WIND DATA REPORT

Bishop and Clerks

December 1, 2003 – February 29, 2004

Prepared for

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June 11, 2004

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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 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.

During the season covered by this report, December 2003 – February 2004, the mean recorded wind speed was 8.57 m/s (19.28 mph) and the prevailing wind direction was from the west-northwest. The gross data recovery percentage (the actual percentage of expected data received) was 99.992% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.002%. Both of these percentages are very high, indicating that the sensors and data logger were performing well. There were between 20 and 30 hours of icing events detected, which is similar to other sites on or near the coast

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).

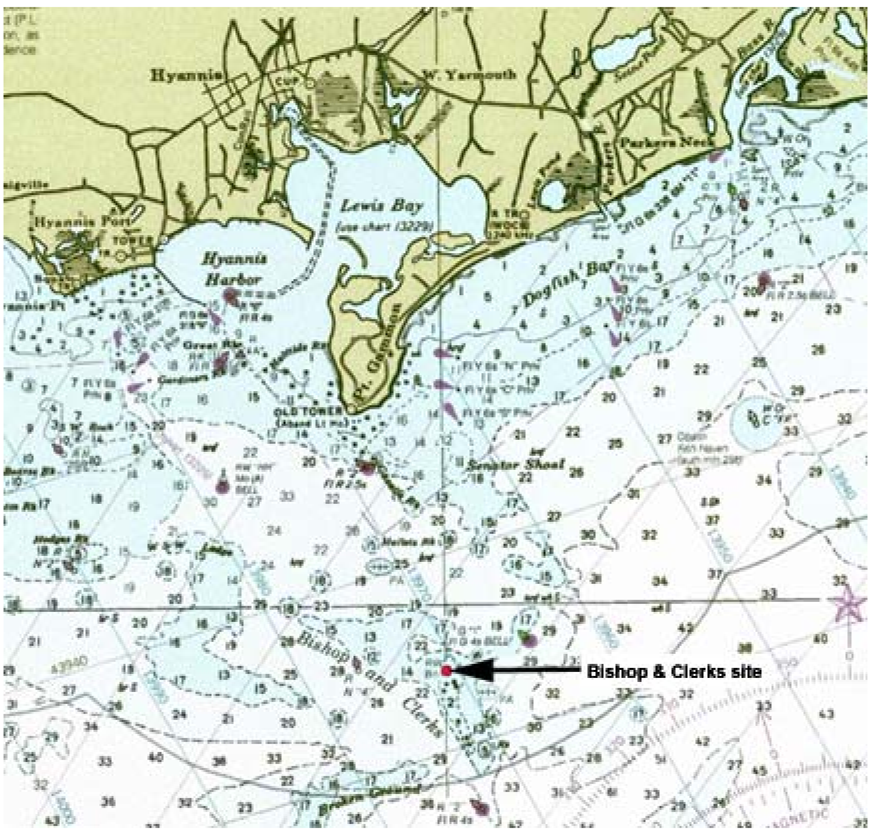

Figure 1 - Site location at Bishop & Clerks light

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 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:

- 12/5/03 06:50 – Missing data. No other problems with the data were encountered.
- No maintenance operations were needed or performed.

Data Statistics Summary

Date	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turbulence Intensity [ ]	Prevailing Wind Direction [ ]
Dec 2003	9.61	21.85	0.1	WSW
Jan 2004	8.74	19.18	0.11	WNW
Feb 2004	7.28	17.52	0.1	N
Dec 03 – Feb 04	**8.57**	**21.85**	**0.1**	**WNW**

SECTION 4 - Significant Meteorological Events

A low pressure area formed over the southeastern states on December 5. At the same time, a large arctic high became established over eastern Canada. The storm tracked off the Virginia coastline on December 6, then took a track along the eastern seaboard as a classic nor'easter. The storm interacted with the strong high in eastern Canada, which caused it to move very slowly. It took over a day for the storm to move northeast of Cape Cod, which was not until late December 7. The result was the first major snowstorm of the early winter season across the Berkshires. Nine to 18 inches fell across the Berkshires with Dalton receiving 17 inches.

A low pressure area formed in the Gulf States early on December 14. This storm hugged the coast line as it tracked northward to become the second nor'easter of the winter season. This storm moved a little quicker than its predecessor. In addition, enough warm air moved in aloft to change the snow to sleet and freezing rain, thus reducing snow fall accumulations, especially in southern sections of the county. By the time the storm moved off the New England coastline, 5 to 10 inches of snow had accumulated in Berkshire County. The city of West Otis received 10.5 inches, the most reported in the county. (http://www4.ncdc.noaa.gov)

January began with a week of warm temperatures and rainy days. The entire Northeast was at least 2 degrees above normal from the 1st to the 7th of January, with the majority of the region between 8 and 12 degrees warmer than average during this period. Beginning on the 7th, the continental weather pattern changed drastically and January ended up the 11th coldest on record in the Northeast. Wave after wave of arctic air sank into the region from Canada setting many minimum temperature records at observation sites all over the Northeast. Cold snaps occurred from January 9-11, 13-16, and 24-26 causing pipe bursts across the region and prompting school closures even in the winter-hardy northern New England states. The entire region was more than 4 degrees below normal. Massachusetts recorded the coldest January in that state (16.4 degrees) since records began in 1895, surpassing the old record of 16.7 degrees that had stood since

1981. New York, Rhode Island, and Connecticut all fell more than 7 degrees below their respective normals setting January 2004 among the ten coldest on record in each state. The region as a whole was 5.7 degrees below normal and, at 17.3 degrees, was the coldest month since 1994 and 0.8 degrees colder than last January.

When the region changed from warm to cold after the first week in January, it also went from wet to extremely dry. Many observation sites, especially in the northern half of the region, measured less than a quarter inch of rain/melted snow after the first week. All six New England states were more than 2 inches below the normal amount. Maine, New Hampshire and Vermont averaged only about an inch of precipitation (rain plus the liquid equivalent of snow) making this January one of the five driest on record in those states.. The near continuous fresh snow pack contributed to temperature departures in the 14 to 16 degree below normal range in these areas during the latter part of the month. Overall the Northeast fell more than 1 inch short of its January precipitation total but amazingly this was the wettest January since 2000. The lack of rain and snow this month puts an end to an 8-month streak of wet weather here in the Northeast.

The Northeast was very close to normal in terms of temperature this February. While southern portions of the region were at or slightly below normal this month, the New England states saw a more significant positive temperature departure. Overall, the land-area weighted regional average was 26.0 degrees, or 0.5 degrees above normal. While not a very impressive temperature departure, this month was 4.5 degrees warmer than February 2003. All six New England states were above normal, and all of these except Vermont were more than 1 degree above normal. The general weather pattern this February brought storm systems northward over the Appalachians rather than over the coast, keeping New England on the warm side of the storms. This western storm trend also prevented any deep or prolonged cold snaps from taking hold in the northern states which could potentially have dropped the average temperatures down a notch. New Jersey was the only other state above normal this month, and the remaining 5 states were all within 0.5 degrees of their respective averages. Whether warmer or colder than normal, February temperatures in all 12 states were a welcome change after a bitterly cold January. Many states in the region saw a temperature increase of over 10 degrees from last month to this month. In fact, the region as a whole was 8.7 degrees warmer in February than in January.

One trend that did continue from January was the lack of precipitation across the Northeast (rain and water equivalent of snow). The region's measure of 1.97 inches makes February 2004 the driest since 1991. Rain and snow from two storms early in the month was followed by 20 days of no significant precipitation. High pressure was dominant during this time and the majority of the region received less than 1/2 an inch of rain/melted snow. Large portions of the region didn't see even a quarter of an inch after the 8th of February. This dry period was more extreme in the region's southern states, but early rains in that area seemed to cover for the future lack. Northern states were the most dry overall. Of six states in the region falling more than an inch short of their normal amounts, five were in New England (the sixth was Delaware). New Hampshire and

Vermont both totaled less than an inch and a half on the month which was enough to put 2004 among the ten driest on record for both states. West Virginia was the most wet state in the region at 2.98 inches but still failed to reach its average value (precipitation departure: -.13 inches). This February was the first month since January 2003 in which all 12 states in the Northeast were on the dry side of their respective normals. A precipitation total of 1.97 inches is the lowest of any month since November 2001. (http://met-www.cit.cornell.edu/climate/Impacts.html)

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. 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 [%]	99.992
Net Data Recovered [%]	99.002

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 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.

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

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 wide peak centered around 9 m/s. This is similar to the behavior measured last winter.
- 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 March 2003 – February 2004. The noticeable changes between the current winter quarter and the previous winter are higher average wind speeds in December 2003 and lower average speeds in February 2004.
- Diurnal – A plot of the average wind speed for each hour of the day. This graph shows a fairly constant wind speed distribution over the course of the day. This level plot was also observed during this quarter last year.
- 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 between 5 and 7 m/s. With an average wind speed of 8.57 m/s, 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 strong trend to the west-northwest, which is typical of winter 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.

<u>Wind Speed Time Series</u>

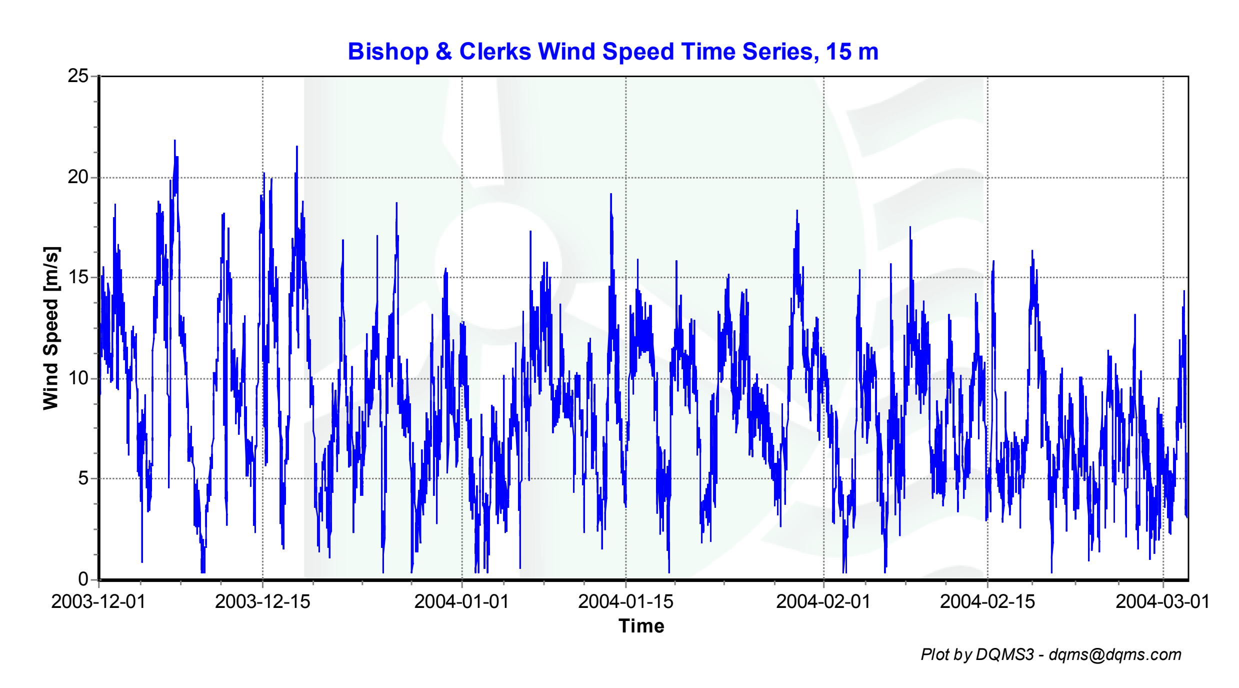

Figure 4 - Wind Speed Time Series, December 2003 – February 2004

Wind Speed Distributions (update)

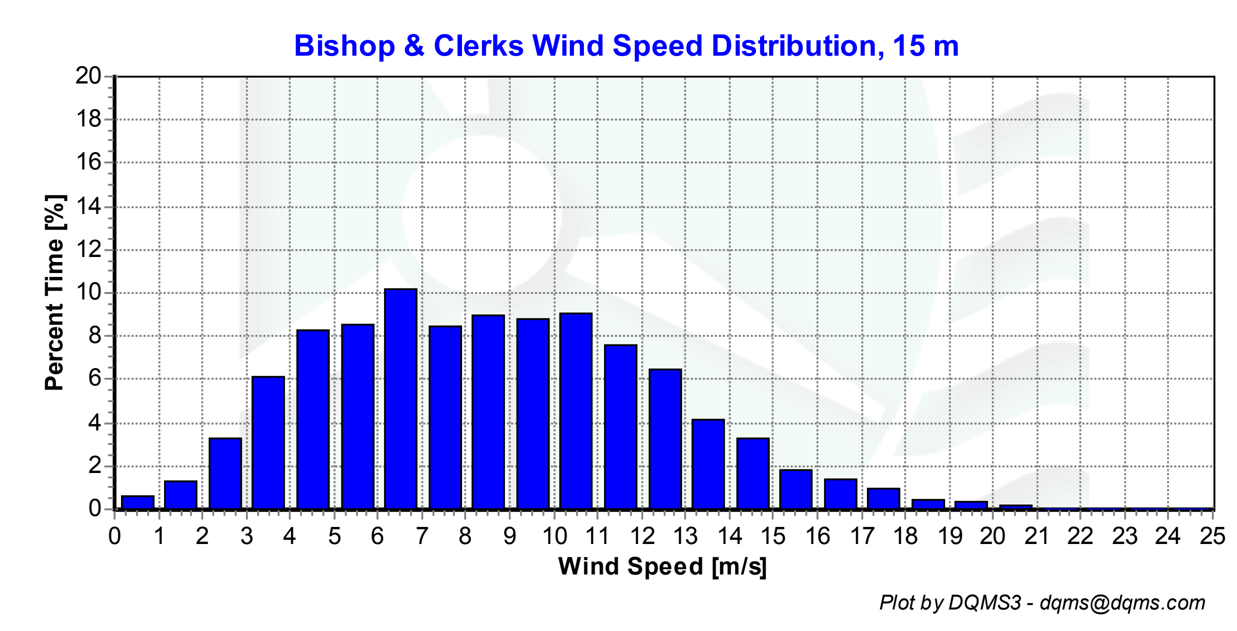

Figure 5 - Wind Speed Distribution, December 2003 – February 2004

Monthly Average Wind Speeds

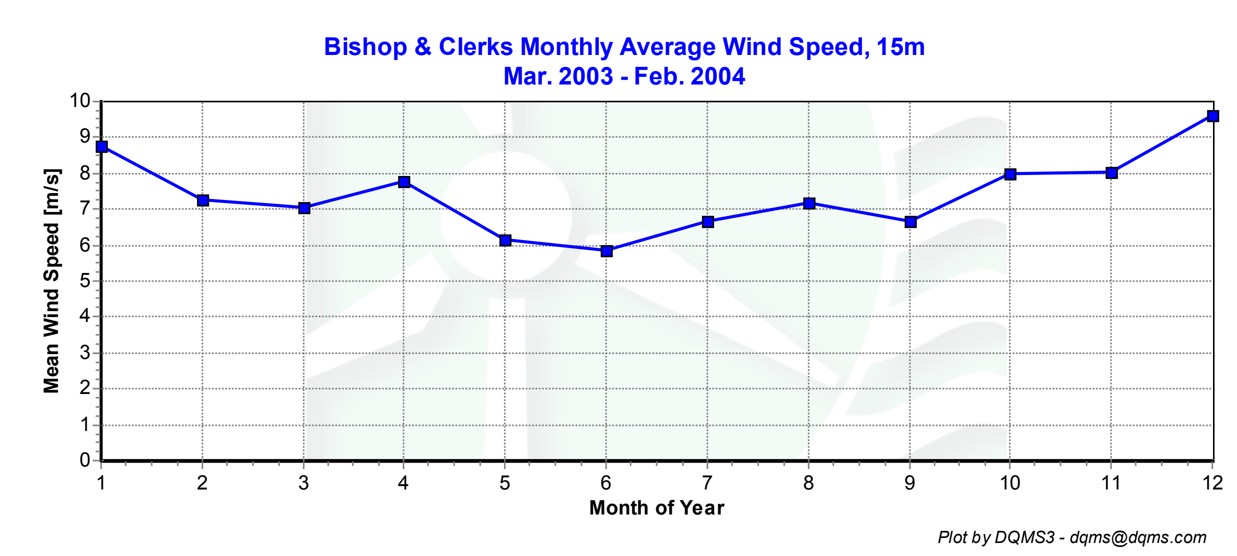

Figure 6 - Monthly average wind speed

Diurnal Average Wind Speeds

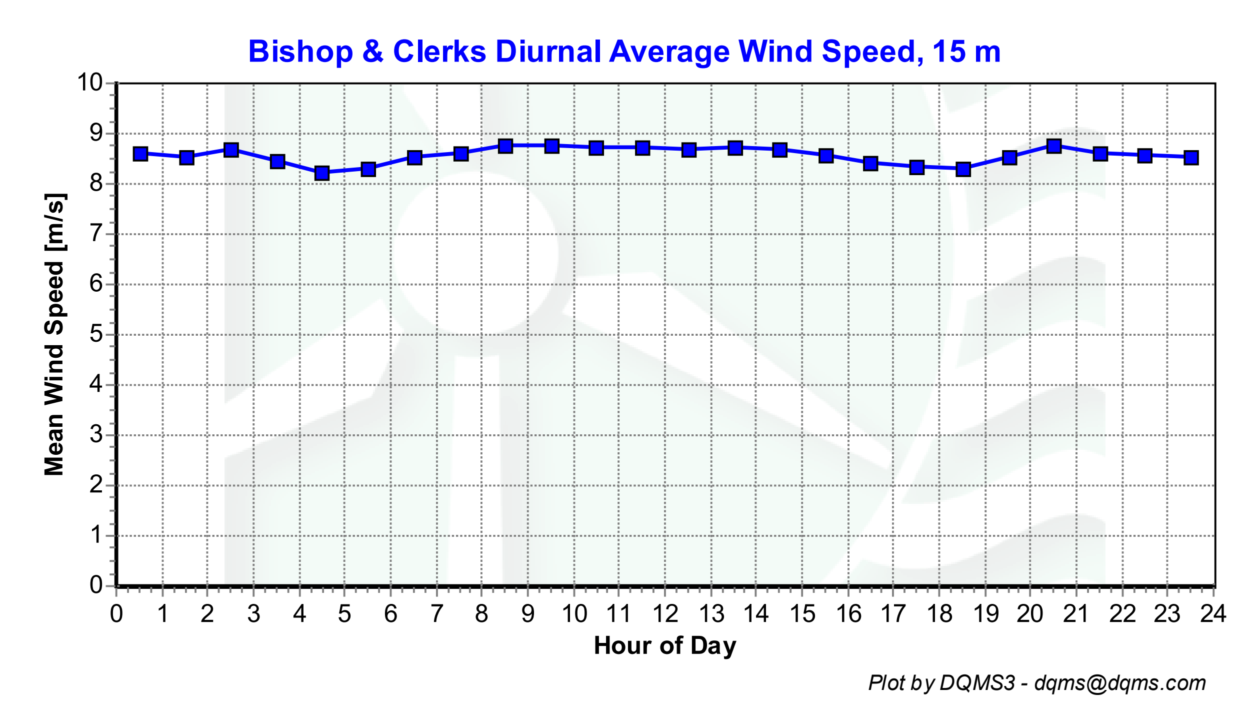

Figure 7 - Diurnal Wind Speed, December 2003 – February 2004

Turbulence Intensities

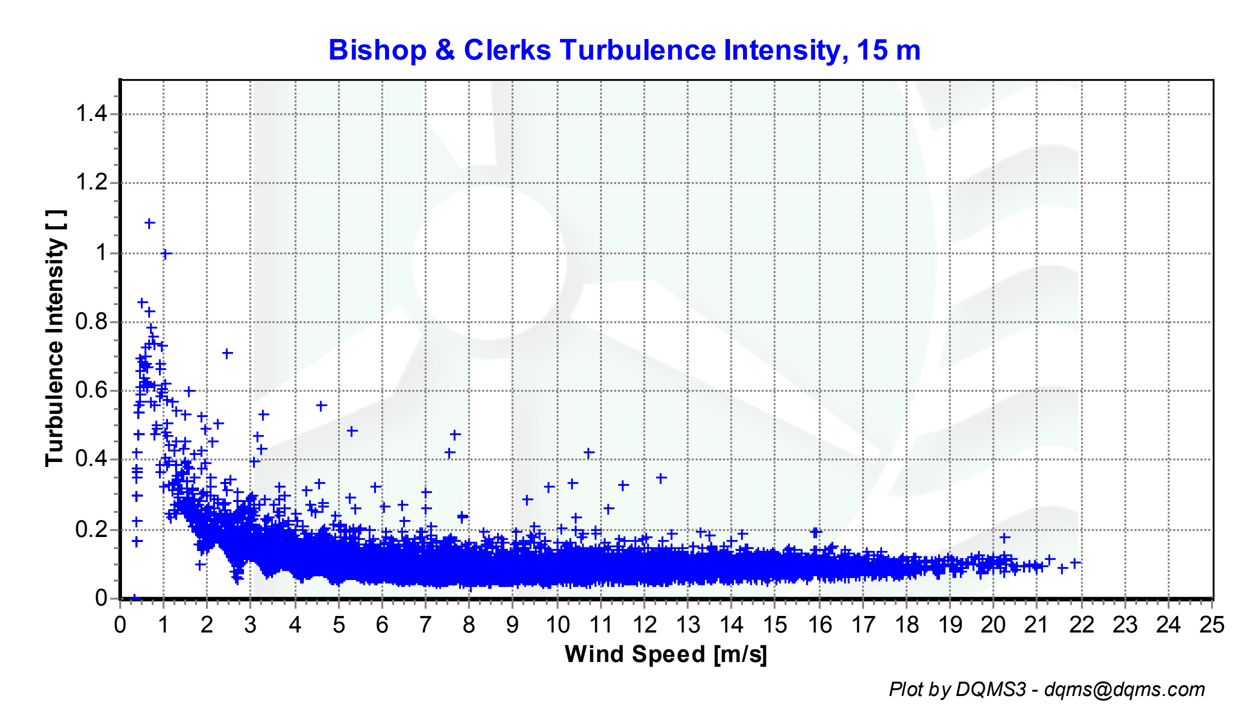

Figure 8 - Turbulence Intensity vs Wind Speed, December 2003 – February 2004

Wind Roses

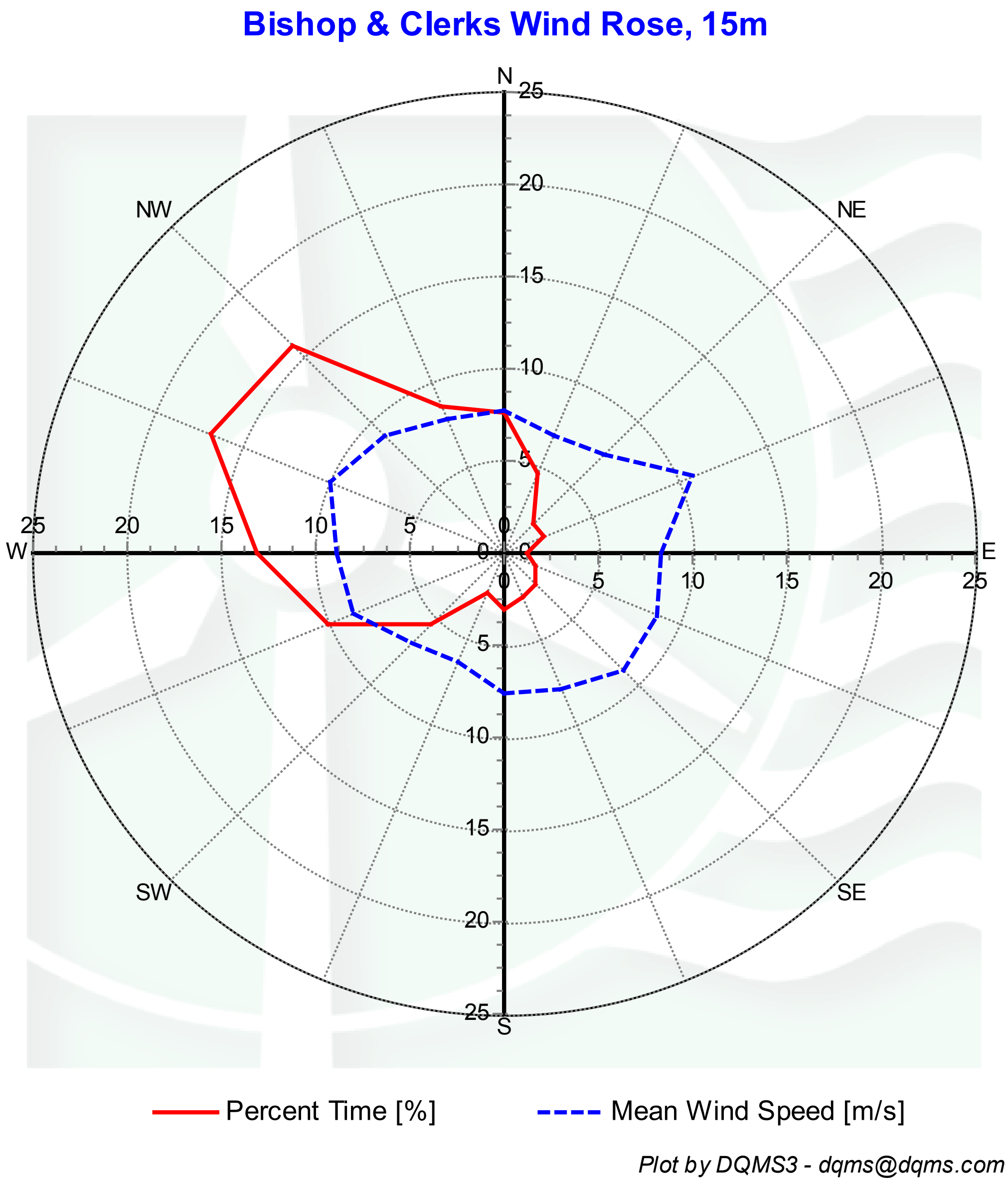

Figure 9 - Wind Rose, December 2003 – February 2004

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	13104	13103	99.992	0	0	0	99.992
Batt13aVDC	13104	13103	99.992	0	0	0	99.992
Anem15aMS	13104	13103	99.992	0.333	29.667	0.333	98.603
AnemSD15aMS	13104	13103	99.992	0.333	29.667	0.333	98.603
Anem15bMS	13104	13103	99.992	0.333	23.833	0	98.886
AnemSD15bMS	13104	13103	99.992	0.333	23.833	0	98.886
Vane15aDEG	13104	13103	99.992	0.167	29.667	0	98.626
VaneSD15aDEG	13104	13103	99.992	0.167	29.667	0	98.626
Vane15bDEG	13104	13103	99.992	0	23.833	0	98.901
VaneSD15bDEG	13104	13103	99.992	0	23.833	0	98.901
Total	**131040**	**131030**	**99.992**	**1.667**	**214**	**0.667**	**99.002**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.34
1.5	0.66
2.5	2.13
3.5	4.56
4.5	7.59
5.5	8.3
6.5	9.65
7.5	9.01
8.5	8.55
9.5	9.08
10.5	9.09
11.5	8.39
12.5	7.6
13.5	4.67
14.5	3.72
15.5	2.51
16.5	1.54
17.5	1.14
18.5	0.77
19.5	0.31
20.5	0.27
21.5	0.08
22.5	0.02
23.5	0
24.5	0

Table 1 - Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Mar 2003	7.20
Apr	7.82
May	6.22
Jun	5.88
Jul	6.65
Aug	7.19
Sep	6.64
Oct	7.98
Nov	8.04
Dec	9.61
Jan 2004	8.74
Feb	7.28

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0	8.62
1	8.55
2	8.69
3	8.45
4	8.22
5	8.33
6	8.54
7	8.6
8	8.76
9	8.75
10	8.72
11	8.72
12	8.71
13	8.73
14	8.68
15	8.58
16	8.41
17	8.36
18	8.3
19	8.55
20	8.75
21	8.63
22	8.57
23	8.55

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	7.64	7.76
NNE	4.62	6.86
NE	2.25	7.55
ENE	2.24	10.84
E	1.2	8.35
ESE	1.8	8.77
SE	2.36	8.94
SSE	2.56	7.96
S	3.06	7.63
SSW	2.31	6.45
SW	5.48	6.96
WSW	10.08	8.65
W	13.1	8.86
WNW	16.84	9.96
NW	15.84	9.01
NNW	8.62	7.87

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