WIND DATA REPORT

Bishop and Clerks

March 1, 2003 – May 31, 2003

Prepared for

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EXECUTIVE SUMMARY

This report summarizes the wind data collected during the Spring of 2003, March – May. The mean recorded wind speed was 7.07 m/s (15.91 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 99.82%. Both of these percentages are very high, indicating that the sensors and data logger were performing well.

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

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, tower location marked by a red star). A photo of the lighthouse can be seen at http://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).

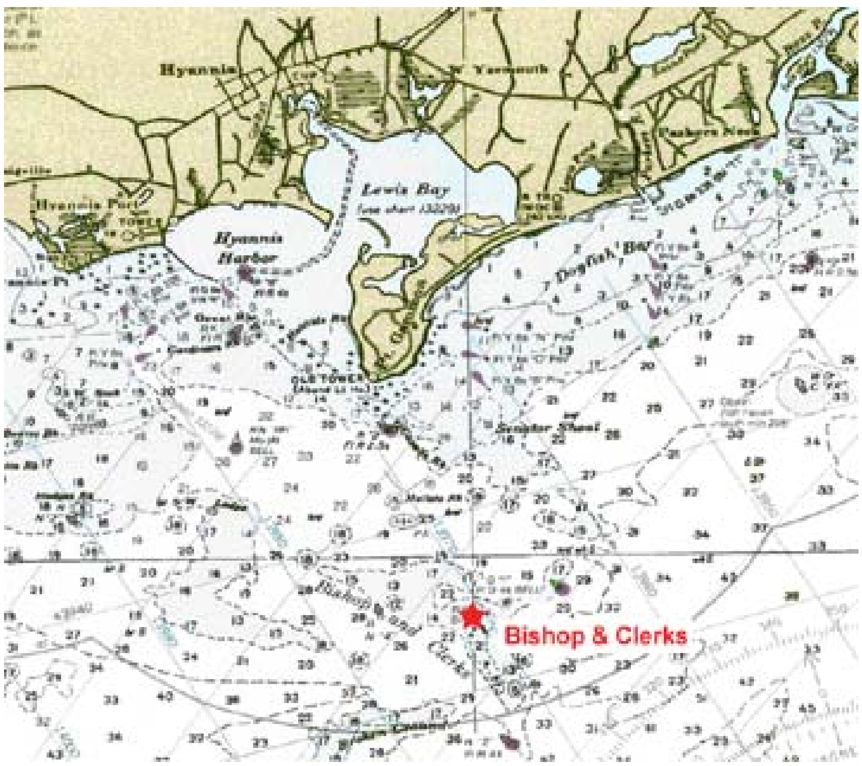

Figure 1 - Site location at Bishop & Clerks light

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 - Raining 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 QA tests prior to using the data.

SECTION 3 - Data Collection and Maintenance

There are no equipment problems or maintenance actions to report. A data summary is provided below.

Data Statistics Summary

Date	Mean 10 min [m/s]	Max 10 min [m/s]	Turbulence Intensity [ ]	Prevailing Wind Direction [ ]
Mar 2003	7.2	17.99	0.12	SSW
Apr 2003	7.82	20.22	0.10	ENE
May 2003	6.22	17.61	0.12	SW
Mar 03 – May 03	**7.07**	**20.22**	**0.11**	**SW**

SECTION 4 - Significant Meteorological Events

Spring 2003 was colder and wetter than normal. In Boston, MA, the average temperature of 45.7 °F, 3.1 °F less than normal, and the total precipitation was 12.33 inches, 1.84 inches above normal. Since snowfall for the season was close to normal, the additional precipitation was probably in the form of rain. Providence, RI, recorded similar seasonal trends (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 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 [%]	100.0
Net Data Recovered [%]	99.82

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. The majority of the 0.18 % of the data which were flagged as invalid is attributable to icing conditions.

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 is 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, the wind speed (TF1) is greater than Factor 2, and the temperature (CF2) is less than Factor 3.

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

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

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*.

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. The peak of the distribution occurs between 5 and 7 m/s, with the center between 6 and 8 m/s.

- 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. The trend seen here follows the expected pattern of higher wind speeds in the winter months and lower wind speeds during summer months. May 2003 is seen to have had lower-than-normal wind speeds.

- Diurnal – A plot of the average wind speed for each hour of the day. This Spring, the diurnal variation was not as pronounced at it was last year. Historically, diurnal variations are greater during the Spring and smaller during the Fall.

- 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 average turbulence intensity for this period was 0.11, very consistent with last year's measurements.

- 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 prevailing wind direction was from the SW as was the case during most of 2002. There was a significant percentage of wind coming from the NE as well. The average wind speeds were fairly equal from the different directions, with the smallest winds speeds coming from the south-southeast and west.

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

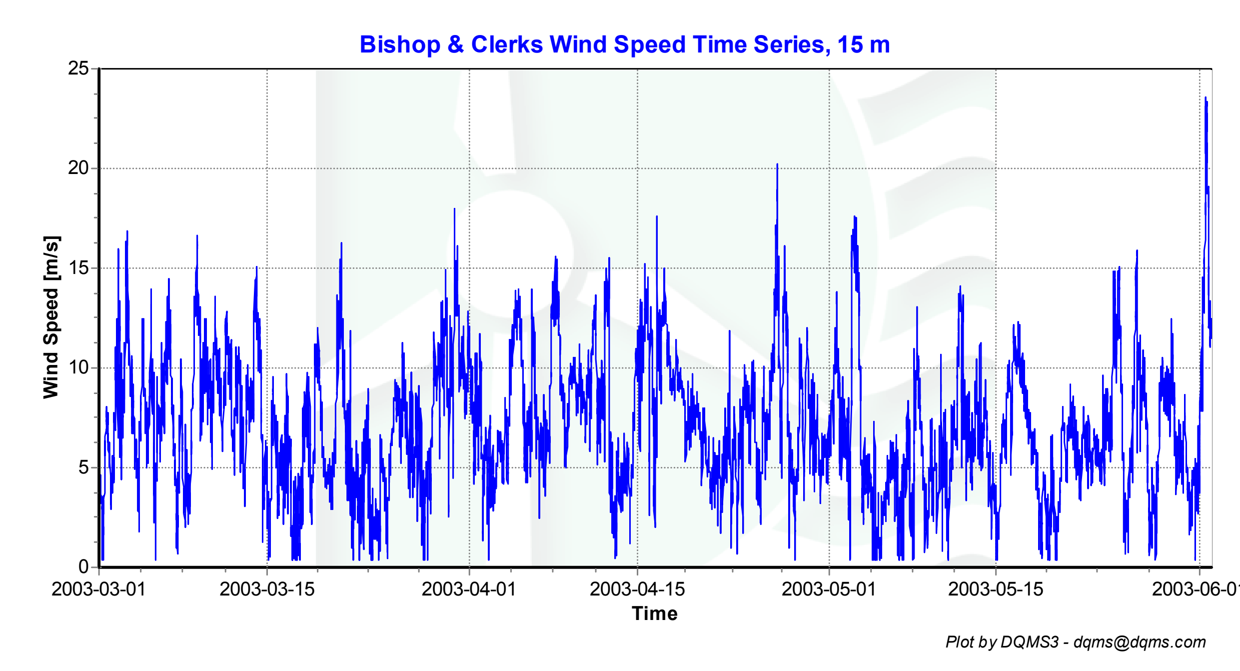

Figure 4 - Wind Speed Time Series, March 2003 – May 2003

Wind Speed Distributions

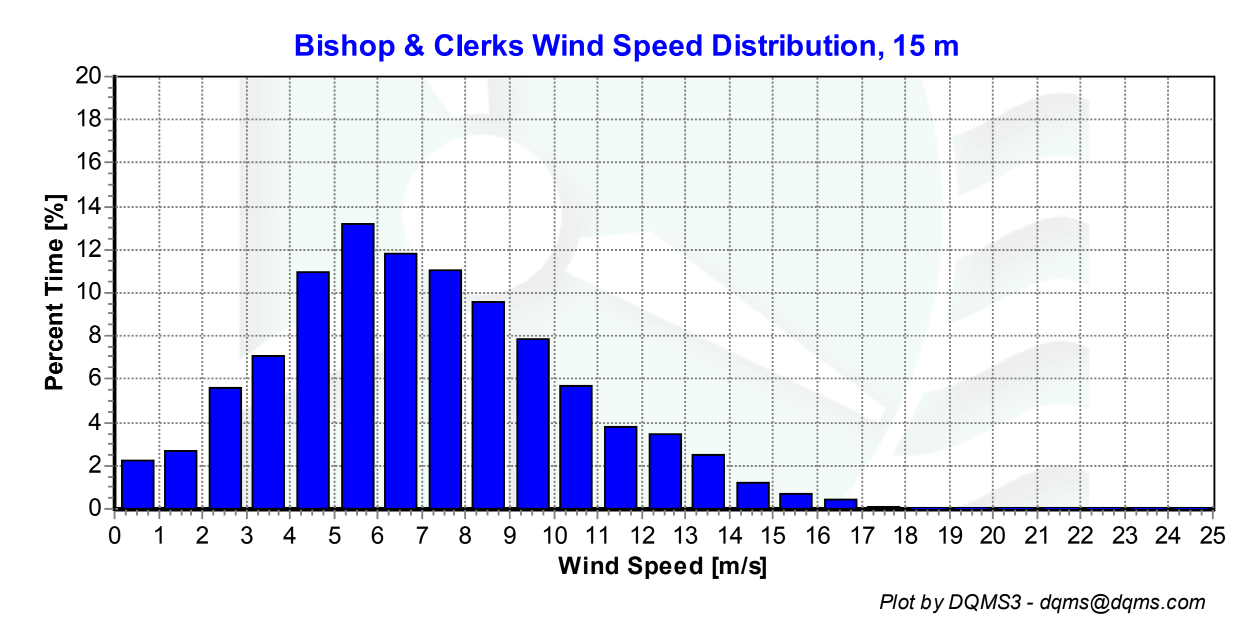

Figure 5 - Wind Speed Distribution, March 2003 – May 2003

Monthly Average Wind Speeds

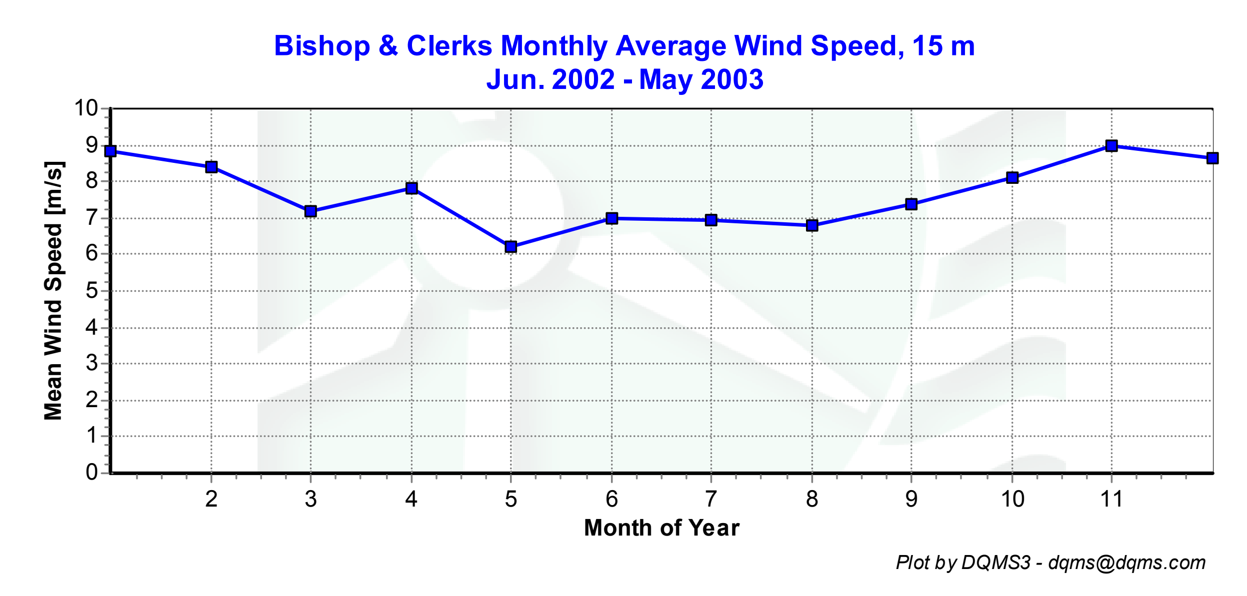

Figure 6 - Monthly average wind speed

Diurnal Average Wind Speeds

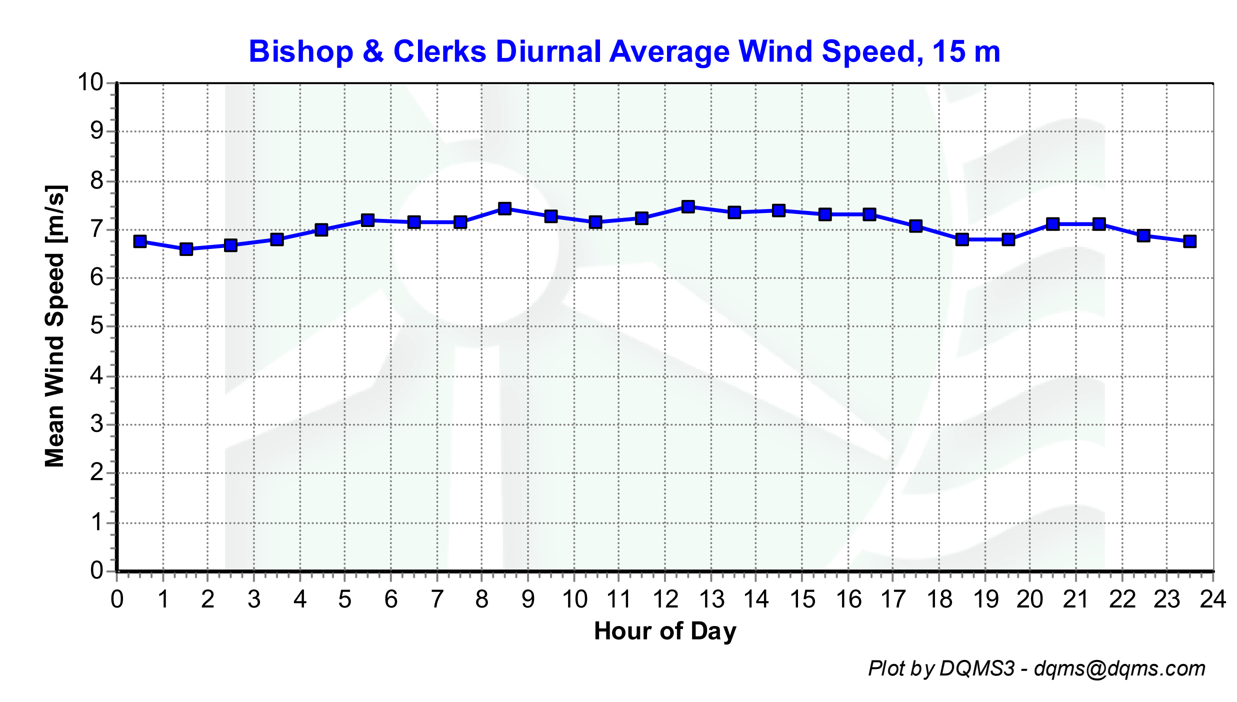

Figure 7 - Diurnal Wind Speed, March 2003 – May 2003

Turbulence Intensities

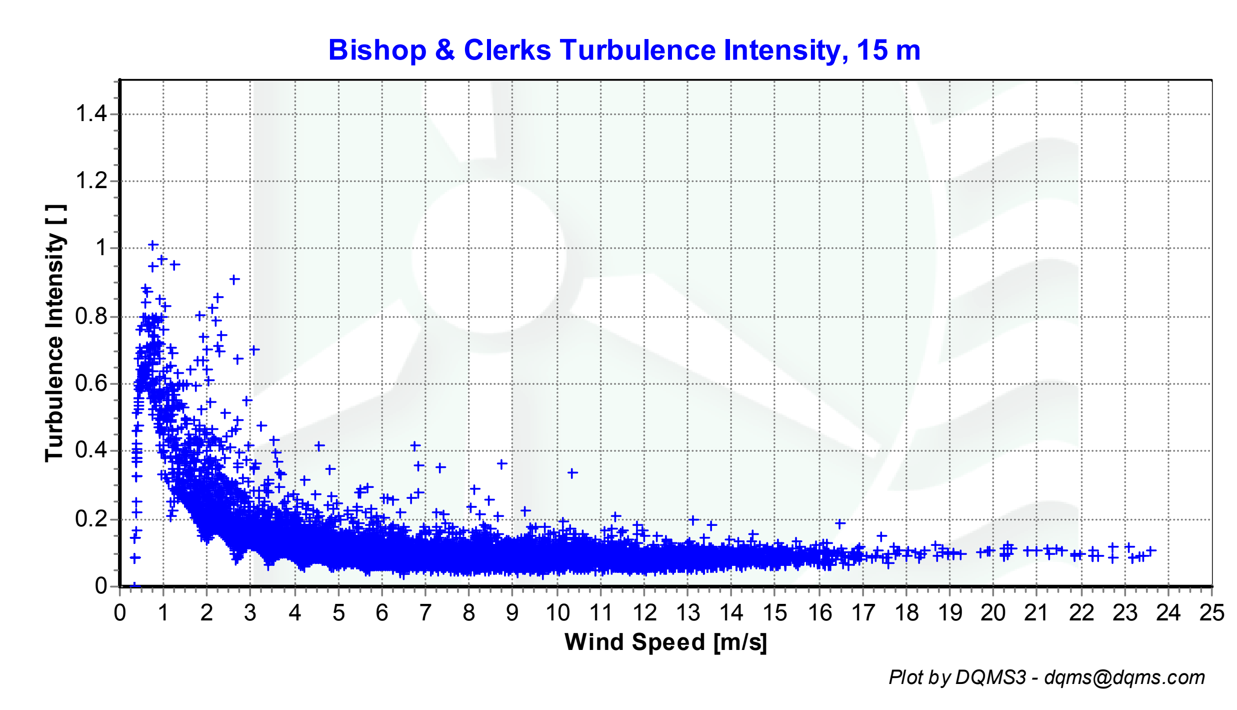

Figure 8 - Turbulence Intensity vs Wind Speed, March 2003 – May 2003

Wind Roses

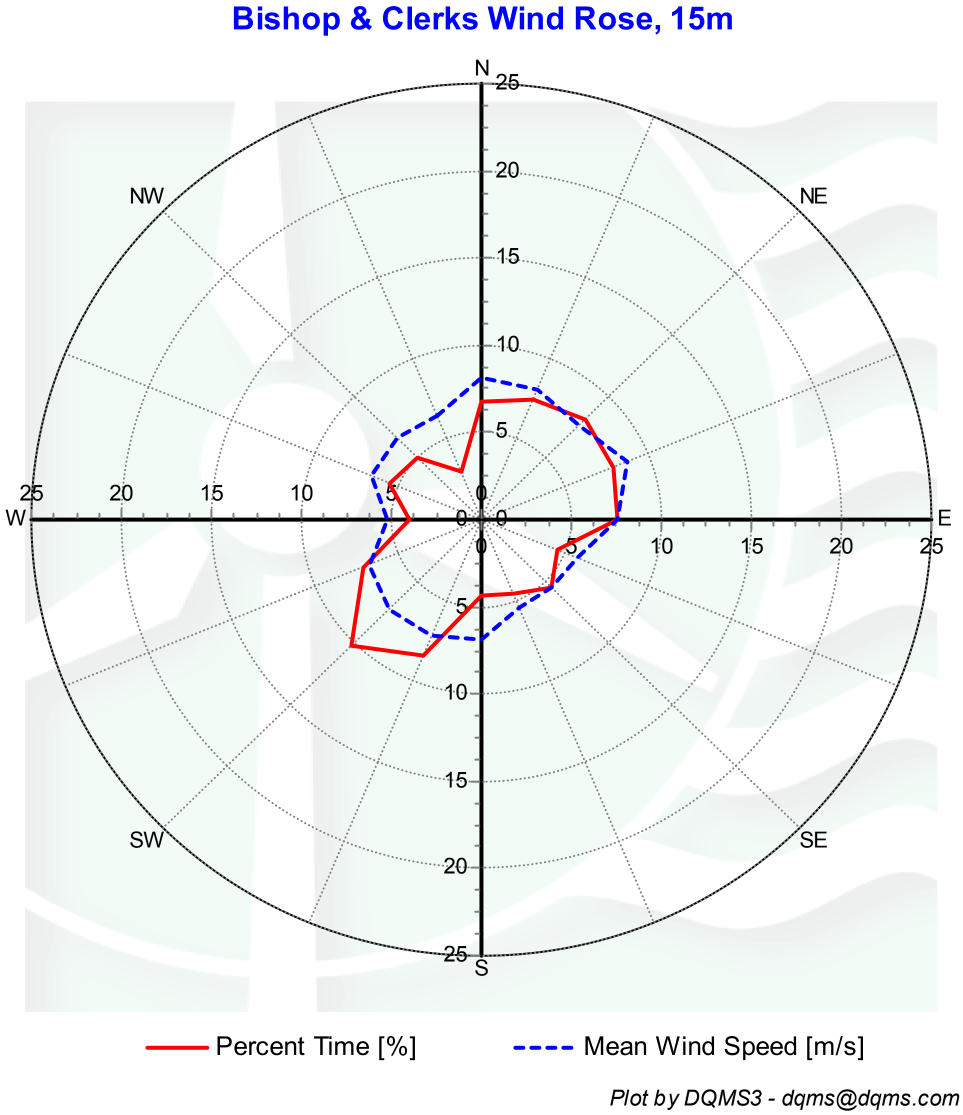

Figure 9 - Wind Rose, March 2003 – May 2003

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	
301	Anem15bMS	AnemSD15bMS	Vane15bDEG	VaneSD15bDEG	Itmp13aDEGC		Icing	0.5	1	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	0	0	100
Anem15aMS	13248	13248	100	0	3.5	0.833	99.804
AnemSD15aMS	13248	13248	100	0	3.5	0.833	99.804
Anem15bMS	13248	13248	100	0	4.667	1.333	99.728
AnemSD15bMS	13248	13248	100	0	4.667	1.333	99.728
Vane15aDEG	13248	13248	100	0.667	3.5	0	99.811
VaneSD15aDEG	13248	13248	100	0.667	3.5	0	99.811
Vane15bDEG	13248	13248	100	0.667	4.667	0	99.758
VaneSD15bDEG	13248	13248	100	0.667	4.667	0	99.758
Total	**132480**	**132480**	**100**	**2.667**	**32.667**	**4.333**	**99.82**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.98
1.5	1.86
2.5	4.22
3.5	6.26
4.5	8.68
5.5	12.49
6.5	12.38
7.5	10.98
8.5	10.58
9.5	9.33
10.5	6.99
11.5	5
12.5	3.46
13.5	3.27
14.5	1.8
15.5	0.83
16.5	0.6
17.5	0.2
18.5	0.05
19.5	0.03
20.5	0.02
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]
2002 Jun	6.98
July	6.95
Aug	6.80
Sept	7.40
Oct	8.13
Nov	8.97
Dec	8.64
2003 Jan	8.83
Feb	8.40
Mar	7.20
Apr	7.82
May	6.22

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0	6.75
1	6.61
2	6.69
3	6.8
4	6.98
5	7.2
6	7.14
7	7.17
8	7.42
9	7.26
10	7.17
11	7.23
12	7.47
13	7.34
14	7.38
15	7.31
16	7.33
17	7.08
18	6.8
19	6.79
20	7.1
21	7.1
22	6.87
23	6.74

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	6.71	8.14
NNE	7.41	8.01
NE	8.17	7.69
ENE	7.9	8.74
E	7.53	7.6
ESE	4.61	5.83
SE	5.53	5.45
SSE	4.56	5.41
S	4.38	6.91
SSW	8.46	7.16
SW	10.14	7.28
WSW	7.11	6.78
W	4.03	5.25
WNW	5.5	6.59
NW	4.97	6.58
NNW	2.96	6.51

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