

WIND DATA REPORT

Ashfield, MA

January 1, 2011 to March 31, 2011

Prepared for:

Echo for Sustainable Development
Springfield, MA

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 Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

The wind monitoring equipment was installed on a hill approximately 2 miles north of Highland Lake in Ashfield, Massachusetts, in December of 2010. The base of the 50 meter meteorological tower is installed 513 meters above sea level. Anemometers and wind direction vanes are installed at 49 and 38 m (160.8 and 124.7 ft) above the tower base. There are two anemometers and a wind vane at both heights. There is a temperature sensor installed near the base of the tower. This report summarizes the wind data collected between January, 1st 2011 and March, 31st 2011.

The mean recorded wind speed 6.35 m/s (14.20 mph^{*}) at 49 m and the prevailing wind direction was from the northwest. The average wind shear exponent between the two measured heights was 0.5731. The average turbulence intensity at 49 m for wind speeds between 10 m/s and 11 m/s was 0.19.

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 84.71% for the reporting period. The low net data recovery percentage is primarily attributed to the intermittent periods of icing experienced over this quarter.

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. This document is found at the following URL:

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 meteorological tower is located at a clear wooded area on a mountain top, in Ashfield, Massachusetts. The 50 m (164 ft) tower is located at 42° 28.698' North, 72° 47.97' West, between Route 112 and W Road, and approximately two miles north of Highland Lakes. The tower base is 513 m (1683.07 ft) above sea level. The tower is identified with a white square in the center of Figure 1 below, which was generated using Google Earth.

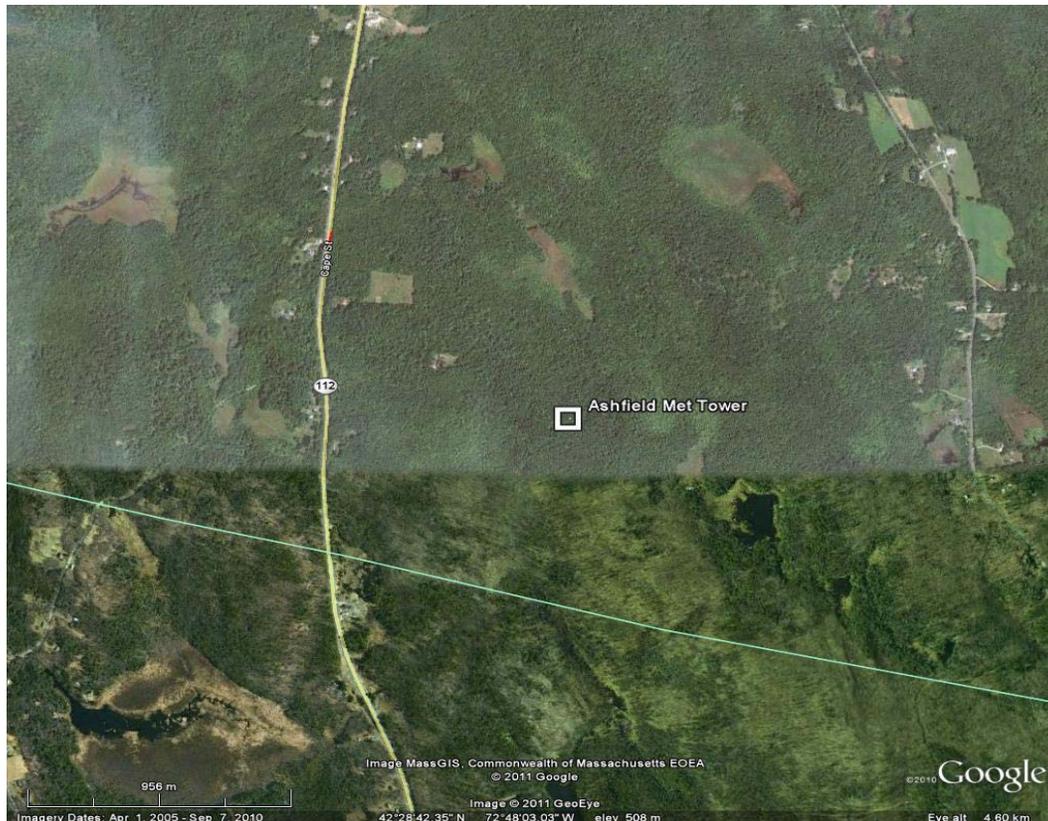


Figure 1 – Site Location

SECTION 2- Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164 ft) meteorological tower. The wind monitoring equipment consists of the following items:

- NRG SymphoniePlus#1 data logger, Model# 4280, Serial # 04710
- An NRG #40 Calibrated Anemometer (Slope – 0.755 m/s, Offset – 0.430 m/s) and a Favonius Model A75-104 Anemometer (mfg. by Comptus, Inc., calibration: slope—0.765 m/s, offset—0.35 m/s) are located at 49 m (160.8 ft).
- Two Favonius Model A75-104 Anemometers (mfg. by Comptus, Inc., calibration: slope—0.765 m/s, offset—0.35 m/s) are located at 38 m (124.7 ft).
- Two wind direction vanes. One NRG #200P wind direction vane at 49m (160.8 ft). One DV200 Wind Vane located at 38 m (124.7 ft).
- An NRG #110S temperature sensor near the base of the tower

The logger samples wind speed and direction once every two seconds. 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. Data from the Symphonie logger is sent to WEC via a cellular modem once a day. The binary files are converted to ASCII text files using NRG software. These 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.

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 are used to determine the data statistics is noted. During this quarter all of the sensors used in this report were below the 90% range due to intermittent icing throughout the winter quarter. Both of the anemometers and wind vane at the 49 m station were between the 70 -80% threshold. The two anemometers and wind vane located at the 38 m station collected valid data of approximately 82% out of the total data received.

Table 1. Wind Speed and Direction Data Summary

Height	49 m					38 m				
Month	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	NDR [%]	Prevailing Direction [deg]	NDR [%]	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	NDR [%]	Prevailing Direction [deg]	NDR [%]
Jan-11	5.96	14.38	83%	NW	83%	4.88	12.93	93%	WNW	93%
Feb-11	6.84	18.83	65%	SW	65%	6.19	17.11	64%	WNW	64%
Mar-11	6.39	18.27	86%	WNW	86%	5.54	16.14	89%	NW	89%
Jan - Mar 2011	6.35	18.83	79%	NW	79%	5.44	17.11	83%	NW	83%

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 $\pm 2\%$ 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.

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

Table 2. Shear and Turbulence Intensity Data Summary

Height	49 m		38 m		Between 49 m and 38 m
Month	TI at 10 m/s [-]	NDR [%]	TI at 10 m/s [-]	NDR [%]	Mean Wind Shear Coefficient, α
Jan	0.19	83%	0.23	93%	0.79
Feb	0.21	65%	0.25	64%	0.39
Mar	0.19	86%	0.22	89%	0.56
Jan – Mar 2011	0.19	79%	0.24	83%	0.61

The mean wind shear coefficient values calculated at the site during this quarter are believed to have been artificially elevated due to the frequent icing conditions. Care need to be taken when using these values.

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 – This graph shows the trends in the wind speed over the course of months but because data availability is less than 90%, the graph of the monthly average is not plotted.
- 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 Ashfield site, the following observations are noted:

- Time Series, Figure 2: wind speeds seldom exceeded 15m/s at the site during the reporting period. Icing was significant during portions of the quarter which is evident by the gaps in data reported from the anemometers.
- Wind Speed Distribution, Figure 3: we can see that wind speeds between 4 and 8 m/s during the reporting period account for approximately 55% of the total wind speeds reported.
- Diurnal Average Wind Speeds, Figure 4: The diurnal curve displays a minimum at 0900 hours and a maximum at 2100 hours.
- Turbulence Intensity, Figure 6: we can see that turbulence numbers are lower than 0.4 for most wind speeds above 3 m/s and converges to approximately 0.2 at higher wind speeds.
- Wind Rose, Figure 7: a northwesterly wind direction bias is shown for the reporting period.

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

Wind Speed Time Series

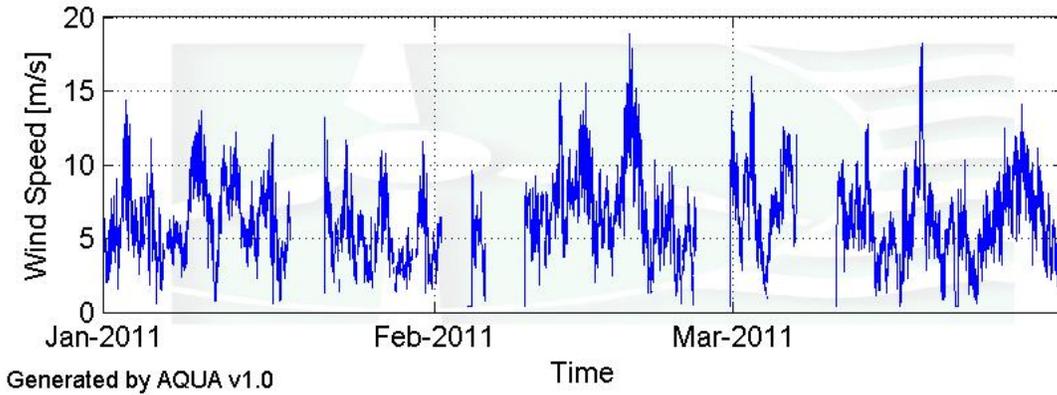


Figure 2 – Wind Speed Time Series, January 1, 2011 to March31, 2011

Wind Speed Distributions

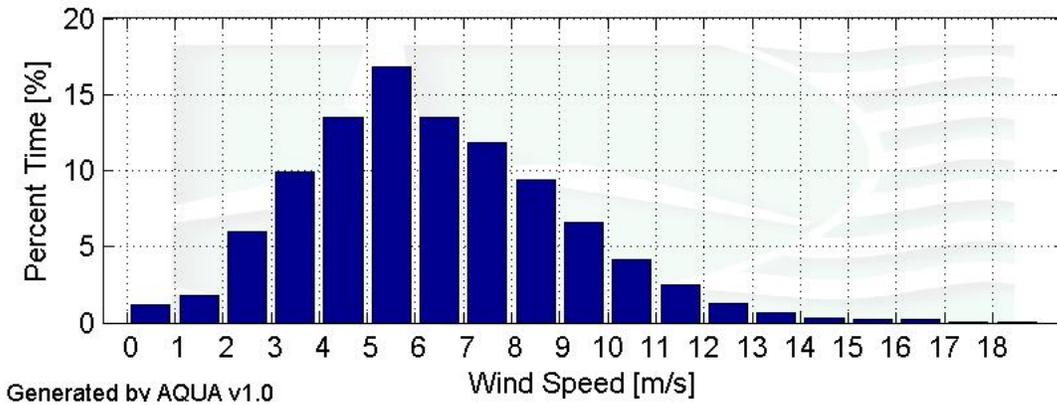


Figure 3 – Wind Speed Distribution, January 1, 2011 to March31, 2011

Monthly Average Wind Speeds

Not available due to lack of valid data

Diurnal Average Wind Speeds

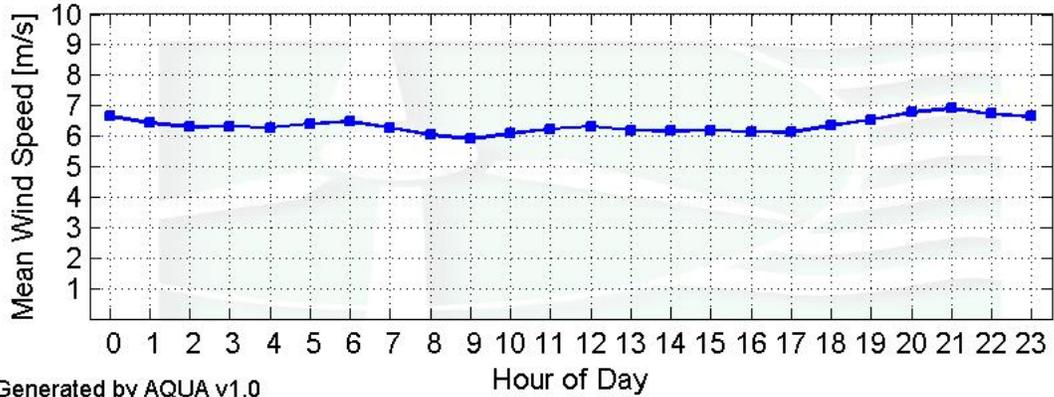


Figure 4 – Diurnal Average Wind Speeds, January 1, 2011 to March31, 2011

Turbulence Intensities

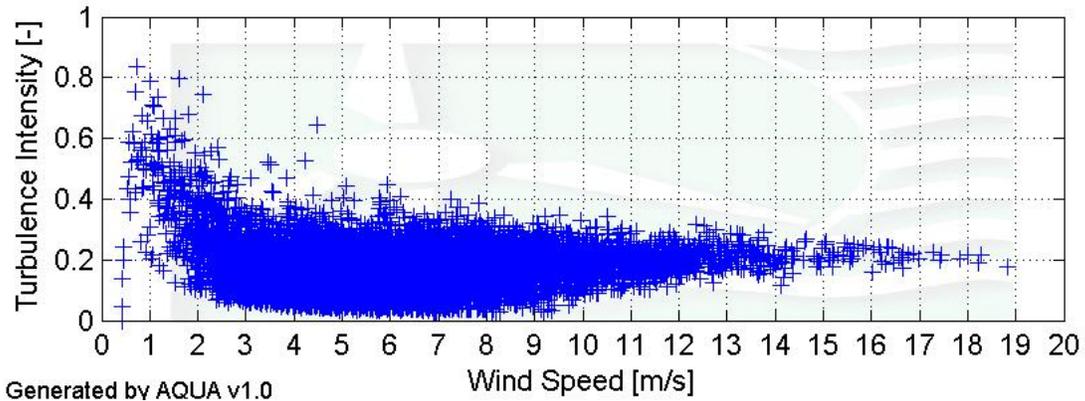
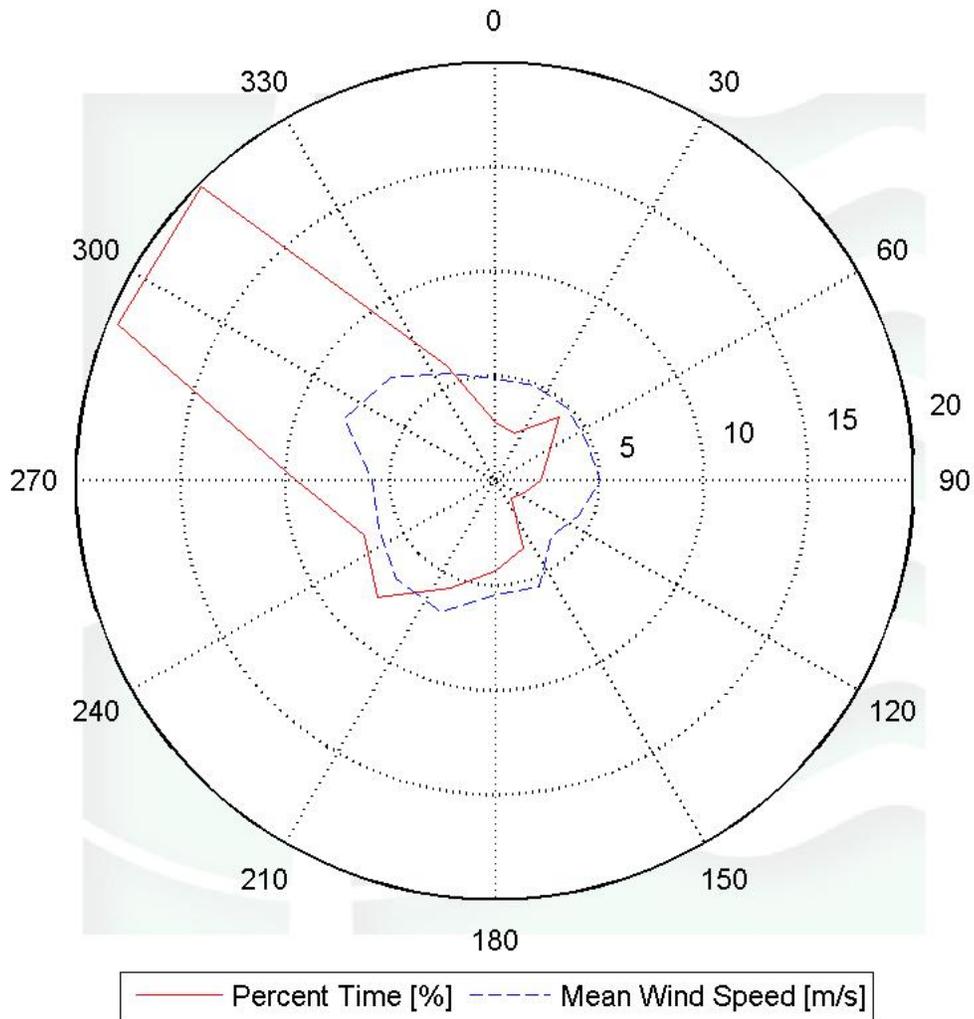


Figure 5 – Turbulence Intensity vs. Wind Speed, January 1, 2011 to March31, 2011

Wind Rose



Generated by AQUA v1.0

Figure 6 – Wind Rose, January 1, 2011 to March 31, 2011

SECTION 5- Significant Meteorological Events

The highest wind speed during this time interval reached approximately 19.34 m/s (43.26 mph). However the most significant meteorological events during this quarter were extreme icing conditions, the most significant of which are shown below.

- 1/18/2011 12:40 P.M. to approximately 1/21/2011 4:50 A.M.
- 2/1/2011 16:35 P.M. to approximately 2/4/2011 10:15A.M.
- 2/5/2011 20:15P.M. to approximately 2/9/2011 12:15P.M.
- 2/25/2011 10:55 A.M. to approximately 2/28/2011 15:30 P.M.
- 3/6/2011 22:55P.M. to approximately 3/9/2011 22:40A.M.

SECTION 6- Data Collection and Maintenance

With the exception of icing periods the sensors 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. The percentage reduction exhibited in the net data recovered value is mostly attributable to the icing periods during this quarter (see Section 3).

Gross Data Recovered [%]	100
Net Data Recovered [%]	84.71

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.

$$\begin{aligned} & (TF1 < F1) \\ & \text{or } (TF2 < F4 \text{ and } TF1 > F2) \\ & \text{or } (TF2 \geq F4 \text{ and } TF1 > F3) \end{aligned}$$

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.

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

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

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
NRG #40c - 49	12960	12960	100	3	463.33	9.17	78.03
A75-104 Comptus - 49	12960	12960	100	1.83	463.33	108.83	73.89
#200P Vane - 49	12960	12960	100	0.5	463.33	0	78.53
A75 Comptus-a - 38	12960	12960	100	2.83	374.83	22.83	82.27
A75 Comptus-b - 38	12960	12960	100	4	374.83	24.67	82.34
DV200 Vane - 38	12960	12960	100	0.17	374.83	0	82.64
iPack	12960	12960	100	0	0	0	100
NRG #110S Temp	12960	12960	100	0	0	0	100
Total	103680	103680	100	12.33	2514.5	165.5	84.71

APPENDIX B- Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent Time [%] 1/1/11- 3/31/11
0.5	1.19
1.5	1.83
2.5	5.99
3.5	9.93
4.5	13.48
5.5	16.81
6.5	13.53
7.5	11.86
8.5	9.38
9.5	6.59
10.5	4.14
11.5	2.53
12.5	1.3
13.5	0.68
14.5	0.28
15.5	0.25
16.5	0.19
17.5	0.04
18.5	0.04

Monthly Average Wind Speed Data

Not available due to lack of valid data

Wind Rose Data

DIRECTION	1-Jan-2011 through 31-Mar-2011	
	Percent Time [%] 49 M	Mean Wind Speed [m/s]
N	2.79	4.91
NNE	2.44	4.92
NE	4.33	4.9
ENE	2.68	4.78
E	2.16	5.06
ESE	1.51	4.38
SE	1.15	3.79
SSE	3.53	5.5
S	4.34	5.46
SWS	5.59	6.78
SW	7.9	6.66
WSW	6.74	5.97
W	9.45	5.86
WNW	19.54	7.77
NW	19.88	7
NNW	5.98	5.55

Diurnal Average Wind Speed Data

Hour of Day	1-Jan-2011 through 31-Mar-2011 Mean Wind Speed [m/s]
0	6.64
1	6.43
2	6.3
3	6.33
4	6.27
5	6.42
6	6.48
7	6.27
8	6.03
9	5.91
10	6.07
11	6.24
12	6.33
13	6.19
14	6.16
15	6.19
16	6.14
17	6.13
18	6.35
19	6.54
20	6.78
21	6.9
22	6.72
23	6.66