WIND DATA REPORT

Bourne Water District

December 2009 to February 2010

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Dylan Chase
James F. Manwell
Utama Abdulwahid
Anthony F. Ellis

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Renewable **E**nergy **R**esearch **L**aboratory
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.ceere.org/rerl • (413) 545-4359 • rerl@ecs.umass.edu

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

Wind monitoring equipment was installed at the Bourne Water District site on November 18th 2009. The base of the 50 meter meteorological tower was installed 24 meters above sea level. Anemometers were installed at heights of 38 and 50 meters (124.7 and 164.0 feet) above the tower base. Redundant anemometers and wind vanes were installed at both heights. A temperature sensor was installed near the base of the tower.

This report summarizes the wind data collected during the winter of 2009 and 2010, between December and February. The mean recorded wind speed was 5.66 m/s (12.66 mph*) at 50 meters, and the prevailing wind direction was from the southwest. The average wind shear component was 0.36 and the average turbulence intensity at 50 meters was 0.20.

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 98.078%.

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 site is located in a wooded area that can be reached by an access road. The site was cleared to erect the tower. The location of the tower is 41°42’35.00 N, 70°35’44.10 W and the base of the 50 meter tower is 24 meters above sea level. The approximate tower location is marked by the blue box shown in Figure 1.

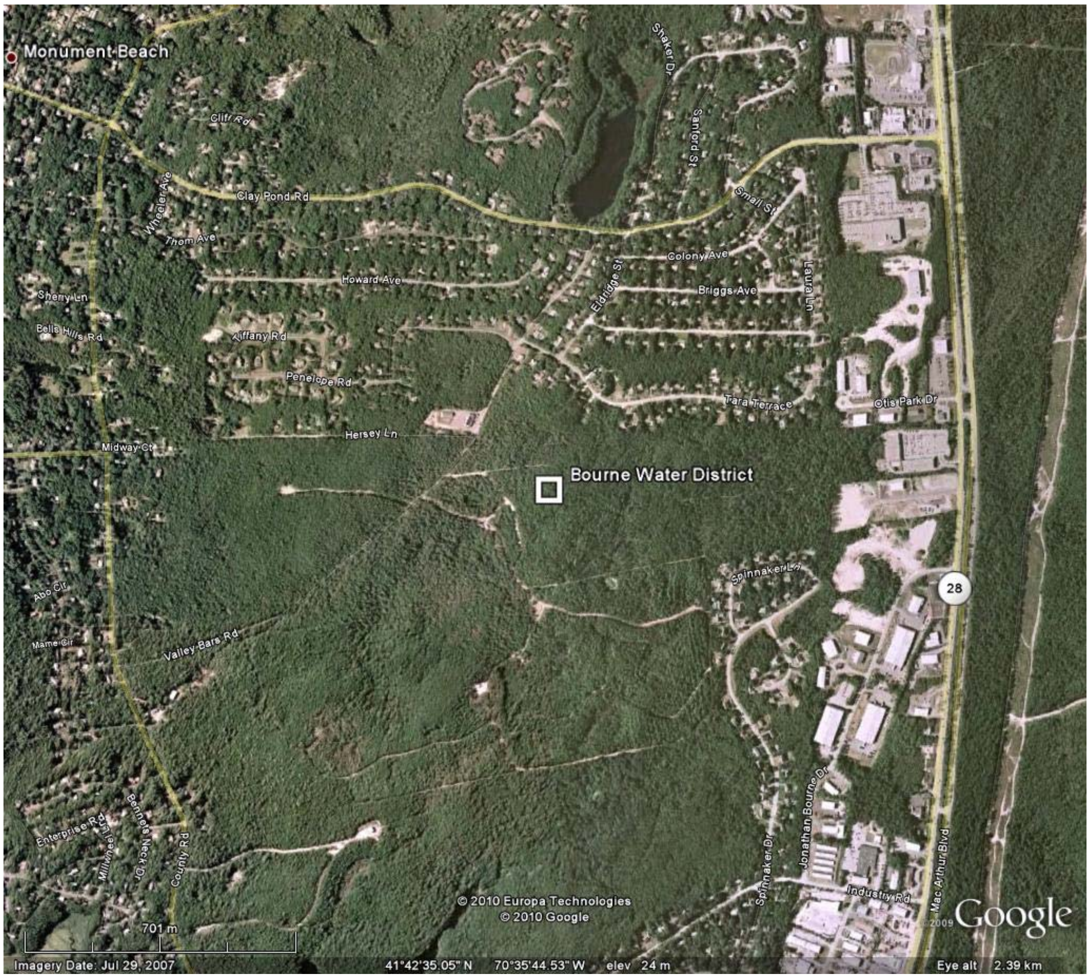

Figure 1 – Site Location

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
- 1 – NRG#40C Anemometer, calibrated (Slope – 0.755 m/s, offset – 0.37 m/s) located at 50 m (164.0 ft).
- 3 – NRG #40C3 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). One anemometer is located at 50 m (164.0 ft), and two anemometers are located at 38 m (124.7 ft).
- 2 – NRG #200P Wind direction vanes. The vanes are located at 50 m (164.0 ft) and 38 m (124.7 ft).
- NRG 110S temperature Sensor located near the base of the tower.

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 [m/s]**	**38 m [m/s]**	**38 m [m/s]**	**38 m [m/s]**
Dec 2009	6.14	17.29	WSW	5.53	15.84	WSW
Jan 2010	5.31	17.78	SW	4.81	16.31	SW
Feb 2010	5.48	17.14	SW	5.02	16.03	SW
Dec 2009 - Feb 2010	**5.66**	**17.78**	**SW**	**5.13**	**16.31**	**WSW**

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 ± 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.

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

Table 2. Shear and Turb ulence Intensity Data Summary

Date Height Units	Turbulence Intensity at 10 m/s 50 m [-]	Turbulence Intensity at 10 m/s 38 m [-]	Mean Wind Shear Coefficient, α Between 50 m and 38 m [-]
Dec 2009	0.20	0.23	0.38
Jan 2009	0.21	0.23	0.36
Feb 2009	0.21	0.23	0.32
Dec 2009 -Feb 2010	**0.21**	**0.23**	**0.36**

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 Bourne Water District site, the following observations are noted.

- Time Series, Figure 2: shows that the wind speed seldom exceeded 15 m/s at the site during the winter months.
- Wind Speed Distribution, Figure 3: wind speeds are primarily between 3 and 7 m/s during the winter months and the most common wind speed is between 4 and 5 m/s. The wind speed distribution is skewed towards higher wind speeds.
- Monthly Average, Figure 4: shows that the average monthly wind speeds at the site were highest in December and slightly lower in January and February.
- Diurnal, Figure 5: shows that on average the wind speed was fairly constant. The wind speed was slightly higher during the daytime hours during the winter months.
- 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 at this site are from the southwest and the west-southwest directions during the winter months. However, the maximum wind speeds came from the east and northwest directions.

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>

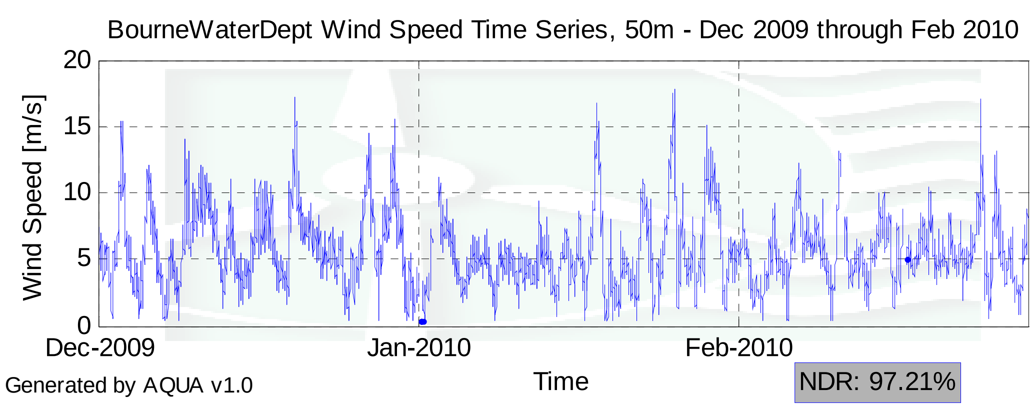

Figure 2 – Wind Speed Time Series, December 2009 – February 2010

Wind Speed Distributions

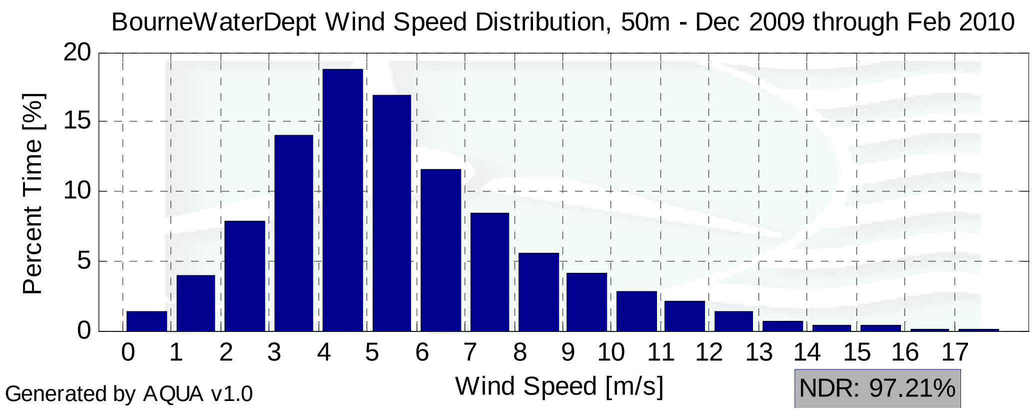

Figure 3 – Wind Speed Distribution, December 2009 – February 2010

Monthly Average Wind Speeds

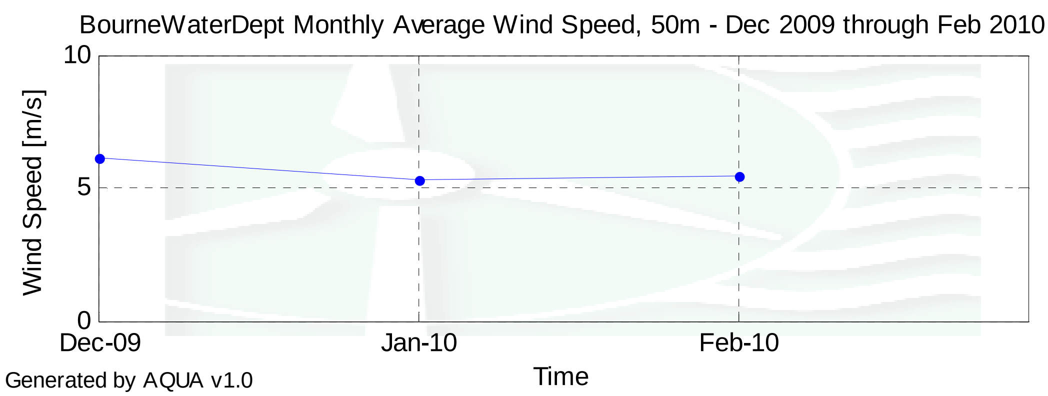

Figure 4 – Monthly Average Wind Speed, December 2009 – February 2010

Diurnal Average Wind Speeds

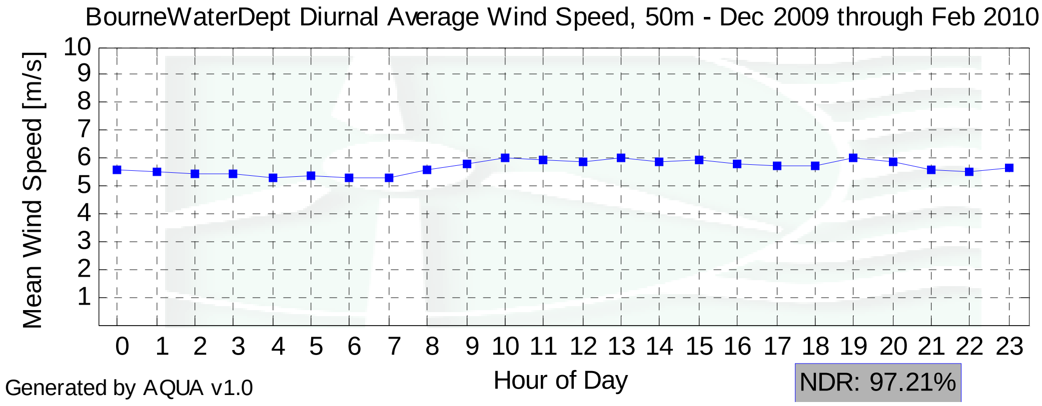

Figure 5 – Diurnal Average Wind Speeds, December 2009 – February 2010

Turbulence Intensities

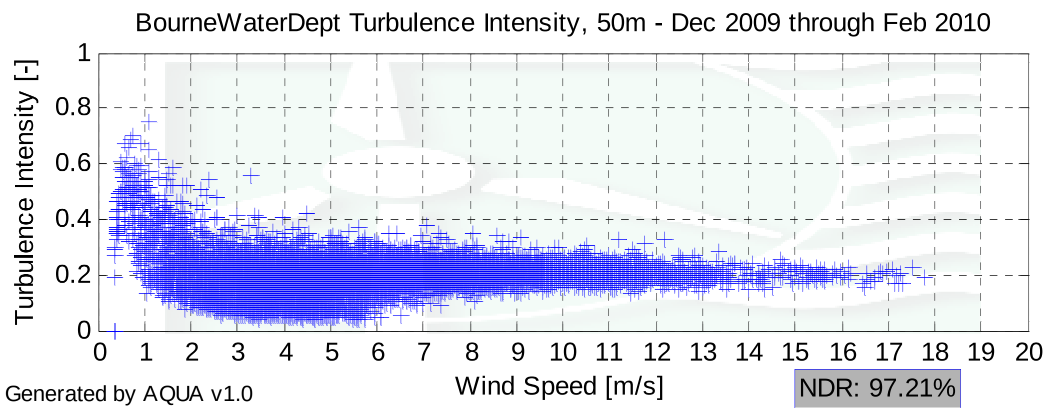

Figure 6 – Turbulence Intensity, December 2009 – February 2010

Wind Roses

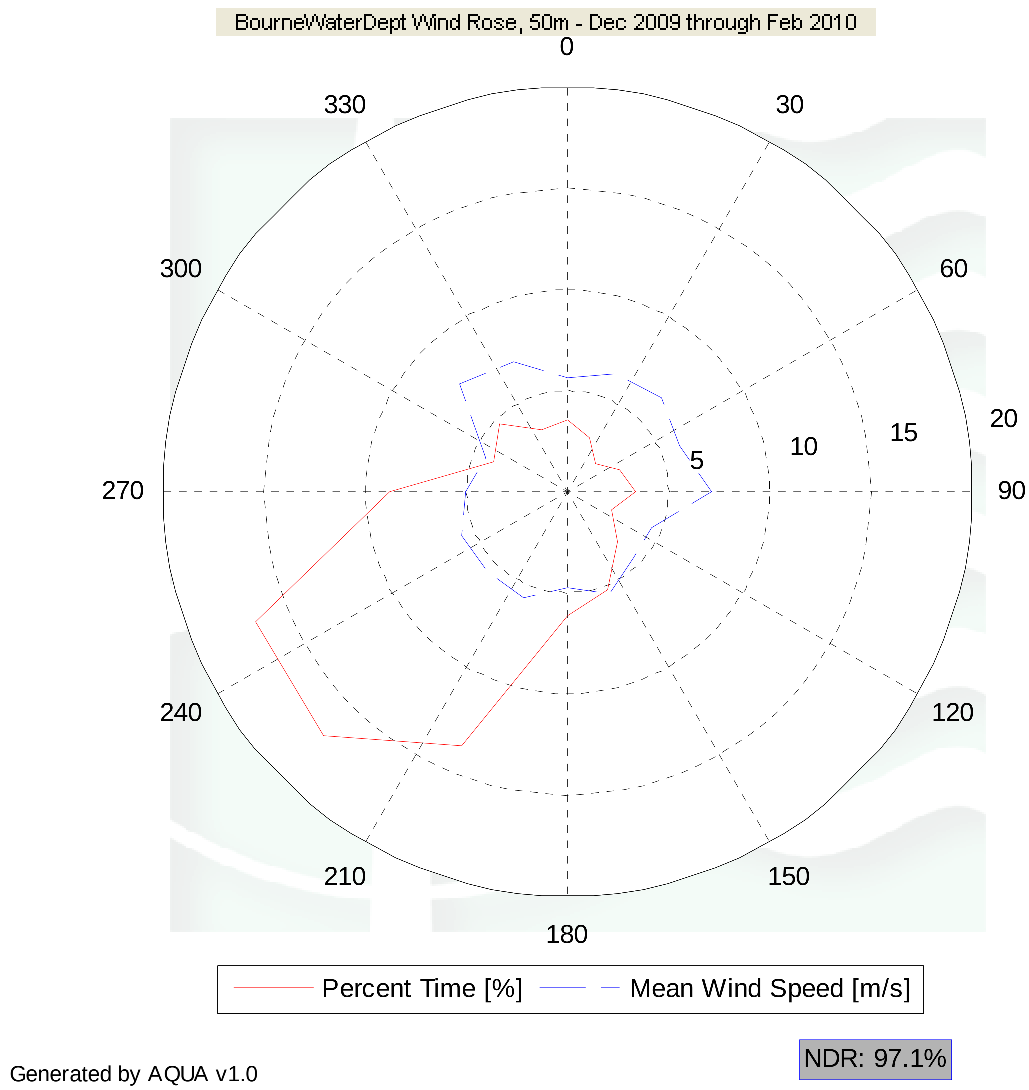

Figure 7 – Wind Rose, December 2009 – February 2010

SECTION 5 - Significant Meteorological Events

There were no extreme metrological events during this data collection period. The highest recorded wind speed was 17.78 m/s (39.77 mph) at 50 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 [%]	98.078

<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.

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

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

MinMax Test			
Description	**Variable**	**Min**	**Max**
Wind Speed	WS_val	0	90
Standard Deviation of the Wind Speed	WS_SD	0	4
Minimum Wind Speed	WS_min	0	90
Maximum Wind Speed	WS_max	0	90
Wind Direction	WD_val	0	359.9
Standard Deviation of the Wind Direction	WD_SD	0	100
Temperature	T_val	-30	60
Standard Deviation of the Temperature	T_SD	0	0
Minimum Temperature	T_max	-30	60
Maximum Temperature	T_min	-30	60

Compare Sensors Test	
Wind Speed Regime Threshold	3
Allowable Speed Difference - low	1
Allowable Ratio Difference - high	0.25

Icing Test	
Wind Speed Bound	1
Wind Direction Standard Deviation Bound	0.5
Temperature Bound	2
Wind Direction Standard Deviation Exit	4

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
Temp	12960	12960	100	0	0	0	100
Anem38a	12960	12960	100	0.167	32.667	3.333	98.326
Vane38	12960	12960	100	0	32.833	0	98.48
Anem38b	12960	12960	100	0	32.167	3	98.418
Anem50b	12960	12960	100	0	56.667	6	97.099
Vane50	12960	12960	100	0	62.667	0	97.099
Anem50a	12960	12960	100	0.167	61.333	0.667	97.122
Total	90720	90720	100	0.333	278.333	13	98.078

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Dec. – Feb. Percent Time [%]
0.5	1.44
1.5	3.94
2.5	7.81
3.5	14.02
4.5	18.77
5.5	16.91
6.5	11.57
7.5	8.36
8.5	5.52
9.5	4.07
10.5	2.8
11.5	2.02
12.5	1.34
13.5	0.6
14.5	0.33
15.5	0.33
16.5	0.12
17.5	0.06

Monthly Average Wind Speed Data

Month	Wind Speed at 50 m 10 min Average [m/s]
Dec-09	6.144
Jan-10	5.313
Feb-10	5.483

Diurnal Average Wind Speed Data

Hour of Day	Dec. - Feb. Mean Wind Speed [m/s]
0	5.58
1	5.49
2	5.46
3	5.45
4	5.29
5	5.34
6	5.28
7	5.27
8	5.56
9	5.79
10	5.97
11	5.91
12	5.86
13	6.02
14	5.87
15	5.93
16	5.81
17	5.7
18	5.7
19	5.98
20	5.85
21	5.55
22	5.48
23	5.61

Wind Rose Data

Bin Center [deg]	Dec. - Feb.	
	Percent Time [%]	Mean Wind Speed [m/s]
0	3.55	5.65
22.5	2.91	6.29
45	1.92	6.63
67.5	2.8	6.01
90	3.32	7.08
112.5	2.36	4.55
135	3.5	4.61
157.5	5.27	5.47
180	6.17	4.79
202.5	13.61	5.72
225	17.07	5.62
247.5	16.73	5.72
270	8.78	5.01
292.5	4.01	4.44
315	4.71	7.58
337.5	3.31	6.95