WIND DATA REPORT

Paxton, MA

July 1, 2011 – September 30, 2011

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 MassCEC 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

Wind monitoring equipment was first installed at the Yankee Network Tower in Paxton, MA in late September 2003, with data collection starting on the 24th of the month. Anemometers and a wind direction vanes are installed at 78 and 79 meters (256 and 259 feet) above the base of the tower. There is a temperature sensor installed near the base of the tower.

This report summarizes the wind data collected during the summer of 2011, between July 2011 and September 2011. The mean recorded wind speed was 6.76 m/s (15.12 mph) at 79 meters and the prevailing wind direction was from the west-southwest. The average turbulence intensity at 79 m was 0.084.

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 91.43%.

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 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

The Yankee Network Tower is located on Mount Asnebumskit, southeast of the town of Paxton, at an elevation of approximately 420 m. The wind monitoring equipment is mounted higher still, on the tower at 79 m. Site coordinates are 42-18-11.6 North, 71-53-50.9 West per the WGS84 standard (the World Geodetic System 1984, an international standard for absolute localization with earthly coordinates). See the figure below for a map of the tower.

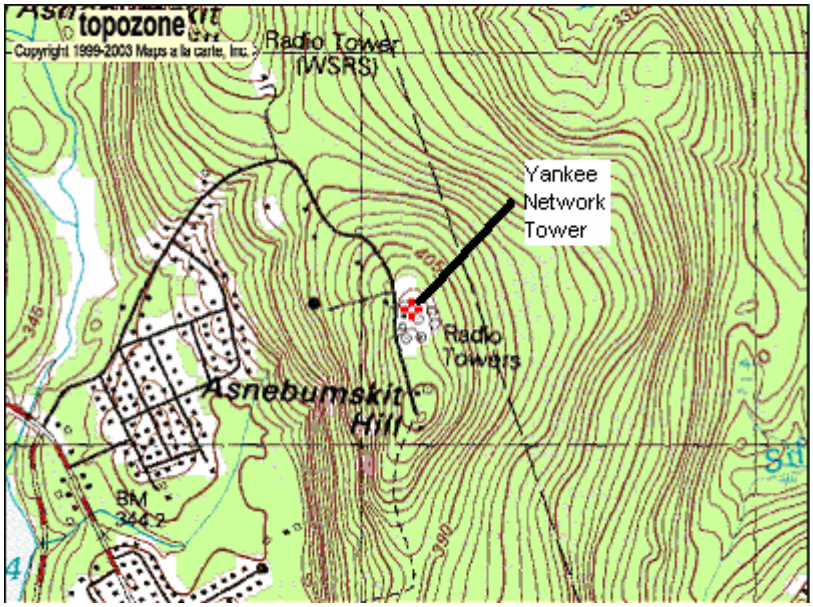

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an 8.2 foot aluminum tube that is attached vertically to the main network tower. The primary and secondary anemometers and two vanes are attached on short booms off the tube. A picture of the setup is below – note the horizontal booms where the anemometers and vanes are attached:

Figure 2 - Instrumentation at top of Yankee Network Tower – note the anemometers on the left (horizontal boom and at the top of the left-hand vertical tube.

Figure 3 - Bottom view of sensor array, anemometer is at photo top and wind vanes are mounted on the shorter side booms.

SECTION 3 - Equipment

The installed equipment of note comprises:

- NRG Symphonie data logger with ipack modem
- One NRG #40 cup anemometers, custom calibration (slope 0.758 m/s, offset 0.350 m/s)
- Two NRG #200P wind direction vanes
- One P2546A anemometer
- One NRG #110S temperature sensor
- Short booms for vanes, 14” from mast
- Long side booms for anemometers, 43” from mast
- Lightning rod and ground cable
- Shielded sensor wire

SECTION 4 - 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
Height	**79 m**	**79 m**	**79 m**
Units	**(m/s)**	**(m/s)**	**(-)**
Jul-11	6.78	13.85	WSW
Aug-11	6.92	21.59	WSW
Sep-11	6.57	15.73	WSW
Jul 2011 - Sep 2011	**6.76**	**17.06**	**WSW**

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 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.

Table 2. Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10 m
Height **Units**	**79 m** **[-]**
July 2011	0.079
August 2011	0.086
September 2011	0.088
July 2011 - September 2011	**0.084**

SECTION 5 - 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 A.

Wind Speed Time Series

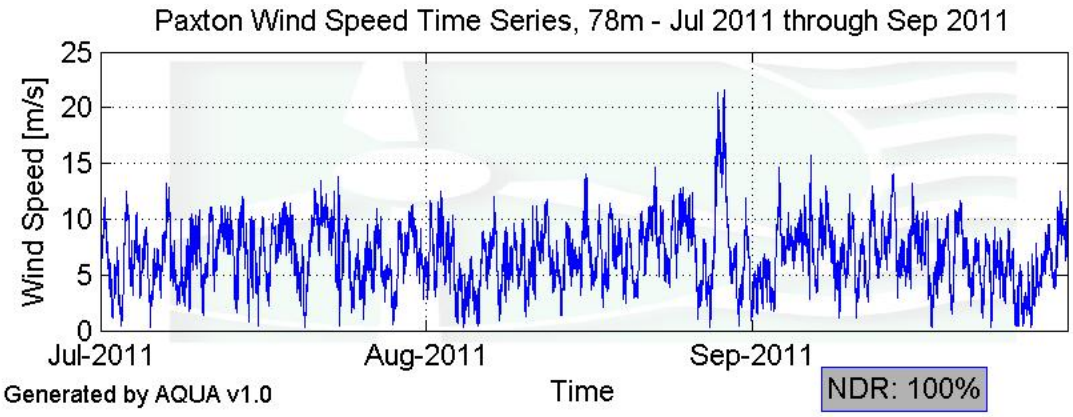

Figure 4- Wind Speed Time Series, July 2011 – September 2011

Wind Speed Distributions

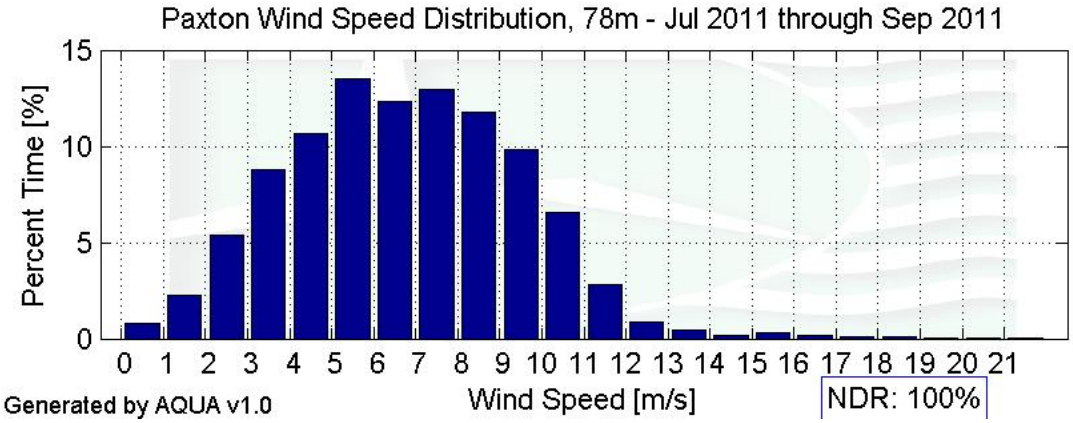

Figure 5– Wind Speed Distribution, July 2011 – September 2011

Monthly Average Wind Speeds

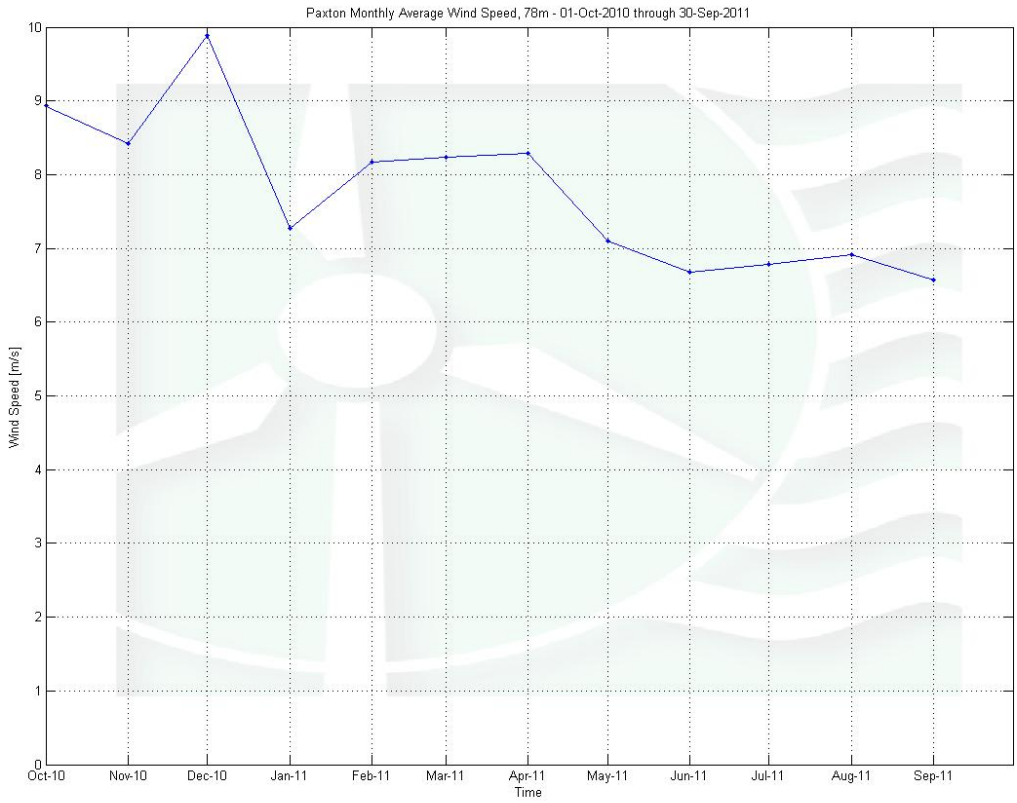

Figure 6 - Monthly Average Wind Speed**,** July 2010 – September 2011

Diurnal Average Wind Speeds

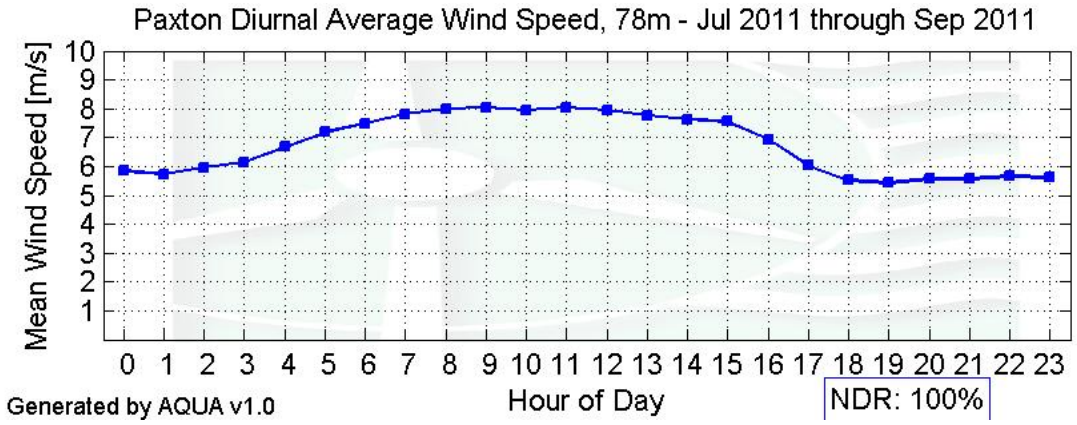

Figure 7 - Diurnal Average Wind Speed, July 2011 – September 2011

Turbulence Intensities

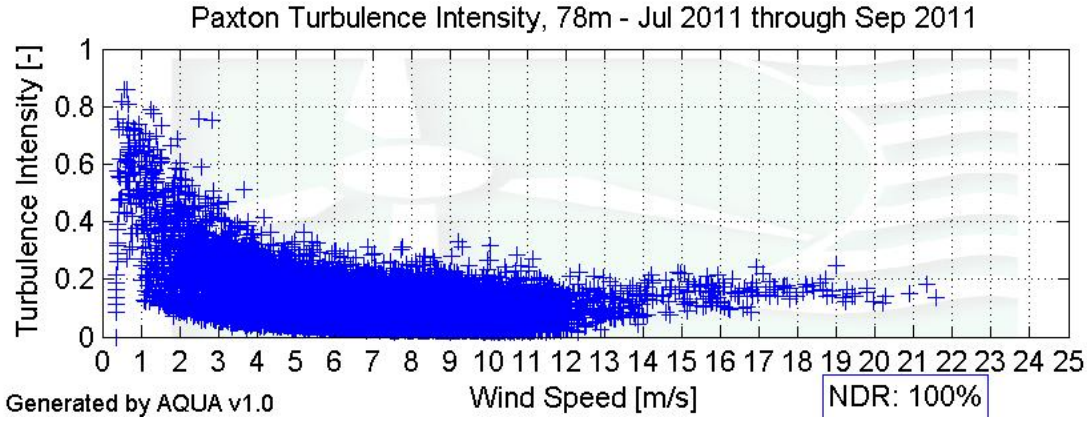

Figure 8 - Turbulence Intensity, July 2011 – September 2011

Wind Rose

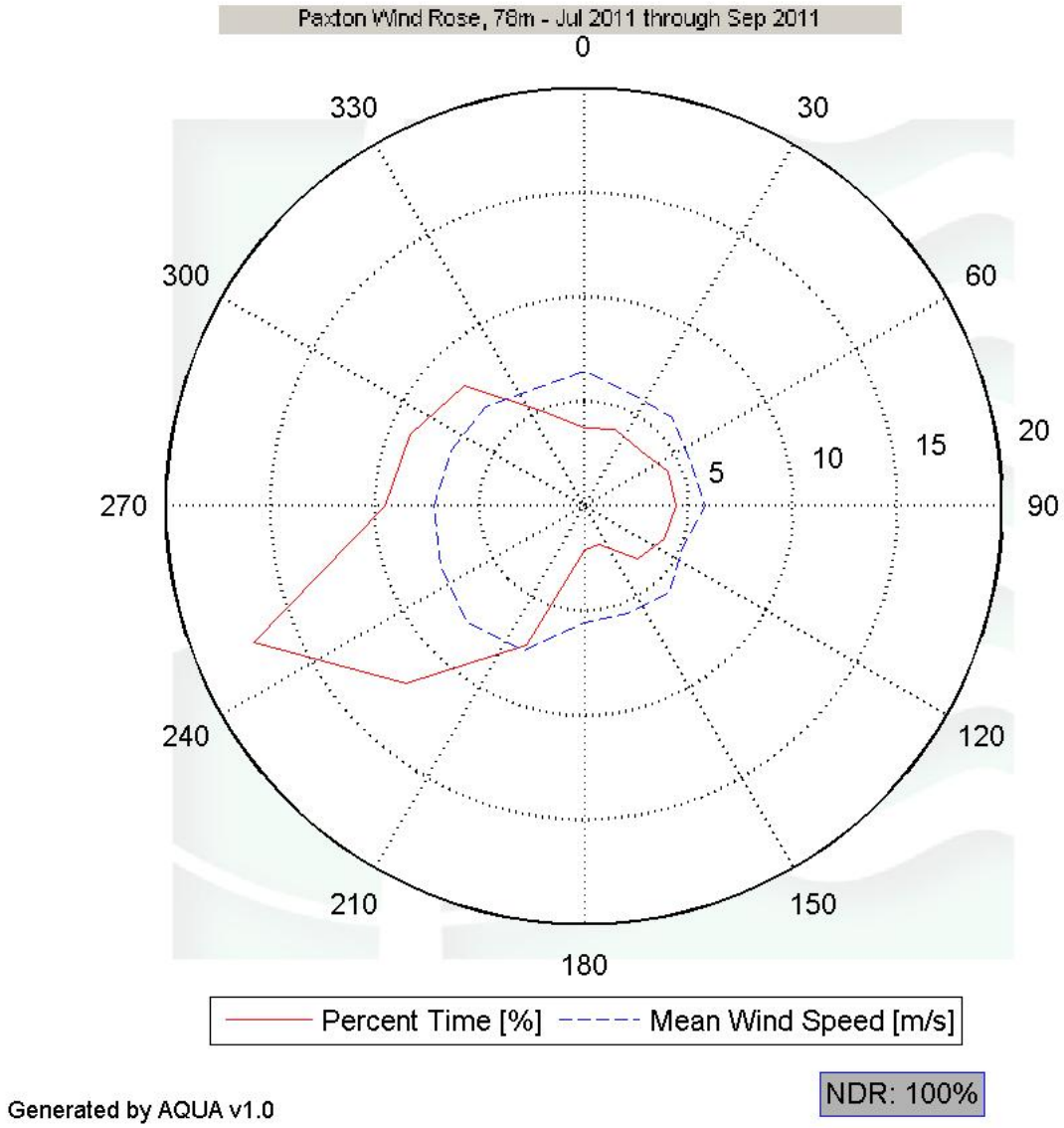

Figure 9 – Wind Rose July 2011-September2011

SECTION 5 - Significant Meteorological Events

Hurricane Irene struck New England during the weekend of August 27-28 causing high winds and flooding throughout that region. Figure 10shows the time series wind data for the event. The prevailing wind direction was from the west.

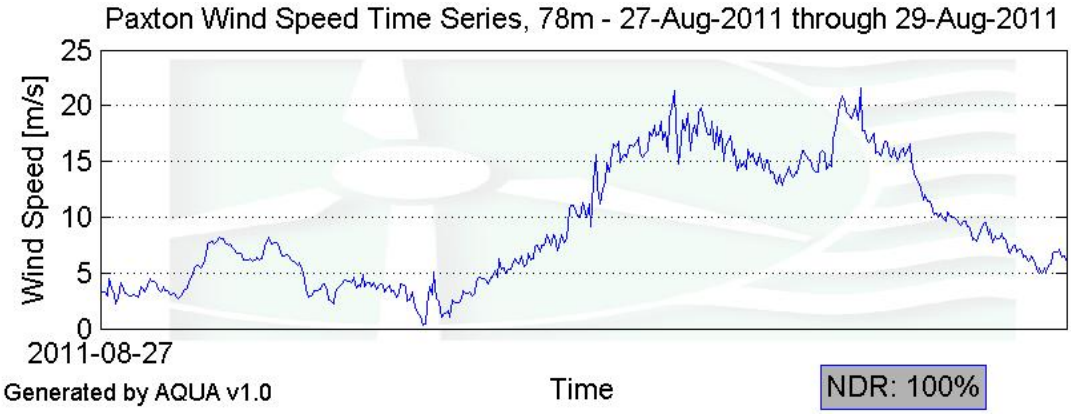

Figure 10 – Time series wind data for the weekend on August 27-28 during Hurricane Irene.

SECTION 6 - Data Collection and Maintenance

During this period a faulty wind vane was discovered. The wind vane itself still reports wind direction, but it appears that the boom to which it is attached is moving. Thus, the reported wind directions are incorrect. The wind directions at Paxton were compared to a nearby site in Spencer, MA to determine which of the two wind vanes was correct. The faulty wind vane does not contribute to the data statistics used in this report.

The Riso anemometer is reporting data intermittently for an unknown reason. The data recovery for the sensor was 48.94% over the interval from July 2011 through September 2011.

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 [%]	91.43

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 0. 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*.

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
Channel 9	13248	13248	100	0	0	0	100
Channel 10	13248	13248	100	0	0	0	100
Channel 8	13248	13248	100	0	0	0	100
Channel 7	13248	13248	100	0	0	0	100
Channel 1	13248	13248	100	0	0	7.5	99.66
Channel 4	13248	13248	100	0	0	1127.5	48.936
Total	79488	79488	100	0	0	1135	91.433

APPENDIX APlot Data

Wind Speed Distribution Data

Bin Center [m/s]	Percent Time [%]
0.5	0.82
1.5	2.26
2.5	5.37
3.5	8.8
4.5	10.68
5.5	13.49
6.5	12.32
7.5	12.93
8.5	11.79
9.5	9.85
10.5	6.54
11.5	2.79
12.5	0.86
13.5	0.48
14.5	0.2
15.5	0.3
16.5	0.2
17.5	0.14
18.5	0.09
19.5	0.07
20.5	0.02
21.5	0.02

Monthly Average Wind Speed Data

Month	Mean Wind Speed [m/s]
Oct-10	8.931
Nov-10	8.42
Dec-10	9.887
Jan-11	7.277
Feb-11	8.167
Mar-11	8.235
Apr-11	8.288
May-11	7.104
Jun-11	6.672
Jul-11	6.781
Aug-11	6.916
Sep-11	6.568

Diurnal Average Wind Speed Data

Hour of Day	Mean Wind Speed [m/s]
0	5.85
1	5.73
2	5.97
3	6.15
4	6.68
5	7.19
6	7.49
7	7.82
8	8
9	8.05
10	7.95
11	8.04
12	7.96
13	7.77
14	7.62
15	7.56
16	6.94
17	6.03
18	5.51
19	5.43
20	5.57
21	5.57
22	5.66
23	5.62

Wind Rose Data

Bin Center [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	3.74	6.48
22.5	3.96	5.81
45	3.77	5.97
67.5	4.36	5.52
90	4.38	5.8
112.5	4.18	5.12
135	3.59	5.82
157.5	1.97	5.53
180	2.12	5.56
202.5	7.22	7.47
225	12.05	7.93
247.5	17.1	7.42
270	9.53	7.2
292.5	9.01	6.89
315	8.14	6.72
337.5	4.88	6.12