WIND DATA REPORT

Mt. Tom

July 1, 2010 – September 30, 2010

Prepared for

Massachusetts Clean Energy Center
55 Summer Street, 9th Floor
Boston, MA 02110

by

Meltem Duran
James F. Manwell
Utama Abdulwahid
Anthony F. Ellis

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Wind **E**nergy **C**enter
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.umass.edu/windenergy • (413) 545-4359 • rerl@ecs.umass.edu

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 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.

TABLE OF CONTENTS

TABLE OF FIGURES

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.

This wind measurement station is installed on the FAA tower and on the University of Massachusetts wind turbine at Mt. Tom in Holyoke, MA. Installed in December of 1999, the station is in continuous operation to this day. Two sets of 3 horizontal anemometers and one wind vane are mounted at 24.4 m (80.0 ft) and 36.6 m (120.0 ft), respectively. One vertical anemometer is mounted each at 18 m (59.1 ft) and 22 m (72.2 ft) on the wind turbine tower at Mt tom.

During the period covered by this report, July 2010 – September 2010, the mean recorded wind speed for this quarter was 5.56m/s (12.44 mph)* and the prevailing wind direction was west-northwest. The gross data recovery percentage (the actual percentage of expected data received) was 43.15 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 40.28 %. The relatively low gross data recovery percentage indicates that a logger failure was experienced. The logger stopped reporting on August 10, 2010 and resumed reporting on October 3, 2010. Therefore, the last day that data was received for this report was August 9, 2010.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by the Renewable Energy Research Lab (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 Mt. Tom site is located at an existing FAA tower on top of Mt. Tom in Holyoke, MA. Some trees are located in the vicinity, as is an ESI-80 wind turbine. The location of the tower base is at 42° 14’ 59.2” N, 72° 38’ 42.2” W (NAD 27).

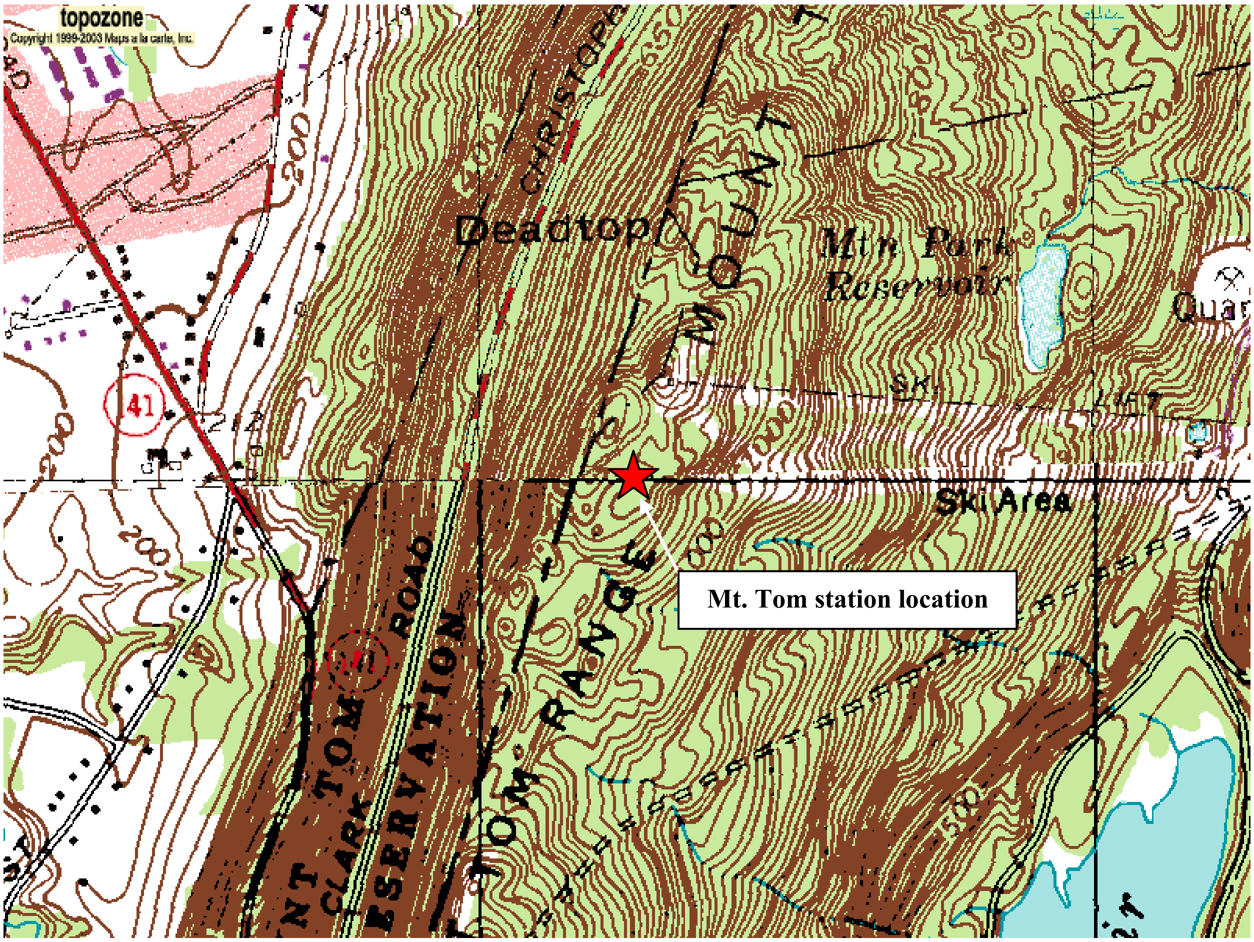

Figure 1 – Station location of Mt. Tom.

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SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on two towers, the first, a 160 ft lattice tower and the second, a 90 ft lattice tower. The wind monitoring equipment can be listed as follows:

- 1 Nomad2 Logger within an electrical enclosure box
- 4 – #40 Anemometers, two anemometers are located at both 24.4 m (80.0 ft) and 36.6 m (120.0 ft).
- 2 - Risoe P2546A Anemometers, one is located at both 24.4 m (80.0 ft) and 36.6 m (120.0 ft).
- 2 - #200P Wind direction vanes. They are located at at both 24.4 m (80.0 ft) and 36.6 m (120.0 ft).
- 2 – RMYoung RMY27106 Anemometers, one is located at both 18 m (59.1 ft) and 22 m (72.2 ft). These are the only sensors on the second tower.
- Shielded sensor wire

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.

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	**36.6 m [m/s]**	**36.6 m [m/s]**	**36.6 m [m/s]**	**24.4 m [m/s]**	**24.4 m [m/s]**	**24.4 m [m/s]**
Jul 2010	5.59	15.48	WNW	4.62	12.81	WNW
Aug 2010[1]	5.44	19.27	S	4.57	14.91	S
Sep 2010[2]	N/A	N/A	N/A	N/A	N/A	N/A
Jul 2010 – Sep 2010[3]	**5.56**	**19.27**	**WNW**	**4.61**	**14.91**	**WNW**

[1] In August 2010, only 28.1% of the data during the month are valid.
[2] There was no data collected during the month of September 2010.
[3] Data availability for the whole quarter is 43.15%.

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 36.6 m [-]	Turbulence Intensity at 10 m/s 24.4 m [-]	Mean Wind Shear Coefficient, α Between 36.6 m and 24.4 m [-]
Jul 2010	0.145	0.227	0.47
Aug 2010[4]	0.163	0.243	0.43
Sep 2010[5]	N/A	N/A	N/A
Jul 2010 – Sep 2010[6]	**0.146**	**0.231**	**0.46**

SECTION 4- Graphs

This report contains several types of wind data graphs. Under normal conditions, each graph represents data from 1 quarter (3 months). For this case, however, the following graphs represent data between July 1, 2010 and August 9, 2010. 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.

[4] In August 2010, only 28.1% of the data during the month are valid.
[5] There was no data collected during the month of September 2010.
[6] Data availability for the whole quarter is 43.15%.

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

Wind Speed Time Series

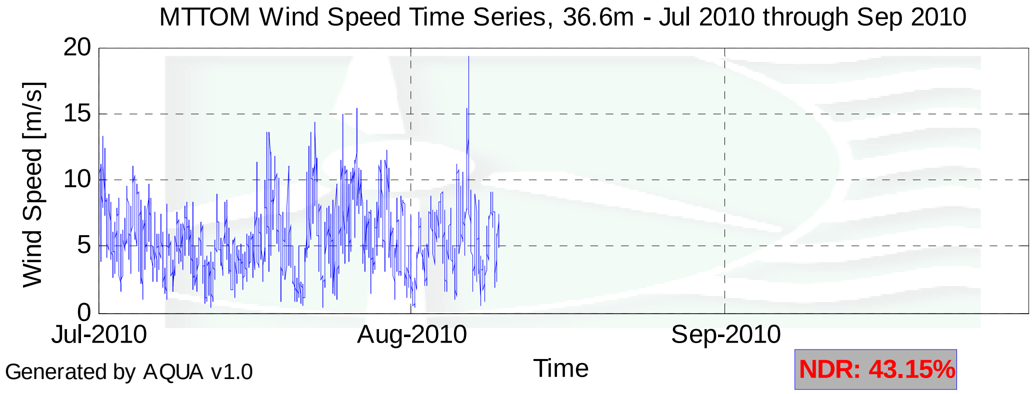

Figure 2 – Mt. Tom Wind Speed Time Series, 36.6 m, July 1 – August 9, 2010

Wind Speed Distributions

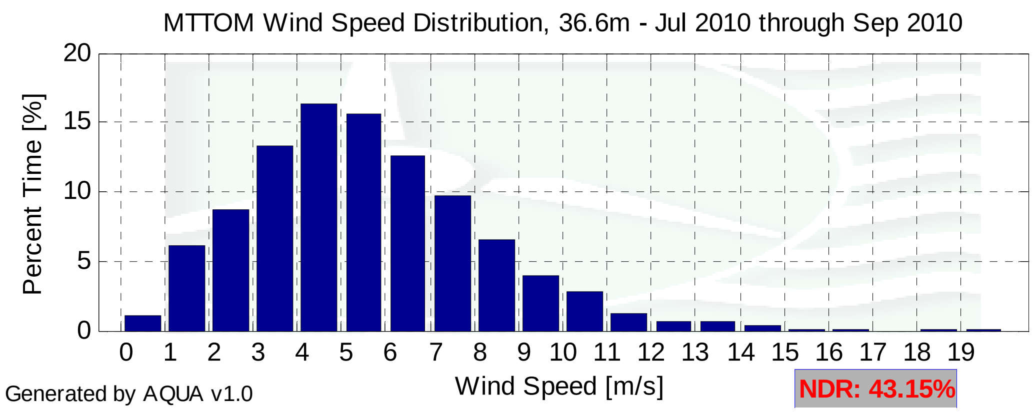

Figure 3 - Mt. Tom Wind Speed Distributions, 36.6 m, July 1 – August 9, 2010

Monthly Average Wind Speeds

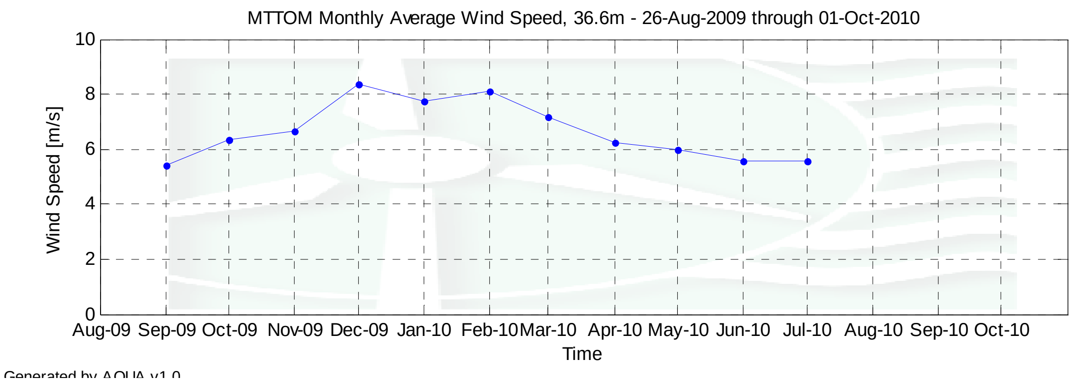

Figure 4 – Mt. Tom Monthly Average Wind Speeds, August 2009 – July 2010

Diurnal Average Wind Speeds

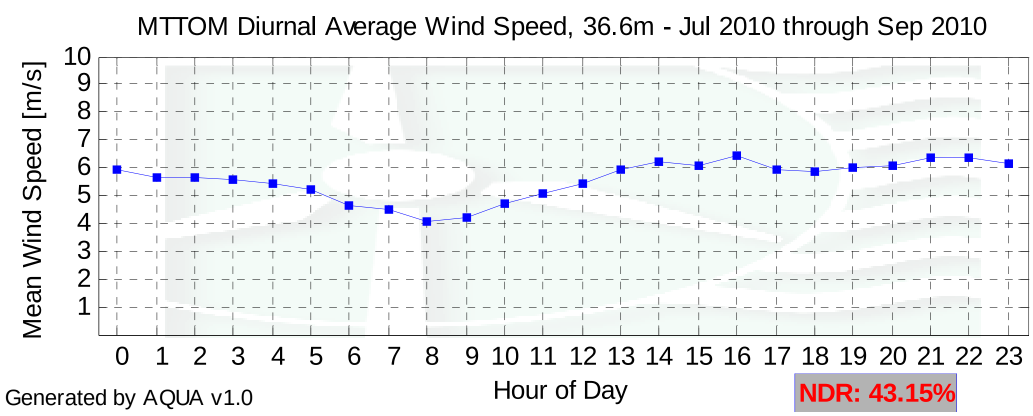

Figure 5 - Mt. Tom Diurnal Average Wind Speed, 36.6 m, July 1 – August 9, 2010

Turbulence Intensities

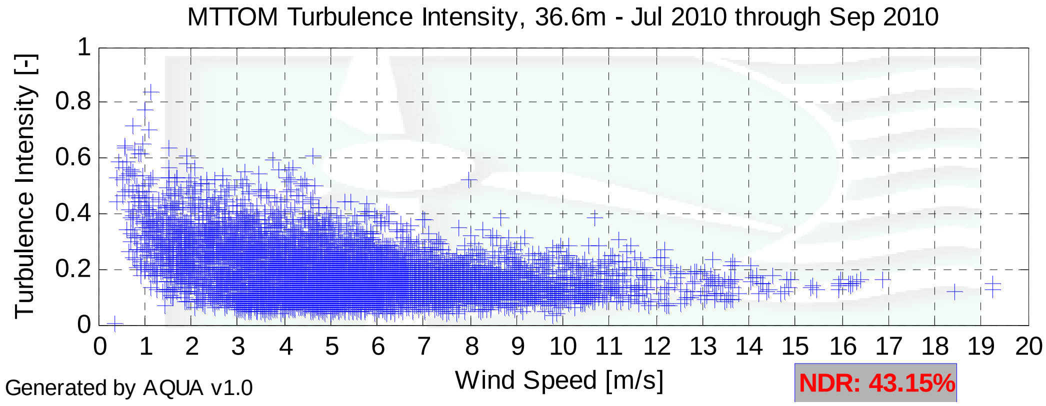

Figure 6 - Mt. Tom Turbulence Intensity, 36.6 m, July 1 – August 9, 2010

Wind Roses

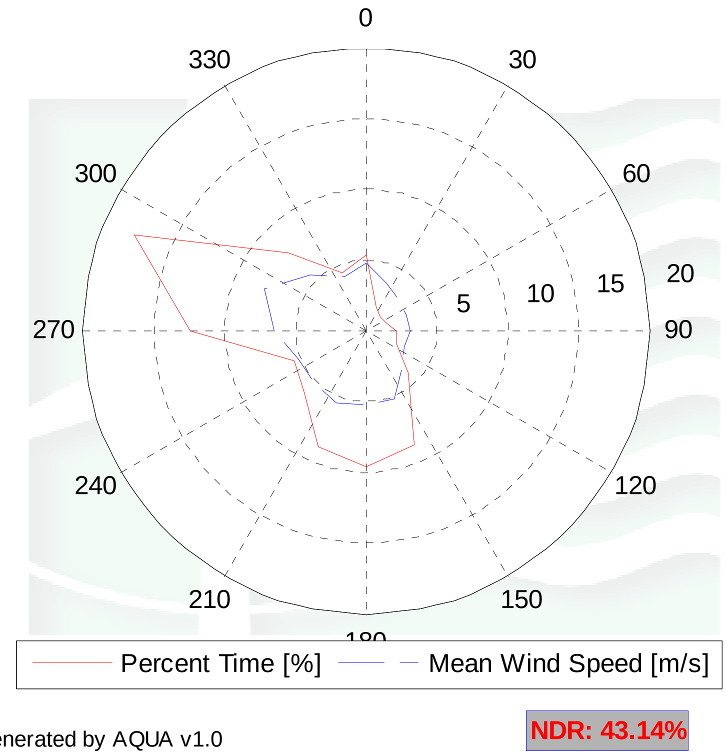

Figure 7 – Mt. Tom Wind Rose, 36.6 m, July 1 – August 9, 2010

SECTION 5 - Significant Meteorological Events

No significant meteorological events were recorded during the time period of this report.

SECTION 6 - Data Collection and Maintenance

On August 9, 2010, the logger stopped recording and sending wind monitoring data, due to a failure. A new logger was deployed on October 3, 2010. Data collection has resumed.

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 [%]	43.15
Net Data Recovered [%]	40.28

The low data recovery was due to the logger failure which was not caught early and compounded by the time it took to prepare a replacement logger.

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.

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

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.

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

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
Batt3aVDC	13248	5717	43.15	0.17	0	0	43.15
Bat2	13248	5717	43.15	0.17	0	0	43.15
Power	13248	5717	43.15	0	0	0	43.15
Temp	13248	5717	43.15	0.17	0	0	43.15
Anem24.4W	13248	5717	43.15	0	0	0	43.15
Anem24.4WSW	13248	5717	43.15	0	0	0	43.15
Anem24.4SWRisoe	13248	5717	43.15	0	0	0	43.15
Anem24.4WDC	13248	5717	43.15	642.67	0	0	14.05
Vane24.4E	13248	5717	43.15	0.17	0	0	43.15
Anem36.6W	13248	5717	43.15	0	0	6.5	42.86
Anem36.6WSW	13248	5717	43.15	0	0	14.5	42.50
Anem36.6SWRisoe	13248	5717	43.15	0	0	0	43.15
Anem36.6WDC	13248	5717	43.15	222.167	0	0	33.09
Vane36.6E	13248	5717	43.15	0.333	0	0	43.14
Total	185472	80038	43.15	865.84	0	21	40.28

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	1.12
1.5	6.12
2.5	8.76
3.5	13.36
4.5	16.3
5.5	15.55
6.5	12.61
7.5	9.74
8.5	6.49
9.5	4.01
10.5	2.87
11.5	1.26
12.5	0.59
13.5	0.61
14.5	0.3
15.5	0.12
16.5	0.12
17.5	0
18.5	0.02
19.5	0.03

<u>**Monthly Average Wind Speed Data**</u>

Month	Mean Wind Speed |[m/s]
Aug-09	4.699
Sep-09	5.396
Oct-09	6.324
Nov-09	6.638
Dec-09	8.382
Jan-10	7.738
Feb-10	8.110
Mar-10	7.174
Apr-10	6.248
May-10	5.985
Jun-10	5.591
Jul-10	5.590
Aug-10	5.438
Sep-10	NaN

Diurnal Average Wind Speed Data

Hour of Day	Mean Wind Speed [m/s]
0	5.94
1	5.63
2	5.63
3	5.59
4	5.4
5	5.19
6	4.64
7	4.5
8	4.07
9	4.24
10	4.72
11	5.09
12	5.43
13	5.92
14	6.2
15	6.11
16	6.43
17	5.95
18	5.85
19	5.97
20	6.11
21	6.37
22	6.34
23	6.12

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	5.35	4.74
NNE	1.91	3.7
NE	1.4	3.16
ENE	1.59	3.07
E	2.06	3.11
ESE	2.24	2.95
SE	4.25	3.61
SSE	8.7	5.17
S	9.66	5.28
SSW	8.82	5.44
SW	6.14	5.15
WSW	5.56	5.28
W	12.41	6.49
WNW	17.69	7.82
NW	7.72	5.63
NNW	4.5	4.1