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Ministry of New and Renewable Energy
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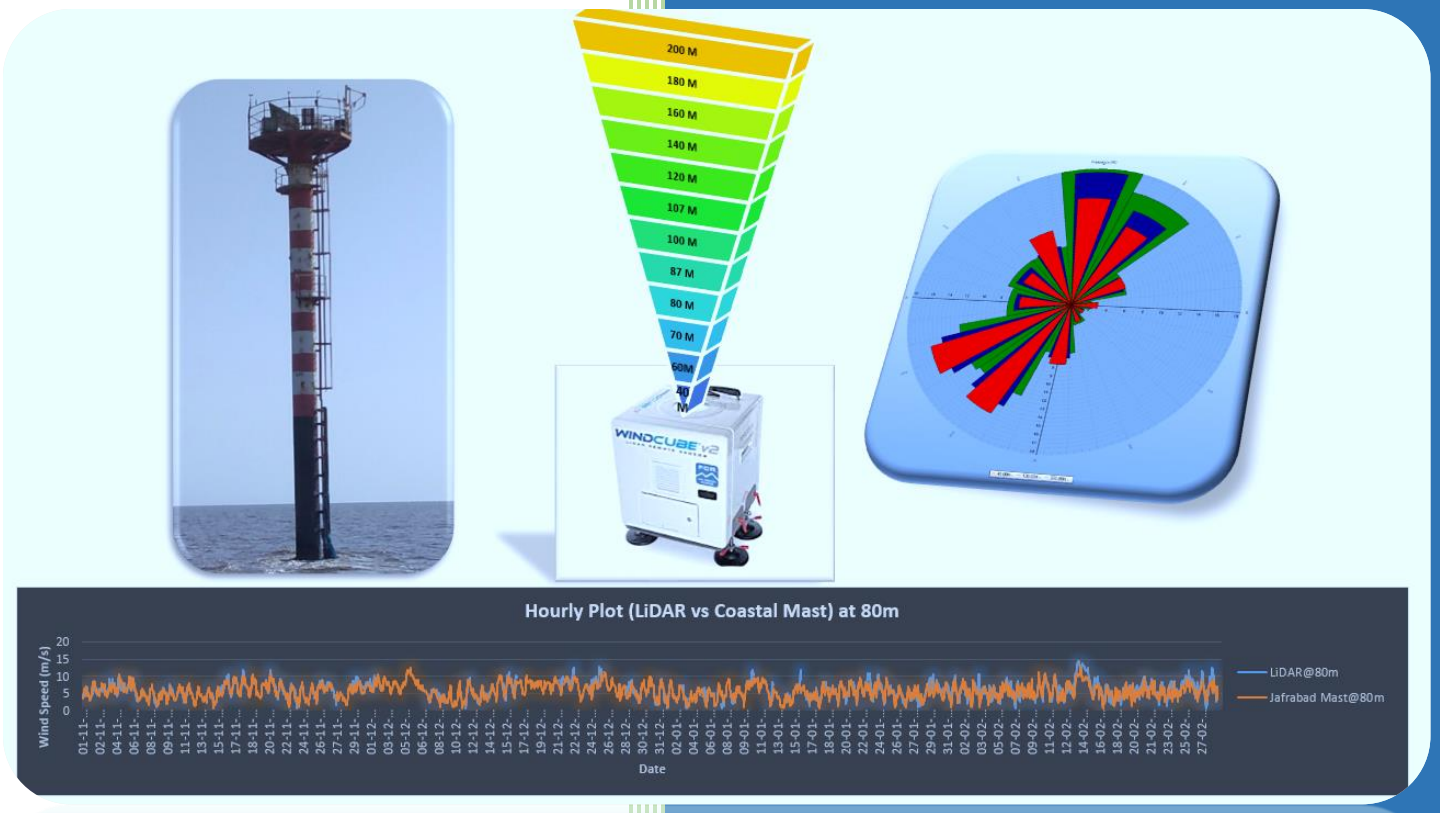
Report

(First Offshore Lidar Wind Data Analysis)

December 2018



Prepared by

National Institute of Wind Energy (NIWE)

Wind Resource Assessment & Offshore Unit

Chennai, India

NATIONAL INSTITUTE OF WIND ENERGY
CHENNAI

Ministry of New and Renewable Energy
Government of India

REPORT ON
FIRST OFFSHORE LIDAR WIND DATA ANALYSIS

Measurement Campaign

November 2017 to November 2018

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Prepared by	: Mr. B. Krishnan & Mr. J.Bastin
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Table of Contents

1. Introduction

The MNRE/NIWE has made consistent efforts to create a conducive environment for the development of offshore wind in the country. During the preparation of the Indian Wind Atlas, RISO DTU Denmark, along with NIWE indicated some offshore wind potential in the southern & western shore of the country.

To assess the actual potential, NIWE has also installed masts along the coastline for preliminary estimates on the offshore potential. Besides this, agencies like Indian National Centre for Ocean Information Services (INCOIS) have given some estimates based on the secondary data available with them.

With the preliminary assessment showing good promising offshore wind potential in the southern tip and west coast of India. Further to facilitate development of offshore wind energy, the National Offshore Wind Energy Policy was announced by the Government of India in October 2015 to establish the policy framework for tapping the offshore wind potential in the country. FOWIND (Facilitating offshore wind energy project in India) led by GWEC with NIWE as knowledge partner has prepared the Pre-feasibility report in which 8 zones have been identified for Gujarat and Tamil Nadu coast.

Based on the satellite data/desktop analysis offshore potential needs to be re-checked by long-term measurements to take better decision for identifying & notifying the zones/sub-zones as per offshore policy. Accordingly, a Lidar based offshore measurement campaign, and first of its kind in the country was initiated in Gulf of Khambhat, Off Gujarat coast.

2. First Offshore wind resource assessment at Gulf of Khambhat

2.1 Site Information-LiDAR based measurement

NIWE has initiated first of its kind LIDAR based wind measurements to validate the potential at the preliminary demarcated zones. The first site was selected at Gulf of Khambhat for carrying out the Lidar based measurements on a monopole structure. The monopile (platform + sub structure) has been installed together with Automatic weather station comprising Anemometer, Wind Vane, Temperature & Pressure at 17m level on March 2017 and subsequently the LiDAR was installed and commissioned successfully on 31st October 2017 after the withdrawal of sea ban imposed by Gujarat Maritime Board. The Lidar location is situated approx. 23km from the Gujarat coast (Pipavav Port) in South-East direction. The site details are tabulated in Table 1.

Table 1: Site Description-LIDAR

Site Name	Gulf of Khambhat (Zone –B as identified by FOWIND)
Taluk/District / State	Jafrabad/Amerli / Gujarat
Lidar location	20°45'19.10"N , 71°41'10.93"E
Water Depth	15m (based on NHO chart)
Distance from coast	23km
Nearest Village	Pipavav
Nearest Town	Jafrabad
Nearest Railway Station	Rajula Junction
Nearest Airport	Diu
Nearest Port	Pipavav/ Jafrabad
Nearest Electrical Substations onshore	Ultratech 220kV
CRZ (as per 2011 notification)	Zone IV

2.2 Site information- Jafrabad coastal mast (100m)

NIWE has also installed the 100m height meteorological mast at Jafrabad coast in line of sight with the LiDAR location at a distance 25km, for the purpose of correlation & validation with the LiDAR measurement. The site details are tabulated in Table 2. Figure 1 shows the satellite images marking the LiDAR location and Jafrabad coastal

mast location. The coastal mast was commenced on November 2017. The wind speed has been measured at multi levels viz., 100m N, 100m S, 80m, 50m and 20m agl and wind direction has been measured at 98m, 78m and 48m agl.

Table 2: Site Description-Jafrabad coastal mast (100m)

Site Name	Jafrabad
Taluk/District / State	Jafrabad/Amerli / Gujarat
Met Mast location	20°53'29.81"N , 71°27'35.68"E
Elevation	9m agl
Distance from LIDAR	25km
Nearest Village	Pipavav
Nearest Town	Jafrabad
Nearest Railway Station	Rajula Junction
Nearest Airport	Diu
Nearest Port	Pipavav/ Jafrabad
Nearest Electrical Substations onshore	Ultratech 220kV

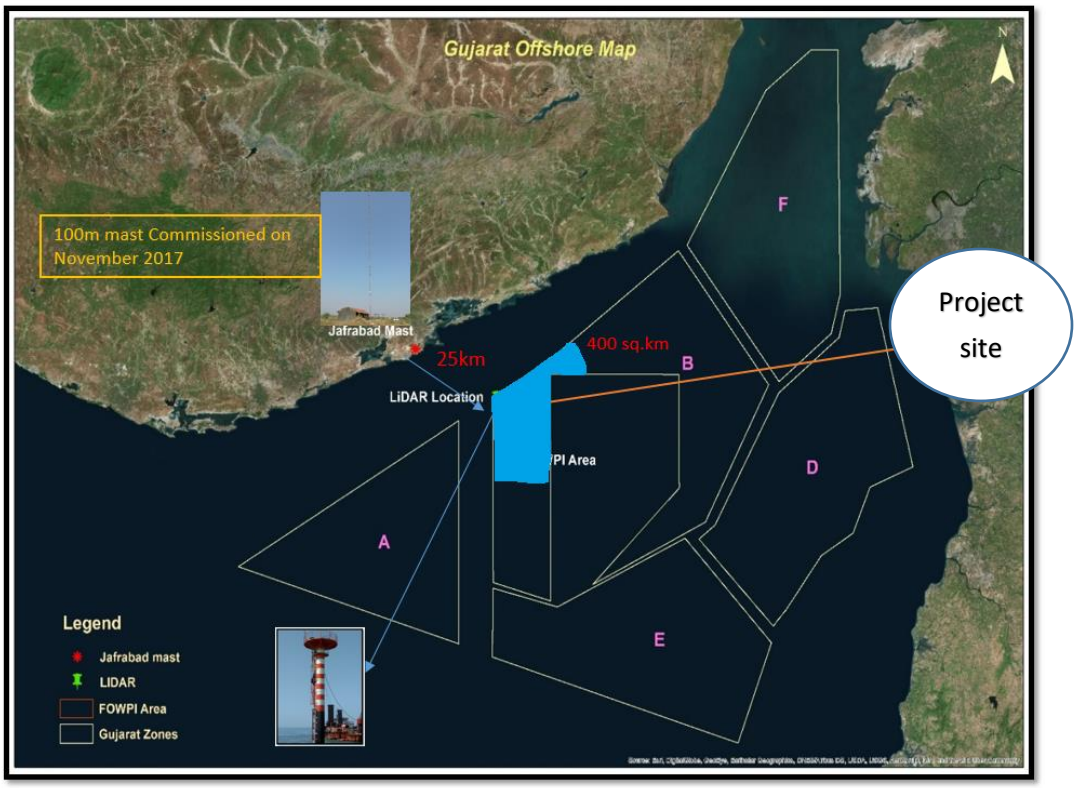


Figure 1: LiDAR and Jafrabad mast location

2.3 LIDAR measurement

Windcube V2 LiDAR can be programmable for 12 various heights with minimum height 40m and Maximum height 200m. The remaining 10 level heights have been configured towards matching the hub heights of currently available offshore wind turbines in the present market. Prior to the offshore installation, the LIDAR instrument (Wind cube) was validated against the 120m high met mast at NIWE's test station at Kayathar, Tamil Nadu. The verification study has shown good correlation coefficients with meteorological mast data (wind speed & wind direction) at inspected height (60m, 90m & 120m) and the details of the study are shown in **Annexure I.** Table 3 depicts the Lidar measurement characteristics. Figure 2 illustrates the different configured heights & vertical wind shear profile. The wind and related weather data were logged as 10 minute averages. Analysis was performed with 10 minutes average data as per standard practice of wind energy sector. The details of the specifications of Installed Windcube V2 LiDAR are attached in **Annexure II**.

As per the Installation/maintenance report prepared by MeteoPole/FOWIND, an offset **-38°** was configured in the Windcube to align the system with north direction.

Table 3: Lidar measurement characteristics

Measurement Type	WindCube V2 LIDAR
Structure height (monopile)	17m LAT*
LIDAR Measurement heights (from platform level)	40,60,80,87,100, 107,120,140,160, 180 & 200m
Location coordinates	(UTM WGS 84, 42Q) 779721 Easting, 2297392 Northing
Date of Commissioning	31/10/2017
Measurement Period (Duration)	01/11/2017 – 30/11/2018 (13 months)
Measurement interval	10-minute
Parameters	Wind Speed, Wind direction, Temperature$, Pressure$ & RH (Relative Humidity) $
Site Air Density (based on measured temperature & Pressure at Platform (m)	1.150 Kg/m^3 (Nov-17 to Jul-18)

*LAT-Low Astronomical Tide, $ -measured at platform level.

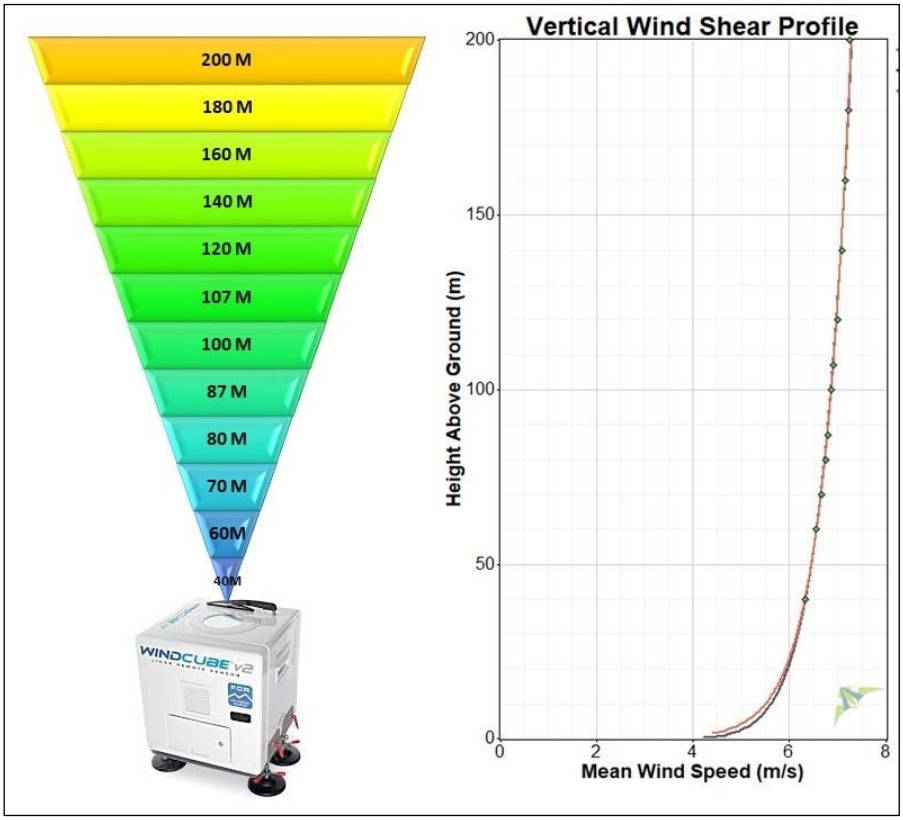


Figure 2: Configuration of LiDAR at different heights & vertical wind shear profile

2.4 Lidar Data Analysis – Synthesis & Validation

Based on the data analysis, the data recovery from the LIDAR instrument seems to be low during November 2017 to January 2018 and No data recorded during 13th July 2018 to 12th September 2018 owing to the technical issues. However, the data gaps pertaining to this period have been synthesized through MCP (Measure-Correlate-Predict) method. After due quality check, the Jafarabad coastal mast data has been extrapolated upto 150m height as per MEASNET guidelines and has been used for the MCP analysis.

Under the MCP method, sector-wise daily mean wind speed data (12 sectors) from the Lidar measurement (40m to 200m height) were correlated with the concurrent data of Jafarabad coastal measurement by using LLS (Least Linear Square) algorithm. The correlation coefficient of determination (R^2) between Lidar data and Coastal mast data was estimated above **0.80,** which seems to be good correlation.

The correlation coefficient of determination (R^2) between Lidar data and coastal mast data are given in Table 4.

Table 4: Correlation coefficient of determination (R^2) between Lidar data and Jafrabad coastal mast data

Lidar (amsl)	Coastal Mast (amsl)	Daily Correlation (R2)
57 (40+17)	59 (50+9)	0.823
77 (60+17)	89 (80+9)	0.835
87 (70+17)	89 (80+9)	0.840
97 (80+17)	109 (100+9)	0.850
104 (87+17)	109 (100+9)	0.854
117 (100+17)	129 (120*+9)	0.846
124 (107+17)	129 (120*+9)	0.846
137 (120+17)	149 (140*+9)	0.847
157 (140+17)	159 (150*+9)	0.842
177 (160+17)	159 (150*+9)	0.837
197 (180+17)	159 (150*+9)	0.831
217 (200+17)	159 (150*+9)	0.822

*Extrapolated data
amsl: above mean seal level

a) Wind Characteristics

Based on the synthesized/validated results, the mean wind speed summary of Lidar data can be obtained from Table 5 and represented in Figure 3. Table 6 represents the Wind Power Density values wherein the air density values calculated at the station are based on the measured temperature, measured pressure and measured humidity installed at platform level (17m) and representation in Figure 4. The details of Lidar data are represented in **Annexure III** and detailed data analysis from Automatic Weather Station is given in **Annexure IV.**

Also, the details of data analysis from the wind monitoring station at Jafrabad is given in **Annexure V**.

Table 5: Wind Speed (Nov 2017 - Nov 2018) – Validated/Synthesized with Jafarabad Costal mast

Height (m)	40m	60m	70m	80m	87m	100m	104m	120m	140m	160m	180m	200m
Nov 17	5.39	5.64	5.73	5.83	5.89	6.00	6.06	6.21	6.36	6.50	6.64	6.73
Dec 17	6.41	6.94	7.05	7.17	7.25	7.36	7.44	7.58	7.74	7.89	8.00	8.06
Jan 18	4.96	5.25	5.35	5.43	5.49	5.58	5.63	5.75	5.87	5.97	6.06	6.11
Feb 18	5.72	6.06	6.18	6.27	6.31	6.36	6.39	6.48	6.51	6.56	6.59	6.57
Mar 18	6.20	6.56	6.72	6.87	6.95	7.05	7.11	7.26	7.35	7.41	7.45	7.49
Apr 18	6.49	6.66	6.74	6.81	6.84	6.88	6.90	6.98	7.02	7.07	7.10	7.12
May 18	8.36	8.50	8.57	8.62	8.65	8.68	8.71	8.78	8.83	8.88	8.91	8.86
Jun 18	9.33	9.52	9.60	9.67	9.72	9.77	9.82	9.75	9.85	9.98	10.10	10.17
Jul 18	9.62	10.01	10.10	10.52	10.57	10.57	10.58	10.70	10.83	10.96	11.07	11.14
Aug 18	8.83	9.10	9.20	9.68	9.72	9.79	9.81	9.89	10.00	10.13	10.24	10.29
Sep 18	6.28	6.41	6.48	6.77	6.81	6.91	6.94	7.05	7.14	7.21	7.27	7.29
Oct 18	4.33	4.49	4.58	4.68	4.73	4.80	4.85	4.98	5.08	5.16	5.23	5.25
Annual Average	**6.83**	**7.09**	**7.19**	**7.36**	**7.41**	**7.48**	**7.52**	**7.62**	**7.72**	**7.81**	**7.89**	**7.92**
Nov 18	4.79	4.96	5.05	5.13	5.18	5.22	5.26	5.36	5.42	5.48	5.55	5.58

Note: *The period from November 2017 to January 2018 and 13th July 2018 to 12th September 2018 data has been synthesized by using MCP technique.*

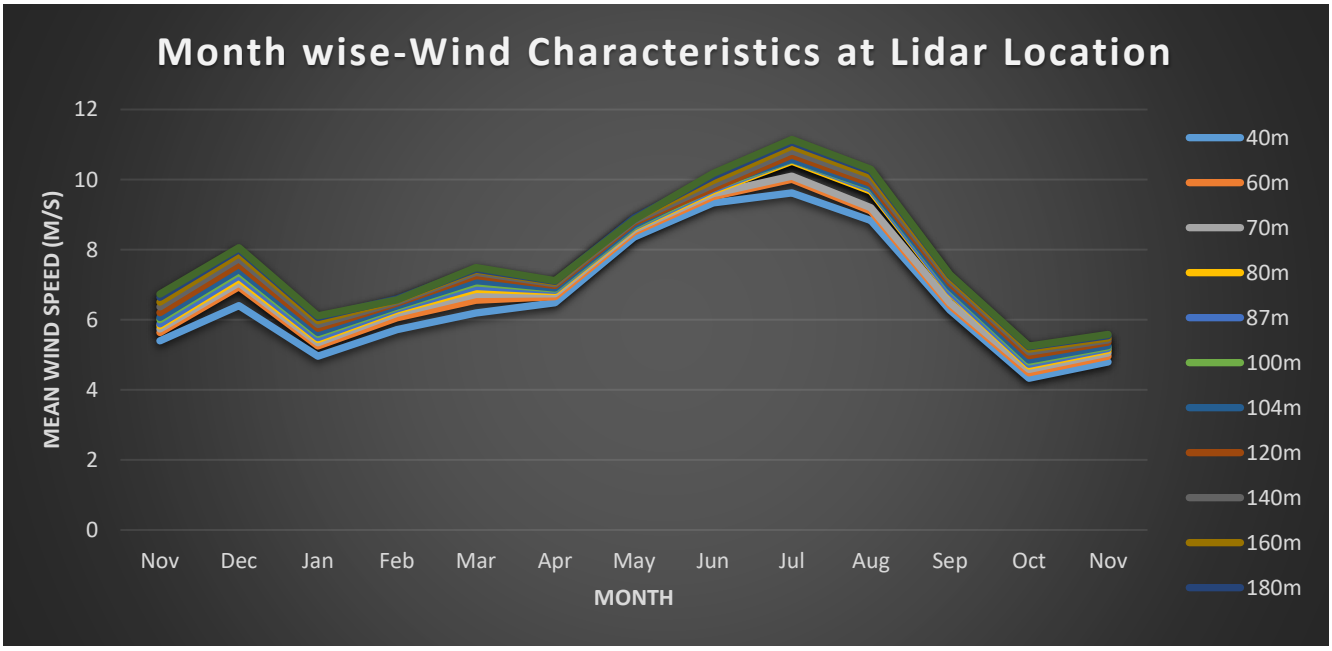


Figure 3: Monthly mean wind speed

Table 6: Wind Power Density (Nov 2017 - Nov 2018) – Validated/Synthesized with Jafarabad Costal mast

Height (m)	40m	60m	70m	80m	87m	100m	104m	120m	140m	160m	180m	200m
Nov 17	105	122	128	134	138	147	151	162	176	189	201	210
Dec 17	192	244	256	268	277	291	299	317	340	362	379	389
Jan 18	85	105	111	117	121	128	132	141	150	159	166	170
Feb 18	138	164	176	185	191	198	203	214	225	236	246	249
Mar 18	147	175	188	202	209	218	224	239	248	256	261	266
Apr 18	174	186	193	198	201	204	207	213	218	223	228	231
May 18	351	369	378	385	388	392	396	406	413	421	427	421
Jun 18	491	523	538	550	558	569	578	576	597	622	648	666
Jul 18	558	621	637	716	725	724	725	748	775	803	830	846
Aug 18	440	481	495	577	585	598	602	616	637	662	684	695
Sep 18	177	191	197	231	234	247	249	262	273	283	290	294
Oct 18	58	65	69	74	77	81	83	91	97	102	107	108
Annual Average	**243**	**271**	**281**	**303**	**309**	**316**	**321**	**332**	**346**	**360**	**372**	**379**
Nov 18	76	85	90	95	98	101	104	111	118	124	130	134

Note: The data for the period from November 2017 to January 2018 and 13th July 2018 to 12th September 2018 Synthesized using MCP technique

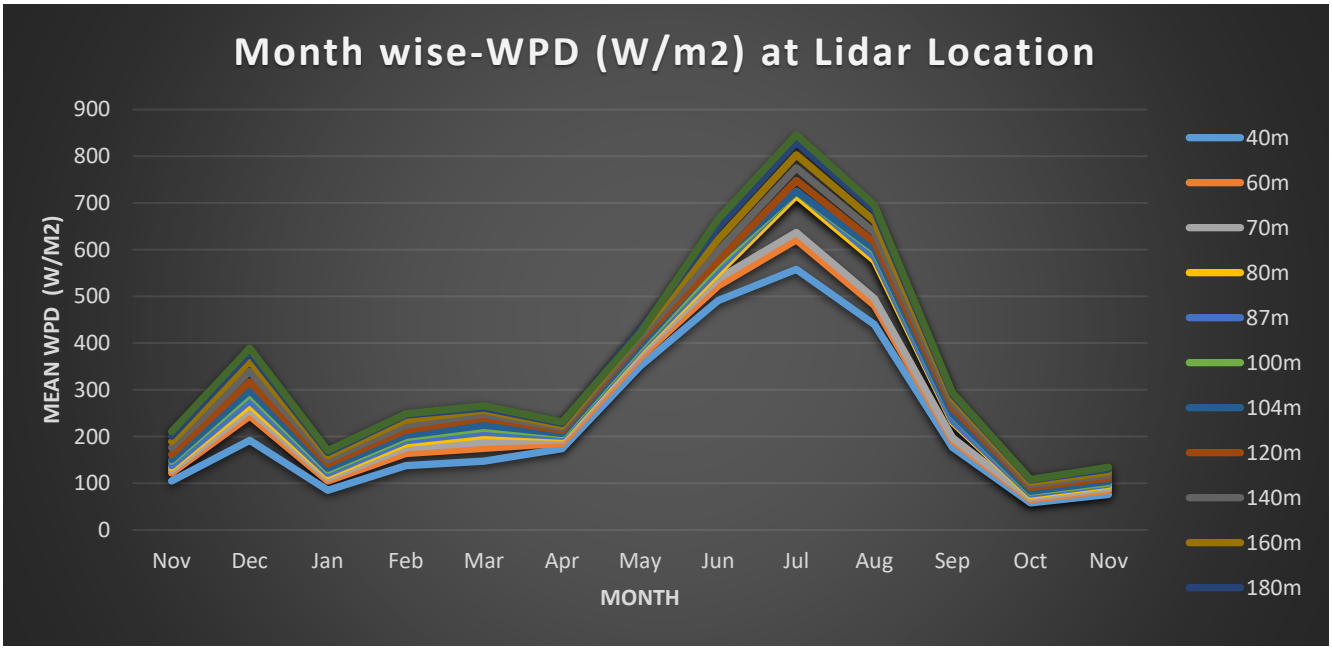


Figure 4: Monthly-Mean Wind Power Density

b) Wind Rose

Based on the data, it is revealed that the primary prevalent wind direction is SSW (south of south west) with a wind speed occurrence about 20% and secondary prevalent wind direction is North (wind speed occurrence in North direction is about 15%). The wind rose indicating all measured heights is given in Figure 5.

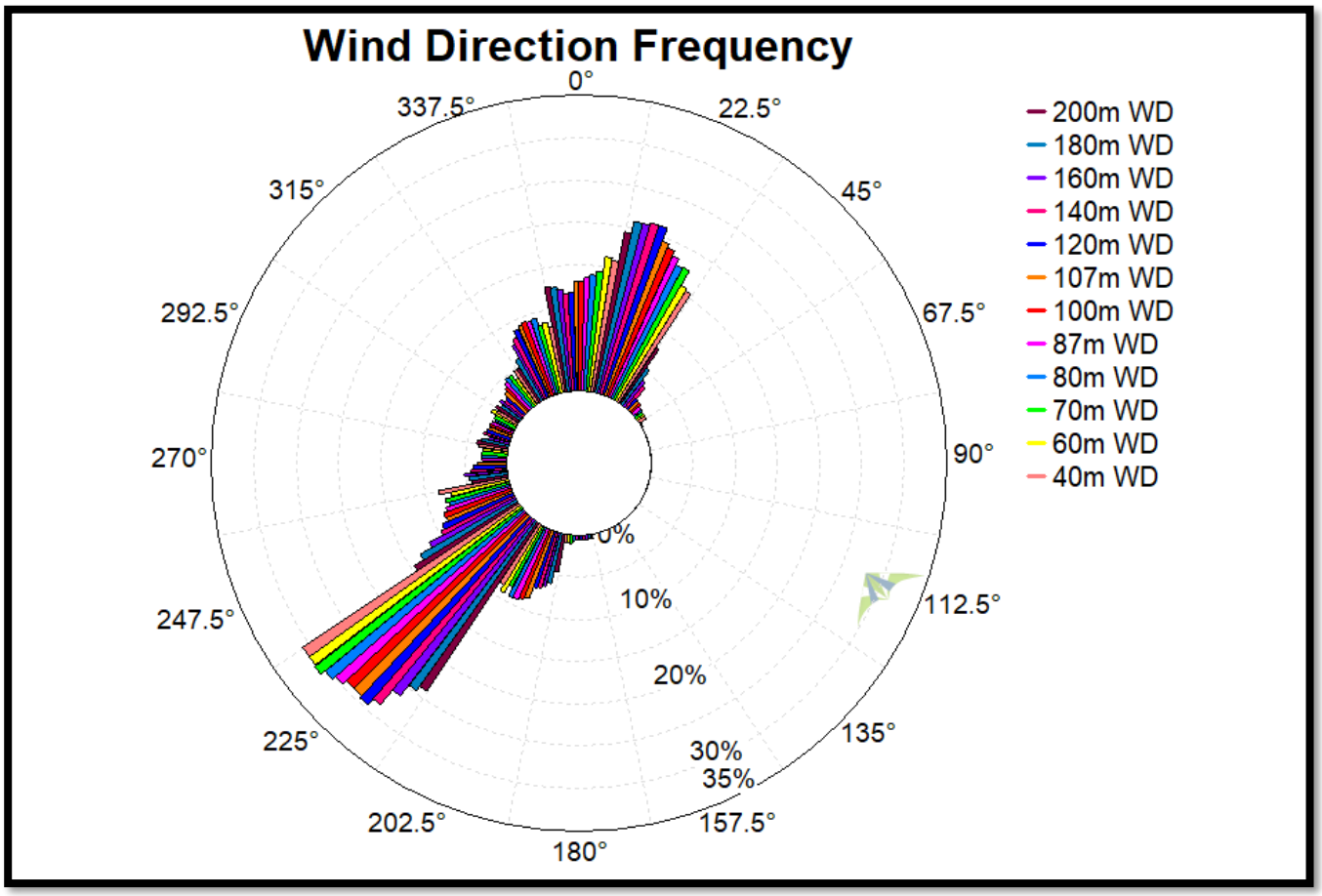


Figure 5: Wind Rose (Nov 2017 – Nov 2018)

Annexures

Annexure : I

VALIDATION OF LiDAR

The Windcube Offshore LIDAR has validated with 120m height met mast, which was installed at a distance of 40m apart in parallel to the meteorological tower (120m height) which is used as reference mast located at Wind Turbine Test Station, Kayathar, Tirunelveli district, Tamil Nadu. The terrain of the selected area is a homogeneous terrain, which is already known for its wind potential. Data have been collected for 52 days (22.05.2016 - 13.07.2016) from the met mast and from the LIDAR instruments. The LIDAR data was validated by comparing it with measurements from the met mast in order to determine the correlation of the wind Data from both LIDAR and Mast and determine the correlation coefficient. The actual site images of met mast and LIDAR is shown in Figure 1 & 2.

Figure 1: LiDAR set up

Figure 2: 120m Met Mast

Based on the analysis, it was found that the LIDAR gives good correlation coefficients with the metrological mast wind speed & direction at inspected heights (60m, 90m, 120m) as shown below.

Correlation Coefficient (R2) for Wind Speed

Description	120m	90m	60m
Mast v/s Lidar	0.998	0.997	0.997

Correlation Coefficient (R2) for Wind Direction

Description	120m	90m	60m
Mast v/s Lidar	0.998	0.998	0.999

Annexure : II

Specifications of Installed Windcube V2 LiDAR

PERFORMANCE	
Range	40 to 290m*
Data sampling rate	1s
Averaging time	1 min, 2 min, 5 min, 10 min (user programmable)
Number of programmable heights	12 measured simultaneously
Speed accuracy	0.1 to 0.5 m/s
Speed range	0 to +60 m/s
Direction accuracy	2°

* The measurement range may depend on atmospheric conditions

HARDWARE AND ENVIRONMENTAL	
Dimensions	L-W-H : 543 x 552 x 540 mm
Weight	45 kg
Power consumption	45 W nominal
Environmental	• Temperature range -30°C to +45°C/-22°F to 108°F • Operating humidity: 0 to 100% RH (non-condensing) • Housing classification IP67 (for inner racks)
Safety	Class 1M IEC / EN 60825-1
Compliance	CE

SOFTWARE / DATA	
Data format	ASCII
Data storage	SSD and compact flash (backup storage)
Data transfer	LAN / USB / 3G
Software features	• Configuration and control • Real time display • Diagnostic
Output data	• 1s & 1/2/5/10min horizontal & vertical wind speed • Min & Max • Turbulence • Direction • SNR Quality factor (data availability) • GPS coordinates

ANNEXURE III

1. Lidar Analysis Details

a) Time Series Profile

A time series profile will be helpful to understand the variation of parameters within the measured duration in detail and handy in the identification & removal of the erroneous data. The time series profile for the wind speed measurement at various heights for available data is shown in Figure 1.

Similarly, Figure 2 & 2a represents the daily mean wind profile and daily mean wind profile after synthesis using MCP. Also Figure 3 & 3a represents the monthly mean wind profile and monthly mean wind profile after synthesis using MCP along with Figure 4 & Figure 5 illustrating diurnal mean wind speed profiles and the month wise diurnal pattern for visualization.

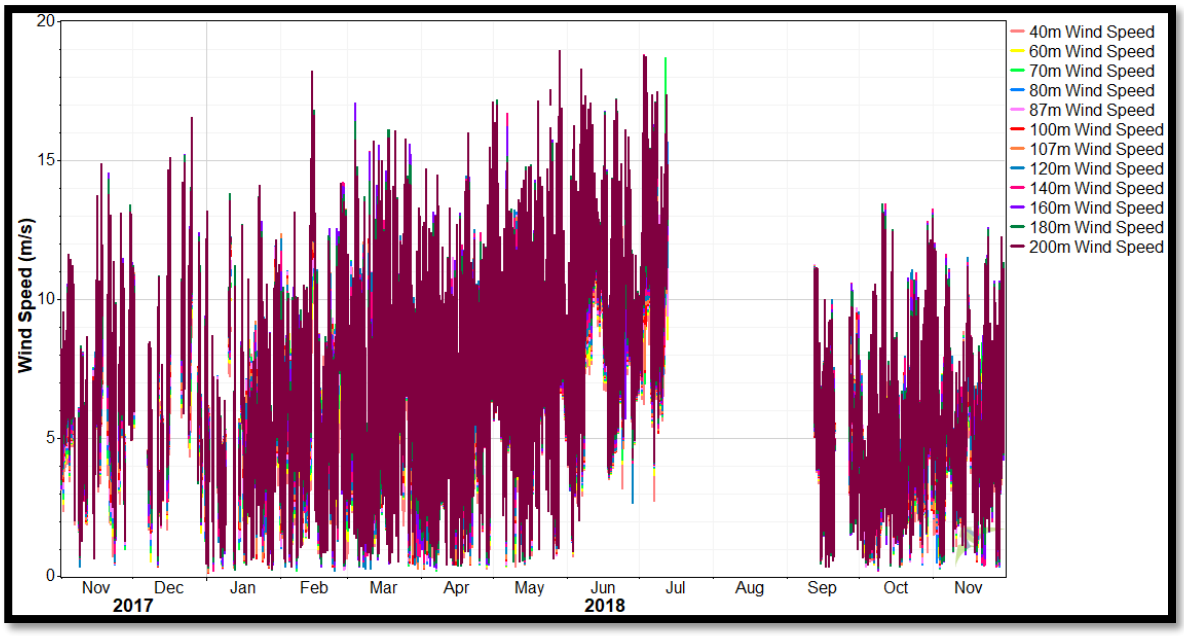


Figure 1: Time Series (10minute) Profile of Wind Speed (40m to 200m)

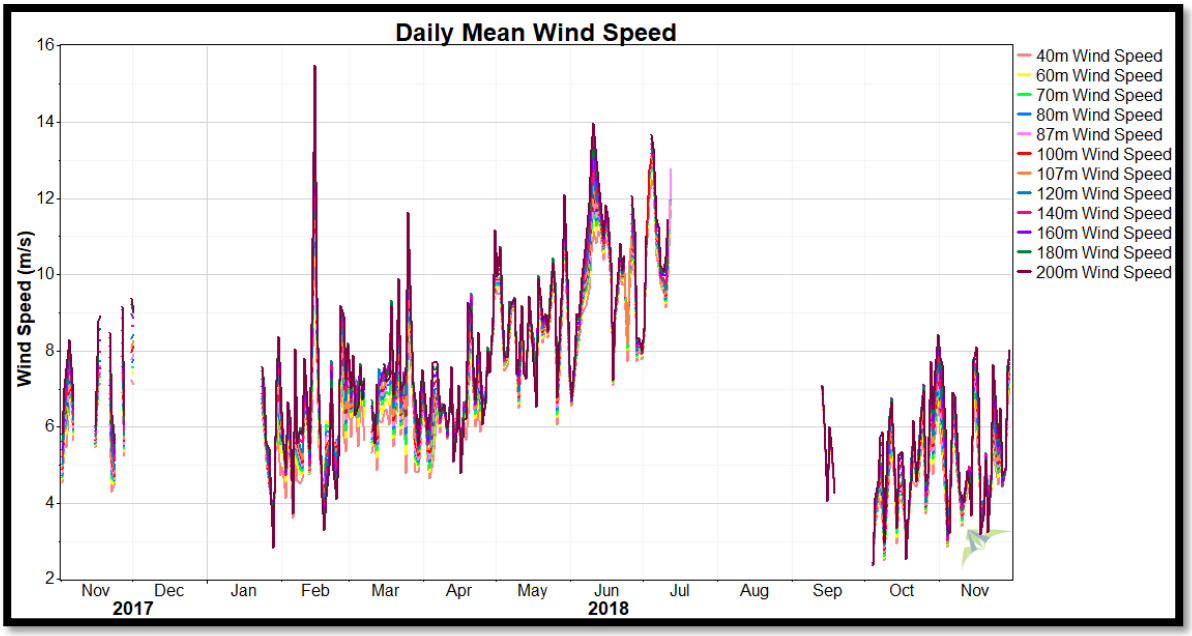


Figure 2: Daily Mean Wind Profile (Nov 2017 - Nov 2018)

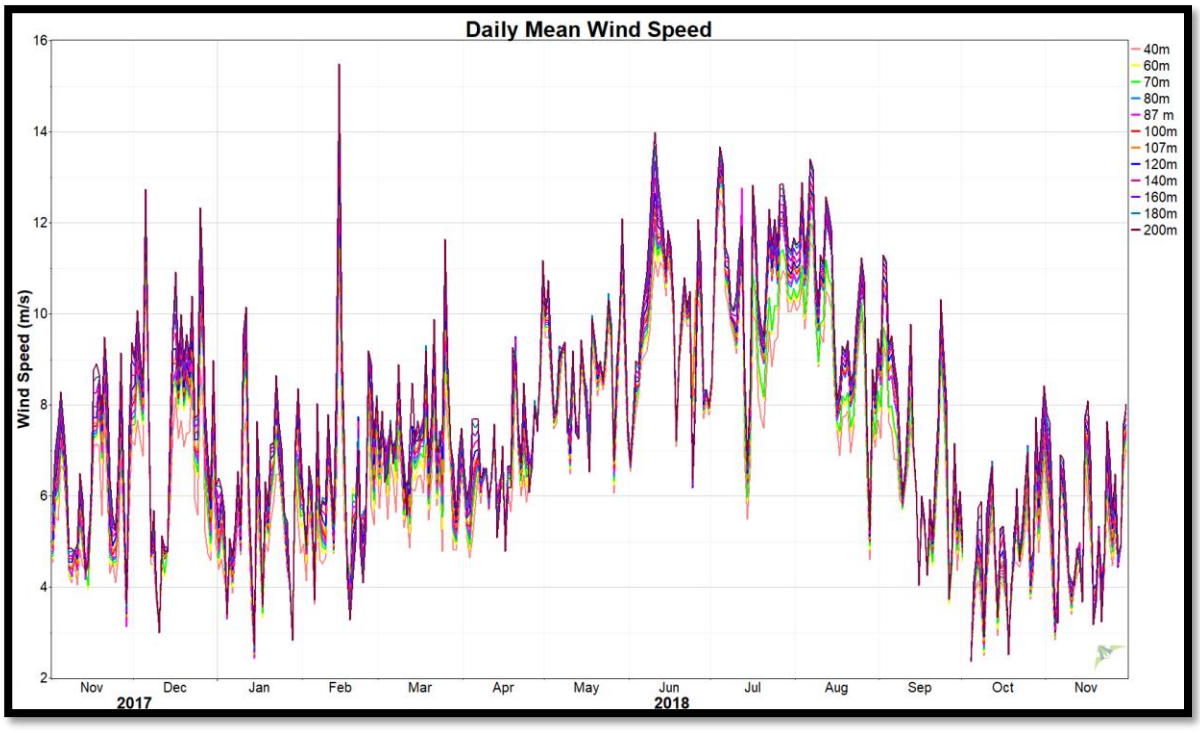


Figure 2a: Daily Mean Wind Profile after synthesis using MCP (Nov 2017 - Nov 2018)

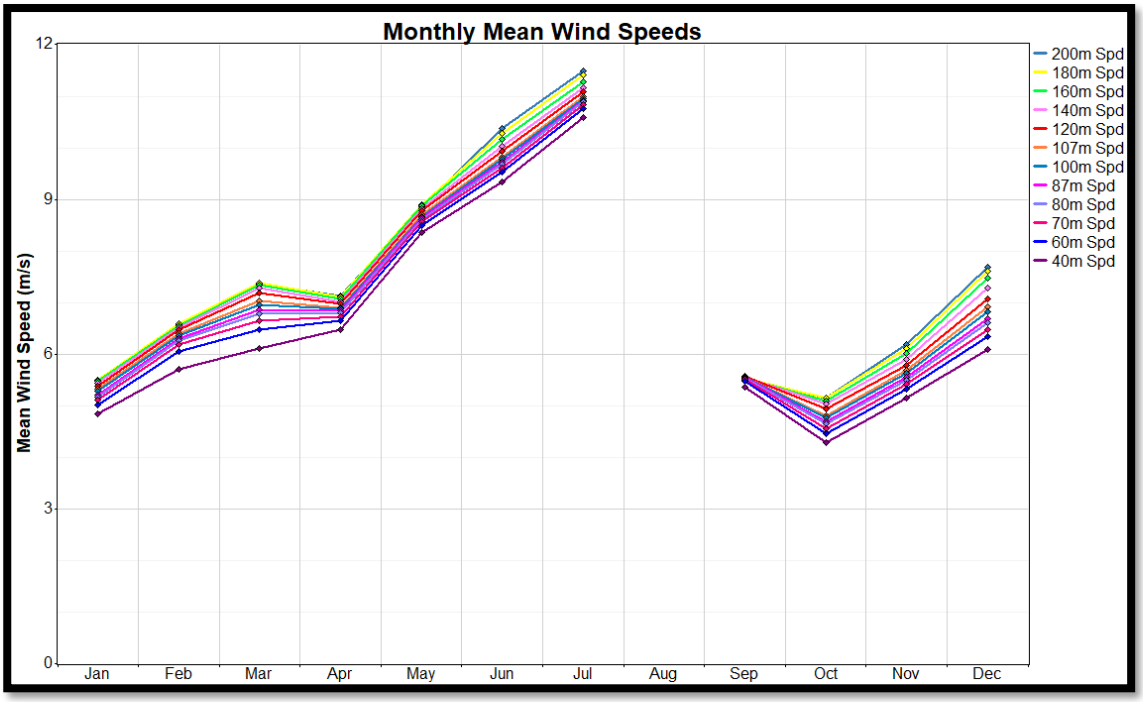


Figure 3: Monthly Wind Profile (Nov 2017 – Nov 2018)

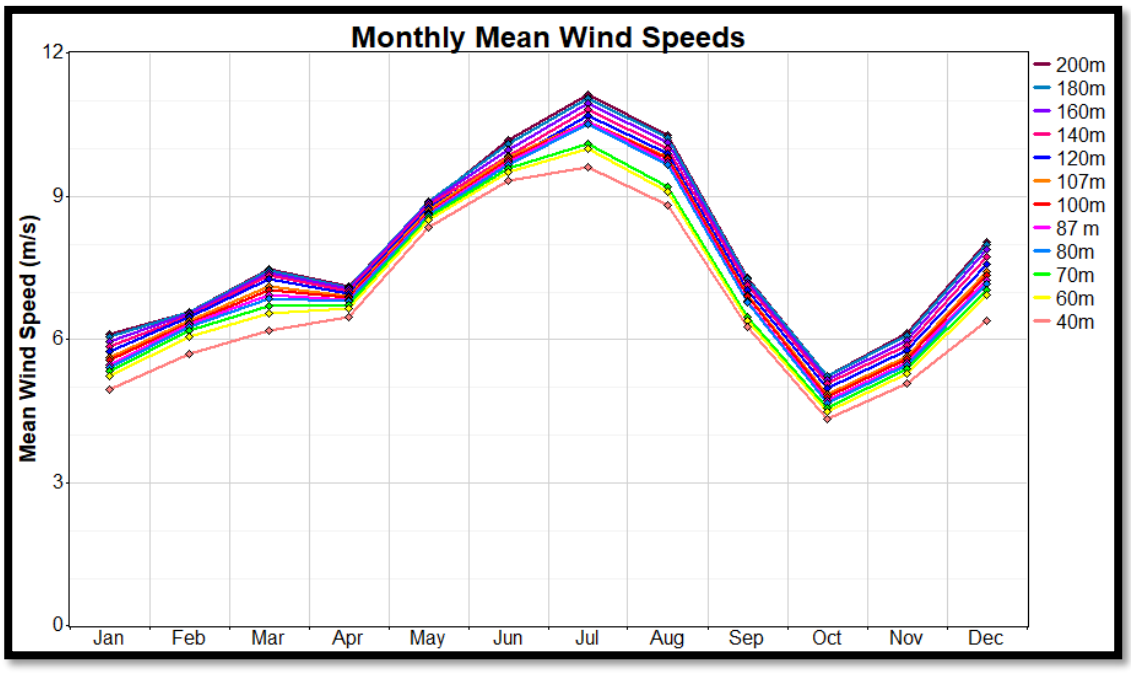


Figure 3a: Monthly Wind Profile after synthesis using MCP (Nov 2017 – Nov 2018)

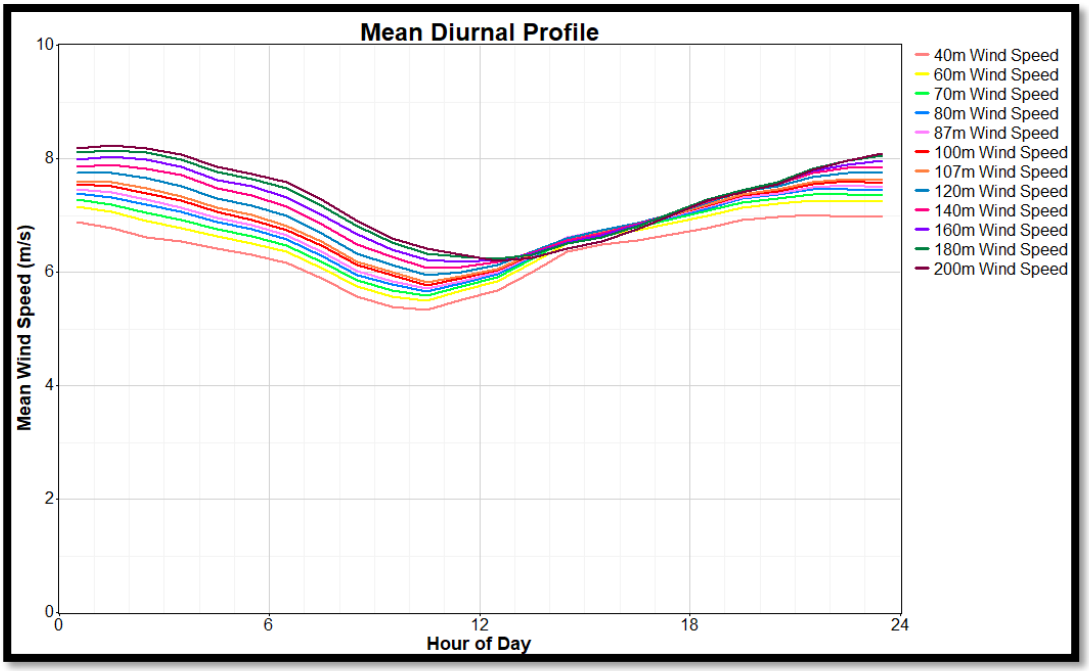
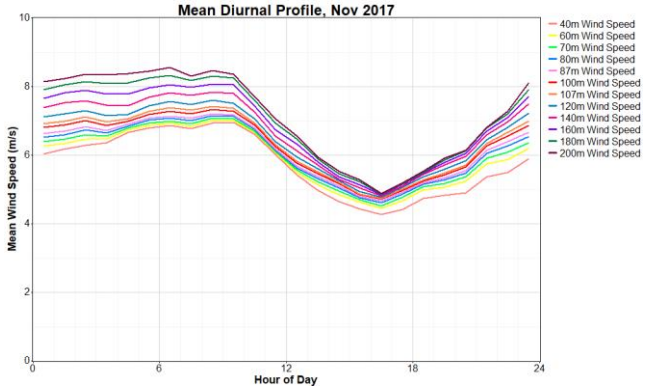
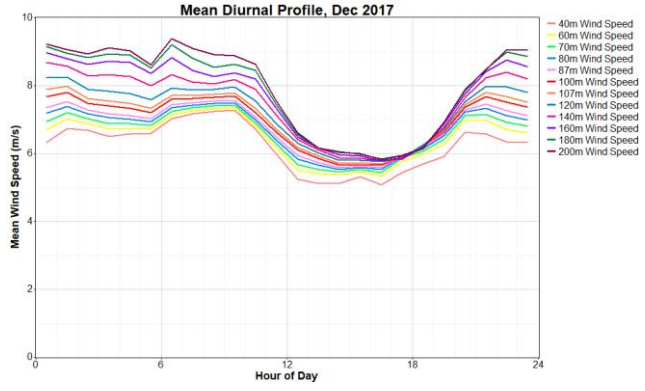


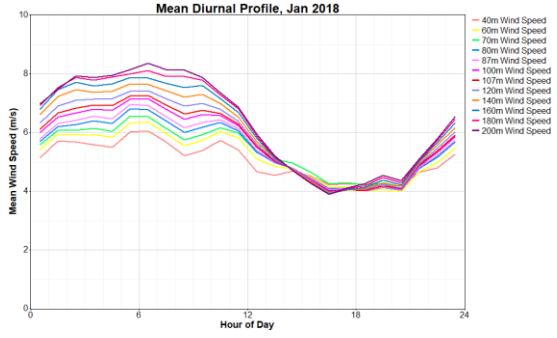
Figure 4: Diurnal Wind Profile (Nov 2017 – Nov 2018)



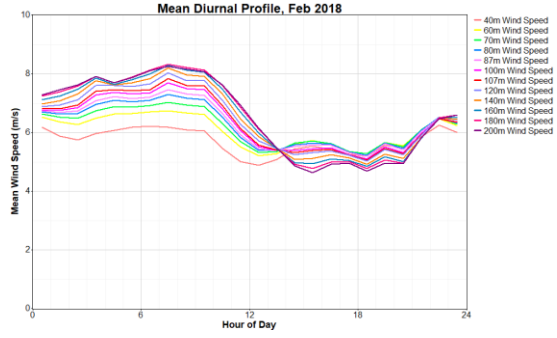
Nov-17



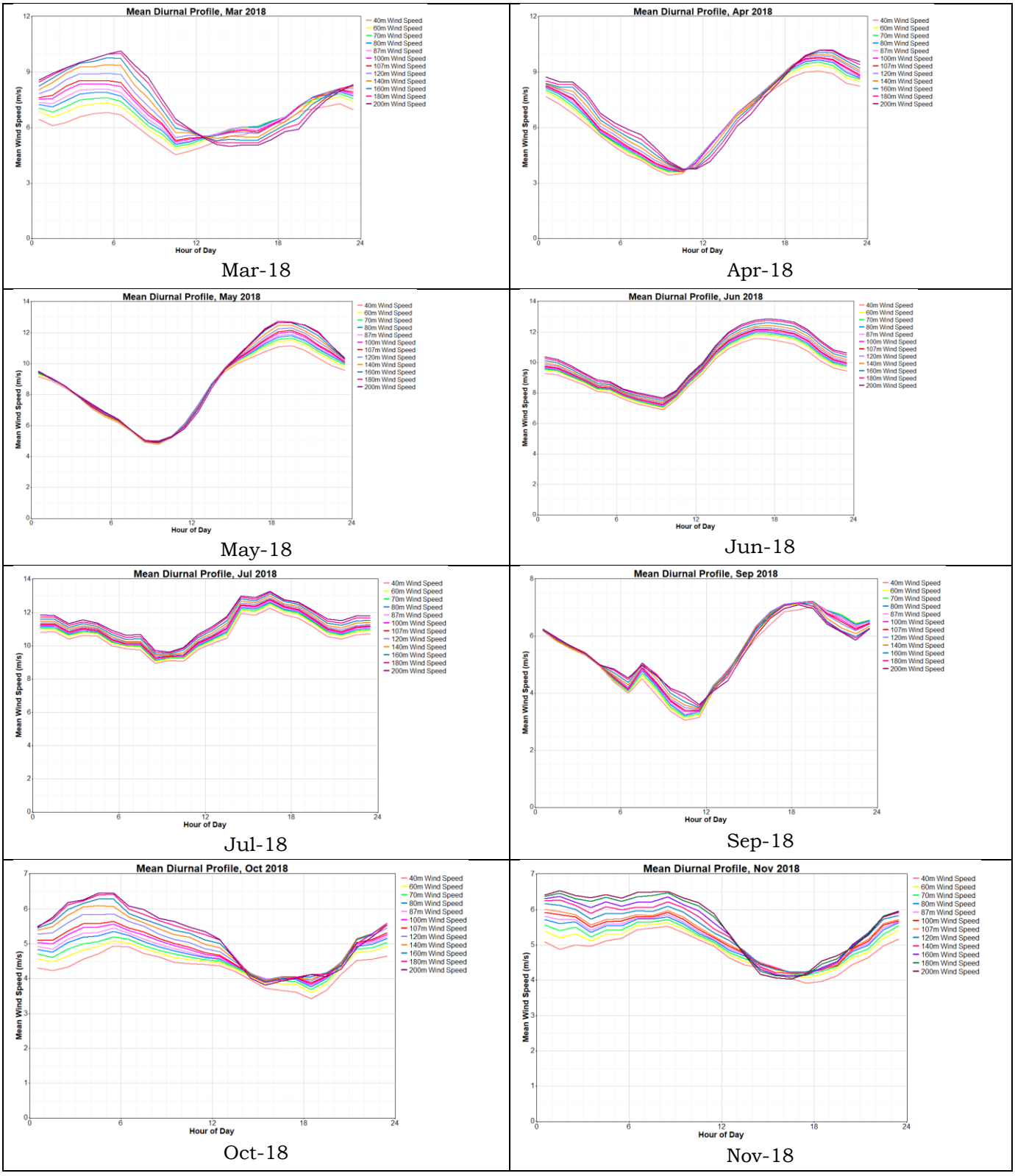
Dec-17



Jan-18



Feb-18



Mar-18 Apr-18

May-18 Jun-18

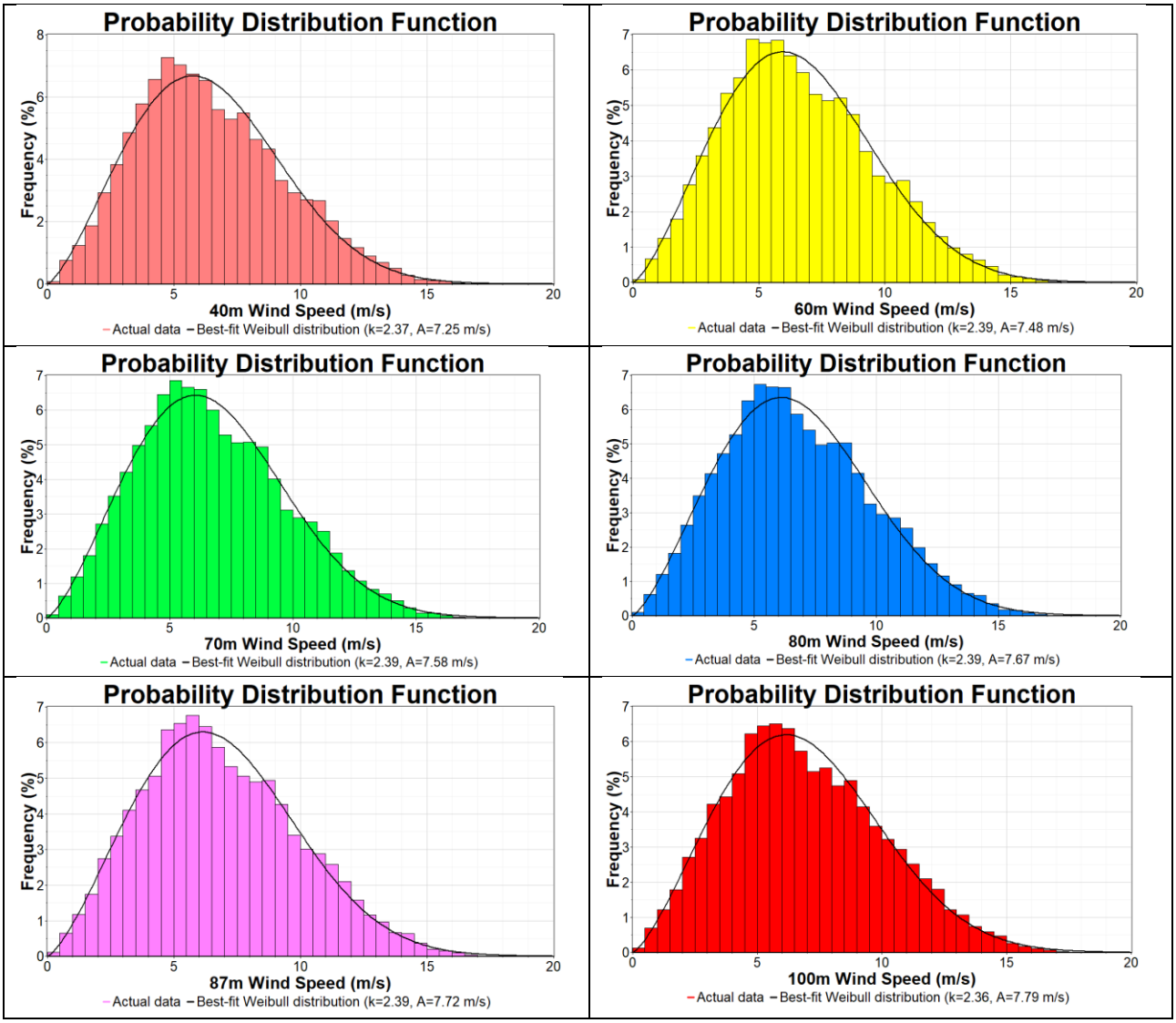
Jul-18 Sep-18

Oct-18 Nov-18

Figure 5: Month-wise diurnal pattern

b) Wind Frequency Distribution

The distribution of the wind speed data is presented by histogram plots, which is a common method of displaying a year of wind data. It is also known as wind frequency distribution, which shows the percentage of time each wind speed occurs. Figure 6 shows the measured frequency distribution as well as the Weibull distribution for wind speed measurements at various heights recorded. Weibull distribution is commonly used to approximate the wind speed frequency distribution. Table 1 depicts the 1 m/s binned percentage frequency distribution at different heights.



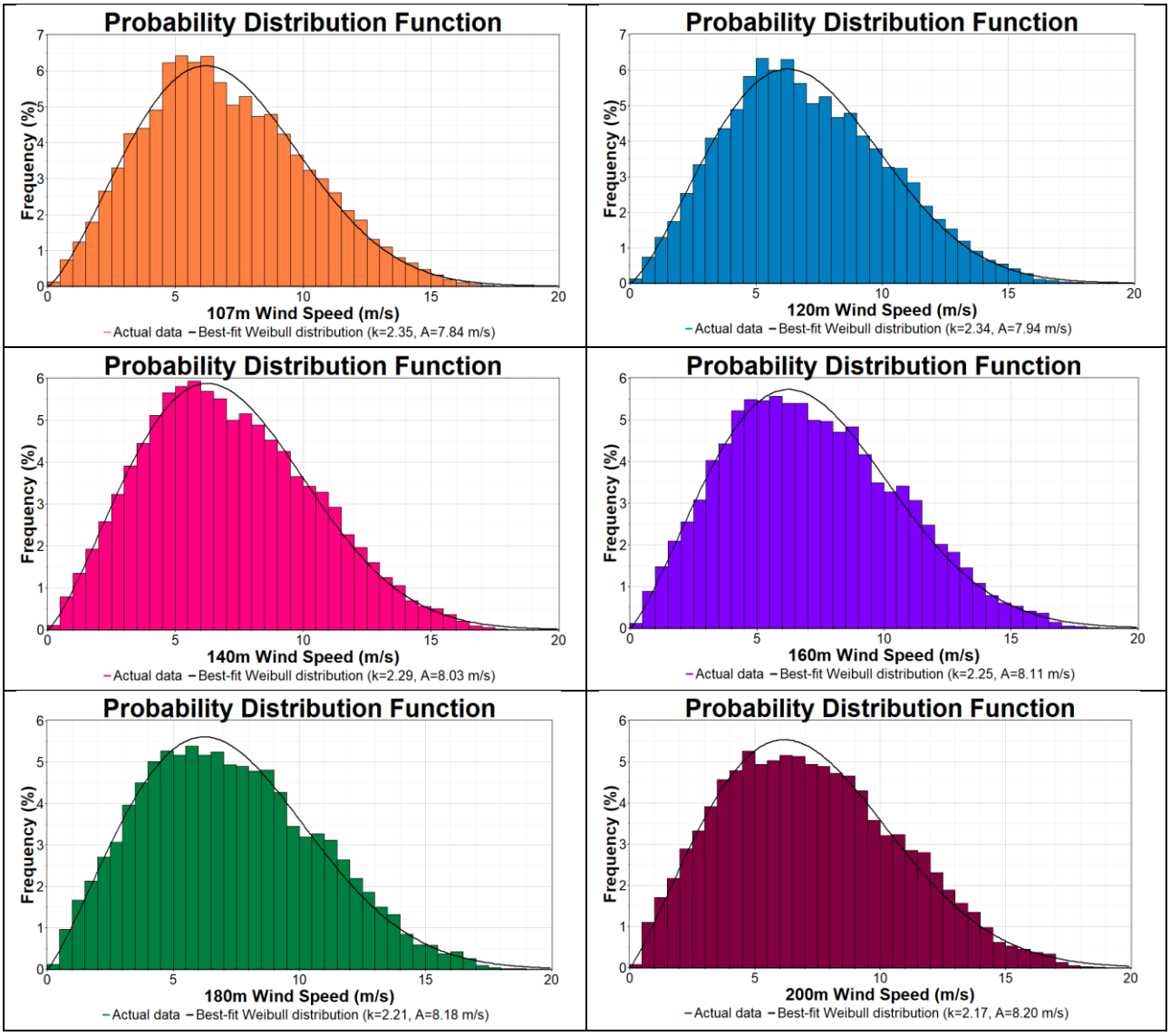


Figure 6: Wind Speed Histogram (Nov 17 - Nov 18)

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Table 1: Percentage Frequency Distribution Table (Nov 17 – Nov 18)

Bin (m/s)		Percentage Frequency Distribution (%)											
Lower Point	Upper Point	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
0	1	0.84	0.75	0.73	0.72	0.76	0.83	0.87	0.86	0.90	1.01	1.08	1.20
1	2	3.11	3.03	2.99	3.02	2.92	3.01	3.01	3.03	3.29	3.57	3.80	3.88
2	3	6.77	6.34	6.25	6.13	6.11	5.97	5.95	5.88	5.82	5.64	5.79	6.22
3	4	10.65	9.71	9.19	8.85	8.78	8.66	8.66	8.45	8.38	8.46	8.48	8.49
4	5	13.84	12.65	12.00	11.53	11.43	11.33	11.14	10.72	10.79	10.72	10.29	10.05
5	6	13.79	13.61	13.52	13.41	13.31	12.97	12.67	12.34	11.75	11.04	10.57	9.97
6	7	12.13	12.35	12.61	12.52	12.33	12.12	12.08	11.93	11.22	10.80	10.42	10.29
7	8	10.78	10.46	10.36	10.38	10.39	10.40	10.34	10.32	10.17	9.95	9.84	9.83
8	9	8.98	9.96	10.02	10.06	9.84	9.65	9.52	9.46	9.41	9.55	9.60	9.38
9	10	6.27	6.71	7.12	7.41	7.68	7.76	7.90	7.94	7.92	7.67	7.73	7.89
10	11	5.39	5.70	5.66	5.80	5.89	6.16	6.23	6.50	6.72	6.69	6.47	6.46
11	12	3.48	3.98	4.39	4.53	4.68	4.62	4.73	5.01	5.21	5.55	5.76	5.66
12	13	2.07	2.27	2.44	2.67	2.73	3.01	3.16	3.33	3.58	3.84	4.06	4.20
13	14	1.20	1.44	1.52	1.56	1.64	1.82	1.89	2.10	2.32	2.53	2.83	2.92
14	15	0.44	0.66	0.80	0.95	1.00	1.06	1.11	1.20	1.26	1.40	1.46	1.60
15	16	0.21	0.28	0.29	0.34	0.36	0.44	0.51	0.69	0.87	0.95	0.96	0.99
16	17	0.04	0.08	0.10	0.12	0.14	0.17	0.19	0.20	0.32	0.51	0.70	0.72
17	18	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.05	0.07	0.10	0.14	0.20
18	19	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.06
19	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

c) Wind Shear Profile

The wind shear profile at the site is useful to understand the wind speed variation with respective height. Table 2 represents the month-wise power law and log law values. Figure 7 shows the nature of wind shear at Gulf of Khambhat, off Gujarat Coast based on the measured data using log law and power law.

Table 2: Vertical Wind Shear Profile Table

Month	Power Law (alpha)	Log Law (z0)
Nov-17	0.145	0.093765
Dec-17	0.157	0.159204
Jan-18	0.111	0.011593
Feb-18	0.083	0.000480
Mar-18	0.120	0.020547
Apr-18	0.063	0.000011
May-18	0.040	0.000000
Jun-18	0.063	0.000012
Jul-18	0.054	0.000001
Aug-18	-	-
Sep-18	0.012	0.000000
Oct-18	0.124	0.028941
Nov-18	0.119	0.021307

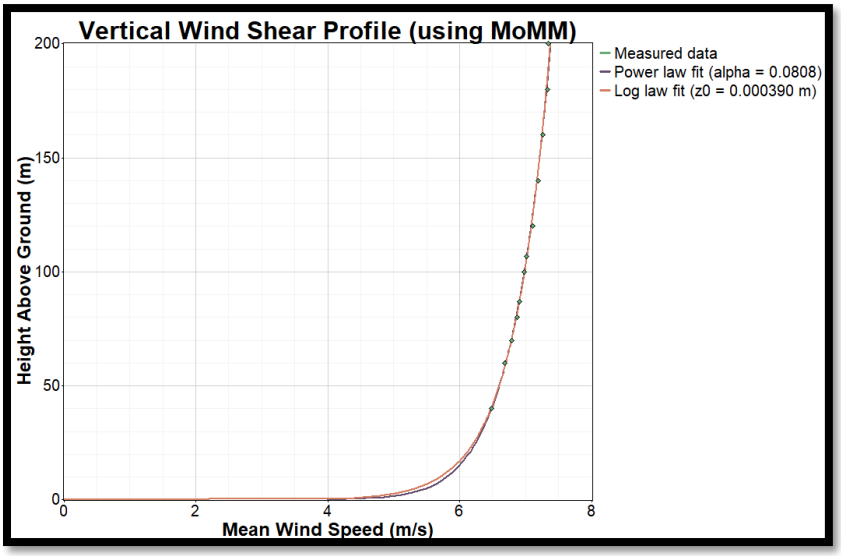
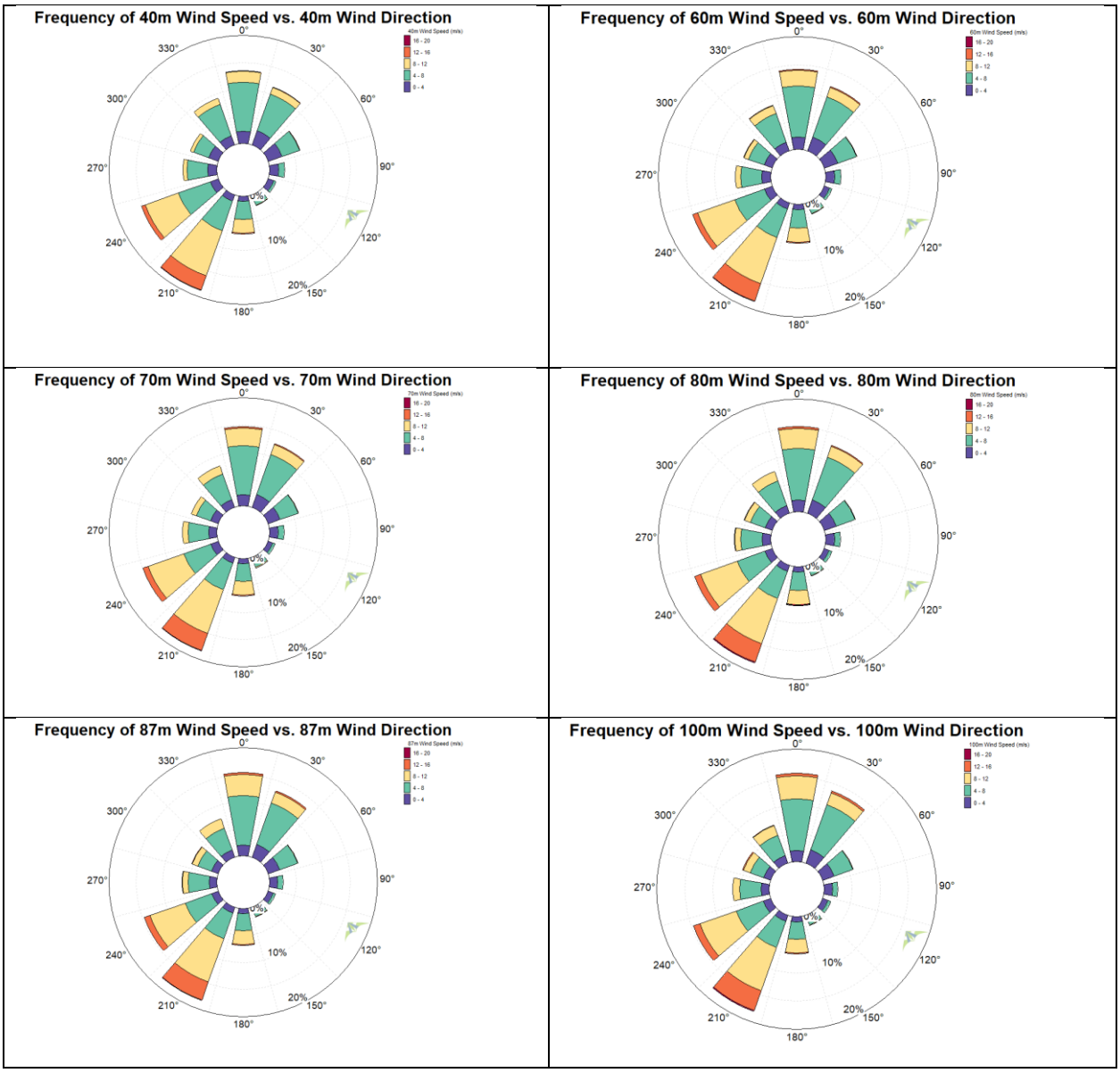


Figure 7: Vertical Wind Shear Profile

d) Wind Rose

The 12 sector wind roses based on wind direction data available at various heights (40m to 200m) are shown in Figure 7.



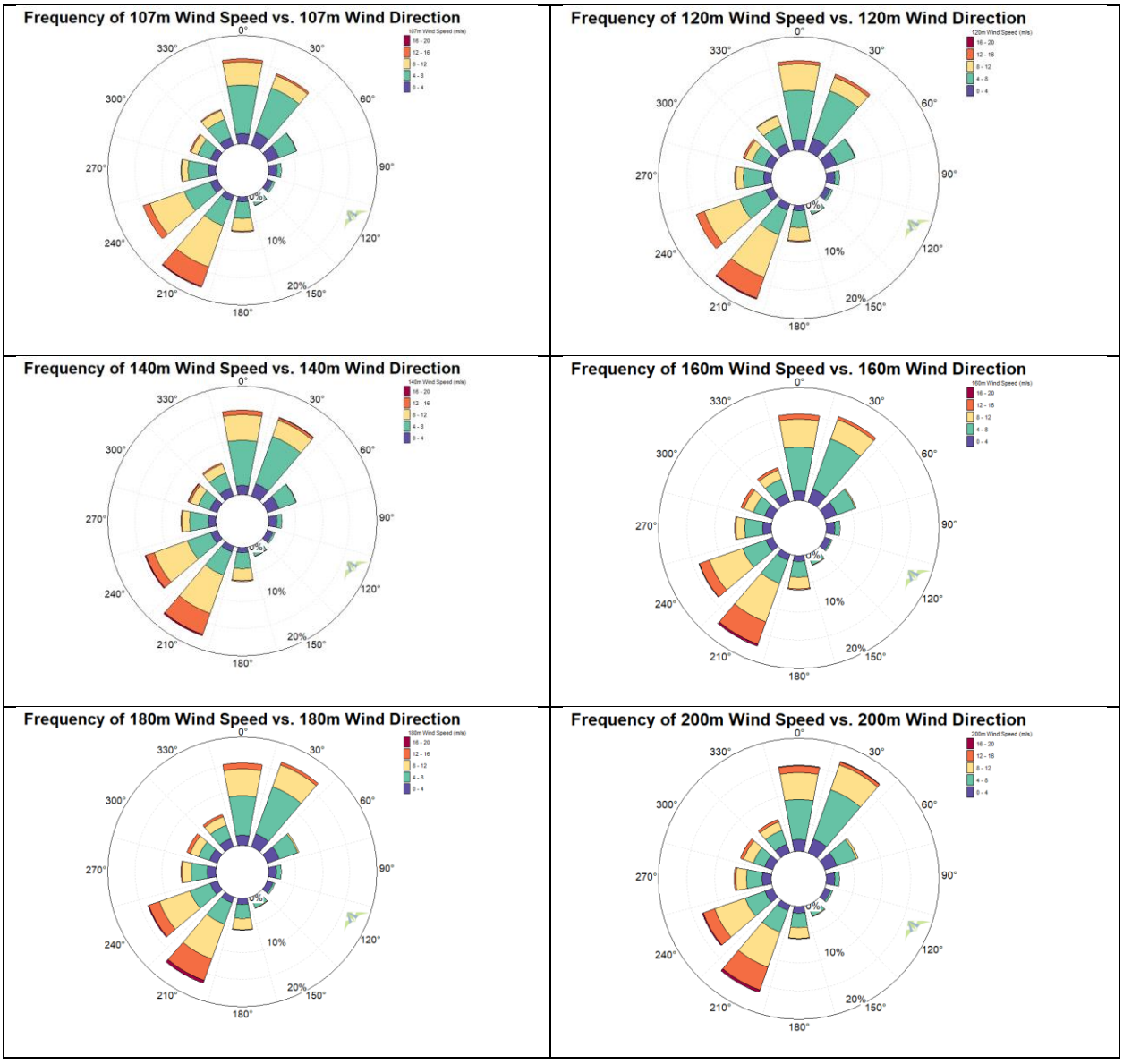


Figure 8: Wind Rose – 40m to 200m

e) Data Availability

Based on the actual Lidar data, the data recovery from the LIDAR instrument seems to be low during November 2017 to January 2018 and No data recorded during 13th July 2018 to 12th September 2018 owing to the technical issues. However, the data gaps pertaining to this period have been filled with the support of MCP (Measure-Correlate-Predict) method by correlating the Lidar measurement with the Jafarabad coastal 100m high met mast. The Table 3 shows the month-wise data availability and Table 4 represents the month-wise data availability after synthesis using MCP at different level of Lidar measurement

Table 3. Month-Wise Data Availability (Nov 2017- Nov 2018)

Month	40	60	70	80	87	100	107	120	140	160	180	200
Nov-17	68.31	68.31	68.31	68.31	68.31	68.31	68.31	68.31	68.31	68.31	68.31	68.31
Dec-17	37.01	37.01	37.01	37.01	37.01	37.01	37.01	37.01	37.01	37.01	37.01	37.01
Jan-18	58.85	58.85	58.85	58.85	58.85	58.85	58.85	58.85	58.85	58.85	58.85	58.85
Feb-18	100	100	100	100	100	100	100	100	100	100	100	99.83
Mar-18	97.07	96.91	96.89	96.86	96.77	96.57	96.35	95.83	95.39	95.07	94.51	93.93
Apr-18	100	99.98	99.98	99.91	99.88	99.81	99.77	99.72	99.72	99.68	99.05	98.03
May-18	100	99.96	99.96	99.91	99.91	99.93	99.91	99.91	99.8	99.66	99.22	98.57
Jun-18	99.88	99.47	99.28	98.87	98.59	98.31	98.29	97.62	97.41	97.2	96.99	96.94
Jul-18	38.71	38.19	37.59	36.96	36.58	36.16	35.73	35.35	34.79	34.39	34.16	34.14
Aug-18	-	-	-	-	-	-	-	-	-	-	-	-
Sep-18	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39
Oct-18	96.68	96.55	96.51	96.46	96.46	96.44	96.44	96.42	96.42	96.35	96.30	96.30
AVG	**75.63**	**75.51**	**75.43**	**75.32**	**75.25**	**75.16**	**75.10**	**74.95**	**74.83**	**74.72**	**74.53**	**74.30**
Nov-18	97.94	97.71	97.52	97.45	97.43	97.36	97.34	97.31	97.29	97.27	97.25	97.06

Table 4. Month-Wise Data Availability after synthesis using MCP (Nov 2017- Nov 2018)

Month	40	60	70	80	87	100	107	120	140	160	180	200
Nov-17	100	100	100	100	100	100	100	100	100	100	100	100
Dec-17	100	100	100	100	100	100	100	100	100	100	100	100
Jan-18	100	100	100	100	100	100	100	100	100	100	100	100
Feb-18	100	100	100	100	100	100	100	100	100	100	100	100
Mar-18	100	100	100	100	100	100	100	100	100	100	100	100
Apr-18	100	100	100	100	100	100	100	100	100	100	100	100
May-18	100	100	100	100	100	100	100	100	100	100	100	100
Jun-18	100	100	100	100	100	100	100	100	100	100	100	100
Jul-18	100	100	100	100	100	100	100	100	100	100	100	100
Aug-18	100	100	100	100	100	100	100	100	100	100	100	100
Sep-18	100	100	100	100	100	100	100	100	100	100	100	100
Oct-18	93.55	93.55	93.55	93.55	93.55	93.55	93.55	93.55	93.55	93.55	93.55	93.55
AVG	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**	**99.46**
Nov-18	100	100	100	100	100	100	100	100	100	100	100	100

ANNEXURE IV

AUTOMATIC WEATHER STATION

Automatic weather station was also deployed during the installation of offshore structure (Monopile & platform) in March 2017. The Station consists of one Anemometer and one Wind Vane, which will measure the wind speed and wind direction at platform level i.e., 17m. The measured wind data is directly monitored by NIWE server using GSM modem. This will be useful for better correlation and standby mode of measuring instruments. Figures 9 depicts the arrangement of instrumentation.

Figure 9: Anemometer and Wind vane setup Installed at the platform rail

a) Data analysis

In the data logger, wind speed and directions are sampled at 10 minutes average values. Analysis was performed with 10 minutes average data as per standard practice of wind energy sector. After due quality check, the information about wind speed and WPD are further segregated into month-wise values in Table 4. The air density values calculated at the station are based on the measured temperature and pressure.

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Table 4. Monthly Mean Wind Speed

Month	Temp (°C)	Pressure (mb)	Air Density (Kg/m^3)	WS (m/s)	WPD (W/m^2)	No. of data available (10 minutes Interval)	Data availability in Percentage
Apr-17	27.76	1006.68	1.165	6.92	263.75	**4320**	100.00%
May-17	28.98	1004.51	1.158	8.06	418.06	**4464**	100.00%
Jun-17	29.90	1000.87	1.151	8.30	447.61	**4320**	100.00%
Jul-17	28.66	1000.60	1.155	9.58	609.27	**4464**	100.00%
Aug-17	20.50	1001.61	1.155	8.34	405.58	**4464**	100.00%
Sep-17	28.45	1004.85	1.161	5.45	138.84	**4320**	100.00%
Oct-17	29.62	1004.34	1.156	4.67	113.12	**4464**	100.00%
Nov-17	21.79	1010.32	1.193	5.16	121.60	**4320**	100.00%
Dec-17	22.54	1010.72	1.191	4.62	73.08	**431***	9.66%
Jan-18	23.21	1010.95	1.188	4.39	73.01	**2313****	51.81%
Feb-18	26.03	1010.10	1.160	3.71	51.18	**873**	21.65%
Mar-18	27.18	1008.39	1.000	4.18	72.50	**2204**	49.37%
Annual Average	**26.22**	**1006.16**	**1.150**	**6.12**	**232.30**	**3821.30**	**77.71%**
Jun-18	27.91	1000.15	1.157	9.63	610.26	**4261**	98.63%
Jul-18	26.90	1003.35	1.170	9.15	522.82	**2016*****	45.16%

Note: 1) *Data not recorded from 03/12/2017 23:40 to 01/03/2018 10:10 due to ockhi storm

2) **Data missing from 07/01/2018 01:00 to 12/01/2018 14:10 & 16/01/2018 10:00 to 22/01/2018 14:40

3) *** Data not recorded due to Power supply issue from July 2018

b) Wind Rose

The 12 sector wind roses based on wind directions available are shown in Figure 10. It indicates that SSW direction is prominent wind direction.

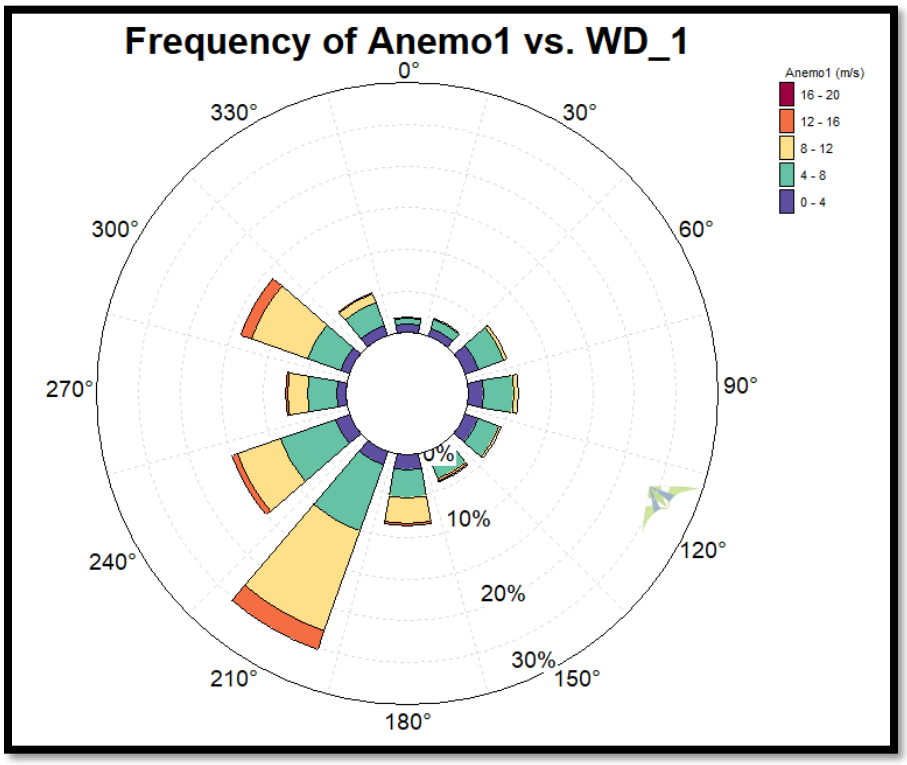

Figure 10: Wind Rose

ANNEXURE V

JAFRABAD MAST (coastal mast)

NIWE also installed the 100m height meteorological mast at Jafrabad coast in the line of sight with the LiDAR at a distance of approximately 25km, for the purpose of correlation & validation with the LIDAR measurement. The measurement was commenced on November 2017 in concurrence with the Lidar measurement. Figure 11 shows the geographical location of the 100m meteorological mast.

The reference geographical coordinates for 100m mast location (Jafrabad) are as follows:

Latitude: 20° 53' 29.81" N

Longitude: 71° 27' 35.68" E

Altitude: 9m agl

UTM coordinates: WGS84, 42Q zone 755896 m E, 2312117 m N

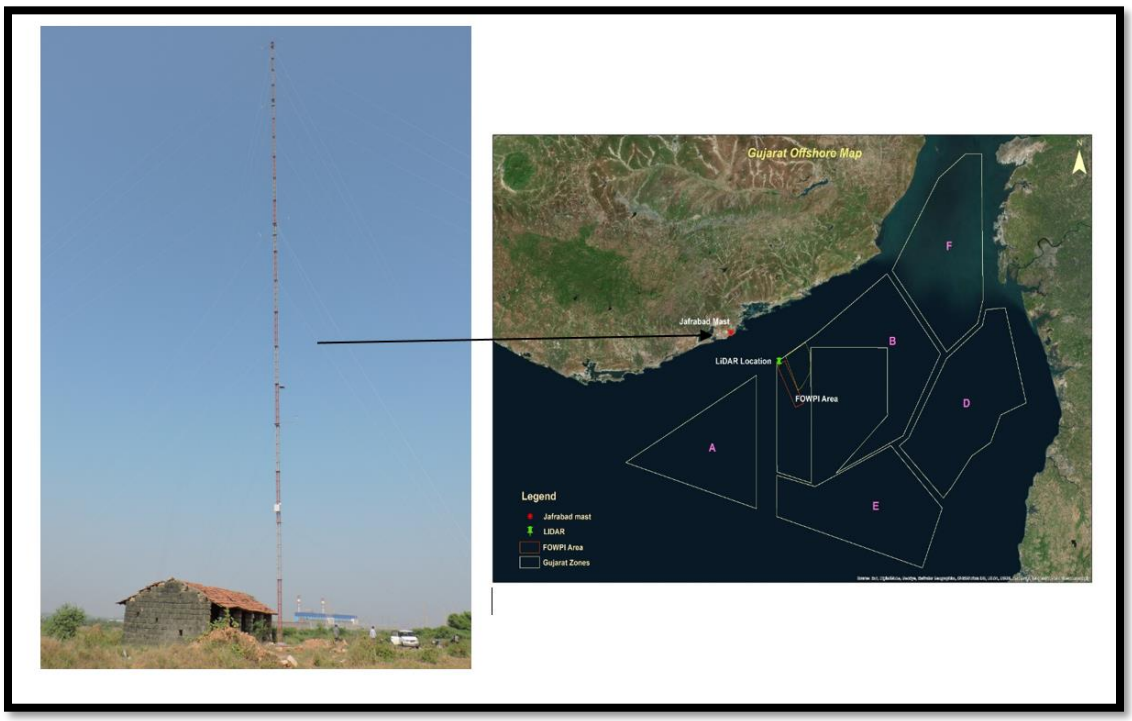

Figure 11: Coastal mast – 100m height at Jafrabad

a) Wind Characteristics

The information about wind speed and WPD are further segregated into month-wise values and given in Table 5. The air density values are calculated based on the measured temperature and pressure sensor.

Table 5. Monthly Mean Wind Speed

Month	Air Density (kg/m^3)	100m North		100m South		80m		50m		20m	
		WS (m/s)	WPD (W/m^2)	WS (m/s)	WPD (W/m^2)	WS (m/s)	WPD (W/m^2)	WS (m/s)	WPD (W/m^2)	WS (m/s)	WPD (W/m^2)
Nov 17	1.192	5.95	181.71	6.00	186.82	5.59	146.82	4.76	83.75	3.53	35.60
Dec 17	1.194	6.84	265.98	6.91	276.18	6.42	218.08	5.47	128.93	4.14	58.68
Jan 18	1.193	5.44	152.45	5.48	155.28	5.14	121.92	4.49	73.70	3.39	31.46
Feb 18	1.183	6.07	193.19	6.09	194.79	5.76	160.36	5.02	101.59	3.80	47.10
Mar 18	1.172	6.75	242.75	6.71	235.05	6.10	172.09	5.33	111.00	4.15	54.50
Apr 18	1.165	6.63	253.36	6.63	252.06	6.38	219.93	5.81	162.79	4.82	99.12
May 18	1.157	7.97	415.62	7.95	409.65	7.64	361.16	7.01	278.52	5.94	179.03
Jun-18	1.150	9.02	551.93	8.99	544.91	8.57	474.90	7.86	374.48	4.27	145.64
Jul-18	1.159	9.16	517.85	9.15	515.26	8.60	432.66	7.71	310.83	3.87	94.48
Aug-18	1.163	8.74	448.96	8.74	446.70	8.28	376.00	7.47	291.60	5.98	148.00
Sep-18	1.168	6.50	222.87	6.50	221.66	6.05	178.00	5.54	141.85	4.18	67.00
Oct-18	1.160	5.09	126.29	5.11	125.99	4.76	97.00	4.19	62.61	3.18	27.69
Annual Avg.	**1.171**	**7.01**	**296.75**	**7.02**	**295.96**	**6.60**	**245.55**	**5.88**	**176.09**	**4.27**	**81.97**
Nov-18	1.175	5.31	127.20	5.35	130.69	4.94	98.00	4.42	64.65	3.30	27.11

b) Data Availability

Month	100m N	100m S	80m	50m	20m
Nov-17	98.87	87.62	100	100	100
Dec-17	99.08	92.45	100	100	100
Jan-18	96.44	88.17	100	100	100
Feb-18	97.22	83.61	100	100	100
Mar-18	96.03	75.49	100	100	100
Apr-18	95.65	93.40	100	100	100
May-18	97.80	98.68	100	100	100
Jun-18	99.91	99.14	100	100	100
Jul-18	100.00	99.89	100	100	100
Aug-18	100.00	99.93	100	100	100
Sep-18	98.84	92.99	100	100	100
Oct-18	90.19	78.72	93.55	93.55	93.55
Annual Avg	**97.50**	**90.84**	**99.46**	**99.46**	**99.46**
Nov-18	97.08	91.48	100	100	100

c) Wind Rose

The 12 sector wind roses at 98m, 78m and 48m are shown in Figures 6a, 6b and 6c respectively.

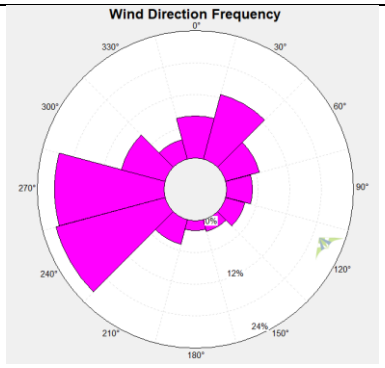

Figure 6a: 98m Annual Wind Rose

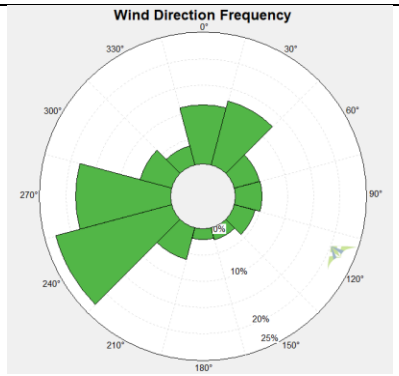

Figure 6b: 78m Annual Wind Rose

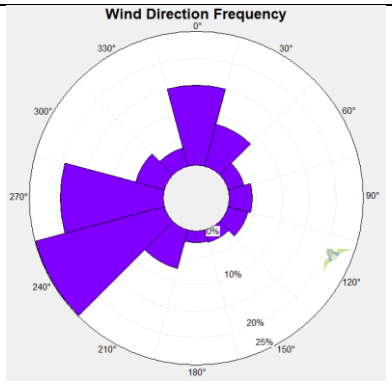

Figure 6c: 48m Annual Wind Rose