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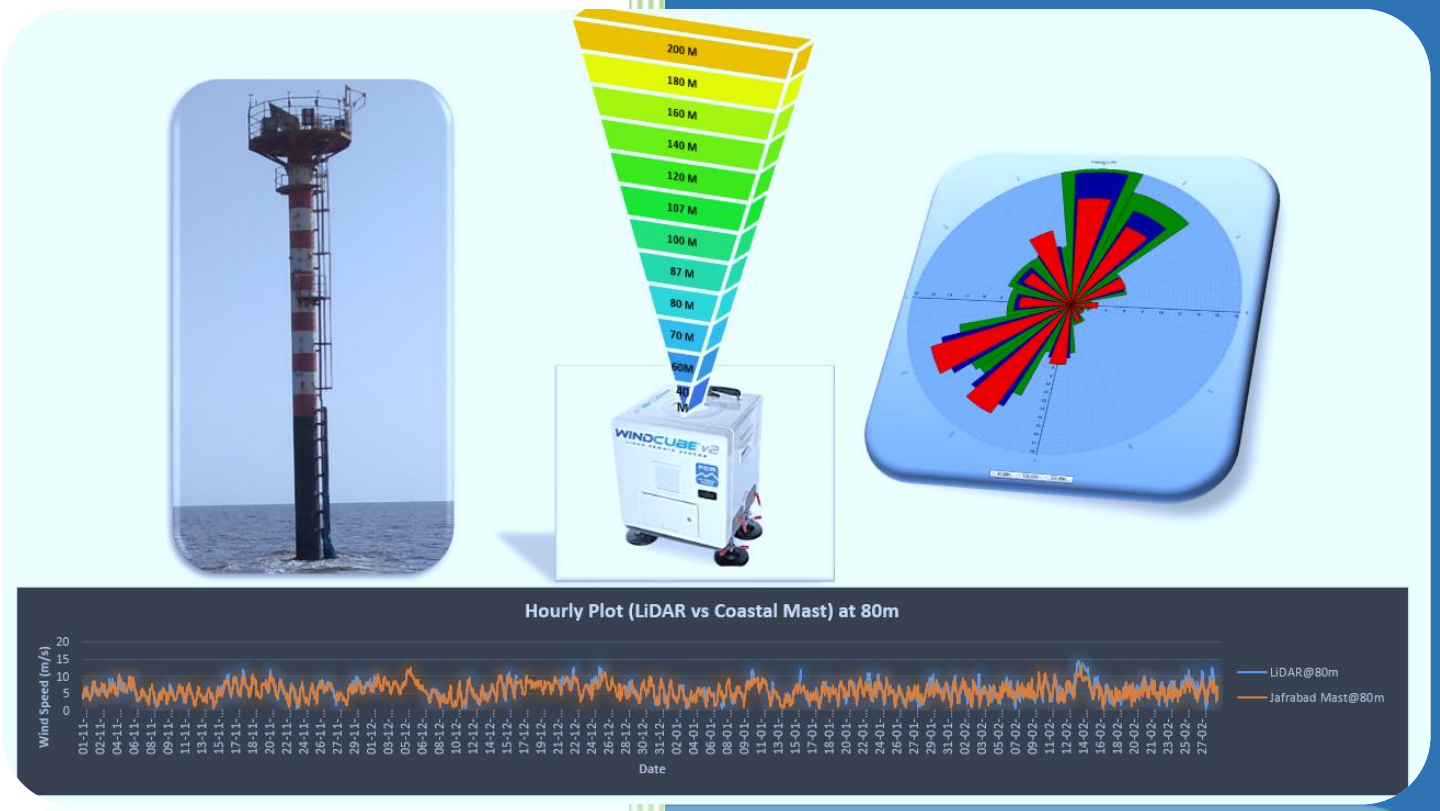
Report

(First Offshore Lidar Wind Data (2nd year) analysis

December 2019



Prepared by

National Institute of Wind Energy (NIWE)

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Chennai, India

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Ministry of New and Renewable Energy
Government of India

REPORT ON
FIRST OFFSHORE LIDAR WIND DATA (2nd year) ANALYSIS

Measurement Campaign

December 2018 to November 2019

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Disclaimer

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1. Introduction

The MNRE/NIWE has made consistent efforts to create a conductive environment for the development of offshore wind in the country. The preliminary assessment study showing promising offshore wind potential in the southern tip of Tamil Nadu and west coast of Gujarat. 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. In addition to that, European Union (EU) has funded the project namely FOWIND with NIWE as knowledge partner to have been identified 8 zones for Gujarat and Tamil Nadu coast.

In order to validate the desktop analysis, a LiDAR based offshore measurement campaign was commenced on November 2017 in Zone B, Gulf of Khambhat, Off Gujarat coast, which is first of its kind in the country. The measurements are still underway. Based on the real-time LiDAR measurements, the period from November 2017 to November 2018 data analysis report namely "First Offshore LiDAR Wind data analysis report" dated 20.12.2018 has been hosted in NIWE website for the benefit of the offshore stakeholders.

In Continuation with the First Offshore LiDAR Wind data analysis report, the second year data for the period from December 2018 to November 2019 has been analysed & reported below.

2. 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 monopile structure. 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. Figure 1 shows the satellite images marking the LiDAR location and Jafrabad coastal mast location.

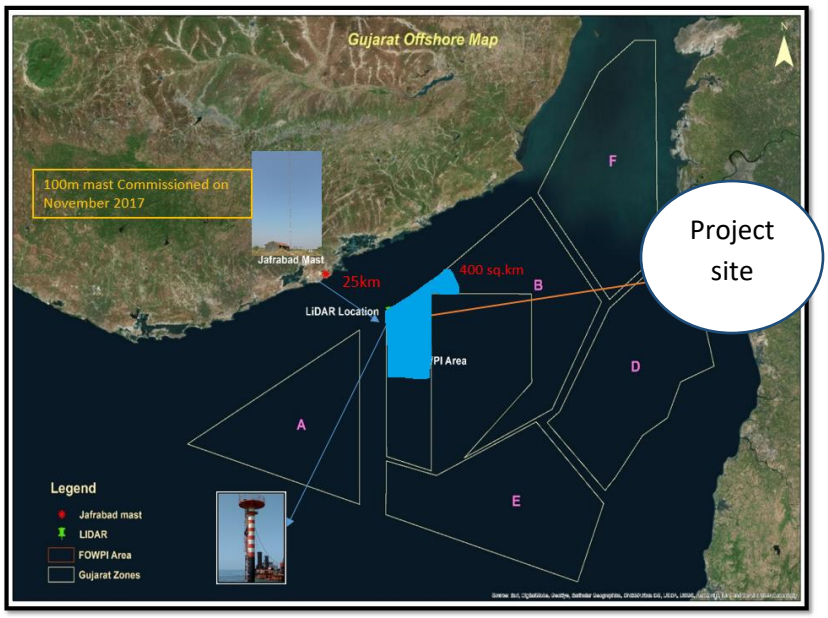


Figure 1: LiDAR and Jafrabad mast location

2.2 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.

2.3 LiDAR

Data Analysis – Synthesis & Validation

Based on the data analysis, the overall data recovery percentage for the period from December 2018 to November 2019 is 75.85 % (about 24% of data are not recorded owing to the technical issues during the period from May 2019 to November 2019). The detailed data recovery percentage at all heights are given in Annexure-I, section e.

However, the data gaps pertaining to this period have been synthesized through MCP (Measure-Correlate-Predict) method. After the due quality check, the Jafarabad coastal mast data has been extrapolated up to 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 **0.85,** which seems to be a good correlation. The correlation coefficient of determination (R^2) between LiDAR data and coastal mast data are given in Table 1.

Table 1: 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)	0.874
77 (60+17)	89 (80+9)	0.871
87 (70+17)	89 (80+9)	0.872
97 (80+17)	109 (100+9)	0.874
107 (87+17)	109 (100+9)	0.874
117 (100+17)	129 (120*+9)	0.875
127 (107+17)	129 (120*+9)	0.876
137 (120+17)	149 (140*+9)	0.870
157 (140+17)	159 (150*+9)	0.874
177 (160+17)	159 (150*+9)	0.872
197 (180+17)	159 (150*+9)	0.865
217 (200+17)	159 (150*+9)	0.857

*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 2a representing for the period of November 2017 to November 2018 & 2b representing for the period of December 2018 to November 2019. The graphical representation of the mean wind speed for the combined two years is given in Figure 2. Similarly, Table 3a represents the Wind Power Density values for the period of November 2017 to November 2018 & 3b for the period of December 2018 to November 2019 where in the air density values calculated at the station are based on the measured pressure and measured humidity and ERA_5 temperature. The graphical representation of the mean Wind Power density for the combined two years in Figure 3. The details of second year LiDAR data for the period from December 2018 to November 2019 are represented

in **Annexure I** and details of data analysis from the wind monitoring station at Jafrabad is given in **Annexure-II**.

Table 2a: 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
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

Table 2b: Wind Speed (Dec 2018 – Nov 2019) – Validated/Synthesized with Jafarabad Costal mast

Height(m)	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
Dec-18	6.34	6.46	6.54	6.62	6.66	6.71	6.76	6.86	6.98	7.11	7.20	7.27
Jan-19	6.78	7.16	7.33	7.44	7.52	7.63	7.70	7.83	7.95	8.08	8.14	8.18
Feb-19	6.08	6.41	6.52	6.60	6.68	6.72	6.78	6.88	6.97	7.09	7.17	7.18
Mar-19	5.84	6.24	6.38	6.49	6.55	6.62	6.67	6.80	6.88	6.96	7.03	7.03
Apr-19	6.62	6.91	7.05	7.16	7.21	7.25	7.29	7.38	7.39	7.40	7.41	7.32
May-19	8.60	8.77	8.88	8.95	8.99	9.00	9.04	9.11	9.01	9.10	9.16	9.12
Jun -19	9.38	9.51	9.67	9.70	9.81	9.78	9.84	9.89	9.95	10.09	10.21	10.24
Jul-19	8.99	9.27	9.37	9.40	9.51	9.46	9.50	9.55	9.59	9.68	9.77	9.78
Aug-19	8.32	8.73	8.89	9.02	9.14	9.06	9.10	9.17	9.23	9.33	9.43	9.46
Sep-19	6.42	7.41	7.48	7.50	7.59	7.52	7.54	7.61	7.64	7.69	7.74	7.89
Oct-19	4.89	5.24	5.32	5.30	5.33	5.40	5.44	5.53	5.60	5.71	5.80	5.83
Nov-19	4.61	5.01	5.08	4.95	5.01	5.16	5.20	5.32	5.37	5.43	5.47	5.47
Average	6.91	7.23	7.35	7.40	7.47	7.51	7.55	7.64	7.70	7.79	7.86	7.88

Note: *The missing data from December 2018 to November 2019has been synthesized by using MCP technique.*

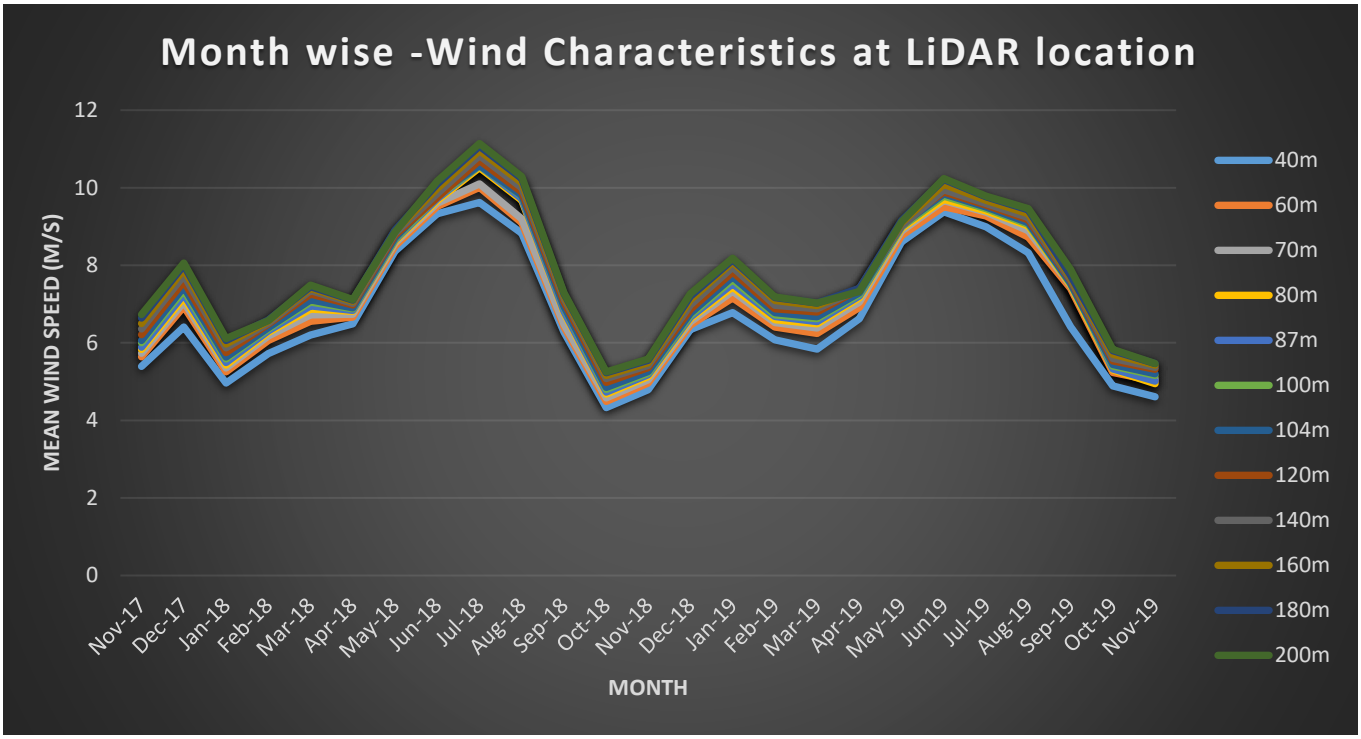


Figure 2: Monthly mean wind speed

Table 3a: 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

Table 3b: Wind Power Density (Dec 2018 – Nov 2019) – Validated/Synthesized with Jafarabad Costal mast

Height(m)	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
Dec-18	238	250	259	265	269	274	279	289	302	318	331	340
Jan-19	291	332	354	370	381	396	407	428	453	483	503	519
Feb-19	158	184	194	202	209	213	218	227	238	251	261	265
Mar-19	127	156	168	176	181	187	191	202	211	220	228	230
Apr-19	183	206	219	230	236	241	245	255	256	258	258	247
May-19	380	404	419	429	435	438	444	455	439	452	462	457
Jun -19	649	654	690	697	717	720	734	742	757	792	823	833
Jul-19	542	593	613	626	644	638	646	657	668	687	705	711
Aug-19	422	478	525	556	582	565	575	588	601	626	647	655
Sep-19	201	312	319	323	330	325	328	335	338	345	351	368
Oct-19	100	146	151	153	156	160	162	168	173	182	189	191
Nov-19	68	92	96	97	99	107	109	118	122	127	130	130
Average	281	315	332	342	351	354	360	371	379	394	407	411

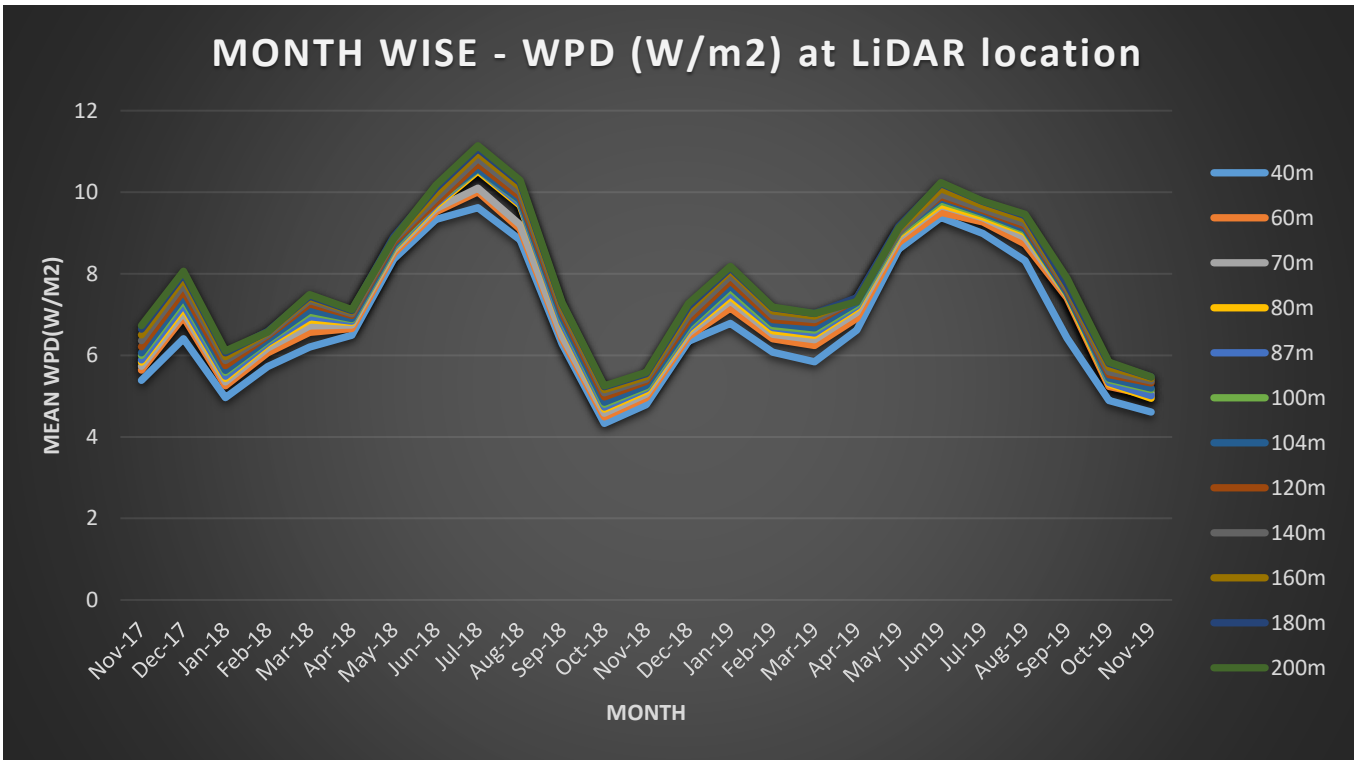


Figure 3: Monthly-Mean Wind Power Density

b) Wind Rose

The wind rose indicating all measured heights is given in Figure 4a during the period from November 2017 to November 2018 and Figure 4b during the period from December 2018 to November 2019.

Based on the second year data, it is observed that the primary prevalent wind direction is SSW (south of south west) with wind speed occurrence about 15.8% and secondary prevalent wind direction is N (North) with wind speed occurrence about 11.1%.

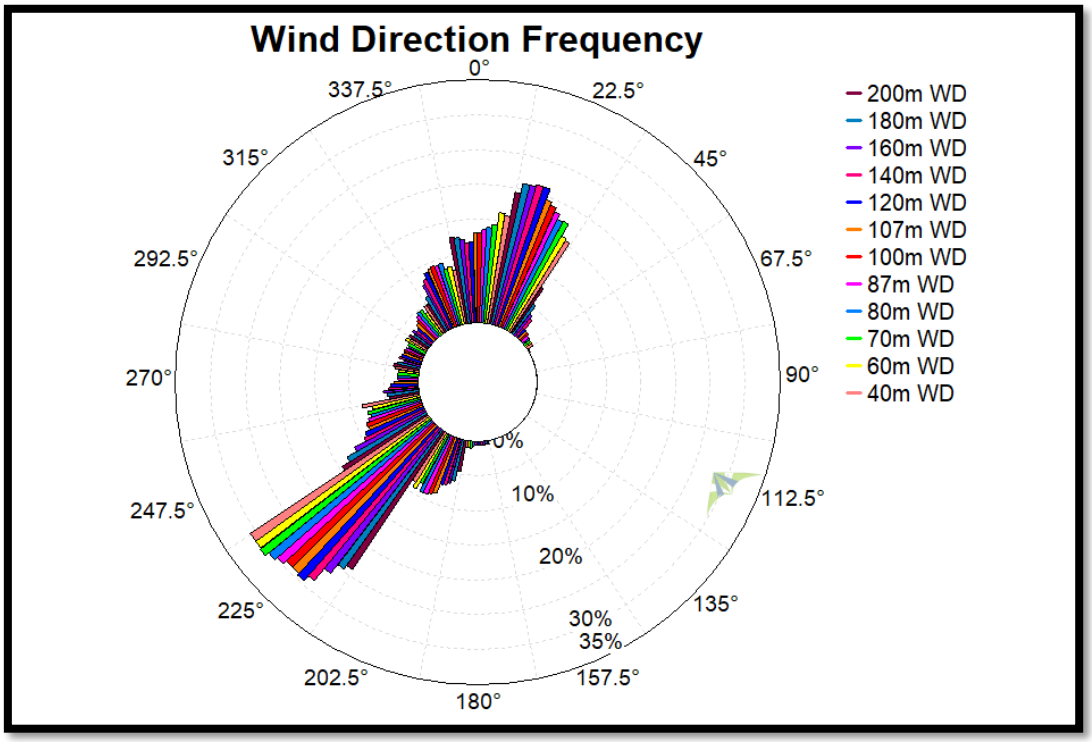


Figure 4a: Wind Rose (Nov 2017 – Nov 2018)

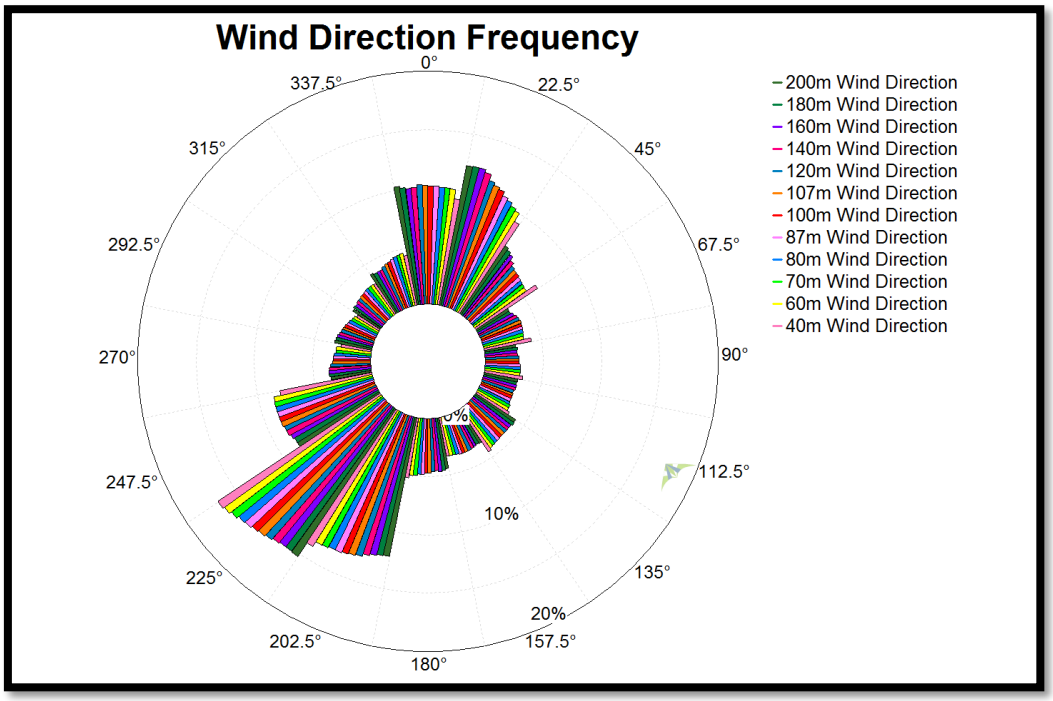


Figure 4b: Wind Rose (Dec 2018 – Nov 2019)

Annexures

ANNEXURE -I

LiDAR Data 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 & Figure 2a represents the daily mean wind profile and daily mean wind profile after synthesis using MCP. Figure 3 & Figure 4 illustrating diurnal mean wind speed profiles and the month-wise diurnal pattern for visualization.

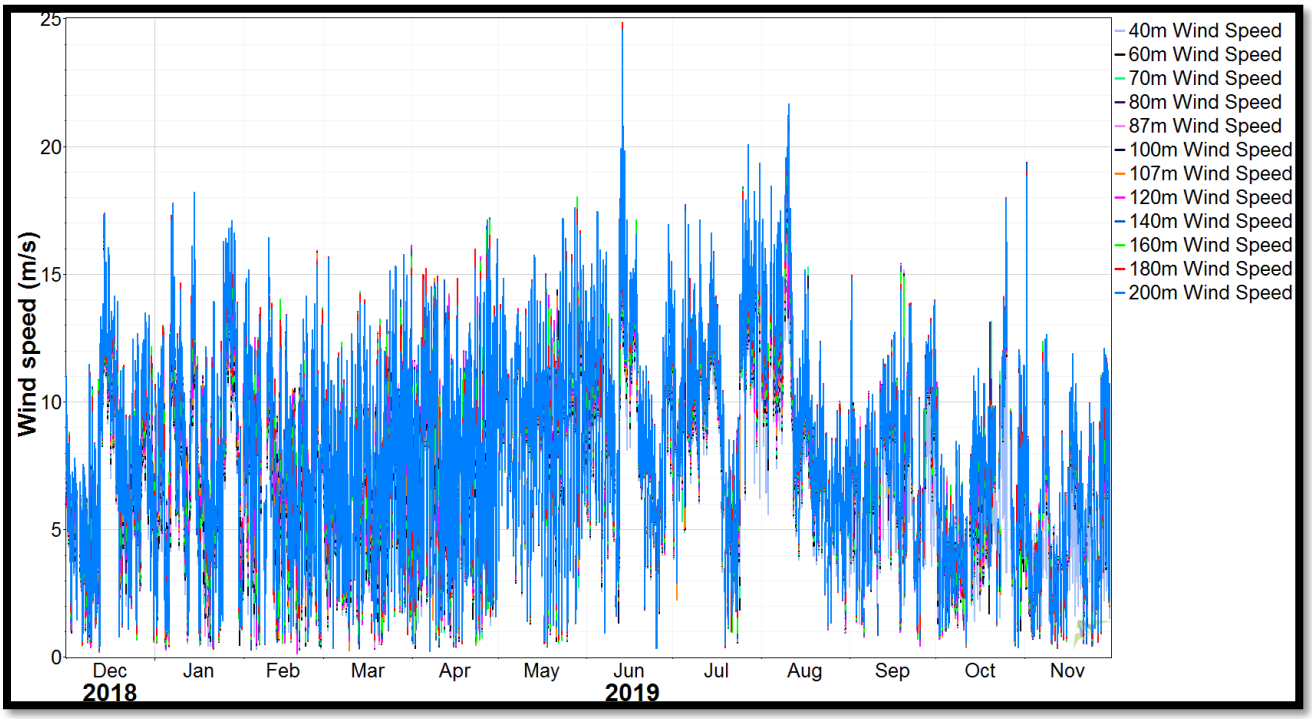


Figure 1: Time Series (10minute) Profile of Wind Speed (40m to 200m)

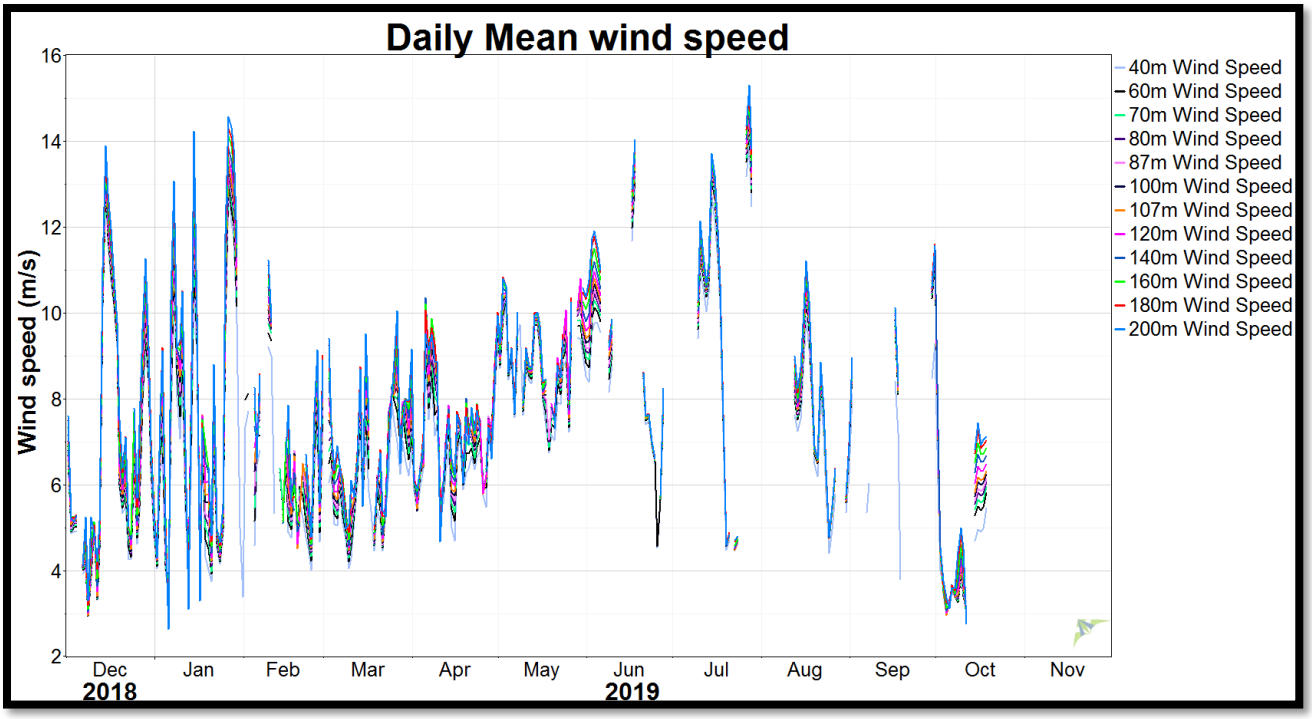


Figure 2: Daily Mean Wind Profile (Dec 2018 - Nov 2019)

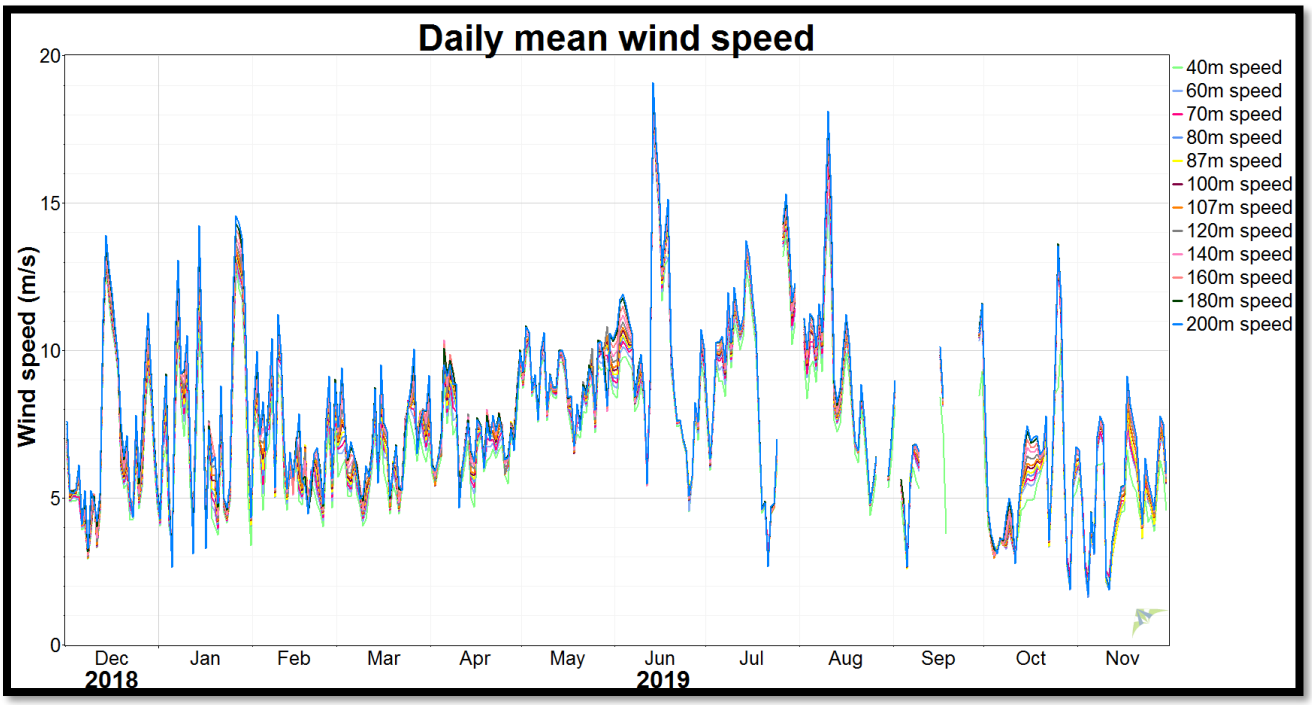


Figure 2a: Daily Mean Wind Profile after synthesis using MCP (Dec 2018 - Nov 2019)

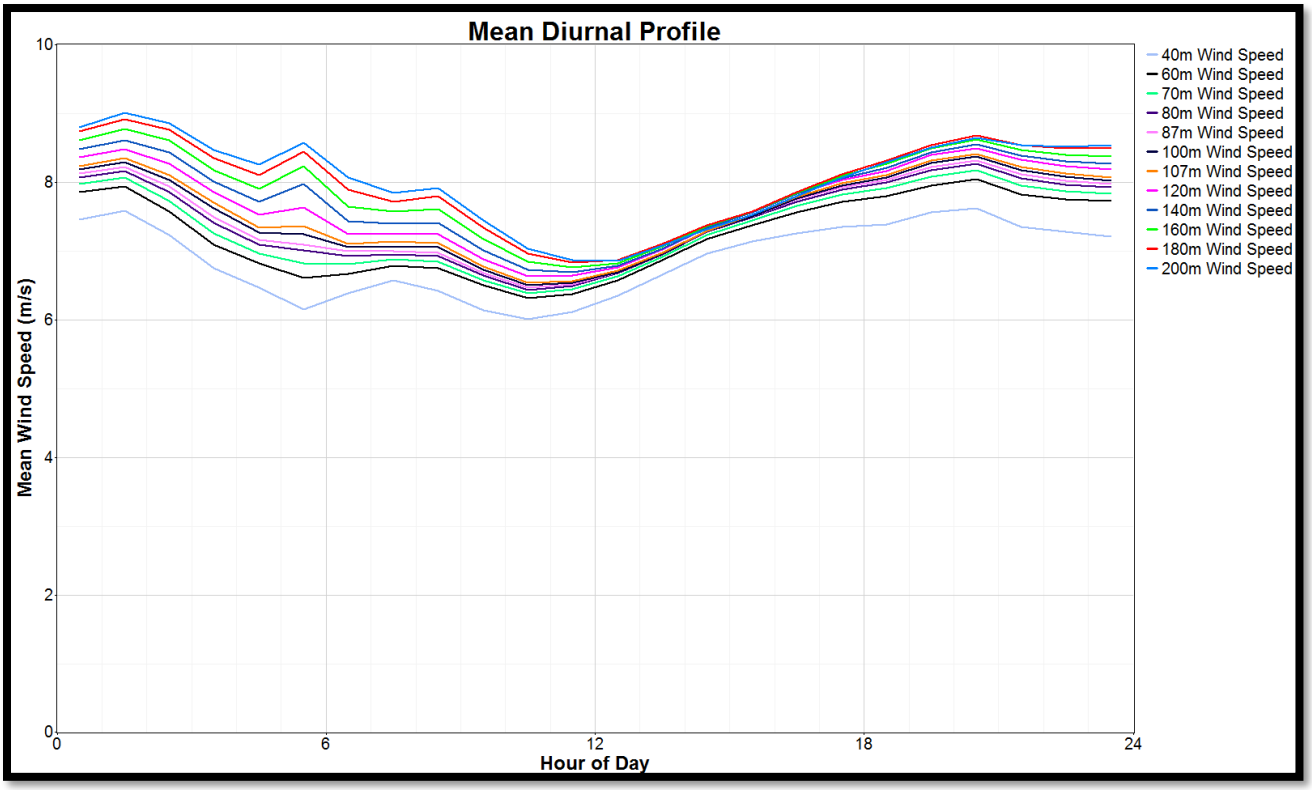
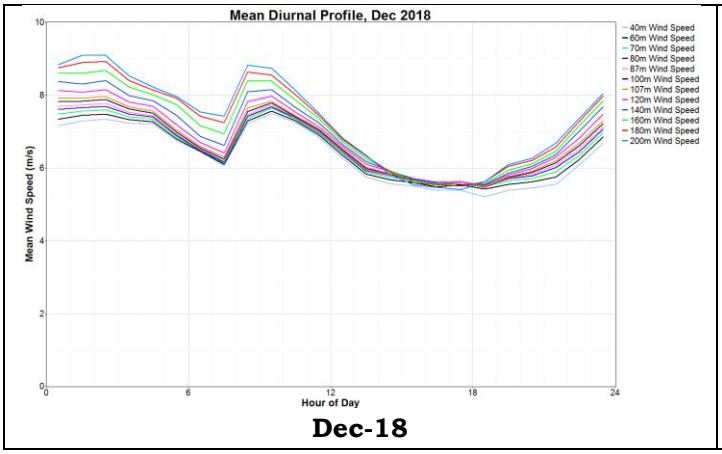
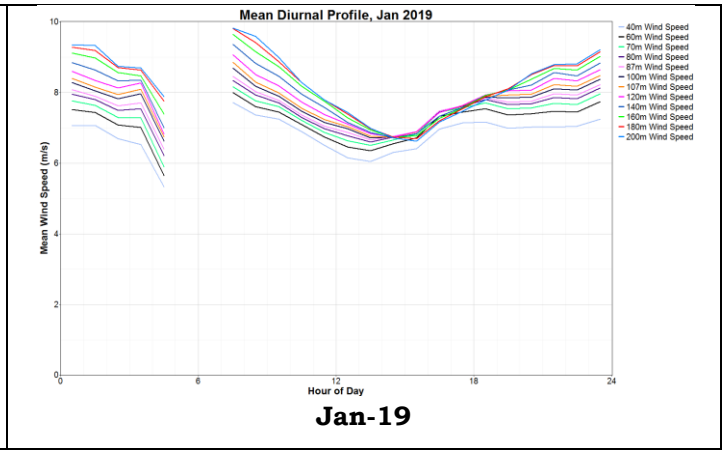


Figure 3: Diurnal Wind Profile (Dec 2018 - Nov 2019)



Dec-18



Jan-19

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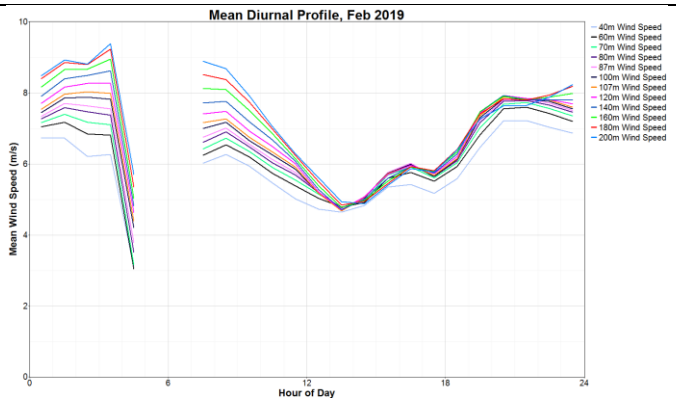
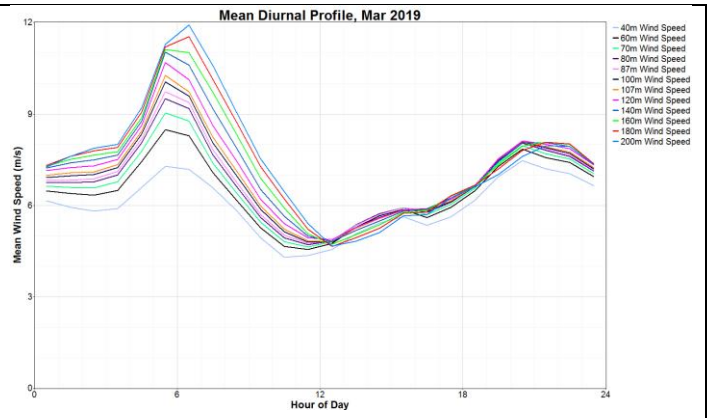
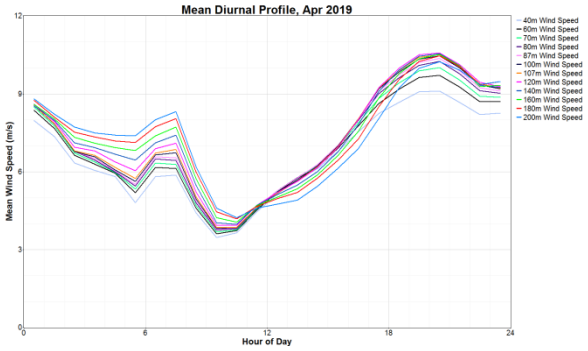


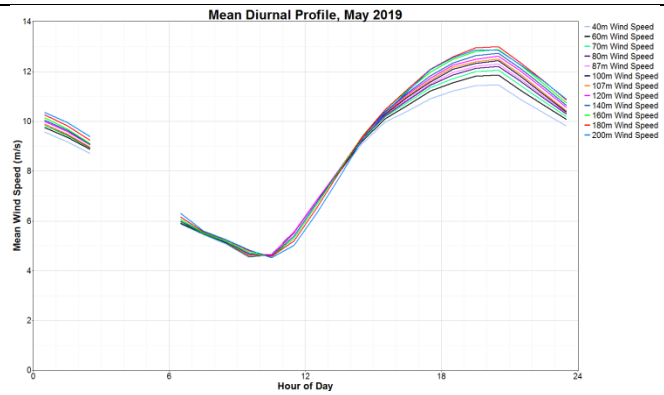
Feb-19



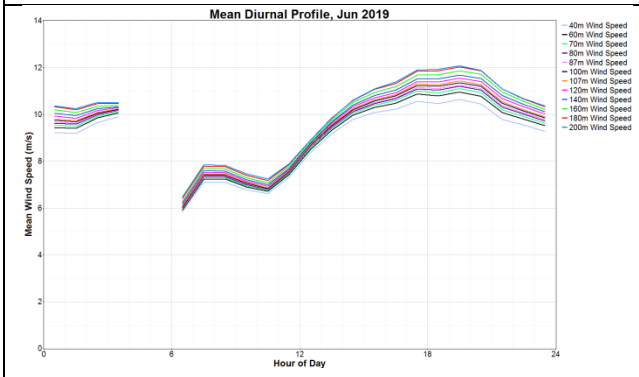
Mar-19



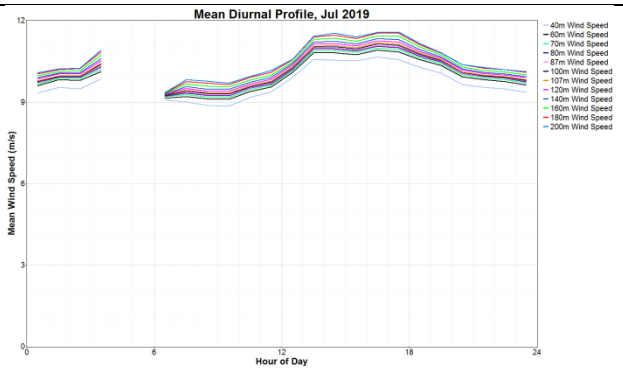
Apr-19



May-19



Jun-19



Jul-19

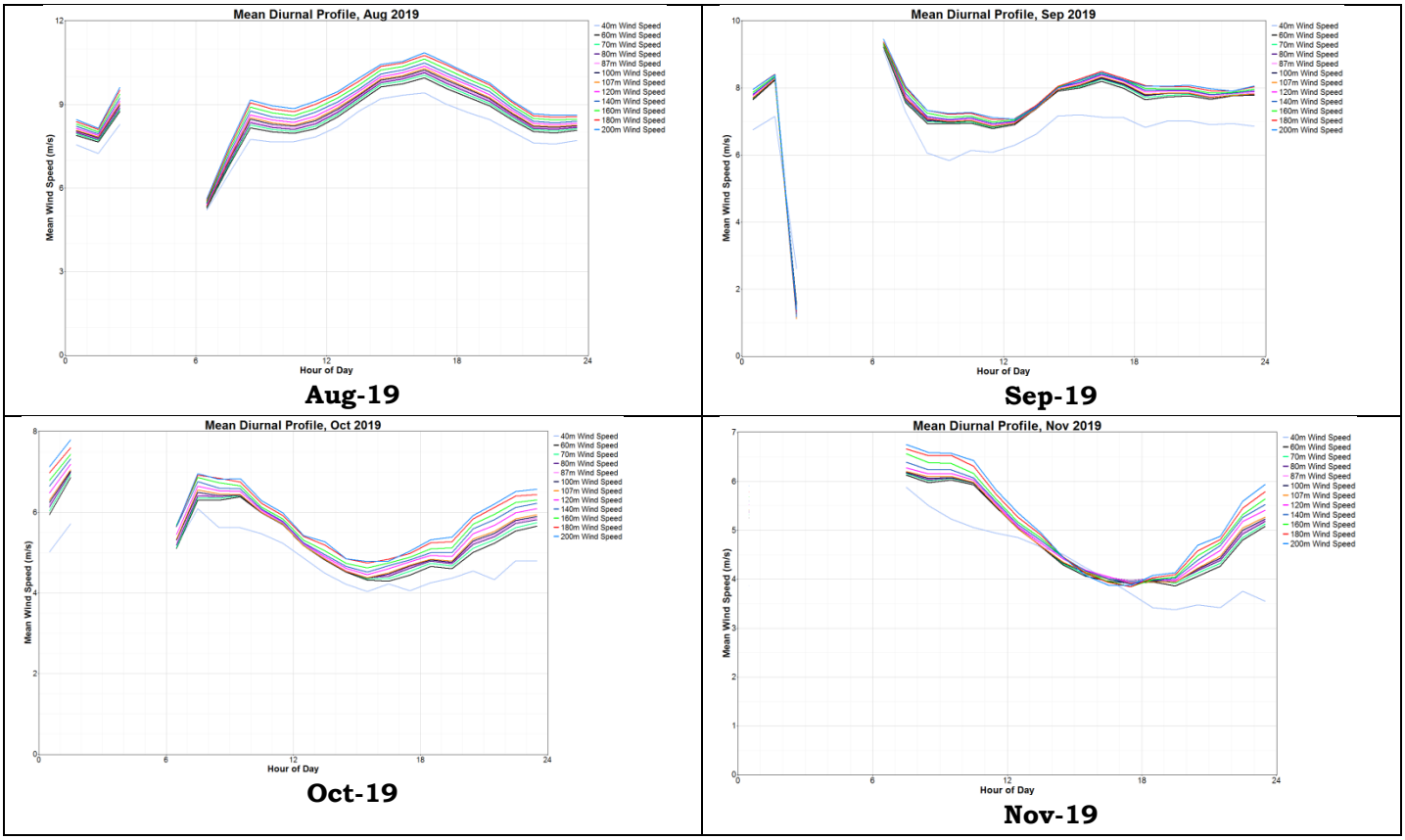


Figure 4: Month-wise diurnal pattern

Note: The missing data was found from the LiDAR instrument during the period from January, February and from May 2019 to November 2019 (Between the time duration of 02:00 to 09:00 hours) owing to the technical issues. Hence, the gap has been filled through MCP technique using coastal mast 100m (Jafarabad) and synthesized graph illustrated in below Figure 5.

Figure 5 depicts the missing month diurnal pattern after synthesis using MCP technique.

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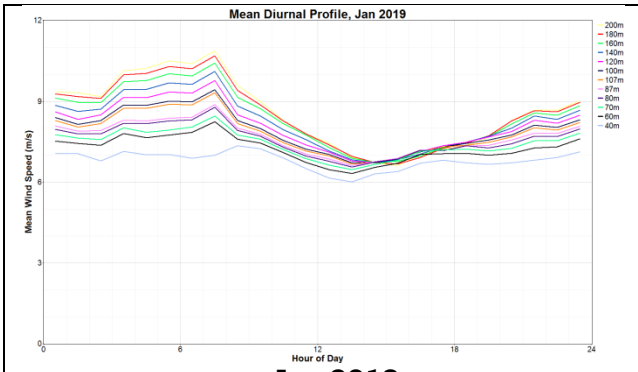
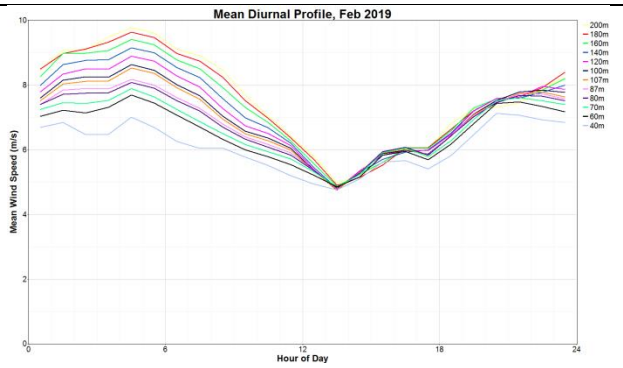
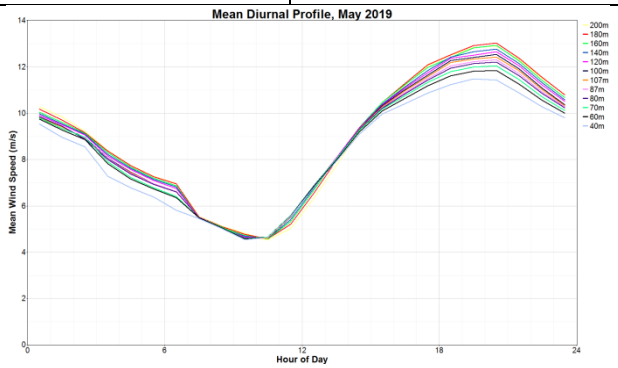


Jan-2019



Feb -2019



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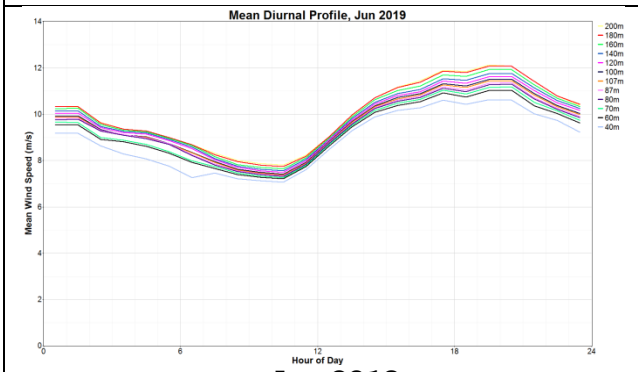

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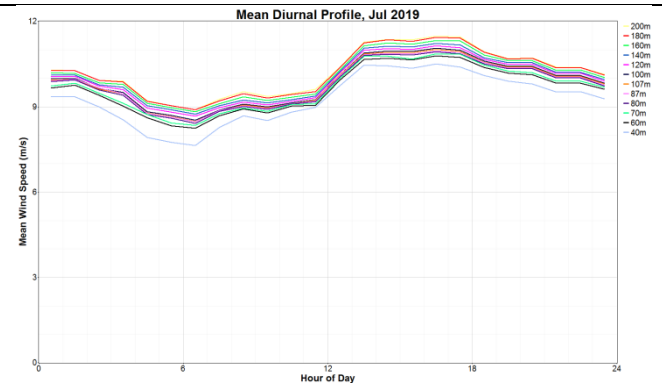
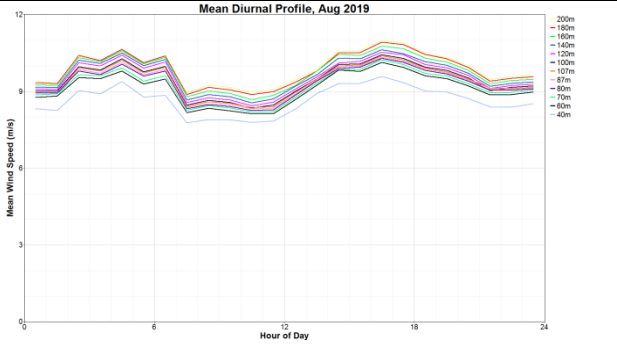


Jul-2019



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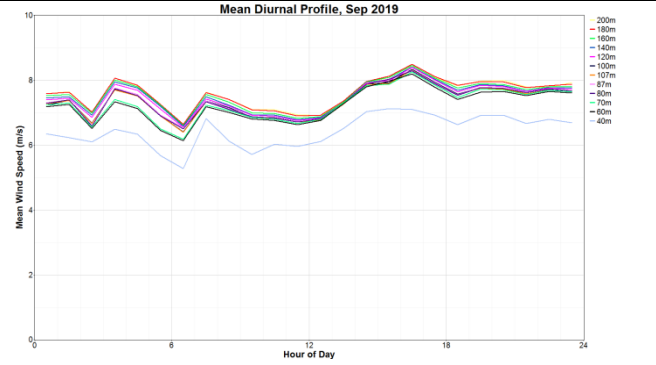

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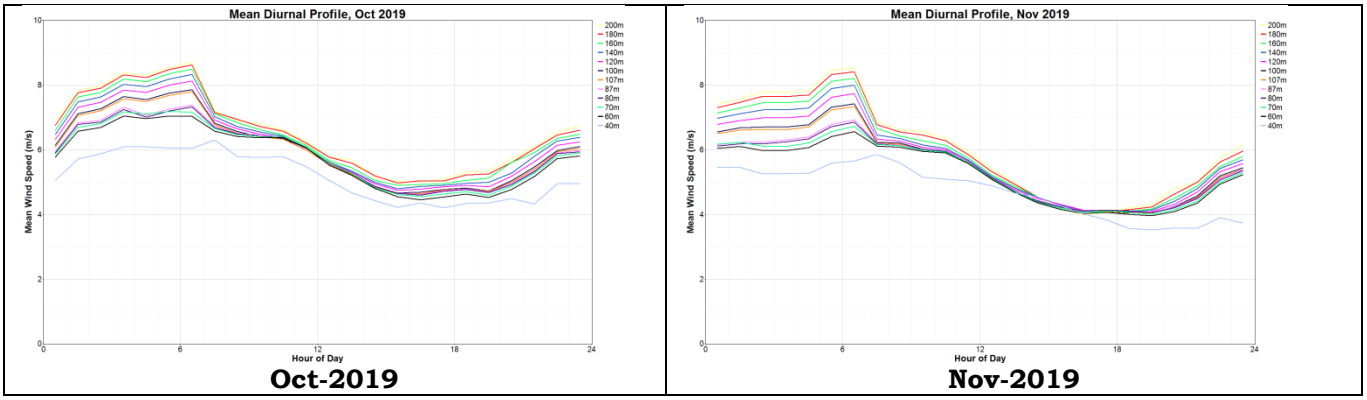

Figure 5: Month-wise diurnal pattern after synthesis using MCP

b) Wind Frequency Distribution

The distribution of 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. Table 1 depicts the weibull values (A and K) for various heights. 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 2 depicts the 1 m/s binned percentage frequency distribution at different heights.

Table 1: Weibull parameters

Height	Weibull K	Weibull A (m/s)
40m	2.28	7.73
60m	2.39	8.22
70m	2.39	8.34
80m	2.40	8.43
87m	2.40	8.48
100m	2.39	8.54
107m	2.39	8.59
120m	2.40	8.70
140m	2.39	8.79
160m	2.38	8.91
180m	2.37	9.02
200m	2.36	9.07

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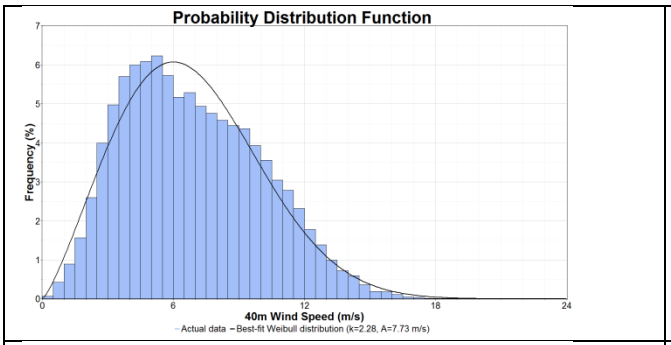

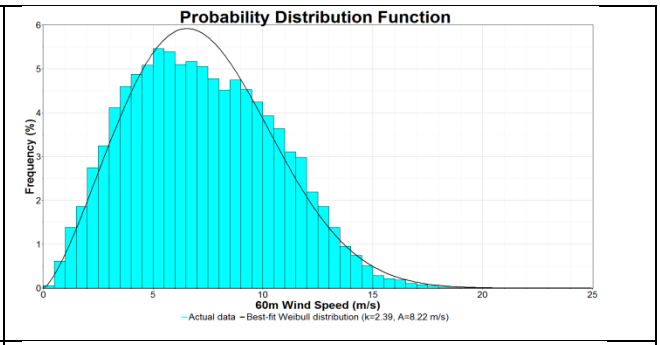

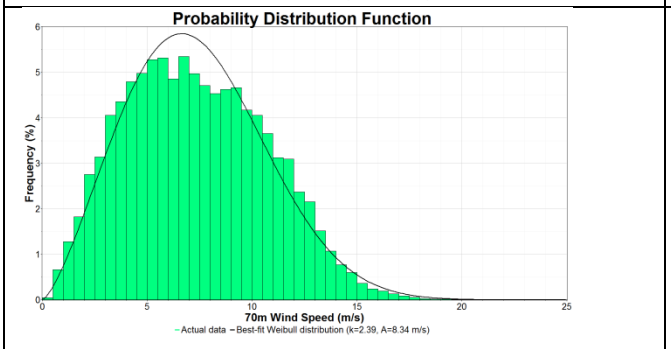

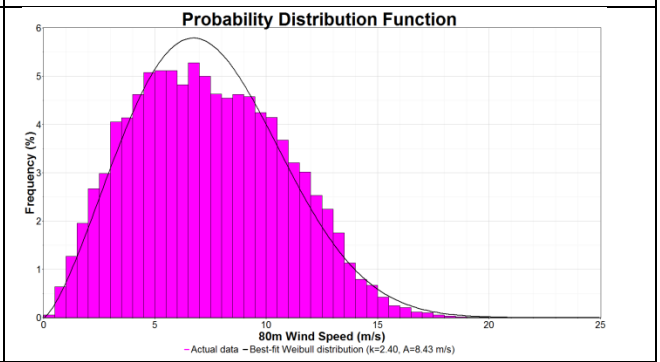

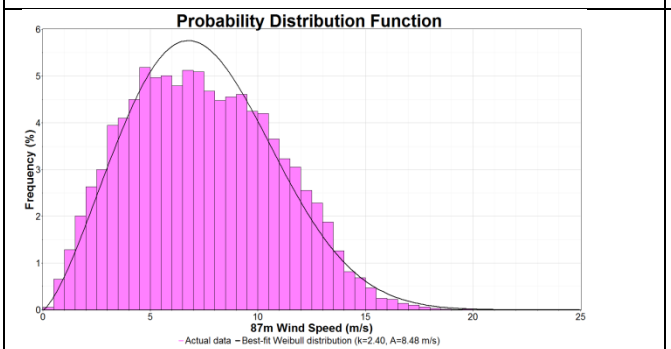

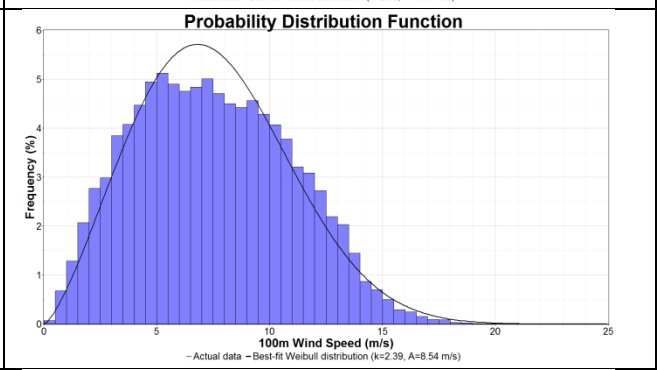

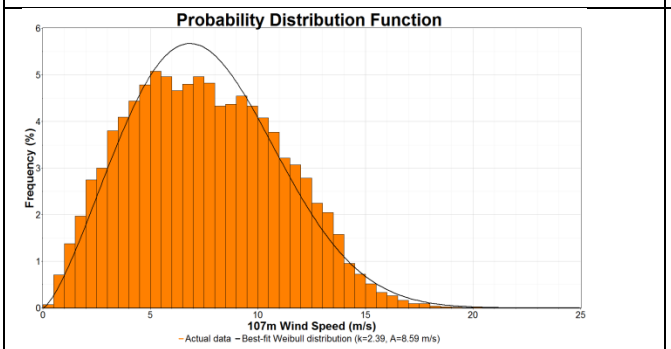

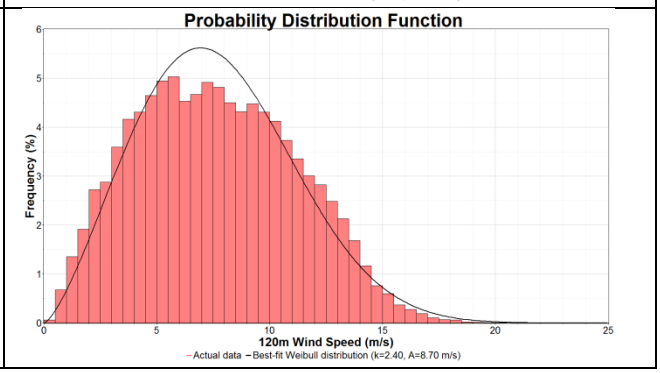

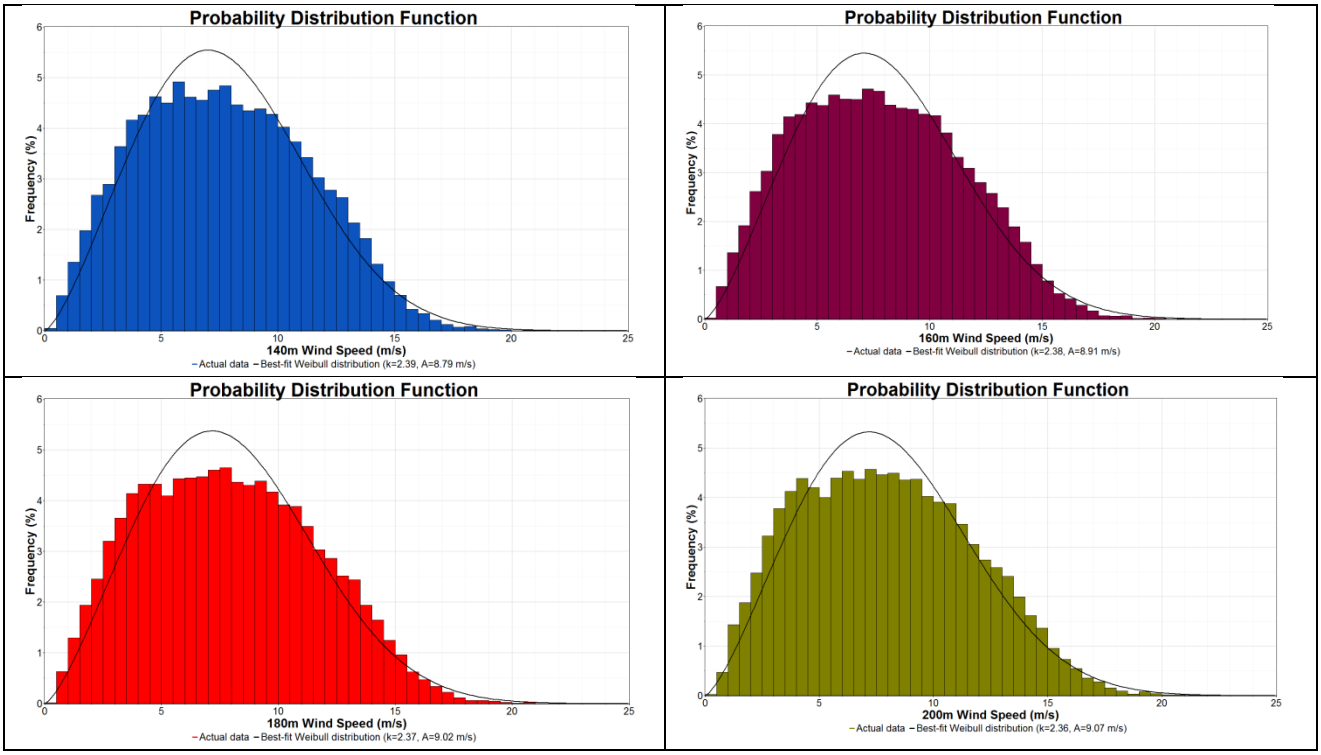

Figure 6: Wind Speed Histogram (Dec 2018 - Nov 2019)

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Table 2: Percentage Frequency Distribution Table (Dec 2018 - Nov 2019)

Bin (m/s)		Percentage Frequency Distribution (%)											
Lower Point	Upper Point	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
0	1	0.49	0.68	0.72	0.70	0.71	0.76	0.78	0.75	0.74	0.70	0.65	0.50
1	2	2.46	3.25	3.11	3.23	3.31	3.37	3.35	3.28	3.35	3.28	3.24	3.32
2	3	6.60	6.00	5.90	5.66	5.64	5.76	5.75	5.61	5.57	5.65	5.66	5.71
3	4	10.68	8.72	8.41	8.21	8.05	7.94	7.90	7.76	7.81	7.94	7.80	7.91
4	5	12.09	9.97	9.78	9.71	9.69	9.42	9.23	8.96	8.90	8.64	8.66	8.59
5	6	11.97	10.86	10.60	10.24	9.99	10.03	10.05	9.99	9.42	8.98	8.53	8.40
6	7	10.46	10.28	10.21	10.11	9.92	9.61	9.47	9.20	9.18	9.02	8.93	8.91
7	8	9.71	9.84	9.68	9.64	9.78	9.72	9.79	9.73	9.60	9.40	9.26	9.04
8	9	9.03	9.27	9.16	9.18	9.03	8.93	8.71	8.82	8.81	8.72	8.67	8.85
9	10	8.30	8.78	8.84	8.83	8.86	8.85	8.89	8.79	8.67	8.51	8.56	8.40
10	11	6.61	7.58	7.72	7.84	7.86	7.85	7.86	7.86	7.76	7.99	7.81	7.79
11	12	5.11	6.09	6.22	6.24	6.29	6.30	6.29	6.37	6.46	6.41	6.53	6.52
12	13	3.17	4.06	4.53	4.78	4.84	4.92	5.04	5.31	5.41	5.38	5.39	5.33
13	14	1.72	2.35	2.59	2.90	3.15	3.48	3.63	3.82	3.96	4.18	4.39	4.41
14	15	0.97	1.27	1.38	1.47	1.51	1.58	1.69	1.94	2.29	2.71	2.90	2.99
15	16	0.38	0.51	0.60	0.68	0.73	0.80	0.86	0.98	1.13	1.31	1.59	1.69
16	17	0.17	0.30	0.33	0.33	0.37	0.41	0.43	0.48	0.56	0.71	0.82	0.90
17	18	0.06	0.13	0.14	0.16	0.17	0.18	0.19	0.19	0.20	0.25	0.35	0.43
18	19	0.03	0.04	0.04	0.06	0.06	0.07	0.07	0.09	0.13	0.14	0.13	0.13
19	20	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.05	0.08	0.12
20	21	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.04
21	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02

c) Wind Shear Profile

The wind shear profile at the site is useful to understand the wind speed variation with respect to 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 based on the measured data using power law and log law. The Power law index (α) for proposed location is 0.078 indicating water/offshore conditions.

Table 2: Vertical Wind Shear Profile Table

Month	Power Law (alpha)	Log Law (z0)
Dec-18	0.090	0.001474
Jan-19	0.118	0.019193
Feb-19	0.103	0.005642
Mar-19	0.114	0.013007
Apr-19	0.065	0.000016
May-19	0.036	0.000000
Jun -19	0.055	0.000001
Jul-19	0.048	0.000000
Aug-19	0.072	0.000081
Sep-19	0.073	0.000067
Oct-19	0.102	0.004878
Nov-19	0.103	0.005196

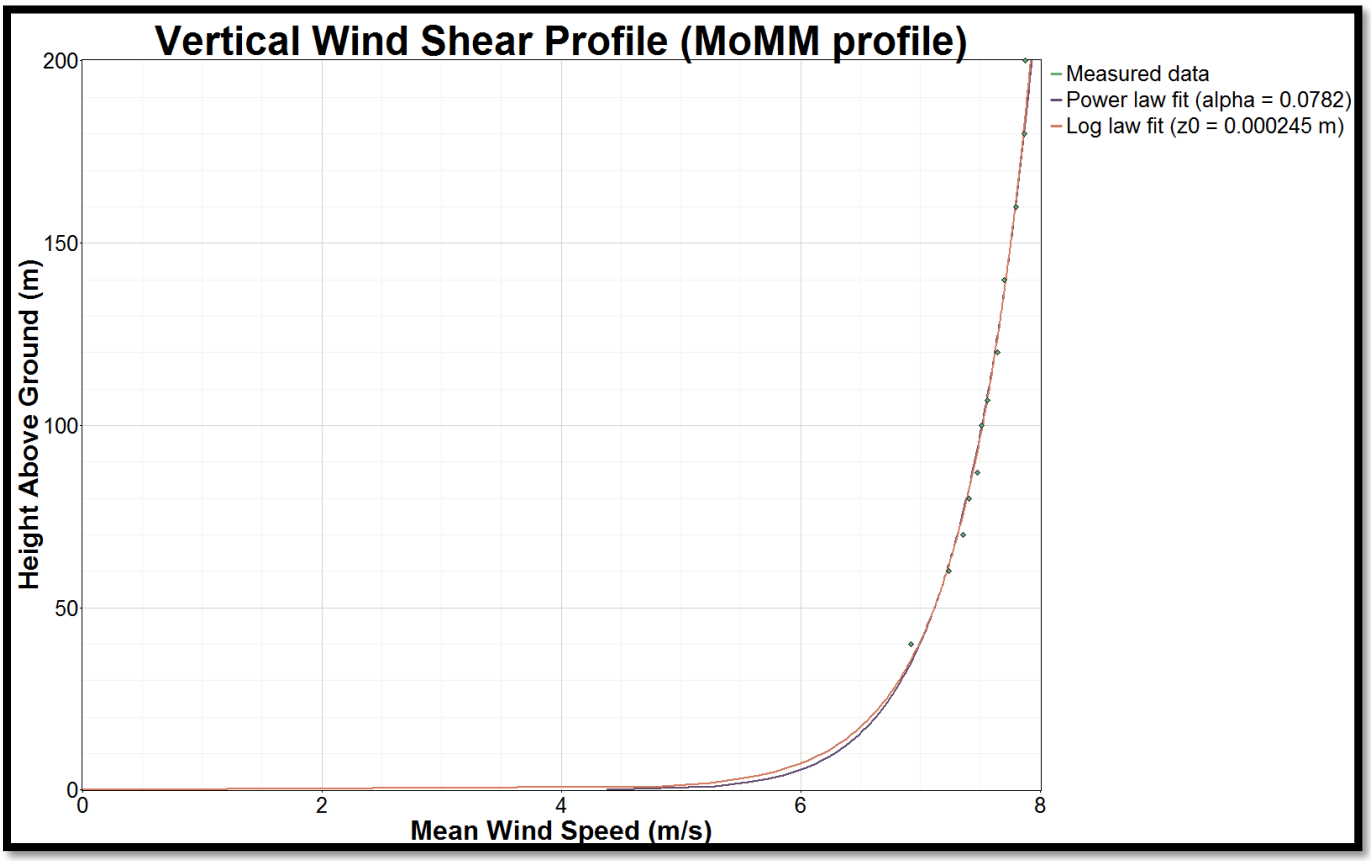
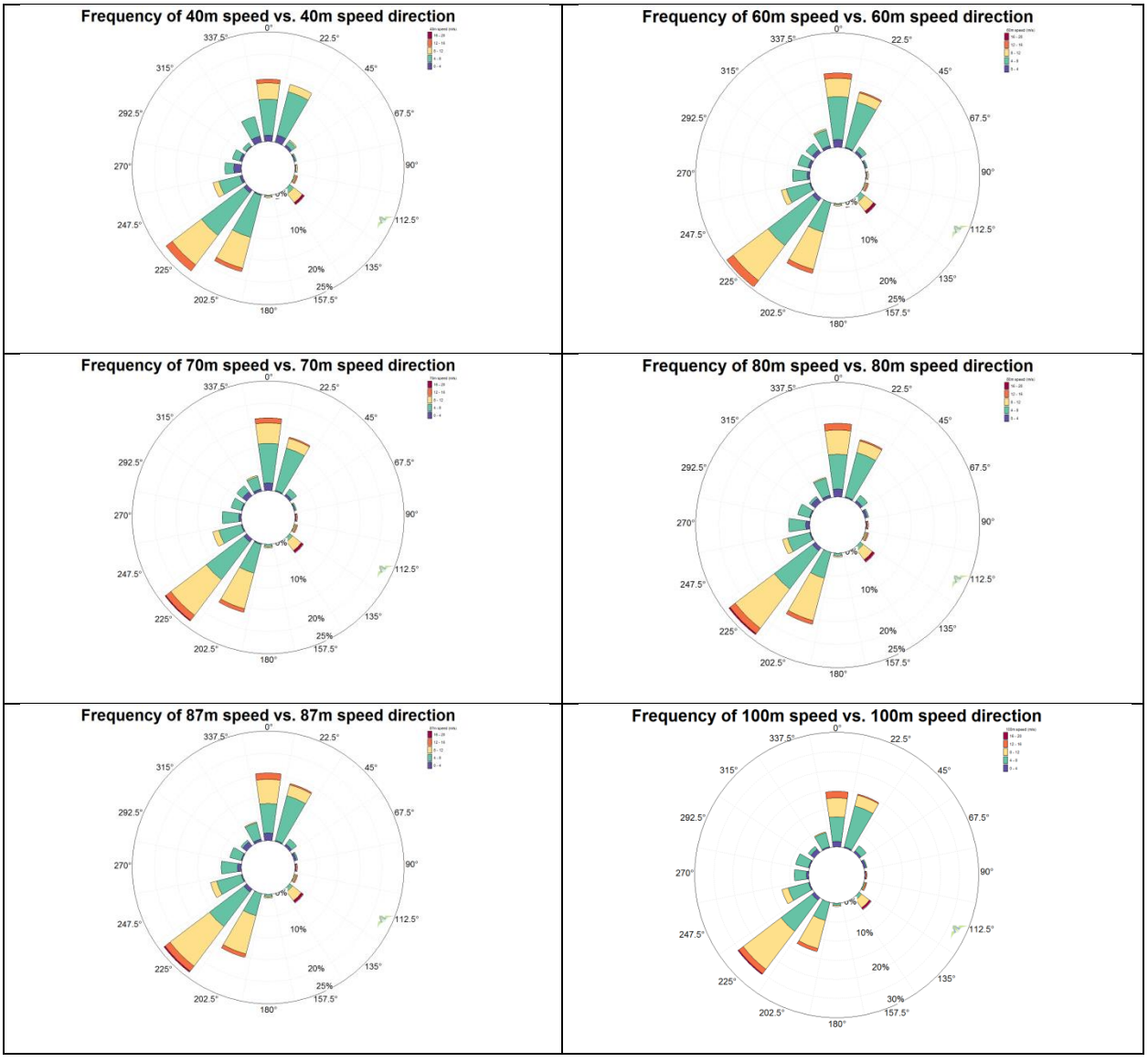


Figure 7: Vertical Wind Shear Profile

d) Wind Rose

The wind roses based on wind direction data available at various heights (40m to 200m) are shown in Figure 8.



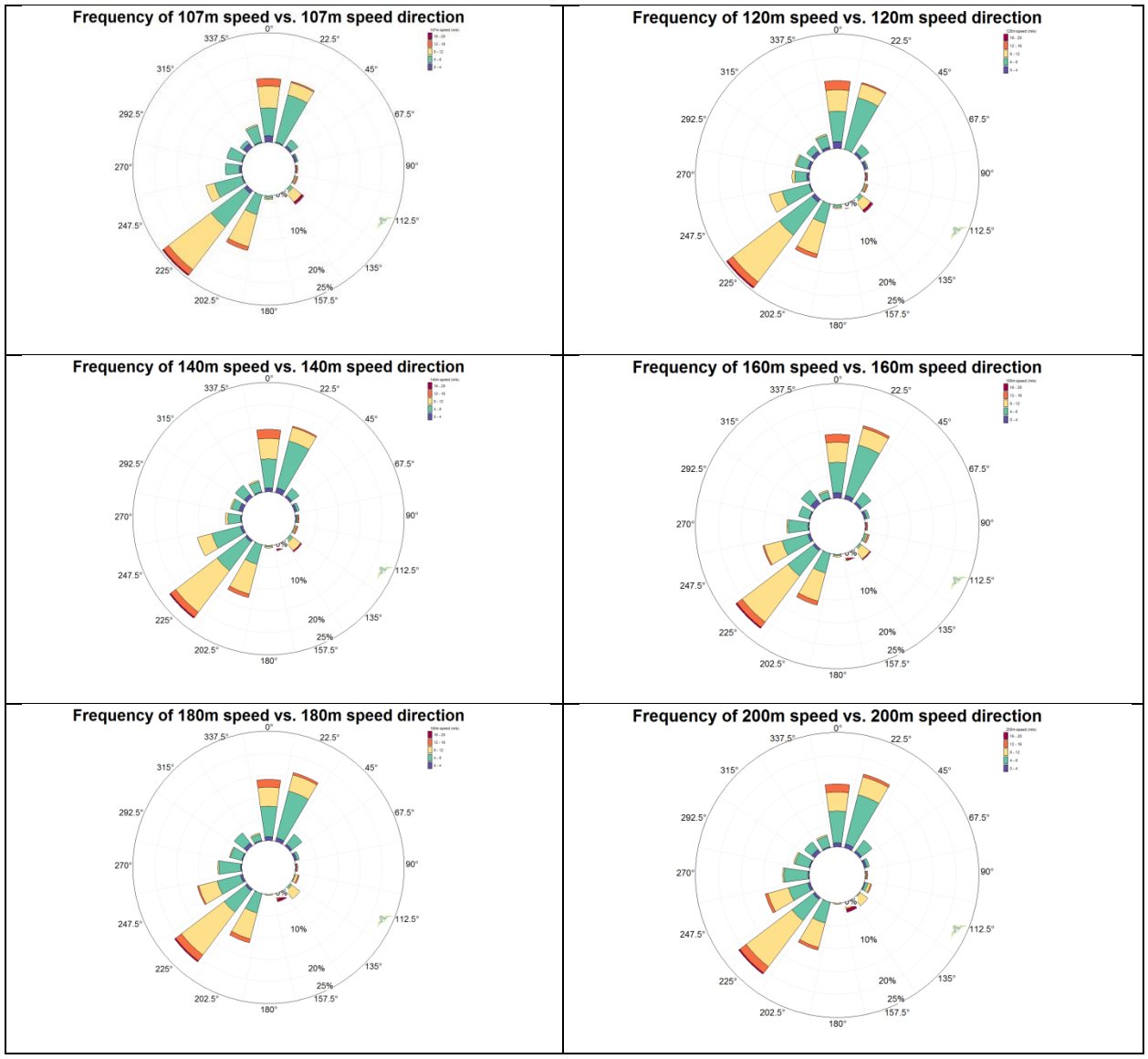


Figure 8: Wind Rose – 40m to 200m

e) Data Availability

Based on the actual LiDAR data, the data from LiDAR instrument seems to be low during the period from May 2019 to November 2019 (Between the time duration of 02:00 to 09:00 hours) 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.Table 3shows the month-wise data availability and Table 4 represents the month-wise data availability after synthesis using MCP ata different level of LiDAR measurement.

Table 3. Month-Wise Data Availability (Dec 2018 - Nov 2019)

Month	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
Dec-18	85.66	85.46	85.30	85.19	85.08	84.95	84.90	84.79	84.77	84.68	84.57	84.36
Jan-19	79.93	79.59	78.94	78.67	78.47	78.23	78.09	78.07	77.82	77.78	77.67	77.35
Feb-19	77.08	76.56	76.17	75.92	75.84	75.57	75.45	74.93	74.60	74.06	72.89	71.58
Mar-19	89.87	89.47	89.36	89.20	89.14	88.93	88.91	88.60	88.35	88.17	88.02	87.84
Apr-19	92.52	90.90	90.02	89.38	89.03	88.84	88.63	88.10	87.52	87.22	86.67	85.44
May-19	80.49	79.88	79.77	79.59	79.53	79.46	79.32	79.21	79.08	78.92	78.74	78.36
Jun -19	74.61	74.47	74.38	74.35	74.31	74.24	74.12	74.03	73.98	73.80	73.61	72.92
Jul-19	73.79	73.14	72.92	72.60	72.51	72.38	72.42	72.31	72.20	71.98	71.73	71.53
Aug-19	69.83	69.38	69.09	68.91	68.73	68.48	68.30	68.19	68.08	67.92	67.85	67.90
Sep-19	67.78	65.14	64.65	64.54	64.38	64.24	64.24	64.24	64.03	63.77	63.54	62.59
Oct-19	68.15	67.16	67.45	67.56	67.52	67.54	67.54	67.52	67.25	66.55	65.28	63.28
Nov-19	68.59	68.54	68.56	68.54	68.54	68.56	68.56	68.54	68.50	68.24	67.41	65.76
AVG	77.38	76.66	76.41	76.23	76.11	75.98	75.90	75.74	75.54	75.29	74.87	74.12

Table 4. Month-Wise Data Availability after synthesis using MCP (Dec 2018 - Nov 2019)

Month	40m	60m	70m	80m	87m	100m	107m	120m	140m	160m	180m	200m
Dec-18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jan-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Feb-19	99.65	99.65	99.65	99.65	99.65	99.65	99.65	99.65	99.65	99.65	99.65	99.65
Mar-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Apr-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
May-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jun-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Jul-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Aug-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sep-19	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96
Oct-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nov-19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
AVG	99.88	99.88	99.88	99.88	99.88	99.88	99.88	99.88	99.88	99.88	99.88	99.88

ANNEXURE II

JAFRABAD MAST (coastal mast)

NIWE has installed the 100m height meteorological mast at Jafrabad coast in the line of sight with the LiDAR at a distance of approximately 25km. The measurement was commenced on November 2017 in concurrence with the LiDAR measurement. Further all the sensors are re-installed in February 2019. Figure 1 shows the geographical location of the 100m meteorological mast.

The reference geographical coordinates for 100m mast location (Jafrabad) are given in Table 1. The UTM coordinates are WGS84, 42Q zone 755896 m E, 2312117 m N. Table 2 details about the installation of sensors along with the details of calibration. Subsequently the calibration certificates are attached.

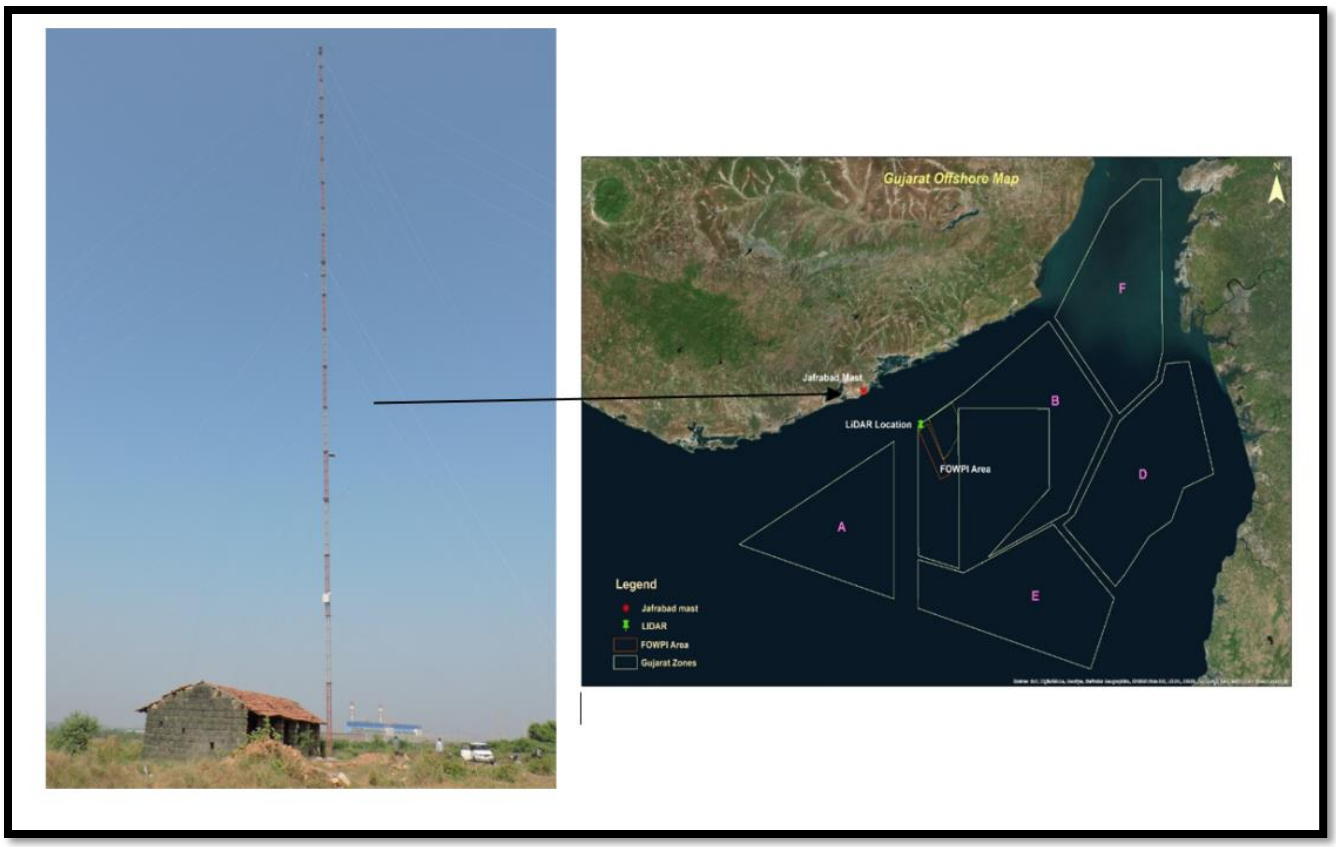


Figure 1: Coastal mast – 100m height at Jafrabad

Table 1: Co-ordinates of the Location

Site Name	Latitude	Longitude	Altitude	Mast Height
Jafrabad	20° 53' 29.81" N	71° 27' 35.68" E	9m agl	100m

Table 2: Details of sensors

Sensors	Height	Sensor serial Number	Slope	offset
Data Logger	12m	3157608942	-	-
Anemometer	100m N 100m S 80m 50m 20m 10m	01112164 01112163 01112162 01112161 01112160 01112159	0.04595 0.04595 0.04599 0.04594 0.04609 0.04594	0.2421 0.2478 0.2348 0.2343 0.2227 0.2379
Wind Vane	98m 78m 48m	08160786 08160787 08160788	-	-
Temperature sensor& Rel. Humidity	100m 12m	169314 169287	-	-
Pressure Sensor	12m	20288	-	-

a) Wind Characteristics

The information about wind speed and WPD are further segregated into month-wise values and given in Table 2. The air density values are calculated based on the measured temperature and pressure sensor.

Table 2. Monthly Mean Wind Speed

Month	Air Density (kg/m^3)	100m		80m		50m		20m		10m*	
		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)
Dec 18	1.182	6.57	248	5.85	186	5.28	121	4.03	57	-	-
Jan 19	1.191	6.84	276	6.43	228	5.55	140	4.23	69	-	-
Feb 19	1.189	6.48	236	6.05	189	5.30	120	4.09	57	3.49	37
Mar 19	1.174	6.50	219	6.03	171	5.27	108	4.11	53	3.59	38
Apr 19	1.157	6.71	250	6.29	203	5.70	145	4.63	82	4.08	59
May 19	1.155	8.03	408	7.69	359	6.97	272	5.80	166	5.17	122
Jun-19	1.146	8.93	586	8.58	529	7.80	409	6.48	240	5.71	161
Jul-19	1.150	8.56	474	8.20	419	7.41	316	6.07	180	5.37	127
Aug-19	1.158	8.08	400	7.67	343	6.81	244	5.43	129	4.72	87
Sep-19	1.163	6.46	230	6.14	203	5.48	154	4.46	86	3.66	47
Oct-19	1.151	5.54	148	5.24	124	4.60	83	4.51	71	3.01	27
Nov-19	1.159	5.12	124	4.86	100	4.22	60	3.41	41	2.71	18
Avg.	**1.165**	**6.99**	**300**	**6.59**	**255**	**5.87**	**181**	**4.81**	**106**	**4.16**	**73**

**commissioned on February 2019*

b) Data Availability

The data availability at various heights is given in Table 3.

Table 3: Data availability in percentage

Month	100m	80m	50m	20m	10m
Dec 18	100.00	38.84	100.00	100.00	0.00
Jan 19	100.00	0.00	100.00	100.00	0.00
Feb 19	99.65	94.20	99.65	99.65	93.82
Mar 19	100.00	100.00	100.00	100.00	100.00
Apr 19	100.00	100.00	100.00	100.00	100.00
May 19	100.00	100.00	100.00	100.00	100.00
Jun-19	100.00	100.00	100.00	100.00	100.00
Jul-19	100.00	100.00	100.00	100.00	100.00
Aug-19	100.00	100.00	100.00	100.00	100.00
Sep-19	98.96	98.96	98.96	98.96	98.96
Oct-19	100.00	100.00	100.00	50.04	100.00
Nov-19	100.00	100.00	100.00	78.61	100.00
Annual Avg.	**99.89**	**85.78**	**99.89**	**93.89**	**82.45**

c) Wind Rose

The wind roses at 98m, 78m and 48mare shown in Figures 2a, 2b and 2c respectively.

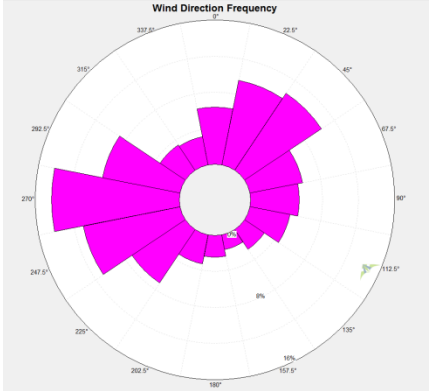


Figure 2a: 98m Annual Wind Rose

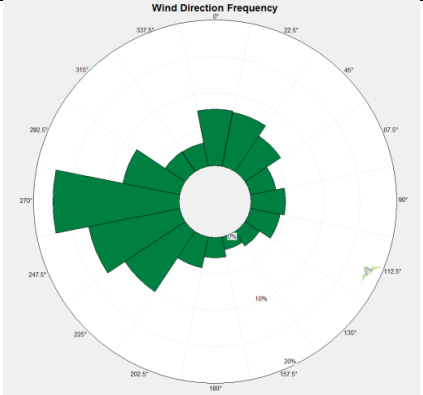


Figure 2b: 78m Annual Wind Rose

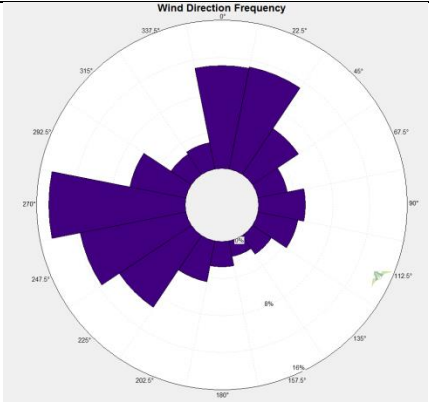


Figure 2c: 48m Annual Wind Rose

The predominant wind direction is West with 14.24% at 98m, 17.36% at 78m and 14.71% at 48m.

Calibration Certificates

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

DEUTSCHE WINDGUARD

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst

DKD

ilac-MRA DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

Calibration certificate *Kalibrierschein*	1730372
Calibration mark *Kalibrierzeichen*	D-K-15140-01-00 01/2017

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121459
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.01.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
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The user is obliged to have the object recalibrated at appropriate intervals.
Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
19.01.2017	Dipl. Phys. Dieter Westermann	Techniker Dennis Böckmann

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Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	19.2 °C ± 0.1 °C
air pressure	1037.5 hPa ± 0.3 hPa
relative air humidity	33.0 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks
Zusätzliche Anmerkungen

Calibration after refurbishment

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Calibration result
Kalibrierergebnis

Sensor out	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
81.872	3.989	0.050
125.327	6.005	0.050
167.981	7.961	0.050
211.183	9.921	0.051
254.250	11.913	0.051
297.757	13.922	0.051
338.458	15.787	0.051
317.458	14.828	0.051
276.125	12.925	0.051
232.652	10.925	0.051
189.685	8.950	0.051
146.206	6.970	0.050
104.478	5.038	0.050

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Statistical analysis	Slope	0.04594 (m/s)/(Hz) ±0.00003 (m/s)/(Hz)
	Offset	0.2379 m/s ±0.007 m/s
	Standard error (Y)	0.002 m/s
	Correlation coefficient	0.999997

Remarks The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH - measnet

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

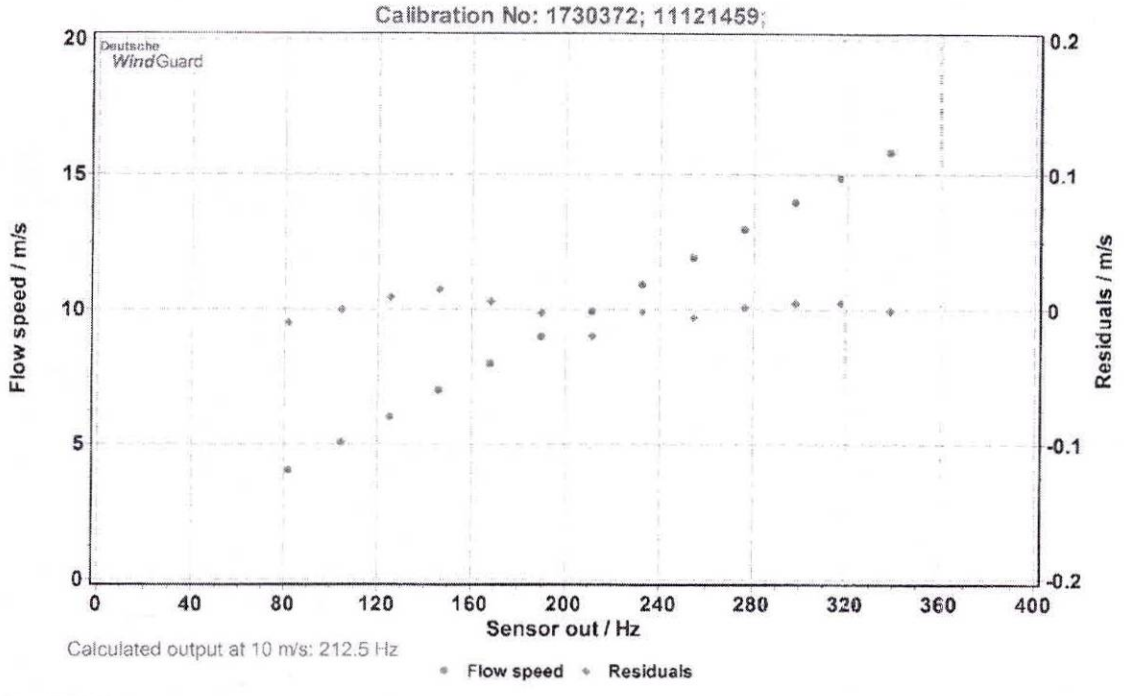
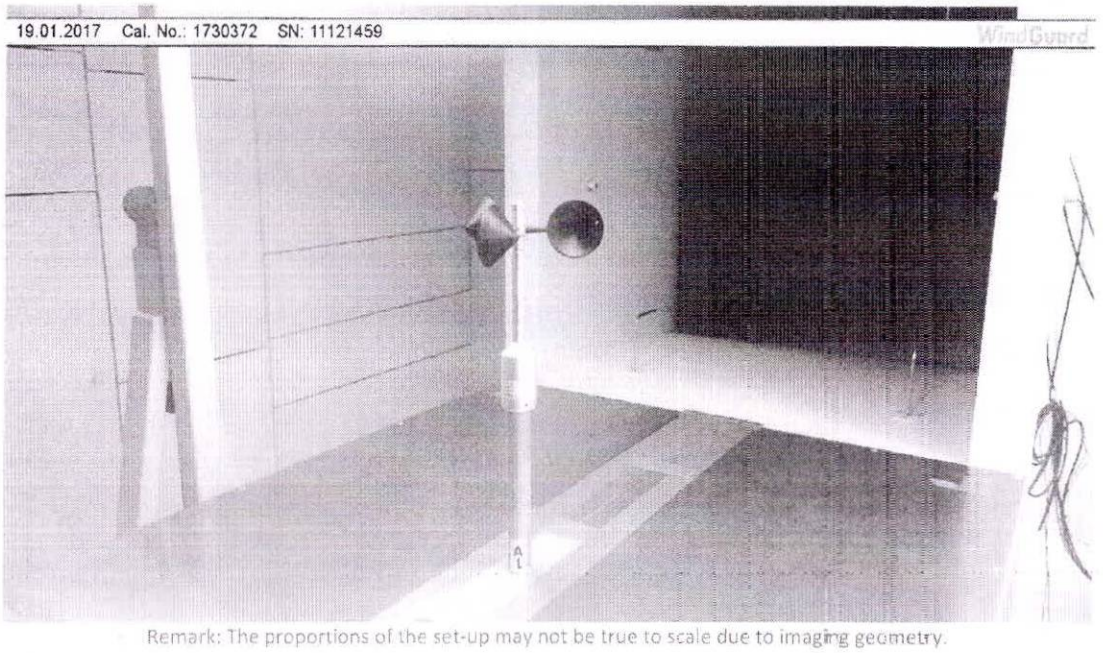


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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as calibration laboratory in the / *als Kalibrierlaboratorium im*

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DKD

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01/2017

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121460
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	20.01.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
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Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
20.01.2017	Dipl. Phys. Dieter Westermann	Philip Behnecke, M. Sc.

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Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	19.7 °C ± 0.1 °C
air pressure	1034.6 hPa ± 0.3 hPa
relative air humidity	32.3 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks
Zusätzliche Anmerkungen

Calibration after refurbishment

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Calibration result
Kalibrierergebnis

Sensor output	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
81.540	3.990	0.050
125.981	6.005	0.050
168.253	7.964	0.050
210.440	9.922	0.051
253.411	11.914	0.051
297.493	13.932	0.051
337.718	15.787	0.051
317.151	14.832	0.051
275.379	12.928	0.051
232.206	10.923	0.051
189.295	8.952	0.051
146.466	6.973	0.050
104.228	5.039	0.050

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Statistical analysis

Slope	0.04609 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
Offset	0.2227 m/s ±0.009 m/s
Standard error (Y)	0.008 m/s
Correlation coefficient	0.999996

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

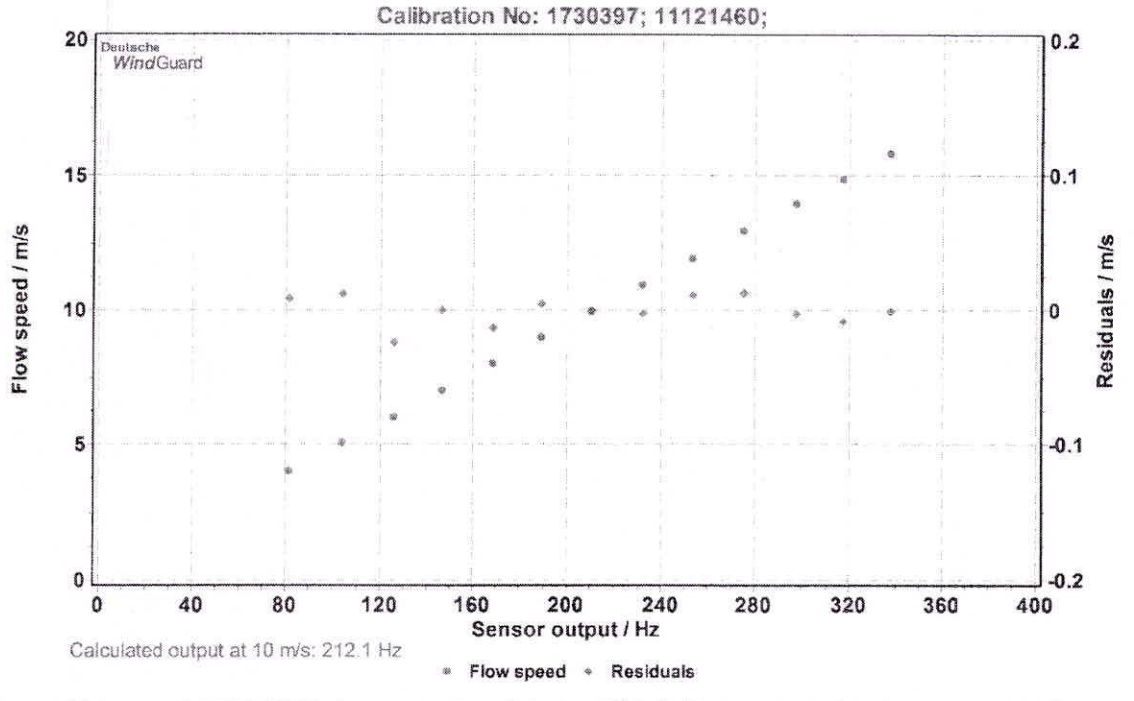
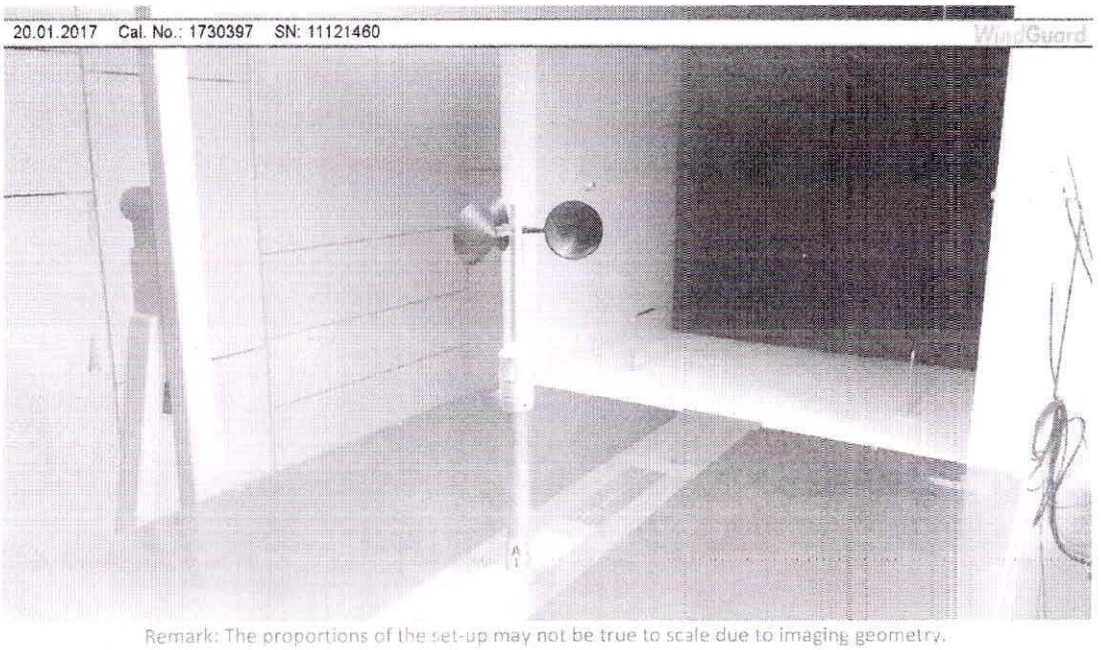


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121461
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	18.01.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
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Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
18.01.2017	D. Westermann	P. Behnecke
	Dipl. Phys. Dieter Westermann	Philip Behnecke, M. Sc.

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Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	19.9 °C ± 0.1 °C
air pressure	1038.1 hPa ± 0.3 hPa
relative air humidity	32.2 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks
Zusätzliche Anmerkungen

Calibration after refurbishment

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Calibration result
Kalibrierergebnis

Sensor out	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
82.159	3.992	0.050
126.316	6.005	0.050
167.406	7.962	0.050
210.122	9.920	0.051
254.270	11.913	0.051
298.148	13.928	0.051
339.031	15.790	0.052
317.992	14.831	0.051
275.929	12.924	0.051
233.152	10.924	0.051
189.434	8.951	0.050
146.445	6.970	0.050
104.942	5.046	0.050

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Statistical analysis

Slope	0.04594 (m/s)/(Hz) ±0.00008 (m/s)/(Hz)
Offset	0.2343 m/s ±0.017 m/s
Standard error (Y)	0.021 m/s
Correlation coefficient	0.999985

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH - measnet

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

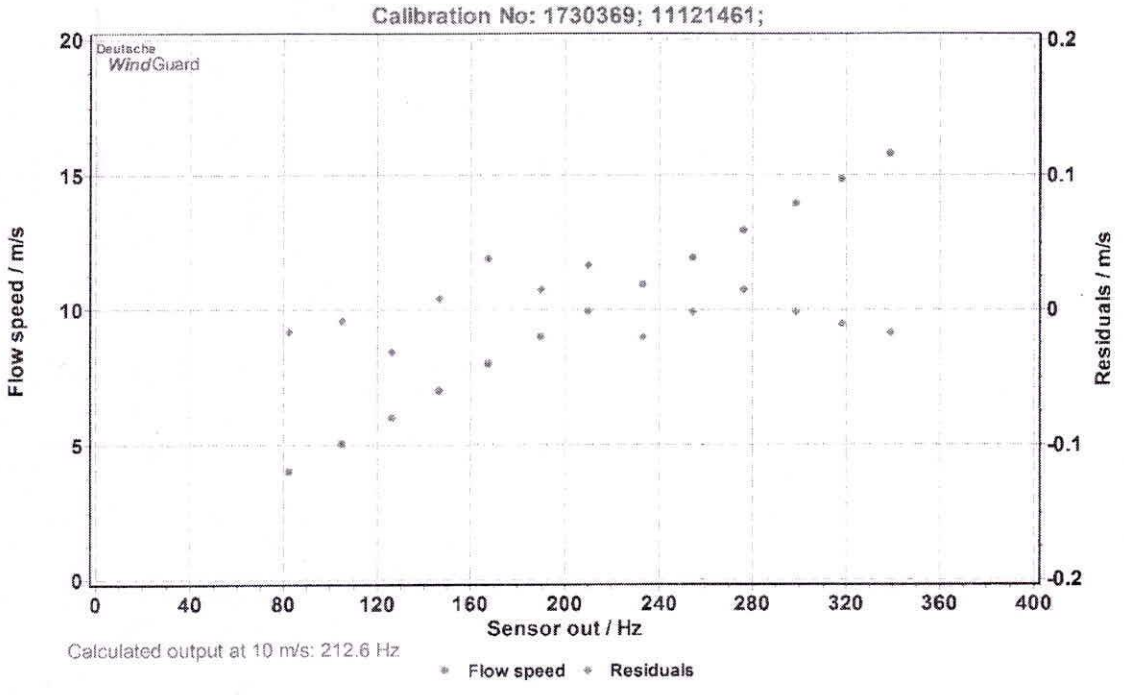
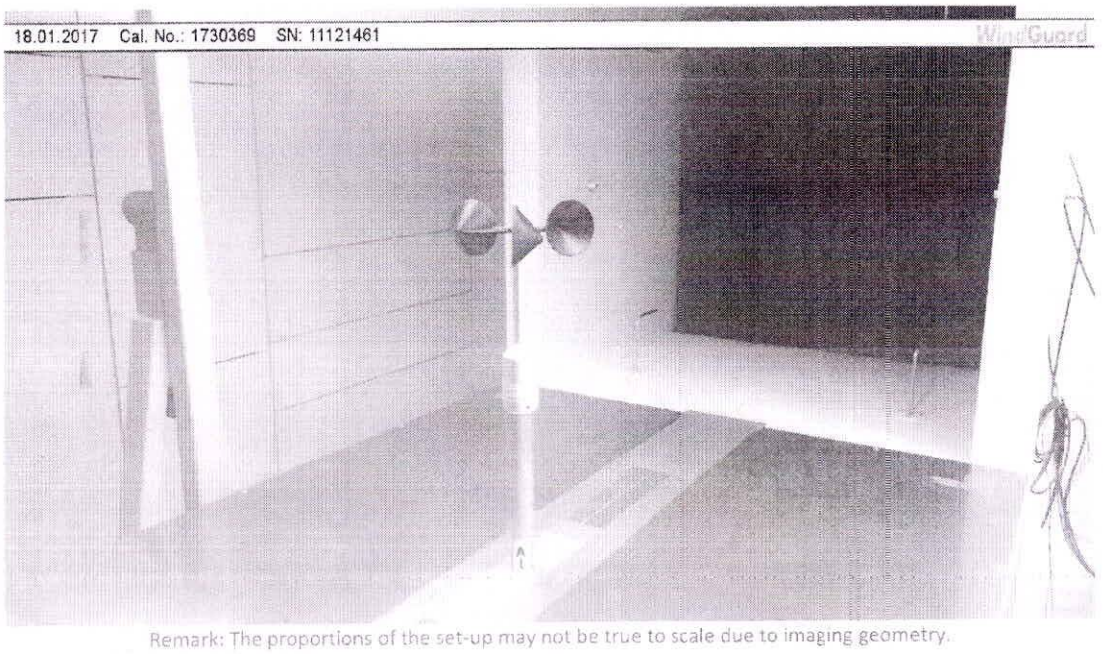


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121462
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.01.2017

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Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
19.01.2017	Dipl. Phys. Dieter Westermann	Techniker Dennis Böckmann

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Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm²
anemometer frontal area	230 cm²
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	19.7 °C ± 0.1 °C
air pressure	1037.3 hPa ± 0.3 hPa
relative air humidity	32.5 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks
Zusätzliche Anmerkungen

Calibration after refurbishment

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Calibration result
Kalibrierergebnis

Sensor out	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
81.947	3.989	0.050
125.813	6.004	0.050
167.787	7.960	0.050
210.711	9.918	0.051
253.606	11.912	0.051
297.735	13.926	0.051
338.679	15.789	0.051
317.205	14.829	0.051
276.275	12.928	0.051
232.322	10.924	0.051
189.103	8.952	0.051
146.343	6.973	0.050
104.672	5.048	0.050

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Statistical analysis

Slope	0.04599 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
Offset	0.2348 m/s ±0.010 m/s
Standard error (Y)	0.011 m/s
Correlation coefficient	0.999994

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH - measnet

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01/2017

Graphical representation of the result
Grafische Darstellung des Ergebnisses

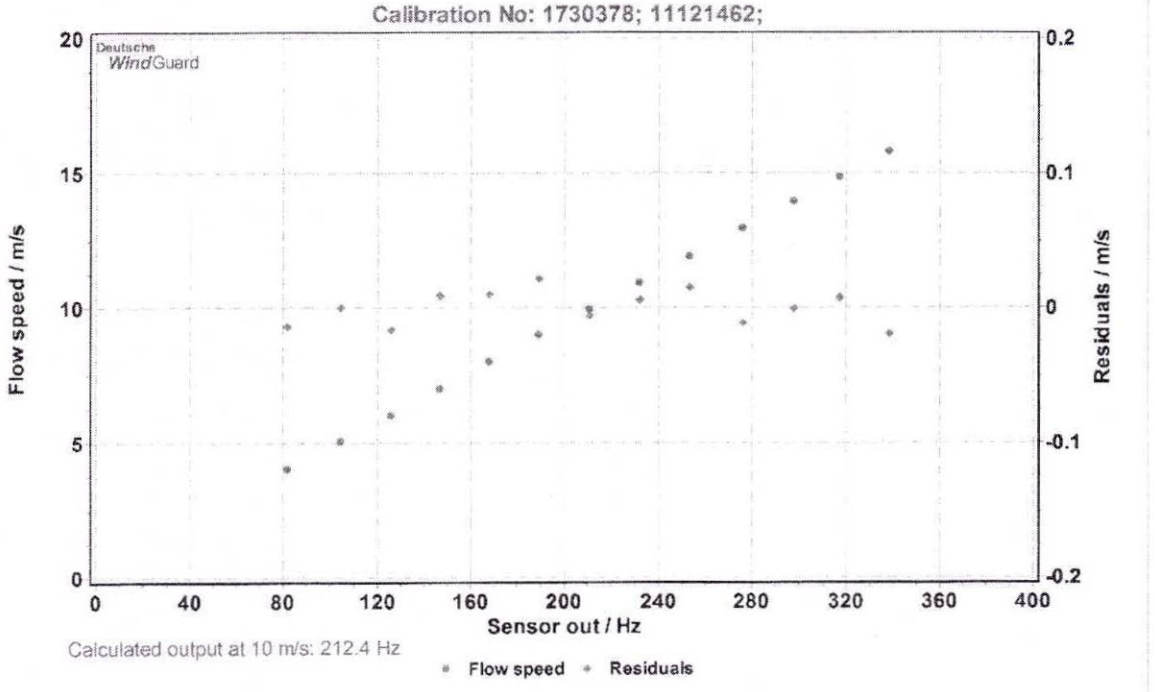
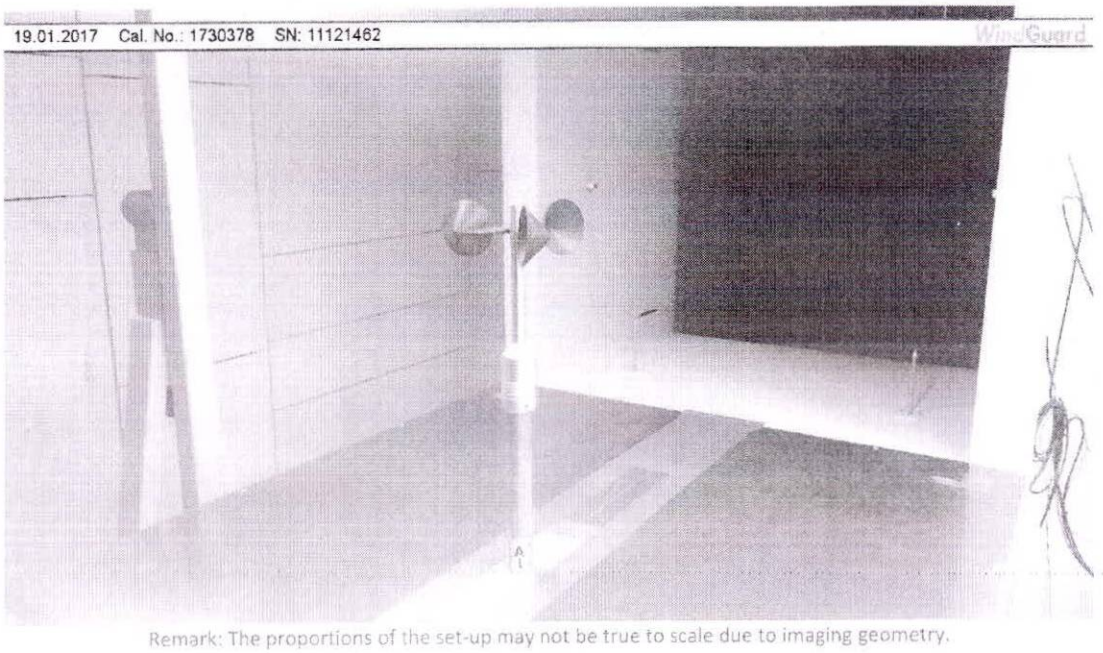


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

DEUTSCHE WINDGUARD

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst

DKD

ilac-MRA DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

Calibration mark *Kalibrierzeichen*	1730379 D-K-15140-01-00 01/2017

Calibration certificate
Kalibrierschein

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121463
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.01.2017

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Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
19.01.2017	D. Westermann	D. Böckmann
	Dipl. Phys. Dieter Westermann	Techniker Dennis Böckmann

1730379
D-K-15140-01-00
01/2017

Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm^2
anemometer frontal area	230 cm^2
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	19.7 °C ± 0.1 °C
air pressure	1036.9 hPa ± 0.3 hPa
relative air humidity	32.5 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Standard Uncertainty 0.2 %, k=2)

Additional remarks
Zusätzliche Anmerkungen

Calibration after refurbishment

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Calibration result
Kalibrierergebnis

Sensor out	Tunnel speed	Uncertainty (k=2)
Hz	m/s	m/s
81.524	3.990	0.050
125.340	6.005	0.050
167.454	7.961	0.050
210.125	9.922	0.051
254.085	11.915	0.051
297.563	13.928	0.051
338.423	15.790	0.051
317.060	14.829	0.051
276.254	12.927	0.051
232.303	10.925	0.051
189.556	8.951	0.051
146.496	6.973	0.050
104.402	5.043	0.050

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Statistical analysis	Slope	0.04595 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
	Offset	0.2478 m/s ±0.009 m/s
	Standard error (Y)	0.006 m/s
	Correlation coefficient	0.999996

Remarks The calibrated sensor complies with the demanded linearity of MEASNET

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

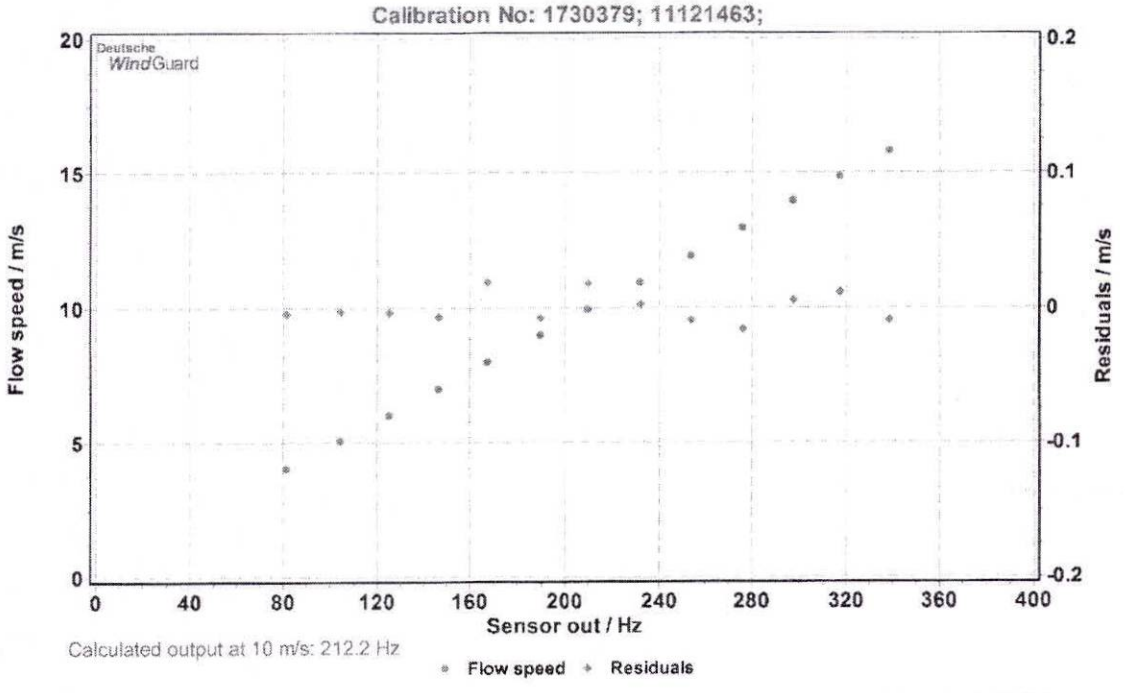
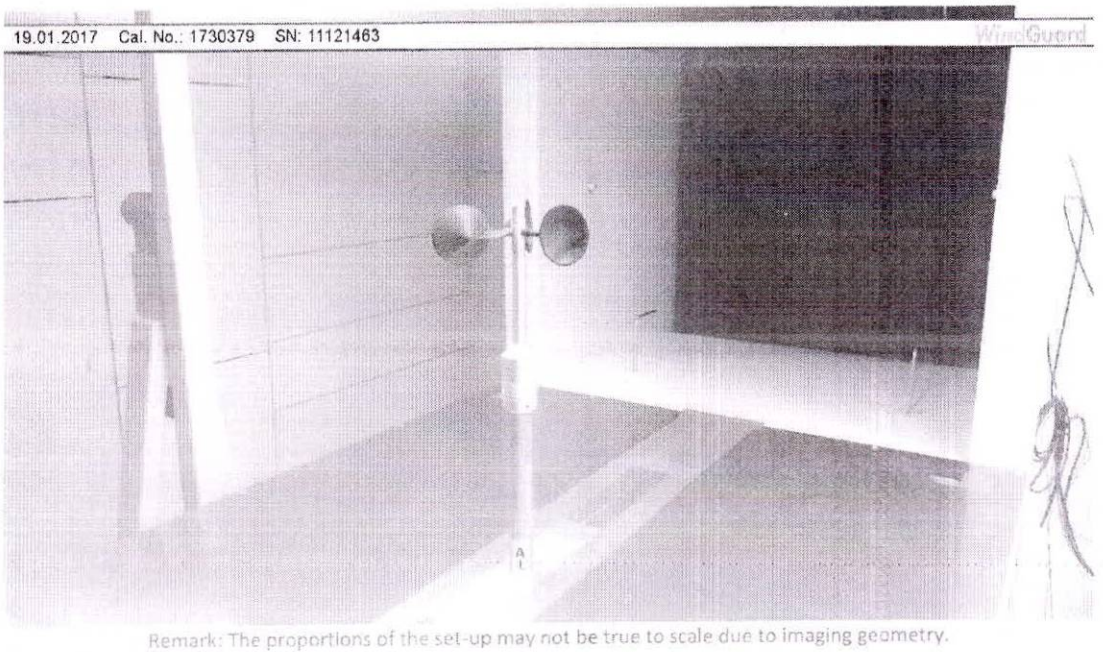


Photo of the measurement setup
Foto des Messaufbaus



Remark: The proportions of the set-up may not be true to scale due to imaging geometry.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

DEUTSCHE WINDGUARD

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

ilac-MRA DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst

DKD

Calibration certificate *Kalibrierschein*	1730371
Calibration mark *Kalibrierzeichen*	D-K-15140-01-00 01/2017

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	11121464
Customer *Auftraggeber*	National Institute of Wind Energy Chennai 600 100
Order No. *Auftragsnummer*	NIWE/PUR/2/210/16/043
Project No. *Projektnummer*	VT160632
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.01.2017

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.
Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
19.01.2017	D. Westermann	D. Böckmann
	Dipl. Phys. Dieter Westermann	Techniker Dennis Böckmann

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Calibration object
Kalibriergegenstand

Cup Anemometer

Calibration procedure
Kalibrierverfahren

- Deutsche WindGuard Wind Tunnel Services: QM-KL-AK-VA

Based on following standards:

- MEASNET: Anemometer calibration procedure
- IEC 61400-12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-2: Power performance of electricity producing wind turbines based on nacelle anemometry
- ISO 3966: Measurement of fluid in closed conduits
- ISO 16622: Meteorology - Sonic anemometers/thermometers

Place of calibration
Ort der Kalibrierung

Windtunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel area	10000 cm^2
anemometer frontal area	230 cm^2
diameter of mounting pipe	34 mm
blockage ratio [1)]	0.023 [-]
software version	7.64

[1)] Due to the special construction of the test section no blockage correction is necessary.

Ambient conditions
Umgebungsbedingungen

air temperature	18.9 °C ± 0.1 °C
air pressure	1037.4 hPa ± 0.3 hPa
relative air humidity	33.4 % ± 2.0 %

Measurement uncertainty
Messunsicherheit

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.
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Additional remarks
Zusätzliche Anmerkungen

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Calibration result
Kalibrierergebnis

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168.740	7.968	0.050
211.022	9.927	0.051
253.673	11.922	0.051
297.272	13.909	0.051
338.617	15.791	0.051
317.339	14.831	0.051
276.108	12.927	0.051
232.604	10.933	0.051
189.789	8.957	0.051
146.855	6.982	0.050
104.536	5.059	0.050

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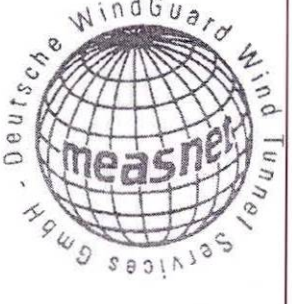
Statistical analysis

Slope	0.04595 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
Offset	0.2421 m/s ±0.011 m/s
Standard error (Y)	0.011 m/s
Correlation coefficient	0.999994

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET



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Graphical representation of the result
Grafische Darstellung des Ergebnisses

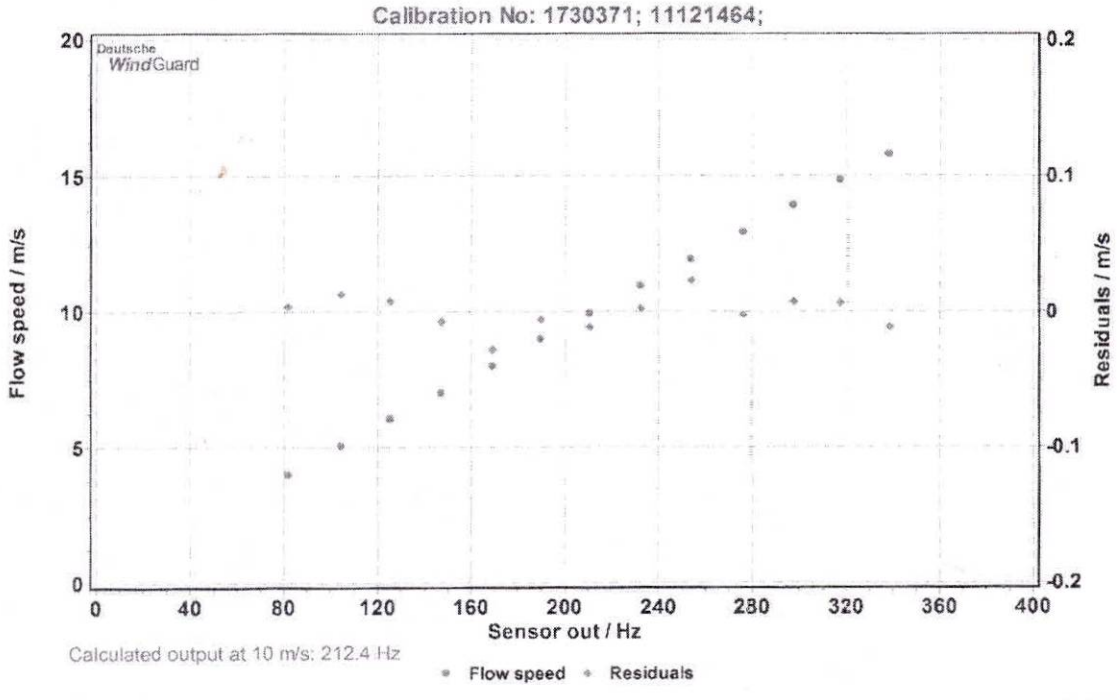
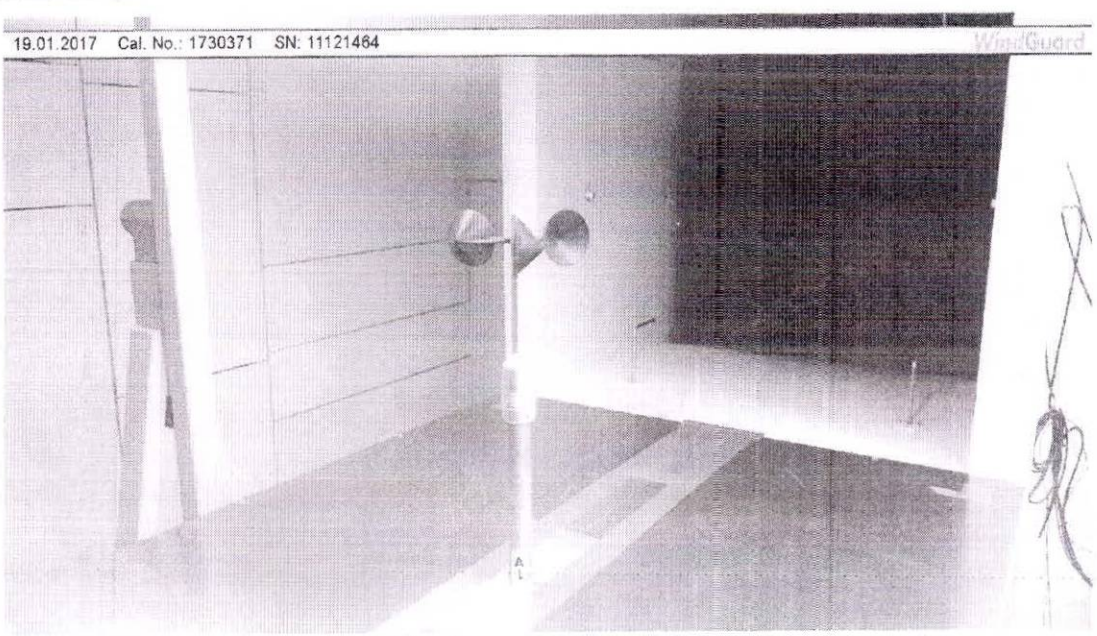


Photo of the measurement setup
Foto des Messaufbaus



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