WIND DATA REPORT

Bishop and Clerks

June 1, 2004 – August 31, 2004

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

James F. Manwell
Anthony L. Rogers
Anthony F. Ellis
Christopher N. Elkinton

October 8, 2004

Renewable **E**nergy **R**esearch **L**aboratory
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.ceere.org/rerl • (413) 545-4359 • rerl@ecs.umass.edu

TABLE OF CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

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.

During the season covered by this report, June 2004 – August 2004, the mean recorded wind speed was 6.74 m/s (15.2 mph)* and the prevailing wind direction was from the southwest. The gross data recovery percentage (the actual percentage of expected data received) was 100% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.196%. Both of these percentages are very high, indicating that the sensors and data logger were performing well. It should be noted, however, that the anemometers started to show signs indicative of the fact that they have exceeded their expected lifetimes. The percentage of faulty data was small (2.4%) during this quarter, but the sensors will be removed or replaced during the next site visit.

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:

www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf.

* 1 m/s = 2.25 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's waters, at 41^0-34'-27.6" North, 070^0-14'-59.5" West (Figure 1). A photo of the lighthouse as it stands today can be seen at www.ceere.org/rerl/rerl_offshore.html. 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).

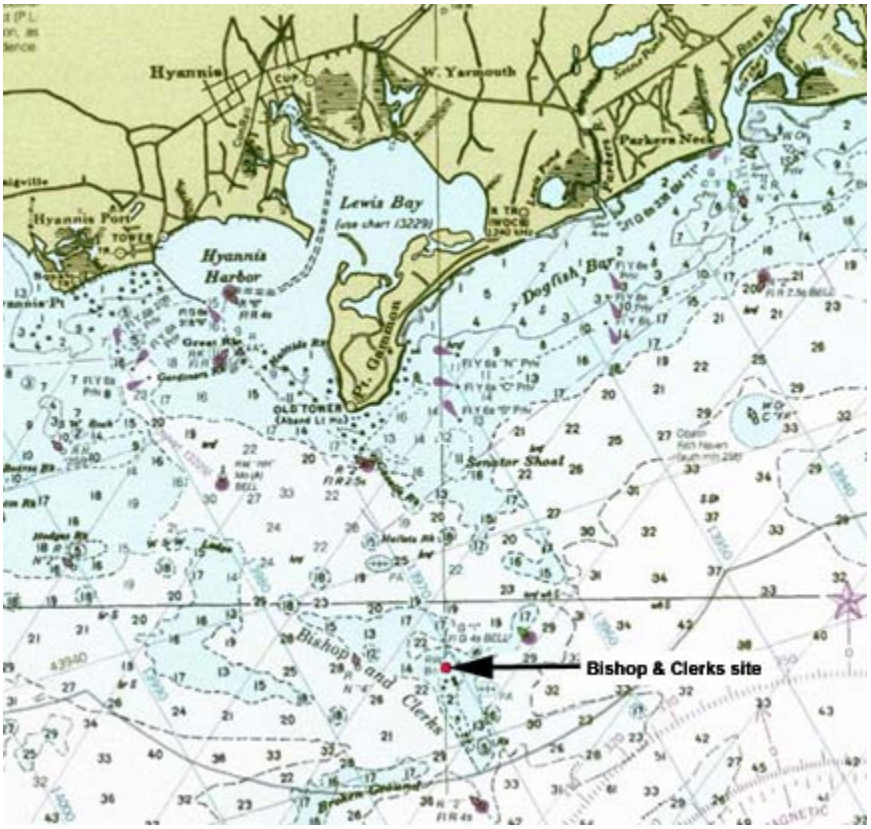

Figure 1 - Site location at Bishop & Clerks light

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 deck railing at the top of the lighthouse (Figure 2). All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Model 9300 Cellogger®, serial # 0258
- Electrical enclosure box with 5 watt PV panel
- Yagi directional antenna and mount
- 2 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)
- 2 - #200P Wind direction 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

A limitation in this setup is 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 and can interfere with the free flow of air. The mast height is limited by the stiffness of the railing. In fact, it was necessary to reinforce the free end of the railing to the USCG lighthouse PV panel brackets in order to use even the 12 ft mast (Figure 3) which otherwise shook severely in high winds.

Figure 3 - Railing stiffener connecting PV bracket to rail

The NRG 9300 system logger is equipped with a built-in cell phone so that the data can be transmitted weekly to a PC, located at the University of Massachusetts/ Amherst. The logger samples wind speed and direction once every second. 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 quality assurance (QA) tests prior to using the data.

SECTION 3 - Data Collection and Maintenance

The following maintenance/equipment problems occurred during the report period, and the following corrective actions taken:

- No data were missing.
- Both anemometers started to show signs of failure. The primary ("a") anemometer failed for 35 hours and the secondary ("b") failed for 52 hours. These sensors will be replaced at the next site visit.
- No maintenance operations were performed during this quarter.

Data Statistics Summary

Date	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turbulence Intensity [ ]	Prevailing Wind Direction [ ]
Jun 2004	6.66	14.56	0.11	WSW
Jul 2004	6.41	14.71	0.11	SW
Aug 2004	7.14	15.8	0.11	SW
Jun 03 – Aug 04	**6.74**	**15.8**	**0.11**	**SW**

SECTION 4 - Significant Meteorological Events

June, July, and August 2004 all had close to average wind conditions. There are no major wind events shown in the wind speed time series. The summer of 2004 was a cooler and wetter than average summer, but this did not cause abnormal wind conditions.

Source: http://www.erh.noaa.gov/box/MonthlyClimate2.shtml.

SECTION 5 - 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 QA controls are given below under Test Definitions and Sensor Statistics. 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 [%]	100.0
Net Data Recovered [%]	99.196

The high Gross Data Recovery Percentage is an indication that the logger was recording and transmitting properly. The high Net Data Recovery Percentage is an indication that the sensors were functioning properly and that little or no icing conditions were present.

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 (F4).

$$CF1 \leq F1 \text{ and } TF1 > F2 \text{ and } CF2 < F3$$

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

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. It should be noted that, while this test is tuned to detect sensor icing events, it is possible for the conditions that are representative of icing to occur at other times. The error due to this possibility is considered to be insignificant.

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*.

SECTION 6 - Data Summary

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. This plot shows a peak centered between 6 and 7 m/s (13.5 and 15.8 mph), a typical value for this site.
- Monthly Average – A plot of the monthly average wind speed over the 12 month period ending August 2004. The peak month was December 2003, with the summer of 2004 being the lowest. This is the typical pattern for this site.

- Diurnal – A plot of the average wind speed for each hour of the day. The hourly average varied between 6 and 7.5 m/s (13.5 and 16.9 mph), with the highest average speeds in the afternoon, as is typical.

- 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 turbulence intensities recorded at this site have been almost constant at about 0.11. In the graph (below), the turbulence intensity flattens out at about 7 m/s (15.8 mph). With an average wind speed of 6.74 m/s (15.2 mph), this site, on average, experienced low turbulence conditions.

- 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. This wind rose shows the strong prevailing direction from the southwest, which is typical of summer quarters at this site.

SECTION 7 - Graphs

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

Wind Speed Time Series

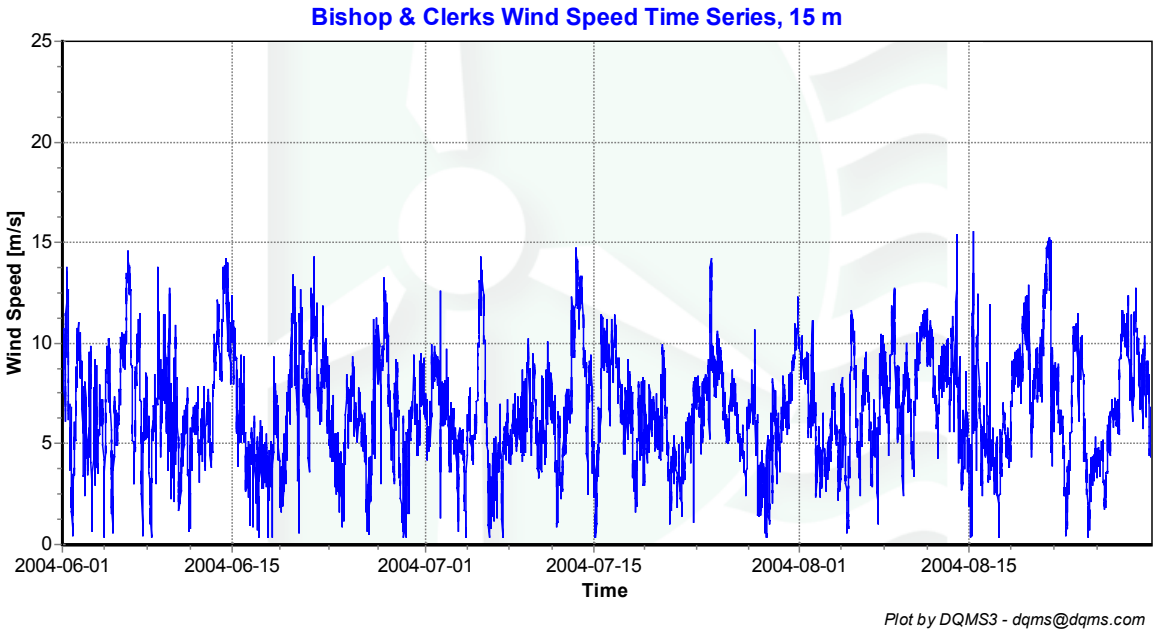

Figure 4 - Wind Speed Time Series, June 2004 – August 2004

Wind Speed Distributions

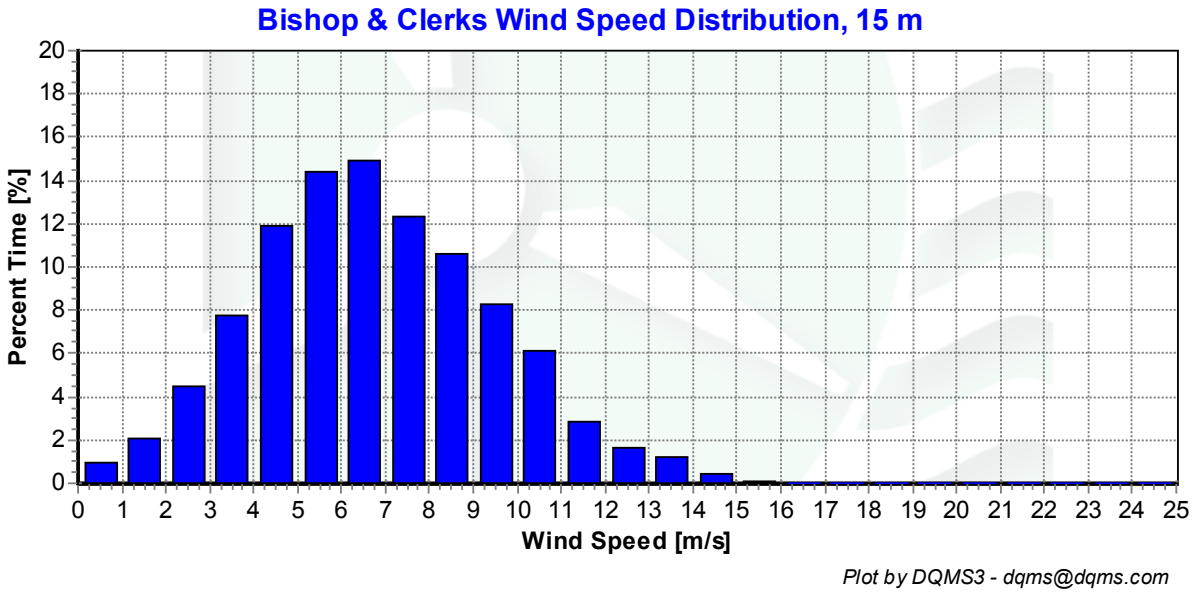

Figure 5 - Wind Speed Distribution, June 2004 – August 2004

Monthly Average Wind Speeds

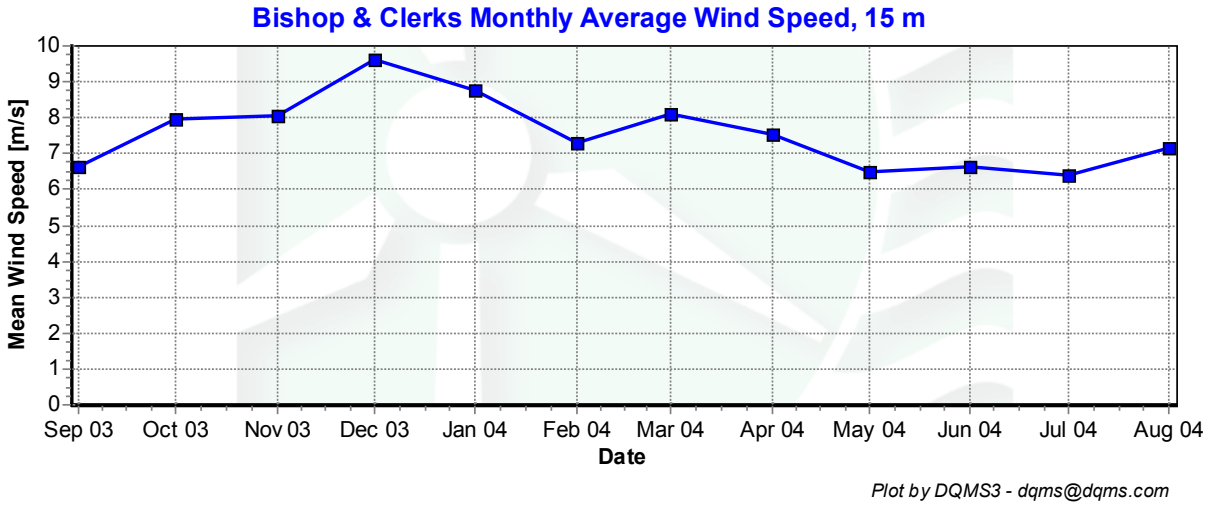

Figure 6 - Monthly average wind speed

Diurnal Average Wind Speeds

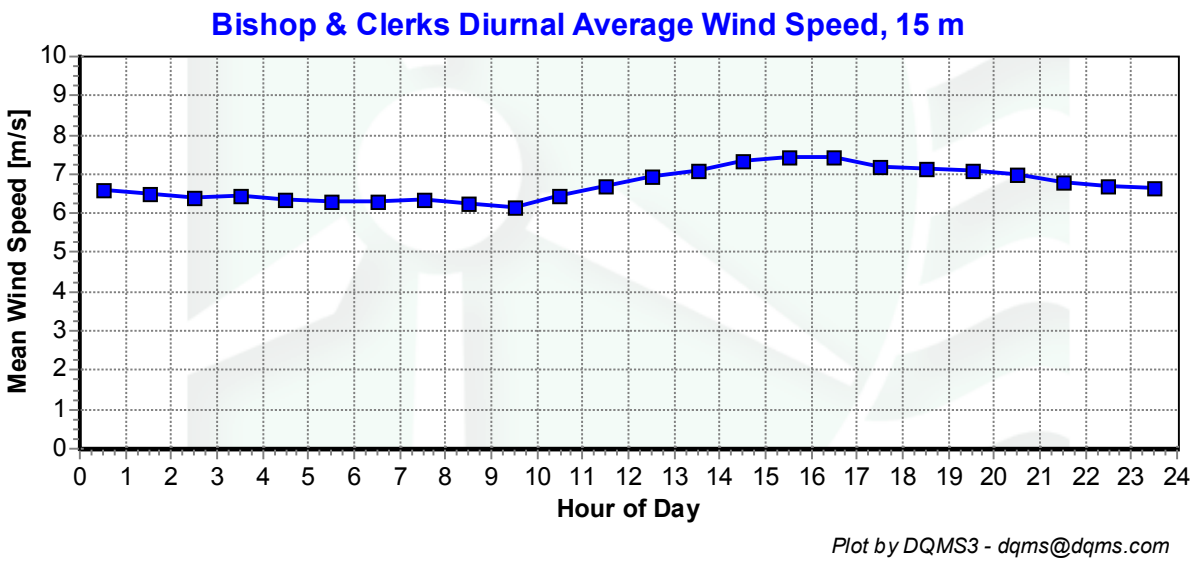

Figure 7 - Diurnal Wind Speed, June 2004 – August 2004

Turbulence Intensities

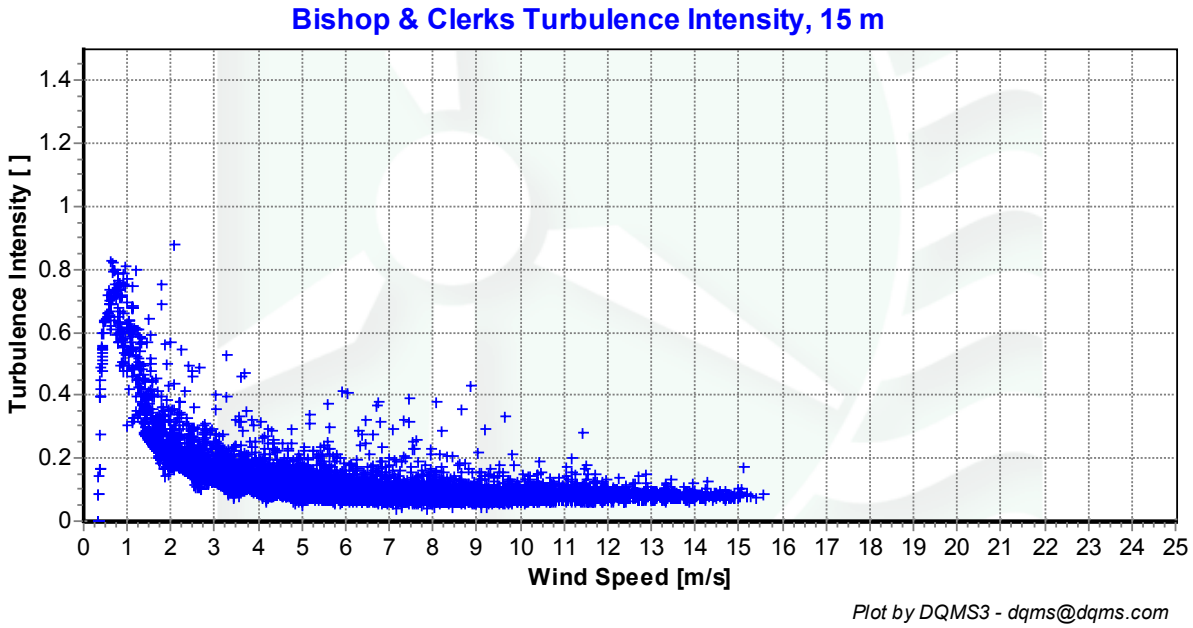

Figure 8 - Turbulence Intensity vs Wind Speed, June 2004 – August 2004

Wind Roses

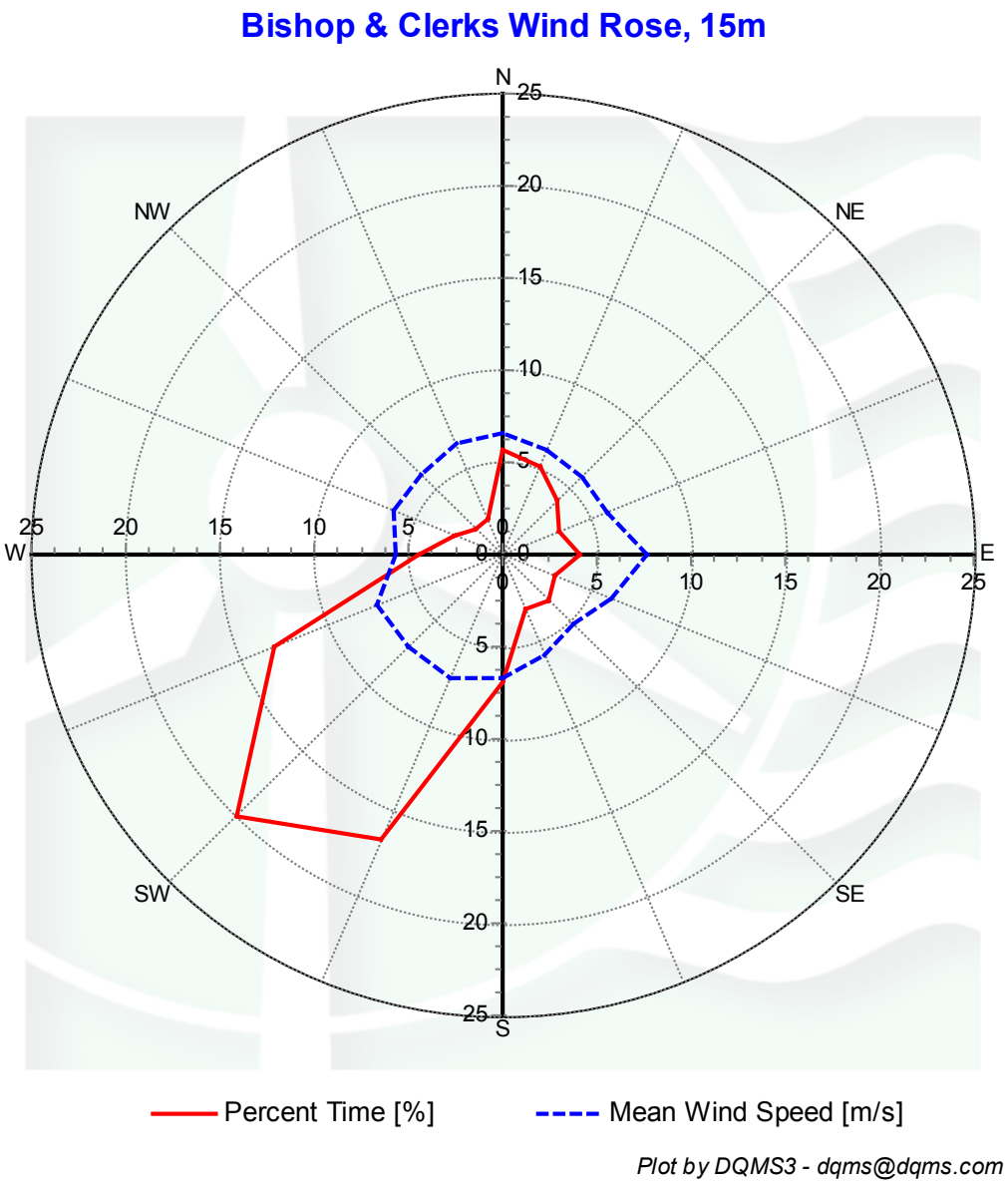

Figure 9 - Wind Rose, June 2004 – August 2004

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	Test Field1	Test Field2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor 1	Factor 2	Factor 3	Factor 4
1							TimeTest Insert				
3	Itmp13aDEGC						MinMax	-30	60		
4	Batt13aVDC						MinMax	10.5	15		
10	Anem15aMS						MinMax	0	90		
11	Anem15bMS						MinMax	0	90		
12	Anem15yMS						MinMax	0	90		
20	AnemSD15aMS						MinMax	0	4		
21	AnemSD15bMS						MinMax	0	4		
22	AnemSD15yMS						MinMax	0	4		
30	Vane15aDEG						MinMax	0	359.9		
31	Vane15bDEG						MinMax	0	359.9		
32	Vane15yDEG						MinMax	0	359.9		
50	Turb15zNONE						MinMax	0	2		
200	VaneSD15aDEG	Anem15aMS					MinMaxT	0	100	100	10
201	VaneSD15bDEG	Anem15bMS					MinMaxT	0	100	100	10
300	Anem15aMS	AnemSD15aMS	Vane15aDEG	VaneSD15aDEG	Itmp13aDEGC		Icing	0.5	1	2	2
301	Anem15bMS	AnemSD15bMS	Vane15bDEG	VaneSD15bDEG	Itmp13aDEGC		Icing	0.5	1	2	2
400	Anem15aMS	Anem15bMS					CompareSensors	1	0.25	3	

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Itmp13aDEGC	13248	13248	100	0	0	0	100
Batt13aVDC	13248	13248	100	0.167	0	0	99.992
Anem15aMS	13248	13248	100	0.333	0	34.833	98.407
AnemSD15aMS	13248	13248	100	0.333	0	34.833	98.407
Anem15bMS	13248	13248	100	0.833	0	52.333	97.592
AnemSD15bMS	13248	13248	100	0.833	0	52.333	97.592
Vane15aDEG	13248	13248	100	0	0	0	100
VaneSD15aDEG	13248	13248	100	0	0	0	100
Vane15bDEG	13248	13248	100	0.333	0	0	99.985
VaneSD15bDEG	13248	13248	100	0.333	0	0	99.985
Total	**132480**	**132480**	**100**	**3.167**	**0**	**174.333**	**99.196**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.94
1.5	2.08
2.5	4.46
3.5	7.8
4.5	11.86
5.5	14.39
6.5	14.94
7.5	12.33
8.5	10.59
9.5	8.27
10.5	6.11
11.5	2.88
12.5	1.65
13.5	1.18
14.5	0.42
15.5	0.11
16.5	0
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Sep 2003	6.65
Oct	7.98
Nov	8.04
Dec	9.61
Jan 2004	8.74
Feb	7.28
Mar	8.12
Apr	7.54
May	6.49
Jun	6.66
Jul	6.41
Aug	7.14

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0	6.6
1	6.48
2	6.41
3	6.47
4	6.34
5	6.31
6	6.3
7	6.38
8	6.24
9	6.18
10	6.43
11	6.7
12	6.94
13	7.11
14	7.33
15	7.44
16	7.44
17	7.17
18	7.16
19	7.1
20	6.98
21	6.82
22	6.69
23	6.66

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	5.65	6.64
NNE	5.13	6.09
NE	4.16	6.01
ENE	3.28	5.97
E	4.11	7.63
ESE	3.02	6.3
SE	3.49	5.28
SSE	3.14	5.89
S	6.94	6.69
SSW	16.7	7.3
SW	20.03	7.12
WSW	13.1	7.19
W	4.43	5.67
WNW	2.76	6.23
NW	1.99	6.05
NNW	2.07	6.46

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction