WIND DATA REPORT

Rockport School Complex
Rockport, Massachusetts

December 1, 2006 – February 28, 2007

Prepared for

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

This report covers wind data measured at a meteorological tower installed at Rockport school complex in the town of Rockport, MA. Installed on October 27^{th}, 2006, the wind monitoring station has been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 49 m (160.7 ft) and 38 m (124.6 ft), and an additional anemometer and vane are mounted at 20 m (65.6 ft). Reports are made on a quarterly basis; and this report is the second such report for Rockport.

The season covered by this second quarterly report is December 2006 – February 2007 (winter quarter). Because of low valid data returns (79.3 % overall) due to a logger fault from late January until late February, care is advised in comparing the results reported here with other sites that possess a full quarter's worth of data. Due to the logger fault, valid statistics can only be calculated for the month of December. On February 21 the faulty logger was replaced and data collection has proceeded without incident since then. Though the amount of missing data is large, it is expected that this loss will only affect this quarter and that capabilities that the RERL has developed will allow for meaningful results to be produced for the final yearly report.

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 Rockport site is located very near the Rockport school complex in Rockport, MA. Latitude and Longitude are 42° 39.09’N and 70° 36.57’W, respectively, using the NAD 83 datum. Figure 1 shows the site on a topographic map.

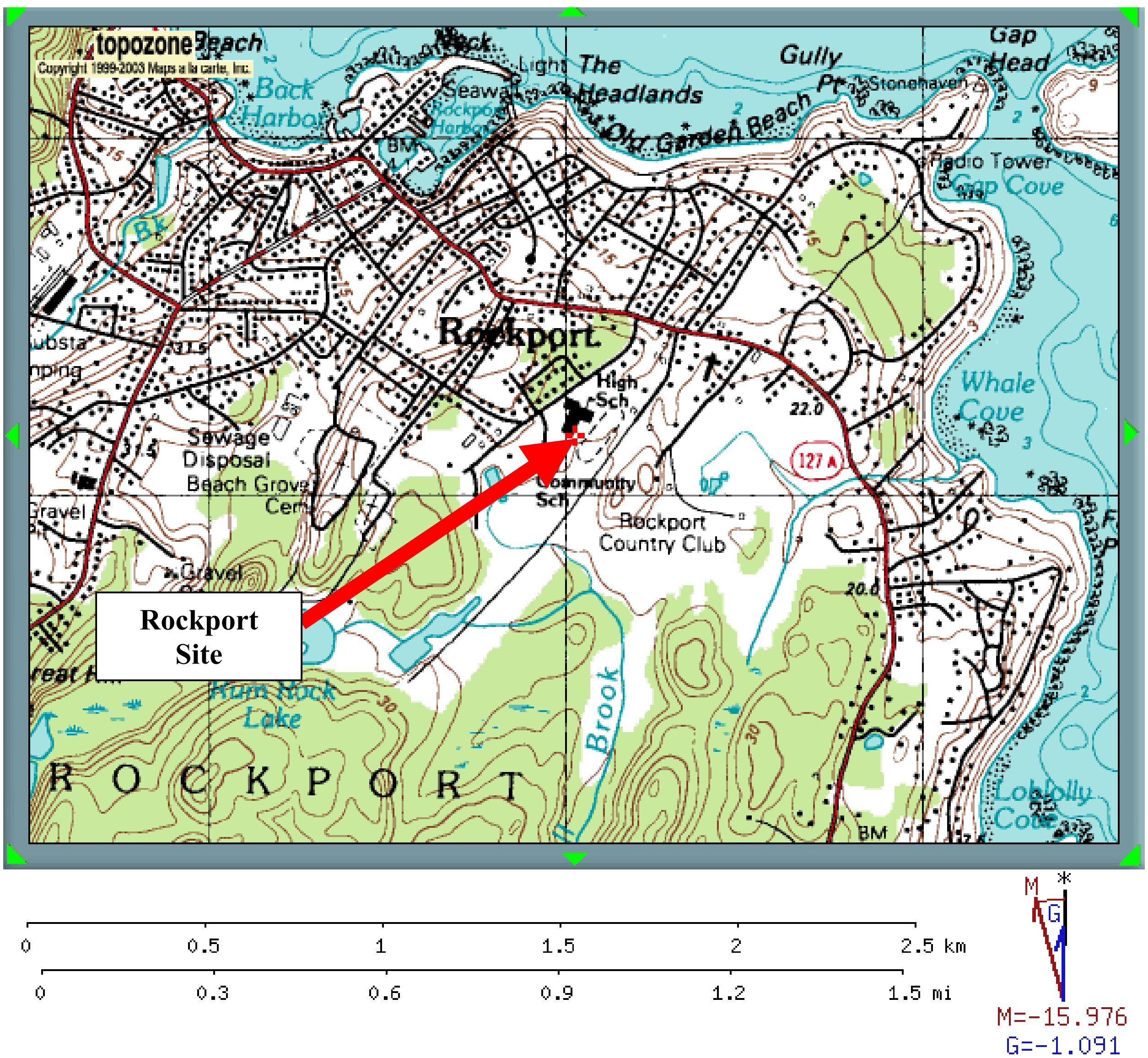

Figure 1 – Topographic Map Showing Rockport Site Location--Source Topozone.com

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) NRG tower. All other monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- Electrical enclosure box
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 49 m (160.7 ft), two at 38 m(124.6 ft) and one at 20 m (65.6 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 49 m (160.7 ft), 38 m(124.6 ft) and 20 m (65.6 ft) each.
- 5 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 – Preparation to raise the Met-tower at Rockport Site

The data from the Symphonie logger is mailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These data 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 quality assurance (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	**49 m [m/s]**	**49 m [m/s]**	**49 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]**
Dec 2006	6.05	15.21	NNW	5.39	13.95	NNW	2.98	11.73	WNW
Jan 2007	--	--	NNW	--	--	NNW	--	--	NNW
Feb 2007	--	--	NNW	--	--	WNW	--	--	WNW
Dec 2006 -Feb 2007	**--**	**--**	**NNW**	**--**	**--**	**NNW**	**--**	**--**	**NNW**

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 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_{high} 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	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, α
Height Units	**49 m [-]**	**38 m [-]**	**20 m [-]**	**Between 49 m and 38 m [-]**
Dec 2006	0.21	0.24	0.27	0.454
Jan 2007	--	--	--	--
Feb 2007	--	--	--	--
Dec 2006 -Feb 2007	**--**	**--**	**--**	**--**

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 gaps in wind speed data are clearly visible in the time series graph (Figure 3). Due to the paucity of data for the quarter, only graphs that do not depend on quarterly statistics (i.e. the monthly average wind speed graph (Figure 5), and the turbulence intensity graph (Figure 6)) are available.

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

Wind Speed Time Series

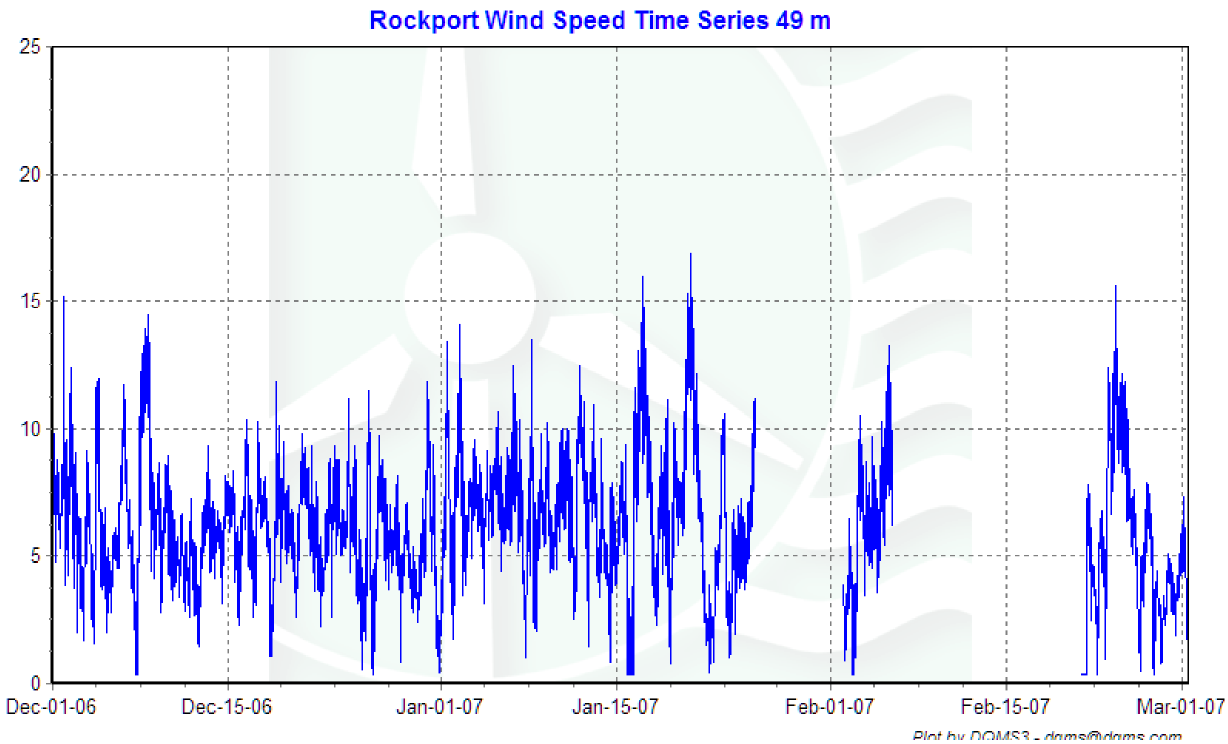

Figure 3 - Wind Speed Time Series, December 1st 2006—March 1st 2007

Wind Speed Distributions

Not available due to lack of valid data

Figure 4 - Wind Speed Distribution, December 1st 2006—March 1st 2007

Monthly Average Wind Speeds

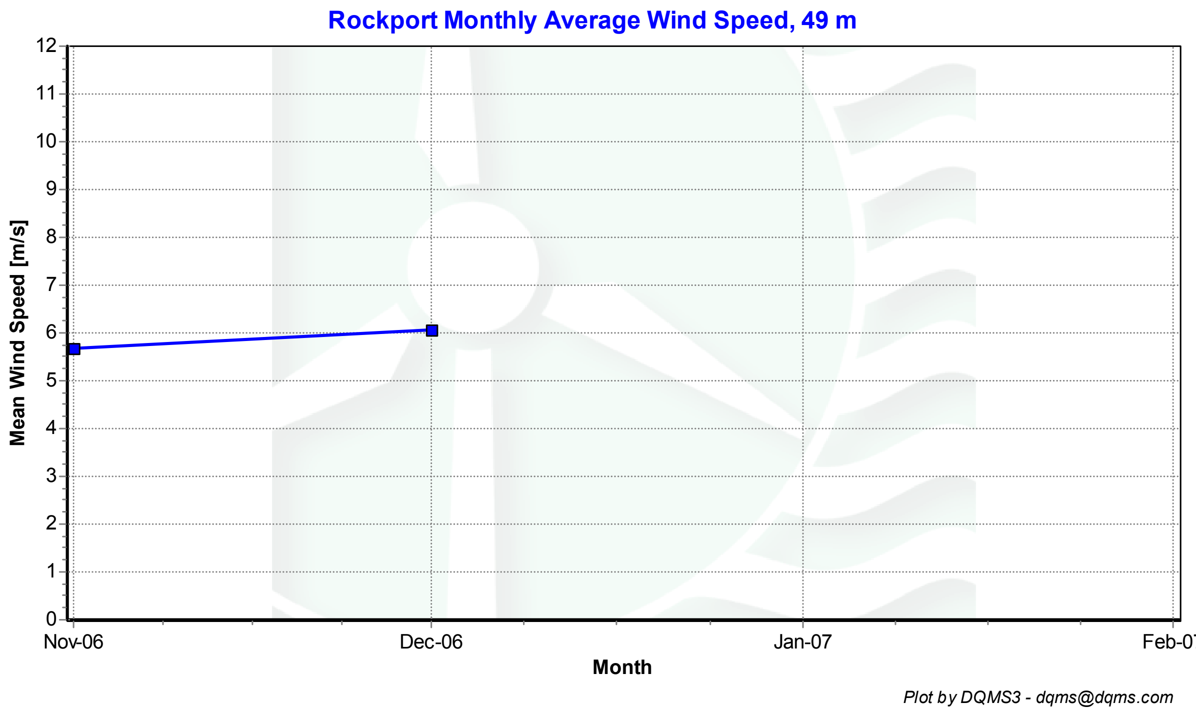

Figure 5 - Monthly Average Wind Speed

Diurnal Average Wind Speeds

Not available due to lack of valid data

Figure 6 - Diurnal Average Wind Speed, December 1st 2006—March 1st 2007

Turbulence Intensities

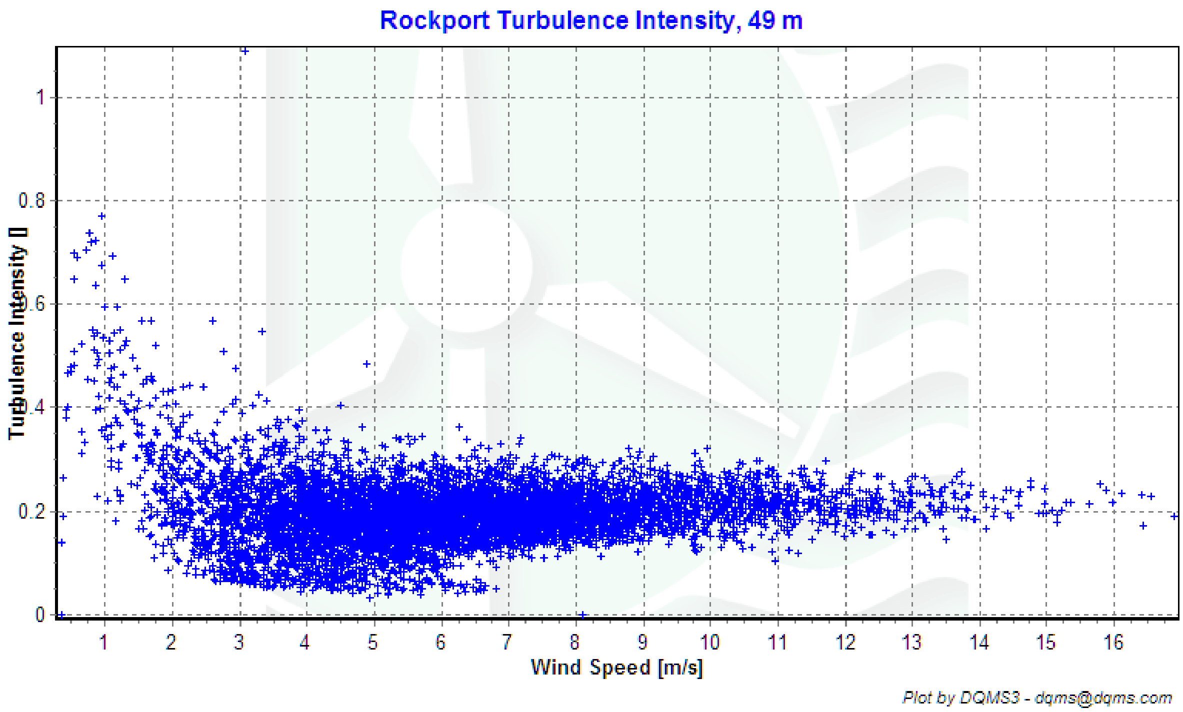

Figure 7 - Turbulence Intensity, December 1st 2006—March 1st 2007

Wind Roses

Not available due to lack of valid data

Figure 8 - Wind Rose, December 1st 2006—March 1st 2007

SECTION 5 - Significant Meteorological Events

Other than normal winter storm activity, there were no weather conditions that would have significantly affected wind speed or wind direction data.

Sources:
http://www.wunderground.com/, http://www.erh.noaa.gov/box/MonthlyClimate2.shtml

SECTION 6 - Data Collection and Maintenance

As can be seen in Figure 3 problems with the wind speed data began to occur on about January 26 and lasted until the logger was replaced on February 21—though there is a brief period (Feb 2 until Feb 6) where valid data was also collected. The faulty logger was returned to NRG, and it was confirmed as the cause of the invalid data. The logger fault has resulted in only 83% and 53% valid data for the months of January and February, respectively; with the wind speed data being disproportionately affected. For example only 77% and 28% valid data were collected from the 49 m anemometer set for the months of January and February, respectively.

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 [%]	95.024
Net Data Recovered [%]	79.313

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

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	Calc Field2	Calc Field3	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
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
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
52	Turb20zNONE						MinMax	0	2	0	0
60	Wshr0zNONE						MinMax	-100	100	0	0
200	VaneSD50aDEG	Anem50yMS					MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS					MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS					MinMaxT	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2	10
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	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
Anem50aMS	12961	12961	100	499.5	54.333	102	69.64
AnemSD50aMS	12961	12961	100	499.5	54.333	102	69.64
Anem50bMS	12961	12961	100	602.667	55.833	0	69.516
AnemSD50bMS	12961	12961	100	602.667	55.833	0	69.516
Anem50yMS	12961	9791	75.542	0.333	30.833	99.5	69.493
AnemSD50yMS	12961	12961	100	499.5	54.333	100.167	69.725
Anem38aMS	12961	12961	100	511.333	41.5	1	74.362
AnemSD38aMS	12961	12961	100	511.333	41.5	1	74.362
Anem38bMS	12961	12961	100	4.167	41	512.5	74.184
AnemSD38bMS	12961	12961	100	4.167	41	512.5	74.184
Anem38yMS	12961	12961	100	511.333	40.167	1	74.423
AnemSD38yMS	12961	12961	100	511.333	40.167	1	74.423
Anem20aMS	12961	9503	73.32	69.5	36.167	0	68.428
Vane50aDEG	12961	12961	100	0	55.833	0	97.415
VaneSD50aDEG	12961	12961	100	0	55.833	0	97.415
Vane38aDEG	12961	12961	100	0	42.333	0	98.04
VaneSD38aDEG	12961	12961	100	0	42.333	0	98.04
Vane20aDEG	12961	9503	73.32	0	36.167	0	71.646
VaneSD20aDEG	12961	9503	73.32	0	36.167	0	71.646
Etmp2aDEGC	12961	12961	100	11.333	0	0	99.475
EtmpSD2aDEGC	12961	12961	100	0	0	0	100
Total	272181	258637	95.024	4838.667	855.667	1432.667	79.313

APPENDIX B - Plot Data

Wind Speed Distribution Data

Not available due to lack of valid data

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Nov-06	5.67
Dec-06	6.05
Jan-06	--
Feb-06	--

Diurnal Average Wind Speed Data

Not available due to lack of valid data

Wind Rose Data

Not available due to lack of valid data