FRØYA SEAWATCH WIND LIDAR BUOY PRE-DEPLOYMENT VALIDATION

Assessment of the Fugro OCEANOR Seawatch Wind LiDAR Buoy Pre-Deployment Validation on Frøya, Norway

Fugro / OCEANOR AS

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Task and objective: 3rd Party Assessment of an Offshore/Nearshore Pre-Deployment Validation of the Fugro/Oceanor SEAWATCH Wind LiDAR Buoy at the Island Frøya, Norway

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Reference to part of this report which may lead to misinterpretation is not permissible.

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List of abbreviations

Abbreviation	**Meaning**
SWLB	Seawatch Wind Lidar Buoy
GH-D	GL Garrad Hassan Deutschland GmbH, part of DNV GL group
FO	Fugro OCEANOR
RLL	Reference Land Lidar
FLD	Floating LiDAR Device
MSL	Mean Sea Level
SL	actual Sea Level
LAT	Lowest astronomical tide
KPI	Key Performance Indicator
AC	Acceptance Criterion
WS	Wind Speed
WD	Wind Direction

1 INTRODUCTION

Fugro OCEANOR AS (FO or the Client) commissioned GL Garrad Hassan Deutschland GmbH (“GH-D”), part of the DNV GL group (“DNV GL”) to perform a pre-deployment validation campaign and to provide a validation report for a SEAWATCH Wind LiDAR Buoy (SWLB) unit moored next to the Island Frøya in the Norwegian Sea.

The pre-deployment validation of this already “Roadmap-Pre-Commercial” staged Floating Lidar Device (FLD) [1] was performed over a period of 2 weeks against a fixed/land based industry accepted Lidar (Reference Land Lidar or RLL), that was used as the only validation reference. Data evaluation was performed for specific wind data quality related Key Performance Indicators (KPIs) and Acceptance Criteria (AC) as formulated in the Roadmap towards Commercial Acceptance [2].

DNV GL has not been involved in the data collection. Data from both the SWLB and the RLL were provided by FO.

The Campaign started March 11^{th}, 2015 with the deployment of the SWLB at a position South of Frøya in 75 m water depth, see Figure 1 “Lidar buoy”. The mooring point is about 820 m to the Southwest of the shore of a place called Stabben and 960 m from the “Land Lidar” at Stabben. The campaign was finished by the recovery of the SWLB on March 25^{th}, 2015.

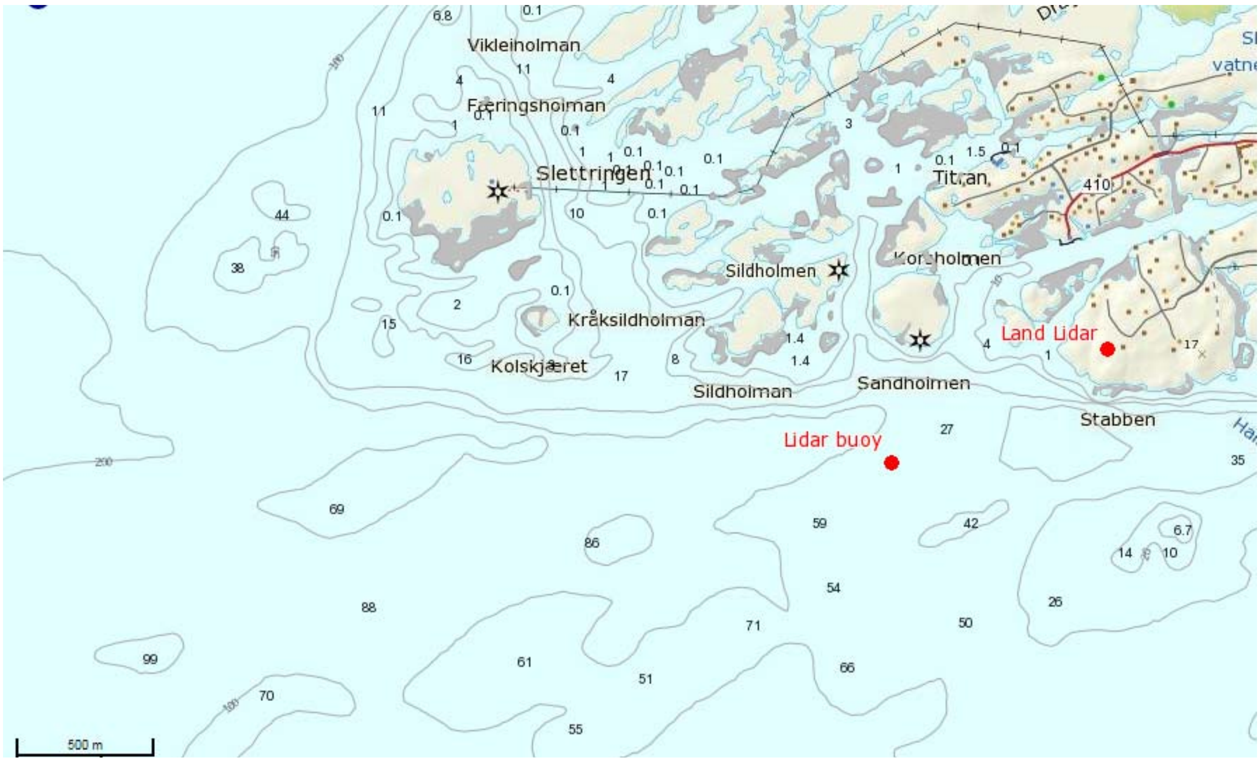


Figure 1: Positions of SWLB (Lidar buoy) and RLL (Land Lidar) near or at the Island Frøya /Stabben.

This report is aimed in documenting the results with respect to the pre-deployment validation trial of the Fugro OCEANOR Seawatch Wind Lidar Buoy (SWLB) with S/N WS 149 against a Reference Land Lidar (RLL) of type ZephIR with the S/N Z495 at the new FO test site near and on the Norwegian Island Frøya at a place call Stabben, in the Norwegian Sea.

1.1 Clarification Note

It is important to note that the validation approach applied for this campaign focusses on the capabilities of floating LiDAR technology (namely in this case for the SWLB with the buoy's S/N WS 149 employing a ZephIR Lidar with the S/N 428) measuring primary wind data, namely wind speed and wind direction. Therefore, while the SWLB currently features additional measures the scope of this document is limited to its primary wind data measurements.

DNV GL under stands that the tested SWLB Floating Lidar unit is planned to be deployed in the Dutch offshore wind planning area Borssele in the Dutch North Sea sector, and that this campaign serves as the according pre-deployment validation.

DNV GL understands and assumes that there is agreement between FO and their client *Rijksdienst voor Ondernemend Nederland* (RvO) that a pre-deployment validation of an already "Roadmap-Pre-Commercial" staged FLD against a fixed/land based industry accepted Lidar to be used as the only validation reference (Reference Land Lidar, RLL) is acceptable.

It is further understood that the following conditions have to be fulfilled in this validation context:

- The RLL has successfully been validated against an IEC compliant onshore met mast:
  → this is fulfilled by a Lidar validation performed at the ZephIR site in Pershore, UK, independently validated by DNV GL [4]
- The ZephIR Lidar mounted on the SWLB has successfully been validated against an IEC compliant onshore met mast
  → this is fulfilled by a Lidar validation performed at the ZephIR site in Pershore, UK [5]
- The suitability of Frøya test site, i.e. given comparativeness of wind conditions between locations of Reference Land Lidar (RLL) and SWBL
- Setup of RLL in compliance with industry best practice
  → confirmed by installation report from DNV GL [3]
- The wind speed data coverage and bin wise completeness according to the Roadmap [1] is achieved.
- The wind speed and wind direction comparison results yielded according to relevant Roadmap KPIs and ACs meet at least the Roadmap minimum Acceptance Criteria.
- The representativeness of wave conditions experienced at the Frøya test site for the projected deployment site (Borssele in this case) is shown.

All conclusions on the capabilities of the FO SWLB drawn from this Frøya pre-deployment validation campaign are valid under sea state and meteorological conditions similar to those experienced during the campaign duration, only.

2 SETUP OF THE SWLB PRE-DEPLOYMENT VALIDATIONS

DNV GL has performed a site visit at the Stabben/Frøya site on March 25th, 2015 [3] in order to inspect the suitability to serve as a test site for FLD validations. Subject to further evidence based on data from substantially longer verification trials at this site, but by

1. acknowledging the information provided by FO to DNV GL on the side upfront,
2. seeing the generally consistent resemblance between SWLB and RLL over the full height range in this report and
3. from the inspection itself,

DNV GL considers this test site suitable for pre-deployment verifications of Floating Lidar Devices (FLD).

2.1 Positions of Installed SWLB and RLL Units

Position of ZephIR Reference Land Lidar (RLL), see Figure 2, right:

- The location is called Stabben on the Island Frøya and the RLL is placed at 14 m above sea level (mean sea level or MSL).
- The GPS position of the RLL is 63° 39' 46.60'' N, 008° 18' 35.50'' E.

Position of Seawatch Wind Lidar Buoy (SWLB) Floating Lidar Device, see Figure 2, left:

- The SWLB is deployed at a position of 63° 39' 29.40" N, 008° 17' 39.10" E.
- It is moored in 75 m of water depth and the mooring array allows a horizontal sway freedom of movement around the anchor of about 115 m.
- The mooring point is about 820 m from the shore of a place called Stabben and about 960 m to the South West of the RLL position.

These positions were confirmed during a site visit and RLL inspection by DNV GL, on March 25th 2015 [3].

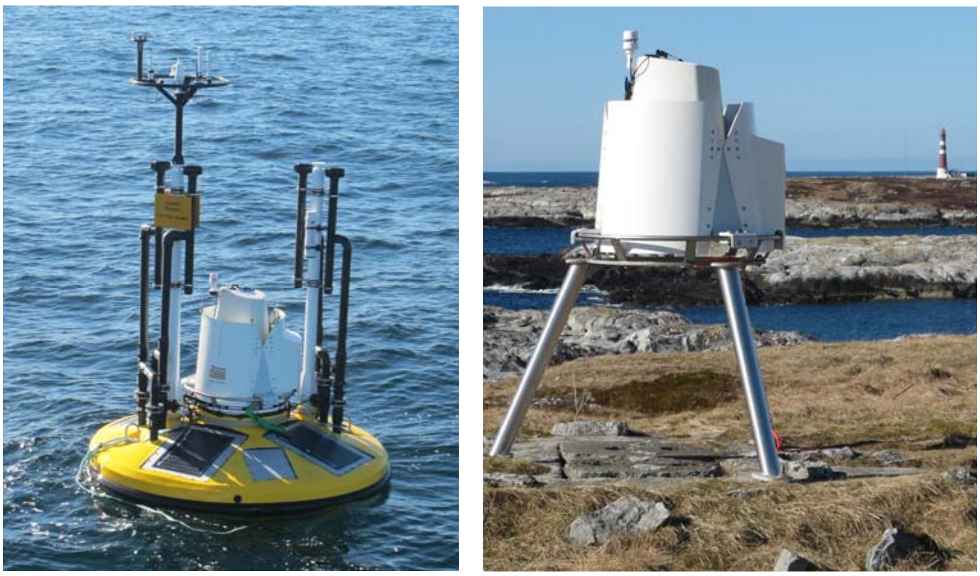


Figure 2: Seawatch Wind Lidar Buoy (left) and Reference Land Lidar as installed near/at Frøya test site.

2.2 Settings and Specs of SWLB and RLL Units

SWLB Floating Lidar:

- SWLB S/N WS 149
- ZephIR S/N Z428
- Height settings 200, 170, 150, 130, 110, 90, 70, 55, 35 m relative to actual sea level

Reference Land Lidar:

- ZephIR S/N Z495
- Height settings 200, 170, 150, 130, 110, 90, 70, 55, 35 m above mean sea level

These specs were confirmed during the site visit and RLL inspection by DNV GL, on March 25th 2015 [3].

Table 1: List of heights relevant for wind data comparisons between SWLB and RLL (green shading, targeted heights above MSL / SL

	Reference Land Lidar (RLL)		Floating Lidar (SWLB)	
Window Height above sea level (SL)	14		2	
Height level #	True Height above MSL [m]	Configured Height [m]	True Height above SL [m[	Configured Height [m]
0			4	Gill Sonic
1	25	11	25	23
2	35	21	35	33
3	52	not configurable	40	not configurable
4	55	41	55	53
5	70	56	70	68
6	90	76	90	88
7	110	96	110	108
8	130	116	130	128
9	150	136	150	148
10	170	156	170	168
11	200	186	200	198

The assessment of the KPIs and their respective Acceptance Criteria regarding wind data accuracy was performed at height levels between 35 m and 200 m as mentioned in Table 1.

All data collected from the deployment 2015-03-11 of SWLB until its decommissioning on 2015-03-25 were taken into account in the overall data processing scheme, regardless of the environmental conditions.

3 VALIDATION RESULTS

For the pre-deployment validation of FO's SWLB against the RLL data from the employed FLD ZephIR 300 LiDAR with the serial number Z428 and from the RLL ZephIR with the serial number Z495 were provided by FO for a campaign period lasting 2015-03-11 to 2015-03-25, yielding a duration of 2 weeks.

3.1 Data provision

The Following remarks and reservations with respect to data transfer, traceability and processing are noted:

- RLL and SWLB data were provided to DNV GL for the whole campaign period by FO, directly.
- SWLB LiDAR wind statistics were returned by the central controller unit (called GENI) installed on the SWLB. This unit collected the 1-sec raw data from the ZephIR 300 to calculate the 10 minute wind data statistics.

3.2 Wind and sea state conditions during the trial

During the validation period of the SWLB the device encountered a wide range of wind conditions facing 10 minute average wind speeds of up to 25.5 m/s at the lowest comparison level (35 m) and 31.5 m/s at the upper most level (200 m) – see Table 2.

The significant wave heights observed during the trial period at Frøya were in the range of above 4 m, with 8% of the observations above 2.5 m, compare Figure 3. The experienced maximum wave heights cover a range up to above 6 m.

An extreme value extrapolation on this very short data set indicates that the extreme value for a 20 year recurrence interval would be around 7.3 m. This indicates a reasonably good representativeness for the targeted Borssele area conditions presented in the *Deltares Report* [available from FO], which for a 20 years period shows that the highest significant wave height would be about 7.0 m, with 8.8% above 2.5 m. But one would not expect 20 year extreme values to occur with a short trial period of two weeks.

The wave measurements were recorded by the SWLB under trial using a 30 min data acquisition and processing interval.

Table 2: Maximum 10 min averaged wind speeds measure at the RLL and by the SWLB across the total campaign period.

WS Max	RLL	SWLB
Level / [m]	WS [m/s]	
35	25,65	25,02
55	27,10	27,71
70	27,97	28,54
90	28,90	29,47
110	29,66	29,47
130	30,42	29,88
150	30,38	29,82
170	30,98	30,41
200	31,54	30,64

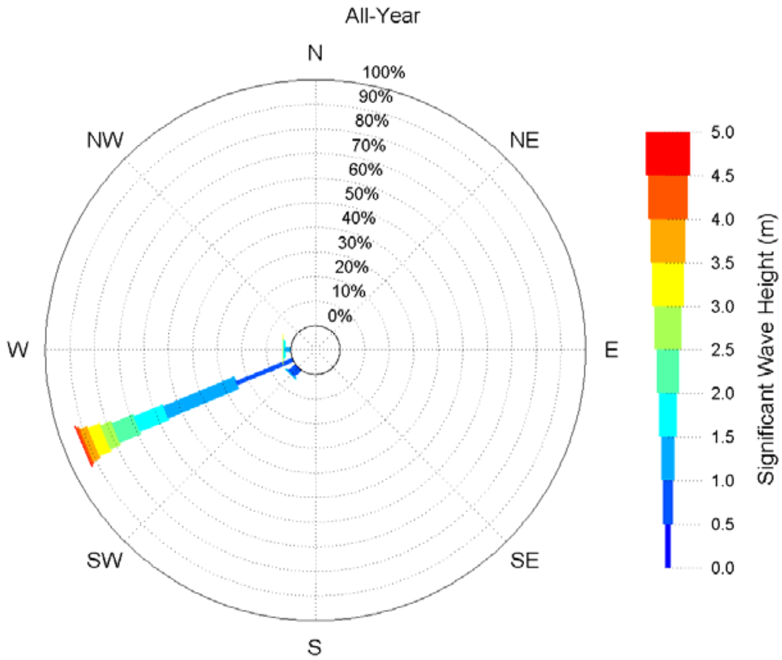


Figure 3: Direction rose of significant wave height as measured by the SWL Buoy itself, across the validation trial period.

3.3 Accuracy

DNV GL has analysed the wind data against the relevant KPIs and Acceptance Criteria given in [1] and in Appendix A which are related to the WS and WD accuracy of the SWLB unit.

The comparisons in this section are based on ten-minute average values at both the floating LiDAR unit and the RLL. For the analysis conducted in this section, a low wind speed cut-off of 2 m/s has been applied for the wind speed comparisons and for the wind direction comparisons.

No wind direction sector filtering has been applied.

3.3.1 Data coverage requirements for accuracy assessment

In accordance with the data coverage requirements outlined in the Roadmap A, DNV GL has assessed the data coverage of the floating LiDAR system at the four measurement heights considered. This has been conducted according to the following requirements:

a) Minimum number of 40 data points required in each 1 m/s bin wide reference wind speed bin centred between 2.5 m/s and 11.5 m/s, i.e. covering a range between 2 and 12 m/s.

b) Minimum number of 40 data points required in each 2 m/s bin wide reference wind speed bin centred on 13 m/s and 15 m/s, i.e. covering a range 12 m/s to 16 m/s.

c) Minimum number of 40 data points in each 2 m/s bin wide reference wind speed bin centred on 17 m/s and above, i.e. covering a range above 16 m/s only if such number of data is available. This is not mandatory.

For the period considered in this report, the Roadmap related WS bin wise data completeness was achieved for all WS bins up to 20 m/s at all treated comparison heights, with the marginal and hence insignificant exception in the WS bin centred at 11.5 m/s. All other bins above and below this bin include more than 40 values, compare Table 3.

Table 3: Summary of data coverage per WS bin. Complete bins including at least 40 values are marked in green.

WS Bins / [m/s]	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 14	14 to 16	16 to 18	18 to 20	20 to 22	22 to 24	24 to 26	26 to 28	28 to 30
Bin Center	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	13	15	17	19	21	23	25	27	29
Level / [m]	FLD number of 10 min data entries per WS bin - AFTER filtering for data to be used for regression analysis																		
35	193	146	186	205	143	81	52	67	42	30	64	77	62	56	37	38	22	1	0
55	200	131	163	129	171	109	82	77	53	38	52	76	61	61	44	36	32	21	1
70	195	145	140	130	150	118	105	76	50	48	49	76	65	55	50	32	36	25	4
90	188	138	144	123	129	123	110	87	62	42	52	75	65	51	62	32	34	26	10
110	181	136	123	120	150	113	99	97	65	45	60	59	78	41	69	36	31	28	16
130	177	131	126	117	159	103	91	103	68	39	67	57	77	49	62	38	28	34	21
150	164	149	125	106	161	108	83	97	74	36	72	49	82	46	58	49	35	25	31
170	169	152	117	109	153	104	86	96	72	45	60	49	82	53	52	57	33	28	32
200	172	154	134	100	149	97	82	89	79	39	54	57	80	53	48	56	40	36	34

3.3.2 Wind speed accuracy

A summary of the findings for each wind-speed-related KPI is presented in Table 4. The wind speed accuracy assessment has been conducted at nine heights between 35 and 200 m above MSL.

The slopes (X_{MWS}) and Coefficient of Determination (R^2_{mws}) are presented for all compared heights. It can be seen that these fall within the best practice acceptance criteria [0.98 > X_{MWS} > 1.02] as given in [1] for the data period considered here. Plots for WS regression results together with WS time series plots selected for a few heights can be found in Appendix B.

Table 4: Overview of linear regression analysis results for wind speed comparisons between the SWL Buoy and the reference Lidar at all available comparison levels. Colour shading indicates the compliance with the prescribed best practice or minimum KPI's Acceptance Criteria (see legend).

WS comparison		slope	regr. coeff.	WS RLL avg	WS FLD avg	WS diff.	relative WS diff.
		KPIs					
Level / [m]	#	X_{mws}	R^2_{mws}				
35	1504	0,993	0,991	8,41	8,38	-0,03	-0,3%
55	1515	1,019	0,994	8,89	9,08	0,19	2,1%
70	1520	1,014	0,994	9,13	9,28	0,15	1,6%
90	1511	1,011	0,994	9,42	9,54	0,13	1,3%
110	1498	1,011	0,994	9,66	9,79	0,12	1,3%
130	1491	1,011	0,994	9,85	9,98	0,13	1,3%
150	1491	1,009	0,994	10,03	10,15	0,12	1,2%
170	1490	1,006	0,993	10,22	10,32	0,10	1,0%
200	1484	0,999	0,990	10,50	10,56	0,07	0,6%

Legend	
KPI	failed
KPI	passed minimum
KPI	passed best practice

3.3.3 Wind direction accuracy:

The wind direction data comparison was conducted at nine (9) heights between 35 and 200 m above MSL.

The results for the wind direction comparison are presented in Table 5 where the Wind Direction Regression Slope (M_{mwd}), the Mean Offset (OFF_{mwd}) and the Coefficient of Determination (R^2_{mwd}) are presented. Most of the KPI values fall within the best practice acceptance criteria. All other KPI values meet the minimum criteria. Plots for WD regression results selected for a few heights can be found in Appendix C.

Table 5: Overview of linear regression results for WD comparisons between SWLB and reference Lidar at the nine (9) WD comparison levels. Colour shading indicates compliance with prescribed best practice or minimum KPI's Acceptance Criteria (see legend).

WD comparison		slope	regr. Coeff.	mean diff.
		KPIs		
Level / [m]	#	M_{mwd}	R^2_{mwd}	OFF_{mwd}
35	1504	0,976	0,985	-5,35
55	1513	0,963	0,980	-6,51
70	1519	0,975	0,985	-4,45
90	1510	0,975	0,982	-4,89
110	1498	0,977	0,980	-4,97
130	1491	0,975	0,977	-4,69
150	1491	0,972	0,975	-4,74
170	1489	0,962	0,965	-3,62
200	1483	0,963	0,972	-3,71

Legend	
KPI	failed
KPI	passed minimum
KPI	passed best practice

3.4 Summary of verification results

3.4.1 Campaign Duration

The campaign duration is considered rather short, with only 14 days. However, due to the achieved data completeness and WS coverage up to 20 m/s this campaign is considered significant and compliant to the Roadmap in terms proving the wind data accuracy of the SWLB.

3.4.2 Wind Measurement Accuracy

The wind speeds of both the SWLB and the RLL at all comparison heights correlated very well, showing a low level of scatter and good agreement in terms of linear regression analyses. This comparison campaign indicates that the SWBL is able to reproduce fixed Lidar wind speeds at a high level of accuracy. The Best Practice criteria for the KPIs “Mean Wind Speed – Slope” and “Mean Wind Speed – Coefficient of Determination” were passed.

For wind direction Best Practice criteria (or in a few instances at least the Minimum criteria) were passed at all comparison heights for the KPIs “Mean Wind Direction – Slope”, “Mean Wind Direction – Coefficient of Determination” and “Mean Wind Direction – Offset”, indicating the SWLB capability of reproducing fixed Lidar wind directions at a good level of accuracy.

The detailed results with respect to KPIs and ACs for wind speed and wind direction comparisons are given in Table 6, below.

Table 6: Summary of achievement after 14 days wrt KPIs and Acceptance Criteria for data accuracy assessment

KPI	Definition / Rationale	Acceptance Criteria across total campaign duration	
		Best Practice	**Minimum**
X_{mws}	**Mean Wind Speed – Slope** Assessed for wind speed range [all above 2 m/s]	0.98 – 1.02 Results: [0.993 to 1.019] Passed at all compared heights	0.97 – 1.03
R^2_{mws}	**Mean Wind Speed – Coefficient of Determination** Assessed for wind speed range [all above 2 m/s]	>0.98 Results: [0.990 to 0.994] Passed at all compared heights	>0.97
M_{mwd}	**Mean Wind Direction – Slope** Assessed for wind speed range [all above 2 m/s] Regardless of the wind direction, i.e. no WD filtering applied	0.97 – 1.03 Results: [0.972 to 0.977] Passed at comparison at heights at 35 m and between 70 and 150 m	0.95 – 1.05 Results: [0.962 to 0.963] Passed at comparison height of 55, 170 and 200 m
OFF_{mwd}	**Mean Wind Direction – Offset, in terms of the mean absolute WD difference over the total campaign duration** (same as for M_{mwd})	< 5° Results: [3.62° to 4.97°] Passed at comparison heights from 70 to 200 m	< 10° Results: [5.35 to 6.51] Passed at comparison heights 35 and 55 m

<table>
<tr><th rowspan="2">KPI</th><th rowspan="2">Definition / Rationale</th><th colspan="2">Acceptance Criteria across total campaign duration</th></tr>
<tr><th>Best Practice</th><th>Minimum</th></tr>
<tr><td>R^2_{mwd}</td><td>Mean Wind Direction – Coefficient of Determination

(same as for M_{mwd})</td><td>> 0.97

Results:

[0.972 to 0.985]

Passed at comparison heights from 35 to 150 m and at 200 m</td><td>> 0.95

Results:

[0.965]

Passed at comparison height of 170 m</td></tr>
</table>

4 REMARKS AND LIMITATIONS

The presented results have to be regarded under the following reservations and limitations:

- Both data sets, (a) the one for the Reference Land Lidar (RLL) and (b) the one for the SWLB were provided to DNV GL by Fugro/OCEANOR (FO), i.e. they've had full access to the data from the tested device and from the reference data.
- The campaign duration is considered rather short, with only 14 days. However, due to the achieved data completeness for the covered WS range of WS well above 20 m/s, this campaign is considered significant and compliant to the Roadmap for informing on the wind data accuracy of the SWLB unit under test.
- For the shortness of the campaign meaningful conclusions with respect to reliability in terms of system or data availability of the SWLB device are not possible.
- FO has mentioned to have applied an offset correction to the RLL wind direction data due to misalignment to North. In this context it is stated by FO *"that when the Land lidar was first deployed at Frøya the alignment was off by 10° relative to true north, later it was rotated 10° the wrong way (!) and finally it was rotated back 20°, so that it is now aligned with true north."* DNV GL is confident that this statement is true.
- In the WS regressions for the treated heights between 55 m and 200 m a decrease (improvement) of the slope towards unity with increasing height can be detected. This indicates a slight ground friction effect on the RLL data which tends to decrease with height. However, all "forced" (through the origin) regression slopes are within the Roadmap allowance, i.e. below 1.02. And the yielded coefficients of determination are excellent. They are indicating that non-synchronicity at the mentioned distance between SWLB and RLL of about 940 m is no issue.
- All conclusions on the capabilities of the SWLB drawn from this Frøya pre-deployment verification campaign are valid under sea states and meteorological conditions similar to those experienced during this trial, only.

5 CONCLUSIONS ON SWL BUOY TECHNOLOGY IN CONTEXT OF COMMERCIAL ROADMAP

An evaluation of the Fugro/OCEAN Seawatch Wind Lidar Buoy floating LiDAR system was completed by comparing its measurements against data of a Reference Land Lidar installed on the Island Frøya in the Norwegian Sea. Sufficient data in terms of WS data completeness and coverage were collected to allow an assessment in line with the Roadmap.

DNV GL concludes that the FO SWBL unit with the S/N 149 has demonstrated its capability to produce accurate wind speed and direction data across the range of sea states and meteorological conditions experienced in this trial. I.e. significant wave heights of up to about > 4 m (and > 6 m for maximum wave height) were recorded by the Buoy. These wave measures are considered representative for the project site in the Borrsele area. The Lidar wind speeds recorded at Frøya covered a range of up to 25 m/s at 35 m and 31 m/s at 200 m.

The assessments of the Roadmap KPIs for the complete data set (from March 11th until March 25th 2015) show that all FLD-Roadmap Acceptance Criteria for wind speed and wind direction related Key Performance Indicators (KPI) are met at all relevant heights between 35 and 200 m above MSL, passing at least the minimum Roadmap Acceptance Criteria but mostly the best practice criteria.

FLD Roadmap related WS bin wise data completeness was achieved for all WS bins up to 20 m/s at all treated comparison heights, with the marginal and hence insignificant exception in the WS bin centred at 11.5 m/s. All other bins above and below this bin include more than 40 values.

6 REFERENCES

[1] Offshore Wind Accelerator Roadmap for the commercial acceptance of floating Lidar technology. The Carbon Trust, 21 November 2013.

[2] DNV GL Report GLGH-4257 13 10378 266-R-0002 Issue B , “A ROADMAP FOR THE COMMERCIAL ACCEPTANCE OF THE FUGRO/OCEANOR SEAWATCH WIND LIDAR BUOY”, dated 2015-01-29.

[3] DNV GL Report GLGH-4275 13 10378 271-T-0003-A, ”Technical note for inspection of Reference Land Lidar at Frøya”, date TBC.

[4] DNV GL Report GLGH-4257 13 11068 267-R-0021-A, ”ZP495 Independent analysis and reporting of ZephIR Lidar performance verification executed by ZephIR Ltd. At their test site and reference mast in Pershore, UK”, dated 2015-03-27

[5] Onshore performance verification report for ZephIR Lidar Z428 (TBC).

APPENDIX A – APPLIED KEY PERFORMANCE INDICATORS AND ACCEPTANCE CRITERIA FOR FLD PRE-DEPLOYMENT VALIDATION

Wind Data Accuracy assessment

The KPIs and Acceptance Criteria relating to accuracy are defined in the following table. To assess the accuracy a statistical linear regression approach has been selected which is based on:

a) a two variant regression y = mx+b (with m slope and b offset) to be applied to wind direction data comparisons between floating instrument and the reference ; and,

b) a single variant regression, with the regression analysis constrained to pass through origin (y = mx+b; b = 0) to be applied to wind speed, turbulence intensity and wind shear data comparisons between floating instrument and the reference.

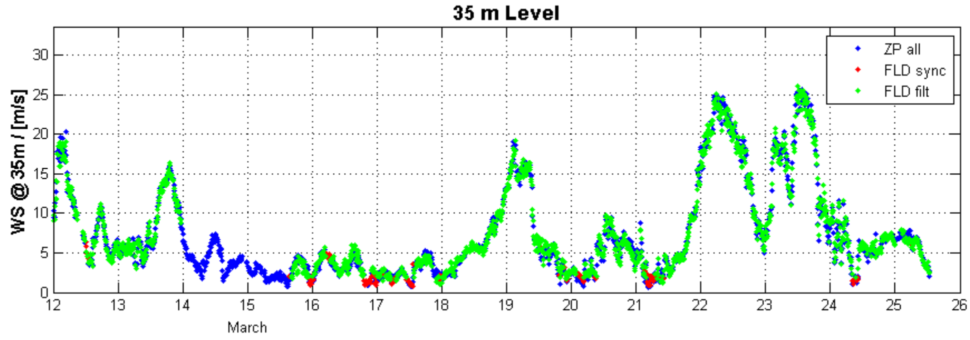
In addition, Acceptance Criteria in the form of "best practise" and "minimum" allowable tolerances have been imposed on slope and offset values as well as on coefficient of determination returned from each reference height for KPIs related to the primary parameters of interest; wind speed and wind direction.

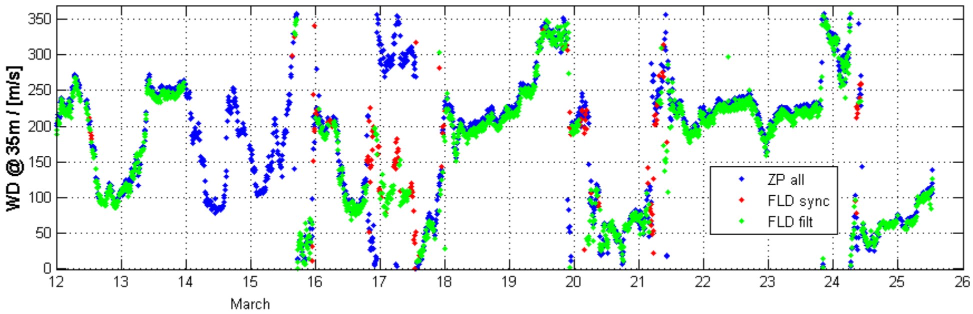
<table>
<tr><th rowspan="2">KPI</th><th rowspan="2">Definition / Rationale</th><th colspan="2">Acceptance Criteria</th></tr>
<tr><th>Best Practice</th><th>Minimum</th></tr>
<tr><td>X_{mws}</td><td>Mean Wind Speed – Slope
Slope returned from single variant regression with the regression analysis constrained to pass through the origin.
A tolerance is imposed on the Slope value.
Analysis shall be applied to wind speed range
a) all above 2 m/s
given achieved data coverage requirements.</td><td>0.98 – 1.02</td><td>0.97 – 1.03</td></tr>
<tr><td>R^2_{mws}</td><td>Mean Wind Speed – Coefficient of Determination
Coefficient returned from single variant regression
A tolerance is imposed on the Coefficient value.
Analysis shall be applied to wind speed range
a) all above 2 m/s
given achieved data coverage requirements.</td><td>>0.98</td><td>>0.97</td></tr>
</table>

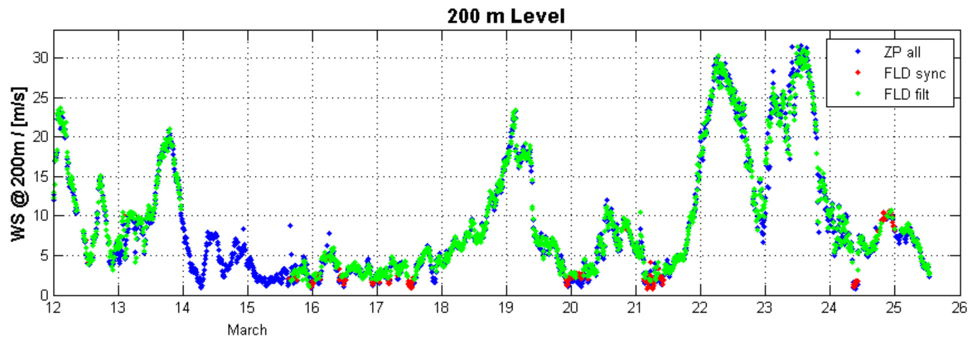
KPI	Definition / Rationale	Acceptance Criteria	
		Best Practice	Minimum
M_{mwd}	**Mean Wind Direction – Slope** Slope returned from a two-variant regression. A tolerance is imposed on the Slope value. Analysis shall be applied to a) all wind directions b) all wind speeds above 2 m/s regardless of coverage requirements.	0.97 – 1.03	0.95 – 1.05
OFF_{mwd}	**Mean Wind Direction – Offset, in terms of the mean WD difference over the total campaign duration** (same as for M_{mwd})	< 5°	< 10°
R^2_{mwd}	**Mean Wind Direction – Coefficient of Determination** (same as for M_{mwd})	> 0.97	> 0.95

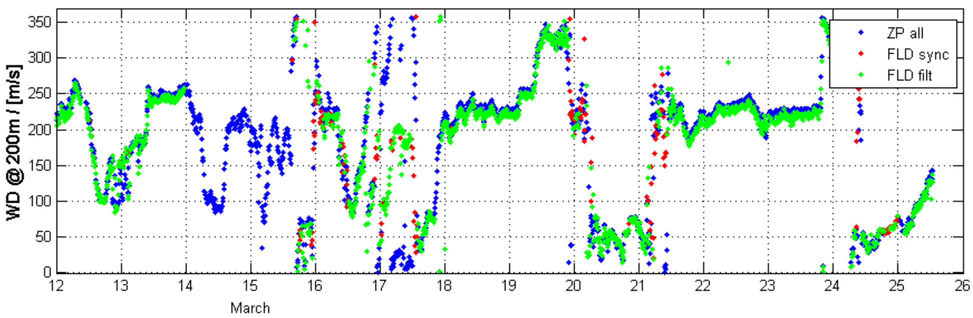
APPENDIX B – WS TIME SERIES AND CORRELATION PLOTS

Wind speed and wind directions time series for 35 m and 200 m comparison heights:



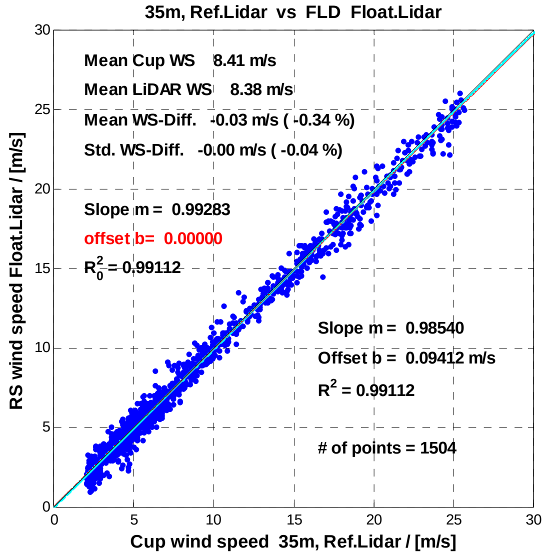


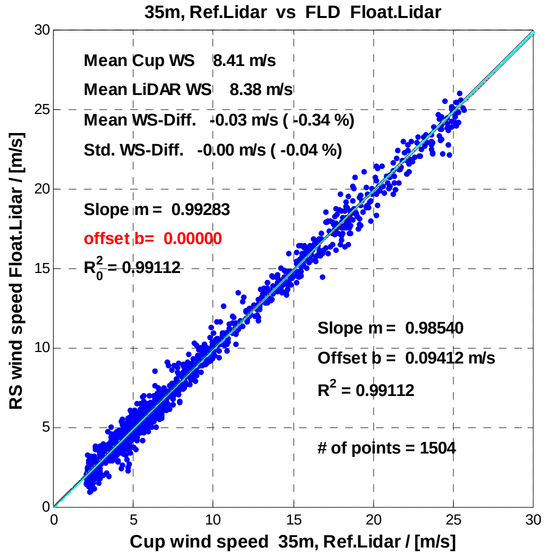


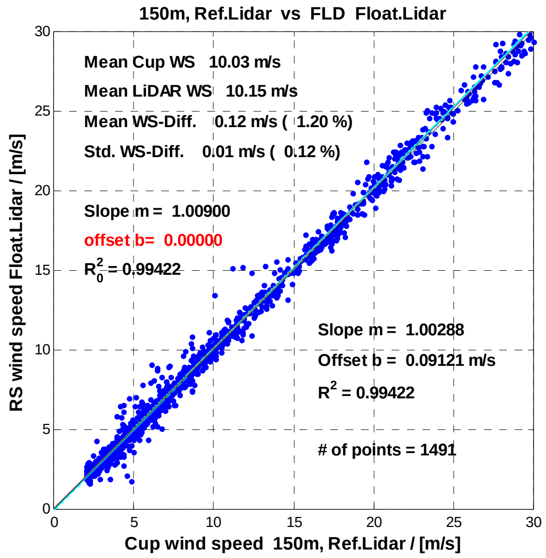


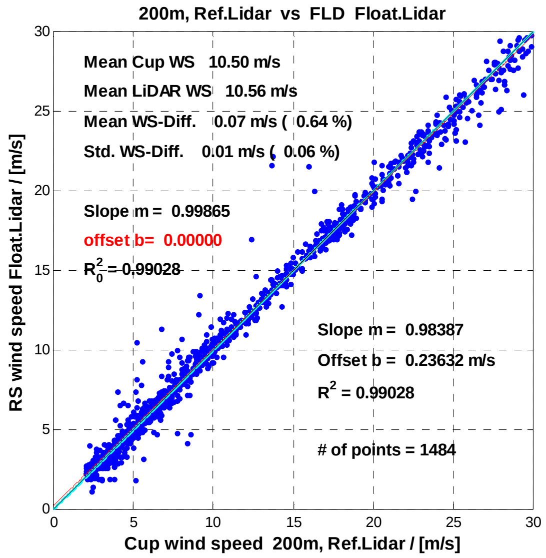
WS regression plots for four (4) selected comparison heights, i.e. at 35, 90, 150 and 200 m above MSL

Shown are results for linear WS regressions "forced" through the origin as discussed above, and for information "un-forced" linear WS regressions, yielding as well the WS offset in terms of intercept of the regression line of the y-axis.



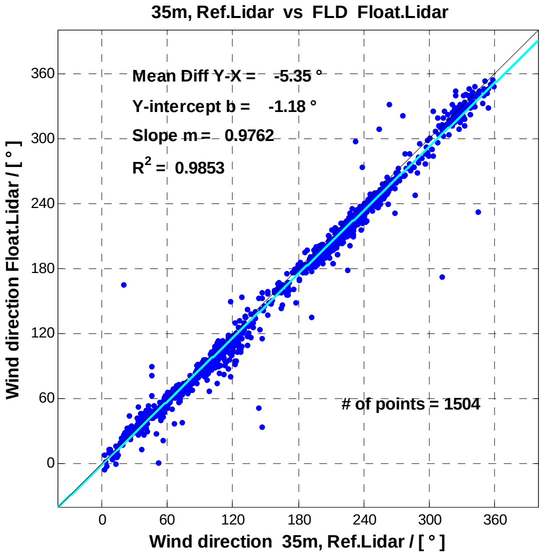


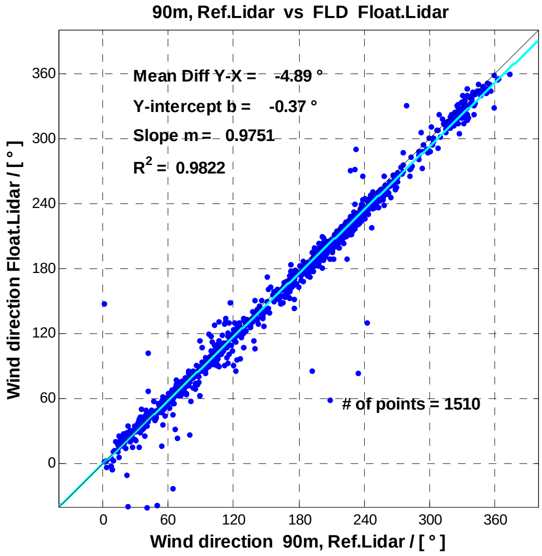


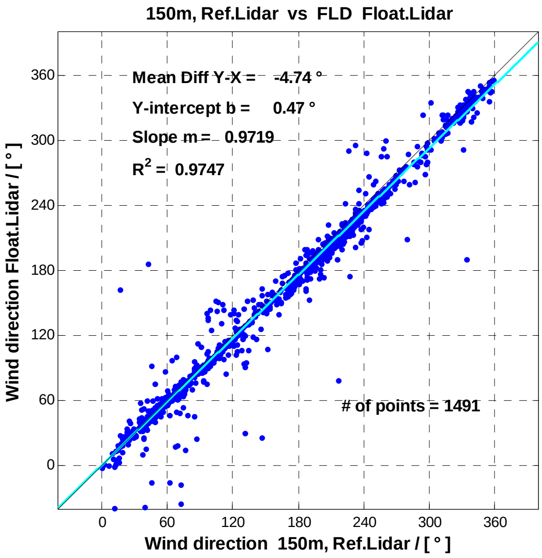


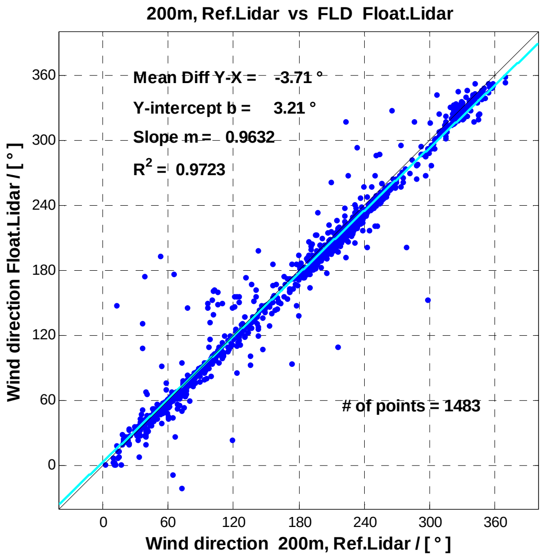
WD correlation plots for four (4) selected comparison heights, i.e. at 35, 90, 150 and 200 m above MSL

Shown are results for linear "un-forced" WD regressions "un-forced" linear WS regressions, yielding as well the WD offset in terms of intercept of the regression line of the y-axis and in terms of the mean WD difference.









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