WIND DATA REPORT

Thompson Island

March 1, 2005 – May 31, 2005

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Christopher N. Elkinton
Anthony L. Rogers
Anthony F. Ellis

June 27, 2005

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), 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.

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.

Wind monitoring equipment was first installed at Thompson Island in 1998. Due to planned construction by the Outward Bound School on the island, the monitoring tower was relocated in November 2001 from a central, inland site, to the current site, which is closer to the western shoreline, 4 m (13 ft) above sea level. Anemometers and wind direction vanes are installed at 25 and 40 m (82 and 131 ft) above the tower base. A temperature sensor and a solar sensor (pyranometer) are installed near the base.

This report summarizes the wind data collected during the spring of 2005, between March 2005 and May 2005. The mean recorded wind speed was 6.15 m/s (13.8 mph) at 40 m and the prevailing wind direction was from the west-southwest. The average wind shear exponent of 0.14 is the same value reported in the spring of 2004 report. The average turbulence intensity at 40 m was 0.15, which is typical for this site.

The gross data recovery percentage (the actual percentage of expected data received) was 99.98% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 98.99%. The vast majority of the invalid data were caused by icing in March.

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:

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

* 1 m/s = 2.25 mph.

SECTION 1 - Station Location

Thompson Island is located in Boston Harbor, approx 2 ½ miles south of Logan Airport. It is home to the Outward Bound School of Boston. The 40 m (131 ft) monitoring tower is located at 42^0-18'- 54.1" North, 071^0- 00'-44.7" West (see Figure 1). The location is near the western shore of the island, located on a small bluff, 4 m (13 ft) above sea level.

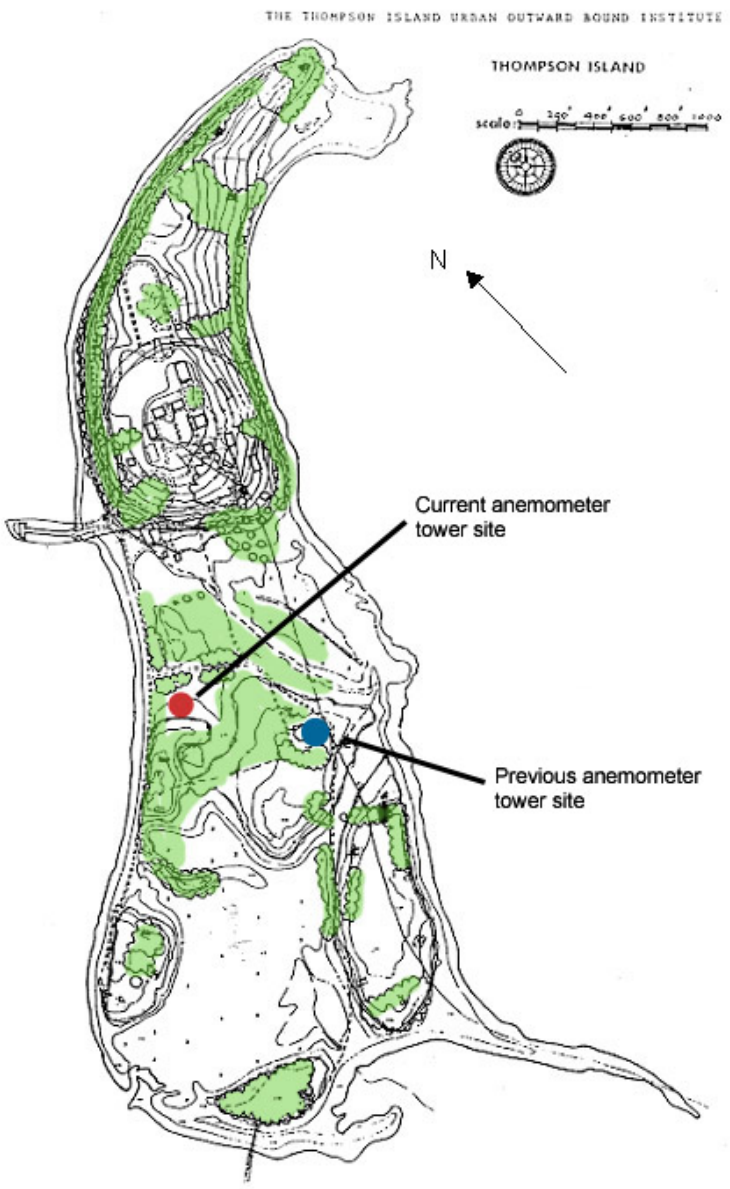

Figure 1 - Site location on Thompson Island

SECTION 2 - Instrumentation and Equipment

The 40 m (131 ft) monitoring tower and associated equipment are supplied by NRG systems, with the exceptions of custom made anemometer booms, temperature sensor, and the FAA-approved L-810 warning light. The wind speed and direction were measured at both 25 and 40 m (82 and 131 ft) height. The monitoring equipment (Figure 2) consists of the following items:

- Model 9300 Cellogger®, serial # 0568
- Electrical enclosure box with 5 watt PV panel
- Yagi directional antenna and mount
- NRG 40m tower, 4.5" diameter model
- 4 – #40 Anemometers, standard calibration (Slope 0.765, Offset 0.350)
- 2 - #200P Wind direction vanes (Slope 1.0, Offset 0.0)
- 1 – Li-Cor Solar sensor (Slope 70.9, Offset 0.0)
- 1- Custom temp sensor (Slope 0.1356, Offset -17.78)
- 2 – Sensor booms, 54" length at 25 m
- 2 - Sensor booms, 44" length at 40 m
- 2 – 'Z' masts, for vane mount
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 - Monitoring Station/Data Equipment at Thompson Island

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 quality assurance (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:

- There were 2 isolated instances of single missing data. These are most likely due to interruptions in the measurements during the data transmission process.
- The majority of the invalid data were flagged by the icing filter.
- An upgrade of the communication software was made at the RERL office on 4/7/05, and the quarterly site visit was performed on 5/31/05. The FAA light was found not to be working during the site visit. This problem was corrected in early June.

Data Statistics Summary

Date	Anemometer 40m			Anemometer 25m				Vane 40m	Vane 25m
	Mean [m/s]	Max [m/s]	Turb. Int. [ ]	Mean [m/s]	Max [m/s]	Turb. Int. [ ]	Shear (α) [ ]	Prev. Dir	Prev. Dir
Mar 2005	6.42	17.9	0.15	6.22	18.09	0.16	0.08	W	W
Apr 2005	5.85	16.75	0.15	5.48	16.01	0.17	0.18	E	E
May 2005	6.18	21.96	0.16	5.89	20.94	0.17	0.15	NNW	NNW
Mar 2005 – May 2005	**6.15**	**21.96**	**0.15**	**5.87**	**20.94**	**0.17**	**0.14**	**WSW**	**WSW**

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.

SECTION 4 - 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 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 [%]	99.98
Net Data Recovered [%]	98.99

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 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 5 - 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. The wind speed time series is shown in Figure 3.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. This plot shows a peak centered between 5 and 6 m/s (11.3 and 13.5 mph). The wind speed distribution is shown in Figure 4.

- 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 does not show a dominant prevailing direction, although the largest percentage of the wind came from the west-southwest. The wind rose is shown in Figure 5.

SECTION 6 - Graphs

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

Wind Speed Time Series

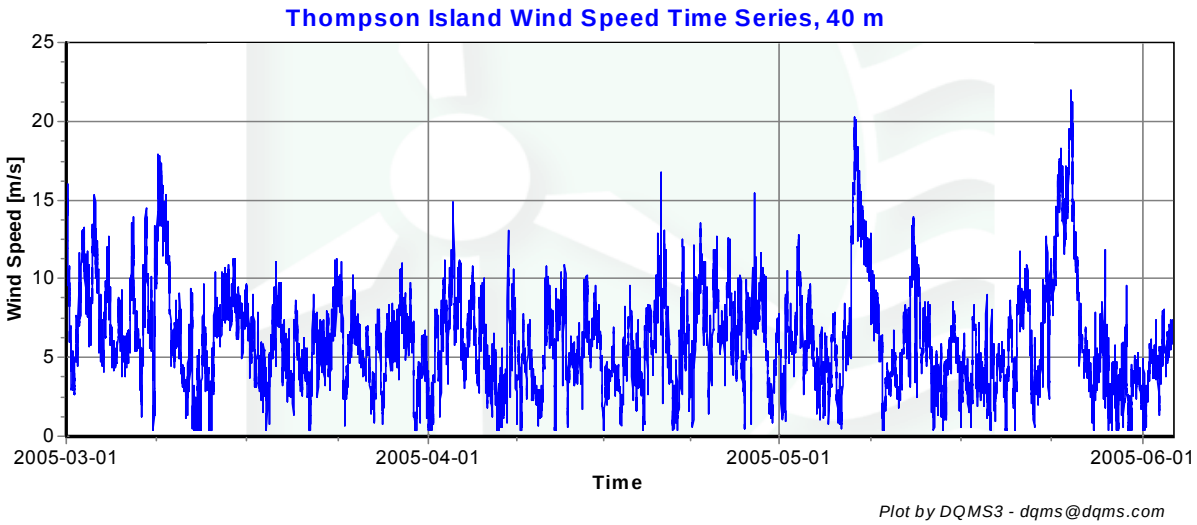

Figure 3 - Wind Speed Time Series, March 2005 – May 2005

Wind Speed Distribution

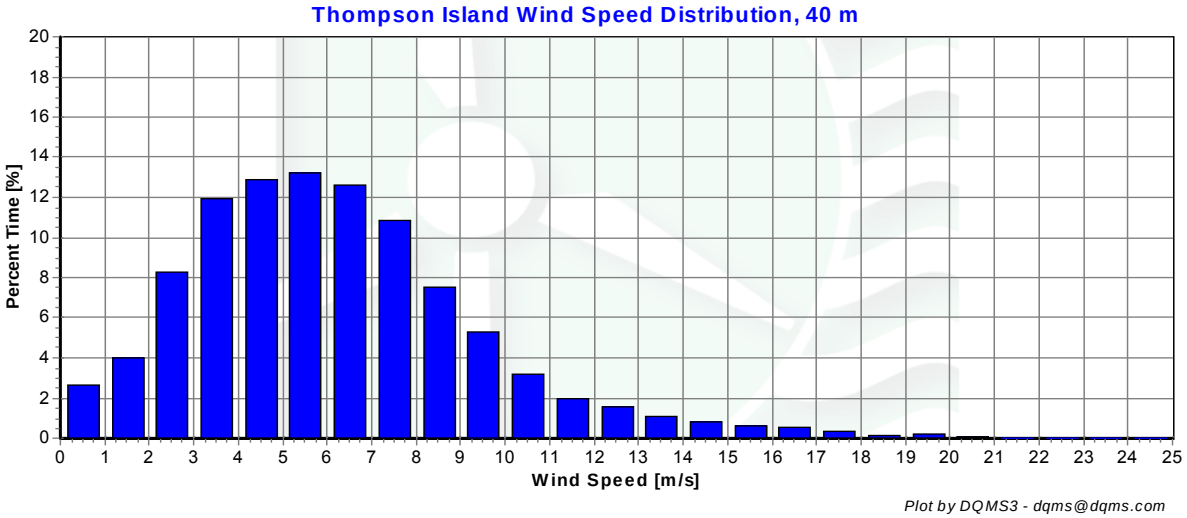

Figure 4 - Wind Speed Distribution, March 2005 – May 2005

Wind Roses

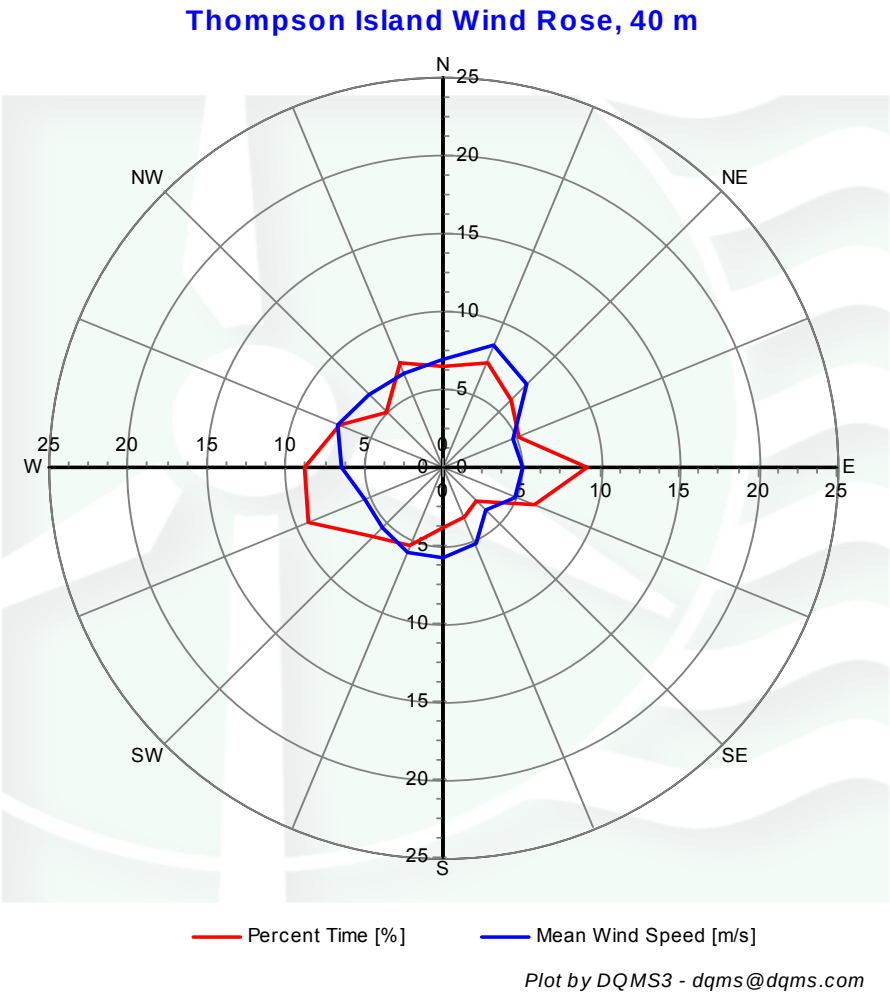

Figure 5 - Wind Rose, March 2005 – May 2005

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				
2	Itmp2aDEGC						MinMax	-30	60	0	0
3	Batt2aVDC						MinMax	10.5	15	0	0
4	Etmp3aDEGC						MinMax	-30	60		
5	EtmpSD3aDEGC						MinMax	-30	60		
10	Anem40aMS						MinMax	0	90	0	0
11	Anem40bMS						MinMax	0	90	0	0
12	Anem25aMS						MinMax	0	90		
13	Anem25bMS						MinMax	0	90		
14	Anem40yMS						MinMax	0	90		
15	Anem25yMS						MinMax	0	90		
20	AnemSD40aMS						MinMax	0	4	0	0
21	AnemSD40bMS						MinMax	0	4	0	0
22	AnemSD25aMS						MinMax	0	4		
23	AnemSD25bMS						MinMax	0	4		
24	AnemSD40yMS						MinMax	0	4		
25	AnemSD25yMS						MinMax	0	4		
30	Vane40aDEG						MinMax	0	359.9		
31	Vane25aDEG						MinMax	0	359.9		
40	Pyro3aWMS						MinMax	0	1500		
41	PyroSD3aWMS						MinMax	0	1500		
50	Turb40zNONE						MinMax	0	2		
51	Turb25zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	-100	100		
200	VaneSD40aDEG	Anem40yMS					MinMaxT	0	100	100	10
201	VaneSD25aDEG	Anem25yMS					MinMaxT	0	100	100	10
300	Anem40aMS	AnemSD40aMS	Vane40aDEG	VaneSD40aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
301	Anem40bMS	AnemSD40bMS	Vane40aDEG	VaneSD40aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
302	Anem25aMS	AnemSD25aMS	Vane25aDEG	VaneSD25aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
303	Anem25bMS	AnemSD25bMS	Vane25aDEG	VaneSD25aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
400	Anem40aMS	Anem40bMS					CompareSensors	1	0.25	3	0
401	Anem25aMS	Anem25bMS					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
Itmp2aDEGC	13248	13245	99.977	0	0	0	99.977
Batt2aVDC	13248	13245	99.977	6	0	0	99.706
Anem40aMS	13248	13245	99.977	0.167	27.833	0.167	98.702
AnemSD40aMS	13248	13245	99.977	0.167	27.833	0.167	98.702
Anem40bMS	13248	13245	99.977	0.167	29	0	98.656
AnemSD40bMS	13248	13245	99.977	0.167	29	0	98.656
Anem25aMS	13248	13245	99.977	0	32.333	6	98.241
AnemSD25aMS	13248	13245	99.977	0	32.333	6	98.241
Anem25bMS	13248	13245	99.977	0	33.5	1.167	98.407
AnemSD25bMS	13248	13245	99.977	0	33.5	1.167	98.407
Vane25aDEG	13248	13245	99.977	0.5	33.5	0	98.438
VaneSD25aDEG	13248	13245	99.977	0.5	33.5	0	98.438
Vane40aDEG	13248	13245	99.977	0.667	29	0	98.634
VaneSD40aDEG	13248	13245	99.977	0.667	29	0	98.634
Etmp3aDEGC	13248	13245	99.977	0.167	0	0	99.97
EtmpSD3aDEGC	13248	13245	99.977	0	0	0	99.977
Pyro3aWMS	13248	13245	99.977	0	0	0	99.977
PyroSD3aWMS	13248	13245	99.977	0	0	0	99.977
Total	**238464**	**238410**	**99.977**	**9.167**	**370.333**	**14.667**	**98.986**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	2.63
1.5	4.02
2.5	8.31
3.5	11.94
4.5	12.9
5.5	13.25
6.5	12.62
7.5	10.84
8.5	7.52
9.5	5.32
10.5	3.17
11.5	1.99
12.5	1.57
13.5	1.12
14.5	0.85
15.5	0.6
16.5	0.52
17.5	0.35
18.5	0.17
19.5	0.2
20.5	0.09
21.5	0.03
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	6.44	6.93
NNE	7.28	8.51
NE	6.17	7.53
ENE	5.18	4.83
E	9.13	5.13
ESE	6.32	4.9
SE	3.05	3.85
SSE	3.51	5.35
S	3.81	5.81
SSW	5.43	5.87
SW	6.3	5.42
WSW	9.27	5.39
W	8.74	6.48
WNW	7.11	7.17
NW	5.02	6.64
NNW	7.25	6.53

Table 2 - Wind Rose, Time Percentage and Mean Wind Speed by Direction