MOLAS B300

Classification of the Molas B300 lidar, summary report according to IEC 61400-50-2

Nanjing Movelaser Co., Ltd

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Date: 30-06-2026

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Device:	Molas B300	DNV – Energy Systems
Report title:	Classification of the Molas B300 lidar, summary report according to IEC 61400-50-2	House No.9, No.1591 Hongqiao Road, Shanghai 200336, China
Customer:	Nanjing Movelaser Co., Ltd Building B2, Hongfeng Science and Technology Park, Kechuang Road, Qixia District, 21000 Nanjing, China	+86 21 3279 9000
Contact person:	Liu Zhixin	
Date of issue:	30-06-2026	
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Task and objective:
Lidar classification summary report in accordance with IEC 61400-50-2 for three Molas B300 lidars tested at 2 different sites. This document is intended to provide all interested parties with the classification results and methodology.

Prepared by:	Verified by:	Approved by:
Yongkun Zhao Senior Engineer Measurement	Richard Fruehmann Senior Engineer Wind & Turbine Testing	Minmin Lu Team Leader Measurement

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A	30-06-2026	Final report (electronic version only)	Yongkun Zhao	Richard Fruehmann	Minmin Lu

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EXECUTIVE SUMMARY

DNV performed the classification of the Molas B300 light detection and ranging (lidar) with firmware version 4.0. Three measurement campaigns were performed with two different lidar units at two different test sites. This report presents the summary results as per the International Electrotechnical Commission (IEC) standard 61400-50-2:2022 [1].

The first campaign was conducted at the Rodewald test site in Germany, where turbulence intensity (TI) and flow inclination angle were identified and retained as independent environmental variables (EVs) following the cross-correlation assessment. The two subsequent campaigns were conducted at the Saihantala test site in China, where TI and wind shear were identified and retained as independent EVs following the cross-correlation assessment.

Based on the combined results from all three campaigns, TI, flow inclination angle, and wind shear are identified as the final EVs for the Molas B300 lidar classification with firmware version 4.0. The resulting class numbers are presented in the table below.

Final classification results for the combined EVs TI, shear, and flow inclination

Height	Max influence			Preliminary accuracy	Type specific class	Standard uncertainty
(m)	TI	Shear	Flow inclination	%	%	%
40	3.393	-0.954	3.804	5.185	3.667	2.117
45	3.059	-1.456	3.686	5.006	3.540	2.044
50	2.724	-1.959	3.664	4.969	3.513	2.028
55	2.464	-2.462	3.643	5.040	3.564	2.058
60	2.365	-2.937	3.622	5.228	3.697	2.134
65	2.309	-2.781	3.409	4.969	3.513	2.028
70	2.260	-2.597	3.210	4.707	3.328	1.922
75	2.228	-2.413	3.155	4.555	3.221	1.859
80	2.197	-2.230	3.100	4.405	3.115	1.799
85	2.165	-2.046	3.045	4.260	3.012	1.739
90	2.134	-1.862	2.991	4.119	2.912	1.681
95	2.147	-1.875	2.818	4.009	2.835	1.637
100	2.161	-1.888	2.646	3.904	2.760	1.594
105	2.210	-1.979	2.545	3.909	2.764	1.596
110	2.288	-2.070	2.443	3.936	2.783	1.607
115	2.365	-2.162	2.342	3.969	2.806	1.620
120	2.442	-2.253	2.241	4.008	2.834	1.636
125	2.449	-2.336	2.144	4.007	2.833	1.636
130	2.455	-2.420	2.048	4.010	2.835	1.637
135	2.464	-2.503	1.951	4.018	2.841	1.640
140	2.505	-2.587	1.855	4.050	2.864	1.654
145	2.550	-2.674	1.822	4.120	2.913	1.682
150	2.595	-2.730	1.790	4.170	2.949	1.703
155	2.640	-2.720	1.750	4.175	2.952	1.704
160	2.691	-2.612	1.711	4.122	2.915	1.683
165	2.833	-2.436	1.231	3.934	2.782	1.606
170	2.982	-2.152	0.842	3.772	2.667	1.540
175	3.131	-1.868	0.735	3.720	2.630	1.518
180	3.301	-1.583	0.674	3.723	2.632	1.520
185	3.253	-1.628	0.584	3.685	2.606	1.504
190	3.206	-1.669	0.495	3.648	2.579	1.489
195	3.158	-1.597	0.405	3.562	2.519	1.454
200	3.110	-1.525	0.315	3.478	2.459	1.420

1 INTRODUCTION

Nanjing Movelaser Co., Ltd contracted DNV China Company Limited, a member of the DNV Group (“DNV”), to complete a classification of the Molas B300 lidar with firmware version 4.0 (a ground-based vertical profiling lidar) in accordance with the International Electrotechnical Commission (IEC) standard 61400-50-2:2022 (50-2) [1]. This report summarises the results of the three individual campaigns and presents the final combined classification results.

The individual campaigns were conducted at two 200-m tall reference meteorological (met) masts in Rodewald, Germany (operated by GEO-NET Umweltconsulting GmbH) and Saihantala, China (operated by CQC Standard Testing Technology (Shanghai) Co., Ltd). Two lidar units (SN 3088 and 3029) were tested at the Saihantala site, and one unit (SN 3088) was tested at the Rodewald site. Further details of the individual campaigns are available in the sensitivity reports [2,3,4].

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2 SITE INFORMATION

The following section briefly describes the two test sites where the measurement campaigns were completed. Both test sites meet the requirement of IEC 61400-12-5:2022 [5] for simple terrain and the sensors on the met masts are regularly calibrated in accordance with MEASNET requirements.

The met mast configurations differed between the test sites. At the Rodewald test site, primary and control cup anemometers were installed on side-mounted booms at each available height from 80 m to 200 m, and the reference wind speed was calculated as the average of the two measurements except where either anemometer was affected by mast wake. In those wind direction sectors, only the measurement from the free-stream anemometer was used. It is noteworthy that the 60 m height was found to be impacted by unclarified local phenomena leading to observed sensitivities that are not considered to reflect a physically meaningful or generalisable dependence of the lidar measurement on environmental variables (EVs) and was therefore excluded from the sensitivity analysis in this campaign. Further details are provided in [2].

At the Saihantala test site, a primary and control anemometer was only available at 40 m. The primary cup anemometer was installed at heights from 60 m to 200 m with control cup anemometers 4 m below. At 40 m, the reference wind speed was calculated as the average of the two measurements, except in mast wake sectors. At all other heights, data from mast-disturbed wind direction sectors were excluded and only measurements from free-stream sectors were used. Additional details are provided in [3,4].

The three campaigns were completed between May 2025 and March 2026. An overview of the campaign periods is provided in Table 2-1.

Table 2-1 Overview of the measurement campaigns

	Lidar serial number	Site	Start	End
Campaign 1	B300-3088	Rodewald	24-May-2025	23-Sep-2025
Campaign 2	B300-3029	Saihantala	12-Aug-2025	19-Jan-2026
Campaign 3	B300-3088	Saihantala	15-Nov-2025	23-Mar-2026

2.1 Rodewald

The Rodewald test site is located in northwest Germany, as shown in Figure 2-1. The Rodewald test site is operated by GEO-NET Umweltconsulting GmbH. There are wind turbines to the east of the test site leaving a wake-free sector from 121° to 90°. An overview of the sensors and heights used to obtain the EVs is provided in Table 2-1.

Additional site and mast details are provided in [2].

DNV

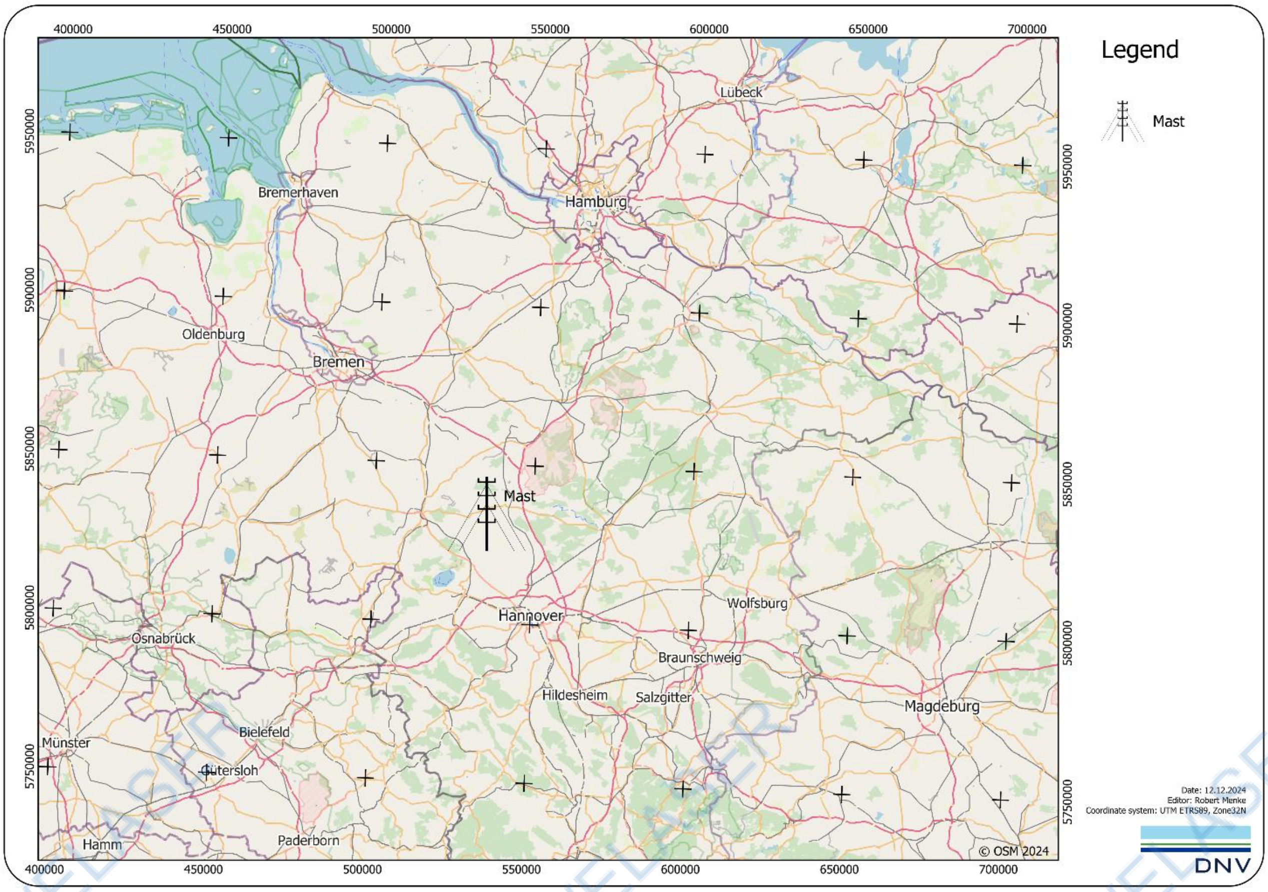

Figure 2-1 Location of the Rodewald test site (N52° 39.53', E 009° 31.29')

Table 2-2 Description of sensor and height pairing for environmental variables at Rodewald

EV	Associated sensor heights [m]*							
Comparison height	**200**	**180**	**160**	**140**	**120**	**100**	**80**	**60**
Temperature gradient	Temperature at 192 and 30							
Air temperature	192	192	155	155	155	95	95	55
Air density	Temperature at 155, humidity at 155, pressure at 133							
Wind veer	Wind vanes at 77 and 197							
Wind direction	197	177	157	137	117	97	77	77
Wind shear	200, 180	200, 180, 160	180, 160, 140	160, 140, 120	140, 120, 100	120, 100, 80	100, 80, 60	80, 60
Flow inclination	197		177		117		77	
Availability	200	180	160	140	120	100	80	60
Turbulence intensity	200	180	160	140	120	100	80	60
Rain	3.5							

* Heights are rounded to the nearest meter

2.2 Saihantala

The Saihantala test site is located in north China as shown in Figure 2-2. The Saihantala test site is operated by CQC Standard Testing Technology (Shanghai) Co., Ltd. Considering mast and obstacles, the wake-free sector is 247°to 145°, except for a few heights where the sector was further reduced to remove local mast effect on the lidar. An overview of the sensors and heights used to obtain the EVs is provided in Table 2-2.

Additional site and mast details are provided in [3,4].

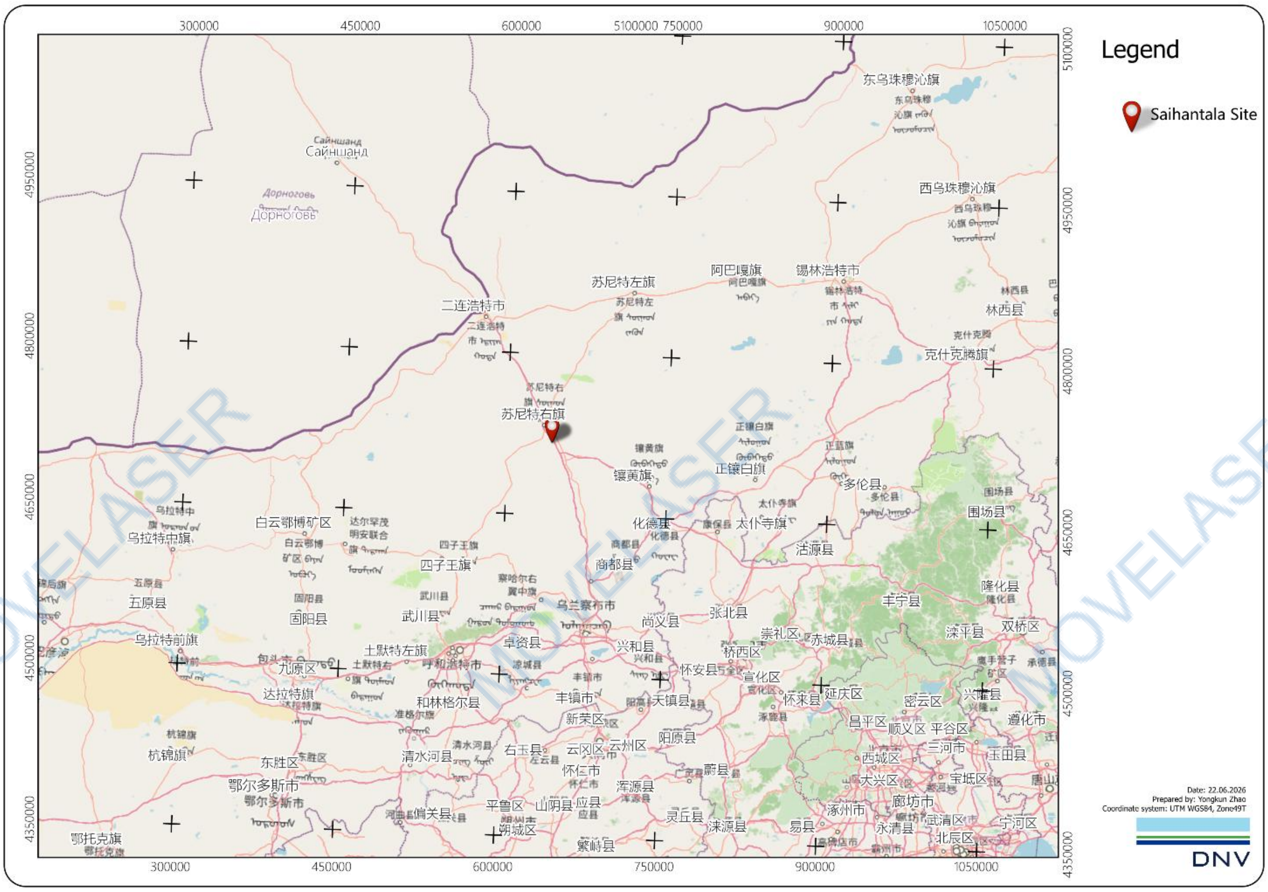

Figure 2-2 Location of the Saihantala test site (N 42° 47.11' E 111° 42.51')

Table 2-3 Description of sensor and height pairing for environmental variables at Saihantala

EV	Associated sensor heights [m]*					
Comparison height	**200**	**180**	**150**	**120**	**90**	**60**	**40**
Temperature gradient	Temperature at 146 and 86						
Air temperature	146				86		
Air density	Temperature, humidity and pressure at 146						
Wind veer	Wind vanes at 86 and 196						
Wind direction	196	176	146	116	86	56	38
Wind shear	200, 180	200, 180, 150	180, 150, 120	150, 120, 190	120, 90, 60	90, 60, 40	90, 60, 40
Flow inclination	150				90		

EV	Associated sensor heights [m]*						
Comparison height	**200**	**180**	**150**	**120**	**90**	**60**	**40**
Availability	200	180	160	1340	120	100	80
Turbulence intensity	200	180	160	140	120	100	80
Rain	precipitation events were identified using a derived precipitation flag based on wiper counts and humidity						

* Heights are rounded to the nearest meter

3 LIDAR CLASSIFICATION APPROACH

The lidar classification approach is provided in Clause 6 of 50-2 [1]. A summary of key evaluation steps and criteria are described in this section.

The 50-2 [1] requires a minimum of three campaigns at two test locations with two lidar devices at one location, and one of these two lidar devices moved to the second location. The period of each campaign must be at least 3 months (or 90 days) and cover a wide range of environmental conditions.

The classification is evaluated for wind speeds from 4 m/s to 16 m/s in bins of 0.5 m/s width (total range 3.75 m/s to 16.25 m/s). For each 10-minute data pair (lidar and reference wind speed) the deviation is calculated as the percent difference between the reference anemometer $(v_{reference})$ and the lidar wind speeds (v_{RSD}) to the reference anemometer wind speed -

$$deviation = \frac{(v_{RSD} - v_{reference})}{v_{reference}}$$

As provided in Table 3-1, Clause 6.5 of 50-2 prescribes a number of EVs against which the deviation should be evaluated to determine if it has a significant influence on the measurement accuracy. The sensitivity of the deviation to a given EV is defined as a two-variant linear relationship fitted to the binned deviations. Binning of the deviation and EV data is done as per the specifications detailed in Table 3-1.

Bin-average deviation and EV values are considered valid if the bins meet criteria requiring (a) minimum data counts; and (b) constraints on the variability of the within-bin deviation data, per 50-2 equations 3 and 4 respectively. Data bins that meet these criteria are considered “qualified,” and the sensitivity results are considered valid if at least 25% of the possible bins (as defined by the bin width and range) are qualified (50-2 Clause 6.5.).

Table 3-1 List of EVs defined in the IEC standard including defined ranges and bin widths

EV (Label)	Min	Max	Range	Bin width	Max number of bins	Unit	Source of range definition
Temperature gradient	-0.02	0.06	0.08	0.002	40	$K\ m^{-1}$	IEC
Air temperature	0	40	40	2	20	°C	IEC
Wind direction	0	360	180	5	72	°	IEC
Availability	80	100	20	1	20	%	Sensor specific
Turbulence intensity	0.03	0.24	0.21	0.01	21	-	IEC
Air density	0.9	1.35	0.45	0.05	9	$Kg.m^{-3}$	IEC
Wind veer gradient	-0.2	0.2	0.4	0.04	12	°/m	IEC
Wind shear exponent	-0.4	0.8	1.2	0.05	24	-	IEC
Rain	0	1	1	1	2	no/yes	Sensor specific
Flow inclination	-3	3	6	0.2	30	°	IEC

Using the above criteria, significant EVs are then assessed for intercorrelation. The aim is to avoid double counting the uncertainties from correlated EVs. This process is conducted independently for each measurement campaign.

If an EV is identified as being significant in one campaign, then the results for this EV from all campaigns are carried forward for the further evaluation.

The outputs of the sensitivity analysis are then evaluated for convergence to identify if any of the test campaigns should be considered as an outlier. According to Clause 6.9 of 50-2, if the magnitude of the sensitivity derived from any individual campaign differs by more than 50% from the mean value across all campaigns for a particular significant EV, then the campaign is considered unrepresentative and can be excluded from the classification.

To calculate the final accuracy class for the lidar type, the slopes of the significant EVs are first interpolated to a set of common heights. The slopes from the individual campaigns are then combined to give the final slope as follows:

$$m_{final} = \frac{1}{N_{CT}} \sum_{n=1}^{N_{CT}} m_n + \frac{m_{max} - m_{min}}{2} \times \frac{1}{\sqrt{3}}$$

where N_{CT} is the number of classification tests, m_n is the slope of the *n*th test, and m_{max} and m_{min} are the maximum and minimum slopes of the N_{CT} campaigns.

The maximum influence of each EV is then calculated as the final slope times the range defined in Table 3-1. The Preliminary accuracy is given by the summing the maximum influences of all EVs in quadrature. The Type Class is the preliminary accuracy divided by the square root of 2, and the standard uncertainty the preliminary accuracy divided by the square root of 3. Thus, an uncertainty is calculated for each measurement height separately.

3.1 Deviations from the IEC Standards

As presented in the sensitivity reports [2,3,4], the database requirements for wind speed bin completion were not fulfilled for some of the upper wind speed bins for all campaigns. The missing wind speed bins are not expected to have a significant influence on the results. In the case of the Rodewald campaign, the wind speed distribution as a whole was strongly biased to very low wind speeds. Therefore, any phenomena that may be more prevalent at low wind speeds will be more strongly represented in the results for that campaign.

Wind direction has been ignored as an EV. With the symmetrical arrangement of beams around the cone, any directional effect would have to show a periodicity with four cycles around the circle. Furthermore, a linear fit to define the sensitivity as described in the 50-2 is not suited to periodic relationships.

As described in Section 2, the Rodewald campaign data at 60 m were excluded from the evaluation. Results for the heights below 80 m are therefore based only on two campaigns from one site.

4 RESULTS

4.1 Summary of the sensitivity results from the individual campaigns

The sensitivity analyses performed for the Rodewald and Saihantala campaigns identified TI, flow inclination angle, wind shear, temperature gradient, and wind veer as significant EVs at one or more measurement heights. Cross-correlation analyses were subsequently carried out to determine whether the observed sensitivities represented independent influences on lidar performance or were primarily attributable to relationships with other atmospheric parameters.

For the Rodewald campaign (Serial No. 3088), TI and flow inclination angle exceeded the significance threshold and were found to exhibit only weak cross-correlation. Although a moderate reduction in sensitivity was observed at 80 m following decorrelation, no systematic reduction was identified at the upper measurement heights and no clear interdependence was observed between the two EVs. Both parameters were therefore retained for the final classification analysis.

For the Saihantala campaign (Serial No. 3029), TI and wind shear were identified as the significant EVs. Decorrelation reduced the sensitivity and sensitivity × r values at several heights, indicating a degree of shared variability. However, the overall sensitivity behavior remained largely unchanged and no sufficiently strong dependency was identified. Both TI and wind shear were therefore retained for the final classification analysis.

For the Saihantala campaign (Serial No. 3088), TI, wind shear, temperature gradient, and wind veer exceeded the significance threshold at several heights. However, decorrelation analysis demonstrated that the sensitivities associated with temperature gradient and wind veer were largely attributable to their correlation with TI. Significant reductions in sensitivity and sensitivity × r were observed following decorrelation, indicating strong interdependence. Consequently, temperature gradient and wind veer were excluded from the final classification analysis and only TI and wind shear were carried forward as independent EVs.

Overall, TI was retained as an independent EV in all campaigns and represents the most consistently observed atmospheric influence on lidar performance. Flow inclination angle was retained for the Rodewald campaign and was found to be independent of TI, while wind shear was retained in both Saihantala campaigns and exhibited only limited interdependence with the other EVs. Based on these findings, turbulence intensity, flow inclination angle, and wind shear were selected as the final EVs for the combined IEC 61400-50-2 classification analysis. A more detailed discussion of the arguments for EV selection can be found in the individual campaign reports [2,3,4].

4.2 Convergence test

Table 4-1 through Table 4-3 show the slopes from all three campaigns for each of the three significant EVs. The results from Rodewald for the heights below 80 m are shown in italics with a grey font to highlight that these have been extrapolated according to the trend between the last two heights (80 and 100 m).

The slopes of the sensitivity evaluation have been interpolated to 5 m intervals. The slope from each campaign is compared to the average slope from all three campaigns. The sensitivity deviations from mean that exceed the criterion of less than 50% are highlighted in orange. The sensitivities generally lie within 50% of the three-campaign average. Where this criterion is exceeded, the corresponding slope values do not usually indicate a systematic campaign outlier. The main exception is wind shear at the lower heights, where larger sensitivity deviations are consistent with clear differences in the interpolated slopes.

TI shows very consistent slopes for all three campaigns; notable differences are observed only at lowest and uppermost heights where no individual campaign stands out as an outlier.

Similarly for shear, most of the slopes are consistent across all three campaigns, despite the fact that shear did not appear as a significant EV at the Rodewald campaign. Larger differences are only observed at the lower heights, particularly at 60 m and 80 m, where the spread between the campaign slopes is more pronounced.

Flow inclination was identified as a significant EV only at Rodewald. The observed difference in slopes between the Rodewald and Saihantala campaigns is consistent with the differing sensitivities to flow inclination at the two locations. In conclusion, all three sites will be weighted equally for the calculation of the final class number, and no individual results will be discarded as outliers.

Table 4-1 interpolated TI slopes for all three campaigns

Height	Slope for TI		
	Rodewald_3088	Saihantala_3029	Saihantala_3088
40	*10.99*	17.71	13.94
45	*10.97*	15.47	13.36
50	*10.96*	13.22	12.78
55	*10.95*	10.98	12.20
60	*10.93*	8.73	11.62
65	*10.92*	8.56	11.22
70	*10.90*	8.38	10.82
75	*10.89*	8.21	10.41
80	10.88	8.03	10.01
85	10.86	7.86	9.61
90	10.85	7.68	9.21
95	10.83	8.35	9.34
100	10.82	9.01	9.48
105	11.05	9.67	9.61
110	11.28	10.33	9.75
115	11.51	10.99	9.88
120	11.73	11.66	10.01
125	11.85	11.48	10.40
130	11.96	11.31	10.79
135	12.08	11.13	11.18
140	12.19	10.95	11.57
145	12.34	10.78	11.96
150	12.49	10.60	12.34
155	12.64	11.23	12.62
160	12.79	11.86	12.89
165	13.74	12.48	13.17
170	14.68	13.11	13.44
175	15.63	13.73	13.72
180	16.57	14.36	13.99
185	16.22	14.46	13.08
190	15.87	14.55	12.18
195	15.52	14.64	11.27
200	15.17	14.74	10.36

Table 4-2 interpolated shear slopes for all three campaigns

Height	Slope for shear		
	Rodewald_3088	Saihantala_3029	Saihantala_3088
40	*-0.72*	-1.78	-0.80
45	*-0.76*	-2.58	-1.87
50	*-0.81*	-3.39	-2.94
55	*-0.85*	-4.19	-4.01
60	*-0.89*	-5.00	-5.08
65	*-0.93*	-4.97	-4.54
70	*-0.98*	-4.95	-4.01
75	*-1.02*	-4.93	-3.47
80	-1.06	-4.90	-2.93
85	-1.11	-4.88	-2.40
90	-1.15	-4.86	-1.86
95	-1.19	-4.50	-1.86
100	-1.23	-4.14	-1.86
105	-1.38	-3.78	-1.86
110	-1.53	-3.42	-1.86
115	-1.68	-3.06	-1.86
120	-1.83	-2.70	-1.86
125	-1.83	-2.72	-2.07
130	-1.83	-2.73	-2.27
135	-1.83	-2.75	-2.47
140	-1.83	-2.77	-2.67
145	-1.89	-2.78	-2.88
150	-1.94	-2.80	-3.08
155	-1.99	-2.76	-2.72
160	-2.04	-2.73	-2.36
165	-2.01	-2.69	-1.99
170	-1.98	-2.65	-1.63
175	-1.95	-2.62	-1.27
180	-1.92	-2.58	-0.91
185	-2.00	-2.32	-0.94
190	-2.08	-2.07	-0.98
195	-2.16	-1.81	-1.02
200	-2.24	-1.55	-1.05

Table 4-3 interpolated flow inclination slopes for all three campaigns

Height	Slope for flow inclination		
	Rodewald_3088	Saihantala_3029	Saihantala_3088
40	*0.95*	0.12	0.06
45	*0.92*	0.11	0.11
50	*0.88*	0.11	0.17
55	*0.85*	0.10	0.22
60	*0.82*	0.10	0.28
65	*0.78*	0.14	0.23
70	*0.75*	0.19	0.18
75	*0.71*	0.23	0.13
80	0.68	0.27	0.08
85	0.65	0.31	0.03
90	0.61	0.36	-0.02
95	0.58	0.33	0.01
100	0.54	0.31	0.03
105	0.53	0.28	0.06
110	0.51	0.25	0.08
115	0.50	0.23	0.11
120	0.48	0.20	0.14
125	0.46	0.20	0.13
130	0.44	0.20	0.12
135	0.41	0.19	0.11
140	0.39	0.19	0.11
145	0.38	0.19	0.10
150	0.37	0.19	0.09
155	0.37	0.18	0.09
160	0.36	0.17	0.09
165	0.23	0.17	0.09
170	0.11	0.16	0.08
175	-0.02	0.16	0.08
180	-0.14	0.15	0.08
185	-0.12	0.13	0.07
190	-0.10	0.11	0.06
195	-0.08	0.09	0.05
200	-0.06	0.07	0.03

4.3 Intermediate results

The intermediate results presented in the individual campaign reports are provided in Table 4-4 through Table 4-6. These show only those EVs that were found to be significant in the respective campaign.

Table 4-4 Intermediate results for Rodewald 3088 – EVs TI and flow inclination

Height	Maximum influence		Preliminary class number	Accuracy class	Standard uncertainty
	TI	Flow inclination			
[m]	[-]	[-]	[-]	[-]	[-]
200	3.185	-0.379	3.207	2.268	1.309
180	3.480	-0.847	3.582	2.533	1.462
160	2.687	2.154	3.444	2.435	1.406
140	2.560	2.321	3.455	2.443	1.411
120	2.464	2.897	3.803	2.689	1.553
100	2.272	3.260	3.973	2.810	1.622
80	2.284	4.078	4.674	3.305	1.908

Table 4-5 Intermediate results for Saihantala 3029 – EVs TI and shear

Height	Maximum influence		Preliminary class number	Accuracy class	Standard uncertainty
	TI	Shear			
[m]	[-]	[-]	[-]	[-]	[-]
200	3.095	-1.862	3.612	2.554	1.475
180	3.016	-3.098	4.323	3.057	1.765
150	2.227	-3.356	4.028	2.848	1.644
120	2.448	-3.242	4.062	2.872	1.658
90	1.613	-5.828	6.048	4.276	2.469
60	1.833	-5.997	6.271	4.435	2.560
40	3.720	-2.131	4.287	3.031	1.750

Table 4-6 Intermediate results for Saihantala 3088 – EVs TI and shear

Height	Maximum Influence		Preliminary Class number	Accuracy Class	Standard Uncertainty
	TI	Shear			
[m]	[-]	[-]	[-]	[-]	[-]
200	2.176	-1.262	2.516	1.779	1.027
180	2.938	-1.090	3.134	2.216	1.279
150	2.592	-3.694	4.513	3.191	1.842
120	2.103	-2.237	3.071	2.171	1.254
90	1.934	-2.234	2.955	2.090	1.206
60	2.440	-6.094	6.564	4.642	2.680
40	2.928	-0.964	3.083	2.180	1.258

4.4 Type specific classification results

The classification aims to present a quantitative uncertainty of the horizontal wind speed measurement to be expected from the remote sensing device with regards to its sensitivity to meteorological conditions. For this, a combined slope is calculated based on the significant sensitivity slopes from each of the three campaigns. This is done here for the combination of TI, shear, and flow inclination angle.

To derive the application specific uncertainty as described in Section 5, it is necessary to use the final slopes (i.e., the aggregated slope from all three measurement campaigns, m_{final}, as described in Section 3).

The final slopes are listed in APPENDIX A for the three significant EVs.

Table 4-7 Final classification results for the combined EVs TI, shear, and flow inclination

Height	Max influence			Preliminary accuracy	Type specific class	Standard uncertainty
(m)	TI	Shear	Flow inclination	%	%	%
40	3.393	-0.954	3.804	5.185	3.667	2.117
45	3.059	-1.456	3.686	5.006	3.540	2.044
50	2.724	-1.959	3.664	4.969	3.513	2.028
55	2.464	-2.462	3.643	5.040	3.564	2.058
60	2.365	-2.937	3.622	5.228	3.697	2.134
65	2.309	-2.781	3.409	4.969	3.513	2.028
70	2.260	-2.597	3.210	4.707	3.328	1.922
75	2.228	-2.413	3.155	4.555	3.221	1.859
80	2.197	-2.230	3.100	4.405	3.115	1.799
85	2.165	-2.046	3.045	4.260	3.012	1.739
90	2.134	-1.862	2.991	4.119	2.912	1.681
95	2.147	-1.875	2.818	4.009	2.835	1.637
100	2.161	-1.888	2.646	3.904	2.760	1.594
105	2.210	-1.979	2.545	3.909	2.764	1.596
110	2.288	-2.070	2.443	3.936	2.783	1.607
115	2.365	-2.162	2.342	3.969	2.806	1.620
120	2.442	-2.253	2.241	4.008	2.834	1.636
125	2.449	-2.336	2.144	4.007	2.833	1.636
130	2.455	-2.420	2.048	4.010	2.835	1.637
135	2.464	-2.503	1.951	4.018	2.841	1.640
140	2.505	-2.587	1.855	4.050	2.864	1.654
145	2.550	-2.674	1.822	4.120	2.913	1.682
150	2.595	-2.730	1.790	4.170	2.949	1.703
155	2.640	-2.720	1.750	4.175	2.952	1.704
160	2.691	-2.612	1.711	4.122	2.915	1.683
165	2.833	-2.436	1.231	3.934	2.782	1.606
170	2.982	-2.152	0.842	3.772	2.667	1.540
175	3.131	-1.868	0.735	3.720	2.630	1.518
180	3.301	-1.583	0.674	3.723	2.632	1.520
185	3.253	-1.628	0.584	3.685	2.606	1.504
190	3.206	-1.669	0.495	3.648	2.579	1.489
195	3.158	-1.597	0.405	3.562	2.519	1.454
200	3.110	-1.525	0.315	3.478	2.459	1.420

5 DERIVING APPLICATION UNCERTAINTY

The type-specific class and standard uncertainties are the maximum wind speed measurement uncertainty that may be expected from the lidar due to differences in the environmental conditions between a verification and specific measurement campaign. However, it is likely that the differences are smaller than those assumed in the calculation of the type-class and standard uncertainties. In this case the category B uncertainty of the wind speed measurement due to the influence of EVs on the performance of the remote sensing device is calculated as follows,

$$u_{class,i} = \sqrt{\sum_{j=1}^{M} \left(\frac{m_j}{100} \left| \bar{x}_{SMC,j,i} - \bar{x}_{ver,j,i} \right| \right)^2}$$

where:

$u_{class,i}$ is the type-specific class uncertainty in wind speed bin i,

M is the number of significant EVs,

m_j is the slope describing the sensitivity of the wind speed measurement of the remote sensing device on the EV j,

$\bar{x}_{SMC,j,i}$ is the mean value of the EV j in wind speed bin i as present during the specific measurement campaign,

$\bar{x}_{ver,j,i}$ is the mean value of the environmental variable j in wind speed bin i as present during the verification test.

Table 5-1 shows an example of how the information from the classification results provided in [1]. Table 4-7 can be used to obtain the final slope for each EV. Sample calculations to determine $u_{class,i}$ for a fictive specific measurement campaign and verification are provided in Table 5-2 for an assumed hub height of 120 m.

Table 5-1 EV parameters from classification and IEC table

EV	Max influence	IEC range (from Table 3-1)	Slope
TI	2.442	0.21	11.629
Shear	-2.253	1.2	-1.878
Flow inclination	2.241	6	0.374

Table 5-2 Example calculation of classification uncertainty for a specific measurement campaign

Wind speed	TI				Shear				Flow inclination				u_classification
	Verification	Campaign	Difference	(Diff. x m/100)^2	Verification	Campaign	Difference	(Diff. x m/100)^2	Verification	Campaign	Difference	(Diff. x m/100)^2	[%]
4	0.11	0.08	0.03	1.39E-05	0.04	-0.02	0.05	1.04E-06	0.416	0.031	0.385	2.07E-06	0.413
4.5	0.10	0.08	0.02	4.53E-06	0.12	0.07	0.05	9.17E-07	0.213	0.190	0.023	7.14E-09	0.234
5	0.10	0.07	0.02	7.23E-06	0.11	0.07	0.04	5.00E-07	0.199	0.138	0.061	5.23E-08	0.279
5.5	0.08	0.08	0.01	8.97E-07	0.13	0.08	0.05	7.50E-07	0.126	0.208	-0.082	9.28E-08	0.132
6	0.07	0.07	0.00	9.65E-08	0.17	0.09	0.07	1.96E-06	0.152	0.145	0.008	8.29E-10	0.143
6.5	0.06	0.07	-0.01	1.76E-06	0.16	0.11	0.05	8.00E-07	0.221	0.172	0.049	3.30E-08	0.161
7	0.06	0.06	-0.01	5.91E-07	0.20	0.16	0.04	5.61E-07	0.119	0.043	0.075	7.93E-08	0.111
7.5	0.05	0.06	-0.01	4.59E-07	0.18	0.13	0.06	1.10E-06	0.001	-0.061	0.061	5.28E-08	0.127
8	0.05	0.06	-0.01	8.12E-07	0.20	0.17	0.03	3.44E-07	-0.071	-0.142	0.072	7.20E-08	0.111
8.5	0.05	0.06	-0.01	9.49E-07	0.22	0.21	0.01	8.94E-09	-0.045	-0.094	0.049	3.40E-08	0.100
9	0.05	0.06	-0.01	8.43E-07	0.21	0.17	0.04	4.67E-07	0.126	-0.121	0.247	8.51E-07	0.147
9.5	0.05	0.05	0.00	6.36E-12	0.21	0.15	0.06	1.23E-06	-0.018	0.000	-0.018	4.65E-09	0.111
10	0.05	0.05	-0.01	5.48E-07	0.19	0.22	-0.03	3.43E-07	-0.098	-0.039	-0.059	4.79E-08	0.097
10.5	0.05	0.06	-0.01	1.38E-06	0.19	0.25	-0.06	1.35E-06	0.062	-0.013	0.075	7.76E-08	0.168
11	0.05	0.06	-0.01	4.13E-07	0.19	0.24	-0.05	7.30E-07	-0.407	-0.034	-0.373	1.94E-06	0.176
11.5	0.06	0.05	0.00	3.07E-08	0.23	0.24	-0.02	9.19E-08	-0.547	0.129	-0.676	6.38E-06	0.255
12	0.05	0.06	-0.01	6.10E-07	0.24	0.24	-0.01	1.35E-08	-0.528	-0.027	-0.501	3.50E-06	0.203
12.5	0.05	0.05	-0.01	7.77E-07	0.24	0.22	0.02	1.41E-07	-0.734	0.128	-0.863	1.04E-05	0.336
13	0.05	0.06	-0.01	1.35E-06	0.24	0.20	0.04	6.42E-07	-0.468	0.218	-0.686	6.56E-06	0.292
13.5	0.04	0.06	-0.01	2.38E-06	0.23	0.18	0.05	8.46E-07	-0.461	0.157	-0.618	5.32E-06	0.292
14	0.04	0.06	-0.02	3.72E-06	0.22	0.16	0.06	1.19E-06	-1.517	0.266	-1.783	4.44E-05	0.702
14.5	0.04	0.06	-0.02	3.15E-06	0.21	0.16	0.06	1.07E-06	-0.642	0.290	-0.932	1.21E-05	0.404
15	0.05	0.06	-0.02	3.75E-06	0.21	0.21	0.00	8.20E-11	-0.280	0.614	-0.894	1.11E-05	0.386
15.5	0.04	0.06	-0.02	4.59E-06	0.21	0.15	0.05	1.04E-06	-0.418	0.375	-0.792	8.76E-06	0.379
16	0.04	0.07	-0.02	8.24E-06	0.22	0.06	0.16	8.61E-06	-0.871	0.232	-1.104	1.70E-05	0.582

When evaluating the measurement uncertainty in a specific measurement campaign, several uncertainty components are added in quadrature. The classification uncertainty is only one of several uncertainty components.

6 CONCLUSION

The Molas B300 lidar with firmware version 4.0 has successfully undergone a type classification over a range of heights from 40 m to 200 m. DNV has independently followed the methodology defined in IEC 50-2.

Three EVs were identified as significant and sufficiently independent according to the IEC 61400-50-2 criteria [1]: TI, flow inclination angle, and wind shear. TI was identified in all three campaigns, while flow inclination angle was retained for the Rodewald campaign and wind shear was retained for both Saihantala campaigns. The cross-correlation analyses presented in Section 4.1 did not indicate sufficiently strong interdependence to justify the exclusion of any of these EVs.

It is therefore recommended to consider TI, wind shear, and flow inclination angle as the final EVs for the Molas B300 lidar classification. The resulting class numbers are presented in Section 5.

The heights below 80 m have been assessed based on the measurements at Saihantala and extrapolated values from Rodewald. DNV presents the results including the heights below 80 m. Since these have been obtained from two tests, and combined with the extrapolated values, they are deemed to provide a reasonable representation of the device performance. However, this is noted as a deviation from IEC 61400-50-2 [1].

The classification uncertainties are fully compliant with IEC 61400-50-2 between 80 and 200 m. DNV recommends the use from 40 m to 200 m. The classification uncertainties can therefore be applied to heights from 30 m to 267 m (hub height ±25%) for power performance testing in accordance with IEC 61400-12-1 [6] provided a suitable additional uncertainty is applied for those heights below 40 m or above 200 m. For other applications and measurement heights, the user is advised to exercise engineering judgment.

7 REFERENCES

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2. “10557341-R-1-B: Sensitivity Analysis for Molas B300 lidar (serial no. B300-3088) at the remote sensing test site, Rodewald”, DNV report, Hamburg, 26.06.2026
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5. “Wind energy generation systems – Part 12-5: Power performance, Assessment of obstacles and terrain, IEC 61400-21-5 Edition 1.0.” International Electrotechnical Commission, Geneva, Switzerland, 2022.
6. “Wind energy generation systems – Part 12-1: Power performance measurement of electricity producing wind turbines, IEC 61400-21-1 Edition 3.0.” International Electrotechnical Commission, Geneva, Switzerland, 2022.

APPENDIX A FINAL SLOPES

The table below lists the final slopes interpolate to height intervals of 5 m for the three EVs identified as significant.

Height	Final slope (m_{final})		
m	TI	Shear	Flow inclination
40	16.16	-0.79	0.63
45	14.57	-1.21	0.61
50	12.97	-1.63	0.61
55	11.74	-2.05	0.61
60	11.26	-2.45	0.60
65	11.00	-2.32	0.57
70	10.76	-2.16	0.54
75	10.61	-2.01	0.53
80	10.46	-1.86	0.52
85	10.31	-1.70	0.51
90	10.16	-1.55	0.50
95	10.23	-1.56	0.47
100	10.29	-1.57	0.44
105	10.52	-1.65	0.42
110	10.89	-1.73	0.41
115	11.26	-1.80	0.39
120	11.63	-1.88	0.37
125	11.66	-1.95	0.36
130	11.69	-2.02	0.34
135	11.73	-2.09	0.33
140	11.93	-2.16	0.31
145	12.14	-2.23	0.30
150	12.36	-2.28	0.30
155	12.57	-2.27	0.29
160	12.81	-2.18	0.29
165	13.49	-2.03	0.21
170	14.20	-1.79	0.14
175	14.91	-1.56	0.12
180	15.72	-1.32	0.11
185	15.49	-1.36	0.10
190	15.26	-1.39	0.08
195	15.04	-1.33	0.07
200	14.81	-1.27	0.05

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