

WIND DATA REPORT

Marion, MA

July 2009 to July 2010

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 Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

Wind monitoring equipment was installed at the Marion site in July 2009 and removed in July 2010. The base of the 50 meter meteorological tower is installed 35 meters above sea level. Anemometers and wind direction vanes are installed at 38 and 50 m (128 and 164 ft) above the tower base. There are redundant anemometers at both heights. There is a temperature sensor installed near the base of the tower.

This report summarizes the wind data collected during throughout the whole period. Annual statistics are calculated between July 16, 2009 and July 15, 2010. The mean recorded wind speed was 6.28 m/s (14.0 mph*) at 50 m and the prevailing wind direction was from the south-southwest. The average turbulence intensity between 10 m/s and 11 m/s at 50 m height was 0.15.

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 99.08%.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by WEC and the Massachusetts Clean Energy Center (MassCEC). This document is found through the WEC 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 Marion monitoring tower is located on a small peninsula that extends into Buzzards Bay in Marion, MA. The 50 m (164 ft) tower is located at $41^{\circ} 42' 33.84''$ North, $70^{\circ} 43' 21''$ West. The tower base is 35 m (114.83 ft) above sea level. The tower is identified with a yellow box in the center of Figure 1 below.



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 with internal temperature.
- 4 – NRG #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50 m (164 ft) and two anemometers are located at 39 m (128 ft).
- 2 – NRG #200P Wind direction vanes. The vanes are located at 50 m (164 ft) and 39 m (128 ft).

The data from the Symphonie logger is sent to RERL via a cellular modem once a day. The logger samples wind speed and direction once every two seconds. 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
Height Units	50 m [m/s]	50 m [m/s]	50 m [deg]	38 m [m/s]	38 m [m/s]	38 m [deg]
Aug-09	5.12	11.27	SSW	4.64	10.37	SSW
Sep-09	5.73	14.19	NE	5.08	12.76	NE
Oct-09	6.93	20.01	NE	6.07	18.00	NNE
Nov-09	6.78	14.83	NE	5.85	13.31	NE
Dec-09	7.28	22.65	NW	6.35	19.77	NW
Jan-10	6.49	25.90	WNW	5.78	22.50	WNW
Feb-10	6.59	19.16	WNW	5.81	17.37	WNW
Mar-10	7.85	21.59	NNE	6.91	19.52	NNE
Apr-10	5.85	14.39	SSW	5.20	12.94	SSW
May-10	5.64	14.84	SW	5.05	13.16	SSW
Jun-10	5.65	16.39	SSW	5.08	15.11	SSW
Jul-10	5.49	13.03	SSW	4.92	11.71	SSW
Jul 16, 2009 – Jul 15, 2010	6.28	25.90	SSW	5.56	22.50	SSW

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 ± 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 ± 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 the highest measurement height is between 9.5 and 10.5 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α , 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	Mean Wind Shear Coefficient, α
Height Units	50 m [-]	38 m [-]	Between 50 m and 38 m [-]
Aug-09	0.15	0.19	0.36
Sep-09	0.12	0.17	0.44
Oct-09	0.14	0.18	0.48
Nov-09	0.14	0.18	0.53
Dec-09	0.17	0.20	0.50
Jan-10	0.16	0.20	0.42
Feb-10	0.14	0.16	0.46
Mar-10	0.14	0.17	0.46
Apr-10	0.17	0.19	0.43
May-10	0.16	0.20	0.40
Jun-10	0.14	0.17	0.38
Jul-10	0.15	0.18	0.40
Jul 16, 2009 – Jul 15, 2010	0.15	0.18	0.44

The annual statistics are calculated for the period between July 16, 2009 and July 15, 2010.

SECTION 4- Long Term Estimate and Capacity Factor

Wind speed varies year by year and the mean obtained over the measurement period may be less or more compared to what is seen over a longer time period. Therefore, the use of the long term mean at the site is preferred when projecting the performance of a wind turbine. The long term mean at a site may be estimated by using the Measure-Correlate-Predict (MCP) method.

The MCP method correlates wind speed measurements at the target site to a reference site which collects data over the same period of time and has been collecting data for a much

longer period. Based on this correlation, the reference wind speed data is used to predict long term mean at the site.

Long term data from the BUZM3 buoy between January 1st, 1998 and December 31st, 2009 is used as reference in the case of Marion. Correlation between the two sites are obtained from concurrent data between July 15, 2009 and July 29, 2010. The long term mean at Marion at 50 m is estimated to be 6.5 m/s with an uncertainty of 4% for the MCP process. This estimate may also be used to calculate the long term mean at different heights by using the mean wind shear at site and the equation described in the previous section. The long term mean wind speed at 70 m height is estimated at 7.5 m/s.

The capacity factor of a wind turbine at a given site depends on the hub height, wind speed distribution at the hub height, the wind turbine power curve and any assumptions about down time and losses due to wake effects from upwind wind turbines, etc. If the hub height wind speed is estimated from data at lower heights, then the capacity factor will also depend on the estimated wind shear and the wind speeds measured at lower heights. No simple estimate of capacity factor at a site could take all of these effects and choices into account. Nevertheless, an estimate of the capacity factor of a wind turbine at this site is provided here to help the reader understand the order of magnitude of the wind resource at this site.

The estimates assume a GE 1.5 sl turbine with a hub height of 80 m and the long term mean wind speed estimate at the highest measurement height and the mean wind shear at the site, in order to determine the mean hub height wind speed, in this case 8.0 m/s. The wind speed probability distribution is assumed to be given by a Rayleigh distribution. The average wind turbine power is then estimated from:

$$\overline{P_w} = \int_0^{\infty} P_w(U) p(U) dU$$

where $P_w(U)$ is the wind turbine power curve and $p(U)$ is the wind speed probability distribution. The capacity factor is then calculated from:

$$CF = \frac{\overline{P_w}}{P_{rated}}$$

where P_{rated} is the rated capacity of the turbine, i.e., 1500 kW. Based on this equation, the estimated capacity factor of a wind turbine at this site would be about 0.45.

SECTION 5- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from one calendar year (July 16, 2009 to July 15, 2010). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. This graph includes all of the collected data.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. More than half of the time the wind speeds are between 4 m/s and 8 m/s.
- 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 whole period of data collection with a higher average wind speed over the winter months compared to summer.
- Diurnal – A plot of the average wind speed for each hour of the day. There is a slightly higher wind speed in the early afternoon, but the speed difference is not more than 1 m/s.
- 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. The location of this site, close to the coast, results in a generally lower turbulence intensity overall.
- 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. The wind comes mainly from 3 separate directions, Southwest, Northwest and Northeast. The wind from the Northeast occur less of the time but with a higher average speed, thereby increasing the potential of power generation from this direction.

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

Wind Speed Time Series

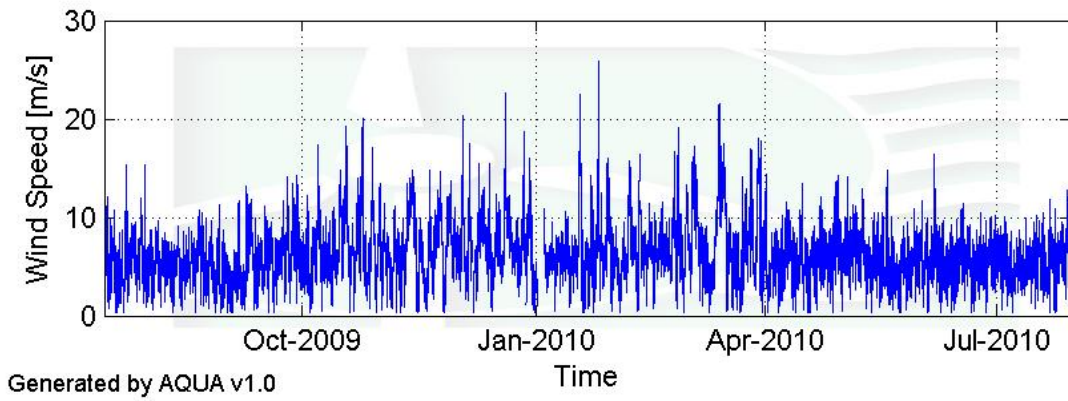


Figure 2 – Wind Speed Time Series, Jul 15, 2009 through Jul 29, 2010

Wind Speed Distributions

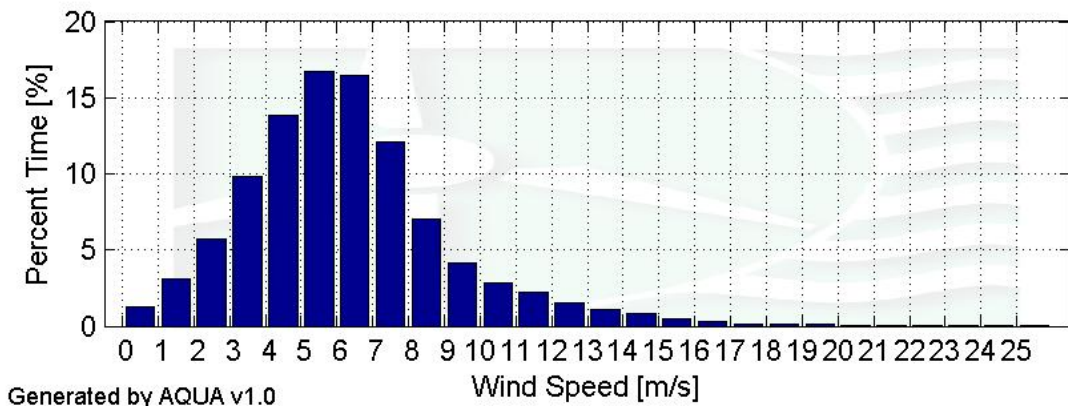


Figure 3 – Wind Speed Distribution, July 16, 2009 through July 15, 2010

Monthly Average Wind Speeds

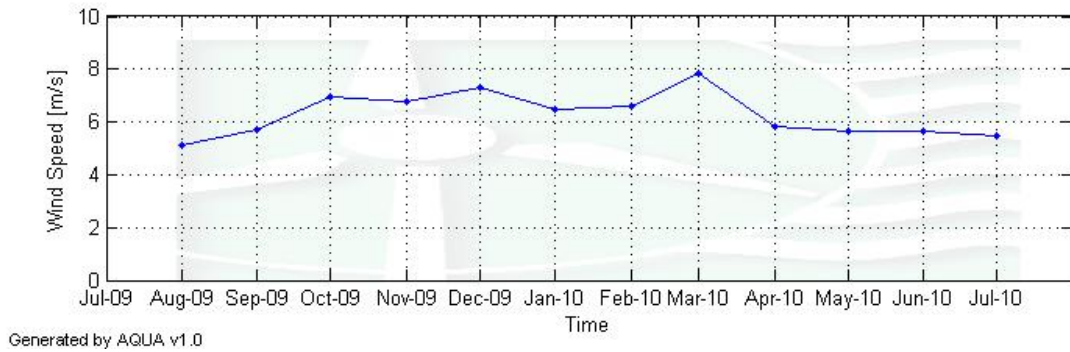


Figure 4 – Monthly Average Wind Speeds, August 2009 through July 2010

Diurnal Average Wind Speeds

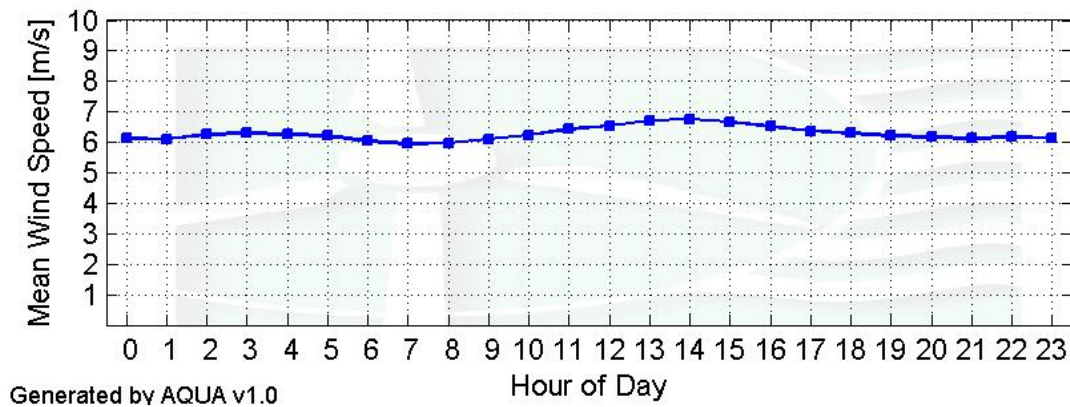


Figure 5 – Diurnal Average Wind Speed, July 16, 2009 through July 15, 2010

Turbulence Intensities

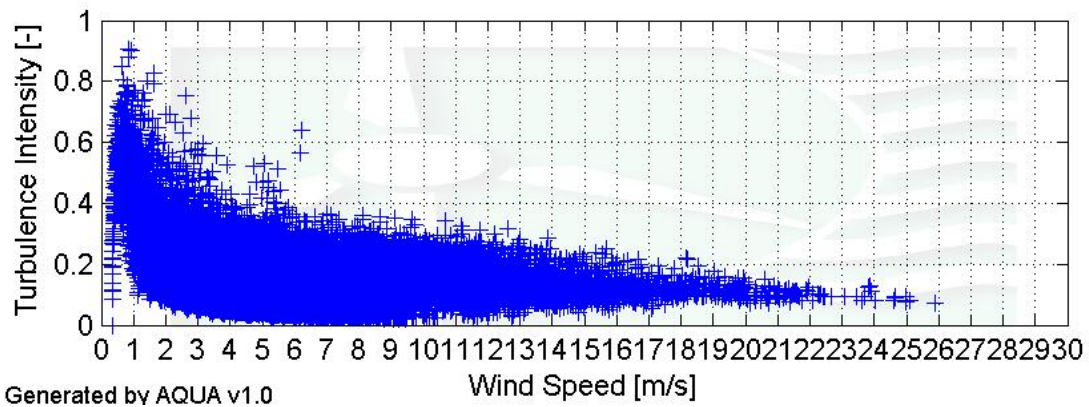
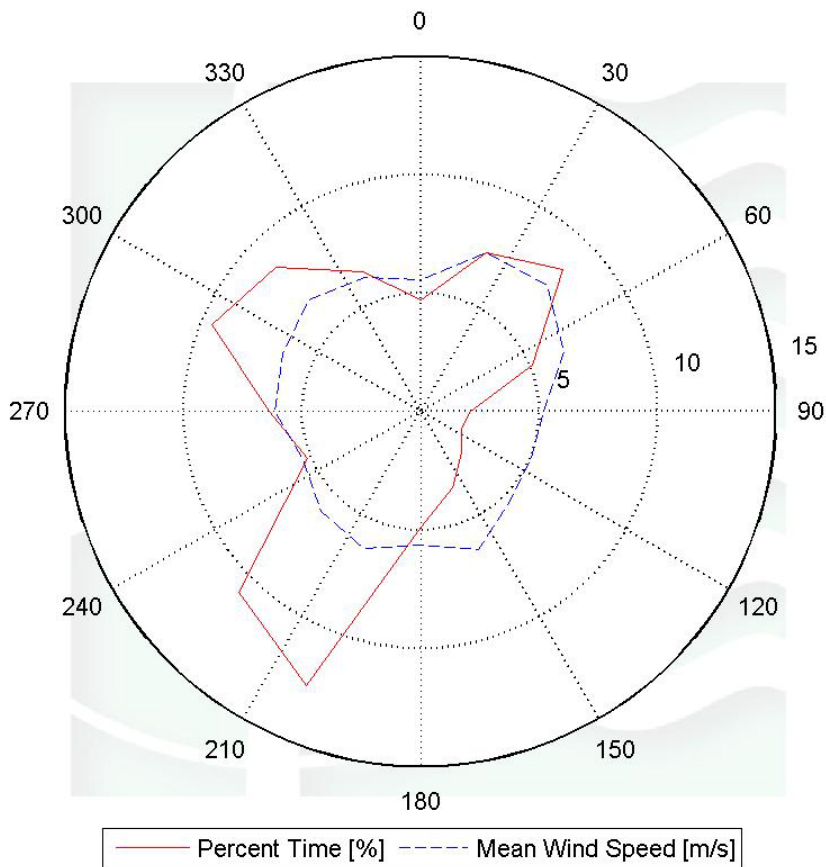


Figure 6 – Turbulence Intensity, July 16, 2009 through July 15, 2010

Wind Roses



Generated by AQUA v1.0

Figure 7 – Wind Roses, July 16, 2009 through July 15, 2010

SECTION 6 – Significant Meteorological Events

There were no severe meteorological events outside of the expected seasonal conditions.

SECTION 7 – Data Collection and Maintenance

There were no equipment or maintenance issues and no maintenance was performed once the tower is up.

SECTION 8 – 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 [%]	99.08

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 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	TestField1	TestField2	TestField3	CalcField1	CalcField2	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1	Temp00> T_val						MinMax	-30	60	0	0
2	Anem38a> WS_val						MinMax	0	90	0	0
3	Anem38a> WS_SD						MinMax	0	4	0	0
4	Anem38b> WS_val						MinMax	0	90	0	0
5	Anem38b> WS_SD						MinMax	0	4	0	0
6	Vane38a> WD_val						MinMax	0	359.9	0	0
7	Vane38a> WD_SD						MinMax	0	100	0	0
8	Anem50a> WS_val						MinMax	0	90	0	0
9	Anem50a> WS_SD						MinMax	0	4	0	0
10	Anem50b> WS_val						MinMax	0	90	0	0
11	Anem50b> WS_SD						MinMax	0	4	0	0
12	Vane50a> WD_val						MinMax	0	359.9	0	0
13	Vane50a> WD_SD						MinMax	0	100	0	0
14	Anem38a> WS_val	Anem38b> WS_val					Compare Sensors	1	0.25	3	0
15	Anem50a> WS_val	Anem50b> WS_val					Compare Sensors	1	0.25	3	0
16	Anem38a> WS_val	Anem38a> WS_SD	Vane38a> WD_val	Vane38a> WD_SD	Temp00> T_val		Icing	0.5	1	2	4
17	Anem38b> WS_val	Anem38b> WS_SD	Vane38a> WD_val	Vane38a> WD_SD	Temp00> T_val		Icing	0.5	1	2	4
18	Anem50a> WS_val	Anem50a> WS_SD	Vane50a> WD_val	Vane50a> WD_SD	Temp00> T_val		Icing	0.5	1	2	4
19	Anem50b> WS_val	Anem50b> WS_SD	Vane50a> WD_val	Vane50a> WD_SD	Temp00> T_val		Icing	0.5	1	2	4

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
Temp00	52560	52560	100	0	0	0	100
IntBatt00	52560	52560	100	0	0	0	100
Anem38a	52560	52560	100	0.17	43.67	53.17	98.90
Anem38b	52560	52560	100	0	44	50.83	98.92
Vane38a	52560	52560	100	2.17	44	0	99.47
Anem50a	52560	52560	100	0.17	104.83	14	98.64
Anem50b	52560	52560	100	0.33	104.67	74.5	97.95
Vane50a	52560	52560	100	1.17	104.83	0	98.79
Total	420480	420480	100	4	446	192.5	99.08

APPENDIX B – Plot Data

Wind Speed Distribution Data

Bin Center [m/s]	Percent Time [%]
0.5	1.25
1.5	3.13
2.5	5.73
3.5	9.78
4.5	13.84
5.5	16.7
6.5	16.46
7.5	12.09
8.5	7.03
9.5	4.19
10.5	2.88
11.5	2.24
12.5	1.53
13.5	1.07
14.5	0.83
15.5	0.46
16.5	0.31
17.5	0.14
18.5	0.1
19.5	0.09
20.5	0.05
21.5	0.05
22.5	0.02
23.5	0.01
24.5	0.01
25.5	0

Monthly Average Wind Speed Data

Month	Mean Wind Speed [m/s]
Jul-09	5.77
Aug-09	5.12
Sep-09	5.73
Oct-09	6.93
Nov-09	6.78
Dec-09	7.28
Jan-10	6.49
Feb-10	6.59
Mar-10	7.85
Apr-10	5.85
May-10	5.64
Jun-10	5.65
Jul-10	5.49

Wind Rose Data

Bin Center [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	4.7	5.55
22.5	7.23	7.27
45	8.4	7.57
67.5	5.07	6.55
90	2.12	5.2
112.5	1.88	5.08
135	2.46	5.36
157.5	3.51	6.35
180	4.91	5.64
202.5	12.59	6.28
225	10.9	5.98
247.5	5.24	5.37
270	6.41	6.15
292.5	9.56	6.3
315	8.64	6.68
337.5	6.38	6.11

Diurnal Average Wind Speed Data

Hour of Day	Mean Wind Speed [m/s]
0	6.11
1	6.1
2	6.25
3	6.3
4	6.27
5	6.22
6	6.04
7	5.95
8	5.97
9	6.09
10	6.23
11	6.43
12	6.53
13	6.71
14	6.76
15	6.69
16	6.52
17	6.36
18	6.29
19	6.22
20	6.18
21	6.13
22	6.17
23	6.16