

WIND DATA REPORT

Little Brewster Island, Massachusetts

June 1, 2006 – August 31, 2006

Prepared for

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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 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. Installed on February 9th 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 SecondWind Nomad2 data logger and have been sampled at a rate of 1 Hz.

The season covered by this report is June 2006 – August 2006. The mean recorded wind speed for this quarter was 4.8 m/s (10.7 mph)¹ and the prevailing wind direction was from the southwest direction. The gross data recovery percentage (the actual percentage of expected data received) was 61.0% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 59.4%. The net data recovery percentage is low due to the fact that the data logger box was replaced by another logger system. This replacement caused the loss of all data between the dates of June 15th 2006 and June 30th 2006. See section 3 for more detail. Furthermore, the standard deviation data was missing for nearly the entire quarter because the new logger was not programmed properly when it was installed. These issues have since been resolved.

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

- SecondWind Nomad2 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:

- The previous data logger (NRG 9300) was removed on June 15th 2006 and a new logger (SecondWind NOMAD2) was installed on June 30th 2006. As a result, this portion of the June data is missing and the June 2006 averages are not considered complete enough to report in the table below. When the logger was replaced, the standard deviation data needed to calculate the turbulence intensity was not programmed for collection. This problem has since been resolved. However, the table below does not present turbulence intensity values for any part of the spring quarter because more than 10% of the standard deviation data is missing for all of the months in this summary period. As described in the following section, if more than 10% of the data is missing, then an average is not reported.

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, [] |
| Jun 2006 | -- | -- | -- | -- |
| July 2006 | 4.92 | 12.07 | SW | -- |
| Aug 2006 | 4.38 | 11.18 | SW | -- |
| Jun '06 – Aug '06 | 4.84 | 16.27 | SW | --- |

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 $\pm 2\%$ 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 June, July and August 2006 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 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 [%] | 61.0 |
| Net Data Recovered [%] | 59.4 |

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 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.

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

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 in Figure 2. This plot represents data collected from June 1st, 2006 at 12:00 AM to August 31st, 2006 at 11:50 PM at a height of 10m.
- 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 June 1st, 2006 at 12:00 AM to August 31st, 2006 at 11:50 PM 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 9th, 2006 to August 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. Also, note that the average that is presented for February 2006 does not represent the entire month of data since the tower was erected on 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 June 1st, 2006 at 12:00 AM to August 31st, 2006 at 11:50 PM 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 June 1st, 2006 at 12:00 AM through June 15th, 2006 at 3:50 PM only. This plot presents data at 10 meters. **Note:** **when the logger was replaced, the standard deviation data needed to calculate the turbulence intensity was not programmed for collection. This problem has since been resolved. Thus, the plot below only represents turbulence intensity data for the first part of June 2006, when the previous data logger was still in use.**
- 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 June 1st, 2006 at 12:00 AM to August 31st, 2006 at 11:50 PM at a height of 10m.

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

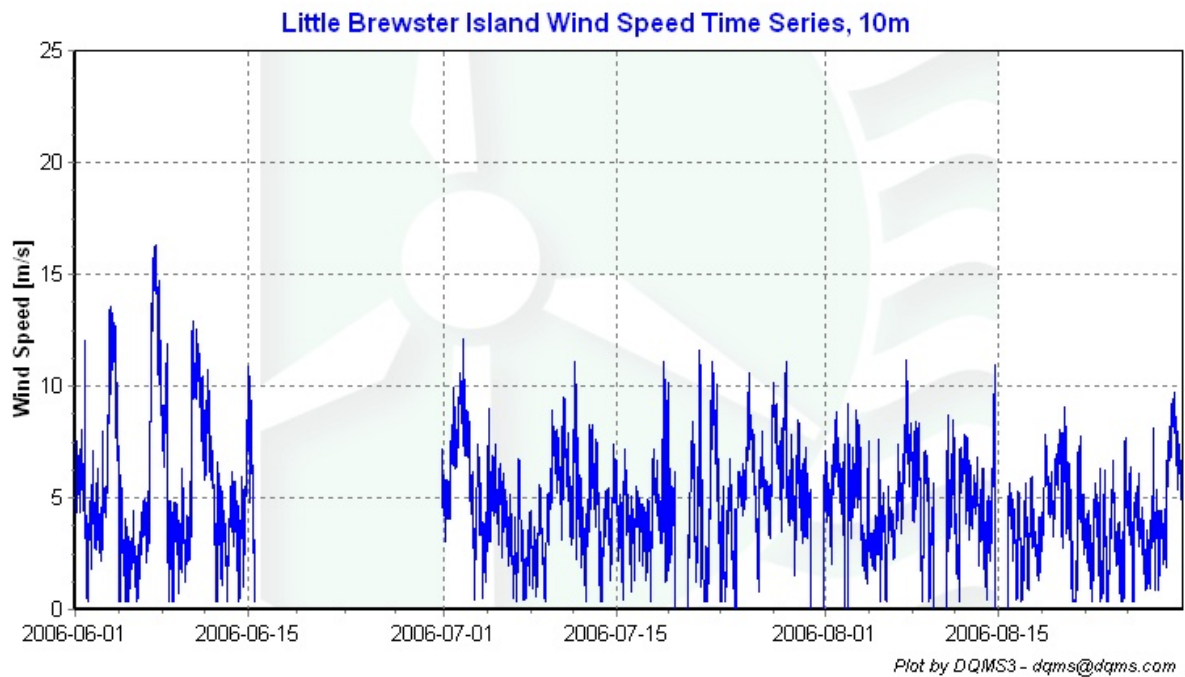


Figure 2 - Little Brewster Island Wind Speed Time Series June 1st 2006 – August 31st 2006

Wind Speed Distributions

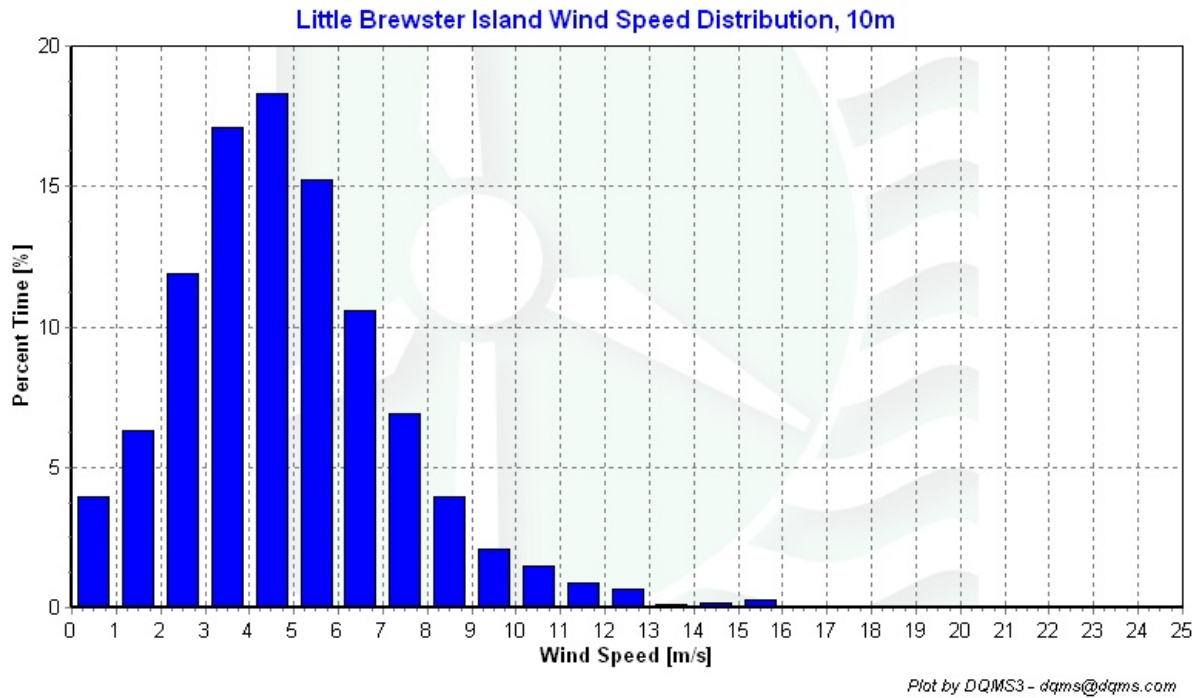


Figure 3 - Little Brewster Island Wind Speed Distribution June 1st 2006 – August 31st 2006

Monthly Average Wind Speeds

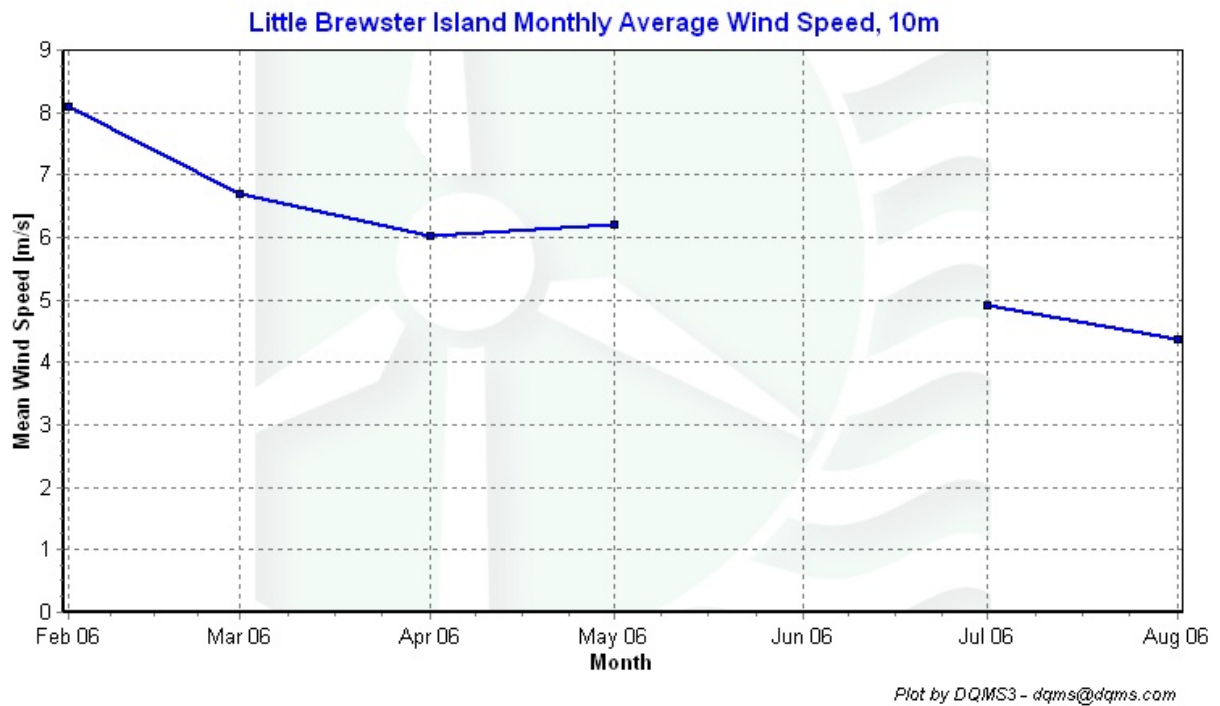


Figure 4 - Little Brewster Island Monthly Average Wind Speed February 2006 – August 2006

Diurnal Average Wind Speeds

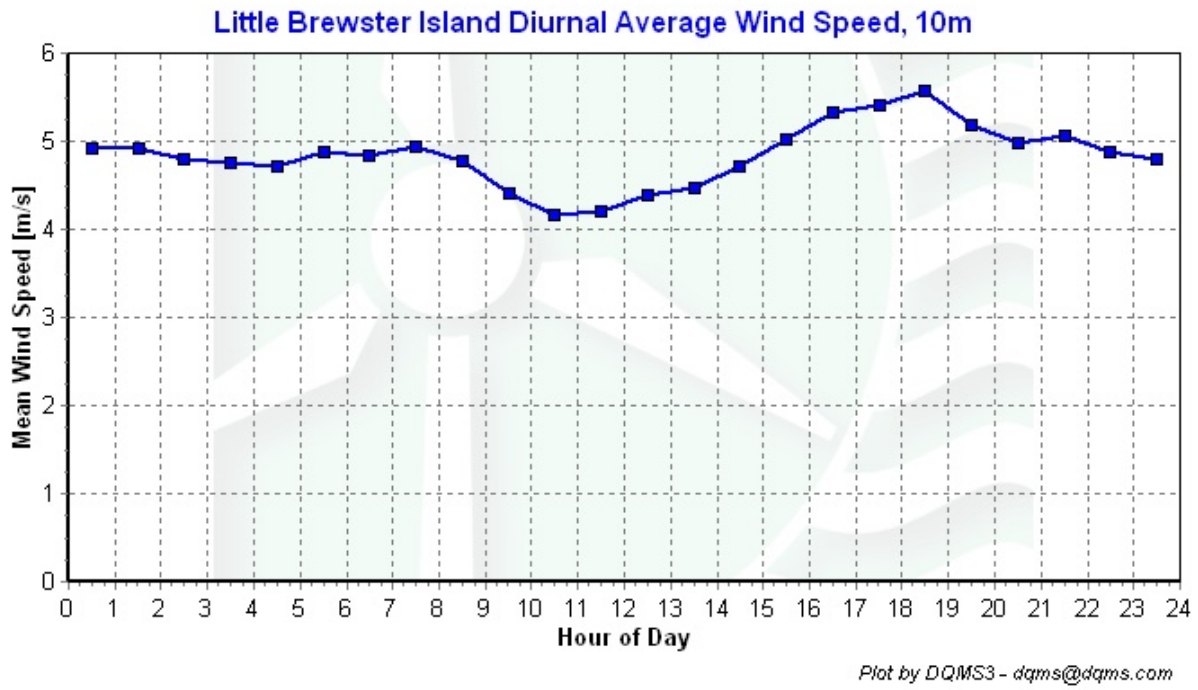


Figure 5 - Little Brewster Island Diurnal Average Wind Speed June 1st 2006 – August 31st 2006

Turbulence Intensities

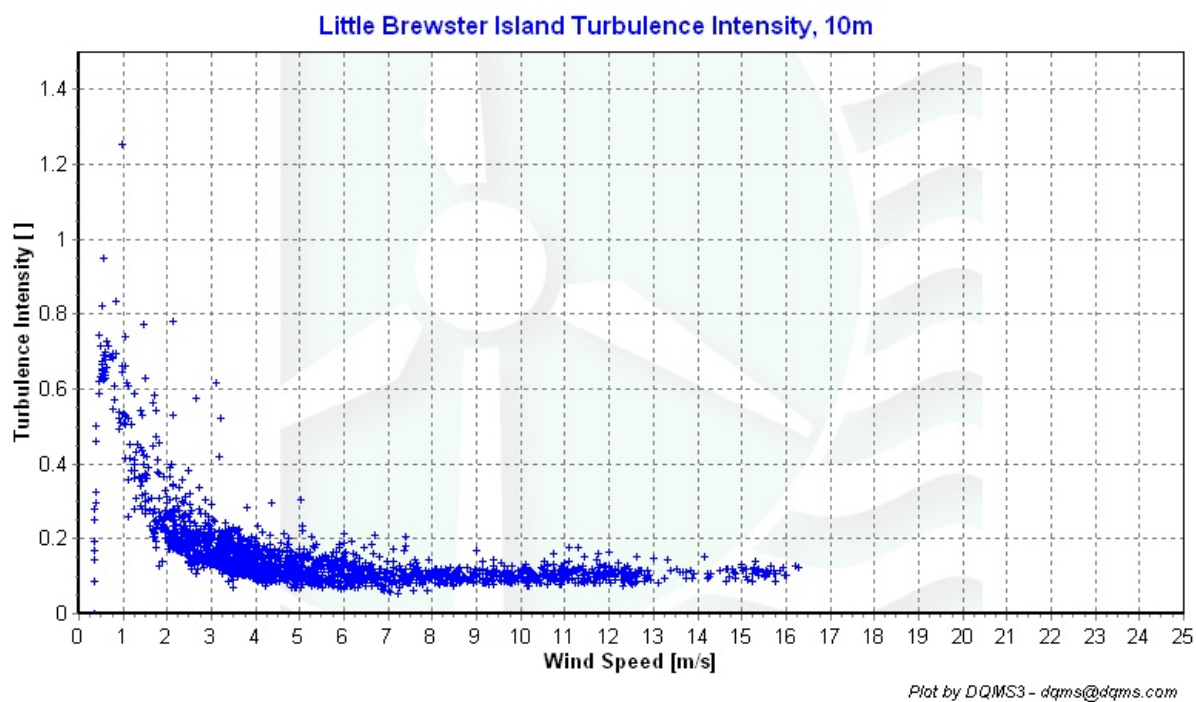
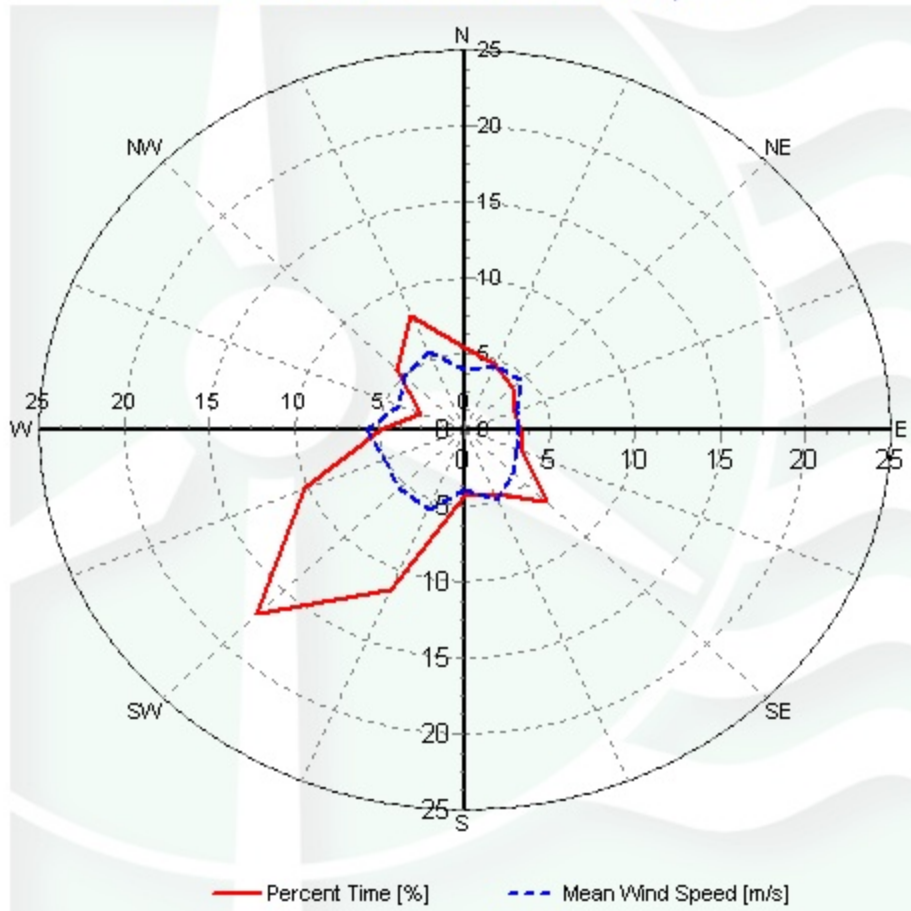


Figure 6 – Little Brewster Island Turbulence Intensity, June 1st 2006– June 15th 2006*

* See Section 6 Turbulence Intensity description for details

Wind Roses

Little Brewster Island Wind Rose, 10m



Plot by DQMS3 - dqms@dqms.com

Figure 7 – Little Brewster Island Wind Rose June 1st 2006 – August 31st 2006

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 | ltmp13aDEGC | | | | | 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 | ltmp13aDEGC | 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 |
|--------------|----------------------|--------------------|------------------|--------------------|----------------|----------------|---------------|
| ltmp13aDEGC | 13248 | 11068 | 83.545 | 0 | 0 | 0 | 83.545 |
| Batt13aVDC | 13248 | 11068 | 83.545 | 0 | 0 | 0 | 83.545 |
| Anem10aMS | 13248 | 11068 | 83.545 | 105 | 0 | 0 | 78.789 |
| AnemSD10aMS | 13248 | 2112 | 15.942 | 0 | 0 | 0 | 15.942 |
| Vane10aDEG | 13248 | 11068 | 83.545 | 106.167 | 0 | 0 | 78.736 |
| VaneSD10aDEG | 13248 | 2112 | 15.942 | 0.167 | 0 | 0 | 15.934 |
| Total | 79488 | 48496 | 61.01 | 211.333 | 0 | 0 | 59.415 |

APPENDIX B - Plot Data

Wind Speed Distribution Data

| Anem10ams | Percent |
|------------------|----------------|
| 0.5 | 3.97 |
| 1.5 | 6.28 |
| 2.5 | 11.91 |
| 3.5 | 17.12 |
| 4.5 | 18.33 |
| 5.5 | 15.21 |
| 6.5 | 10.6 |
| 7.5 | 6.92 |
| 8.5 | 3.93 |
| 9.5 | 2.11 |
| 10.5 | 1.47 |
| 11.5 | 0.89 |
| 12.5 | 0.67 |
| 13.5 | 0.11 |
| 14.5 | 0.17 |
| 15.5 | 0.3 |
| 16.5 | 0.03 |
| 17.5 | 0 |
| 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 | 4.92 |
| Aug | 4.38 |
| Sep | ---- |
| Oct | ----- |
| Nov | ----- |
| Dec | ----- |

Diurnal Average Wind Speed Data

| hr | Anem10aMS |
|-----------|------------------|
| 0.5 | 4.92 |
| 1.5 | 4.92 |
| 2.5 | 4.8 |
| 3.5 | 4.76 |
| 4.5 | 4.71 |
| 5.5 | 4.87 |
| 6.5 | 4.83 |
| 7.5 | 4.93 |
| 8.5 | 4.78 |
| 9.5 | 4.42 |
| 10.5 | 4.16 |
| 11.5 | 4.2 |
| 12.5 | 4.39 |
| 13.5 | 4.47 |
| 14.5 | 4.72 |
| 15.5 | 5.02 |
| 16.5 | 5.33 |
| 17.5 | 5.41 |
| 18.5 | 5.58 |
| 19.5 | 5.18 |
| 20.5 | 4.99 |

| | |
|------|------|
| 21.5 | 5.05 |
| 22.5 | 4.88 |
| 23.5 | 4.8 |

Wind Rose Data

| Direction | Mean Wind Speed [m/s] | Percent Time [%] |
|------------------|------------------------------|-------------------------|
| N | 4 | 5.45 |
| NNE | 4.51 | 4.73 |
| NE | 4.57 | 3.93 |
| ENE | 3.3 | 3.17 |
| E | 3.12 | 3.26 |
| ESE | 3.29 | 3.7 |
| SE | 4.06 | 6.78 |
| SSE | 4.94 | 4.6 |
| S | 3.92 | 4.29 |
| SSW | 5.63 | 11.34 |
| SW | 5.48 | 17.2 |
| WSW | 5.1 | 10.11 |
| W | 5.71 | 4.95 |
| WNW | 4.25 | 2.77 |
| NW | 4.93 | 5.57 |
| NNW | 5.58 | 8.14 |