WIND DATA REPORT

Yarmouth

September 2009 – November 2009

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Daniel Finn-Foley
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

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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 Yarmouth Water Dept site in August 2009. The base of the 50 meter meteorological tower was installed 5 meters above sea level. Anemometers were installed at heights of 38 and 49 meters (124.7 and 160.8 feet) above the tower base. Redundant anemometers 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 fall of 2009, between September and November. The mean recorded wind speed was 5.483 m/s (12.27 mph*) at 49 meters, and the prevailing wind direction was from the northeast. The average wind shear component was 0.40 and the average turbulence intensity at 49 meters was 0.21.

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 99.35%

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 tower is located on a field adjacent to the Water Department of Yarmouth Massachusetts with the coordinates of 41.66215º N, 70.22458º W. The location is marked by a white square 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), and two anemometers are located at 38 m (124.7 ft).
- 2 – NRG #200P Wind direction vanes. The vanes are located at 49 m (160.8 ft) and 38 m (124.7 ft).
- NRG 110S temperature Sensor located near the base of the tower.

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 data file from the Symphonie logger is sent to RERL via a cellular modem daily. These files are converted to ASCII text files using NRG software. The 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	**49 m [m/s]**	**49m [m/s]**	**49m [m/s]**	**38 m [m/s]**	**38 m [m/s]**	**38 m [m/s]**
Sep 2009	4.884	12.09	WSW	4.441	11.46	WSW
Oct 2009	5.779	15.37	NNE	5.169	13.97	NE
Nov 2009	5.785	13.11	NE	5.227	12.06	NE
Sept 2009 Nov 2009	**5.483**	**15.37**	**NE**	**4.946**	**13.97**	**NE**

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.

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

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	**49 m [-]**	**38 m [-]**	**Between 49 m and 38 m [-]**
Sept 2009	.2025	.2233	.3681
Oct 2009	.2065	.2204	.4391
Nov 2009	.2112	.2366	.3991
Sept 2009 -Nov 2009	**.2084**	**.2288**	**.4049**

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 respect to the Yarmouth Water Dept location the graphs show the following trends:

- Time Series, Figure 2: Wind speed generally stayed below 15 m/s during the fall months.
- Distribution, Figure 3: Wind speeds are primarily between 2 and 10 m/s, with the most common wind speed between 4 and 5 m/s.
- Monthly Average, Figure 4: Average wind speed increased during the fall.
- Diurnal, Figure 5: Wind speeds on average were highest during the hours around noon each day.
- Turbulence Intensity, Figure 6: Turbulence intensity clusters between .1 and .3 for most wind speeds, increasing at low wind speeds.
- Wind Rose, Figure 7: The wind came primarily from the northeast during the fall months.

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

Wind Speed Time Series

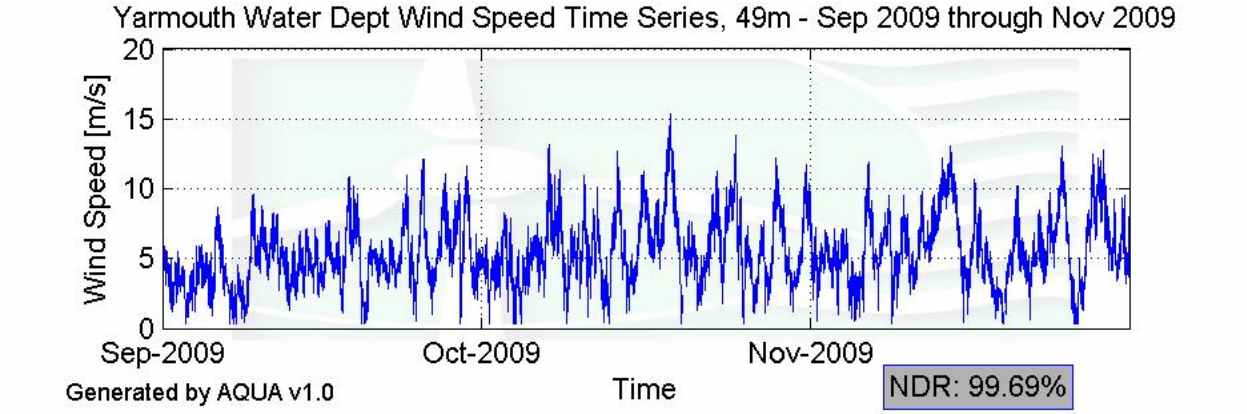

Figure 2 – Wind Speed Time Series, 49m, September 1, 2009 – November 30, 2009

Wind Speed Distributions

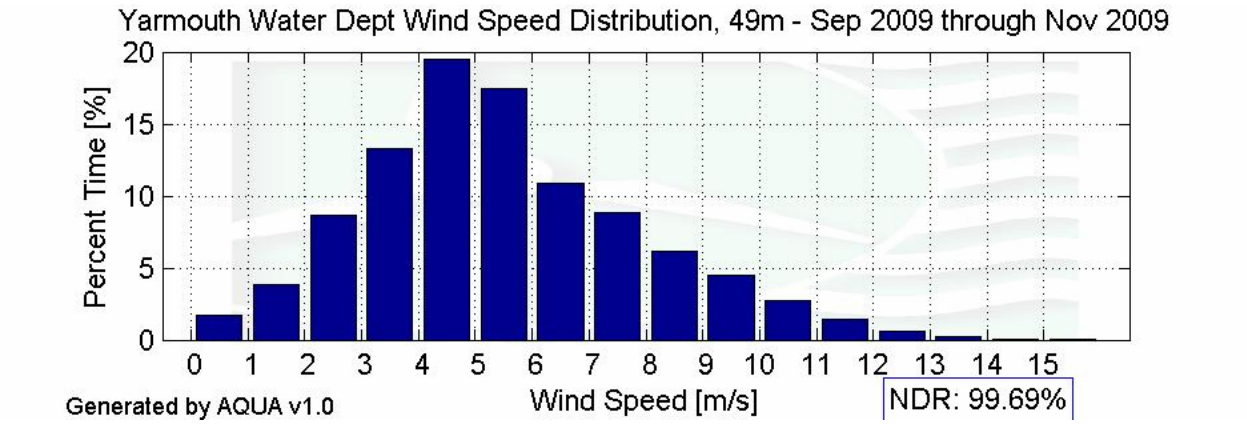

Figure 3 – Wind Speed Distributions, 49m, September 1, 2009 – November 30, 2009

Monthly Average Wind Speeds

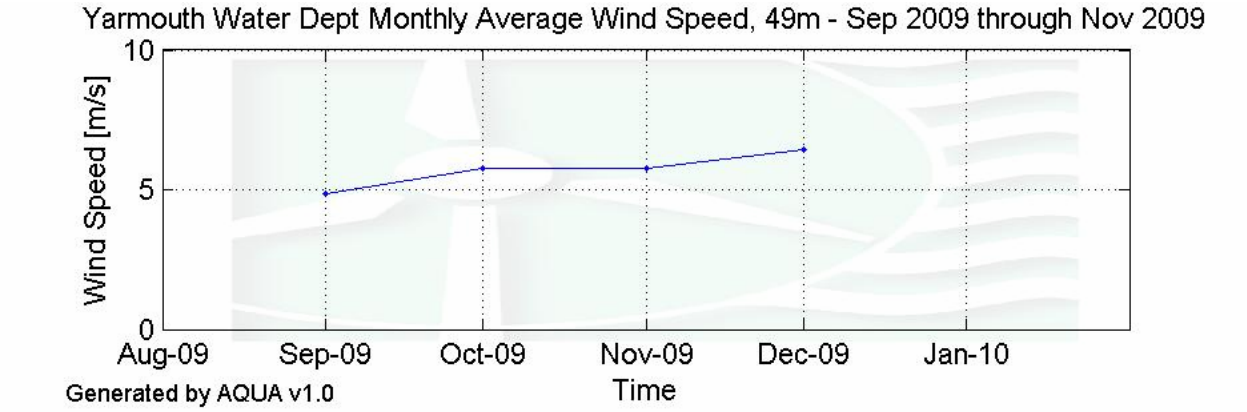

Figure 4 – Monthly Average Wind Speeds, 49m, September 2009 – December 2009

Diurnal Average Wind Speeds

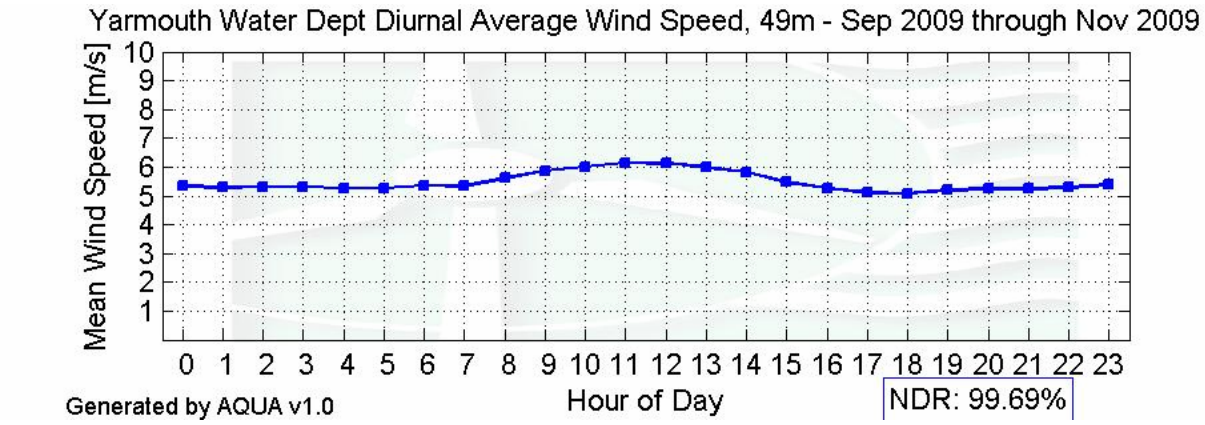

Figure 5 – Diurnal Average Wind Speeds, 49m, September 1, 2009 – November 30, 2009

Turbulence Intensities

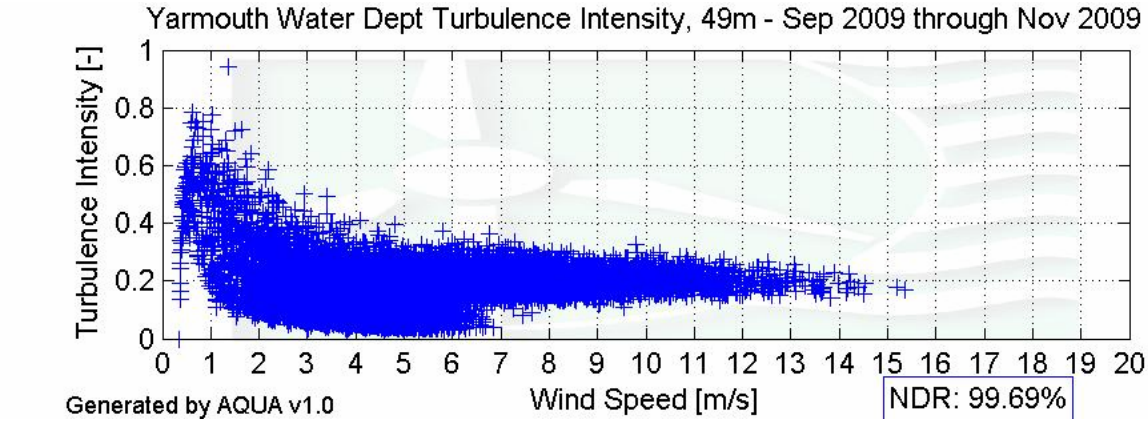

Figure 6 – Turbulence Intensity, 49m, September 1, 2009 – November 30, 2009

Wind Rose

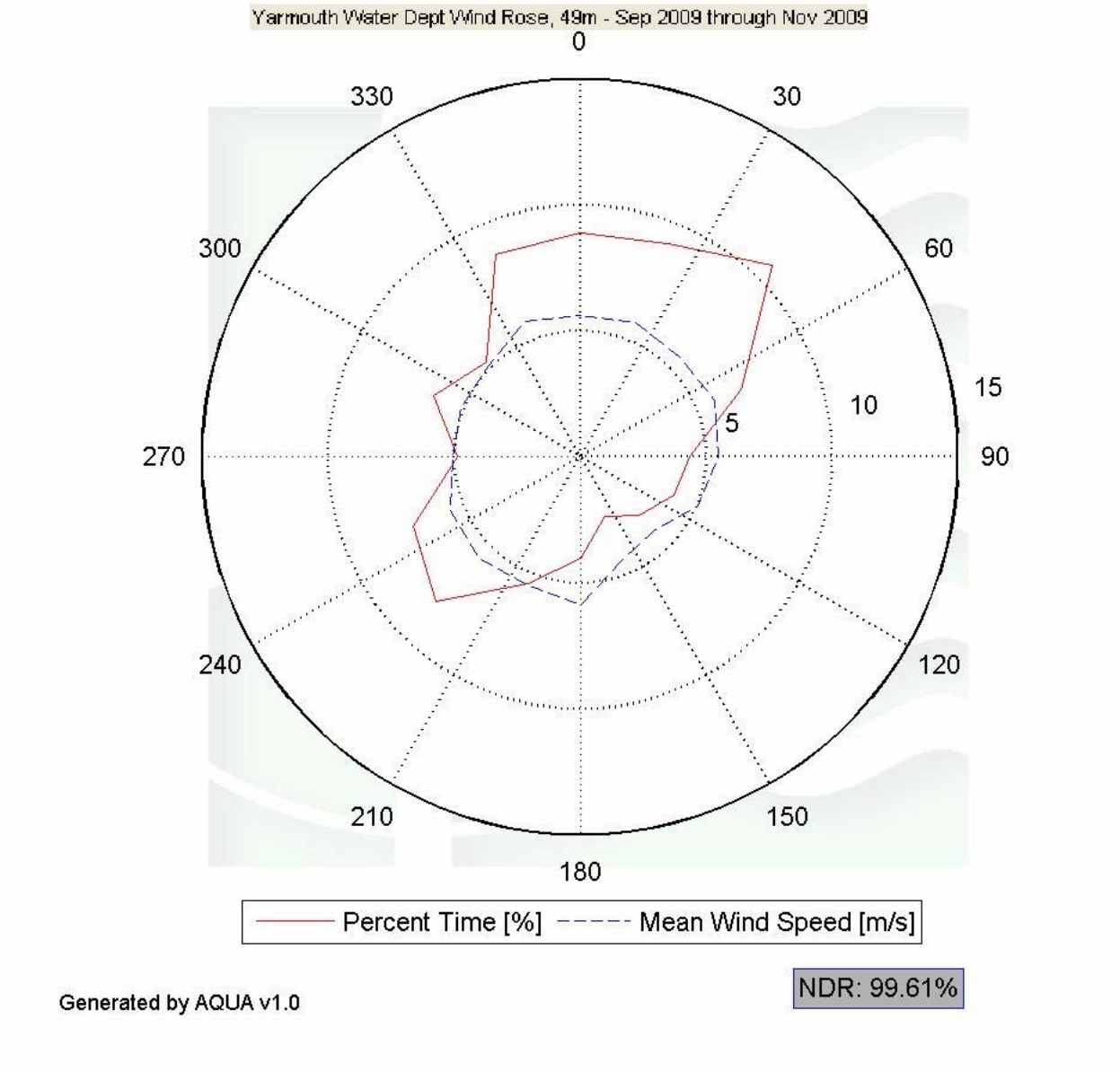

Figure 7 – Wind Rose, 49m, September 1, 2009 – November 30, 2009

SECTION 5 - Significant Meteorological Events

Outside of a few minor snow storms no significant meteorological events took place over the time period recorded.

SECTION 6 - Data Collection and Maintenance

No data collection or maintenance problems were encountered.

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 [%]	99.35

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	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
3	Batt2aVDC					MinMax	10.5	15	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	Anem38aMS					MinMax	0	90	0	0
13	Anem38bMS					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	AnemSD38aMS					MinMax	0	4	0	0
23	AnemSD38bMS					MinMax	0	4	0	0
24	AnemSD49yMS					MinMax	0	4	0	0
30	Vane49aDEG					MinMax	0	359.9	0	0
31	Vane38aDEG					MinMax	0	359.9	0	0
50	Turb49zNONE					MinMax	0	2	0	0
51	Turb38zNONE					MinMax	0	2	0	0
200	VaneSD49aDEG	Anem49yMS				MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS				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	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
303	Anem38bMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	4
400	Anem49aMS	Anem49bMS				Compare Sensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS				Compare Sensors	1	0.25	3	0
500	Amax49aMS					MinMax	0	90	0	0
501	Amax49bMS					MinMax	0	90	0	0
502	Amax38aMS					MinMax	0	90	0	0
503	Amax38bMS					MinMax	0	90	0	0
504	Amin49aMS					MinMax	0	90	0	0
505	Amin49bMS					MinMax	0	90	0	0
506	Amin38aMS					MinMax	0	90	0	0
507	Amin38bMS					MinMax	0	90	0	0
510	Vmax49aDEG					MinMax	0	359.9	0	0
511	Vmax38aDEG					MinMax	0	359.9	0	0
512	Vmin49aDEG					MinMax	0	359.9	0	0
513	Vmin38aDEG					MinMax	0	359.9	0	0
520	Etmpmax2aDEGC					MinMax	-30	60	0	0
521	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
Batt 10	13104	13104	100	0	0	0	100
Temp	13104	13104	100	0	0	0	100
Anem 38	13104	13104	100	0	12.667	4	99.237
Anem 38	13104	13104	100	0	14.833	3.167	99.176
Vane 38	13104	13104	100	0.5	14.833	0	99.298
Anem 49	13104	13104	100	0	6.833	13.667	99.061
Anem 49	13104	13104	100	0	8.167	26.167	98.428
Vane 49	13104	13104	100	0.333	8.167	0	99.611
Total	104832	104832	100	0.833	65.5	47	99.351

APPENDIX B - Plot Data

Wind Speed Distribution Data

49m - Sep 2009 through Nov 2009

Bin Center [m/s]	Percent Time [%]
0.5	1.69
1.5	3.85
2.5	8.69
3.5	13.33
4.5	19.52
5.5	17.48
6.5	10.86
7.5	8.86
8.5	6.16
9.5	4.49
10.5	2.76
11.5	1.45
12.5	0.56
13.5	0.21
14.5	0.06
15.5	0.02

Wind Rose Data

49m - Sep 2009 through Nov 2009

Bin Center [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	8.91	5.63
22.5	9.15	5.75
45	10.78	5.58
67.5	6.93	5.8
90	4.34	5.5
112.5	4.01	5.06
135	3.32	4.16
157.5	2.59	4.42
180	4.05	5.9
202.5	5.43	5.53
225	8.12	5.7
247.5	7.19	5.58
270	4.89	5.07
292.5	6.31	5.14
315	5.29	5.12
337.5	8.7	5.79

Monthly Average Wind Speed Data

49m Aug 09 through Dec 09

Month	Mean Wind Speed |[m/s]
Sep-09	4.844
Oct-09	5.779
Nov-09	5.785
Dec-09	6.433

Diurnal Average Wind Speed Data

49m - Sep 2009 through Nov 2009

Hour of Day	Mean Wind Speed [m/s]
0	5.33
1	5.28
2	5.3
3	5.31
4	5.27
5	5.28
6	5.35
7	5.34
8	5.61
9	5.87
10	6.01
11	6.14
12	6.13
13	5.97
14	5.83
15	5.48
16	5.26
17	5.11
18	5.08
19	5.19
20	5.25
21	5.24
22	5.28
23	5.39