LONG TERM SITE
WIND DATA QUARTERLY REPORT

Bishop and Clerks

October 1, 2011 – December 31, 2011

Prepared for

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

by

Frederick Letson
James F. Manwell
Anthony F. Ellis

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Wind **E**nergy **C**enter
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
http://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.

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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.

This wind measurement station is installed on the Bishop & Clerks US Coast Guard (USCG) automated lighthouse, almost 3 miles south-southeast of Pt. Gammon on Cape Cod, MA. Installed in November of 2000, the wind monitoring station has been in continuous operation to this day. The two anemometers and wind vanes are mounted 15 m (49 ft) above the Mean Low Water Level.

This quarterly report covers the period October 1, 2011 – December 31, 2011. During this period, the mean recorded wind speed at 15 m was 7.96 m/s (17.8 mph) and the prevailing wind direction was from the Southwest. The average turbulence intensity at 15 m was 0.09. The gross data recovery percentage (the actual percentage of expected data received) was 98.91% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 91.12%. Most of the data that did not pass quality assurance tests was due a progressive failure of the primary anemometer starting on Oct 18th 2011. Due to sensor redundancy, wind speed statistics in this report are based on data from the full reporting period.

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 WEC and the Massachusetts Technology Collaborative (MTC). This document is found through the WEC website:

http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1 - Station Location

Bishop & Clerks was originally a small island south of Hyannis in the 1800's. Over time, it has eroded down to a few exposed rocks. The concrete and stone base of the lighthouse is currently the largest remaining piece above water. The lighthouse is located within the three-mile state limit of Massachusetts' waters, at 41^0-34'-27.6" North, 070^0-14'-59.5" West (Figure 1). The wind monitoring station at Bishop and Clerks is located on the top of the USCG lighthouse facility. Relative to the Mean Low Water Level, the anemometry is mounted at a height of 15 m (49 ft).

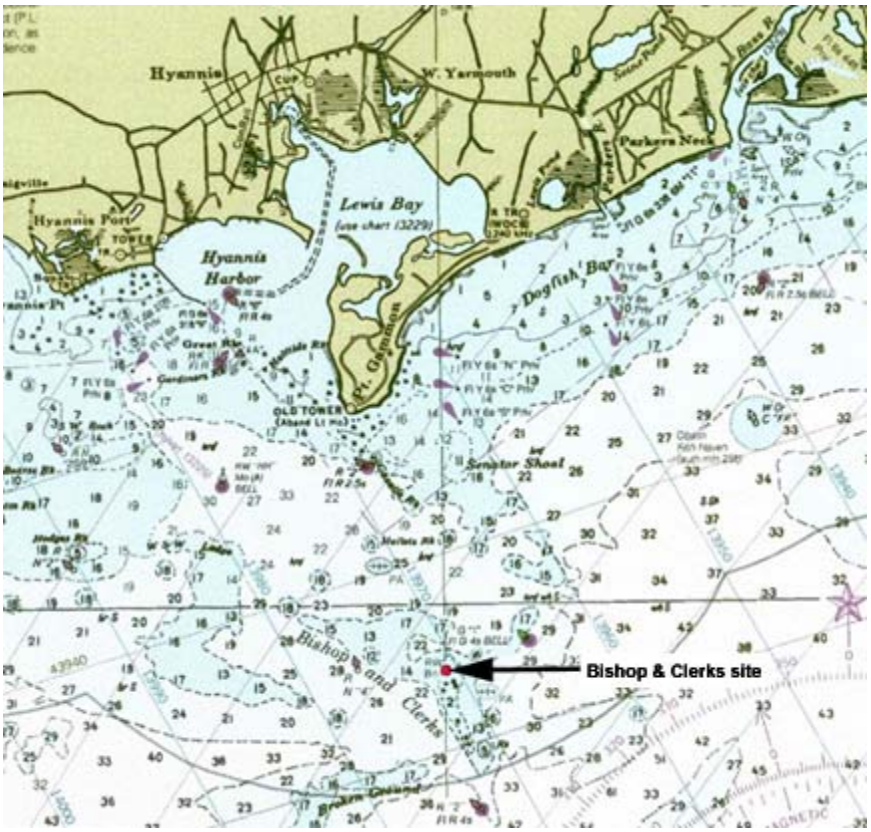

Figure 1 - Site location at Bishop & Clerks light

SECTION 2- Instrumentation and Equipment

The wind monitoring equipment is mounted on a 12 ft long, 3" diameter, aluminum mast that is secured to the permanent solar panel mount for the lighthouse. Figure 2 shows the sensor load-out at Bishop and Clerks. This photograph was taken before the mast was moved in June of 2011, but it still reflects the appearance of the current monitoring equipment. The wind monitoring equipment consists of the following items:

- Symphonie ® Data Logger with iPack Modem
- Electrical enclosure box with 5 watt PV panel
- 1 – #40 Anemometer, standard calibration (Slope - 0.7652 m/s, Offset – 0.425 m/s)
- 1 – Wind Sensor P2546A anemometer (Slope - 0.6216 m/s, Offset – 0.21002 m/s)
- 2 – DV-200 wind vanes
- 4 – Sensor booms, 43" length
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 - Anemometry mast and data collection equipment at Bishop & Clerks

Limitations of this setup are that the mast height is low relative to the diameter of the lighthouse and the fact that the warning light and a PV panel mounted on top of the tower can interfere with the free flow of air.

The Symphonie® logger is equipped with a built-in cell phone so that the data can be transmitted to a PC, located at the University of Massachusetts, Amherst. 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. 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, the maximum instantaneous wind speed and the prevailing wind direction. 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

Month	Mean Wind Speed [m/s]	NDR [%]	Max Wind Speed [m/s]	NDR [%]	Prevailing Direction [deg]	NDR [%]	TI at 10 m/s [-]	NDR [%]
Oct-11	8.671	96.77 %	23.45	96.77 %	SW	96.77 %	0.09029	96.77 %
Nov-11	8.449	100 %	21.04	100 %	SW	98.68 %	0.08417	100 %
Dec-11	7.96	99.91 %	21.4	99.91 %	SSW	99.1 %	0.09554	99.91 %
Quarter	8.355	98.88 %	23.45	98.88 %	SW	98.18 %	0.08967	98.88 %

A summary of the turbulence intensity during the reporting period is also included in Table 1. 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 1 is the mean turbulence intensity when the wind speed at each measurement height is between 10 and 11 m/s.

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. 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 the sensor mast and booms. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

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.

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

Wind Speed Time Series

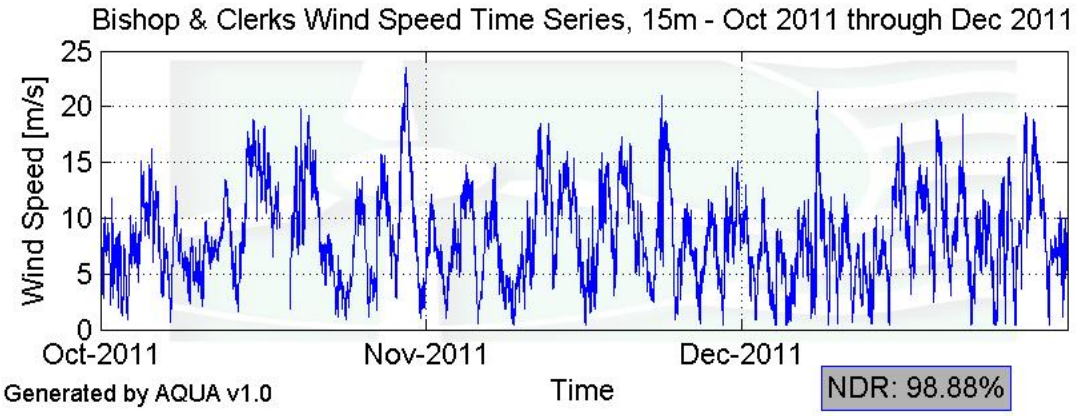

Figure 3 – Wind Speed Time Series

Wind Speed Distributions

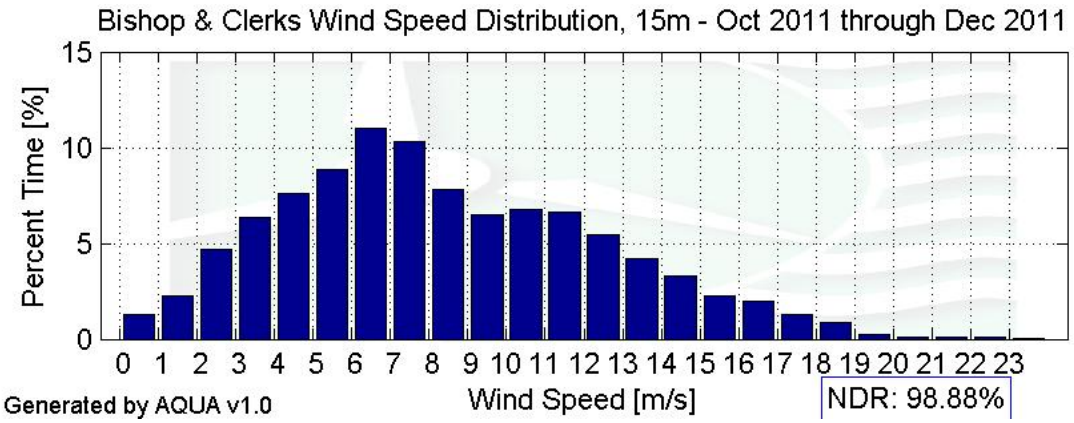

Figure 4 – Wind Speed Distribution

Monthly Average Wind Speeds

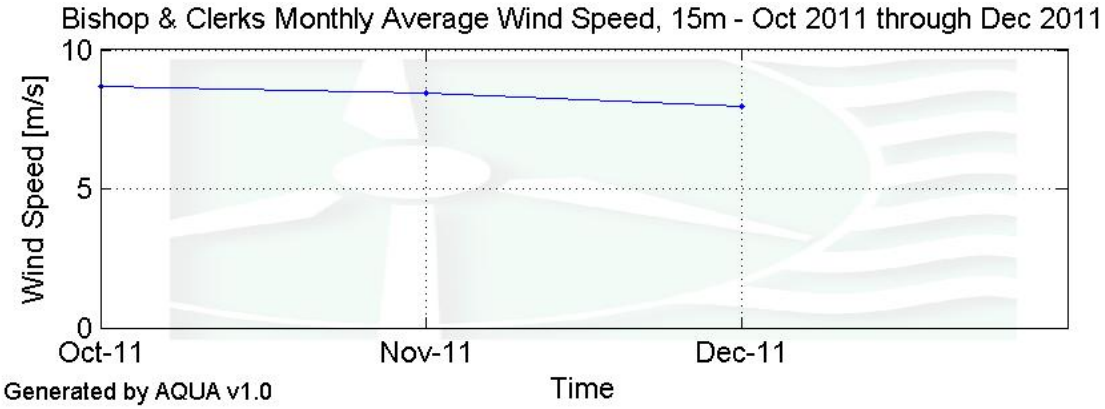

Figure 5 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

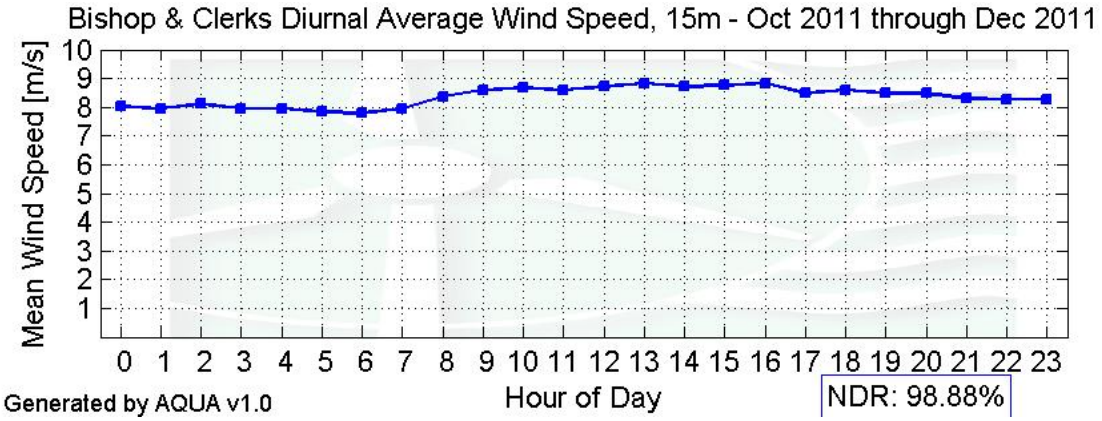

Figure 6 – Diurnal Average Wind Speeds

Turbulence Intensities

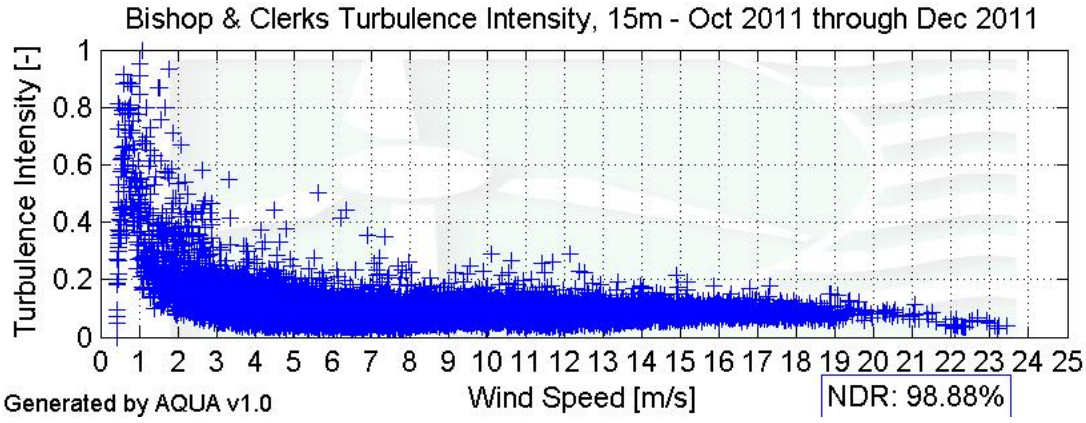

Figure 7 – Turbulence Intensity

Wind Roses

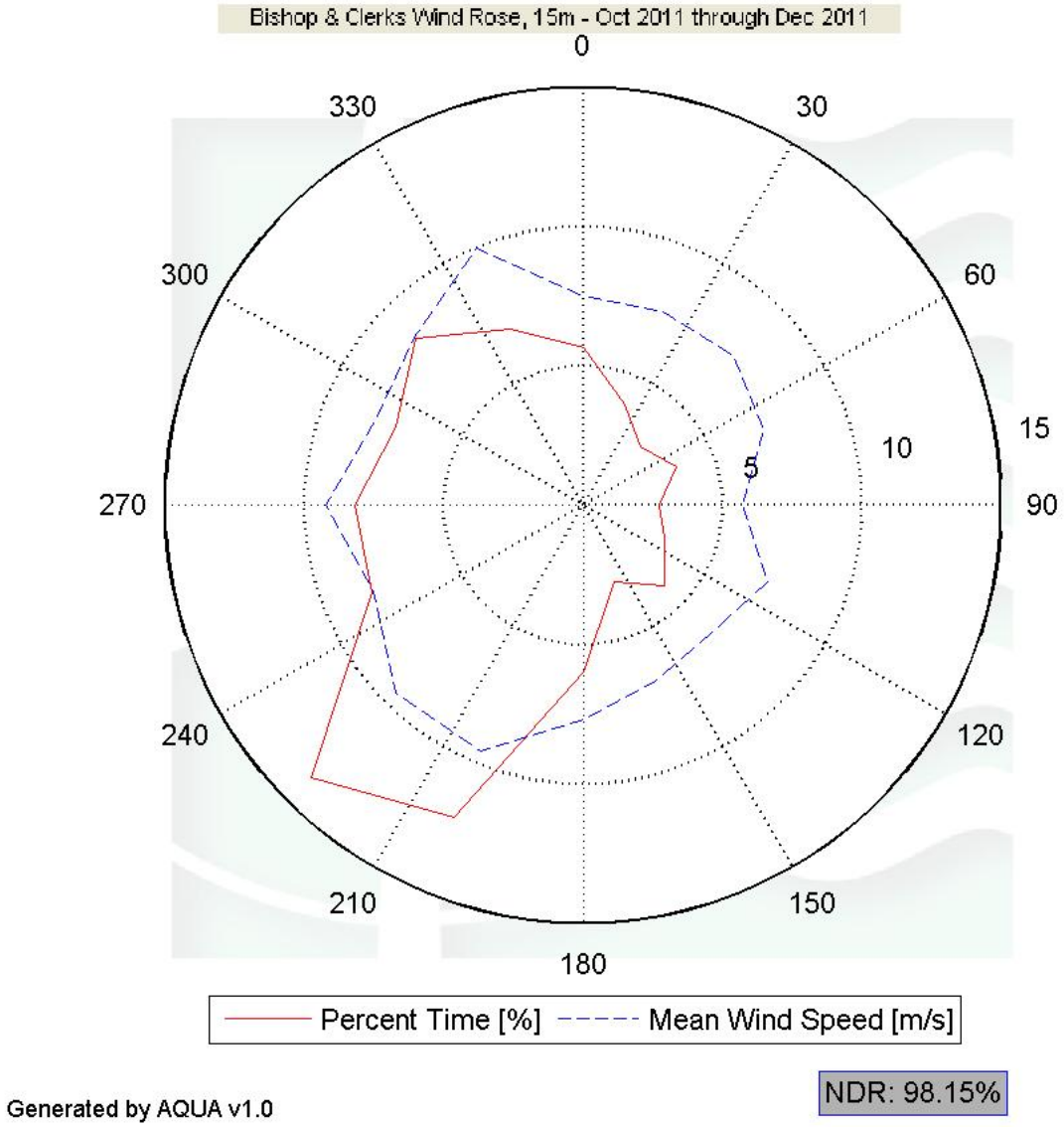

Figure 8 – Wind Rose

SECTION 5 - Significant Meteorological Events

There were no meteorological events during this reporting period significant enough to affect monthly statistics.

SECTION 6 - Data Collection and Maintenance

- No Maintenance was performed during this reporting period

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 [%]	98.91
Net Data Recovered [%]	91.12

Most of the data that did not pass quality assurance tests was due a progressive failure of the primary anemometer starting on Oct 18th 2011. Due to sensor redundancy, wind speed statistics in this report are based on data from the full reporting period.

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.

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

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

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1	itmp>T_val						MinMax	-30	60	0	0
2	VDC>V_val						MinMax	10.5	90	0	0
3	anem15a>WS_val						MinMax	0.3501	90	0	0
4	anem15a>WS_SD						MinMax	0	4	0	0
5	anem15b>WS_val						MinMax	0.3501	90	0	0
6	anem15b>WS_SD						MinMax	0	4	0	0
7	RMY15a>WS_val						MinMax	0.3501	90	0	0
8	RMY15a>WS_SD						MinMax	0	4	0	0
9	RMY15b>WS_val						MinMax	0.3501	90	0	0
10	RMY15b>WS_SD						MinMax	0	4	0	0
11	RMYvane15a>WD_val						MinMax	0	359.9	0	0
12	RMYvane15a>WD_SD						MinMax	0.01	100	0	0
13	RMYvane15b>WD_val						MinMax	0	359.9	0	0
14	RMYvane15b>WD_SD						MinMax	0.01	100	0	0
15	anem15a>WS_val	anem15b>WS_val					CompareSensors	1	0.25	3	0

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
itmp	13248	13104	98.913	0	0	0	98.913
VDC	13248	13104	98.913	0	0	0	98.913
anem15a	13248	13104	98.913	957.667	0	18.167	54.718
anem15b	13248	13104	98.913	0.667	0	28.833	97.577
vane15a	13248	13104	98.913	16.167	0	0	98.181
vane15b	13248	13104	98.913	11	0	0	98.415
Total	79488	78624	98.913	985.501	0	47	91.1195

APPENDIX B- Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent Time [%]
0.5	0.12
1.5	1.90
2.5	4.24
3.5	7.15
4.5	8.31
5.5	7.87
6.5	11.90
7.5	10.07
8.5	7.01
9.5	6.02
10.5	6.76
11.5	6.50
12.5	5.42
13.5	3.94
14.5	3.15
15.5	3.43
16.5	2.36
17.5	1.16

Monthly Average Wind Speed Data

Month	Wind Speed at 15 m 10 min Average [m/s]
11-Oct	8.671
11-Nov	8.449
11-Dec	7.96

Diurnal Average Wind Speed Data

Hour of Day	Mean Wind Speed [m/s]
0	8.02
1	7.95
2	8.12
3	7.94
4	7.96
5	7.84
6	7.78
7	7.96
8	8.36
9	8.61
10	8.67
11	8.61
12	8.72
13	8.84
14	8.70
15	8.77
16	8.82
17	8.48
18	8.60
19	8.48
20	8.48
21	8.29
22	8.27
23	8.27

Wind Rose Data

Bin Center [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	5.67	7.50
22.5	3.92	7.50
45	2.94	7.62
67.5	3.61	7.02
90	2.73	5.70
112.5	3.14	7.16
135	4.13	6.50
157.5	2.96	6.83
180	5.97	7.71
202.5	12.14	9.58
225	13.84	9.52
247.5	8.18	8.13
270	8.18	9.23
292.5	7.29	8.05
315	8.48	8.55
337.5	6.82	9.98