

FRØYA SEAWATCH WIND LIDAR BUOY WS 157  
PRE-DEPLOYMENT VALIDATION

# Assessment of the Fugro OCEANOR Seawatch Wind LiDAR Buoy WS 157 Pre- Deployment Validation on Frøya, Norway

Fugro/OCEANOR AS

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Customer:	Fugro/OCEANOR AS, Trondheim, Norway	
Contact person:	Arve Berg	Tel: +49 40 36149 8693
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Prepared by:	Verified by:	Approved by:
P. Schwenk Project Engineer	D.Stein Global Head of Practice Resource Measurements	Michael Lange Head of Section Project Engineering

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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

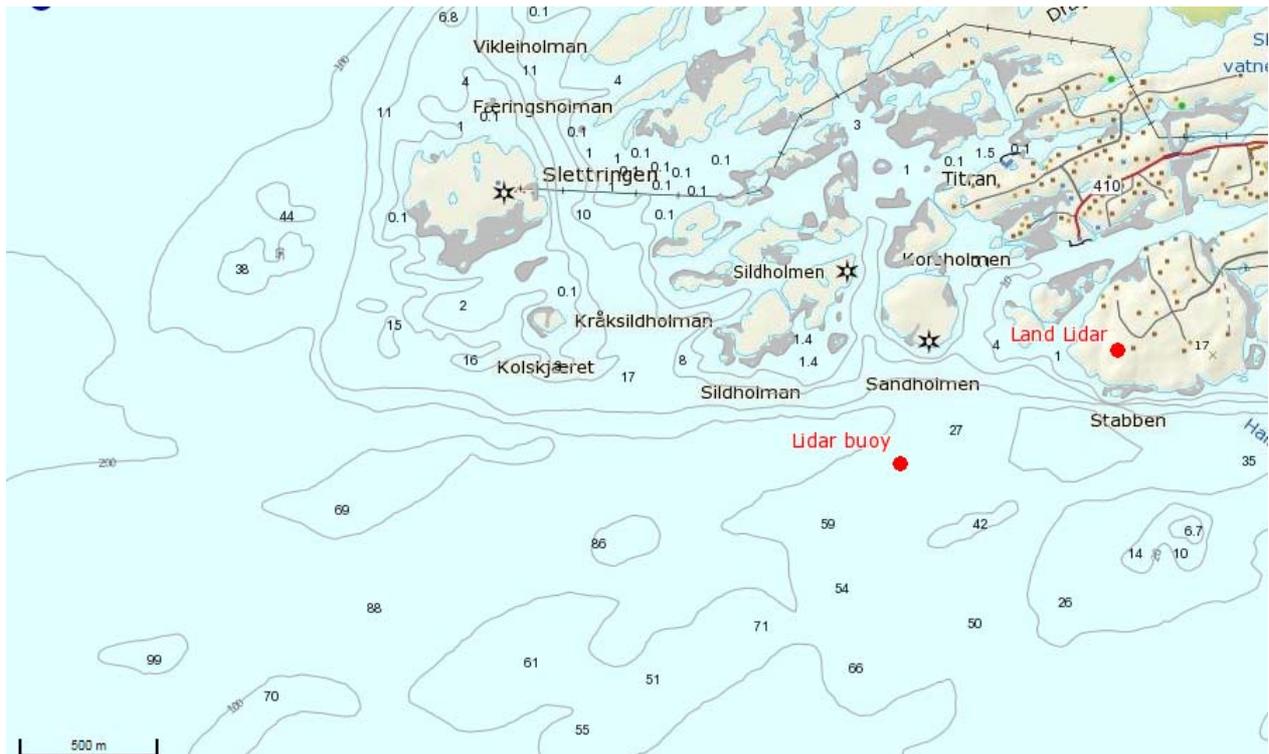
# 1 INTRODUCTION

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 with the serial number WS 157 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 24 days 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 December 11<sup>th</sup>, 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 approx. 950 m from the “Land Lidar” at Stabben. The campaign was finished by the recovery of the SWLB on 2016-01-04.



**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 157 against a Reference Land Lidar (RLL) of type ZephIR with the S/N Z495 at the 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 157 employing a ZephIR Lidar with the S/N Z442) 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 understands 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, which was independently verified by GL Garrad Hassan [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 2015-03-25 [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

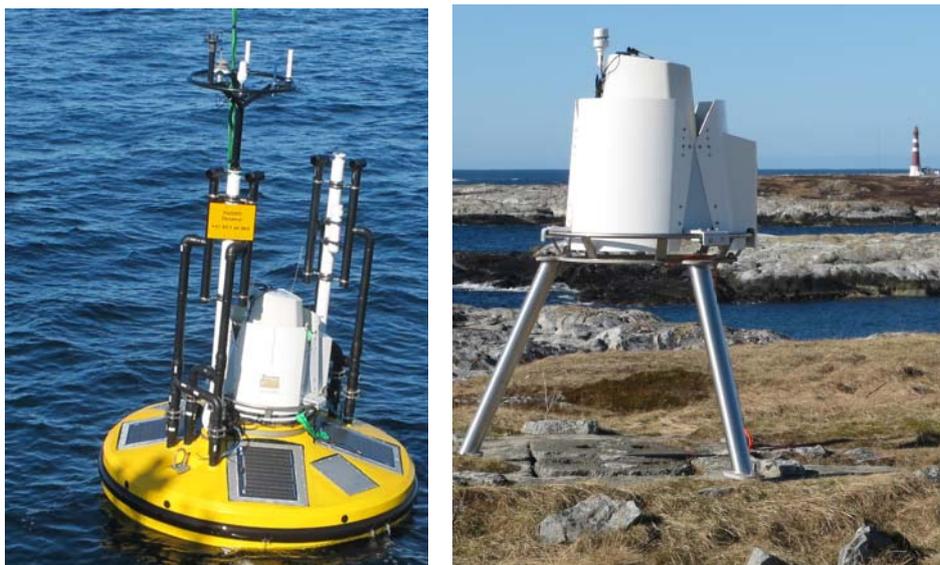
Position of ZephIR Reference Land Lidar (RLL), see Figure 2, right:

- 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 approx. 950 m to the South West of the RLL position.

These positions were confirmed during a site visit and RLL inspection by DNV GL, on 2015-03-25 [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 157
- ZephIR S/N                    Z442
- Height settings                200, 180, 160, 140, 120, 100, 80, 60, 40 m relative to actual sea level

### Reference Land Lidar:

- ZephIR S/N                    Z495
- Height settings                200, 180, 160, 140, 120, 100, 80, 60, 40 m above mean sea level

These specs and height settings are confirmed from

- original ZephIR product data (ZPH-files) for both units provided by FO, and
- during the site visit and RLL inspection by DNV GL, on 2015-03-15 [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	30	16	30	28
2	40	26	40	38
3	52	not configurable	40	not configurable
4	60	46	60	58
5	80	66	80	78
6	100	86	100	98
7	120	106	120	118
8	140	126	140	138
9	160	146	160	158
10	180	166	180	178
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 40 m and 200 m as mentioned in Table 1.

All data collected from the deployment 2015-12-11 of SWLB until its decommissioning on 2016-01-04 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 Z442 and from the RLL ZephIR with the serial number Z495 were provided by FO for a campaign period lasting 2015-12-11 to 2016-01-04, yielding a duration of 24 days.

#### 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 on-board ZephIR 300 Lidar to calculate the 10 minute wind data statistics.

#### 3.2 Meteorological 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 at the RLL of up to 27.6 m/s at the lowest comparison level (40 m) and 32.2 m/s at the upper most level (200 m) – see Table 2. The air temperatures covered during the campaign at the RLL location and on the SWLB buoy range from -6°C to +10°C, related time series are displayed in Appendix B.

The significant wave heights observed during the trial period at Frøya were in a range up to 5.5 m, with 13.1% of the observations above 2.5 m. The experienced maximum wave heights cover a range up to 8.5 m. Compare Appendix C for wave statistics as provided by FO. The wave measurements were recorded by the SWLB under trial itself using a 30 min data acquisition and processing interval.

The tidal or water level as observed during the campaign at a place in the North of Frøya called Mausund varies between -1.1 and +1.8 m over MSL. See related time series plot in Appendix C.

**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]	
40	27,56	26,60
60	28,82	28,71
80	29,78	29,65
100	30,56	30,29
120	31,51	29,77
140	32,08	30,47
160	32,00	31,58
180	32,04	31,29
200	32,15	30,82

### 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.

A wind direction sector filtering needed to be applied for a North-easterly to South-easterly sector due to a risk of wind flow deflections potentially caused by topographic features from the nearby Island Frøya and the Islands to the East of the test site. I.e. wind speed and direction data from a 100° wide sector between 40° and 140° were omitted from the comparison analysis.

#### 3.3.1 Data coverage requirements for accuracy assessment

In accordance with the data coverage requirements outlined in the Roadmap [1], 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 – to include more than 40 values per bin – was achieved for all WS bins between 3 and 22 m/s at all treated comparison heights, and up to 26 m/s with the exception in the WS bin centred at 25 m/s at the levels between 40 and 140 m. WS data completeness for very low wind speeds in the range 2 to 3 m/s was achieved at the levels above 140 m. The minor lack of data in the lower most WS bin, however, is considered insignificant (compare Table 3).

**Table 3: Wind speed data coverage per WS bin. Bins including at least 40 values 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]	RLL number of 10 min data entries per WS bin - AFTER filtering for data to be used for regression analysis																		
40	19	86	126	164	148	177	161	169	163	139	266	184	126	70	51	28	16	4	-
60	26	80	131	149	158	152	161	174	159	161	261	214	123	97	49	39	16	11	2
80	27	89	123	127	166	144	152	184	143	186	274	204	142	107	42	50	20	14	5
100	22	92	127	104	162	156	148	170	167	161	312	207	148	112	49	51	25	15	7
120	25	97	126	99	140	154	146	170	161	170	315	221	163	110	63	48	31	13	10
140	33	97	117	111	119	138	154	167	157	166	324	248	154	134	72	43	34	12	15
160	45	97	111	113	108	110	155	170	152	165	325	269	166	130	85	44	42	14	17
180	49	94	119	106	105	99	132	177	161	160	327	278	185	137	93	47	44	20	15
200	55	89	121	103	93	90	130	172	158	155	323	298	206	133	100	56	43	24	18

### 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 40 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 for the data period considered here KPIs for slope at heights between 60 and 200 m fall within the best practice acceptance criterion [ $0.98 > X_{MWS} > 1.02$ ] as given in [1], at 40 m this KPI is within the minimum acceptance criterion [ $0.97 > X_{MWS} > 1.03$ ]. With regards to the Coefficient of Determination ( $R^2_{mws}$ ) the best practice criterion [ $R^2_{mws} > 0.98$ ] is passed at all heights up to 80 m, while the minimum acceptance criterion [ $R^2_{mws} > 0.97$ ] is achieved at the other measurement level between 100 and 200 m. Plots for WS regression results together with WS time series plots selected for a few comparison levels 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	#	KPIs		WS RLL avg	WS FLD avg	WS diff.	relative WS diff.
		slope $X_{mws}$	regr. coeff. $R^2_{mws}$				
Level / [m]	#	$X_{mws}$	$R^2_{mws}$				
40	2097	1,023	0,983	10,63	10,90	0,27	2,6%
60	2163	1,016	0,984	10,93	11,14	0,20	1,9%
80	2199	1,014	0,981	11,16	11,37	0,21	1,8%
100	2236	1,014	0,974	11,38	11,60	0,22	2,0%
120	2264	1,015	0,972	11,58	11,80	0,23	2,0%
140	2298	1,014	0,972	11,79	12,01	0,22	1,9%
160	2321	1,012	0,974	12,00	12,19	0,19	1,6%
180	2355	1,008	0,974	12,23	12,39	0,16	1,3%
200	2377	1,009	0,970	12,45	12,63	0,19	1,5%

Legend	
KPI	failed
KPI	passed minimum
KPI	passed best practice

### 3.3.3 Wind direction accuracy:

The wind direction data comparison was conducted at the same nine (9) heights between 40 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. All KPI values for  $R^2_{mwd}$ ,  $OFF_{mwd}$  and  $M_{mwd}$  fall within the best practice acceptance criteria. Plots for WD regression results selected for a few heights can be found in Appendix B.

**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]	#	$M_{mwd}$	$R^2_{mwd}$	$OFF_{mwd}$
40	2097	1,002	0,990	-3,55
60	2163	1,004	0,987	-3,45
80	2199	1,008	0,986	-3,34
100	2236	1,005	0,981	-3,07
120	2264	1,012	0,977	-3,50
140	2298	1,008	0,974	-3,58
160	2321	1,015	0,973	-3,83
180	2355	1,014	0,977	-3,54
200	2377	1,011	0,979	-3,28

Legend	
KPI	failed
KPI	passed minimum
KPI	passed best practice

### 3.4 Summary of verification results

#### 3.4.1 Campaign Duration

The campaign duration with almost 24 days is considered rather short, compared to a typically expected duration of 6 to 8 weeks. However, due to the winter season this duration was sufficient to achieve the required data completeness in useable WS bins for data analysis, in order to be compliant to the Roadmap in terms of significance of SWLB wind data accuracy results.

#### 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 KPI "Mean Wind Speed – Slope" were passed at all heights with a minor exception at 40 m. The Best Practice criteria for the KPI "Mean Wind Speed – Coefficient of Determination" were passed at the measurement levels between 40 and 80 m, at all other levels above 80 m the minimum Acceptance Criteria were passed.

For wind direction Best Practice criteria for the KPIs "Mean Wind Direction – Slope", "Mean Wind Direction – Coefficient of Determination" and "Mean Wind Direction – Offset" were passed at all comparison heights, indicating the SWLB's 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 90 days with regards to KPIs and Acceptance Criteria for the data accuracy assessment**

KPI	Definition / Rationale	Acceptance Criteria across total campaign duration	
		Best Practice	Minimum
$X_{mws}$	<p><b>Mean Wind Speed – Slope</b></p> <p>Assessed for wind speed range [all above 2 m/s]</p>	<p>0.98 – 1.02</p> <p>Results:</p> <p>[1.008 to 1.016]</p> <p>Passed at compared heights 60 to 200 m</p>	<p>0.97 – 1.03</p> <p>Results:</p> <p>[1.023]</p> <p>Passed at compared height 40 m</p>
$R^2_{mws}$	<p><b>Mean Wind Speed – Coefficient of Determination</b></p> <p>Assessed for wind speed range [all above 2 m/s]</p>	<p>&gt;0.98</p> <p>Results:</p> <p>[0.981 to 0.984]</p> <p>Passed at compared heights 40 to 80 m</p>	<p>&gt;0.97</p> <p>Results:</p> <p>[0.970 to 0.974]</p> <p>Passed at compared heights 100 to 200 m</p>
$M_{mwd}$	<p><b>Mean Wind Direction – Slope</b></p> <p>Assessed for wind speed range [all above 2 m/s]</p> <p>(WD filtering/clipping applied for Easterly sector from 40° to 140° due to potential wind flow deflection by land masses / islands)</p>	<p>0.97 – 1.03</p> <p>Results:</p> <p>[1.002 to 1.015]</p> <p>Passed at all compared heights</p>	<p>0.95 – 1.05</p> <p>Results:</p>
$OFF_{mwd}$	<p><b>Mean Wind Direction – Offset, in terms of the mean absolute WD difference over the total campaign duration</b></p> <p>(same as for <math>M_{mwd}</math>)</p>	<p>&lt; 5°</p> <p>Results:</p> <p>[-3.07 to -3.83]</p> <p>Passed at all compared heights</p>	<p>&lt; 10°</p>
$R^2_{mwd}$	<p><b>Mean Wind Direction – Coefficient of Determination</b></p> <p>(same as for <math>M_{mwd}</math>)</p>	<p>&gt; 0.97</p> <p>Results:</p> <p>[0.973 to 0.990]</p> <p>Passed at all compared heights</p>	<p>&gt; 0.95</p>

## 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.
- In the WS regressions for the treated heights between 40 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 1.03. And the yielded coefficients of determination are excellent. They are indicating that non-synchronicity at the mentioned distance between SWLB and RLL of approx. 950 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 for commercialization of Floating Lidar Devices [1].

DNV GL concludes that the FO SWBL unit with the S/N 157 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 > 5 m (and > 8 m for maximum wave height) were recorded by the Buoy. The Lidar wind speeds recorded at Frøya covered a range of up to 27.6 m/s at 40 m and 32.2 m/s at 200 m.

The assessments of the Roadmap KPIs for the complete data set (from 2015-12-11 until 2016-01-04) show that all FLD-Roadmap Acceptance Criteria are met at all relevant heights between 40 and 200 m above MSL for wind speed and – with a minor deviation – as well for wind direction related Key Performance Indicators (KPI), 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 22 m/s at all treated comparison heights, with a marginal deviation in the lowest WS-bin centred at 2.5 m/s for the measurement level between 40 to 140 m.

## 6 REFERENCES

- [1] Offshore Wind Accelerator Roadmap for the commercial acceptance of floating Lidar technology. CTC 819 Version 1.0, 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, Draft, "Technical note for inspection of Reference Land Lidar at Frøya", Mai 2015.
- [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] GL Garrad Hassan Report: GLGH-4257 13 11068 267-R-0011-A, by D. Stein "INDEPENDENT ANALYSIS OF A ZEPHIR LIDAR PERFORMANCE VERIFICATION AT PERSHORE, UK, ZEPHIR 300 – ZP442", dated 2014-01-30.

## 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.

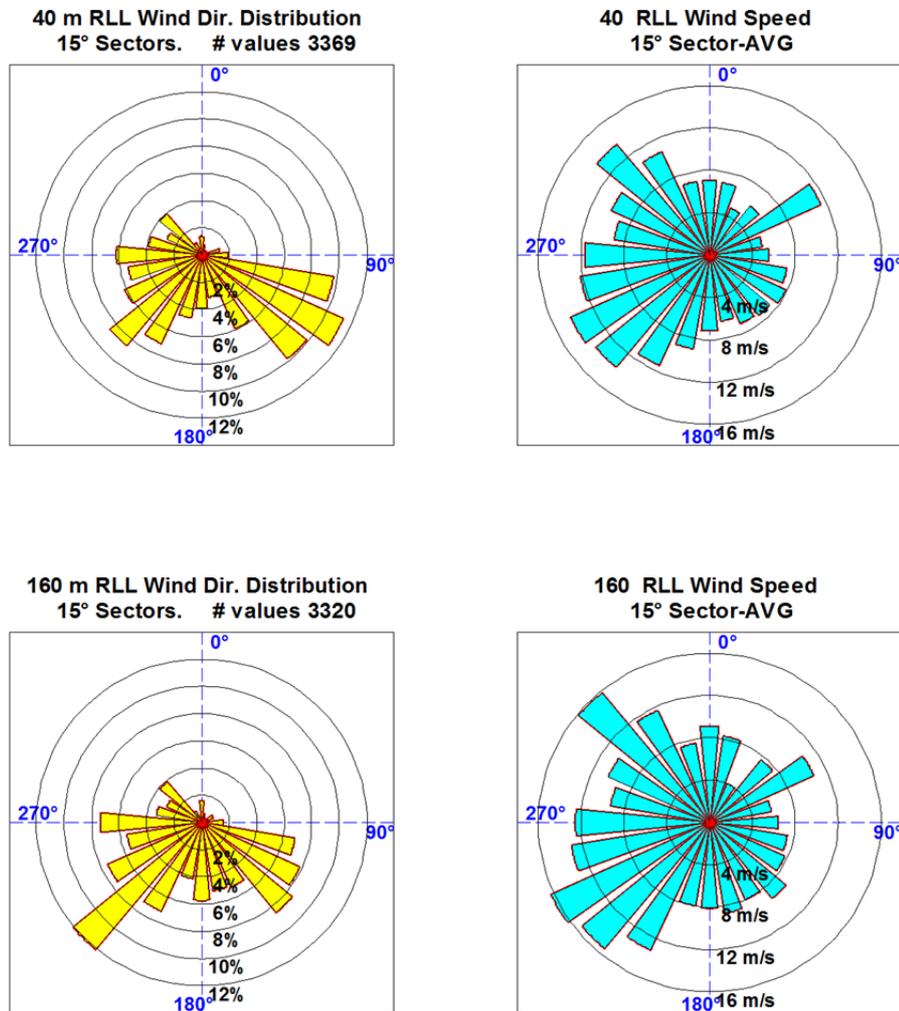
In addition, Acceptance Criteria in the form of “best practise” and “minimum” allowable tolerances have been imposed on slope and offset values as well as on coefficient of determination returned from each reference height for KPIs related to the primary parameters of interest; wind speed and wind direction.

KPI	Definition / Rationale	Acceptance Criteria	
		Best Practice	Minimum
$X_{mws}$	<p><b>Mean Wind Speed – Slope</b></p> <p>Slope returned from single variant regression with the regression analysis constrained to pass through the origin.</p> <p>A tolerance is imposed on the Slope value.</p> <p>Analysis shall be applied to wind speed range</p> <p style="padding-left: 40px;">a) all above 2 m/s</p> <p>given achieved data coverage requirements.</p>	0.98 – 1.02	0.97 – 1.03
$R^2_{mws}$	<p><b>Mean Wind Speed – Coefficient of Determination</b></p> <p>Coefficient returned from single variant regression</p> <p>A tolerance is imposed on the Coefficient value.</p> <p>Analysis shall be applied to wind speed range</p> <p style="padding-left: 40px;">a) all above 2 m/s</p> <p>given achieved data coverage requirements.</p>	>0.98	>0.97

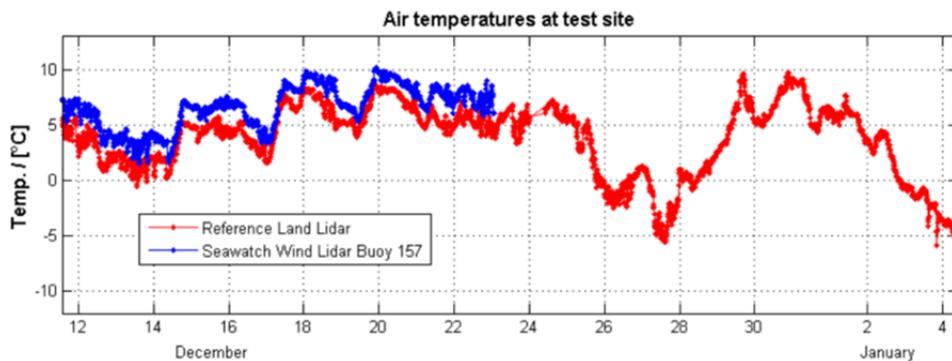
KPI	Definition / Rationale	Acceptance Criteria	
		Best Practice	Minimum
$M_{mwd}$	<p><b>Mean Wind Direction – Slope</b></p> <p>Slope returned from a two-variant regression.</p> <p>A tolerance is imposed on the Slope value.</p> <p>Analysis shall be applied to</p> <ul style="list-style-type: none"> <li>a) all wind directions</li> <li>b) all wind speeds above 2 m/s</li> </ul> <p>regardless of coverage requirements.</p>	0.97 – 1.03	0.95 – 1.05
$OFF_{mwd}$	<p><b>Mean Wind Direction – Offset, in terms of the mean WD difference over the total campaign duration</b></p> <p>(same as for <math>M_{mwd}</math>)</p>	< 5°	< 10°
$R^2_{mwd}$	<p><b>Mean Wind Direction – Coefficient of Determination</b></p> <p>(same as for <math>M_{mwd}</math>)</p>	> 0.97	> 0.95

## APPENDIX B – CAMPAIGN METEOROLOGICAL CONDITIONS, TIME SERIES AND WS/WD CORRELATION PLOTS

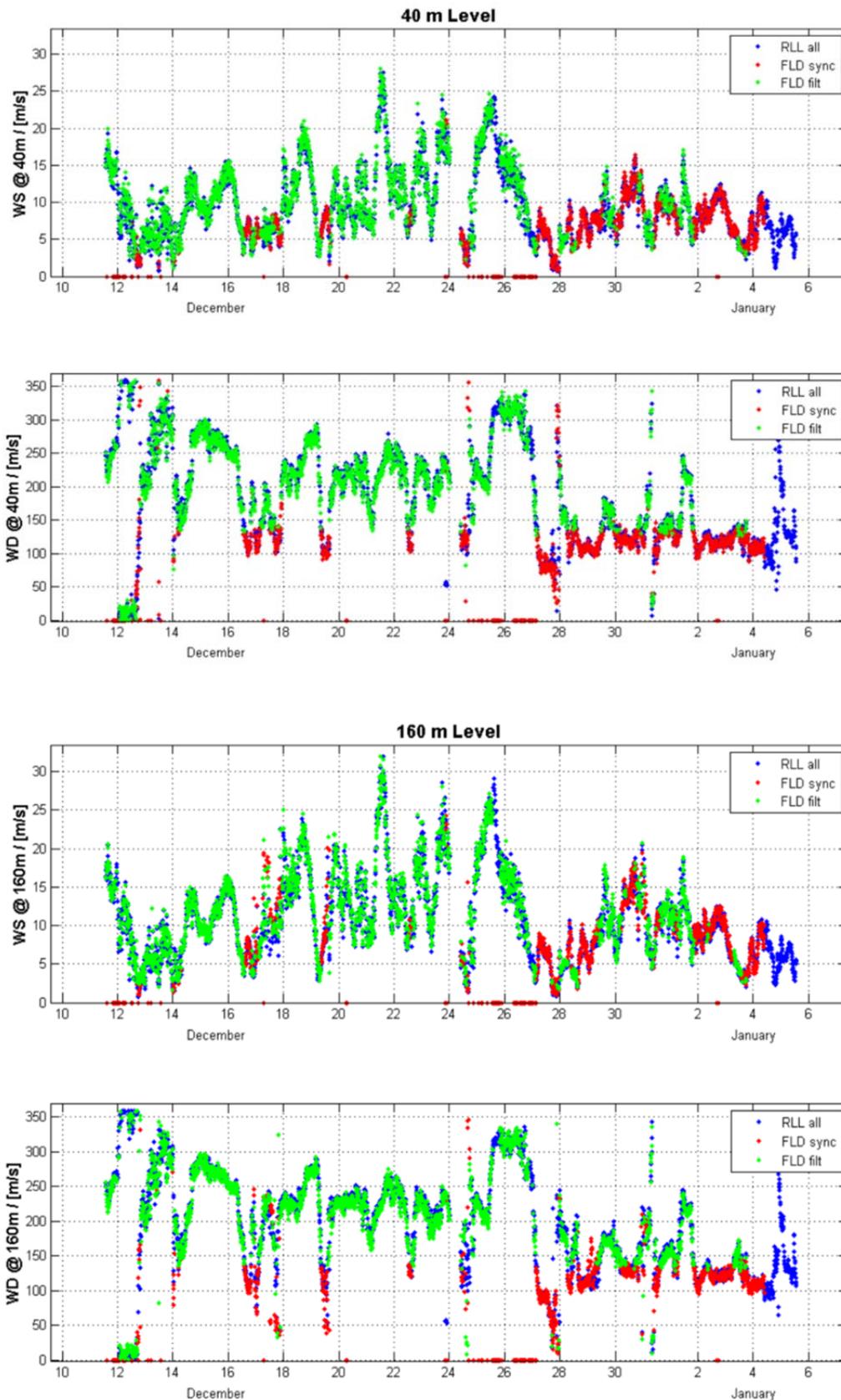
Polar plots of wind directions and wind speed for 40 m and 160 m comparison heights:



Time series of air temperature at RLL location and on SWLB:

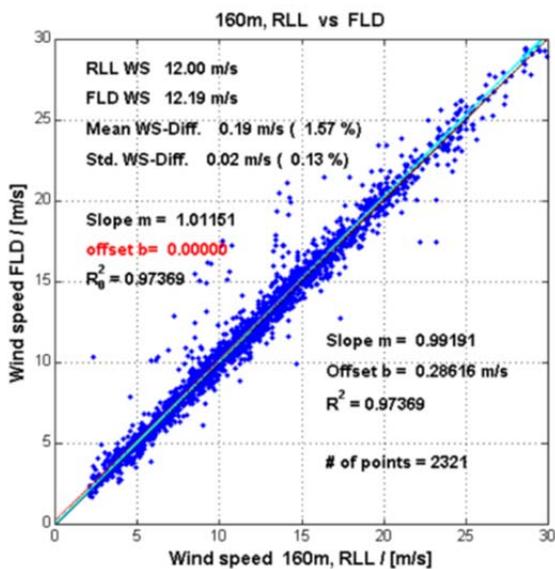
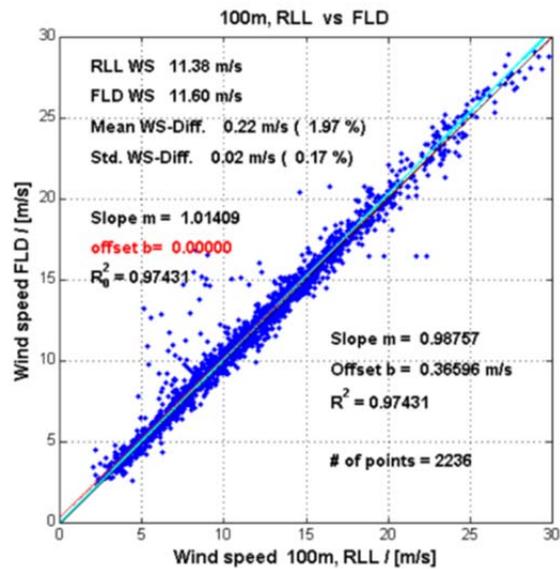
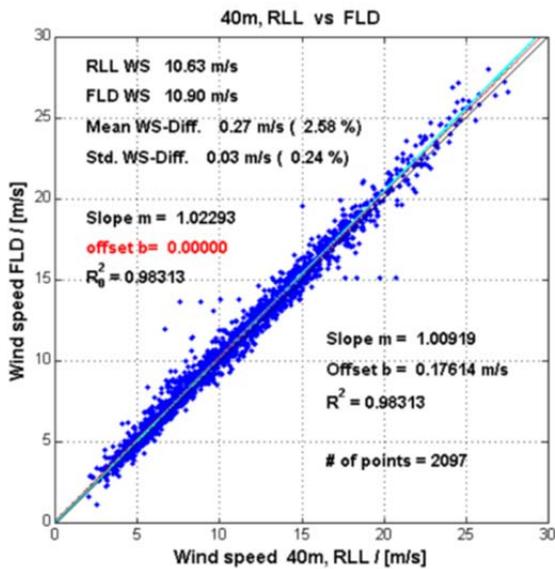


Wind speed and wind directions time series for 40 m and 160 m comparison heights:



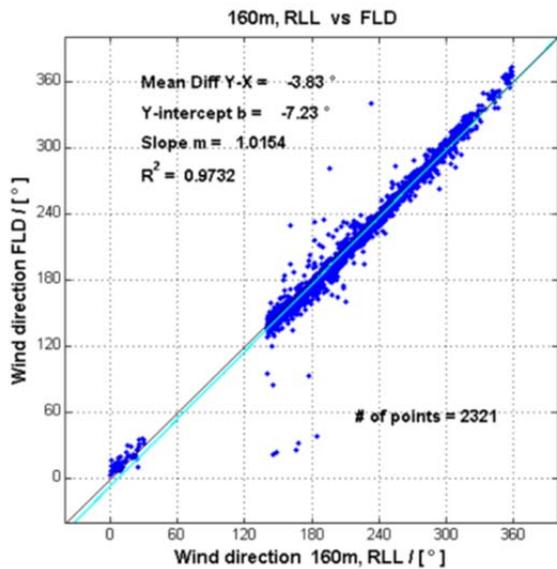
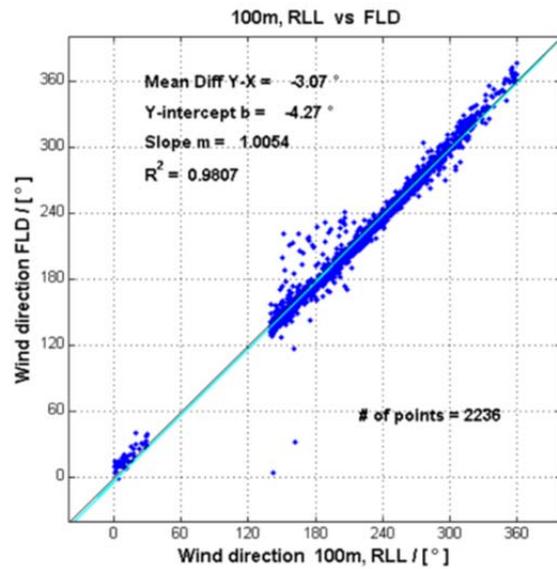
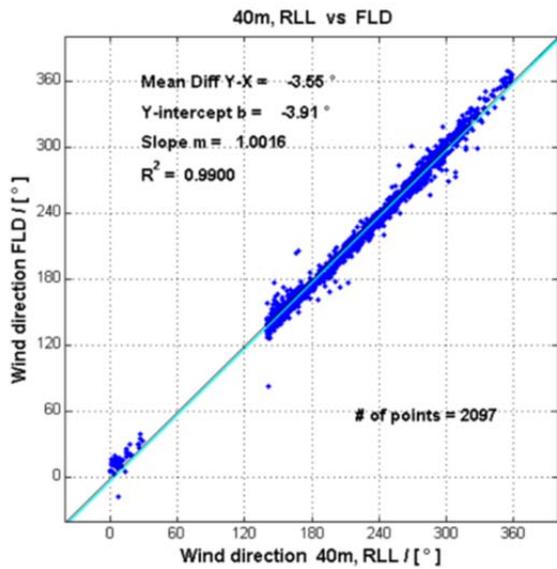
WS regression plots for four (4) selected comparison heights, i.e. at 40, 100 and 160 m above MSL

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 40, 100 and 160 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.



## APPENDIX C – WAVES AND TIDES

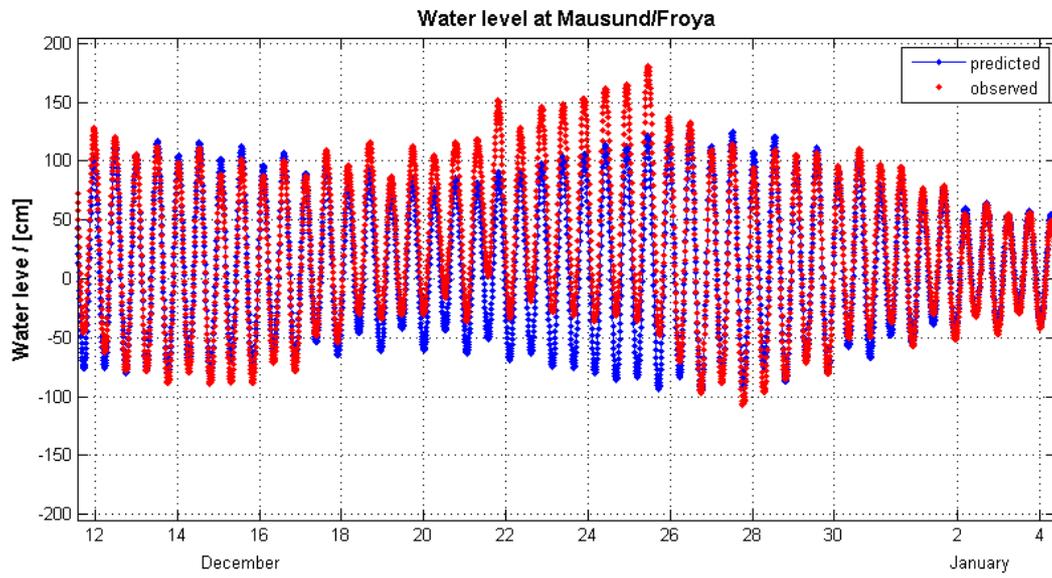
Mean wave period and significant wave height distribution across total campaign period:

Tm02 Mean wave period (Tm02) (s) Slettringen, Wavescan buoy														
Hm0 Significant wave height (m) Slettringen, Wavescan buoy														
Measuring depth : 0.00 m														
Water depth : 75.00 m														
Sampling interval:														
Period : 2015.12.11 13:40 - 2016.01.04 09:41														
Tm02 (s)	2	3	4	5	6	7	8	9	10	11	12 >=	SUM	% OF	
Hm0 (m)	3	4	5	6	7	8	9	10	11	12	13	13	TOTAL	
0.0 - 0.5		16	33	29	6								84	2,5
0.5 - 1.0		96	313	324	130	42							905	26,5
1.0 - 1.5		17	188	334	295	194	8						1036	30,4
1.5 - 2.0			78	221	197	123	25						644	18,9
2.0 - 2.5			1	94	129	43	23	5					295	8,7
2.5 - 3.0				30	103	31	22	2					188	5,5
3.0 - 3.5				1	86	33	17						137	4
3.5 - 4.0					39	15	7						61	1,8
4.0 - 4.5						7	40						47	1,4
4.5 - 5.0					1	8	3						12	0,4
5.0 - 5.5							1						1	0
>= 5.5													0	0
SUM	0	129	613	1033	993	530	105	7	0	0	0	0	3410	100
% OF TOTAL	0	3,8	18	30,3	29,1	15,5	3,1	0,2	0	0	0	0	100	
SUM ACCUM.	0	129	742	1775	2768	3298	3403	3410	3410	3410	3410	3410	3410	
CUM. PROB.	0	0,0378	0,2175	0,5204	0,8115	0,9669	0,9977	0,9997	0,9997	0,9997	0,9997	0,9997	0,99971	
MIN. VALUE		0,39	0,39	0,41	0,47	0,74	1,05	2,07					0,39	
AVE. VALUE		0,76	0,99	1,31	1,85	1,97	2,49	2,37					1,53	
MAX. VALUE		1,21	2,19	3,18	4,51	5,02	4,8	2,73					5,02	
STD. DEV.		0,21	0,37	0,55	0,85	1,04	0,74	0,21					0,83	

Highest wave period and maximum wave height distribution across total campaign period:

THmax Period of highest wave (s) Slettringen, Wavescan buoy														
Hmax Maximum wave height (m) Slettringen, Wavescan buoy														
Measuring depth : 0.00 m														
Water depth : 75.00 m														
Sampling interval:														
Period : 2015.12.11 13:40 - 2016.01.04 09:41														
THmax (s)	2	3	4	5	6	7	8	9	10	11	12 >=	SUM	% OF	
Hmax (m)	3	4	5	6	7	8	9	10	11	12	13	13	TOTAL	
0.0 - 0.5					1		1						2	0,1
0.5 - 1.0		1	9	29	53	73	99	75	30	16	9	4	398	11,7
1.0 - 1.5		3	36	50	98	77	105	123	98	63	32	8	693	20,3
1.5 - 2.0			22	51	62	85	104	122	131	77	27	4	685	20,1
2.0 - 2.5			4	54	60	56	104	107	113	72	39	10	619	18,2
2.5 - 3.0			1	17	52	40	43	42	60	36	15	5	311	9,1
3.0 - 3.5				6	16	38	30	34	25	21	16	13	199	5,8
3.5 - 4.0				4	23	26	25	27	23	12	12	1	153	4,5
4.0 - 4.5				1	11	19	20	21	15	10	6		103	3
4.5 - 5.0					4	22	28	15	14	11			94	2,8
5.0 - 5.5					2	16	17	14	16	4	2		71	2,1
5.5 - 6.0					1	2	8	10	6	2	1		30	0,9
6.0 - 6.5						5	7	5	12				29	0,9
6.5 - 7.0							4	7					11	0,3
7.0 - 7.5						1	2	2	1				6	0,2
7.5 - 8.0						2		1					3	0,1
8.0 - 8.5								3					3	0,1
>= 8.5													0	0
SUM	0	4	72	212	383	462	597	608	544	324	159	45	3410	100

Time series of tidal/water level at Mausund, Frøya over total campaign period:



End of report



## **ABOUT DNV GL**

Driven by our purpose of safeguarding life, property and the environment, DNV GL 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.