WIND DATA REPORT

New Bedford

December 1, 2008 – February 28, 2009

Prepared for

Massachusetts Technology Collaborative
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by

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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 in New Bedford in October 2008. The base of the 50 meter meteorological tower is installed 4 meters above sea level. Anemometers and wind direction vanes are installed at 38 and 49 meters (125 and 160 feet) above the base of the tower. 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 the winter of 2008, between December 2008 and February 2009. The mean recorded wind speed was 7.24 m/s (16.2 mph) at 49 meters and the prevailing wind direction was from the west-northwest. The average wind shear exponent was 0.195. The average turbulence intensity at 49m was 0.137.

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 96.78%.

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.

SECTION 1 - Station Location

The New Bedford monitoring tower is located on a concrete pad owned by the Waste Water Treatment Facility. The 49 (161 ft) meter is located at 41° 35.638' North, 70° 54.331' West, shown below in Figure 1. The tower base is 4 meters (13 feet) above sea level.

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The 49 m (161 ft) monitoring tower is supplied by SecondWind, the sensors and logger are supplied by NRG systems. The wind speed and direction were measured at both 38 and 49 m height. The monitoring equipment consists of the following items:

- Symphony Data Logger, serial #3204
- SecondWind 50m tower
- 4-#40 Anemometers, standard calibration (Slope 0.765, Offset 0.350)
- 2-#200P Wind direction vanes (Slope 1.0, Offset 0.0)
- #110S Temperature sensor (Slope 0.138, Offset -86.383)
- 4- Sensor booms for anemometers, 54" length
- 2- Sensor booms for vanes, 44" length
- Lightning rod and grounding cable
- Shielded sensor wire

The logger samples data from the sensors once every two seconds. These samples are combined into 10-minute averages and are put into a binary file along with the standarddeviation for each 10-minute interval. These binary files are emailed to the University of Massachusetts, Amherst every morning. Using the NRG software BaseStation®, the binary files are converted into ASCII text files.

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.

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 is missing, the percent of the available data that is used to determine the data statistics is noted.

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	**49 m**	**49 m**	**49 m**	**38 m**	**38 m**	**38 m**
Units	**(m/s)**	**(m/s)**	**(-)**	**(m/s)**	**(m/s)**	**(-)**
Dec-08	8.05	25.98	SW	7.66	24.83	SW
Jan-09	6.21	23.67	WNW	5.92	24.44	WNW
Feb-09	7.46	24.83	WNW	7.07	24.05	W
Dec 2008 - Feb 2009	**7.24**	**25.98**	**WNW**	**6.88**	**24.83**	**W**

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

Date Height Units	Turbulence Intensity at 10 m/s 49 m [-]	Turbulence Intensity at 10 m/s 38 m [-]	Mean Wind Shear Coefficient, α Between 49 m and 38 m [-]
Dec 2008	.13	.14	.195
Jan 2009	.15	.13	.182
Feb 2009	.13	.14	.211
Dec 2008-Feb 2009	**.137**	**.137**	**.195**

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.

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

Wind Speed Time Series

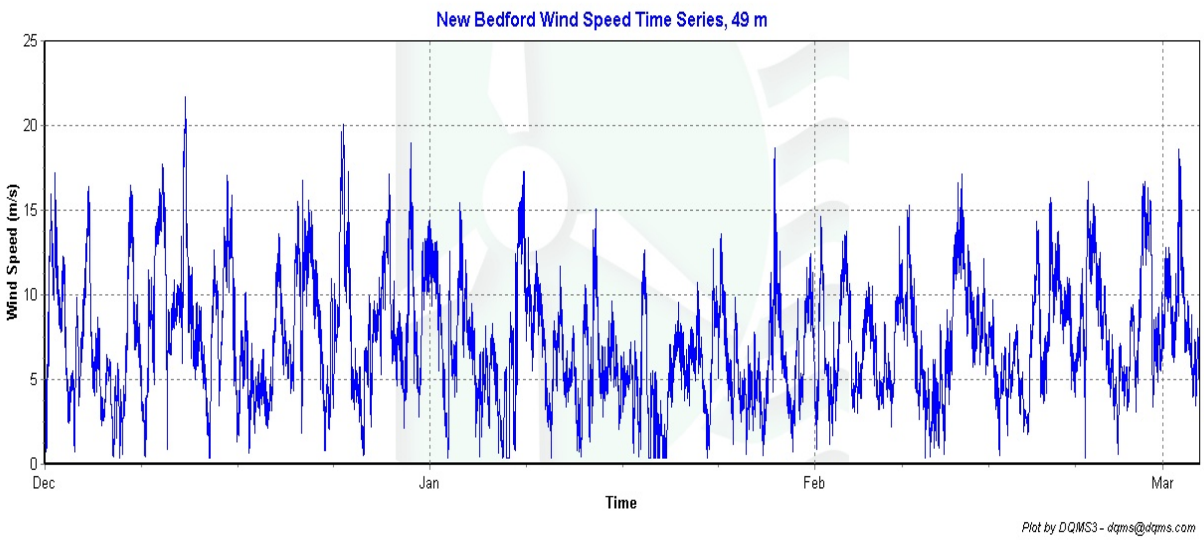

Figure 2 - Wind Speed Time Series, December 2008 – February 2009

Wind Speed Distributions

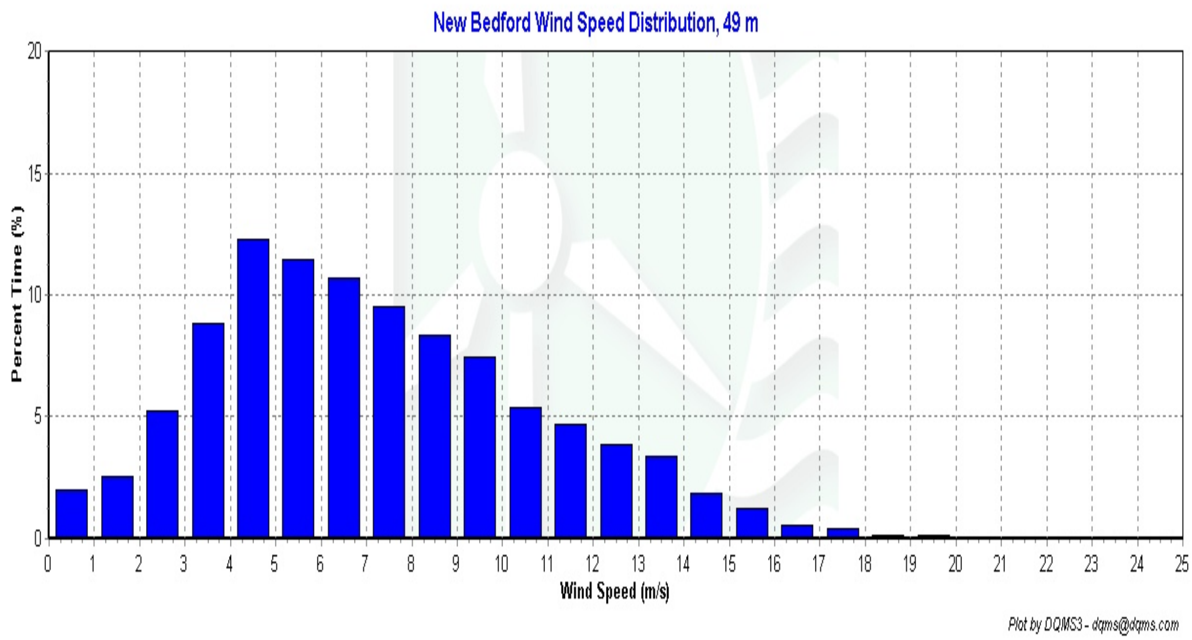

Figure 3 – Wind Speed Distribution, December 2008 – February 2009

Monthly Average Wind Speeds

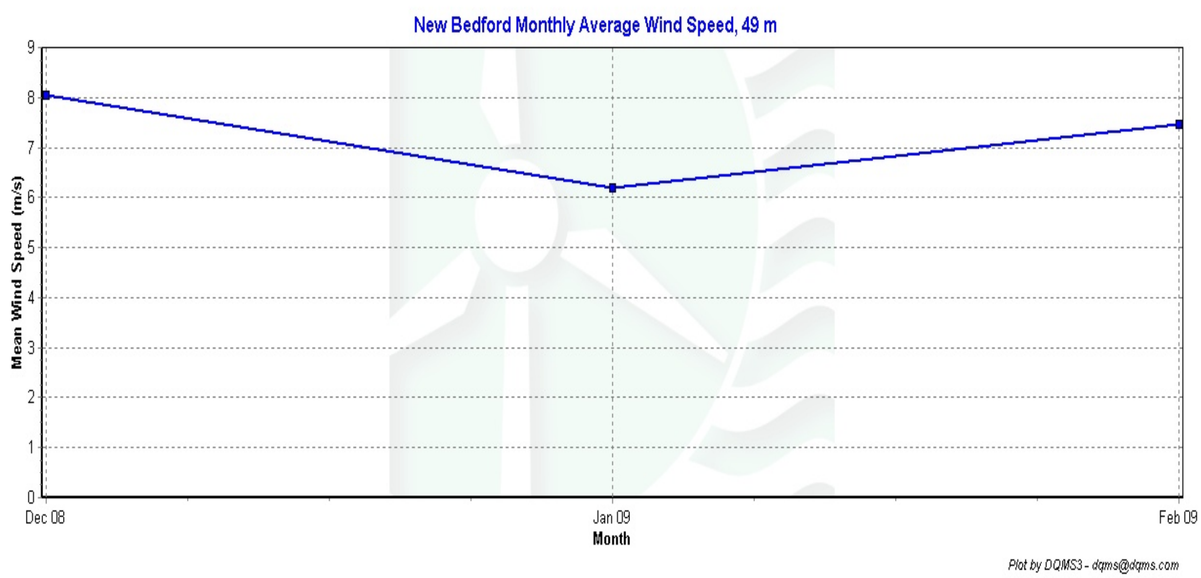

Figure 4 - Monthly Average Wind Speed, December 2008 – February 2009

Diurnal Average Wind Speeds

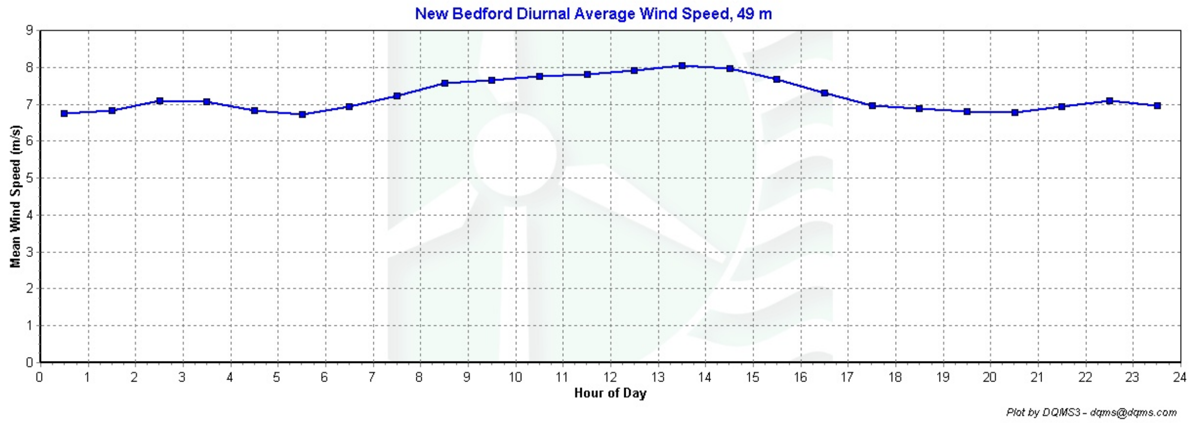

Figure 5 - Diurnal Average Wind Speed, December 2008 – February 2009

Turbulence Intensities

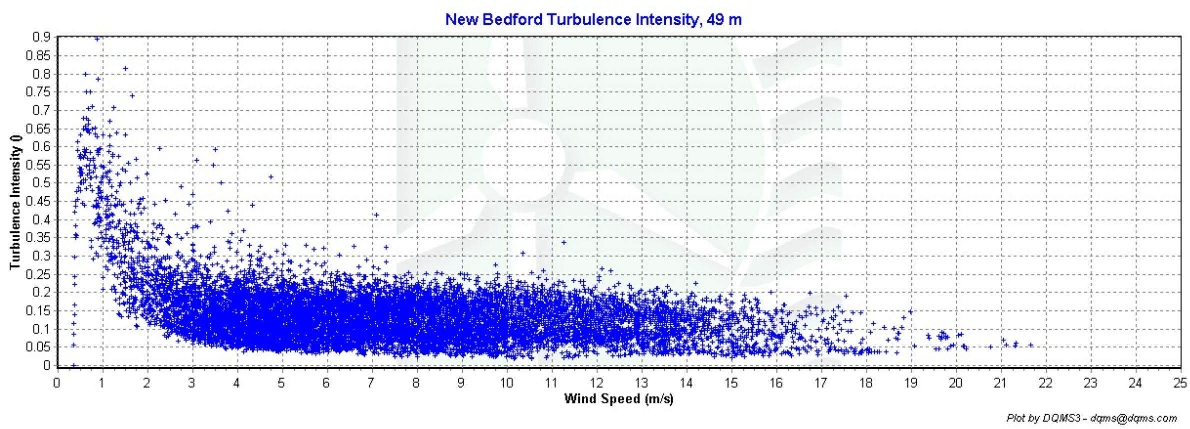

Figure 6 - Turbulence Intensity, December 2008 – February 2009

Wind Roses

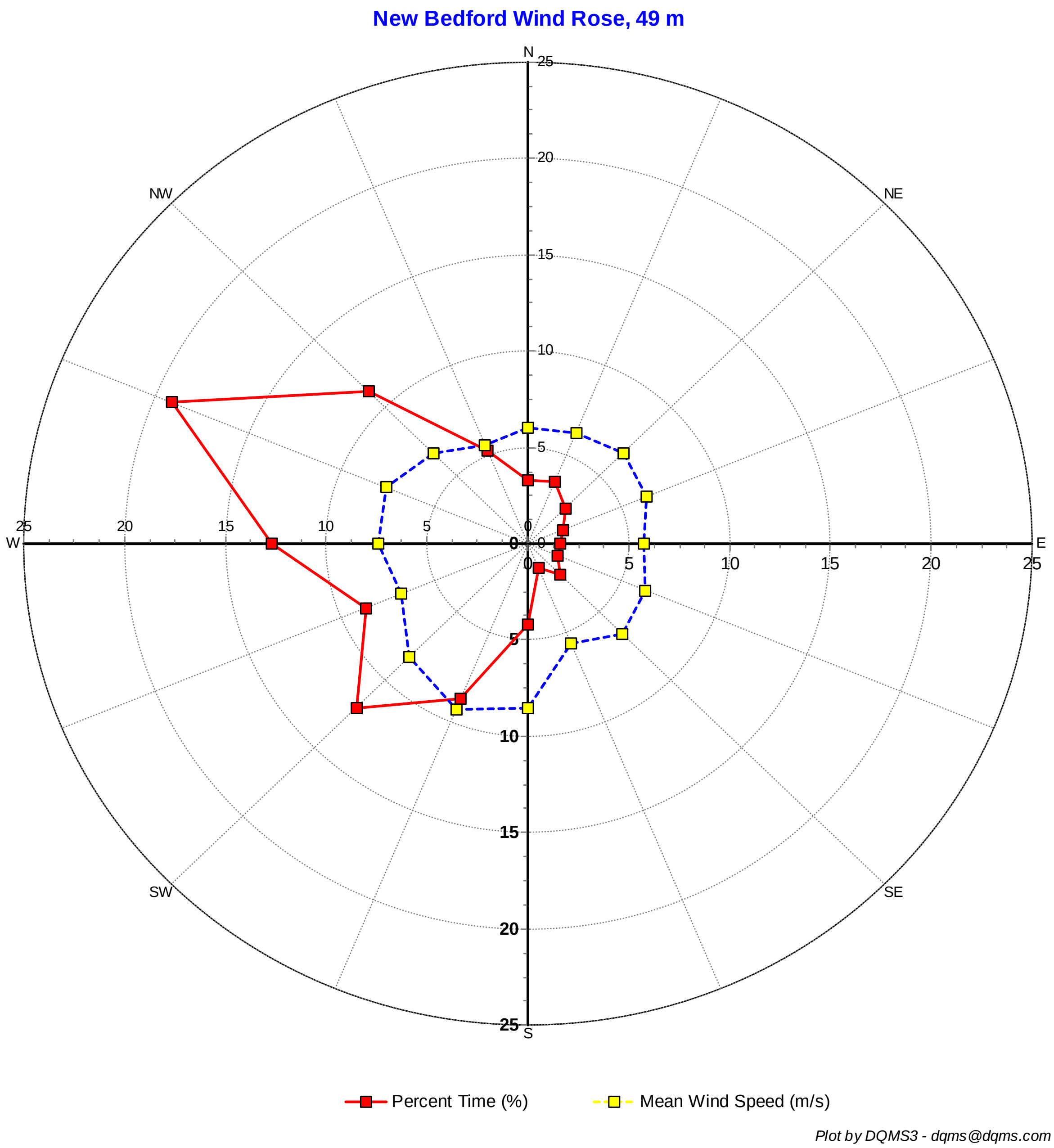

Figure 7 - Wind Rose, December 2008 – February 2009

SECTION 5 - Significant Meteorological Events

Winter of 2008-2009 experienced, on average, normal winds and precipitation, though on December 25th and February 12th both experienced 47 mile-per-hour gusts.

SECTION 6 - Data Collection and Maintenance

There were no maintenance/equipment problems during the report period, and no maintenance performed.

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 [%]	96.775

<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.

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

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.

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

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

Rec Code	Test Order	Test Active	Test Field 1	Test Field 2	Test Field 3	Calc Field 1	Calc Field 2	Calc Field 3	Test Type	Factor 1	Factor 2	Factor 3	Factor 4
A	1	☑							TimeTest Insert	0	0	0	0
A	3	☑	Batt0aVDC						MinMax	10.5	15	0	0
A	4	☑	Etmp0aDEG						MinMax	-30	60	0	0
A	5	☑	EtmpSD0aDI						MinMax	-30	60	0	0
A	10	☑	Anem49aMS						MinMax	0	90	0	0
A	11	☑	Anem49bMS						MinMax	0	90	0	0
A	12	☑	Anem38aMS						MinMax	0	90	0	0
A	13	☑	Anem49yMS						MinMax	0	90	0	0
A	14	☑	Anem38yMS						MinMax	0	90	0	0
A	16	☑	Anem38bMS						MinMax	0	90	0	0
A	17	☐								0	200	0	0
A	18	☐								0	200	0	0
A	20	☑	AnemSD49a						MinMax	0	4	0	0
A	21	☑	AnemSD49b						MinMax	0	4	0	0
A	22	☑	AnemSD38a						MinMax	0	4	0	0
A	23	☑	AnemSD38b						MinMax	0	4	0	0
A	30	☑	Vane49adeg						MinMax	0	359.9	0	0
A	31	☑	Vane38aDEC						MinMax	0	359.9	0	0
A	32	☑	VMax49aDEC						MinMax	0	359	0	0
A	33	☑	Vmin49aDEC						MinMax	0	359	0	0
A	34	☑	VMax38DEG						MinMax	0	359	0	0
A	35	☑	Vmin38DEG						MinMax	0	359	0	0
A	210	☑	VaneSD49aD	Anem49aMS					MinMaxT	0	100	100	10
A	211	☑	VaneSD38aD	Anem38aMS					MinMaxT	0	100	100	10
A	300	☑	Anem49aMS	AnemSD49	Vane49ade	VaneSD4	Etmp0aDE		Icing	0.5	1	2	4
A	301	☑	Anem49bMS	AnemSD49	Vane49ade	VaneSD4	Etmp0aDE		Icing	0.5	1	2	4
A	302	☑	Anem38aMS	AnemSD38	Vane38aDE	VaneSD4	Etmp0aDE		Icing	0.5	1	2	4
A	400	☑	Anem49aMS	Anem49bMS					CompareSensor	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem49aMS	12817	12817	100	0.333	93.833	20.333	94.64
AnemSD49aMS	12817	12817	100	0.333	93.833	20.333	94.64
Anem49bMS	12817	12817	100	0.333	96.333	72.167	92.096
AnemSD49bMS	12817	12817	100	0.333	96.333	72.167	92.096
Anem38aMS	12817	12817	100	0.167	95.667	0	95.514
AnemSD38aMS	12817	12817	100	0.167	95.667	0	95.514
Anem38bMS	12817	12817	100	0.167	0	0	99.992
AnemSD38bMS	12817	12817	100	0.167	0	0	99.992
Vane49adeg	12817	12817	100	0.167	96.333	0	95.483
VaneSD49aDEG	12817	12817	100	0.167	96.333	0	95.483
Vane38aDEG	12817	12817	100	0.167	95.667	0	95.514
VaneSD38aDEG	12817	12817	100	0.167	95.667	0	95.514
Anem49yMS	12817	12817	100	0	0	0	100
AnemSD49yMS	12817	12817	100	0.333	93.833	2.5	95.475
Anem38yMS	12817	12817	100	0	0	0	100
AnemSD38yMS	12817	12817	100	0.167	0	0	99.992
Etmp0aDEGC	12817	12817	100	0	0	0	100
EtmpSD0aDEGC	12817	12817	100	0	0	0	100
Total	230706	230706	100	3.167	1049.5	187.5	96.775

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed (m/s)	Percent of Time (%)
0.5	1.98
1.5	2.52
2.5	5.22
3.5	8.8
4.5	12.28
5.5	11.48
6.5	10.68
7.5	9.51
8.5	8.36
9.5	7.44
10.5	5.35
11.5	4.69
12.5	3.84
13.5	3.39
14.5	1.87
15.5	1.25
16.5	0.55
17.5	0.41
18.5	0.17
19.5	0.12
20.5	0.05
21.5	0.04
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Month	Average Wind Speed (m/s)
Dec	8.05
Jan	6.21
Feb	7.46

Diurnal Average Wind Speed Data

Bin Center Wind Speed (m/s)	Average Wind Speed (m/s)
0.5	6.76
1.5	6.83
2.5	7.09
3.5	7.06
4.5	6.83
5.5	6.73
6.5	6.94
7.5	7.23
8.5	7.58
9.5	7.65
10.5	7.76
11.5	7.81
12.5	7.91
13.5	8.04
14.5	7.96
15.5	7.67
16.5	7.3
17.5	6.97
18.5	6.88
19.5	6.81
20.5	6.78
21.5	6.94
22.5	7.1
23.5	6.95

Wind Rose Data

Direction	Percent Time (%)	Mean Wind Speed (m/s)
0	3.3	6.02
22.5	3.46	6.25
45	2.62	6.67
67.5	1.91	6.38
90	1.62	5.77
112.5	1.6	6.32
135	2.26	6.6
157.5	1.34	5.58
180	4.2	8.58
202.5	8.75	9.3
225	12.04	8.3
247.5	8.71	6.8
270	12.67	7.42
292.5	19.13	7.61
315	11.15	6.65
337.5	5.23	5.5