TYPE MOLAS B300 LIDAR

Remote Sensing Device Type-specific Classification Summary

Nanjing Movelaser Co., Ltd

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1 INTRODUCTION

GL Garrad Hassan Deutschland GmbH ("GH-D"), a member of the DNV Group ("DNV"), has been assigned on 2020-10-30 by Nanjing Movelaser Co., Ltd , to conduct an independent classification assessment of three lidar units of type MOLAS B300.

The performance of a remote sensing device (RSD) may be influenced by environmental variables (EV), such as wind shear and air temperature. Since the environmental conditions may differ between verification and application of the RSD, any sensitivity of its measurement accuracy to a particular EV can lead to an increased uncertainty in the measurement results of the application. The task of the classification test is to identify influential EVs and quantify the sensitivity of the RSD measurement accuracy to different EVs for a range of measurement heights. This report aims to present the quantitative uncertainty of wind measurements to be expected from the type MOLAS B300 lidar with regards to its sensitivity to meteorological conditions.

The classification measurement campaigns took place over two sites, with one Lidar deployed at two different sites and another lidar deployed at one site, so a total of three separate campaigns were analysed. DNV was responsible for conducting all three classfication campaigns. The first and the second classification campaigns took place at the Hamburg and Janneby test site to classify the unit MOLAS B300-117 [1] [2]. The third classification campaign took place also in Hamburg to classify the second unit MOLAS B300-202 [3].

According to the IEC 61400-12-1 Ed. 2 [4] to obtain a device type-specific classification it is required to test a minimum of two units at a minimum of two different measurement sites. At least one unit has to be deployed on two sites, which results in a minimum of three classification tests for each instrument type. For the given number of classification tests of MOLAS B300 lidars, the IEC criteria for issuing the type-specific classification have been fully met.

In this report, a summary of all classification task assessments of the type MOLAS B300 lidar are shown, and the type-specific classification figures are presented.

2 RESULTS

In this chapter, all steps and intermediate results towards the type-specific accuracy class are addressed.

2.1 Data coverage of the classification campaigns

The classification trial of unit MOLAS B300-117 at the Hamburg test-site took place between 2020-02-18 and 2020-06-03 for a total of 106 days. This trial covered a wind speed range of 3.00 to 21.97 m/s at hub height (121 m) and 3.00 to 15.52 m/s at the lowest height (45 m). The campaign data coverage, representing the number of filtered and useful concurrent measurements per wind speed bin is shown in Table 1.

	Center of WS bin / m/s																								
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
# values at 121m	529	681	784	851	817	872	909	715	645	546	447	361	339	286	273	217	131	99	78	60	49	26	25	26	21
# values at 80m	870	944	1025	968	918	809	659	545	512	397	337	308	251	178	123	87	66	44	43	27	22	27	12	7	4
# values at 65m	981	1086	1019	943	822	677	578	501	439	357	311	248	178	128	70	62	46	37	24	25	19	9	8	3	0
# values at 45m	1128	1044	895	789	716	591	460	446	342	245	182	111	61	62	38	31	23	16	13	3	2	4	1	1	0

Table 1: MOLAS B300-117 @ Hamburg - Wind speed coverage for all assessed heights.

With regards to the classification trial of unit MOLAS B300-117 at the Janneby test-site, it took place between 2020-07-16 and 2020-11-09 for a total of 117 days. This trial covered a wind speed range of 3.00 to 18.44 m/s at hub height (100 m) and 3.00 to 14.19 m/s at the lowest height (57 m). The campaign data coverage, representing the number of filtered and useful concurrent measurements per wind speed bin is shown in Table 2.

	Center of WS bin / m/s																								
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
# values at 100m	751	725	744	727	750	752	778	723	726	658	566	438	359	313	238	193	121	76	51	42	32	26	34	18	20
# values at 75m	812	760	824	854	915	876	793	741	631	482	387	340	316	236	160	111	61	58	33	39	25	23	21	18	10
# values at 57m	956	978	992	1046	921	867	688	567	442	366	355	289	212	155	95	67	45	42	29	26	19	17	12	2	2

Table 2: MOLAS B300-117 @ Janneby- Wind speed coverage for all assessed heights.

When it comes to the classification trial of unit MOLAS B300-202 at the Hamburg test-site, it took place between 2020-10-01 and 2021-02-02 for a total of 124.5 days. This trial covered a wind speed range of 3.00 to 16.64 m/s at hub height (121 m) and 3.00 to 12.46 m/s at the lowest height (45 m). The campaign data coverage, representing the number of filtered and useful concurrent measurement per wind speed bin is shown in Table 3.

	Center of WS bin / m/s																								
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
# values at 121m	435	601	815	869	940	959	959	1063	948	731	580	421	348	312	223	154	112	66	58	39	21	8	2	4	4
# values at 80m	852	1137	1100	1145	1163	1118	854	653	498	412	317	242	153	117	72	47	39	20	11	4	4	2	0	0	0
# values at 65m	1162	1245	1195	1208	1106	836	652	460	420	312	204	152	93	61	41	35	13	12	6	2	0	0	0	0	0
# values at 45m	1443	1278	1242	929	713	547	454	328	218	127	71	50	47	29	10	13	1	1	0	0	0	0	0	0	0

Table 3: MOLAS B300-202 @ Hamburg - Wind speed coverage for all assessed heights.

As observed, some wind speed bins did not completely fulfil the given IEC criteria of wind speed coverage threshold. In fact, it is challenging to find the most suitable period in which the wind speed and EVs variability are met to perform a classification test in North Europe. Usually, higher wind speeds are found in cold seasons. However, every variable that is somehow dependent on temperature is affected due to temperature ranges below zero or not higher than 10°C. Conversely, between Spring and Summer, the variability of temperature and air density increases significantly. DNV notes, it would require more than 3 months to cover the whole wind speed range due to usually lower wind speed.

Therefore, the observed wind speeds and EV range variability during the classification tests are considered significant and appropriate to provide the basis for calculating the final IEC accuracy class of the type MOLAS B300 lidar.

2.2 Intermediate classification results

The classification results for all units were calculated based on the sensitivity analysis and on the IEC criteria for defining an environmental variable to be significant. Each classification trials identified significant environmental variables that were correlated with the size of the difference between wind speed measurements made by a type MOLAS B300 lidar and a high-quality reference cup anemometer.

For the classification results of unit MOLAS B300-117 at the Hamburg test site, seven out of ten EVs were found to be significant and they were kept in the classification calculation. The method proposed by [5] was used to assess the intercorrelation between EVs and, in case of strong correlation, the same reference proposes a method for removing the dependence. Based on this methodology, it was observed that there was a strong intercorrelation between turbulence intensity and temperature gradient, wind shear exponent and temperature gradient, turbulence Intensity and wind shear exponent. Therefore, the decorrelation method to remove the influence of TI on temperature gradient, wind shear on temperature gradient and TI on wind shear was performed. In summary, the selected independent EVs for composing the accuracy class of unit MOLAS B300-117 at the Hamburg test-site were temperature gradient, air temperature, turbulence intensity, wind veer, wind shear exponent, rain and flow inclination angle.

Table 4 lists all significant and independent EVs, their slopes and ranges. Multiplying the regression slopes by the associated range results in the maximum deviation influence of each independent variable on the RSD accuracy (Column 5). Assuming that all selected variables are fully independent from each other, to build-up the preliminary accuracy class, each individual max influence is added in quadrature (Column 6). The final accuracy class is calculated by dividing the preliminary accuracy class by $\sqrt{2}$ (Column 7) while the RSD standard uncertainty is obtained by dividing the final accuracy class by $\sqrt{3}$ (Column 8).

Regarding the classification results of unit MOLAS B300-117 at Janneby, the selected independent EVs for composing the accuracy class were temperature gradient, wind direction, turbulence intensity, wind veer, wind shear exponent, rain and flow inclination angle. Table 6 lists the selected independent EVs, their slopes and ranges along with the unit MOLAS B300-117 accuracy class and standard uncertainty in Janneby test-site.

Lastly, with regards to the classification results of unit MOLAS B300-202 at Hamburg, the selected independent EVs for composing the accuracy class were temperature gradient, air temperature, wind direction, turbulence intensity, wind shear exponent, rain and flow inclination angle. Table 8 lists the selected independent EVs, their slopes and ranges along with the unit MOLAS B300-202 accuracy class and standard uncertainty at the Hamburg test-site.

In summary, the selected independent and significant EVs among all the classification campaigns are temperature gradient, air temperature, wind direction, turbulence intensity, wind veer, wind shear exponent, rain and flow inclination angle.

Height above ground level	Independent Variable	*m*	Range	Max Influence m × range	Preliminary Accuracy Class	Final Accuracy Class	Standard Uncertainty
[m]	[-]	[%/unit variable]	[u.v]	[-]	[%]	[%]	[%]
121	Temperature Gradient	6.439	0.080	0.515	3.544	2.506	1.447
121	Air Temperature	0.039	40.000	1.561			
121	Turbulence Intensity	9.583	0.210	2.013			
121	Wind Veer between 97m and 57m	-2.578	0.400	1.031			
121	Wind shear exponent	-1.728	1.200	2.074			
121	Rain (yes = 1, no = 0)	0.002	1.000	0.002			
121	Flow Inclination Angle	-0.111	6.000	0.664			
80	Temperature Gradient	16.767	0.080	1.341	3.541	2.504	1.446
80	Air Temperature	0.017	40.000	0.696			
80	Turbulence Intensity	6.571	0.210	1.380			
80	Wind Veer between 97m and 57m	-0.996	0.400	0.398			
80	Wind shear exponent	-2.330	1.200	2.796			
80	Rain (yes = 1, no = 0)	0.200	1.000	0.200			
80	Flow Inclination Angle	-0.096	6.000	0.577			
65	Temperature Gradient	12.433	0.080	0.995	4.144	2.930	1.692
65	Air Temperature	0.013	40.000	0.517			
65	Turbulence Intensity	6.088	0.210	1.278			
65	Wind Veer between 97m and 57m	-1.893	0.400	0.757			
65	Wind shear exponent	-2.959	1.200	3.551			
65	Rain (yes = 1, no = 0)	0.368	1.000	0.368			
65	Flow Inclination Angle	-0.164	6.000	0.983			
45	Temperature Gradient	-19.262	0.080	1.541	2.095	1.481	0.855
45	Air Temperature	0.003	40.000	0.110			
45	Turbulence Intensity	2.337	0.210	0.491			
45	Wind Veer between 97m and 57m	-1.255	0.400	0.502			
45	Wind shear exponent	-0.923	1.200	1.108			
45	Rain (yes = 1, no = 0)	0.334	1.000	0.334			
45	Flow Inclination Angle	-0.069	6.000	0.412			

Table 4: Classification Results of unit MOLAS B300-117 at Hamburg. List of selected independent EVs along with their maximum influence on the RSD accuracy, the RSD preliminary and final accuracy class and the standard uncertainty per assessed height.

Height above ground level	Independent Variable	*m*	Range	Max Influence m × range	Preliminary Accuracy Class	Final Accuracy Class	Standard Uncertainty
[m]	[-]	[%/unit variable]	[u.v]	[-]	[%]	[%]	[%]
100	Temperature Gradient	-11.266	0.080	0.901	3.598	2.544	1.469
100	Wind Direction	0.003	180.000	0.541			
100	Turbulence Intensity	9.866	0.210	2.072			
100	Wind Veer between 97m and 57m	-3.904	0.400	1.562			
100	Wind shear exponent	-1.650	1.200	1.980			
100	Rain (yes = 1, no = 0)	0.587	1.000	0.587			
100	Flow Inclination Angle	-0.153	6.000	0.919			
75	Temperature Gradient	-10.470	0.080	0.838	4.703	3.326	1.920
75	Wind Direction	0.002	180.000	0.297			
75	Turbulence Intensity	12.425	0.210	2.609			
75	Wind Veer between 97m and 57m	-5.687	0.400	2.275			
75	Wind shear exponent	-2.406	1.200	2.888			
75	Rain (yes = 1, no = 0)	0.633	1.000	0.633			
75	Flow Inclination Angle	-0.130	6.000	0.779			
57	Temperature Gradient	-15.307	0.080	1.225	4.475	3.165	1.827
57	Wind Direction	0.007	180.000	1.187			
57	Turbulence Intensity	12.368	0.210	2.597			
57	Wind Veer between 97m and 57m	-5.860	0.400	2.344			
57	Wind shear exponent	-1.660	1.200	1.992			
57	Rain (yes = 1, no = 0)	0.955	1.000	0.955			
57	Flow Inclination Angle	0.000	6.000	0.000			

Table 5: Classification Results of unit MOLAS B300-117 at Janneby. List of selected independent EVs along with their maximum influence on the RSD accuracy, the RSD preliminary and final accuracy class and the standard uncertainty per assessed height.

Height above ground level	Independent Variable	*m*	Range	Max Influence m × range	Preliminary Accuracy Class	Final Accuracy Class	Standard Uncertainty
[m]	[-]	[%/unit variable]	[u.v]	[-]	[%]	[%]	[%]
121	Temperature Gradient	-12.624	0.080	1.010	3.000	2.121	1.225
121	Air Temperature	-0.023	40.000	0.939			
121	Wind Direction	-0.005	0.210	0.001			
121	Turbulence Intensity	5.124	0.400	2.050			
121	Wind shear exponent	-1.833	1.200	2.200			
121	Rain (yes = 1, no = 0)	0.271	1.000	0.271			
121	Flow Inclination Angle	-0.097	6.000	0.582			
80	Temperature Gradient	-11.353	0.080	0.908	3.988	2.820	1.628
80	Air Temperature	-0.042	40.000	1.670			
80	Wind Direction	-0.008	0.210	0.002			
80	Turbulence Intensity	3.167	0.400	1.267			
80	Wind shear exponent	-2.555	1.200	3.066			
80	Rain (yes = 1, no = 0)	0.364	1.000	0.364			
80	Flow Inclination Angle	-0.097	6.000	0.579			
65	Temperature Gradient	-16.629	0.080	1.330	5.972	4.223	2.438
65	Air Temperature	-0.070	40.000	2.791			
65	Wind Direction	-0.009	0.210	0.002			
65	Turbulence Intensity	0.531	0.400	0.212			
65	Wind shear exponent	-3.948	1.200	4.737			
65	Rain (yes = 1, no = 0)	0.480	1.000	0.480			
65	Flow Inclination Angle	-0.158	6.000	0.947			
45	Temperature Gradient	-18.132	0.080	1.451	2.945	2.082	1.202
45	Air Temperature	-0.053	40.000	2.103			
45	Wind Direction	-0.004	0.210	0.001			
45	Turbulence Intensity	1.085	0.400	0.434			
45	Wind shear exponent	-0.713	1.200	0.856			
45	Rain (yes = 1, no = 0)	0.480	1.000	0.480			
45	Flow Inclination Angle	-0.142	6.000	0.850			

Table 6: Classification Results of unit MOLAS B300-202 at Hamburg. List of selected independent EVs along with their maximum influence on the RSD accuracy, the RSD preliminary and final accuracy class and the standard uncertainty per assessed height.

2.3 RSD type-specific classification results

The variation in environmental conditions between the test-site and calibration site may influence the performance of a remote sensing device. Therefore, the main objective of the classification test is to identify the environmental variables that impact the RSD horizontal wind speed measurement and therefore quantify the RSD sensitivity to these EVs for many objective heights. In summary, the classification aims to present the quantitative uncertainty of horizontal wind measurements to be expected from the RSD with regards to its sensitivity to meteorological conditions.

The IEC [4] in its Annex L.2.9 establishes a procedure to combine all the classification results for every significant independent variable,

1. Interpolate the slope to the height of interest for every classification test,
2. Combine the slope from the various classification test using the following equation

$$m_i = \frac{1}{N}\sum_{n=1}^{N} m_{i,n} + \frac{m_{i,max} - m_{i,min}}{2\sqrt{3}} \quad (1)$$

where $\boldsymbol{m_i}$ is the combined slope of environmental variable $\boldsymbol{i}$, $\boldsymbol{m_{i,n}}$ is the sensitivity slope of environmental variable $\boldsymbol{i}$ resulted from the classification $\boldsymbol{n}$. $\boldsymbol{N}$ is total number of classification tests.

With the final slopes calculated using the IEC methodology of interpolating the slope for the objective heights (Table 10 in Annex A), the max influence can be derived multiplying the final EV sensitivity slope with its range (Table 7). The max influence indicates the maximum error that can occur assuming that the calibration and application tests take place under the opposite range of an environmental variable. The preliminary accuracy class is calculated adding in quadrature every EV max influence. The type-specific class is obtained dividing the preliminary accuracy class by square root of 2.

EV (Label)	Range Limits min	Range Limits max	Range	Bin Width	Max number of bins	unit	source
Temperature Gradient (ΔT)	-0.02	0.06	0.08	0.002	40	$K.m^{-1}$	IEC
Temperature (T)	0	40	40	2	20	°C	IEC
Wind direction (dir)	0	360	180	5	72	°	IEC
RSD data quality (ava)	0	100	100	5	20	-	RSD specific
Turbulence intensity (TI)	0.03	0.24	0.21	0.01	21	-	IEC
Air density (ρ)	0.9	1.35	0.45	0.05	9	$Kg.m^{-3}$	IEC
Wind Veer (Δ dir)	-0.2	0.2	0.4	0.04	10	$°.m^{-1}$	N/A
Wind shear coef. (α)	-0.4	0.8	1.2	0.05	24	-	IEC
Rain	0	1	1	1	2	-	Def.Sensor
Flow inclination angle (f_inc)	-3	3	6	1	6	°	IEC

Table 7: EVs and their parameters used in the sensitivity analysis.

Table 8 shows the results of the IEC methodology for combining the outcome of all classification tests along with the preliminary accuracy class, the type-specific class and standard uncertainty per height.

MOLAS B300 Type Class Table											
EVs / Heights	Max influence (m x Range)								Preliminary accuracy	Type specific class	Standard uncertainty
	Temperature Gradient	Air Temperature	Wind Direction	Turbulence Intensity	Wind Veer	Wind Shear	Rain	Flow inclination angle			
`	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
121	0.19	1.03	-0.83	1.81	-1.03	-2.10	0.21	-0.60	3.31	2.34	1.35
115	0.29	0.91	-0.91	1.73	-0.94	-2.21	0.23	-0.60	3.30	2.34	1.35
110	0.37	0.81	-0.98	1.66	-0.86	-2.30	0.25	-0.59	3.31	2.34	1.35
105	0.46	0.71	-1.05	1.59	-0.78	-2.39	0.26	-0.59	3.33	2.36	1.36
100	0.24	0.60	0.19	1.89	-0.89	-2.16	0.48	-0.61	3.18	2.25	1.30
95	0.31	0.50	0.14	1.93	-0.86	-2.31	0.49	-0.60	3.28	2.32	1.34
90	0.38	0.40	0.08	1.97	-0.83	-2.46	0.50	-0.60	3.39	2.40	1.39
85	0.44	0.30	0.03	2.01	-0.80	-2.61	0.51	-0.59	3.51	2.48	1.43
80	0.51	0.20	-0.02	2.05	-0.76	-2.75	0.52	-0.59	3.64	2.57	1.49
75	0.44	0.07	-0.08	2.09	-0.89	-2.97	0.54	-0.71	3.87	2.74	1.58
70	0.32	-0.06	0.11	2.07	-0.99	-2.93	0.61	-0.66	3.84	2.72	1.57
65	0.21	-0.18	0.29	2.05	-1.09	-2.88	0.68	-0.57	3.83	2.71	1.56
60	-0.22	-0.23	0.53	1.98	-1.04	-2.48	0.74	-0.40	3.50	2.48	1.43
55	-0.65	-0.27	0.78	1.92	-0.99	-2.08	0.79	-0.22	3.28	2.32	1.34
50	-1.02	-0.31	-0.88	0.58	-0.56	-1.74	0.45	-0.62	2.48	1.76	1.01
45	-1.47	-0.36	-0.64	0.44	-0.49	-0.91	0.45	-0.50	2.10	1.48	0.86

Table 8: Type-specific class per 5 m height.

3 DERIVING APPLICATION UNCERTAINTY – A CALCULATION EXAMPLE

The type-specific class shown in Table 8 are the maximum wind speed measurement uncertainty that can be expected from the type MOLAS B300 lidar due to difference in environmental conditions between verification and application site. In reality, this difference is unlikely to be as great as the used EV ranges (Table 7). Therefore, the category B uncertainty of the wind speed measurement due to the influence of environmental variables on the performance of the remote sensing device is calculated as follows,

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

where

$u_{class,i}$	is the MOLAS B300 uncertainty of wind speed measurements in wind speed bin *i* due to influence of environmental variables;
M	is number of environmental variables considered to have a relevant influence on the accuracy of the remote sensing device according to the classification test;
m_j	is slope describing the sensitivity of the wind speed measurement of the remote sensing device on the environmental variable j as gained from the combination of the results from a minimum of 3 classification tests. The values derived during the type classification reported here can be found in Table 10, Annex A of this document;
$\bar{x}_{app,j,i}$	is mean value of the environmental variable j in wind speed bin *i* as present during the application test;
$\bar{x}_{ver,j,i}$	is mean value of the environmental variable j in wind speed bin *i* as present during the verification test.

As an example of how to combine the verification and application uncertainty, Table 9 presents the environmental condition per wind speed bin from hypothetical verification and application tests. The classification uncertainty (%) column presents the derived uncertainty calculated by applying Equation 2 for combining the individual uncertainty contributions from each environmental variable. Assuming that the classification and verification uncertainty are independent, adding them in quadrature leads to the final combined uncertainty (%). This is then multiplied by the mean bin wind speed and divided by 100 to convert to a wind speed uncertainty in m/s.

Application Class Uncertainty @ 100m																														
Wind speed			Temperature gradient			Temperature			Turbulence intensity			Wind Direction			Wind veer			Wind shear coef.			Flow inclination angle			Rain			Uncertainty (k = 1)			
			Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Classification	Verification	Combined	
BIN lower [m/s]	BIN upper [m/s]	[m/s]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[%]	[%]	[%]	[m/s]
3.75	4.25	4.01	0.006	-0.004	0.032	3.34	19.66	0.25	0.08	0.14	0.55	259.89	199.68	0.06	0.29	-0.37	-1.46	0.30	0.19	-0.20	0.07	0.41	-0.03	1.00	0.00	0.48	1.66	2.28	2.82	0.11
4.25	4.75	4.50	0.005	-0.003	0.024	3.33	18.98	0.24	0.09	0.13	0.39	256.22	192.33	0.07	0.24	-0.41	-1.44	0.35	0.18	-0.32	-1.22	-0.12	-0.11	1.00	0.00	0.48	1.62	2.12	2.67	0.12
4.75	5.25	5.02	0.006	-0.003	0.026	3.25	18.56	0.23	0.08	0.12	0.41	247.64	195.15	0.06	0.24	-0.44	-1.50	0.31	0.21	-0.19	-1.01	-0.01	-0.10	1.00	0.00	0.48	1.66	2.05	2.64	0.13
5.25	5.75	5.52	0.006	-0.004	0.029	3.49	18.91	0.23	0.07	0.12	0.46	240.34	199.05	0.04	0.23	-0.45	-1.51	0.32	0.21	-0.20	-0.70	-0.08	-0.06	1.00	0.00	0.48	1.68	2.00	2.61	0.14
5.75	6.25	6.01	0.005	-0.002	0.021	3.63	18.25	0.22	0.08	0.12	0.35	239.85	198.67	0.04	0.18	-0.50	-1.51	0.35	0.22	-0.22	-0.97	0.04	-0.10	1.00	0.00	0.48	1.66	1.93	2.55	0.15
6.25	6.75	6.50	0.004	0.000	0.010	3.65	16.54	0.19	0.08	0.10	0.18	230.00	201.29	0.03	0.12	-0.51	-1.40	0.35	0.25	-0.17	-0.94	-0.16	-0.08	1.00	0.00	0.48	1.52	2.11	2.59	0.17
6.75	7.25	7.00	0.003	0.001	0.006	3.95	16.52	0.19	0.08	0.10	0.19	239.27	210.93	0.03	0.09	-0.53	-1.37	0.34	0.26	-0.14	-0.92	0.10	-0.10	1.00	0.00	0.48	1.48	2.01	2.50	0.18
7.25	7.75	7.49	0.003	0.002	0.004	3.88	15.83	0.18	0.08	0.10	0.19	238.15	209.74	0.03	0.07	-0.62	-1.54	0.36	0.27	-0.15	-1.02	0.07	-0.11	1.00	0.00	0.48	1.65	1.95	2.55	0.19
7.75	8.25	7.99	0.002	0.001	0.004	3.90	15.50	0.18	0.09	0.11	0.21	233.30	212.79	0.02	0.03	-0.74	-1.73	0.35	0.29	-0.09	-0.99	0.28	-0.13	1.00	0.00	0.48	1.82	1.68	2.48	0.20
8.25	8.75	8.50	0.001	0.000	0.005	3.70	16.46	0.19	0.09	0.13	0.34	225.63	214.28	0.01	0.01	-0.72	-1.60	0.35	0.26	-0.17	-1.07	0.44	-0.15	1.00	0.00	0.48	1.73	1.73	2.44	0.21
8.75	9.25	8.98	0.001	-0.003	0.014	3.93	16.77	0.19	0.09	0.15	0.51	224.22	211.84	0.01	0.00	-0.78	-1.72	0.34	0.24	-0.18	-1.00	0.25	-0.13	1.00	0.00	0.48	1.88	1.57	2.45	0.22
9.25	9.75	9.49	0.000	-0.004	0.014	4.00	15.54	0.17	0.10	0.16	0.54	224.83	215.03	0.01	-0.02	-0.76	-1.66	0.32	0.24	-0.14	-1.44	0.30	-0.18	1.00	0.00	0.48	1.83	1.54	2.39	0.23
9.75	10.25	9.99	-0.001	-0.004	0.010	4.42	16.15	0.18	0.10	0.15	0.42	233.16	212.12	0.02	-0.04	-0.79	-1.65	0.30	0.22	-0.15	-1.43	0.31	-0.18	1.00	0.00	0.48	1.80	1.35	2.25	0.22
10.25	10.75	10.47	-0.002	-0.004	0.007	4.43	16.57	0.18	0.11	0.15	0.37	233.02	210.38	0.02	-0.06	-0.81	-1.66	0.28	0.19	-0.17	-1.40	0.25	-0.17	1.00	0.00	0.48	1.79	1.33	2.23	0.23
10.75	11.25	11.01	-0.002	-0.004	0.006	4.85	15.88	0.17	0.11	0.15	0.35	238.40	211.98	0.03	-0.07	-0.85	-1.72	0.28	0.22	-0.10	-1.22	0.07	-0.13	1.00	0.00	0.48	1.84	1.33	2.27	0.25
11.25	11.75	11.49	-0.002	-0.005	0.006	5.09	16.67	0.17	0.11	0.14	0.28	233.57	222.23	0.01	-0.09	-0.83	-1.63	0.26	0.18	-0.14	-0.59	0.11	-0.07	1.00	0.00	0.48	1.74	1.44	2.26	0.26
11.75	12.25	12.00	-0.002	-0.005	0.009	5.69	15.56	0.15	0.11	0.16	0.44	242.93	211.53	0.03	-0.10	-0.86	-1.68	0.25	0.22	-0.05	-0.63	-0.17	-0.05	1.00	0.00	0.48	1.81	1.49	2.34	0.28
12.25	12.75	12.50	-0.002	-0.005	0.008	5.93	15.68	0.15	0.11	0.15	0.32	239.68	207.06	0.03	-0.11	-0.94	-1.85	0.25	0.20	-0.08	-0.59	-0.15	-0.04	1.00	0.00	0.48	1.94	1.27	2.32	0.29
12.75	13.25	12.99	-0.003	-0.003	0.001	6.40	16.63	0.15	0.11	0.14	0.25	242.68	202.98	0.04	-0.11	-0.96	-1.88	0.24	0.19	-0.10	-0.77	-0.06	-0.07	1.00	0.00	0.48	1.97	1.39	2.41	0.31
13.25	13.75	13.49	-0.003	-0.001	0.006	6.49	18.73	0.18	0.11	0.13	0.17	236.47	204.70	0.03	-0.12	-1.16	-2.33	0.24	0.17	-0.13	-0.77	0.44	-0.12	1.00	0.00	0.48	2.39	1.23	2.69	0.36
13.75	14.25	14.00	-0.003	-0.002	0.003	6.19	14.55	0.13	0.12	0.15	0.29	229.26	227.10	0.00	-0.11	-1.00	-1.98	0.24	0.24	-0.01	-0.95	0.11	-0.11	1.00	0.00	0.48	2.06	1.66	2.65	0.37
14.25	14.75	14.49	-0.004	0.000	0.011	6.15	0.00	0.09	0.12	0.00	1.06	223.38	0.00	0.23	-0.11	0.00	-0.23	0.23	0.00	-0.42	-0.64	0.00	-0.06	1.00	0.00	0.48	1.29	1.46	1.95	0.28
14.75	15.25	15.01	-0.004	0.000	0.011	6.30	0.00	0.10	0.12	0.00	1.06	218.69	0.00	0.23	-0.11	0.00	-0.24	0.24	0.00	-0.43	-0.62	0.00	-0.06	1.00	0.00	0.48	1.28	1.26	1.80	0.27
15.25	15.75	15.49	-0.004	0.000	0.012	6.27	0.00	0.09	0.12	0.00	1.06	221.26	0.00	0.23	-0.13	0.00	-0.29	0.23	0.00	-0.41	-0.63	0.00	-0.06	1.00	0.00	0.48	1.29	1.06	1.68	0.26
15.75	16.25	15.98	-0.004	0.000	0.011	6.38	0.00	0.10	0.12	0.00	1.08	234.46	0.00	0.25	-0.13	0.00	-0.29	0.23	0.00	-0.41	-0.75	0.00	-0.08	1.00	0.00	0.48	1.31	0.66	1.47	0.24

Table 9: Example of combining uncertainty of a hypothetical verification and application test.

4 IMPORTANT REMARKS AND LIMITATIONS

The final accuracy classes and standard uncertainties presented in section 2.3 of this report represent the maximum values that could be applied due to differences in environmental conditions between the verification and the application test. The example in section 3 shows how, in practice, the uncertainty due to environmental conditions can be much smaller than the standard uncertainty calculated from the accuracy class.

DNV have independently followed the methodology defined in the latest version of the IEC 61400-12-1 [4]. Three classification trials were analysed covering three Lidars at two locations, with one Lidar classified at two of the locations and one Lidar classified at one of the locations, fully meeting the IEC criteria for a type classification. The outcome of the given methodology is the final accuracy class per height of Movelaser type MOLAS B300 lidar, shown in Table 8.

DNV do not take responsibility for how these results are used.

5 CONCLUSION

A type-specific classification based on the IEC 61400-12-1, Ed. 2 [4] for the Movelaser type MOLAS B300 lidar was independently conducted by DNV.

The main significant environmental variables which influenced the wind measurement of the type MOLAS B300 lidar are

- temperature gradient,
- air temperature,
- wind direction
- turbulence intensity,
- wind veer,
- wind shear,
- rain,
- and flow inclination angle.

The type-specific class numbers were given in discrete heights from 45 m to 121 m in 5 m steps. The type-class range between 1.48 % at 45 m and 2.74 % at 75 m.

6 REFERENCES

[1] DNV GL - Energy, „Classification and performance related assessment of a MOLAS B300 lidar at DNV GL test site in Hamburg - MOLAS B300-117,“ Hamburg, 2020.

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[3] DNV - Energy,, „Classification and performance related assessment of a MOLAS B300 lidar at DNV test site in Hamburg - MOLAS B300-202,“ Hamburg, 2021.

[4] „IEC 61400-12-1 International Standard. Part 12-1, Power performance measurements of electricity producing wind turbines, International Electrotechnical Commission,Edition 2.0 2017-03“.

[5] W. Barker, J. Gottschall, M. Harris, J. Medley, B. d. E. Roziers, C. Slinger und M. Pitter, „Correlation effects in the field classification of ground based remote wind sensors,“ in *Europe's Premier Wind Energy Event*, Barcelona, Spain, 2014.

APPENDIX A COMBINED SLOPES

MOLAS B300 - Combined slope *m*								
EVs / Heights	Temperature Gradient	Air Temperature	Wind Direction	Turbulence Intensity	Wind Veer	Wind Shear	Rain	Flow inclination angle
[m]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
121	2.410	0.026	-0.005	8.641	-2.578	-1.750	0.214	-0.100
115	3.642	0.023	-0.005	8.233	-2.346	-1.842	0.231	-0.099
110	4.668	0.020	-0.005	7.893	-2.153	-1.919	0.245	-0.099
105	5.694	0.018	-0.006	7.552	-1.960	-1.995	0.259	-0.099
100	3.005	0.015	0.001	9.001	-2.219	-1.804	0.476	-0.101
95	3.849	0.013	0.001	9.186	-2.142	-1.926	0.487	-0.101
90	4.692	0.010	0.000	9.371	-2.065	-2.049	0.497	-0.100
85	5.536	0.007	0.000	9.556	-1.989	-2.171	0.508	-0.099
80	6.379	0.005	0.000	9.742	-1.912	-2.293	0.518	-0.098
75	5.455	0.002	0.000	9.967	-2.223	-2.478	0.539	-0.118
70	4.030	-0.001	0.001	9.864	-2.469	-2.440	0.610	-0.110
65	2.605	-0.005	0.002	9.762	-2.715	-2.401	0.682	-0.096
60	-2.788	-0.006	0.003	9.445	-2.594	-2.067	0.737	-0.067
55	-8.181	-0.007	0.004	9.129	-2.472	-1.732	0.792	-0.036

Table 10: Combined slope using interpolation between heights.

About DNV

Driven by our purpose of safeguarding life, property and the environment, DNV enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.