WIND DATA REPORT

Wellfleet, MA

June 1st, 2007 – August 31st, 2007

Prepared for

Massachusetts Technology Collaborative
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by

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November 20, 2007

Report template version 3.1.1

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

This report covers data from June 1, 2007 through August 31, 2007. The wind vane at 50m is not functioning for the times included in this report. Consequently, the wind direction data is presented from the 38m wind vane. The mean wind speed at 50m, during the period covered by this report, is 6.2 m/s (13.9 mph*). The prevailing direction is West-Southwest.

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 at a parking lot near the beach on Ocean View Drive in Wellfleet. The site elevation is 29 m above sea level. The circle in Figure 1 shows the exact location of the tower. The location of the tower base is at 41.93366°N, 69.98101°W (WGS84/NAD83).

Figure 1 - Wellfleet Site Location

Source: Google Earth

SECTION 2 - Instrumentation and Equipment

Wind monitoring equipment is mounted on a standard NRG 50 m tall 6-inch diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 50 m, 38 m, and 20 m. Redundant anemometers are positioned at 50 m and 38 m. The wind vane at 50 m is not functioning currently.

Additional equipment and models:

- NRG model Symphonie Cellogger
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)

- 3 - #200P Wind direction vanes
- Lightning rod and grounding cable
- NRG 11S Temperature Sensor

The data from the Symphonie logger is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These are then combined into 10-minute averages, and along with the standard deviation for those 10-minute periods, are put into a binary file. These binary files are converted to ASCII text files using the NRG software BaseStation®. These text files are then imported into a database software program where they are subjected to QA tests prior to using the data.

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	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]**	**20 m [m/s]**	**20 m [m/s]**	**20 m [m/s]**
June 2007	7.0	16.6	-	6.6	15.7	WSW	5.5	13.8	WSW
July 2007	5.8	13.4	-	5.5	12.8	WSW	4.5	11.0	WSW
August 2007	5.9	13.0	-	5.5	12.6	WSW	4.5	11.0	WSW
June 2007 -Aug 2007	**6.2**	**16.6**	**-**	**5.9**	**15.7**	**WSW**	**4.8**	**13.8**	**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 larger amounts 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.

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

<u>Table 2. Shear and Turbulence Intensity Data Summary</u>

Date Height Units	Turbulence Intensity at 10 m/s 50 m [-]	Turbulence Intensity at 10 m/s 38 m [-]	Turbulence Intensity at 10 m/s 20 m [-]	Mean Wind Shear Coefficient, α Between 50 m and 38 m [-]
June 2007	0.12	0.12	0.12	0.21
July 2007	0.15	0.17	0.19	0.19
August 2007	0.13	0.15	0.21	0.26
June 2007 -August 2007	**0.13**	**0.14**	**0.16**	**0.18**

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. The plot is shown for the period from June 1, 2007 to August 31, 2007.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The plot is shown for the period from June 1, 2007 to August 31, 2007.

- 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. March, 2007 has been the windiest month of the last 9 months. The plot is shown for the period from December 1, 2006 to August 31, 2007.

- Diurnal – A plot of the average wind speed for each hour of the day. The wind is strongest between 2AM and 3AM, and weakest between 6AM and 7AM. The plot is shown for the period from June 1, 2007 to August 31, 2007.

- 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. The plot is shown for the period from June 1, 2007 to August 31, 2007.

- 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. The WSW direction is the prevailing direction, with over 22% falling into that bin. The plot is shown for the period from June 1, 2007 to August 31, 2007.

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

Wind Speed Time Series

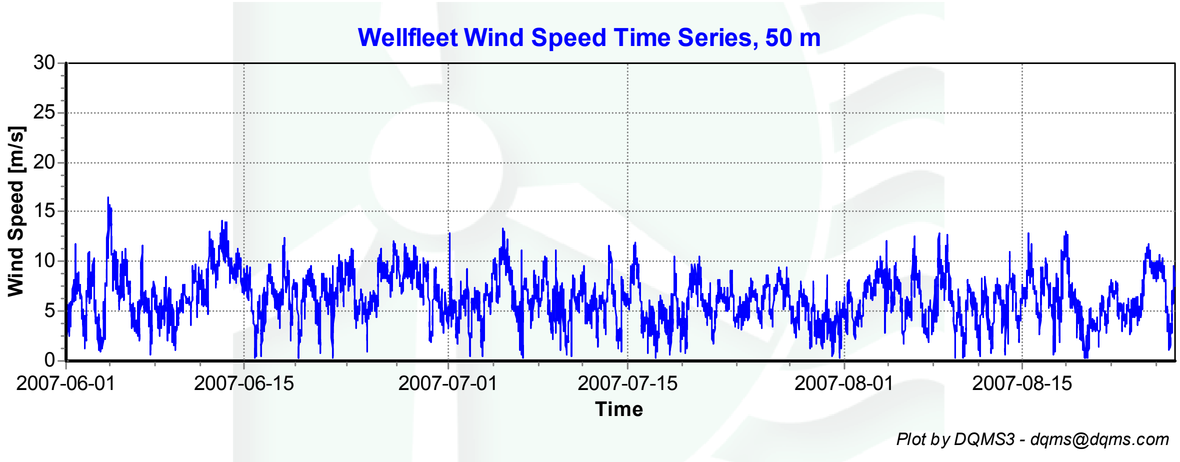

Figure 2 – Wind Speed Time Series, June 1, 2007 – August 31, 2007

Wind Speed Distributions

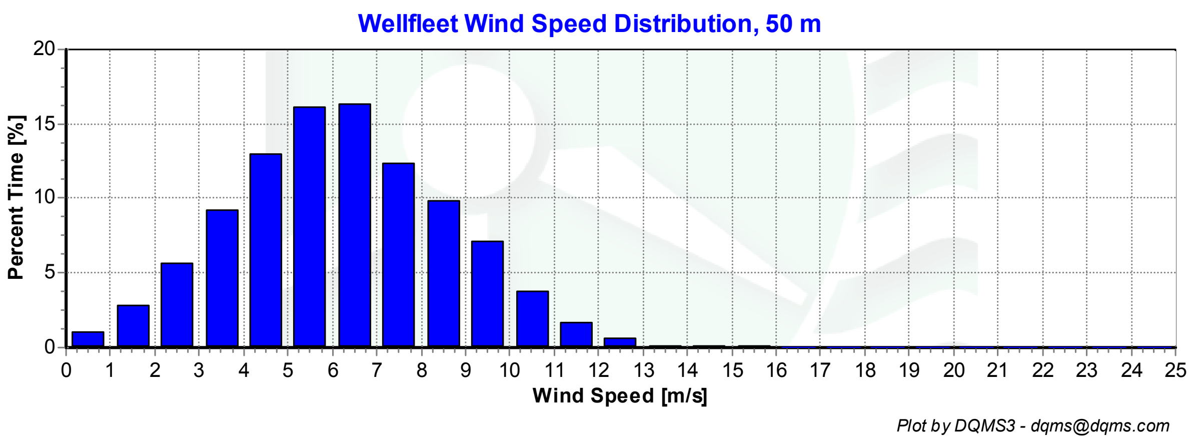

Figure 3 – Wind Speed Distribution, June 1, 2007 – August 31, 2007

Monthly Average Wind Speeds

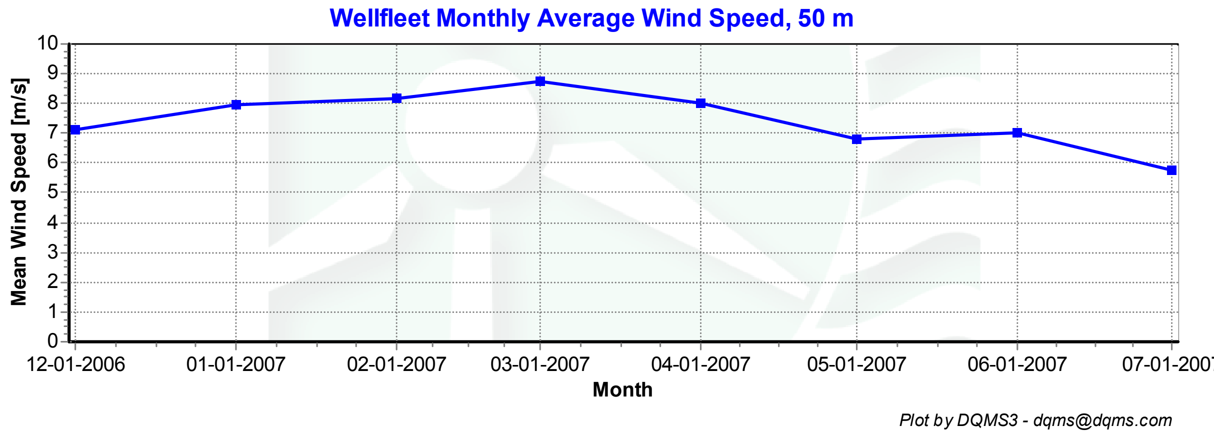

Figure 4 – Monthly Average Wind Speed, December 1, 2006 – August 31, 2007

Diurnal Average Wind Speeds

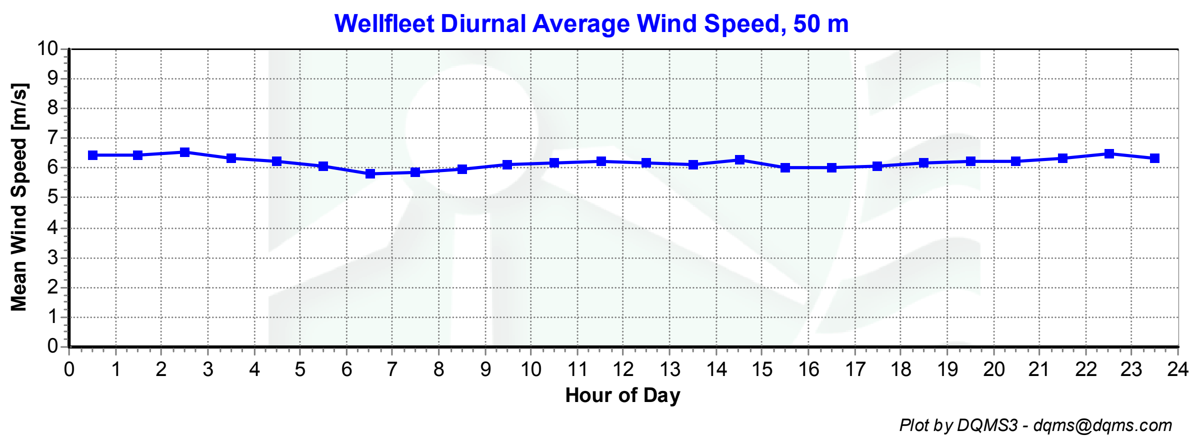

Figure 5 – Diurnal Average Wind Speed, June 1, 2007 – August 31, 2007

Turbulence Intensities

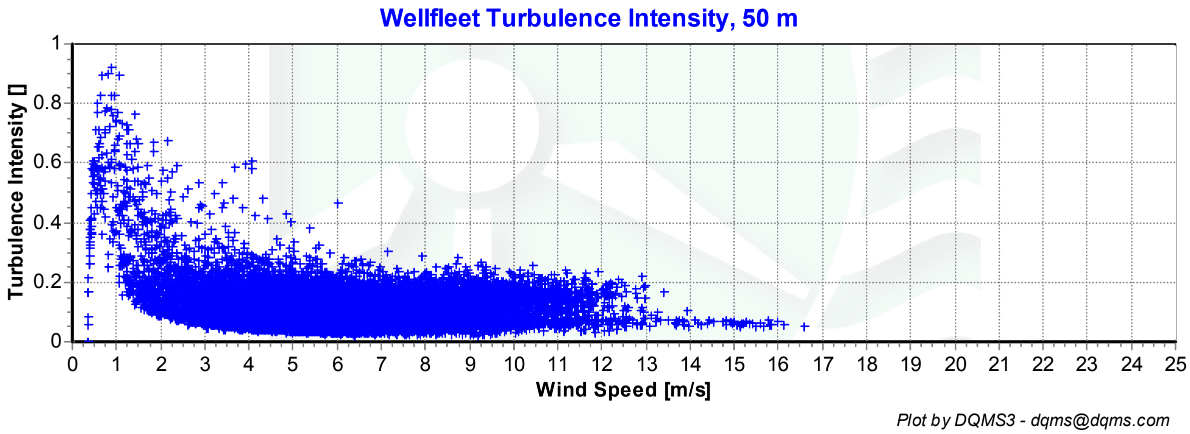

Figure 6 – Turbulence Intensity, June 1, 2007 – August 31, 2007

Wind Roses

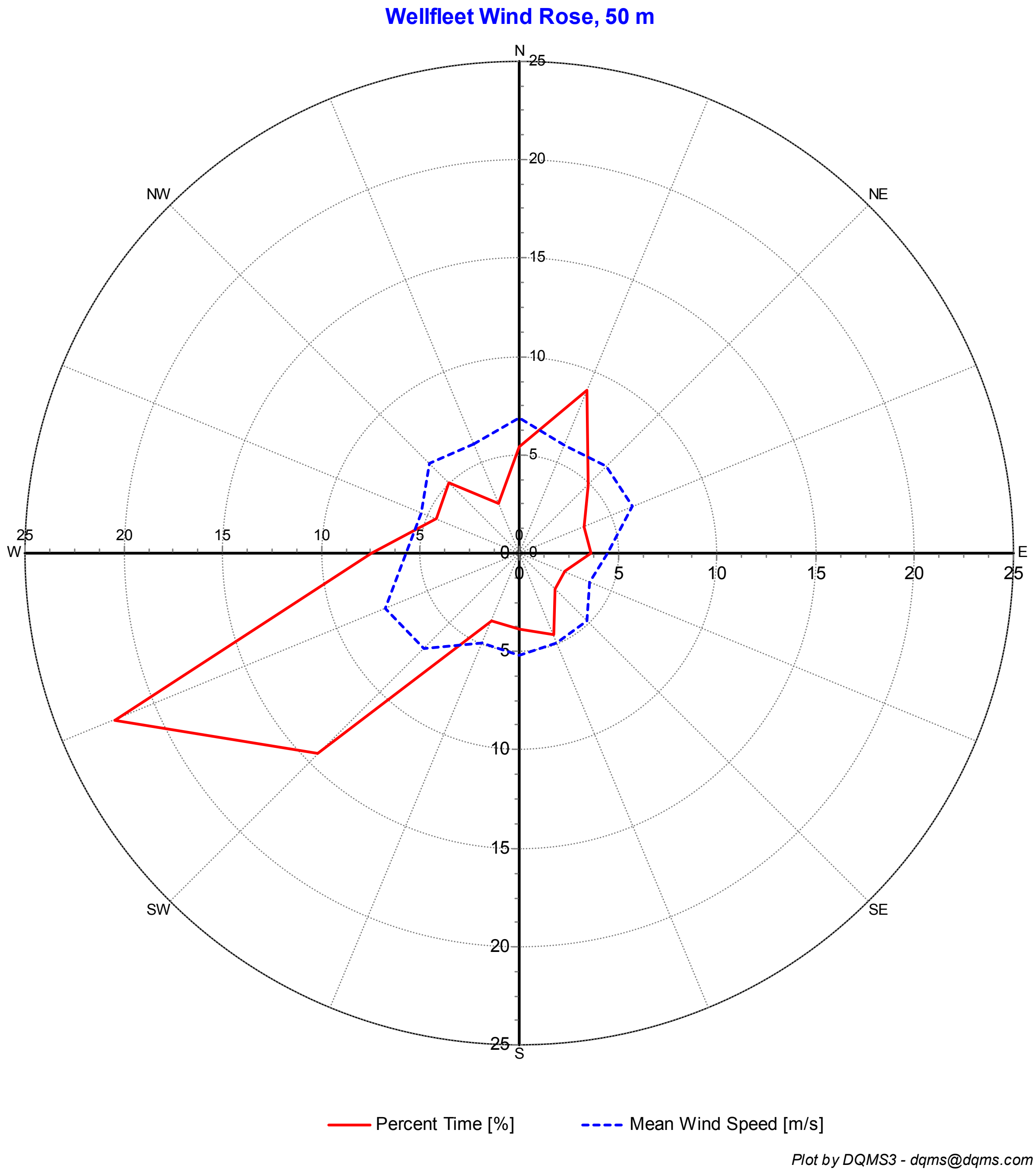

Figure 7 – Wind Rose, June 1, 2007 – August 31, 2007

SECTION 5 - Significant Meteorological Events

There were no significant meteorological events during this quarter.

SECTION 6 - Data Collection and Maintenance

No maintenance was performed in 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 [%]	99.2

<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.

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

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	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert	0	0	0	0
2	Etmp2aDEGC					MinMax	-30	60	0	0
3	Etmx2aDEGC					MinMax	-30	60	0	0
4	Etmn2aDEGC					MinMax	-30	60	0	0
5	EtmpSD2aDEGC					MinMax	-30	60	0	0
10	Anem50aMS					MinMax	0	90	0	0
11	Anem50bMS					MinMax	0	90	0	0
12	Anem38aMS					MinMax	0	90	0	0
13	Anem38bMS					MinMax	0	90	0	0
14	Anem20aMS					MinMax	0	90	0	0
15	Anem50yMS					MinMax	0	90	0	0
16	Anem38yMS					MinMax	0	90	0	0
20	AnemSD50aMS					MinMax	0	4	0	0
21	AnemSD50bMS					MinMax	0	4	0	0
22	AnemSD38aMS					MinMax	0	4	0	0
23	AnemSD38bMS					MinMax	0	4	0	0
24	AnemSD20aMS					MinMax	0	4	0	0
25	AnemSD50yMS					MinMax	0	4	0	0
26	AnemSD38yMS					MinMax	0	4	0	0
30	Vane50aDEG					MinMax	0	359.9	0	0
31	Vane38aDEG					MinMax	0	359.9	0	0
32	Vane20aDEG					MinMax	0	359.9	0	0
50	Turb50zNONE					MinMax	0	2	0	0
51	Turb38zNONE					MinMax	0	2	0	0
60	Wshr0zNONE					MinMax	-100	100	0	0
70	Pwrd50zWMS					MinMax	0	5000	0	0
71	Pwrd38zWMS					MinMax	0	5000	0	0
200	VaneSD50aDEG	Anem50yMS				MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS				MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS				MinMax	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
302	Anem38aMS	AnemSD38aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
303	Anem38bMS	AnemSD38bMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
400	Anem50aMS	Anem50bMS				CompareSensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS				CompareSensors	1	0.25	3	0

500	Amax50aMS					MinMax	0	90	0	0
501	Amax50bMS					MinMax	0	90	0	0
502	Amax38aMS					MinMax	0	90	0	0
503	Amax38bMS					MinMax	0	90	0	0
504	Amax20aMS					MinMax	0	90	0	0
510	Amin50aMS					MinMax	0	90	0	0
511	Amin50bMS					MinMax	0	90	0	0
512	Amin38aMS					MinMax	0	90	0	0
513	Amin38bMS					MinMax	0	90	0	0
514	Amin20aMS					MinMax	0	90	0	0
520	Vmax50aDEG					MinMax	0	359.9	0	0
521	Vmax38aDEG					MinMax	0	359.9	0	0
522	Vmax20aDEG					MinMax	0	359.9	0	0
530	Vmin50aDEG					MinMax	0	359.9	0	0
531	Vmin38aDEG					MinMax	0	359.9	0	0
532	Vmin20aDEG					MinMax	0	359.9	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
Etmp2aDEGC	13248	13248	100	0	0	0	100
EtmpSD2aDEGC	13248	13248	100	0	0	0	100
Anem50ams	13248	13248	100	0	0	26.333	98.807
AnemSD50ams	13248	13248	100	0	0	26.333	98.807
Anem50bms	13248	13248	100	0	0	114.5	94.814
AnemSD50bms	13248	13248	100	0	0	114.5	94.814
Vane50aDEG	-	-	-	-	-	-	-
VaneSD50aDEG	-	-	-	-	-	-	-
Anem38aMS	13248	13248	100	0	0	2.833	99.872
AnemSD38aMS	13248	13248	100	0	0	2.833	99.872
Anem38bMS	13248	13248	100	0	0	18.5	99.162
AnemSD38bMS	13248	13248	100	0	0	18.5	99.162
Vane38aDEG	13248	13248	100	0.667	0	0	99.97
VaneSD38aDEG	13248	13248	100	0.667	0	0	99.97
Anem20aMS	13248	13248	100	0	0	0	100
AnemSD20aMS	13248	13248	100	0	0	0	100
Vane20aDEG	13248	13248	100	0.333	0	0	99.985
VaneSD20aDEG	13248	13248	100	0.333	0	0	99.985
Total	**238464**	**238464**	**100**	**2**	**0**	**324.333**	**99.179**[*]

[*] The total percent good data does not take into account the malfunctioning 50m wind vane.

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent Time [%]
0.5	1.09
1.5	2.84
2.5	5.67
3.5	9.17
4.5	13.01
5.5	16.08
6.5	16.34
7.5	12.35
8.5	9.84
9.5	7.1
10.5	3.81
11.5	1.68
12.5	0.63
13.5	0.15
14.5	0.09
15.5	0.13
16.5	0.02
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

June 1, 2007 – August 31, 2007

Monthly Average Wind Speed Data

Month	Mean Wind Speed [m/s]
Dec-06	7.11
Jan-07	7.94
Feb-07	8.17
Mar-07	8.76
Apr-07	8.01
May-07	6.83
Jun-07	7.00
Jul-07	5.75
Aug-07	5.88

December, 2006 – August, 2007

Diurnal Average Wind Speed Data

Hour of Day	Wind Speed [m/s]
0.5	6.47
1.5	6.45
2.5	6.56
3.5	6.33
4.5	6.24
5.5	6.08
6.5	5.83
7.5	5.85
8.5	5.99
9.5	6.14
10.5	6.18
11.5	6.21
12.5	6.18
13.5	6.12
14.5	6.26
15.5	6.03
16.5	6.04
17.5	6.09
18.5	6.2
19.5	6.2
20.5	6.23
21.5	6.31
22.5	6.48
23.5	6.34

June 1, 2007 – August 31, 2007

Wind Rose Data

Wind Direction	Mean Wind Speed [m/s]	Percent of Time [%]
N	6.87	5.41
NNE	5.93	8.94
NE	6.24	4.91
ENE	6.21	3.55
E	4.48	3.62
ESE	3.88	2.48
SE	4.88	2.57
SSE	4.97	4.51
S	5.21	3.86
SSW	4.93	3.7
SW	6.83	14.43
WSW	7.36	22.16
W	5.73	7.5
WNW	5.38	4.55
NW	6.42	5.07
NNW	5.97	2.76

June 1, 2007 – August 31, 2007