



# **Lake Michigan Offshore Wind Assessment Project**

## **Preliminary Data Summary and Analysis**

**July, 2012**

**(Updated - September 2012)**

## Part I – Satellite Transmitted Data

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

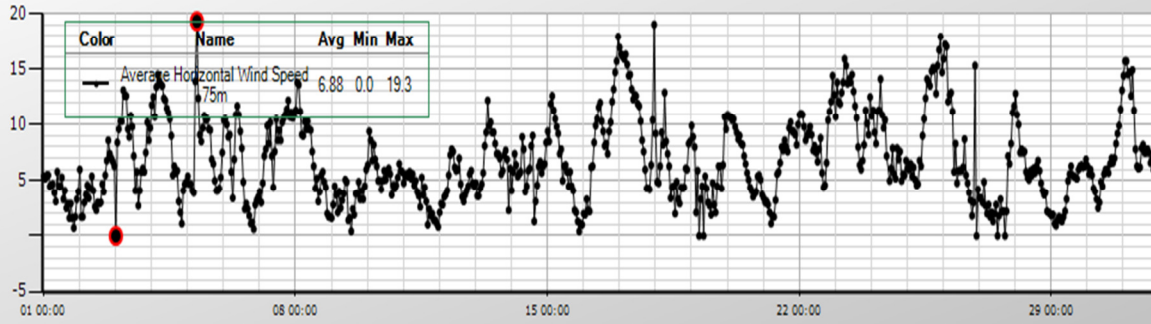
<b>Location:</b>	Lake Michigan – Mid-lake Plateau (4320.5100N 8707.2057W)
<b>Date:</b>	July 1 through July 31, 2012 (UTC)
<b>Cup Anemometer:</b>	3 meters mounted on the buoy
<b>Range Gates 1-6:</b>	75, 90, 105, 125, 150, 175 meters
<b>Observations:</b>	10-minute averages, transmitted via satellite at the rate of one 10-minute average per hour
<b>Number of Observations:</b>	31 days at 24 observations per day = 744 observations
<b>Missing Observations:</b>	1 – 11:10 on July 24
<b>Good Observations:</b>	743

### Notes:

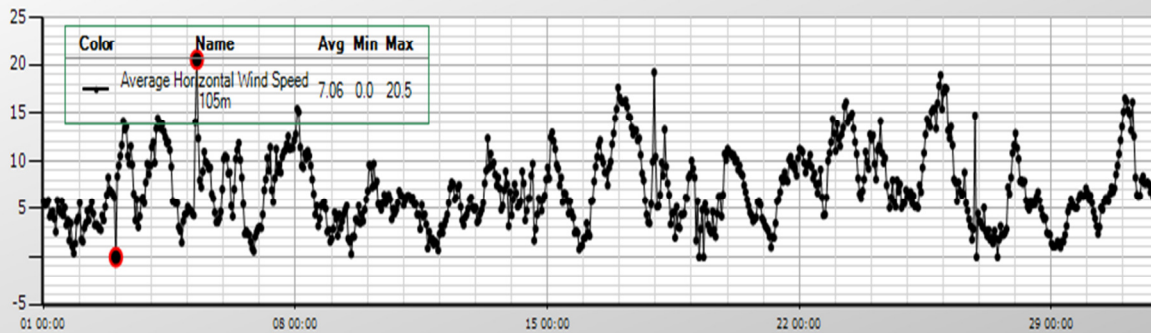
- o Data for Range Gates 2 and 5 are available and stored on the buoy, but not transmitted (by choice) in the real-time 10 minute average data.
- o Range Gate 6 (175 meters) is a test range gate to observe the performance of the sensor at the extreme operating height limit for this configuration. Thus, 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 ranges gates 1, 3, 4, and 6 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.

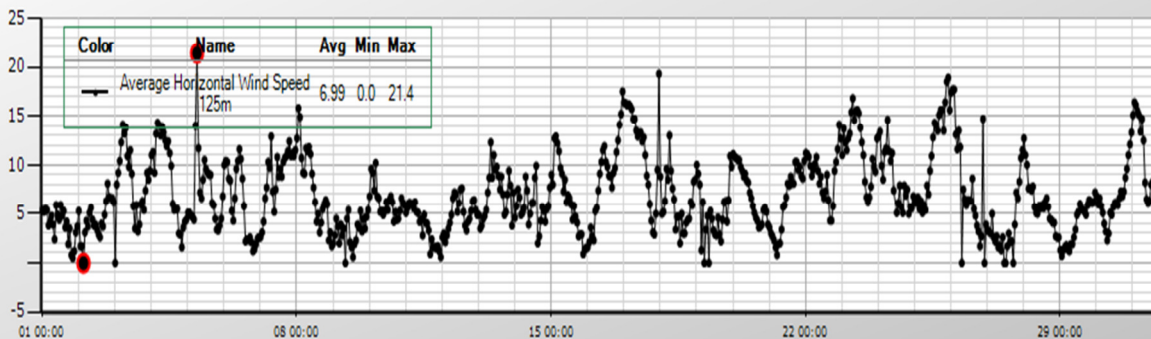
GVSU Primary  
Iridium Combined Message  
Average Horizontal Wind Speed 75m



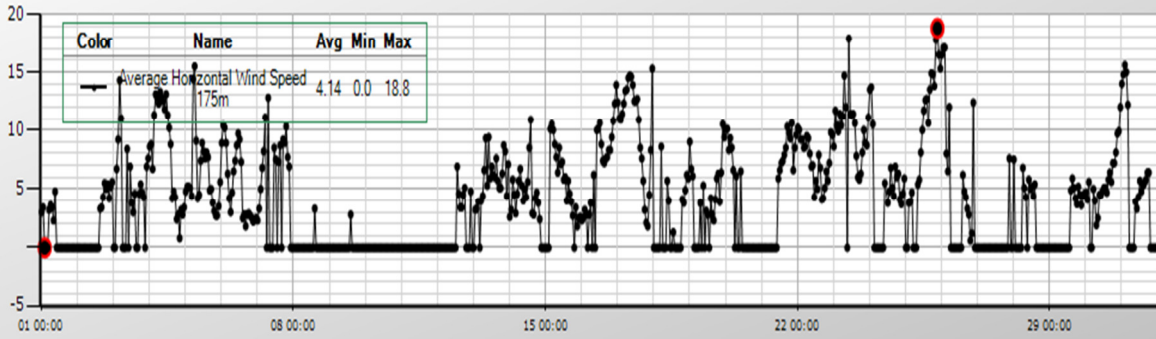
GVSU Primary  
Iridium Combined Message  
Average Horizontal Wind Speed 105m



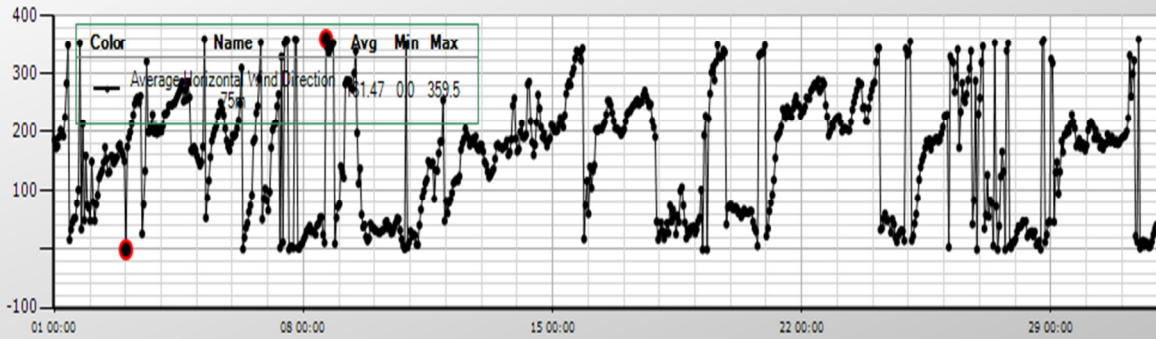
GVSU Primary  
Iridium Combined Message  
Average Horizontal Wind Speed 125m



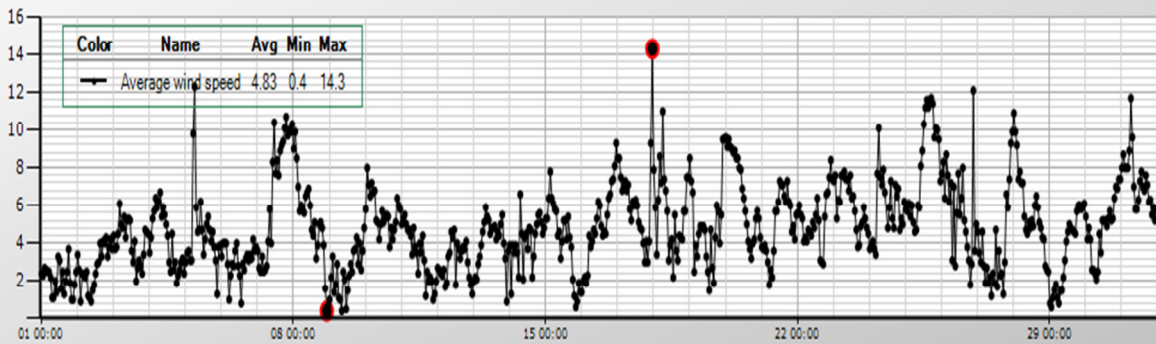
GVSU Primary  
Iridium Combined Message  
Average Horizontal Wind Speed 175m



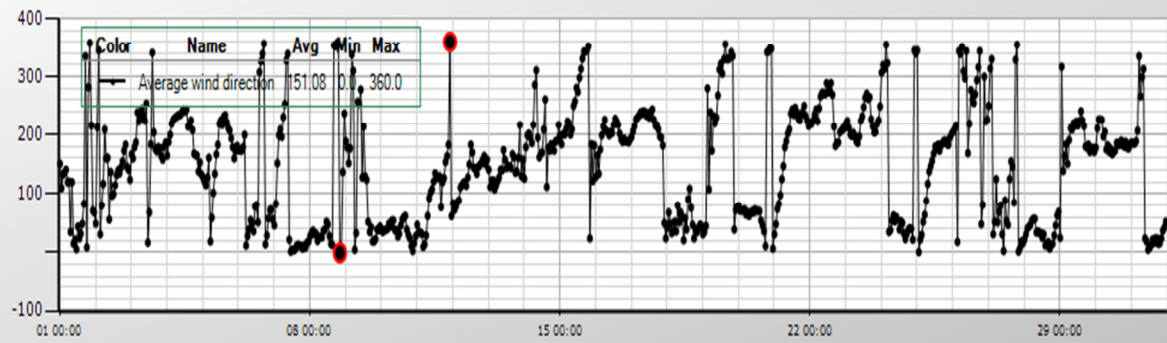
GVSU Primary  
Iridium Combined Message  
Average Horizontal Wind Direction 75m



GVSU Primary  
Iridium Combined Message  
Average wind speed



GVSU Primary  
Iridium Combined Message  
Average wind direction



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 743 hours with one 10-minute average transmitted.

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

<b>Statistic</b>	<b>N001S007P006 Average Wind Speed Cup Anemometer</b>	<b>N001S009P083 Average Horizontal Wind Speed RG#1</b>	<b>N001S009P085 Average Horizontal Wind Speed RG#3</b>	<b>N001S009P086 Average Horizontal Wind Speed RG#4</b>	<b>N001S009P088 Average Horizontal Wind Speed RG#6</b>
Good Observations	743	706	707	703	308
% of Total (743)	100.0%	95.0%	95.2%	94.6%	41.5%
Average	4.8	7.0	7.2	7.2	7.6
Standard Deviation	2.3	3.7	3.8	3.8	3.7
Minimum	0.4	0.4	0.4	0.5	0.6
1st quartile	3.1	4.3	4.4	4.4	4.6
Median	4.7	6.3	6.4	6.3	7.0
3rd quartile	6.1	9.6	9.7	9.6	10.1
Maximum	14.3	19.3	20.5	21.4	18.8
99% CI for Mean – Lower Bound	4.6	6.7	6.8	6.8	7.0
99% CI for Mean – Upper Bound	5.0	7.4	7.6	7.5	8.1

**Table 2: Wind Speed (meters per second) Frequencies by Range Gate**

<b>Wind Speed Range</b>	<b>N001S007P006 Average Wind Speed Cup Anemometer</b>	<b>N001S009P083 Average Horizontal Wind Speed RG#1</b>	<b>N001S009P085 Average Horizontal Wind Speed RG#3</b>	<b>N001S009P086 Average Horizontal Wind Speed RG#4</b>	<b>N001S009P088 Average Horizontal Wind Speed RG#6</b>
0-4	38.9%	21.7%	21.2%	21.5%	16.6%
4-8	52.5%	43.1%	42.3%	43.0%	40.9%
8-12	8.2%	23.8%	24.0%	23.2%	28.6%
12-16	0.4%	9.9%	10.0%	10.1%	12.0%
16-20	0.0%	1.6%	2.3%	2.1%	1.9%
20-24	0.0%	0.0%	0.1%	0.1%	0.0%
24-28	0.0%	0.0%	0.0%	0.0%	0.0%
28-32	0.0%	0.0%	0.0%	0.0%	0.0%

**Table 3: Wind Direction Frequencies and Average Speed by Range Gate**

<b>Wind Direction Range (Degrees)</b>	<b>N001S009P089 Average Horizontal Wind Direction RG#1</b>	<b>N001S009P083 Average Horizontal Wind Speed RG#1</b>
0 – 45 (NNE)	20.0%	7.0
45 – 90 (NE)	12.0%	5.6
90 – 135 (SE)	5.9%	4.0
135 – 180 (SSE)	12.2%	5.6
180 – 225 (SSW)	21.7%	8.5
225 – 270 (SW)	13.9%	9.4
270 – 315 (NW)	6.2%	6.8
315 – 360 (NNW)	8.1%	5.7

Notes for July:

1. The average wind speed for ranges gates 1, 3, and 4 appears to be equivalent.
2. The same pattern indicating equivalent wind speed at range gates 1, 3, and 4 is seen in the other summary statistics as well as the distribution of wind speeds.
3. The distribution of the wind speeds shows more values in the 4-8m/sec range for range gates 1, 3, and 4.
4. Ranges gates 1, 3, and 4 have higher average wind speeds than the cup anemometer. The difference in the averages between the cup anemometer and range gate 4 of 2.2m/sec is statistically significant ( $\alpha = 0.01$ ).
5. The relatively small percent of good observations is consistent with the idea that range gate 6 is a test range gate with performance degradation expected.
6. The most prevalent wind direction is 180 – 225 degrees (SSW). Slightly more than 47% percent of the time, the wind direction is between 135 and 270 degrees (SSE to SSW). About 32% percent of the time the wind direction is between 0 and 90 degrees (NNE to NE).
7. Slightly more than one-third of the time, the wind direction is between 180 and 270 degrees (SW to SSW) and the average wind speed in this direction appears to be higher than the overall average of 7.0m/sec for range gate 1.

Notes comparing June and July:

1. The July wind speed seems less than the June wind speed. This is seen in the average, the median, and the quartiles. The variability as measured by the standard deviation is less as well.
2. In June versus July, a greater percentage of the wind speeds were greater than 12m/s, approximately 30% at all range gates in June versus approximately 12% in July.
3. Approximately 47% of the time in July the wind direction was between 135 and 270 degrees (SSE to SW) down slightly from 55% in June.
4. In July versus June, there seems to be a slight shift in direction from the NW to the NE when the wind is not coming from the SSW, SW or SSW.



## Part II – Buoy Stored Data

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

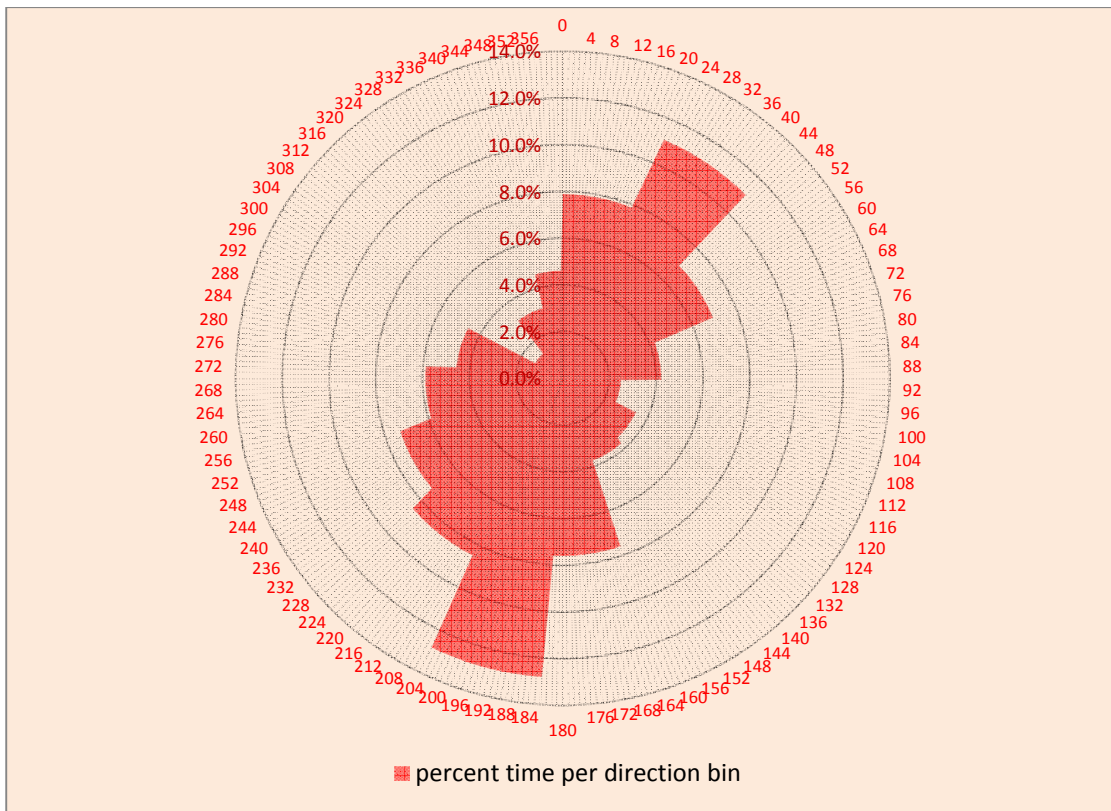
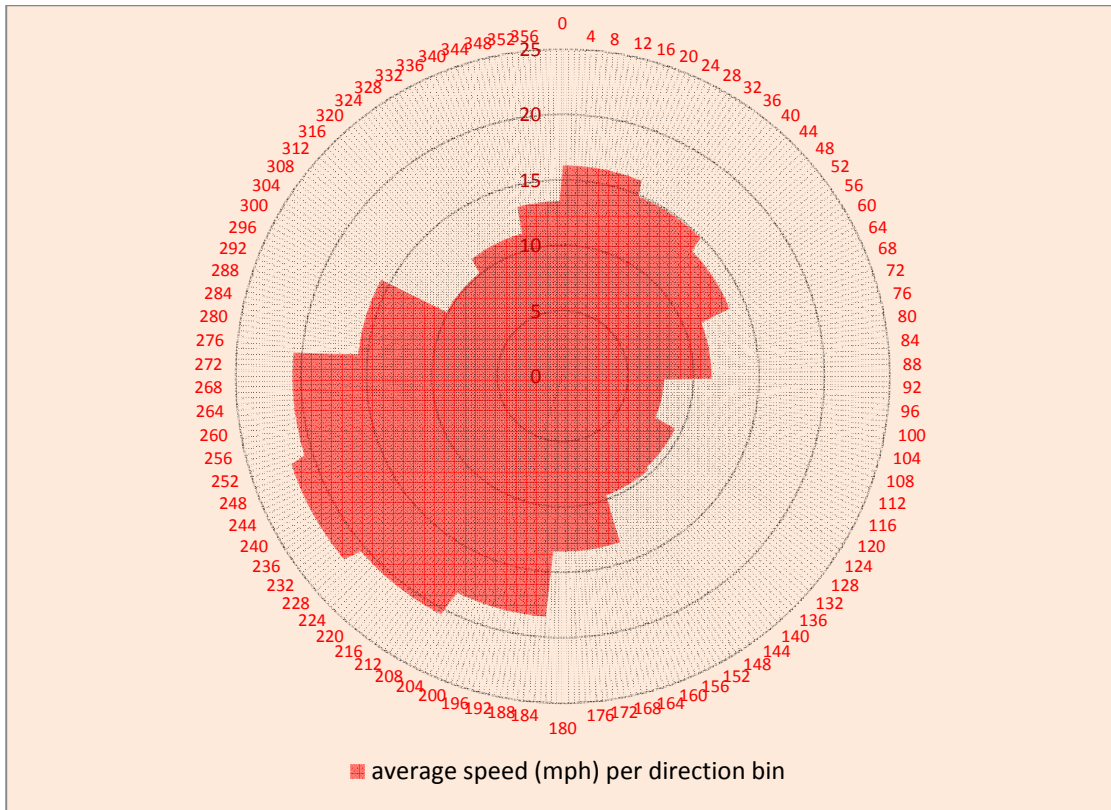
<b>Location:</b>	Lake Michigan – Mid-lake Plateau (4320.5100N 8707.2057W)
<b>Date:</b>	July 1 through July 31, 2012 (UTC)
<b>Range Gates 1-6:</b>	75, 90, 105, 125, 150, 175 meters
<b>Cup Anemometer:</b>	3 meters mounted on the buoy
<b>Observations:</b>	10-minute averages, stored on the buoy and retrieved manually
<b>Number of Observations:</b>	31 days at 24 X 6 observations per day = 4464 observations
<b>Missing Observations:</b>	As shown in table 4.
<b>Good Observations:</b>	As shown in table 4.

Table 4 shows information concerning the horizontal wind speed and the potential energy generated at each range gate. The amount of energy generated depends on the turbine model selected, in this case the Gamesa Elioca G58 850kW. The energy estimate was computed assuming that the turbine will always face the wind.

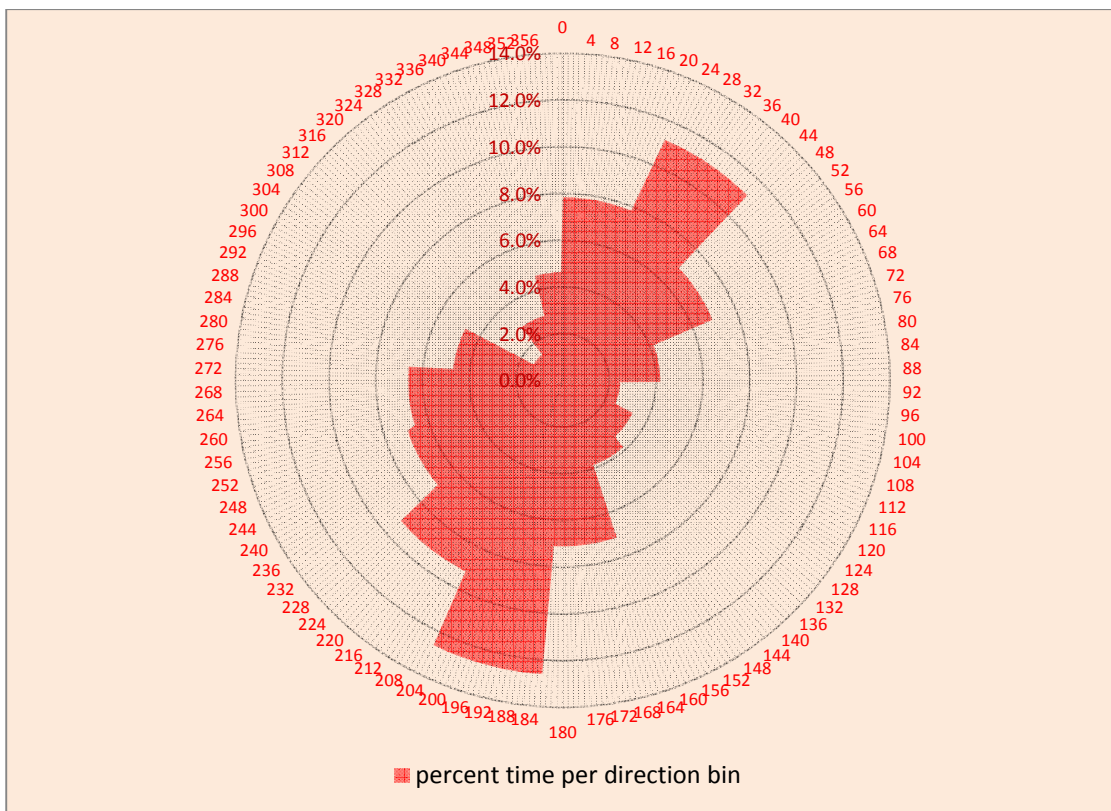
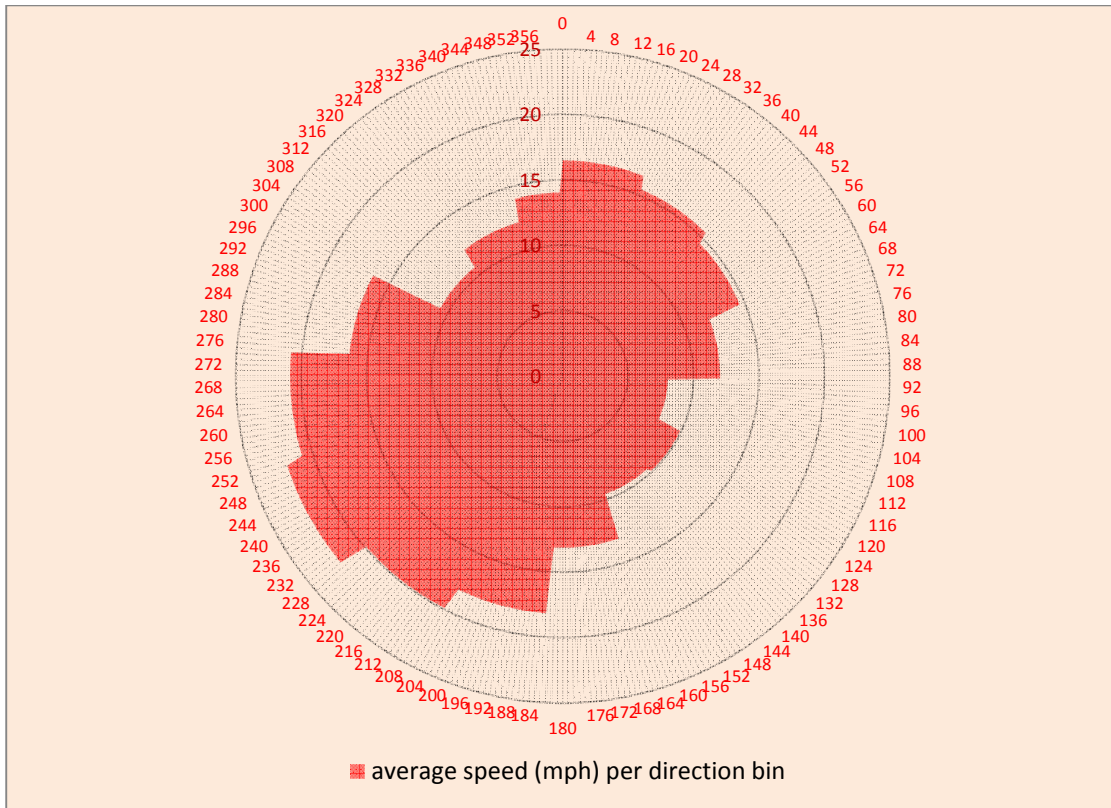
The wind rose graphs show the wind speed as well as percent of time by direction.

**Table 4: Wind Speed (meters per second) and Energy Generated (kWh/time unit) by Range Gate**

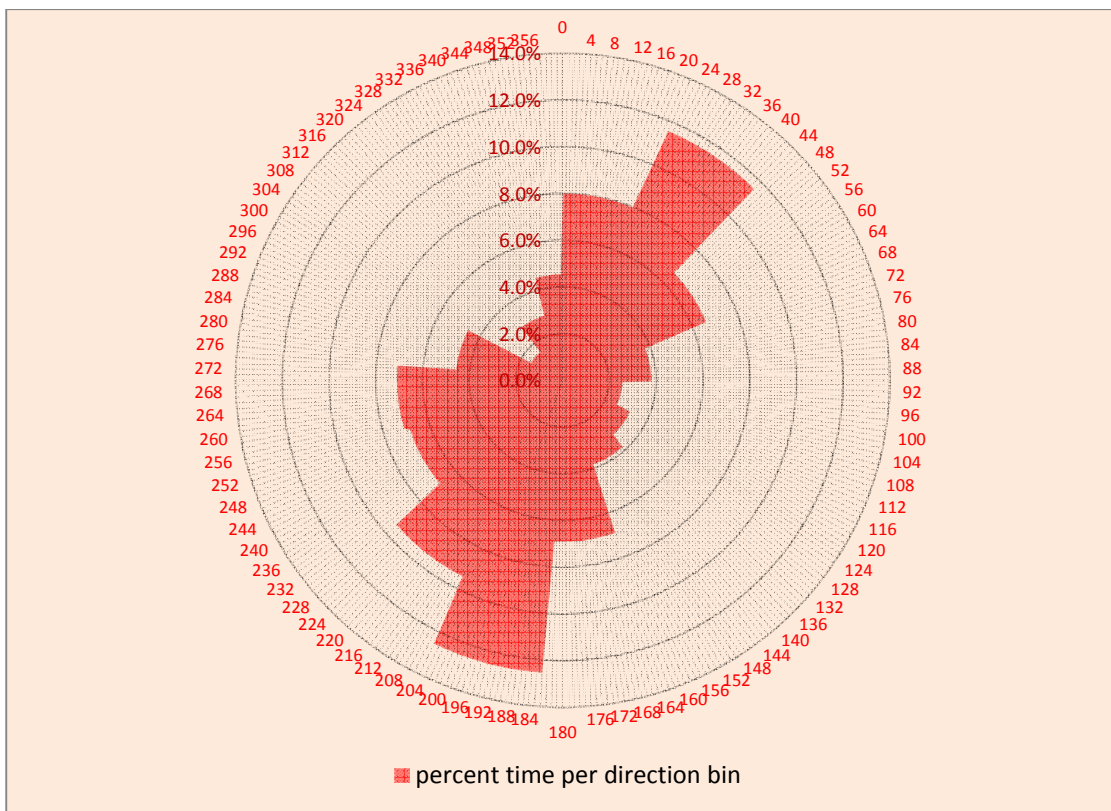
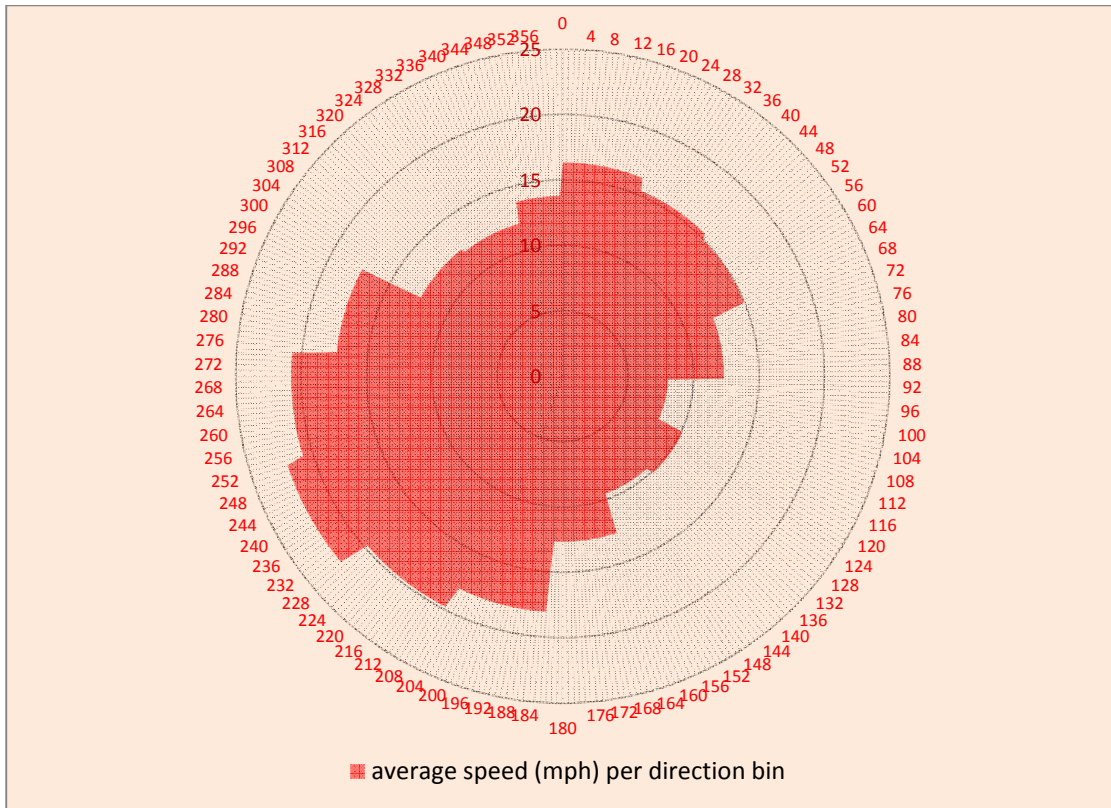
Range Gate	Number of Obs. (Possible = 4464)	% Good Obs.	Average Horizontal Wind Speed	Average Horizontal Wind Speed -- 1 Obs. per hour	Average Horizontal Wind Speed -- Difference	Average Power (MW)	Average Daily Energy (MWh)
<b>1</b>	4242	95.3%	7.0	7.0	0.0	0.32	7.55
<b>2</b>	4257	95.6%	7.2			0.33	7.78
<b>3</b>	4255	95.5%	7.2	7.2	0.0	0.33	7.80
<b>4</b>	4217	94.7%	7.1	7.2	-0.1	0.32	7.63
<b>5</b>	3550	79.7%	7.1			0.31	7.50
<b>6</b>	1845	41.4%	7.6	7.6	0.0	0.35	8.40
<b>Buoy Cup</b>	4452	99.98%	4.8	4.9	-0.1	0.1208	3.06



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

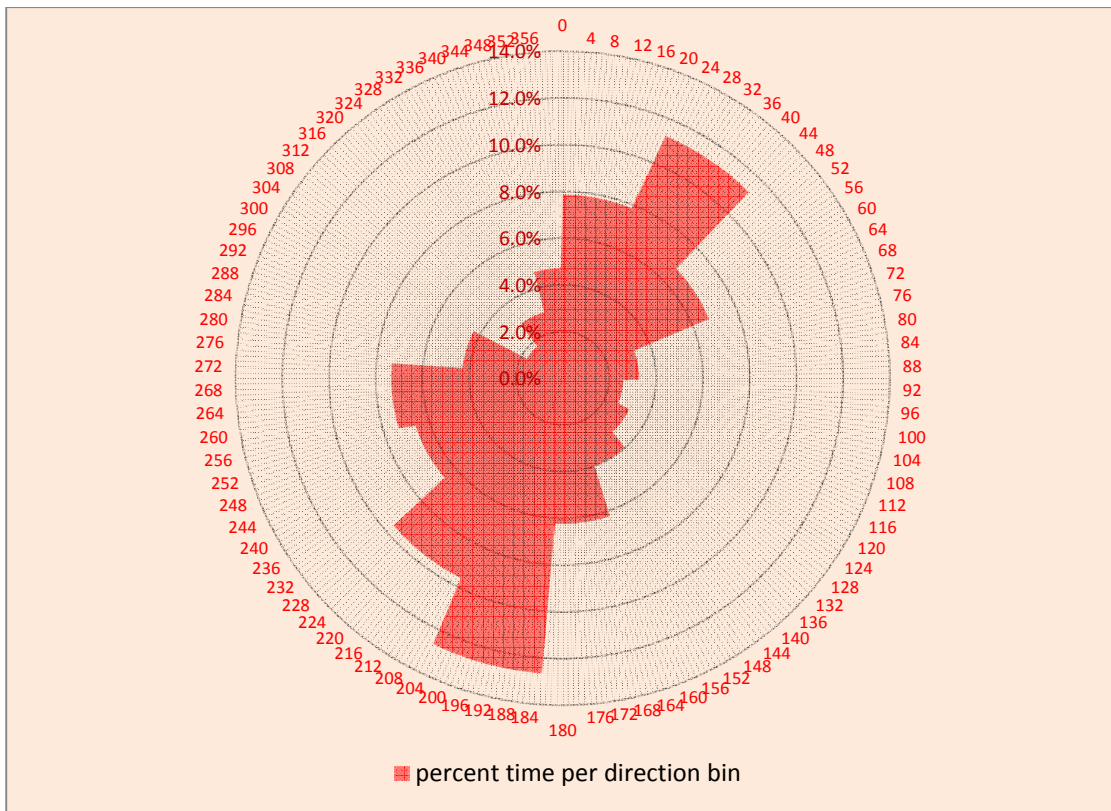
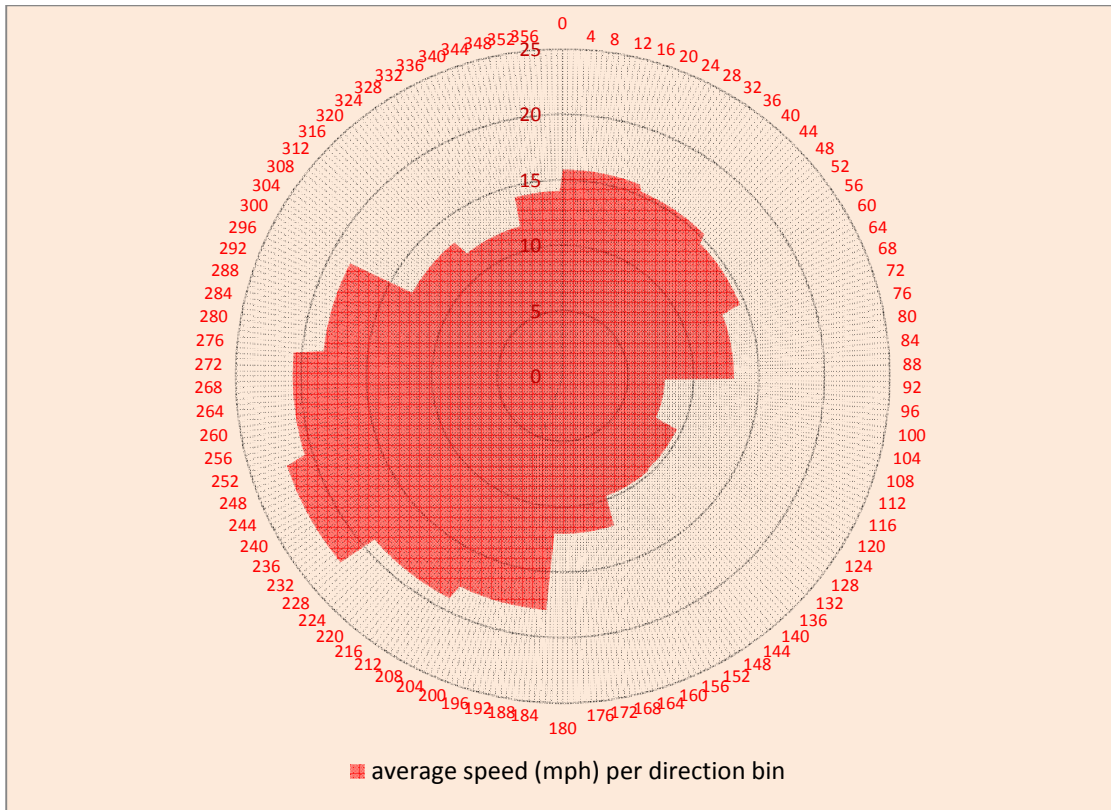


**Range Gate 2 (90m): Average Wind Speed and Percent Time by Direction**

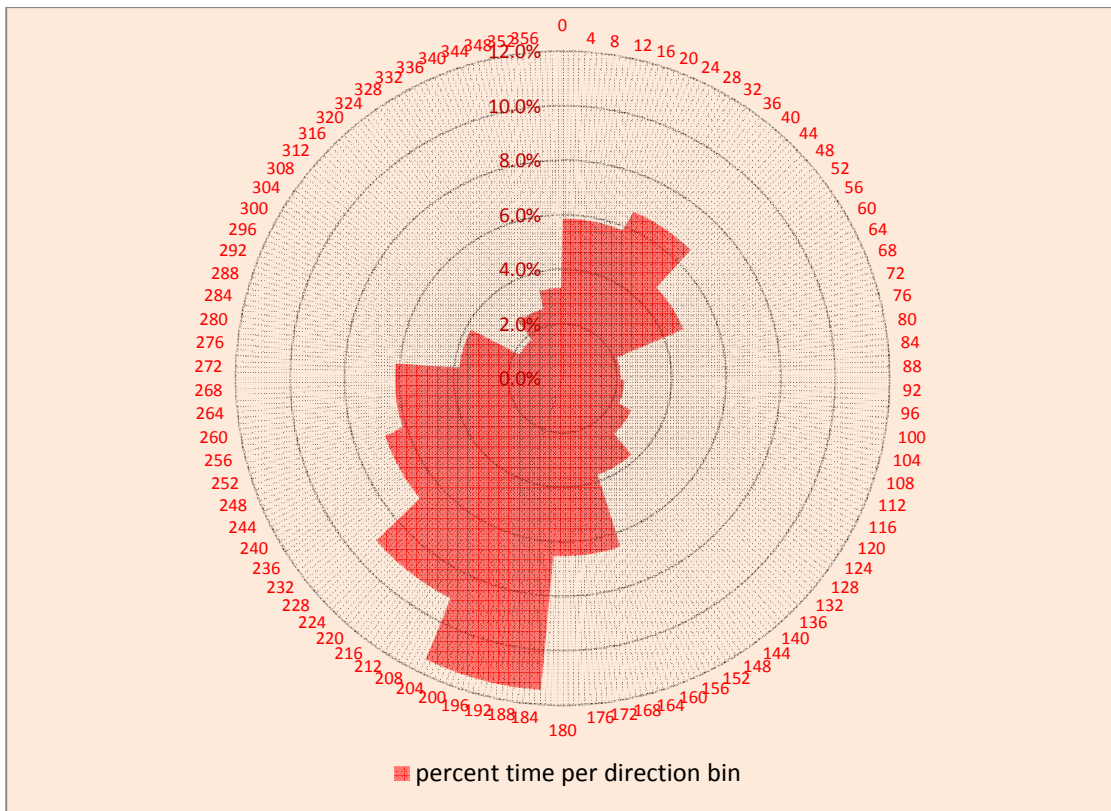
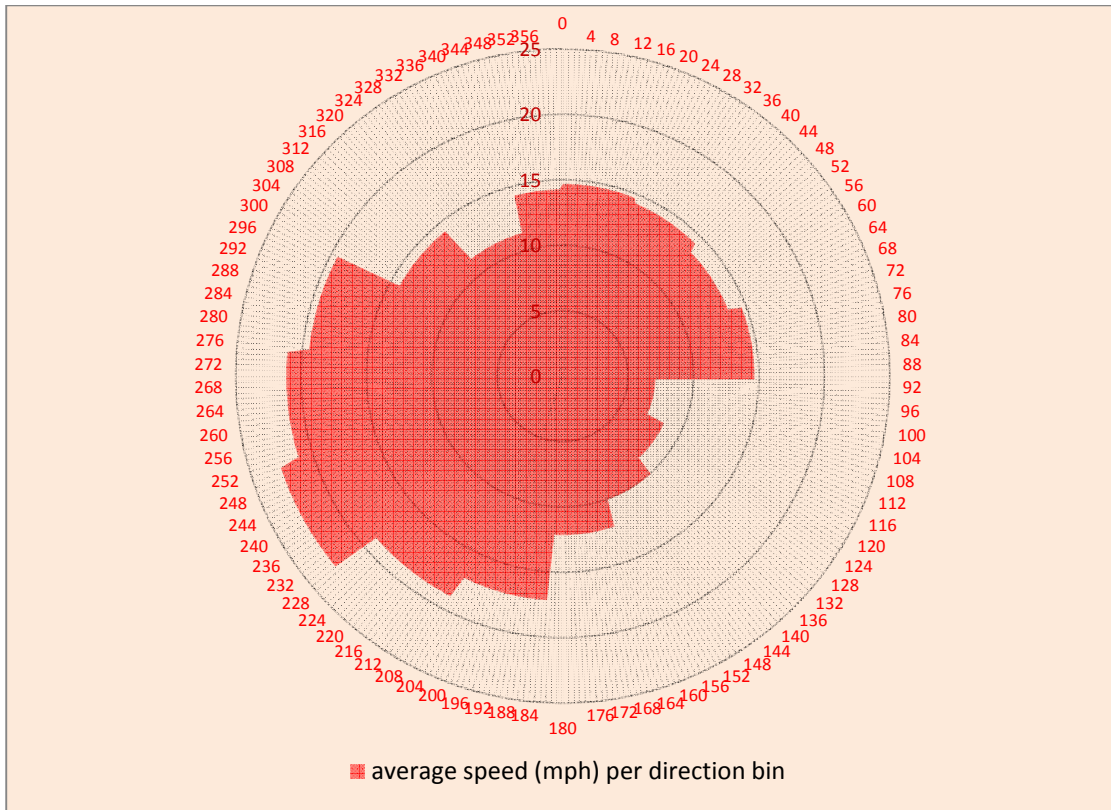


**Range Gate 3: Average Wind Speed and Percent Time by Direction**

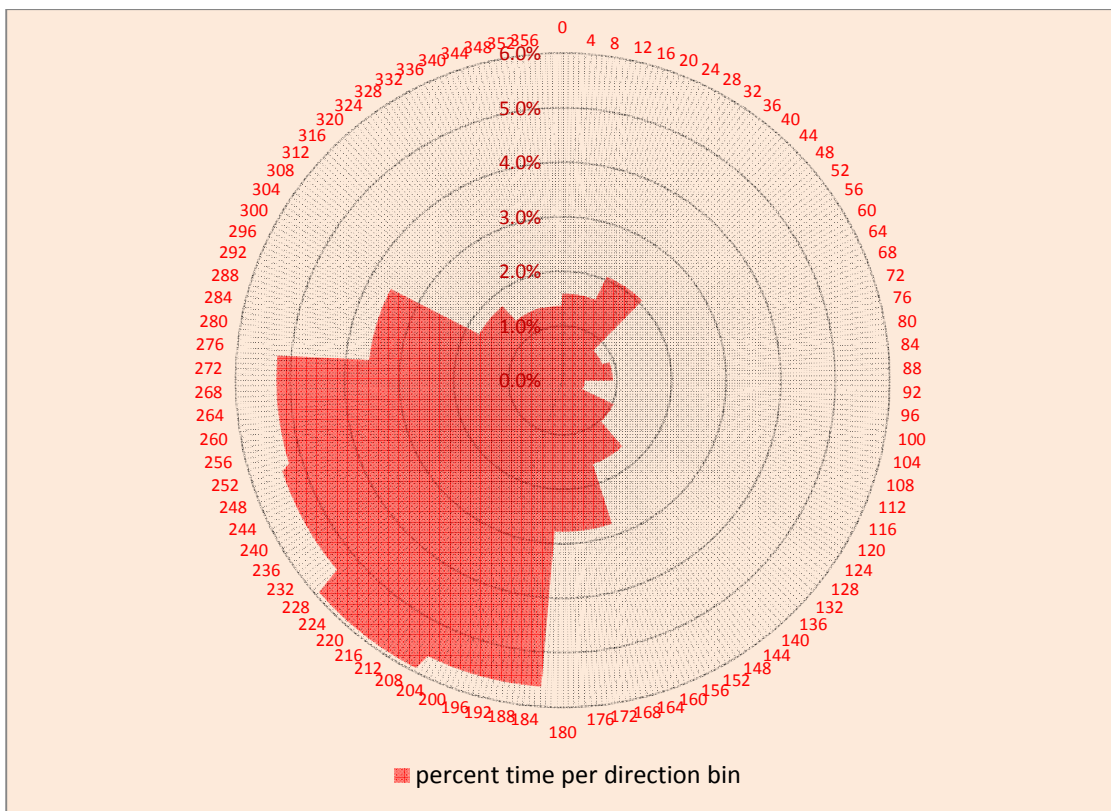
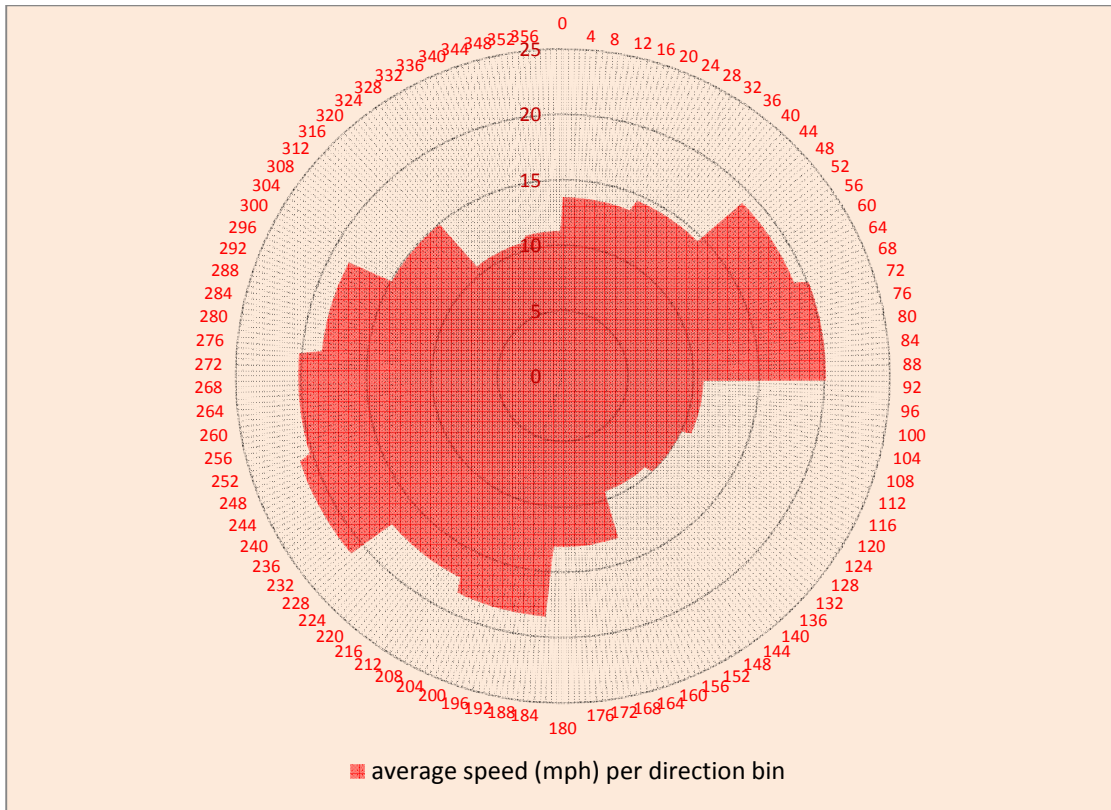




**Range Gate 4: Average Wind Speed and Percent Time by Direction**

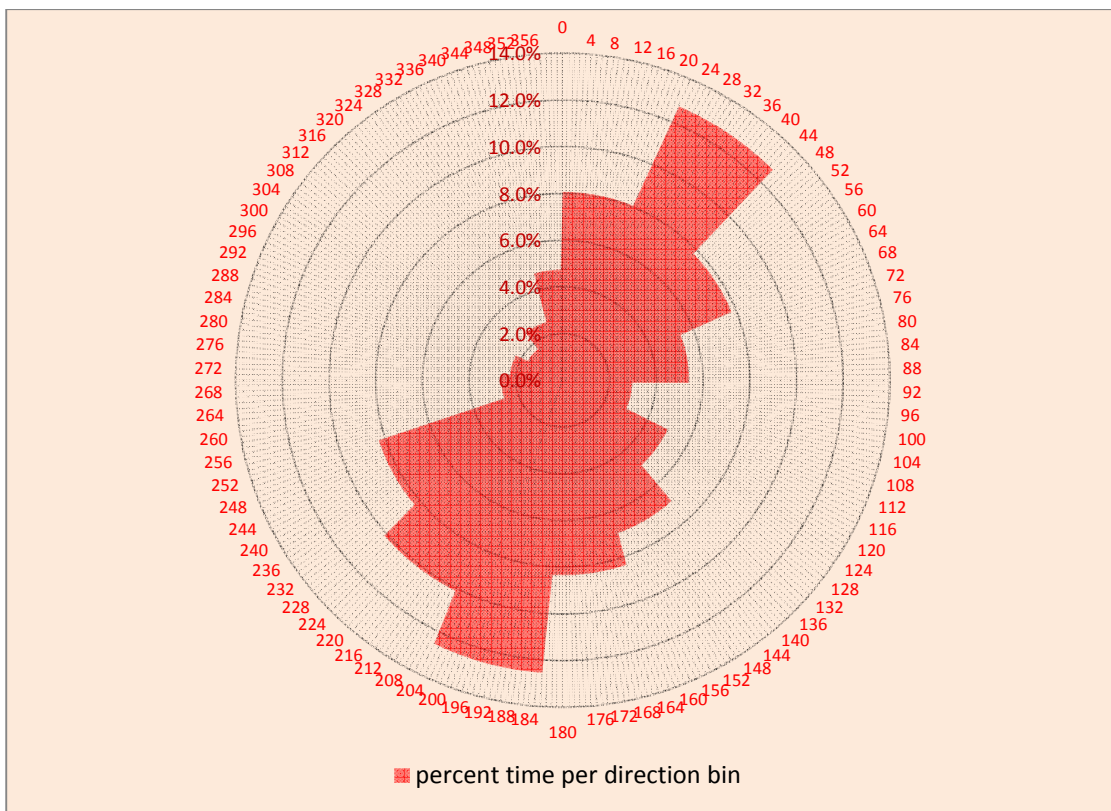
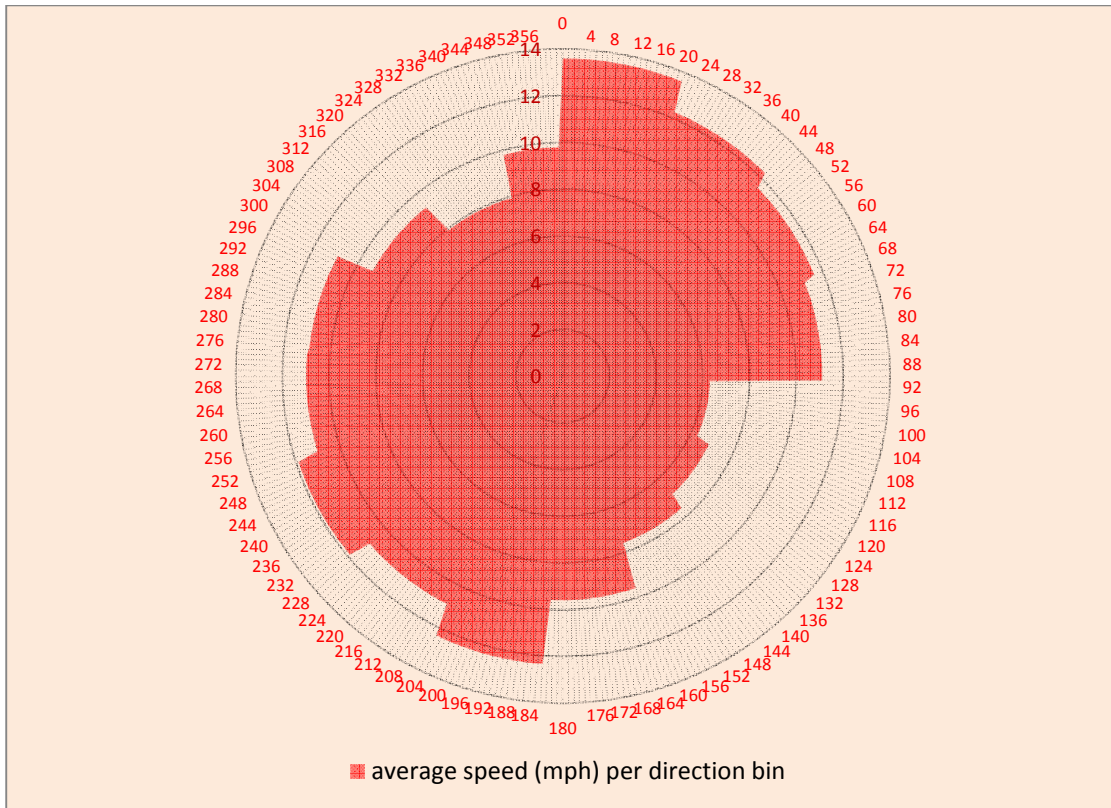


**Range Gate 5: Average Wind Speed and Percent Time by Direction**



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





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



Notes:

1. Based on the percent of good observations in Table 4, performance appears to be degraded for range gates 5 (150m) and 6 (175m). This was expected for range gate 6 which is approaches the optical limits of the Vindicator. Likewise, the reliability for range gate 5 will need further investigation as well.
2. Energy potential ranges from 7.5 to 7.8 megawatt hours per day, much less than in June.
3. The energy potential of the wind at the surface as measured by the cup anemometer on the buoy is about 40% of the energy potential at the higher elevations. The wind speed at sea surface is about two-thirds of that at the higher elevations.
4. The average wind speed estimated by six 10-minute averages per hour and one 10-minute average per hour are the equivalent, varying at most by 0.1 m/s or about 1.4%. Differences in variability estimates are yet to be explored.
5. The highest average wind speed is in the southwest direction, which is the same direction from which the greatest percent of the wind comes.