REMOTE SENSING DEVICE CLASSIFICATION REPORT

RSD Type: MeteoLaser

PREPARED FOR:
Ammonit Measurement GmbH

Report Number:
UL-CHN-PPT-22-14406541-RSDC-01.01

Site1:
MeteoLaser, Serial No. 21906 and 21908
Zhangbei Test Site
Hebei Province, China

Site2:
MeteoLaser, Serial No. 21908
Hami Test Site
Xinjiang Province, China

2022-07-31

CLASSIFICATION
CLIENT'S DISCRETION

ISSUE
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1. INTRODUCTION

On behalf of Ammonit Measurement GmbH (“client”), UL International GmbH, a UL Company (“UL”) conducted an independent classification measurements and assessment on the remote sensing device (“RSD”) of type MeteoLaser.

The performance of a remote sensing device (RSD) may be influenced by environmental variables (EV), such as wind shear, turbulence intensity, precipitation 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 increasing uncertainty in the measurement results of the application. The purpose of the classification 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 RSD type MeteoLaser with regards to its sensitivity to meteorological conditions.

According to IEC 61400-12-1 Ed.2 [1] Annex L, a full classification of a type of RSD requires measurements on at least two different RSD units and one RSD unit at two different sites, i.e, at least three measurements. This requirement is fulfilled. UL conducted two campaigns on RSD of type MeteoLaser, units 21906 and 21908 at Zhangbei test site, Hebei, China. UL also conducted one campaign on RSD of type MeteoLaser, unit 21908 at Hami test site, Xinjiang, China, see table below for classification measurements detail.

Table 1.1: Classification Measurements

RSD Serial No.	Test Period	Test Site	Reference
21906	2021-03-19 (15:00) ~ 2021-06-30 (24:00)	Zhangbei Site, Hebei, China	[2]
21908	2021-03-19 (15:00) ~ 2021-06-30 (24:00)	Zhangbei Site, Hebei, China	[3]
21908	2021-09-24 (00:00) ~ 2022-01-14 (24:00)	Hami Site, Xinjiang, China	[4]

In present report, all classification measurements of the RSD of type MeteoLaser are shown, and the type-specific classification figures are presented.

2. MEASUREMENT RESULT

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

2.1 Wind Speed Coverage of Each Classification Measurement

Classification measurement shall cover a wind speed range of 4.0 m/s to 16.0 m/s for all measuring height for each measurement campaign. To achieve this, each wind speed bin shall have at least 3 pairs of data sets from wind speed 4 m/s to 16 m/s. In this case, the filtered and useful concurrent measurements data points of three classification measurements are shown in Table 2.1.

Table 2.1: Wind Speed Coverage of Each Classification Measurements

	SN 21906 at Zhangbei Site					SN 21908 at Zhangbei Site					SN 21908 at Hami Site			
Wind Speed [m/s]	40.5m [-]	60.5m [-]	99.5m [-]	135.5m [-]	139.5m [-]	40.5m [-]	60.5m [-]	99.5m [-]	135.5m [-]	139.5m [-]	40.5m [-]	89.5m [-]	99.5m [-]	135.5m [-]
4.0	258	232	190	145	106	150	119	123	89	65	47	31	36	33
4.5	523	422	342	270	191	305	233	220	190	135	101	61	57	48
5.0	572	464	442	334	230	310	274	265	218	151	98	91	91	82
5.5	551	552	481	367	289	303	294	255	218	163	95	90	86	73
6.0	523	522	454	442	325	285	307	227	238	145	100	87	80	88
6.5	486	491	423	403	302	263	263	239	185	126	137	98	98	74
7.0	434	456	447	419	321	264	258	253	223	148	133	91	81	90
7.5	405	474	466	351	217	258	285	277	215	110	122	88	93	76
8.0	360	466	484	446	260	222	286	277	252	140	115	119	108	107
8.5	295	393	462	462	302	146	240	293	271	175	96	112	119	102
9.0	324	347	450	426	274	186	185	242	262	158	88	83	86	82
9.5	253	292	408	419	239	141	161	240	242	132	91	90	74	73
10.0	281	247	353	384	245	142	126	213	202	119	65	84	87	82
10.5	184	290	273	347	246	89	147	145	216	130	49	71	82	86
11.0	215	205	269	298	215	116	110	128	158	100	59	58	57	74
11.5	171	190	233	307	205	98	110	120	180	118	68	54	55	55
12.0	141	160	209	244	180	65	97	129	123	94	62	62	73	76
12.5	120	171	176	198	133	50	83	96	105	68	57	60	56	50
13.0	85	138	156	169	126	35	69	85	92	58	35	71	67	88
13.5	52	93	135	163	137	26	42	81	105	81	32	54	51	48
14.0	45	83	116	124	86	20	34	67	71	54	31	41	50	42
14.5	21	42	86	99	74	11	21	42	60	45	17	40	43	51
15.0	24	35	70	88	69	10	15	31	50	42	11	39	30	42
15.5	13	23	62	76	45	7	13	27	34	23	5	14	29	24
16.0	3	17	13	32	22	2*	6	4	12	12	5	9	8	11
Total	**6339**	**6805**	**7200**	**7013**	**4839**	**3502**	**3778**	**4079**	**4011**	**2592**	**1719**	**1698**	**1697**	**1657**

Note *: The RSD of type MeteoLaser, SN 21908 tested in Zhangbei site at 40 m height at wind speed bin 16 m/s did not completely fulfil the given IEC criteria of wind speed coverage threshold.

2.2 Intermediate Result of Each Measurement

The classification results for all RSD units were calculated based on the sensitivity analysis and on the IEC 61400-12-1 [1] for defining an environmental variable to be significant. Each classification campaign identified significant environmental variables that were correlated with the size of the difference between wind speed measurements made by the RSD of type MeteoLaser and a high-quality reference cup anemometer.

Sensitivity test has been conducted on each RSD submitted for classification. According to IEC standard, the sensitivity tests may indicate that a significant relationship exists between the dependent variable and some of the independent variables. The procedure shall be followed to process the significant and independent EV:

1) A sensitivity of at least 0.5 is demonstrated or a product of correlation coefficient *r* and sensitivity of at least 0.1 is found.
2) The sensitivity analysis of an independent variable shall be relevant for all measurement heights if one of the above conditions is fulfilled for a single height.
3) EV that do not have a direct influence on the measurement deviation and which are correlated with one or more variables that do have a direct influence on measurement deviation have been eliminated from the sensitivity test.
4) Assuming that all selected variables are fully independent from each other to build-up the preliminary accuracy class, each individual maximum influence is added in quadrature. The final accuracy class is calculated by dividing the preliminary accuracy class by $\sqrt{2}$ while the RSD standard uncertainty is obtained by dividing the final accuracy class by $\sqrt{3}$.

The range of each environmental variables (EV) was given in Table 2.2, the maximum influence is derived by multiplying each EV sensitivity slope with its range.

Table 2.2: The Range of Environmental Variables

Indep. EV	Range Limits		Range	Bin Width	Max Number of Bins	Units
	Max	Min				
Wind shear exponent	0.8	-0.4	1.2	0.05	24	[-]
Turbulence Intensity	0.24	0.03	0.21	0.01	21	[-]
Rain (yes=1 and no=0)	1	0	1	0.05	20	[-]
Availability	100	80	20	1	20	[-]
Wind direction	360	0	180	5	72	[°]
Air temperature	40	0	40	1	40	[°C]
Air density	1.35	0.90	0.45	0.005	90	[kg/m³]
Temperature gradient	0.060	-0.020	0.080	0.002	40	[°C/m]
Upflow angle	3	-3	6	0.2	30	[°]
Wind veer	0.20	-0.20	0.40	0.02	20	[°/m]

According to IEC 61400012-1, the used database shall cover at least 25 % of the bins as described in Table 2.2 with a minimum number of data points as defined in IEC 61400-12-1 L2.2 for all variables which are known to influence the accuracy of the RSD. This requirement is fulfilled.

Table 2.3: EV Range Coverage

Indep. EV	Units	SN 21906 at Zhangbei			SN 21908 at Zhangbei site			SN 21908 at Hami site		
		Max	Min	Range	Max	Min	Range	Max	Min	Range
Wind shear exponent	[-]	0.7	-0.2	0.8	0.7	-0.1	0.8	0.6	-0.4	1.0
Turbulence Intensity	[-]	0.24	0.03	0.21	0.24	0.03	0.21	0.24	0.03	0.21
Rain (yes=1 and no=0)	[-]	1	0	1	1	0	1	NA	NA	NA
Availability	[-]	100	80	20	100	80	20	100	80	20
Wind direction	[°]	360	0	360	360	0	360	139	55	84
Air temperature	[°C]	17	-2	20	17	-1	18	25	-3	29
Air density	[kg/m3]	1.10	1.01	0.09	1.09	1.01	0.08	1.18	1.05	0.13
Temperature gradience	[°C/m]	0.043	-0.004	0.047	0.038	-0.004	0.042	0.060	-0.019	0.079
Upflow angle	[°]	3	-3	6	3	-3	6	NA	NA	NA
Wind veer	[°/m]	0.20	-0.20	0.40	0.20	-0.20	0.40	0.20	-0.20	0.40

2.2.1 Classification Result of SN 21906 at Zhangbei Site

Regarding RSD SN 21906 at Zhangbei test site, five out of ten EVs were found to be significant in the sensitivity test in Table 2.4. and dependencies between EVs have been analyzed for the data used, and the selected independent EVs for composing the accuracy class of SN 21906 were shear, turbulence intensity, rain flag, air temperature and veer.

Table 2.4: Sensitivity Test for SN21906 at Zhangbei Site

Height	Indep. EV	Avg of Indep. EV	Std of Indep. EV	*m*	r^2	Sensitivity *m x std*	Sensitivity *m x std x r*	Significant EV or not?
[m]	[-]	[unit of EV]	[unit of EV]	[%/unit of EV]	[-]	[%]	[%]	
139.5	Shear	0.187	0.146	-2.609	0.321	-0.381	-0.216	Yes
135.5		0.213	0.148	-4.339	0.694	-0.642	-0.535	
99.5		0.201	0.137	-4.031	0.877	-0.552	-0.517	
59.5		0.203	0.136	-4.404	0.748	-0.599	-0.518	
40.5		0.196	0.128	1.667	0.695	0.213	0.178	
139.5	Turbulence Intensity	0.121	0.044	-0.333	0.003	-0.015	-0.001	Yes
135.5		0.099	0.045	7.034	0.278	0.317	0.167	
99.5		0.108	0.047	4.709	0.454	0.221	0.149	
59.5		0.122	0.047	5.343	0.463	0.251	0.171	
40.5		0.136	0.046	-5.254	0.431	-0.242	-0.159	
139.5	Rain	0.092	0.287	1.391	1.000	0.399	0.399	Yes
135.5		0.108	0.309	0.761	1.000	0.235	0.235	
99.5		0.158	0.364	0.938	1.000	0.341	0.341	
59.5		0.122	0.325	0.571	1.000	0.186	0.186	
40.5		0.121	0.325	0.659	1.000	0.214	0.214	
139.5	Availability	98.901	2.744	-0.020	0.013	-0.055	-0.006	No
135.5		99.217	2.522	-0.083	0.407	-0.209	-0.134	
99.5		99.700	1.651	0.012	0.001	0.020	0.001	
59.5		99.707	1.546	-0.039	0.004	-0.060	-0.004	
40.5		99.540	2.034	-0.075	0.027	-0.153	-0.025	
139.5	Direction	247.274	122.303	-0.002	0.029	-0.245	-0.042	No
135.5		209.278	98.891	-0.003	0.060	-0.297	-0.073	
99.5		206.484	101.067	-0.003	0.050	-0.303	-0.068	
59.5		211.199	97.689	-0.003	0.052	-0.293	-0.067	
40.5		211.074	97.374	-0.003	0.090	-0.292	-0.088	
139.5	Temperature	6.642	4.211	0.032	0.053	0.135	0.031	Yes
135.5		6.802	4.211	0.019	0.094	0.080	0.025	
99.5		4.762	3.283	0.011	0.041	0.036	0.007	
59.5		6.129	4.196	-0.020	0.061	-0.084	-0.021	
40.5		5.991	4.179	-0.120	0.557	-0.501	-0.374	
139.5	Air Density	1.038	0.018	0.287	0.001	0.005	0.000	No
135.5		1.039	0.018	-4.264	0.057	-0.077	-0.018	
99.5		1.053	0.015	1.525	0.008	0.023	0.002	
59.5		1.053	0.019	-3.669	0.032	-0.070	-0.012	
40.5		1.057	0.019	6.089	0.153	0.116	0.045	
139.5	Temperature Gradient	0.003	0.005	3.774	0.002	0.019	0.001	No
135.5		0.006	0.007	3.657	0.003	0.026	0.001	

99.5		0.005	0.007	6.085	0.008	0.043	0.004	
59.5		0.006	0.007	-8.470	0.009	-0.059	-0.006	
40.5		0.006	0.007	-6.579	0.033	-0.046	-0.008	
139.5	Upflow Angle	-1.248	1.285	0.080	0.064	0.103	0.026	No
135.5		-0.856	1.330	0.127	0.205	0.169	0.076	
99.5		-0.851	1.306	0.130	0.286	0.170	0.091	
59.5		-0.828	1.301	0.085	0.115	0.111	0.038	
40.5		-0.817	1.296	-0.106	0.215	-0.137	-0.064	
139.5	Veer	-0.039	0.057	-2.218	0.154	-0.126	-0.050	Yes
135.5		-0.020	0.059	-2.134	0.139	-0.126	-0.047	
99.5		-0.011	0.052	-2.417	0.472	-0.126	-0.086	
59.5		-0.017	0.061	-6.150	0.643	-0.375	-0.301	
40.5		-0.018	0.059	-1.894	0.152	-0.112	-0.044	

The Table 2.5 lists all significant and independent EVs, their slopes and ranges. Multiplying the regression slopes by the associated EV range results in the maximum influence of each independent variable on the RSD accuracy.

Table 2.5: Classification Result for SN21906 at Zhangbei Site

Height	Indep. EV	*m*	Range	Max Influence *m x range*	Preliminary Accuracy	Final Accuracy	Standard Uncertainty
[m]	[-]	[%/unit of EV]	[unit of EV]	[-]	[%]	[%]	[%]
139.5	Shear	-2.609	1.200	-3.131	3.76	2.66	1.54
	TI	-0.333	0.210	-0.070			
	Rain	1.391	1.000	1.391			
	Temperature	0.032	40.000	1.280			
	Veer	-2.218	0.400	-0.887			
135.5	Shear	-4.339	1.200	-5.207	5.58	3.95	2.28
	TI	7.034	0.210	1.477			
	Rain	0.761	1.000	0.761			
	Temperature	0.019	40.000	0.760			
	Veer	-2.134	0.400	-0.854			
99.5	Shear	-4.031	1.200	-4.837	5.14	3.63	2.10
	TI	4.709	0.210	0.989			
	Rain	0.938	1.000	0.938			
	Temperature	0.011	40.000	0.440			
	Veer	-2.417	0.400	-0.967			
59.5	Shear	-4.404	1.200	-5.285	6.02	4.25	2.46
	TI	5.343	0.210	1.122			
	Rain	0.571	1.000	0.571			
	Temperature	-0.020	40.000	-0.800			
	Veer	-6.150	0.400	-2.460			
40.5	Shear	1.667	1.200	2.000	5.41	3.83	2.21
	TI	-5.254	0.210	-1.103			
	Rain	0.659	1.000	0.659			
	Temperature	-0.120	40.000	-4.800			
	Veer	-1.894	0.400	-0.758			

2.2.2 Classification Result of SN 21908 at Zhangbei Site

Regarding RSD SN 21908 at Zhangbei test site, five out of ten EVs were found to be significant in the sensitivity test in Table 2.6. and dependencies between EVs have been analyzed for the data used, and the selected independent EVs for composing the accuracy class of SN 21908 were shear, turbulence intensity, rain flag, air temperature and veer.

Table 2.6: Sensitivity Test for SN21908 at Zhangbei Site

Height	Indep. EV	Avg of Indep. EV	Std of Indep. EV	*m*	r^2	Sensitivity *m x std*	Sensitivity *m x std x r*	Significant EV or not?
[m]	[-]	[unit of EV]	[unit of EV]	[%/unit of EV]	[-]	[%]	[%]	
139.5	Shear	0.186	0.141	2.295	0.395	0.324	0.203	Yes
135.5		0.214	0.148	0.866	0.371	0.128	0.078	
99.5		0.216	0.147	1.292	0.697	0.190	0.159	
59.5		0.206	0.136	2.388	0.766	0.325	0.284	
40.5		0.199	0.128	3.711	0.408	0.475	0.303	
139.5	Turbulence Intensity	0.127	0.043	-1.720	0.014	-0.074	-0.009	Yes
135.5		0.101	0.046	2.294	0.124	0.106	0.037	
99.5		0.109	0.047	-1.506	0.163	-0.071	-0.029	
59.5		0.127	0.047	-2.529	0.266	-0.119	-0.061	
40.5		0.140	0.046	-6.802	0.753	-0.313	-0.272	
139.5	Rain	0.021	0.138	-2.055	1.000	-0.284	-0.284	Yes
135.5		0.035	0.178	-1.006	1.000	-0.179	-0.179	
99.5		0.034	0.175	0.103	1.000	0.018	0.018	
59.5		0.034	0.176	-0.511	1.000	-0.090	-0.090	
40.5		0.034	0.178	-0.476	1.000	-0.085	-0.085	
139.5	Availability	96.830	5.141	0.006	0.007	0.031	0.003	No
135.5		97.116	4.905	-0.007	0.028	-0.034	-0.006	
99.5		97.269	4.742	-0.018	0.084	-0.085	-0.025	
59.5		97.172	4.830	-0.006	0.019	-0.029	-0.004	
40.5		97.086	4.930	0.007	0.022	0.035	0.005	
139.5	Direction	254.135	113.650	0.003	0.069	0.341	0.090	No
135.5		209.931	92.141	0.002	0.033	0.184	0.033	
99.5		212.472	91.872	-0.001	0.019	-0.092	-0.013	
59.5		215.579	91.186	-0.001	0.004	-0.091	-0.006	
40.5		213.238	90.358	-0.001	0.029	-0.090	-0.015	
139.5	Air Temperature	8.168	3.473	0.087	0.462	0.302	0.205	Yes
135.5		8.568	3.393	0.081	0.427	0.275	0.180	
99.5		8.267	3.356	-0.024	0.085	-0.081	-0.023	
59.5		8.016	3.324	0.063	0.320	0.209	0.118	
40.5		7.919	3.336	0.051	0.225	0.170	0.081	
139.5	Air Density	1.032	0.015	-7.942	0.183	-0.119	-0.051	No
135.5		1.031	0.015	-7.756	0.364	-0.116	-0.070	
99.5		1.038	0.015	-5.286	0.095	-0.079	-0.024	
59.5		1.045	0.015	2.970	0.026	0.045	0.007	
40.5		1.048	0.015	-1.794	0.010	-0.027	-0.003	
139.5		0.003	0.005	-13.171	0.014	-0.066	-0.008	No

135.5	Temperature Gradient	0.006	0.007	5.088	0.015	0.036	0.004	
99.5		0.006	0.008	4.153	0.038	0.033	0.006	
59.5		0.006	0.008	3.244	0.011	0.026	0.003	
40.5		0.006	0.007	6.867	0.034	0.048	0.009	
139.5	Upflow Angle	-1.192	1.302	0.042	0.004	0.055	0.003	No
135.5		-0.829	1.326	0.033	0.009	0.044	0.004	
99.5		-0.843	1.314	0.030	0.028	0.039	0.007	
59.5		-0.837	1.296	-0.019	0.005	-0.025	-0.002	
40.5		-0.824	1.288	-0.122	0.113	-0.157	-0.053	
139.5	Veer	-0.047	0.052	4.265	0.563	0.222	0.166	Yes
135.5		-0.023	0.060	-3.636	0.425	-0.218	-0.142	
99.5		-0.021	0.062	-0.442	0.036	-0.027	-0.005	
59.5		-0.019	0.062	-2.128	0.442	-0.132	-0.088	
40.5		-0.020	0.060	3.034	0.480	0.182	0.126	

The Table 2.7 lists all significant and independent EVs, their slopes and ranges. Multiplying the regression slopes by the associated EV range results in the maximum influence of each independent variable on the RSD accuracy.

Table 2.7: Classification Result for SN21908 at Zhangbei Site

Height	Indep. EV	*m*	Range	Max Influence *m x range*	Preliminary Accuracy	Final Accuracy	Standard Uncertainty
[m]	[-]	[%/unit of EV]	[unit of EV]	[-]	[%]	[%]	[%]
139.5	Shear	2.295	1.200	2.754	5.19	3.67	2.12
	TI	-1.720	0.210	-0.361			
	Rain	-2.055	1.000	-2.055			
	Temperature	0.087	40.000	3.480			
	Veer	4.265	0.400	1.706			
135.5	Shear	0.866	1.200	1.039	3.86	2.73	1.58
	TI	2.294	0.210	0.482			
	Rain	-1.006	1.000	-1.006			
	Temperature	0.081	40.000	3.240			
	Veer	-3.636	0.400	-1.454			
99.5	Shear	1.292	1.200	1.550	1.86	1.32	0.76
	TI	-1.506	0.210	-0.316			
	Rain	0.103	1.000	0.103			
	Temperature	-0.024	40.000	-0.960			
	Veer	-0.442	0.400	-0.177			
59.5	Shear	2.388	1.200	2.866	3.98	2.81	1.62
	TI	-2.529	0.210	-0.531			
	Rain	-0.511	1.000	-0.511			
	Temperature	0.063	40.000	2.520			
	Veer	-2.128	0.400	-0.851			
40.5	Shear	3.711	1.200	4.453	5.27	3.72	2.15
	TI	-6.802	0.210	-1.428			
	Rain	-0.476	1.000	-0.476			
	Temperature	0.051	40.000	2.040			
	Veer	3.034	0.400	1.214			

2.2.3 Classification Result of SN 21908 at Hami Site

Regarding RSD SN 21908 at Hami test site, four out of ten EVs were found to be significant in the sensitivity test in Table 2.8. and dependencies between EVs have been analyzed for the data used, and the selected independent EVs for composing the accuracy class of SN 21908 were shear, turbulence intensity, air temperature and temperature gradient. The fifth significant EV rain was not available at this site.

Table 2.8: Sensitivity Test for SN21908 at Hami Site

Height	Indep. EV	Avg of Indep. EV	Std of Indep. EV	*m*	r^2	Sensitivity *m x std*	Sensitivity *m x std x r*	Significant EV or not?
[m]	[-]	[unit of EV]	[unit of EV]	[%/unit of EV]	[-]	[%]	[%]	
135.5	Shear	0.157	0.112	-4.669	0.894	-0.523	-0.494	Yes
99.5		0.153	0.115	-4.950	0.975	-0.569	-0.562	
89.5		0.153	0.116	-2.296	0.777	-0.266	-0.235	
40.5		0.156	0.115	3.950	0.774	0.454	0.400	
135.5	Turbulence Intensity	0.068	0.030	11.467	0.808	0.344	0.309	Yes
99.5		0.073	0.032	9.081	0.825	0.291	0.264	
89.5		0.074	0.031	8.454	0.881	0.262	0.246	
40.5		0.083	0.032	5.603	0.566	0.179	0.135	
135.5	Rain	NA	NA	NA	NA	NA	NA	Not Applicable
99.5		NA	NA	NA	NA	NA	NA	
89.5		NA	NA	NA	NA	NA	NA	
40.5		NA	NA	NA	NA	NA	NA	
135.5	Availability	97.752	4.369	-0.008	0.013	-0.035	-0.004	No
99.5		97.567	4.541	0.018	0.123	0.082	0.029	
89.5		97.551	4.546	-0.001	0.001	-0.005	0.000	
40.5		97.453	4.540	0.035	0.303	0.159	0.087	
135.5	Direction	91.751	16.899	0.012	0.221	0.203	0.095	No
99.5		92.268	16.629	0.011	0.261	0.183	0.093	
89.5		91.953	16.832	0.009	0.163	0.151	0.061	
40.5		90.399	19.631	-0.009	0.099	-0.177	-0.056	
135.5	Air Temperature	14.428	5.610	-0.023	0.275	-0.129	-0.068	Yes
99.5		13.670	5.306	-0.026	0.387	-0.138	-0.086	
89.5		13.494	5.214	0.009	0.028	0.047	0.008	
40.5		12.705	4.802	0.058	0.349	0.279	0.165	
135.5	Air Density	1.082	0.026	-2.779	0.030	-0.072	-0.013	No
99.5		1.090	0.025	3.662	0.166	0.092	0.037	
89.5		1.093	0.025	1.216	0.019	0.030	0.004	
40.5		1.103	0.023	-5.675	0.202	-0.131	-0.059	
135.5	Temperature Gradient	0.017	0.019	12.835	0.336	0.244	0.141	Yes
99.5		0.017	0.019	-18.777	0.701	-0.357	-0.299	
89.5		0.018	0.019	-10.841	0.485	-0.206	-0.143	
40.5		0.019	0.019	12.835	0.336	0.244	0.141	
135.5	Upflow Angle	NA	NA	NA	NA	NA	NA	Not Applicable
99.5		NA	NA	NA	NA	NA	NA	
89.5		NA	NA	NA	NA	NA	NA	
40.5		NA	NA	NA	NA	NA	NA	

135.5	Veer	-0.023	0.069	-1.187	0.040	-0.082	-0.016	No
99.5		-0.024	0.069	-1.619	0.234	-0.112	-0.054	
89.5		-0.024	0.069	-1.035	0.135	-0.071	-0.026	
40.5		-0.022	0.067	2.202	0.252	0.148	0.074	

The Table 2.9 lists all significant and independent EVs, their slopes and ranges. Multiplying the regression slopes by the associated EV range results in the maximum influence of each independent variable on the RSD accuracy.

Table 2.9: Classification Result for SN21908 at Hami Site

Height	Indep. EV	*m*	Range	Max Influence *m x range*	Preliminary Accuracy	Final Accuracy	Standard Uncertainty
[m]	[-]	[%/unit of EV]	[unit of EV]	[-]	[%]	[%]	[%]
135.5	Shear	-4.669	1.200	-5.603	6.25	4.42	2.55
	TI	11.467	0.210	2.408			
	Temperature	-0.023	40.000	-0.920			
	Temp Gradient	12.835	0.080	1.027			
99.5	Shear	-4.950	1.200	-5.940	6.50	4.60	2.65
	TI	9.081	0.210	1.907			
	Temperature	-0.026	40.000	-1.040			
	Temp Gradient	-18.777	0.080	-1.502			
89.5	Shear	-2.296	1.200	-2.755	3.41	2.41	1.39
	TI	8.454	0.210	1.775			
	Temperature	0.009	40.000	0.360			
	Temp Gradient	-10.841	0.080	-0.867			
40.5	Shear	3.950	1.200	4.740	5.50	3.89	2.25
	TI	5.603	0.210	1.177			
	Temperature	0.058	40.000	2.320			
	Temp Gradient	12.835	0.080	1.027			

2.3 RSD type-specific Classification Result.

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 61400-12-1 Ed.2 Annex L2.9 [1] 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.

$$m_j = \frac{1}{N}\sum_{n=1}^{N} m_{j,n} + \frac{m_{j,max} - m_{j,min}}{2 \cdot \sqrt{3}}$$

Where,
$\boldsymbol{m_j}$ is the combined slope of environmental variable j,
$\boldsymbol{m_{j,n}}$ is the sensitivity slope of environmental variable j resulted from the classification $\boldsymbol{n}$.
$\boldsymbol{N}$ is total number of classification tests, here 3.

For each independent and significant EVs, Table 2.10 summarizes the interpolated and combined slopes for every 5 m of measurement height between 40 m and 140 m.

Table 2.10: Interpolated and Combined Slope of EVs

Height	Interpolated and Combined Slope, m_j					
	Shear	TI	Rain	Temp	TempG	Veer
[m]	[%]	[%]	[%]	[%/°C]	[%.m/°C]	[%.m/°]
*140	1.259	-0.626	0.663	0.075	0.193	2.895
135	-1.116	9.580	0.388	0.056	9.843	-1.612
130	-1.067	9.242	0.440	0.046	7.084	-1.643
125	-1.018	8.905	0.491	0.037	4.628	-1.673
120	-0.968	8.568	0.543	0.027	4.464	-1.704
115	-0.919	8.230	0.595	0.018	4.425	-1.610
110	-0.870	7.893	0.647	0.010	4.396	-1.482
105	-0.820	7.556	0.699	0.004	4.366	-1.228
100	-0.771	7.218	0.751	-0.001	4.337	-0.973
95	-0.553	7.039	0.701	0.001	3.340	-1.029
90	-0.074	6.860	0.652	0.005	2.767	-1.085
85	0.225	6.696	0.602	0.010	2.217	-1.015
80	0.524	6.531	0.552	0.018	1.667	-0.895
75	0.823	6.367	0.502	0.025	1.116	-0.775
70	1.122	6.203	0.452	0.033	1.354	-0.656
65	1.421	6.038	0.403	0.041	2.020	-0.536
60	1.721	5.874	0.353	0.049	2.686	-0.416
55	2.215	4.763	0.369	0.048	4.461	0.262
50	2.710	3.652	0.386	0.048	6.300	0.940
45	3.205	2.541	0.403	0.047	8.140	1.618
40	3.768	1.430	0.419	0.048	9.979	2.537

Table 2.11 indicates 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 independent and significant EV max influence. To calculate the final class, the preliminary accuracy class shall be divided by $\sqrt{2}$. while the RSD standard uncertainty is obtained by dividing the final accuracy class by $\sqrt{3}$. Figure 2.1 shows for all independent and significant EVs with maximum influence, the Preliminary Accuracy and Final Accuracy or class number.

Table 2.11: RSD Type-Specific Classification Per 5 m Height

Height	Max Influence (m x Range)						Preliminary Accuracy	Final Accuracy Class	Standard Uncertainty
	Shear	TI	Rain	Temp	TempG	Veer			
[m]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
*140	1.51	-0.13	0.66	3.02	0.02	1.16	3.63	2.57	1.48
135	-1.34	2.01	0.39	2.23	0.79	-0.64	3.46	2.45	1.41
130	-1.28	1.94	0.44	1.85	0.57	-0.66	3.13	2.21	1.28
125	-1.22	1.87	0.49	1.47	0.37	-0.67	2.82	2.00	1.15
120	-1.16	1.80	0.54	1.09	0.36	-0.68	2.58	1.83	1.05
115	-1.10	1.73	0.60	0.71	0.35	-0.64	2.37	1.67	0.97
110	-1.04	1.66	0.65	0.40	0.35	-0.59	2.21	1.56	0.90
105	-0.98	1.59	0.70	0.17	0.35	-0.49	2.09	1.48	0.85
100	-0.93	1.52	0.75	-0.05	0.35	-0.39	2.00	1.41	0.82
95	-0.66	1.48	0.70	0.03	0.27	-0.41	1.83	1.30	0.75
90	-0.09	1.44	0.65	0.18	0.22	-0.43	1.67	1.18	0.68
85	0.27	1.41	0.60	0.40	0.18	-0.41	1.66	1.18	0.68
80	0.63	1.37	0.55	0.70	0.13	-0.36	1.79	1.27	0.73
75	0.99	1.34	0.50	1.02	0.09	-0.31	2.04	1.44	0.83
70	1.35	1.30	0.45	1.34	0.11	-0.26	2.36	1.67	0.96
65	1.71	1.27	0.40	1.65	0.16	-0.21	2.74	1.94	1.12
60	2.06	1.23	0.35	1.97	0.21	-0.17	3.14	2.22	1.28
55	2.66	1.00	0.37	1.94	0.36	0.10	3.48	2.46	1.42
50	3.25	0.77	0.39	1.90	0.50	0.38	3.91	2.77	1.60
45	3.85	0.53	0.40	1.86	0.65	0.65	4.42	3.13	1.81
40	4.52	0.30	0.42	1.91	0.80	1.01	5.10	3.61	2.08

*Note – EV was not assessed on height 140m. In Zhangbei test site, the two classification tests cover 40.5m to 139.5m, but in Hami test site, the classification test only covers 40.5m to 135.5m, and the EV analysis at height 139.5m have one classification test less than at height between 40.5 and 135.5m. that results in the EV analysis shows inconsistent performance at 140m heigh. See Tables 2.1, 2.10 and 2.11 for detail. Therefore, the evaluation result at height 140m was excluded in final classification.

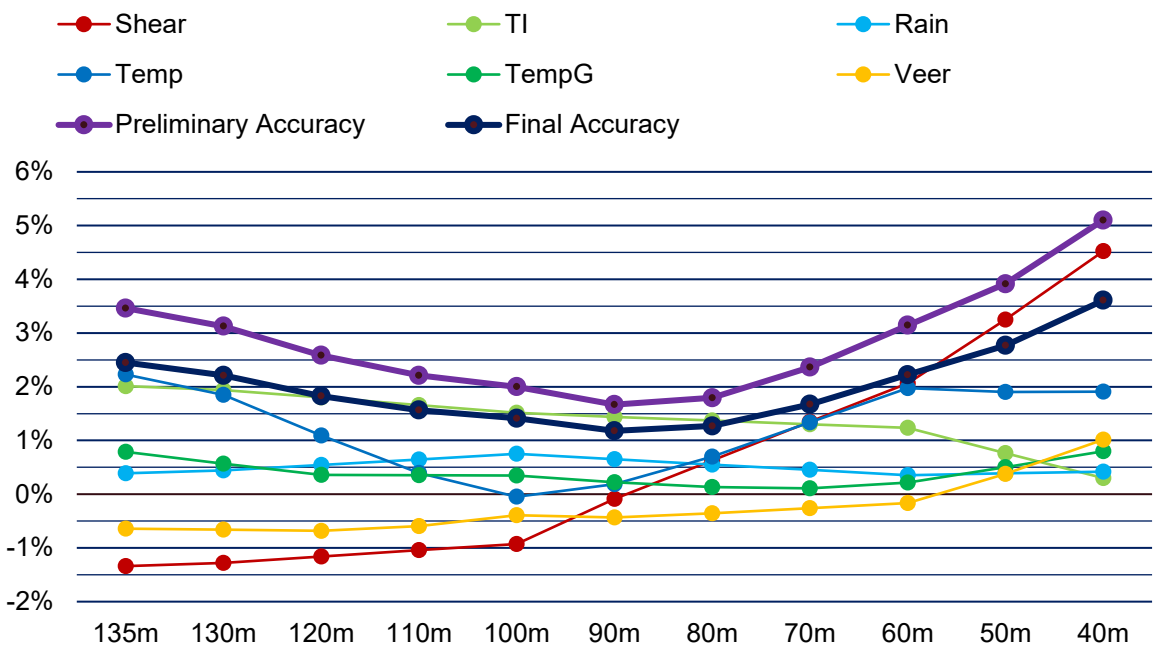

Figure 2.1: RSD Type-Specific Classification Result

3. DERIVING APPLICATION UNCERTAINTY – EXAMPLE

The type-specific class shown in Table 2.11 are the maximum wind speed measurement uncertainty that can be expected from the RSD type MeteoLaser 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 in Table 2.2. 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,

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

Where,

$u_{class,i}$ is the RSD type MeteoLaser uncertainty of wind speed measurements in wind speed bin i due to the influence of environmental variables;

M is the 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 Section 2.2 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 3.1 presents the environmental condition per wind speed bin from hypothetical verification and application tests at 100 m height. The classification uncertainty (%) presents the derived uncertainty calculated by applying equation 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 (%).

Table 3.1: Example of Combining Uncertainty of Hypothetical Verification and Application Test (100m)

WS Bin	Wind Shear			Turbulence Intensity			Rain			Air Temperature			Temperature Gradient			Wind Veer			Uncertainty		
	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Ver	App	Unc	Classification	Verification	Combined
[m/s]	[-]	[-]	[%]	[-]	[-]	[%]	[-]	[-]	[%]	[°C]	[°C]	[%]	[°C/m]	[°C/m]	[%]	[°/m]	[°/m]	[%]	[%]	[%]	[%]
4.0	0.23	-0.02	0.19	0.14	0.13	0.07	0.04	0.00	0.03	8.37	11.65	0.00	0.01	0.01	0.02	-0.01	-0.04	0.03	0.21	2.74	2.75
4.5	0.24	0.04	0.15	0.12	0.13	0.08	0.10	0.00	0.08	8.83	12.19	0.00	0.01	0.00	0.02	-0.01	-0.04	0.03	0.19	2.61	2.62
5.0	0.26	0.05	0.16	0.11	0.11	0.02	0.05	0.00	0.04	8.21	7.84	0.00	0.01	0.00	0.02	-0.01	-0.03	0.02	0.17	2.53	2.54
5.5	0.23	0.09	0.10	0.12	0.10	0.11	0.06	0.00	0.04	8.96	10.67	0.00	0.01	0.01	0.01	0.00	-0.02	0.02	0.16	2.46	2.47
6.0	0.23	0.05	0.14	0.12	0.09	0.22	0.05	0.00	0.04	8.67	11.24	0.00	0.01	0.01	0.03	0.01	-0.02	0.02	0.27	2.41	2.42
6.5	0.24	0.13	0.09	0.11	0.08	0.19	0.03	0.00	0.02	8.77	13.34	0.00	0.01	0.02	0.06	0.00	-0.01	0.01	0.22	2.37	2.38
7.0	0.24	0.12	0.09	0.11	0.08	0.24	0.02	0.00	0.02	8.74	12.35	0.00	0.01	0.02	0.03	-0.01	-0.05	0.04	0.26	2.33	2.34
7.5	0.23	0.15	0.07	0.10	0.08	0.18	0.04	0.00	0.03	8.69	14.64	0.01	0.01	0.02	0.06	-0.01	-0.03	0.02	0.20	2.30	2.31
8.0	0.23	0.13	0.08	0.11	0.08	0.21	0.02	0.00	0.01	8.66	14.58	0.01	0.01	0.02	0.06	-0.02	-0.04	0.02	0.23	2.28	2.29
8.5	0.22	0.19	0.02	0.10	0.07	0.23	0.04	0.00	0.03	8.18	14.03	0.01	0.01	0.02	0.07	-0.02	-0.03	0.01	0.24	2.25	2.26
9.0	0.20	0.19	0.01	0.10	0.08	0.19	0.02	0.00	0.01	8.19	15.17	0.01	0.01	0.02	0.08	-0.03	0.00	0.03	0.21	2.25	2.26
9.5	0.22	0.20	0.01	0.10	0.07	0.21	0.02	0.00	0.01	8.30	15.45	0.01	0.01	0.03	0.09	-0.02	0.00	0.02	0.23	2.22	2.23
10.0	0.21	0.18	0.02	0.11	0.06	0.32	0.05	0.00	0.04	7.31	15.93	0.01	0.01	0.02	0.07	-0.03	-0.01	0.02	0.33	2.21	2.23
10.5	0.19	0.18	0.01	0.11	0.07	0.33	0.07	0.00	0.05	7.37	16.12	0.01	0.00	0.02	0.07	-0.04	-0.02	0.02	0.35	2.20	2.23
11.0	0.16	0.20	0.04	0.12	0.06	0.38	0.03	0.00	0.02	7.13	14.70	0.01	0.00	0.02	0.09	-0.04	-0.01	0.03	0.40	2.18	2.22
11.5	0.16	0.20	0.03	0.11	0.06	0.35	0.01	0.00	0.01	7.02	14.63	0.01	0.00	0.02	0.07	-0.04	-0.02	0.02	0.36	2.17	2.20
12.0	0.18	0.18	0.00	0.11	0.06	0.37	0.00	0.00	0.00	7.58	13.92	0.01	0.00	0.02	0.05	-0.04	-0.02	0.02	0.37	2.16	2.19
12.5	0.18	0.16	0.02	0.11	0.06	0.40	0.00	0.00	0.00	8.21	13.25	0.01	0.00	0.01	0.03	-0.05	-0.02	0.03	0.40	2.16	2.20
13.0	0.19	0.13	0.05	0.12	0.06	0.39	0.00	0.00	0.00	8.49	12.15	0.00	0.00	0.00	0.00	-0.05	-0.05	0.00	0.39	2.15	2.19
13.5	0.17	0.14	0.02	0.12	0.06	0.41	0.00	0.00	0.00	8.53	12.92	0.00	0.00	0.01	0.02	-0.05	-0.03	0.02	0.41	2.14	2.18
14.0	0.21	0.18	0.02	0.10	0.05	0.33	0.00	0.00	0.00	8.12	14.14	0.01	0.01	0.02	0.04	-0.03	-0.02	0.01	0.33	2.14	2.17
14.5	0.19	0.12	0.05	0.11	0.05	0.40	0.00	0.00	0.00	8.12	10.56	0.00	0.00	0.01	0.02	-0.05	-0.06	0.01	0.40	2.13	2.17
15.0	0.16	0.14	0.01	0.12	0.05	0.52	0.00	0.00	0.00	8.91	9.71	0.00	0.00	0.01	0.03	-0.05	-0.07	0.02	0.52	2.14	2.20
15.5	0.16	0.18	0.02	0.08	0.05	0.24	0.00	0.00	0.00	7.78	11.48	0.00	0.00	0.01	0.03	-0.03	-0.04	0.01	0.25	2.13	2.14
16.0	0.24	0.17	0.06	0.12	0.05	0.49	0.00	0.00	0.00	5.47	11.66	0.01	0.01	0.01	0.02	-0.06	-0.03	0.03	0.50	2.27	2.32

Note: Lidar SN21908 test data were used as example, the lidar test data at 100m height at Zhangbei site was used as verification purpose and the lidar test data at 100m at Hami site was used as application purpose. See reference report [3] and [4] for detail.

4. CONCLUSION

A type-specific classification based on the IEC 61400-12-1, Ed. 2 [1] for the RSD MeteoLaser was independently conducted by UL. The main significant environmental variables which influenced the wind measurement of RSD MeteoLaser are:

- Wind Shear,
- Turbulence Intensity,
- Rain,
- Air Temperature,
- Temperature Gradient,
- Wind Veer.

UL has followed the methodology described in the standard to identify these significant environmental variables. The standard also suggests further approaches to reduce the number of EVs to avoid double counting of uncertainty factors. UL has not engaged in such a discussion given the bandwidth of the results and number of available data sets. Adding further data sets is basically a possibility and may lead to a further refinement of the classification results.

The type-specific class numbers were given in discrete heights from 40 m to 135 m in 5 m steps. The type class numbers range from 3.6 at 40 m and 2.5 at 135 m.

5. REFERENCES

[1] International Electrotechnical Commission, "IEC 61400-12-1 Ed. 2: Wind Energy Generation Systems - Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines," March 2017.

[2] UL International GmbH, "Remote Sensing Device Verfication Report of SN21906 at Zhangbei," 2022.

[3] UL International GmbH, "Remote Sensing Device Verfication Report of SN21908 at Zhangbei," 2022.

[4] UL International GmbH, "Remote Sensing Device Verfication Report of SN21908 at Hami," 2022.

[5] UL International GmbH, "Remote Sensing Device Classification Report UL-CHN-PPT-21-13785723-RSDC-01.00," 2022.

[6] Applicant: Beijing Leviathan Technology Co., Ltd, "Statement letter of Company name in Classification Report," 2022-07-06.

[7] Ammonit Measurement GmbH, "Authorisation for application for MeteoLaser Lidar Classification Report," 2022-06-10.