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Period: 12 October 2023 to 5 December 2023

Verification of the Wind@Sea LiDAR system ZX563 at the EWTW test site near meteorological mast MM6

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RvA is participant in the ILAC MRA.

TNO Wind Energy is accredited conform ISO / IEC 17025 and accepted as RETL under IECRE WE.

- Power performance measurements conform to IEC 61400-12-1, MEASNET Power Performance measurement procedure, FGW TR2, FGW TR5
- NTF/NPC measurements conform to IEC 61400-12-2
- Mechanical loads measurements conform to IEC 61400-13
- Meteorological measurements (wind speed, wind direction, temperature, air pressure and relative humidity) conform to IEC 61400-12-1
- Verification of ground-based or nacelle-mounted Remote Sensing Devices conform to IEC 61400-12-1, Appendix L
- Verification of Floating LiDAR Systems conform to IEC 61400-12-1, Appendix L and IEA Recommended Practices 18

Adaptation of scope for remote sensing verification to IEC 61400-50-2 by RvA is currently pending.

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.

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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
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
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 ZX 300M with serial number ZX563 was installed at the EWTW test site near meteorological mast MM6 on 12 October 2023. The LiDAR was validated before using it for wind field measurements at Lichteiland Goeree.

The official measurement campaign started on 12 October 2023 12:20 UTC and lasted until 5 December 2023 00:00 UTC, covering 53 days. The comparison of the LiDAR against meteorological mast MM6 is performed for 3 measurement heights, 42 m, 81 m and 118 m.

For all comparison heights the regression slope is close to 1.00 and the offset is up to 0.05 m/s with an R^2 close to 1. The maximum deviation observed is 2.1 %. The sensitivity analysis did not result in any significant sensitivities for the LiDAR.

The results of this verification are based on IEC 61400-50-2:2022 (formerly Annex L of the IEC 61400-12-1:2017) standard and the TNO *Work instructions for verification RSD* (v.3).

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

1 Introduction

A ZX Lidars ZX 300M with serial number ZX563 was installed at the EWTW test site near MM6 on 12 October 2023. The LiDAR was verified before using it for wind field measurements at Lichteiland Goeree (LEG) in the Wind@Sea project. This report presents the verification results.

After verifying correct operation of the LiDAR, the measurement campaign was started on 12 October 2023 12:20 UTC and lasted until 5 December 2023 00:00 UTC.

The results of this verification are based on the IEC 61400-50-2:2022 [1] (formerly Annex L of the IEC 61400-12-1:2017) standard and the TNO *Work instructions for verification RSD* (v.3).

2 Measurement campaign

2.1 RSD verification location

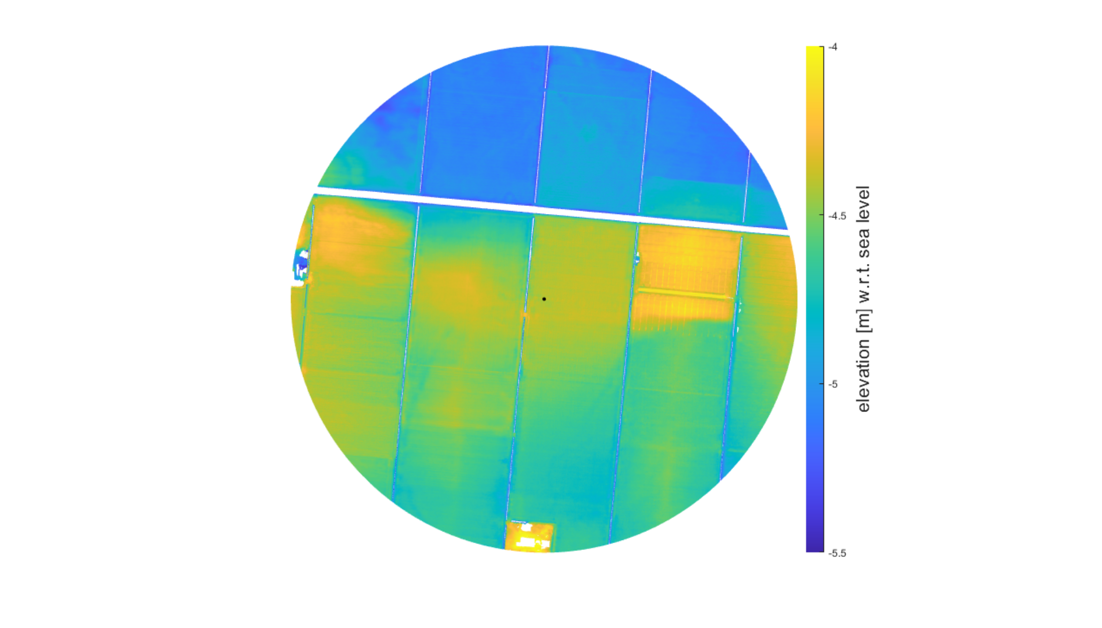
The LiDAR system is verified near meteorological mast MM6 at the EWTW test site [2]. The terrain at the EWTW test site consists mainly of agricultural land, with single farmhouses and rows of trees as shown in fig. 2.1. It is located in the Wieringermeer, a polder in the north east of the province of 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.

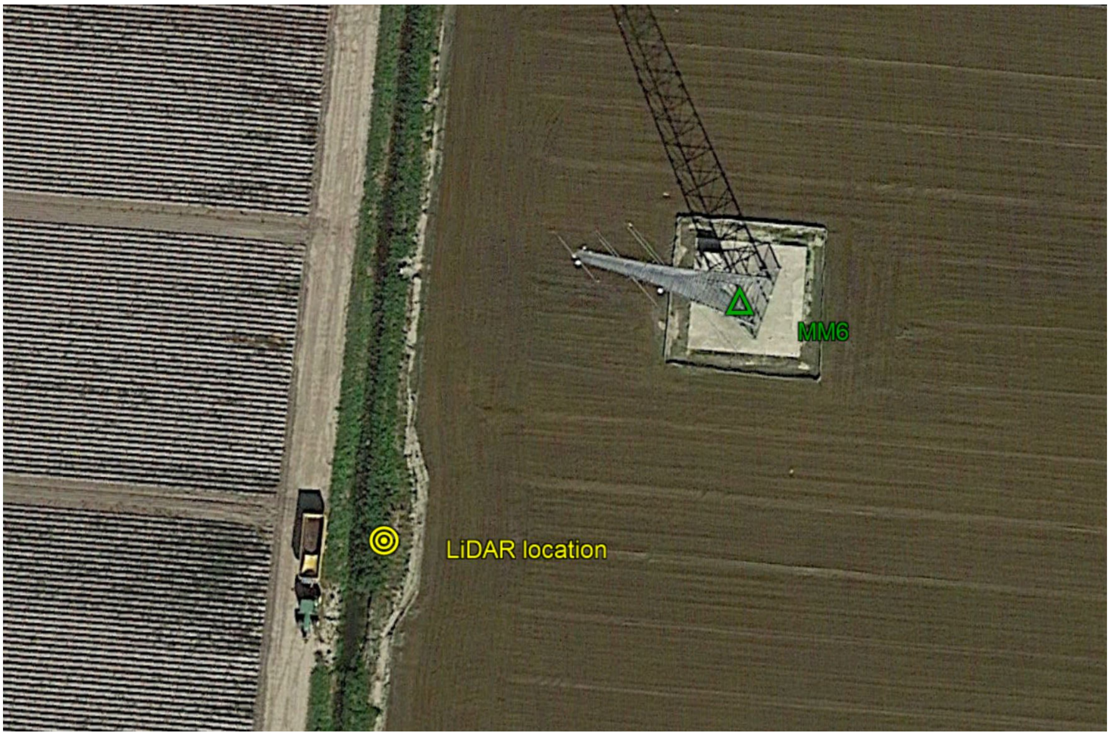
In table 2.1 the coordinates of the meteorological mast and LiDAR locations are summarized.

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 Rijksdriehoeksmeting (Dutch geodetic datum)
WGS 84 world geodetic system 1984

In fig. 2.4 the location of the verification platform 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 the meteorological mast 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.

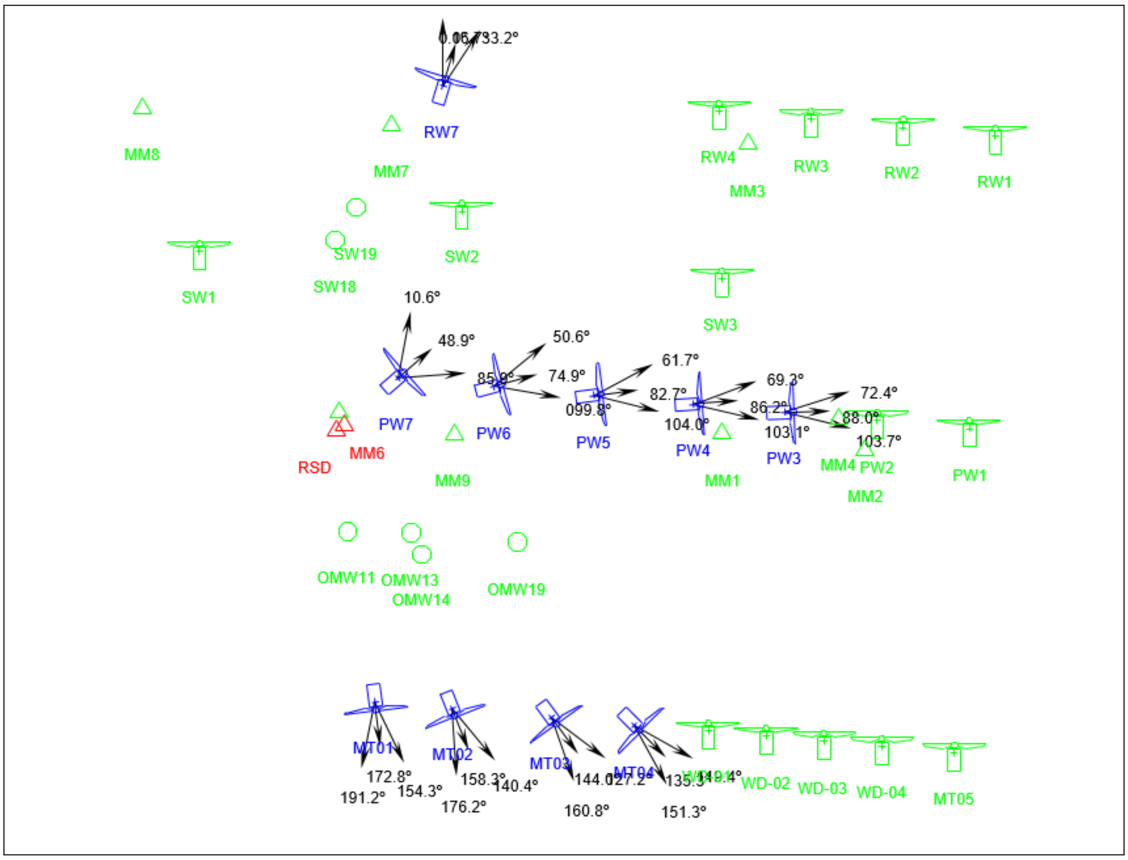


Figure 2.5: Layout of the EWTW test site used to determine the measurement sector

The measurement sector is height dependent as for the boom mounted measuring heights an extra sector is excluded where the wind direction is in line with the boom orientation, 320° +/- 10°, see table 2.2.

Table 2.2: Excluded sectors per measuring height.

Excluded sector	comparison height		
	117.5m	81.4m	41.9m
0.1° to 104.0°	x	x	x
119.4° to 191.2°	x	x	x
310° to 330°		x	x

2.3 Remote Sensing Device

The Remote Sensing Device (RSD) is a ZX 300M LiDAR. This unit has identification number ZX563 (software version 3.3002). It is configured to perform measurements at 10 heights: 21 m, 42 m, 61 m, 81 m, 101 m, 113 m, 118 m, 141 m, 161 m and 181 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.

The ZX 300M LiDAR at the RSD verification location is presented in fig. 2.6.

Table 2.3: Measurement heights for verification

comparison height	MM6 height	LiDAR height
m	m	m
117.5	117.5	118
81.4	81.4	81
41.9	41.9	42

Figure 2.6: ZX 300M ZX563 (right LiDAR in yellow) 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.

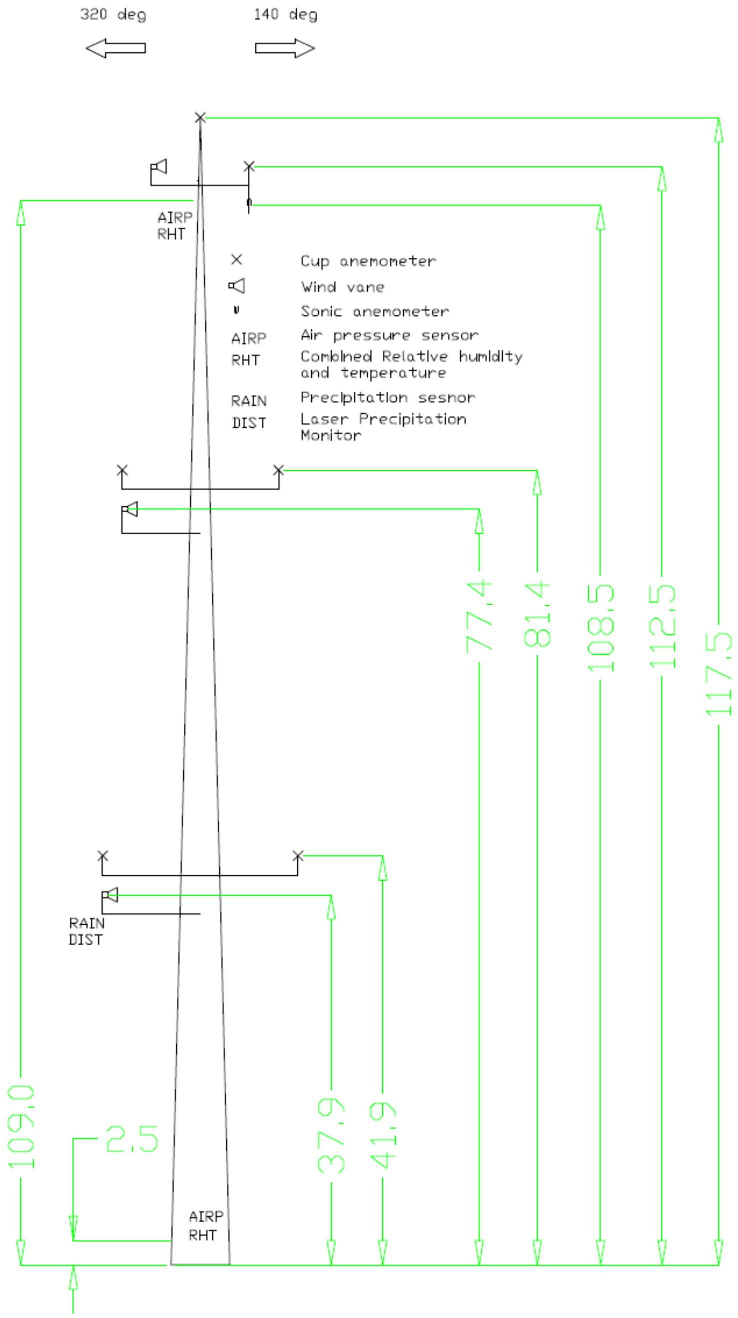


Figure 2.7: Layout of the meteorological mast MM6

3 Data selection

The LiDAR measurement campaign officially starts on 12 October 2023 12:20 and ends on 5 December 2023 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.

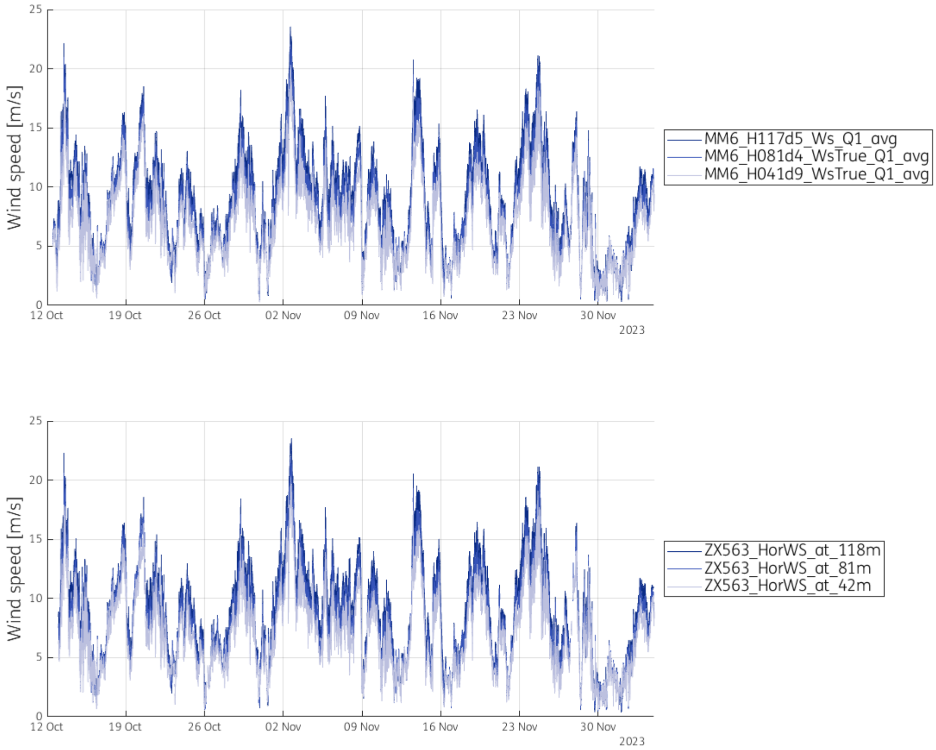


Figure 3.1: Unfiltered wind speed time series for the comparison heights by the reference meteorological mast at the RSD verification location (top) and the LiDAR (bottom)

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 paragraph 2.3 and the filtering is applied to the wind direction measurements at each comparison height individually.

b) *LiDAR free of wakes*
The LiDAR is located 49 m from the base of MM6. At 117.5 m MM6 is inside the (circular) measurement volume of the LiDAR. Due to the cone angle of the LiDAR, the radius of this circle increases with measurement height.

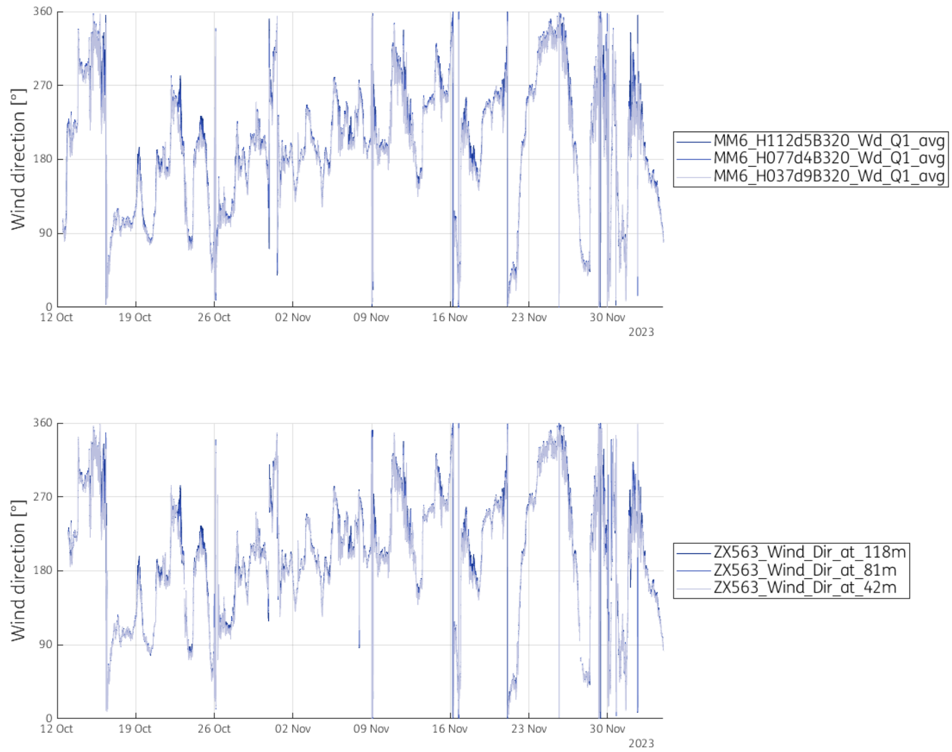


Figure 3.2: Unfiltered wind direction time series for various heights by the reference meteorological mast at the RSD verification location (top) and the LiDAR (bottom)

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.

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*
For the LiDAR system no availability filtering is applied, other than the data that is being rejected by the LiDAR system itself.

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.

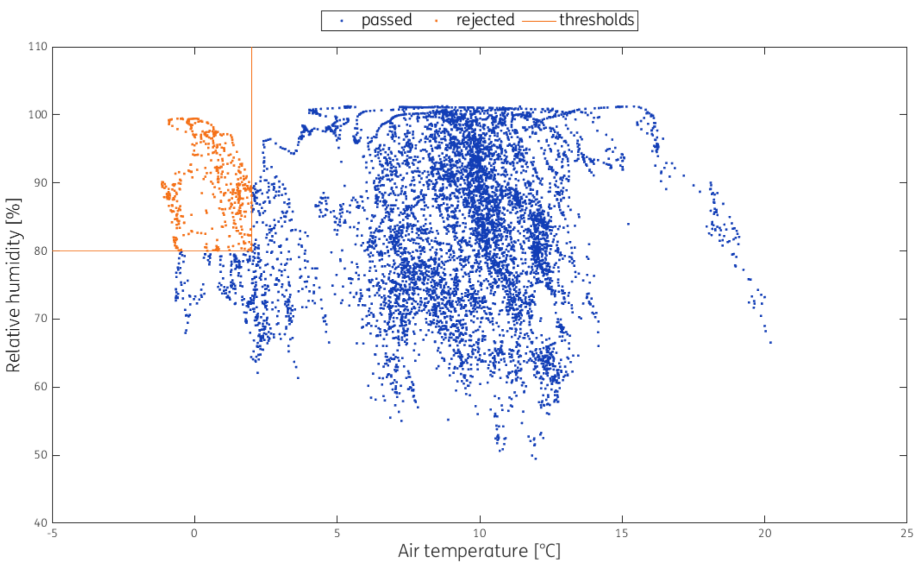


Figure 3.3: Filter: MEASNET icing criterion

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 2.0.13.

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 4 m/s to 16 m/s are used.

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. Because the range is 4 m/s to 16 m/s, the first and last bin are given half the prescribed width and are centred at 4.125 m/s and 15.875 m/s respectively.

The resulting bin count histograms are presented in fig. A.3. Due to the smaller bin width, the first and last bin have a significantly lower bin count.

The resulting 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	0.997	-0.002	1.000
81.4	0.999	-0.032	1.000
41.9	1.006	-0.047	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. These tables covers all the measured environmental variables. However, the DNV-GL classification report [5] for the ZX300 LiDAR names seven significant environmental variables in the conclusion, among which ‘temperature gradient’ is not measured in this verification.

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 speed[1].

[1] For 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.

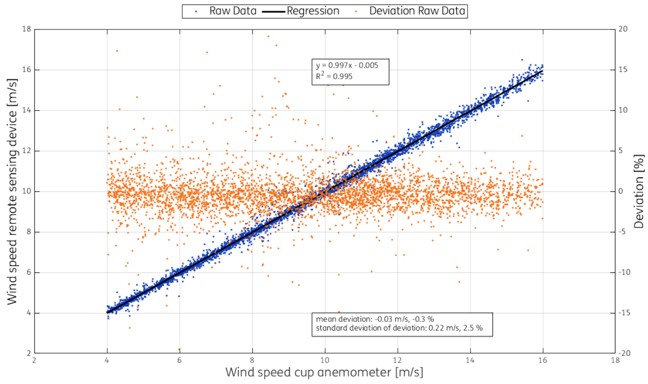


Figure 4.1: Wind speed comparison @117.5 m

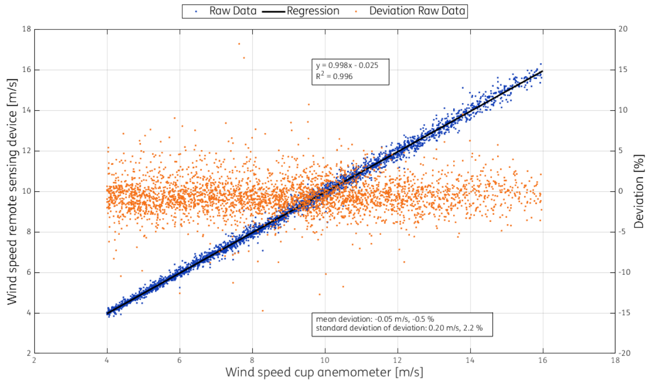


Figure 4.2: Wind speed comparison @81.4 m

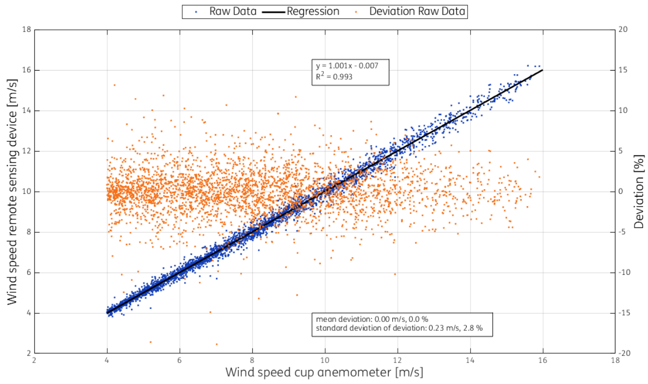


Figure 4.3: Wind speed comparison @41.9 m

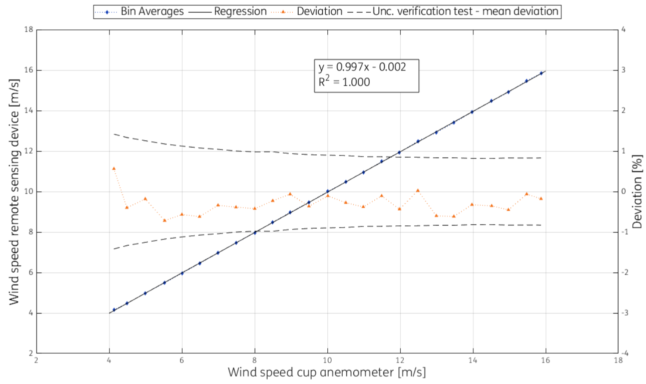


Figure 4.4: Bin-wise wind speed comparison @117.5 m

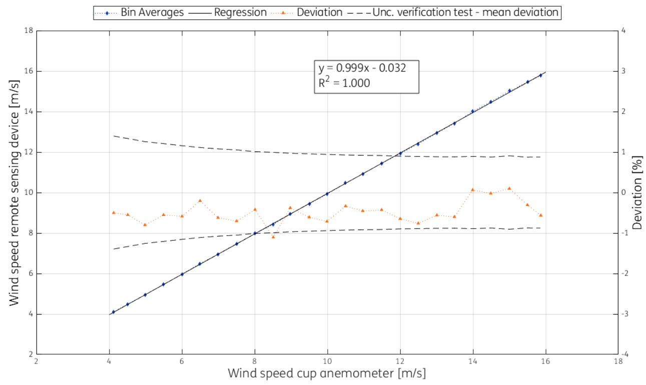


Figure 4.5: Bin-wise wind speed comparison @81.4 m

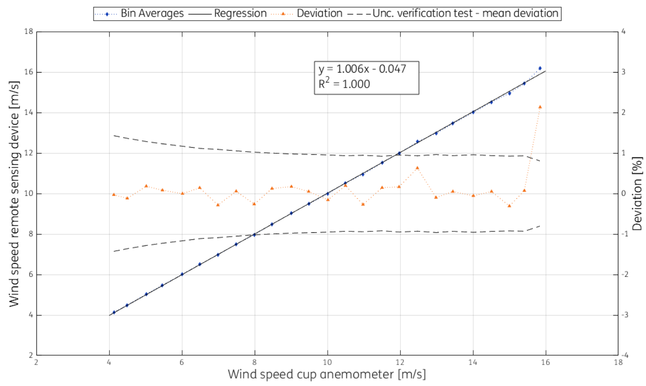


Figure 4.6: Bin-wise wind speed comparison @41.9 m

Table 4.2: Uncertainty calculations of the LiDAR @117.5 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	V_{rsd} $\frac{std}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.13	4.15	66	4.50	3.72	0.118	0.014	0.561	1.355	0.10	1.525
4.49	4.47	198	5.02	3.85	0.189	0.013	-0.400	1.280	0.10	1.392
4.99	4.98	158	5.46	4.15	0.200	0.016	-0.183	1.193	0.10	1.268
5.53	5.49	149	6.10	4.85	0.184	0.015	-0.719	1.120	0.10	1.377
6.00	5.97	169	6.58	4.82	0.208	0.016	-0.568	1.066	0.10	1.257
6.49	6.44	171	7.38	5.76	0.212	0.016	-0.621	1.022	0.10	1.242
6.99	6.97	165	8.03	6.25	0.242	0.019	-0.339	0.982	0.10	1.097
7.49	7.46	173	8.10	6.90	0.222	0.017	-0.386	0.949	0.10	1.072
8.00	7.97	174	8.98	7.13	0.276	0.021	-0.423	0.918	0.10	1.068
8.50	8.48	178	10.22	7.52	0.388	0.029	-0.229	0.893	0.10	1.008
8.97	8.97	161	10.01	8.09	0.294	0.023	-0.066	0.872	0.10	0.938
9.49	9.46	187	10.29	8.21	0.286	0.021	-0.364	0.855	0.10	0.981
10.01	10.00	160	11.46	9.41	0.282	0.022	-0.107	0.841	0.10	0.905
10.51	10.48	198	11.88	8.85	0.332	0.024	-0.277	0.829	0.10	0.930
10.99	10.94	217	11.60	10.21	0.226	0.015	-0.381	0.819	0.10	0.940
11.49	11.48	203	12.49	10.17	0.288	0.020	-0.108	0.809	0.10	0.865
11.98	11.93	163	12.70	11.01	0.261	0.020	-0.438	0.801	0.10	0.955
12.49	12.49	137	13.41	11.88	0.272	0.023	0.022	0.793	0.10	0.845
12.99	12.92	134	13.71	12.18	0.249	0.022	-0.601	0.786	0.10	1.028
13.48	13.39	131	14.20	12.16	0.293	0.026	-0.616	0.780	0.10	1.036
13.97	13.93	112	14.56	13.37	0.228	0.022	-0.325	0.773	0.10	0.882
14.52	14.46	109	15.13	13.93	0.262	0.025	-0.355	0.766	0.10	0.891
14.97	14.91	79	15.74	13.71	0.323	0.036	-0.453	0.761	0.10	0.945
15.48	15.47	77	16.48	14.46	0.336	0.038	-0.065	0.757	0.10	0.829
15.87	15.84	28	16.23	15.45	0.223	0.042	-0.180	0.753	0.10	0.849

Table 4.3: Uncertainty calculations of the LiDAR @81.4 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	V_{rsd} $\frac{std}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.12	4.10	95	4.34	3.81	0.107	0.011	-0.503	1.350	0.10	1.482
4.51	4.49	170	4.91	3.92	0.184	0.014	-0.552	1.277	0.10	1.443
4.98	4.94	191	5.59	4.48	0.185	0.013	-0.802	1.207	0.10	1.491
5.50	5.46	166	6.10	5.08	0.195	0.015	-0.554	1.154	0.10	1.329
6.00	5.97	181	6.57	5.25	0.193	0.014	-0.588	1.109	0.10	1.297
6.50	6.49	161	7.00	6.03	0.200	0.016	-0.206	1.062	0.10	1.131
6.99	6.95	171	7.52	6.24	0.211	0.016	-0.622	1.028	0.10	1.244
7.50	7.45	161	9.03	6.63	0.264	0.021	-0.705	0.991	0.10	1.267
8.01	7.98	180	9.05	7.32	0.227	0.017	-0.424	0.960	0.10	1.094
8.51	8.42	163	9.17	7.07	0.237	0.019	-1.106	0.943	0.10	1.486
8.98	8.94	182	9.83	8.24	0.252	0.019	-0.380	0.920	0.10	1.041
9.50	9.44	223	10.58	8.85	0.242	0.016	-0.609	0.914	0.10	1.134
9.99	9.92	208	10.45	8.46	0.279	0.019	-0.714	0.894	0.10	1.181
10.50	10.46	180	11.37	9.27	0.257	0.019	-0.336	0.881	0.10	0.986
10.97	10.92	177	11.68	10.05	0.267	0.020	-0.455	0.872	0.10	1.026
11.49	11.44	138	12.21	10.55	0.265	0.023	-0.429	0.864	0.10	1.009
12.00	11.92	139	12.76	11.12	0.266	0.023	-0.648	0.849	0.10	1.107
12.50	12.40	120	13.27	11.66	0.258	0.024	-0.762	0.842	0.10	1.173
13.01	12.94	88	13.75	12.49	0.264	0.028	-0.560	0.827	0.10	1.046
13.49	13.41	94	14.10	12.82	0.285	0.029	-0.601	0.825	0.10	1.067
13.99	14.00	73	15.10	13.43	0.331	0.039	0.062	0.818	0.10	0.895
14.49	14.49	61	15.20	13.90	0.281	0.036	-0.022	0.810	0.10	0.877
15.00	15.02	56	15.78	14.14	0.344	0.046	0.096	0.823	0.10	0.911
15.50	15.45	33	15.97	15.01	0.243	0.042	-0.309	0.799	0.10	0.926
15.87	15.78	18	16.28	15.35	0.210	0.050	-0.565	0.791	0.10	1.046

Table 4.4: Uncertainty calculations of the LiDAR @41.9 m

V_{ref}	V_{rsd}	data sets	V_{rsd} max	V_{rsd} min	V_{rsd} std	$V_{\text{rsd}} \frac{\text{std}}{\sqrt{n}}$	mean deviation	V_{ref} unc.	mounting unc. rsd	V_{rsd} unc.
m/s	m/s	#	m/s	m/s	m/s	m/s	%	%	%	%
4.13	4.13	111	4.76	3.82	0.124	0.012	-0.032	1.381	0.10	1.428
4.50	4.49	239	5.04	3.91	0.200	0.013	-0.120	1.313	0.10	1.368
5.02	5.03	202	5.77	4.24	0.207	0.015	0.180	1.229	0.10	1.295
5.47	5.47	193	6.22	4.90	0.218	0.016	0.081	1.173	0.10	1.230
6.02	6.02	193	6.76	5.45	0.233	0.017	-0.004	1.111	0.10	1.167
6.49	6.50	210	7.28	5.82	0.219	0.015	0.141	1.067	0.10	1.124
6.99	6.97	192	7.71	5.70	0.263	0.019	-0.286	1.031	0.10	1.127
7.49	7.50	190	8.12	6.79	0.266	0.019	0.057	0.997	0.10	1.055
7.99	7.97	217	8.76	7.10	0.260	0.018	-0.264	0.971	0.10	1.054
8.48	8.49	186	9.55	7.85	0.287	0.021	0.123	0.940	0.10	1.005
9.01	9.03	190	10.27	8.05	0.295	0.021	0.170	0.921	0.10	0.991
9.48	9.49	151	10.52	8.83	0.281	0.023	0.049	0.910	0.10	0.969
10.01	10.00	138	10.87	8.99	0.311	0.026	-0.158	0.888	0.10	0.966
10.50	10.52	139	11.29	9.74	0.293	0.025	0.196	0.875	0.10	0.954
10.98	10.95	125	11.87	9.88	0.343	0.031	-0.273	0.874	0.10	0.983
11.50	11.52	113	12.25	10.73	0.328	0.031	0.144	0.852	0.10	0.932
11.97	11.99	85	13.06	10.71	0.396	0.043	0.164	0.854	0.10	0.967
12.47	12.55	70	13.25	11.71	0.339	0.040	0.627	0.844	0.10	1.123
12.99	12.97	49	13.81	12.21	0.376	0.054	-0.100	0.840	0.10	0.968
13.45	13.45	50	14.36	12.68	0.347	0.049	0.049	0.831	0.10	0.936
14.01	14.00	39	14.72	13.39	0.380	0.061	-0.058	0.824	0.10	0.960
14.51	14.52	30	15.28	13.76	0.326	0.059	0.050	0.812	0.10	0.938
15.00	14.95	30	15.76	14.40	0.333	0.061	-0.310	0.800	0.10	0.975
15.41	15.42	18	16.21	15.03	0.286	0.067	0.070	0.791	0.10	0.934
15.85	16.19	2	16.19	16.18	0.007	0.005	2.132	0.770	0.10	2.278

Table 4.5: Environmental conditions @117.5 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	–	%	%	°	°C	%	kg/m³	°	°/m
4.125	0.1715	7.23	7.13	241.8	8.27	82.29	1.230	0.912	-0.2343
4.500	0.2201	7.18	11.57	248.5	8.32	81.43	1.231	0.830	-0.2193
5.000	0.2324	6.85	13.08	248.2	8.43	80.76	1.228	0.969	-0.1773
5.500	0.2839	8.12	11.83	257.1	8.40	81.20	1.226	1.002	-0.1747
6.000	0.2959	8.11	7.34	254.5	8.74	81.53	1.221	0.942	-0.1499
6.500	0.2954	7.94	7.68	255.2	8.82	81.23	1.221	0.989	-0.1358
7.000	0.2869	8.56	11.96	255.4	8.95	80.84	1.223	1.049	-0.1052
7.500	0.2883	8.09	11.28	242.7	9.34	81.88	1.218	1.053	-0.1055
8.000	0.2808	8.83	16.94	257.9	9.40	79.26	1.219	1.133	-0.1044
8.500	0.2884	9.11	14.85	254.2	9.68	79.39	1.217	1.123	-0.1016
9.000	0.2783	8.56	16.01	239.0	9.69	81.85	1.215	1.113	-0.0952
9.500	0.2715	9.14	20.68	241.1	9.57	80.48	1.216	1.079	-0.0771
10.000	0.2760	8.98	19.71	240.1	9.58	80.44	1.219	1.148	-0.0706
10.500	0.2566	8.99	15.94	235.8	9.74	82.64	1.216	1.052	-0.0599
11.000	0.2568	8.97	15.29	240.0	9.64	81.27	1.217	0.988	-0.0540
11.500	0.2441	9.77	18.13	236.0	9.94	82.44	1.213	1.002	-0.0483
12.000	0.2339	10.02	24.39	236.4	10.06	81.71	1.211	0.965	-0.0427
12.500	0.2320	10.10	18.56	248.0	9.73	80.07	1.213	1.071	-0.0432
13.000	0.2281	10.16	23.75	245.3	9.98	82.16	1.211	1.062	-0.0379
13.500	0.2221	10.57	20.14	249.1	10.39	81.51	1.209	1.145	-0.0369
14.000	0.2237	10.62	22.66	248.5	10.31	82.36	1.212	1.193	-0.0364
14.500	0.2213	10.32	25.34	239.4	10.68	82.52	1.207	1.144	-0.0346
15.000	0.2104	10.15	18.76	233.3	10.69	81.89	1.204	1.035	-0.0341
15.500	0.2149	10.73	18.01	237.3	11.83	80.69	1.201	1.092	-0.0336
15.875	0.2253	10.47	7.53	230.4	12.98	77.80	1.194	1.064	-0.0332

Table 4.6: Environmental conditions @81.4 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	–	%	%	°	°C	%	kg/m³	°	°/m
4.125	0.1668	8.08	7.23	237.0	8.07	80.40	1.231	0.889	-0.1978
4.500	0.2072	7.66	18.01	235.6	8.58	81.72	1.227	0.923	-0.1769
5.000	0.2401	7.92	12.12	239.2	8.53	80.40	1.227	0.966	-0.1592
5.500	0.2689	8.63	8.83	239.8	8.70	81.64	1.222	0.844	-0.1445
6.000	0.2649	8.65	9.77	240.5	8.87	82.37	1.221	0.865	-0.1178
6.500	0.2677	8.93	12.35	240.3	8.86	80.89	1.219	0.983	-0.1168
7.000	0.2837	9.92	12.87	245.3	9.50	80.31	1.217	1.039	-0.0993
7.500	0.2655	9.95	15.29	241.7	9.52	80.93	1.218	1.020	-0.0931
8.000	0.2756	9.41	17.05	230.8	9.83	81.76	1.214	0.994	-0.1045
8.500	0.2726	9.57	19.06	236.0	9.87	79.42	1.214	1.033	-0.0909
9.000	0.2584	10.34	21.27	232.4	9.76	81.85	1.215	1.078	-0.0718
9.500	0.2665	10.26	13.63	236.5	9.92	80.98	1.217	1.051	-0.0583
10.000	0.2481	10.65	17.16	231.2	9.59	83.28	1.216	0.996	-0.0553
10.500	0.2348	11.35	24.90	228.8	9.60	83.72	1.214	0.936	-0.0445
11.000	0.2290	10.94	17.78	229.1	10.08	82.20	1.211	0.862	-0.0410
11.500	0.2145	11.36	24.49	232.5	10.08	81.19	1.211	0.912	-0.0406
12.000	0.2162	11.80	19.39	239.7	10.65	82.32	1.207	1.053	-0.0360
12.500	0.2263	11.66	22.27	238.3	10.64	83.25	1.207	1.073	-0.0373
13.000	0.2125	12.07	26.85	237.8	11.14	83.45	1.203	1.054	-0.0347
13.500	0.2198	11.83	15.91	237.8	11.37	82.69	1.205	1.130	-0.0342
14.000	0.2158	11.76	20.63	221.3	11.79	81.61	1.197	1.014	-0.0350
14.500	0.2054	11.72	10.10	222.7	12.97	79.52	1.193	0.915	-0.0350
15.000	0.2056	12.22	12.04	244.9	11.71	78.34	1.203	0.857	-0.0361
15.500	0.2042	12.54	1.12	253.7	13.17	76.39	1.198	1.212	-0.0341
15.875	0.2094	13.09	8.47	250.9	13.11	78.27	1.198	1.308	-0.0287

Table 4.7: Environmental conditions @41.9 m

wind speed	shear exponent	turbulence intensity	precipitation	wind direction	air temperature	relative humidity	air density	flow inclination	wind veer
m/s	–	%	%	°	°C	%	kg/m³	°	°/m
4.125	0.1756	8.88	12.58	232.0	8.53	79.26	1.227	0.931	-0.2117
4.500	0.1938	9.45	11.82	234.9	8.60	80.66	1.225	1.041	-0.1755
5.000	0.2207	10.22	12.31	228.8	8.62	81.86	1.222	0.879	-0.1226
5.500	0.2485	11.14	10.50	228.5	9.22	82.68	1.218	0.887	-0.0901
6.000	0.2614	11.83	11.21	236.4	9.49	81.27	1.216	1.052	-0.1010
6.500	0.2634	11.37	14.26	230.9	9.67	79.80	1.216	1.040	-0.1085
7.000	0.2496	11.68	14.19	225.6	9.97	79.14	1.215	1.069	-0.0983
7.500	0.2598	12.80	25.01	229.3	9.64	81.02	1.216	1.055	-0.0665
8.000	0.2582	12.53	15.03	234.7	9.76	81.10	1.218	1.031	-0.0529
8.500	0.2355	13.18	27.27	225.0	9.48	84.70	1.216	0.971	-0.0487
9.000	0.2375	13.64	23.24	235.3	9.66	82.31	1.214	0.993	-0.0446
9.500	0.2209	13.25	20.83	225.0	9.81	84.29	1.212	0.892	-0.0411
10.000	0.2238	13.52	26.73	232.9	10.46	82.13	1.209	1.024	-0.0410
10.500	0.2161	13.70	18.98	235.5	10.67	82.32	1.208	1.017	-0.0354
11.000	0.2100	13.91	19.71	240.4	10.86	82.71	1.207	1.083	-0.0337
11.500	0.2136	13.91	17.45	232.8	11.58	81.36	1.201	1.078	-0.0342
12.000	0.2065	13.98	17.31	238.1	11.74	79.96	1.202	1.141	-0.0334
12.500	0.2096	13.69	22.03	237.0	12.09	80.76	1.200	1.128	-0.0355
13.000	0.1964	14.10	9.23	221.1	12.37	78.28	1.198	0.885	-0.0340
13.500	0.1909	13.57	4.03	241.2	12.25	77.42	1.200	0.891	-0.0324
14.000	0.1937	14.20	13.17	255.6	12.13	77.01	1.203	1.186	-0.0289
14.500	0.1953	13.80	3.76	254.7	12.24	75.68	1.203	1.214	-0.0292
15.000	0.1897	14.09	17.11	247.7	13.32	78.28	1.197	1.203	-0.0295
15.500	0.1918	13.94	10.09	248.4	13.00	77.47	1.196	1.282	-0.0308
15.875	0.2034	15.01	76.83	219.9	18.76	81.32	1.169	1.361	-0.0330

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 4 m/s to 16 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.

$$\text{deviation} = \frac{v_{\text{ref}} - v_{\text{rsd}}}{v_{\text{rsd}}} \tag{5.1}$$

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 [6] 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

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

2. **Reference turbulence intensity [-]**
   The reference turbulence intensity, measured on the meteorological mast, is defined by

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

   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/m^3]**
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

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

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.

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

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.

$$n_i > \frac{N}{2 \cdot n_b} \tag{5.6}$$

The sensitivity, presented in column 'sens.', is defined by

$$\text{sensitivity} = m \cdot \text{std} \tag{5.7}$$

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 red. 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 none of the environmental variables result 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.

The last column of table 5.3 represents the contribution to the preliminary accuracy class for each EV. From this we can draw the conclusion that shear has the highest influence on the accuracy.

Table 5.2: Sensitivity to environmental variables for the LiDAR

variable	unit	height	avg	std	m	sens.	R^2	sens.$\times R$
		m	unit	unit	%/unit	%	-	%
shear exponent		41.9	0.24	0.08	0.893	0.070	0.002	0.003
		81.4	0.25	0.08	−4.849	−0.396	0.034	−0.073
		117.5	0.26	0.09	−5.122	−0.461	0.038	−0.090
turbulence intensity	%	41.9	12.09	2.43	0.050	0.121	0.003	0.006
		81.4	9.63	2.85	0.051	0.144	0.005	0.010
		117.5	8.49	2.69	0.054	0.145	0.005	0.010
precipitation†	%	41.9	16.83	32.74	0.003	0.096	0.000	0.000
		81.4	16.28	32.53	0.007	0.212	0.001	0.005
		117.5	15.87	31.96	0.010	0.310	0.006	0.023
wind direction	°	41.9	232.76	48.70	0.000	0.019	0.000	0.000
		81.4	236.68	50.53	−0.005	−0.271	0.032	−0.049
		117.5	245.91	53.94	−0.005	−0.291	0.023	−0.044
air temperature	°C	41.9	9.70	2.42	0.010	0.025	0.000	0.000
		81.4	9.58	2.41	0.034	0.082	0.000	0.001
		117.5	9.37	2.37	−0.009	−0.020	0.000	0.000
relative humidity	%	41.9	81.55	9.65	0.011	0.101	0.000	0.002
		81.4	81.65	9.73	0.016	0.152	0.007	0.013
		117.5	81.26	9.82	0.032	0.314	0.024	0.049
air density	kg/m^3	41.9	1.21	0.02	−5.408	−0.100	0.001	−0.002
		81.4	1.21	0.02	−6.244	−0.113	0.005	−0.008
		117.5	1.22	0.02	−3.983	−0.073	0.005	−0.005
flow inclination	°	41.9	1.04	0.51	0.160	0.081	0.000	0.001
		81.4	0.99	0.54	−0.359	−0.194	0.009	−0.018
		117.5	1.07	0.55	−0.314	−0.173	0.006	−0.013
wind veer	°/m	41.9	−0.05	0.03	3.257	0.100	0.001	0.003
		81.4	−0.06	0.04	8.162	0.327	0.022	0.049
		117.5	−0.06	0.04	6.337	0.257	0.016	0.032
reference wind speed	m/s	41.9	7.39	2.09	0.002	0.003	0.000	0.000
		81.4	8.47	2.60	−0.002	−0.006	0.000	0.000
		117.5	9.23	3.00	−0.004	−0.013	0.000	0.000

- The sensitivity, computed as $m \times$ 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 (sensitity $\times$ 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.

† These variables employ 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	$m\times$ range
		unit	*unit*	*unit*	*unit*	m	%	%
shear exponent		-0.4	0.8	0.05	1.2	41.9	33	1.072
						81.4	33	−5.818
						117.5	38	−6.146
turbulence intensity	%	3	24	1	21	41.9	52	1.047
						81.4	57	1.064
						117.5	52	1.130
precipitation	%	0	100	10	100	41.9	100	0.294
						81.4	100	0.653
						117.5	100	0.968
wind direction	°	0	360	5	180	41.9	42	0.071
						81.4	43	−0.966
						117.5	49	−0.971
air temperature	°C	0	40	2	40	41.9	30	0.404
						81.4	30	1.356
						117.5	30	−0.344
relative humidity	%	0	100	10	100	41.9	40	1.051
						81.4	40	1.560
						117.5	40	3.194
air density	kg/m^3	0.9	1.35	0.05	0.45	41.9	22	−2.433
						81.4	22	−2.810
						117.5	22	−1.792
flow inclination	°	-3	3	0.2	6	41.9	40	0.959
						81.4	43	−2.155
						117.5	43	−1.884
wind veer	°/m	-0.3	0.1	0.04	0.4	41.9	40	1.303
						81.4	50	3.265
						117.5	50	2.535
reference wind speed	m/s	4	16	0.5	12	41.9	62	0.019
						81.4	79	−0.026
						117.5	92	−0.051

- 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 LiDAR sensitivity study

variable	unit	height	min	Q1	median	Q3	max
		m	*unit*	*unit*	*unit*	*unit*	*unit*
shear exponent		41.9	−2.00	0.14	0.22	0.29	1.31
		81.4	−2.00	0.14	0.22	0.29	1.31
		117.5	−2.00	0.14	0.22	0.29	1.31
turbulence intensity	%	41.9	1.68	10.30	12.40	14.07	41.72
		81.4	1.83	7.73	10.12	12.18	43.54
		117.5	1.44	6.42	8.71	10.99	48.66
precipitation	%	41.9	0.00	0.00	0.00	0.00	100.00
		81.4	0.00	0.00	0.00	0.00	100.00
		117.5	0.00	0.00	0.00	0.00	100.00
air temperature	°C	41.9	−1.15	7.07	9.39	10.99	20.20
		81.4	−1.15	7.07	9.39	10.99	20.20
		117.5	−1.15	7.07	9.39	10.99	20.20
relative humidity	%	41.9	49.48	75.08	84.14	92.93	101.26
		81.4	49.48	75.08	84.14	92.93	101.26
		117.5	49.48	75.08	84.14	92.93	101.26
air density	kg/m^3	41.9	1.17	1.20	1.22	1.24	1.28
		81.4	1.17	1.20	1.22	1.24	1.28
		117.5	1.17	1.20	1.22	1.24	1.28
flow inclination	°	41.9	−22.33	0.17	0.80	1.30	24.14
		81.4	−22.33	0.17	0.80	1.30	24.14
		117.5	−22.33	0.17	0.80	1.30	24.14
wind veer	°/m	41.9	−2.19	−0.11	−0.05	−0.03	2.05
		81.4	−2.19	−0.11	−0.05	−0.03	2.05
		117.5	−2.19	−0.11	−0.05	−0.03	2.05
reference wind speed	m/s	41.9	4.00	5.87	7.83	10.13	15.90
		81.4	4.00	6.38	8.88	11.11	15.96
		117.5	4.00	6.74	9.43	11.84	15.99

- The lower and upper quartiles are indicated by Q1 and Q3. The minimum, median and maximum values represent Q0, Q2 and Q4. These quartiles indicate below what value 0 %, 25 %, 50 %, 75 % and 100 % of the data is found.
- The filters described in section 3.1 are only applied to the wind-related variables: rsd availability, reference wind speed, wind direction and - by extension - shear exponent, wind veer and turbulence intensity. All other variables are not filtered.
- All wind-related variables data is discarded when the wind speed is less than 2 m/s. At very low wind speeds, differences in the measured wind speed between the LiDAR and the reference meteorological mast lead to high percentage deviations that could skew the sensitivity regression. This filtering also causes the reference wind speed variable to not contain values below 2 m/s.
- Wind direction is omitted from this table, because it is a directional quantity.

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 B.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 B.2 for the classification results according the IEC 61400-50-1:2022 [7]. The uncertainty in the wind speed due to operational characteristics therefore is

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

3. Mounting effects
   The default values for the uncertainty associated with the mounting of the anemometer on mast are specified in Annex E.6.3.5 [8]. At the height of 117.5 m a top mounted anemometers is used, for which the default uncertainty is

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

   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 %.

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

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.

$$u_{\mathrm{f}} = 0.1\,\% \cdot F + 0.5\,\mathrm{Hz}.$$

Table B.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

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

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).

   $$\text{standard uncertainty}_i = \frac{\sigma_{v_i}}{\sqrt{n_i}} \tag{6.1}$$

   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 [8, p.74].

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

   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 [9] based on the terrain information shown in fig. 2.2.

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

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. For this verification campaign the following deviations are noted.

1. The highest wind bin for comparison height 41.9 m is included in the analysis with an insufficient bin count of 2, as the minimum requirement is 3 data sets per wind bin. This low bin count explains the high deviation in fig. 4.6.

8 Conclusions

The Wind@Sea LiDAR ZX 300M ZX563 is validated against reference meteorological mast MM6 at the RSD verification location at the EWTW test site in the Wieringermeer. In this campaign the LiDAR is validated at three measurement heights ranging from 42 m to 118 m.

During the measurement campaign that ran from 12 October 2023 12:20 UTC until 5 December 2023 00:00, spanning 53 days, all data coverage requirements of the IEC 61400-50-2:2022 are met, except for the highest wind speed bin for the lowest measuring height, 42 m, for which the bin count is 2 instead of the minimum required bin count of 3.

For all comparison heights the regression slope is close to 1.00 and the offset is up to 0.05 m/s with an R^2 close to 1. The LiDAR system underestimates the wind speed by up to 2.1 %. The sensitivity analysis did not result in any significant sensitivities for the LiDAR. For the air density at all comparison heights the range covered was insufficient.

References

[1] IEC 61400-50-2:2022-08. *Wind energy generation systems – Part 50-2: Wind measurement – Application of ground-mounted remote sensing technology*. Aug. 2022.

[2] G. Bergman and J. P. Verhoef. *TNO Ground Based RSD Verification Facility*. TNO 2020 R10781. TNO, July 2020.

[3] IEC 61400-12-5:2022-10. *Wind energy generation systems – Part 12-5: Power performance – Assessment of obstacles and terrain*. Oct. 2022.

[4] *Power performance measurement procedure - Version 5*. MEASNET, Dec. 2009.

[5] T. Rafael. *TYPE ZX300 LIDAR - Remote Sensing Device Type-specific Classification Summary*. GLGH-4275 18 14741 258-R-0003. Version Rev. D. DNV GL - Energy, Nov. 9, 2018.

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

[7] IEC 61400-50-1:2022-11. *Wind energy generation systems – Part 50-1: Wind measurement – Application of meteorological mast, nacelle and spinner mounted instruments*. Nov. 2022.

[8] IEC 61400-12-1:2022-09. *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*. Sept. 2022.

[9] D. A. J. Wouters. *Non-homogeneous flow within a lidar measurement volume at EWTW*. TNO 2019 M10109. ECN part of TNO, Jan. 2019.

[10] G. Bergman, J. Schoorl, and F. Danzl. *Meteorological Mast 6 (lowered 2022) at EWTW, Instrumentation Report*. TNO 2022 R10731. TNO, Nov. 2022.

Signature

	Date: March 2024	Report number: TNO 2024 R10316
Title	Verification of the Wind@Sea LiDAR system ZX563 at the EWTW test site near meteorological mast MM6 Period: 12 October 2023 to 5 December 2023	
Author(s)	C. Liu and G. Bergman	
Principal(s)	Ministry of Economic Affairs and Climate (EZK)	
Project number	060.55419	
Programme(s)	Wind Energy	

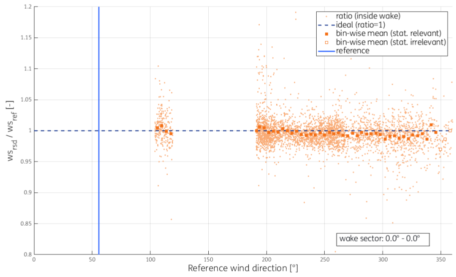
Abstract
As part of a LiDAR verification campaign a ZX Lidars LiDAR with serial number ZX563 was deployed near MM6 at the EWTW test site in the Wieringermeer. This report describes the verification campaign for the LiDAR.

Keywords	Wind@Sea, ZX 300M, ECN Wind Turbine test site Wieringermeer, LEG, LiDAR, verification

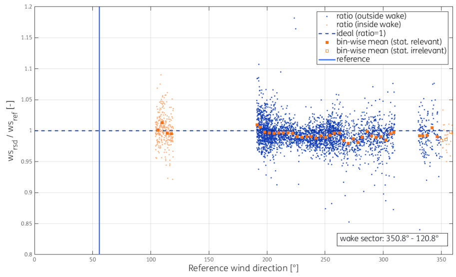
Task	Name	Role	Signature
Author	C. Liu	Data analyst	ValidSigned by Chao Liu on 2024-03-04 13:46:47
Expert review	D.A.J. Wouters	Data analyst	ValidSigned by Dennis Wouters on 2024-03-04 13:46:56
Generic review	C.B.H. Eeckels	Project manager	ValidSigned by Catherine Eeckels on 2024-03-07 09:57:54
Approval	R.H.M. Giepman	Deputy research manager	ValidSigned by Rogier Giepman on 2024-03-07 17:02:42
Authorization	E.D. Nennie	Research manager	ValidSigned by Erik Nennie on 2024-03-06 14:29:25

Appendix A
IEC visualisations

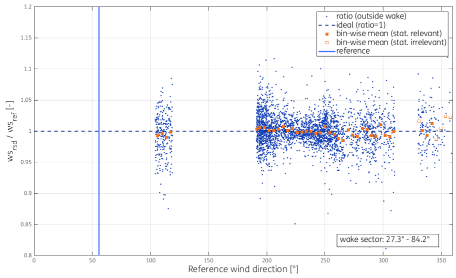
This appendix contains visualizations associated with the IEC analysis reported in chapters 4 and 5 that are not a reporting requirement.



(a) 118 m

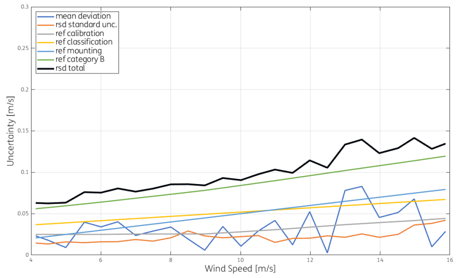


(b) 81 m

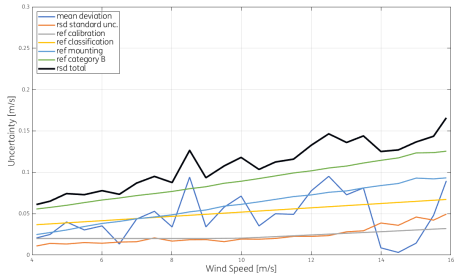


(c) 42 m

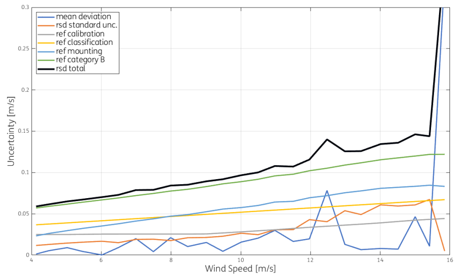
Figure A.1: Influence of the wake of meteorological mast on the LiDAR. The ratio of the wind speed measured by the LiDAR (rsd) and the reference meteorological mast MM6 (ref) is plotted against the wind direction measured by the reference meteorological mast. The blue line marks the direction for which 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.



(a) 118 m

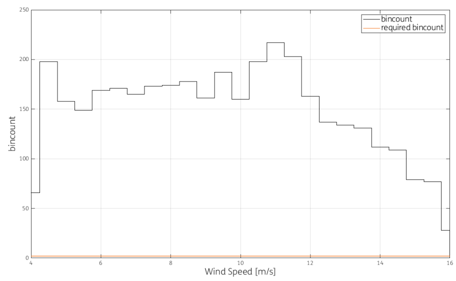


(b) 81 m

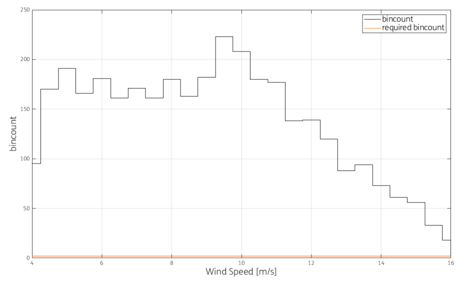


(c) 42 m

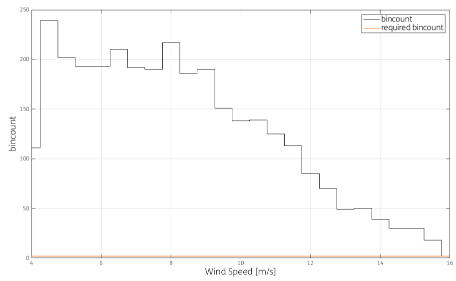
Figure A.2: Contributions to the LiDAR uncertainty



(a) 118 m



(b) 81 m



(c) 42 m

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

Appendix B
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 [10].

At the meteorological mast measurement heights, as seen in fig. 2.7, the meteorological mast measurements are compared to the LiDAR measurements. Table B.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 B.2. Other statistics are based on pseudo signals, presented in table B.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 B.3. This table also presents installation and calibration due dates.

Table B.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 B.2: List of measured signals

name	location	short name	sensor	unit	installed	rate Hz	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 B.3: List of equipment used per signal

Signal	Sensor						Module				
short name	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	4.579e-2	2.375e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H112d5B140_Ws_Q1_m	Thies 4.3352.00.000	94025512	4.588e-2	2.243e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H081d4B140_Ws_Q1_m	Thies 4.3352.00.000	94025502	4.577e-2	2.330e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H081d4B320_Ws_Q1_m	Thies 4.3352.00.000	94025517	4.579e-2	2.350e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H041d9B140_Ws_Q1_m	Thies 4.3352.00.000	94025504	4.593e-2	2.172e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H041d9B320_Ws_Q1_m	Thies 4.3352.00.000	94025506	4.572e-2	2.376e-1	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	2026-12-11
MM6_H112d5B320_Wd_Q1_m	Thies 4.3150.00.400	94012542	1.000e-1	2.528e+2	2024-06-21	2023-06-21	NI 9871	94012138	1.000	0.000	N/A
MM6_H077d4B320_Wd_Q1_m	Thies 4.3150.00.400	94012052	1.000e-1	-1.510e+1	2024-06-21	2023-06-21	NI 9871	94012138	1.000	0.000	N/A
MM6_H037d9d9B320_Wd_Q1_m	Thies 4.3150.00.400	94012461	1.000e-1	-3.162e+2	2024-06-21	2023-06-21	NI 9871	94012138	1.000	0.000	N/A
MM6_H109_Temp_Q1_m	Vaisala HMP155	94012136	1.000e-2	0.000	2024-06-21	2023-06-21	NI 9871	94012165	1.000	0.000	N/A
MM6_H109_RH_Q1_m	Vaisala HMP155	94012136	1.000e-2	0.000	2024-06-21	2023-06-21	NI 9871	94012165	1.000	0.000	N/A
MM6_H109_Pair_Q1_m	Vaisala PTB210	94012651	1.000e-2	0.000	2024-06-21	2023-06-21	NI 9871	94012138	1.000	0.000	N/A
MM6_H040_Prec_Q1_m	Thies 5.4103.10.000	94012476	1.000	0.000	2024-06-21	2023-06-21	NI 9423	94011863	1.000	0.000	N/A
MM6_H036_Prec_Disdro_Q1_m	Thies 5.4110.00.300	94012652	1.000e-3	0.000	2024-10-14	2019-10-14	NI 9871	94012164	1.000	0.000	N/A
MM6_H108d5B140_WsUS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2023-11-28	2020-09-02	NI 9871	94012165	1.000	0.000	N/A
MM6_H108d5B140_WsVS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2023-11-28	2020-09-02	NI 9871	94012165	1.000	0.000	N/A
MM6_H108d5B140_WsWS_Q1_m	Metek 3D ultrasonic	94012039	1.000e-2	0.000	2023-11-28	2020-09-02	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). Note that the campaign end date exceeded the due date of the sonic anemometer. The sensor has been replaced on 27th Feb. 2024.

Table B.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 MM6_H081d4B320_Ws_MFDC_Q1_m	B.1
wind speed, 41.9 m	MM6_H041d9_Ws_True_Q1	m/s	4	*	MM6_H037d9_Wd_Q1 MM6_H041d9B140_Ws_MFDC_Q1_m MM6_H041d9B320_Ws_MFDC_Q1_m	B.2
horizontal wind speed, sonic, 108.5 m	MM6_H108d5B140_WsHor_Q1	m/s	4	*	MM6_H108d5B140_WsUSon_Q1_m MM6_H108d5B140_WsVSon_Q1_m	B.3

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

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

$$f(\#1,\#2) = \sqrt{\#1^2 + \#2^2} \tag{B.3}$$

B.1 Calibration sheets

B.1.1 Cup anemometer

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

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

Member of / *Mitglied im*
Deutschen Kalibrierdienst

DKD

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

Calibration mark
Kalibrierzeichen

2211676 | D-K-15140-01-00 | 04/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201553
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100333110
Project No. *Projektnummer*	VT220163
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	13.04.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
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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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
13.04.2022	Heiko Westermann, B. Sc.	Marcel Beierling, B. Eng.

(a) Cup anemometer 94025503, page 1/4

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Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	P_9.1.0

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(22.4 ± 0.4) °C – (22.8 ± 0.4) °C
	air pressure	(1015.4 ± 0.4) hPa – (1015.5 ± 0.4) hPa
	relative air humidity	(34.7 ± 6.0) % – (35.4 ± 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: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

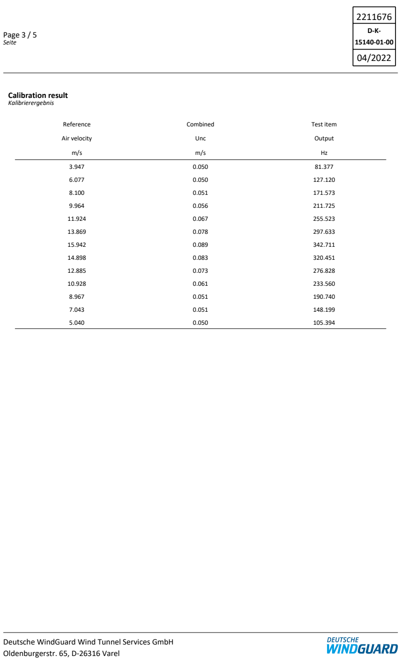
Certificate ID *Zertifikat ID*: 9vcUAGdWfwQUsZkXibZjPb

Additional remarks *Zusätzliche Anmerkungen*: Calibration after refurbishment

Revision *Revision*: 0

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

(b) Cup anemometer 94025503, page 2/4



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2211676 | D-K-15140-01-00 | 04/2022

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.947	0.050	81.377
6.077	0.050	127.120
8.100	0.051	171.573
9.964	0.056	211.725
11.924	0.067	255.523
13.869	0.078	297.633
15.942	0.089	342.711
14.898	0.083	320.451
12.885	0.073	276.828
10.928	0.061	233.560
8.967	0.051	190.740
7.043	0.051	148.199
5.040	0.050	105.394

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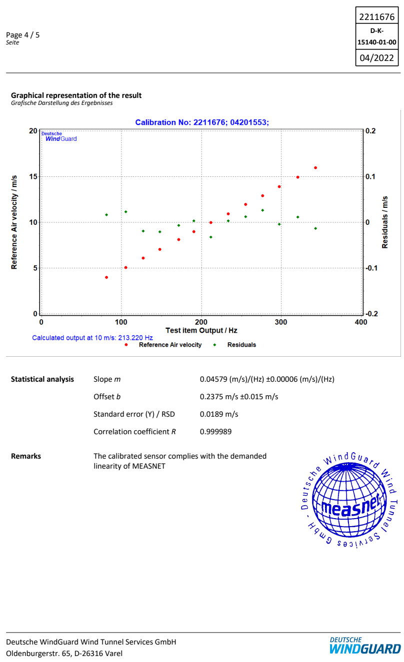
(c) Cup anemometer 94025503, page 3/4



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Graphical representation of the result
Grafische Darstellung des Ergebnisses

Statistical analysis	Slope *m*	0.04579 (m/s)/(Hz) ±0.00006 (m/s)/(Hz)
	Offset *b*	0.2375 m/s ±0.015 m/s
	Standard error (Y) / RSD	0.0189 m/s
	Correlation coefficient *R*	0.999989

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

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(d) Cup anemometer 94025503, page 4/4

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Calibration Certificate / *Kalibrierschein*

issued by the calibration laboratory / *erstellt durch das Kalibrierlaboratorium*

Deutsche WindGuard Wind Tunnel Services GmbH

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

Member of / *Mitglied im*
Deutschen Kalibrierdienst

DKD

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

Calibration mark
Kalibrierzeichen

2221388
D-K-15140-01-00
04/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201568 DEWS2724
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100334634
Project No. *Projektnummer*	VT220221
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	21.04.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
21.04.2022	Heiko Westermann, B. Sc.	Techniker Andre Krummen

(e) Cup anemometer 94025512, page 1/4

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D-K-15140-01-00
04/2022

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	P_9.1.0
Ambient conditions *Umgebungsbedingungen*	air temperature	(21.5 ± 0.4) °C – (21.8 ± 0.4) °C
	air pressure	(1016.1 ± 0.4) hPa – (1016.1 ± 0.4) hPa
	relative air humidity	(32.0 ± 6.0) % – (32.2 ± 6.0) %

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

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: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

Certificate ID *Zertifikat ID*: NdFJSphSBfwL8idVdSv8B5

Additional remarks *Zusätzliche Anmerkungen*: Calibration after refurbishment

Revision *Revision*: 0

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(f) Cup anemometer 94025512, page 2/4

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D-K-15140-01-00
04/2022

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.972	0.040	82.099
6.070	0.040	127.420
8.030	0.041	170.443
10.065	0.041	214.498
12.064	0.049	257.818
14.067	0.057	301.769
16.109	0.065	347.686
15.076	0.061	322.970
13.044	0.053	278.821
11.054	0.045	235.184
9.032	0.041	192.224
6.986	0.040	147.116
4.999	0.040	104.060

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(g) Cup anemometer 94025512, page 3/4

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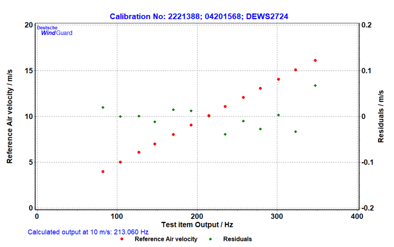
2221388
D-K-15140-01-00
04/2022

Graphical representation of the result
Grafische Darstellung des Ergebnisses



Statistical analysis	Slope m	0.04588 (m/s)/(Hz) ±0.00010 (m/s)/(Hz)
	Offset b	0.2243 m/s ±0.022 m/s
	Standard error (Y) / RSD	0.0285 m/s
	Correlation coefficient R	0.999976
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET	

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DEUTSCHE WINDGUARD

(h) Cup anemometer 94025512, page 4/4

DEUTSCHE WINDGUARD

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DIN EN ISO/IEC 17025:2018

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

DKD

Calibration mark
Kalibrierzeichen

2222333 | D-K-15140-01-00 | 07/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201552
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	Email 2022-06-24, Danzl
Project No. *Projektnummer*	VT220621
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	06.07.2022

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
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The presented results relate only to the calibrated object. The user is obliged to have the object recalibrated at appropriate intervals.
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Date *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
06.07.2022	Heiko Westermann, B. Sc.	Techniker Robert Riedel

(i) Cup anemometer 94025502, page 1/4

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2222333 | D-K-15140-01-00 | 07/2022

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	P_9.1.0_CAN_NI

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(24.9 ± 0.4) °C – (25.2 ± 0.4) °C
	air pressure	(1022.9 ± 0.4) hPa – (1023.1 ± 0.4) hPa
	relative air humidity	(39.7 ± 6.0) % – (40.2 ± 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: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

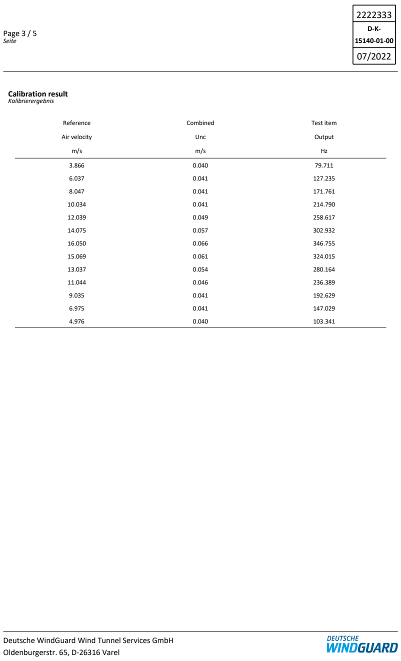
Certificate ID *Zertifikat ID*: CturqtNTw8dovNPFyPT37x

Additional remarks *Zusätzliche Anmerkungen*: Calibration before refurbishment

Revision *Revision*: 0

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

(j) Cup anemometer 94025502, page 2/4



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2222333 | D-K-15140-01-00 | 07/2022

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.866	0.040	79.711
6.037	0.041	127.235
8.047	0.041	171.761
10.034	0.041	214.790
12.039	0.049	258.617
14.075	0.057	302.932
16.050	0.066	346.755
15.069	0.061	324.015
13.037	0.054	280.164
11.044	0.046	236.389
9.035	0.041	192.629
6.975	0.041	147.029
4.976	0.040	103.341

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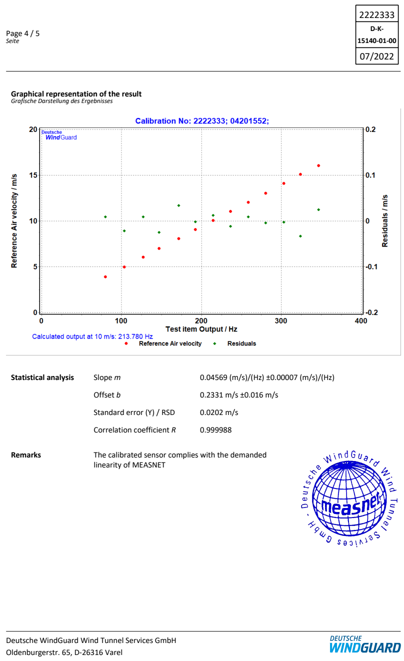
(k) Cup anemometer 94025502, page 3/4



Statistical analysis	Slope *m*	0.04569 (m/s)/(Hz) ±0.00007 (m/s)/(Hz)
	Offset *b*	0.2331 m/s ±0.016 m/s
	Standard error (Y) / RSD	0.0202 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

(l) Cup anemometer 94025502, page 4/4

DEUTSCHE WINDGUARD

IECRE and MEASNET approved test laboratory

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Deutsche WindGuard
Wind Tunnel Services GmbH

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

Member of / *Mitglied im*
Deutschen Kalibrierdienst

DKD

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

Calibration mark
Kalibrierzeichen

2221387
D-K-
15140-01-00
04/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201564
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100334634
Project No. *Projektnummer*	VT220221
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	21.04.2022

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
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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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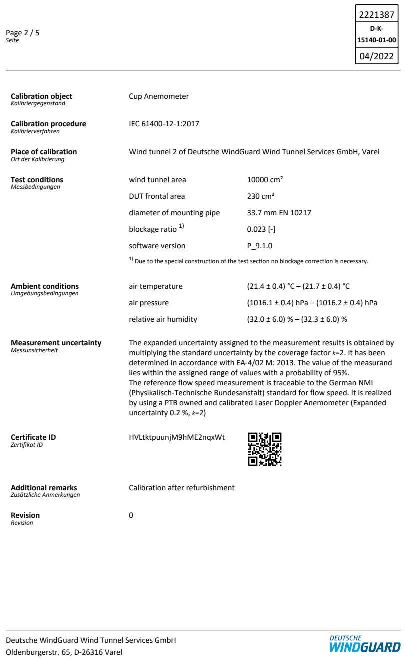
Date *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
21.04.2022	Heiko Westermann, B. Sc.	Techniker Andre Krummen

(m) Cup anemometer 94025517, page 1/4



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2221387
D-K-
15140-01-00
04/2022

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	P_9.1.0

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(21.4 ± 0.4) °C – (21.7 ± 0.4) °C
	air pressure	(1016.1 ± 0.4) hPa – (1016.2 ± 0.4) hPa
	relative air humidity	(32.0 ± 6.0) % – (32.3 ± 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 EA-4/02 M: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

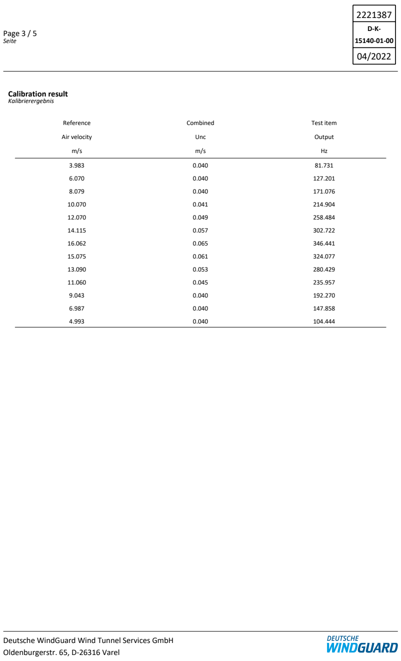
Certificate ID *Zertifikat ID* HVLtktpuunjM9hME2nqxWt

Additional remarks *Zusätzliche Anmerkungen* Calibration after refurbishment

Revision *Revision* 0

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

(n) Cup anemometer 94025517, page 2/4



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2221387
D-K-
15140-01-00
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Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.983	0.040	81.731
6.070	0.040	127.201
8.079	0.040	171.076
10.070	0.041	214.904
12.070	0.049	258.484
14.115	0.057	302.722
16.062	0.065	346.441
15.075	0.061	324.077
13.090	0.053	280.429
11.060	0.045	235.957
9.043	0.040	192.270
6.987	0.040	147.858
4.993	0.040	104.444

Deutsche WindGuard Wind Tunnel Services GmbH
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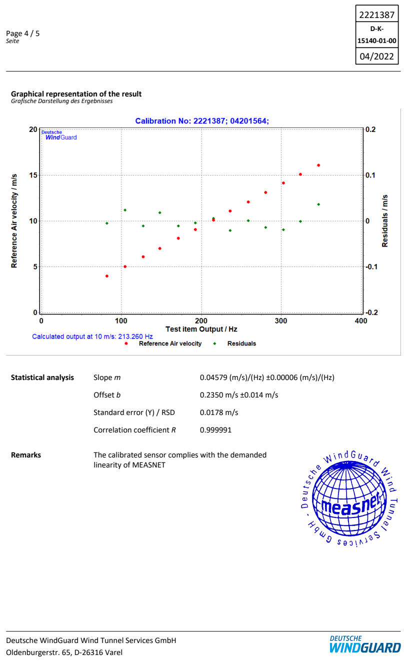
(o) Cup anemometer 94025517, page 3/4



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Graphical representation of the result
Grafische Darstellung des Ergebnisses

Statistical analysis	Slope *m*	0.04579 (m/s)/(Hz) ±0.00006 (m/s)/(Hz)
	Offset *b*	0.2350 m/s ±0.014 m/s
	Standard error (Y) / RSD	0.0178 m/s
	Correlation coefficient *R*	0.999991

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

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

DKD

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

Calibration mark
Kalibrierzeichen

2211679
D-K-
15140-01-00
04/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201560
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100333110
Project No. *Projektnummer*	VT220163
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	13.04.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
13.04.2022	Heiko Westermann, B. Sc.	Marcel Beierling, B. Eng.

(q) Cup anemometer 94025504, page 1/4

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Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio 1)	0.023 [-]
	software version	P_9.1.0

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(22.8 ± 0.4) °C – (23.2 ± 0.4) °C
	air pressure	(1015.8 ± 0.4) hPa – (1015.8 ± 0.4) hPa
	relative air humidity	(34.7 ± 6.0) % – (35.3 ± 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 EA-4/02 M: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

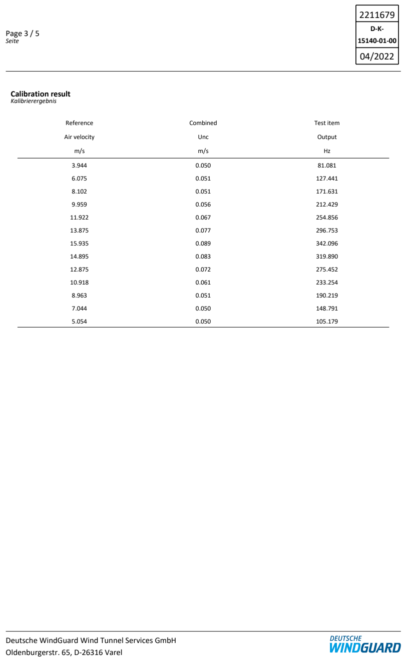
Certificate ID *Zertifikat ID*: X8gRnueZELmrStb649fBZC

Additional remarks *Zusätzliche Anmerkungen*: Calibration after refurbishment

Revision *Revision*: 0

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

(r) Cup anemometer 94025504, page 2/4



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Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.944	0.050	81.081
6.075	0.051	127.441
8.102	0.051	171.631
9.959	0.056	212.429
11.922	0.067	254.856
13.875	0.077	296.753
15.935	0.089	342.096
14.895	0.083	319.890
12.875	0.072	275.452
10.918	0.061	233.254
8.963	0.051	190.219
7.044	0.050	148.791
5.054	0.050	105.179

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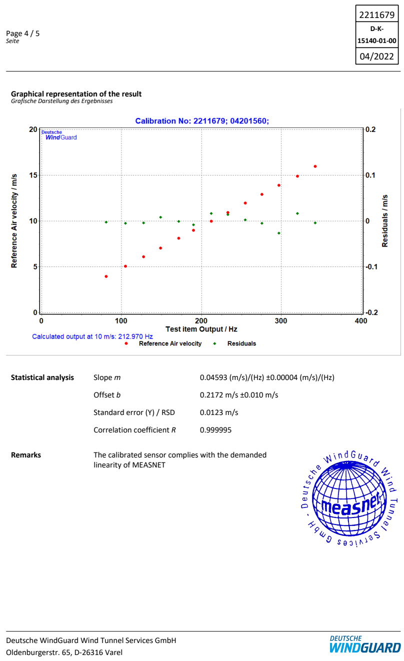
(s) Cup anemometer 94025504, page 3/4



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15140-01-00
04/2022

Graphical representation of the result
Grafische Darstellung des Ergebnisses

Statistical analysis	Slope m	0.04593 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
	Offset b	0.2172 m/s ±0.010 m/s
	Standard error (Y) / RSD	0.0123 m/s
	Correlation coefficient R	0.999995

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

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(t) Cup anemometer 94025504, 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

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

Member of / *Mitglied im*
Deutschen Kalibrierdienst

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

Calibration mark
Kalibrierzeichen

2213871
D-K-15140-01-00
09/2022

Object *Gegenstand*	Cup Anemometer
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3352.00.000
Serial number *Fabrikat/Serien-Nr.*	04201556 DEWS2718
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	-
Project No. *Projektnummer*	VT220707
Number of pages *Anzahl der Seiten*	5
Date of Calibration *Datum der Kalibrierung*	07.09.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
07.09.2022	Heiko Westermann, B. Sc.	Dipl.-Ing. (FH) Catharina Herold

(u) Cup anemometer 94025506, page 1/4

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D-K-15140-01-00
09/2022

Calibration object *Kalibriergegenstand*	Cup Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	230 cm²
	diameter of mounting pipe	33.7 mm EN 10217
	blockage ratio [1)]	0.023 [-]
	software version	P_9.1.0_CAN_NI
	[1)] Due to the special construction of the test section no blockage correction is necessary.	
Ambient conditions *Umgebungsbedingungen*	air temperature	(23.7 ± 0.4) °C – (24.0 ± 0.4) °C
	air pressure	(1012.3 ± 0.4) hPa – (1012.4 ± 0.4) hPa
	relative air humidity	(47.5 ± 6.0) % – (48.4 ± 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: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%. The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)	
Certificate ID *Zertifikat ID*	j6QzdLyCZvyXrqTPGMxtwJ	
Additional remarks *Zusätzliche Anmerkungen*	Calibration after refurbishment	
Revision *Revision*	0	

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

(v) Cup anemometer 94025506, page 2/4

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09/2022

Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Combined Unc m/s	Test item Output Hz
3.925	0.050	81.186
6.051	0.051	127.168
8.078	0.051	171.287
9.937	0.056	211.940
11.895	0.067	255.278
13.842	0.077	297.216
15.920	0.089	343.165
14.878	0.084	320.678
12.855	0.072	275.756
10.903	0.061	233.499
8.956	0.051	190.625
7.021	0.051	148.053
5.027	0.050	104.706

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(w) Cup anemometer 94025506, page 3/4

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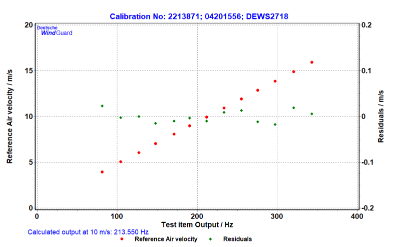
Graphical representation of the result
Grafische Darstellung des Ergebnisses



Statistical analysis	Slope m	0.04572 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
	Offset b	0.2376 m/s ±0.011 m/s
	Standard error (Y) / RSD	0.0138 m/s
	Correlation coefficient R	0.999994
Remarks	The calibrated sensor complies with the demanded linearity of MEASNET	

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(x) Cup anemometer 94025506, page 4/4

B.1.2 Wind vane

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

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

Member of / *Mitglied im*
Deutschen Kalibrierdienst

DKD

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

Calibration mark
Kalibrierzeichen

2211573
D-K-15140-01-00
04/2022

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3150.00.400
Serial number *Fabrikat/Serien-Nr.*	04120058
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100333110
Project No. *Projektnummer*	VT220163
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	07.04.2022

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
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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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
07.04.2022	Heiko Westermann, B. Sc.	Tobias Schmid, B. Sc.

(a) Wind vane 94012542, page 1/6

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2211573
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Calibration object *Kalibriergegenstand*	Wind Vane	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 1 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	200 cm²
	diameter of mounting pipe	33.7 mm
	blockage ratio [1)]	0.020 [-]
	software version	P_9.1.0

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(19.7 ± 0.4) °C – (20.2 ± 0.4) °C
	air pressure	(976.6 ± 0.4) hPa – (977.9 ± 0.4) hPa
	relative air humidity	(39.0 ± 6.0) % – (39.7 ± 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-4/02 M: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

Additional remarks *Zusätzliche Anmerkungen*: North alignment via north mark

Revision *Revision*: 0

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DEUTSCHE WINDGUARD

(b) Wind vane 94012542, page 2/6

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

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
7.88	0.04	5.01	0.80	1.11	4.52	-0.49
7.87	0.04	10.00	0.80	1.11	9.41	-0.60
7.88	0.04	15.01	0.80	1.11	14.38	-0.63
7.88	0.04	20.01	0.80	1.11	19.33	-0.69
7.88	0.04	25.01	0.80	1.11	24.36	-0.65
7.88	0.04	30.00	0.80	1.11	29.41	-0.59
7.88	0.04	35.01	0.80	1.11	34.45	-0.56
7.88	0.04	39.67	0.80	1.11	39.18	-0.49
7.88	0.04	44.99	0.80	1.11	44.57	-0.42
7.88	0.04	50.00	0.80	1.11	49.60	-0.40
7.88	0.04	55.01	0.80	1.11	54.67	-0.34
7.88	0.04	59.99	0.80	1.11	59.66	-0.33
7.89	0.04	64.99	0.80	1.11	64.65	-0.34
7.89	0.04	70.00	0.80	1.11	69.64	-0.36
7.88	0.04	75.00	0.80	1.11	74.60	-0.40
7.89	0.04	80.00	0.80	1.11	79.53	-0.47
7.88	0.04	85.00	0.80	1.11	84.48	-0.52
7.88	0.04	90.00	0.80	1.11	89.40	-0.60
7.88	0.04	95.00	0.80	1.11	94.28	-0.71
7.88	0.04	100.00	0.80	1.11	99.21	-0.79
7.88	0.04	105.00	0.80	1.11	104.19	-0.81
7.88	0.04	110.00	0.80	1.11	109.20	-0.80
7.89	0.04	115.00	0.80	1.11	114.27	-0.72
7.88	0.04	120.00	0.80	1.11	119.29	-0.71
7.88	0.04	124.99	0.80	1.11	124.32	-0.68
7.88	0.04	129.99	0.80	1.11	129.39	-0.61
7.88	0.04	135.00	0.80	1.11	134.48	-0.52
7.89	0.04	140.00	0.80	1.11	139.54	-0.46
7.88	0.04	145.00	0.80	1.11	144.55	-0.45
7.88	0.04	150.00	0.80	1.11	149.59	-0.40
7.88	0.04	154.99	0.80	1.11	154.64	-0.35

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(c) Wind vane 94012542, page 3/6

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

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
7.88	0.04	159.99	0.80	1.11	159.65	-0.35
7.88	0.04	164.99	0.80	1.11	164.62	-0.38
7.88	0.04	169.99	0.80	1.11	169.53	-0.46
7.88	0.04	175.00	0.80	1.11	174.47	-0.53
7.88	0.04	180.00	0.80	1.11	179.37	-0.63
7.88	0.04	185.00	0.80	1.11	184.32	-0.68
7.88	0.04	190.01	0.80	1.11	189.29	-0.72
7.88	0.04	195.00	0.80	1.11	194.28	-0.72
7.88	0.04	200.00	0.80	1.11	199.29	-0.71
7.88	0.04	205.00	0.80	1.11	204.34	-0.66
7.88	0.04	209.98	0.80	1.11	209.39	-0.60
7.88	0.04	214.99	0.80	1.11	214.46	-0.53
7.88	0.04	220.00	0.80	1.11	219.57	-0.43
7.88	0.04	224.99	0.80	1.11	224.69	-0.30
7.88	0.04	229.99	0.80	1.11	229.76	-0.23
7.89	0.04	235.00	0.80	1.11	234.83	-0.17
7.88	0.04	240.00	0.80	1.11	239.86	-0.14
7.88	0.04	244.99	0.80	1.11	244.81	-0.17
7.88	0.04	249.98	0.80	1.11	249.83	-0.15
7.88	0.04	255.01	0.80	1.11	254.79	-0.21
7.88	0.04	259.99	0.80	1.11	259.73	-0.27
7.88	0.04	264.99	0.80	1.11	264.70	-0.29
7.88	0.04	270.02	0.80	1.11	269.63	-0.39
7.88	0.04	274.99	0.80	1.11	274.52	-0.47
7.88	0.04	279.99	0.80	1.11	279.52	-0.47
7.88	0.04	285.01	0.80	1.11	284.49	-0.52
7.88	0.04	290.01	0.80	1.11	289.49	-0.52
7.88	0.04	295.01	0.80	1.11	294.54	-0.47
7.88	0.04	300.01	0.80	1.11	299.57	-0.44
7.88	0.04	305.00	0.80	1.11	304.65	-0.35
7.88	0.04	309.99	0.80	1.11	309.70	-0.29

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Oldenburgerstr. 65, D-26316 Varel
DEUTSCHE WINDGUARD

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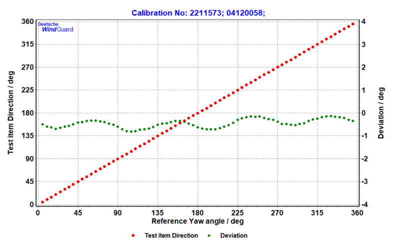
Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
7.88	0.04	315.00	0.80	1.11	314.76	-0.24
7.88	0.04	320.01	0.80	1.11	319.83	-0.18
7.88	0.04	325.00	0.80	1.11	324.86	-0.15
7.88	0.04	330.00	0.80	1.11	329.87	-0.13
7.88	0.04	335.01	0.80	1.11	334.86	-0.16
7.88	0.04	340.01	0.80	1.11	339.83	-0.18
7.88	0.04	345.01	0.80	1.11	344.79	-0.22
7.88	0.04	350.01	0.80	1.11	349.72	-0.29
7.87	0.04	355.01	0.80	1.11	354.67	-0.35

Graphical representation of the result
Grafische Darstellung des Ergebnisses



Statistical analysis Average offset -0.45 deg

Deutsche WindGuard Wind Tunnel Services GmbH
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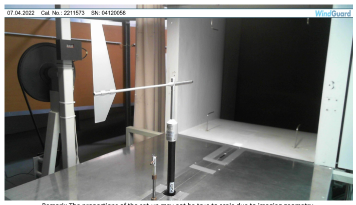
Photo of the measurement setup
Foto des Messaufbaus



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

- End of document / Ende des Dokuments -

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

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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

Deutsche Akkreditierungsstelle D-K-15140-01-00

Member of / *Mitglied im*
Deutschen Kalibrierdienst

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

Calibration mark
Kalibrierzeichen

2221199
D-K-15140-01-00
04/2022

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3150.00.400
Serial number *Fabrikat/Serien-Nr.*	08130089
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100333195
Project No. *Projektnummer*	VT220167
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	07.04.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Die dargestellten Ergebnisse beziehen sich nur auf den kalibrierten Gegenstand. Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
07.04.2022	Heiko Westermann, B. Sc.	Tobias Schmid, B. Sc.

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Calibration object *Kalibriergegenstand*	Wind Vane	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	200 cm²
	diameter of mounting pipe	33.7 mm
	blockage ratio [1)]	0.020 [-]
	software version	P_9.1.0

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

Ambient conditions *Umgebungsbedingungen*	air temperature	(21.5 ± 0.4) °C – (21.6 ± 0.4) °C
	air pressure	(976.9 ± 0.4) hPa – (977.8 ± 0.4) hPa
	relative air humidity	(35.2 ± 6.0) % – (35.3 ± 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 EA-4/02 M: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

Certificate ID *Zertifikat ID*: DhUKrxJdeRJj4nEbm7n4rm

Additional remarks *Zusätzliche Anmerkungen*: Calibration after refurbishment
North alignment via north mark

Revision *Revision*: 0

Deutsche WindGuard Wind Tunnel Services GmbH
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Calibration result (1/3)
Kalibrierergebnis (1/3)

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.05	0.04	4.96	0.80	1.11	4.43	-0.53
8.04	0.04	10.04	0.80	1.11	9.49	-0.54
8.04	0.04	15.00	0.80	1.11	14.45	-0.56
8.04	0.04	19.97	0.80	1.11	19.44	-0.53
8.05	0.04	24.95	0.80	1.11	24.45	-0.49
8.05	0.04	29.92	0.80	1.11	29.47	-0.45
8.05	0.04	34.97	0.80	1.11	34.56	-0.41
8.04	0.04	39.69	0.80	1.11	39.33	-0.35
8.05	0.04	45.00	0.80	1.12	44.69	-0.30
8.05	0.04	49.98	0.80	1.12	49.77	-0.21
8.05	0.04	54.95	0.80	1.12	54.74	-0.21
8.05	0.04	60.02	0.80	1.12	59.83	-0.19
8.05	0.04	64.99	0.80	1.12	64.75	-0.24
8.05	0.04	70.02	0.80	1.12	69.82	-0.21
8.05	0.04	74.99	0.80	1.12	74.68	-0.31
8.05	0.04	79.98	0.80	1.12	79.59	-0.39
8.05	0.04	85.01	0.80	1.12	84.56	-0.45
8.05	0.04	89.97	0.80	1.12	89.46	-0.52
8.04	0.04	95.06	0.80	1.12	94.46	-0.59
8.05	0.04	99.99	0.80	1.12	99.35	-0.64
8.05	0.04	105.04	0.80	1.12	104.43	-0.60
8.04	0.04	110.07	0.80	1.12	109.48	-0.59
8.05	0.04	115.01	0.80	1.12	114.44	-0.57
8.05	0.04	119.91	0.80	1.12	119.40	-0.50
8.06	0.04	124.99	0.80	1.12	124.56	-0.42
8.04	0.04	130.04	0.80	1.12	129.71	-0.32
8.04	0.04	135.08	0.80	1.12	134.79	-0.29
8.04	0.04	139.99	0.80	1.12	139.74	-0.24
8.06	0.04	144.95	0.80	1.12	144.81	-0.14
8.05	0.04	150.01	0.80	1.12	149.87	-0.15
8.06	0.04	155.02	0.80	1.12	154.85	-0.17

Deutsche WindGuard Wind Tunnel Services GmbH
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Calibration result (2/3)
Kalibrierergebnis (2/3)

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.04	0.04	159.98	0.80	1.12	159.83	-0.15
8.05	0.04	164.95	0.80	1.12	164.75	-0.20
8.05	0.04	169.93	0.80	1.12	169.69	-0.25
8.05	0.04	174.97	0.80	1.12	174.67	-0.30
8.05	0.04	179.96	0.80	1.12	179.56	-0.39
8.04	0.04	184.97	0.80	1.12	184.55	-0.42
8.04	0.04	190.01	0.80	1.12	189.63	-0.38
8.04	0.04	195.02	0.80	1.12	194.61	-0.41
8.04	0.04	200.03	0.80	1.12	199.62	-0.41
8.05	0.04	204.99	0.80	1.12	204.65	-0.34
8.05	0.04	209.98	0.80	1.12	209.68	-0.30
8.05	0.04	214.95	0.80	1.12	214.69	-0.26
8.05	0.04	220.03	0.80	1.12	219.86	-0.17
8.04	0.04	224.96	0.80	1.12	224.83	-0.12
8.04	0.04	230.00	0.80	1.12	229.92	-0.08
8.05	0.04	234.98	0.80	1.12	234.90	-0.08
8.04	0.04	239.90	0.80	1.12	239.85	-0.06
8.05	0.04	244.99	0.80	1.12	244.92	-0.07
8.05	0.04	249.98	0.80	1.12	249.89	-0.09
8.05	0.04	254.97	0.80	1.12	254.87	-0.10
8.05	0.04	259.96	0.80	1.12	259.81	-0.15
8.04	0.04	264.88	0.80	1.12	264.68	-0.19
8.06	0.04	270.03	0.80	1.12	269.76	-0.27
8.04	0.04	275.01	0.80	1.12	274.75	-0.26
8.05	0.04	279.97	0.80	1.12	279.71	-0.26
8.05	0.04	284.97	0.80	1.12	284.70	-0.28
8.05	0.04	289.99	0.80	1.12	289.71	-0.28
8.05	0.04	295.00	0.80	1.12	294.78	-0.22
8.05	0.04	300.01	0.80	1.12	299.84	-0.17
8.05	0.04	305.02	0.80	1.12	304.87	-0.15
8.05	0.04	309.96	0.80	1.12	309.85	-0.12

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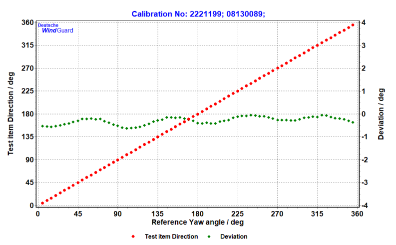
Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.04	0.04	314.99	0.80	1.12	314.86	-0.13
8.06	0.04	319.88	0.80	1.12	319.82	-0.05
8.05	0.04	324.99	0.80	1.12	324.92	-0.07
8.05	0.04	330.00	0.80	1.12	329.86	-0.14
8.04	0.04	335.02	0.80	1.12	334.85	-0.18
8.05	0.04	340.00	0.80	1.12	339.80	-0.19
8.05	0.04	344.96	0.80	1.12	344.72	-0.24
8.04	0.04	350.04	0.80	1.12	349.74	-0.30
8.05	0.04	354.99	0.80	1.12	354.63	-0.36

Graphical representation of the result
Grafische Darstellung des Ergebnisses



Statistical analysis Average offset -0.29 deg

Deutsche WindGuard Wind Tunnel Services GmbH
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Photo of the measurement setup
Foto des Messaufbaus

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

- End of document / Ende des Dokuments -

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

(l) Wind vane 94012052, page 6/6

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

Deutsche Akkreditierungsstelle D-K-15140-01-00

Member of / *Mitglied im*
Deutschen Kalibrierdienst

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

Calibration mark
Kalibrierzeichen

2221201
D-K-15140-01-00
04/2022

Object *Gegenstand*	Wind Vane
Manufacturer *Hersteller*	Thies Clima D-37083 Göttingen
Type *Typ*	4.3150.00.400
Serial number *Fabrikat/Serien-Nr.*	02110032
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	3100333195
Project No. *Projektnummer*	VT220167
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	07.04.2022

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 Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
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 *Datum*	Freigegeben durch / *Approval by* Head of the calibration laboratory	Person in charge *Bearbeiter*
07.04.2022	Heiko Westermann, B. Sc.	Tobias Schmid, B. Sc.

(m) Wind vane 94012461, page 1/6

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2221201
D-K-15140-01-00
04/2022

Calibration object *Kalibriergegenstand*	Wind Vane	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel 2 of Deutsche WindGuard Wind Tunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	DUT frontal area	200 cm²
	diameter of mounting pipe	33.7 mm
	blockage ratio [1)]	0.020 [-]
	software version	P_9.1.0
Ambient conditions *Umgebungsbedingungen*	air temperature	(21.6 ± 0.4) °C – (21.7 ± 0.4) °C
	air pressure	(977.5 ± 0.4) hPa – (978.1 ± 0.4) hPa
	relative air humidity	(35.2 ± 6.0) % – (35.3 ± 6.0) %

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

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: 2013. The value of the measurand lies within the assigned range of values with a probability of 95%.
The reference flow speed measurement is traceable to the German NMI (Physikalisch-Technische Bundesanstalt) standard for flow speed. It is realized by using a PTB owned and calibrated Laser Doppler Anemometer (Expanded uncertainty 0.2 %, k=2)

Certificate ID *Zertifikat ID*: CqYPX7wFvRtGpXXZ5649jd

Additional remarks *Zusätzliche Anmerkungen*: Calibration after refurbishment
North alignment via north mark

Revision *Revision*: 0

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

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

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.01	0.04	5.00	0.80	1.11	5.54	0.54
8.01	0.04	10.02	0.80	1.11	10.49	0.46
8.01	0.04	14.95	0.80	1.11	15.35	0.40
8.02	0.04	19.98	0.80	1.11	20.45	0.46
8.01	0.04	24.98	0.80	1.11	25.46	0.48
8.02	0.04	30.02	0.80	1.11	30.57	0.55
8.02	0.04	35.02	0.80	1.11	35.63	0.61
8.02	0.04	39.65	0.80	1.11	40.34	0.69
8.02	0.04	44.95	0.80	1.12	45.68	0.73
8.02	0.04	49.95	0.80	1.12	50.67	0.72
8.02	0.04	55.01	0.80	1.12	55.79	0.77
8.01	0.04	59.99	0.80	1.12	60.80	0.81
8.01	0.04	65.03	0.80	1.12	65.80	0.77
8.01	0.04	70.05	0.80	1.12	70.77	0.73
8.01	0.04	75.01	0.80	1.12	75.70	0.70
8.01	0.04	79.91	0.80	1.12	80.55	0.64
8.01	0.04	84.93	0.80	1.12	85.49	0.56
8.02	0.04	90.04	0.80	1.12	90.55	0.51
8.02	0.04	95.06	0.80	1.12	95.47	0.41
8.01	0.04	100.02	0.80	1.12	100.47	0.44
8.01	0.04	105.01	0.80	1.12	105.49	0.47
8.02	0.04	110.00	0.80	1.12	110.50	0.51
8.01	0.04	115.02	0.80	1.12	115.54	0.53
8.02	0.04	120.00	0.80	1.12	120.58	0.58
8.01	0.04	125.03	0.80	1.12	125.64	0.61
8.01	0.04	130.05	0.80	1.12	130.71	0.66
8.01	0.04	135.02	0.80	1.12	135.77	0.75
8.01	0.04	139.92	0.80	1.12	140.69	0.77
8.02	0.04	144.96	0.80	1.12	145.80	0.84
8.01	0.04	149.94	0.80	1.12	150.79	0.85
8.02	0.04	154.95	0.80	1.12	155.79	0.84

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

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.01	0.04	160.00	0.80	1.12	160.80	0.80
8.02	0.04	164.99	0.80	1.12	165.72	0.73
8.01	0.04	170.03	0.80	1.12	170.73	0.70
8.01	0.04	174.99	0.80	1.12	175.66	0.67
8.02	0.04	180.06	0.80	1.12	180.66	0.59
8.02	0.04	185.05	0.80	1.12	185.62	0.58
8.01	0.04	190.00	0.80	1.12	190.55	0.56
8.02	0.04	195.05	0.80	1.12	195.62	0.57
8.00	0.04	200.01	0.80	1.12	200.57	0.56
8.02	0.04	204.97	0.80	1.12	205.55	0.58
8.01	0.04	209.99	0.80	1.12	210.64	0.66
8.02	0.04	215.01	0.80	1.12	215.70	0.70
8.01	0.04	220.00	0.80	1.12	220.75	0.75
8.01	0.04	225.01	0.80	1.12	225.78	0.77
8.01	0.04	230.02	0.80	1.12	230.81	0.79
8.02	0.04	234.96	0.80	1.12	235.81	0.85
8.01	0.04	239.92	0.80	1.12	240.73	0.81
8.01	0.04	244.98	0.80	1.12	245.79	0.81
8.02	0.04	250.00	0.80	1.12	250.82	0.82
8.02	0.04	255.00	0.80	1.12	255.78	0.78
8.01	0.04	260.00	0.80	1.12	260.73	0.74
8.01	0.04	265.00	0.80	1.12	265.70	0.69
8.02	0.04	270.03	0.80	1.12	270.69	0.67
8.02	0.04	274.96	0.80	1.12	275.62	0.66
8.02	0.04	280.07	0.80	1.12	280.69	0.62
8.02	0.04	284.98	0.80	1.12	285.62	0.64
8.02	0.04	290.03	0.80	1.12	290.67	0.65
8.02	0.04	295.04	0.80	1.12	295.73	0.69
8.02	0.04	300.00	0.80	1.12	300.70	0.70
8.02	0.04	305.05	0.80	1.12	305.78	0.73
8.02	0.04	310.03	0.80	1.12	310.84	0.80

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(p) Wind vane 94012461, page 4/6

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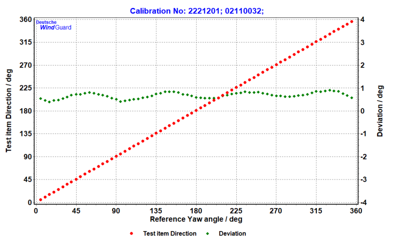
Calibration result (3/3)
Kalibrierergebnis (3/3)

Reference Air velocity m/s	Reference Unc m/s	Reference Yaw angle deg	Reference Unc deg	Combined Unc deg	Test item Direction deg	Test item Deviation deg
8.02	0.04	315.02	0.80	1.12	315.88	0.86
8.02	0.04	320.01	0.80	1.12	320.86	0.84
8.02	0.04	325.07	0.80	1.12	325.95	0.88
8.01	0.04	330.04	0.80	1.12	330.95	0.91
8.02	0.04	335.00	0.80	1.12	335.88	0.88
8.02	0.04	339.98	0.80	1.12	340.84	0.85
8.02	0.04	344.95	0.80	1.12	345.72	0.76
8.02	0.04	349.95	0.80	1.12	350.62	0.67
8.02	0.04	354.92	0.80	1.12	355.51	0.59

Graphical representation of the result
Grafische Darstellung des Ergebnisses



Statistical analysis Average offset 0.68 deg

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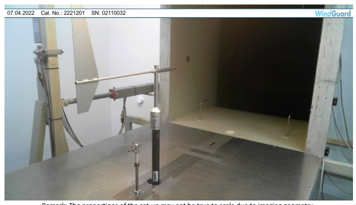
Photo of the measurement setup
Foto des Messaufbaus



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

- End of document / Ende des Dokuments -

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(r) Wind vane 94012461, page 6/6

B.1.3 Relative humidity and temperature

VAISALA
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MEASUREMENT STANDARDS LABORATORY
ACCREDITED CALIBRATION LABORATORY

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

CERTIFICATE OF CALIBRATION no K008-G03619

Customer TNO

Instrument Humidity and Temperature Probe
Manufacturer Vaisala Oyj
Model HMP155E
Serial number M1141112
Instrument number 94012136
Calibration date From June 12 to 13, 2023
Calibration due date August 12, 2024
Issue date June 13, 2023
Signature Jarno Suutari
Calibration Engineer
Page 1 (4)
Documents attached -
NOTES The instrument was adjusted during calibration.

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 Certificates 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 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 MLA) of the European co-operation for Accreditation (EA).

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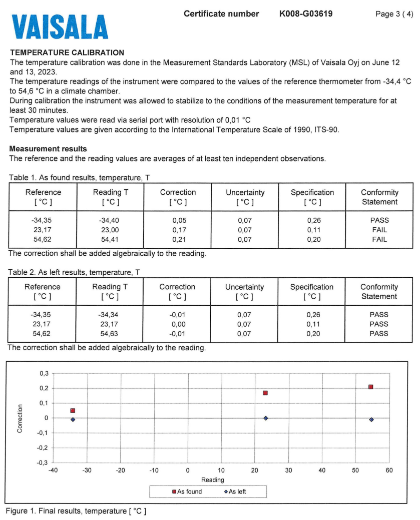
Domicile Vantaa, Finland • VAT FI01244162 • Business ID 0124416-2

(a) RHT 94012136, page 1/2



VAISALA **Certificate number** **K008-G03619** Page 3 (4)

TEMPERATURE CALIBRATION
The temperature calibration was done in the Measurement Standards Laboratory (MSL) of Vaisala Oyj on June 12 and 13, 2023.
The temperature readings of the instrument were compared to the values of the reference thermometer from -34,4 °C to 54,6 °C in a climate chamber.
During calibration the instrument was allowed to stabilize to the conditions of the measurement temperature for at least 30 minutes.
Temperature values were read via serial port with resolution of 0,01 °C
Temperature values are given according to the International Temperature Scale of 1990, ITS-90.

Measurement results
The reference and the reading values are averages of at least ten independent observations.

Table 1. As found results, temperature, T

Reference [°C]	Reading T [°C]	Correction [°C]	Uncertainty [°C]	Specification [°C]	Conformity Statement
-34,35	-34,40	0,05	0,07	0,26	PASS
23,17	23,00	0,17	0,07	0,11	FAIL
54,62	54,41	0,21	0,07	0,20	FAIL

The correction shall be added algebraically to the reading.

Table 2. As left results, temperature, T

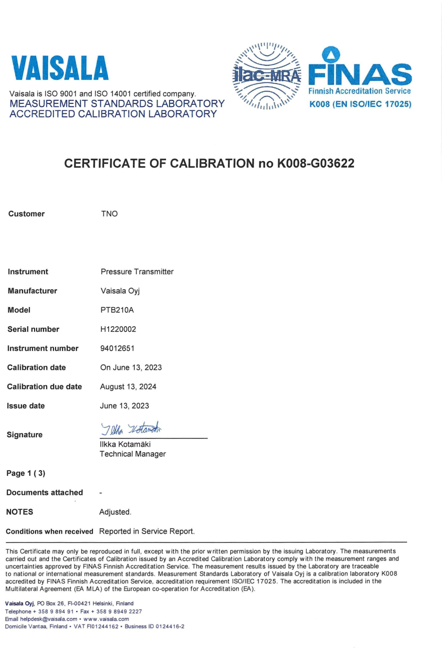
Reference [°C]	Reading T [°C]	Correction [°C]	Uncertainty [°C]	Specification [°C]	Conformity Statement
-34,35	-34,34	-0,01	0,07	0,26	PASS
23,17	23,17	0,00	0,07	0,11	PASS
54,62	54,63	-0,01	0,07	0,20	PASS

The correction shall be added algebraically to the reading.

Figure 1. Final results, temperature [°C]

(b) RHT 94012136, page 2/2

B.1.4 Air pressure



VAISALA

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MEASUREMENT STANDARDS LABORATORY
ACCREDITED CALIBRATION LABORATORY

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

CERTIFICATE OF CALIBRATION no K008-G03622

Customer	TNO
Instrument	Pressure Transmitter
Manufacturer	Vaisala Oyj
Model	PTB210A
Serial number	H1220002
Instrument number	94012651
Calibration date	On June 13, 2023
Calibration due date	August 13, 2024
Issue date	June 13, 2023
Signature	Ilkka Kotamäki Technical Manager
Page 1 (3)	
Documents attached	-
NOTES	Adjusted.
Conditions when received	Reported in Service Report.

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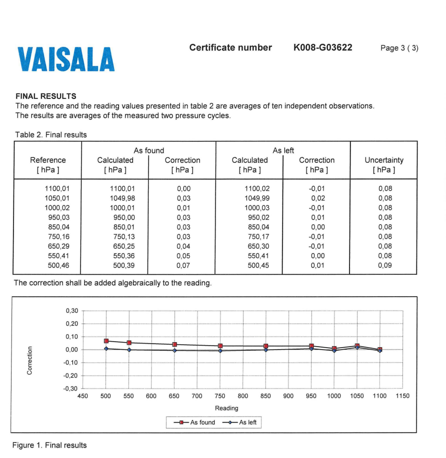
(a) Air pressure sensor 94012651, page 1/2



VAISALA **Certificate number K008-G03622** Page 3 (3)

FINAL RESULTS
The reference and the reading values presented in table 2 are averages of ten independent observations.
The results are averages of the measured two pressure cycles.

Table 2. Final results

Reference [hPa]	As found Calculated [hPa]	As found Correction [hPa]	As left Calculated [hPa]	As left Correction [hPa]	Uncertainty [hPa]
1100,01	1100,01	0,00	1100,02	-0,01	0,08
1050,01	1049,98	0,03	1049,99	0,02	0,08
1000,02	1000,01	0,01	1000,03	-0,01	0,08
950,03	950,00	0,03	950,02	0,01	0,08
850,04	850,01	0,03	850,04	0,00	0,08
750,16	750,13	0,03	750,17	-0,01	0,08
650,29	650,25	0,04	650,30	-0,01	0,08
550,41	550,36	0,05	550,41	0,00	0,08
500,46	500,39	0,07	500,45	0,01	0,09

The correction shall be added algebraically to the reading.

Figure 1. Final results

(b) Air pressure sensor 94012651, page 2/2

B.1.5 Sonic 3D

DEUTSCHE WINDGUARD

Deutsche WindGuard
Wind Tunnel Services GmbH

IECRE and MEASNET approved test laboratory

accredited by the / *akkreditiert durch die*

Deutsche Akkreditierungsstelle GmbH

as calibration laboratory in the / *als Kalibrierlaboratorium im*

Deutschen Kalibrierdienst DKD

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

Calibration certificate
Kalibrierschein

Calibration mark
Kalibrierzeichen

1823950
D-K-15140-01-00
11/2018

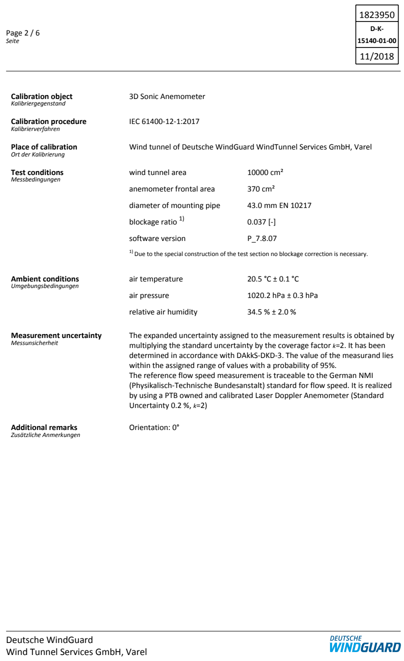
Object *Gegenstand*	3D Sonic Anemometer
Manufacturer *Hersteller*	METEK GmbH D-25337 Elmshorn
Type *Typ*	USONIC-3 BASIC
Serial number *Fabrikat/Serien-Nr.*	0106074061 DEMO2203
Customer *Auftraggeber*	TNO 2509 JE The Hague - The Netherlands
Order No. *Auftragsnummer*	1114-01
Project No. *Projektnummer*	VT181106
Number of pages *Anzahl der Seiten*	6
Date of Calibration *Datum der Kalibrierung*	28.11.2018

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

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

Date *Datum*	Head of the calibration laboratory *Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
28.11.2018	Dipl. Phys. Dieter Westermann	Kai Schuster, B. Eng.

(a) Sonic 3D 94012039, page 1/6



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1823950
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Calibration object *Kalibriergegenstand*	3D Sonic Anemometer	
Calibration procedure *Kalibrierverfahren*	IEC 61400-12-1:2017	
Place of calibration *Ort der Kalibrierung*	Wind tunnel of Deutsche WindGuard WindTunnel Services GmbH, Varel	
Test conditions *Messbedingungen*	wind tunnel area	10000 cm²
	anemometer frontal area	370 cm²
	diameter of mounting pipe	43.0 mm EN 10217
	blockage ratio 1)	0.037 [-]
	software version	P_7.8.07
Ambient conditions *Umgebungsbedingungen*	air temperature	20.5 °C ± 0.1 °C
	air pressure	1020.2 hPa ± 0.3 hPa
	relative air humidity	34.5 % ± 2.0 %

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

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

Additional remarks *Zusätzliche Anmerkungen*: Orientation: 0°

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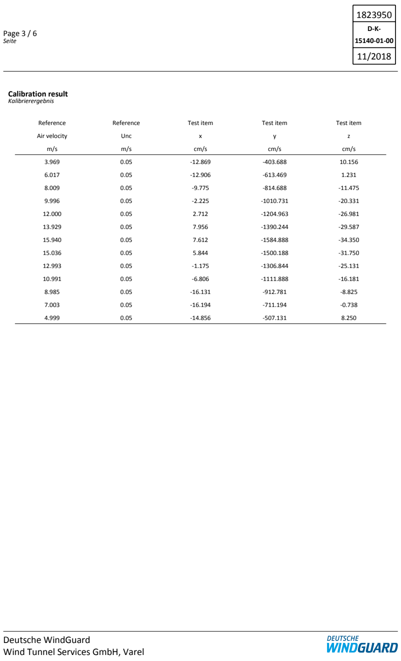
Wind Tunnel Services GmbH, Varel

(b) Sonic 3D 94012039, page 2/6



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Calibration result
Kalibrierergebnis

Reference Air velocity m/s	Reference Unc m/s	Test item x cm/s	Test item y cm/s	Test item z cm/s
3.969	0.05	-12.869	-403.688	10.156
6.017	0.05	-12.906	-613.469	1.231
8.009	0.05	-9.775	-814.688	-11.475
9.996	0.05	-2.225	-1010.731	-20.331
12.000	0.05	2.712	-1204.963	-26.981
13.929	0.05	7.956	-1390.244	-29.587
15.940	0.05	7.612	-1584.888	-34.350
15.036	0.05	5.844	-1500.188	-31.750
12.993	0.05	-1.175	-1306.844	-25.131
10.991	0.05	-6.806	-1111.888	-16.181
8.985	0.05	-16.131	-912.781	-8.825
7.003	0.05	-16.194	-711.194	-0.738
4.999	0.05	-14.856	-507.131	8.250

Deutsche WindGuard
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(c) Sonic 3D 94012039, page 3/6

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Photo of the measurement setup
Foto des Messaufbaus

28.11.2018 Cal. No.: 1823950 SN: 0106074061 / DEMO2203 WindGuard

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

Deutsche WindGuard
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(d) Sonic 3D 94012039, page 4/6

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Sensor config during calibration (1/2)
Sensorkonfiguration während der Kalibrierung (1/2)

C:?
R:AD=0
R:AE=0
R:AO=0
R:AT=0
R:AV=5
R:AZ=0
R:BR=9600
R:EC=1
R:FR=0
R:HC=1
R:HD=0
R:HE=0
R:HT=0
R:LC=07.11.18 11:11:01
R:MD=20
R:N0=
R:N1=REPCALL071118
R:N2=REPCALL071118
R:N3=REPCALL071118
R:NO=31
R:O1=2297
R:O2=2279
R:O3=2257
R:O4=2256
R:O5=2287
R:O6=2284
R:OA=0
R:OD=1
R:P1=1762
R:P2=1762
R:P3=1754
R:PR=0

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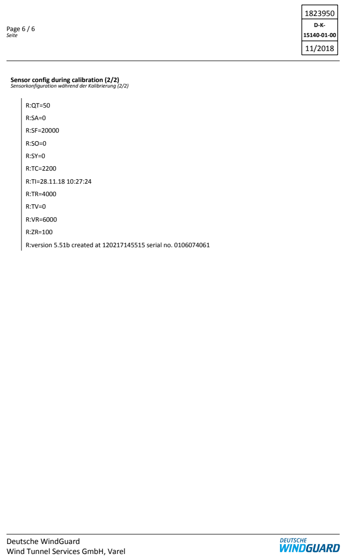
(e) Sonic 3D 94012039, page 5/6



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11/2018

Sensor config during calibration (2/2)
Sensorkonfiguration während der Kalibrierung (2/2)

R:QT=50
R:SA=0
R:SF=20000
R:SO=0
R:SY=0
R:TC=2200
R:TI=28.11.18 10:27:24
R:TR=4000
R:TV=0
R:VR=6000
R:ZR=100
R:version 5.51b created at 120217145515 serial no. 0106074061

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(f) Sonic 3D 94012039, page 6/6

B.2 Thies cup classification sheet

Summary report of cup anemometer classification

DEUTSCHE WINDGUARD

Class S Classification

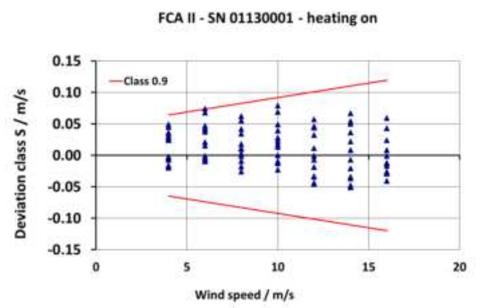
Reference:

IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing
2017-03

Result:
Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class S definition.

Internal shaft heating ON

Classification index: S 0.9
(average of five sensors)



Class S Classification

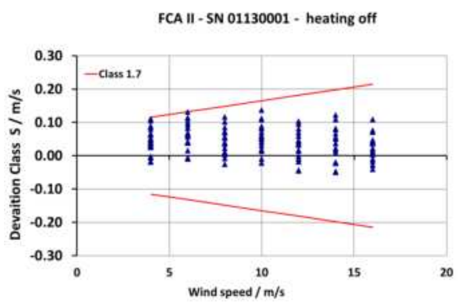
Reference:

IEC 61400-12-1 Edition 2.0
Wind Turbine Power Performance Testing
2017-03

Result:
Figure showing the calculated total deviation of the Thies First Class Advanced anemometer type 4.3352.00.000 taking into account all influencing parameters according to Class S definition.

Internal shaft heating OFF

Classification index: S 1.7
(average of five sensors)



Deutsche WindGuard Wind Tunnel Services GmbH — Page 10 of 11

(a) Thies cup 4.3352 classification report, page 10/11

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