

ANNUAL WIND DATA REPORT

Bishop & Clerks

March 1, 2002 – February 28, 2003

Prepared for

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EXECUTIVE SUMMARY

Wind monitoring equipment was first installed on the Bishop & Clerks USCG automated lighthouse, beginning in Nov 2000 and continuing to the present. The logger batteries and sensors were replaced Oct 10, 2002, following a site visit. Data collection percentage during the current monitoring period (Mar 02 – Feb 03) was very good (raw 99.98%, 96% after quality assurance (QA) filtering) with an annual average wind speed of 7.87 m/sec at 15 m height (17.6 mph at 49 ft) being recorded. Turbulence intensity, measured at 0.11 is low. The prevailing wind direction pattern for spring and autumn tracked in a more southerly direction, closer in character to the typical Summer pattern. Summer and Winter wind directions showed a more typical seasonal pattern similar to earlier measurements made at this location.

SECTION 1 - Station Location

Bishop & Clerks was originally a small island south of Hyannis back in the 1800's. Over the course of 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 $41^{\circ} - 34' - 27.6''$ North, $070^{\circ} - 14' - 59.5''$ West (Figure 1, tower location marked by the red dot). 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).

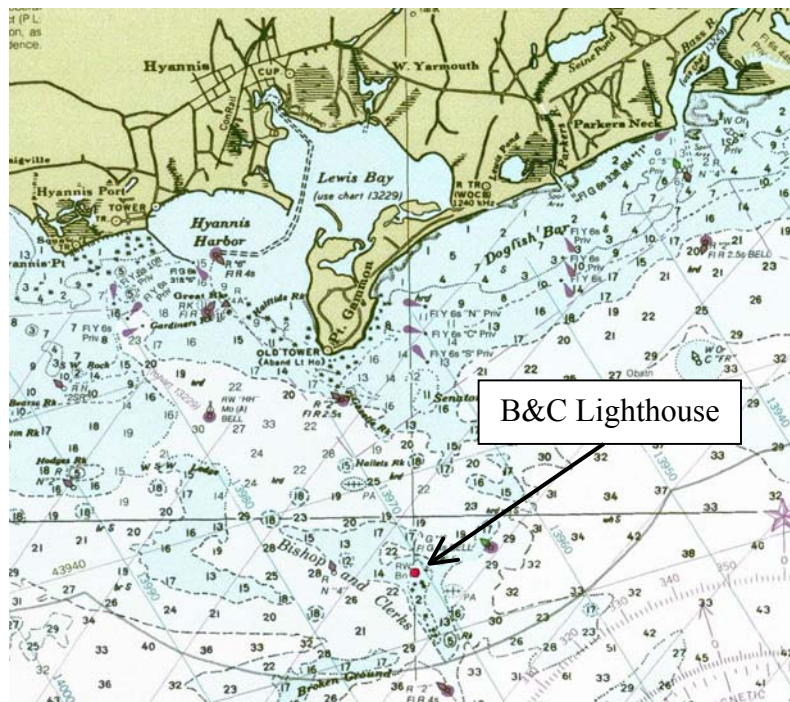


Figure 1 - Station location at Bishop & Clerks light

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 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.

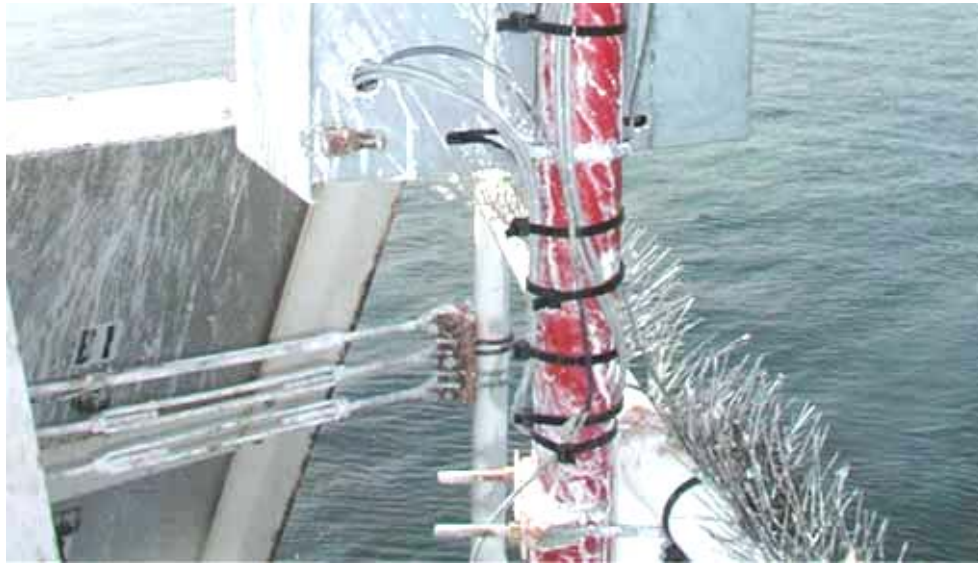


Figure 3 - Railing stiffener connecting PV bracket to rail

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 period of Mar 02 – Apr 03 and the following corrective actions taken:

- March 02 - The base station PC was replaced. The old PC had problems with the internal clock, which caused timestamp errors on prior data sets.
- June through Aug 02 – Cell phone connections from logger to base station PC become increasingly prone to disconnect; however, no data was lost.
- Aug & Sept 02 – Two maintenance trips were attempted to fix the cell phone problem. Both tries failed as rough sea conditions prevented landing of equipment to the lighthouse.
- Oct 02 – Successful landing of repair personnel. Cell phone difficulties are traced to a weak battery, which was replaced. Additionally, all sensors were replaced in anticipation of the sensors not lasting an additional year.

Data collection during this period was good, with the redundant wind speed sensor covering for the primary one that slowly began to fail over a period of months. The sensor replacement interval was the major missing data segment, along with 20 min lost over the year's period due to resetting of the logger clock. The results are summarized below.

Data Statistics Summary

Date	Mean 10 min [m/s]	Max 10 min [m/s]	Turbulence Intensity []	Prevailing Wind Direction []
<i>2002</i>				
Mar	8.47	20.36	0.11	SSW
Apr	7.78	21.7	0.11	SSW
May	7.82	19.21	0.11	SW
Jun	6.98	17.24	0.12	SW
July	6.95	16.48	0.12	SW
Aug	6.8	15.88	0.11	SW
Sept	7.4	20.55	0.11	SSW
Oct	8.13	20.55	0.12	E
Nov	8.97	19.48	0.11	SW
Dec	8.64	22.86	0.11	W
<i>2003</i>				
Jan	8.83	19.64	0.11	WNW
Feb	8.4	21.56	0.11	WNW
Mar 02 – Feb 03	7.87	22.86	0.11	SW

SECTION 4 - Significant Meteorological Events

There were a few significant events that occurred during the monitoring period. First were the changes in precipitation from their historic long-term averages. Spring 02 (Mar-May) was far wetter (14.2 inches vs 11.2 inches) than usual, while Summer 02 (June-August) was substantially drier (5.1 inches vs 9.5) as measured by the National Weather Service. The second significant event was that the North Atlantic Oscillation (NAO) remained slightly negative during this period (Intellicast Weather – <http://66.100.248.10>). The NAO is a pressure variation between the Arctic and the North Atlantic region. It typically varies on a decade long cycle. A negative value signifies that the Arctic region

is at a higher pressure relative to the North Atlantic. In the mid-latitudes, this can increase windiness as colder arctic air comes down into our more temperate zone. The measured wind speed average during this one-year period, 7.87 m/s, is higher than was seen at this site in 2001. The wind roses for this period are also somewhat different from the ones seen a year earlier. Typically, the prevailing winds come from the NW quadrant, except during summertime, when they shift to the SW. For the Mar 02 – Feb 03 monitoring period, the directional aspect of the wind rose was summer-like, with the prevailing winds coming from the SW from March until September.

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. In this particular data set, the gross data recovery is very high, with less than two hours missing over the one-year long period. Most of this missing data occurred when the sensors were replaced in Oct 02.

Gross Data Recovered [%]	99.985
Net Data Recovered [%]	96.001

The failure of the #1 wind speed sensor accounts for the difference between the Net and Gross data recovered. This sensor failed in a subtle fashion, occurring over a six-month period. It was detected by comparing its output against the #2 wind speed. These sensors would typically track well against each other, disagree for a short period, and then resume agreeing. The periods of disagreement gradually became more pronounced over time until the #1 sensor had completely failed by Sept 02. During these periods, data from the backup #2 anemometer fills in for the #1 wind speed sensor.

The exact mechanism of failure is unknown, but the output signal level of the anemometer falls until the analog/digital (A/D) converters in the logger can no longer count the pulses of the anemometer. Possibly this is an effect of the salt-water air, as NRG has little experience with the anemometers used under these conditions. The anemometers and vanes will be sent to NRG for analysis to determine the failure mode.

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.

$$\begin{aligned} & (TF1 < F1) \\ & \text{or } (TF2 < F4 \text{ and } TF1 > F2) \\ & \text{or } (TF2 \geq F4 \text{ and } TF1 > F3) \end{aligned}$$

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.

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

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 maximum percentage, or most likely seen wind speed varies from about 8 m/s in Spring, increasing to 10-11 m/s during the Winter months. The distribution also varies, with a longer tail (i.e. flatter peak, broader length) seen in the Fall and Winter graphs.
- 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 peak monthly average winds occurred in Nov, with Aug being the slowest month. However, at 6.8 m/s, this is still quite high; many land-based sites have lower annual wind speeds than B&C in Aug.

- Diurnal – A plot of the average wind speed for each hour of the day. The diurnal variation was most noticeable in Spring, where the winds tend to peak in afternoon and are at a minimum late at night. Summer and Winter patterns are similar, but with a smaller variability. Fall is closer to uniform throughout the day than any of the other plots.
- 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 value of 0.11 is low and is quite consistent over the 1-year period. These low values are reached at wind speeds near the typical startup values for wind turbines, 4 m/sec.
- 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 wind roses for this 1-year period are different for those taken the previous year in that the winds tend to persist from the SW, Spring through Fall. This SW pattern is seen most strongly in the Summer data. At most other sites that UMass has monitored over the years, the prevailing winds tend to be W - NW, with SW prevailing winds being a Summertime observation. However, Thompson Island also showed a similar SW tendency during this same time period so it reflects a significant difference between this 1-year period and the last one.

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

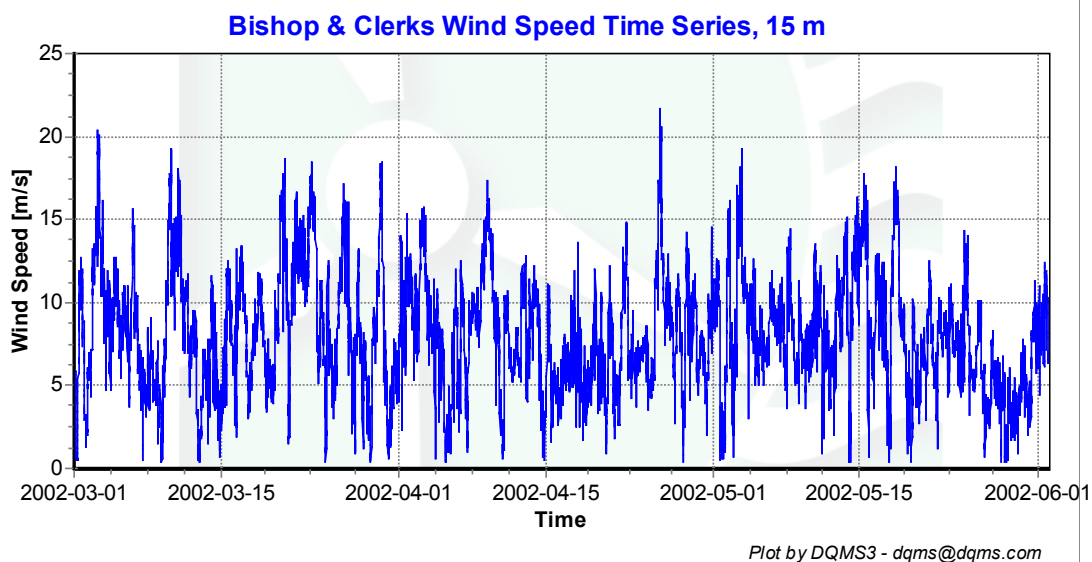


Figure 4 - Wind Speed Time Series, March 2002 – May 2003

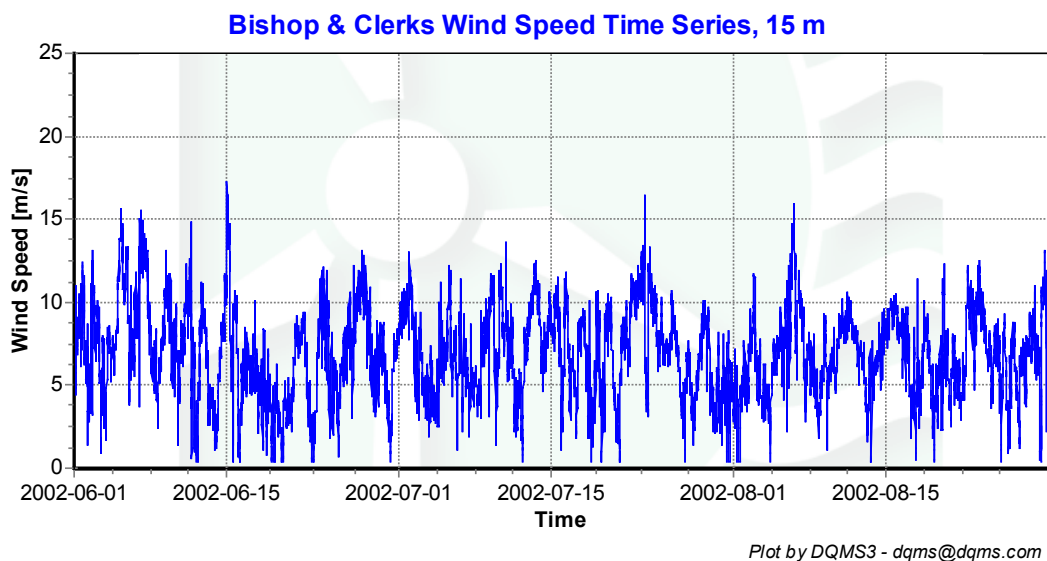


Figure 5 - Wind Speed Time Series, June 2002– August 2002

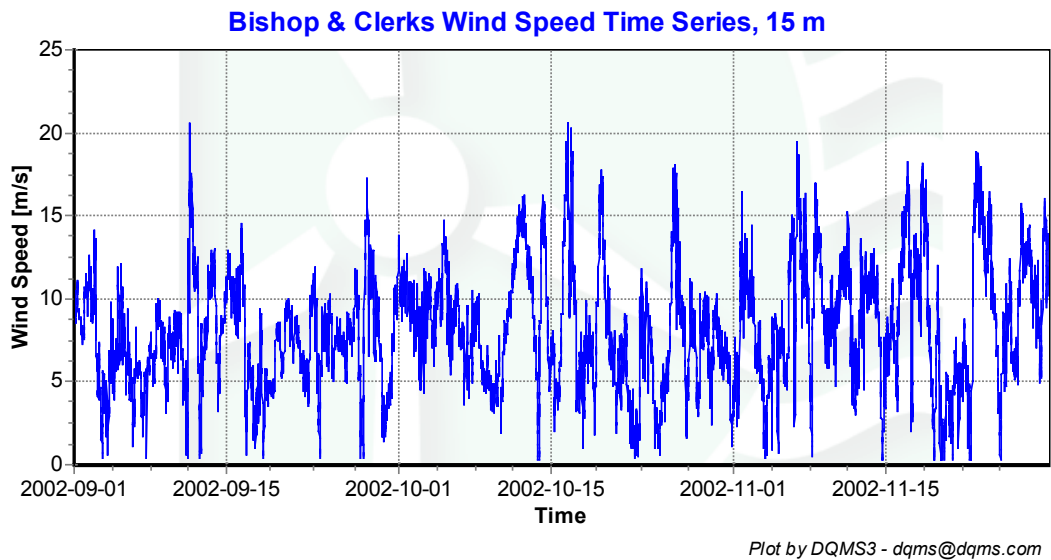


Figure 6 - Wind Speed Time Series, September 2002– November 2002

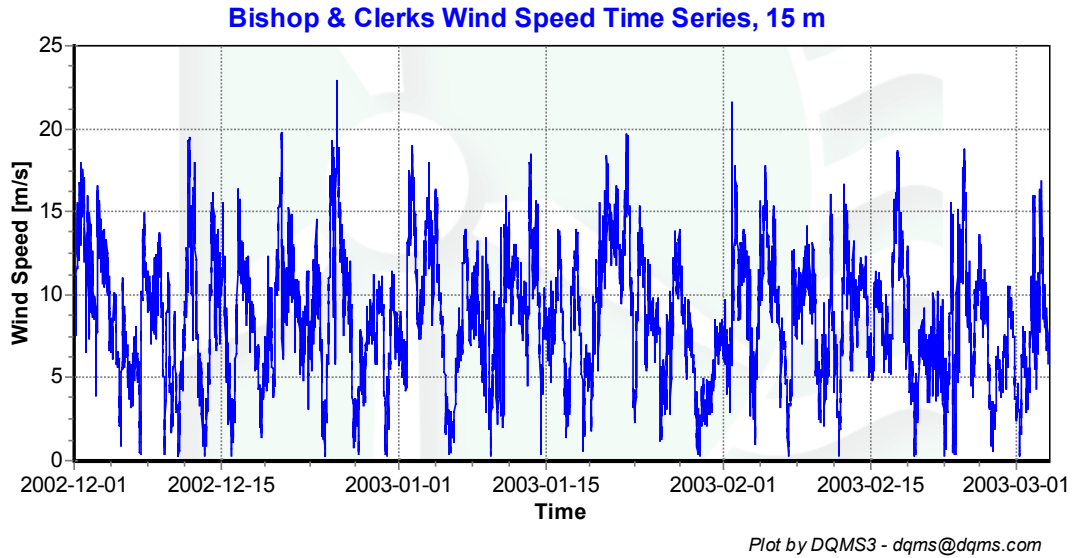


Figure 7 - Wind Speed Time Series, December 2002 – February 2003

Wind Speed Distributions

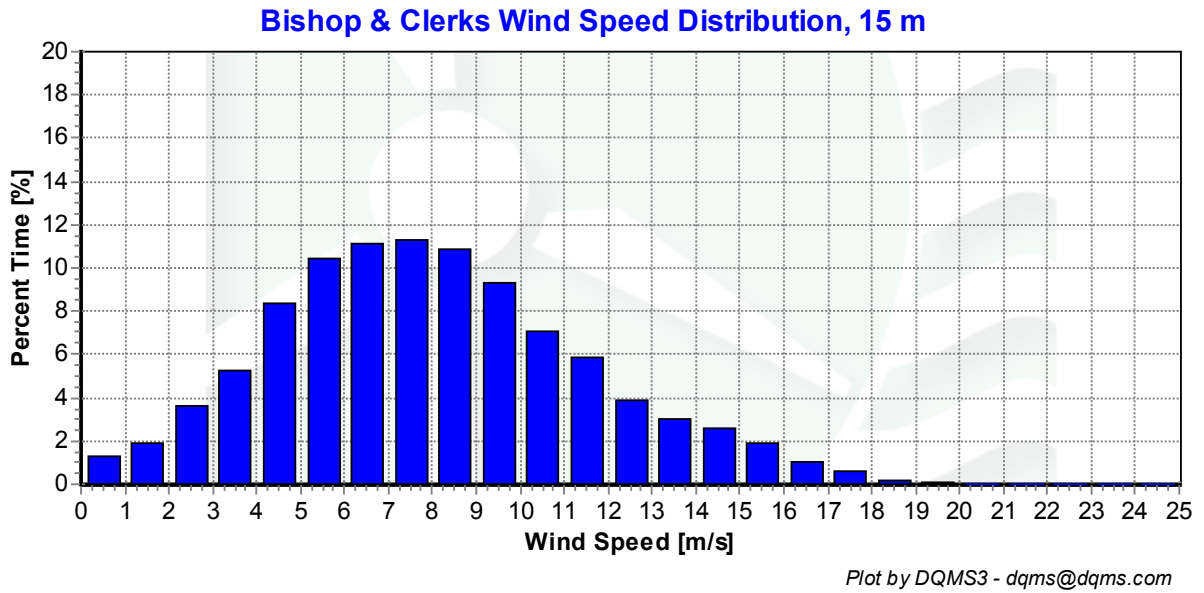


Figure 8 - Wind Speed Distribution, March 2002 – May 2002

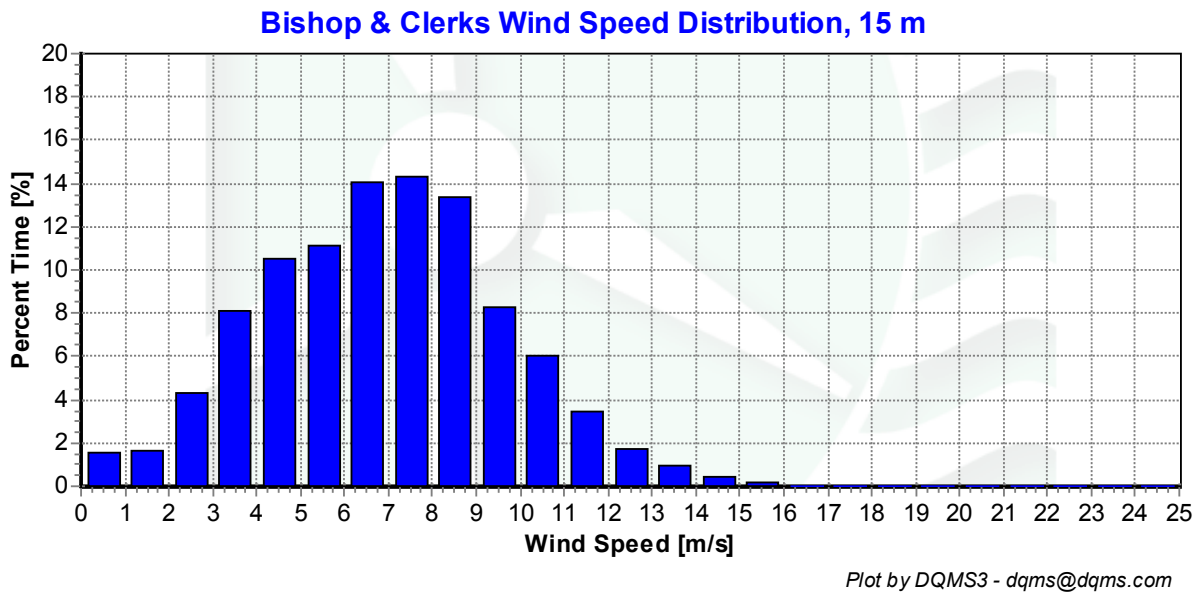


Figure 9 - Wind Speed Distribution, June 2002 – August 2002

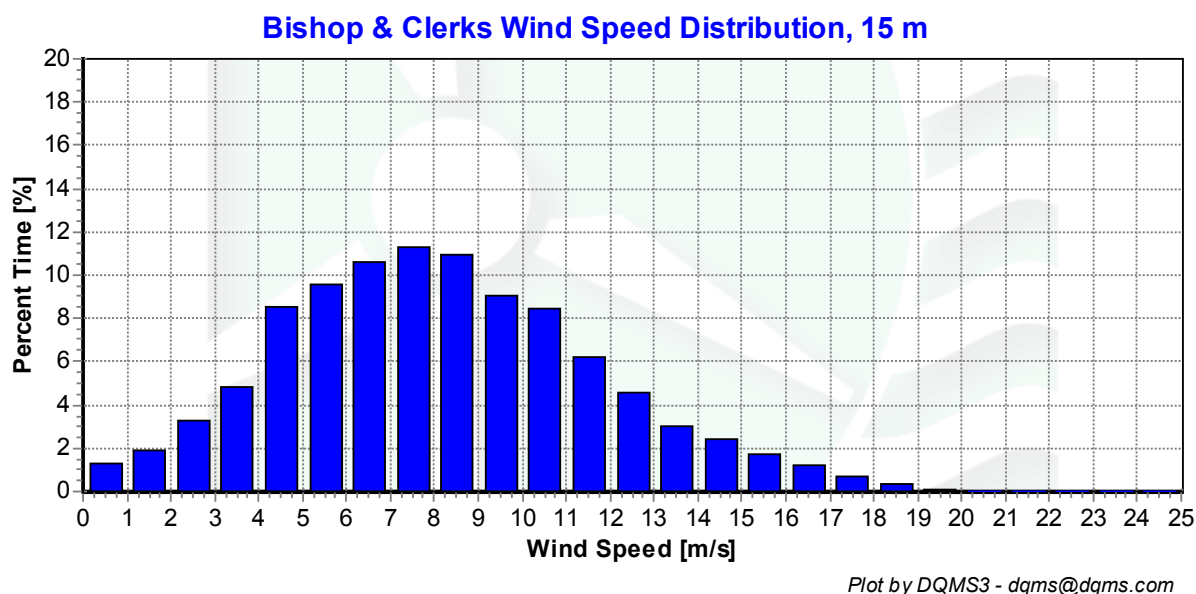


Figure 10 - Wind Speed Distribution, September 2002 - November 2002

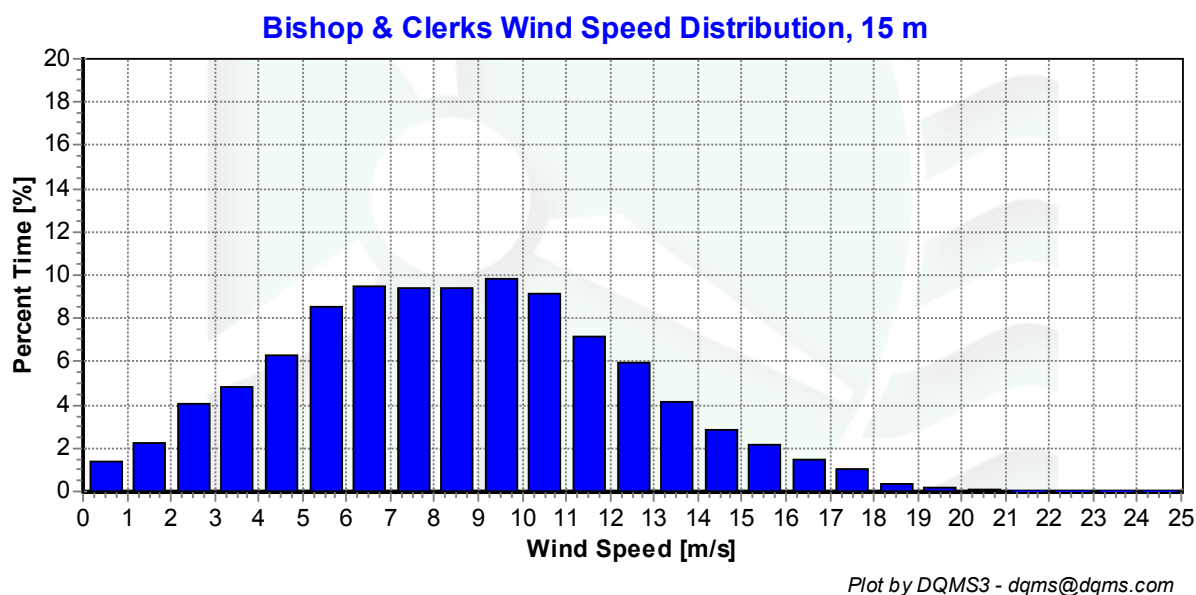


Figure 11 - Wind Speed Distribution, December 2002 – February 2003

Monthly Average Wind Speeds

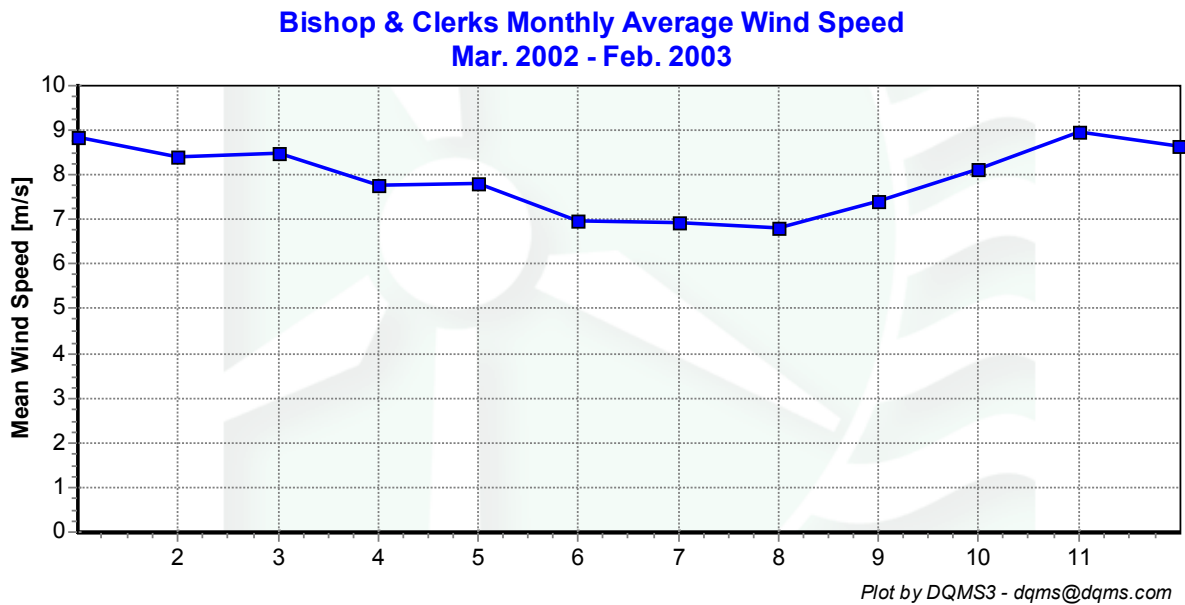


Figure 12 - Monthly Avg Wind Speed

The above graph shows monthly average wind speeds from March 2002 through February 2003. March 2002 is shown as month 3, April as month 4, and so on. January 2003 is shown as month 1 and February 2003 is shown as month 2.

Diurnal Average Wind Speeds

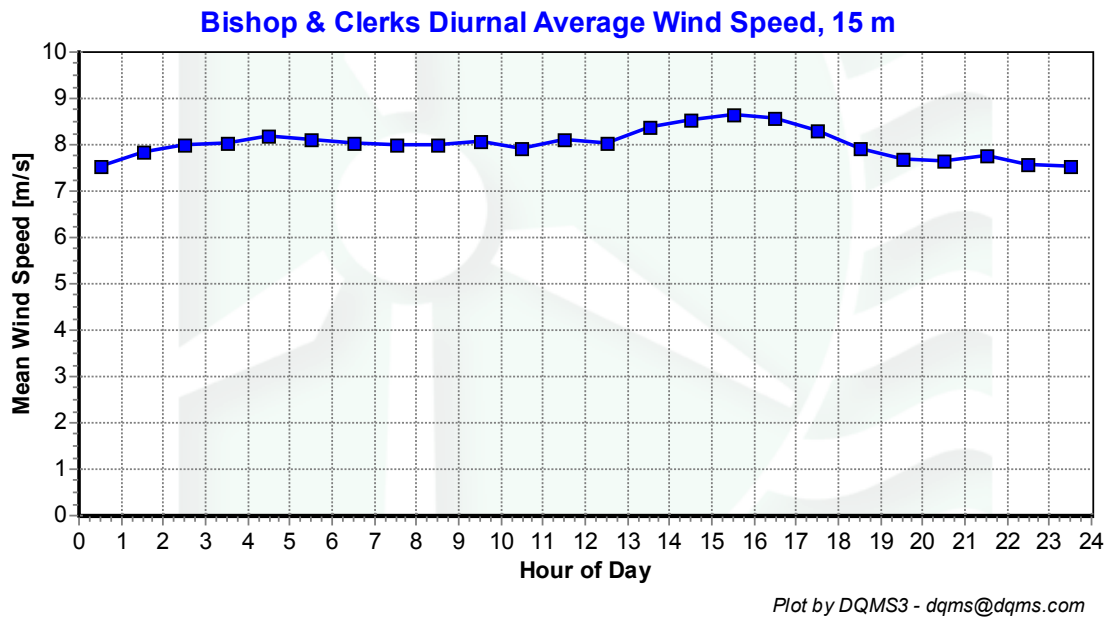


Figure 13 - Diurnal Wind Speed, March 2002 – May 2002

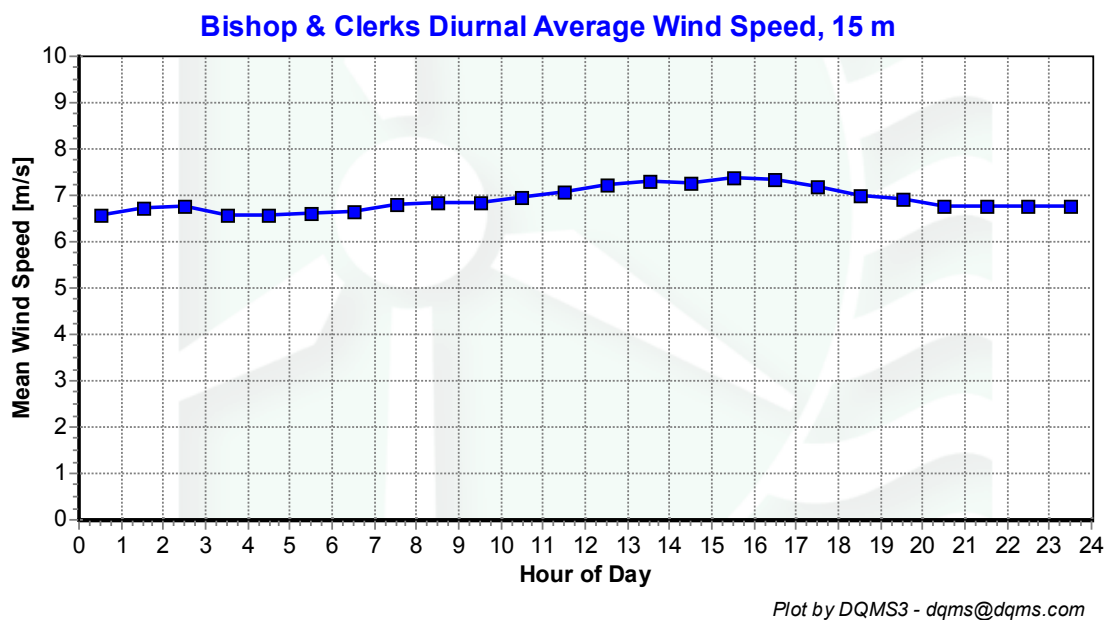


Figure 14 - Diurnal Wind Speed, June 2002 – August 2002

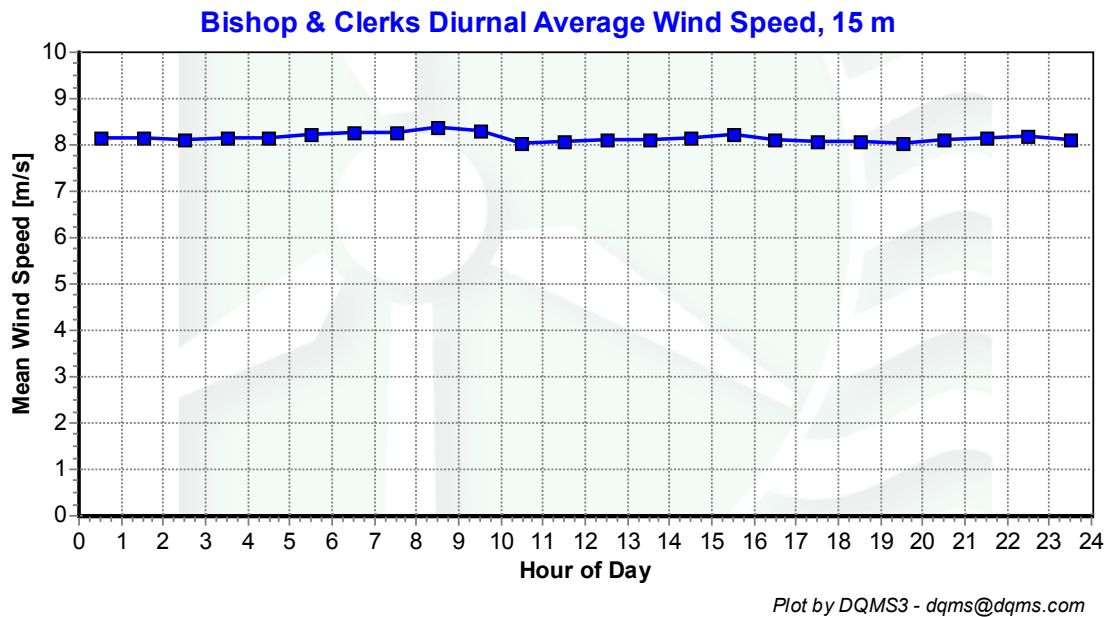


Figure 15 - Diurnal Wind Speed, September 2002 – November 2002

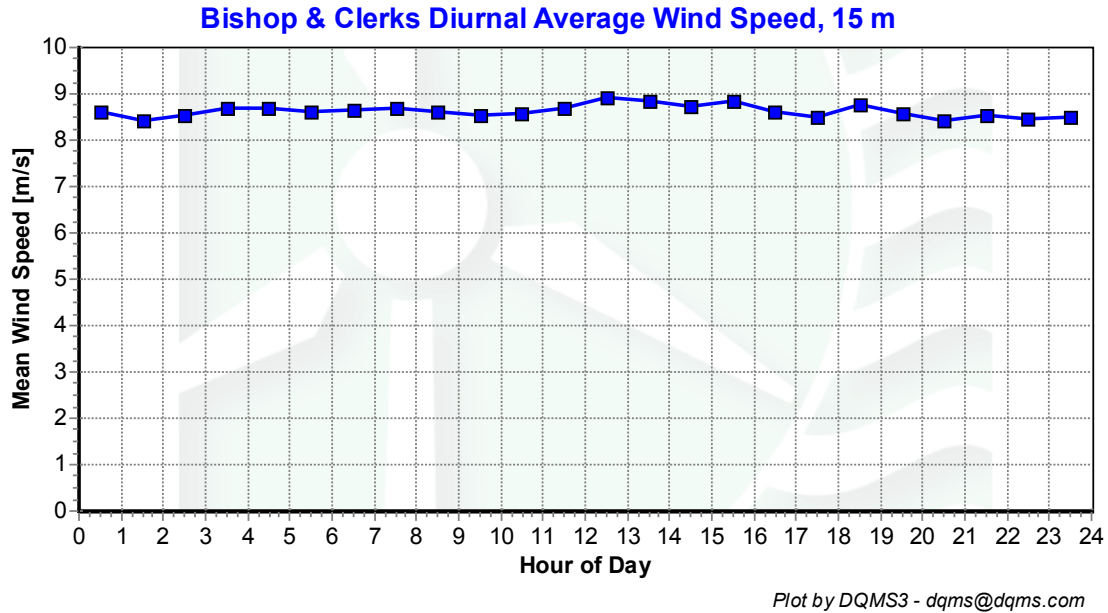


Figure 16 - Diurnal Wind Speed, December 2002 – February 2003

Turbulence Intensities

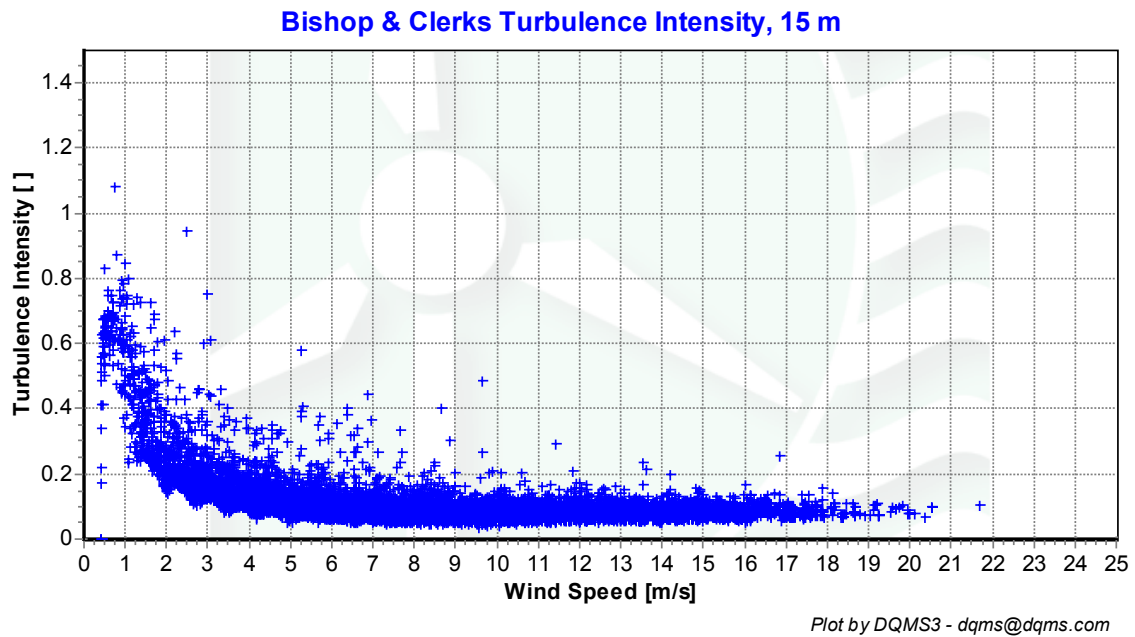


Figure 17 - Turbulence Intensity vs Wind Speed, March 2002 – May 2002

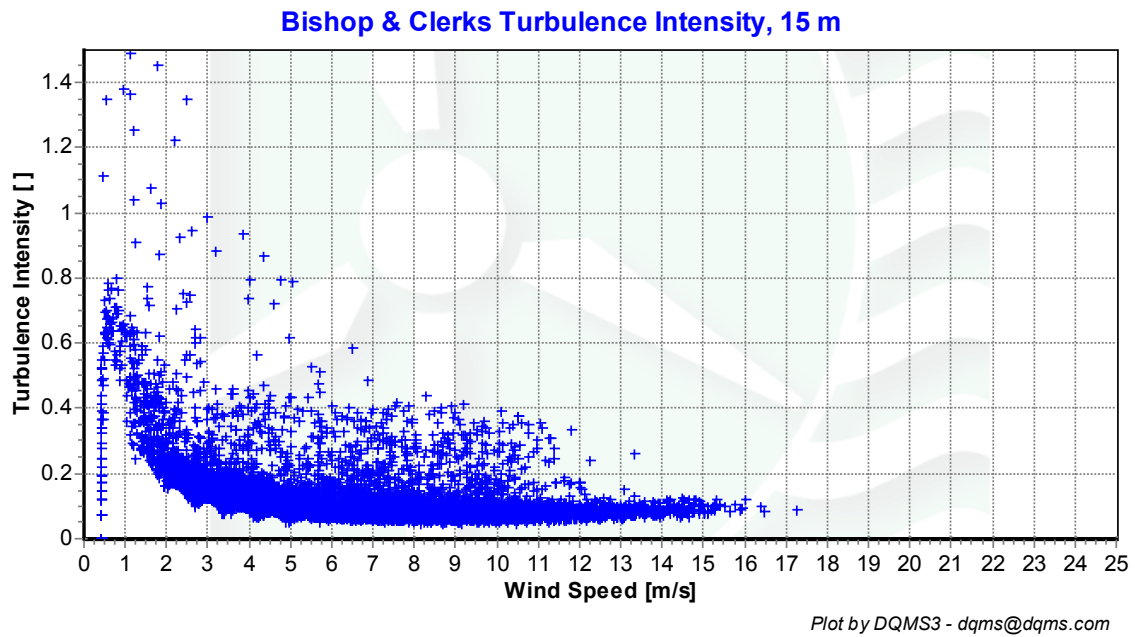


Figure 18 - Turbulence Intensity vs Wind Speed, June 2002 – August 2002

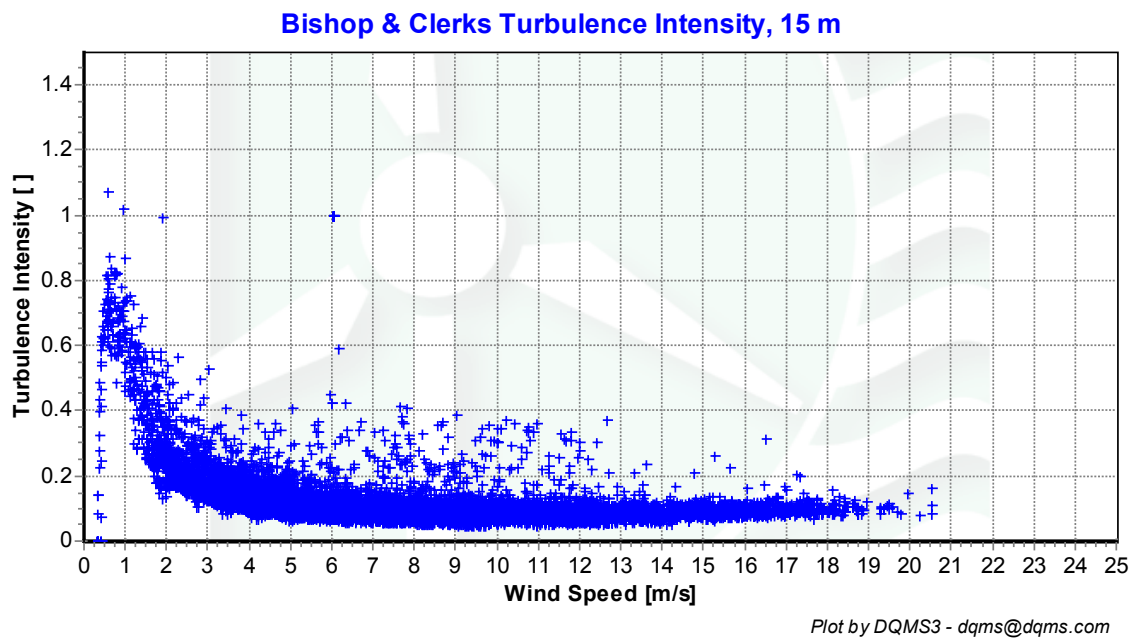


Figure 19 - Turbulence Intensity vs Wind Speed, September 2002 – November 2002

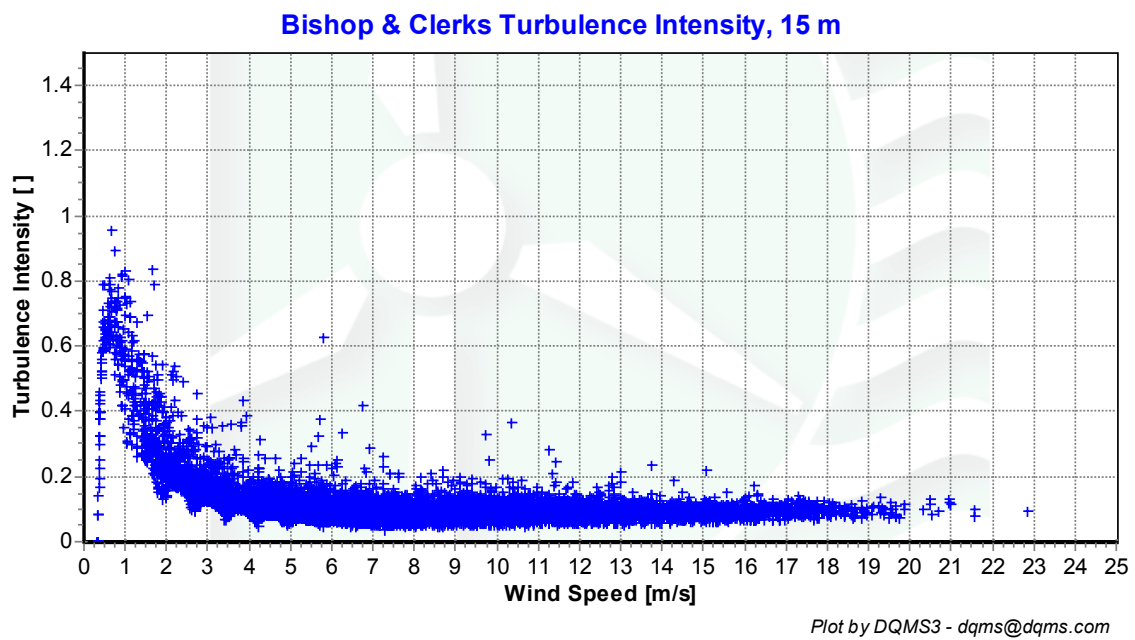


Figure 20 - Turbulence Intensity vs Wind Speed, December 2002 – February 2003

Wind Roses

Bishop & Clerks Wind Rose, 15m

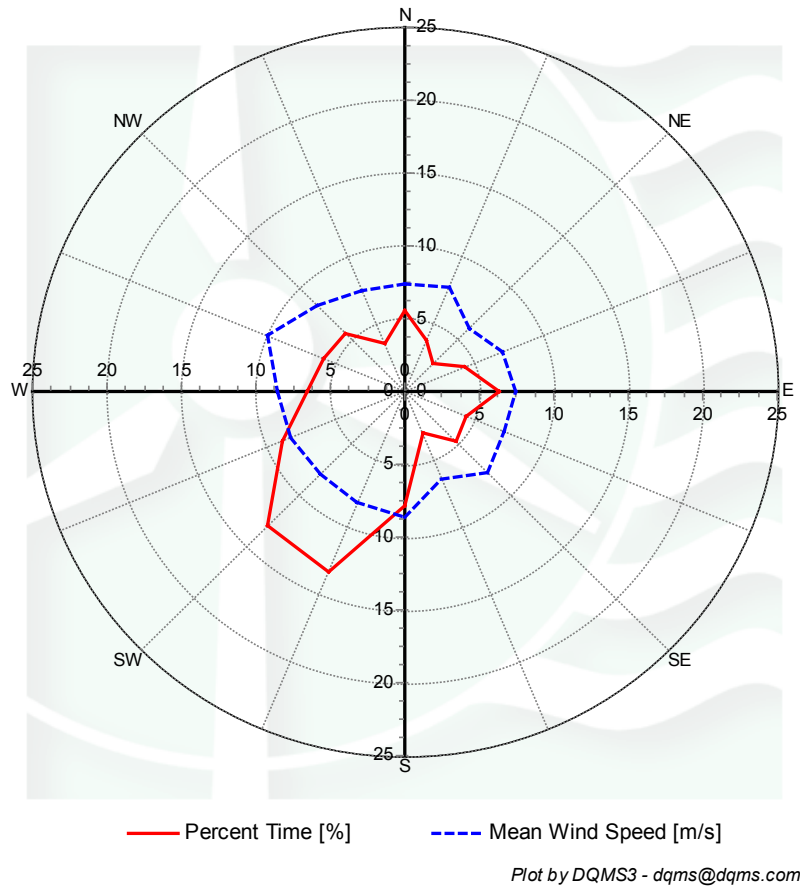


Figure 21 - Wind Rose, March 2002– May 2002

Bishop & Clerks Wind Rose, 15m

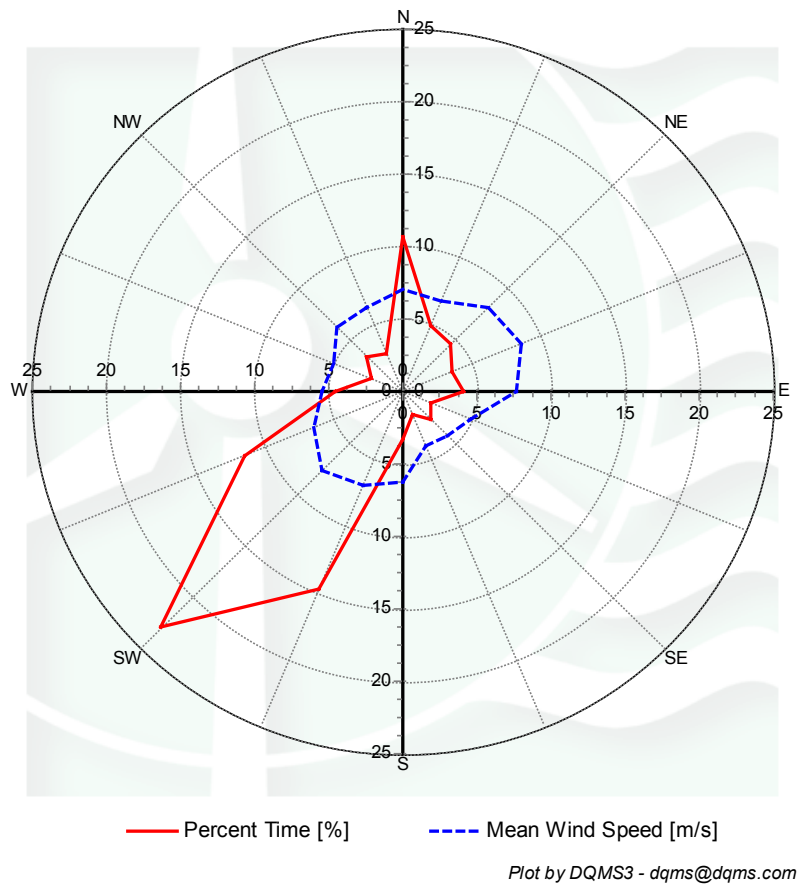
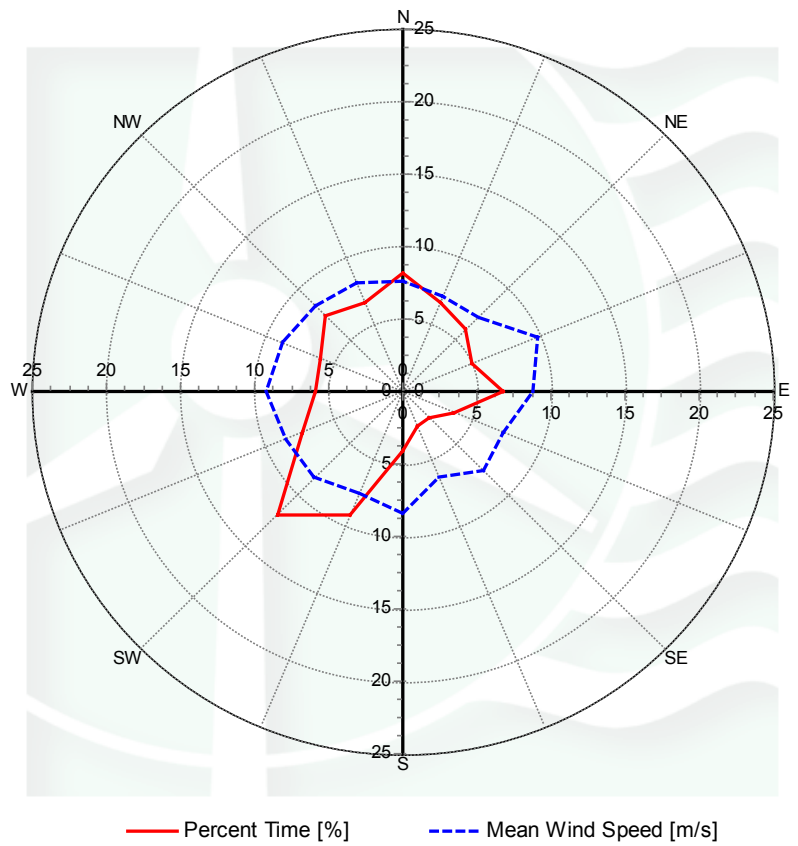


Figure 22 - Wind Rose, June 2002 - August 2002

Bishop & Clerks Wind Rose, 15m



Plot by DQMS3 - dqms@dqms.com

Figure 23 - Wind Rose, September 2002 - November 2002

Bishop & Clerks Wind Rose, 15m

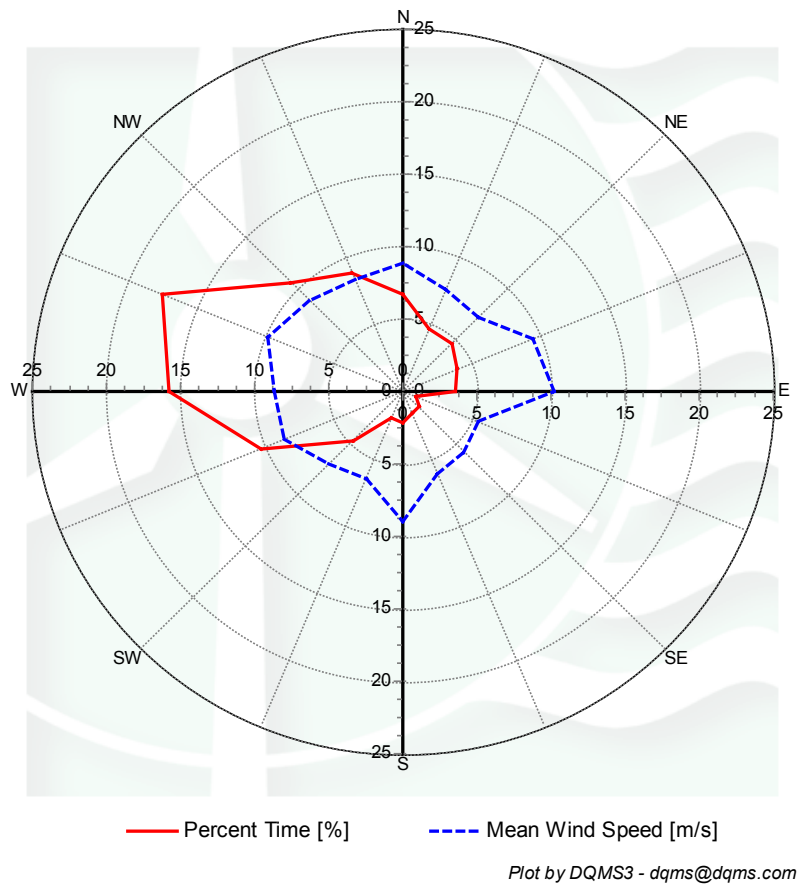


Figure 24 - Wind Rose, December 2002 – February 2003

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	52560	52552	99.985	0	0	0	99.985
Batt13aVDC	52560	52552	99.985	0.167	0	0	99.983
Anem15aMS	52560	52552	99.985	22	46.5	1495	82.137
AnemSD15aMS	52560	52552	99.985	22	46.5	1495	82.137
Anem15bMS	52560	52552	99.985	1.833	56.5	19.5	99.096
AnemSD15bMS	52560	52552	99.985	1.833	56.5	19.5	99.096
Vane15aDEG	52560	52552	99.985	0.5	46.5	0	99.448
VaneSD15aDEG	52560	52552	99.985	0.5	46.5	0	99.448
Vane15bDEG	52560	52552	99.985	0	56.5	0	99.34
VaneSD15bDEG	52560	52552	99.985	0	56.5	0	99.34
Total	525600	525520	99.985	48.833	412	3029	96.001

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Mar - May 2002	Jun - Aug 2002	Sept - Nov 2002	Dec - Feb 2003
0.5	0.37%	0.76%	0.49%	0.57%
1.5	1.46%	1.03%	1.22%	1.39%
2.5	2.75%	2.95%	2.92%	3.16%
3.5	4.39%	6.15%	4.11%	4.63%
4.5	6.57%	9.57%	6.47%	5.25%
5.5	9.21%	10.73%	8.74%	6.39%
6.5	11.24%	12.09%	10.32%	8.77%
7.5	11.50%	14.80%	10.94%	9.76%
8.5	10.87%	14.61%	11.35%	8.83%
9.5	10.30%	10.24%	10.06%	9.90%
10.5	8.21%	7.67%	8.51%	9.82%
11.5	6.52%	4.71%	7.50%	8.83%
12.5	5.13%	2.43%	5.58%	6.87%
13.5	3.42%	1.31%	3.53%	5.42%
14.5	2.76%	0.60%	2.73%	3.63%
15.5	2.42%	0.28%	2.20%	2.79%
16.5	1.52%	0.06%	1.57%	1.84%
17.5	0.76%	0.01%	0.95%	1.10%
18.5	0.37%	0.00%	0.58%	0.69%
19.5	0.14%	0.00%	0.18%	0.20%
20.5	0.08%	0.00%	0.04%	0.10%
21.5	0.02%	0.00%	0.02%	0.04%
22.5	0.01%	0.00%	0.00%	0.02%
23.5	0.00%	0.00%	0.00%	0.01%
24.5	0.00%	0.00%	0.00%	0.00%

Table B1: Wind Speed Distributions, by Quarters

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
2002 Mar	8.47
Apr	7.78
May	7.82
Jun	6.98
July	6.95
Aug	6.8
Sept	7.4
Oct	8.13
Nov	8.97
Dec	8.64
2003 Jan	8.83
Feb	8.4
Mar 02 – Feb 03	7.87

Table B2: Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Mar - May 2002 [m/s]	Jun - Aug 2002 [m/s]	Sept - Nov 2002 [m/s]	Dec - Feb 2003 [m/s]
0	7.56	6.59	8.15	8.62
1	7.84	6.72	8.14	8.44
2	8.02	6.75	8.12	8.53
3	8.03	6.59	8.15	8.7
4	8.2	6.59	8.17	8.7
5	8.13	6.63	8.25	8.61
6	8.02	6.67	8.25	8.65
7	7.99	6.81	8.27	8.69
8	8.02	6.86	8.4	8.61
9	8.07	6.84	8.31	8.55
10	7.93	6.97	8.04	8.56
11	8.12	7.09	8.08	8.7
12	8.05	7.22	8.13	8.91
13	8.38	7.3	8.12	8.85
14	8.52	7.25	8.15	8.75
15	8.65	7.37	8.24	8.84
16	8.58	7.33	8.12	8.61
17	8.31	7.19	8.09	8.49
18	7.93	7	8.07	8.78
19	7.7	6.93	8.04	8.58
20	7.65	6.78	8.13	8.4
21	7.77	6.76	8.16	8.55
22	7.59	6.77	8.21	8.47
23	7.55	6.76	8.12	8.52

Table B3: Diurnal Wind Speed

Wind Rose Data

	March 2002 to May 2002		June 2002 to August 2002		September 2002 to November 2002		December 2002 to February 2003	
Direction Sector (center)	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]
N	5.56%	7.41	10.63%	7.08	8.19%	7.62	6.66%	8.82
NNE	3.84%	7.79	4.88%	6.78	6.67%	7.11	4.71%	7.66
NE	2.75%	6.13	4.59%	8.12	6.04%	7.18	4.64%	7.25
ENE	4.37%	7.08	3.65%	8.67	5.08%	9.88	4.01%	9.46
E	6.35%	7.5	4.17%	7.64	6.75%	8.81	3.56%	10.27
ESE	4.42%	7.21	2.07%	4.98	3.76%	7.28	0.97%	5.48
SE	4.82%	7.87	2.66%	4.29	2.52%	7.65	1.52%	5.87
SSE	3.13%	6.5	1.75%	4.11	2.60%	6.44	1.64%	6.19
S	7.87%	8.6	3.25%	6.2	4.04%	8.46	2.20%	8.95
SSW	13.35%	8.28	14.73%	7	9.23%	7.61	2.01%	6.46
SW	13.00%	8.03	23.04%	7.75	12.02%	8.41	4.76%	7.09
WSW	8.93%	8.26	11.50%	6.52	7.33%	8.54	10.35%	8.6
W	6.51%	8.61	4.53%	5.49	5.86%	9.26	15.83%	8.65
WNW	5.88%	10.04	2.31%	5.1	5.99%	8.84	17.61%	9.87
NW	5.68%	8.41	3.42%	6.3	7.33%	8.38	10.67%	8.92
NNW	3.56%	7.52	2.82%	6.33	6.58%	8.09	8.87%	8.39

Table B4: Wind Rose, Time Percentage and Mean Wind Speed by Direction