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Lake Michigan Offshore Wind Assessment Project

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Lake Michigan Wind Assessment Project

Data Summary and Analysis

December 2012

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

Location: Lake Michigan – Mid-lake Plateau (4320.5105N 8707.1962W)

Date: December 1 through December 17, 2012 (UTC)

Cup Anemometer: 3 meters mounted on the buoy

Range Gates 1-6: 75, 90, 105, 125, 150, 175 meters

Observations: 10-minute averages, collected on board the buoy. A subsample of the first 10-minute average in each hour was taken.

Number of Observations: 17 days at 24 observations per day = 408 observations

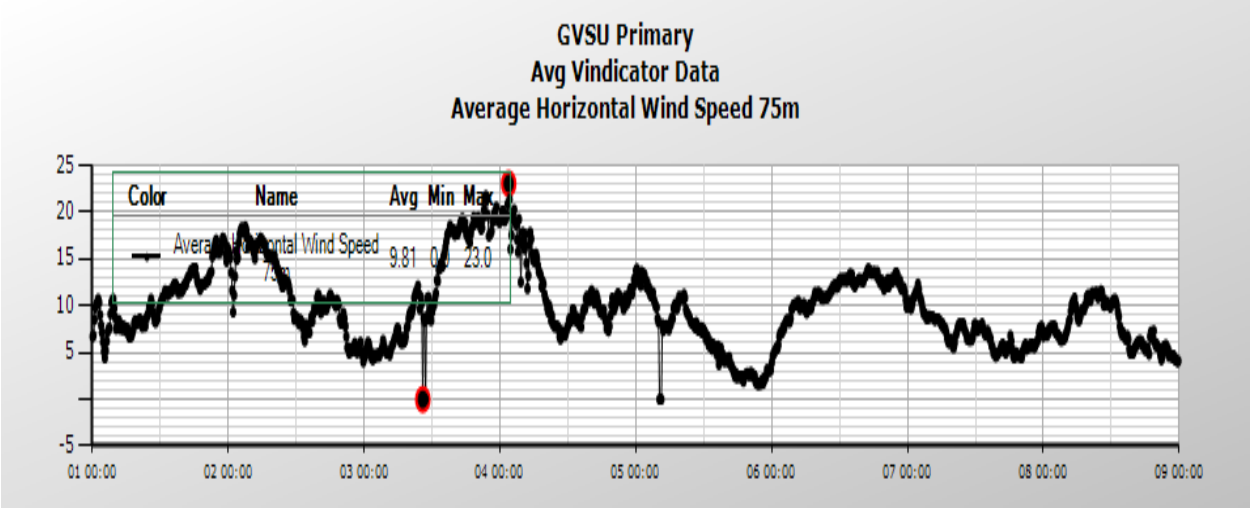
Missing Observations: None

Good Observations: 408 (100%)

Notes:

- 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.
- 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 5 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.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Average Horizontal Wind Speed 75m
Color
Name
Avg Min Max
Average Horizontal Wind Speed
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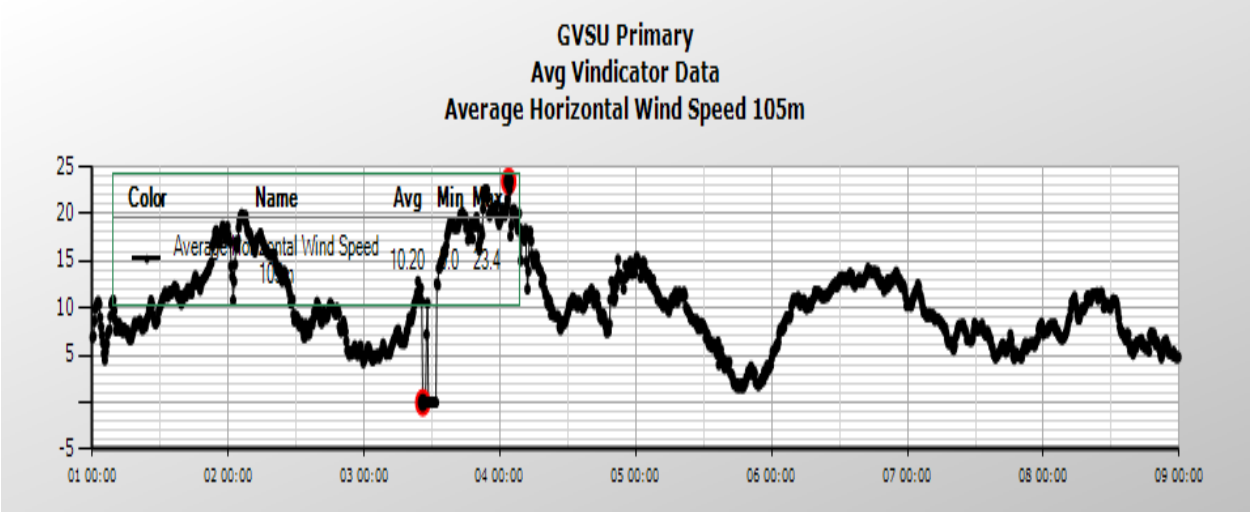
25
20
15
10
5
-5
01 00:00
02 00:00
03 00:00
04 00:00
05 00:00
06 00:00
07 00:00
08 00:00
09 00:00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Avg Vindicator Data
Average Horizontal Wind Speed 105m
Color
Name
Avg Min Max
Average Horizontal Wind Speed
10.20 0.0 23.4
25
20
15
10
5
-5
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02 00:00
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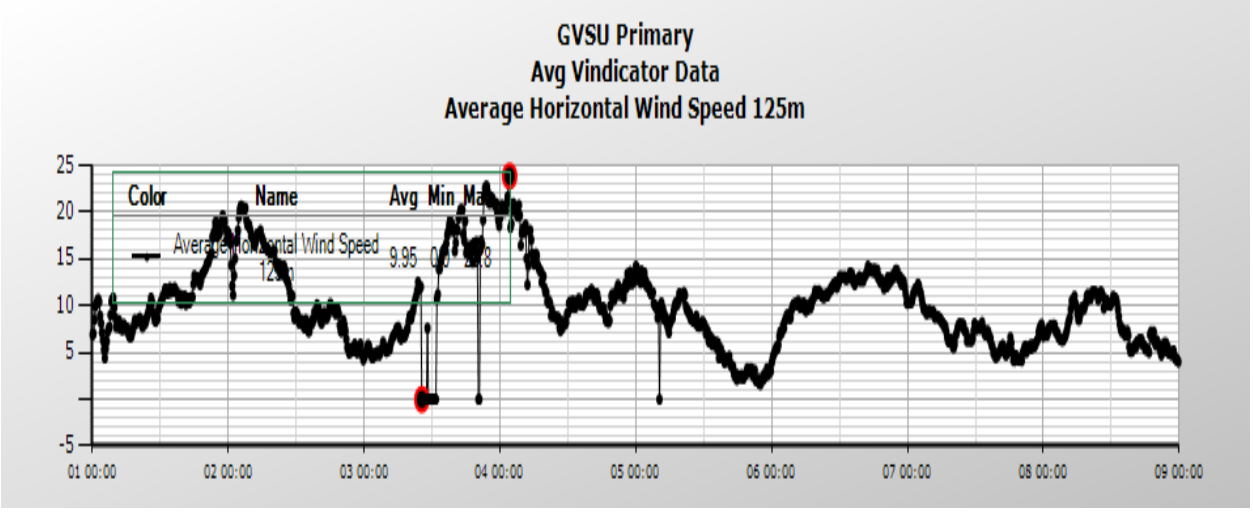
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Color
Name
Avg Min Max
Average Horizontal Wind Speed
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20
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10
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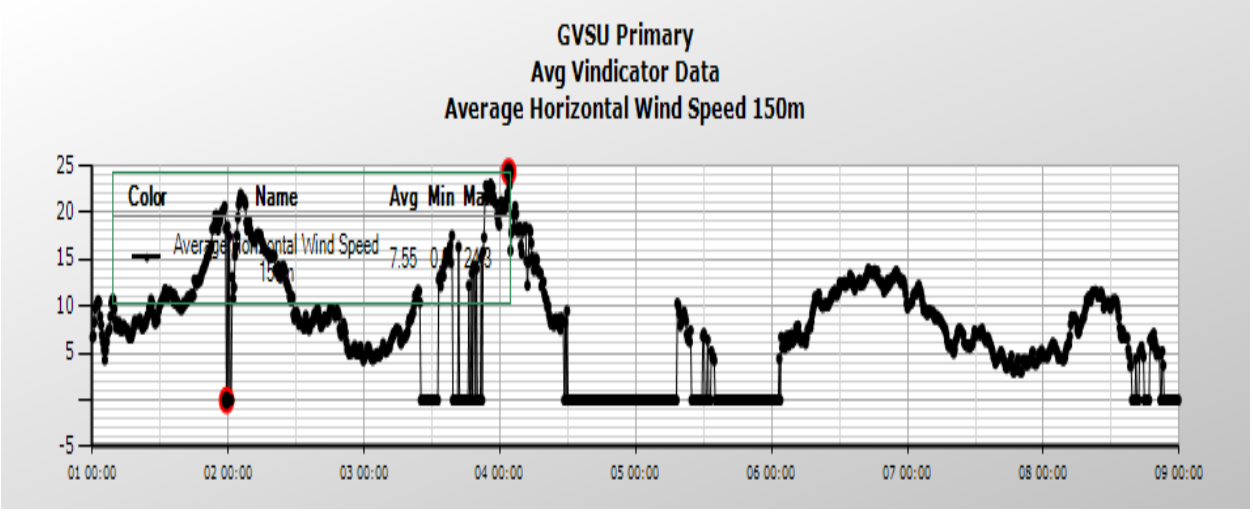
GVSU Primary
Avg Vindicator Data
Average Horizontal Wind Speed 150m
Color
Name
Avg Min Max
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20
15
10
5
-5
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05 00:00
06 00:00
07 00:00
08 00:00
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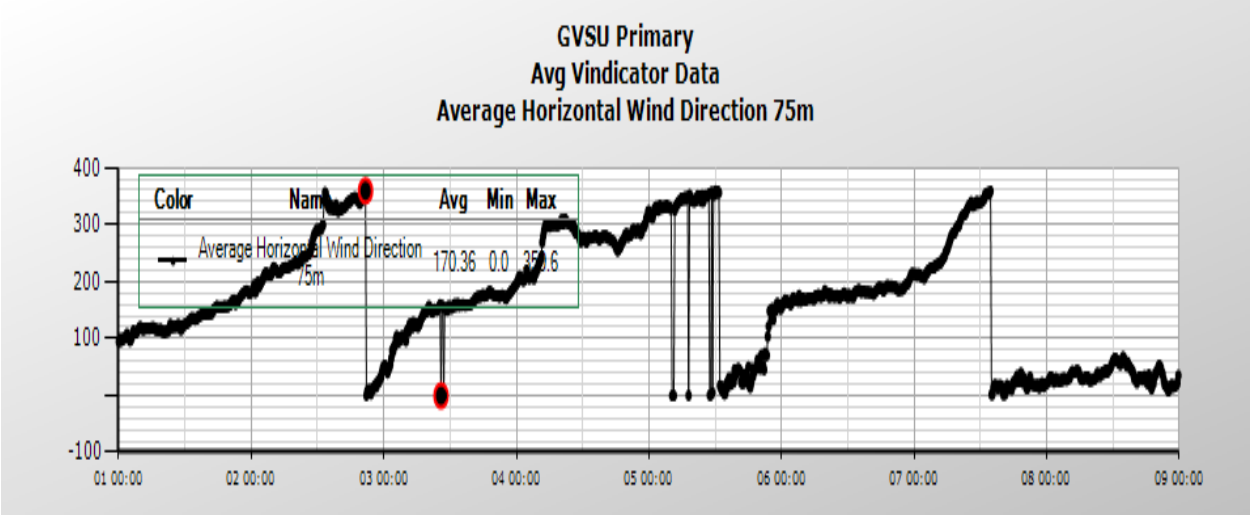
GVSU Primary
Avg Vindicator Data
Average Horizontal Wind Direction 75m
Color
Avg Min Max
400
300
200
100
-100
01 00:00
02 00:00
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05 00:00
06 00:00
07 00:00
08 00:00
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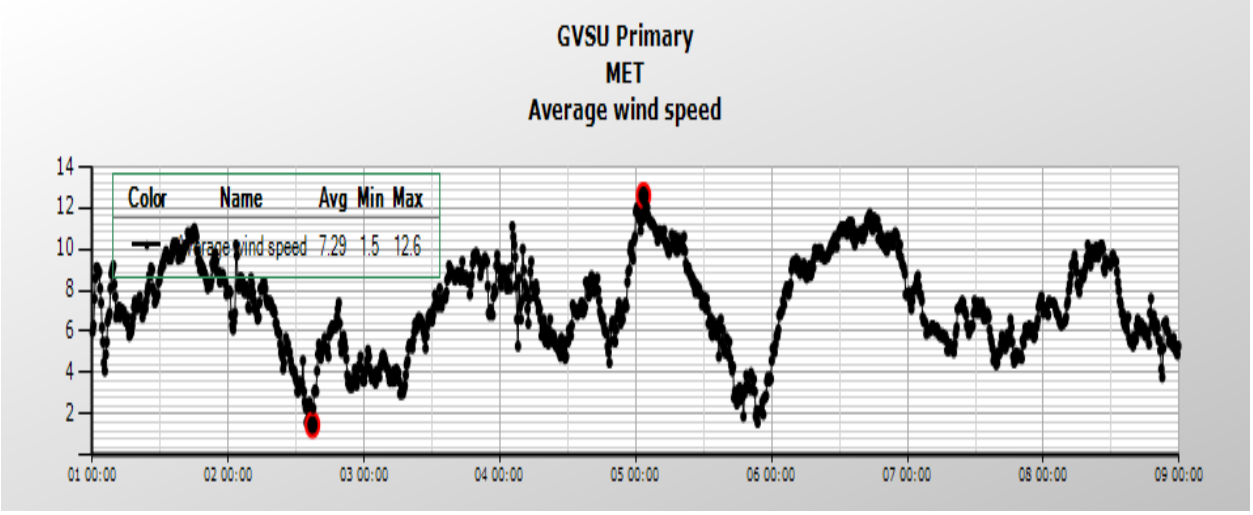
GVSU Primary
MET
Average wind speed
Color
Name
Avg Min Max
14
12
10
8
6
4
2
01 00:00
02 00:00
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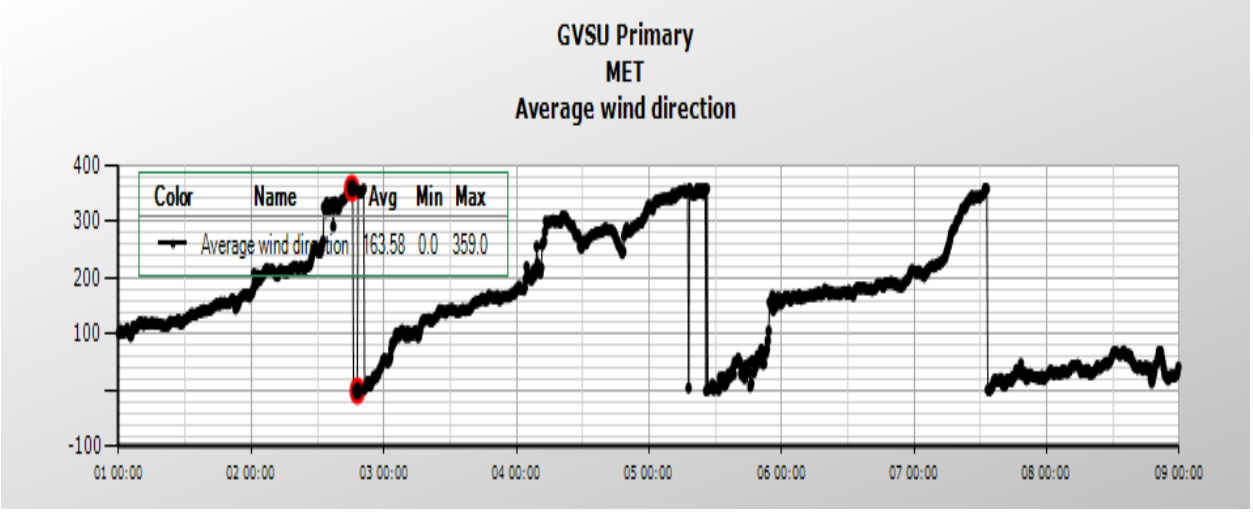
05 00:00
06 00:00
07 00:00
08 00:00
09 00:00


GVSU Primary
MET
Average wind direction
Color
Name
Avg
Min
Max
Average wind direction
163.58
0.0
359.0
400
300
200
100
-100
01 00:00
02 00:00
03 00:00
04 00:00
05 00:00
06 00:00
07 00:00
08 00:00
09 00:00

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 408 hours each with one good 10-minute average.

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

Statistic	N001S007P006 Average Wind Speed Cup Anemometer	N001S009P083 Average Horizontal Wind Speed RG #1	N001S009P085 Average Horizontal Wind Speed RG #3	N001S009P086 Average Horizontal Wind Speed RG #4	N001S009P087 Average Horizontal Wind Speed RG #5
Good Observations	408	398	399	384	312
% of Total (408)	100.0%	97.5%	97.8%	94.1%	76.5%
Average	7.7	9.7	10.1	10.0	9.8
Standard Deviation	2.6	3.9	4.1	4.1	4.1
Coefficient of variation	0.34	0.41	0.40	0.41	0.42
Minimum	1	0.9	0.8	0.8	1.1
1st quartile	5.8	6.7	7.2	7.0	6.8
Median	7.5	9.5	10.0	9.8	9.8
3rd quartile	9.7	12.5	12.9	12.8	12.5
Maximum	13.9	19.9	20.6	21	21.4
99% CI for Mean – Lower Bound	7.3	9.2	9.6	9.5	9.2
99% CI for Mean – Upper Bound	8.0	10.2	10.6	10.5	10.4

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

Wind Speed Range	N001S007P006 Average Wind Speed Cup Anemometer	N001S009P083 Average Horizontal Wind Speed RG #1	N001S009P085 Average Horizontal Wind Speed RG #3	N001S009P086 Average Horizontal Wind Speed RG #4	N001S009P087 Average Horizontal Wind Speed RG #5
0-4	9.1%	6.3%	5.5%	6.0%	5.8%
4-8	47.8%	30.9%	27.6%	28.9%	31.1%
8-12	40.0%	33.9%	35.3%	34.4%	32.4%
12-16	3.2%	21.9%	23.6%	22.7%	24.4%
16-20	0.0%	7.0%	7.5%	6.5%	4.5%
20-24	0.0%	0.0%	0.5%	1.6%	1.9%
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

Wind Direction Range (Degrees)	N001S009P089 Average Horizontal Wind Direction RG#1	N001S009P083 Average Horizontal Wind Speed RG#1
0 – 45 (NNE)	10.8%	6.3
45 – 90 (NE)	4.3%	5.6
90 – 135 (SE)	14.3%	9.0
135 – 180 (SSE)	14.6%	11.2
180 – 225 (SSW)	17.8%	13.5
225 – 270 (SW)	12.8%	10.6
270 – 315 (NW)	14.1%	7.9
315 – 360 (NNW)	11.3%	8.7

Notes for December:

1. The average wind speed for ranges gates 1, 3, 4, and 5 appears to be equivalent. However, the average wind speed for range gate 1 may be slightly less. The difference in the averages between range gate 1 and range gate 3 of 0.4m/sec is statistically significant ($\alpha = 0.01$).
2. The same pattern indicating equivalent wind speed at range gates 1, 3, 4, and 5 is seen in the other summary statistics, as well as the distribution of wind speeds.
3. The coefficient of variation (standard deviation / average) is less for the cup anemometer mounted on the buoy than for the LWS range gates. The coefficients of variation are equivalent for range gates 1, 3, 4, and 5. This indicates less variable winds at the surface level of the buoy.
4. Ranges gates 1, 3, 4, and 5 have higher average wind speeds than the cup anemometer. The difference in the averages between the cup anemometer and range gate 4 of 2.3m/sec is statistically significant ($\alpha = 0.01$).
5. The distribution of the wind speeds shows more values in the 4-8m/sec range and the 8-12m/sec range together for all range gates.
6. The most prevalent wind direction is 180 – 225 degrees (SSW). Almost 40% percent of the time, the wind direction is between 180 and 270 degrees (SSW to SW).
7. About one-sixth of the time, the wind direction is between 180 and 225 degrees (SSW) and the average wind speed in this direction appears to be higher than the overall average of 9.7m/sec for range gate 1.

Notes comparing November and December:

1. The average December wind speed seems higher than the November wind speed. This is seen in average, the median, and the quartiles.
2. The variability of the wind seems less in December than in November, as seen in the standard deviation.
3. In November and December, about two-thirds of the time the wind speed was between 4 and 12m/s.
4. Slightly less than 50% of the time in December the wind direction was between 135 and 270 degrees (SSE to SW). In November, about two-thirds of the wind came from this direction.
5. In both November and December, about one-third of the time the wind direction was between 270 and 90 degrees (NW to NE).

Part II – Buoy Stored Data

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

Location: Lake Michigan – Mid-lake Plateau (4320.5105N 8707.1962W)

Date: December 1 through December 17, 2012 (UTC)

Range Gates 1-6: 75, 90, 105, 125, 150, 175 meters

Cup Anemometer: 3 meters mounted on the buoy

Observations: 10-minute averages, stored on the buoy and retrieved manually

Number of Observations: 17 days at 24 X 6 observations per day = 2448 observations

Missing Observations: As shown in table 4.

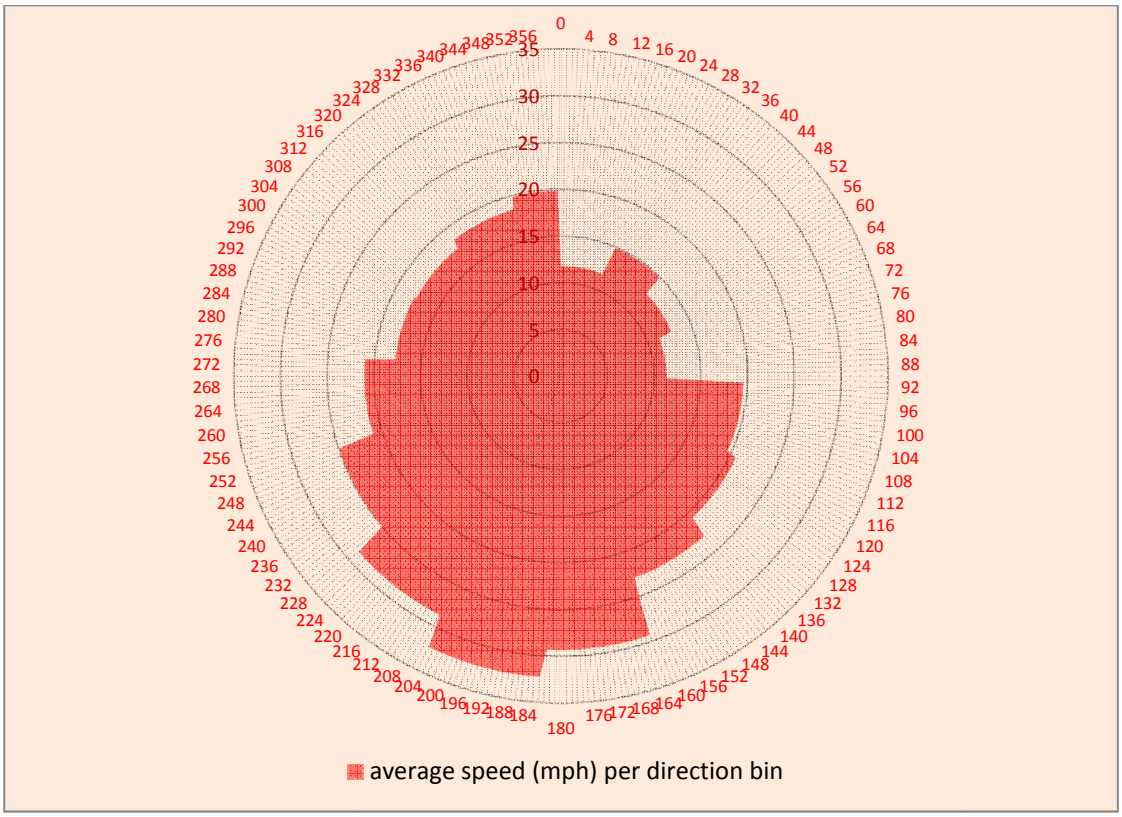
Good Observations: As shown in table 4.

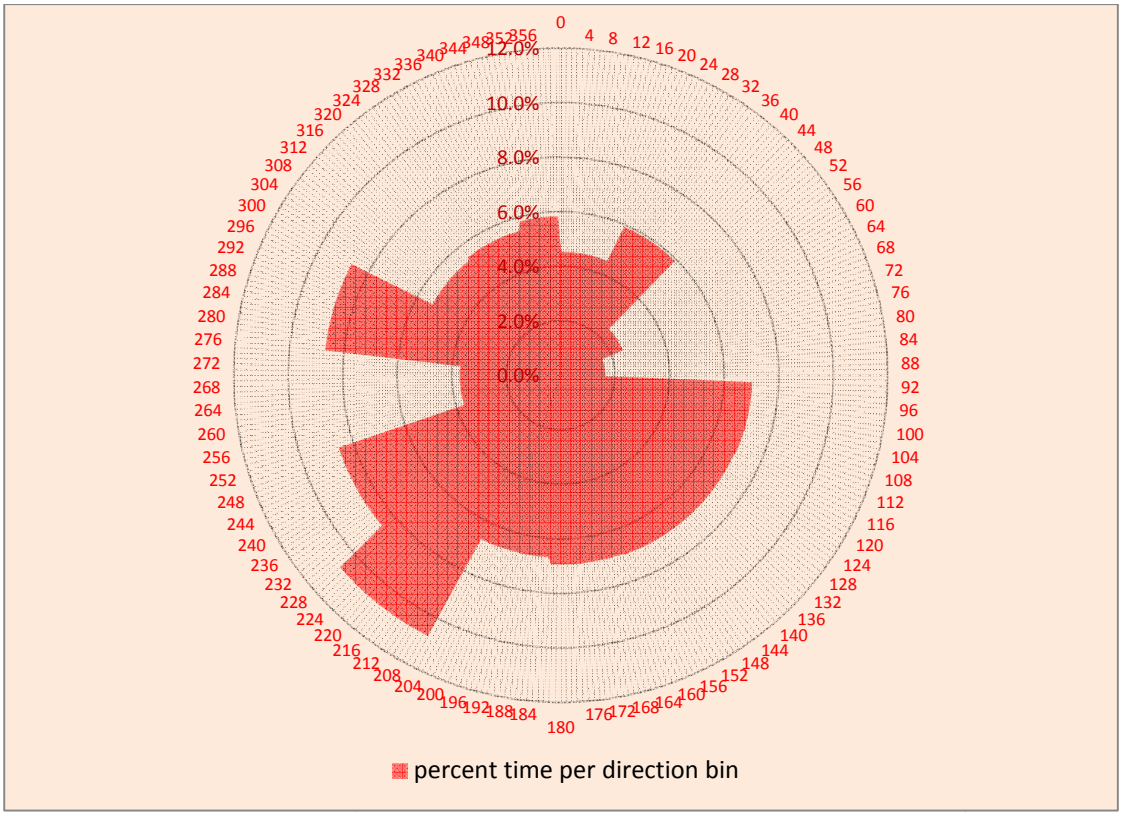
Table 4 shows information concerning the horizontal wind speed and the energy generated for each range gate. The amount of energy generated depends on the turbine employed in this case the Gamesa Elioca G58 850kW. The energy estimate was computed assuming that the turbine will always face the wind.

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

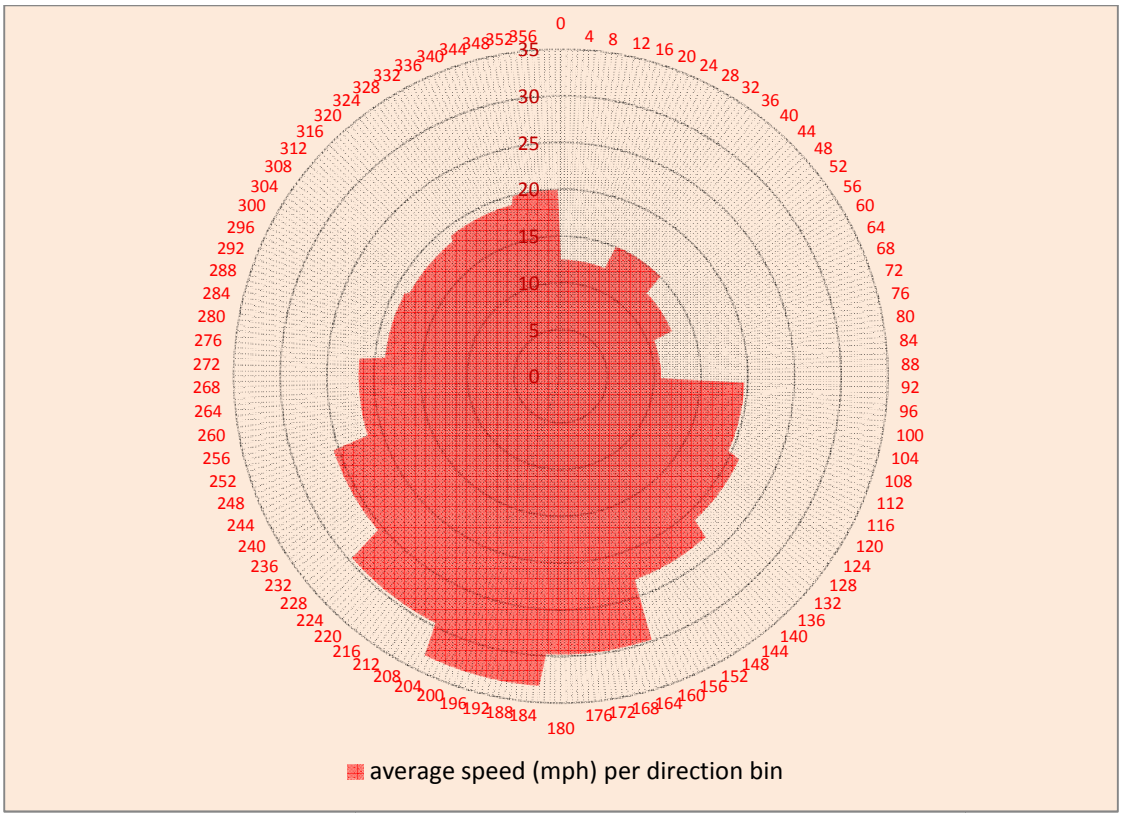
Table 4: Wind Speed (meters per second) and Energy (kWh/time unit) by Range Gate

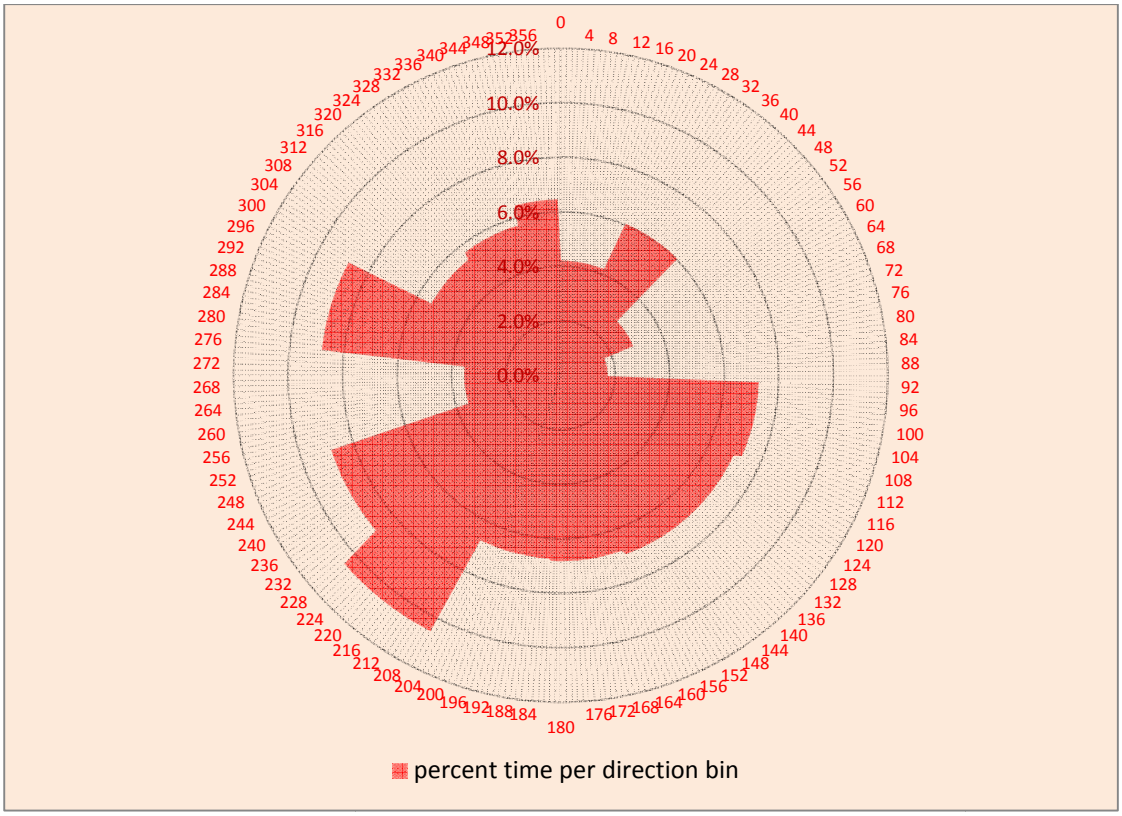
Range Gate	Number of Obs. (Possible = 2448)	% Good Obs.	Average Horizontal Wind Speed	Average Horizontal Wind Speed -- 1 Obs. per hour	Average Horizontal Wind Speed -- Difference	Average Power (kW)	Average Daily Energy (kWh)
1	2382	97.3%	9.7	9.7	0.0	527	12640
2	2417	98.7%	9.9			541	12990
3	2389	97.6%	10.1	10.1	0.0	551	13230
4	2297	93.8%	10.0	10.0	0.0	542	13010
5	1854	75.7%	9.9	9.8	0.1	530	12710
6	1382	56.5%	9.3			479	11500
Buoy Cup	2448	100.0%	7.7	7.7	0.0	391	9380



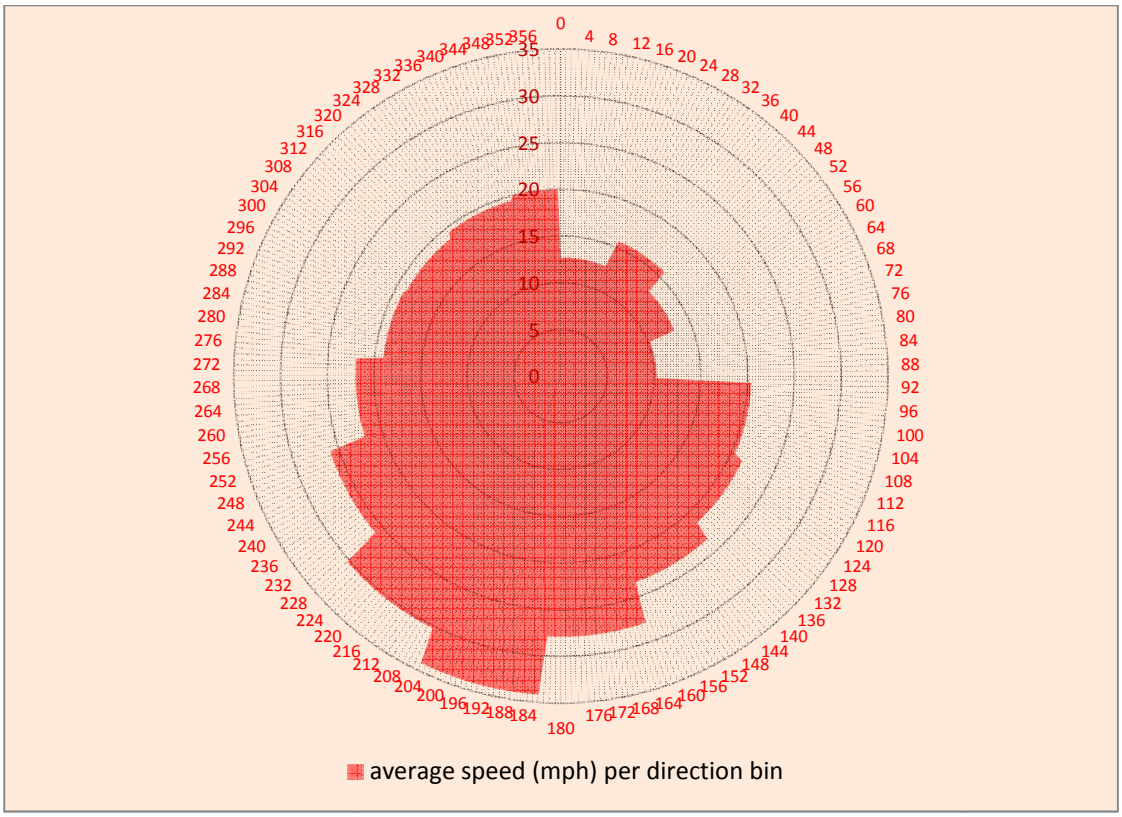


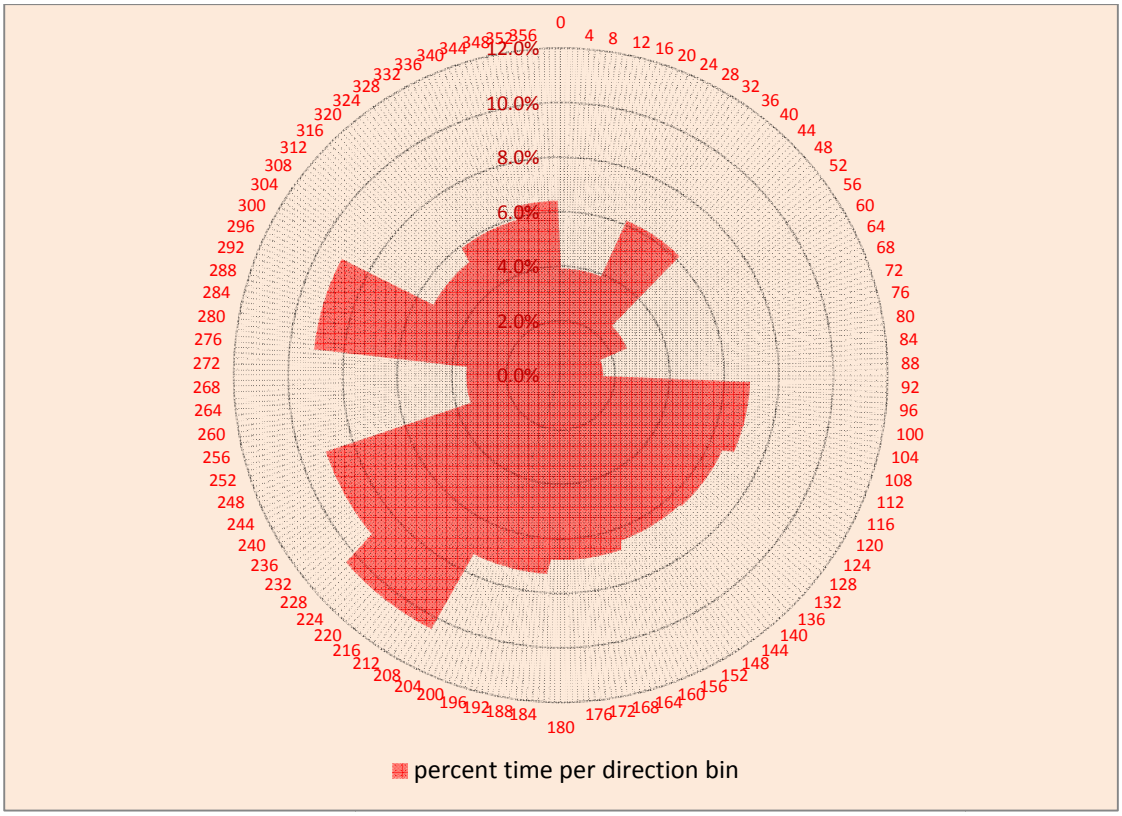
Range Gate 1: Average Wind Speed and Percent Time by Direction



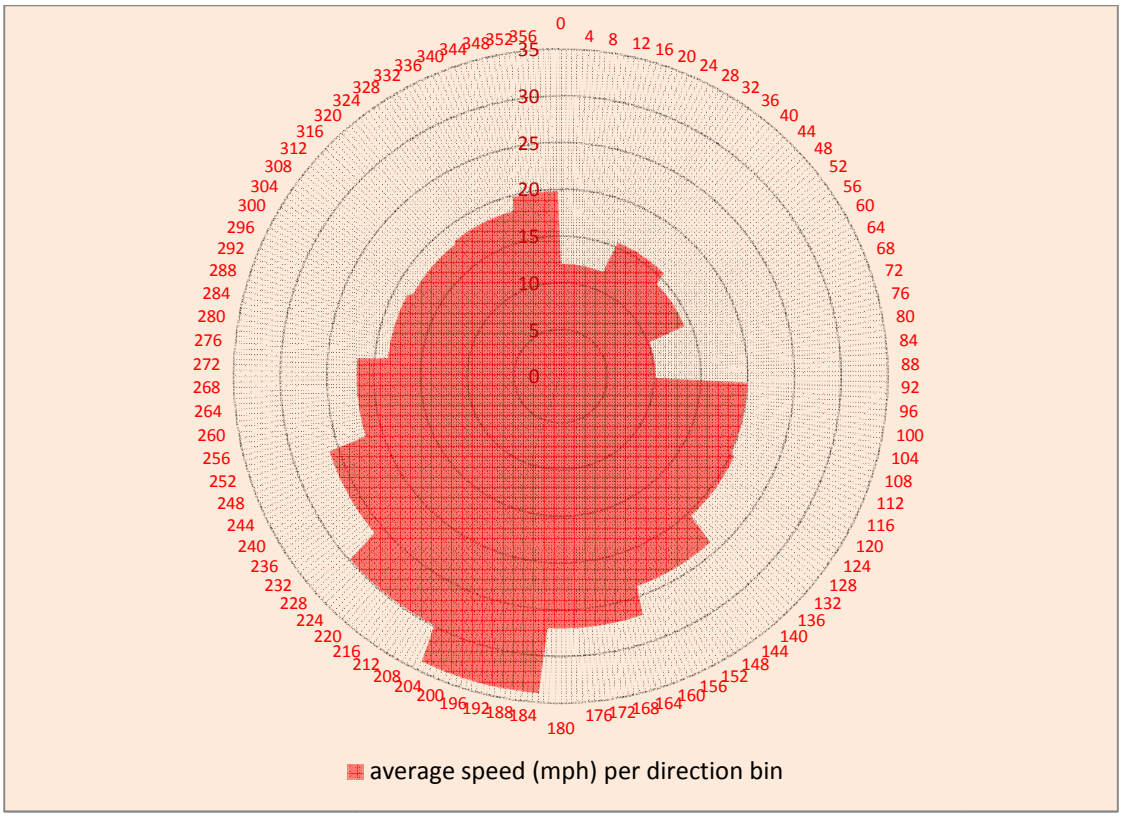


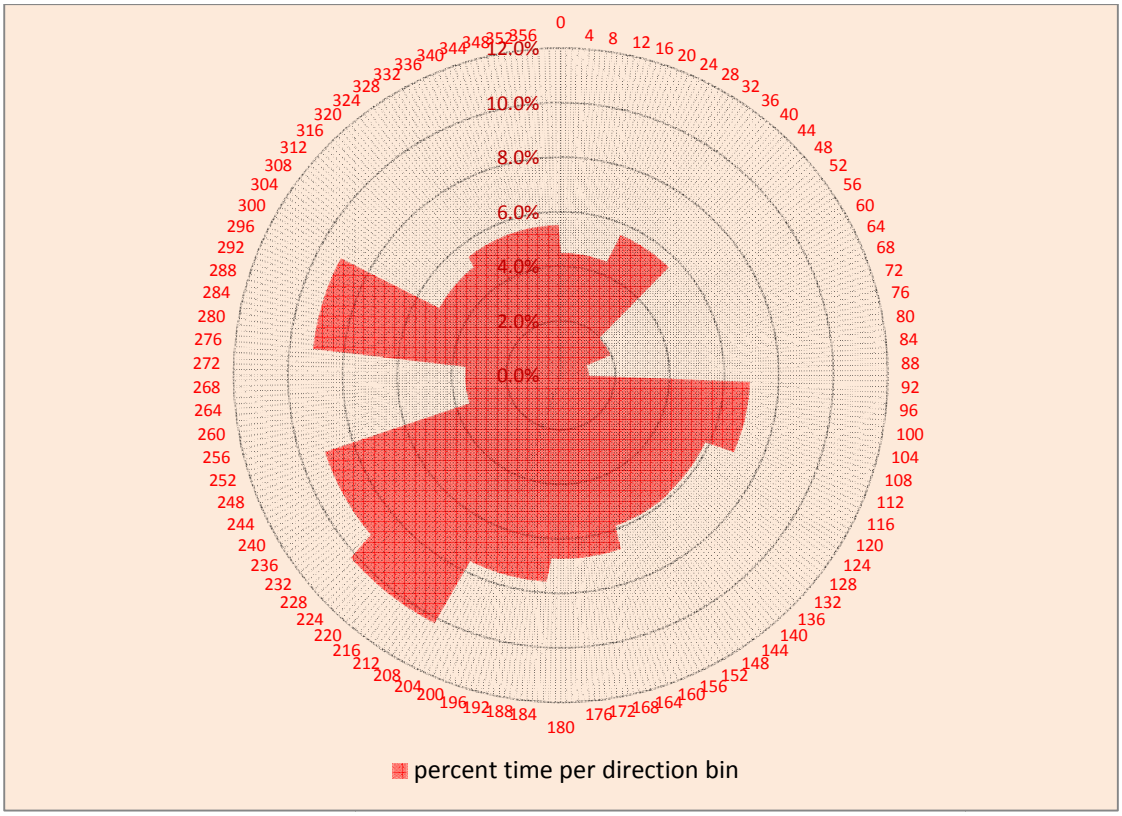
Range Gate 2: Average Wind Speed and Percent Time by Direction



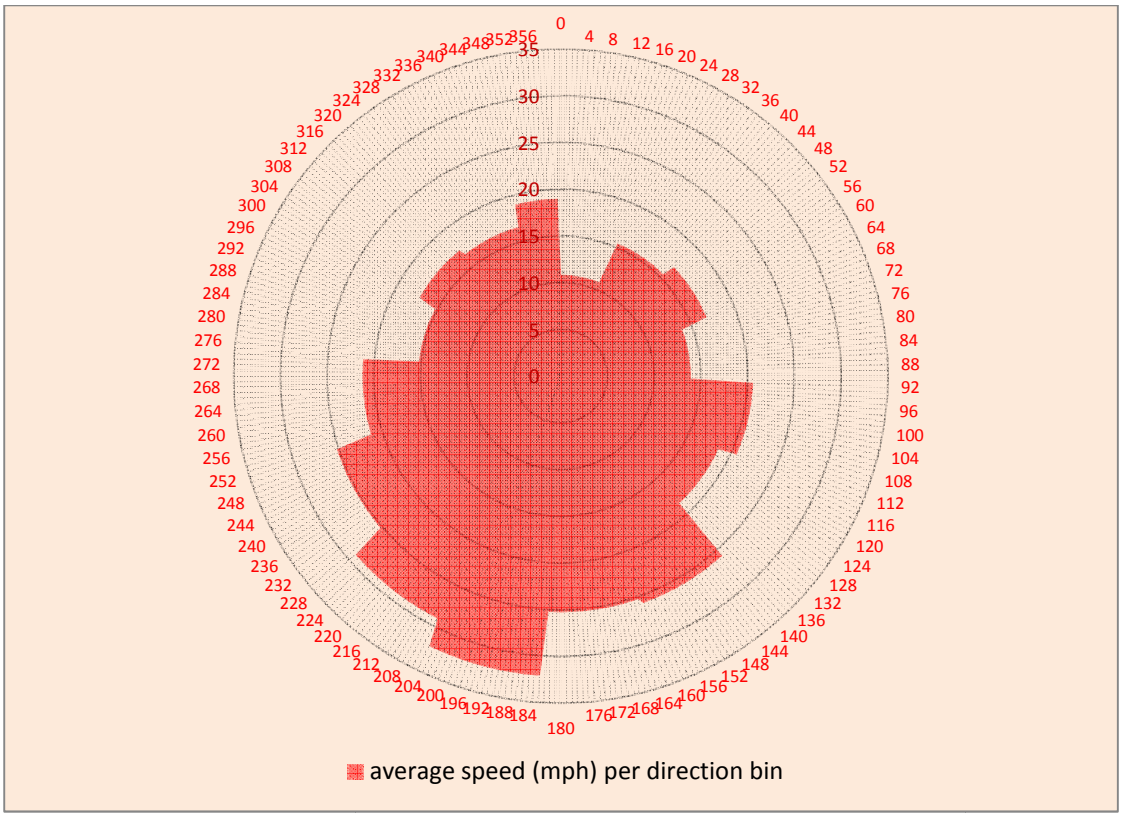


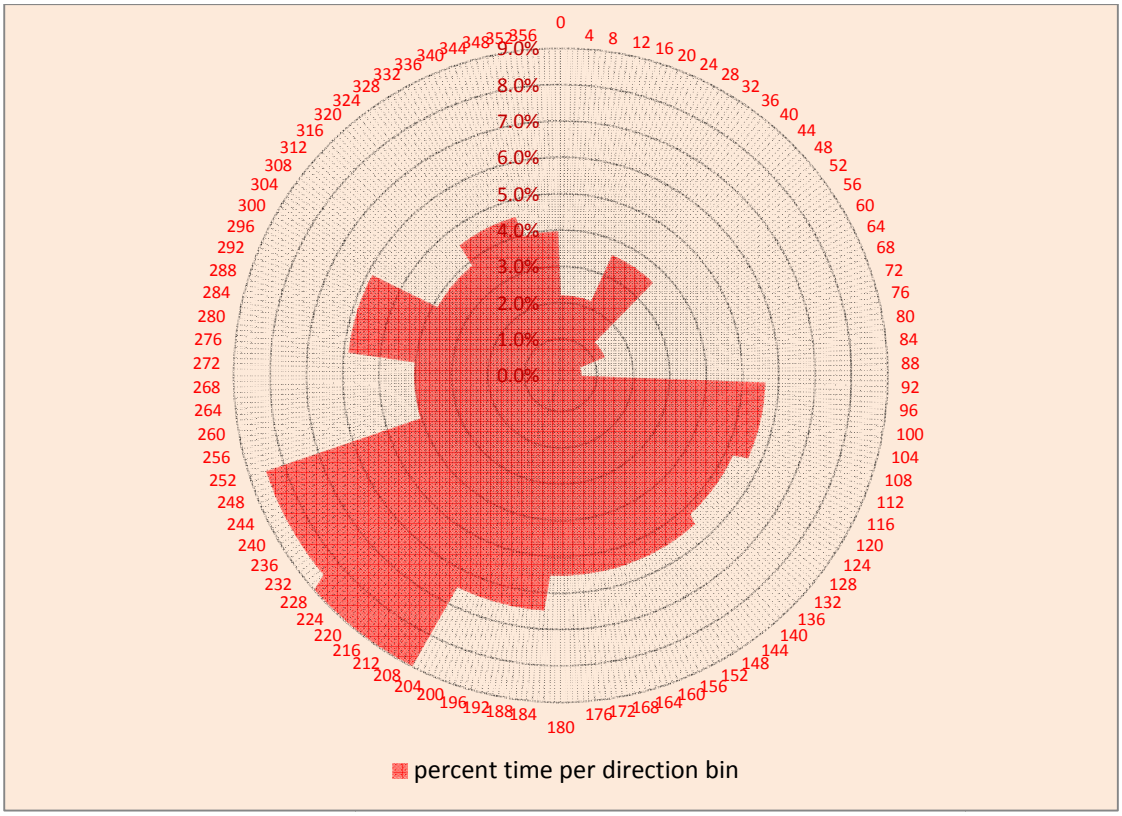
Range Gate 3: Average Wind Speed and Percent Time by Direction



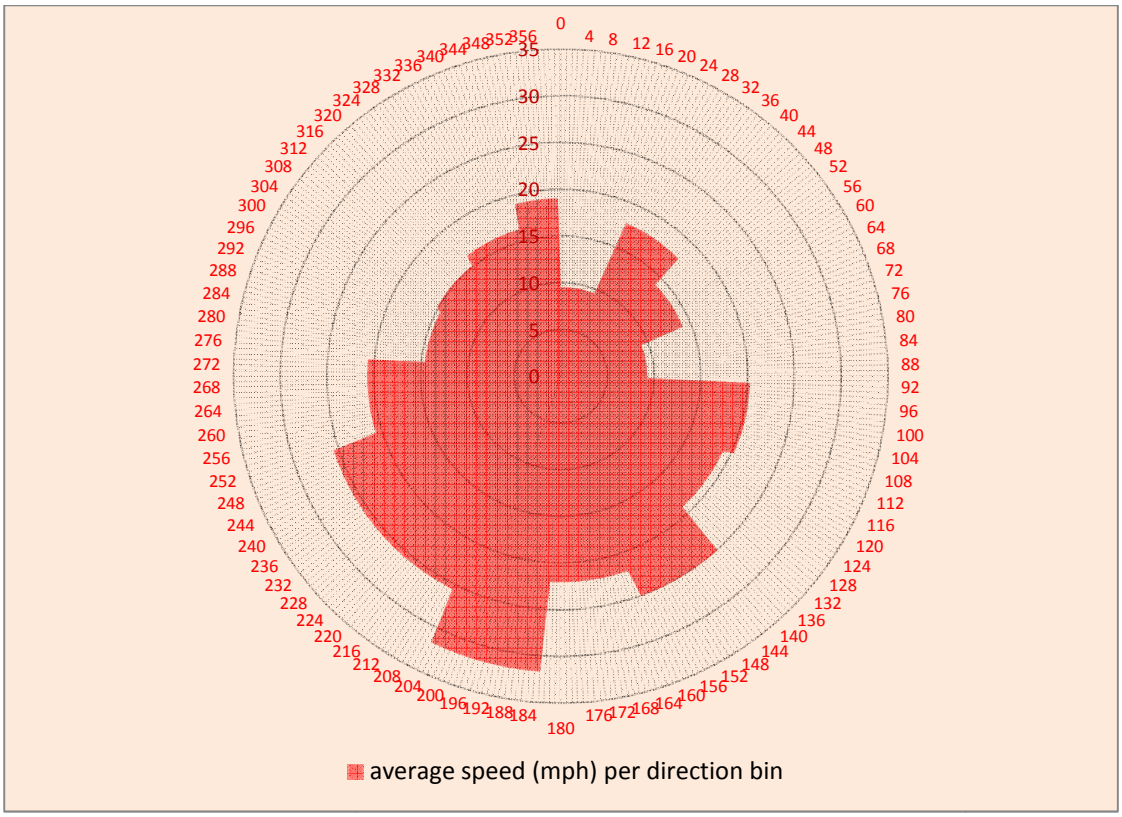


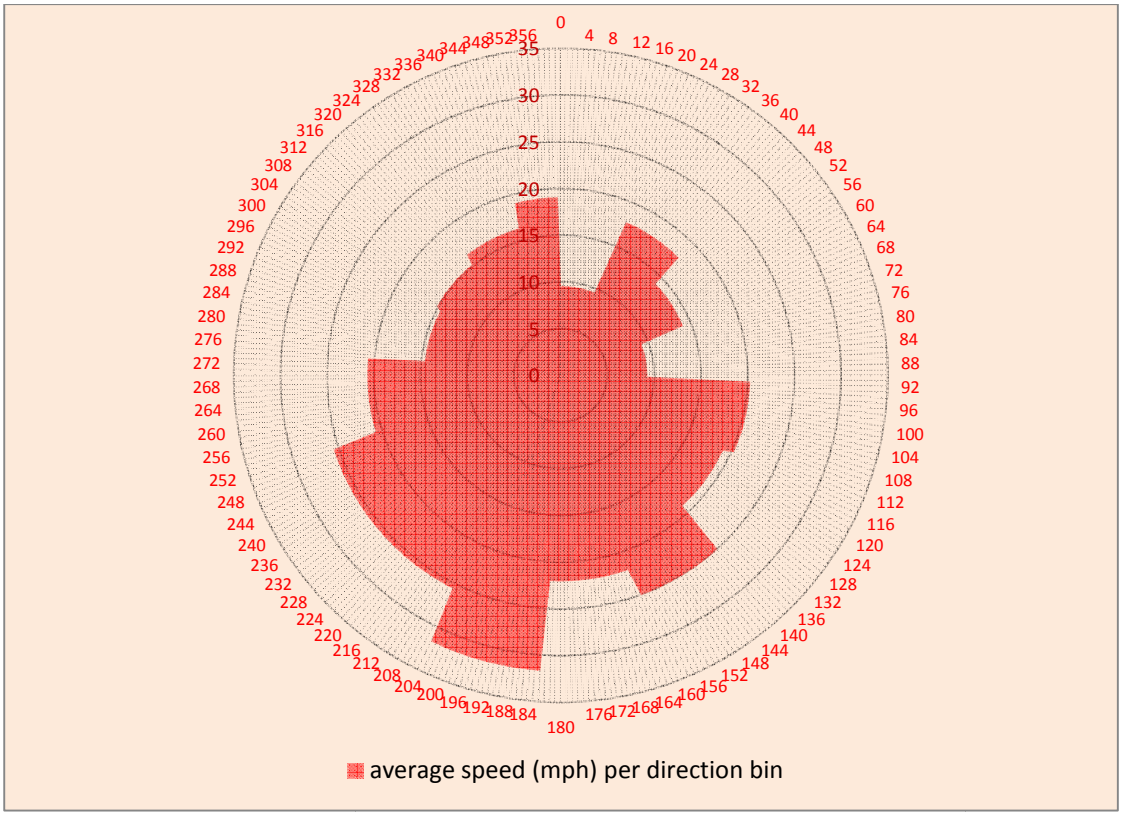
Range Gate 4: Average Wind Speed and Percent Time by Direction



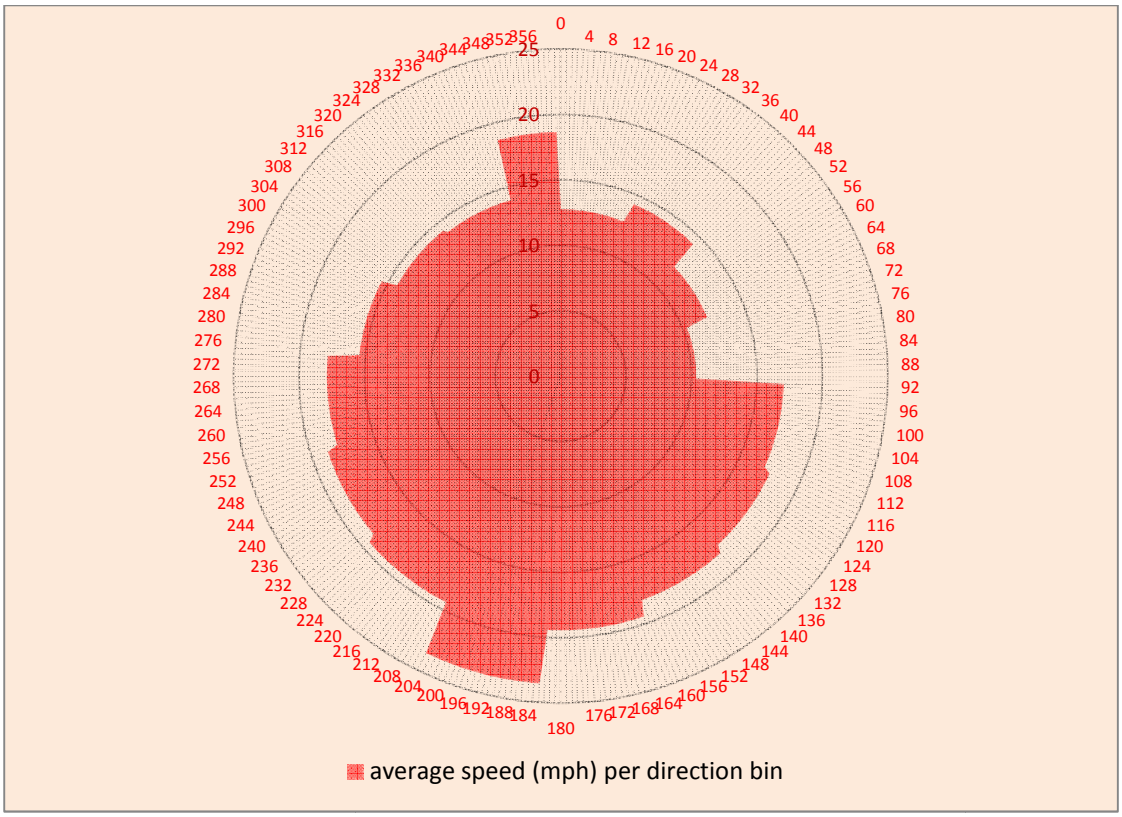


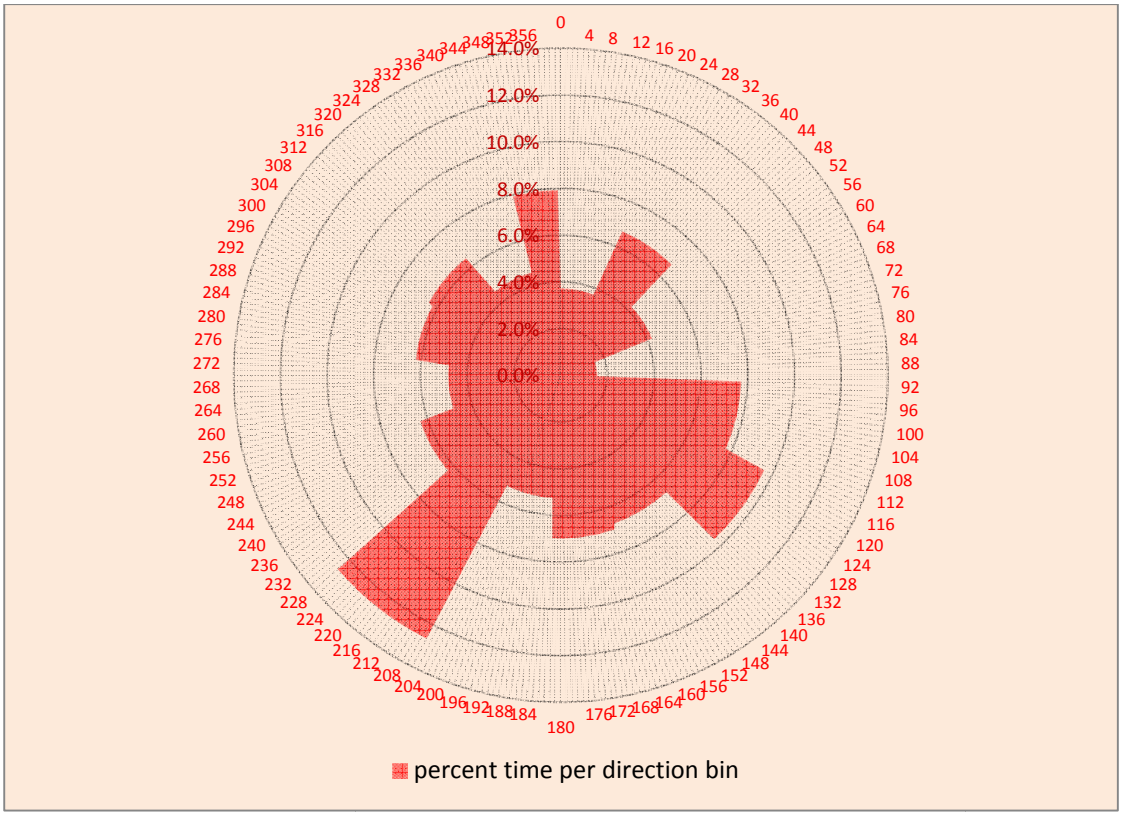
Range Gate 5: Average Wind Speed and Percent Time by Direction





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





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

Notes:

1. Based on the percent of good observations in Table 4, performance appears to be degraded for range gates 5 and 6. This was expected for range gate 6 which is experimental. To demonstrate reliability, the results for range gate 5 need further investigation.
2. Energy potential ranges from 12.6 to 13.2 megawatts hours per day, about 1/3rd more megawatts hours per day than in November and slightly more than in October.
3. The energy potential of the wind at the surface as measured by the cup anemometer on the buoy is about 75% of the energy potential at the higher elevations. The average wind speed is also 75% 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. The maximum difference is about 0.1 m/s about 1%. 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.