MOLAS B300-117

Independent performance verification at the DNV GL Remote Sensing Test Site in Hamburg

Nanjing Movelaser Co., Ltd

Report No.: 10179759-R-1, Rev. B
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Task and objective:

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Reference to part of this report which may lead to misinterpretation is not permissible.

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2020-04-02	Final report (electronic version, only)	OlgBel	AniVen	BScm
B	2020-04-08	Final report (electronic version, only), update of SNR.	OlgBel	AniVen	BScm

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DNV GL Performance Verification Summary

General measurement configuration	
Associated Report	10179759-R-1, Rev. B
Customer	Nanjing Movelaser Co., Ltd
DNV GL entity	GL Garrad Hassan Deutschland GmbH
Location	DNV GL Hamburg Test Site
Device make, model, and serial number	Molas B300-117, V2.0
Measurement heights Lidar [m]	45, 62, 65, 78, 80, 112, 115, 121, 141, 161, 181, 201
Measurement start	2020-02-18
Measurement end	2020-03-28
Verification standard and/or criteria	IEC 61400-12-1 Ed. 2 (2017) DNV GL Best Practices / NORSEWInD Criteria
Deviation from above Standard	Incomplete wind speed bins for 16 m/s at 65 m, for 14.0 m/s and 15 m/s and greater at 45 m.

Molas B300-117 Verification results summary against Hamburg Test Mast					
	KPI Best Acceptance Criteria [1]	**Verification Height [m]**			
		121	**80**	**65**	**45**
DNV GL / NORSEWInD database completion	See Section 3.1 [2]	yes	yes	yes	yes
IEC database completion	See Section 3.2 [2]	yes	yes	no	no
System availability [%]	$SA_{CA} \geq 95$	99.98%			
Data availability [%]	$DA_{CA} \geq 90$	98.9	99.2	99.1	98.2
Concurrent availability for verification [%]	See Section 4.2 [2]	76.2	75.2	73.8	70.3
Wind speed correlation coefficient, R^2 [3]	$R^2_{mw} > 0.98$	0.999	0.998	0.998	0.997
Wind speed correlation slope, m [3]	$0.98 \geq X_{mws} \leq 1.02$	1.001	1.005	1.002	1.002
Wind speed relative mean difference [%] [3]	$C_{mwsd} \leq \pm 1.0$	0.20%	0.56%	0.20%	0.22%
Wind direction correlation coefficient, R^2 [3]	$R^2_{mwd} > 0.97$	0.999	NA	0.999	NA
Wind direction slope, m [3]	$0.98 \geq X_{mwd} \leq 1.02$	1.004	NA	1.003	NA
Wind direction Y-intercept, b [°] [3]	$OFF_{mwd} < \pm 5.0$	-0.026	NA	0.409	NA
IEC uncertainty, V_{RSD} (K=1) [%]	See Section 5.1 [2]	0.89 to 1.71	0.93 to 1.59	0.93 to 1.42	0.94 to 1.35
Verification concerns	None				
Device recommendation	The device is able to reproduce cup anemometer wind speeds and wind directions at an accurate and acceptable level. DNV GL considers that the device can be used for formal wind potential and long-term wind resource assessments if the aforementioned limitation is considered.				

[1] Defined in APPENDIX B of 10179759-R-1

[2] 10179759-R-1

[3] All wind speed ≥ 3 m/s.

1 INTRODUCTION

Nanjing Movelaser Co., Ltd ("Nanjing Movelaser") retained GL Garrad Hassan Deutschland GmbH ("GH-D"), a member of the DNV GL Group ("DNV GL"), to complete an independent remote sensing verification of a Molas B300-117 at The DNV GL Hamburg Test Site near Hamburg, Germany between 2020-02-18 and 2020-03-28.

The meterological reference mast (met mast) used in the lidar verification was equipped with classical anemometry components (cup anemometers, wind vanes etc.). Wind speed and wind direction comparisons are performed using the method provided in EU-FP7-Projekt NORSEWInD [1] against corresponding Key Performance Indicators (KPIs) and Acceptance Criteria (ACs; see APPENDIX B).

This verification also includes results and uncertainty calculations as defined in the International Electrotechnical Commission (IEC) 61400-12-1 power performance test standard Edition 2 (the IEC Standard) [2], Annex L.

DNV GL is accredited according to ISO 17025 for measurements on wind turbines and for wind resource measurements, energy assessments and Lidar verifications. DNV GL is also a full member of the network of measurement institutes in Europe 'MEASNET' and in the FGW (Fördergesellschaft Windenergie und anderer Erneuerbaren Energien).

The work has been conducted in compliance with all relevant health and safety legislation. GL Garrad Hassan Deutschland GmbH operates an Occupational Health and Safety Management System certified according to the OHSAS 18001:2007.

2 SITE INFORMATION

The following section decribes the DNV GL Hamburg Test Site and verification set-up.

Coordinates for the measurement site is provided in Table 2-1.

Table 2-1 Meteorological mast and remote sensing coordinates and wake-free sectors

ID	Easting [°]	Northing [°]	Elevation [m ASL[1]]	Distance to verification mast [m] (orientation [° true north])	Wake Free Sectors [° true north]
Mast	10.20683	53.47098	2	NA	120 to 20
Molas B300-117	10.20639	53.47098	2	~8 (180°)	

[1] Above sea level

Figure 2-1 DNV GL Hamburg Test Site near Hamburg, Germany.

2.1 Site Description

The verification test site is located approximately 15 km southwest Hamburg, Germany in the Curslack district. The test site can be described as having simple terrain with site elevations ranging from 1 m to 2 m above mean sea level. The surface roughness is considered moderate with typical rural structures such as grass fields, tree rows and villages. Table 2-2 decribes nearby structures, and 360° photos of the site are provided in APPENDIX C . DNV GL completed a site visit during the installation of the remote sensing device.

Table 2-2 Description of obstacles surrounding the mast and lidar

Obstacle	IEC significant obstacle	Height [m ASL[1]]	Distance to reference lidar [m]	Orientation to verification mast [° true north]
Five Nordex N117	Yes	120	80 to 800	40 to 120
Electrical pylons	Yes	35	100	20
Village of Curslack	Yes [2]	NA	1300	South Easterly
Village of Bergedorf	Yes [2]	NA	~ 500	West to north
Trees rows	No	15-20	≥15 m	East to west

[1] Above sea level
[2] Depending on the wind direction, measurements at or below 45 m may be biased by surrounding settlements and has therefore been excluded from the analysis.

Figure 2-2 is a schematic diagram of the test site that shows the mast, boom, guywire and lidar pad configuration. The lidar under test was installed on the lidar testing pad.

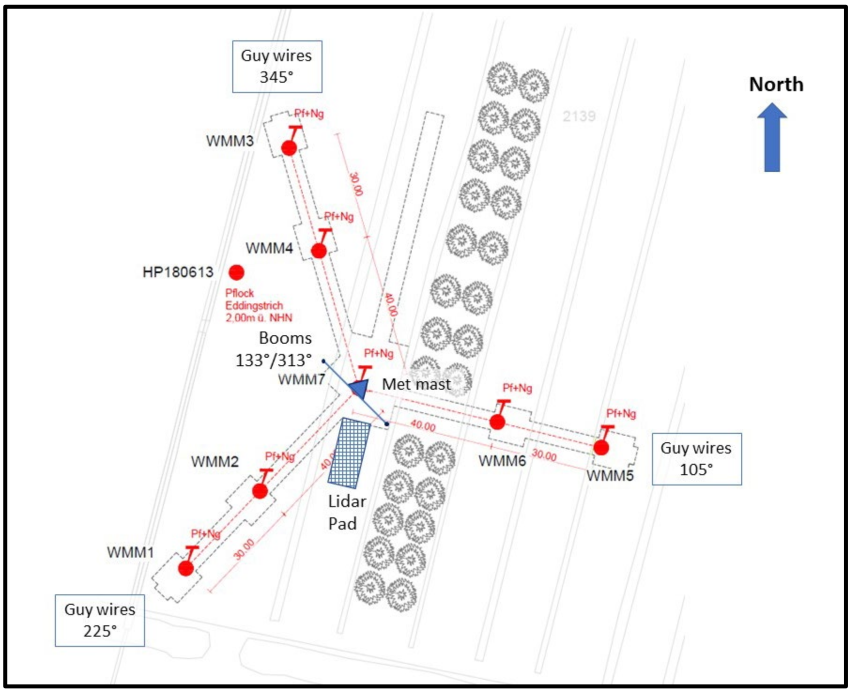


Figure 2-2 As-built schematic of met mast and lidar test pad

2.2 Measuring equipment

This section provides a description of the remote sensing device for verification and the reference met mast including its sensors and data acquisition system.

A DNV GL expert verified the following during a site visit on 18 May 2018:

- Site suitability and exact positions of mast and lidar test pad
- Mast height, measurement heights and boom orientations
- Distribution and mounting of sensors at the mast
- Validity of MEASNET [3] calibrations of cups and correct application of calibration factors and offsets
- Wind vane offset
- Data acquisition components, logger configuration
- Data storage and data provision

2.2.1 Meteorological mast

The met mast configuration is compliant with IEC 61400-12-1 Edition 2 [2] and the terrain of the test site falls within requirements for testing without a site calibration. All cup anemometers installed on the reference mast are class 1A instruments as defined by [2] and have undergone individual rotor specific MEASNET [3] calibration at a MEASNET certified wind tunnel.

A drawing indicating the dimensions of the reference met mast, sensors, and mounting equipment is shown in Figure 2-3. The as-built sensors and mounting equipment configurations are provided in APPENDIX A .

Data acquisition systems sample all input ports and connected sensors continuously with a sampling rate of 1-Hz and compress the values to 10-minute-average-values.

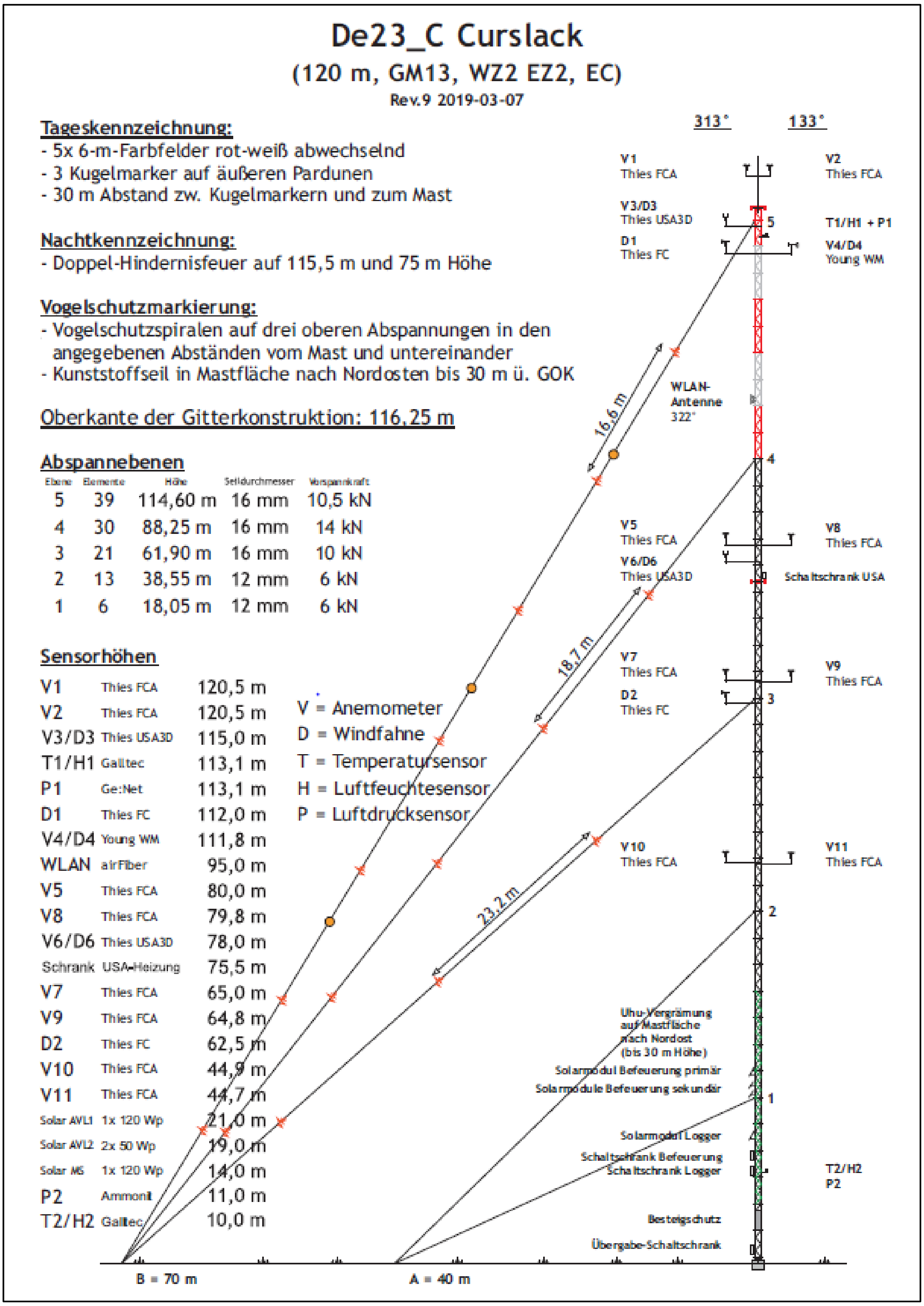


Figure 2-3 As-built reference mast instrumentation.

2.2.2 The Molas B300-117 Lidar

The Molas B300-117 is a pulsed Doppler Lidar that is specifically designed to measure wind speeds at heights in the lower boundary layer of the atmosphere. During the measurement campaign, the Lidar Molas B300-117 was configured to record wind speed measurements at 12 discrete heights between 40 m and 300 m. The lidar was orientated 87.5° from True North to avoid the mast structure, and this orientation is accounted for in the lidar offset.

Figure 2-4 shows the lidar under test installed on the lidar pad at approximately 8 m south from the met mast base. Table 2-3 lists wind speed and wind direction measurement and comparison heights selected for the performance verification.

Figure 2-4 Molas B300-117 installed at the Hamburg Remote Sensing Test Site.

Table 2-3 Lidar and reference mast measurement heights

Device	**Measurement heights [m] [1]**											
Molas B300-117	**45**	**62**	**65**	78	**80**	**112**	115	**121**	141	161	181	201
Mast cup Wind speed	**45**		**65**		**80**			**120.5**				
Mast vane or sonic wind direction		**62.5**				**112**						

[1] Wind speed and wind direction comparison heights are highlighted in bold typeface.

3 LIDAR PERFORMANCE VERIFICATION APPROACH

3.1 Best Practice Verification

The best practice verification follows the standard lidar DNV GL and NORSEWInD performance requirements. The following describes the general methods used for this verification:

- All comparisons are based on 10-minute averages from MEASNET calibrated cup anemometers, 3D sonic anemometers, and wind vanes on the reference mast (primary reference) and concurrent wind speed and wind direction data from the lidar under test.
- Only undisturbed free-stream wind data at both the reference mast and lidar are used in the analysis.
- The following data coverage requirements are regarded as achievable for a typical test period of four weeks:
  - A minimum of 600 10-minute valid data points for the wind speeds greater than 3 m/s;
  - A minimum of 600 10-minute valid data points for the wind speeds from 4 m/s to 16 m/s;
  - A minimum of 200 10-minute valid data points for the wind speeds from 4 and 8 m/s; and
  - A minimum of 200 10-minute valid data points for the wind speeds from 8 and 12 m/s.
- System availability was defined as the ratio between the number of 10-minute data points available for at least one measurement as compared to the number of possible records. The number of possible records excludes power outages and this availability is reported seperately.
- Data availability was defined as the ratio between the number of 10-minute valid data points available for at least one measurement as compared to the total number of data points present.
- Cup anemometers are regarded as the current industry standard for wind speed measurements at wind farm sites. Measurements with cup anemometers must therefore be considered the standard reference against which any new measurement device needs to be judged.
- Wind speed in this lidar performance verification (LPV) are assessed by means of linear regressions through the origin of the form

  $y = m\ x + b$ *and* $b =: 0$

  between lidar (y-axis) wind speeds and cup (x-axis) wind speeds. Data are compared for all greater than 3 m/s and from 4 m/s to 16 m/s [1].
- Wind directions were compared quantitatively by two variant regressions solving for the slope, m, and the interception of the best-fit line with the y-axis, b, (according to y = m x + b), as defined in APPENDIX B .

The performance of the lidar under test is based on several KPIs and ACs. The evaluation approach is provided in in APPENDIX B .

3.2 IEC Standard, Annex L verification

Verification was completed in accordance with the IEC Standard. This approach is based on a wind speed bin averaged procedure in order to compare the horizontal wind speed measurements acquired by the

[1] In consistency with the IEC bin selection criteria, the actual range spans from 3.75 to 16.25 since 4 m/s and 16 m/s are the central points of the corresponding 0.5 m/s wide bins.

remote sensing device (RSD) and the reference sensors at the mast. The objective of the IEC approach is to calculate the bin-wise deviation of the two sources and report the associated uncertainty.

The bin averaging procedure was performed using 0.5 m/s wide wind speed bins centred on integers of from 4 to 16 m/s. In order to achieve statistical relevance this IEC approach requires the following:

- A minimum of three (3) 10-minunte values available within each wind speed bin; and
- 180 hours or 1080 10-minute records of valid data

According to the IEC Standard, the verification uncertainty consists of five independent uncertainty components, which are summarized below:

1. Reference/anemometer uncertainty
2. Mean deviation of the remote sensor measurements and the reference measurements
3. Standard uncertainty of the measurement of the RSD
4. Mounting uncertainty of the remote sensor at the verification test
5. Uncertainty due to non-homogenous flow

The different uncertainty components are added in quadrature for each wind speed bin. The uncertainty due to non-homogenous flow between the measurement volume of the lidar and at the met mast is assumed to be negligible due to the proximity of the lidar to the mast and the benign terrain conditions at the remote sensing test site. Details on the calculation of the separate uncertainty components are described in APPENDIX G .

3.3 Data Filtering

Table 3-1 below summarizes the data filters applied to the mast and lidar.

Table 3-1 Data filtering

Filter	Criteria for removal		
Wind direction [°]	See sector filtering below		
Mast Signal QC filter (see below)	Value < Min or Value > Max	OR	Value = Standard Deviation
Mast Icing [°C]	Temperature < 0.5		
Mast wake free selectively averaged wind speeds	[Primary WS_{cup} – Redundant WS_{cup}] < 0.3 m/s		
Lidar Availability [%]	Availability < 80		
Signal QC filter at mast			
	Minimum	**Maximum**	**Standard deviation**
Wind speed [m/s]	0	30	0.0
Wind direction [°]	0	360	≤ 0.1
Temperature [°C]	-15	40	N/A
Pressure [hPa]	700	1100	N/A
Relative humidity [%]	0	100	N/A

Sector filtering

Figure 3-1 shows the booms at the mast are orientated northwest and southeast with data excluson zones between 103° and 163° for cups mounted on northwest booms and between 283° and 343° for cups mounted on southeast booms.

When free stream wind speeds are available at both the primary and redunant cup anemometer mounted at the same height, the average wind speeds are used as reference for the lidar comparison. Data is only considered valid when the wind speed difference between both cups is less than 0.3 m/s.

Cup aneometer data at 65 m are filtered using wind direction data from the 62.5 m wind vane. Cup aneometer data at 80 m and 120 m are filtered using wind direction data from the 112 m wind vane.

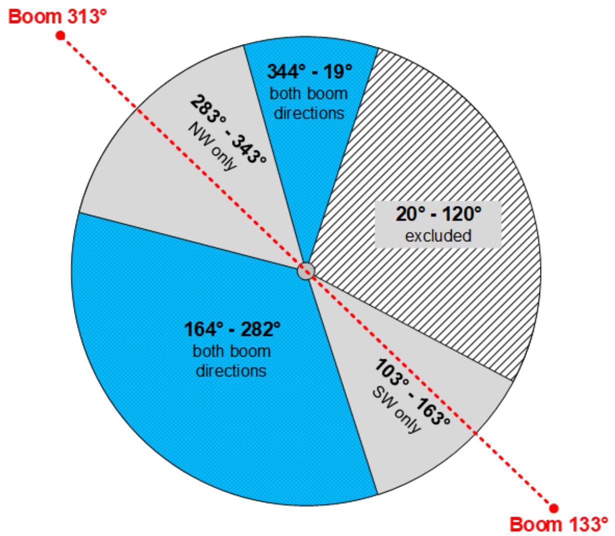


Figure 3-1 Wake free (blue), mast waked (grey) and turbine waked (hatched) wind direction sectors at the Mast.

4 RESULTS OF THE BEST PRACTICE VERIFICATION

Data for the lidar verification were available from 2020-02-18 to 2020-03-28. This verification campgain was completed after 40,0 days and included wind speeds from 3.0 m/s to 22,0 m/s at the upper mast height (121 m) and 3.0 m/s to 15,5 m/s at the lower mast height (45 m). Data coverage by wind speed ranges are presented in Table 4-1.

Table 4-1 Valid concurrent lidar and mast 10-minute data points for each verification height

	# of Data points			
WS-range	**121**	**80**	**65**	**45**
All >= 3 m/s	4173	4116	4041	3846
4 - 8 m/s	1931	2408	2504	2595
8 - 12 m/s	1664	1239	1040	625
4 - 16 m/s	4038	3933	3786	3447

As outlined in Section 3.1, the database requirements for all wind speed ranges are fulfilled.

4.1 System availability

The lidar device campaign duration was 40,0 days, which represents 5759 concurrent data points. After excluding power outages shown in Table 4-2, the lidar possible availability is reduced to 5474 records. Considering all 10-minute lidar records, there were 5473 records available for at least one measurement height, and therefore the lidar device has achieved a system availability of 99.98% (38,0 days) as presented in Table 4-3. This meets the acceptance criterion for system availability (KPI SACA) of ⩾ 95 %.

Table 4-2 Description of power outages

Power Outage Period		
Start	**End**	**Missed Data points**
2020-Mar-03 14:10:00	2020-Mar-05 13:30:00	285
	Total missed data	285

Table 4-3 Summary of system and data availabilities

	LiDAR Availability Assessment			
Height / m	**121**	**80**	**65**	**45**
Max. # of 10-min points in period	5759	5759	5759	5759
After accounting power outages	5474	5474	5474	5474
Data present	5473	5473	5473	5473
System availability (**KPI SA_{CA}**)	99.98%	99.98%	99.98%	99.98%
Total # of 10-minute valid data	5415	5429	5427	5373
Data availability (**KPI DA_{CA}**)	98.9%	99.2%	99.1%	98.2%
# after external filtering	4173	4116	4041	3846
Data availability for comparison	76.2%	75.2%	73.8%	70.3%

4.2 Data availability

Figure 4-1 shows the lidar system availability and the data recovery rate for each of the four (4) measurement heights. The valid lidar data availability from 45 m to 121 m ranges from 98,2 % to 99,2 %. The acceptance criterion for data availability (KPI DACA) of ⩾90 % has been met successfully for the lidar.

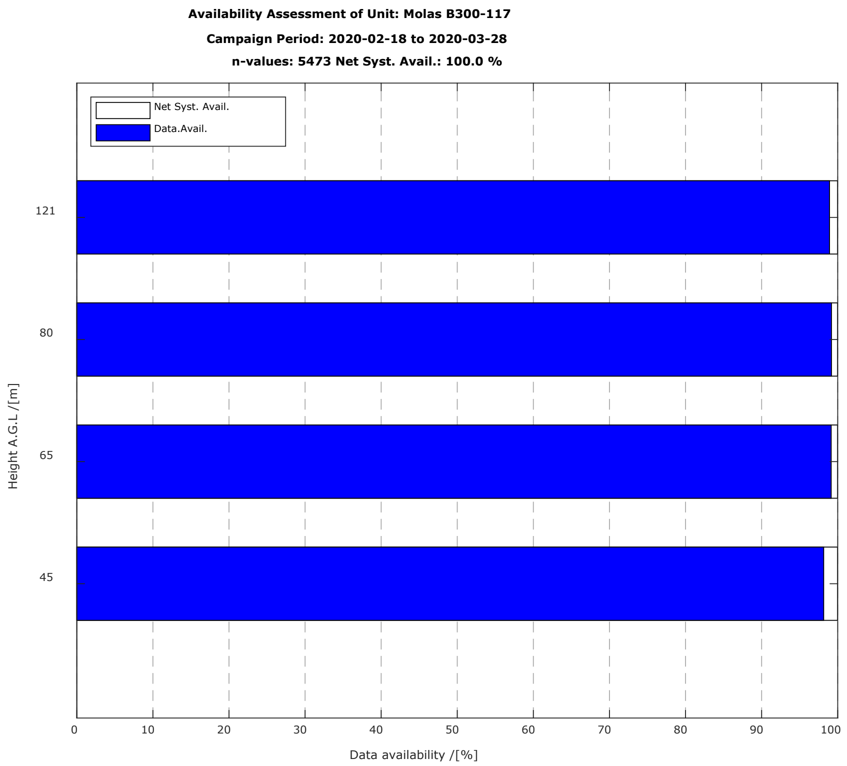


Figure 4-1 Lidar system and data availability

After the data from both the lidar and the mast were filtered, the number of 10-minute data points remaining reduced to 70,3 % at 45 m and 76,2 % at 121 m, as shown in Table 4-3.

4.3 Wind speed comparison

Table 4-4 summarizes the wind speed regression results for all four (4) verfication heights and shows that the lidar achieved a high level of accuracy relative to the cup aneometers. The regression slopes (m) are close to unity with a good regression coefficient R^2 (**KPI** R^2_{mws}). Figure 4-2 provides the corresponding regression plots for wind speeds greater than or equal to 3 m/s.

The average lidar wind speeds for each verfication height (**KPI** C_{mwsd}) are in good agreement with the average cup aneometer measurement (see columns 5 and 6 in Table 4-4), yielding very good relative Campaign Mean wind Speed Differences (**KPI** C_{mwsd}).

Table 4-5 provides the absolute wind speed error criterion. It shows that for the wind speed range from 4 m/s to 16 m/s between 45 m and 121 m there are between 0,1% and 0,3% for the concurrent 10-minute data points. This sucessfully meets the prescribed wind speed difference threshold of 0.5 m/s, which is below the allowed upper limit of 5%.

The lidar has passed the following wind speed KPIs and ACs for all verification heights:

- ✓ The Best Practice Acceptance Criterion for slope (**KPI** X_{mws}) to be between 0.98 and 1.02.
- ✓ The Best Practice Acceptance Criterion for R^2 (**KPI** R^2_{mws}) to be > 0.98.
- ✓ The Best Practice Acceptance Criterion for the relative Campaign Mean Wind Speed Difference (**KPI** C_{mwsd}) as shown in Table 4-4, column 8.
- ✓ The Acceptance Criterion for absolute Wind Speed Difference (**KPI** A_{wsd}) as shown in Table 4-5.

The concurrent time series of wind speeds from the lidar and met mast at 45 m and 121 m are shown in Appendix D.

Table 4-4 Regression results for comparison

121 m level	# values	slope	R^2	WS-avg Cup	WS-avg LiDAR	mean diff.	rel. mean difference
	-	-	-	[m/s]	[m/s]	[m/s]	%
WS-range		KPI X_{mws}	KPI R^2_{mws}				KPI C_{mwsd}
All >= 3 m/s	4173	1.001	0.999	8.42	8.44	0.017	0.20%
4 - 16 m/s	4038	1.002	0.998	8.43	8.45	0.017	0.20%

80 m level	# values	slope	R^2	WS-avg Cup	WS-avg LiDAR	mean diff.	rel. mean difference
	-	-	-	[m/s]	[m/s]	[m/s]	%
WS-range		KPI X_{mws}	KPI R^2_{mws}				KPI C_{mwsd}
All >= 3 m/s	4116	1.005	0.998	7.36	7.40	0.041	0.56%
4 - 16 m/s	3933	1.005	0.998	7.50	7.54	0.042	0.56%

65 m level	# values	slope	R^2	WS-avg Cup	WS-avg LiDAR	mean diff.	rel. mean difference
	-	-	-	[m/s]	[m/s]	[m/s]	%
WS-range		KPI X_{mws}	KPI R^2_{mws}				KPI C_{mwsd}
All >= 3 m/s	4041	1.002	0.998	6.90	6.92	0.014	0.20%
4 - 16 m/s	3786	1.002	0.998	7.11	7.12	0.014	0.19%

45 m level	# values	slope	R^2	WS-avg Cup	WS-avg LiDAR	mean diff.	rel. mean difference
	-	-	-	[m/s]	[m/s]	[m/s]	%
WS-range		KPI X_{mws}	KPI R^2_{mws}				KPI C_{mwsd}
All >= 3 m/s	3846	1.002	0.997	6.13	6.15	0.013	0.22%
4 - 16 m/s	3447	1.002	0.996	6.45	6.46	0.015	0.23%

Table 4-5 Summary of absolute wind speed differences between cups and Lidar.

Criterion for abs WS error	> 0.5 m/s for 4 to 16 m/s KPI A_{wsd}		
Height Level	total #	identified #	fraction
121 m	4038	4	0.10%
80 m	3933	10	0.25%
65 m	3786	8	0.21%
45 m	3447	4	0.12%

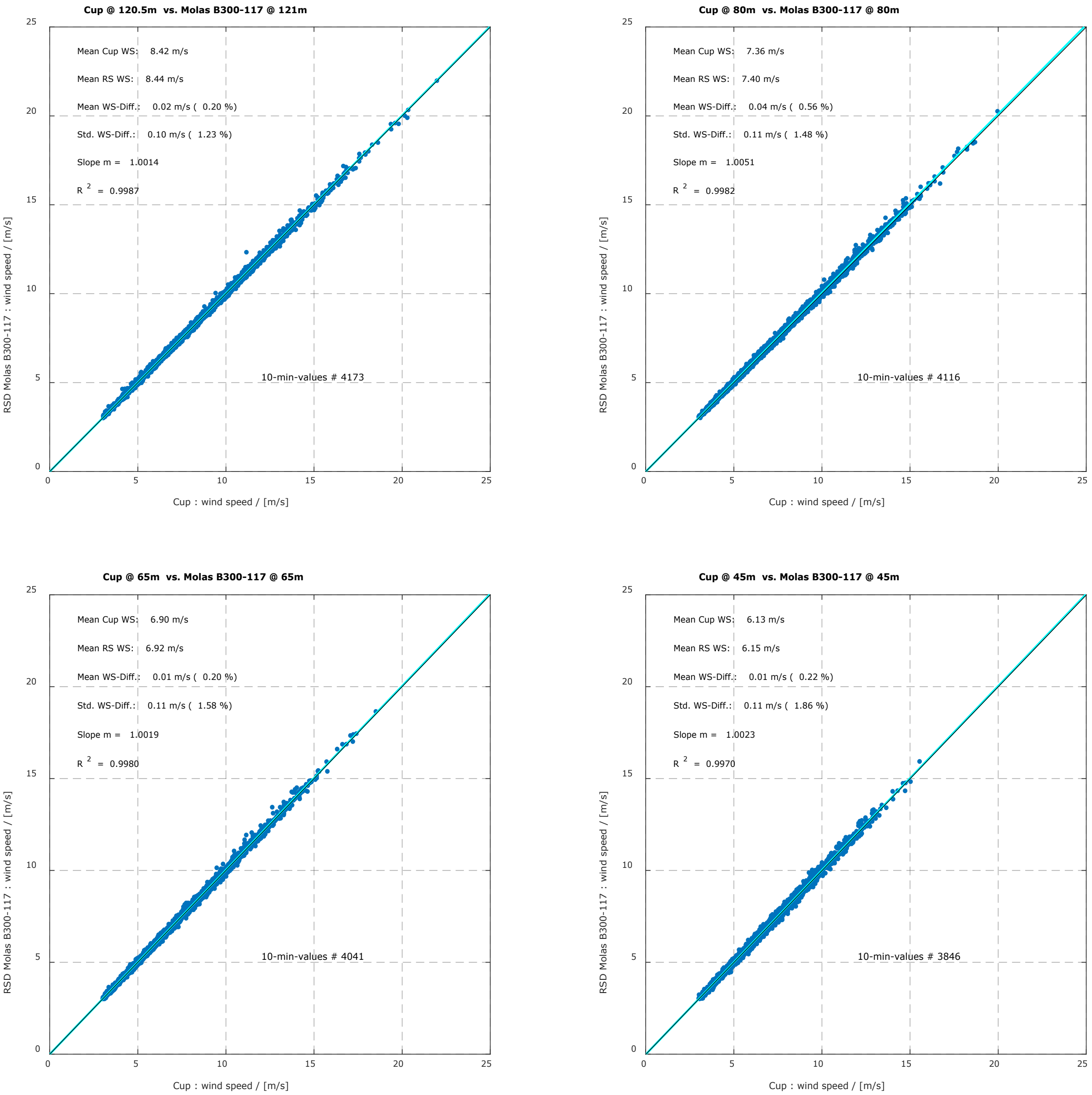


Figure 4-2 Linear wind speed regression results for 121 m, 80 m, 65 m and 45 m

4.4 Wind direction comparison

Figure 4-3 presents scatter plots of valid mast (x-axis) and lidar (y-axis) wind directions when anemometer wind speeds at 65 m for the lower vane and 121 m for the upper vane are ≥3 m/s.

Time series of wind direction, raw data correlations, and wind direction distribution statistics can be found in APPENDIX E .

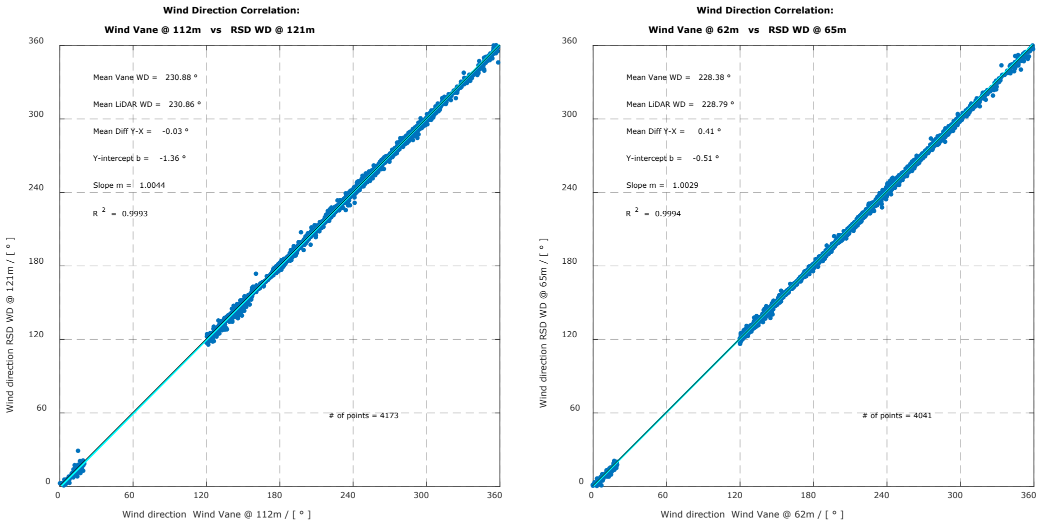


Figure 4-3 Regression plot of wind direction comparisons at 112 m (left) and 62 m (right)

The regression plots in Figure 4-3 show satisfactory agreement between lidar and vane wind direction measurements at 112 m and 65 m with a mean offset of 0,0° and 0,4° repectively. The difference between the upper wind vane and bottom wind vane offsets relative to the lidar are likely an artifact of a small misaglignement of the wind vanes. However, this is within typical directional setup uncertainties for wind vanes and RSDs.

Table 4-6 summarizes the wind direction comparisons and show that the lidar wind direction passes KPIs for the mean wind direction slope (X_{mwd}), absolute offset (OFF_{mwd}), and coefficient of determination (R^2_{mwd}).

Table 4-6 Summary of wind direction comparison

WS filtering for WS > 3 m/s				
Height level	**# values**	**slope**	**offset [°]**	**R^2**
[m]	[-]	**KPI X_{mwd}**	**KPI OFF_{mwd}**	**KPI R^2_{mwd}**
112	4173	1.004	-0.026	0.999
62	4041	1.003	0.409	0.999

5 PERFORMANCE VERIFICATION ACCORDING TO IEC STANDARD, ANNEX L

This section presents verification results as defined in the IEC Standard. This approach is described in Section 3.2.

Figure 5-1 through Figure 5-4 how scatter plots of the wind speed comparison based on 10-minute averages between the data pairs of the lidar and the cups at 121 m, 80 m, 65 m, and 45 m respectively. In addition, the 10-minute averaged deviation for each data point of the two data sets is plotted.

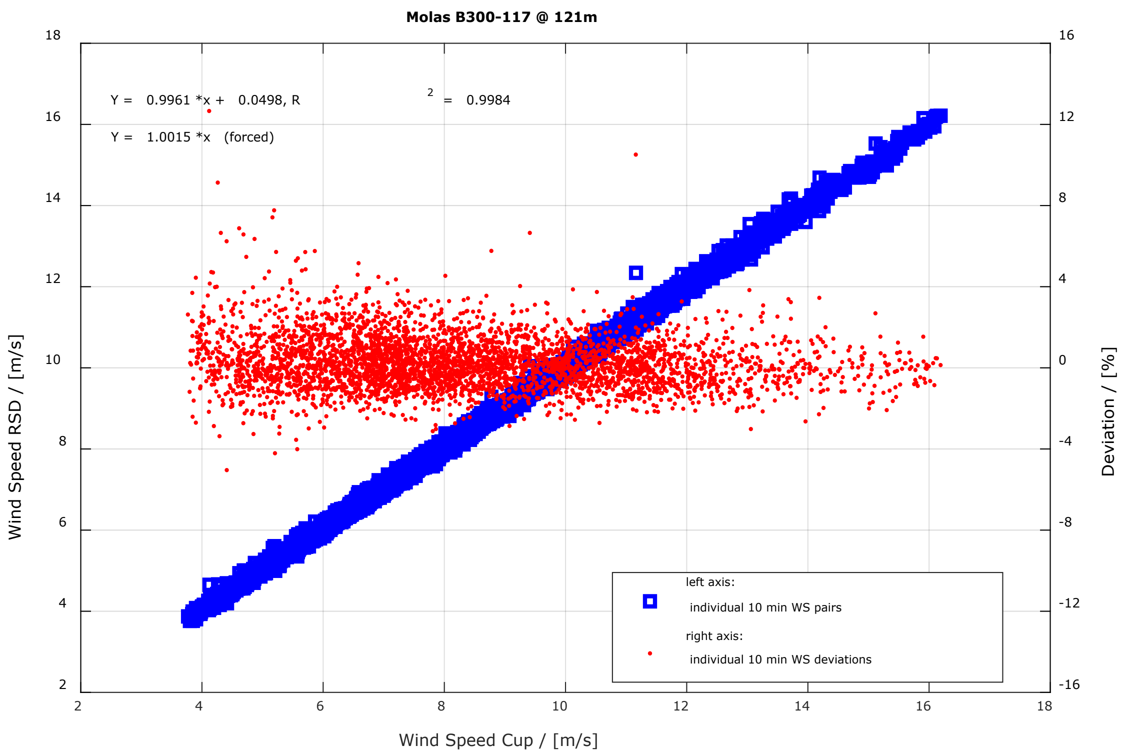


Figure 5-1 Comparison of the horizontal wind speed component at 121 m

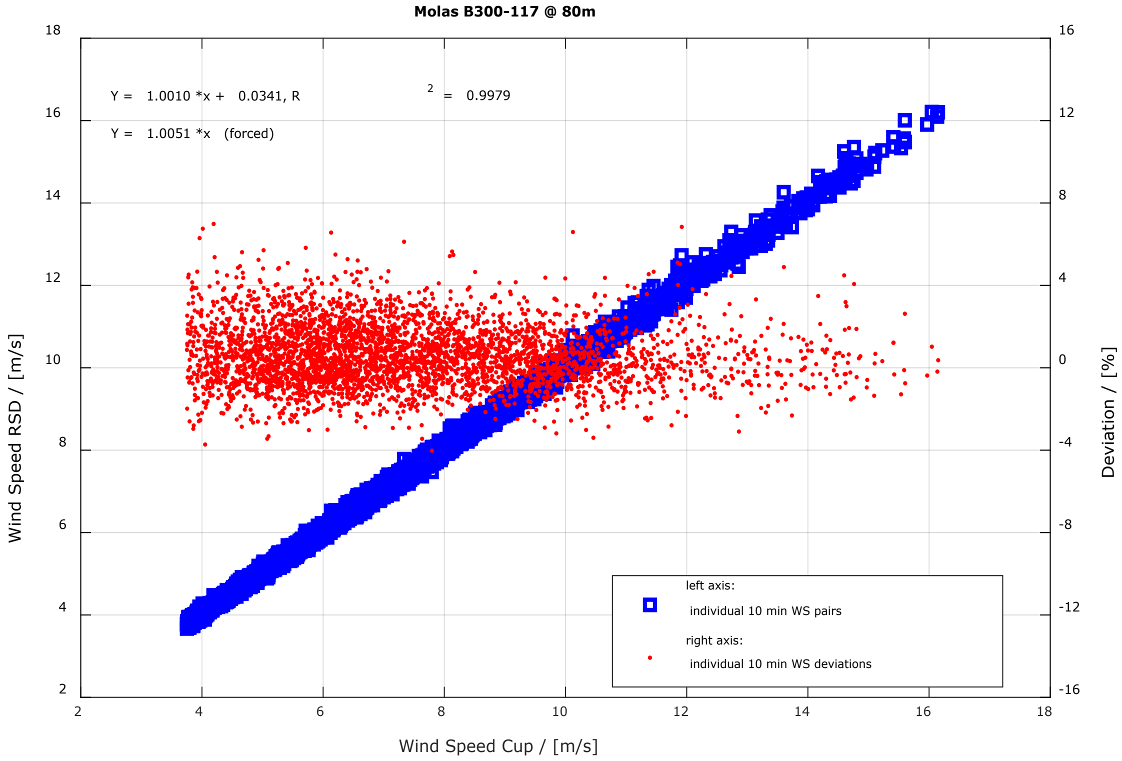


Figure 5-2 Comparison of the horizontal wind speed component at 80 m

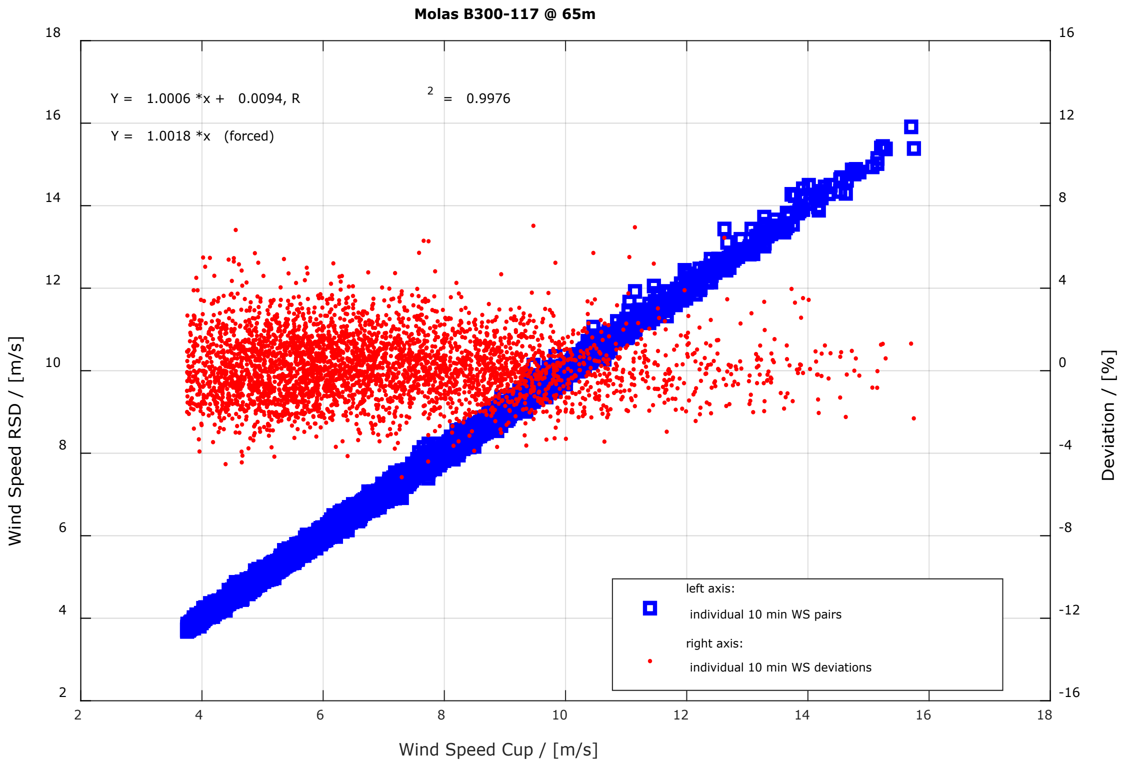


Figure 5-3 Comparison of the horizontal wind speed component at 65 m

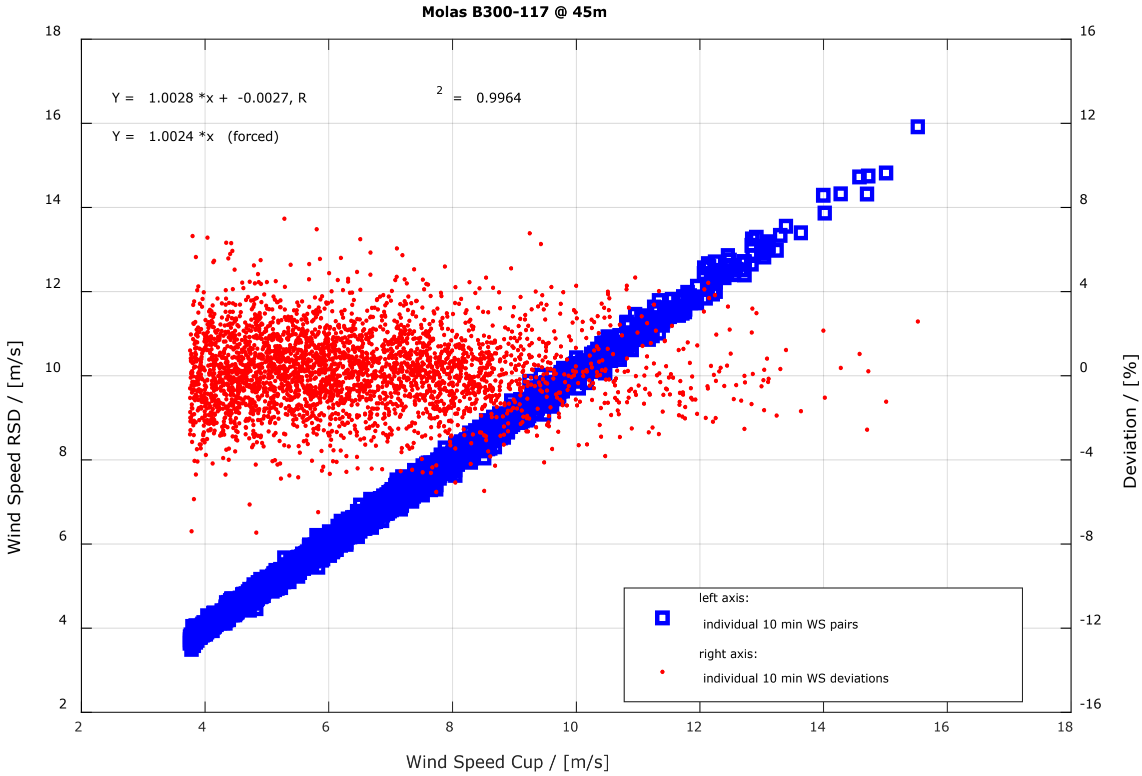


Figure 5-4 Comparison of the horizontal wind speed component at 45 m

Table 5-1 Statistical parameters of wind speed deviation

Height level	Coefficient of Determination	Mean Deviation		STD of Deviations	Data Points
[m]	(R^2)	[m/s]	[%]	[%]	#
121	0.998	0.017	0.20%	1.29%	4038
80	0.998	0.042	0.56%	1.46%	3933
65	0.998	0.014	0.19%	1.54%	3786
45	0.996	0.015	0.23%	1.77%	3447

5.1 Performance verification uncertainty

The database requirement for the lidar verification of 180 hours between 4 m/s and 16 m/s has been met for each comparison height. The additional database requirement of a minimum of 3 data pairs in each 0.5 m/s wind speed bin has not been fulfilled for the following:

- 16.0 m/s bin at 65 m.
- 14.0 m/s bin and from 15.0 m/s to 16.0 m/s bin at 45 m.

The bin-averaged wind speeds of the lidar and the reference measurements are shown in Figure 5-5 through Figure 5-8. The bin-averaged deviation, shown as a solid red line in the figures below, can be compared to the standard uncertainty of the cup anemometers with the binned verification statistical uncertainty. The low sample size at higher wind speeds has resulted in a greater validation uncertainty.

The correlation coefficient, mean deviation, and standard deviation of the deviations are provided in

Table 5-2 through Table 5-5. The relative deviation of the data pairs is calculated in relation to the cup wind speeds as the reference.

APPENDIX F presents the environmental parameters for the verification test.

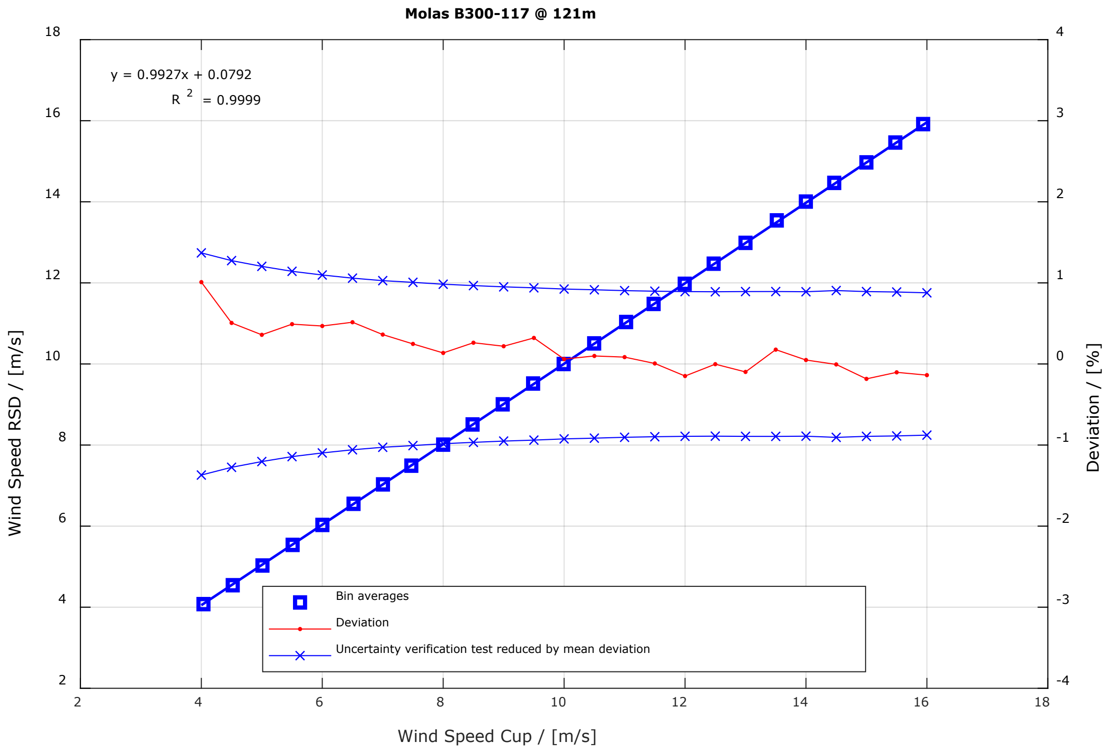


Figure 5-5 Bin-wise comparison of the horizontal wind speed component at 121 m

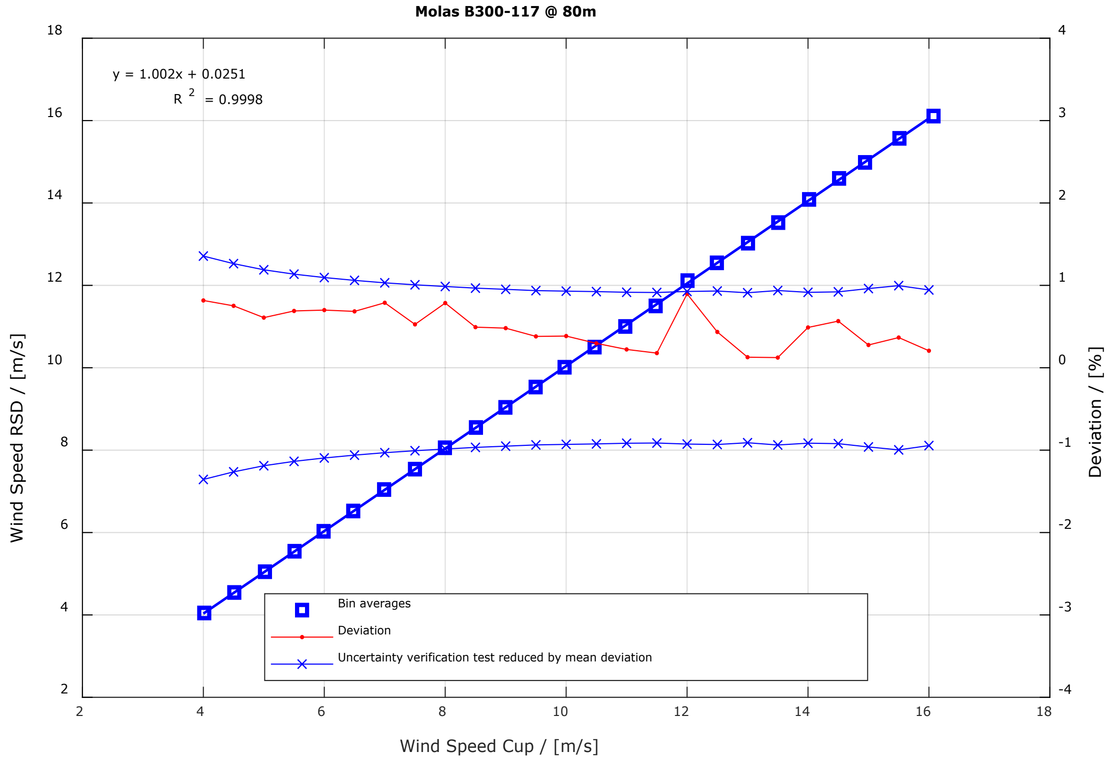


Figure 5-6 Bin-wise comparison of the horizontal wind speed component at 80 m

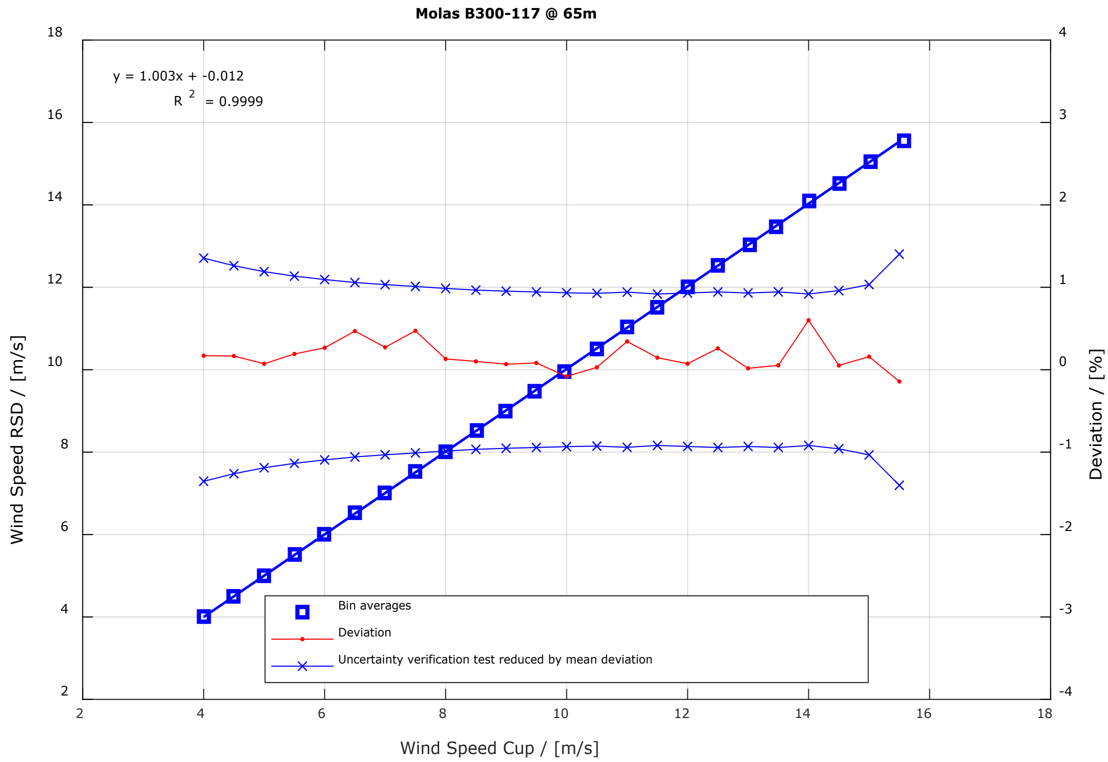


Figure 5-7 Bin-wise comparison of the horizontal wind speed component at 65 m

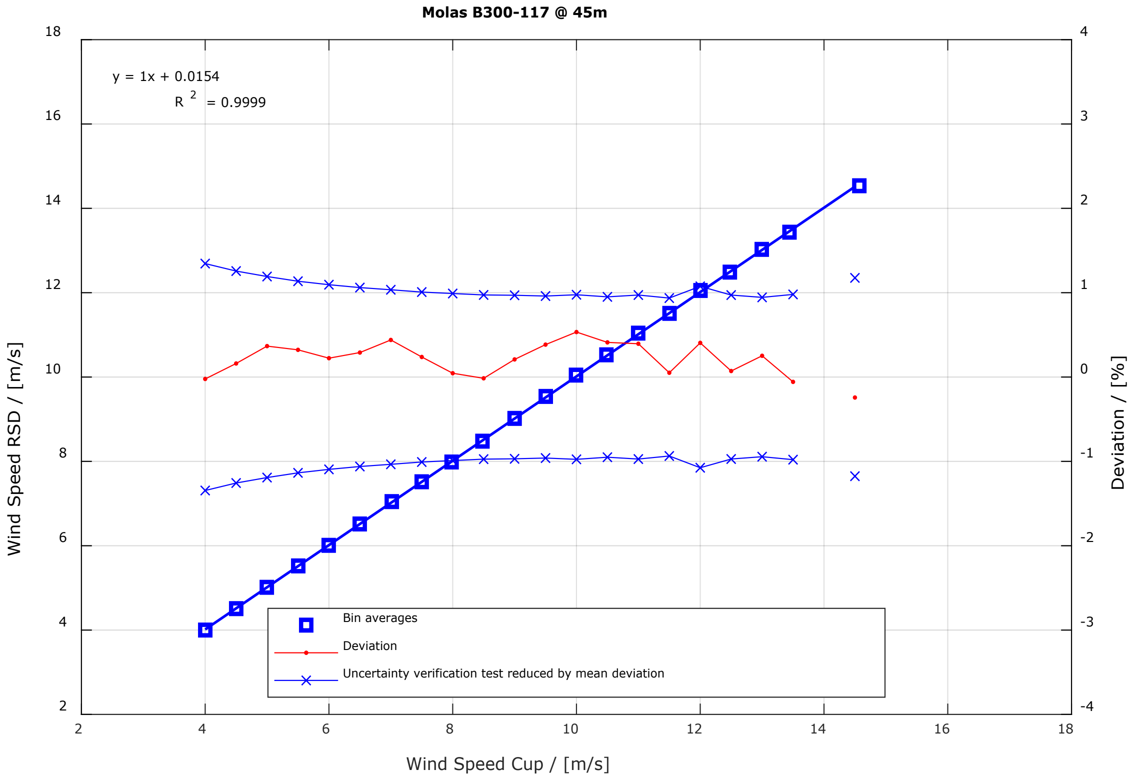


Figure 5-8 Bin-wise comparison of the horizontal wind speed component at 45 m

Table 5-2 Uncertainty calculation at 121 m

Height level 121m												
BIN lower [m/s]	BIN upper [m/s]	# of 10 min data sets	V_{rsd} [m/s]	V_{mm} [m/s]	V_{maxrsd} [m/s]	V_{minrsd} [m/s]	Std_{Vrsd} [m/s]	$Std_{Vrsd}/\sqrt{n}$ [m/s]	Mean deviation [%]	RSD Mounting uncertainty [%]	V_{cup} Uncertainty [%]	**V_{RSD} Uncertainty (k=1) [%]**
3.75	4.25	95	4.08	4.04	4.64	3.75	0.15	0.016	1.01%	0.50%	1.22%	**1.71%**
4.25	4.75	140	4.54	4.52	4.99	4.15	0.17	0.014	0.51%	0.50%	1.13%	**1.37%**
4.75	5.25	173	5.03	5.01	5.59	4.69	0.18	0.013	0.36%	0.50%	1.06%	**1.26%**
5.25	5.75	226	5.54	5.51	6.03	5.10	0.17	0.012	0.49%	0.50%	1.01%	**1.24%**
5.75	6.25	253	6.03	6.00	6.48	5.59	0.17	0.011	0.47%	0.50%	0.96%	**1.19%**
6.25	6.75	283	6.55	6.52	6.98	6.19	0.17	0.010	0.51%	0.50%	0.92%	**1.18%**
6.75	7.25	360	7.03	7.00	7.52	6.64	0.17	0.009	0.36%	0.50%	0.89%	**1.09%**
7.25	7.75	293	7.49	7.47	7.94	7.14	0.16	0.010	0.25%	0.50%	0.86%	**1.04%**
7.75	8.25	298	8.01	8.00	8.41	7.57	0.18	0.010	0.14%	0.50%	0.84%	**0.99%**
8.25	8.75	275	8.51	8.49	9.00	8.11	0.18	0.011	0.26%	0.50%	0.82%	**1.00%**
8.75	9.25	230	9.00	8.98	9.43	8.65	0.17	0.011	0.22%	0.50%	0.80%	**0.98%**
9.25	9.75	189	9.52	9.49	10.04	9.08	0.18	0.013	0.32%	0.50%	0.78%	**0.99%**
9.75	10.25	213	10.00	9.99	10.51	9.63	0.17	0.012	0.06%	0.50%	0.77%	**0.93%**
10.25	10.75	191	10.51	10.50	10.98	10.09	0.19	0.014	0.10%	0.50%	0.76%	**0.92%**
10.75	11.25	194	11.03	11.03	12.33	10.64	0.20	0.014	0.08%	0.50%	0.74%	**0.91%**
11.25	11.75	172	11.48	11.48	11.98	11.10	0.18	0.014	0.01%	0.50%	0.74%	**0.90%**
11.75	12.25	111	11.98	11.99	12.44	11.53	0.18	0.017	-0.15%	0.50%	0.73%	**0.91%**
12.25	12.75	81	12.47	12.47	13.01	12.13	0.19	0.021	0.00%	0.50%	0.72%	**0.89%**
12.75	13.25	68	12.99	13.00	13.55	12.55	0.23	0.028	-0.10%	0.50%	0.71%	**0.90%**
13.25	13.75	54	13.54	13.52	14.16	12.97	0.24	0.033	0.18%	0.50%	0.70%	**0.91%**
13.75	14.25	42	14.01	14.00	14.68	13.59	0.22	0.035	0.05%	0.50%	0.70%	**0.89%**
14.25	14.75	25	14.47	14.47	14.85	13.98	0.22	0.045	-0.01%	0.50%	0.69%	**0.91%**
14.75	15.25	25	14.97	15.00	15.52	14.68	0.21	0.043	-0.18%	0.50%	0.68%	**0.91%**
15.25	15.75	26	15.46	15.48	15.79	14.98	0.22	0.043	-0.10%	0.50%	0.68%	**0.90%**
15.75	16.25	21	15.92	15.94	16.21	15.63	0.18	0.040	-0.14%	0.50%	0.68%	**0.89%**

Table 5-3 Uncertainty calculation at 80 m

Height level 80m												
BIN lower [m/s]	BIN upper [m/s]	# of 10 min data sets	V_{rsd} [m/s]	V_{mm} [m/s]	V_{maxrsd} [m/s]	V_{minrsd} [m/s]	Std_{Vrsd} [m/s]	$Std_{Vrsd}/\sqrt{n}$ [m/s]	Mean deviation [%]	RSD Mounting uncertainty [%]	V_{cup} Uncertainty [%]	**V_{RSD} Uncertainty (k=1) [%]**
3.75	4.25	183	4.05	4.01	4.49	3.68	0.16	0.012	0.82%	0.50%	1.23%	**1.59%**
4.25	4.75	223	4.55	4.51	4.92	4.21	0.17	0.011	0.75%	0.50%	1.14%	**1.47%**
4.75	5.25	290	5.05	5.02	5.46	4.69	0.16	0.010	0.61%	0.50%	1.06%	**1.34%**
5.25	5.75	343	5.55	5.51	6.05	5.16	0.17	0.009	0.69%	0.50%	1.01%	**1.33%**
5.75	6.25	377	6.03	5.99	6.54	5.59	0.17	0.009	0.70%	0.50%	0.96%	**1.30%**
6.25	6.75	374	6.52	6.48	7.04	6.14	0.17	0.009	0.68%	0.50%	0.93%	**1.26%**
6.75	7.25	311	7.04	6.99	7.49	6.67	0.17	0.010	0.79%	0.50%	0.89%	**1.30%**
7.25	7.75	258	7.54	7.50	8.01	7.09	0.18	0.011	0.53%	0.50%	0.86%	**1.14%**
7.75	8.25	253	8.06	8.00	8.60	7.48	0.19	0.012	0.79%	0.50%	0.84%	**1.26%**
8.25	8.75	209	8.55	8.51	8.93	8.16	0.17	0.012	0.49%	0.50%	0.82%	**1.09%**
8.75	9.25	201	9.04	9.00	9.56	8.61	0.17	0.012	0.48%	0.50%	0.80%	**1.07%**
9.25	9.75	209	9.53	9.50	10.09	9.18	0.17	0.011	0.38%	0.50%	0.78%	**1.01%**
9.75	10.25	174	10.01	9.97	10.79	9.54	0.20	0.015	0.38%	0.50%	0.77%	**1.01%**
10.25	10.75	133	10.50	10.47	11.12	10.03	0.21	0.019	0.30%	0.50%	0.76%	**0.97%**
10.75	11.25	93	11.00	10.98	11.58	10.66	0.20	0.020	0.22%	0.50%	0.75%	**0.94%**
11.25	11.75	74	11.50	11.48	12.01	11.03	0.21	0.024	0.18%	0.50%	0.74%	**0.93%**
11.75	12.25	52	12.11	12.01	12.73	11.42	0.25	0.035	0.90%	0.50%	0.72%	**1.29%**
12.25	12.75	41	12.55	12.49	13.31	12.16	0.26	0.041	0.43%	0.50%	0.72%	**1.03%**
12.75	13.25	36	13.02	13.01	13.58	12.46	0.22	0.037	0.13%	0.50%	0.71%	**0.92%**
13.25	13.75	27	13.52	13.51	14.27	13.02	0.26	0.051	0.12%	0.50%	0.70%	**0.95%**
13.75	14.25	22	14.09	14.02	14.66	13.77	0.22	0.046	0.49%	0.50%	0.69%	**1.04%**
14.25	14.75	27	14.60	14.51	15.25	14.17	0.27	0.052	0.57%	0.50%	0.69%	**1.08%**
14.75	15.25	12	14.98	14.94	15.36	14.54	0.24	0.068	0.28%	0.50%	0.69%	**1.00%**
15.25	15.75	7	15.57	15.51	16.01	15.34	0.22	0.084	0.37%	0.50%	0.68%	**1.07%**
15.75	16.25	4	16.11	16.08	16.21	15.91	0.14	0.071	0.21%	0.50%	0.67%	**0.97%**

Table 5-4 Uncertainty calculation at 65 m

Height level 65m												
BIN lower [m/s]	BIN upper [m/s]	# of 10 min data sets	V_{rsd} [m/s]	V_{mm} [m/s]	V_{maxrsd} [m/s]	V_{minrsd} [m/s]	Std_{Vrsd} [m/s]	$Std_{Vrsd}/\sqrt{n}$ [m/s]	Mean deviation [%]	RSD Mounting uncertainty [%]	V_{cup} Uncertainty [%]	**V_{RSD} Uncertainty (k=1) [%]**
3.75	4.25	207	4.01	4.00	4.40	3.68	0.16	0.011	0.17%	0.50%	1.23%	**1.37%**
4.25	4.75	305	4.50	4.49	4.94	4.15	0.17	0.009	0.17%	0.50%	1.14%	**1.27%**
4.75	5.25	366	5.00	5.00	5.38	4.59	0.16	0.008	0.07%	0.50%	1.07%	**1.19%**
5.25	5.75	370	5.52	5.51	6.02	5.13	0.17	0.009	0.19%	0.50%	1.01%	**1.15%**
5.75	6.25	380	6.01	5.99	6.49	5.63	0.17	0.009	0.27%	0.50%	0.96%	**1.13%**
6.25	6.75	321	6.53	6.50	7.07	6.10	0.16	0.009	0.47%	0.50%	0.92%	**1.16%**
6.75	7.25	281	7.01	6.99	7.53	6.62	0.18	0.011	0.27%	0.50%	0.89%	**1.07%**
7.25	7.75	257	7.53	7.50	8.23	6.92	0.20	0.013	0.47%	0.50%	0.86%	**1.12%**
7.75	8.25	225	8.01	8.00	8.55	7.60	0.18	0.012	0.13%	0.50%	0.84%	**1.00%**
8.25	8.75	212	8.53	8.52	9.02	8.11	0.18	0.012	0.10%	0.50%	0.82%	**0.97%**
8.75	9.25	211	8.99	8.99	9.52	8.54	0.19	0.013	0.07%	0.50%	0.80%	**0.96%**
9.25	9.75	169	9.48	9.47	10.14	9.01	0.20	0.015	0.08%	0.50%	0.78%	**0.95%**
9.75	10.25	118	9.95	9.96	10.40	9.50	0.18	0.017	-0.08%	0.50%	0.77%	**0.94%**
10.25	10.75	96	10.50	10.50	11.06	10.06	0.21	0.021	0.03%	0.50%	0.76%	**0.93%**
10.75	11.25	56	11.04	11.00	11.92	10.68	0.24	0.032	0.34%	0.50%	0.74%	**1.00%**
11.25	11.75	51	11.51	11.50	12.05	11.16	0.20	0.027	0.15%	0.50%	0.73%	**0.93%**
11.75	12.25	40	12.01	12.00	12.47	11.60	0.23	0.037	0.07%	0.50%	0.72%	**0.94%**
12.25	12.75	33	12.53	12.50	13.43	12.14	0.26	0.045	0.26%	0.50%	0.72%	**0.98%**
12.75	13.25	24	13.03	13.03	13.43	12.67	0.22	0.045	0.02%	0.50%	0.71%	**0.93%**
13.25	13.75	25	13.47	13.46	14.27	13.02	0.26	0.052	0.05%	0.50%	0.70%	**0.95%**
13.75	14.25	19	14.09	14.01	14.49	13.82	0.21	0.047	0.60%	0.50%	0.70%	**1.10%**
14.25	14.75	9	14.52	14.51	14.87	14.29	0.20	0.065	0.05%	0.50%	0.69%	**0.96%**
14.75	15.25	8	15.05	15.03	15.43	14.77	0.26	0.090	0.16%	0.50%	0.68%	**1.05%**
15.25	15.75	3	15.56	15.58	15.91	15.37	0.31	0.177	-0.14%	0.50%	0.68%	**1.42%**
15.75	16.25	0										

Table 5-5 Uncertainty calculation at 45 m

Height level 45m												
BIN lower [m/s]	BIN upper [m/s]	# of 10 min data sets	V_{rsd} [m/s]	V_{mm} [m/s]	V_{maxrsd} [m/s]	V_{minrsd} [m/s]	Std_{Vrsd} [m/s]	$Std_{Vrsd}/\sqrt{n}$ [m/s]	Mean deviation [%]	RSD Mounting uncertainty [%]	V_{cup} Uncertainty [%]	**V_{RSD} Uncertainty (k=1) [%]**
3.75	4.25	356	4.00	4.00	4.37	3.50	0.17	0.009	-0.02%	0.50%	1.23%	**1.35%**
4.25	4.75	396	4.51	4.50	4.93	4.12	0.17	0.008	0.16%	0.50%	1.14%	**1.27%**
4.75	5.25	378	5.01	5.00	5.41	4.47	0.18	0.009	0.37%	0.50%	1.07%	**1.25%**
5.25	5.75	364	5.52	5.50	5.99	5.11	0.17	0.009	0.32%	0.50%	1.01%	**1.18%**
5.75	6.25	351	6.01	6.00	6.54	5.45	0.17	0.009	0.22%	0.50%	0.96%	**1.12%**
6.25	6.75	299	6.52	6.50	7.07	6.00	0.18	0.010	0.29%	0.50%	0.92%	**1.10%**
6.75	7.25	239	7.05	7.02	7.60	6.54	0.20	0.013	0.44%	0.50%	0.89%	**1.13%**
7.25	7.75	263	7.52	7.50	7.94	7.02	0.19	0.012	0.24%	0.50%	0.86%	**1.04%**
7.75	8.25	222	7.99	7.98	8.48	7.57	0.20	0.013	0.05%	0.50%	0.84%	**0.99%**
8.25	8.75	167	8.48	8.48	9.02	7.95	0.19	0.014	-0.02%	0.50%	0.82%	**0.97%**
8.75	9.25	115	9.02	9.00	9.87	8.53	0.23	0.021	0.21%	0.50%	0.80%	**0.99%**
9.25	9.75	78	9.54	9.50	10.08	9.09	0.21	0.024	0.38%	0.50%	0.78%	**1.04%**
9.75	10.25	43	10.05	9.99	10.52	9.64	0.22	0.034	0.53%	0.50%	0.77%	**1.11%**
10.25	10.75	54	10.53	10.48	10.96	10.07	0.22	0.031	0.41%	0.50%	0.76%	**1.04%**
10.75	11.25	30	11.04	11.00	11.47	10.62	0.23	0.042	0.39%	0.50%	0.74%	**1.05%**
11.25	11.75	30	11.51	11.50	11.88	11.02	0.19	0.035	0.05%	0.50%	0.73%	**0.94%**
11.75	12.25	22	12.05	12.00	12.71	11.52	0.35	0.076	0.41%	0.50%	0.72%	**1.15%**
12.25	12.75	16	12.49	12.48	12.86	12.01	0.22	0.054	0.07%	0.50%	0.72%	**0.98%**
12.75	13.25	13	13.03	12.99	13.30	12.66	0.18	0.049	0.25%	0.50%	0.71%	**0.98%**
13.25	13.75	3	13.43	13.44	13.56	13.34	0.11	0.063	-0.06%	0.50%	0.71%	**0.99%**
13.75	14.25	2										
14.25	14.75	4	14.54	14.57	14.75	14.33	0.24	0.120	-0.24%	0.50%	0.69%	**1.21%**
14.75	15.25	1										
15.25	15.75	1										
15.75	16.25	0										

6 IMPORTANT REMARKS AND LIMITATIONS

The reported lidar verification presents a reasonable means to assure overall system integrity of the lidar unit after maintenance by the manufacturer and is meant to give an indication of the quality of wind data produced by the lidar unit.

The IEC-complaint bin-wise uncertainty results provided in this report may serve as a traceable means to judge the uncertainty of the lidar unit.

Any statement given in the context of system integrity and data quality related results within this report are limited to the given test site conditions, to the prevailing atmospheric (in particular wind) conditions and to the specific lidar configuration as selected for this verification campaign.

7 OBSERVATIONS AND RECOMMENDATIONS

Concurrent Molas B300-117 Lidar and cup anemometer wind measurements were carried out at the Hamburg Remote Sensing Test Site to validate lidar Molas B300-117 wind data quality against a well-known high quality standard cup anemometer. Measurement heights of 120.5 m, 80.0 m, 65.0 and 45.0 m were available for wind speed correlations and 112.0 m and 62.5 m for wind direction. The duration of the verification was 38,0 days excluding power outages. The test period and wind data coverage were considered sufficient for the purpose of characterizing the lidar performance.

The performance verification and uncertainty calculation have been carried out in accordance with the IEC Standard yielding a traceable uncertainty measure.

The following deviations from IEC verification were observed:

- The database requirement that there are at least 3 concurrent lidar and mast data points in each wind speed bin was not fulfilled for 16.0 m/s at 65 m and for 14.0 m/s and from 15.0 m/s and greater at 45 m.

In summary, this Hamburg Remote Sensing Test Site Verification campaign indicates that the Molas B300-117 Lidar with the serial number Molas B300-117 is able to reproduce cup anemometer wind speeds and wind directions at an accurate and acceptable level for the wind speeds observed during the verificaiton. However, this conclusion is limited to the wind speeds observed during the verification. DNV GL considers that the Molas B300-117 device under test can be used for formal wind resource assessments if the aforementioned limitation is considered. Specifically, DNV GL concludes that this lidar may be employed as a standalone measurement system – replacing a conventional met mast – given the following criteria are met:

(1) The lidar is deployed on an offshore platform or in relatively simple terrain.

(2) In addition, it is considered good practice to ensure the long-term stability of the device through correlations with on-site masts or through the use of a post deployment performance verification campaign.

Finally, DNV GL recommends that care be taken with respect to the formal use of lidar turbulence and extreme wind speed measurements as they are known to be different from classical anemometry measurements. DNV GL notes that good measurement and data collection practices need to be maintained for all wind speed measurements, be they lidar or more conventional anemometry. Therefore, special care needs to be exercised in the transportation, installation, and ongoing maintenance of the lidar as it may be exposed to a wide range of environmental conditions. A key element of any formal wind study is the traceability of the wind speed data uncertainty. Hence, a strict uncertainty assessment (which is not part of this report) should be employed. Furthermore, it is recommended that thorough practices of documenting the salient features of lidar installation and maintenance are instigated from the outset.

8 REFERENCES

1. DNV GL, "*Best Practice Test and Verification Procedure for Wind Lidars on the Høvsøre Test Site",* GL GH-D Report WT 6960/09 for EU-Project NORSEWInD, Deliv. 1.1, June 2009.

2. International Standard: IEC 61400-12-1: Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines. Ed. 2., Apr. 2017

3. MEASNET: "Cup Anemometer Calibration Procedure". Version 1, September 1997

4. IEA expert group study on recommended practices for wind turbine testing and evaluation 11. Wind speed measurement and use of cube anemometry, edition 1, 1999.

9 GLOSSARY

The following table lists abbreviations and acronyms used in this report.

Abbreviation Acronym	Meaning
AC	Acceptance Criterion
agl	Above ground level
asl	Above sea level
DNV GL	New company name, successor of legacy GL GH
IEC	International Electro-technical Commission
IEA	International Energy Agency
GH-D	GL Garrad Hassan Deutschland GmbH
KPI	Key Performance Indicator
LPV	Lidar Performance Verification
PAR	Performance Assessment Requirement
RSD	Remote Sensing Device
TFCA	Thies First Class Advanced (cup anemometer)
TI	Turbulence Intensity
WD	Wind direction
WS	Wind speed

APPENDIX A METEOROLOGICAL MAST: LAYOUT, SENSORS DISTRIBUTION AND DATA ACQUISITION

The met mast is a 120-m triangular lattice guyed tower that has been constructed to be fully compliant with the IEC standard. The terrain of the test site falls within requirements for testing without a site calibration [2].The MEASNET calibrated [3] Thies First Class Advanced (TFCA) cup anemometers are on side mounted booms at 45 m, 65 m and 80 m, and mounted on goal posts at 120.5 m. This mounting configuration is complaint with the IEC [2] and IEA [4] recommendations.

The mast configuration during the lidar campaign are summarized in the Table A-1 and Table A-2 with the instrument calibration certificates in APPENDIX H .

The following transfer functions were applied in the logger configuration to the output signal from the anemometers:

Adjusted wind speed [m/s] = Slope x recorded wind speed [Hz] + Offset [m/s]

The slope and offset parameters are taken from wind tunnel calibrations according to the high-quality standards MEASNET [3].

The TFCA wind vanes are installed at 112.0 m and 62.5 m above ground mounted on side booms. To account for the instrument orientations an offset of 133° has been applied so that wind directions are recorded from True North.

The data acquisition system is a Ammonit Meteo-40 data logger that continously samples data at 1-Hz and records 10-minute average, maximum, minimum, and standard deviation.

Table A-1 Meterological mast sensor configuration

Label	Height [m]	Orientation - Mast to Instrument [°]	Instrument Type	Instrument Model	Cup to Boom Centre Height [mm]	Instrument to Mast (*Instrument to Mast Center) Centre Length [mm]
V1	120.5	313	Cup Anemometer	Thies First Class Advanced 4.3351.10.000	970	*1300
V2	120.5	133	Cup Anemometer	Thies First Class Advanced 4.3351.10.000	970	*1300
V3/D3	115.0	313	Ultrasonic Anemometer / Vane	Thies USA3D	700	3285
D1	112.0	313	Wind Vane	Thies First Class	700	3285
T1	113.1		Thermometer	Galltec	-	-
H1	113.1		Humidity	Galltec	-	-
P1	113.1		Barometer	GE:Net	-	-
V4/D4	111.8	133	Young Windmonitor	Young Windmonitor	700	3285
V5	80.0	313	Cup Anemometer	Thies First Class Advanced 4.3351.10.000	700	3285
V8	79.8	133	Cup Anemometer	Thies First Class Advanced 4.3351.00.000	700	3285
V6/D6	78.0	313	Ultrasonic Anemometer / Vane	Thies USA3D	700	3285
V7	65.0	313	Cup Anemometer	Thies First Class Advanced 4.3351.10.000	700	3285
V9	64.8	133	Cup Anemometer	Thies First Class Advanced 4.3351.00.000	700	3285
D2	62.5	313	Wind Vane	Thies First Class	700	3285
V10	44.9	313	Cup Anemometer	Thies First Class Advanced 4.3351.00.000	700	3285
V11	44.7	133	Cup Anemometer	Thies First Class Advanced 4.3351.00.000	700	3285
T2	10.0		Thermometer	Galltec	-	-
H2	10.0		Humidity	Galltec	-	-
P2	10.0		Barometer	GE:Net	-	-

Table A-2 Summay of cup anemomter calibrations

Label		V1	V2	V5	V8	V7	V9	V10	V11
Model		Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced	Thies First Class Advanced
S/N		02149430	02149431	02149432	08154580	02149433	02126229	0310559	06113972
Height [m]		120.5	120.5	80.0	79.8	65.0	64.8	44.9	44.7
Orientation - Mast to		313	133	313	133	313	133	313	133
DWG*	Calibration date	19/06/2018	19/06/2018	19/06/2018	18/05/2018	02/03/2017	15/05/2018	15/05/2018	15/05/2018
	Slope	0.04609	0.04626	0.04622	0.04609	0.04619	0.04614	0.04603	0.04608
	Offset	0.234	0.2032	0.2165	0.2159	0.2556	0.2279	0.2592	0.2363
Applied	Slope	0.04609	0.04626	0.0462	0.04609	0.04619	0.04614	0.04603	0.04608
	Offset	0.234	0.2032	0.2165	0.2159	0.2556	0.2279	0.2592	0.2363

APPENDIX B KEY PERFORMANCE INDICATORS AND ACCEPTANCE CRITERIA [1]

Table B-3 List of KPIs and ACs relevant for System and Data Availability assessment

KPI	Definition / Rationale	Acceptance Criteria [1]
SA_{CA}	**System Availability** The lidar system is ready to function according to specifications and to deliver data, taking into account all time stamped data entries in the output data files including flagged data (e.g., by NaNs or 9999s) for the pre-defined total campaign length. The System Availability is the number of these time stamped data entries relative to the maximum possible number of data entries (for 10-minute intervals) within the pre-defined total campaign period. (Any conditions affecting the test's data availability outside of the lidar system's control is not to be included in this calculation. Such as: power outages, acts of nature causing system damage, communication outages, maintenance, etc.).	≥95%
DA_{CA}	**Data Availability** The Data Availability is defined as the number of valid data points returned by the lidar unit as compared to maximum number of possible points that can be acquired during the test (Any conditions affecting the test's data availability outside of the lidar system's control is not to be included in this calculation. Such as: power outages, acts of nature causing system damage, communication outages, maintenance, etc.)	≥90%

[1] Acceptance Criteria across total campaign duration

Table B-4 List of KPIs and ACs relevant for Wind Data Accuracy assessment

KPI	Definition / Rationale	Acceptance Criteria [1] Best Practice	 Minimum
C_{mwsd}	**Campaign Mean Wind Speed – Difference** Absolute difference of mean wind speeds between lidar and reference as measured over the whole verification campaign duration, expressed as percentage relative to the Campaign Mean Wind Speed A threshold is imposed on the Difference. Analysis shall be applied to wind speed ranges a) all above 3 m/s b) 4 to 16 m/s [2] given achieved data coverage requirements	< 1 %	1 – 1.5 %
A_{wsd}	**Absolute Wind Speed Differences** Absolute 10-minute mean wind speed differences between lidar and reference for all data points treated after filtering. A threshold is imposed on the Difference. Analysis shall be applied to wind speed ranges • 4 to 16 m/s [2] given achieved data coverage requirements.	a) < 0.5 m/s b) within 5% Not more than 10% of data to exceed the criteria above.	
X_{mws}	**Mean Wind Speed – Slope** Slope returned from single variant regression with the regression analysis constrained to pass through the origin. A tolerance is imposed on the Slope value. Analysis shall be applied to wind speed ranges a) all above 3 m/s b) 4 to 16 m/s [2] given achieved data coverage requirements.	0.98 – 1.02	0.97 – 1.03

KPI	Definition / Rationale	Acceptance Criteria [1]	
		Best Practice	Minimum
R^2_{mws}	**Mean Wind Speed – Coefficient of Determination** Correlation Co-efficient returned from single variant regression A threshold is imposed on the Correlation Coefficient value. Analysis shall be applied to wind speed ranges a) all above 3 m/s b) 4 to 16 m/s [2] given achieved data coverage requirements.	>0.98	>0.97
X_{mwd}	**Mean Wind Direction – Slope** Slope returned from a two-variant regression. A tolerance is imposed on the Slope value. Analysis shall be applied to a) all wind speeds above 3 m/s regardless of coverage requirements.	0.98– 1.02	0.97 – 1.03
OFF_{mwd}	**Mean Wind Direction – Offset (absolute value)** (same as for M_{mwd})	< 5°	< 7.5°
R^2_{mwd}	**Mean Wind Direction – Coefficient of Determination** (same as for M_{mwd})	> 0.97	> 0.95

1 Acceptance Criteria in the form of "**best practice**" and "**minimum**" allowable tolerances have been imposed on mean differences, slope and offset values as well as on coefficient of determination returned from each reference height for KPIs related to the primary parameters of interest; wind speed and wind direction. KPIs outside the best practice or minimum acceptance criteria are marked as "**deviation**".

2 The bin averaging procedure was performed using 0.5 m/s wide wind speed bins centred on integers from 4 to 16 m/s in order to match the averaging procedure defined in the IEC.

APPENDIX C HAMBURG REMOTE SENSING TEST SITE PHOTOS

Figure C-1 Panoramic Photos at the base of the Hamburg remote sensing site mast

Figure C-2 View of the Hamburg remote sensing site mast

APPENDIX D TIME SERIES OF WIND SPEED

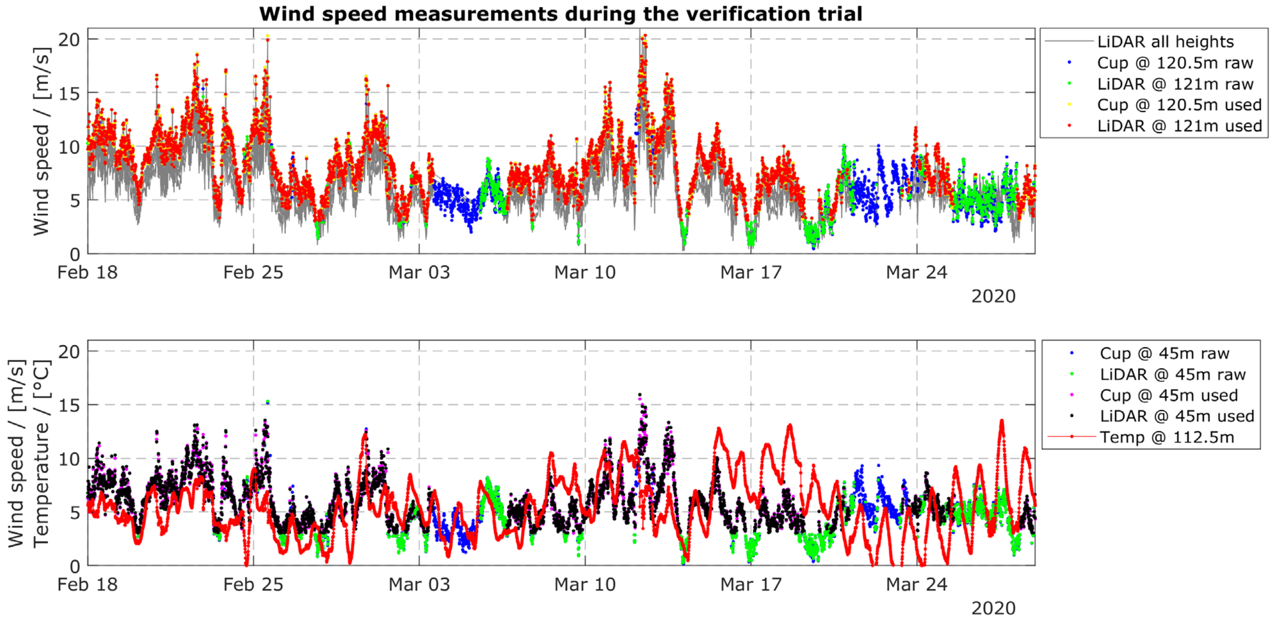
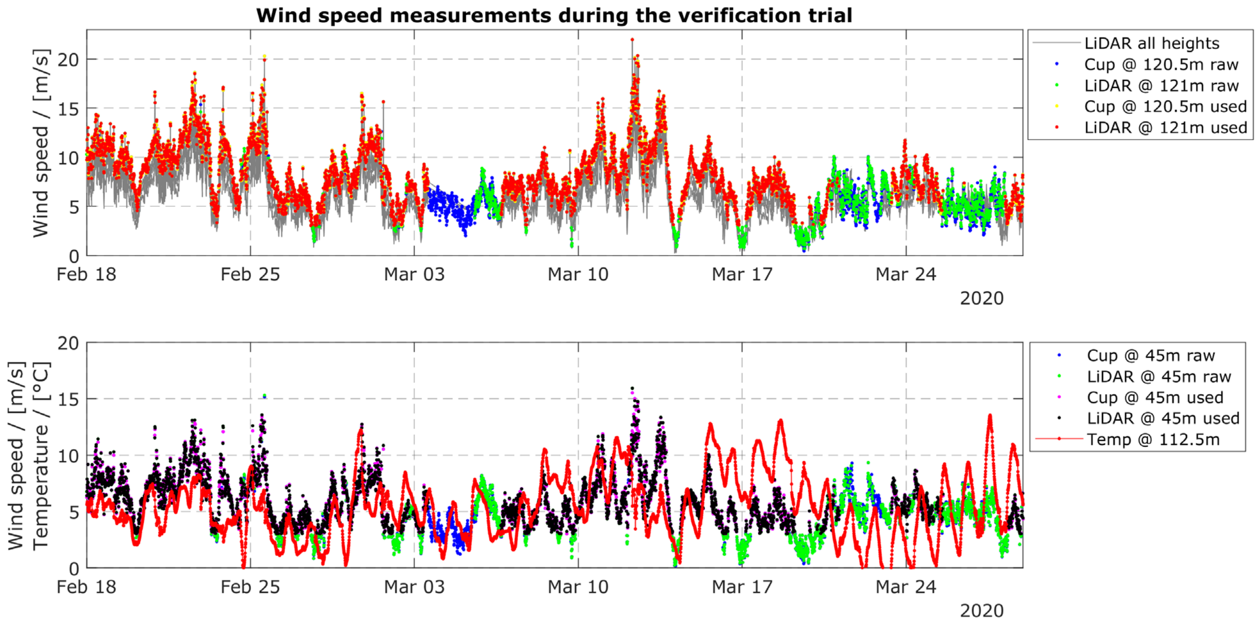
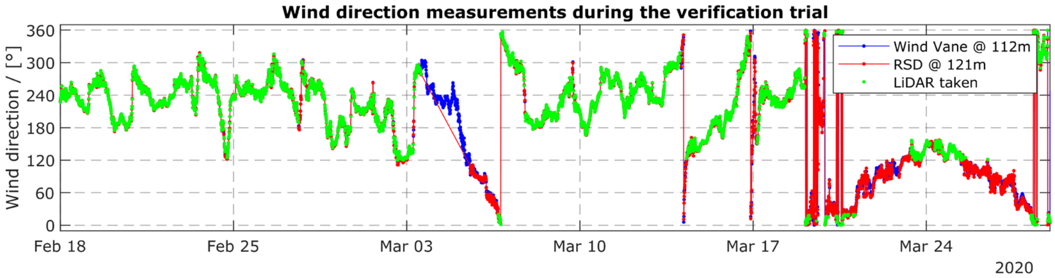


Figure D-3 Wind Speed time series for 121 m (upper panel) and 45 m (lower panel). The bottom plot includes temperature time series (red) from mast sensor.



APPENDIX E WIND DIRECTION

The scatter plots of wind direction below show wind directions for wind speed greater than or equal to 3 m/s. The red dots are the raw wind speeds and the green dots show the 180° ambiguity corrected data between wind vane and Lidar measures.



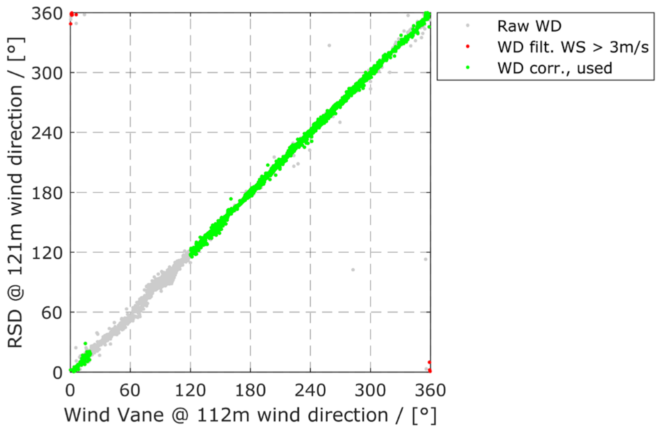


Figure E-1 Wind direction time series and scatter plot of the lidar at 112 and reference wind vane at 112 m.

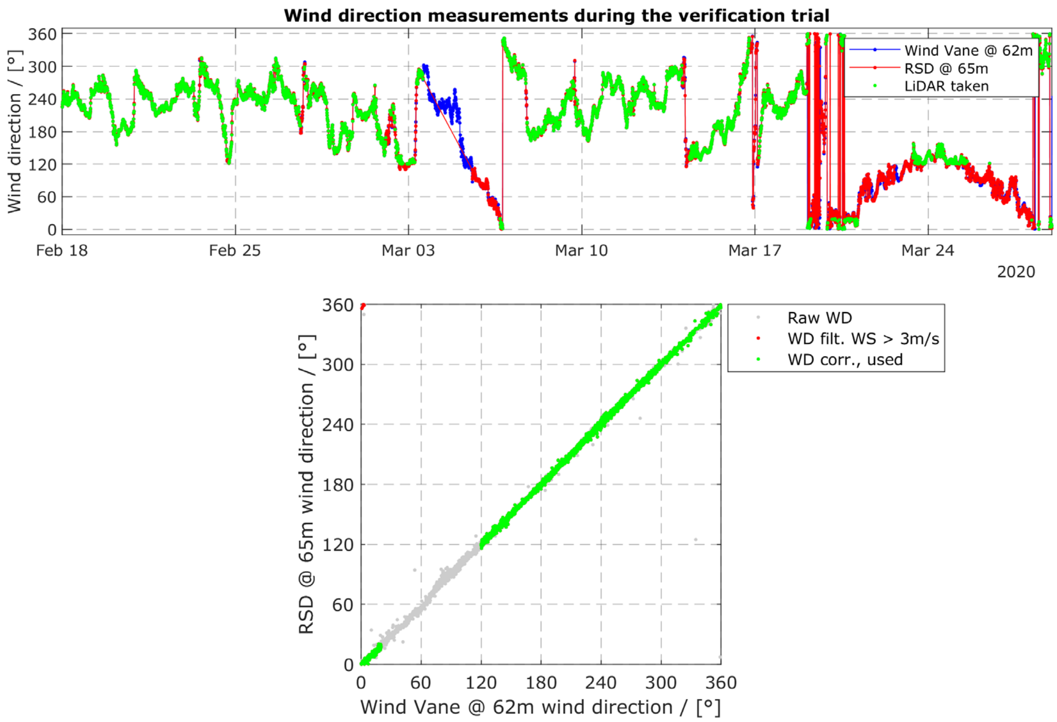


Figure E-2 Wind direction time series and scatter plot of the lidar at 62 m and reference wind vane at 62 m.

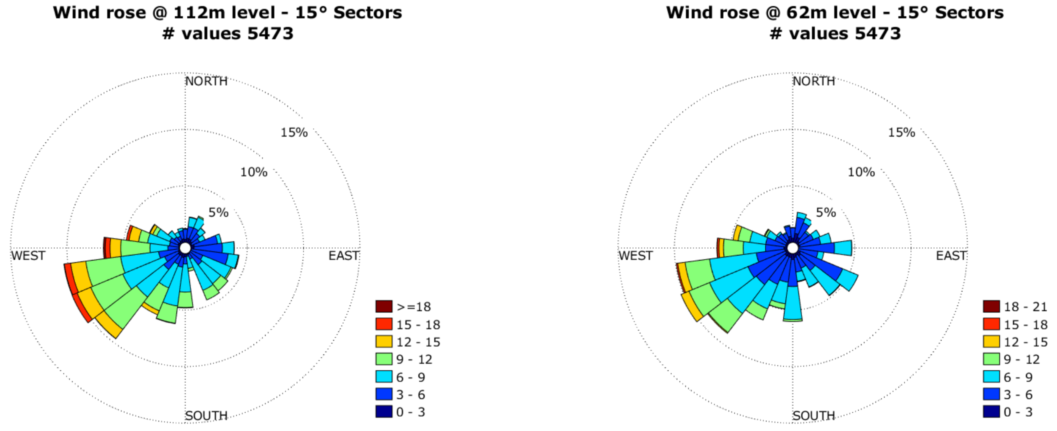


Figure E-3 Wind rose and sector averaged wind speed distribution for the valid measurement sector at 112 m and 62 m

APPENDIX F ENVIRONMENTAL CONDITION DURING THE VERIFICATION CAMPAIGN

Environmental Variables @ 121m																			
BIN lower	BIN upper	nbin	Vmm	Wind direction		Turbulence Intensity		Shear coef. between 121-45m		Wind veer between 112-62m		Temperature gradient		Air temperature		Air density		LiDAR Data Quality	
[m/s]	[m/s]	#	Avg [m/s]	Avg [°]	Std [°]	Avg [-]	Std [-]	Avg #	Std #	Avg [°/m]	Std [°/m]	Avg [°C/m]	Std [°C/m]	Avg [°C]	Std [°C]	Avg [kg/m^3]	Std [kg/m^3]	Avg [% or -]	Std [% or -]
3.75	4.25	95	4.04	290.48	86.81	0.12	0.06	0.13	0.12	0.14	0.20	-0.006	0.011	5.4	2.1	1.245	0.016	100.00	0.00
4.25	4.75	140	4.52	250.37	71.78	0.12	0.05	0.15	0.12	0.09	0.16	-0.008	0.009	4.9	2.7	1.246	0.016	100.00	0.00
4.75	5.25	173	5.01	255.62	66.01	0.11	0.05	0.17	0.11	0.11	0.13	-0.008	0.007	5.2	2.8	1.244	0.015	100.00	0.00
5.25	5.75	226	5.51	242.97	66.50	0.11	0.05	0.15	0.10	0.11	0.13	-0.008	0.007	5.2	3.0	1.245	0.017	100.00	0.00
5.75	6.25	253	6.00	238.34	60.65	0.10	0.04	0.15	0.10	0.09	0.11	-0.007	0.008	5.6	3.4	1.247	0.018	99.99	0.14
6.25	6.75	283	6.52	223.57	57.47	0.11	0.04	0.16	0.09	0.10	0.11	-0.007	0.008	6.0	3.1	1.244	0.017	100.00	0.00
6.75	7.25	360	7.00	219.19	63.64	0.10	0.05	0.17	0.09	0.12	0.13	-0.005	0.008	5.8	3.0	1.244	0.020	100.00	0.09
7.25	7.75	293	7.47	222.72	56.96	0.09	0.05	0.18	0.09	0.11	0.12	-0.004	0.009	5.9	3.1	1.245	0.020	100.00	0.00
7.75	8.25	298	8.00	207.52	50.31	0.09	0.04	0.18	0.08	0.13	0.11	-0.003	0.010	5.6	2.9	1.245	0.022	100.00	0.00
8.25	8.75	275	8.49	207.82	47.09	0.10	0.04	0.16	0.06	0.09	0.09	-0.005	0.008	5.5	3.0	1.244	0.022	100.00	0.00
8.75	9.25	230	8.98	215.60	46.34	0.11	0.04	0.15	0.06	0.07	0.06	-0.006	0.008	5.7	2.5	1.243	0.020	100.00	0.00
9.25	9.75	189	9.49	216.93	41.54	0.11	0.03	0.15	0.05	0.06	0.04	-0.007	0.006	5.9	2.7	1.241	0.018	99.93	0.89
9.75	10.25	213	9.99	225.53	44.34	0.11	0.04	0.15	0.05	0.06	0.05	-0.006	0.007	6.1	2.7	1.241	0.021	99.96	0.60
10.25	10.75	191	10.50	231.20	31.94	0.12	0.03	0.14	0.04	0.05	0.04	-0.007	0.004	6.3	2.3	1.235	0.018	100.00	0.00
10.75	11.25	194	11.03	231.71	30.64	0.12	0.03	0.14	0.04	0.04	0.04	-0.006	0.005	6.0	2.3	1.235	0.019	100.00	0.00
11.25	11.75	172	11.48	241.48	29.02	0.12	0.03	0.14	0.04	0.04	0.04	-0.007	0.006	6.2	2.1	1.234	0.017	100.00	0.00
11.75	12.25	111	11.99	240.22	25.98	0.13	0.03	0.13	0.03	0.04	0.02	-0.008	0.002	6.6	2.0	1.231	0.016	100.00	0.00
12.25	12.75	81	12.47	249.45	22.37	0.13	0.02	0.13	0.03	0.03	0.02	-0.008	0.003	6.5	2.1	1.231	0.015	99.99	0.06
12.75	13.25	68	13.00	257.81	24.75	0.13	0.02	0.12	0.03	0.03	0.02	-0.008	0.003	6.5	1.7	1.231	0.014	100.00	0.00
13.25	13.75	54	13.52	258.49	23.28	0.14	0.03	0.12	0.02	0.03	0.02	-0.008	0.003	6.9	1.6	1.232	0.014	100.00	0.00
13.75	14.25	42	14.00	257.58	20.36	0.14	0.03	0.11	0.02	0.03	0.02	-0.009	0.003	6.9	1.4	1.231	0.012	100.00	0.00
14.25	14.75	25	14.47	258.02	20.56	0.14	0.02	0.11	0.02	0.03	0.02	-0.010	0.003	6.3	1.5	1.233	0.012	100.00	0.00
14.75	15.25	25	15.00	257.58	19.37	0.14	0.03	0.11	0.03	0.03	0.02	-0.010	0.003	6.9	1.6	1.227	0.013	100.00	0.00
15.25	15.75	26	15.48	260.42	18.28	0.15	0.02	0.11	0.03	0.03	0.02	-0.010	0.003	6.5	1.4	1.230	0.009	100.00	0.00
15.75	16.25	21	15.94	256.74	19.97	0.15	0.04	0.10	0.02	0.02	0.02	-0.010	0.003	7.1	1.7	1.223	0.016	100.00	0.00

Environmental Variables @ 121m																			
BIN lower	BIN upper	nbin	Vmm	Wind direction		Turbulence Intensity		Shear coef. between 121-45m		Wind veer between 112-62m		Temperature gradient		Air temperature		Air density		LiDAR Data Quality	
[m/s]	[m/s]	#	Avg [m/s]	Avg [°]	Std [°]	Avg [-]	Std [-]	Avg #	Std #	Avg [°/m]	Std [°/m]	Avg [°C/m]	Std [°C/m]	Avg [°C]	Std [°C]	Avg [kg/m³]	Std [kg/m³]	Avg [% or -]	Std [% or -]
3.75	4.25	95	4.04	290.48	86.81	0.12	0.06	0.13	0.117	0.14	0.20	-0.006	0.011	5.4	2.1	1.245	0.016	100.00	0.00
4.25	4.75	140	4.52	250.37	71.78	0.12	0.05	0.15	0.118	0.09	0.16	-0.008	0.009	4.9	2.7	1.246	0.016	100.00	0.00
4.75	5.25	172	5.01	255.20	66.15	0.11	0.05	0.17	0.106	0.11	0.13	-0.008	0.007	5.2	2.8	1.245	0.015	100.00	0.00
5.25	5.75	224	5.51	243.86	65.83	0.11	0.05	0.15	0.104	0.11	0.13	-0.008	0.007	5.2	3.0	1.244	0.017	100.00	0.00
5.75	6.25	245	6.00	240.57	58.81	0.10	0.04	0.15	0.105	0.09	0.11	-0.008	0.007	5.7	3.4	1.246	0.016	99.99	0.14
6.25	6.75	278	6.52	224.70	56.81	0.11	0.04	0.16	0.088	0.10	0.11	-0.007	0.008	6.0	3.1	1.244	0.016	100.00	0.00
6.75	7.25	349	7.00	222.48	62.55	0.10	0.05	0.17	0.090	0.12	0.13	-0.005	0.008	5.9	3.0	1.243	0.019	99.99	0.10
7.25	7.75	283	7.47	225.28	55.21	0.09	0.05	0.18	0.087	0.12	0.12	-0.004	0.009	5.9	3.1	1.243	0.019	100.00	0.00
7.75	8.25	285	8.00	210.36	48.82	0.09	0.04	0.18	0.080	0.13	0.11	-0.003	0.010	5.8	2.9	1.243	0.021	100.00	0.00
8.25	8.75	267	8.49	209.39	46.17	0.10	0.04	0.16	0.061	0.09	0.08	-0.005	0.007	5.6	3.0	1.243	0.021	100.00	0.00
8.75	9.25	225	8.99	215.21	45.10	0.11	0.04	0.15	0.056	0.07	0.06	-0.006	0.008	5.8	2.5	1.243	0.019	100.00	0.00
9.25	9.75	187	9.49	216.70	41.71	0.11	0.03	0.15	0.051	0.06	0.04	-0.007	0.006	6.0	2.8	1.241	0.018	99.93	0.90
9.75	10.25	210	9.99	224.85	44.22	0.11	0.04	0.15	0.055	0.06	0.05	-0.006	0.007	6.1	2.6	1.242	0.021	100.00	0.00
10.25	10.75	190	10.50	231.16	32.02	0.12	0.03	0.14	0.044	0.05	0.04	-0.007	0.004	6.3	2.3	1.235	0.018	100.00	0.00
10.75	11.25	189	11.02	231.45	30.99	0.12	0.03	0.15	0.041	0.04	0.04	-0.006	0.005	6.0	2.2	1.235	0.018	100.00	0.00
11.25	11.75	172	11.48	241.48	29.02	0.12	0.03	0.14	0.043	0.04	0.04	-0.007	0.006	6.2	2.1	1.234	0.017	100.00	0.00
11.75	12.25	109	11.99	240.33	26.21	0.13	0.03	0.13	0.030	0.04	0.02	-0.008	0.002	6.6	2.0	1.231	0.016	100.00	0.00
12.25	12.75	76	12.47	249.61	23.08	0.13	0.02	0.13	0.025	0.03	0.02	-0.008	0.002	6.3	1.9	1.233	0.014	99.99	0.06
12.75	13.25	66	13.00	258.33	24.96	0.13	0.02	0.12	0.026	0.03	0.02	-0.009	0.003	6.3	1.6	1.231	0.014	100.00	0.00
13.25	13.75	52	13.52	258.84	23.67	0.14	0.03	0.12	0.023	0.03	0.02	-0.008	0.003	6.8	1.6	1.233	0.013	100.00	0.00
13.75	14.25	41	14.00	257.88	20.53	0.14	0.03	0.11	0.023	0.03	0.02	-0.009	0.003	6.8	1.4	1.231	0.012	100.00	0.00
14.25	14.75	24	14.47	258.28	20.97	0.14	0.02	0.11	0.020	0.03	0.02	-0.010	0.003	6.3	1.5	1.233	0.012	100.00	0.00
14.75	15.25	24	15.01	257.63	19.79	0.14	0.02	0.11	0.027	0.03	0.02	-0.010	0.003	6.9	1.6	1.227	0.013	100.00	0.00
15.25	15.75	25	15.48	260.91	18.50	0.15	0.02	0.11	0.032	0.03	0.02	-0.010	0.003	6.4	1.4	1.230	0.010	100.00	0.00
15.75	16.25	21	15.94	256.74	19.97	0.15	0.04	0.10	0.025	0.02	0.02	-0.010	0.003	7.1	1.7	1.223	0.016	100.00	0.00

Environmental Variables @ 80m																				
BIN lower	BIN upper	nbin	Vmm	Wind direction		Turbulence Intensity		Shear coef. between 121-45m		Wind veer between 112-62m		Temperature gradient		Air temperature		Air density		LiDAR Data Quality	
[m/s]	[m/s]	#	Avg [m/s]	Avg [°]	Std [°]	Avg [-]	Std [-]	Avg #	Std #	Avg [°/m]	Std [°/m]	Avg [°C/m]	Std [°C/m]	Avg [°C]	Std [°C]	Avg [kg/m³]	Std [kg/m³]	Avg [% or -]	Std [% or -]
3.75	4.25	183	4.01	249.97	63.28	0.13	0.05	0.08	0.07	0.12	0.14	-0.006	0.010	5.1	2.6	1.245	0.013	100.00	0.00
4.25	4.75	223	4.51	245.00	63.74	0.13	0.05	0.09	0.06	0.13	0.15	-0.005	0.009	5.1	2.7	1.244	0.015	100.00	0.00
4.75	5.25	289	5.02	230.56	61.19	0.12	0.05	0.09	0.05	0.12	0.13	-0.005	0.009	5.3	3.1	1.244	0.017	100.00	0.07
5.25	5.75	338	5.51	223.24	59.10	0.12	0.05	0.09	0.05	0.11	0.12	-0.005	0.009	5.7	3.2	1.245	0.019	100.00	0.00
5.75	6.25	370	5.99	221.69	61.48	0.12	0.05	0.08	0.04	0.11	0.11	-0.005	0.009	6.0	3.0	1.244	0.019	100.00	0.00
6.25	6.75	365	6.48	218.77	61.21	0.13	0.05	0.08	0.04	0.09	0.09	-0.006	0.008	6.1	3.1	1.244	0.020	99.99	0.17
6.75	7.25	303	6.99	208.32	55.69	0.12	0.05	0.08	0.03	0.10	0.09	-0.005	0.009	5.5	2.9	1.247	0.023	100.00	0.00
7.25	7.75	253	7.50	217.83	46.02	0.14	0.05	0.08	0.03	0.07	0.05	-0.007	0.007	5.8	2.8	1.244	0.020	100.00	0.00
7.75	8.25	246	8.00	215.97	45.83	0.13	0.04	0.08	0.03	0.06	0.05	-0.007	0.007	5.9	2.6	1.242	0.020	100.00	0.00
8.25	8.75	203	8.51	223.80	38.99	0.14	0.03	0.07	0.02	0.05	0.04	-0.008	0.005	6.3	2.8	1.239	0.019	100.00	0.00
8.75	9.25	200	9.00	228.56	36.69	0.15	0.04	0.07	0.02	0.05	0.04	-0.007	0.006	6.3	2.5	1.237	0.019	100.00	0.00
9.25	9.75	206	9.49	236.38	29.94	0.15	0.03	0.07	0.02	0.04	0.03	-0.008	0.003	6.1	2.2	1.235	0.018	100.00	0.00
9.75	10.25	171	9.97	235.47	26.83	0.16	0.03	0.07	0.02	0.04	0.02	-0.008	0.003	6.2	2.0	1.233	0.016	100.00	0.00
10.25	10.75	131	10.47	245.21	25.13	0.16	0.03	0.07	0.01	0.03	0.02	-0.008	0.003	6.6	1.9	1.231	0.015	100.00	0.00
10.75	11.25	87	10.98	247.46	26.66	0.16	0.03	0.07	0.02	0.03	0.02	-0.009	0.003	6.4	2.1	1.234	0.013	100.00	0.00
11.25	11.75	72	11.48	252.56	23.65	0.16	0.02	0.07	0.01	0.03	0.02	-0.009	0.003	6.7	1.8	1.231	0.013	100.00	0.00
11.75	12.25	50	12.01	261.44	23.26	0.17	0.04	0.06	0.02	0.03	0.02	-0.008	0.003	6.5	1.7	1.233	0.015	100.00	0.00
12.25	12.75	40	12.49	259.43	23.54	0.17	0.03	0.06	0.01	0.03	0.02	-0.009	0.003	6.8	1.1	1.233	0.009	100.00	0.00
12.75	13.25	33	13.01	256.02	21.29	0.17	0.02	0.06	0.01	0.03	0.02	-0.009	0.003	6.9	1.6	1.231	0.014	100.00	0.00
13.25	13.75	27	13.51	259.44	19.01	0.17	0.03	0.06	0.01	0.03	0.02	-0.009	0.003	6.8	1.6	1.228	0.013	100.00	0.00
13.75	14.25	22	14.02	260.42	17.62	0.18	0.03	0.06	0.01	0.02	0.02	-0.011	0.003	6.2	1.5	1.229	0.010	100.00	0.00
14.25	14.75	26	14.51	263.34	23.23	0.17	0.03	0.06	0.02	0.03	0.02	-0.010	0.003	6.7	1.8	1.227	0.015	100.00	0.00
14.75	15.25	12	14.94	255.97	15.93	0.19	0.04	0.05	0.01	0.02	0.03	-0.011	0.003	7.0	1.5	1.222	0.013	100.00	0.00
15.25	15.75	7	15.51	253.75	13.90	0.18	0.03	0.06	0.01	0.01	0.01	-0.012	0.004	7.1	0.4	1.227	0.005	100.00	0.00
15.75	16.25	4	16.08	255.59	6.38	0.17	0.03	0.06	0.01	0.02	0.01	-0.014	0.002	6.8	0.2	1.221	0.007	100.00	0.00

Environmental Variables @ 65m

BIN lower	BIN upper	nbin	Vmm	Wind direction		Turbulence Intensity		Shear coef. between 121-45m		Wind veer between 112-62m		Temperature gradient		Air temperature		Air density		LiDAR Data Quality	
[m/s]	[m/s]	#	Avg [m/s]	Avg [°]	Std [°]	Avg [-]	Std [-]	Avg #	Std #	Avg [°/m]	Std [°/m]	Avg [°C/m]	Std [°C/m]	Avg [°C]	Std [°C]	Avg [kg/m³]	Std [kg/m³]	Avg [% or -]	Std [% or -]
3.75	4.25	207	4.00	248.36	64.92	0.14	0.06	0.45	0.25	0.14	0.14	-0.004	0.010	5.1	2.6	1.245	0.014	100.00	0.00
4.25	4.75	305	4.49	236.10	60.99	0.14	0.06	0.46	0.21	0.12	0.13	-0.004	0.010	5.4	3.1	1.244	0.014	100.00	0.00
4.75	5.25	364	5.00	228.92	60.19	0.13	0.05	0.44	0.21	0.11	0.12	-0.005	0.009	5.6	3.1	1.244	0.017	100.00	0.08
5.25	5.75	364	5.51	223.36	62.56	0.13	0.06	0.42	0.19	0.11	0.10	-0.005	0.008	6.0	3.2	1.245	0.019	100.00	0.00
5.75	6.25	379	5.99	225.00	62.48	0.14	0.05	0.40	0.18	0.09	0.09	-0.007	0.008	5.9	3.1	1.245	0.021	99.99	0.16
6.25	6.75	313	6.50	211.22	61.92	0.14	0.05	0.37	0.15	0.08	0.07	-0.007	0.008	5.6	2.9	1.248	0.022	100.00	0.00
6.75	7.25	273	6.99	218.35	49.98	0.15	0.05	0.39	0.13	0.07	0.05	-0.006	0.007	5.7	2.7	1.244	0.019	100.00	0.00
7.25	7.75	249	7.49	220.65	45.83	0.16	0.04	0.37	0.12	0.06	0.04	-0.007	0.007	6.1	2.7	1.241	0.020	99.98	0.29
7.75	8.25	220	8.00	224.72	42.59	0.16	0.04	0.38	0.12	0.05	0.04	-0.008	0.006	6.1	2.8	1.240	0.020	100.00	0.00
8.25	8.75	210	8.52	230.13	32.78	0.17	0.03	0.38	0.09	0.04	0.03	-0.008	0.003	6.3	2.3	1.234	0.018	100.00	0.00
8.75	9.25	209	8.99	234.90	30.24	0.17	0.03	0.38	0.09	0.03	0.02	-0.009	0.004	6.2	2.2	1.235	0.016	100.00	0.00
9.25	9.75	166	9.47	237.87	27.80	0.18	0.03	0.37	0.09	0.04	0.02	-0.008	0.003	6.3	2.1	1.232	0.017	100.00	0.00
9.75	10.25	113	9.96	245.45	25.21	0.18	0.03	0.38	0.07	0.03	0.02	-0.009	0.003	6.5	2.0	1.233	0.014	100.00	0.00
10.25	10.75	93	10.50	251.51	24.82	0.18	0.03	0.38	0.08	0.03	0.02	-0.009	0.003	6.6	1.9	1.232	0.013	100.00	0.03
10.75	11.25	54	11.00	254.68	25.51	0.19	0.03	0.37	0.06	0.03	0.02	-0.009	0.003	6.8	2.0	1.232	0.014	100.00	0.00
11.25	11.75	50	11.50	257.94	24.90	0.18	0.03	0.36	0.08	0.03	0.02	-0.009	0.002	6.5	1.4	1.232	0.012	100.00	0.00
11.75	12.25	36	12.01	261.93	21.58	0.19	0.03	0.38	0.09	0.03	0.02	-0.009	0.003	6.7	1.3	1.233	0.010	100.00	0.00
12.25	12.75	33	12.50	257.21	19.43	0.19	0.03	0.37	0.09	0.03	0.02	-0.009	0.003	6.9	1.5	1.227	0.014	100.00	0.00
12.75	13.25	24	13.03	266.52	18.67	0.19	0.02	0.36	0.07	0.03	0.02	-0.010	0.004	6.5	1.7	1.231	0.011	100.00	0.00
13.25	13.75	25	13.46	257.78	21.37	0.20	0.03	0.37	0.07	0.03	0.02	-0.010	0.003	6.7	1.7	1.228	0.015	100.00	0.00
13.75	14.25	18	14.00	261.76	19.36	0.21	0.04	0.34	0.05	0.03	0.02	-0.011	0.003	6.3	1.7	1.225	0.014	100.00	0.00
14.25	14.75	9	14.51	254.04	17.32	0.19	0.03	0.33	0.08	0.00	0.01	-0.012	0.003	6.9	0.7	1.228	0.007	100.00	0.00
14.75	15.25	8	15.03	260.52	7.48	0.19	0.03	0.40	0.04	0.02	0.01	-0.012	0.003	6.9	0.4	1.225	0.006	100.00	0.00
15.25	15.75	3	15.58	266.97	4.07	0.22	0.01	0.42	0.04	0.02	0.01	-0.014	0.004	6.7	0.8	1.228	0.004	100.00	0.00
15.75	16.25	0																	

Environmental Variables @ 45m																			
BIN lower	BIN upper	nbin	Vmm	Wind direction		Turbulence Intensity		Shear coef. between 121-45m		Wind veer between 112-62m		Temperature gradient		Air temperature		Air density		LiDAR Data Quality	
[m/s]	[m/s]	#	Avg [m/s]	Avg [°]	Std [°]	Avg [-]	Std [-]	Avg #	Std #	Avg [°/m]	Std [°/m]	Avg [°C/m]	Std [°C/m]	Avg [°C]	Std [°C]	Avg [kg/m³]	Std [kg/m³]	Avg [% or -]	Std [% or -]
3.75	4.25	356	4.00	237.02	61.43	0.16	0.06	0.46	0.21	0.12	0.12	-0.005	0.008	5.8	3.1	1.243	0.015	99.99	0.22
4.25	4.75	396	4.50	227.14	63.24	0.17	0.06	0.42	0.19	0.11	0.10	-0.005	0.008	5.6	3.1	1.244	0.018	99.97	0.51
4.75	5.25	378	5.00	229.58	67.41	0.18	0.06	0.39	0.15	0.09	0.09	-0.006	0.008	5.6	3.1	1.247	0.021	100.00	0.09
5.25	5.75	364	5.50	223.66	62.21	0.18	0.06	0.36	0.14	0.07	0.07	-0.007	0.008	5.9	3.1	1.247	0.022	100.00	0.08
5.75	6.25	351	6.00	212.13	56.98	0.18	0.06	0.35	0.14	0.07	0.06	-0.007	0.007	5.8	2.6	1.247	0.020	100.00	0.01
6.25	6.75	299	6.50	220.19	51.36	0.19	0.05	0.36	0.13	0.06	0.04	-0.008	0.006	5.8	2.5	1.244	0.020	99.93	0.69
6.75	7.25	239	7.02	228.15	43.80	0.20	0.04	0.35	0.12	0.04	0.04	-0.009	0.004	6.1	2.7	1.240	0.020	99.98	0.24
7.25	7.75	263	7.50	224.15	38.46	0.20	0.04	0.36	0.11	0.04	0.03	-0.009	0.004	6.2	2.5	1.236	0.021	99.99	0.14
7.75	8.25	222	7.98	233.25	33.44	0.21	0.04	0.36	0.09	0.04	0.02	-0.009	0.003	6.4	2.2	1.234	0.018	100.00	0.05
8.25	8.75	167	8.48	236.69	31.12	0.21	0.03	0.36	0.09	0.03	0.02	-0.009	0.003	6.4	2.4	1.233	0.018	99.85	1.56
8.75	9.25	115	9.00	245.96	27.23	0.22	0.03	0.36	0.08	0.03	0.02	-0.009	0.003	6.9	2.1	1.230	0.013	99.97	0.22
9.25	9.75	78	9.50	254.58	24.35	0.22	0.03	0.37	0.07	0.03	0.02	-0.009	0.003	6.9	1.8	1.232	0.013	99.99	0.09
9.75	10.25	43	9.99	249.59	27.11	0.23	0.03	0.36	0.07	0.03	0.02	-0.010	0.003	6.6	1.9	1.231	0.012	100.00	0.03
10.25	10.75	54	10.48	259.96	23.46	0.22	0.03	0.36	0.08	0.03	0.02	-0.009	0.003	6.7	1.6	1.230	0.014	99.97	0.15
10.75	11.25	30	11.00	259.22	21.86	0.22	0.03	0.35	0.08	0.03	0.02	-0.010	0.003	6.8	1.2	1.232	0.011	100.00	0.00
11.25	11.75	30	11.50	263.36	20.14	0.22	0.02	0.36	0.06	0.03	0.02	-0.011	0.003	6.5	1.6	1.231	0.012	100.00	0.00
11.75	12.25	22	12.00	265.39	23.48	0.24	0.03	0.34	0.06	0.03	0.02	-0.010	0.003	6.7	2.0	1.227	0.016	100.00	0.00
12.25	12.75	16	12.48	255.32	16.45	0.23	0.04	0.34	0.05	0.02	0.02	-0.011	0.003	6.8	1.5	1.222	0.014	100.00	0.00
12.75	13.25	13	12.99	261.70	14.18	0.24	0.03	0.37	0.07	0.02	0.02	-0.013	0.003	6.7	0.6	1.227	0.007	100.00	0.00
13.25	13.75	3	13.44	267.23	17.54	0.23	0.04	0.31	0.09	0.01	0.02	-0.012	0.002	6.9	0.4	1.224	0.008	100.00	0.00
13.75	14.25	2																	
14.25	14.75	4	14.57	267.21	4.69	0.24	0.02	0.38	0.05	0.03	0.02	-0.015	0.003	6.5	0.6	1.231	0.001	100.00	0.00
14.75	15.25	1																	
15.25	15.75	1																	
15.75	16.25	0																	

APPENDIX G IEC ANNEX L UNCERTAINTY ANALYSES

1. Reference or anemometer uncertainty

The anemometer uncertainty of the specific reference heights is calculated based on the wind tunnel calibration of the individual anemometer, the anemometer classification (0.9) and the mounting effect (0.005) at the met tower.

Based on the calibration reports for the Hamburg Mast anemometers a K=1 value of 0.0265 was used.

2. Mean deviation of the remote sensor measurements and the reference measurements

This is the relative deviation between the bin averages of the RSD and the mast reference measurement divided by with the reference measurement.

3. Standard uncertainty of the measurement of the remote sensing device

The standard deviation of the measurements was divided by the square root of the number of data records per bin. The relative uncertainty was calculated by dividing the value by the bin average wind speed of the mast (reference) measurement.

4. Mounting uncertainty of the remote sensor at the verification test

The uncertainty of the remote sensing device due to non-ideal levelling was estimated to be 0.5 %.

5. Uncertainty due to non-homogenous flow

The Lidar device is located approximately 8 m south from the met mast base. As a result, the uncertainty due to non-homogenous flow within the measurement volume is considered to be negligible.

APPENDIX H CUP CALIBRATION CERTIFICATES

V1 Anemometer at 120.5 m

V1
119,25

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812540
D-K-15140-01-00
06/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	02149430
Customer *Auftraggeber*	GE:NET GmbH 38678 Clausthal-Zellerfeld
Order No. *Auftragsnummer*	Email 2018-06-14, Rethfeld
Project No. *Projektnummer*	VT180611
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.06.2018

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.

This calibration certificate may not be reproduced other than in full except with the permission of both the German Accreditation Body and the issuing laboratory. Calibration certificates without signature are not valid. This calibration certificate has been generated electronically.
Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit. Dieser Kalibrierschein wurde elektronisch erzeugt.

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
19.06.2018	D. Westermann	B. Schütz
	Dipl. Phys. Dieter Westermann	Techniker Bendix Schütz

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 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	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.4 °C ± 0.1 °C
	air pressure	1022.2 hPa ± 0.3 hPa
	relative air humidity	45.2 % ± 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

-

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Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.955	0.05	81.025
5.870	0.05	122.375
7.867	0.05	165.592
9.873	0.05	208.769
11.889	0.05	252.832
13.815	0.05	294.627
15.835	0.05	339.138
14.793	0.05	315.549
12.882	0.05	273.969
10.875	0.05	231.538
8.857	0.05	186.725
6.916	0.05	144.560
4.889	0.05	101.210

Statistical analysis

Slope	0.04609 (m/s)/(Hz) ±0.00006 (m/s)/(Hz)
Offset	0.2340 m/s ±0.014 m/s
Standard error (Y)	0.014 m/s
Correlation coefficient	0.999990

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

DEUTSCHE WINDGUARD

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Graphical representation of the result
Grafische Darstellung des Ergebnisses

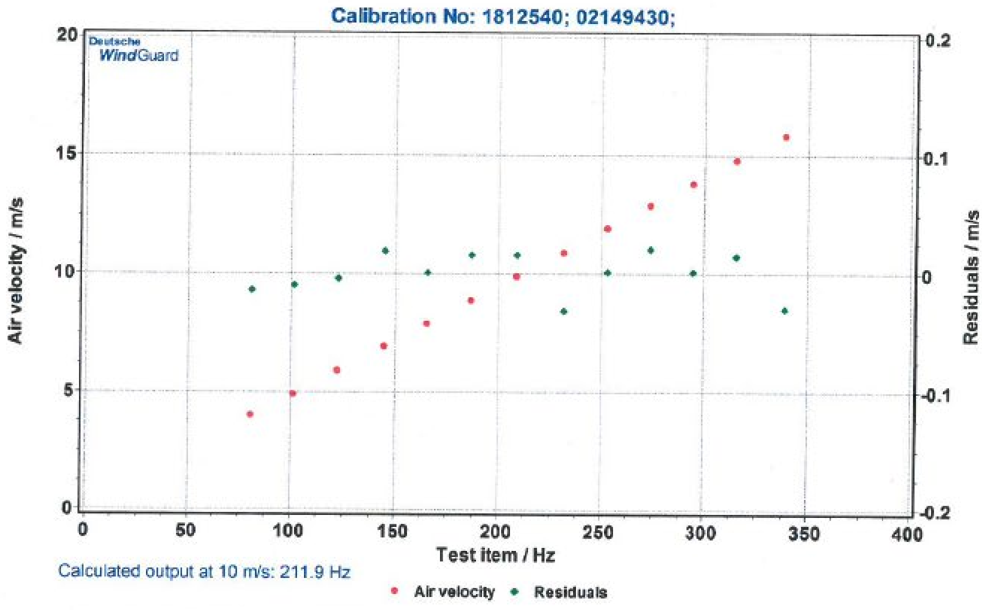
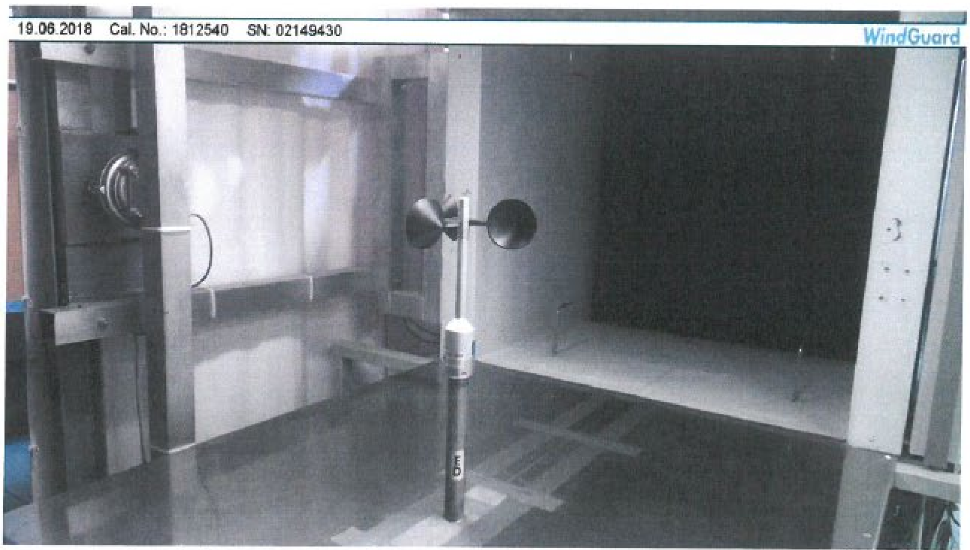


Photo of the measurement setup
Foto des Messaufbaus



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

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

V2 Anemometer at 121.5 m

V2
119,25

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812541
D-K-15140-01-00
06/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	02149431
Customer *Auftraggeber*	GE:NET GmbH 38678 Clausthal-Zellerfeld
Order No. *Auftragsnummer*	Email 2018-06-14, Rethfeld
Project No. *Projektnummer*	VT180611
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.06.2018

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*
19.06.2018	D. Westermann	B. Schütz
	Dipl. Phys. Dieter Westermann	Techniker Bendix Schütz

1812541
D-K- 15140-01-00
06/2018

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.5 °C ± 0.1 °C
	air pressure	1022.3 hPa ± 0.3 hPa
	relative air humidity	44.8 % ± 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

-

1812541
D-K-15140-01-00
06/2018

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.949	0.05	81.205
5.864	0.05	122.592
7.872	0.05	165.201
9.866	0.05	208.703
11.884	0.05	253.179
13.818	0.05	294.614
15.846	0.05	338.077
14.793	0.05	315.411
12.890	0.05	274.003
10.897	0.05	231.023
8.855	0.05	187.096
6.922	0.05	145.039
4.890	0.05	101.412

Statistical analysis

Slope	0.04626 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
Offset	0.2032 m/s ±0.012 m/s
Standard error (Y)	0.012 m/s
Correlation coefficient	0.999993

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard - Wind Tunnel Services GmbH measnet

Graphical representation of the result
Grafische Darstellung des Ergebnisses

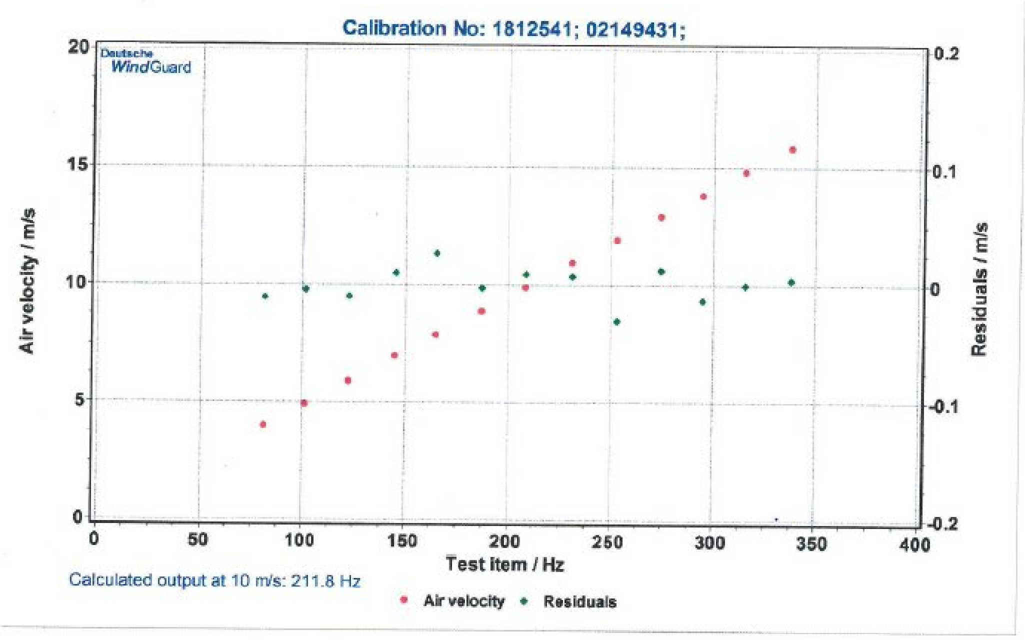
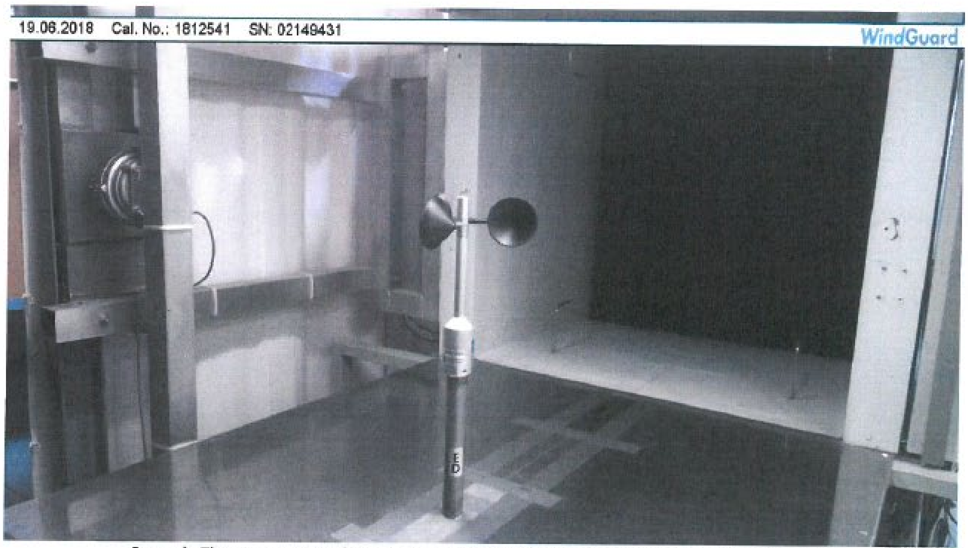


Photo of the measurement setup
Foto des Messaufbaus



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

V5 Anemometer at 80 m

V5
80,0

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812542
D-K-15140-01-00
06/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	02149432
Customer *Auftraggeber*	GE:NET GmbH 38678 Clausthal-Zellerfeld
Order No. *Auftragsnummer*	Email 2018-06-14, Rethfeld
Project No. *Projektnummer*	VT180611
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.06.2018

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*
19.06.2018	D. Westermann Dipl. Phys. Dieter Westermann	B. Schütz Techniker Bendix Schütz

1812542
D-K- 15140-01-00
06/2018

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio 1)	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.6 °C ± 0.1 °C
	air pressure	1022.4 hPa ± 0.3 hPa
	relative air humidity	44.6 % ± 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

-

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D-K-15140-01-00
06/2018

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.949	0.05	81.154
5.833	0.05	121.445
7.871	0.05	165.867
9.872	0.05	209.098
11.877	0.05	252.626
13.822	0.05	293.789
15.836	0.05	338.628
14.801	0.05	315.510
12.889	0.05	273.867
10.893	0.05	230.548
8.858	0.05	186.526
6.912	0.05	144.663
4.906	0.05	101.432

Statistical analysis

Slope	0.04622 (m/s)/(Hz) ±0.00006 (m/s)/(Hz)
Offset	0.2165 m/s ±0.014 m/s
Standard error (Y)	0.014 m/s
Correlation coefficient	0.999990

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH - measnet

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

DEUTSCHE WINDGUARD

1812542
D-K- 15140-01-00
06/2018

Graphical representation of the result
Grafische Darstellung des Ergebnisses

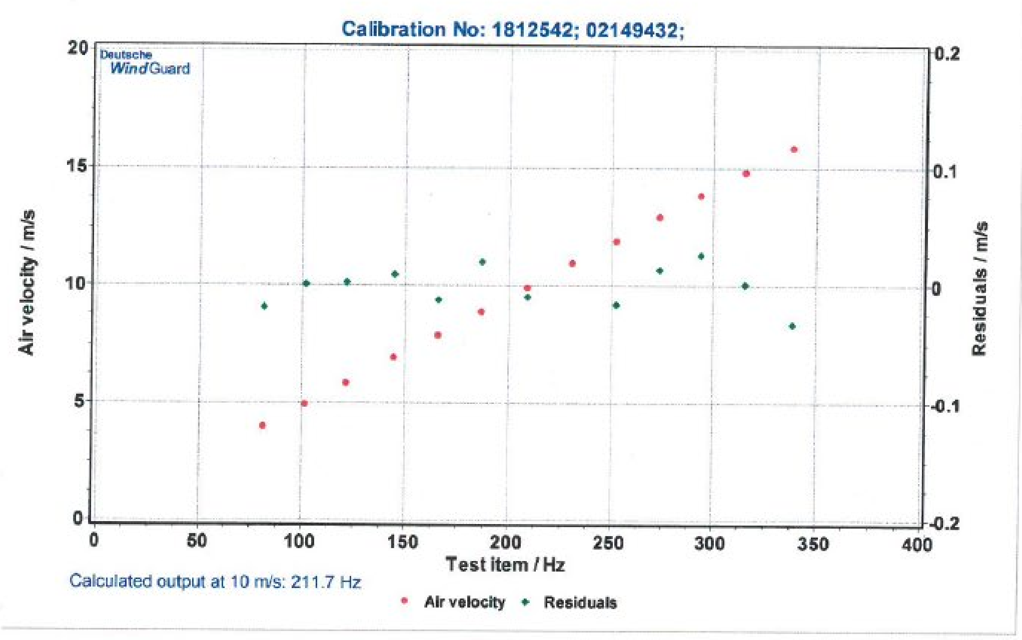
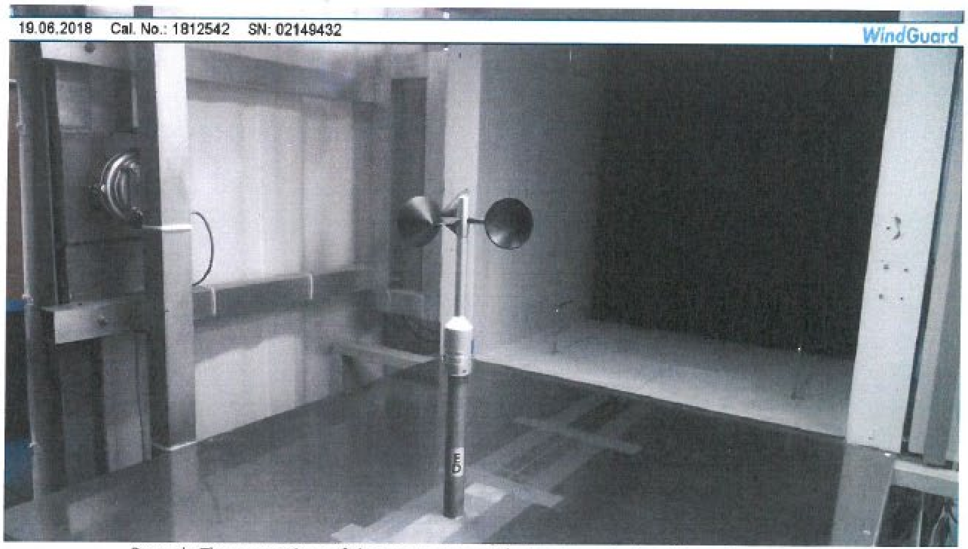


Photo of the measurement setup
Foto des Messaufbaus



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

V7 Anemometer at 80 m

V7
65,0

DEUTSCHE
WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812543
D-K-15140-01-00
06/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.10.000
Serial number *Fabrikat/Serien-Nr.*	02149433
Customer *Auftraggeber*	GE:NET GmbH 38678 Clausthal-Zellerfeld
Order No. *Auftragsnummer*	Email 2018-06-14, Rethfeld
Project No. *Projektnummer*	VT180611
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	19.06.2018

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*
19.06.2018	D. Westermann Dipl. Phys. Dieter Westermann	B. Schütz Techniker Bendix Schütz

1812543
D-K- 15140-01-00
06/2018

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.6 °C ± 0.1 °C
	air pressure	1022.4 hPa ± 0.3 hPa
	relative air humidity	44.3 % ± 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

-

1812543
D-K- 15140-01-00
06/2018

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.953	0.05	80.058
5.872	0.05	121.589
7.869	0.05	164.842
9.871	0.05	209.023
11.891	0.05	251.350
13.819	0.05	293.734
15.838	0.05	336.862
14.793	0.05	315.320
12.885	0.05	273.183
10.887	0.05	230.510
8.861	0.05	186.087
6.902	0.05	143.673
4.906	0.05	100.607

Statistical analysis		
	Slope	0.04619 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
	Offset	0.2556 m/s ±0.015 m/s
	Standard error (Y)	0.015 m/s
	Correlation coefficient	0.999989

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH measnet

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06/2018

Graphical representation of the result
Grafische Darstellung des Ergebnisses

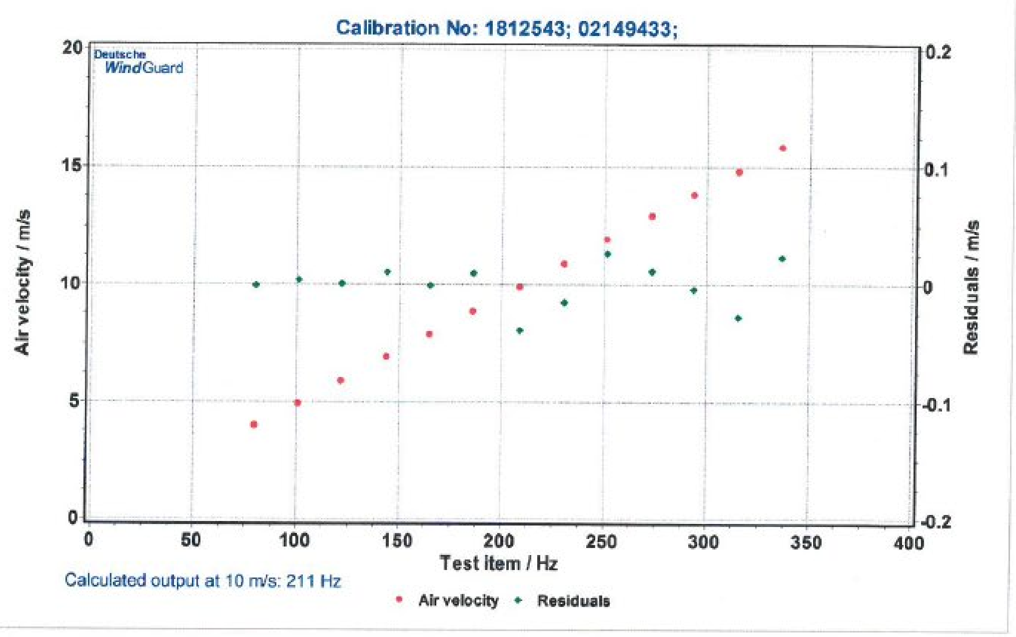
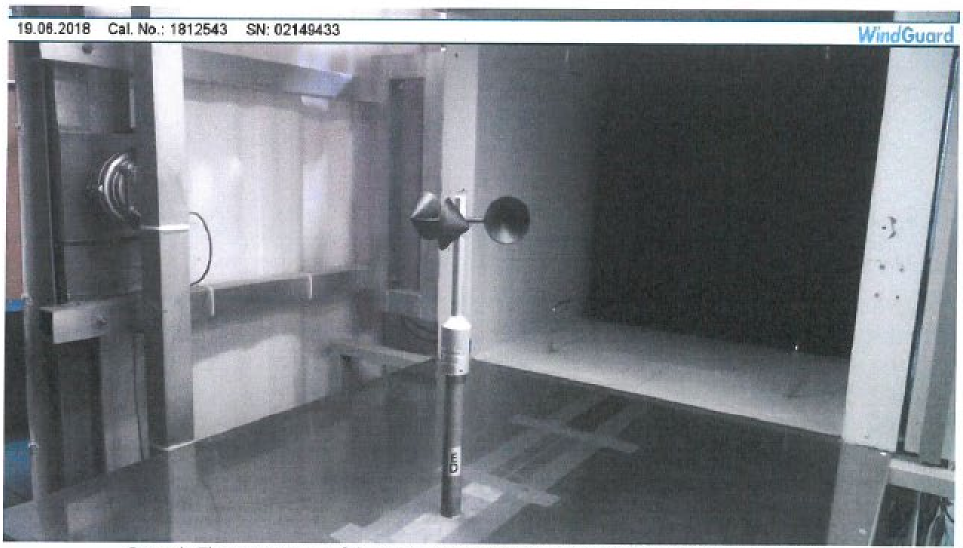


Photo of the measurement setup
Foto des Messaufbaus



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

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

V8 Anemometer at 65 m

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate *Kalibrierschein*	Calibration mark *Kalibrierzeichen*	1812237
		D-K-15140-01-00
		05/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	08154580
Customer *Auftraggeber*	GL Garrad Hassan D-25709 Kaiser-Wilhelm-Koog
Order No. *Auftragsnummer*	PR19035/CC4270/NHb/LDo
Project No. *Projektnummer*	VT180382
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	18.05.2018

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*
18.05.2018	Dipl. Phys. Dieter Westermann	Techniker Dirk Henninges

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 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 EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	24.2 °C ± 0.1 °C
	air pressure	1020.9 hPa ± 0.3 hPa
	relative air humidity	36.8 % ± 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

-

1812237
D-K-15140-01-00
05/2018

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.962	0.05	81.680
5.865	0.05	122.789
7.855	0.05	165.531
9.873	0.05	209.897
11.880	0.05	252.868
13.813	0.05	295.916
15.808	0.05	338.371
14.787	0.05	315.682
12.886	0.05	274.833
10.881	0.05	231.378
8.843	0.05	186.923
6.908	0.05	144.809
4.920	0.05	101.961

Statistical analysis	Slope	0.04609 (m/s)/(Hz) ±0.00006 (m/s)/(Hz)
	Offset	0.2159 m/s ±0.014 m/s
	Standard error (Y)	0.014 m/s
	Correlation coefficient	0.999990

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Graphical representation of the result
Grafische Darstellung des Ergebnisses

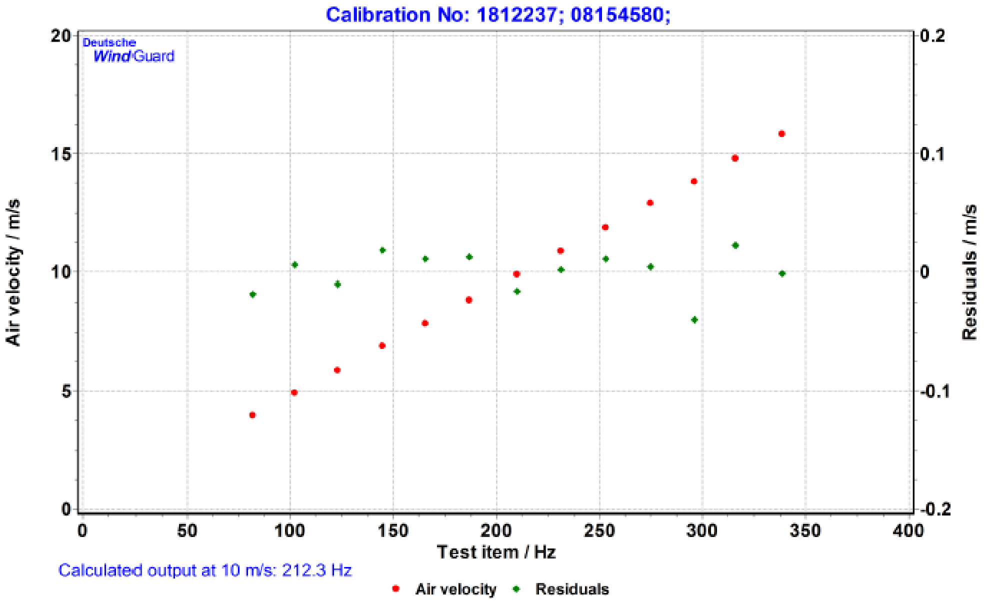
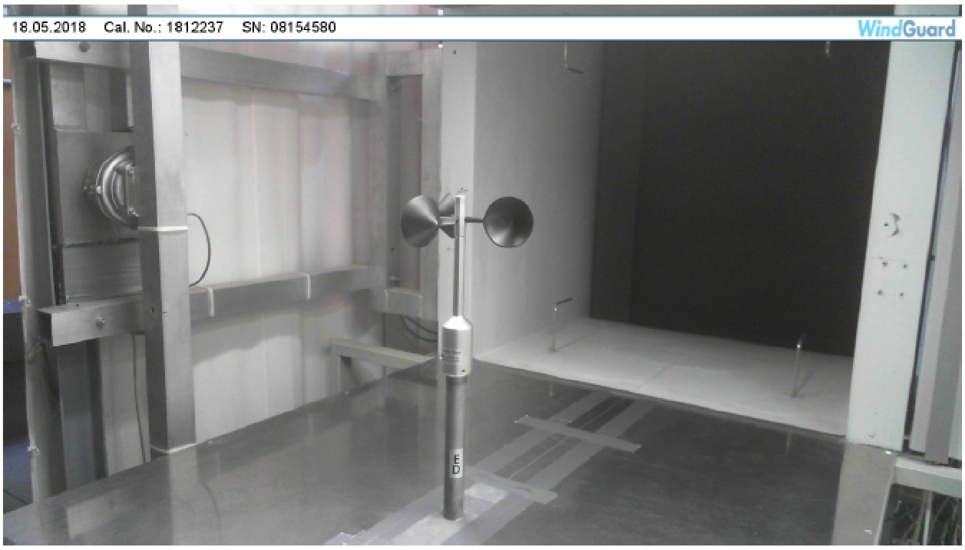


Photo of the measurement setup
Foto des Messaufbaus



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

Anemometer at 65 m

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812200
D-K-15140-01-00
05/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	02126229 427012-113000086
Customer *Auftraggeber*	GL Garrad Hassan D-25709 Kaiser-Wilhelm-Koog
Order No. *Auftragsnummer*	PO19088/CC4270/NHb/LDo
Project No. *Projektnummer*	VT180498
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	15.05.2018

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.

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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
15.05.2018	D. Westermann Dipl. Phys. Dieter Westermann	B. Schütz Techniker Bendix Schütz

1812200
D-K-15140-01-00
05/2018

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 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 EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	27.0 °C ± 0.1 °C
	air pressure	1015.2 hPa ± 0.3 hPa
	relative air humidity	39.4 % ± 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%.
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 result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.937	0.05	80.477
5.862	0.05	122.212
7.868	0.05	165.649
9.872	0.05	209.074
11.893	0.05	252.496
13.812	0.05	294.618
15.853	0.05	339.040
14.791	0.05	315.526
12.888	0.05	273.987
10.903	0.05	231.241
8.845	0.05	187.105
6.912	0.05	144.688
4.879	0.05	100.757

Statistical analysis

Slope 0.04614 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)

Offset 0.2279 m/s ±0.009 m/s

Standard error (Y) 0.009 m/s

Correlation coefficient 0.999996

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH measnet

Graphical representation of the result
Grafische Darstellung des Ergebnisses

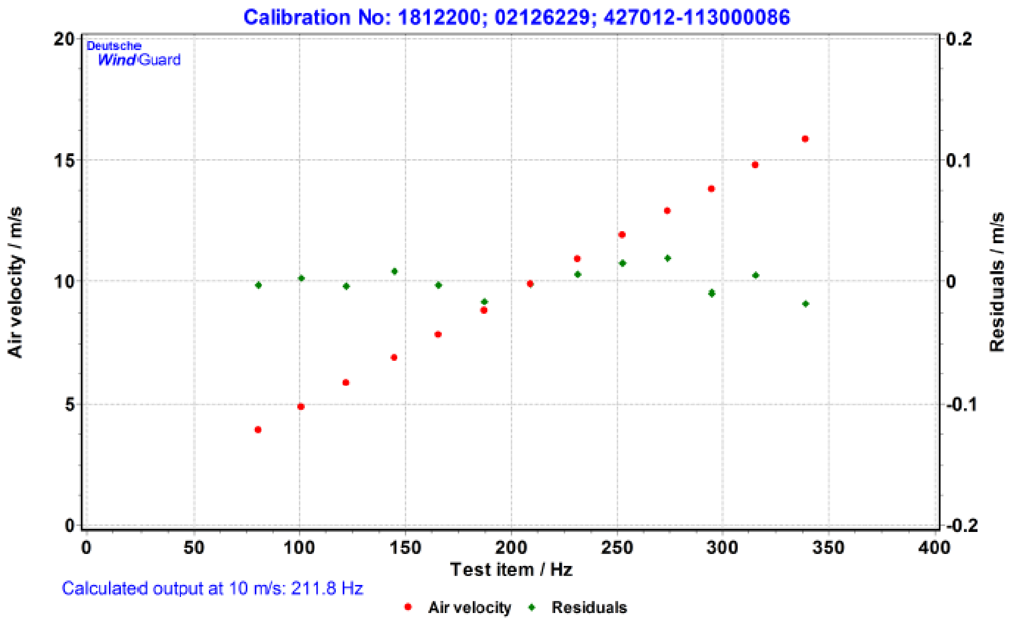
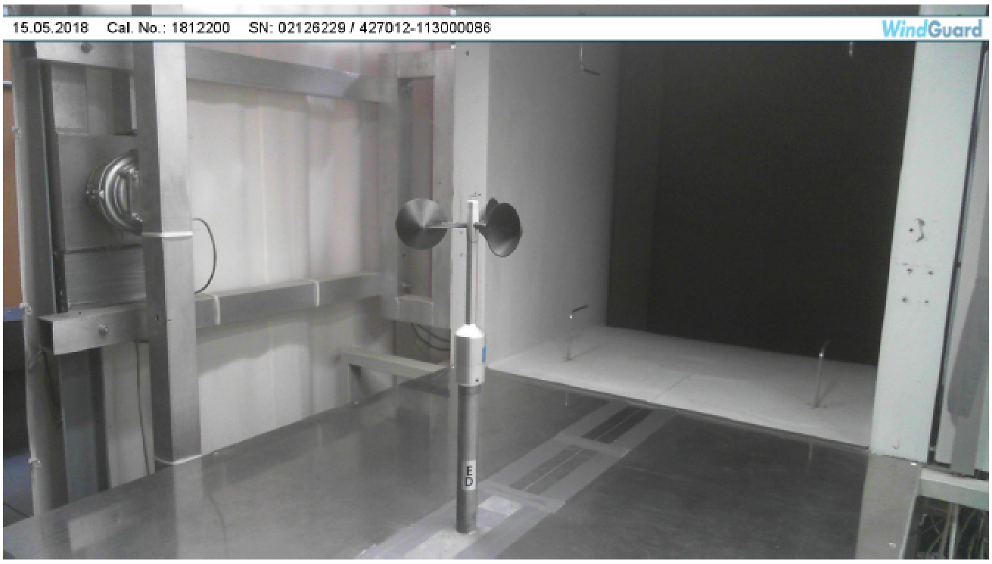


Photo of the measurement setup
Foto des Messaufbaus



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

V10 Anemometer at 45 m

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812199
D-K-
15140-01-00
05/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	0310559 427010-113000124
Customer *Auftraggeber*	GL Garrad Hassan D-25709 Kaiser-Wilhelm-Koog
Order No. *Auftragsnummer*	PO19088/CC4270/NHb/LDo
Project No. *Projektnummer*	VT180498
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	15.05.2018

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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
15.05.2018	Dipl. Phys. Dieter Westermann	Techniker Bendix Schütz

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 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 EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.9 °C ± 0.1 °C
	air pressure	1015.3 hPa ± 0.3 hPa
	relative air humidity	39.5 % ± 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 result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item Test item Hz
3.945	0.05	80.561
5.873	0.05	121.998
7.872	0.05	165.151
9.877	0.05	208.728
11.885	0.05	252.345
13.816	0.05	294.588
15.848	0.05	339.360
14.797	0.05	315.701
12.885	0.05	274.464
10.924	0.05	231.350
8.860	0.05	186.412
6.915	0.05	144.803
4.879	0.05	100.464

Statistical analysis

Slope	0.04603 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
Offset	0.2592 m/s ±0.012 m/s
Standard error (Y)	0.012 m/s
Correlation coefficient	0.999992

Remarks

The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH measnet

Graphical representation of the result
Grafische Darstellung des Ergebnisses

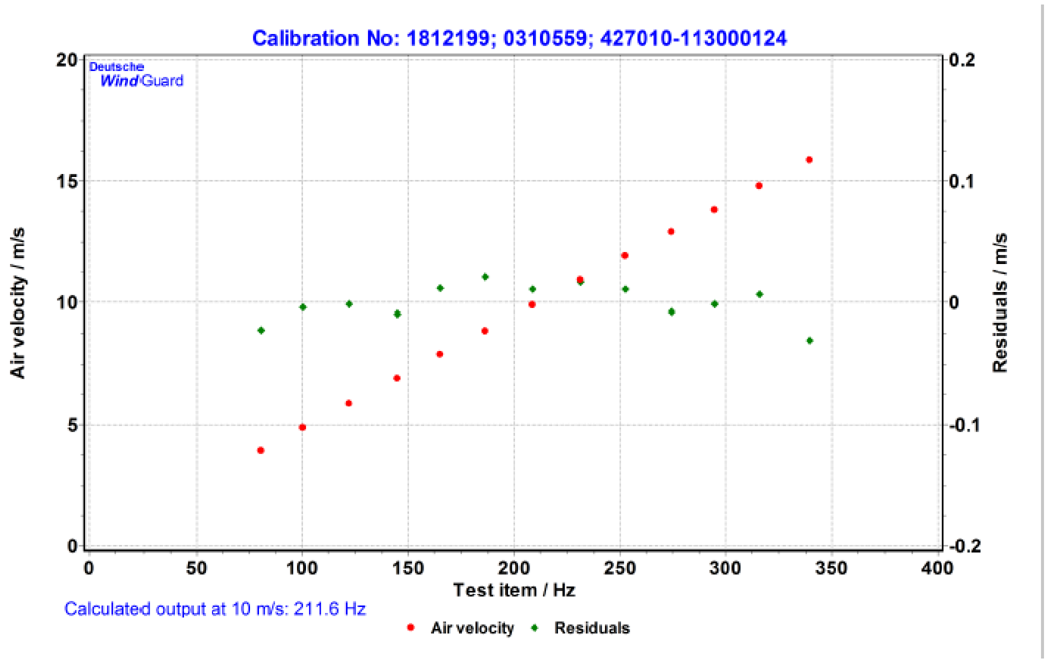
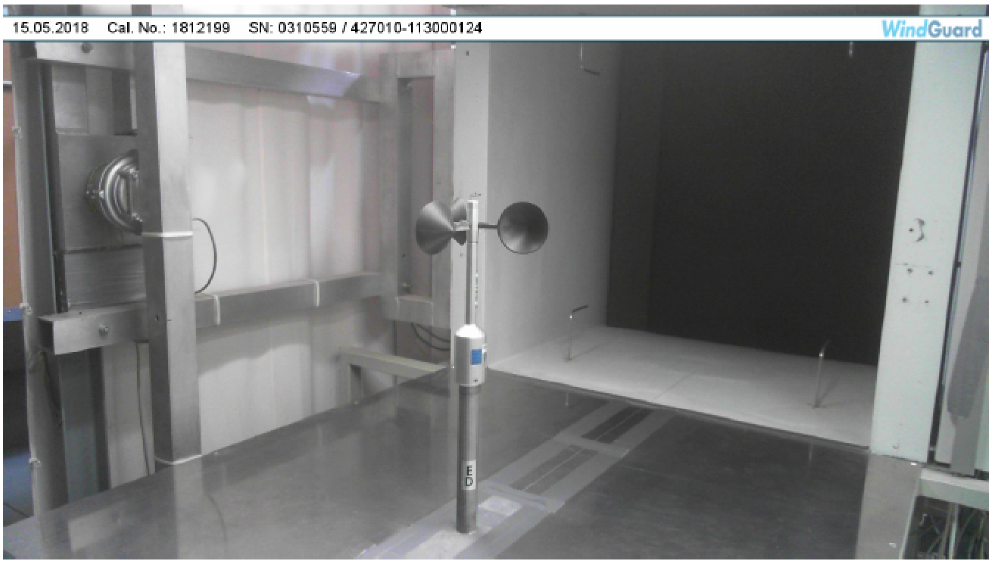


Photo of the measurement setup
Foto des Messaufbaus



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

V11 Anemometer at 45 m

DEUTSCHE WINDGUARD

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Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

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Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1812198
D-K-15140-01-00
05/2018

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3351.00.000
Serial number *Fabrikat/Serien-Nr.*	06113972 427011-113000015
Customer *Auftraggeber*	GL Garrad Hassan D-25709 Kaiser-Wilhelm-Koog
Order No. *Auftragsnummer*	PO19088/CC4270/NHb/LDo
Project No. *Projektnummer*	VT180498
Number of pages *Anzahl der Seiten*	4
Date of Calibration *Datum der Kalibrierung*	15.05.2018

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Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
15.05.2018	Dipl. Phys. Dieter Westermann	Techniker Bendix Schütz

1812198
D-K-15140-01-00
05/2018

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 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 EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	7.8

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

Ambient conditions *Umgebungsbedingungen*	air temperature	26.7 °C ± 0.1 °C
	air pressure	1015.4 hPa ± 0.3 hPa
	relative air humidity	39.8 % ± 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

-

Graphical representation of the result
Grafische Darstellung des Ergebnisses

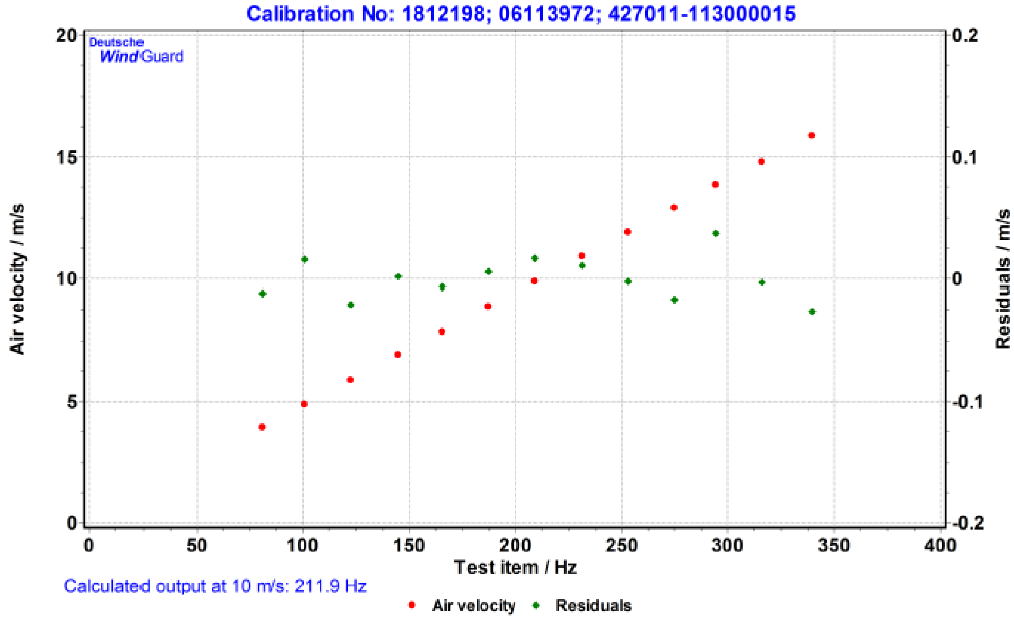
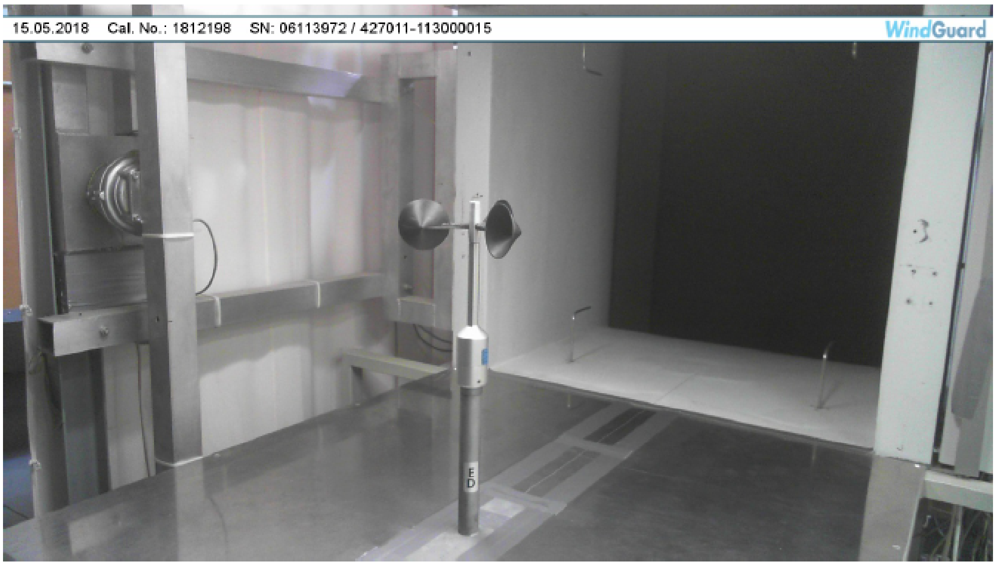


Photo of the measurement setup
Foto des Messaufbaus



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