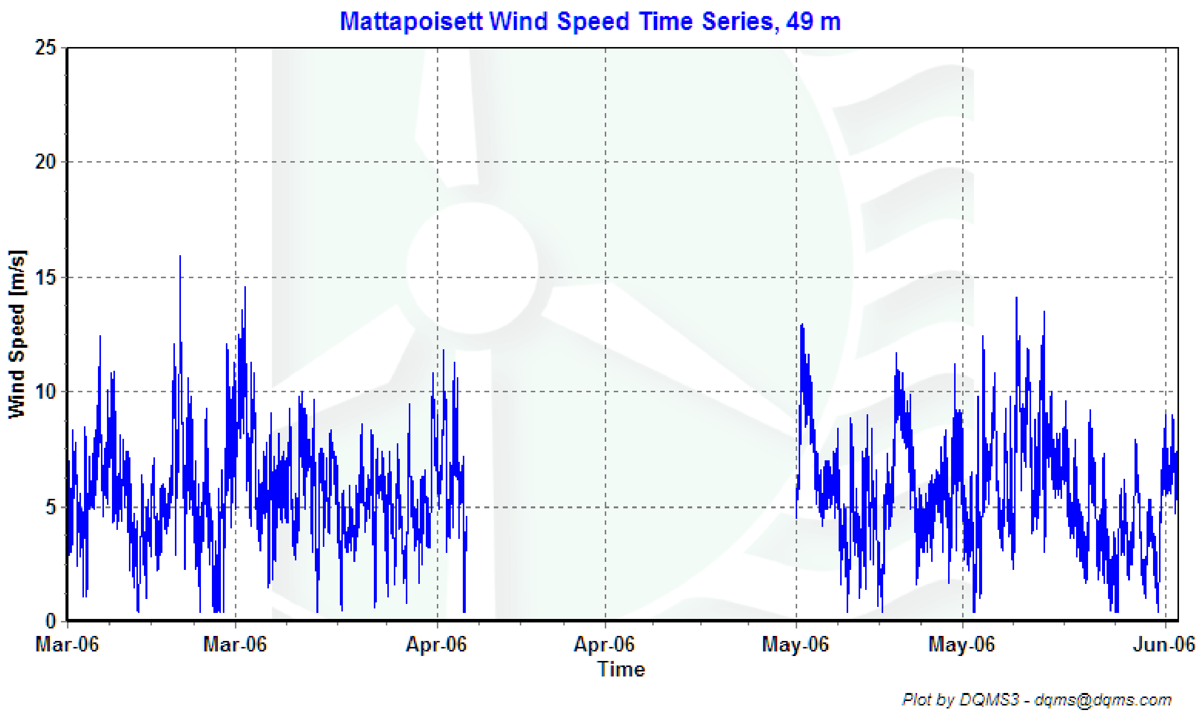

Figure 2 – Wind Speed Time Series, March 1, 2006 through May 31, 2006

Wind Speed Distributions

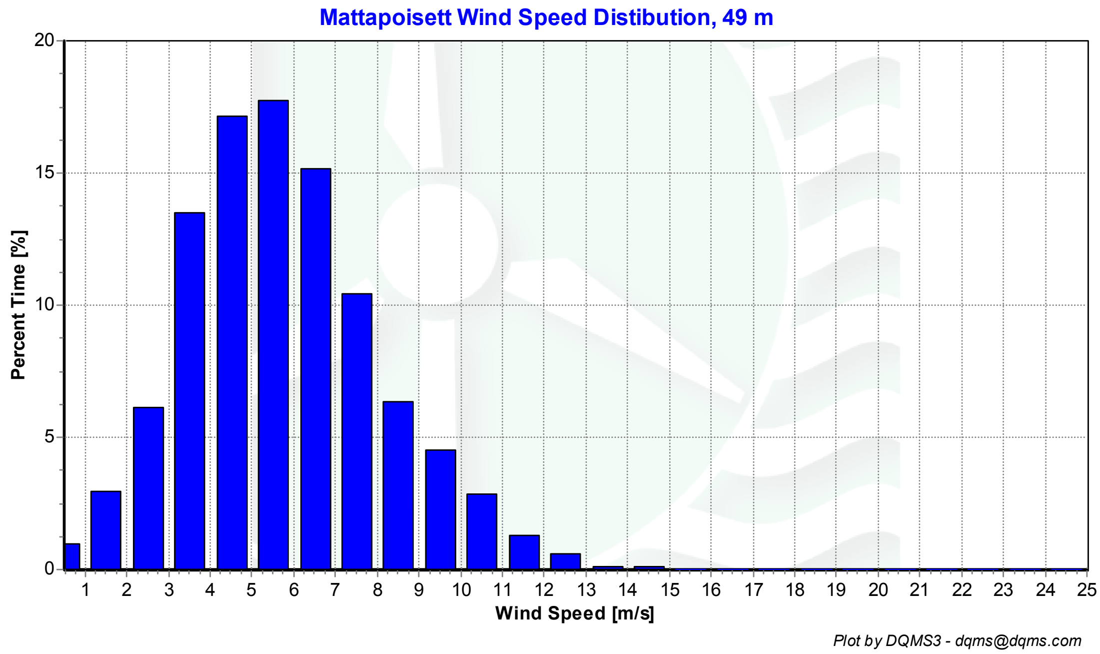

Figure 3 – Wind Speed Distribution, March 1, 2006 through May 31, 2006

Monthly Average Wind Speeds

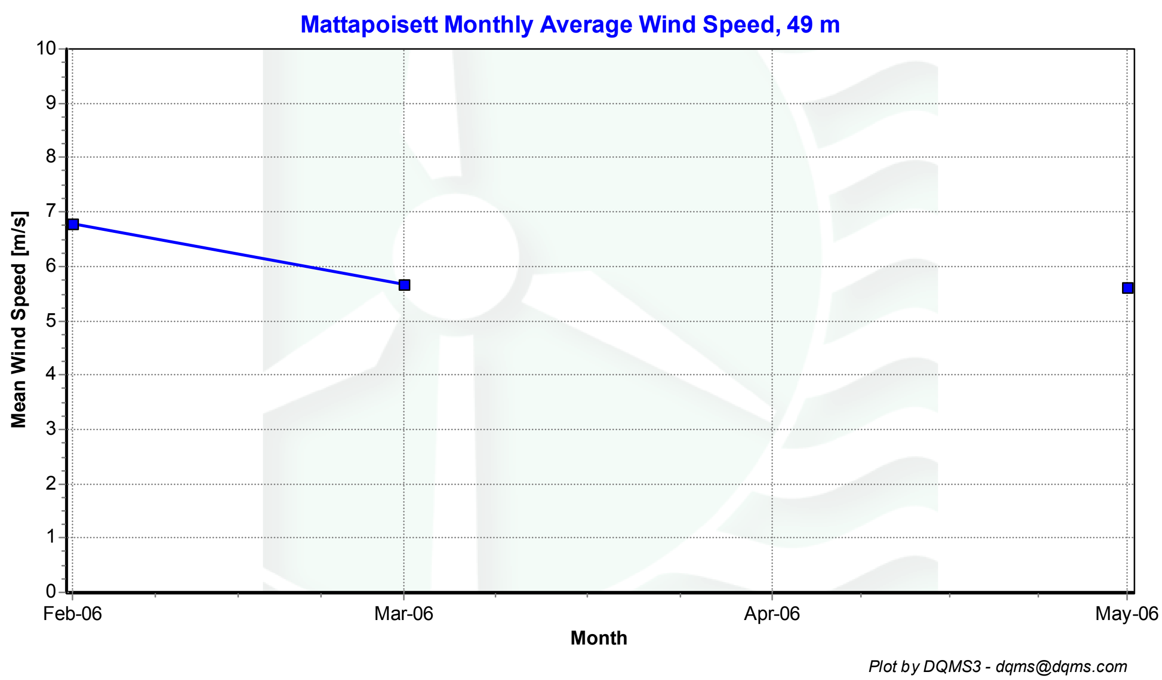

Figure 4 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

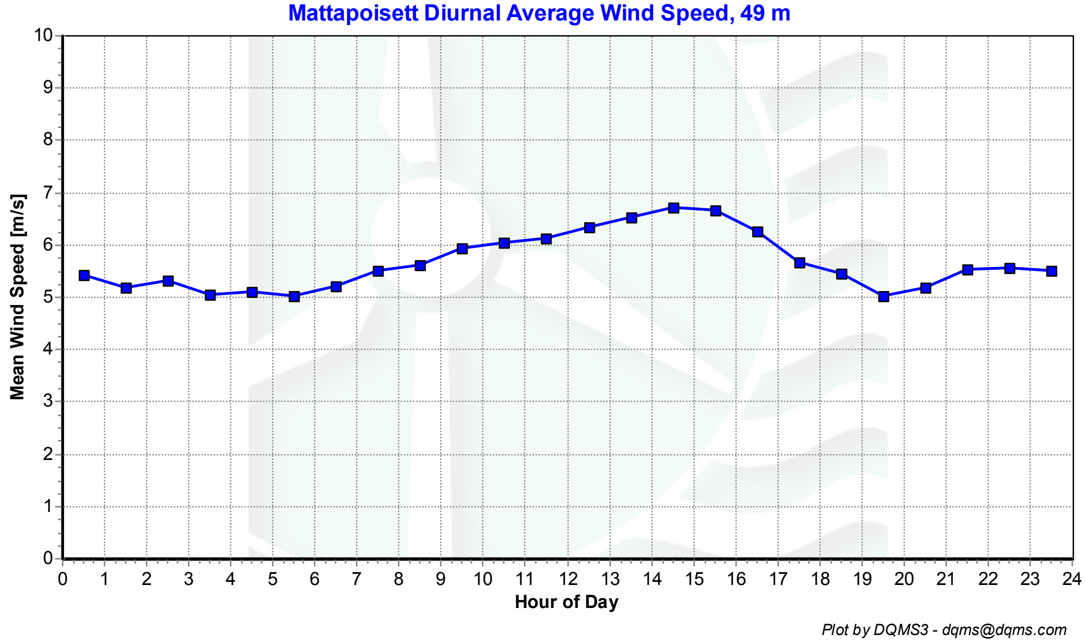

Figure 5 – Diurnal Average Wind Speed, March 1, 2006 through May 31, 2006

Turbulence Intensities

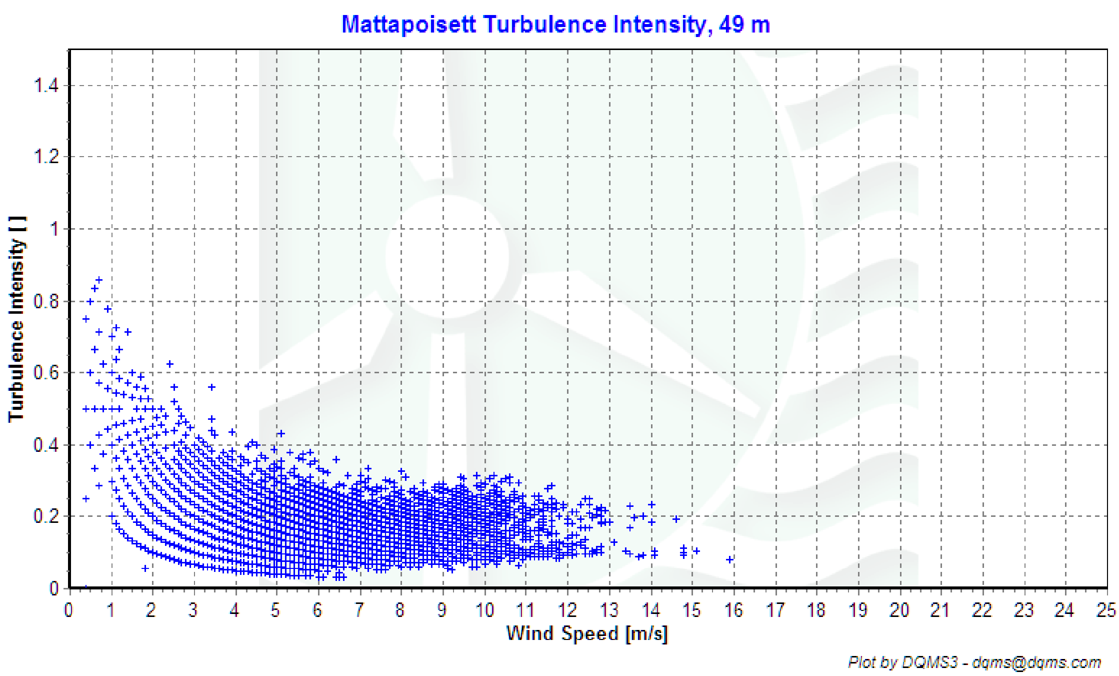

Figure 6 – Turbulence Intensity, March 1, 2006 through May 31, 2006

Wind Roses

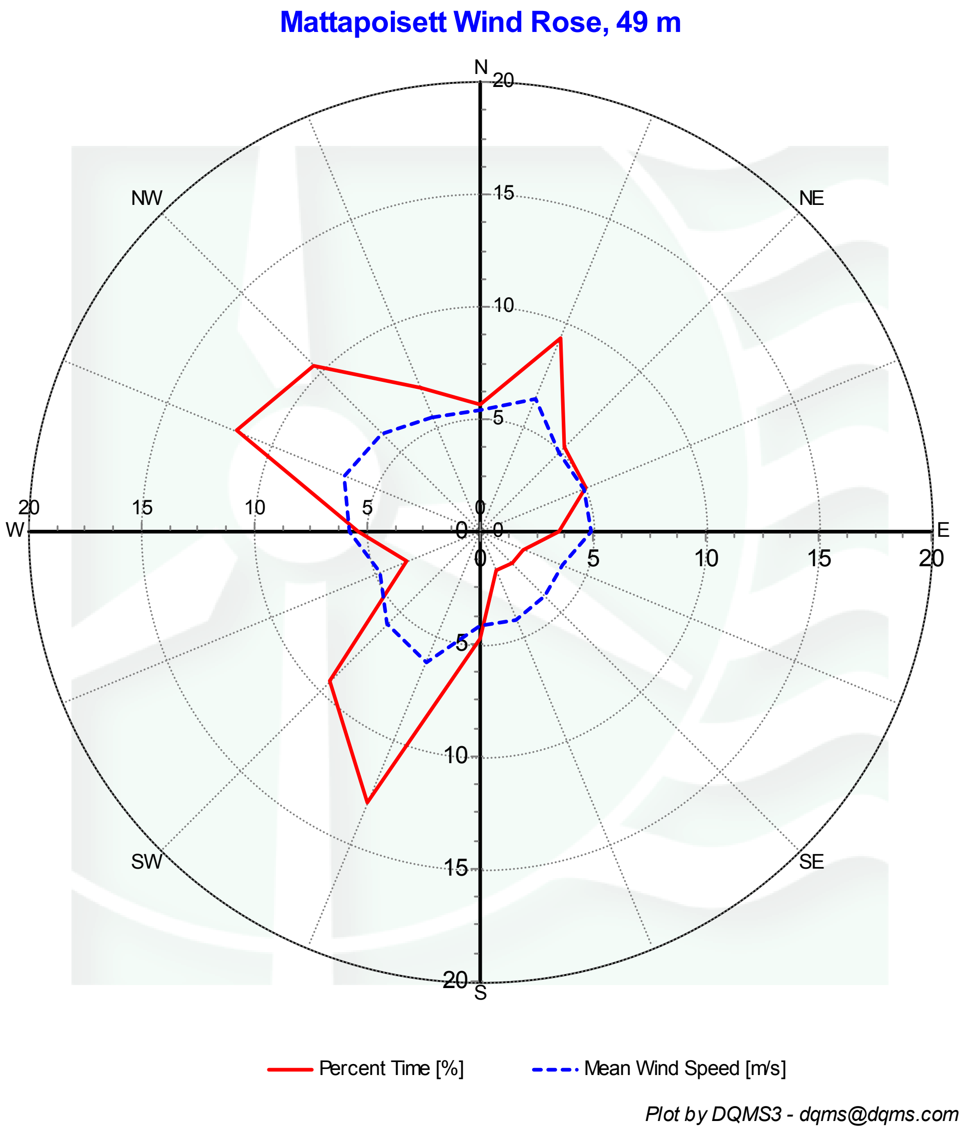

Figure 7 – Wind Rose, March 1, 2006 through May 31, 2006

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert			
2	Etmp2aDEGC						MinMax	Etmp2aDEGC		
3	Etmx2aDEGC						MinMax	Etmx2aDEGC		
4	Etmn2aDEGC						MinMax	Etmn2aDEGC		
5	EtmpSD2aDEGC						MinMax	EtmpSD2aDEGC		
10	Anem49aMS						MinMax	Anem49aMS		
11	Anem49bMS						MinMax	Anem49bMS		
12	Anem38aMS						MinMax	Anem38aMS		
13	Anem38bMS						MinMax	Anem38bMS		
14	Anem20aMS						MinMax	Anem20aMS		
15	Anem49yMS						MinMax	Anem49yMS		
16	Anem38yMS						MinMax	Anem38yMS		
20	AnemSD49aMS						MinMax	AnemSD49aMS		
21	AnemSD49bMS						MinMax	AnemSD49bMS		
22	AnemSD38aMS						MinMax	AnemSD38aMS		
23	AnemSD38bMS						MinMax	AnemSD38bMS		
24	AnemSD20aMS						MinMax	AnemSD20aMS		
25	AnemSD49yMS						MinMax	AnemSD49yMS		
26	AnemSD38yMS						MinMax	AnemSD38yMS		
30	Vane49aDEG						MinMax	Vane49aDEG		
31	Vane38aDEG						MinMax	Vane38aDEG		
32	Vane20aDEG						MinMax	Vane20aDEG		
49	Turb49zNONE						MinMax	Turb49zNONE		
51	Turb38zNONE						MinMax	Turb38zNONE		
60	Wshr0zNONE						MinMax	Wshr0zNONE		
70	VaneSD49aDEG	Anem49yMS					MinMaxT	VaneSD49aDEG	Anem49yMS	
71	VaneSD38aDEG	Anem38yMS					MinMaxT	VaneSD38aDEG	Anem38yMS	
200	VaneSD20aDEG	Anem20aMS					MinMax	VaneSD20aDEG	Anem20aMS	
201	Anem49aMS	AnemSD49aMS	Vane49aDEG	VaneSD49aDEG	Etmp2aDEGC		Icing	Anem49aMS	AnemSD49aMS	Vane49aDEG
202	Anem49bMS	AnemSD49bMS	Vane49aDEG	VaneSD49aDEG	Etmp2aDEGC		Icing	Anem49bMS	AnemSD49bMS	Vane49aDEG
300	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	Anem38aMS	AnemSD38aMS	Vane38aDEG
301	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	Anem38bMS	AnemSD38bMS	Vane38aDEG
302	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC		Icing	Anem20aMS	AnemSD20aMS	Vane20aDEG
303	Anem49yMS	AnemSD49yMS	Vane49aDEG	VaneSD49aDEG	Etmp2aDEGC		Icing	Anem49yMS	AnemSD49yMS	Vane49aDEG
304	Anem38yMS	AnemSD38yMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	Anem38yMS	AnemSD38yMS	Vane38aDEG
400	Anem49aMS	Anem49bMS					CompareSensors	Anem49aMS	Anem49bMS	
401	Anem38aMS	Anem38bMS					CompareSensors	Anem38aMS	Anem38bMS	
490	Amax49aMS						MinMax	Amax49aMS		
491	Amax49bMS						MinMax	Amax49bMS		

492	Amax38aMS						MinMax	Amax38aMS		
493	Amax38bMS						MinMax	Amax38bMS		
494	Amax20aMS						MinMax	Amax20aMS		
510	Amin49aMS						MinMax	Amin49aMS		
511	Amin49bMS						MinMax	Amin49bMS		
512	Amin38aMS						MinMax	Amin38aMS		
513	Amin38bMS						MinMax	Amin38bMS		
514	Amin20aMS						MinMax	Amin20aMS		
520	Vmax49aDEG						MinMax	Vmax49aDEG		
521	Vmax38aDEG						MinMax	Vmax38aDEG		
522	Vmax20aDEG						MinMax	Vmax20aDEG		
530	Vmin49aDEG						MinMax	Vmin49aDEG		
531	Vmin38aDEG						MinMax	Vmin38aDEG		
532	Vmin20aDEG						MinMax	Vmin20aDEG		

Sensor Statistics

Sensors	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem49ams	13105	9127	69.645	0	37.667	0.667	67.89
AnemSD49ams	13105	9127	69.645	0	37.667	0.667	67.89
Anem49bms	13105	9127	69.645	0	37.667	7	67.6
AnemSD49bms	13105	9127	69.645	0	37.667	7	67.6
Anem38aMS	13105	9127	69.645	0	18.667	0.167	68.783
AnemSD38aMS	13105	9127	69.645	0	18.667	0.167	68.783
Anem38bMS	13105	9127	69.645	0	20	0	68.729
AnemSD38bMS	13105	9127	69.645	0	20	0	68.729
Anem20aMS	13105	9127	69.645	0	7.833	0	69.287
AnemSD20aMS	13105	9127	69.645	0	7.833	0	69.287
Vane49aDEG	13105	9127	69.645	0.5	37.667	0	67.898
VaneSD49aDEG	13105	9127	69.645	0.5	37.667	0	67.898
Vane38aDEG	13105	9127	69.645	0.5	20	0	68.707
VaneSD38aDEG	13105	9127	69.645	0.5	20	0	68.707
Vane20aDEG	13105	9127	69.645	0.167	7.833	0	69.279
VaneSD20aDEG	13105	9127	69.645	0.167	7.833	0	69.279
Etmp2aDEGC	13105	9127	69.645	0	0	0	69.645
EtmpSD2aDEGC	13105	9127	69.645	0	0	0	69.645
Total	235890	164286	69.645	2.333	374.667	15.667	68.646

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.98
1.5	2.97
2.5	6.15
3.5	13.51
4.5	17.17
5.5	17.76
6.5	15.17
7.5	10.45
8.5	6.32
9.5	4.51
10.5	2.87
11.5	1.32
12.5	0.6
13.5	0.11
14.5	0.09
15.5	0.02
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	6.78
March-06	5.66
April-06	--
May-06	5.62

Table 2 - Wind Speed Averages, 49m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.42
1.5	5.19
2.5	5.33
3.5	5.05
4.5	5.11
5.5	5.02
6.5	5.21
7.5	5.51
8.5	5.63
9.5	5.95
10.5	6.04
11.5	6.12
12.5	6.34
13.5	6.52
14.5	6.72
15.5	6.67
16.5	6.26
17.5	5.68
18.5	5.46
19.5	5.03
20.5	5.2
21.5	5.53
22.5	5.56
23.5	5.52

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%], 49 m	Mean Wind Speed [m/s], 49 m
N	5.63	5.38
NNE	9.29	6.42
NE	5.32	4.99
ENE	5.05	4.97
E	3.53	4.94
ESE	2.06	3.92
SE	2	4.07
SSE	1.87	4.24
S	4.78	4.2
SSW	13.08	6.3
SW	9.38	5.82
WSW	3.53	4.79
W	5.41	5.77
WNW	11.69	6.53
NW	10.46	6.18
NNW	6.92	5.5

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