

# WIND DATA REPORT

## Aquinnah

December 2008 to February 2009

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

Wind monitoring equipment was installed at the Old Loran Station junkyard on July 11<sup>th</sup> 2008. The base of the 50 meter meteorological tower was installed 38 meters above sea level. Anemometers were installed at 25, 35 and 49 meters (82.0, 114.8 and 160.8 feet) above the base of the tower. There are redundant anemometers at the 49 meter height. Wind direction vanes were installed at 35 and 49 meters. A temperature sensor is installed near the base of the tower.

This report summarizes the wind data collected during the winter of 2008 and 2009, between December 2008 and February 2009. The mean recorded wind speed was 8.28 m/s (18.52 mph\*) at 49 meters, and the prevailing wind direction was from the northwest. The average wind shear component was 0.5 and the average turbulence intensity at 49 meters was 0.16.

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 97.8%

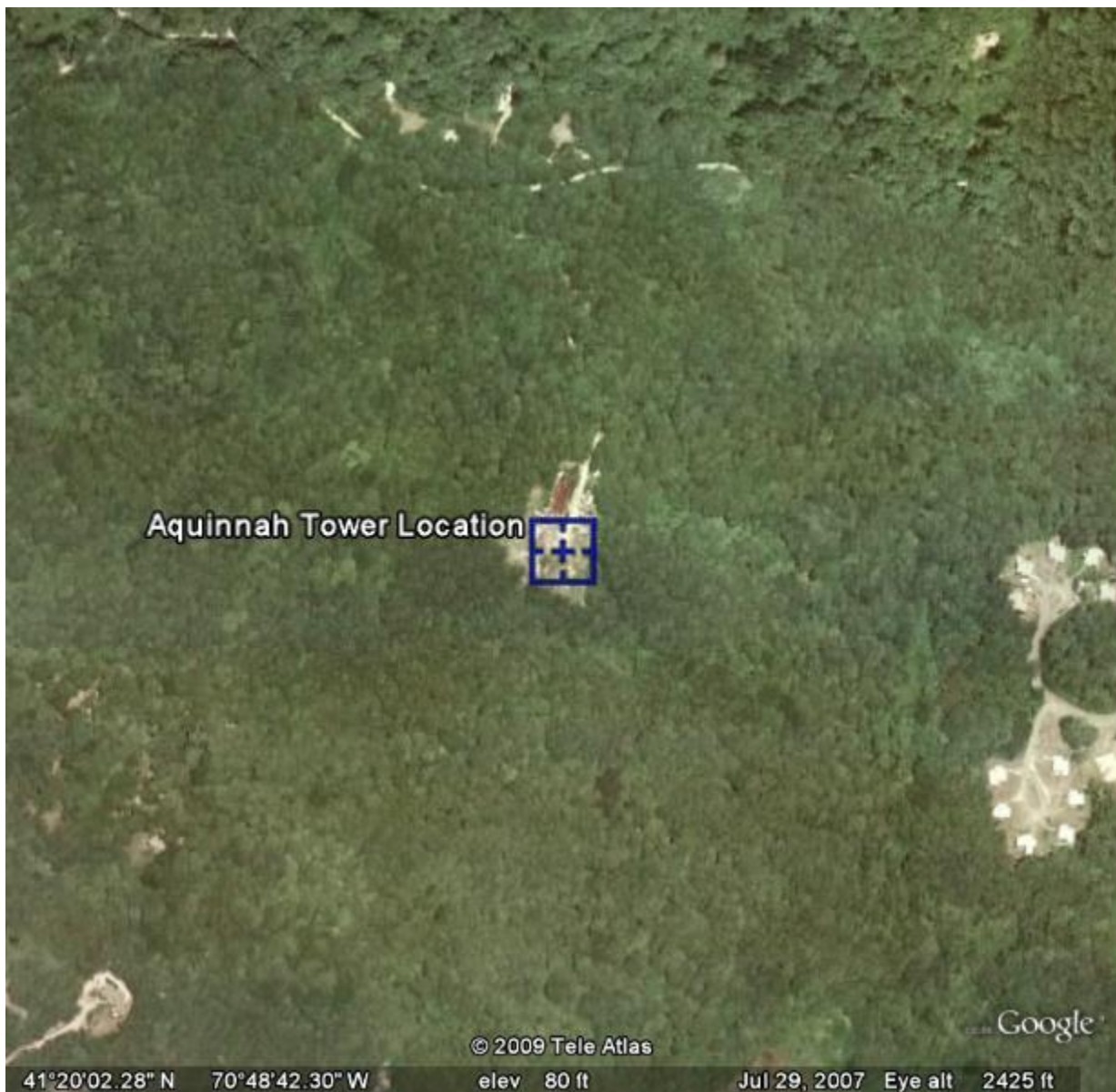
Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by RERL and the Massachusetts Technology Collaborative (MTC). This document is found through the RERL website:

[http://www.ceere.org/rerl/about\\_wind/RERL\\_Fact\\_Sheet\\_6\\_Wind\\_resource\\_interpretation.pdf](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 Aquinnah monitoring tower is located at the old Loran Station junkyard. The 50 meter tower is located at  $41^{\circ}20'04.12''$  N,  $70^{\circ}48'07.05''$  W and the tower base is 24.4 meters above sea level. The approximate tower location is marked by the blue box shown in Figure 1.



**Figure 1 – Site Location**

## **SECTION 2- Instrumentation and Equipment**

The wind monitoring equipment is mounted on a 50 m (164 ft) meteorological tower. The wind monitoring equipment comes from NRG systems and consists of the following items:

- NRG Symphonie data logger
- 4 – NRG #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 49 m (160.8 ft), one anemometer is located at 35 m (114.8 ft), and one anemometer is located at 25 m (82.0 ft)
- 2 – NRG #200P Wind direction vanes. The vanes are located at 49 m (160.8 ft) and 35 m (114.8 ft).
- NRG 110S temperature Sensor

The data from the Symphonie logger is mailed to RERL via a data card on a monthly basis. The logger samples wind speed and direction once every two second. These samples are combined into 10-minute averages and are put into a binary file along with the maximum, minimum and standard deviation for each 10-minute interval. The binary files are converted to ASCII text files using NRG software. These text files are then imported into a database software program where they are subjected to quality assurance tests prior to data usage.

## **SECTION 3- Data Summary**

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

**Table 1. Wind Speed and Direction Data Summary**

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed
<b>Height Units</b>	<b>49 m [m/s]</b>	<b>49 m [m/s]</b>	<b>49 m [m/s]</b>	<b>35 m [m/s]</b>	<b>35 m [m/s]</b>	<b>35 m [m/s]</b>	<b>25 m [m/s]</b>	<b>25 m [m/s]</b>
Dec 2008	9.11	23.7	NW	7.64	20.3	NW	6.2	16.5
Jan 2009	7.56	21.2	NW	6.62	18.1	NW	5.62	15.3
Feb 2009	8.14	18.4	W	6.96	15.8	WNW	5.73	13.2
<b>Dec 2008 -Feb 2009</b>	<b>8.28</b>	<b>23.7</b>	<b>NW</b>	<b>7.08</b>	<b>20.3</b>	<b>NW</b>	<b>5.86</b>	<b>16.5</b>

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 or direction can be perfectly accurate. Wind speed measurement 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  $\pm 0.2$  m/s, whichever is greater. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of  $\pm 5$  degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included in Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed at each measurement height is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients,  $\alpha$ , 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 will not always 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.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where  $z_{high}$  and  $z_{low}$  are the heights of the higher and lower mean wind speeds used in the calculation and  $U(z_{low})$  and  $U(z_{high})$  are the mean wind speeds at the two heights.

$$\alpha = \log \left( \frac{U(z_{high})}{U(z_{low})} \right) / \log \left( \frac{z_{high}}{z_{low}} \right)$$

**Table 2. Shear and Turbulence Intensity Data Summary**

Date	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, $\alpha$	Mean Wind Shear Coefficient, $\alpha$	Mean Wind Shear Coefficient, $\alpha$
Height Units	49 m [-]	35 m [-]	25 m [-]	Between 49 m and 35 m [-]	Between 35 m and 25 m [-]	Between 49 m and 25 m [-]
Dec 2008	0.155	0.175	0.23	0.52	0.62	0.57
Jan 2009	0.165	0.205	0.255	0.39	0.49	0.44
Feb 2009	0.155	0.185	0.24	0.47	0.58	0.52
<b>Dec 2008 -Feb 2009</b>	<b>0.16</b>	<b>0.185</b>	<b>0.24</b>	<b>0.47</b>	<b>0.56</b>	<b>0.51</b>

## SECTION 4- Graphs

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.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed.
- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over the year.
- Diurnal – A plot of the average wind speed for each hour of the day.
- 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.
- 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.

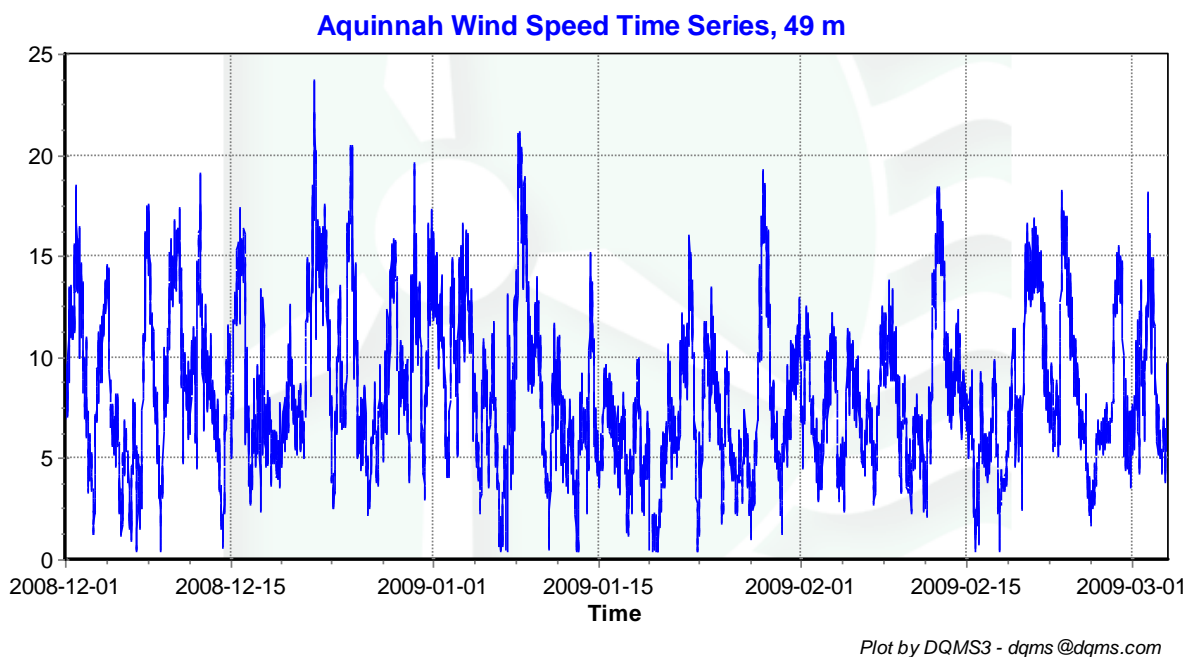
With regards to the Aquinnah site, the following observations are noted.

- Time Series, Figure 2: shows that the wind speed seldom exceeded 20 m/s at the site during the winter months.
- Wind Speed Distribution, Figure 3: shows that the distribution is skewed towards higher wind speeds for the winter months. Wind speeds are primarily between 4 and 10 m/s during the fall months and the most common wind speed is between 6 and 7 m/s.
- Monthly Average, Figure 4: shows that the average monthly wind speed at the site increase through the fall and into the winter with December having the maximum average wind speed at over 9 m/s.
- Diurnal, Figure 5: shows that on average the wind speed is fairly consistent through out the day, with slightly higher winds on average in the evening hours.
- Turbulence Intensity, Figure 6: we can see the turbulence numbers roughly cluster between 0.1 and 0.3 for most wind speeds.

- Wind Rose, Figure 7: shows that the prevailing winds are from the northwest directions and maximum wind speeds occur from the south-southwest direction to the west-northwest direction.

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

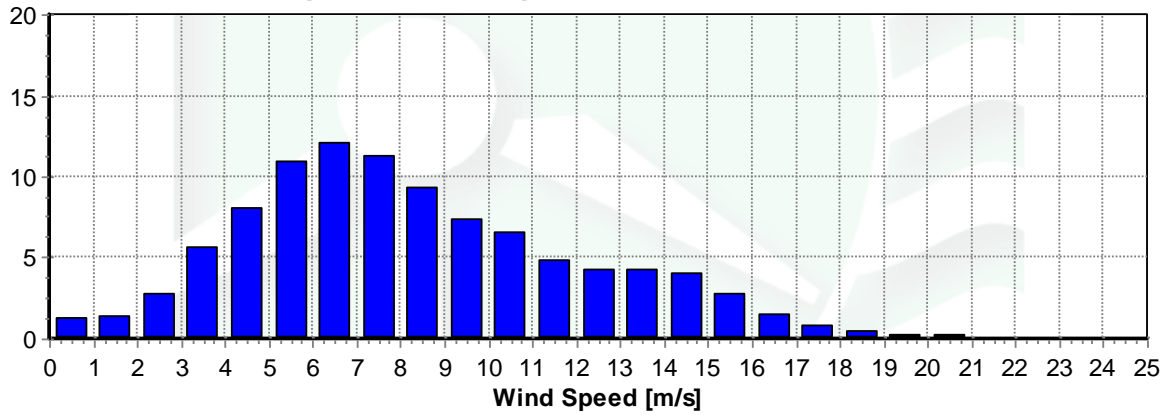
### Wind Speed Time Series



**Figure 2 – Wind Speed Time Series, December 1, 2008 – February 28, 2009**

## Wind Speed Distributions

### Aquinnah Wind Speed Distribution, 49 m

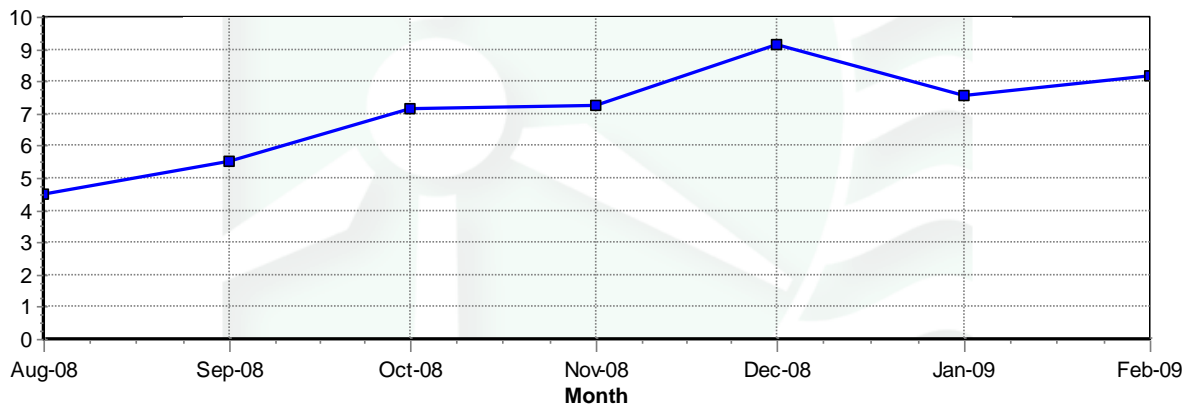


Plot by DQMS3 - dqms@dqms.com

Figure 3 – Wind Speed Distribution, December 1, 2008 – February 28, 2009

## Monthly Average Wind Speeds

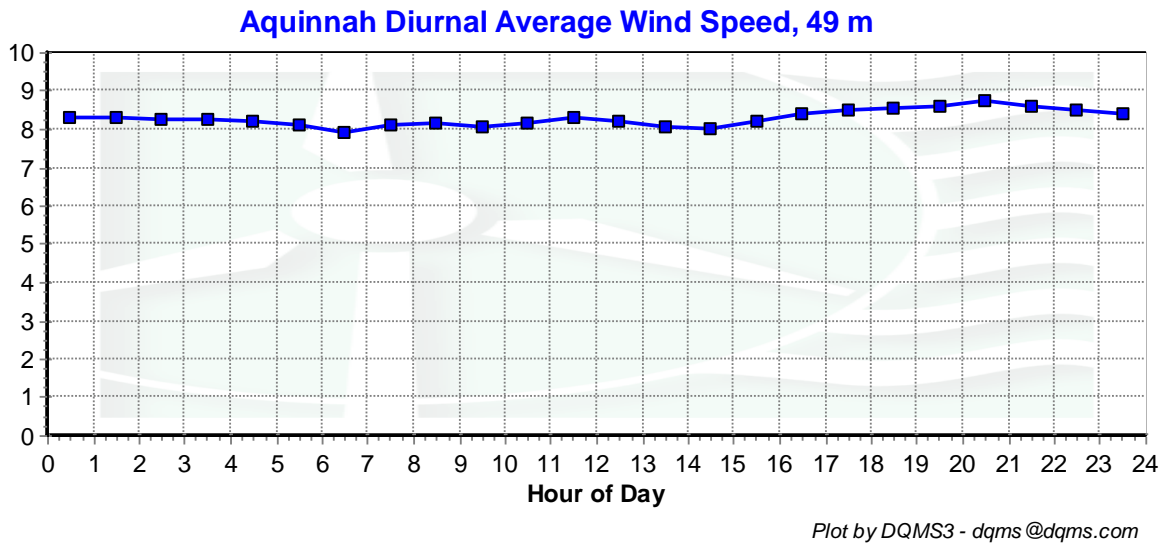
### Aquinnah Monthly Average Wind Speed, 49m



Plot by DQMS3 - dqms@dqms.com

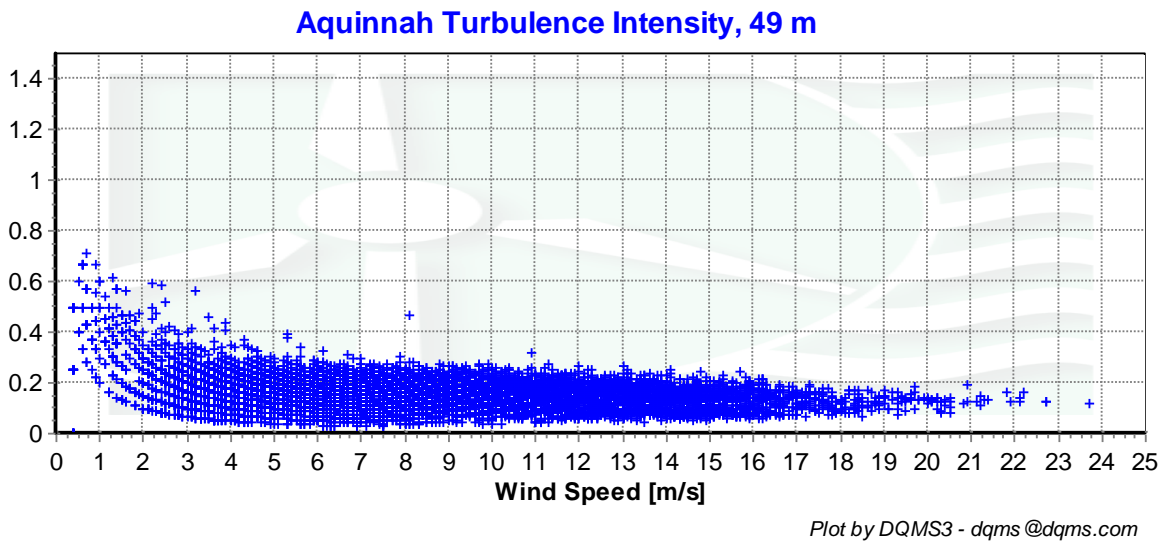
Figure 4 – Monthly Average Wind Speed, August 1, 2008 – February 28, 2009

## Diurnal Average Wind Speeds



**Figure 5 – Diurnal Average Wind Speeds, December 1, 2008 – February 28, 2009**

## Turbulence Intensities

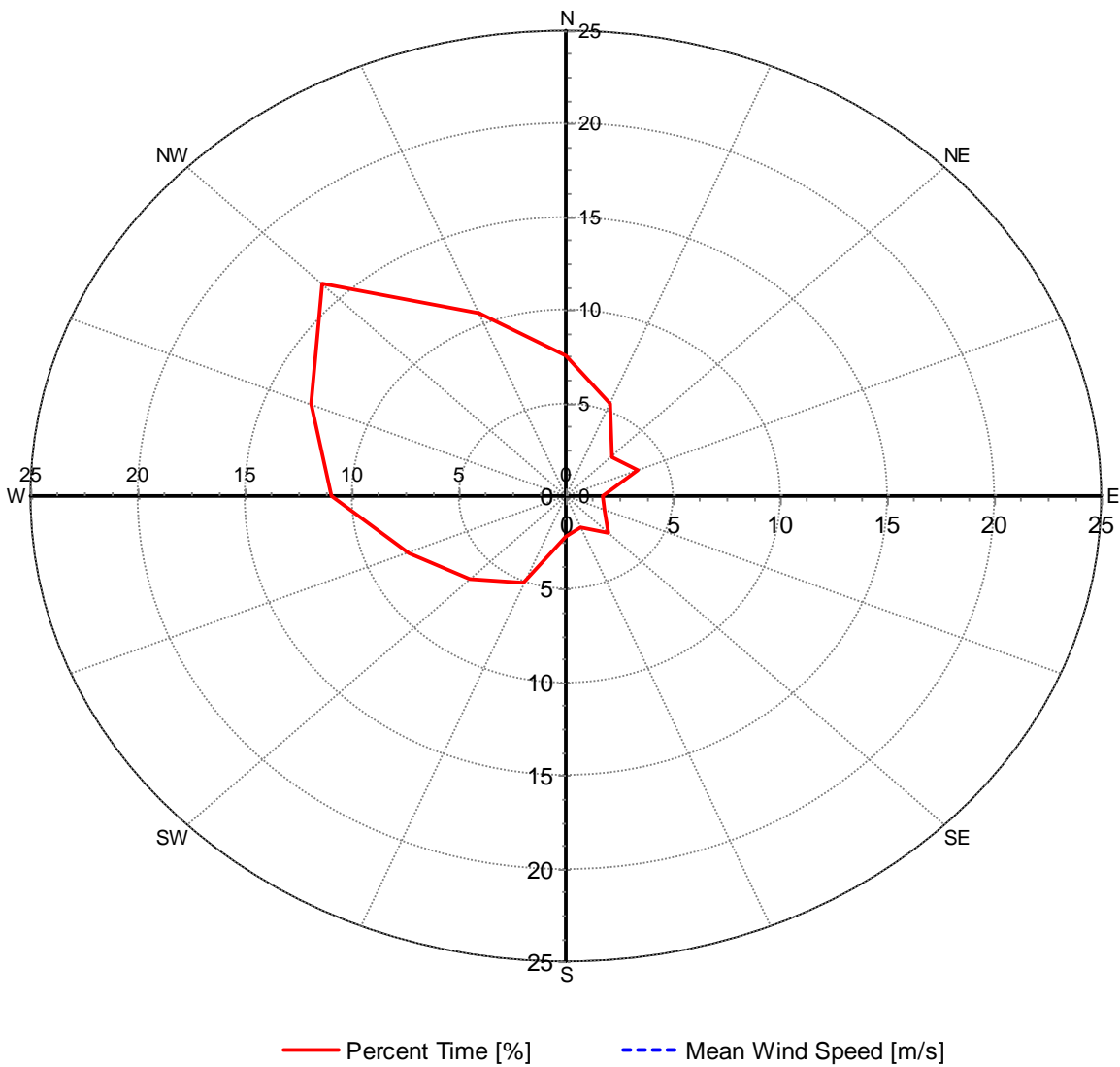


**Figure 6 – Turbulence Intensity vs. Wind Speed, December 1, 2008 – February 28, 2009**

# Wind Roses

5

## Aquinnah Wind Rose, 49m



Plot by DQMS3 - dqms@dqms.com

Figure 7 – Wind Rose, December 1, 2008 – February 28, 2009

## SECTION 5 - Significant Meteorological Events

There were no extreme meteorological events during this data collection period. The highest recorded wind speed was 23.7 m/s (53.0 mph) at 49 meters.

## SECTION 6 - Data Collection and Maintenance

All sensors and equipment functioned properly throughout the monitoring period. No maintenance was performed during this quarter.

## SECTION 7 - 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 [%]	97.794

### 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.

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

**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.

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

**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.

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

### Sensor Statistics

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

**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*.

# APPENDIX A - Sensor Performance Report

## Test Definitions

Test Order	Test Field 1	Test Field 2	Test Field 3	Calc Field 1	Calc Field 2	Test Type	Factor 1	Factor 2	Factor 3	Factor 4
1						TimeTest Insert	0	0	0	0
4	Etmp2aDEGC					MinMax	-30	60	0	0
5	EtmpSD2aDEGC					MinMax	-30	60	0	0
10	Anem49aMS					MinMax	0	90	0	0
11	Anem49bMS					MinMax	0	90	0	0
12	Anem35aMS					MinMax	0	90	0	0
13	Anem25aMS					MinMax	0	90	0	0
14	Anem49yMS					MinMax	0	90	0	0
20	AnemSD49aMS					MinMax	0	4	0	0
21	AnemSD49bMS					MinMax	0	4	0	0
22	AnemSD35aMS					MinMax	0	4	0	0
23	AnemSD25aMS					MinMax	0	4	0	0
24	AnemSD49yMS					MinMax	0	4	0	0
30	Vane49aDEG					MinMax	0	359.9	0	0
31	Vane35aDEG					MinMax	0	359.9	0	0
50	Turb49zNONE					MinMax	0	2	0	0
51	Turb35zNONE					MinMax	0	2	0	0
52	Turb25zNONE					MinMax	0	2	0	0
200	VaneSD49aDEG	Anem49yMS				MinMaxT	0	100	100	10
201	VaneSD35aDEG	Anem35aMS				MinMaxT	0	100	100	10
300	Anem49aMS	AnemSD49aMS	Vane49aDEG	VaneSD49aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
301	Anem49bMS	AnemSD49bMS	Vane49aDEG	VaneSD49aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
302	Anem35aMS	AnemSD35aMS	Vane35aDEG	VaneSD35aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
303	Anem25aMS	AnemSD25aMS	Vane35aDEG	VaneSD35aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
400	Anem49aMS	Anem49bMS				Compare Sensors	1	0.25	3	0
500	Amax49aMS					MinMax	0	90	0	0
501	Amax49bMS					MinMax	0	90	0	0
502	Amin49aMS					MinMax	0	90	0	0
503	Amin49bMS					MinMax	0	90	0	0
510	Amax35aMS					MinMax	0	90	0	0
511	Amin35aMS					MinMax	0	90	0	0
512	Amax25aMS					MinMax	0	90	0	0
513	Amin25aMS					MinMax	0	90	0	0
520	Vmax49aDEG					MinMax	0	359.9	0	0
521	Vmin49aDEG					MinMax	0	359.9	0	0
522	Vmax35aDEG					MinMax	0	359.9	0	0
523	Vmin35aDEG					MinMax	0	359.9	0	0
524	Etmpmax2aDEGC					MinMax	-30	60	0	0
525	Etmpmin2aDEGC					MinMax	-30	60	0	0

### Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Etmp2aDEGC	12960	12960	100	0	0	0	100
Anem49aMS	12960	12960	100	0	52.167	0	97.585
Anem49bMS	12960	12960	100	0	52	6.667	97.284
Anem35aMS	12960	12960	100	0	49.667	0	97.701
Anem25aMS	12960	12960	100	0	60.167	0	97.215
Vane49aDEG	12960	12960	100	0	52.333	0	97.577
Vane35aDEG	12960	12960	100	0.167	60.333	0	97.199
Total	90720	90720	100	0.167	326.667	6.667	97.794

## APPENDIX B - Plot Data

### Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Dec. 2008 – Feb. 2009 [%]
0.5	1.3
1.5	1.35
2.5	2.73
3.5	5.64
4.5	8.05
5.5	10.94
6.5	12.04
7.5	11.22
8.5	9.27
9.5	7.37
10.5	6.6
11.5	4.86
12.5	4.27
13.5	4.25
14.5	4.05
15.5	2.75
16.5	1.49
17.5	0.81
18.5	0.46
19.5	0.25
20.5	0.2
21.5	0.05
22.5	0.04
23.5	0.01
24.5	0

### Monthly Average Wind Speed Data

Date	Wind Speed at 49 m 10 min Average [m/s]
August	4.5
September	5.51
October	7.12
November	7.22
December	9.11
January	7.56
February	8.14

### Diurnal Average Wind Speed Data

Hour of Day	Dec. 2008 – Feb. 2009 Mean Wind Speed [m/s]
0.5	8.3
1.5	8.27
2.5	8.27
3.5	8.27
4.5	8.2
5.5	8.09
6.5	7.91
7.5	8.08
8.5	8.15
9.5	8.05
10.5	8.14
11.5	8.31
12.5	8.21
13.5	8.04
14.5	8.01
15.5	8.18
16.5	8.39
17.5	8.5
18.5	8.51
19.5	8.57
20.5	8.72
21.5	8.58
22.5	8.49
23.5	8.38

### Wind Rose Data

Direction	Dec. 2008 – Feb. 2009	
	Percent Time [%]	Mean Wind Speed [m/s]
N	7.52	5.87
NNE	5.33	6.66
NE	3	6.95
ENE	3.68	6.69
E	1.76	5.3
ESE	1.96	7.05
SE	2.85	7.1
SSE	1.83	6.2
S	2.18	7.75
SSW	5.1	10.67
SW	6.35	9.63
WSW	7.91	9.81
W	10.94	9.93
WNW	12.88	9.93
NW	16.09	8.73
NNW	10.61	6.81