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# Lake Michigan Wind Assessment Project Data Summary and Analysis: October 2013

Lake Michigan Offshore Wind Assessment Project

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## **Lake Michigan Wind Assessment Project**

### **Data Summary and Analysis**

**October 2013**

**Part I – 2013 Data**

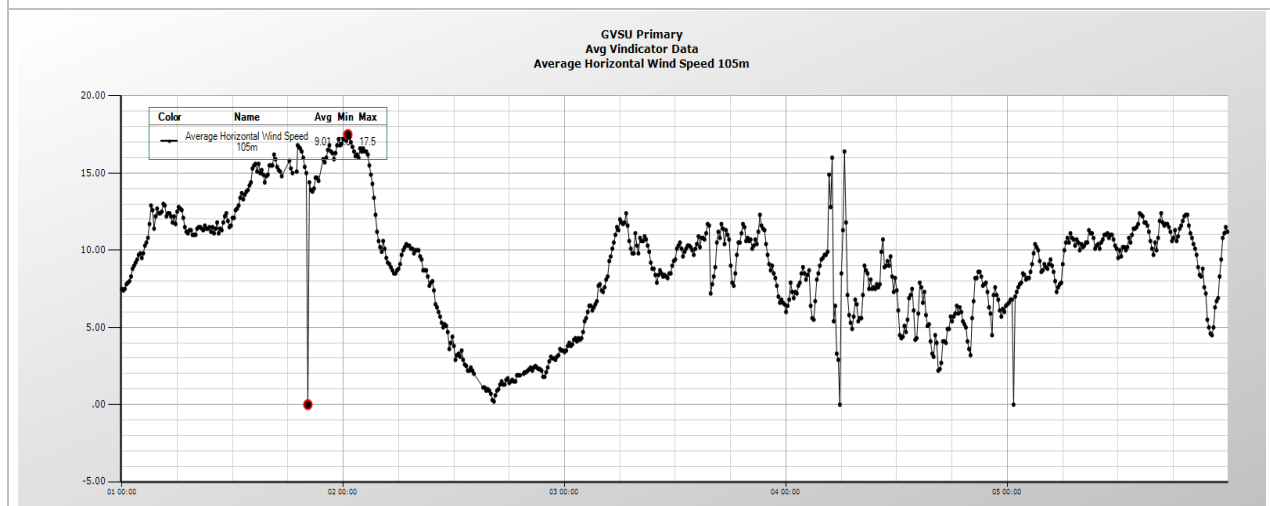
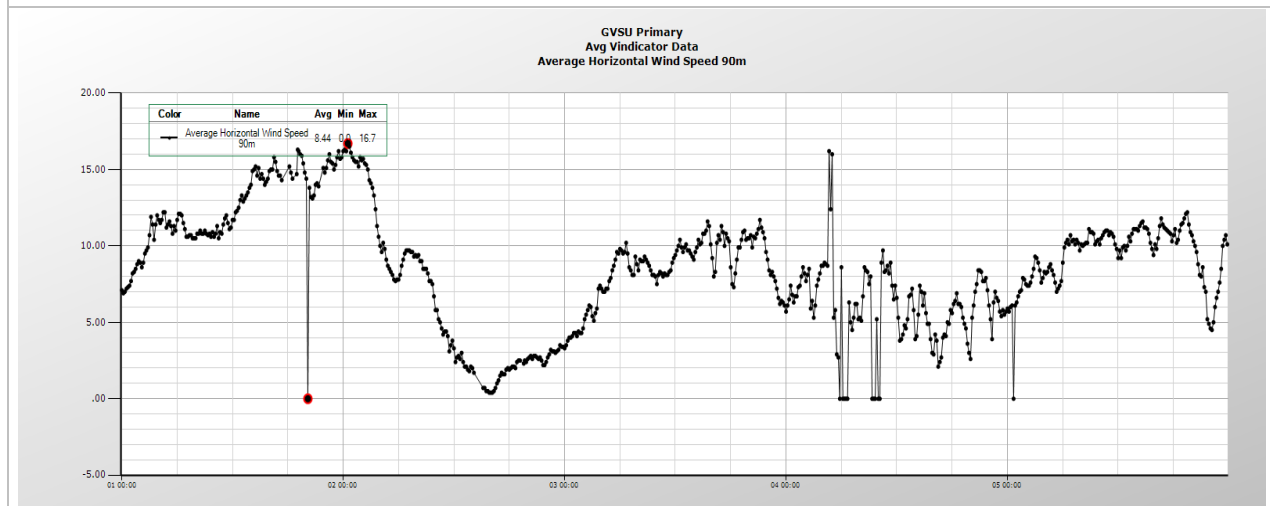
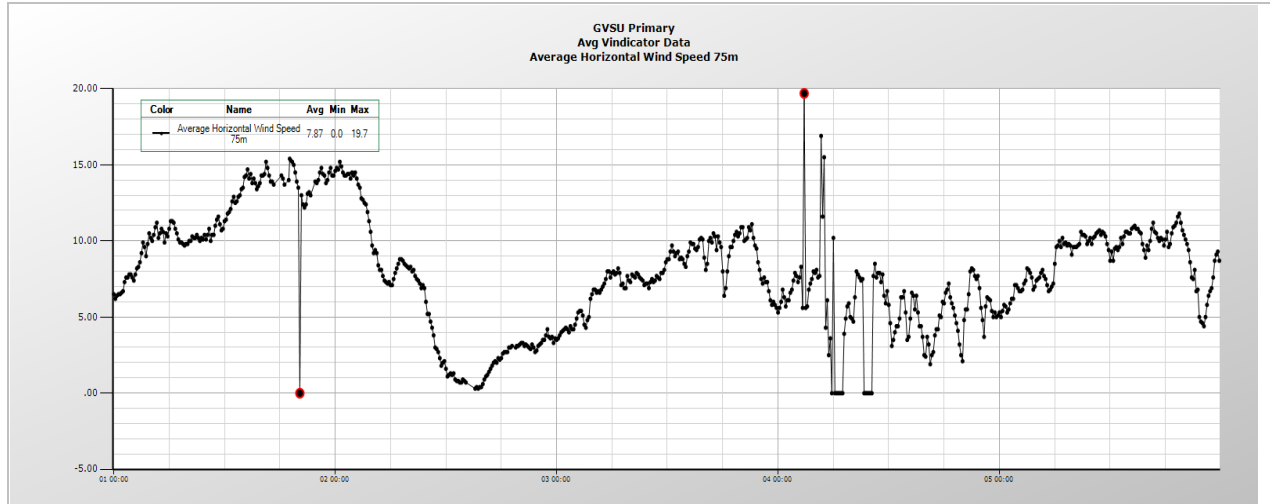
This report summarizes the data collected by the Laser Wind Sensor (LWS) #8 with collection information as follows.

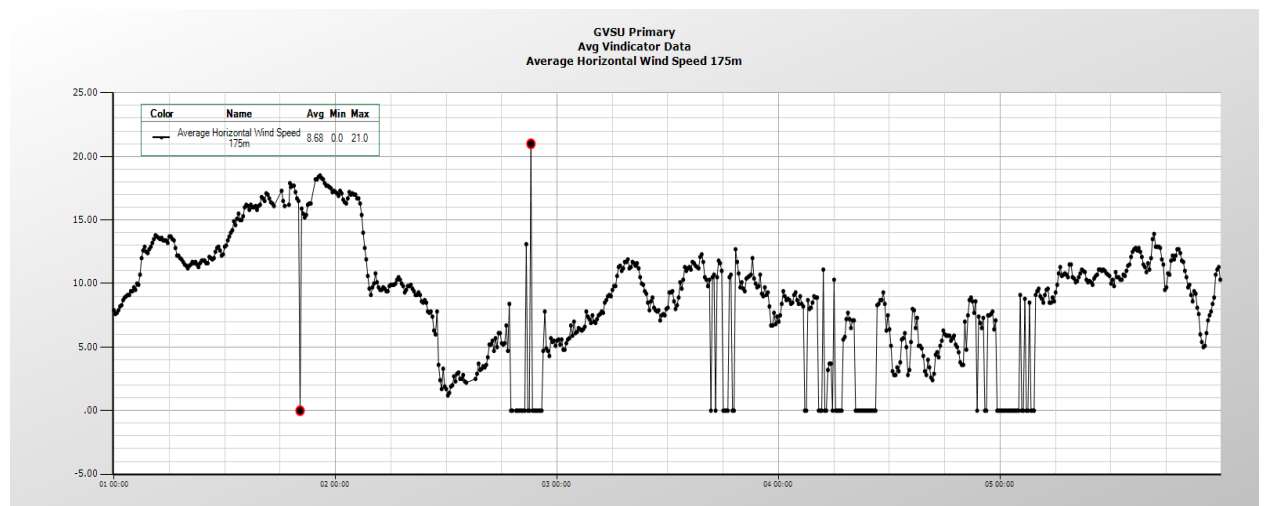
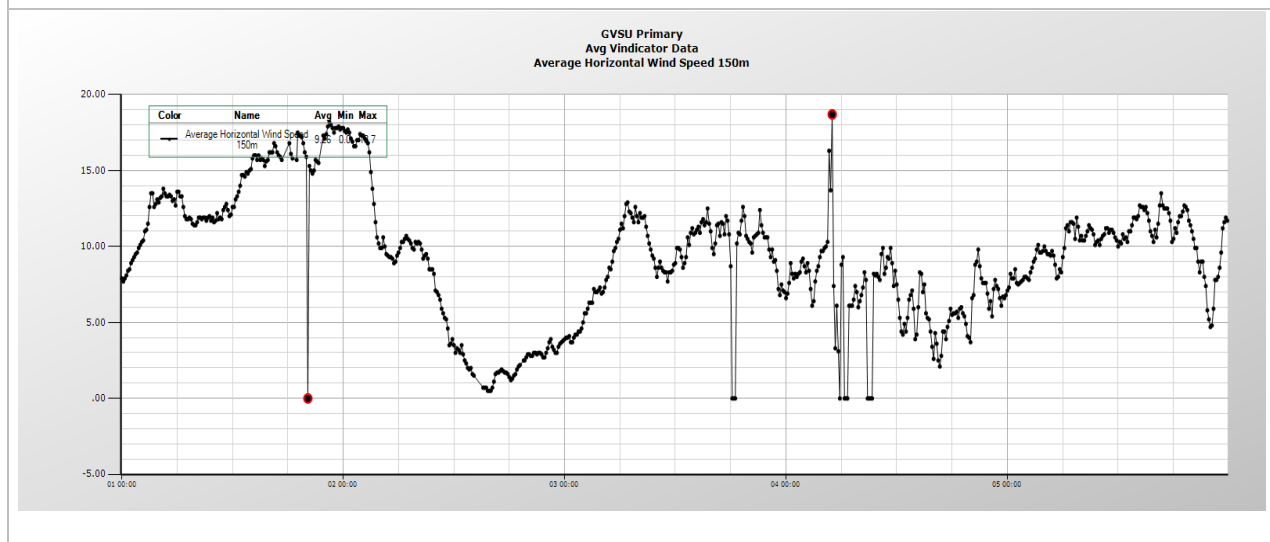
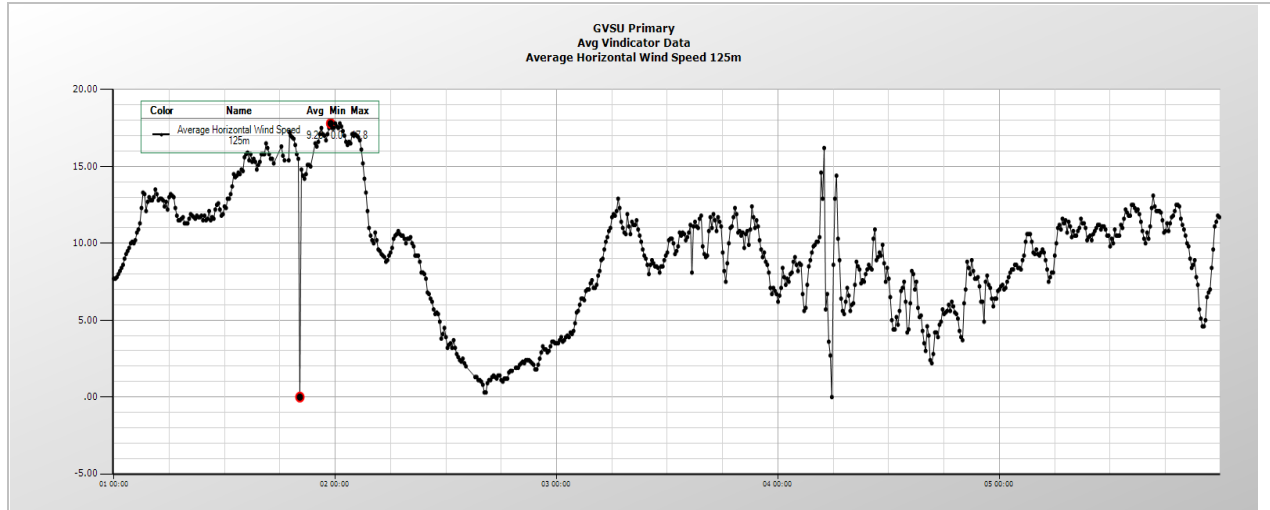
<b>Location:</b>	Lake Michigan – Near Muskegon (4316.542N, 8630.347W)
<b>Date:</b>	October 1 through October 31, 2013 (UTC)
<b>Range Gates 1-6:</b>	75, 90, 105, 125, 150, 175 meters
<b>Cup Anemometer:</b>	3 meters mounted on the buoy
<b>Observations:</b>	10-minute averages
<b>Number of Observations:</b>	31 days at 6 observations per hour = 4464 observations
<b>Missing Observations:</b>	41: 10/1, 1730 to 1800 & 1840 to 1900 & 2130 to 2140; 10/2, 1420 to 1500 & 1920 to 1930; 10/29, 1820 to 2010; 10/31, 1430 to 1630
<b>Good Observations:</b>	4423 (99.1%)

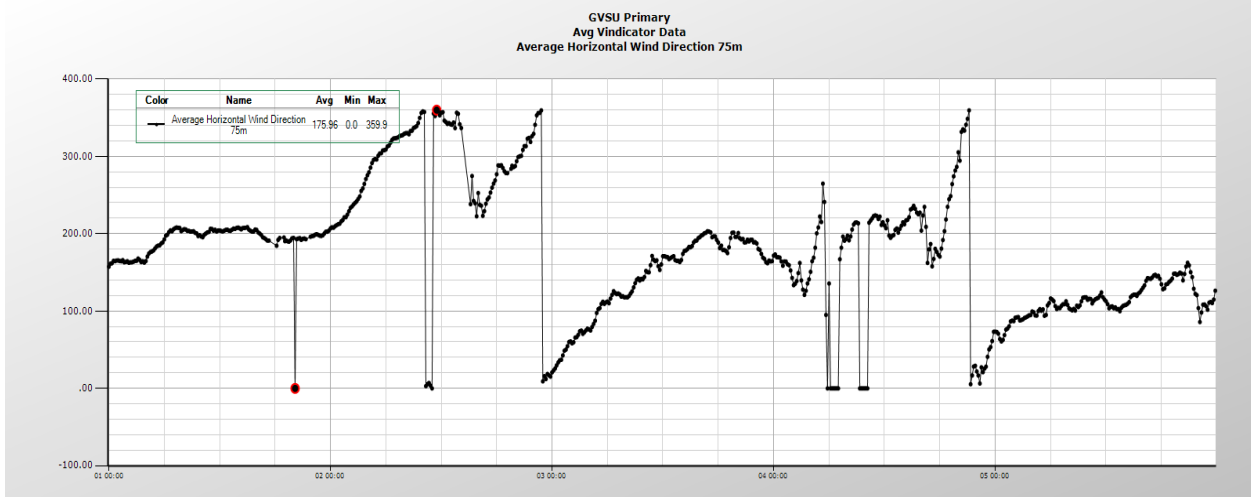
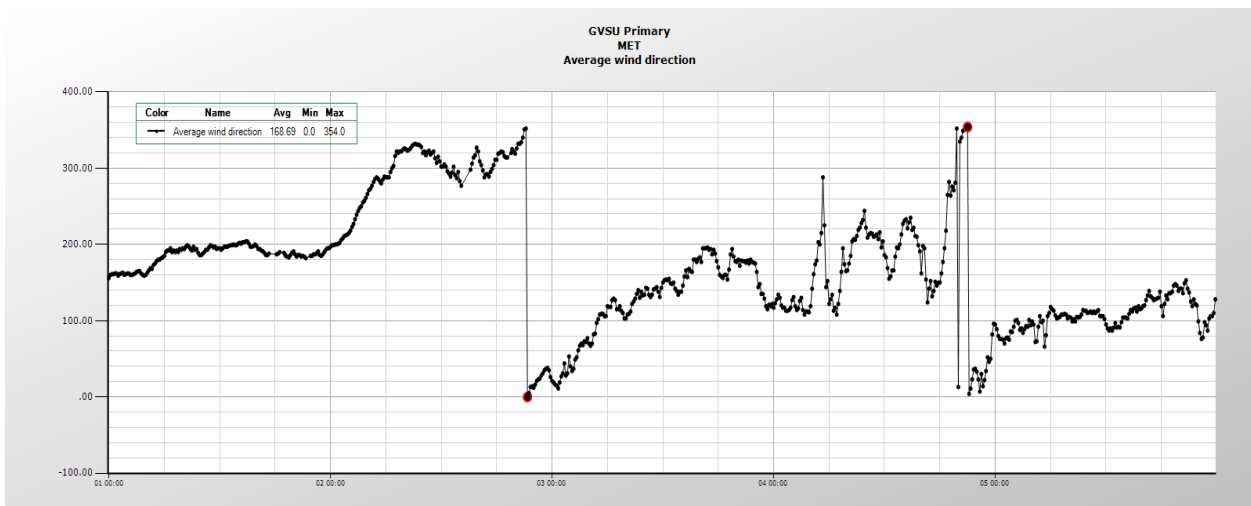
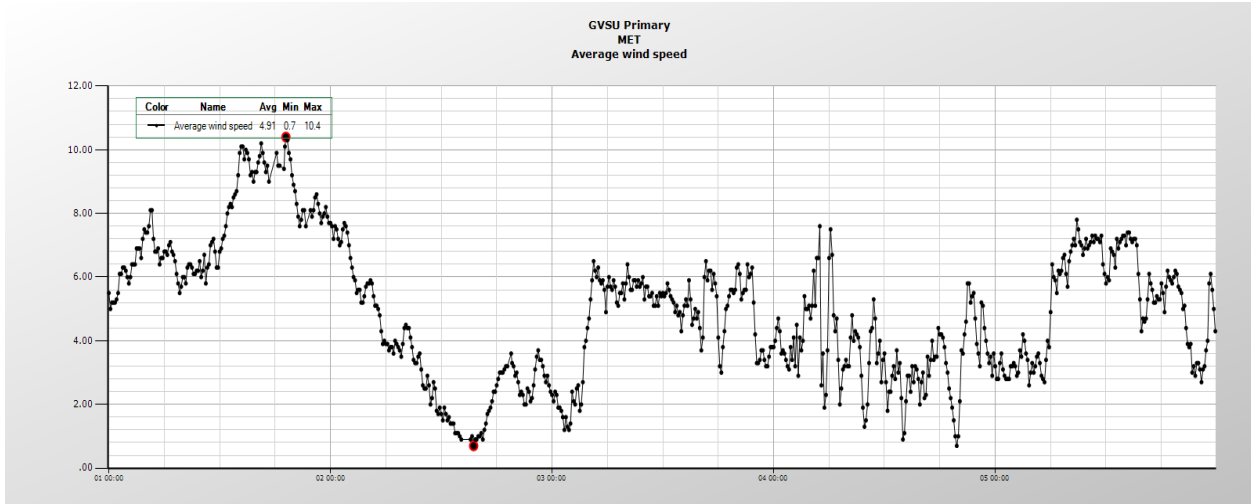
**Notes:**

- o Range Gate 6 (175 meters) is a test range gate to observe the performance of the sensor at the extreme operating height limit for this configuration. Thus, performance degradation was expected.
- o All high resolution 1 second data for all wind speeds is stored onboard the buoy and can be used for further detailed post processing as required.

Graphs for wind speed for all ranges as well as the cup anemometer follow. Graphs of the horizontal wind direction at the cup anemometer and range gate 1 are included as well.







Summary statistics for wind speed by range gate and for the cup anemometer are shown in the following tables. Good observations are 10-minute averages consisting of at least 300 one-second observations. There were 4464 observations of 10-minute averages in total.

**Table 1: Horizontal Wind Speed (meters per second) Statistics by Range Gate**

<b>Statistic</b>	<b>N001S00 7P006 Cup Anemom eter</b>	<b>N001S00 9P083 75m</b>	<b>N001S00 9P084 90m</b>	<b>N001S00 9P085 105m</b>	<b>N001S00 9P086 125m</b>	<b>N001S00 9P087 150m</b>	<b>N001S00 9P088 175m</b>
Good Obs.	4419	2858	3422	4077	4262	3722	2639
% of Total (4464)	99.0	64.0	76.7	91.3	95.5	83.4	59.1
Average	7.0	8.1	8.5	8.8	9.0	9.2	9.6
Std. Dev.	2.8	3.4	3.6	3.5	3.5	3.6	3.5
Coeff. of Variation	0.40	0.42	0.42	0.40	0.39	0.39	0.36
Minimum	0.4	0.3	0.4	0.2	0.3	0.5	1.0
Quartile 1	5.0	5.9	6.1	6.2	6.5	6.7	7.4
Median	6.9	7.8	8.3	8.6	8.8	9.0	9.2
Quartile 3	8.8	9.9	10.4	10.8	11.1	11.2	11.3
Maximum	19.4	24.9	31.6	25.9	26.1	33.1	26
99% CI- Lower Bound	6.9	7.9	8.3	8.7	8.9	9.0	9.4
99% CI Upper Bound	7.1	8.3	8.7	8.9	9.1	9.4	9.8

**Table 2: Wind Speed Frequencies by Range Gate – Percent of Time in Each Wind Speed Range**

<b>Wind Speed Range (m/s)</b>	<b>N001S00 7P006 Cup Anemom eter</b>	<b>N001S00 9P083 75m</b>	<b>N001S00 9P084 90m</b>	<b>N001S00 9P085 105m</b>	<b>N001S00 9P086 125m</b>	<b>N001S00 9P087 150m</b>	<b>N001S00 9P088 175m</b>
0-4	14.3	7.1	6.6	5.7	5.3	4.9	2.5
4-8	49.2	45.6	38.7	35.5	33.5	31.7	28.3
8-12	33.2	37.5	42.6	44.9	45.6	46.3	49.9
12-16	2.1	7.2	9.2	11	12.8	13.4	13.8
16-20	1.1	1.1	1.3	1.6	1.6	2.2	3.8
20-24	0	1.4	1.2	1	0.9	1.1	1.2
24-28	0	0.1	0.3	0.3	0.3	0.4	0.5

28-32	0	0	0.1	0	0	0	0
>32	0	0	0	0	0	0	0

**Table 3: Wind Direction Frequencies by Range Gate – Percent of Time in Each Wind Direction Range**

Wind Direction Range (Degrees)	N001S009P089 Average Horizontal Wind Direction RG#1	N001S009P083 Average Horizontal Wind Speed RG#1
0 – 45 (NNE)	2.8	5.93
45 – 90 (NE)	4.6	5.55
90 – 135 (SE)	16.2	7.38
135 – 180 (SSE)	25.8	7.54
180 – 225 (SSW)	17.8	9.28
225 – 270 (SW)	18.3	9.53
270 – 315 (NW)	10.8	8.27
315 – 360 (NNW)	3.6	7.12

Table 4 contains the summary statistics shown in table 1 for the subset of times when every range gate had a good observation that is there were 300 one-second observations for each range gate.

**Table 4: Horizontal Wind Speed (meters per second) Statistics by Range Gate – All Range Gates with Good Observations (2569/4464= 57.5%)**

Statistic	N001S00 9P083 75m	N001S00 9P084 90m	N001S00 9P085 105m	N001S00 9P086 125m	N001S00 9P087 150m	N001S00 9P088 175m
Average	8.2	8.8	9.3	9.5	9.6	9.6
Std. Dev.	3.4	3.7	3.8	3.8	3.8	3.5
Coeff. of Variation	0.41	0.42	0.41	0.40	0.40	0.36
Minimum	0.3	0.4	0.2	0.3	0.5	1.0
Quartile 1	6.0	6.4	6.7	7.0	7.1	7.4
Median	7.9	8.6	9.1	9.4	9.5	9.2
Quartile 3	9.9	10.7	11.2	11.5	11.7	11.3
Maximum	24.9	25.5	25.9	26.1	26.1	26
99% CI- Lower Bound	8.0	8.6	9.1	9.3	9.4	9.4
99% CI	8.4	9.0	9.5	9.7	9.8	9.8



Upper Bound						
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Table 5 shows the 99% confidence intervals for the mean difference in average wind speed between adjacent range gates for example between the range gates centered at 175 meters and 150 meters. The difference is higher range gate – lower range gate. The confidence intervals are computed using the paired t method. An observation time is included in the difference if the number of observations for each of the two range gates was at least 300.

**Table 5: Horizontal Wind Speed – Average Difference by Pairs of Adjacent Range Gates**

<b>Statistic</b>	<b>175m – 150m</b>	<b>150m- 125m</b>	<b>125m- 105m</b>	<b>105m- 90m</b>	<b>90m- 75m</b>
Good Obs.	2636	3715	4070	3405	2851
% of Total (4320)	59.1	83.2	91.2	76.3	63.9
Average	-0.004	0.078	0.283	0.472	0.603
99% CI- Lower Bound	-0.04	0.06	0.27	0.45	0.58
99% CI Upper Bound	0.04	0.09	0.30	0.49	0.63

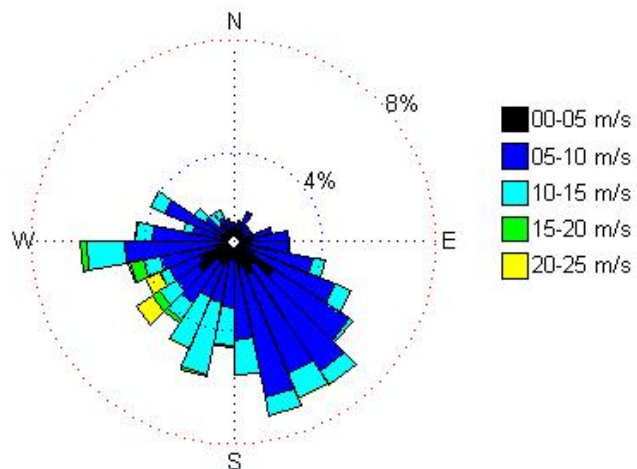
Table 6 shows the energy generated for each range gate both when all data are considered as in Table 1 and the subset of times when every range gate had a good observation as in Table 4. The amount of energy generated depends on the turbine employed in this case the Gamesa Elioca G58 850kW. The energy estimate was computed assuming that the turbine will always face the wind.

**Table 6: Energy (kWh/time unit) by Range Gate**

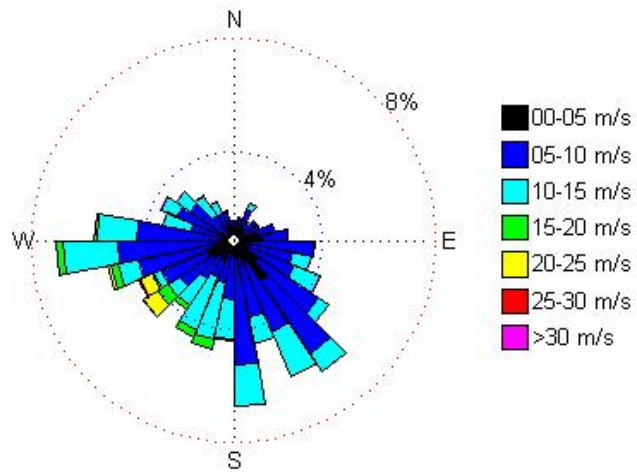
	<b>All data</b>	<b>E v e r y R a n g e G a t e w i t h G</b>
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			o o d O b s .	
<b>Range Gate</b>	<b>Average Power (MW)</b>	<b>Average Daily Energy (MWh)</b>	<b>Average Power (MW)</b>	<b>Average Daily Energy (MWh)</b>
<b>1</b>	0.389	9.35	0.397	7.93
<b>2</b>	0.428	10.27	0.380	9.11
<b>3</b>	0.455	10.93	0.343	9.91
<b>4</b>	0.474	11.39	0.413	10.32
<b>5</b>	0.485	11.64	0.430	10.59
<b>6</b>	0.517	12.40	0.441	10.75
<b>Buoy Cup</b>	0.293	7.03	0.293	7.03

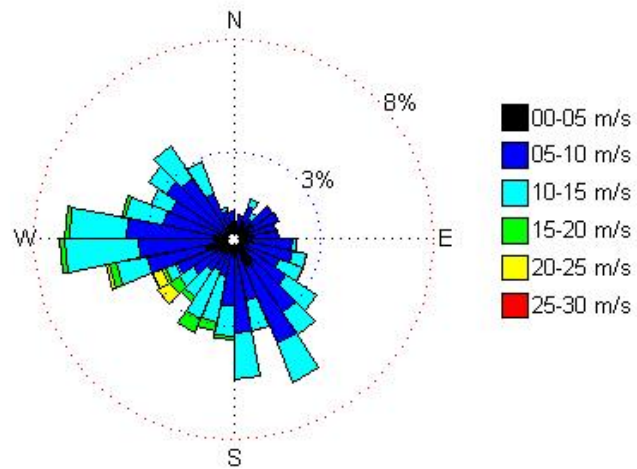
The wind rose graphs show the wind speed by direction as well as the percent of time the wind was blowing in each direction.



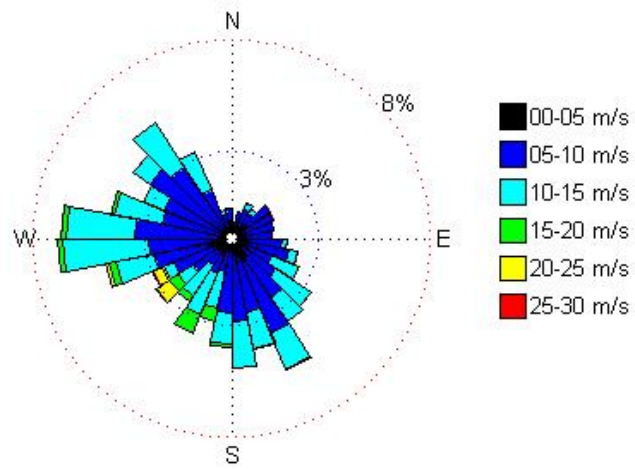
**Range Gate 1: Average Wind Speed and Percent Time by Direction**



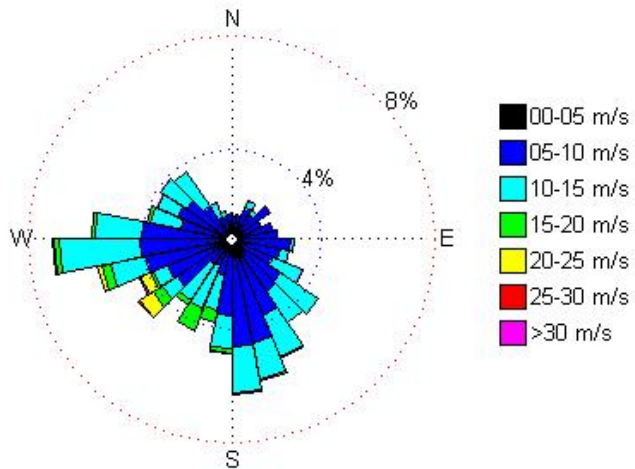
**Range Gate 2: Average Wind Speed and Percent Time by Direction**



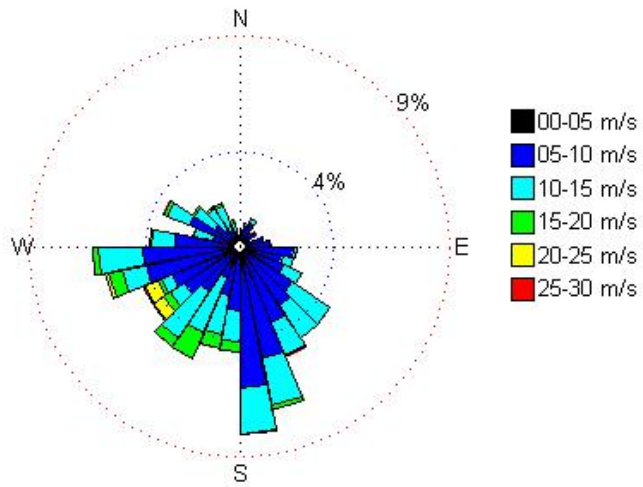
**Range Gate 3: Average Wind Speed and Percent Time by Direction**



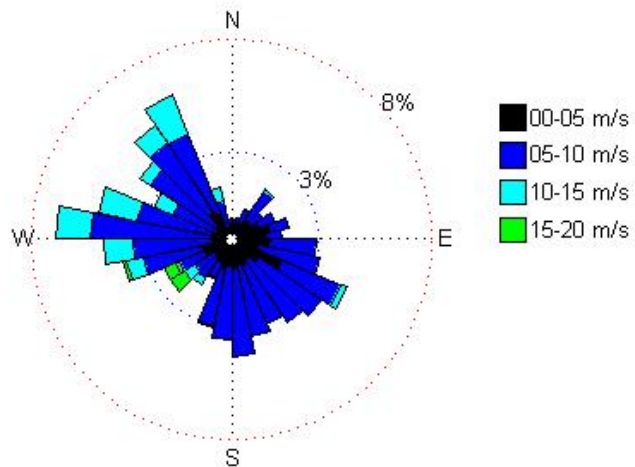
**Range Gate 4: Average Wind Speed and Percent Time by Direction**



**Range Gate 5: Average Wind Speed and Percent Time by Direction**



**Range Gate 6: Average Wind Speed and Percent Time by Direction**



**Buoy Cup Anemometer: Average Wind Speed and Percent Time by Direction**

## Notes:

1. The average wind speed at 75m and above is notably more than the average wind speed on the buoy deck. This conclusion is supported by the statistics in table 1, particularly the average and the median. Further, the data in table 2 show that over 63% of the time the wind speed on the buoy deck is 8m/s or less. For heights 75m and above, this is true about 30%-52% of the time.
2. The average wind speed increases as the range gate height increases through 150m as shown in table 4. The average wind speeds for 150m and 175m are the same. Each difference between adjacent in range gate height pairs is statistically significant ( $\alpha = 0.01$ ) except for 175m and 150m as shown in table 5. This is consistent with the average daily energy values shown in table 6.
3. The highest frequency of wind direction as well as wind speed is SSE through SW, about 61% of the time as shown in table 3. In addition, the wind is from the NNW or NNE about 6% of the time.

**Part II – Comparison of 2013 Data and 2012 Data**

In this section, the data collected from October 1 through October 31, 2012 at the mid-lake plateau (4320.510N, 8707.206W) are compared to data from the same days collected in 2013 as described above. The results are shown in table 7. Homogeneity of variance is assumed. Note that two variables are confounded regarding the comparison:

- Location (mid-lake plateau versus near Muskegon)
- Year (2012 versus 2013)

**Table 7: Comparison of 2012 and 2013 Data**

<b>Statistic</b>	<b>N001S00 7P006 Cup Anemometer</b>	<b>N001S00 9P083 75m</b>	<b>N001S00 9P084 90m</b>	<b>N001S00 9P085 105m</b>	<b>N001S00 9P086 125m</b>	<b>N001S00 9P087 150m</b>	<b>N001S00 9P088 175m</b>
2012							
Good Obs.	4459	3835	4097	4084	3623	2498	1629
% of Total (4464)	99.9	85.9	91.8	91.5	81.2	56.0	36.5
Average	8.3	10.7	11.1	11.2	11	11.5	11.5
2013							
Good Obs.	4419	2858	3422	4077	4262	3722	2639
% of Total (4464)	99.0	64.0	76.7	91.3	95.5	83.4	59.1
Average	7.0	8.1	8.5	8.8	9.0	9.2	9.6
Compare							
Average Difference	1.3	2.6	2.6	2.4	2.0	2.3	1.9
Pooled Std. Dev.	3.3	4.7	4.7	4.6	4.6	4.6	4.5
99% CI- Lower Bound	1.1	2.3	2.3	2.1	1.7	2.0	1.5
99% CI Upper Bound	1.5	2.9	2.9	2.7	2.3	2.6	2.3

Notes:

1. The October 2012 average wind speeds are high due to the residual effects of hurricane Sandy, which impacts the items in notes 2 and 3.
2. The average wind speed at all heights is higher at the mid-lake plateau in 2012 than near to the shore in 2013. For all results  $\alpha = 0.01$ .



3. The average wind speed is greater at the mid-lake plateau in 2012 than near to shore in 2013 on the buoy deck. This result is statistically significant ( $\alpha = 0.01$ ).

**Part III – Comparison of September 2013 Data and October 2013 Data**

In this section, the data collected from September 1 through September 30 are compared with the data collected from October 1 through October 31. The results are shown in table 8. Homogeneity of variance is assumed.

**Table 8: Comparison of Monthly Data: September versus October**

<b>Statistic</b>	<b>N001S00 7P006 Cup Anemom eter</b>	<b>N001S00 9P083 75m</b>	<b>N001S00 9P084 90m</b>	<b>N001S00 9P085 105m</b>	<b>N001S00 9P086 125m</b>	<b>N001S00 9P087 150m</b>	<b>N001S00 9P088 175m</b>
Sept.							
Good Obs.	4320	2898	3541	4131	4237	3850	2616
% of Total (4320)	100	67.1	82	95.6	98.1	89.1	60.6
Average	5.7	7.2	7.5	7.9	8.1	8.3	9.0
October							
Good Obs.	4419	2858	3422	4077	4262	3722	2639
% of Total (4464)	99.0	64.0	76.7	91.3	95.5	83.4	59.1
Average	7.0	8.1	8.5	8.8	9.0	9.2	9.6
Compare							
Average Difference	-1.3	-0.9	-1.0	-0.9	-0.9	-0.9	-0.6
Pooled Std. Dev.	2.5	3.6	3.7	3.8	3.7	3.8	3.8
99% CI- Lower Bound	-1.4	-1.1	-1.2	-1.1	-1.1	-1.1	-0.87
99% CI Upper Bound	-1.2	-0.65	-0.77	-0.68	-0.70	-0.68	-0.33

**Notes:**

1. The average wind speed at all heights is greater in October than in September. All results are statistically significant ( $\alpha = 0.01$ ).
2. The average wind speed is greater in October than in September on the buoy deck. This result is statistically significant ( $\alpha = 0.01$ ).
3. In addition, there appears to be a slight shift of wind direction from September to October. In October, the wind direction is from SSE through SW about 61% of the time. In September, the wind was from this direction about 55% of the time.