

Verification of the Wind@Sea lidar ZX6482 at the EWTW test site near meteorological mast MM6

Period: from 20 November 2025 to 16 January 2026

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Results only apply for the tested lidar with the settings used during the measurement period. In case copies of this report are made, only integral copying is allowed.

Contents

Contents	4
List of tables and figures.....	5
Abbreviations	7
Management summary	8
1 Introduction.....	9
2 Measurement campaign.....	10
2.1 RSD verification location	10
2.2 Measurement sector	12
2.3 Remote Sensing Device	13
2.4 Data stream	14
3 Data selection.....	16
3.1 Filter criteria	16
4 Lidar verification.....	19
4.1 Direct data comparison	19
4.2 Bin-wise data comparison	19
4.3 Systematic uncertainties	19
4.4 Environmental conditions.....	19
5 Sensitivities	29
5.1 Sensitivity analysis.....	29
5.2 Impact on accuracy	30
6 Uncertainty	35
6.1 Reference devices - cup anemometers	35
6.2 Remote sensing device	36
7 Deviations	37
8 Conclusions.....	38
References.....	39
Signature	40
Appendices	
Appendix A: IEC visualisations	41
Appendix B: Turbulence intensity comparison	43
Appendix C: Instrumentation details	44

List of tables and figures

Tables

2.1	Coordinates of the reference mast as well as the lidar.....	12
2.2	Excluded sectors per measuring height	13
2.3	Measurement heights for verification	13
4.1	Lidar verification IEC 61400-50-2 results.....	19
4.2	Uncertainty calculations for the floating lidar system at 118 m.....	23
4.3	Uncertainty calculations for the floating lidar system at 81 m.....	24
4.4	Uncertainty calculations for the floating lidar system at 42 m.....	25
4.5	Environmental conditions at 118 m	26
4.6	Environmental conditions at 81 m.....	27
4.7	Environmental conditions at 42 m.....	28
5.1	Overview of significant sensitivities	31
5.2	Sensitivity to environmental variables for the lidar	32
5.3	Maximum influence of environmental variables on the lidar wind speed.....	33
5.4	Distribution of environmental variables used in the floating lidar sensitivity study	34
C.1	Signals used for each comparison height	44
C.2	List of measured signals.....	45
C.3	List of equipment used per signal.....	46
C.4	List of calculated (pseudo) signals	47

Figures

2.1	Detailed overview of the south EWTW locations.....	10
2.2	Ground level elevation map of the lidar’s surroundings	11
2.3	Meteorological Mast MM6.....	11
2.4	Position of the lidar relative to meteorological mast	12
2.5	Layout of the EWTW test site used to determine the measurement sector	13
2.6	ZX300M ZX6482 lidar at the RSD verification location	14
2.7	Layout of the meteorological mast MM6	15
3.1	Unfiltered wind speed time series	16
3.2	Unfiltered wind direction time series.....	17
3.3	Filter: MEASNET icing criterion.....	18
4.1	Wind speed comparison @117.5 m.....	21
4.2	Wind speed comparison @81.4 m	21
4.3	Wind speed comparison @41.9 m	21
4.4	Bin-wise wind speed comparison @117.5 m	22
4.5	Bin-wise wind speed comparison @81.4 m.....	22
4.6	Bin-wise wind speed comparison @41.9 m.....	22
A.1	Influence of the wake of meteorological mast on the lidar.	41
A.2	Contributions to the lidar uncertainty	42
A.3	Histograms for bin-wise wind speed comparison	42
B.1	Turbulence intensity comparison.....	43

C.1 Thies cup 4.3352 classification report, Class S..... 64

Abbreviations

α	exponent of the power law wind shear model, see equation (5.2)
AHN	Actueel Hoogtebestand Nederland (Dutch laser altimetry map)
DTM	Digital Terrain Model
EV	environmental variable
EWTW	ECN Wind Turbine test site Wieringermeer
h	measurement height, see equation (5.2)
h_r	reference height for shear profile, see equation (5.2)
IEC	International Electrotechnical Commission
IECRE WE	IEC system for certification to standards relating to equipment for use in Renewable Energy applications - Wind Energy
ILAC MRA	International Laboratory Accreditation Cooperation Mutual Recognition Arrangement
LOS	Line Of Sight
N	number of 10-minute samples, see equation (5.6)
n_b	number of bins, see equation (5.6)
n_i	bin-count for bin i , see equation (5.6)
PDOK	Publieke Dienstvoorziening Op de Kaart
RD	Rijksdriehoekscoördinaten (Dutch geodetic datum)
RETL	Renewable Energy Testing Laboratory
RSD	Remote Sensing Device
RvA	Raad voor Accreditatie (Dutch Accreditation Council)
std	standard deviation
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (Netherlands Organisation for applied scientific research)
UTC	Coordinated Universal Time
VA	Vector Averaging
v_{hor}	horizontal wind speed, see equation (5.4)
v_r	wind speed of shear profile at h_r , see equation (5.2)
v_{vert}	vertical wind speed, see equation (5.4)
v_d	wind direction, see equation (5.5)
WDMS	Wind Data Management System
WGS 84	world geodetic system 1984

Management summary

As part of the Wind@Sea project a ZX Lidars ZX300M with serial number ZX6482 was installed at the EWTW test site near meteorological mast MM6 on 20 November 2025. The lidar was verified before being deployed for wind field measurements at offshore platform F2-A-Hanze.

The official measurement campaign started on 20 November 2025 13:30 UTC and lasted until 16 January 2026 00:00 UTC, covering 56 days. The comparison of the lidar against meteorological mast MM6 is performed for three measurement heights, 42 m, 81 m and 118 m.

For all comparison heights the regression slope is close to 1 and the offset is up to 0.10 m/s with an R^2 close to 1. The maximum deviation observed is 2.8 % and the uncertainty is 0.8 % to 2.9 %. The sensitivity analysis did not result in any significant sensitivity for the lidar.

The results of this verification are based on IEC 61400-50-2:2022 and the TNO *Work instructions for verification of RSD* (v.5).

TNO Wind Energy is ISO 17025 accredited for ground based remote sensing device verification.

1 Introduction

A ZX Lidars ZX300M with serial number ZX6482 was installed at the EWTW test site near MM6 on 20 November 2025. The lidar was verified before being deployed for wind field measurements at offshore platform F2-A-Hanze in the Wind@Sea project. This report presents the verification results.

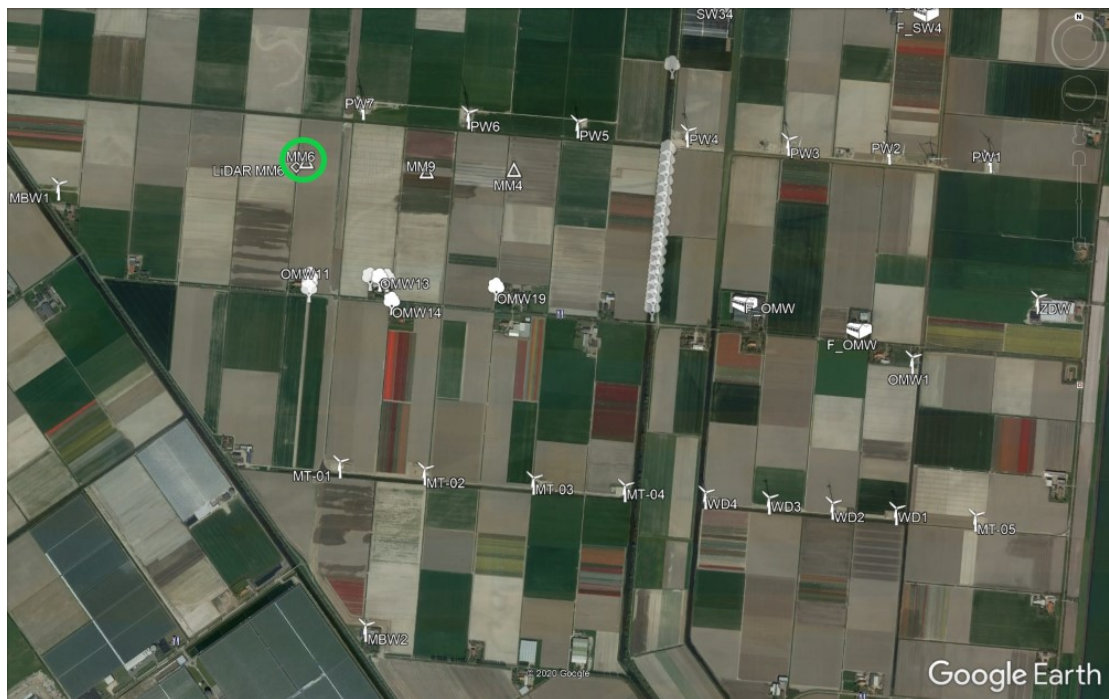
After verifying correct operation of the lidar, the measurement campaign was started on 20 November 2025 13:30 UTC and lasted until 16 January 2026 00:00 UTC.

The results of this verification are based on the IEC 61400-50-2:2022 [1] standard and the TNO *Work instructions for verification of RSD (v.5)*.

2 Measurement campaign

2.1 RSD verification location

The lidar is verified near meteorological mast MM6 at the EWTW test site [2]. The terrain at the EWTW test site consists mainly of agricultural land, with single farmhouses and rows of trees as shown in fig. 2.1. It is located in the Wieringermeer, a polder in the north east of the province of North Holland, 3 km North of the village Medemblik and 1 km West from the vast IJsselmeer lake. The altitude is 5 m below sea level. The site is considered sufficiently flat according to IEC 61400-12-5:2022 [3] as demonstrated by the laser altimetry in fig. 2.2.

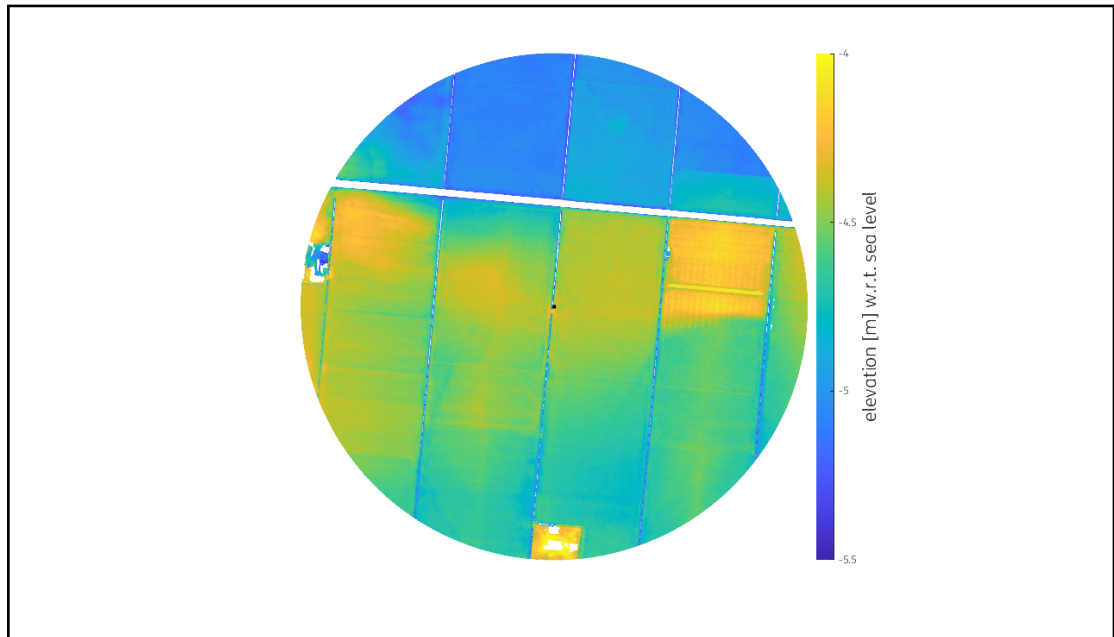


Source: Google Earth

Figure 2.1: Detailed overview of the south EWTW locations and corresponding meteo mast locations as well as the nearby obstacles. Meteorological mast MM6 is highlighted by the green circle

The mast is an un-guyed triangular lattice tower with a height of 115.5 m, see fig. 2.3. At the bottom the width of the tower is 5.86 m. On the top of the mast a vertical tube is installed with a total height of 1.775 m above the mast top. Including the sensor height of 0.225 m this adds up to a top cup measuring height of 117.5 m.

A total of eight booms are mounted on to the mast, as is presented in the layout drawing in fig. 2.7. Five booms, pointing at 320° in relative to North, support three wind vanes and two cup anemometers. Three booms, pointing at 140° relative to North, support anemometers. At the lower and mid measuring heights two cups are installed in opposite directions. Within the large measurement sector a single cup measurement would result in large wake effects at specific wind direction. Combined, the influence is reduced. At the lower and mid measuring heights the vanes are installed on a separate boom 4 m below the cup measuring height. The



Source: PDOK / AHN-3 (0.5 m raster DTM)

Figure 2.2: Ground level elevation map of the lidar's surroundings (radius = 5×117.5 m)



Figure 2.3: Meteorological Mast MM6

measuring heights of the cup anemometers are 41.9 m, 81.4 m, 112.5 m and 117.5 m. The measuring heights of the wind vanes are 37.9 m, 77.4 m and 112.5 m. At 108.5 m, 4 m below the cup anemometer, a sonic anemometer is located. The booms can be retracted for maintenance of the sensors.

In table 2.1 the coordinates of the meteorological mast and lidar locations are summarized.

Table 2.1: Coordinates of the reference mast as well as the lidar

location	RD	WGS 84
MM6	132 384 m, 536 649 m	52°48.997'N, 5°3.105'E
lidar	132 344 m, 536 622 m	52°48.982'N, 5°3.069'E

RD Rijkdriehoeksmeting (Dutch geodetic datum)

WGS 84 world geodetic system 1984

In fig. 2.4 the location of the verification location is shown in more detail.



Source: Google Maps

Figure 2.4: Position of the lidar at 49 m from the meteorological mast; indicated in green is meteorological mast MM6 and in yellow the verification platform

2.2 Measurement sector

The measurement sector is the wind direction sector for which the meteorological mast measurements and lidar measurements are unaffected by obstacles. The measurement sector for this verification test is determined based on IEC 61400-12-5:2022 [3] using *MeasSector* version 2.2.1. In fig. 2.5 the lay-out of the EWTW test site is given with the excluded sectors of all the relevant obstacles. This information is used to determine the undisturbed measurement sector.

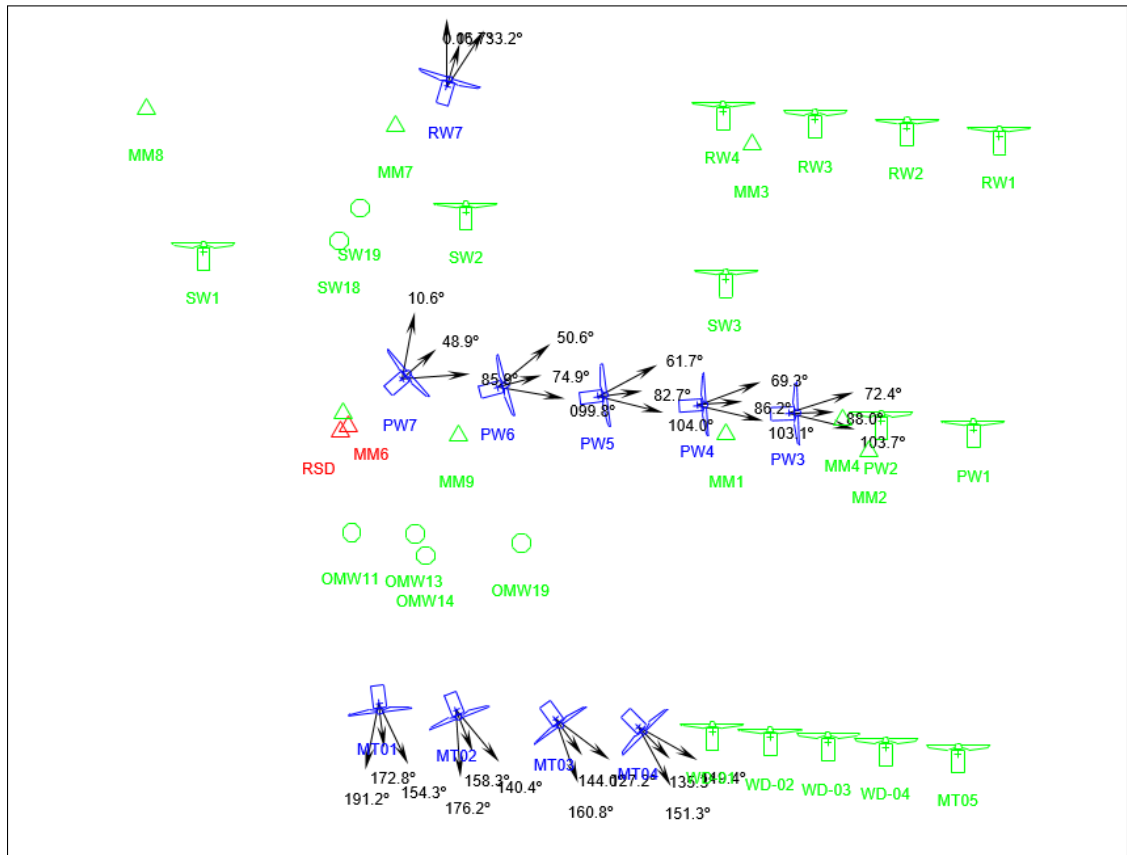


Figure 2.5: Layout of the EWTW test site used to determine the measurement sector

Table 2.2: Excluded sectors per measuring height

excluded sector	comparison height			origin
	117.5m	81.4m	41.9m	
0.1° to 104.0°	x	x	x	nearby obstacles
119.4° to 191.2°	x	x	x	nearby obstacles

2.3 Remote Sensing Device

The Remote Sensing Device (RSD) is a ZX300M lidar. This unit has identification number ZX6482 (software version 4.5004). It is configured to perform measurements at 10 heights: 22 m, 42 m, 60 m, 81 m, 100 m, 112 m, 117 m, 140 m, 160 m, 180 m. The lidar has a cone half-angle of 30°. The comparison heights are specified in table 2.3. During the verification test the lidar was oriented 5° w.r.t. North.

Table 2.3: Measurement heights for verification

comparison height	MM6 height	lidar height
m	m	m
117.5	117.5	117
81.4	81.4	81
41.9	41.9	42

The ZX300M lidar at the RSD verification location is presented in fig. 2.6.



Figure 2.6: ZX300M ZX6482 lidar at the RSD verification location

2.4 Data stream

The Meteorological Mast MM6 is connected via a glass fibre network to the measurement office at the EWTW test site. From here, the data are transported on a daily basis to the TNO offices in Petten, where they are stored on a server and imported in a dedicated Wind Data Management System (WDMS) database. The lidar data are accumulated in the lidar device itself.

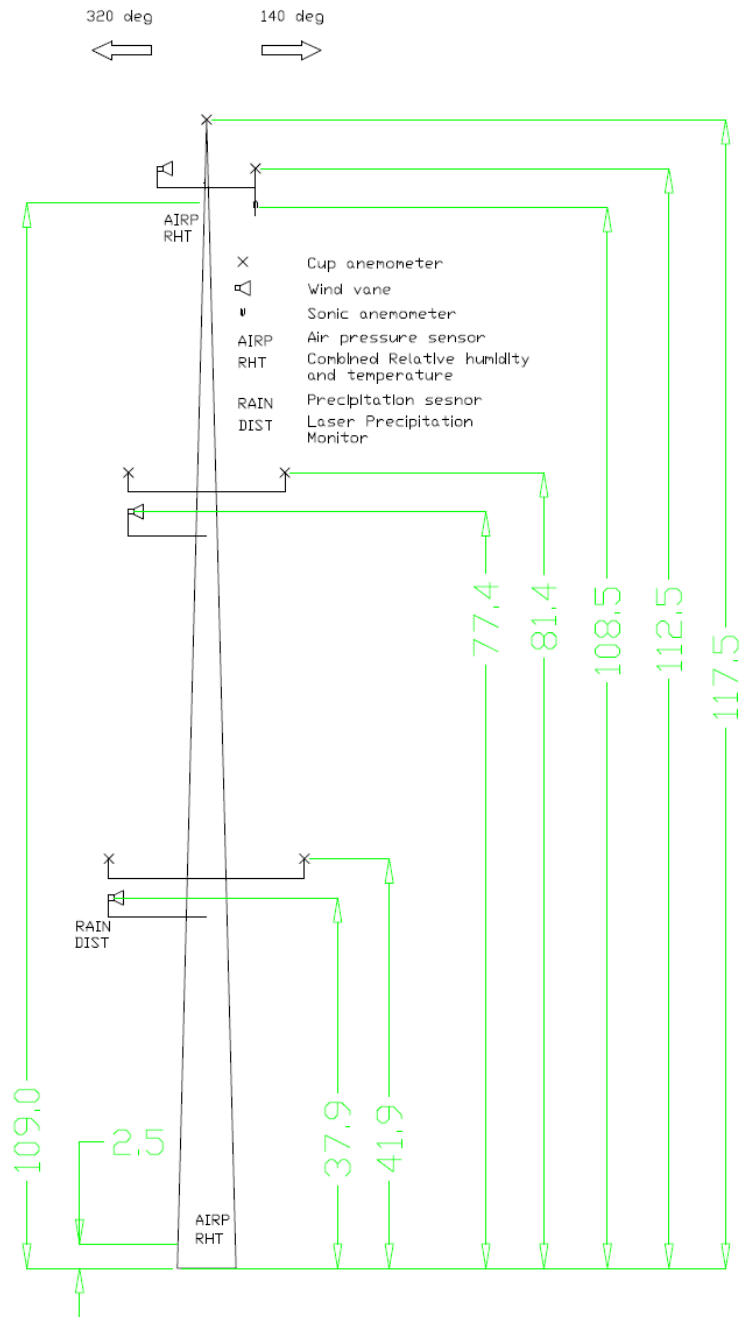


Figure 2.7: Layout of the meteorological mast MM6

3 Data selection

The lidar measurement campaign officially starts on 20 November 2025 13:30 and ends on 16 January 2026 00:00 UTC. Figures 3.1 and 3.2 show the time series for the wind speed and wind direction measured by the reference meteorological mast and the lidar, prior to filtering.

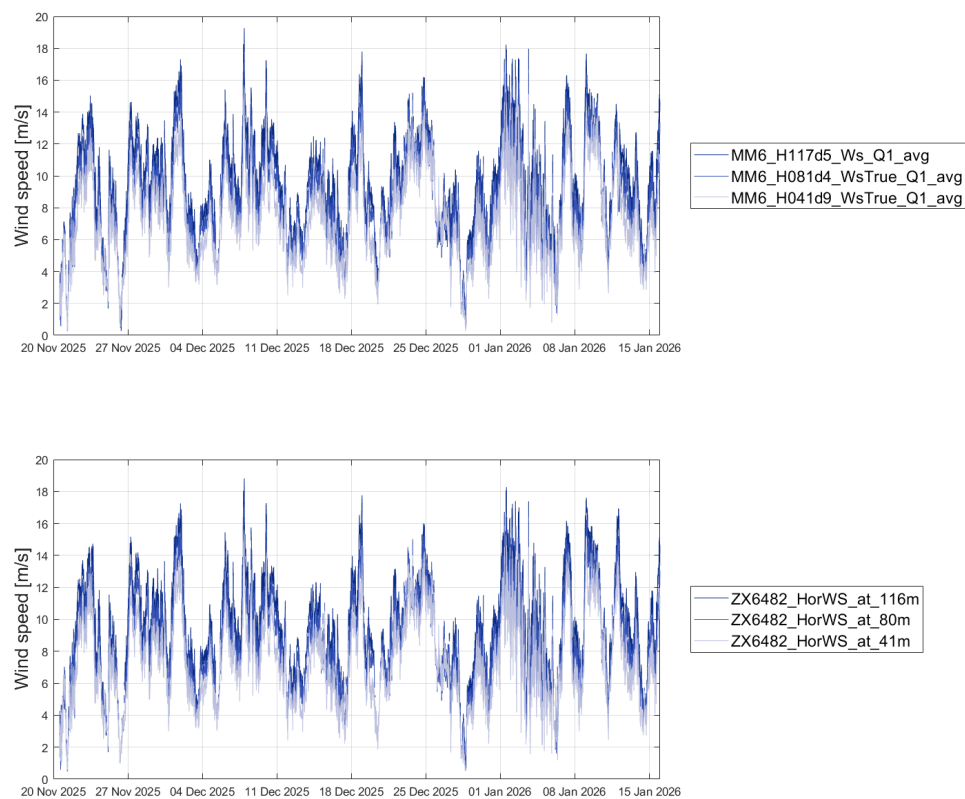


Figure 3.1: Unfiltered wind speed time series for the comparison heights by the reference meteorological mast at the RSD verification location (top) and the lidar (bottom)

3.1 Filter criteria

The data is filtered in accordance with IEC 61400-50-2:2022 [1, clause 6.3, p.15]:

- a) *Reference meteorological mast free of wakes*
The measurement sector is defined in section 2.2 and the filtering is applied to the wind direction measurements at each comparison height individually.
- b) *lidar free of wakes*
The lidar is located near the base of MM6 with the North marker aligned to the boom direction of 320°. Additional measurement filtering is applied where a lidar LOS is in the wake of the meteorological mast, see section 2.2.

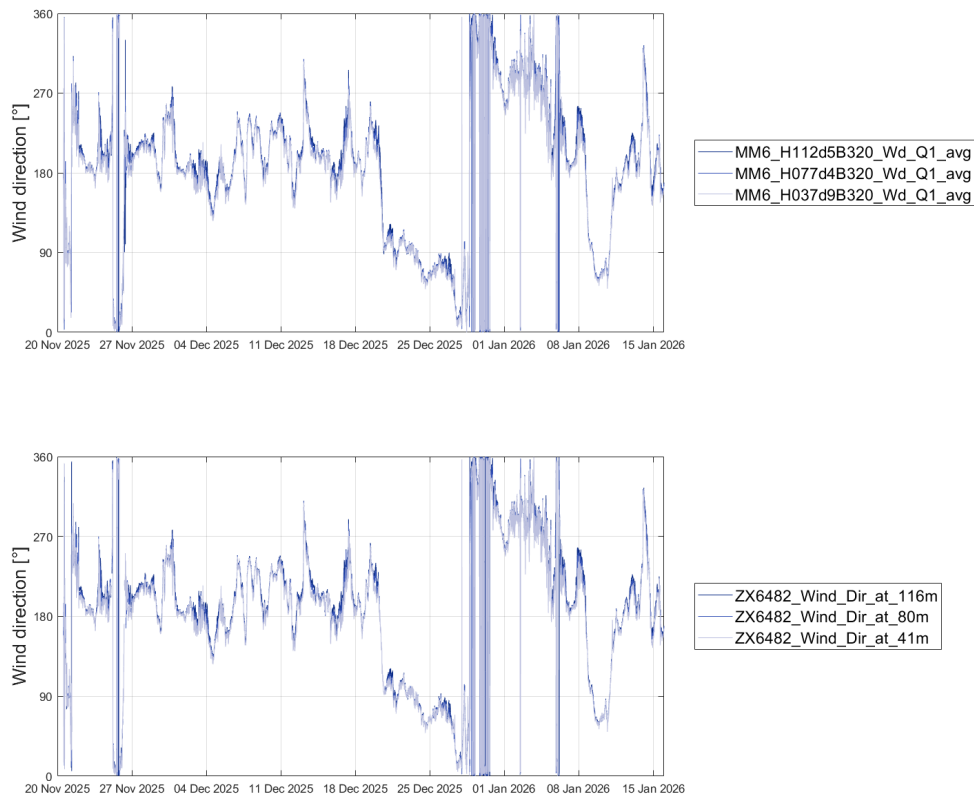


Figure 3.2: Unfiltered wind direction time series for various heights by the reference meteorological mast at the RSD verification location (top) and the lidar (bottom)

The resulting ratio between the wind speeds measured by MM6 and the lidar at each comparison height and within the measurement sector, does not show a strong directional dependency, see fig. A.1.

c) *Anemometers free of mast wake*

For measurement heights below the top cup, the influence of the MM6 wake on the reference cup anemometers is mitigated by combining measurements of two cups on booms at opposite sides of the mast. An additional sector is excluded where both cup measurements are influenced by the MM6, in line with the boom direction of 320°.

d) *Icing*

The MEASNET [4] icing criterion is applied, which eliminates data if the temperature is below 2 °C while the relative humidity is over 80 %. The impact of this criterion is shown in fig. 3.3.

e) *Data availability*

All data with lidar availability less than 100 % are filtered from the data set.

f) *Precipitation*

The lidar performance might be affected by precipitation however no filtering on precipitation was undertaken. The IEC 61400-50-2:2022 describes that in general no filtering on precipitation should be applied unless specifically described by the manufacturers guidelines.

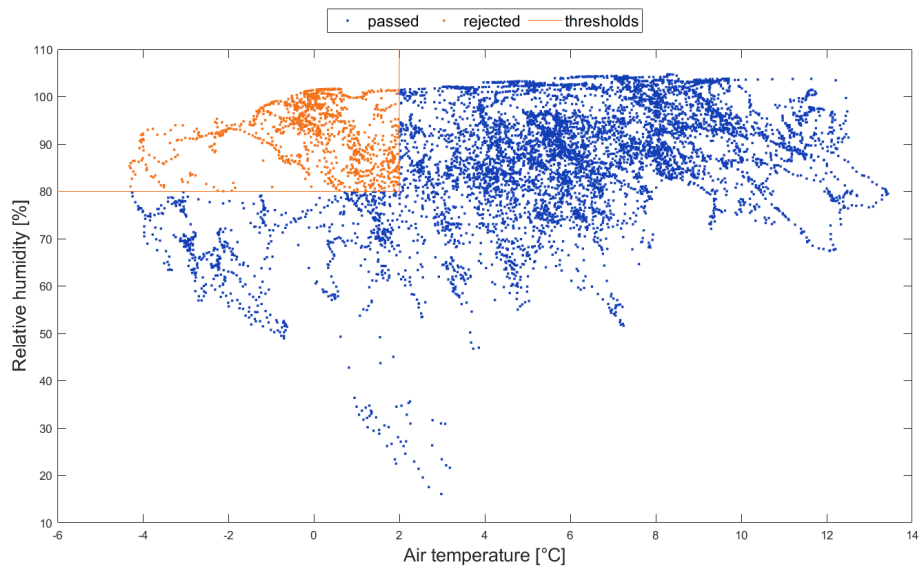


Figure 3.3: Filter: MEASNET icing criterion

4 Lidar verification

This chapter reports the results of the lidar verification analysis as defined in clause 7 [1]. The analysis is performed using the in-house software tool *RSDverification* version 2.3.1.

4.1 Direct data comparison

A comparison of the horizontal wind speed between the meteorological mast devices and the lidar for each comparison height is presented in figs. 4.1 to 4.3. The format is taken from figure 6 [1]. Only samples for which the reference wind speed is in the range of 3.75 m/s to 16.25 m/s are used. Turbulence intensity comparison results for all comparison heights are found in appendix B.

4.2 Bin-wise data comparison

The bin-wise comparison described in clause 7 [1] first requires binning of the reference wind speeds measured on the meteorological mast. The prescribed bin width is 0.5 m/s centred on integer multiples of 0.5 m/s, therefore the range is 3.75 m/s to 16.25 m/s.

The resulting bin count histograms are presented in fig. A.3. The bin-wise comparisons for each measurement height, are presented in figs. 4.4 to 4.6. The results of the regressions are summarised in table 4.1. The uncertainty intervals shown in these figures are discussed in section 6.2.

Table 4.1: Lidar verification IEC 61400-50-2 results

height	slope	offset	R^2
m	–	m/s	–
117.5	1.008	-0.101	1.000
81.4	1.001	-0.080	1.000
41.9	0.992	0.027	1.000

4.3 Systematic uncertainties

The results of the systematic uncertainty analysis, as described in section 6.2, are presented for each comparison height in tables 4.2 to 4.4. The tables are modelled after table 11 [1]. The total lidar uncertainty is reported in column ' V_{rsd} uncertainty'.

If there are fewer than three data sets in any bin, all statistics (mean and standard deviation) and derived properties are omitted from the table.

4.4 Environmental conditions

The uncertainty computation for the lidar as part of a future campaign requires the environmental conditions experienced during the lidar verification test [1, clause 11.1, item i].

The conditions at each comparison height are defined in chapter 5 and reported in tables 4.5 to 4.7. The environmental data is subject to the same filtering steps as the (wind speed) data used for the verification analysis. The environmental data is binned against the reference wind speed¹.

¹For the reference wind speed the bin centre is reported, because each environmental condition may have a slightly different bin-wise mean wind speed depending on the availability of environmental data.

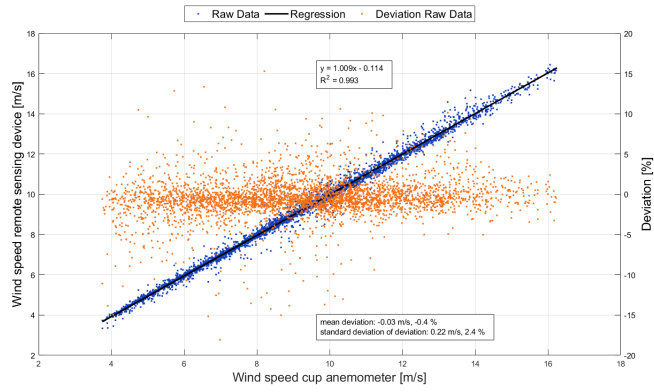


Figure 4.1: Wind speed comparison @117.5 m

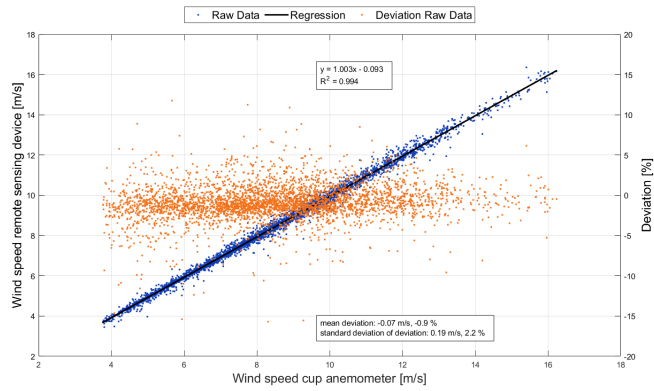


Figure 4.2: Wind speed comparison @81.4 m

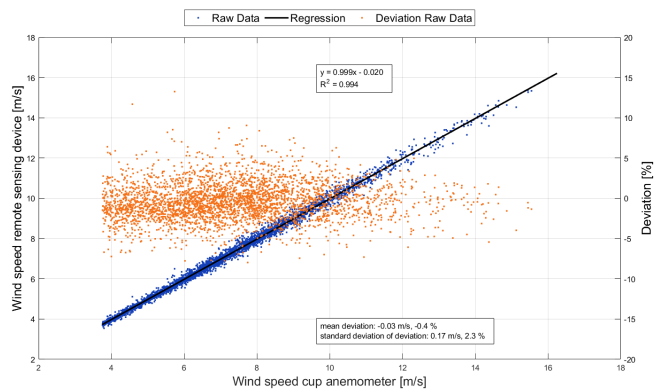


Figure 4.3: Wind speed comparison @41.9 m

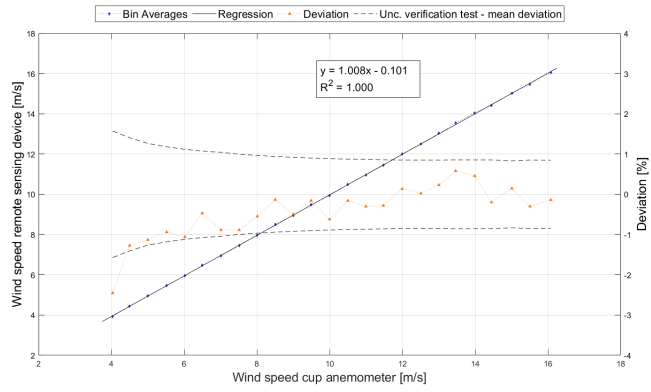


Figure 4.4: Bin-wise wind speed comparison @117.5 m

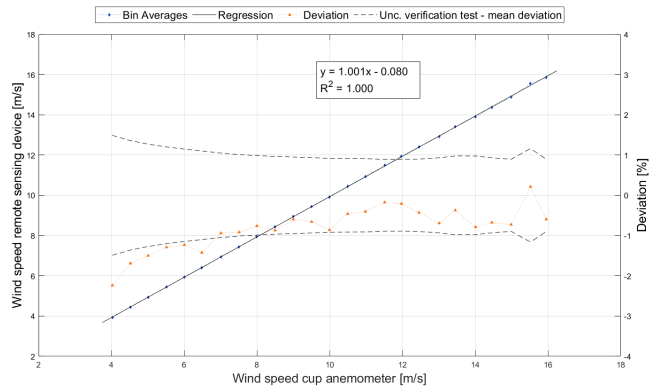


Figure 4.5: Bin-wise wind speed comparison @81.4 m

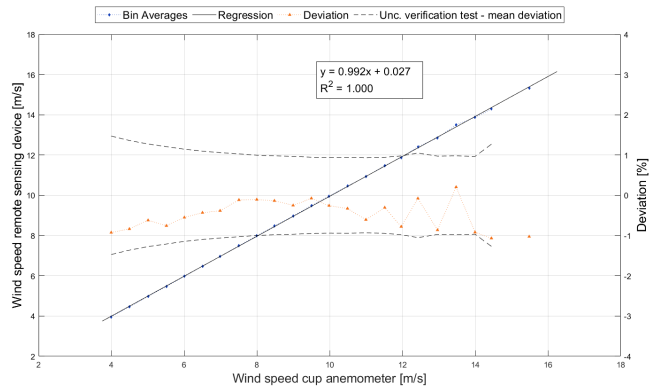


Figure 4.6: Bin-wise wind speed comparison @41.9 m

Table 4.2: Uncertainty calculations for the floating lidar system at 118 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	$dev \frac{std}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.03	3.93	48	4.22	3.34	0.202	0.029	-2.455	1.379	0.10	2.915
4.50	4.44	83	5.24	3.82	0.223	0.024	-1.275	1.278	0.10	1.898
5.00	4.94	120	5.52	4.40	0.194	0.018	-1.130	1.192	0.10	1.695
5.52	5.47	145	6.46	4.95	0.200	0.017	-0.938	1.121	0.10	1.509
6.02	5.95	150	6.41	5.28	0.190	0.016	-1.062	1.065	0.10	1.542
6.50	6.47	179	7.42	5.65	0.214	0.016	-0.469	1.021	0.10	1.172
7.01	6.95	185	7.89	5.72	0.262	0.019	-0.886	0.981	0.10	1.369
7.51	7.45	192	8.05	6.80	0.223	0.016	-0.888	0.947	0.10	1.334
8.01	7.97	232	9.46	6.78	0.243	0.016	-0.549	0.918	0.10	1.110
8.51	8.49	257	9.41	7.19	0.262	0.016	-0.134	0.893	0.10	0.949
9.01	8.96	238	9.80	7.66	0.279	0.018	-0.497	0.870	0.10	1.046
9.49	9.48	265	10.56	8.28	0.270	0.017	-0.159	0.855	0.10	0.915
10.00	9.94	285	10.72	8.51	0.288	0.017	-0.618	0.841	0.10	1.081
10.50	10.48	272	11.54	9.02	0.269	0.016	-0.159	0.829	0.10	0.887
10.99	10.96	196	12.29	10.17	0.284	0.020	-0.302	0.818	0.10	0.919
11.48	11.44	174	12.59	10.86	0.261	0.020	-0.282	0.809	0.10	0.902
11.99	12.01	162	12.97	11.51	0.274	0.022	0.136	0.801	0.10	0.861
12.51	12.51	119	13.51	11.97	0.286	0.026	0.023	0.793	0.10	0.851
13.00	13.03	128	14.59	12.47	0.342	0.030	0.231	0.786	0.10	0.880
13.46	13.54	84	14.78	12.61	0.337	0.037	0.582	0.780	0.10	1.035
13.99	14.05	67	15.16	13.45	0.329	0.040	0.458	0.773	0.10	0.969
14.45	14.42	45	15.00	13.92	0.292	0.044	-0.197	0.767	0.10	0.877
15.01	15.03	33	15.50	14.55	0.216	0.038	0.149	0.761	0.10	0.845
15.51	15.46	24	15.93	14.96	0.241	0.049	-0.300	0.756	0.10	0.901
16.08	16.06	16	16.44	15.65	0.205	0.051	-0.139	0.751	0.10	0.857

Table 4.3: Uncertainty calculations for the floating lidar system at 81 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	$dev \frac{std}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.03	3.94	68	4.46	3.45	0.181	0.022	-2.239	1.368	0.10	2.689
4.53	4.45	117	5.13	3.80	0.192	0.018	-1.689	1.282	0.10	2.168
5.01	4.94	163	5.52	3.97	0.214	0.017	-1.498	1.205	0.10	1.964
5.52	5.45	178	6.33	5.01	0.201	0.015	-1.290	1.149	0.10	1.763
6.01	5.93	172	6.52	5.02	0.204	0.016	-1.232	1.096	0.10	1.684
6.49	6.40	178	6.92	5.49	0.207	0.016	-1.424	1.051	0.10	1.800
7.01	6.95	236	7.52	6.22	0.205	0.013	-0.940	1.008	0.10	1.409
7.51	7.44	291	8.62	6.98	0.199	0.012	-0.917	0.973	0.10	1.365
8.00	7.94	300	8.75	7.14	0.214	0.012	-0.762	0.950	0.10	1.248
8.50	8.43	283	9.08	7.00	0.236	0.014	-0.870	0.924	0.10	1.299
9.00	8.95	301	10.04	8.06	0.242	0.014	-0.597	0.912	0.10	1.124
9.51	9.44	275	10.15	7.84	0.258	0.016	-0.657	0.894	0.10	1.144
10.00	9.91	227	10.63	9.24	0.237	0.016	-0.860	0.877	0.10	1.259
10.49	10.45	178	11.01	9.46	0.254	0.019	-0.460	0.868	0.10	1.024
10.99	10.94	148	11.93	10.38	0.275	0.023	-0.403	0.858	0.10	0.996
11.51	11.49	128	12.27	10.83	0.273	0.024	-0.173	0.839	0.10	0.909
11.97	11.95	113	12.69	11.04	0.266	0.025	-0.210	0.836	0.10	0.915
12.46	12.40	88	12.96	11.64	0.278	0.030	-0.430	0.839	0.10	0.998
13.01	12.92	66	13.47	11.74	0.361	0.044	-0.694	0.839	0.10	1.162
13.45	13.40	33	14.00	12.38	0.338	0.059	-0.372	0.846	0.10	1.047
14.01	13.90	19	14.44	13.05	0.282	0.065	-0.789	0.831	0.10	1.255
14.46	14.36	22	14.90	13.88	0.267	0.057	-0.675	0.814	0.10	1.151
14.99	14.88	15	15.17	14.43	0.205	0.053	-0.728	0.793	0.10	1.154
15.52	15.56	12	16.36	14.78	0.444	0.128	0.214	0.788	0.10	1.182
15.95	15.86	16	16.17	15.13	0.269	0.067	-0.596	0.760	0.10	1.078

Table 4.4: Uncertainty calculations for the floating lidar system at 42 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	$dev \frac{std}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.00	3.96	178	4.40	3.54	0.160	0.012	-0.925	1.423	0.10	1.738
4.49	4.46	222	5.11	3.97	0.179	0.012	-0.836	1.317	0.10	1.599
5.01	4.98	200	5.54	4.54	0.184	0.013	-0.619	1.227	0.10	1.416
5.51	5.47	221	6.50	5.04	0.211	0.014	-0.757	1.161	0.10	1.427
6.01	5.97	282	6.49	5.42	0.203	0.012	-0.550	1.104	0.10	1.270
6.50	6.48	316	7.05	6.02	0.205	0.012	-0.432	1.059	0.10	1.179
6.99	6.96	290	7.87	6.38	0.213	0.012	-0.383	1.022	0.10	1.128
7.51	7.50	285	8.41	6.93	0.248	0.015	-0.115	0.986	0.10	1.036
8.00	7.99	303	8.77	7.44	0.230	0.013	-0.105	0.957	0.10	1.002
8.48	8.47	243	9.11	7.86	0.242	0.016	-0.136	0.937	0.10	0.990
9.00	8.97	179	9.69	8.31	0.258	0.019	-0.251	0.917	0.10	1.000
9.50	9.49	157	10.13	8.86	0.249	0.020	-0.075	0.896	0.10	0.950
9.98	9.96	138	10.82	9.16	0.279	0.024	-0.257	0.882	0.10	0.975
10.49	10.46	95	10.97	9.69	0.267	0.027	-0.329	0.878	0.10	0.999
11.00	10.93	73	11.55	10.14	0.247	0.029	-0.607	0.866	0.10	1.112
11.51	11.48	57	12.04	10.89	0.271	0.036	-0.305	0.863	0.10	0.993
11.97	11.87	36	12.60	11.36	0.294	0.049	-0.779	0.860	0.10	1.251
12.43	12.42	18	12.98	11.81	0.302	0.071	-0.078	0.852	0.10	1.054
12.96	12.85	26	13.40	12.27	0.297	0.058	-0.862	0.834	0.10	1.300
13.48	13.50	16	13.85	12.73	0.271	0.068	0.205	0.812	0.10	1.002
14.00	13.87	15	14.20	13.15	0.272	0.070	-0.919	0.796	0.10	1.333
14.45	14.29	9	14.85	13.60	0.398	0.133	-1.068	0.849	0.10	1.659
		2	14.64	14.53						
15.48	15.33	3	15.37	15.27	0.050	0.029	-1.026	0.797	0.10	1.331
		0								

Table 4.5: Environmental conditions at 118 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	#	%	%	°	°C	%	kg/m ³	°	°/m
4.000	0.0901	7.86	3.69	222.8	5.23	88.99	1.250	1.064	0.1583
4.500	0.1553	9.33	3.83	229.6	5.81	84.91	1.249	1.217	0.1763
5.000	0.1983	8.37	2.77	237.3	5.97	86.17	1.246	1.309	0.1821
5.500	0.2661	7.96	2.78	246.2	6.61	86.79	1.247	1.132	0.1606
6.000	0.3025	7.71	4.85	242.3	6.36	86.86	1.248	1.019	0.1818
6.500	0.3033	7.11	3.77	252.4	6.68	86.14	1.247	1.224	0.1619
7.000	0.2703	6.97	3.21	226.1	6.07	87.19	1.248	0.946	0.1429
7.500	0.2796	6.95	5.66	227.8	5.95	87.99	1.244	1.123	0.1699
8.000	0.2837	6.70	7.46	227.6	6.65	88.96	1.243	1.154	0.1527
8.500	0.2716	7.37	8.54	223.9	7.01	91.85	1.238	1.105	0.1112
9.000	0.2809	7.46	5.25	227.1	6.48	89.54	1.240	1.224	0.1013
9.500	0.2768	7.52	7.76	226.3	6.88	90.33	1.239	1.202	0.0905
10.000	0.2708	7.93	6.63	222.9	7.02	90.24	1.236	1.118	0.0712
10.500	0.2718	7.65	6.79	215.3	7.39	91.01	1.235	1.100	0.0695
11.000	0.2709	7.64	7.83	212.0	6.95	90.93	1.238	1.104	0.0651
11.500	0.2655	7.86	8.55	218.4	6.89	89.52	1.238	1.181	0.0582
12.000	0.2588	8.11	10.48	219.4	7.12	87.85	1.237	1.157	0.0505
12.500	0.2458	8.64	8.26	223.9	7.81	87.53	1.233	1.162	0.0463
13.000	0.2466	8.76	11.87	231.3	7.95	88.59	1.229	1.251	0.0425
13.500	0.2359	8.96	9.01	245.7	6.89	85.88	1.231	1.361	0.0369
14.000	0.2253	9.43	15.15	251.1	5.76	84.25	1.235	1.361	0.0330
14.500	0.2187	9.97	12.18	258.0	5.95	82.26	1.233	1.469	0.0310
15.000	0.2177	10.89	18.07	257.5	7.31	81.64	1.225	1.401	0.0342
15.500	0.2045	10.03	26.73	260.6	7.03	82.66	1.227	1.345	0.0305
16.000	0.2014	9.87	21.92	241.3	9.78	82.82	1.215	1.385	0.0337

Table 4.6: Environmental conditions at 81 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	#	%	%	°	°C	%	kg/m ³	°	°/m
4.000	0.1902	8.87	3.46	230.8	5.30	87.83	1.250	0.926	0.1693
4.500	0.2768	9.47	3.98	249.4	5.95	85.02	1.249	1.292	0.1619
5.000	0.2800	9.01	3.10	250.7	6.15	84.57	1.249	1.223	0.1534
5.500	0.2835	8.24	4.65	253.3	6.42	86.30	1.248	1.126	0.1589
6.000	0.2839	7.80	3.51	241.9	6.53	85.88	1.248	1.181	0.1611
6.500	0.2565	8.12	6.00	231.0	5.98	85.59	1.246	1.015	0.1696
7.000	0.2775	7.82	5.90	225.5	6.45	88.53	1.244	0.969	0.1499
7.500	0.2803	7.67	7.70	221.4	6.90	90.17	1.239	1.101	0.1417
8.000	0.2772	8.20	5.05	225.1	6.48	89.79	1.240	1.171	0.1055
8.500	0.2756	8.52	8.61	224.8	6.87	90.56	1.238	1.206	0.0903
9.000	0.2607	9.03	6.17	220.5	6.91	89.87	1.238	1.161	0.0655
9.500	0.2554	8.87	6.88	213.6	7.49	90.70	1.235	1.056	0.0641
10.000	0.2579	8.89	6.70	212.5	7.18	90.62	1.237	1.046	0.0607
10.500	0.2490	9.35	9.59	213.9	6.92	90.00	1.238	1.124	0.0526
11.000	0.2423	9.64	10.76	219.2	7.04	85.67	1.238	1.100	0.0433
11.500	0.2456	10.01	10.59	230.7	7.84	88.06	1.230	1.227	0.0440
12.000	0.2364	10.14	7.13	236.0	7.45	86.94	1.231	1.244	0.0378
12.500	0.2244	10.88	10.31	245.2	7.05	85.82	1.230	1.313	0.0348
13.000	0.2103	11.16	15.57	246.7	6.30	84.44	1.234	1.442	0.0300
13.500	0.2111	12.16	25.75	259.9	6.00	83.00	1.231	1.428	0.0341
14.000	0.2048	11.81	23.76	259.2	6.45	83.92	1.230	1.314	0.0325
14.500	0.1948	11.40	26.03	253.3	8.04	82.37	1.223	1.372	0.0316
15.000	0.1921	11.47	20.76	246.7	9.37	82.66	1.216	1.323	0.0270
15.500	0.2112	11.30	14.09	237.2	9.94	82.23	1.214	1.438	0.0314
16.000	0.2029	10.73	7.63	241.9	10.93	84.21	1.209	1.472	0.0235

Table 4.7: Environmental conditions at 42 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	#	%	%	°	°C	%	kg/m ³	°	°/m
4.000	0.2609	9.78	1.79	253.8	5.98	84.29	1.252	1.217	0.1488
4.500	0.2616	9.64	4.44	251.7	6.35	85.08	1.249	1.409	0.1484
5.000	0.2800	9.39	2.63	233.4	6.22	85.86	1.251	1.108	0.1441
5.500	0.2796	9.57	4.71	230.6	6.23	86.36	1.247	1.105	0.1464
6.000	0.2822	9.36	8.75	222.7	6.44	88.16	1.243	1.129	0.1533
6.500	0.2797	10.14	5.93	220.0	6.63	88.74	1.240	1.176	0.1122
7.000	0.2638	10.52	7.63	220.7	6.63	89.82	1.240	1.148	0.0903
7.500	0.2509	11.21	6.74	219.7	7.27	90.24	1.237	1.173	0.0660
8.000	0.2475	11.27	6.80	215.7	7.69	90.32	1.234	1.095	0.0590
8.500	0.2341	11.65	6.87	211.5	7.39	91.41	1.236	1.044	0.0481
9.000	0.2370	11.74	9.58	212.4	7.09	89.62	1.238	1.091	0.0456
9.500	0.2351	11.89	9.53	223.5	7.24	87.19	1.235	1.159	0.0408
10.000	0.2294	12.15	10.28	228.4	7.52	86.55	1.233	1.193	0.0392
10.500	0.2305	12.83	13.72	240.8	7.09	86.43	1.231	1.262	0.0362
11.000	0.2081	12.24	6.58	240.5	6.89	85.17	1.233	1.312	0.0302
11.500	0.2073	12.98	21.83	247.9	6.30	84.90	1.233	1.420	0.0312
12.000	0.1992	12.50	15.39	254.9	5.80	83.36	1.234	1.483	0.0307
12.500	0.1914	14.70	24.84	256.2	6.44	82.99	1.231	1.395	0.0357
13.000	0.1981	13.62	24.70	246.9	8.21	83.65	1.221	1.316	0.0355
13.500	0.2054	12.50	19.43	241.6	10.11	82.03	1.213	1.405	0.0232
14.000	0.1906	13.06	8.19	239.8	10.86	85.21	1.209	1.432	0.0254
14.500	0.1871	13.88	28.46	275.3	6.46	79.84	1.225	1.537	0.0229
15.000									
15.500	0.1826	14.05	15.78	254.4	9.76	84.52	1.211	1.211	0.0185
16.000									

5 Sensitivities

This chapter investigates the sensitivity of the lidar measurement for various environmental variables (EVs). The sensitivity analysis is performed in accordance with the classification analysis specified in clause 6 [1]. However, for this analysis we use the same dataset as for the verification analysis. As a result the wind speed range is restricted to 3.75 m/s to 16.25 m/s.

5.1 Sensitivity analysis

The basis of this analysis is the deviation between the wind speeds measured by the ref, v_{ref} , and the rsd, v_{rsd} . The deviation is defined in eq. (5.1). Subsequently the sensitivity of this deviation is tested against various EVs. The list of variables is based on table 4 [1]. The variables considered are described below.

$$\text{deviation} = \frac{v_{ref} - v_{rsd}}{v_{rsd}} \quad (5.1)$$

Unless stated otherwise the EVs are height-independent, meaning the same value was used for the sensitivity analysis at each comparison height.

1. Shear exponent [-]

The shear exponent, α , is computed by fitting a power law wind shear model through the v_{ref} measurements at 41.9 m, 81.4 m and 117.5 m. For the wind shear, the top cup measurement is combined with the mast flow distortion corrected [5] signals for the boom mounted cup measuring heights 41.9 m and 81.4 m. This way the measurements at all heights are effectively undisturbed. The power law is defined by

$$\frac{v_{ref}}{v_r} = \left(\frac{h}{h_r} \right)^\alpha \quad (5.2)$$

2. Reference turbulence intensity [-]

The reference turbulence intensity, measured on the meteorological mast, is defined by

$$\text{reference turbulence intensity} = \frac{\text{std}(v_{ref})}{\text{mean}(v_{ref})} \cdot 100 \% \quad (5.3)$$

This variable is height-dependent.

3. Precipitation [%]

The rain sensor returns a 0 % to 100 % signal indicating the amount of time precipitation was detected in the 10-minute interval. The precipitation is measured at 40 m.

4. Reference wind direction [°]

The wind direction, as measured on the meteorological mast, is height-dependent.

5. Air temperature [°C]

The air temperature is measured at 109 m.

6. Relative humidity [%RH]

The relative humidity is measured at 109 m. (The relative humidity was added to the list of EVs, because it is used in the MEASNET icing criterion in chapter 3.)

7. **Air density [kg/m³]**

The air density is computed from the air pressure, air temperature and relative humidity, all measured at 109 m, in accordance with equation (12) of IEC 61400-12-1:2022.

8. **Flow inclination [°]**

The flow inclination is defined as

$$\text{flow inclination} = \arctan \left(\frac{v_{\text{vert}}}{v_{\text{hor}}} \right) \quad (5.4)$$

The horizontal (v_{hor}) and vertical (v_{vert}) wind speed components are measured by a sonic anemometer at a height of 108.5 m.

9. **Wind veer [°/m]**

The wind veer is computed as the difference between the wind direction measurements by meteorological mast at 37.9 m and 112.5 m, divided by the height difference. This definition was taken from IEC 61400-12-1:2022.

$$\text{wind veer} = \frac{w_{d,112.5} - w_{d,37.9}}{112.5 - 37.9} \quad (5.5)$$

10. **Reference wind speed [m/s]**

This wind speed, as measured on the meteorological mast, is height-dependent.

The sensitivity analysis leads to the results presented in table 5.2, which is presented in the same format as table 4 [1]. In this table column ‘ m ’ represents the slope of the two-parameter regression of the bin-wise averaged data. Column ‘ r^2 ’ represents the correlation coefficient of the two-parameter regression of the scatter data.

For the computation of the bin-wise averages, only those bins are included that meet the following bin-count requirement, stipulated by the criterion in eq. (5.6) [1, eq. 3]. When the reference wind speed is used as the EV, also the criterion in equation (4) needs to be applied.

$$n_i > \frac{N}{2 \cdot n_b} \quad (5.6)$$

The sensitivity, presented in column ‘sens.’, is defined by

$$\text{sensitivity} = m \cdot \text{std} \quad (5.7)$$

where ‘std’ is the standard deviation of the EV data.

The sensitivity of the lidar for an EV is considered as significant if either the sensitivity exceeds a value of 0.5, or the product of sensitivity and r exceeds 0.1. In table 5.2, the sensitivity criteria that exceed their threshold value are highlighted in orange. In case a significant sensitivity for an EV is observed for at least one comparison height, that EV must be considered as significant for all comparison heights. Table 5.1 shows that no environmental variable results in a significant sensitivity. The distribution of the environmental variables is shown in table 5.4.

5.2 Impact on accuracy

The basis for the accuracy class is the product of m , as already presented in table 5.2, and the range of the EV. Although our interest is not in determining the accuracy class, we are

Table 5.1: Overview of significant sensitivities, '-' means the environmental variable is not significant.

environmental variable	comparison height			overall
	117.5m	81.4m	41.9m	
shear exponent	-	-	-	-
turbulence intensity	-	-	-	-
precipitation	-	-	-	-
wind direction	-	-	-	-
air temperature	-	-	-	-
relative humidity	-	-	-	-
air density	-	-	-	-
flow inclination	-	-	-	-
wind veer	-	-	-	-
reference wind speed	-	-	-	-

interested in the effect of the significant sensitivities. However, as presented in section 5.1, no significant sensitivities are found. The EV ranges are largely prescribed by table 5 [1]. The results are presented in table 5.3, which is presented in a similar format as table 8 [1].

The range is a defined quantity, presented in the column 'range' of table 5.3. The IEC 61400-50-2 standard defines the measured range of variation through the ratio of bins that meet the criterion in eq. (5.6). The result is presented in the column 'covered range'. The measured range of variation is considered sufficient if the covered range is at least 25 %.

For the relative humidity no range is prescribed; we used 0 % to 100 %.

The EV air density, for all heights, does not meet the range requirement. This is caused by the limited variation of air density at the site with respect to the prescribed range.

Table 5.2: Sensitivity to environmental variables for the lidar

variable	unit	height	avg	std	<i>m</i>	sens.	<i>R</i> ²	sens. × <i>R</i>
		m	unit	unit	%/unit	%	-	%
shear exponent		41.9	0.26	0.07	-0.274	-0.020	0.000	0.000
		81.4	0.26	0.08	0.211	0.017	0.000	0.000
		117.5	0.27	0.08	-0.054	-0.004	0.001	0.000
turbulence intensity	%	41.9	10.54	2.41	0.136	0.328	0.022	0.049
		81.4	8.71	2.60	0.099	0.257	0.016	0.032
		117.5	7.75	2.43	0.029	0.071	0.004	0.005
precipitation†	%	41.9	7.48	23.05	0.004	0.101	0.001	0.003
		81.4	7.37	22.95	0.003	0.071	0.001	0.002
		117.5	7.30	22.88	0.012	0.268	0.012	0.030
wind direction	°	41.9	224.22	41.11	-0.004	-0.157	0.017	-0.021
		81.4	226.31	43.67	0.002	0.067	0.001	0.002
		117.5	228.02	42.96	0.001	0.038	0.001	0.001
air temperature	°C	41.9	7.01	2.65	0.049	0.129	0.004	0.008
		81.4	6.82	2.48	0.026	0.064	0.003	0.003
		117.5	6.83	2.49	0.078	0.194	0.011	0.020
relative humidity	%	41.9	85.91	9.07	0.014	0.124	0.007	0.010
		81.4	86.11	9.00	-0.020	-0.177	0.002	-0.007
		117.5	86.32	8.91	-0.012	-0.106	0.001	-0.002
air density	kg/m ³	41.9	1.24	0.02	-8.209	-0.141	0.005	-0.010
		81.4	1.24	0.02	-9.767	-0.167	0.011	-0.018
		117.5	1.24	0.02	-15.582	-0.263	0.024	-0.041
flow inclination	°	41.9	1.15	0.42	-0.266	-0.111	0.004	-0.007
		81.4	1.16	0.42	0.379	0.159	0.002	0.007
		117.5	1.17	0.42	0.398	0.167	0.001	0.006
wind veer	°/m	41.9	0.07	0.04	-3.685	-0.161	0.006	-0.012
		81.4	0.07	0.05	-2.825	-0.150	0.006	-0.011
		117.5	0.08	0.05	-4.768	-0.256	0.011	-0.027
reference wind speed	m/s	41.9	7.10	1.84	0.083	0.154	0.009	0.014
		81.4	8.34	2.07	0.172	0.355	0.026	0.057
		117.5	8.94	2.25	0.154	0.346	0.018	0.047

- › The sensitivity, computed as $m \times \text{std}$, is reported in column 'sens.'.
- › The values for 'avg', 'std' and R^2 are derived from a regression of the 10-minute data contained in the bins that have a statistically significant bin-count, while m is the slope derived from a regression of the bin-wise mean values [1, p.18-19]. (As a result, no slope - and by extension no sensitivity - can be computed for variables that only yield a single bin with a significant bin-count.)
- › An environmental variable is considered significant if either the sensitivity exceeds the value of 0.5 %, or the product of the sensitivity and the correlation coefficient of the regression (sensitivity × R), reported in the ultimate column, exceeds the value of 0.1 % [1, Clause 6.5]. The numbers in these columns are highlighted in orange if they cause the variable to be considered significant, otherwise they are blue.
- † This variable employs a modified bin-count criterion [1, eq. 3, p.18]. In order to allow for a sensitivity analysis, the number of data points (N) is reduced to those data points that have a non-zero value.

Table 5.3: Maximum influence of environmental variables on the lidar wind speed

variable	unit	min	max	bin	range	height	covered	$m \times \text{range}$
		unit	unit	unit	unit	m	%	%
shear exponent		-0.4	0.8	0.05	1.2	41.9	29	-0.329
						81.4	33	0.254
						117.5	33	-0.064
turbulence intensity	%	3	24	1	21	41.9	52	2.857
						81.4	52	2.080
						117.5	48	0.610
precipitation	%	0	100	10	100	41.9	100	0.440
						81.4	100	0.308
						117.5	100	1.173
wind direction	°	0	360	5	180	41.9	39	-0.687
						81.4	43	0.276
						117.5	44	0.158
air temperature	°C	0	40	2	40	41.9	30	1.945
						81.4	25	1.031
						117.5	25	3.130
relative humidity	%	0	100	10	100	41.9	40	1.369
						81.4	40	-1.971
						117.5	40	-1.187
air density	kg/m ³	0.9	1.35	0.05	0.45	41.9	22	-3.694
						81.4	22	-4.395
						117.5	22	-7.012
flow inclination	°	-3	3	0.2	6	41.9	33	-1.598
						81.4	33	2.274
						117.5	33	2.387
wind veer	°/m	-0.1	0.3	0.04	0.4	41.9	50	-1.474
						81.4	60	-1.130
						117.5	60	-1.907
reference wind speed	m/s	3.75	16.25	0.5	12	41.9	60	1.001
						81.4	68	2.060
						117.5	72	1.847

- › The columns 'min', 'max' and 'bin' report the minimum and maximum value of the binning interval [1, Table 5, p.21], and the bin width [1, Table 3, p.18], used for the regression. The 'range' columns reports the expected natural range of variation for each environmental variable.
- › The column 'covered' reports the percentage of the range that was covered by bins that meet the bin-count criteria of equations (3) and (4) [1, p.18-19]. If the covered range is less than 25 %, the sensitivity results for this environmental variable are considered unrepresentative. Unrepresentative covered ranges are highlighted in orange, otherwise they are blue.
- › The product of m , the slope of the regression reported in table 5.2, and the full range of variation, reported in the ultimate column, represents the maximum influence an environmental variable can have on the uncertainty of the horizontal wind speed. Note that this result is highly dependent on the chosen range value, which may be far greater than the variations actually observed during the campaign.

Table 5.4: Distribution of environmental variables used in the floating lidar sensitivity study

variable	unit	height	min	P10	median	P90	max
		m	unit	unit	unit	unit	unit
shear exponent		41.9	-0.57	0.15	0.25	0.38	0.78
		81.4	-0.21	0.15	0.25	0.39	0.94
		117.5	-0.26	0.15	0.26	0.39	0.94
turbulence intensity	%	41.9	2.21	6.84	11.00	13.95	37.05
		81.4	1.84	4.42	8.95	12.61	32.74
		117.5	1.55	3.66	7.77	11.49	36.50
precipitation	%	41.9	0.00	0.00	0.00	22.46	100.00
		81.4	0.00	0.00	0.00	20.27	100.00
		117.5	0.00	0.00	0.00	19.71	100.00
air temperature	°C	41.9	-1.36	3.36	6.89	10.50	13.43
		81.4	-1.26	3.38	6.81	10.41	13.43
		117.5	-1.26	3.36	6.81	10.28	13.43
relative humidity	%	41.9	46.76	73.65	89.32	101.39	104.72
		81.4	46.76	74.17	89.53	101.42	104.72
		117.5	46.76	74.43	89.73	101.44	104.72
air density	kg/m ³	41.9	1.20	1.22	1.24	1.27	1.29
		81.4	1.20	1.22	1.24	1.27	1.29
		117.5	1.20	1.22	1.24	1.27	1.29
flow inclination	°	41.9	-2.75	0.49	1.13	1.92	5.60
		81.4	-2.75	0.44	1.13	1.93	5.60
		117.5	-1.78	0.46	1.15	1.95	8.68
wind veer	°/m	41.9	-0.24	0.02	0.06	0.21	0.73
		81.4	-0.18	0.02	0.07	0.23	0.72
		117.5	-0.22	0.02	0.07	0.24	0.72
reference wind speed	m/s	41.9	3.76	4.59	7.17	10.31	15.55
		81.4	3.77	5.29	8.45	11.84	16.24
		117.5	3.75	5.67	9.28	12.87	16.23

- › The 10th and 90th percentiles are indicated by P10 and P90. The minimum, median and maximum values represent P0, P50 and P100. These percentiles indicate below what value 0%, 10%, 50%, 90% and 100% of the data is found.
- › The filters described in section 3.1 are also applied to all EVs. Therefore, the EV ranges reported here are limited to the conditions during the lidar measurements that were actually used in the sensitivity analysis.
- › All directional quantities have been omitted from this table, because percentiles are undefined.

6 Uncertainty

This chapter describes the uncertainty contributions to the horizontal wind speed measurement that were taken into account. These uncertainties are the basis for the lidar verification analysis reported in chapter 4. The uncertainty analysis is performed for application in the verification analysis only, therefore the uncertainty analysis is limited to the (horizontal) wind speed measurements.

All uncertainties are reported with a coverage factor of one ($k = 1$). To obtain uncertainties for $k = 2$ the results have to be doubled.

6.1 Reference devices - cup anemometers

The following contributions to the systematic uncertainty of the cup anemometers are taken into account in accordance with clause 8.2 [1].

1. Wind tunnel calibration

The wind tunnel uncertainty, with a coverage factor of two ($k = 2$), is found in the wind tunnel calibration reports, see section C.1. The standard uncertainty ($k = 1$) is therefore the reported uncertainty divided by two.

2. Effects according to anemometer classification

The classification of the Thies First Class Advanced cup anemometer is 0.9S (heating on), see section C.2 for the classification results according the IEC 61400-50-1:2022 [6]. The uncertainty in the wind speed due to operational characteristics therefore is

$$u_{VS,class,i} = [0.5\% + 0.05 \text{ m/s}] \cdot \frac{0.9}{\sqrt{3}}$$

3. Mounting effects

The default values for the uncertainty associated with the mounting of the anemometer on mast are specified in clause 11.3.5 [6, p.59]. At the height of 117.5 m a top mounted anemometers is used, for which the default uncertainty is

$$u_{VS,mnt,i} = 0.5\%.$$

At all other comparison heights, side-mounted anemometers are used. Normally this results in a 1.5% mounting uncertainty, however for the verification the ‘true wind speed’ pseudo signals are used which make use of mast flow corrected wind speed signals. For flow corrected wind speed signals the uncertainty is determined by the root-sum-square of half the mean correction applied to the wind speed signal and 0.5% of the measured signal. Wake sectors are excluded. So the uncertainty is at least 0.5%.

$$u_{VS,mnt,i} \geq 0.5\%.$$

4. Data acquisition

The cup is connected to a digital pulse counting module. The uncertainty of the module together with the anemometer calibration factors lead to the following uncertainty.

$$u_f = 0.1\% \cdot F + 0.5 \text{ Hz}.$$

Table C.3 shows that the gains of all Thies cup anemometers are close to 0.046 m/s/Hz. This results in an uncertainty of the wind speed of

$$u_{d,VS,i} = 0.1 \% + 0.023 \text{ m/s.}$$

The total systematic uncertainty of the reference sensor is obtained by adding all contributions in quadrature. As in IEC 61400-50-2, this is referred to as ‘reference type B’ uncertainty in fig. A.2.

6.2 Remote sensing device

The following contributions to the uncertainty of the lidar wind speed measurements are taken into account in accordance with clause 8.3 [1].

1. Systematic uncertainty of the reference sensor

This is the systematic uncertainty of the cup anemometer as defined in section 6.1.

2. Mean deviation

No correction of the lidar wind speed measurement is performed. Therefore, this contribution is defined as the bin-wise average deviation between the reference sensor and the lidar.

3. Standard uncertainty of the lidar measurements

The standard uncertainty is defined by eq. (6.1).

$$\text{standard uncertainty}_i = \frac{\sigma_{v_i}}{\sqrt{n_i}} \quad (6.1)$$

Where σ_{v_i} is the standard deviation of 10-minute average measurements in wind speed bin i and n_i is the bincount.

4. Mounting effects of the lidar

We are using the default magnitude stated in clause E.7.5 [7, p.74].

$$u_{VR,mnt,i} = 0.1 \%$$

The mounting uncertainty is reported in tables 4.2 to 4.4.

5. Non-homogeneous flow

The uncertainty due to non-homogeneous flow in the measurement volume of the lidar is estimated from a terrain flow assessment [8] based on the terrain information shown in fig. 2.2.

$$u_{VR,flow,i} = 0.2 \%$$

As the separation distance does not compromise the criteria as stated in clause 6.2, item d [1, p.14], no additional uncertainty contribution is taken into account.

The total lidar uncertainty is obtained by adding in quadrature the contributions above. The result is reported in the last column of tables 4.2 to 4.4. An overview of the various uncertainty contributions is presented in fig. A.2.

The uncertainty interval shown in figs. 4.4 to 4.6 is also obtained by adding in quadrature the contributions above, but with the exception of the mean deviation.

7 Deviations

The lidar verification as presented in chapter 4 is performed in accordance with IEC 61400-50-2:2022. No deviations are to be reported in this respect.

8 Conclusions

The Wind@Sea lidar ZX300M ZX6482 is verified against reference meteorological mast MM6 at the RSD verification location at the EWTW test site in the Wieringermeer. In this campaign the lidar is verified at three measurement heights ranging from 42 m to 117 m.

During the measurement campaign that ran from 20 November 2025 13:30 UTC until 16 January 2026 00:00, spanning 56 days, all data coverage requirements of the IEC 61400-50-2:2022 are met, except for two wind speed bins for the lowest measuring height, 42 m, for which the bin count is less than the minimum required bin count of 3.

For all comparison heights the regression slope is close to 1 and the offset is up to 0.10 m/s with an R^2 close to 1. The maximum deviation observed is 2.8 % and the uncertainty is 0.8 % to 2.9 %.

The sensitivity analysis did not result in any significant sensitivity for the lidar.

References

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- [5] P. Werff and G. Bergman. *Correction of the wind speed for flow distortion by the met mast*. TNO 2019 M10121. TNO, Nov. 2019.
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Signature

	Date: March 2026		Report number: TNO 2026 R10065
Title	Verification of the Wind@Sea lidar ZX6482 at the EWTW test site near meteorological mast MM6 Period: from 20 November 2025 to 16 January 2026		
Author(s)	G. Bergman		
Principal(s)	Ministry of Climate Policy and Green Growth		
Project number	060.63180		
Programme(s)	Wind Energy		
Abstract	As part of a lidar verification campaign a ZX Lidars lidar with serial number ZX6482 was deployed near MM6 at the EWTW test site in the Wieringermeer. This report describes the verification campaign for the lidar.		
Keywords	Wind@Sea, ZX300M, EWTW, MM6, lidar, verification		
Task	Name	Role	Signature
Author	G. Bergman	Data analyst	
Expert review	D.A.J. Wouters	Data analyst	
Generic review	M.F. van Dooren	Project manager	
Authorization	E.D. Nennie	Research manager	

Appendix A

IEC visualisations

This appendix contains visualizations associated with the IEC analysis reported in chapters 4 and 5 that are not a reporting requirement.

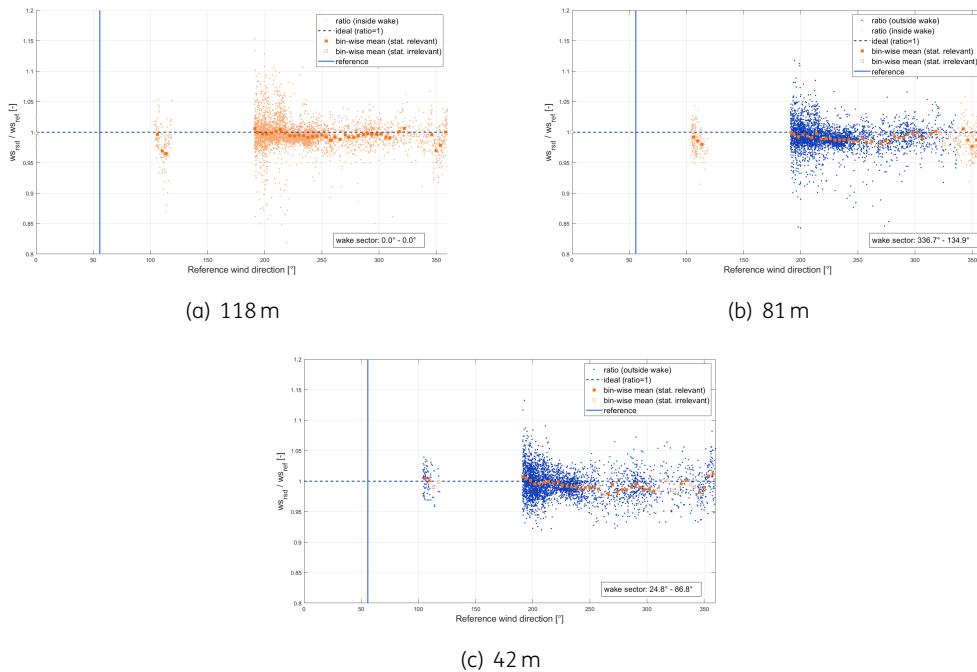


Figure A.1: Influence of the wake of meteorological mast on the lidar. The ratio of the wind speed measured by the lidar (rsd) and the reference meteorological mast $MM6$ (ref) is plotted against the wind direction measured by the reference meteorological mast. The blue line marks the direction for which the wind flows over the reference meteorological mast $MM6$ towards the lidar. The orange squares are the bin-wise average wind speed ratios; these are solid only if the respective bin contains a statistically significant number of data points.

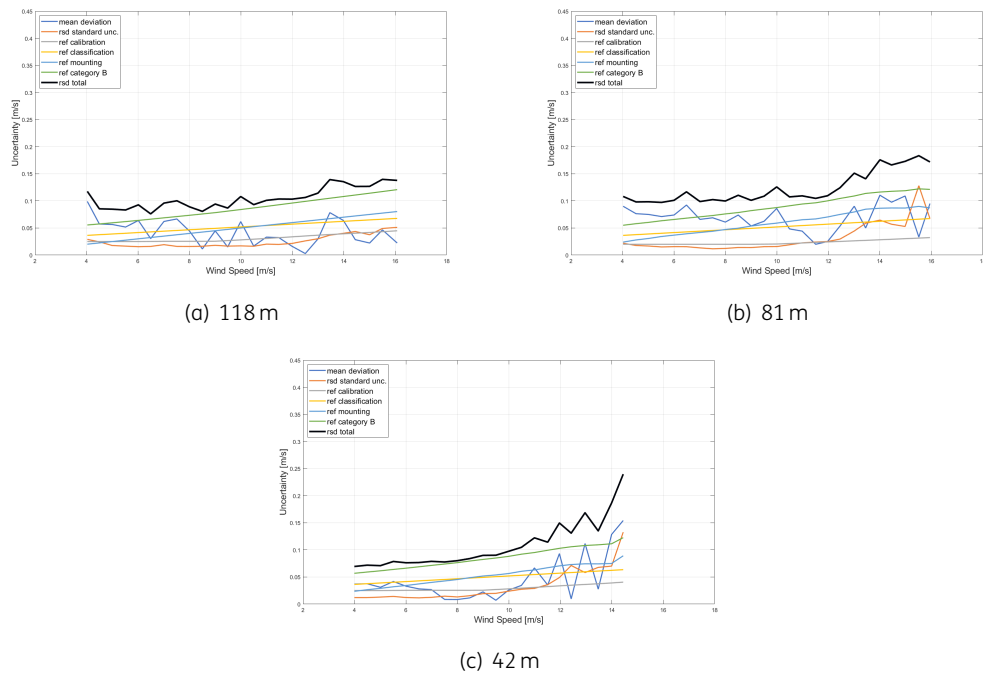


Figure A.2: Contributions to the lidar uncertainty

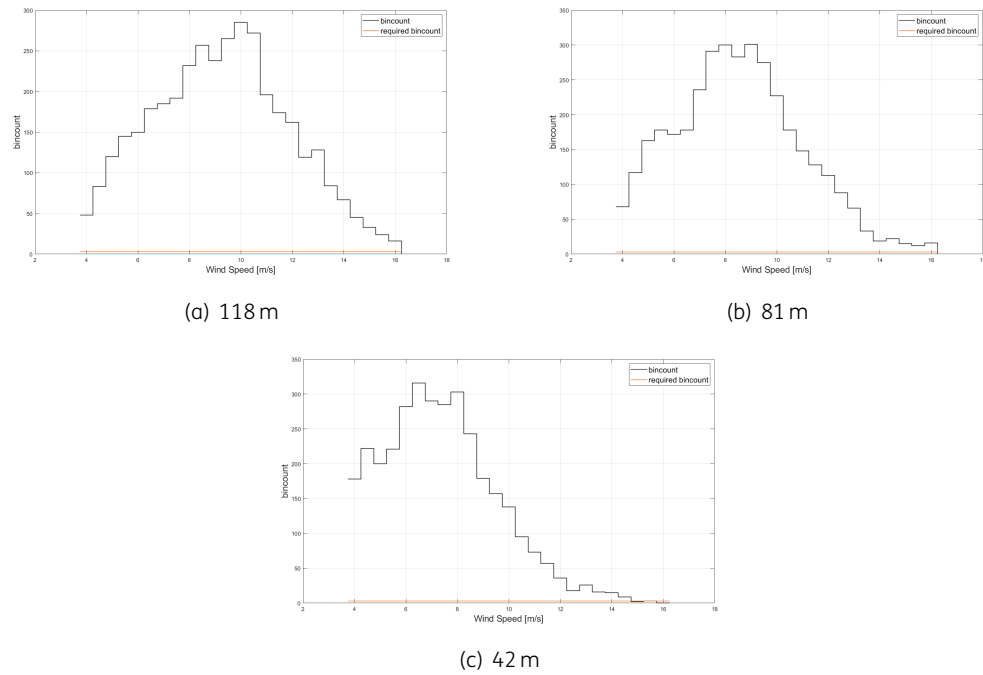
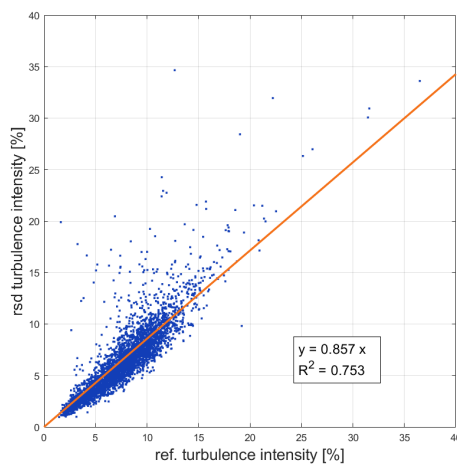


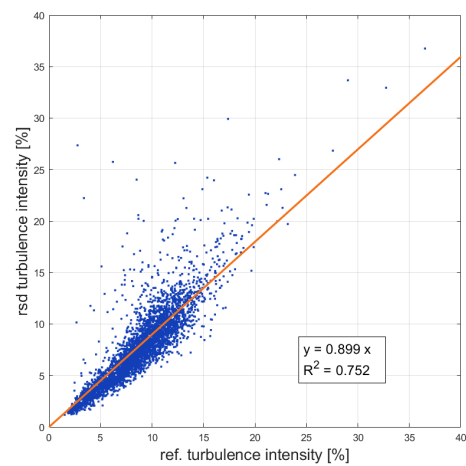
Figure A.3: Histograms for bin-wise wind speed comparison

Appendix B

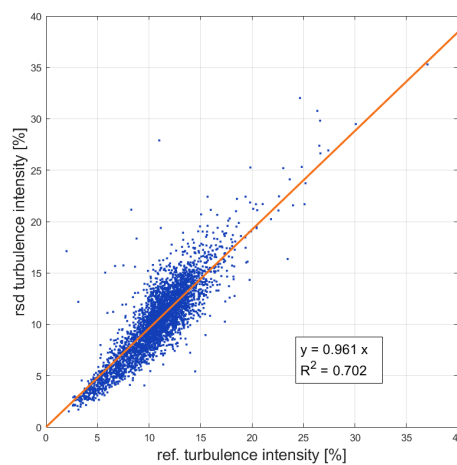
Turbulence intensity comparison



(a) 118m



(b) 81m



(c) 42m

Figure B.1: Turbulence intensity comparison

Appendix C

Instrumentation details

This appendix presents detailed information about the meteorological mast signals and sensors used. More detailed information about meteorological mast MM6 can be found in the meteorological mast instrumentation report [9].

At the meteorological mast measurement heights, as seen in fig. 2.7, the meteorological mast measurements are compared to the lidar measurements. Table C.1 lists these comparison heights and the wind speed and wind direction signals used from both the meteorological mast and the lidar. All of these signals are 10-minute average statistics.

Some of the statistics are directly derived from measured signals, presented in table C.2. Other statistics are based on pseudo signals, presented in table C.4, which are calculated signals.

The sensors used to measure these signals and the data acquisition modules they are attached to are listed in table C.3. This table also presents installation and calibration due dates.

Table C.1: Signals used for each comparison height

height (m)	met mast	lidar
	wind speed	
117.5	MM6_H117d5_Ws_Q1_avg	Horizontal Wind Speed (m/s) at 118m
81.4	MM6_H081d4_Ws_True_Q1_avg	Horizontal Wind Speed (m/s) at 81m
41.9	MM6_H041d9_Ws_True_Q1_avg	Horizontal Wind Speed (m/s) at 42m
	wind direction	
117.5	MM6_H112d5B320_Wd_Q1_avg	Wind Direction (deg) at 118m
81.4	MM6_H077d4B320_Wd_Q1_avg	Wind Direction (deg) at 81m
41.9	MM6_H037d9B320_Wd_Q1_avg	Wind Direction (deg) at 42m

Table C.2: List of measured signals

name	location	short name	sensor	unit	installed	rate	ISO
wind speed, 117.5 m, centre	MM6	MM6_H117d5_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind speed, 112.5 m, 140°	MM6	MM6_H112d5B140_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind speed, 81.4 m, 140°	MM6	MM6_H081d4B140_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind speed, 81.4 m, 320°	MM6	MM6_H081d4B320_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind speed, 41.9 m, 140°	MM6	MM6_H041d9B140_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind speed, 41.9 m, 320°	MM6	MM6_H041d9B320_Ws_Q1_m	Thies First Class Advanced 4.3352.00.000	m/s	TNO	4	*
wind direction, 112.5 m, 320°	MM6	MM6_H112d5B320_Wd_Q1_m	Thies First Class 4.3150.00.400	°	TNO	4	*
wind direction, 77.4 m, 320°	MM6	MM6_H077d4B320_Wd_Q1_m	Thies First Class 4.3150.00.400	°	TNO	4	*
wind direction, 37.9 m, 320°	MM6	MM6_H037d9B320_Wd_Q1_m	Thies First Class 4.3150.00.400	°	TNO	4	*
air temperature, 109 m	MM6	MM6_H109_Temp_Q1_m	Vaisala RHT probe HMP155D	°C	TNO	4	*
relative humidity, 109 m	MM6	MM6_H109_RH_Q1_m	Vaisala RHT probe HMP155D	%	TNO	4	*
air pressure, 109 m	MM6	MM6_H109_Pair_Q1_m	Vaisala digital barometer PTB210	hPa	TNO	4	*
precipitation, 40 m	MM6	MM6_H040_Prec_Q1_m	Thies precipitation sensor 5.4103.10.000	%	TNO	4	*
precipitation, distro, 36 m	MM6	MM6_H036_Prec_Disdro_Q1_m	Thies LPM 5.4110.00.300	%	TNO	4	*
wind speed, sonic u, 108.5 m, 140°	MM6	MM6_H108d5B140_S_U_Q5_m	Metek 3D ultrasonic anemometer	m/s	TNO	4	*
wind speed, sonic v, 108.5 m, 140°	MM6	MM6_H108d5B140_S_V_Q5_m	Metek 3D ultrasonic anemometer	m/s	TNO	4	*
wind speed, sonic w, 108.5 m, 140°	MM6	MM6_H108d5B140_S_W_Q5_m	Metek 3D ultrasonic anemometer	m/s	TNO	4	*

Table C.3: List of equipment used per signal

Signal short name	Sensor						Module				
	brand / type	ID	gain	offset [†]	cal. due date [‡]	inst. date	type	ID	gain	off-set	cal. due date
MM6_H117d5_Ws_Q1_m	Thies 4.3352.00.000	94025503	4.581e-2	2.185e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H112d5B140_Ws_Q1_m	Thies 4.3352.00.000	94025512	4.588e-2	2.0919e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H081d4B140_Ws_Q1_m	Thies 4.3352.00.000	94025513	4.573e-2	2.2527e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H081d4B320_Ws_Q1_m	Thies 4.3352.00.000	94025517	4.583e-2	2.1895e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H041d9B140_Ws_Q1_m	Thies 4.3352.00.000	94025502	4.584e-2	2.0885e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H041d9B320_Ws_Q1_m	Thies 4.3352.00.000	21004567	4.578e-2	2.1532e-1	2026-06-17	2025-06-17	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H112d5B320_Wd_Q1_m	Thies 4.3150.00.400	94012542	1.000e-1	2.0-1	2026-06-17	2025-06-17	NI 9871	94012138	1.000	0.000	N/A
MM6_H077d4B320_Wd_Q1_m	Thies 4.3150.00.400	94012052	1.000e-1	-1.166e+2	2026-06-17	2025-06-17	NI 9871	94012138	1.000	0.000	N/A
MM6_H037d9d9B320_Wd_Q1_m	Thies 4.3150.00.400	94012461	1.000e-1	-4.98e+1	2026-06-17	2025-06-17	NI 9871	94012138	1.000	0.000	N/A
MM6_H109_Temp_Q1_m	Vaisala HMP155	94012136	1.000e-2	0.000	2026-06-17	2025-06-17	NI 9871	94012165	1.000	0.000	N/A
MM6_H109_RH_Q1_m	Vaisala HMP155	94012136	1.000e-2	0.000	2026-06-17	2025-06-17	NI 9871	94012165	1.000	0.000	N/A
MM6_H109_Pair_Q1_m	Vaisala PTB210	94012651	1.000e-2	0.000	2026-06-17	2025-06-17	NI 9871	94012138	1.000	0.000	N/A
MM6_H040_Prec_Q1_m	Thies 5.4103.10.000	94012476	1.000	0.000	2026-06-17	2023-06-21	NI 9423	94011863	1.000	0.000	N/A
MM6_H108d5B140_WsUS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2029-08-2	2024-06-25	NI 9871	94012165	1.000	0.000	N/A
MM6_H108d5B140_WsVS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2029-08-2	2024-06-25	NI 9871	94012165	1.000	0.000	N/A
MM6_H108d5B140_WsWS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2029-08-28	2024-06-25	NI 9871	94012165	1.000	0.000	N/A

† For wind vanes the offset is governed by the North alignment of the vane w.r.t. its mounting orientation. Hence it does not reflect the offset reported on the calibration certificate.

‡ For cup anemometers and wind vanes the (annual) calibration due date is based on the installation date (not the wind tunnel calibration date).

Table C.4: List of calculated (pseudo) signals

name	short name	unit	rate	ISO	constituents/derivation
			Hz		
wind speed, 81.4 m	MM6_H081d4_Ws_True_Q1	m/s	4	*	MM6_H077d4B320_Wd_Q1 MM6_H081d4B140_Ws_MFDC_Q1_m C.1 MM6_H081d4B320_Ws_MFDC_Q1_m
wind speed, 41.9 m	MM6_H041d9_Ws_True_Q1	m/s	4	*	MM6_H037d9_Wd_Q1 MM6_H041d9B140_Ws_MFDC_Q1_m C.2 MM6_H041d9B320_Ws_MFDC_Q1_m
horizontal wind speed, sonic, 108.5 m	MM6_H108d5B140_WsHor_Q1	m/s	4	*	MM6_H108d5B140_WsUSon_Q1_m C.3 MM6_H108d5B140_WsVson_Q1_m

$$f(\#1, \#2, \#3) = \begin{cases} \#2, & \text{if } 50.45^\circ < \#1 \leq 230.45^\circ \\ \#3, & \text{otherwise} \end{cases} \quad (\text{C.1})$$

$$f(\#1, \#2, \#3) = \begin{cases} \#2, & \text{if } 49.84^\circ \leq \#1 < 229.84^\circ \\ \#3, & \text{otherwise} \end{cases} \quad (\text{C.2})$$

$$f(\#1, \#2) = \sqrt{\#1^2 + \#2^2} \quad (\text{C.3})$$

C.1 Calibration sheets

C.1.1 Cup anemometer



IECRE and MEASNET approved test laboratory



2412399
D.K.
15440-01-00
09/2024

Calibration Certificate / Kalibrierschein
issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard
Wind Tunnel Services GmbH

Member of / Mitglied im
Deutschen Kalibrierdienst

accredited to / akkreditiert nach
DIN EN ISO/IEC 17025:2018

Device under test (DUT)
Cup Anemometer

Manufacturer
Thies CLIMA

Type
4.3352.00.000

Serial number
04201553

Customer
TNO
NL - 1755 LE Petten

Order No.
3100501837

Project No.
VT340628

Number of pages
6

Date of Calibration
2024-09-25


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 presented results relate only to the object recalibrated at appropriate intervals. Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normen zur Darstellung der Einheiten in Übereinstimmung mit dem internationalen Einheitensystem (SI). Die DAKKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditierung (EA) und der internationalen Laboratoriums-Akkreditierungszusammenarbeit (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einbeziehung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

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Date 2024-09-25	Prepared by / Approved by Head of the program laboratory  Heiko Weidemann
	Person in charge Bereitsteller  L. Kypas

(a) Cup anemometer 94025503, page 1/4

Page 2 / 6
Seite



2412399
D.K.
15440-01-00
09/2024

Calibration procedure
Kalibrierverfahren

IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)

Summary of procedure
Zusammenfassung des Verfahrens

The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility.

Before the calibration procedure begins, the wind tunnel is set to an air velocity of 50 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration
Ort der Kalibrierung

Wind tunnel WK1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions
Messbedingungen

Wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.036
software version 10.2.15

¹⁾ the length between the center of the DUT measurement volume and the test section boundary.
²⁾ the ratio between DUT frontal area including the mounting and the wind tunnel test section area.

Ambient conditions
Umgebungsbedingungen


air temperature (22.0 ± 0.4) °C – (22.6 ± 0.4) °C
air pressure (1003.3 ± 0.4) hPa – (1003.7 ± 0.4) hPa
relative air humidity (55.5 ± 6.0) % – (57.6 ± 6.0) %

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 EA-4/02 M: 2022. 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 NM (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer.

Certificate ID
Zertifikat-ID


67815PZrgBboyGfPoXXX



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Oldenburgerstr. 65, D-26316 Varel

(b) Cup anemometer 94025503, page 2/4

Page 4 / 6
Seite



2412399
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15440-01-00
09/2024

Calibration result
Kalibrierergebnis


Index	Reference air velocity		DUT Indication Wind speed		DUT Indication Wind speed (Energy scaling)		Deviation $v_{DUT} - v_{REF}$	
	v_{REF}	U_{REF}	v_{DUT}	U_{DUT}	v_{DUT}	U_{DUT}		
i	m/s	Hz	m/s	Hz	m/s	Hz	Δv	
1	4.049	0.050	83.91	0.22	4.062	0.050	0.012	0.051
2	5.956	0.050	124.86	0.29	5.937	0.051	-0.019	0.052
3	7.954	0.050	168.15	0.40	7.939	0.058	-0.015	0.053
4	10.052	0.055	215.52	0.48	10.090	0.022	0.038	0.060
5	12.007	0.067	257.68	0.68	12.019	0.029	0.012	0.073
6	14.035	0.077	301.52	0.70	14.030	0.032	-0.005	0.084
7	15.975	0.086	345.93	0.78	15.972	0.036	-0.003	0.095
8	17.901	0.081	322.70	0.76	17.900	0.035	-0.001	0.090
9	17.934	0.071	277.83	0.65	17.944	0.030	0.010	0.077
10	11.109	0.061	237.74	0.68	11.108	0.029	-0.001	0.068
11	8.504	0.050	190.33	0.47	8.537	0.022	-0.037	0.055
12	6.978	0.050	147.25	0.36	6.963	0.016	-0.015	0.053
13	4.994	0.050	104.80	0.25	4.938	0.021	-0.056	0.051

A right copy of this table is attached to the PDF version of this document.

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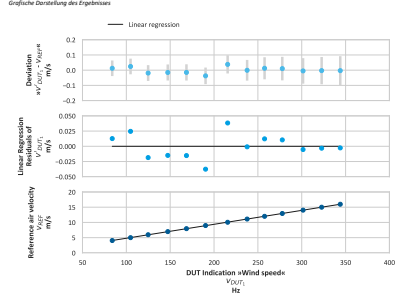
(c) Cup anemometer 94025503, page 3/4

Page 5 / 6
Seite



2412399
D.K.
15440-01-00
09/2024

Graphical representation of the result
Grafische Darstellung des Ergebnisses



Linear regression analysis for DUT Indication vs Wind speed

Slope m	(0.04581 ± 0.00007) (m/s)/Hz
Offset b	(0.21800 ± 0.01613) m/s
Standard error (Y) / RSD	0.02078 m/s
Correlation coefficient R	0.999987

Remarks
The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(d) Cup anemometer 94025503, page 4/4

DEUTSCHE WINDGUARD
IECRE and MEASNET approved test laboratory

Calibration Certificate / Kalibrierschein
issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard
Wind Tunnel Services GmbH

Member of / Mitglied im
Deutschen Kalibrierdienst

accredited to / akkreditiert nach
DIN EN ISO/IEC 17025:2018

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAKS 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 presented results relate only to the calibrated object. 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 DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einholung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date / Datum: 2024-09-25
Freigegeben durch / Approved by: Head of the calibration laboratory
Person in charge: Bearbeiter: L. Kyas
Hella Westermann

(e) Cup anemometer 94025512, page 1/4

2412400
D-K-
151448-01-00
09/2024

Page 2 / 6
Seite

Calibration procedure
Kalibrierverfahren: IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)

Summary of procedure
Zusammenfassung des Verfahrens: The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility.
Before the calibration procedure begins, the wind tunnel is set to an air velocity of 10 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration
Ort der Kalibrierung: Wind tunnel WK1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions
Messbedingungen: wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.034
software version 10.2.15

Ambient conditions
Umgebungsbedingungen: air temperature (22.2 ± 0.4) °C – (22.8 ± 0.4) °C
air pressure (1003.3 ± 0.4) hPa – (1003.6 ± 0.4) hPa
relative air humidity (55.3 ± 6.0) % – (57.2 ± 6.0) %

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 EA-4/02-M:2022. 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 NMJ (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PFB owned and calibrated laser Doppler Anemometer.

Certificate ID
Zertifikat-ID: FB88Pnvkx5662vnoocm6ub

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(f) Cup anemometer 94025512, page 2/4

2412400
D-K-
151448-01-00
09/2024

Page 4 / 6
Seite

Calibration result
Kalibrierergebnis:

Index	Reference air velocity m/s	DUT Indication +Wind speed- Hz	DUT indication +Wind speed- (freq. scaling) m/s	Deviation % _{(DUT) - %_(ref)}				
1	4.029	0.050	83.37	0.20	4.0344	0.0002	0.006	0.051
2	5.965	0.050	125.93	0.33	5.9874	0.0150	0.023	0.052
3	7.941	0.050	168.57	0.45	7.9440	0.0208	0.003	0.054
4	10.055	0.055	214.49	0.48	10.0509	0.0220	-0.004	0.060
5	11.895	0.056	254.40	0.64	11.8821	0.0295	-0.012	0.072
6	14.031	0.071	300.85	0.58	14.0176	0.0265	-0.008	0.082
7	15.972	0.088	344.16	0.68	16.0006	0.0314	0.028	0.093
8	14.906	0.082	320.15	0.73	14.8990	0.0317	-0.006	0.089
9	12.939	0.071	277.05	0.63	12.9232	0.0289	-0.018	0.077
10	11.104	0.061	237.75	0.62	11.1181	0.0284	0.014	0.068
11	8.899	0.050	188.11	0.51	8.8862	0.0151	-0.009	0.055
12	6.917	0.050	148.08	0.33	6.9119	0.0153	-0.005	0.052
13	5.012	0.050	104.43	0.25	5.0009	0.0114	-0.011	0.051

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Oldenburgerstr. 65, D-26316 Varel

(g) Cup anemometer 94025512, page 3/4

2412400
D-K-
151448-01-00
09/2024

Page 5 / 6
Seite

Graphical representation of the result
Graphische Darstellung des Ergebnisses:

Linear regression analysis for DUT Indication +Wind speed

Slope m	(0.04588 ± 0.00005) (m/s)/Hz
Offset b	(0.20919 ± 0.01144) m/s
Standard error (Y) / RSD	0.01473 m/s
Correlation coefficient R	0.999993
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(h) Cup anemometer 94025512, page 4/4

DEUTSCHE WINDGUARD
IECRE and MEASNET approved test laboratory

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issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

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accredited to / akkreditiert nach DIN EN ISO/IEC 17025:2018

Deutsche WindGuard
2411415
D-K-15346-01-00
05/2024

Device under test (DUT) Cup Anemometer
Manufacturer Thies CLIMA
Type 4.3352.00.000
Serial number 94025513
Customer TNO
Order No. 3100409804
Project No. VT340267
Number of pages 6
Date of Calibration 2024-05-17

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI). The DAKS 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 presented results relate only to the calibrated object. 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 DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Kooperation für Akkreditierung (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einholung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date: 2024-05-17
Freigegeben durch / Approved by: Helga Westermann
Person in charge: J. Bachmann

(i) Cup anemometer 94025513, page 1/4

Page 2 / 6
Seite

Calibration procedure IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)
Summary of procedure The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. Before the calibration procedure begins, the wind tunnel is set to an air velocity of 10 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration Wind tunnel WK1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel
Test conditions wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.034
software version 10.2.13

Ambient conditions air temperature (23.4 ± 0.4) °C – (24.0 ± 0.4) °C
air pressure (1007.3 ± 0.4) hPa – (1007.6 ± 0.4) hPa
relative air humidity (43.8 ± 6.0) % – (45.5 ± 6.0) %

Measurement uncertainty 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 EA-4/02:2022. The value of the measurement lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMJ (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a P1B owned and calibrated laser Doppler Anemometer.

Certificate ID cbeghRLMnqTbG6JKVRRka

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(j) Cup anemometer 94025513, page 2/4

Page 4 / 6
Seite

Calibration result
Kalibrierergebnis

Index	Reference air velocity		DUT Indication		DUT Indication		Deviation	
	v_{ref}	$v_{ref}^{(cal)}$	v_{DUT}	$v_{DUT}^{(cal)}$	Δv_{DUT}	$\Delta v_{DUT}^{(cal)}$	Δv_{DUT}	$\Delta v_{DUT}^{(cal)}$
-	m/s		m/s		m/s		m/s	
1	4.015	0.050	83.60	0.18	4.0489	0.0088	-0.034	0.053
2	5.969	0.050	124.97	0.28	5.9407	0.0129	-0.028	0.052
3	7.944	0.050	168.00	0.40	7.9362	0.0182	-0.008	0.053
4	10.048	0.055	214.93	0.57	10.0553	0.0258	0.008	0.061
5	11.988	0.067	257.89	0.59	12.0108	0.2009	0.223	0.072
6	14.032	0.071	301.48	0.59	14.0120	0.0751	-0.009	0.082
7	15.940	0.088	344.00	0.86	15.9579	0.0392	0.009	0.096
8	14.990	0.083	322.24	0.63	14.9627	0.0288	-0.027	0.087
9	12.930	0.071	278.15	0.68	12.9465	0.0100	0.016	0.078
10	11.105	0.061	237.67	0.55	11.0951	0.0292	-0.010	0.066
11	8.973	0.050	191.55	0.45	8.9836	0.0106	0.012	0.054
12	6.971	0.050	147.45	0.43	6.9688	0.0106	-0.003	0.054
13	4.990	0.050	104.23	0.28	4.9922	0.0127	0.002	0.052

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(k) Cup anemometer 94025513, page 3/4

Page 5 / 6
Seite

Graphical representation of the result
Graphische Darstellung des Ergebnisses

Linear regression analysis for DUT Indication vs Wind speed

Slope m	(0.04573 ± 0.00066) (m/s)/Hz
Offset b	(0.22527 ± 0.01291) m/s
Standard error (Y) / RSD	0.01664 m/s
Correlation coefficient R	0.999992
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(l) Cup anemometer 94025513, page 4/4

DEUTSCHE WINDGUARD
IECRE and MEASNET approved test laboratory

Calibration Certificate / Kalibrierschein
issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard
Wind Tunnel Services GmbH

Member of / Mitglied im
Deutschen Kalibrierdienst

accredited to / akkreditiert nach
DIN EN ISO/IEC 17025:2018

Device under test (DUT) Cup Anemometer

Manufacturer Thies CLIMA

Type 4.3352.00.000

Serial number 04201564

Customer TNO
NL - 1755 LE Petten

Order No. 3100501837

Project No. V1240628

Number of pages 6

Date of Calibration 2024-09-25

DAKS
Deutsche Akkreditierungsstelle
D-4 25140-01 00

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151448-01-00
09/2024

Calibration mark
Kalibrierschein

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI). The DAKS 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 presented results relate only to the calibrated object. The user is obliged to have the object recalibrated at appropriate intervals. Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten im Internationalen Einheitensystem (SI). Die DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditierung (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einholung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

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Date	Freigegeben durch / Approved by	Person in charge
2024-09-25		
	Helga Westermann	Linus Kyas

(m) Cup anemometer 94025517, page 1/4

2412404
D-K-
151448-01-00
09/2024

Page 2 / 6
Seite

Calibration procedure IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)
Kalibrierverfahren

Summary of procedure Zusammenfassung des Verfahrens
The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility.
Before the calibration procedure begins, the wind tunnel is set to an air velocity of 10 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration Ort der Kalibrierung
Wind tunnel WK1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions Messbedingungen
wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.034
software version 10.2.15

Ambient conditions Umgebungsbedingungen
air temperature (22.6 ± 0.4) °C – (23.2 ± 0.4) °C
air pressure (1000.9 ± 0.4) hPa – (1001.3 ± 0.4) hPa
relative air humidity (54.3 ± 6.0) % – (56.9 ± 6.0) %

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 EA-4/02: M-2022. 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 NMJ (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a P1B owned and calibrated laser Doppler Anemometer.

Certificate ID Certificate ID
Kpd1zeJ5MdyByvGNQDh

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(n) Cup anemometer 94025517, page 2/4

2412404
D-K-
151448-01-00
09/2024

Page 4 / 6
Seite

Calibration result Kalibrierergebnis

Index	Reference air velocity v_{ref} m/s	DUT Indication +Wind speed- v_{DUT} m/s	DUT indication +Wind speed- (invog. scaling) $v_{DUT} \cdot 10^3$ m/s	Deviation $\Delta v_{DUT} = v_{DUT} - v_{ref}$ m/s	MSD ¹⁾
1	4.026	0.050	83.53	0.18	4.0473
2	5.962	0.050	125.09	0.35	5.9517
3	7.937	0.050	168.38	0.41	7.9360
4	10.063	0.055	214.28	0.54	10.0393
5	11.997	0.067	257.05	0.52	11.9979
6	14.030	0.071	300.90	0.60	14.0093
7	15.962	0.088	344.32	0.60	15.9948
8	15.011	0.083	323.13	0.90	15.0284
9	12.929	0.071	277.07	0.53	12.9170
10	11.004	0.061	234.79	0.47	10.9793
11	8.850	0.050	180.00	0.41	8.8364
12	6.518	0.050	145.88	0.32	6.5049
13	4.984	0.050	104.33	0.25	5.0005

1) A digital copy of this table is attached to the PDF version of this document.

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(o) Cup anemometer 94025517, page 3/4

2412404
D-K-
151448-01-00
09/2024

Page 5 / 6
Seite

Graphical representation of the result Graphische Darstellung des Ergebnisses

Linear regression analysis for DUT Indication +Wind speed

Slope m	(0.04583 ± 0.00007) (m/s)/Hz
Offset b	(0.21895 ± 0.01541) m/s
Standard error (Y) / RSD	0.01992 m/s
Correlation coefficient R	0.999988
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(p) Cup anemometer 94025517, page 4/4

DEUTSCHE WINDGUARD
IECRE and MEASNET approved test laboratory

Calibration Certificate / Kalibrierschein
issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard Wind Tunnel Services GmbH

Member of / Mitglied im **Deutschen Kalibrierdienst**

accredited to / akkreditiert nach **DIN EN ISO/IEC 17025:2018**

Device under test (DUT) Cup Anemometer

Manufacturer Thies CLIMA

Type 4.3352.00.000

Serial number 04201552

Customer TNO

Order No. 3100501857

Project No. V1240628

Number of pages 6

Date of Calibration 2024-09-25

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI). The DAKS 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 presented results relate only to the calibrated object. 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 DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einholung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date 2024-09-25

Freigegeben durch / Approved by: *[Signature]*
Head of the calibration laboratory: *[Signature]*

Person in charge: *[Signature]*
Responsible: *[Signature]*

(q) Cup anemometer 94025502, page 1/4

Page 2 / 6

2412403
D-K-
151448-01-00
09/2024

Calibration procedure
Kalibrierverfahren IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)

Summary of procedure
Zusammenfassung des Verfahrens The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. Before the calibration procedure begins, the wind tunnel is set to an air velocity of 10 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration
Ort der Kalibrierung Wind tunnel WK1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions
Messbedingungen

wind tunnel test section area	1000 mm x 1000 mm
mounting diameter	33.7 mm
mounting length	250 mm
insertion depth ¹⁾	500 mm
blockage ratio ²⁾	0.034
software version	10.2.15

1) The length between the center of the DUT measurement volume and the test section boundary.
2) The ratio between DUT frontal area including the mounting and the wind tunnel test section area.

Ambient conditions
Umgebungsbedingungen

air temperature	(22.5 ± 0.4) °C – (23.1 ± 0.4) °C
air pressure	(1000.0 ± 0.4) hPa – (1001.3 ± 0.4) hPa
relative air humidity	(54.5 ± 6.0) % – (57.2 ± 6.0) %

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 EA-4/02:2022. 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 NMJ (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a P1B owned and calibrated laser Doppler Anemometer.

Certificate ID
Zertifikats-ID 9cD4C3qmQh8agAYkE7by

Deutsche WindGuard Wind Tunnel Services GmbH
Oldenburgerstr. 65, D-26316 Varel

(r) Cup anemometer 94025502, page 2/4

Page 4 / 6

2412403
D-K-
151448-01-00
09/2024

Calibration result
Kalibrierergebnis

Index	Reference air velocity m/s	DUT Indication +Wind speed m/s	DUT Indication +Wind speed (linear scaling) m/s	Deviation $\%_{(DUT)} = \frac{V_{DUT} - V_{REF}}{V_{REF}} \cdot 100$
1	4.026	0.050	83.44	0.23
2	5.968	0.050	125.99	0.39
3	7.944	0.050	168.16	0.35
4	10.055	0.055	214.83	0.38
5	11.901	0.056	254.97	0.54
6	14.034	0.071	305.72	0.56
7	15.881	0.087	343.44	0.70
8	15.001	0.083	322.74	0.59
9	12.934	0.071	276.80	0.61
10	11.109	0.061	237.49	0.52
11	8.971	0.050	180.86	0.49
12	6.522	0.050	146.53	0.38
13	4.986	0.050	104.45	0.30

A digital copy of this table is attached to the PDF version of this document.

Deutsche WindGuard Wind Tunnel Services GmbH
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(s) Cup anemometer 94025502, page 3/4

Page 5 / 6

2412403
D-K-
151448-01-00
09/2024

Graphical representation of the result
Graphische Darstellung des Ergebnisses

Linear regression analysis for DUT Indication +Wind speed

Slope m	(0.04584 ± 0.00066) (m/s)/Hz
Offset b	(0.20885 ± 0.01435) m/s
Standard error (Y) / RSD	0.01846 m/s
Correlation coefficient R	0.999990

Remarks: The calibrated sensor complies with the demanded linearity of MEASNET.

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(t) Cup anemometer 94025502, page 4/4

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Deutsche WindGuard Wind Tunnel Services GmbH
Member of / Mitglied im Deutschen Kalibrierdienst

accredited to / akkreditiert nach DIN EN ISO/IEC 17025:2018

Calibration mark Kalibrierschein 2433493 D-K-15140-01-00 10/2024

Device under test (DUT) Cup Anemometer
Manufacturer Thies CLIMA
Type 4.3352.00.000
Serial number 03212143 21004567
Customer TNO NL - 1755 LE Petten
Order No. 3100505170
Project No. VT240741
Number of pages 6
Date of Calibration 2024-10-17

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI). The DAKS 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 presented results relate only to the calibrated object. 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 DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditierung (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einholung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date: 2024-10-17
Freigegeben durch / Approved by: Helke Westermann
Person in charge: Dirk Krüger

(u) Cup anemometer 21004567, page 1/4

Page 2 / 6 Seite

2433493 D-K-15140-01-00 10/2024

Calibration procedure IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)
Kalibrierverfahren

Summary of procedure Zusammenfassung des Verfahrens
The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. Before the calibration procedure begins, the wind tunnel is set to an air velocity of 10 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration Wind tunnel WK3 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel
Ort der Kalibrierung

Test conditions wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.034
software version 10.2.15

Ambient conditions Umgebungsbedingungen
air temperature (21.7 ± 0.4) °C – (22.3 ± 0.4) °C
air pressure (1011.5 ± 0.4) hPa – (1011.9 ± 0.4) hPa
relative air humidity (46.5 ± 6.0) % – (48.2 ± 6.0) %

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 EA-4/02: M:2022. The value of the measurement lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMJ (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a P1B owned and calibrated laser Doppler Anemometer.

Certificate ID YHjGk5d2PevWkRnZkTNgpP

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Oldenburgerstr. 65, D-26316 Varel

(v) Cup anemometer 21004567, page 2/4

Page 4 / 6 Seite

2433493 D-K-15140-01-00 10/2024

Calibration result Kalibrierergebnis

Index	Reference air velocity		DUT Indication		DUT Indication		Deviation	
	v_{ref}	U_{ref}	v_{DUT}	U_{DUT}	Δv_{DUT}	ΔU_{DUT}	Δv_{DUT}	ΔU_{DUT}
1	4.017	0.050	83.678	0.002	4.0460	0.0042	-0.029	0.050
2	5.997	0.050	126.147	0.127	5.9902	0.0058	-0.007	0.050
3	7.987	0.050	169.569	0.204	7.9781	0.0094	-0.009	0.051
4	9.983	0.055	213.577	0.281	9.9928	0.0128	0.009	0.056
5	11.971	0.056	257.135	0.300	11.9819	0.0138	0.011	0.067
6	13.956	0.071	302.025	0.328	13.9596	0.0146	0.003	0.078
7	15.975	0.088	344.288	0.377	15.9766	0.0173	0.001	0.090
8	14.966	0.082	323.135	0.380	15.0083	0.0174	0.042	0.084
9	12.980	0.071	278.170	0.307	12.9498	0.0141	-0.031	0.073
10	11.005	0.061	234.940	0.233	10.9708	0.0207	-0.034	0.062
11	9.024	0.050	191.380	0.200	8.9834	0.0105	-0.041	0.051
12	6.975	0.050	147.424	0.175	6.9643	0.0080	-0.010	0.051
13	4.973	0.050	104.162	0.099	4.9838	0.0043	0.011	0.050

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Oldenburgerstr. 65, D-26316 Varel

(w) Cup anemometer 21004567, page 3/4

Page 5 / 6 Seite

2433493 D-K-15140-01-00 10/2024

Graphical representation of the result Graphische Darstellung des Ergebnisses

Linear regression analysis for DUT Indication vs Wind speed

Slope m	(0.04578 ± 0.00088) (m/s)/Hz
Offset b	(0.21532 ± 0.01772) m/s
Standard error (Y) / RSD	0.02281 m/s
Correlation coefficient R	0.999984
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET

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(x) Cup anemometer 21004567, page 4/4

C.1.2 Wind vane



IECRE and MEASNET approved test laboratory



Deutscher Akkreditierungsausschuss
DIN EN ISO/IEC 17025:2018

Calibration Certificate / Kalibrierschein

issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard
Wind Tunnel Services GmbH

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DIN EN ISO/IEC 17025:2018

D.K.
15140-01-00
10/2024

Calibration mark
Kalibrierzeichen

Device under test (DUT) Wind Vane
Gegenstand

Manufacturer Thies CLIMA
Hersteller

Type 4.3150.00.400

Serial number 04120064
94012666
Identifizierungs-Nr.

Customer TNO
NL 1755 LE Petten
Auftraggeber

Order No. 3100505170
Auftragsnummer

Project No. VT240741
Projektnummer

Number of pages 7
Anzahl der Seiten

Date of Calibration 2024-10-17
Datum der Kalibrierung

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 agreement of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates. The presented results relate only to the calibrated object. The user is obliged to have the object recalibrated at appropriate intervals. Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normen zur Darstellung der Einheiten in Übereinstimmung mit dem internationalen Einheitensystem (SI). Das DAkkS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Kooperation für Akkreditierung (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse betreffen sich nur auf den kalibrierten Gegenstand. Für die Erhaltung 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 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 des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit. Dieser Kalibrierschein wurde elektronisch erzeugt.

Date / Datum: 2024-10-21

Freigegeben durch / Approved by: Head of the calibration laboratory
Heiko Wollenberg

Person in charge / Verantwortlicher: Robert Nestel
R. Nestel

(a) Wind vane 94012666, page 1/6

2451426
D.K.
15140-01-00
10/2024

Page 2 / 7
Seite

Calibration procedure IEC 61400-50-1:2022 Annex A (formerly IEC 61400-12-1:2017 Annex N)
Kalibrierverfahren

Summary of procedure The device under test (DUT) is mounted perpendicular to the flow in the test section of the wind tunnel, if possible, the measurement volume of the DUT is centered within the wind tunnel test section. The DUT orientation reference mark (north mark) is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. The wind tunnel is set to a fixed air velocity and, after a suitable stabilization period, the DUT is rotated continuously at a fixed rate. After a full rotation, the procedure is repeated in the opposite direction. Once the rotation is complete, the DUT reading and the reference angle are bin-averaged and reported.
Zusammenfassung des Verfahrens


Place of calibration Wind tunnel WKS of Deutsche WindGuard Wind Tunnel Services GmbH, Varel
Ort der Kalibrierung

Test conditions wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.016
software version 10.2.15

Ambient conditions air temperature (21.2 ± 0.4) °C – (21.4 ± 0.4) °C
air pressure (1010.0 ± 0.4) hPa – (1010.5 ± 0.4) hPa
relative air humidity (48.7 ± 6.0) % – (49.4 ± 6.0) %
Umgebungsbedingungen

Measurement uncertainty 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 EA-4/02:2022. 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 NM (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a P18 owned and calibrated Laser Doppler Anemometer.
Messunsicherheit

Certificate ID Re4w342P80rVp3d5UkUw
Zertifikat-ID



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Oldenburgerstr. 65, D-26316 Varel

(b) Wind vane 94012666, page 2/6

2451426
D.K.
15140-01-00
10/2024

Page 3 / 7
Seite

Revision 0
Revision

Remarks and Definitions *Bemerkungen und Definitionen*

General remarks North alignment via DUT reference mark
Calibration after refurbishment

Yaw orientation The measured reference direction (yaw) or angle of attack. A value of 90 deg is equivalent to wind coming from east to west. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.
Yaw / deg

Reference air velocity The reference air velocity. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.
wref / m/s

DUT Indication The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.
Abw. / deg

Deviation The difference between DUT indication and reference direction and the reference orientation (yaw). The given uncertainty is the combined expanded uncertainty with a coverage factor of k=2.
Abw. / deg

Residuals The remaining deviation between the DUT indication after applying a linear regression correction and the reference.

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(c) Wind vane 94012666, page 3/6

2451426
D.K.
15140-01-00
10/2024

Page 4 / 7
Seite

Calibration result (1/3)
Kalibrierergebnis (1/3)

Internal deg	Yaw orientation deg	wref [m/s]	Reference air velocity		DUT indication		Deviation	
			wref [m/s]	U(wref)	Abw. [deg]	U(Abw.)	Abw. [deg]	U(Abw.)
[23.5, 23.5]	0.35	0.80	8.160	0.050	359.795	0.071	-0.55	0.80
[23.5, 23.5]	5.02	0.80	8.160	0.050	4.405	0.070	-0.61	0.80
[23.5, 23.5]	10.00	0.80	8.157	0.050	9.296	0.069	-0.71	0.80
[23.5, 23.5]	15.00	0.80	8.160	0.050	14.326	0.070	-0.68	0.80
[23.5, 23.5]	20.00	0.80	8.160	0.050	19.364	0.069	-0.63	0.80
[23.5, 23.5]	25.00	0.80	8.159	0.050	24.421	0.069	-0.58	0.80
[23.5, 23.5]	30.00	0.80	8.161	0.050	29.504	0.070	-0.50	0.80
[23.5, 23.5]	35.00	0.80	8.157	0.050	34.628	0.071	-0.38	0.80
[23.5, 23.5]	39.66	0.80	8.157	0.050	39.711	0.072	-0.35	0.80
[23.5, 23.5]	45.00	0.80	8.156	0.050	44.770	0.064	-0.27	0.80
[23.5, 23.5]	50.00	0.80	8.162	0.050	49.781	0.063	-0.20	0.80
[23.5, 23.5]	55.00	0.80	8.155	0.050	54.796	0.062	-0.21	0.80
[23.5, 23.5]	60.00	0.80	8.156	0.050	59.812	0.065	-0.19	0.80
[23.5, 23.5]	65.00	0.80	8.161	0.050	64.801	0.062	-0.20	0.80
[23.5, 23.5]	70.00	0.80	8.159	0.050	69.778	0.062	-0.27	0.80
[23.5, 23.5]	74.69	0.80	8.160	0.050	74.657	0.062	-0.34	0.80
[23.5, 23.5]	79.99	0.80	8.157	0.050	79.596	0.062	-0.39	0.80
[23.5, 23.5]	85.00	0.80	8.159	0.050	84.465	0.062	-0.54	0.80
[23.5, 23.5]	90.00	0.80	8.162	0.050	89.441	0.062	-0.56	0.80
[23.5, 23.5]	95.01	0.80	8.156	0.050	94.327	0.062	-0.68	0.80
[23.5, 23.5]	100.00	0.80	8.159	0.050	99.284	0.064	-0.72	0.80
[23.5, 23.5]	104.99	0.80	8.159	0.050	104.232	0.063	-0.76	0.80
[23.5, 23.5]	109.99	0.80	8.160	0.050	109.259	0.062	-0.73	0.80
[23.5, 23.5]	115.00	0.80	8.161	0.050	114.261	0.063	-0.64	0.80
[23.5, 23.5]	119.99	0.80	8.161	0.050	119.262	0.062	-0.54	0.80
[23.5, 23.5]	125.00	0.80	8.160	0.050	124.244	0.061	-0.51	0.80
[23.5, 23.5]	129.99	0.80	8.159	0.050	129.202	0.062	-0.46	0.80
[23.5, 23.5]	135.00	0.80	8.158	0.050	134.189	0.064	-0.41	0.80
[23.5, 23.5]	139.99	0.80	8.161	0.050	139.173	0.063	-0.32	0.80
[23.5, 23.5]	145.00	0.80	8.156	0.050	144.164	0.063	-0.24	0.80
[23.5, 23.5]	150.00	0.80	8.158	0.050	149.150	0.062	-0.24	0.80

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(d) Wind vane 94012666, page 4/6

2451426
D.K.
151440-01-00
10/2024

Page 5 / 7
Seite

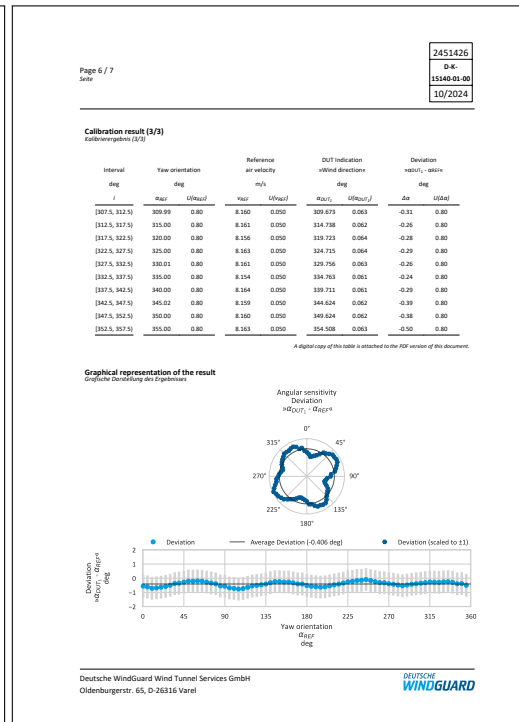
Calibration result (2/3)
Kalibrierergebnis (2/3)

Interval deg	Yaw orientation deg		Reference air velocity m/s		DUT indication +Wind direction deg		Deviation +ind _U - +ref _U deg	
	I	II	Year	U _{ref} (m/s)	Year	U _{DUT} (m/s)	ΔU	U _{DUT} (m/s)
[152.5, 157.5]	155.00	0.80	8.159	0.050	154.731	0.062	-0.27	0.80
[157.5, 162.5]	160.01	0.80	8.161	0.050	159.743	0.062	-0.26	0.80
[162.5, 167.5]	165.00	0.80	8.161	0.050	164.670	0.063	-0.33	0.80
[167.5, 172.5]	169.98	0.80	8.159	0.050	169.577	0.063	-0.40	0.80
[172.5, 177.5]	174.99	0.80	8.164	0.050	174.563	0.062	-0.41	0.80
[177.5, 182.5]	180.00	0.80	8.158	0.050	179.484	0.065	-0.51	0.80
[182.5, 187.5]	185.00	0.80	8.156	0.050	184.436	0.063	-0.57	0.80
[187.5, 192.5]	189.99	0.80	8.159	0.050	189.385	0.062	-0.60	0.80
[192.5, 197.5]	195.00	0.80	8.158	0.050	194.372	0.062	-0.63	0.80
[197.5, 202.5]	200.01	0.80	8.157	0.050	199.402	0.063	-0.60	0.80
[202.5, 207.5]	204.98	0.80	8.160	0.050	204.448	0.062	-0.54	0.80
[207.5, 212.5]	209.99	0.80	8.161	0.050	209.522	0.063	-0.47	0.80
[212.5, 217.5]	215.01	0.80	8.160	0.050	214.595	0.063	-0.41	0.80
[217.5, 222.5]	219.99	0.80	8.163	0.050	219.651	0.062	-0.34	0.80
[222.5, 227.5]	225.01	0.80	8.156	0.050	224.756	0.063	-0.25	0.80
[227.5, 232.5]	230.00	0.80	8.156	0.050	229.790	0.061	-0.21	0.80
[232.5, 237.5]	235.00	0.80	8.160	0.050	234.833	0.062	-0.16	0.80
[237.5, 242.5]	239.99	0.80	8.159	0.050	239.846	0.061	-0.15	0.80
[242.5, 247.5]	245.00	0.80	8.160	0.050	244.913	0.063	-0.09	0.80
[247.5, 252.5]	250.00	0.80	8.158	0.050	249.839	0.064	-0.16	0.80
[252.5, 257.5]	254.99	0.80	8.156	0.050	254.756	0.062	-0.24	0.80
[257.5, 262.5]	260.00	0.80	8.157	0.050	259.695	0.062	-0.30	0.80
[262.5, 267.5]	265.01	0.80	8.160	0.050	264.694	0.062	-0.32	0.80
[267.5, 272.5]	270.01	0.80	8.160	0.050	269.623	0.062	-0.39	0.80
[272.5, 277.5]	275.01	0.80	8.165	0.050	274.590	0.062	-0.42	0.80
[277.5, 282.5]	280.00	0.80	8.161	0.050	279.519	0.062	-0.46	0.80
[282.5, 287.5]	284.99	0.80	8.162	0.050	284.463	0.062	-0.53	0.80
[287.5, 292.5]	290.00	0.80	8.156	0.050	289.514	0.063	-0.48	0.80
[292.5, 297.5]	295.01	0.80	8.163	0.050	294.590	0.062	-0.42	0.80
[297.5, 302.5]	300.01	0.80	8.163	0.050	299.624	0.062	-0.38	0.80
[302.5, 307.5]	305.00	0.80	8.159	0.050	304.656	0.063	-0.35	0.80

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(e) Wind vane 94012666, page 5/6



(f) Wind vane 94012666, page 6/6

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Calibration Certificate / Kalibrierschein
issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard Wind Tunnel Services GmbH

Member of / Mitglied im Deutschen Kalibrierdienst

accredited to / akkreditiert nach DIN EN ISO/IEC 17025:2018

Device under test (DUT) Wind Vane

Manufacturer Thies CLIMA

Type 4.3150.00.400

Serial number 08130088

Customer TNO

Order No. 3100505170

Project No. VT240741

Date of calibration 2024-10-17

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI). The DAKS 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 presented results relate only to the calibrated object. 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 DAKS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditierung (EA) und der Internationalen Laboratoriumsakkreditierungszusammenarbeit (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

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Date 2024-10-21

Freigegeben durch / Approved by Head of the calibration laboratory

Person in charge Robert Resal

2451424
D-K-15346-01-00
10/2024

(g) Wind vane 94012051, page 1/6

Page 2 / 7

2451424
D-K-15346-01-00
10/2024

Calibration procedure
Kalibrierverfahren IEC 61400-50-1:2022 Annex A (formerly IEC 61400-12-1:2017 Annex N)

Summary of procedure
Zusammenfassung des Verfahrens The device under test (DUT) is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. The DUT orientation reference mark (north mark) is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. The wind tunnel is set to a fixed air velocity and, after a suitable stabilization period, the DUT is rotated continuously at a fixed rate. After a full rotation, the procedure is repeated in the opposite direction. Once the rotation is complete, the DUT reading and the reference angle are bin-averaged and reported.

Place of calibration
Ort der Kalibrierung Wind tunnel WKS of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions
Messbedingungen wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33.7 mm
mounting length 250 mm
insertion depth¹⁾ 500 mm
blockage ratio²⁾ 0.016
software version 10.2.15

Ambient conditions
Umgebungsbedingungen air temperature (20.9 ± 0.4) °C – (21.2 ± 0.4) °C
air pressure (1009.6 ± 0.4) hPa – (1010.0 ± 0.4) hPa
relative air humidity (48.5 ± 6.0) % – (49.2 ± 6.0) %

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 EN ISO 17022. The value of the measured lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NM (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer.

Calibration ID
Zertifikat ID: moEFePvGvZw3kQE4TFYV

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DEUTSCHE WINDGUARD

(h) Wind vane 94012051, page 2/6

Page 3 / 7

2451424
D-K-15346-01-00
10/2024

Revision
Revision: 0

Remarks and Definitions
Erläuterungen und Definitionen

General remarks
North alignment via DUT reference mark
Calibration after refurbishment

Tow orientation
θ_{ref} / deg The measured reference direction (yaw) or angle of attack. A value of 90 deg is equivalent to wind coming from east to west. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.

Reference air velocity
v_{ref} / m/s The reference air velocity. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.

DUT indication »Wind direction«
θ_{DUT} / deg The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2. The following uncertainty components are taken into account: short-term stability (repeatability), resolution.

Deviation »θ_{DUT} - θ_{ref}«
Δθ / deg The difference between DUT indication »Wind direction« and the reference orientation (yaw). The given uncertainty (U_{Δθ(DUT)}) is the combined expanded uncertainty with a coverage factor of k=2.

Residuals
The remaining deviation between the DUT indication after applying a linear regression correction and the reference.

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DEUTSCHE WINDGUARD

(i) Wind vane 94012051, page 3/6

Page 4 / 7

2451424
D-K-15346-01-00
10/2024

Calibration result (1/3)
Kalibrierergebnis (1/3)

Interval deg	Yaw orientation deg		Reference air velocity m/s		DUT indication »Wind direction« deg		Deviation θ _{DUT} - θ _{ref} / deg	
	int.	ext.	ext.	int.	ext.	int.	ext.	
(23.5, 23.5)	0.33	0.80	8.161	0.050	359.729	0.072	-0.60	0.80
(23.5, 73.5)	5.00	0.80	8.158	0.050	4.343	0.068	-0.65	0.80
(73.5, 123.5)	8.90	0.80	8.159	0.050	9.194	0.069	-0.80	0.80
(123.5, 173.5)	15.61	0.80	8.156	0.050	14.183	0.070	-0.82	0.80
(173.5, 223.5)	20.00	0.80	8.158	0.050	19.149	0.071	-0.85	0.80
(223.5, 273.5)	24.99	0.80	8.158	0.050	24.199	0.071	-0.79	0.80
(273.5, 323.5)	30.01	0.80	8.161	0.050	29.200	0.070	-0.72	0.80
(323.5, 373.5)	35.01	0.80	8.157	0.050	34.291	0.070	-0.72	0.80
(373.5, 423.5)	39.65	0.80	8.157	0.050	39.045	0.072	-0.61	0.80
(423.5, 473.5)	45.00	0.80	8.157	0.050	44.469	0.062	-0.53	0.80
(473.5, 523.5)	50.01	0.80	8.157	0.050	49.465	0.062	-0.55	0.80
(523.5, 573.5)	55.01	0.80	8.155	0.050	54.558	0.062	-0.46	0.80
(573.5, 623.5)	60.01	0.80	8.155	0.050	59.589	0.065	-0.42	0.80
(623.5, 673.5)	65.01	0.80	8.158	0.050	64.588	0.061	-0.41	0.80
(673.5, 723.5)	69.99	0.80	8.159	0.050	69.529	0.064	-0.46	0.80
(723.5, 773.5)	75.00	0.80	8.156	0.050	74.457	0.062	-0.55	0.80
(773.5, 823.5)	80.01	0.80	8.160	0.050	79.341	0.062	-0.67	0.80
(823.5, 873.5)	85.00	0.80	8.157	0.050	84.267	0.062	-0.74	0.80
(873.5, 923.5)	90.00	0.80	8.157	0.050	89.130	0.061	-0.83	0.80
(923.5, 973.5)	95.01	0.80	8.159	0.050	94.071	0.062	-0.94	0.80
(973.5, 1023.5)	99.99	0.80	8.161	0.050	99.026	0.062	-0.96	0.80
(1023.5, 1073.5)	105.00	0.80	8.157	0.050	103.999	0.063	-1.01	0.80
(1073.5, 1123.5)	110.01	0.80	8.158	0.050	109.045	0.063	-0.96	0.80
(1123.5, 1173.5)	115.01	0.80	8.156	0.050	114.094	0.062	-0.92	0.80
(1173.5, 1223.5)	119.99	0.80	8.160	0.050	119.176	0.061	-0.82	0.80
(1223.5, 1273.5)	125.00	0.80	8.160	0.050	124.262	0.063	-0.74	0.80
(1273.5, 1323.5)	130.01	0.80	8.158	0.050	129.343	0.063	-0.66	0.80
(1323.5, 1373.5)	135.01	0.80	8.155	0.050	134.429	0.062	-0.58	0.80
(1373.5, 1423.5)	140.00	0.80	8.157	0.050	139.561	0.061	-0.44	0.80
(1423.5, 1473.5)	145.00	0.80	8.157	0.050	144.629	0.061	-0.37	0.80
(1473.5, 1523.5)	150.00	0.80	8.158	0.050	149.620	0.062	-0.38	0.80

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DEUTSCHE WINDGUARD

(j) Wind vane 94012051, page 4/6

2451424
D.K.
151440-01-00
10/2024

Page 5 / 7
Seite

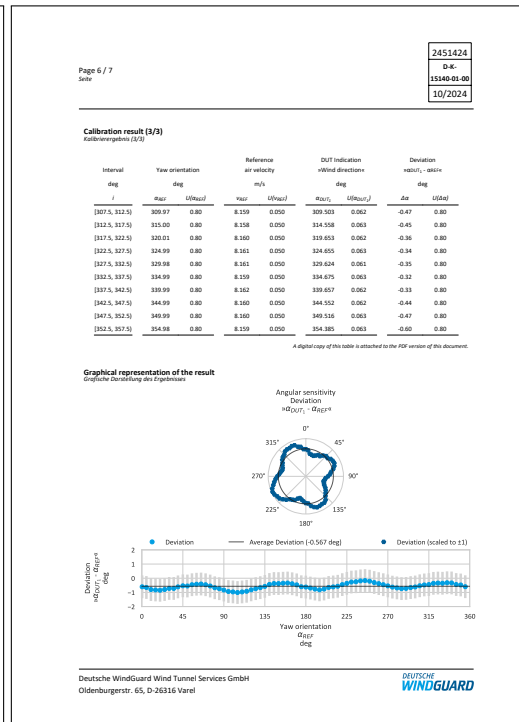
Calibration result (2/3)
Kalibrierergebnis (2/3)

Interval deg	Yaw orientation deg		Reference air velocity m/s		DUT indication +Wind direction deg		Deviation +ind _U - +ind _R deg	
	I	II	Year	U _{ref} (m/s)	Year	U _{DUT} (m/s)	Δe	U _{DUT} (m/s)
[152.5, 157.5]	155.00	0.80	8.159	0.050	154.447	0.062	-0.35	0.80
[157.5, 162.5]	159.99	0.80	8.157	0.050	159.655	0.062	-0.34	0.80
[162.5, 167.5]	164.99	0.80	8.163	0.050	164.605	0.062	-0.39	0.80
[167.5, 172.5]	169.99	0.80	8.158	0.050	169.522	0.064	-0.47	0.80
[172.5, 177.5]	175.00	0.80	8.158	0.050	174.404	0.062	-0.60	0.80
[177.5, 182.5]	180.00	0.80	8.160	0.050	179.377	0.063	-0.62	0.80
[182.5, 187.5]	184.99	0.80	8.159	0.050	184.297	0.062	-0.69	0.80
[187.5, 192.5]	189.98	0.80	8.160	0.050	189.221	0.062	-0.76	0.80
[192.5, 197.5]	195.00	0.80	8.158	0.050	194.180	0.062	-0.82	0.80
[197.5, 202.5]	199.99	0.80	8.155	0.050	199.212	0.063	-0.76	0.80
[202.5, 207.5]	205.01	0.80	8.158	0.050	204.159	0.063	-0.65	0.80
[207.5, 212.5]	210.02	0.80	8.160	0.050	209.406	0.063	-0.61	0.80
[212.5, 217.5]	214.99	0.80	8.158	0.050	214.428	0.063	-0.57	0.80
[217.5, 222.5]	219.99	0.80	8.156	0.050	219.340	0.062	-0.45	0.80
[222.5, 227.5]	224.99	0.80	8.160	0.050	224.634	0.063	-0.36	0.80
[227.5, 232.5]	229.99	0.80	8.156	0.050	229.721	0.062	-0.23	0.80
[232.5, 237.5]	235.01	0.80	8.157	0.050	234.759	0.064	-0.25	0.80
[237.5, 242.5]	239.99	0.80	8.159	0.050	239.803	0.063	-0.19	0.80
[242.5, 247.5]	244.98	0.80	8.159	0.050	244.816	0.065	-0.16	0.80
[247.5, 252.5]	249.99	0.80	8.159	0.050	249.780	0.064	-0.21	0.80
[252.5, 257.5]	255.01	0.80	8.163	0.050	254.713	0.063	-0.26	0.80
[257.5, 262.5]	260.01	0.80	8.157	0.050	259.632	0.062	-0.38	0.80
[262.5, 267.5]	265.00	0.80	8.158	0.050	264.547	0.062	-0.46	0.80
[267.5, 272.5]	270.00	0.80	8.156	0.050	269.459	0.063	-0.54	0.80
[272.5, 277.5]	275.00	0.80	8.160	0.050	274.375	0.063	-0.63	0.80
[277.5, 282.5]	280.00	0.80	8.159	0.050	279.268	0.062	-0.68	0.80
[282.5, 287.5]	285.00	0.80	8.164	0.050	284.169	0.062	-0.73	0.80
[287.5, 292.5]	290.00	0.80	8.160	0.050	289.283	0.062	-0.72	0.80
[292.5, 297.5]	295.01	0.80	8.160	0.050	294.355	0.062	-0.66	0.80
[297.5, 302.5]	300.01	0.80	8.155	0.050	299.395	0.063	-0.63	0.80
[302.5, 307.5]	304.99	0.80	8.158	0.050	304.463	0.063	-0.53	0.80

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DEUTSCHE
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(k) Wind vane 94012051, page 5/6



(l) Wind vane 94012051, page 6/6

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Deutsche WindGuard
Wind Tunnel Services GmbH

Member of / Mitglied im
Deutschen Kalibrierdienst

accredited to / akkreditiert nach
DIN EN ISO/IEC 17025:2018

DAKS
Deutsche Akkreditierungsstelle
04-25140-01-00

DKD
2451294
D-K-155446-01-00
09/2024
Calibration mark
Kalibrierschein

Device under test (DUT) Wind Vane
Impressum
Manufacturer Thies CLIMA
Type 4.3150.00.400
Serial number 04120058
Fabrik-/Serien-Nr. 94012542
Customer TNO
Auftraggeber NL - 1755 LE Petten
Order No. 3100501837
Auftragsnummer
Project No. VT240628
Projektnummer
Number of pages 7
Anzahl der Seiten
Date of calibration 2024-09-23
Datum der Kalibrierung

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Date / Datum: 2024-10-22
Freigegeben durch / Approved by: Head of the calibration laboratory
Person in charge: Head of the calibration laboratory
Hella Westermann
Dirk Krüger

(m) Wind vane 94012461, page 1/6

Page 2 / 7
Seite

2451294
D-K-155446-01-00
09/2024

Calibration procedure IEC 61400-50-1:2022 Annex A (formerly IEC 61400-12-1:2007 Annex N)
Kalibrierverfahren

Summary of procedure Zusammenfassung des Verfahrens
The device under test (DUT) is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. The DUT orientation reference mark (north mark) is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility. The wind tunnel is set to a fixed air velocity and, after a suitable stabilization period, the DUT is rotated continuously at a fixed rate. After a full rotation, the procedure is repeated in the opposite direction. Once the rotation is complete, the DUT reading and the reference angle are bin-averaged and reported.

Place of calibration Wind tunnel WKS of Deutsche WindGuard Wind Tunnel Services GmbH, Varel
Ort der Kalibrierung

Test conditions Messbedingungen
wind tunnel test section area 1000 mm x 1000 mm
mounting diameter 33,7 mm
mounting length 250 mm
insertion depth⁽¹⁾ 500 mm
blockage ratio⁽²⁾ 0.016
software version 10.2.15

Ambient conditions Umgebungsbedingungen
air temperature (22.2 ± 0.4) °C – (22.5 ± 0.4) °C
air pressure (1006.5 ± 0.4) hPa – (1006.9 ± 0.4) hPa
relative air humidity (57.5 ± 6.0) % – (58.3 ± 6.0) %

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 EN ISO GUM: 2022. 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 NM (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer.

Calibration ID XmtzqssjdlwvHhBuJuf8
Zertifikat-ID

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DEUTSCHE WINDGUARD

(n) Wind vane 94012461, page 2/6

Page 3 / 7
Seite

2451294
D-K-155446-01-00
09/2024

Revision 1 (replaces revision 0)
Revision

Change History:
- corrected statistical analysis

Remarks and Definitions Erläuterungen und Definitionen

General remarks
North alignment via DUT reference mark
Calibration after refurbishment
The measured reference direction (yaw) or angle of attack. A value of 90 deg is equivalent to wind coming from east to west. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.

Yaw orientation $\alpha_{ref} / \text{deg}$
The reference air velocity. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.

Reference air velocity $v_{ref} / \text{m/s}$

DUT indication «Wind direction» $\alpha_{DUT} / \text{deg}$
The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2. The following uncertainty components are taken into account: short-term stability (repeatability), resolution.

Deviation «azur1 - azref» $\Delta\alpha / \text{deg}$
The difference between DUT indication «Wind direction» and the reference orientation (yaw). The given uncertainty $U(\Delta\alpha_{DUT})$ is the combined expanded uncertainty with a coverage factor of k=2.

Residuals
The remaining deviation between the DUT indication after applying a linear regression correction and the reference.

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DEUTSCHE WINDGUARD

(o) Wind vane 94012461, page 3/6

Page 4 / 7
Seite

2451294
D-K-155446-01-00
09/2024

Calibration result (1/3) Kalibrierergebnis (1/3)

Interval	Yaw orientation		Reference air velocity		DUT indication «Wind direction»		Deviation «azur1 - azref»	
	deg	deg	m/s	deg	deg	deg	deg	
[23.5, 23.5]	0.34	0.80	8.182	0.050	359.794	0.071	-0.55	0.80
[23.5, 73.5]	5.00	0.80	8.183	0.050	4.328	0.069	-0.67	0.80
[73.5, 123.5]	10.01	0.80	8.180	0.050	9.160	0.070	-0.85	0.80
[123.5, 173.5]	15.00	0.80	8.179	0.050	14.119	0.070	-0.88	0.80
[173.5, 223.5]	20.00	0.80	8.178	0.050	19.074	0.069	-0.91	0.80
[223.5, 273.5]	24.99	0.80	8.180	0.050	24.053	0.069	-0.94	0.80
[273.5, 323.5]	29.99	0.80	8.179	0.050	29.100	0.070	-0.89	0.80
[323.5, 373.5]	34.99	0.80	8.179	0.050	34.162	0.071	-0.82	0.80
[373.5, 423.5]	39.66	0.80	8.179	0.050	38.891	0.071	-0.77	0.80
[423.5, 473.5]	45.00	0.80	8.178	0.050	44.338	0.063	-0.66	0.80
[473.5, 523.5]	50.00	0.80	8.182	0.050	49.411	0.061	-0.59	0.80
[523.5, 573.5]	55.00	0.80	8.182	0.050	54.422	0.062	-0.58	0.80
[573.5, 623.5]	60.00	0.80	8.182	0.050	59.463	0.061	-0.54	0.80
[623.5, 673.5]	65.00	0.80	8.182	0.050	64.644	0.061	-0.54	0.80
[673.5, 723.5]	70.01	0.80	8.182	0.050	69.474	0.062	-0.54	0.80
[723.5, 773.5]	74.99	0.80	8.182	0.050	74.412	0.062	-0.58	0.80
[773.5, 823.5]	79.98	0.80	8.180	0.050	79.315	0.062	-0.67	0.80
[823.5, 873.5]	84.99	0.80	8.184	0.050	84.209	0.061	-0.68	0.80
[873.5, 923.5]	89.99	0.80	8.178	0.050	89.172	0.062	-0.82	0.80
[923.5, 973.5]	94.99	0.80	8.178	0.050	94.095	0.062	-0.89	0.80
[973.5, 1023.5]	100.00	0.80	8.181	0.050	98.998	0.063	-1.00	0.80
[1023.5, 1073.5]	105.01	0.80	8.182	0.050	103.944	0.062	-1.06	0.80
[1073.5, 1123.5]	110.00	0.80	8.181	0.050	108.907	0.064	-1.09	0.80
[1123.5, 1173.5]	114.98	0.80	8.181	0.050	113.962	0.062	-1.04	0.80
[1173.5, 1223.5]	120.00	0.80	8.177	0.050	119.038	0.062	-0.96	0.80
[1223.5, 1273.5]	125.00	0.80	8.181	0.050	124.066	0.062	-0.92	0.80
[1273.5, 1323.5]	130.01	0.80	8.180	0.050	129.172	0.061	-0.84	0.80
[1323.5, 1373.5]	135.01	0.80	8.184	0.050	134.285	0.063	-0.72	0.80
[1373.5, 1423.5]	140.01	0.80	8.182	0.050	139.402	0.064	-0.61	0.80
[1423.5, 1473.5]	144.99	0.80	8.174	0.050	144.484	0.062	-0.51	0.80
[1473.5, 1523.5]	149.99	0.80	8.179	0.050	149.555	0.062	-0.44	0.80

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DEUTSCHE WINDGUARD

(p) Wind vane 94012461, page 4/6

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Page 5 / 7
Seite

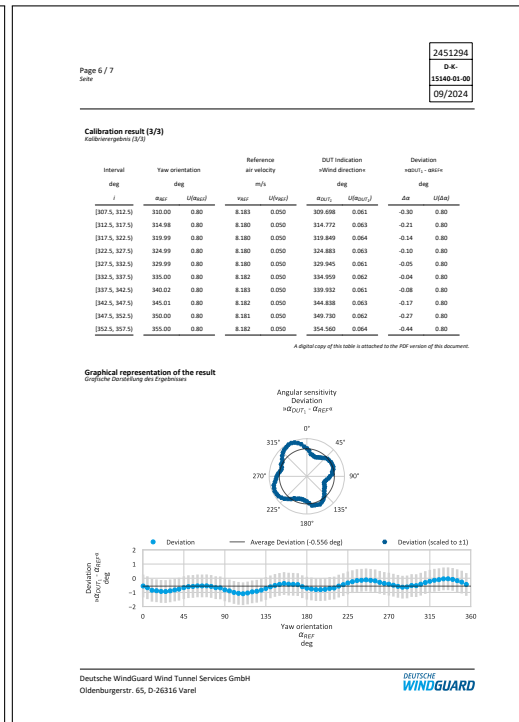
Calibration result (2/3)
Kalibrierergebnis (2/3)

Interval deg	Yaw orientation deg		Reference air velocity m/s	DUT indication +Wind direction deg		Deviation +ind _U - +ind _R deg		
	1	2		1	2			
	deg	deg		deg	deg			
[152.5, 157.5]	155.00	0.80	8.179	0.050	154.633	0.063	-0.37	0.80
[157.5, 162.5]	160.00	0.80	8.182	0.050	159.589	0.061	-0.42	0.80
[162.5, 167.5]	165.00	0.80	8.183	0.050	164.572	0.063	-0.43	0.80
[167.5, 172.5]	170.00	0.80	8.178	0.050	169.554	0.063	-0.45	0.80
[172.5, 177.5]	174.99	0.80	8.181	0.050	174.590	0.062	-0.60	0.80
[177.5, 182.5]	179.99	0.80	8.178	0.050	179.288	0.061	-0.70	0.80
[182.5, 187.5]	185.00	0.80	8.181	0.050	184.243	0.064	-0.76	0.80
[187.5, 192.5]	190.00	0.80	8.179	0.050	189.201	0.064	-0.80	0.80
[192.5, 197.5]	195.00	0.80	8.181	0.050	194.195	0.062	-0.80	0.80
[197.5, 202.5]	200.01	0.80	8.180	0.050	199.230	0.061	-0.78	0.80
[202.5, 207.5]	205.00	0.80	8.181	0.050	204.279	0.062	-0.72	0.80
[207.5, 212.5]	209.99	0.80	8.177	0.050	209.300	0.064	-0.69	0.80
[212.5, 217.5]	215.00	0.80	8.183	0.050	214.445	0.063	-0.55	0.80
[217.5, 222.5]	220.00	0.80	8.181	0.050	219.550	0.062	-0.45	0.80
[222.5, 227.5]	225.00	0.80	8.182	0.050	224.608	0.062	-0.31	0.80
[227.5, 232.5]	230.01	0.80	8.184	0.050	229.743	0.061	-0.24	0.80
[232.5, 237.5]	235.00	0.80	8.181	0.050	234.838	0.062	-0.16	0.80
[237.5, 242.5]	240.00	0.80	8.185	0.050	239.892	0.063	-0.14	0.80
[242.5, 247.5]	245.00	0.80	8.183	0.050	244.886	0.063	-0.12	0.80
[247.5, 252.5]	249.99	0.80	8.180	0.050	249.846	0.062	-0.15	0.80
[252.5, 257.5]	254.99	0.80	8.179	0.050	254.807	0.061	-0.18	0.80
[257.5, 262.5]	260.01	0.80	8.179	0.050	259.716	0.062	-0.29	0.80
[262.5, 267.5]	265.00	0.80	8.186	0.050	264.638	0.063	-0.37	0.80
[267.5, 272.5]	270.01	0.80	8.180	0.050	269.589	0.062	-0.42	0.80
[272.5, 277.5]	275.00	0.80	8.182	0.050	274.513	0.062	-0.49	0.80
[277.5, 282.5]	279.99	0.80	8.181	0.050	279.421	0.061	-0.57	0.80
[282.5, 287.5]	284.99	0.80	8.179	0.050	284.356	0.064	-0.61	0.80
[287.5, 292.5]	290.01	0.80	8.182	0.050	289.393	0.062	-0.61	0.80
[292.5, 297.5]	295.00	0.80	8.180	0.050	294.486	0.064	-0.51	0.80
[297.5, 302.5]	300.00	0.80	8.180	0.050	299.481	0.065	-0.52	0.80
[302.5, 307.5]	305.00	0.80	8.182	0.050	304.577	0.062	-0.42	0.80

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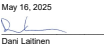
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(q) Wind vane 94012461, page 5/6



(r) Wind vane 94012461, page 6/6


C.1.3 Relative humidity and temperature

 <p>Vaisala is ISO 9001 and ISO 14001 certified company. MEASUREMENT STANDARDS LABORATORY ACCREDITED CALIBRATION LABORATORY</p>   <p>FINAS Finnish Accreditation Service K008 (EN ISO/IEC 17025)</p>		<p>Certificate number K008-J02702 Page 2 (4)</p>	
<p>CERTIFICATE OF CALIBRATION no K008-J02702</p>			
Customer	TNO Wind Energy Westerdijkweg 3 1705 LE Poven		
Instrument	Humidity and Temperature Probe		
Manufacturer	Vaisala Oyj		
Model	HMP155E		
Serial number	F4450014		
Instrument number	94012447		
Calibration date	From May 15 to 16, 2025		
Calibration due date	July 15, 2026		
Issue date	May 16, 2025		
Signature	 Dani Laitinen Calibration Engineer		
Page 1 (4)			
Documents attached	-		
NOTES	The instrument was adjusted during calibration.		
Conditions when received	Reported in Service Report.		
<p><small>This Certificate may only be reproduced in full, except with the prior written permission by the issuing Laboratory. The measurements cannot be used and the Certificate of Calibration issued by an Accredited Calibration Laboratory comply with the measurement range and uncertainties approved by FINAS Finnish Accreditation Service. The measurement results issued by the Laboratory are traceable to national or international measurement standards. Measurement Standards Laboratory of Vaisala Oyj is a calibration laboratory K008 accredited by FINAS Finnish Accreditation Service, accreditation requirement ISO/IEC 17025. The accreditation is included in the Multilateral Agreement (EA-MRA) of the European co-operation for Accreditation (EA).</small></p> <p><small>Vaisala Oyj, PO Box 26, FI-02421 Helsinki, Finland Telephone + 358 9 854 91 • Fax + 358 9 8549 2227 Email helpdesk@vaisala.com • www.vaisala.com Domestic Vainaa, Finland • VAT FI01244162 • Business ID 0124416-2</small></p>			
		<p>DESCRIPTION The measurement results were obtained from the measured values or the results were calculated from the measured values by using adjustment coefficients. The instrument's configuration, settings and coefficients were read from the instrument's memory. Before measurements the instrument was allowed to stabilize to the conditions of the laboratory for at least 1 hour with 24.0 VDC ± 0.3 VDC power supply on. The instrument was configured to use pressure 1013.25 hPa settings for the time of the calibration if there is a pressure compensation setting in the instrument.</p> <p>REFERENCES USED DURING TEMPERATURE CALIBRATION TMP1 / AM1612 Temperature Probe, serial number W3144135, due date 2026-Apr-30 TMP1 / AM1612 Temperature Probe, serial number W3144136, due date 2026-Apr-30</p> <p>REFERENCES USED DURING HUMIDITY CALIBRATION TMP1 / AM1612 Temperature Probe, serial number W3144135, due date 2026-Apr-30 Thunder 2500 Humidity generator, serial number 1209917, due date 2026-Jan-31 PTB330 Digital Barometer, serial number S1920448, due date 2025-Oct-31</p> <p>TRACEABILITY The measurement results are traceable to the international system of units (SI) through national metrology institutes (NIST in USA or equivalent) or accredited calibration laboratories.</p> <p>CALIBRATION PROCEDURE DOC233127 temperature, DOC230528 humidity.</p> <p>UNCERTAINTY The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with EA Publication EA-4/02. The measurement uncertainty represents the situation at the time and conditions of calibration. When using the UUC at different conditions and at different time the effect of the conditions and stability of the UUC shall be evaluated separately. The measurement results and uncertainty are representing the measured instrument and measurement points only. The calibration uncertainty includes known uncertainty components related to the instrument under calibration. The instrument-dependent calibration uncertainty of the calibration point has not been defined entirely when the calibration uncertainty is marked with the text "*" due to a large instrument reading error, due to the possibility of digital or analog output freezing to output a constant reading near the upper or lower limit of the output range or due to equivalent instrument-related reason. In the case of marking "*", the calibration uncertainty is given without considering the effect of above-mentioned not exactly known reasons on the calibration results.</p> <p>STATEMENT OF CONFORMITY The calibration results and the statement of conformity with specification relate only to the calibrated instrument and the calibration points. The statement of conformity is based on simple acceptance, whether the calibration result is within or outside the manufacturer's specification. The calibration uncertainty is not taken into account in the statement of conformity. The probability of accepting a non-conforming result or rejecting a conforming result can be as large as 50 % with this acceptance rule when the calibration result is close to the specification limit. Pass = The calibration result is equal or within the manufacturer's specification. Fail = The calibration result is outside the manufacturer's specification. There is no specified specification when the specification is marked with 'None'.</p> <p>AMBIENT CONDITIONS Temperature 23 °C ± 3 °C Humidity 35 %rh ± 32 %rh</p>	


(a) RHT 94012447, page 1/2

(b) RHT 94012447, page 2/2

C.1.4 Air pressure




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MEASUREMENT STANDARDS LABORATORY
ACCREDITED CALIBRATION LABORATORY



FINAS
Finnish Accreditation Service
K008 (EN ISO/IEC 17025)

CERTIFICATE OF CALIBRATION no K008-J02698

Customer	TNO Wind Energy Westerduinweg 3 1755 LE Pellen
Instrument	Pressure Transmitter
Manufacturer	Vaisala Oy
Model	PTB210A
Serial number	F4960002
Instrument number	94012584
Calibration date	On May 15, 2025
Calibration due date	July 15, 2026
Issue date	May 16, 2025
Signature	 Ilkka Kotamäki Technical Manager

Page 1 (3)

Documents attached -


NOTES Adjusted.

Conditions when received Reported in Service Report.

This Certificate may only be reproduced in full, except with the prior written permission by the issuing Laboratory. The measurements carried out and the Certificate of Calibration issued by an Accredited Calibration Laboratory comply with the measurement ranges and uncertainties approved by FINAS Finnish Accreditation Service. The measurement results issued by the Laboratory are traceable to national or international measurement standards. Measurement Standards Laboratory of Vaisala Oy is a calibration laboratory K008 accredited by FINAS Finnish Accreditation Service, accreditation requirement ISO/IEC 17025. The accreditation is included in the Multilateral Agreement (EA MLA) of the European co-operation for Accreditation (EA).

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(a) Air pressure sensor 94012584, page 1/2



Certificate number **K008-J02698** Page 2 (3)

CONFIGURATION
Before the measurements the instrument's configuration and settings were read from the instrument's memory.

Table 1. Configuration and settings

Setups read from the memory	
Software version	PTB210 Ver 2.01
CPU serial number	F4960002
Multipoint con	ON
Meas per minute	60
Averaging	0
Pressure Min...Max	490 1110

PRESSURE CALIBRATION
The above described instrument was calibrated from 500 to 1100 absolute pressure in the Measurement Standards Laboratory (MSL) of Vaisala Oy on May 15, 2025. The pressure readings of the instrument were compared to the values of the reference. The measurement results were obtained from the measured values or the results were calculated from the measured values by using adjustment coefficients. Before measurements the instrument was allowed to stabilize to the conditions of the laboratory for at least 1 hour with power supply on. The used pressure transmitting medium was air and/or nitrogen.

REFERENCES USED DURING PRESSURE CALIBRATION
DHI PPC3 / HI Pressure Controller/Calibrator, s/n 722 / 105064, due date 2025-Oct-31.

TRACEABILITY
The measurement results are traceable to the international system of units (SI) through national metrology institutes (NIST in USA or equivalent) or accredited calibration laboratories.

CALIBRATION PROCEDURE
DOC236240

UNCERTAINTY
The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor $k = 2$, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with EA Publication EA-402:
- The uncertainty is calculated from the uncertainties caused from the reference equipment, calibration process and unit under calibration (UUC) including resolution, stability (short term), linearity, repeatability, hysteresis and rounding of the final results.
- The measurement results and uncertainty may be interpolated between measurement points.
The measurement uncertainty represents the situation at the time and conditions of calibration. When using the UUC at different conditions and at different time the effect of the conditions and stability of the UUC shall be evaluated separately.
The measurement results and uncertainty are representing the measured instrument and measurement points only.

CALIBRATION CONDITIONS
Temperature 23 °C ± 0.1 °C
Humidity 35 %RH ± 3%RH

(b) Air pressure sensor 94012584, page 2/2

C.1.5 Sonic 3D



IECRE and MEASNET approved test laboratory



Calibration Certificate / Kalibrierschein
 Issued by the calibration laboratory / erstellt durch das Kalibrierlaboratorium

Deutsche WindGuard
Wind Tunnel Services GmbH

Member of / Mitglied im
Deutschen Kalibrierdienst

accredited to / akkreditiert nach
DIN EN ISO/IEC 17025:2018

2421453
 D-K
 15146-01-00
 05/2024

Device under test (DUT) Ultrasonic Anemometer
(Gegenstand)

Manufacturer METEK
(Hersteller)

Type uSonic-3 Sci

Serial number 0111107372
(Identifizierungsnummer)

Customer TNO
Auftraggeber
 NL - 1755 LE Petten

Order No. 3100409804
(Auftragnummer)

Project No. VT740267
(Projektnummer)

Number of pages 10
(Anzahl der Seiten)

Date of Calibration 2024-05-22
(Datum der Kalibrierung)

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 presented results relate only to the calibrated object. The user is obliged to have the object recalibrated at appropriate intervals. Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normen zur Darstellung der Einheiten in Übereinstimmung mit dem internationalen Einheitensystem (SI). Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der Europäischen Zusammenarbeit für Akkreditierung (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. 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 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 des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit. Dieser Kalibrierschein wurde elektronisch erzeugt.

Date 2024-05-24	Freigegeben durch / Approved by Head of the calibration laboratory 	Person in charge Berater 
	Heiko Wiedemann	Alina Bubl

(a) Sonic 3D 94012345, page 1/6

Page 2 / 10
Seite

2421453
 D-K
 15146-01-00
 05/2024

Calibration procedure Kalibrierverfahren
 IEC 61400-50-1:2022 section 8 (formerly IEC 61400-12-1:2017 Annex F)

Summary of procedure Zusammenfassung des Verfahrens
 The device under test (DUT) / anemometer is mounted perpendicular to the flow in the test section of the wind tunnel. If possible, the measurement volume of the DUT is centered within the wind tunnel test section. For directionally sensitive DUTs, the predefined orientation is aligned with the flow centerline. In this step, care is taken to minimize angular deviations to increase reproducibility.
 Before the calibration procedure begins, the wind tunnel is set to an air velocity of 20 m/s for a minimum of 5 minutes. For each test point, the wind tunnel is set to a fixed air velocity. After an appropriate stabilization period, the DUT and reference air velocities are sampled simultaneously for at least 30 seconds, averaged, and reported.

Place of calibration Ort der Kalibrierung
 Wind tunnel WK2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel

Test conditions Messbedingungen
 wind tunnel test section area 3100 mm x 1000 mm
 mounting diameter 42.4 mm
 mounting length not applicable
 insertion depth¹⁾ 535 mm
 blockage ratio²⁾ 0.025
 DUT yaw orientation 0.0°
 software version 10.2.13

1) The length between the center of the DUT measurement volume and the test section boundary.
 2) The ratio between DUT frontal area including the mounting and the wind tunnel test section area.

Ambient conditions Umgebungsbedingungen
 air temperature (22.6 ± 0.4) °C – (23.2 ± 0.4) °C
 air pressure (1005.6 ± 0.4) hPa – (1005.9 ± 0.4) hPa
 relative air humidity (50.4 ± 6.0) % – (52.7 ± 6.0) %

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 EA-402:2022. The value of the measured lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NM (Physikalisches Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer.


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(b) Sonic 3D 94012345, page 2/6

Page 3 / 10
Seite

2421453
 D-K
 15146-01-00
 05/2024

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(c) Sonic 3D 94012345, page 3/6

Page 4 / 10
Seite

2421453
 D-K
 15146-01-00
 05/2024

Revision 0
Revision

Remarks and Definitions Anmerkungen und Definitionen

General remarks **North alignment via DUT geometry**

Reference air velocity v_{ref} / m/s
 The reference air velocity. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2.

DUT indication $w_{DUT,u}$ / m/s
 The indication of the device under test converted to the horizontal wind speed $w_{DUT,u}$ with vectorial averaging according to ISO 16622:2002 from DUT indication w_x (calculated) and DUT indication w_y (calculated). The expanded uncertainty is given with a coverage factor of k=2.

Deviation $w_{DUT,u} - v_{ref}$ Δv / m/s
 The difference between DUT indication $w_{DUT,u}$ and the reference air velocity. The given uncertainty $U(w_{DUT,u})$ is the combined expanded uncertainty with a coverage factor of k=2.

DUT indication w_x $w_{DUT,x}$ / cm/s
 The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2. The following uncertainty components are taken into account: short-term stability (repeatability), resolution.

DUT indication w_x (calculated) $v_{DUT,x}$ / m/s
 The DUT indication converted to the reference unit with the following equation: $v_{DUT,x} = 0.02$. No uncertainties are considered for this conversion.

DUT indication w_y $w_{DUT,y}$ / cm/s
 The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2. The following uncertainty components are taken into account: short-term stability (repeatability), resolution.

DUT indication w_y (calculated) $v_{DUT,y}$ / m/s
 The DUT indication converted to the reference unit with the following equation: $v_{DUT,y} = 0.02$. No uncertainties are considered for this conversion.

DUT indication w_z $w_{DUT,z}$ / cm/s
 The indication of the device under test. The uncertainty is given as the expanded uncertainty with a coverage factor of k=2. The following uncertainty components are taken into account: short-term stability (repeatability), resolution.

DUT indication w_z (calculated) $v_{DUT,z}$ / m/s
 The DUT indication converted to the reference unit with the following equation: $v_{DUT,z} = 0.02$. No uncertainties are considered for this conversion.

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(d) Sonic 3D 94012345, page 4/6

2421453
 D-K:
 15140-01-00
 05/2024

Page 5 / 10
Seite

DUT indication $v_{DUT,ref}$
 $v_{DUT,ref} / \text{deg}$

The indication of the device under test converted to the yaw orientation α_{DUT} with vectorial averaging according to ISO 16672-2002 from "DUT indication xxx (calculated)" and "DUT indication yyy (calculated)". The expanded uncertainty is given with a coverage factor of $k=2$.

Residuals

The remaining deviation between the DUT indication after applying a linear regression correction and the reference.

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DEUTSCHE WINDGUARD

(e) Sonic 3D 94012345, page 5/6

2421453
 D-K:
 15140-01-00
 05/2024

Page 6 / 10
Seite

Calibration result
Kalibrierergebnis

Index	Reference air velocity		DUT indication $v_{DUT,ref}$		Deviation $v_{DUT,ref} - v_{ref}$	
	v_{ref}	$U_{95,ref}$	$v_{DUT,ref}$	$U_{95,DUT,ref}$	Δv	$U_{95,\Delta v}$
1	3.955	0.040	4.0056	0.0500	0.0506	0.0400
2	6.014	0.040	6.0698	0.0500	0.0560	0.0400
3	7.903	0.040	7.9350	0.0501	0.0320	0.0400
4	9.998	0.040	10.0351	0.0501	0.0370	0.0410
5	11.960	0.040	12.0188	0.0503	0.0588	0.0480
6	14.048	0.050	14.1136	0.0506	0.0650	0.0570
7	15.974	0.050	16.0584	0.0505	0.0840	0.0640
8	15.024	0.050	15.0935	0.0505	0.0700	0.0610
9	13.023	0.052	13.0738	0.0503	0.0510	0.0530
10	11.003	0.044	11.0476	0.0502	0.0460	0.0440
11	8.968	0.040	9.0065	0.0502	0.0380	0.0410
12	6.942	0.040	7.0017	0.0500	0.0600	0.0400
13	4.979	0.040	5.0621	0.0501	0.0830	0.0410

A digital copy of this code is attached to the PDF version of this document.

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(f) Sonic 3D 94012345, page 6/6

2421453
 D-K:
 15140-01-00
 05/2024

Page 7 / 10
Seite

Graphical representation of the result
Grafische Darstellung des Ergebnisses

Linear regression analysis for DUT indication $v_{DUT,ref}$

Slope m	$(0.99955 \pm 0.00133) \text{ (m/s)/(m/s)}$
Offset b	$(-0.05134 \pm 0.01423) \text{ m/s}$
Standard error (Y) / RSD	0.01801 m/s
Correlation coefficient R	0.999990
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET

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(g) Sonic 3D 94012345, page 6/6

C.2 Thies cup classification sheet

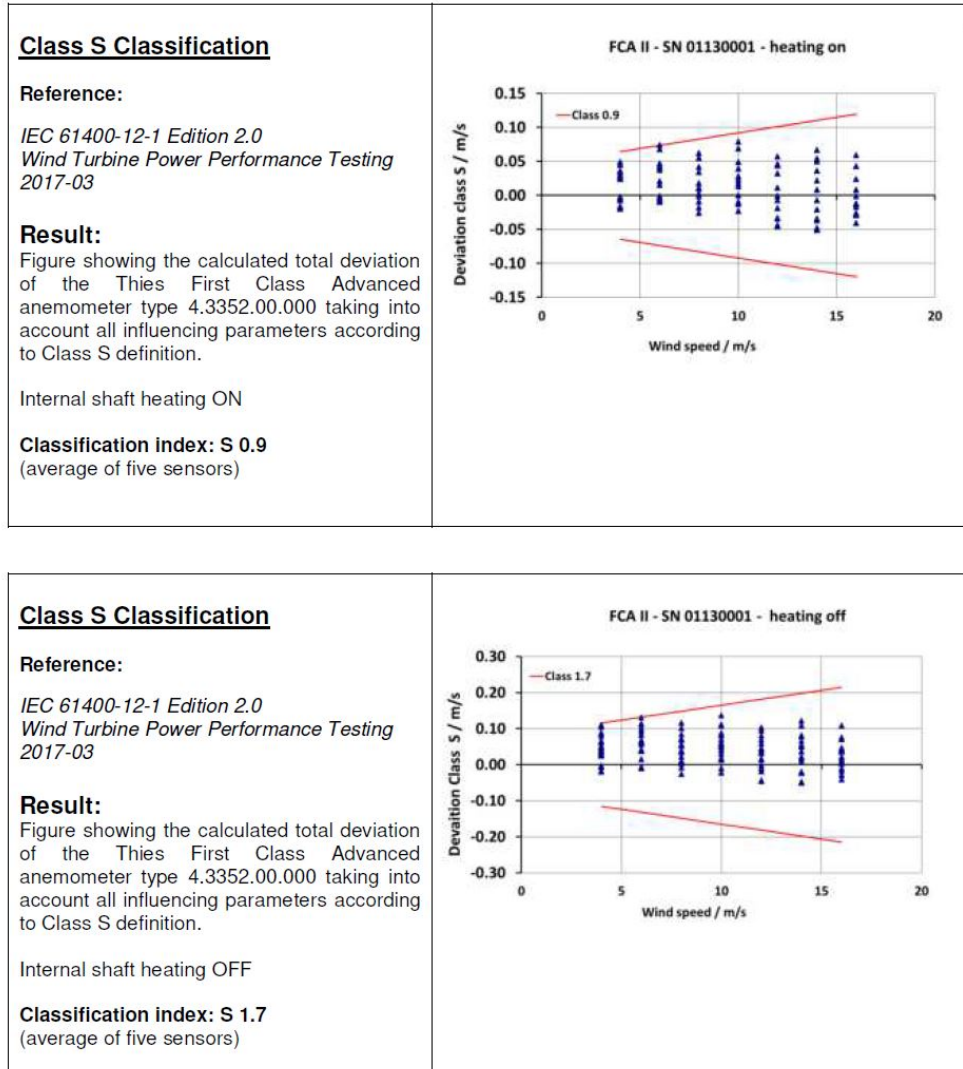


Figure C.1: Thies cup 4.3352 classification report, Class S

Energy & Materials Transition

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