LONG TERM SITE
WIND DATA QUARTERLY REPORT

Thompson Island

January 1, 2012 – March 31, 2012

Prepared for

Massachusetts Clean Energy Center
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by

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NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Wind Energy Center (WEC) at the University of Massachusetts, Amherst in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Clean Energy Center (MassCEC). 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 performed by the Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

Wind monitoring equipment was first installed at Thompson Island in 1998. Due to planned construction by the Outward Bound School on the island, the monitoring tower was relocated in November 2001 from a central, inland site, to the current site, which is closer to the western shoreline, 4 m (13 ft) above sea level. Anemometers and wind direction vanes are installed at 25 and 40 m (82 and 131 ft) above the tower base. A temperature sensor is installed near the base.

During the period covered by this quarterly report, January, 2012 – March 2012, the mean recorded wind speed at 40 m was 6.19 m/s (13.84 mph*) and the prevailing wind direction was from the West-Northwest. The average turbulence intensity measured at wind speeds near 10 m/s at 40 m was 0.13. The gross data recovery percentage (the actual percentage of expected data received) was 98.9% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 82.3%. The majority of the missing data were due to the failure of the primary anemometer at each of the two measurement heights. Wind speed data are available from redundant sensors at each height for more that 98% of the reporting period.

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

http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1 - Station Location

Thompson Island is located in Boston Harbor, approx 2 ½ miles south of Logan Airport. It is home to the Outward Bound School of Boston. The 40 m (131 ft) monitoring tower is located at 420-18'- 54.1" North, 0710- 00'-44.7" West (see Figure 1). The location is near the western shore of the island, located on a small bluff, 4 m (13 ft) above sea level.

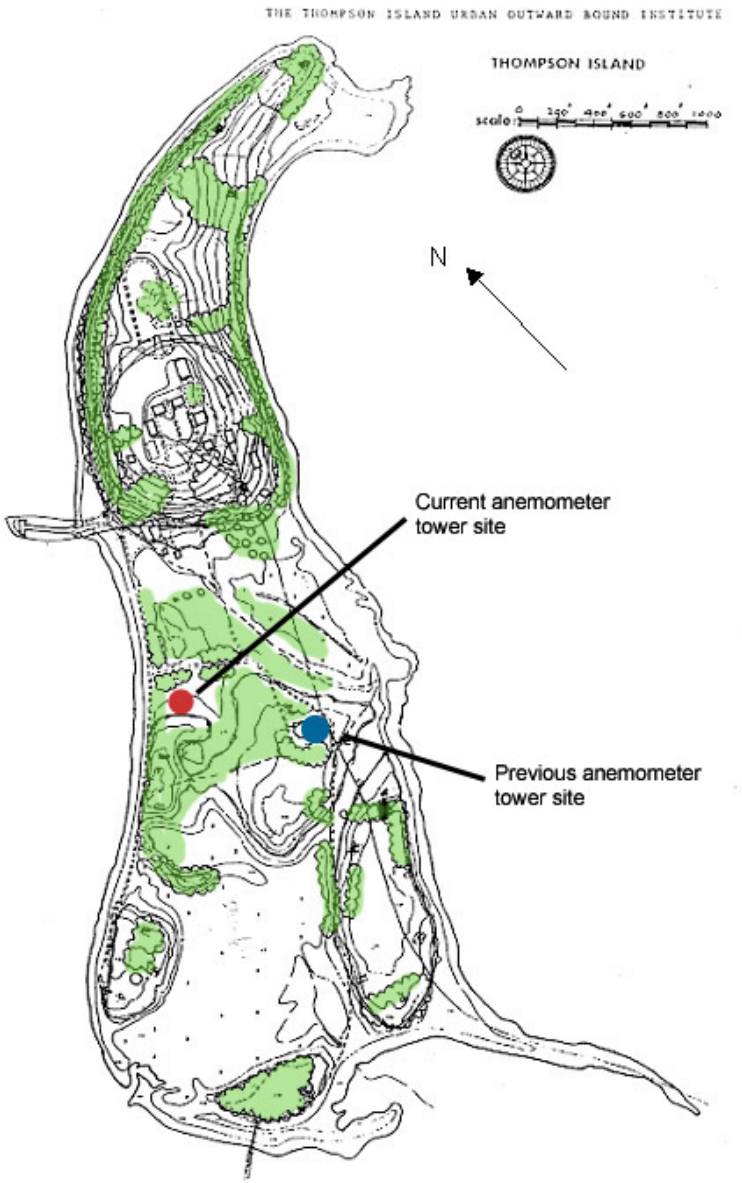

Figure 1 - Site location on Thompson Island

SECTION 2 - Instrumentation and Equipment

The 40 m (131 ft) monitoring tower and associated equipment are supplied by NRG systems, with the exceptions of custom made anemometer booms, temperature sensor, and the FAA-approved L-810 warning light. The wind speed and direction were measured at both 25 and 40 m (82 and 131 ft) height. The monitoring equipment (Figure 2) consists of the following items:

- Symphonie ® Data Logger with iPack Modem
- Electrical enclosure box with 5 watt PV panel
- NRG 40m tower, 6" diameter model
- 3 – NRG Max 40 Anemometers, 2 at 25 meters and 1 at 39 meters
- 1 – RISO anemometer at 39 meters
- 2 - #200P Wind direction vanes, located at 25 and 39 meters
- 1- NRG 110S temperature sensor
- 3 – Sensor booms, 54" length at 25 m
- 3 - Sensor booms, 44" length at 39 m
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 - Monitoring Station/Data Equipment at Thompson Island

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

	Month	Mean Wind Speed [m/s]	NDR [%]	Max Wind Speed [m/s]	NDR [%]	Prevailing Direction [deg]	NDR [%]
39 meters	12-Jan	6.424	96.17 %	19.2	96.17 %	WNW	96.62 %
	12-Feb	6.022	98.71 %	19.01	98.71 %	W	99.04 %
	12-Mar	6.119	99.96 %	19.05	99.96 %	SW	99.98 %
	Quarter	6.189	98.27 %	19.2	98.27 %	WNW	98.53 %
25 meters	12-Jan	6.259	95.86 %	18.12	95.86 %	W	96.01 %
	12-Feb	5.856	98.52 %	19	98.52 %	W	99.21 %
	12-Mar	5.87	99.89 %	17.8	99.89 %	SW	100 %
	Quarter	5.995	98.08 %	19	98.08 %	W	98.39 %

Wind data statistics in the table are reported when more than 90% of the data during the reporting period that are valid. In cases when a large amount of data is 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 ± 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 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, 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.

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

Table 2. Shear and Turbulence Intensity Data Summary

	Month	TI at 10 m/s [-]	NDR [%]	Mean Wind Shear Coefficient Between 39 and 25 meters
39 meters	12-Jan	0.1277	96.17 %	0.05845 NDR: 95.86%
	12-Feb	0.1336	98.71 %	0.06297 NDR: 98.52%
	12-Mar	0.1332	99.96 %	0.0935 NDR: 99.89%
	Quarter	0.1313	98.27 %	0.07188 NDR: 98.08%
25 meters	12-Jan	0.1326	95.86 %	
	12-Feb	0.1386	98.52 %	
	12-Mar	0.1426	99.89 %	
	Quarter	0.1375	98.08 %	

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 the three-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.

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

Wind Speed Time Series

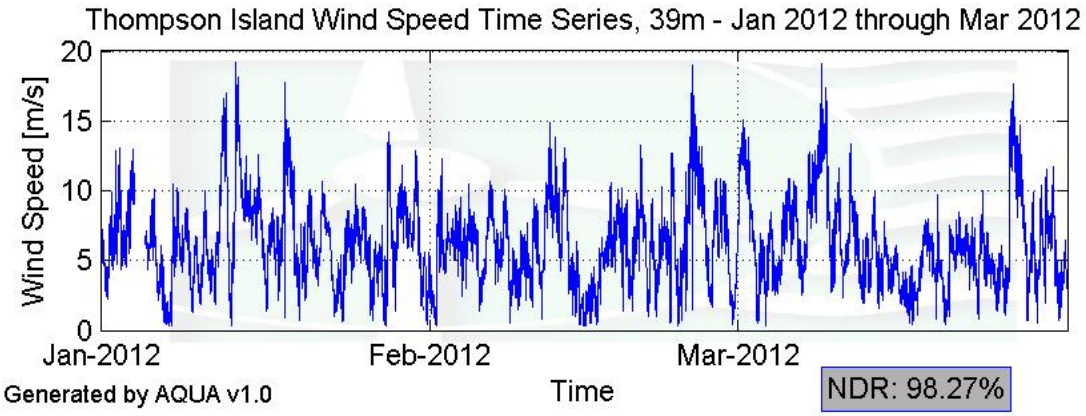

Figure 3 – Wind Speed Time Series

Wind Speed Distributions

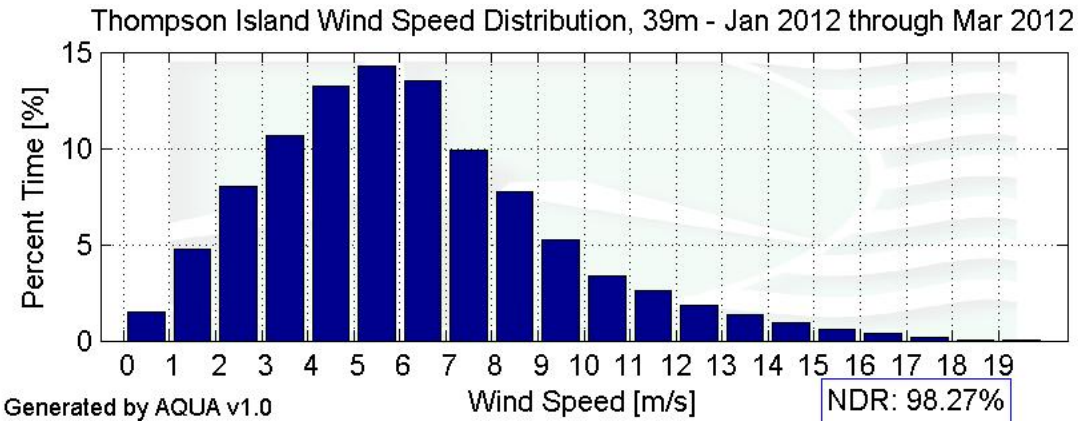

Figure 4 – Wind Speed Distribution

Monthly Average Wind Speeds

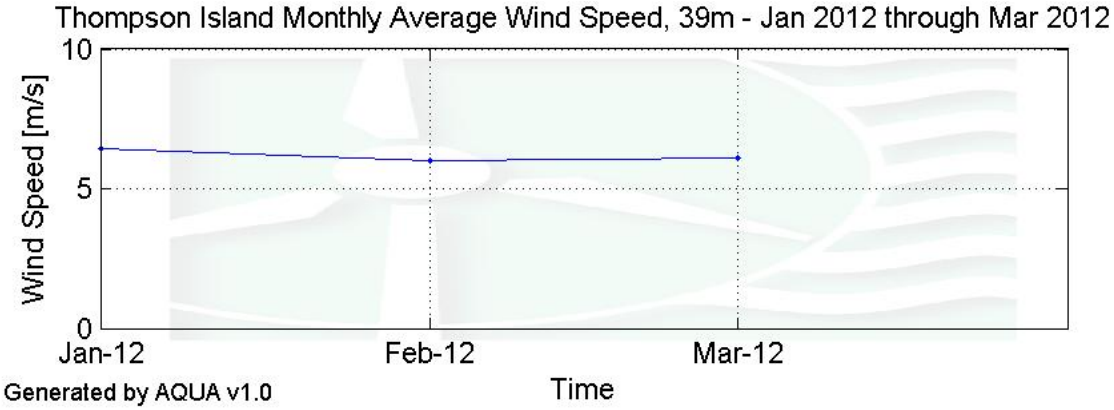

Figure 5 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

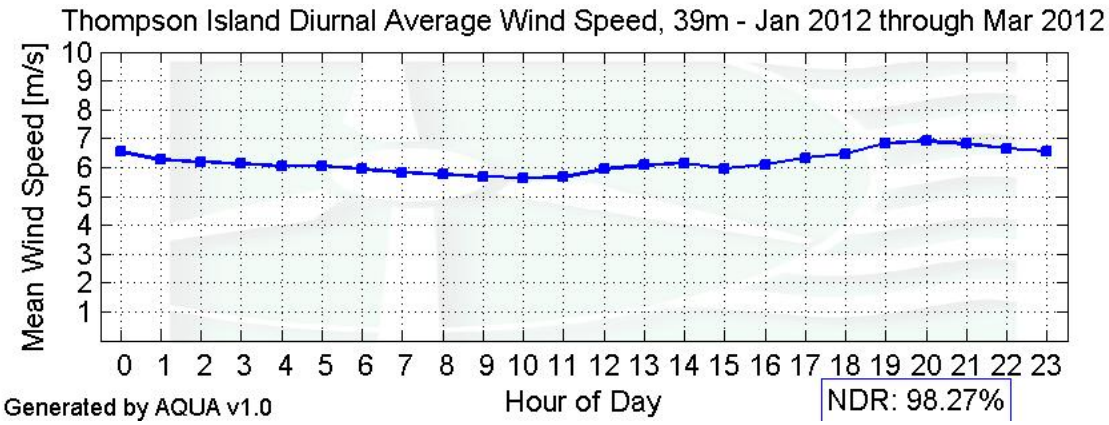

Figure 6 – Diurnal Average Wind Speeds

Turbulence Intensities

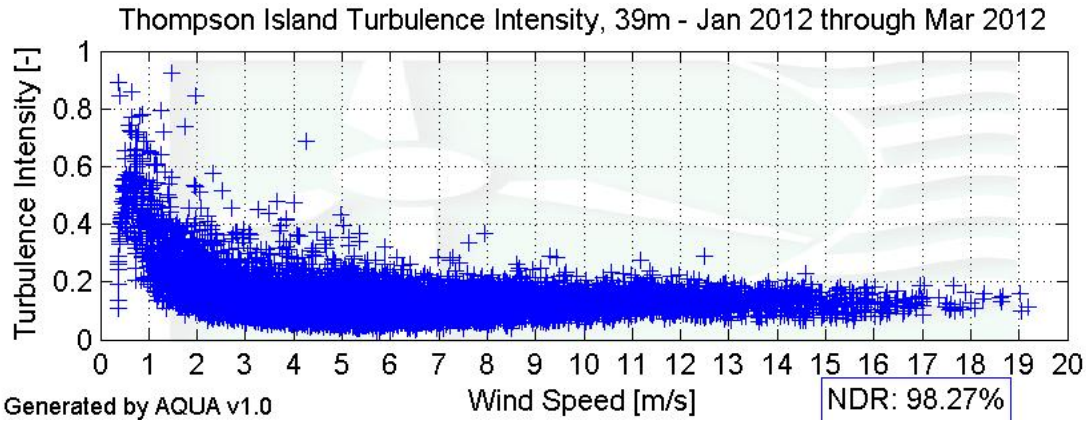

Figure 7 – Turbulence Intensity

Wind Roses

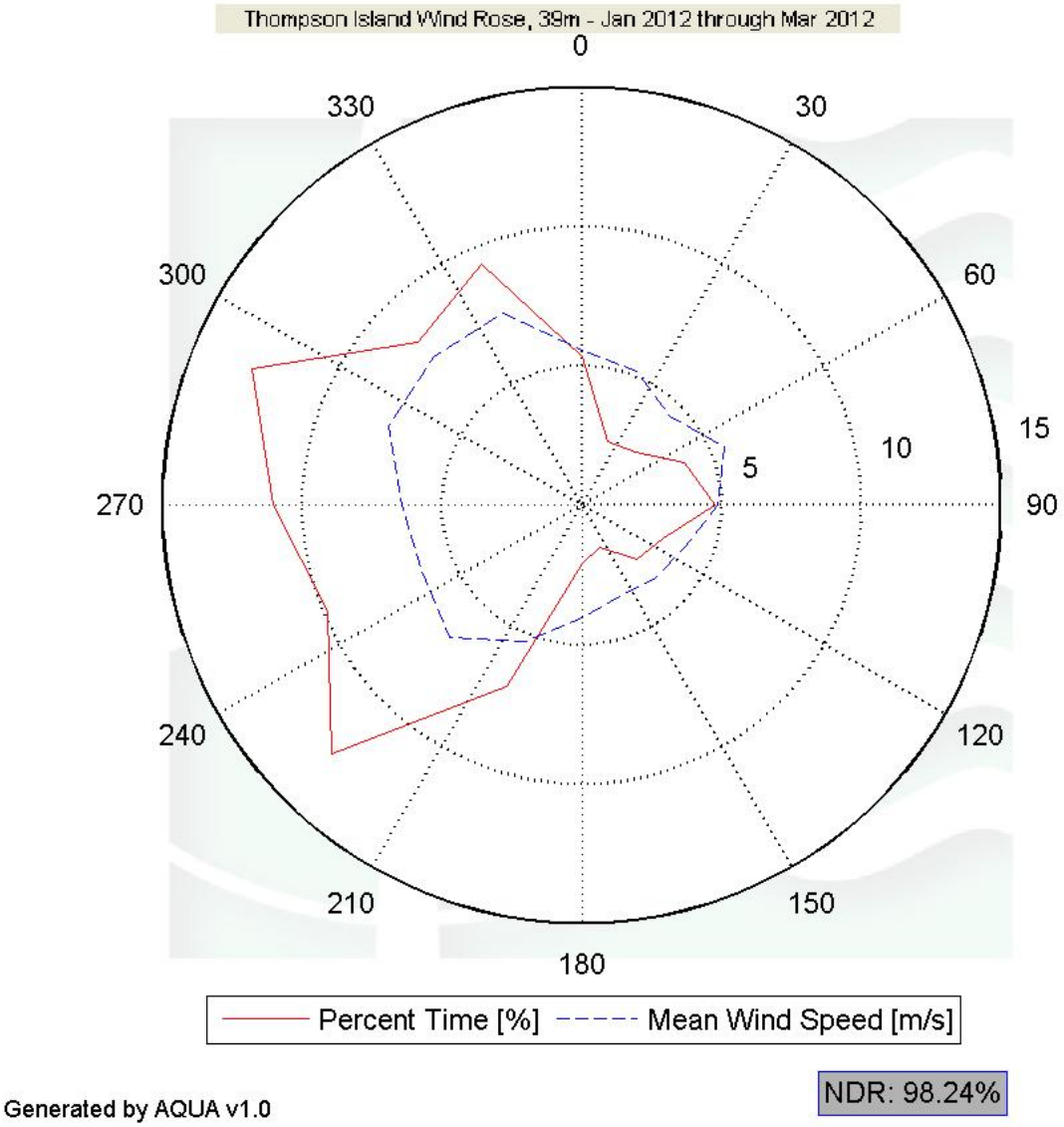

Figure 8 – Wind Rose

SECTION 5 - Significant Meteorological Events

The winter of 2011-2012 was unusually mild due to a strongly positive North Atlantic Oscillation. This may have affected wind conditions at this site.

More information on this phenomenon can be found here:

http://www.nc-climate.ncsu.edu/climate/patterns/NAO.html

SECTION 6 - Data Collection and Maintenance

Primary wind speed sensors at each height failed during the Fall of 2010 and remain only intermittently functional throughout this reporting period. Wind speed data are available from redundant sensors at each height for more that 98% of the reporting period.

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 [%]	98.9
Net Data Recovered [%]	82.3

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.

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

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

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	Temp2a>T_val						MinMax	-30	60	0	0
2	anem25a>WS_val						MinMax	0	90	0	0
3	anem25a>WS_SD						MinMax	0	4	0	0
4	anem25a>WS_min						MinMax	0	90	0	0
5	anem25a>WS_max						MinMax	0	90	0	0
6	anem25b>WS_val						MinMax	0	90	0	0
7	anem25b>WS_SD						MinMax	0	4	0	0
8	anem25b>WS_min						MinMax	0	90	0	0
9	anem25b>WS_max						MinMax	0	90	0	0
10	vane25a>WD_val						MinMax	0	359.9	0	0
11	vane25a>WD_SD						MinMax	0	100	0	0
12	vane25b>WD_val						MinMax	0	359.9	0	0
13	vane25b>WD_SD						MinMax	0	100	0	0
14	max40a>WS_val						MinMax	0	90	0	0
15	max40a>WS_SD						MinMax	0	4	0	0
16	max40a>WS_min						MinMax	0	90	0	0
17	max40a>WS_max						MinMax	0	90	0	0
18	max40b>WS_val						MinMax	0	90	0	0
19	max40b>WS_SD						MinMax	0	4	0	0
20	max40b>WS_min						MinMax	0	90	0	0
21	max40b>WS_max						MinMax	0	90	0	0
22	anem39a>WS_val						MinMax	0	90	0	0
23	anem39a>WS_SD						MinMax	0	4	0	0
24	anem39a>WS_min						MinMax	0	90	0	0
25	anem39a>WS_max						MinMax	0	90	0	0
26	anem39b>WS_val						MinMax	0	90	0	0
27	anem39b>WS_SD						MinMax	0	4	0	0
28	anem39b>WS_min						MinMax	0	90	0	0
29	anem39b>WS_max						MinMax	0	90	0	0
30	vane39a>WD_val						MinMax	0	359.9	0	0
31	vane39a>WD_SD						MinMax	0	100	0	0
32	vane39b>WD_val						MinMax	0	359.9	0	0
33	vane39b>WD_SD						MinMax	0	100	0	0
34	anem25a>WS_val	anem25b>WS_val					CompareSensors	1	0.25	3	0
35	max40a>WS_val	max40b>WS_val					CompareSensors	1	0.25	3	0
36	anem39a>WS_val	anem39b>WS_val					CompareSensors	1	0.25	3	0
37	anem25a>WS_val	anem25a>WS_SD	vane25a>WD_val	vane25a>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
38	anem25b>WS_val	anem25b>WS_SD	vane25a>WD_val	vane25a>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
39	anem25a>WS_val	anem25a>WS_SD	vane25b>WD_val	vane25b>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
40	anem25b>WS_val	anem25b>WS_SD	vane25b>WD_val	vane25b>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
41	anem39a>WS_val	anem39a>WS_SD	vane39a>WD_val	vane39a>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
42	anem39b>WS_val	anem39b>WS_SD	vane39a>WD_val	vane39a>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
43	anem39a>WS_val	anem39a>WS_SD	vane39b>WD_val	vane39b>WD_SD	Temp2a>T_val		Icing	0.5	1	2	4
44	anem39b>WS_val	anem39b>WS_SD	vane39b>WD_val	vane39b>WD_SD	Temp2a>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
temp2a	13104.000	12960.000	98.901	0.000	0.000	0.000	98.901
batt2a	13104.000	12960.000	98.901	0.000	0.000	0.000	98.901
anem25a	13104.000	12960.000	98.901	1414.167	0.833	246.500	22.833
anem25b	13104.000	12960.000	98.901	9.167	11.000	0.833	98.001
vane25a	13104.000	12960.000	98.901	0.167	11.000	0.000	98.390
anem39a	13104.000	12960.000	98.901	915.167	1.667	269.500	44.582
anem39b	13104.000	12960.000	98.901	7.167	7.500	0.000	98.230
vane39a	13104.000	12960.000	98.901	0.167	7.833	0.000	98.535
Total	104832.000	103680.000	98.901	2346.000	39.833	516.833	82.296

APPENDIX B- Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Jan-Mar Percent Time [%]
0.5	1.46
1.5	4.78
2.5	7.99
3.5	10.63
4.5	13.21
5.5	14.28
6.5	13.49
7.5	9.92
8.5	7.74
9.5	5.27
10.5	3.39
11.5	2.59
12.5	1.84
13.5	1.37
14.5	0.93
15.5	0.56
16.5	0.35
17.5	0.14

Monthly Average Wind Speed Data

Month	Wind Speed at 39 m 10 min Average [m/s]
12-Jan	19.2
12-Feb	19.01
12-Mar	19.05

Diurnal Average Wind Speed Data

Hour of Day	Jan-Mar. Mean Wind Speed [m/s]
0	6.54
1	6.25
2	6.20
3	6.12
4	6.05
5	6.06
6	5.94
7	5.83
8	5.74
9	5.69
10	5.63
11	5.65
12	5.93
13	6.07
14	6.14
15	5.97
16	6.09
17	6.32
18	6.48
19	6.85
20	6.92
21	6.82
22	6.65
23	6.56

Wind Rose Data

Direction Sector [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	5.34	5.55
22.5	2.48	5.18
45	2.70	4.49
67.5	3.98	5.52
90	4.79	4.86
112.5	3.14	3.98
135	2.76	3.70
157.5	1.65	3.56
180	2.07	4.02
202.5	7.06	5.32
225	12.66	6.71
247.5	9.87	6.20
270	11.03	6.44
292.5	12.79	7.47
315	8.30	7.53
337.5	9.36	7.44