WIND DATA REPORT

Swan's Island, ME

March 1, 2009 – May 31, 2009

Prepared for

US Department of Energy

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

This report summarizes the wind data recorded for the spring quarter, March 2009 through May 2009, at Swan's Island, ME. The spring months showed an overall decrease in wind resource from the winter. Average wind speed for the quarter was found to be 6.84 m/s at a height of 50m. The prevailing wind direction for the quarter was SW. The amount of valid data recorded for the quarter was 97%.

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 station is a cell phone tower operated by U.S. Cellular, located at Stockbridge Hill on Swans Island, Maine. The coordinates for the tower are 44.11161 N, 68.42218 W. The base of the tower is at an altitude of 54.86 m (180 ft) above mean sea level.

Figure 1 - Location of the Swans Island Tower

SECTION 2- Instrumentation and Equipment

The wind monitoring equipment is mounted on the cell phone tower at a height of 50 m and 40 m. At each height 2 NRG #40 anemometers with standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s) and 1 NRG #200P wind vane are installed. A #110S temperature sensor is mounted at the base of the tower at an approximated height of 2 m. The data is logged by an NRG Symphonie logger and is mailed to the University of Massachusetts, Amherst on a regular basis. 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 standard deviation for each 10-minute interval. The 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 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	**50 m [m/s]**	**50 m [m/s]**	**50 m**	**40 m [m/s]**	**40 m [m/s]**	**40 m**
Mar 2009	7.23	16.29	N	6.55	15.01	N
Apr 2009	6.92	18.37	SW	6.34	16.69	SSW
May 2009	6.37	14.61	SW	5.86	13.5	SSW
Mar 2009 – May 2009	**6.84**	**18.37**	**SW**	**6.25**	**16.69**	**SSW**

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. For this quarter, the percent of available data was 97.23%.

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	50 m [-]	40 m [-]	Between 50 m and 40 m [-]
Mar 2009	0.16	0.19	0.44
Apr 2009	0.16	0.18	0.39
May 2009	0.16	0.18	0.37
Mar 2009 –May 2009	**0.16**	**0.18**	**0.40**

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.

The time series shows the wind to stay between 3-8 m/s for the majority of the time with some highs above 15 m/s and lows below 3 m/s. The lows are more frequent in May. The monthly average wind speed for the quarter is approximately the same as last year with a decline moving into the warmer monthes. The mean wind speeds hold fairly steady over the hours of the day with a high point around sunset and a low point around sunrise. The wind rose displays the prevailing wind direction of SW where the winds are around the average speed (approximately 7 m/s) although stronger winds are shown to come from the East.

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

Wind Speed Time Series

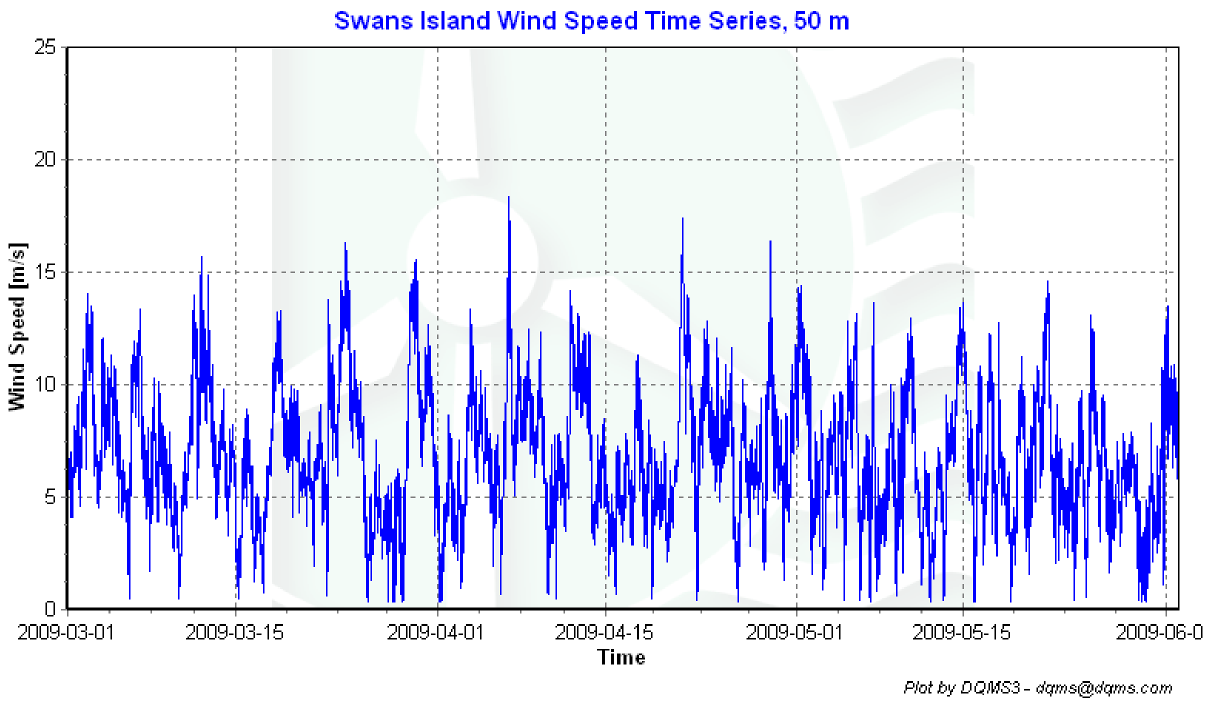

Figure 2 – Wind Speed Time Series, March 1, 2009 – May 31, 2009

Wind Speed Distributions

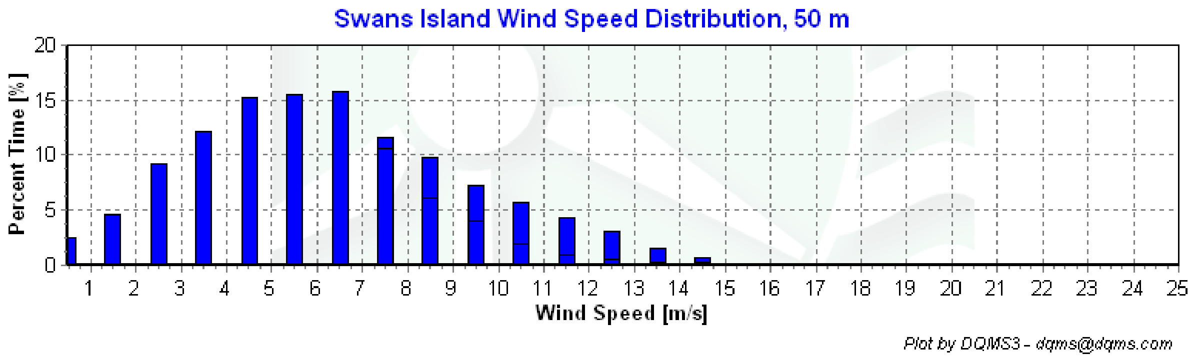

Figure 3 – Wind Speed Distribution, March 1, 2009 – May 31, 2009

Monthly Average Wind Speeds

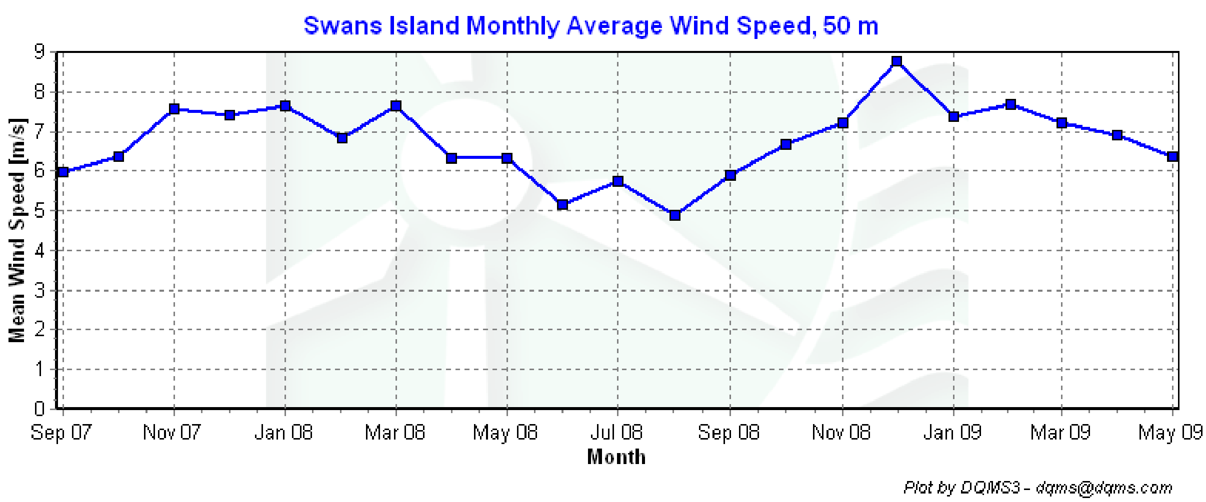

Figure 4 – Monthly Average Wind Speed September 2007 – May 2009

Diurnal Average Wind Speeds

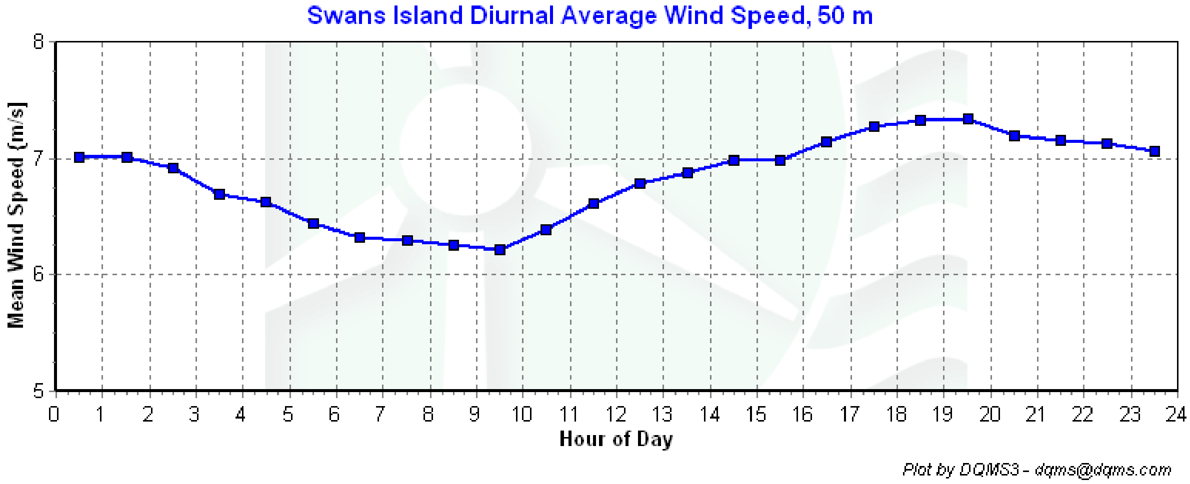

Figure 5 – Diurnal Average Wind Speed, March 1, 2009 – May 31, 2009

Turbulence Intensities

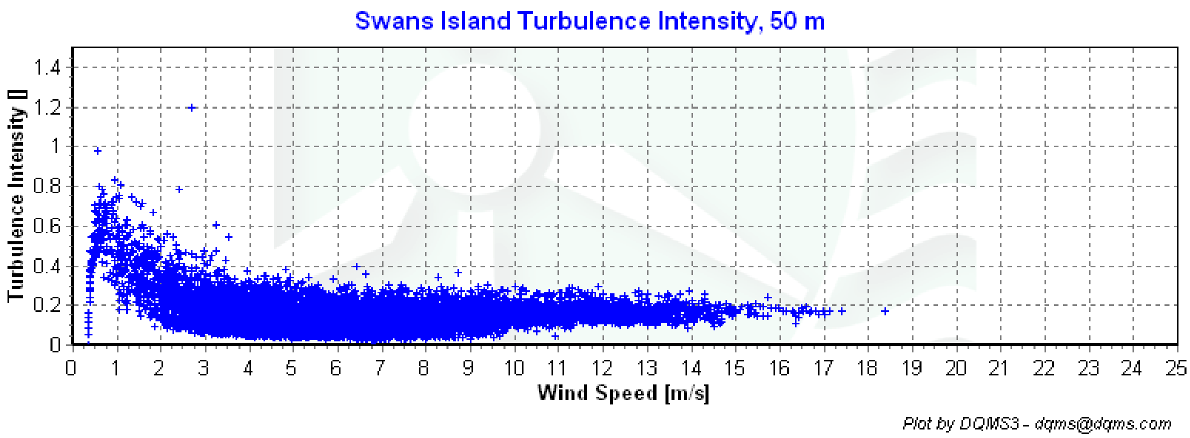

Figure 6 – Turbulence Intensity, March 1, 2009 – May 31, 2009

Wind Roses

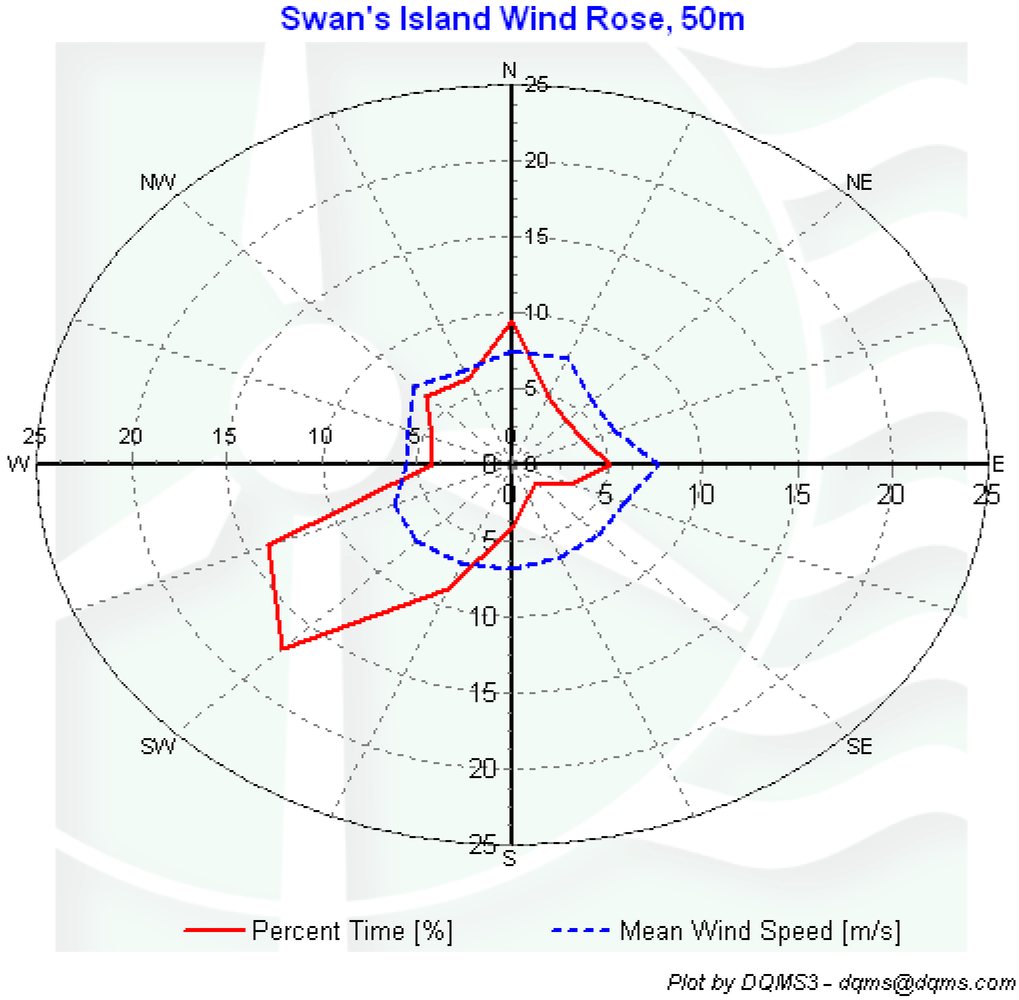

Figure 7 – Wind Rose, March 1, 2009 – May 31, 2009

SECTION 5- Significant Meteorological Events

There were no significant meteorological events occurring in the region between March 2009 and May 2009. Overall, spring started with a very stormy March and then became relatively calm. March experienced 2 large storms which relates to the icing and high wind speeds that occurred during the month.

Source: http://www.weather.gov/climate/index.php?wfo=car

SECTION 6 - Data Collection and Maintenance

There were no maintenance issues with the equipment for this quarter and data collection went well.

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 [%]	97.23

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.

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

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	TestField 2	TestField 3	CalcField 1	CalcField 2	Calc Field3	Test Type	Factor 1	Factor 2	Factor 3	Factor 4
1	Anem50aMS						MinMax	0	90		
2	Anem50bMS						MinMax	0	90		
3	Anem40aMS						MinMax	0	90		
4	Anem40bMS						MinMax	0	90		
5	Anem50yMS						MinMax	0	90		
6	Anem40yMS						MinMax	0	90		
7	Vane50aDEG						MinMax	0	359.9		
8	Vane40aDEG						MinMax	0	359.9		
9	Etemp2aDEGF						MinMax	-30	60		
10	Batt2aVDC						MinMax	10.5	15		
11	Turb50zNONE						MinMax	0	2		
12	Turb40zNONE						MinMax	0	2		
13	AnemSD50aMS						MinMax	0	4		
14	AnemSD50bMS						MinMax	0	4		
15	AnemSD40aMS						MinMax	0	4		
16	AnemSD40bMS						MinMax	0	4		
17	AnemSD50yMS						MinMax	0	4		
18	AnemSD40yMS						MinMax	0	4		
21	EtempSD2aDEGF						MinMax	-30	60		
22	BattSD2aVDC						MinMax	0	5		
200	VaneSD50aDEG	Anem50yMS					MinMaxT	0	100	100	10
201	VaneSD40aDEG	Anem40yMS					MinMaxT	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
302	Anem40aMS	AnemSD40aMS	Vane40aDEG	VaneSD40aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
303	Anem40bMS	AnemSD40bMS	Vane40aDEG	VaneSD40aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
304	Anem50yMS	AnemSD50yMS	Vane50aDEG	VaneSD50aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
305	Anem40yMS	AnemSD40yMS	Vane40aDEG	VaneSD40aDEG	Etemp2aDEGF		Icing	0.5	1	2	4
400	Anem50aMS	Anem50bMS					Compare Sensors	1	0.25	3	0
401	Anem40aMS	Anem40bMS					Compare Sensors	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50aMS	13105	13105	100	0	16.5	108	94.3
Anem50bMS	13105	13105	100	0	16.5	97.833	94.765
Anem40aMS	13105	13105	100	0	23	97.5	94.483
Anem40bMS	13105	13105	100	0	24	80.333	95.223
Vane50aDEG	13105	13105	100	0.167	16.5	0	99.237
Vane40aDEG	13105	13105	100	0.167	24	0	98.894
Etemp2aDEGF	13105	13105	100	0	0	0	100
Anem50yMS	13105	13105	100	0	16.5	0	99.245
Anem40yMS	13105	13105	100	0	23	0	98.947
Total	**117945**	**117945**	**100**	**0.333**	**160**	**383.667**	**97.233**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Time [%]
0.5	1.37
1.5	2.25
2.5	4.62
3.5	8.64
4.5	11.74
5.5	13.64
6.5	13.48
7.5	11.56
8.5	9.8
9.5	7.29
10.5	5.76
11.5	4.3
12.5	3.03
13.5	1.48
14.5	0.7
15.5	0.18
16.5	0.13
17.5	0.02
18.5	0.01
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Diurnal Average Wind Speed Data

Hour of day	Wind Speed [m/s]
0.5	7.01
1.5	7.01
2.5	6.92
3.5	6.69
4.5	6.63
5.5	6.43
6.5	6.32
7.5	6.29
8.5	6.26
9.5	6.22
10.5	6.39
11.5	6.62
12.5	6.78
13.5	6.87
14.5	6.98
15.5	6.98
16.5	7.14
17.5	7.28
18.5	7.32
19.5	7.33
20.5	7.2
21.5	7.15
22.5	7.13
23.5	7.06

Monthly Average Wind Speed Data

Month	50 m Mean Wind Speed [m/s]
March 2008	7.23
April 2008	6.92
May 2008	6.37

Wind Rose Data

Wind Direction	Mean Wind Speed [m/s]	Percent of Time [%]
N	7.54	9.45
NNE	7.55	4.9
NE	5.94	4.03
ENE	5.79	4.14
E	7.62	5.14
ESE	6.39	3.32
SE	6.43	1.73
SSE	6.51	2.31
S	6.84	4.08
SSW	7.01	8.87
SW	7.08	17.04
WSW	6.75	13.82
W	5.52	4.16
WNW	5.91	4.57
NW	7.3	6.33
NNW	6.66	6.12