WIND DATA REPORT

Little Brewster Island, Massachusetts

March 1, 2007 – May 31, 2007

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Daniel W. Jaynes
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

Aug 2nd, 2007

Report template version 3.1

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

NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Technology Collaborative (MTC). 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.

TABLE OF CONTENTS

TABLE OF FIGURES

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 Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data that is measured at a Coast Guard meteorological tower installed on Little Brewster Island, MA. The mast hosts one anemometer and one wind vane at 10 m (32.8 ft). The data are collected by a SecondWind Nomad2 data logger using a sampling rate of 1 Hz.

The quarter covered by this report is March 1 2007 – May 31 2007. The mean recorded wind speed for this quarter was 6.7 m/s (15.1 mph)[1] and the prevailing wind direction was from the west-southwest direction. The gross data recovery percentage (the actual percentage of expected data received) was 81.5% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 81.5%. The low data recovery percentages relates to the fact that the Nomad2 data encountered a low power condition that caused some of the data to be lost during many of the days summarized in this report. This error was previously thought to be associated with a corrupted configuration file. The problem has been properly addressed by replacing the data logger and adding a stable 110 V power supply.

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:

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

[1] 1m/s=2.237 mph

SECTION 1 - Station Location

Figure 1: Little Brewster Island Location

The Little Brewster Island site is located north of the town of Hull, MA in the Boston Harbor at 42.328264 N by 70.890353 W with coordinate system NAD 83. Little Brewster Island is also commonly referred to as "Boston Light" since the island hosts a small lighthouse.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 10 m (32.8 ft) Coast Guard Meteorological tower that is of the lattice structure type. All of the sensor equipment come from NRG Systems Inc. and consists of the following items:

- Electrical enclosure box
- 1 – #40 Anemometer, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s) located at 10 m (32.8 ft).
- 1 - #200P Wind direction vane that is located at 10m (32.8 ft).
- 2 – Sensor boom, 54" length
- Shielded sensor wire
- SecondWind Nomad2 Data Logger

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 measured at the measurement height, the maximum instantaneous wind speed measured at the measurement height and the prevailing wind direction measured at the measurement height. 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

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Height Units	**10 m [m/s]**	**10 m [m/s]**	**10 m [m/s]**
Mar 2007	--	--	--
Apr 2007	6.8	20.0	SW
May 2007	--	--	--
Mar '07 – May '07	**6.7**	**20.0**	**WSW**

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 are missing but the statistics are reported, the percent of the available data that are used to determine the data statistics is noted. See section 6 for a more complete description of the cause of the missing data during March and May 2007.

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 pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

A summary of the turbulence intensity at the measurement height during the reporting period is included In Table 2. 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 2 is the mean turbulence intensity when the wind speed at the measurement height is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α, have been determined. They can be used in the following formula to estimate the average wind speed, $U(z)$, at height z, when the average wind speed, $U(z_r)$, at height z_r is known:

$$U(z)=U(z_r)\left(\frac{z}{z_r}\right)^{\alpha}$$

The change in wind speed with height is a very complicated relationship related to atmospheric conditions, wind speed, wind direction, time of day and time of year. This formula will not always provide the correct answer at any given site. Nevertheless the calculated shear coefficient, based on measurements at two heights, can be used to characterize the degree of increase in wind speed with height at a site.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{low} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right) \Big/ \log\left(\frac{z_{high}}{z_{low}}\right)$$

The Little Brewster Island site is not equipped with anemometers at multiple heights. Therefore the data do not yield values for the shear coefficient.

Table 2. Shear and Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10 m/s
Height Units	**10 m [-]**
Mar 2007	--
Apr 2007	0.11
May 2007	--
Mar '07 – May '07	0.11

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 in Figure 2. This plot represents data collected from March 1st, 2007 to May 31st, 2007 at a height of 10m. The small breaks in the data that appear during the month of March and May 2007 are associated with a weak logger battery that caused the logger to lose power during certain times.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed is shown in Figure 3. This plot represents data collected from March 1st, 2007 to May 31st, 2007 at a height of 10m.

- Monthly Average – A plot of the monthly average wind speed over a 12-month period is shown in Figure 4. This graph shows the trends in the wind speed over the year. This plot represents data collected from February 2007 to May 2007 at the 10m tower. The monthly averages for February, March and May 2007 are missing due to periods during which more than 10% of the wind speed data were missing.

- Diurnal – A plot of the average wind speed for each hour of the day is shown in Figure 5. This plot represents data collected from March 1st, 2007 to May 31st, 2007 at a height of 10m.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed is shown in Figure 6. 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. In general, turbulence intensities range from 0.1 to 0.4. In the graph below, the turbulence intensity flattens out between 6 and 7 m/s (13.4 and 15.7 mph). See Figure 6 for data representing March 1st, 2007 to May 31st, 2007. This plot presents data at 10 meters.

- 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 plot, shown in Figure 7, represents data collected from March 1st, 2007 to May 31st, 2007 at a height of 10m where the prevailing wind direction is from the west-southwest.

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

Wind Speed Time Series

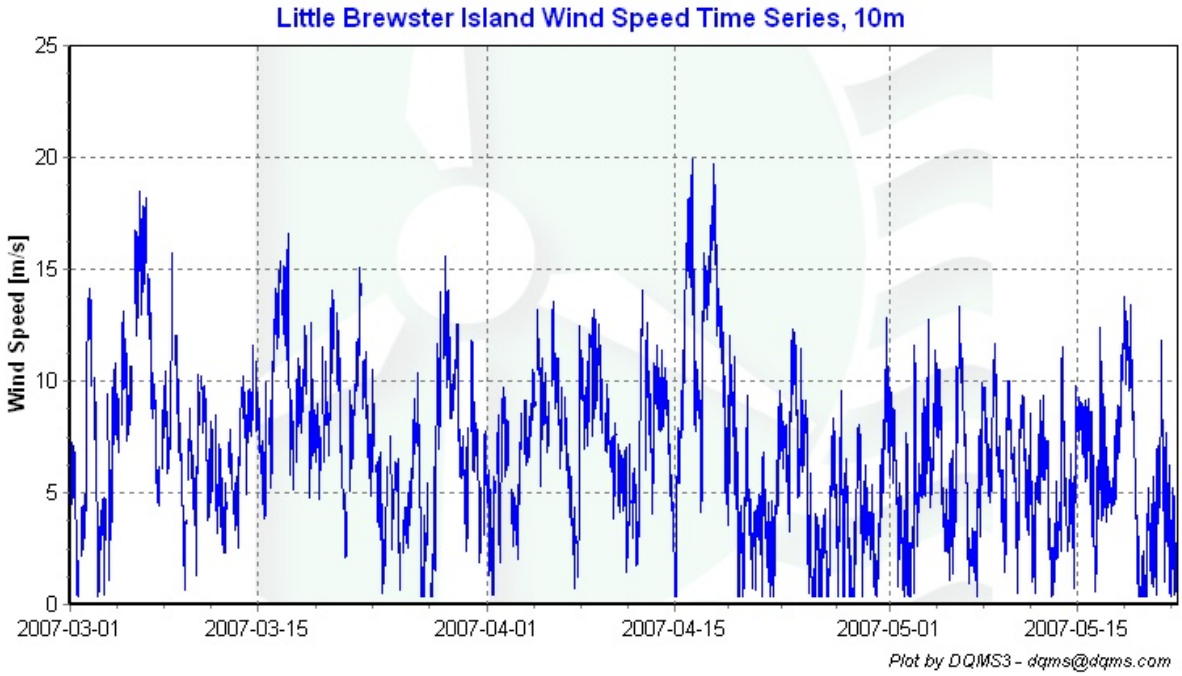

Figure 2 - Little Brewster Island Wind Speed Time Series Mar 1st, 2007 to May 31st, 2007

Wind Speed Distributions

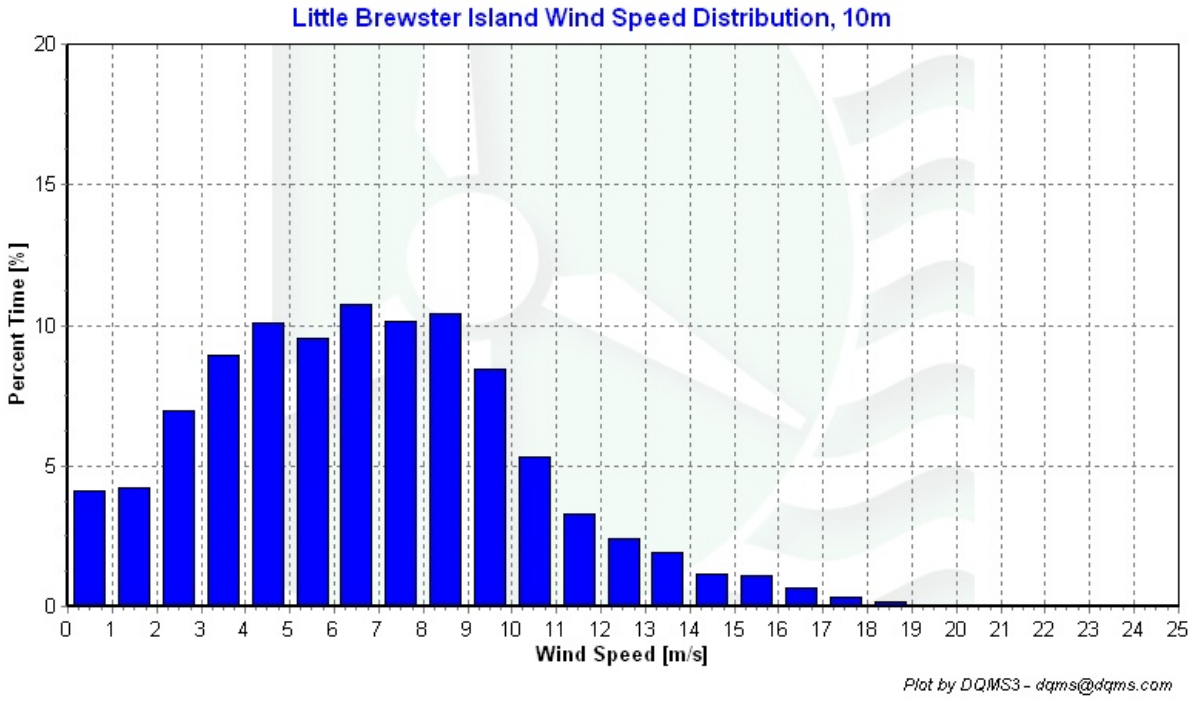

Figure 3 - Little Brewster Island Wind Speed Distribution Mar 1st, 2007 to May 31st, 2007

Monthly Average Wind Speeds

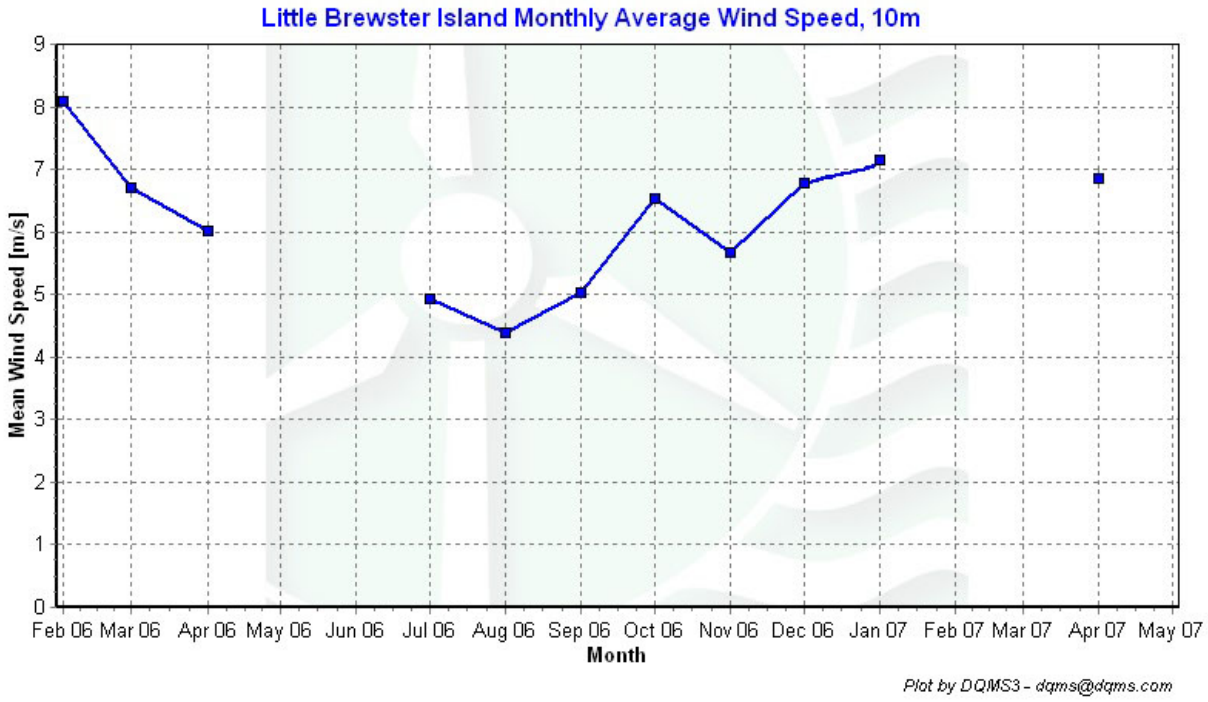

Figure 4 - Little Brewster Island Monthly Average Wind Speed Feb 2006 – May 2007

Diurnal Average Wind Speeds

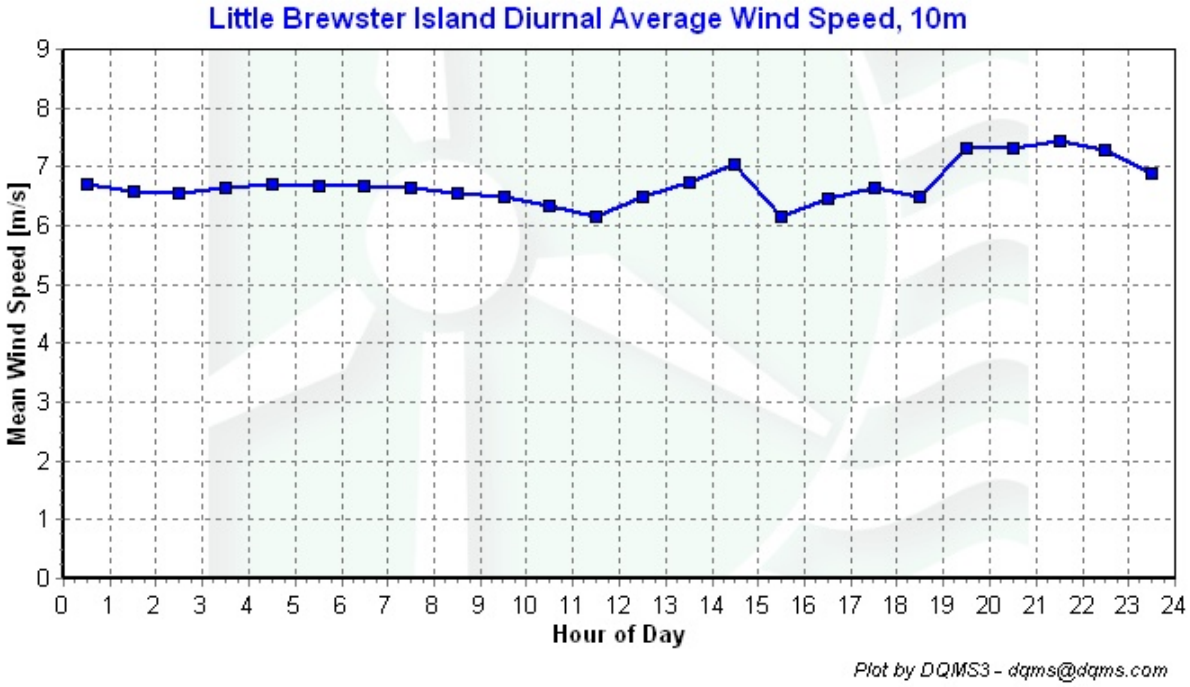

Figure 5 - Little Brewster Island Diurnal Average Wind Speed Mar 1st, 2007 to May 31st, 2007

Turbulence Intensities

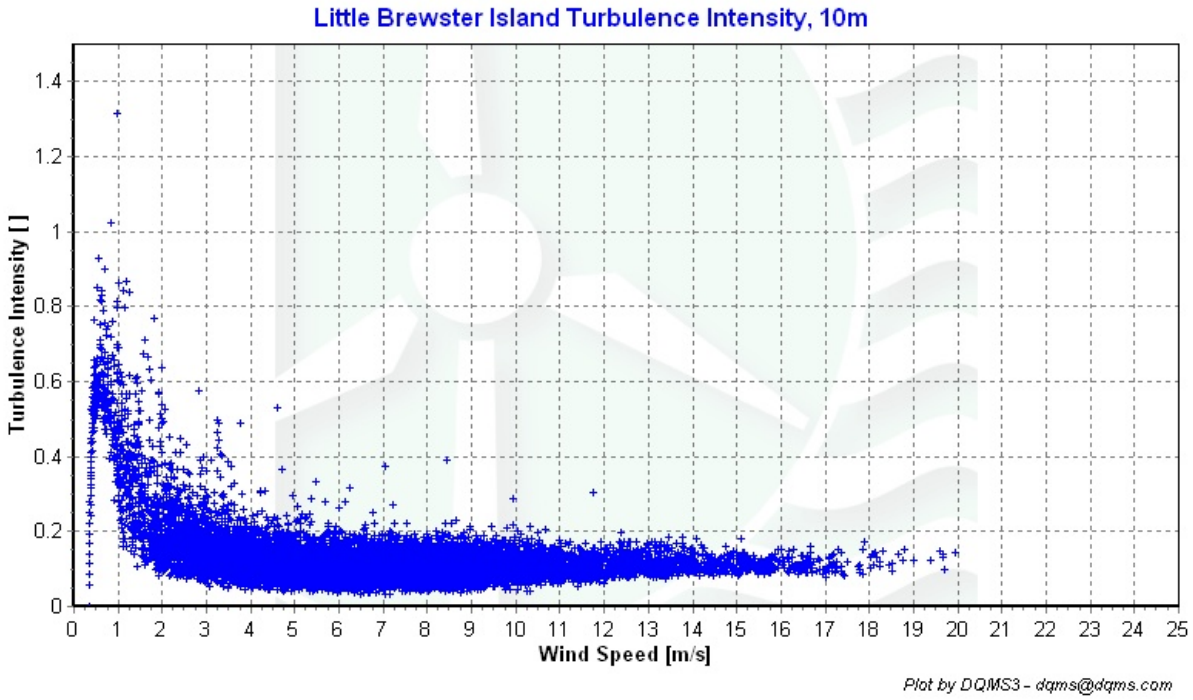

Figure 6 - Little Brewster Island Turbulence Intensity Mar 1st, 2007 to May 31st, 2007

Wind Roses

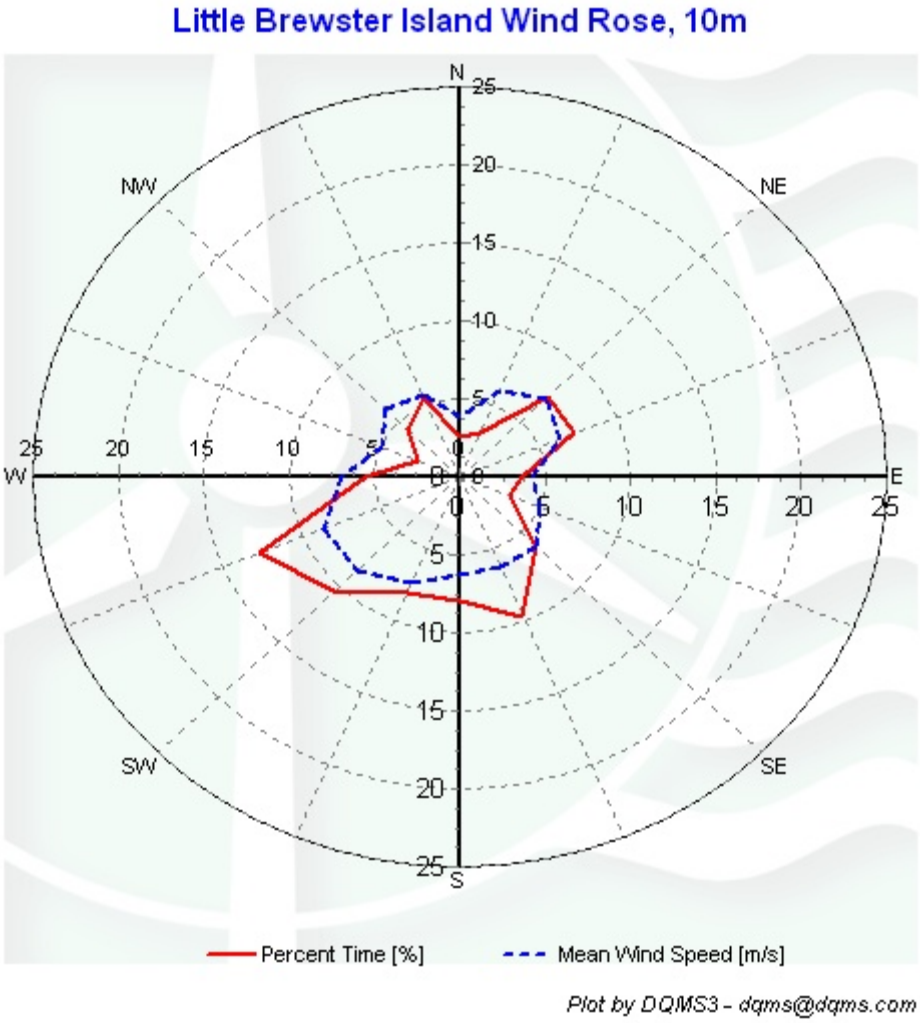

Figure 7 - Little Brewster Island Wind Rose Mar 1st, 2007 to May 31st, 2007

SECTION 5 - Significant Meteorological Events

In March, April and May 2007 there were no sustained meteorological events that would have caused notable fluctuations in wind speed measurements. The average wind speeds for the general Boston area (including the Boston Harbor) were close to normal.

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

SECTION 6 - Data Collection and Maintenance

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

- It was previously believed that a corrupted logger configuration file caused the logger to output no data between certain hours of the day for a large portion of the period summarized in this report. It is now known that this problem was associated with insufficient power supply that was caused by a weak logger battery. To correct this problem, a new logger was taken to Little Brewster Island and a stable power supply was obtained. Because the amount of missing data in the month of March and May 2007 is more than 10%, the statistics for this month are not included in this report.

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 [%]	81.5
Net Data Recovered [%]	81.5

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.

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

Sensor Statistics

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

LB_expRaw	Data Quality Report	2006-03-01 to 2006-06-01								
TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert	0	0	0	0
10	Anem10aMS					MinMax	0	90	0	0
12	Anem10aMS					MinMax	0	90	0	0
20	AnemSD10aMS					MinMax	0	4	0	0
22	AnemSD10aMS					MinMax	0	4	0	0
30	Vane10aDEG					MinMax	0	359.9	0	0
32	Vane10aDEG					MinMax	0	359.9	0	0
200	VaneSD10aDEG	Anem10aMS				MinMaxT	0	100	100	10
400	Anem10aMS	Anem10aMS				CompareSensors	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Fault	% Data Good
Anem10aMS	13248	10794	81.476	0	81.476	13248
AnemSD10aMS	13248	10794	81.476	0	81.476	13248
Vane10aDEG	13248	10794	81.476	0.333	81.461	13248
VaneSD10aDEG	13248	10794	81.476	0	81.476	13248
Total	**52992**	**43176**	**81.476**	**0.333**	**81.473**	**52992**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Anem10ams	Percent
0.5	4.09
1.5	4.24
2.5	6.99
3.5	8.95
4.5	10.07
5.5	9.55
6.5	10.77
7.5	10.14
8.5	10.41
9.5	8.41
10.5	5.33
11.5	3.31
12.5	2.4
13.5	1.9
14.5	1.16
15.5	1.08
16.5	0.67
17.5	0.31
18.5	0.18
19.5	0.06
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Feb 2006	8.1
Mar	6.7
Apr	6.0
May	--
Jun	5.6
Jul	4.9
Aug	4.4
Sep	5.0
Oct	6.5
Nov	5.7
Dec	6.8
Jan 2007	7.2
Feb	--
Mar	--
Apr	6.8
May	--

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	3.89	2.60
NNE	6.01	3.05
NE	7.08	7.25
ENE	6.30	7.28
E	4.26	3.60
ESE	5.10	3.12
SE	6.26	6.34
SSE	6.28	9.65
S	6.29	7.99
SSW	7.31	8.06
SW	8.53	10.38
WSW	8.59	12.73
W	6.87	5.52
WNW	5.00	2.68
NW	6.16	4.34
NNW	5.63	5.42

Diurnal Average Wind Speed Data

hr	Wind Speed [m/s]
0.5	6.71
1.5	6.59
2.5	6.55
3.5	6.65
4.5	6.71
5.5	6.66
6.5	6.68
7.5	6.63
8.5	6.55
9.5	6.48
10.5	6.33
11.5	6.15
12.5	6.5
13.5	6.73
14.5	7.04
15.5	6.14
16.5	6.45
17.5	6.64
18.5	6.48
19.5	7.32
20.5	7.33
21.5	7.43
22.5	7.28
23.5	6.9