WIND DATA REPORT

Little Brewster Island, Massachusetts

March 1, 2006 – May 31, 2006

Prepared for

Massachusetts Technology Collaborative
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by

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October 12, 2006

Report template version 1.3

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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), pursuant to work order number 05-1. 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.

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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 preformed 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. Installed on February 9, 2006, the wind monitoring sensors have been in continuous operation to this day. One anemometer and one wind vane are mounted at 10 m (32.8 ft). The data are collected by a 9300 NRG data logger and have been sampled at a rate of 1 Hz.

The season covered by this report is March 2006 – May 2006 (spring quarter). The mean recorded wind speed for this quarter was 6.3 m/s (14.1 mph)[1] and the prevailing wind direction was from the west-northwest direction. 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 99.9%.

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 by 70.890353 with coordinate system NAD 83.

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 the sensor and logger equipment come from NRG Systems Inc. and consists of the following items:

- 9300 Data Logger
- 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

SECTION 3 - Data Collection and Maintenance

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

- No problems with the data were encountered.
- No maintenance operations were needed or performed.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity
Height units	**10 m, [m/s]**	**10 m, [m/s]**	**10 m, [ ]**	**10 m, [ ]**
March 2006	6.70	17.02	W	0.14
April 2006	6.01	14.03	SSE	0.15
May 2006	6.21	17.57	WNW	0.14
Mar '06–May '06	**6.31**	**17.57**	**WNW**	**0.15**

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when larger amounts of data are missing, the percent of the available data that are used to determine the data statistics is noted.

No measurement of wind speed can be perfectly accurate. 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.

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

SECTION 4 - Significant Meteorological Events

In March, April and May 2006 there were no major meteorological events that would have caused notable fluctuations in wind speed measurements. The average wind speeds for the general Boston area were close to normal.

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 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
Net Data Recovered [%]	99.9

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.

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

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 in Figure 2. This plot represents data collected from March 1st, 2006 at 12:00 AM to May 31st, 2006 at 11:50 PM at the 10m tower.

- 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, 2006 at 12:00 AM to May 31st, 2006 at 11:50 PM at the 10m tower.

- 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 9th, 2006 to May 31st, 2006 at the 10m tower. A full year of average wind speed data is not presented because the wind speed monitoring instruments were not installed until February 9th, 2006.

- 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, 2006 at 12:00 AM to May 31st, 2006 at 11:50 PM at the 10m tower.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed appears 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 4 and 5 m/s (8.9 and 11.2 mph). See Figure 6 for data representing Mar 1st, 2006 at 12:00 AM through May 31th, 2006 at 11:50 PM only. 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, 2006 at 12:00 AM to May 31st, 2006 at 11:50 PM at the 10m tower.

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

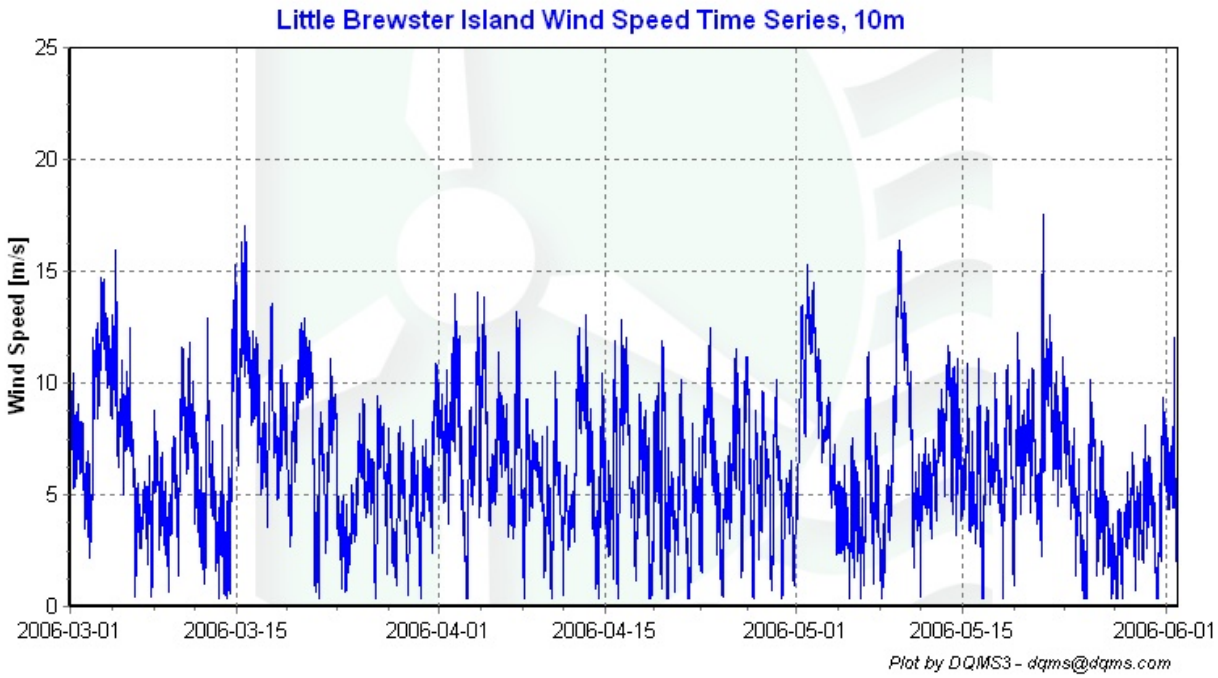

Figure 2 - Little Brewster Island Wind Speed Time Series Mar '06 – May '06

Wind Speed Distributions

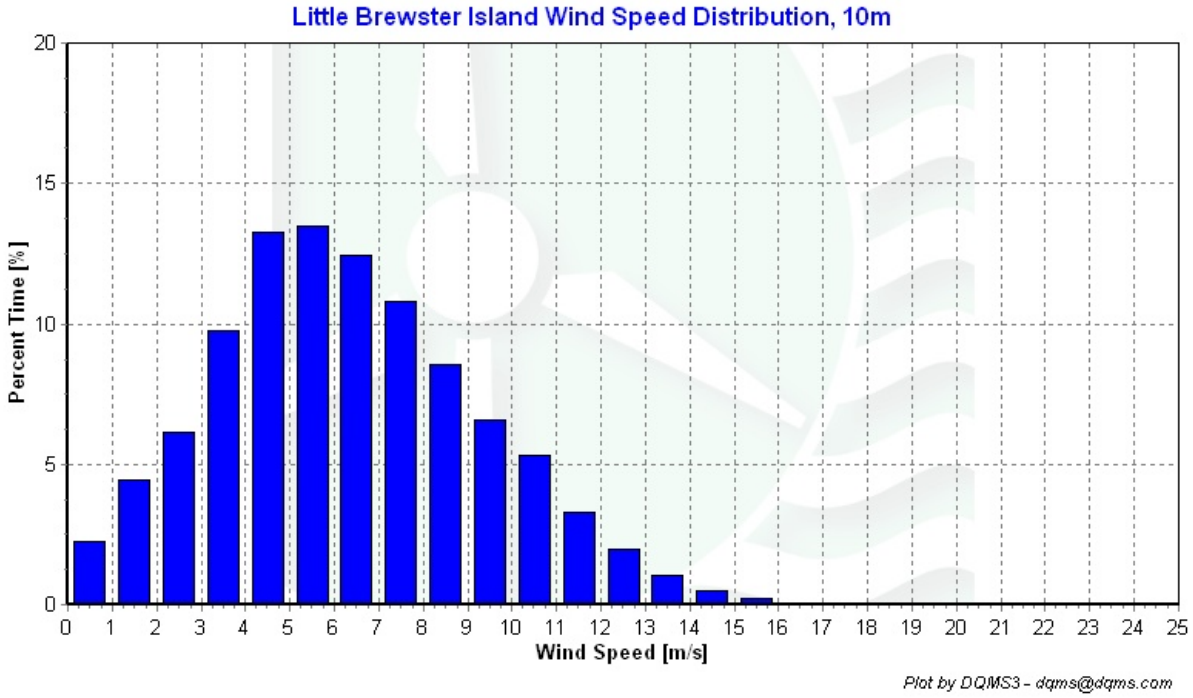

Figure 3 - Little Brewster Island Wind Speed Distribution Mar '06 – May '06

Monthly Average Wind Speeds

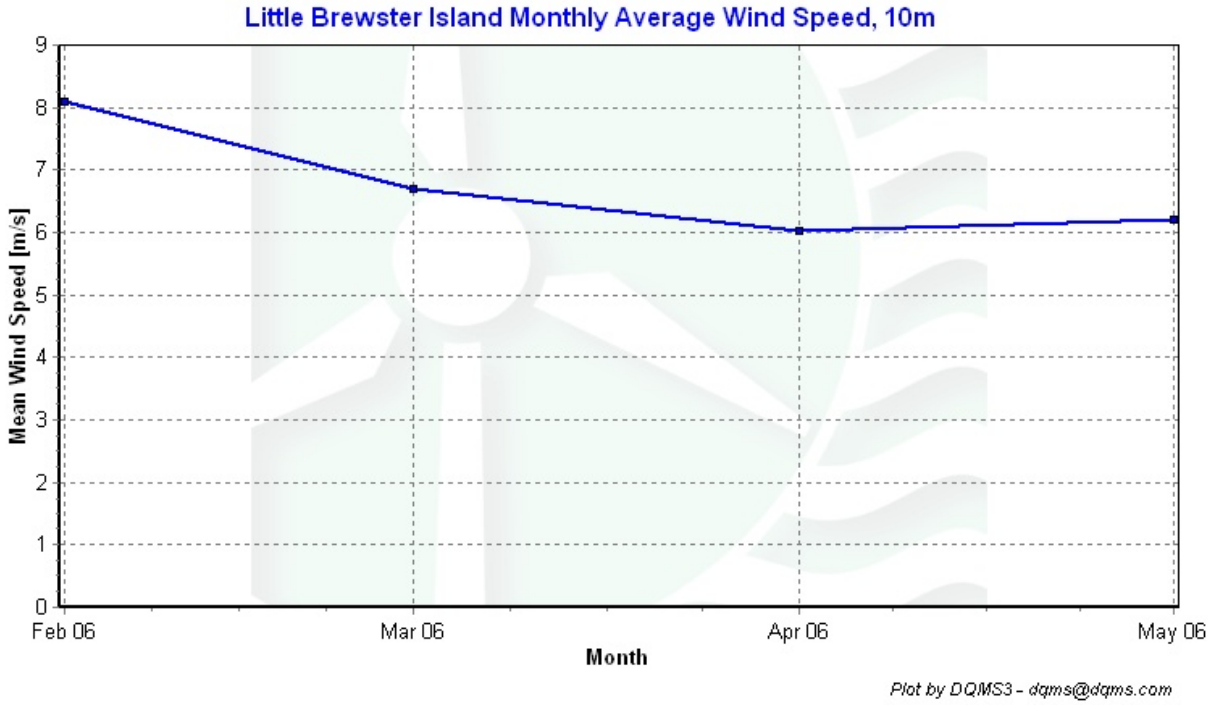

Figure 4 - Little Brewster Island Monthly Average Wind Speed February '06 – May '06

Diurnal Average Wind Speeds

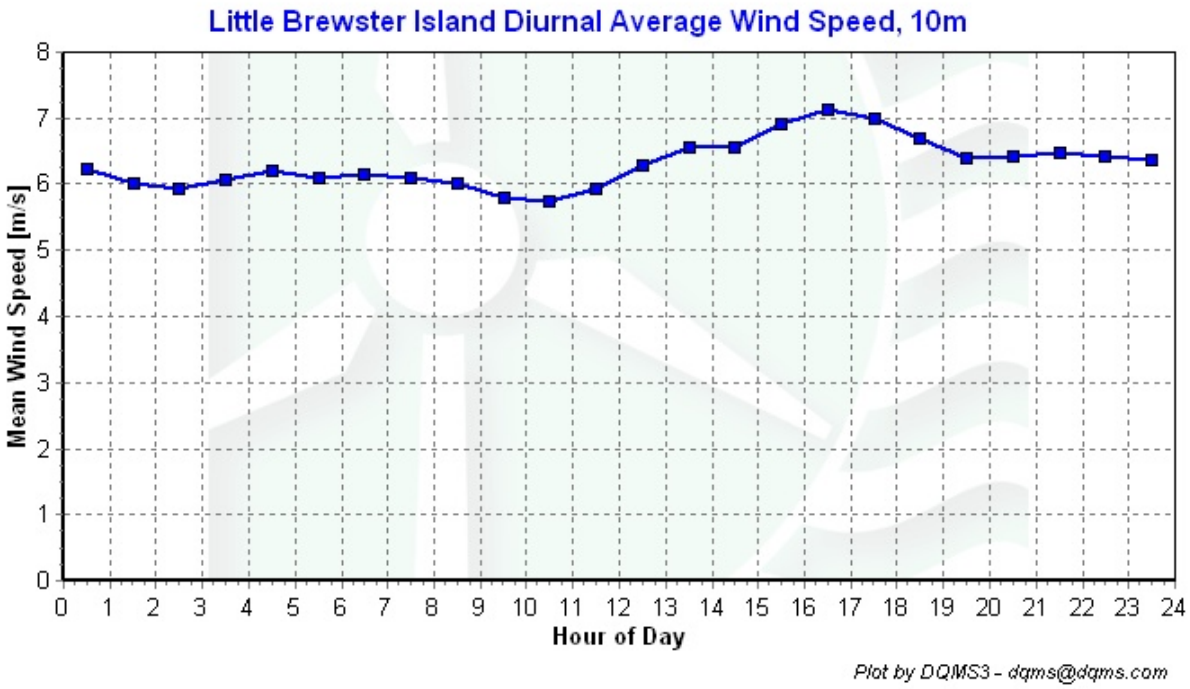

Figure 5 - Little Brewster Island Diurnal Average Wind Speed Mar '06 – May '06

Turbulence Intensities

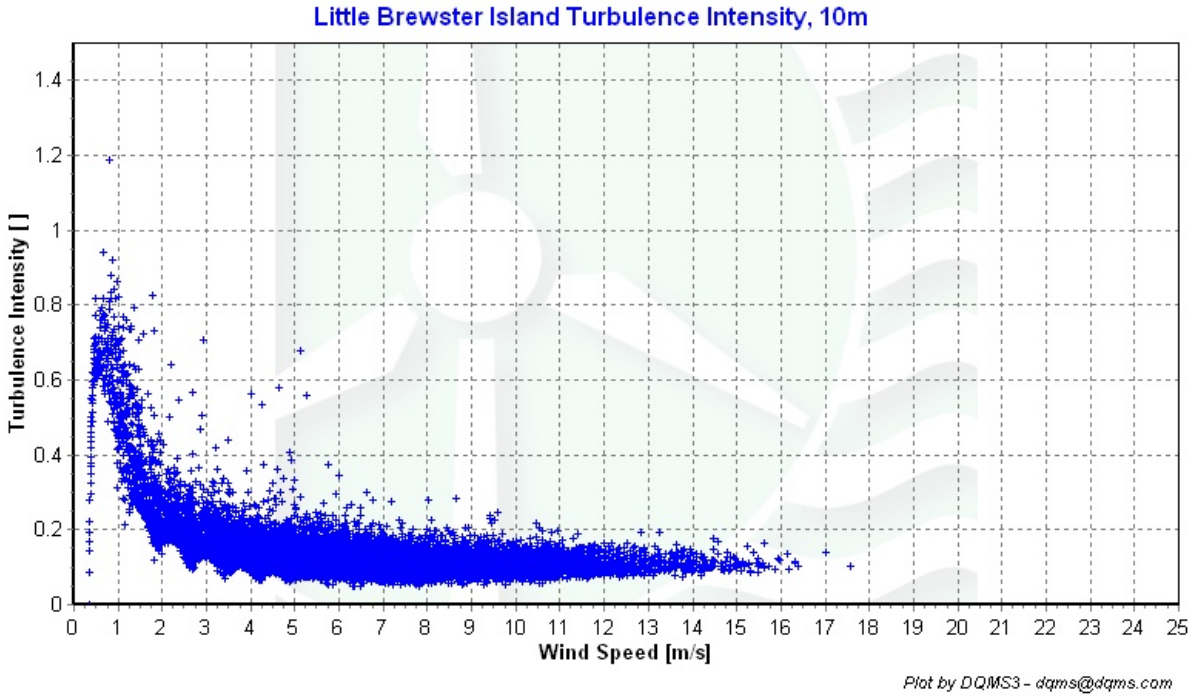

Figure 6 – Little Brewster Island Turbulence Intensity, Mar '06 – May '06

Wind Roses

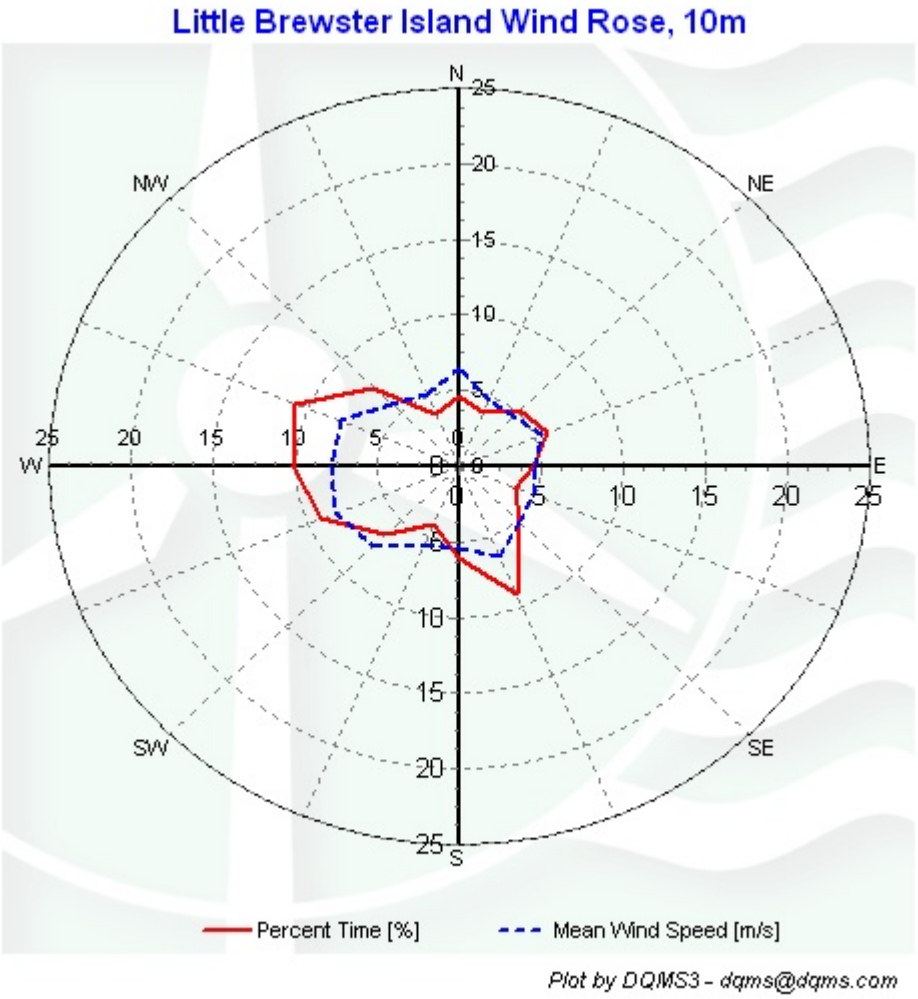

Figure 7 – Little Brewster Island Wind Rose Mar '06 – May '06

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
3	Itmp13aDEGC					MinMax	-30	60	0	0
4	Batt13aVDC					MinMax	10.5	15	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
300	Anem10aMS	AnemSD10aMS	Vane10aDEG	VaneSD10aDEG	Itmp13aDEGC	Icing	0.5	1	2	2
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 Icing	Hours of Fault	% Data Good
Itmp13aDEGC	13249	13249	100	0	0	0	100
Batt13aVDC	13249	13249	100	0	0	0	100
Anem10aMS	13249	13249	100	0.167	0	0	99.992
AnemSD10aMS	13249	13249	100	0.167	0	0	99.992
Vane10aDEG	13249	13249	100	0	0	0	100
VaneSD10aDEG	13249	13249	100	0	0	0	100
Total	**79494**	**79494**	**100**	**0.333**	**0**	**0**	**99.997**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Anem10ams	Percent
0.5	2.25
1.5	4.45
2.5	6.14
3.5	9.73
4.5	13.25
5.5	13.47
6.5	12.43
7.5	10.79
8.5	8.53
9.5	6.58
10.5	5.32
11.5	3.29
12.5	1.97
13.5	1.02
14.5	0.49
15.5	0.23
16.5	0.04
17.5	0.02
18.5	0
19.5	0
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]
Jan 2006	-----
Feb	8.1
Mar	6.7
Apr	6.0
May	6.2
Jun	----
Jul	----
Aug	----
Sep	----
Oct	-----
Nov	-----
Dec	-----

Diurnal Average Wind Speed Data

hr	Anem10aMS
0.5	6.22
1.5	6.01
2.5	5.92
3.5	6.06
4.5	6.21
5.5	6.09
6.5	6.14
7.5	6.1
8.5	6.01
9.5	5.8
10.5	5.75
11.5	5.92
12.5	6.3
13.5	6.57
14.5	6.57
15.5	6.92
16.5	7.12
17.5	7.01
18.5	6.68
19.5	6.39
20.5	6.42

21.5	6.47
22.5	6.43
23.5	6.35

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	4.69	6.42
NNE	3.86	4.67
NE	5.19	4.66
ENE	5.8	5.37
E	4.56	4.64
ESE	3.73	4.91
SE	5.09	5.2
SSE	9.22	6.4
S	6.08	5.38
SSW	4.22	5.57
SW	6.45	7.41
WSW	9.12	8.12
W	10.12	7.82
WNW	10.79	7.79
NW	7.35	5.78
NNW	3.73	5.1