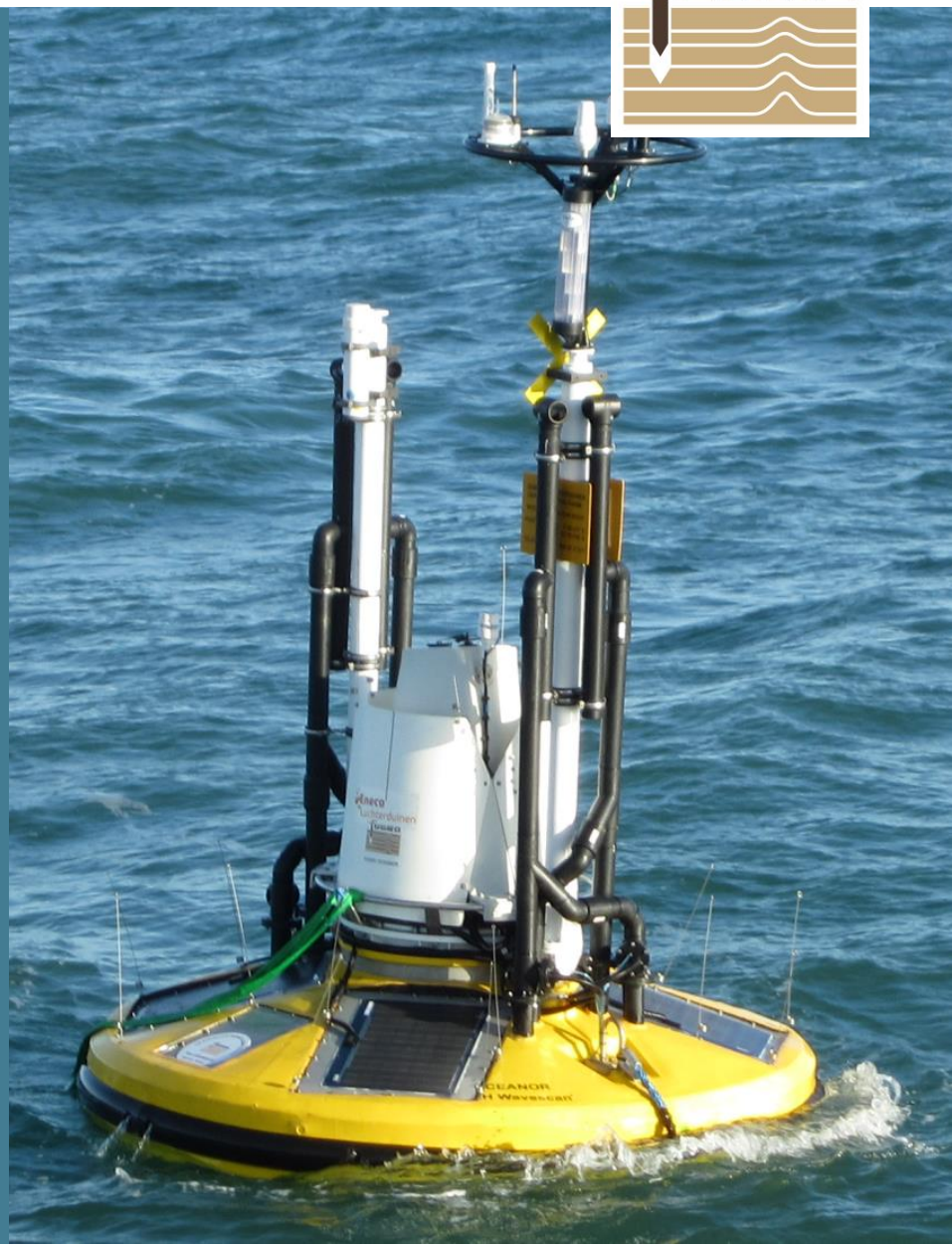
Metocean measurement campaigns

Borssele and Hollandse Kust zuid

Arve Berg
Fugro OCEANOR

Webinar
Amsterdam Jan 2017



Metocean measurements campaign

Content of presentation:

- Introduction – purpose and overview
- SW Wind Lidar buoy
- Quality assurance / pre-deployment validation
- Monthly results – availability and environmental conditions experienced
- Data validation
- Operational experience
- Lessons learned

Metocean measurements – Purpose

Purpose:

The new dataset should allow developers to:

- carry out more accurate calculations of the **annual energy yield**
- calibrate and/or validate metocean models available for the **wind farm design**

The objective of these measurements is to **reduce the uncertainty of the metocean data** at the Wind Farm Site through field measurements

Parameter importance (according to contracts:

1.	Wind	80%
2.	Wave	10%
3.	Current	5%
4.	Atmospheric Pressure	2%
5.	Temperature/Humidity	2%
6.	Water level	1%

Borssele Wind Farm Zone, RVO 2015 - *Ongoing*

Borssele Wind farm survey and Northwind wake effects study

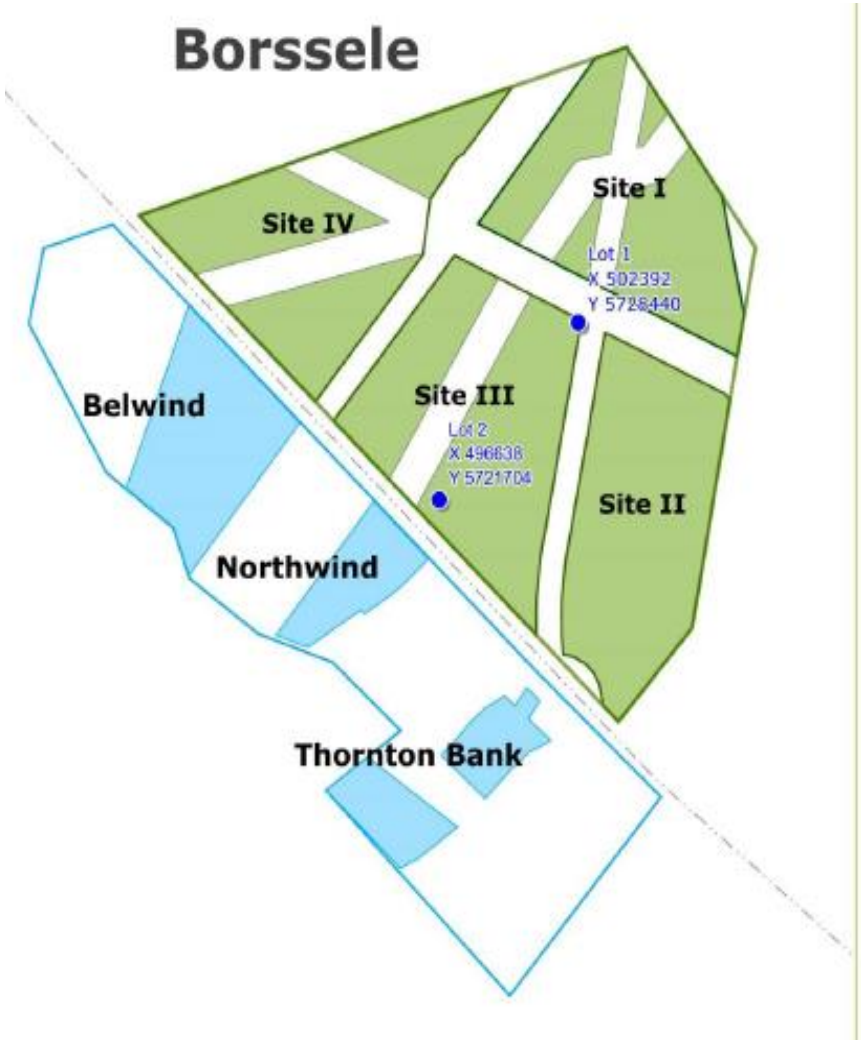
1 SeaWatch Wind Lidar buoy deployed June 2015 (Lot 1) and 1 SW Wind Lidar buoy deployed February 2016 (Lot 2)

Parameters:

- Mooring at 30 m water depth
- Wave height, period and direction
- Current profile (28 m) and water temperature
- Wind speed and direction at 11 elevations
- Air pressure
- Air humidity and temperature
- Water level (tide)

Wind observations:

Wind speed and direction, turbulence intensity, inflow angle and wind shear/veer



Hollandse Kust Wind Farm Zone- RVO- *Ongoing*

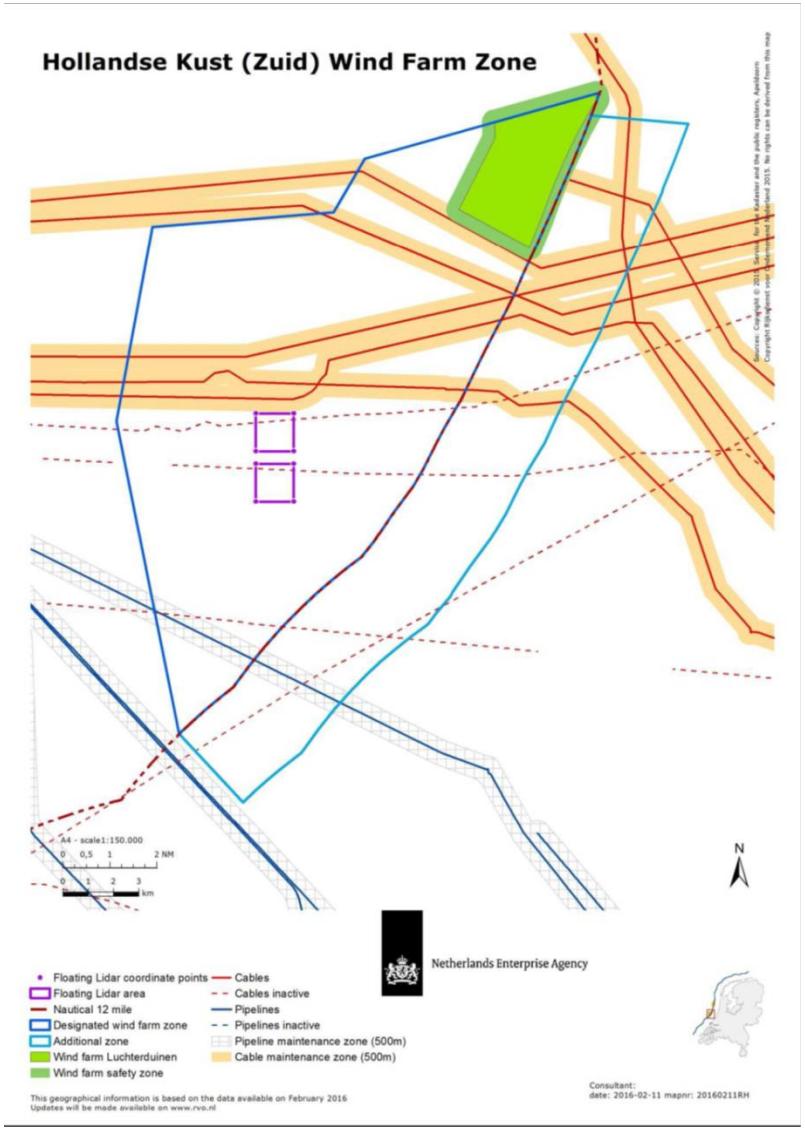
2 SeaWatch Wind Lidar buoys deployed June 2016

Parameters:

- Mooring at 23 m water depth
- Wave height, period and direction
- Current profile (22 m) and water temperature
- Wind speed and direction at 11 elevations
- Air pressure
- Air humidity and temperature
- Water level (tide)

Wind observations

Wind speed and direction, turbulence intensity, inflow angle and wind shear/veer

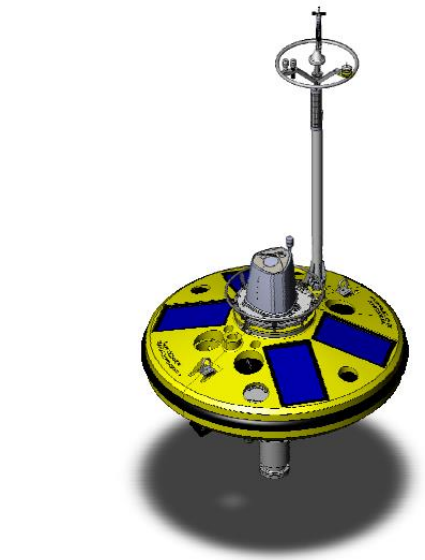


The Seawatch Wind LiDAR Buoy - Concept

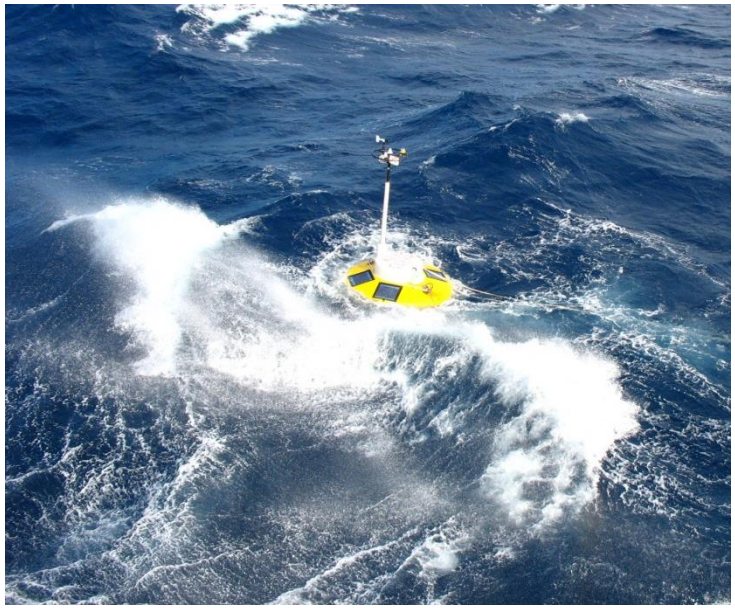
Use a proven oceanographic measurement buoy that has withstood extreme environmental conditions.

Add a proven LiDAR Wind Profiler.

Prototype version.



Seawatch Wavescan design

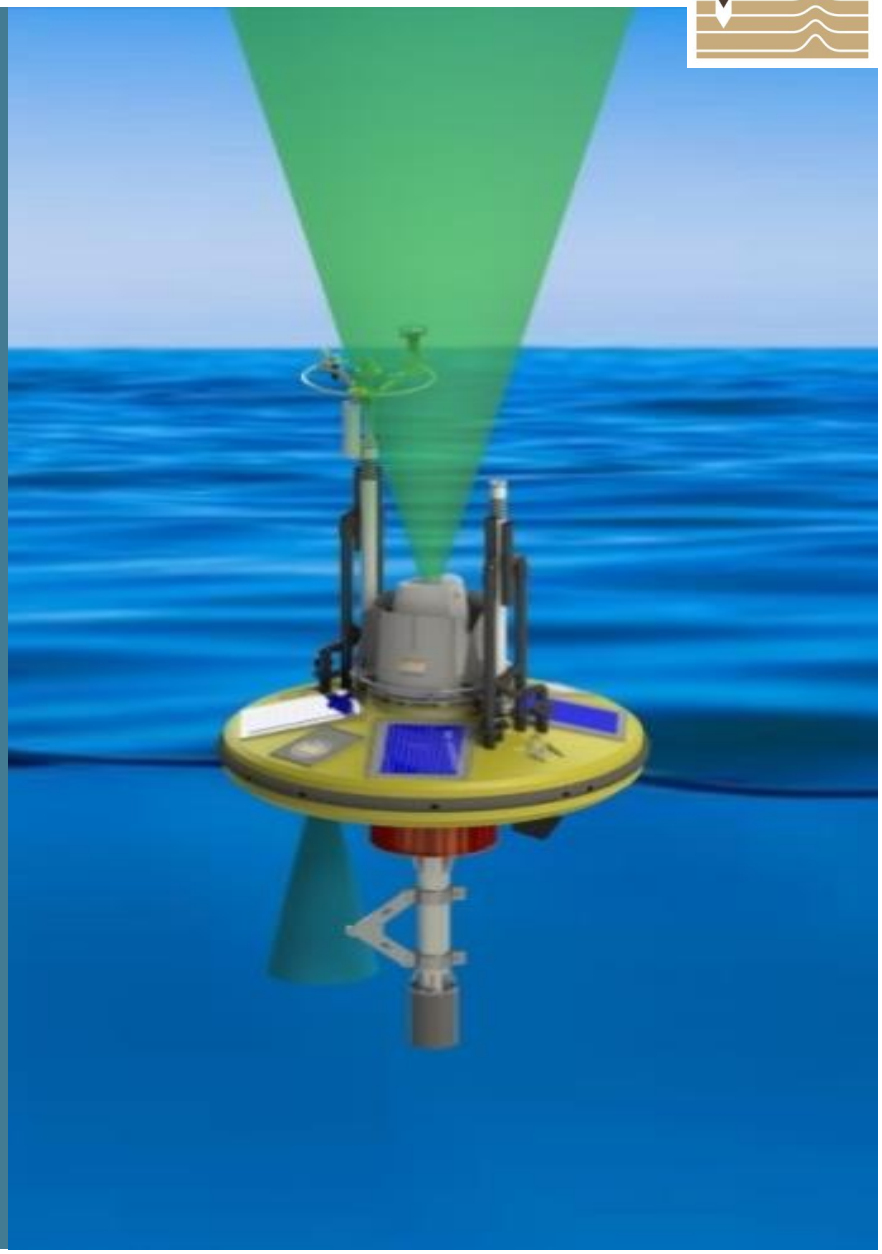


SEAWATCH Wavescan

- Successful track record world-wide since 1985
- Uniquely designed to **optimise wave direction measurements**
- Full on-board processing of all measured data
- Two-way communication link for data transfer and control
- Robust and reliable in temperature extremes and harsh environments

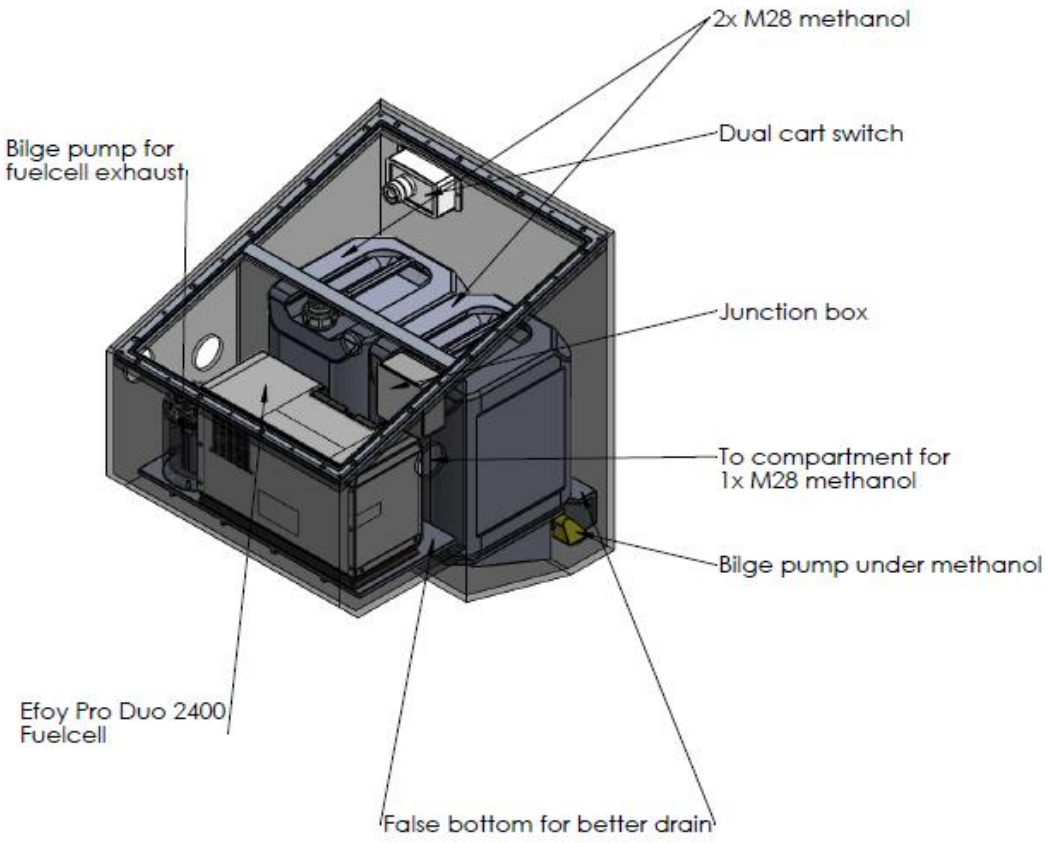
Fugro OCEANOR SEAWATCH Wind LiDAR BUOY

A compact, proven measurement buoy that includes wind profile, waves, current profile, and meteorology



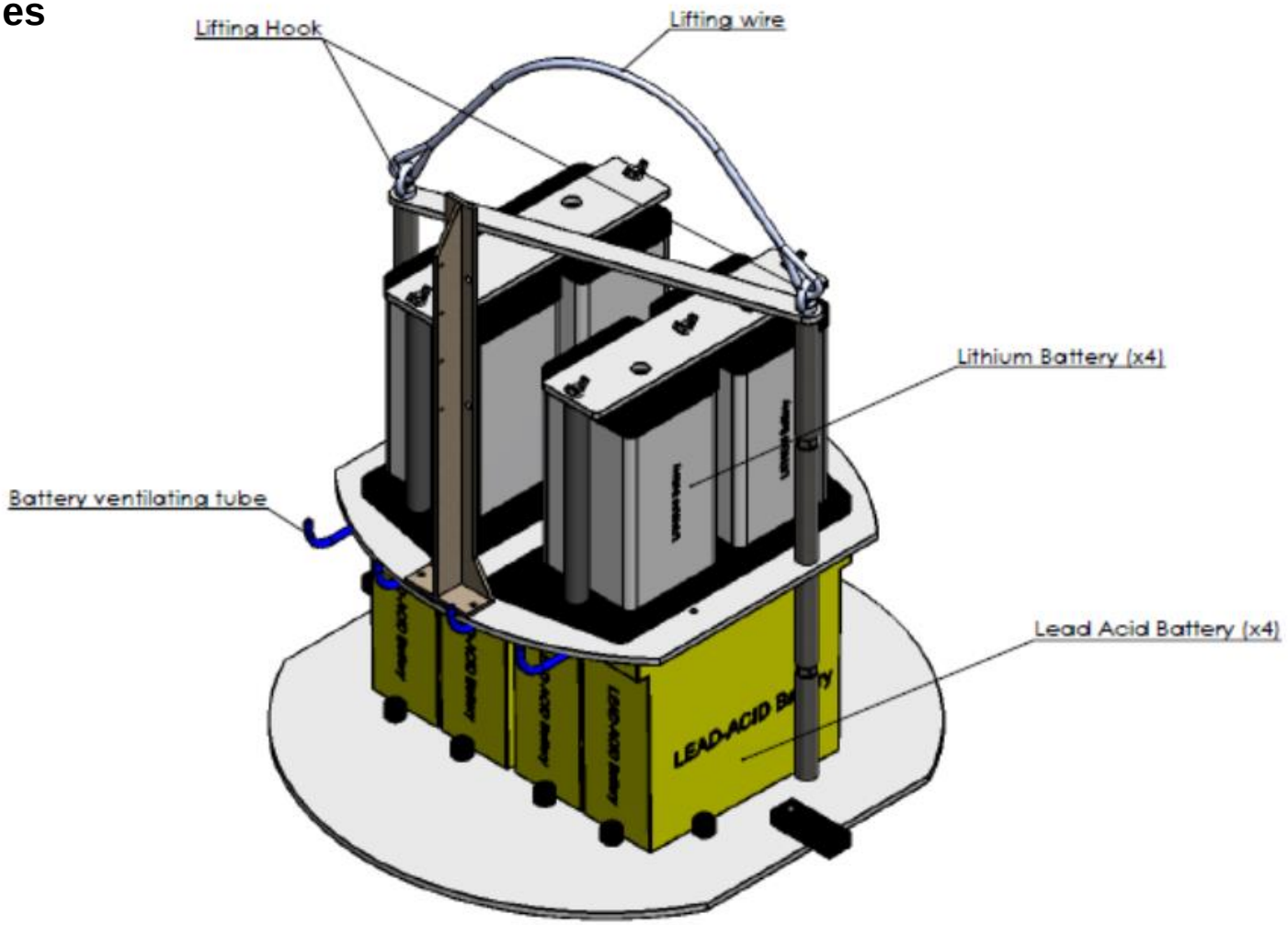
Power – **Fuel cells**

- Average power consumption 70 W (1680 Watt hours per day)
- 4 independent compartment (redundancy)
- 2x2 cans: contribution 37 days each chamber
- 2x3 cans: contribution 55 days each chamber



Power – **Batteries**

- **4 lead acid batteries**
- **4 lithium batteries**



SW Wind Lidar buoy – **Sensors**

Parameter	Manufacturer and Model
Wave height, period and direction	Fugro OCEANOR, WaveSense 3
Current profile and water temperature	Nortek Aquadopp Profiler 600 kHz
Wind speed and direction	Gill Windsonic
Wind speed and direction profile	ZephIR 300 Lidar
Air pressure	Vaisala PTB330
Air humidity and temperature	Vaisala HMP155
Water level (Tide)	Aanderaa Seaguard + acoustic link

SW Wind Lidar buoy – **Redundancy and backup**

POWER

- 4 independent fuel cells and compartments
- 3 different sources (fuel cells, solar panels, lithium batteries

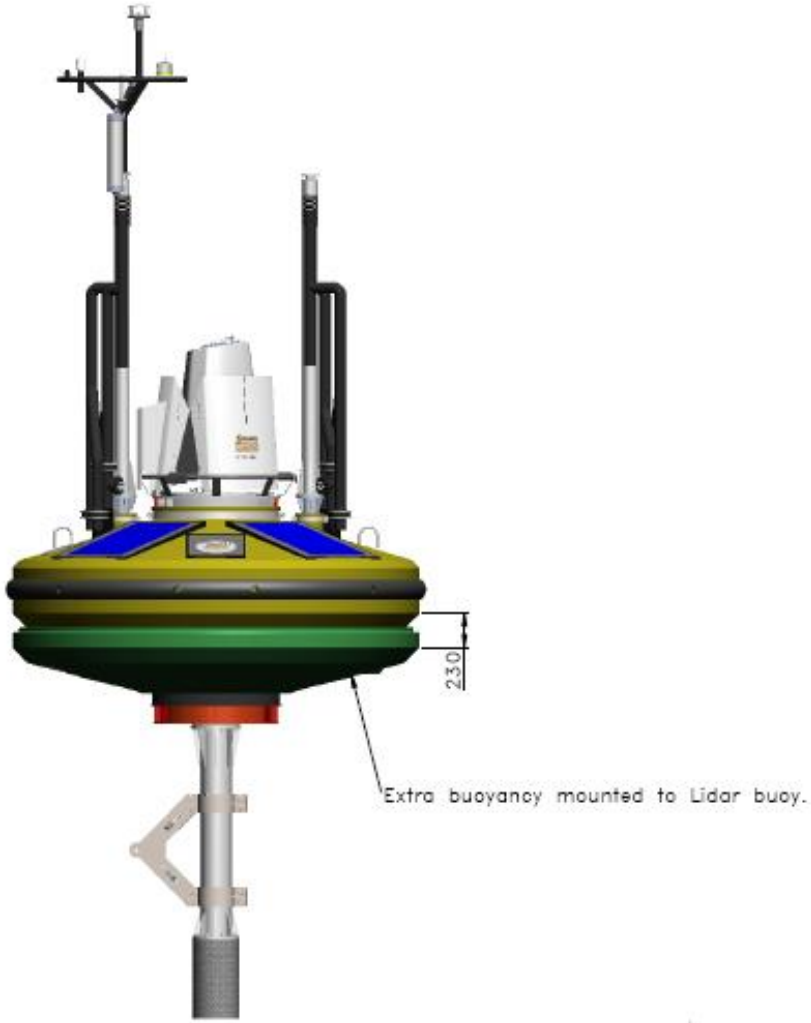
EQUIPMENT/SENSORS

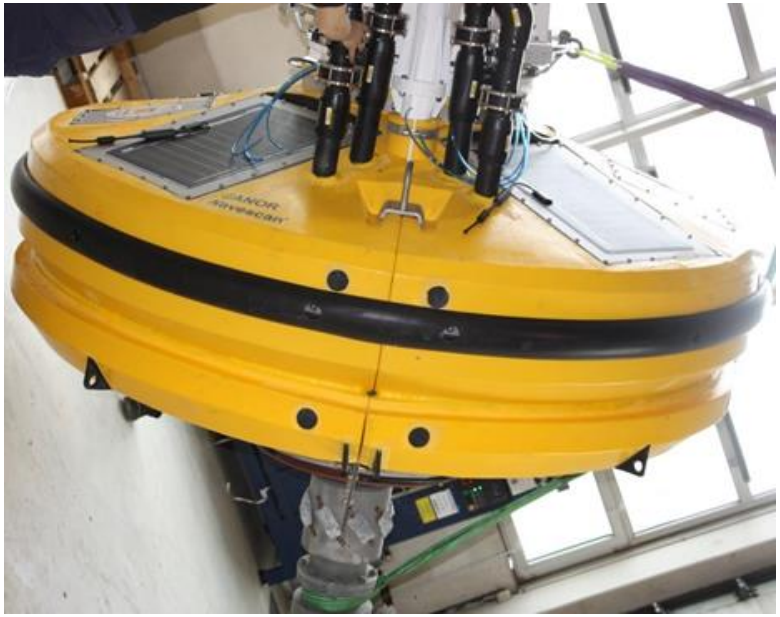
- 3 different compasses
- 2 «met stations» (1 on the Lidar + 1 in the mast)

DATA COLLECTION

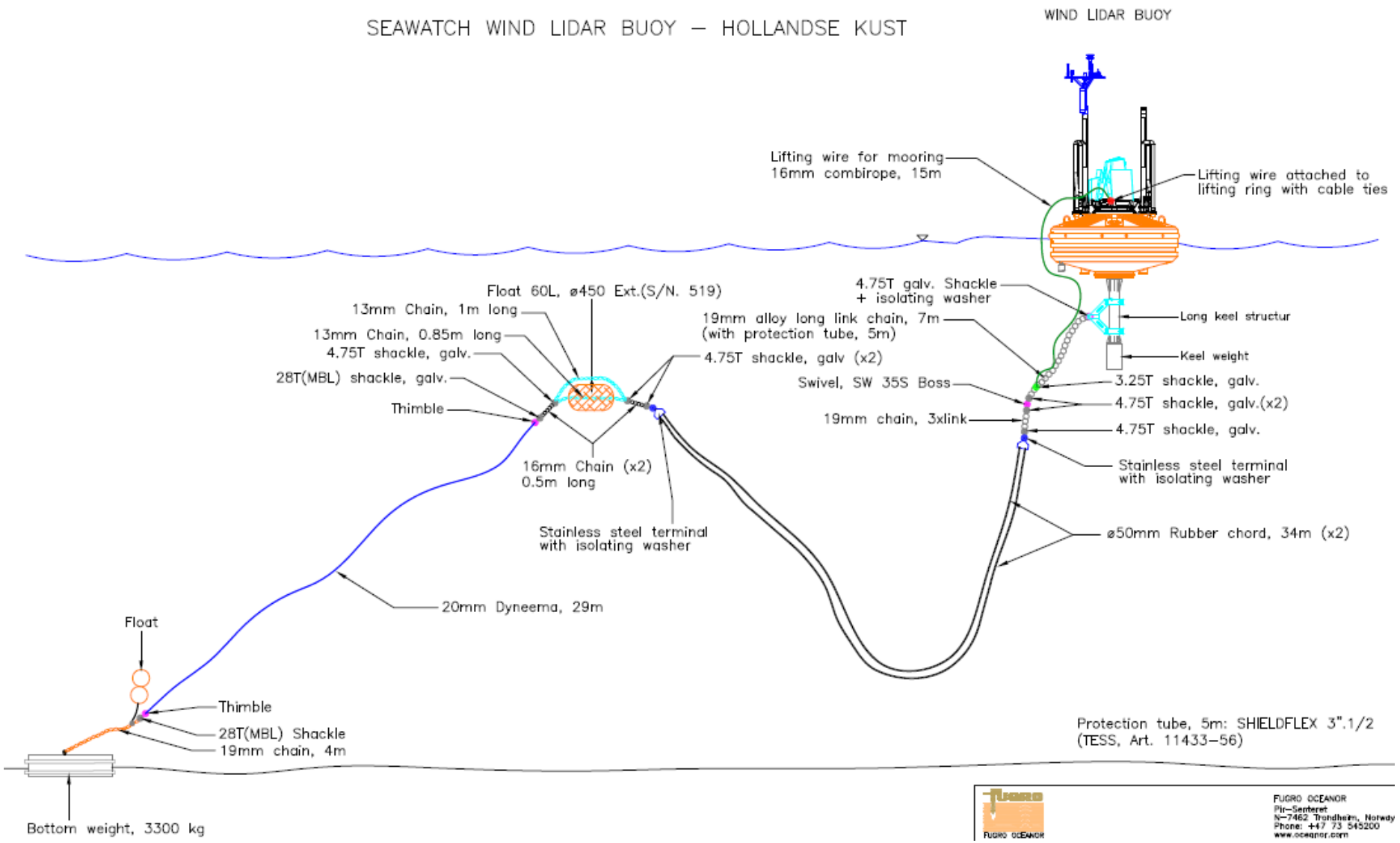
- Raw wind data (10 min average + scanning frequency/pattern of Zephir Lidar (1 Hz)) stored internally in the Lidar
- Raw current data stored internally in the current meter
- Raw wave data stored internally in the wave sensor
- Raw and processed wind data (10 min average + 1 Hz) stored in the datalogger
- All other data stored in the datalogger
- All 10 min data transmitted to shore, in some cases also 1 Hz data
- Erp, ir. F.C.W. van (Frank) 12/01/2017

New buoy hull – **Extra buoyancy**





SW Wind Lidar buoy – **Mooring**



Data Quality Assurance

Measurement System Quality

- **Pre-commercial stage system according to OWA roadmap - 6 month validation against offshore met mast**
- Manufacturing according to ISO standard ISO9001 compliance since 1985 **ISO9001:2008**
- Factory calibrated sensors - Lidar onshore validated against UK met mast
- Factory Acceptance Test
- **Pre-deployment system validation – min 40 measurements in each wind class**

Data Validation

- Comparison with nearby similar measurements (wind and waves)

Double Measurements

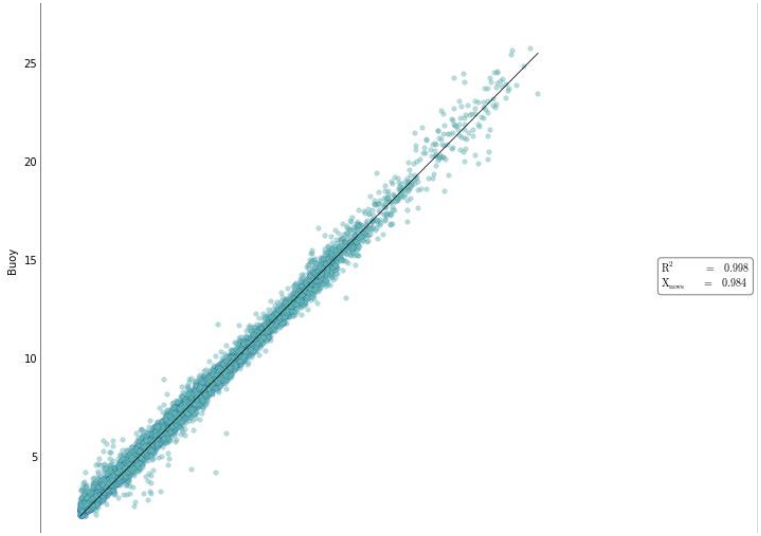
- Comparison with nearby Wind Lidar buoy

IJmuiden Met-mast validation - ENECO

Wind Profile Data Comparison

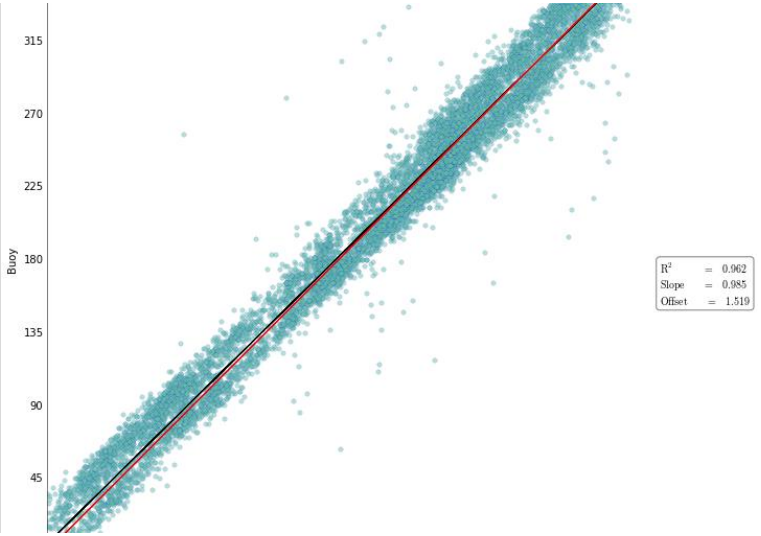
Wind Speed

- **R^2 = 0.99** (Best practice criteria >0.98, minimum 0.97)
- **Slope = 0.98** (Best practice criteria 0.98-1.02, minimum 0.97-1.03)
- Mean offset between 0.11 and 0.15 m/s

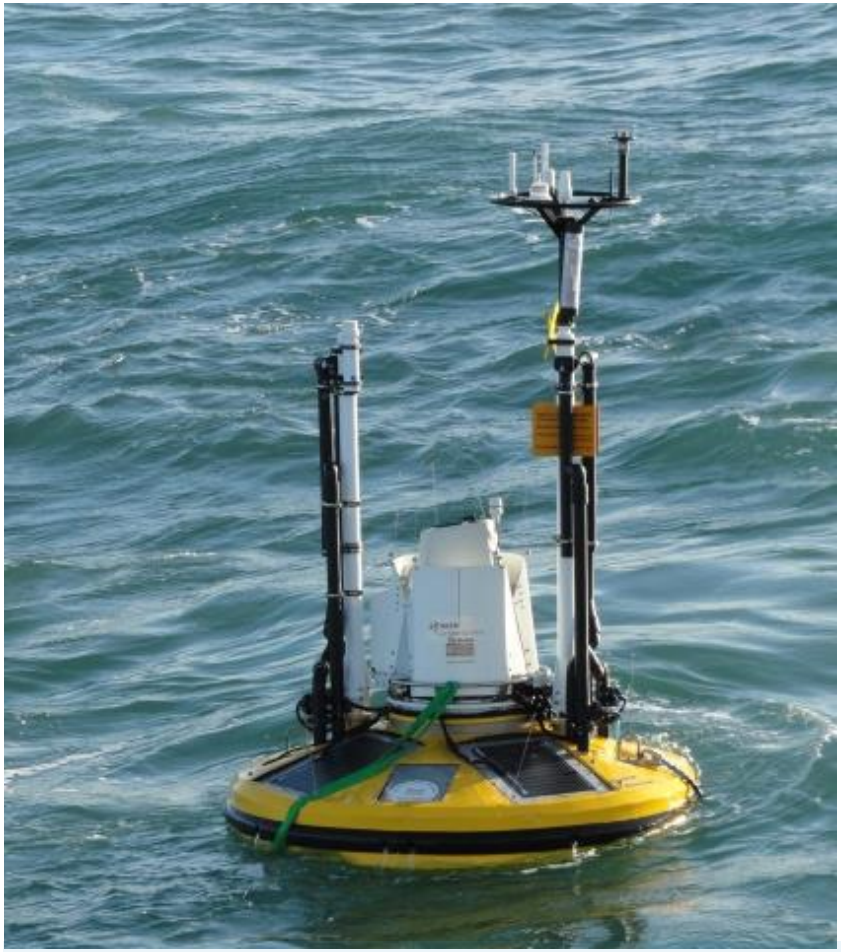


Wind Direction

- **R^2 = 0.96 - 0.97**. (Best practice criteria >0.97, minimum >0.95)
- **Slope = 0.97 - 0.99** (Best practice criteria 0.97-1.03, minimum 0.95-1.05)
- **Mean offset between 1.5 and 5.8 degrees** (Best practice criteria <5 degrees, minimum <10 degrees)



SEAWATCH Wind LiDAR Buoy - approval pre-commercial



Project name:	Fugro/Oceanor Seawatch Wind LiDAR Buoy	DNV GL / GL Garrad Hassan
Report title:	ASSESSMENT OF THE FUGRO/OCEANOR SEAWATCH FLOATING LIDAR VERIFICATION AT RWE IJMUIDEN MET MAST	Deutschland GmbH Section Offshore Germany Brooktorkai 18
Customer:	Fugro/OCEANOR AS, Trondheim, Norway	20457 Hamburg
Contact person:	Lasse Lonseth, Olaf Sveggen	Germany
Date of issue:	2015-01-30	Tel: +49 40 36149 2748
Project No.:	4257 13 10378	DE 118 606 038
Report No.:	GLGH-4257 13 10378-R-0003, Rev. B	

Task and objective: 3rd Party Assessment of an Offshore Performance Verificaton of the Fugro/Oceanor SEAWATCH Wind LiDAR Buoy at RWE IJmuiden Met Mast in the Dutch Northsea Sector

Prepared by:	Verified by:	Approved by:
L.A. D.Stein Deputy Head of Section Offshore, Hamburg	D. Fagiani, A. Beeken, P. Schwenk Senior and Project Engineers	L.A. D. Stein Deputy Head of Section Offshore, Hamburg

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- ☐ DNV GL only
- ☒ Client's Discretion
- ☐ Published

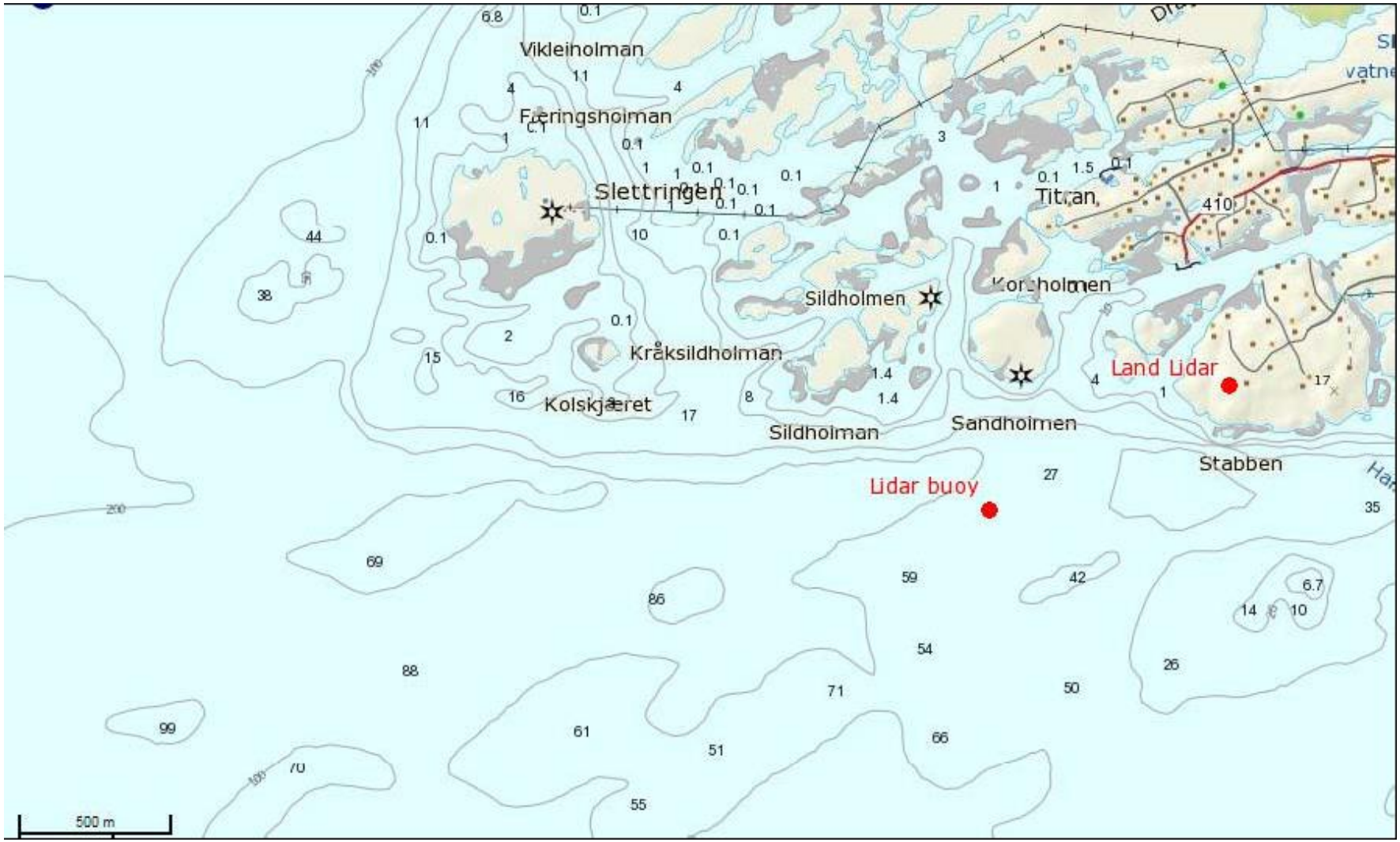
Keywords:
LiDAR, Floating Lidar Device,

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

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2014-12-19	Draft issue, for clients comments, only	DeSte	AnBee	DeSte
B	2015-01-30	Final isue (electronic only)	DeSte	DariF, AnBee, Pasch	DeSte

"An evaluation of the Fugro/Oceanor SWL Buoy floating LiDAR system was completed by comparing its measurements against data from the IEC-compliant IJmuiden met mast. Sufficient data were collected to allow an assessment in line with the Roadmap. In the IJmuiden offshore trial very encouraging results were indeed obtained. DNV GL concludes that the FO SWL Buoy system 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. up to about 5.8 m significant wave height and 9.8 m maximum wave height and 10 min averaged wind speeds up to 26 m/s). Furthermore, it has recorded excellent availability throughout the 6 month period and demonstrated structural survivability in the met-ocean conditions present from early spring."

Fugro Lidar Buoy validation site – Titran, Frøya



Positions of Wind Lidar buoy and Land Lidar at the Island Frøya

Fugro Lidar Buoy validation site – Titran, Frøya

- Pre- and post validation site approved by DNVGL
- On-shore Lidar reference at Stabben Fort is established,
  and standard anemometry reference masts (NTNU/ University) are available
- So far: Five SWLB successfully validated at site since March 2015

Wind Lidar buoys – pre-deployment validation results

Buoy no	Validation period	No of days	Coverage 14-16 m/s	Max WS
WS149	11/3 - 25/3 2015	14 days	49 - 77	25.5 - 31.5 m/s
WS156	1/7 - 29/9 2015	90 days	198-401	17.5 - 22.4 m/s
WS157	11/12 2015 - 4/1 2016	24 days	184-298	27.6 - 32.2 m/s
WS158	5/4 - 3/5 2016	28 days	99-190	18.5 - 23.4 m/s

WIND SPEED ACCURACY

Overview of linear regression analysis results for wind speed comparisons between the SWL Buoy and the reference Lidar for height 100 m

Buoy no	WS149	WS156	WS157	WS158
Slope (X_{mws})	1.011	1.008	1.014	1.010
Regr.coeff. (R^2_{mws})	0.994	0.987	0.974	0.985

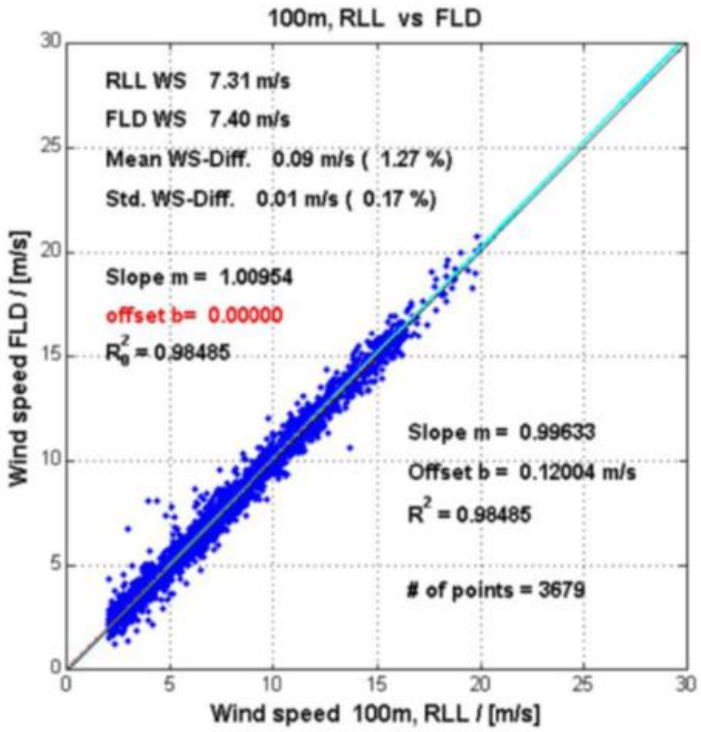
WIND DIRECTION ACCURACY

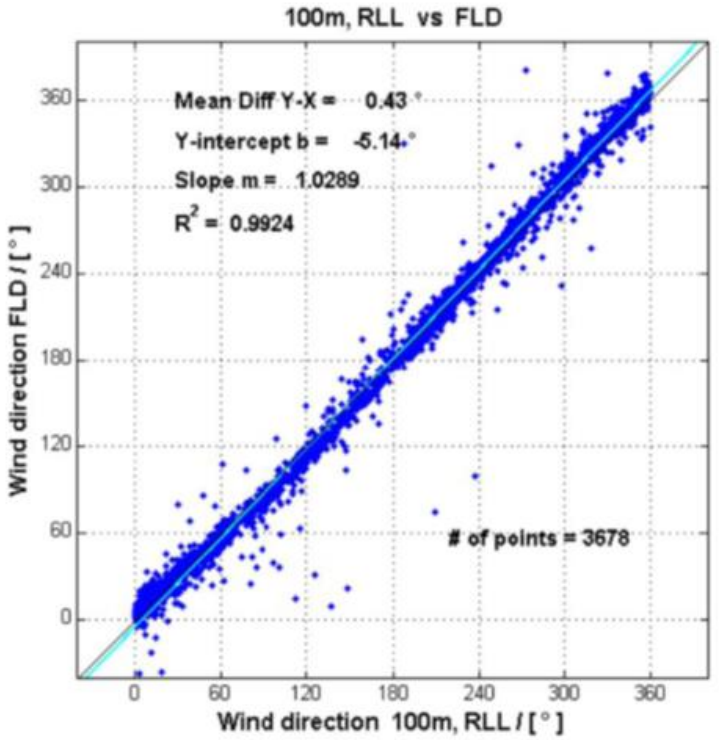
Overview of linear regression analysis results for wind direction comparisons between the SWL Buoy and the reference Lidar for height 100 m

Buoy no	WS149	WS156	WS157	WS158
Slope (X_{MWd})	0.976	0.958	1.005	1.029
Regr.coeff. (R^2_{mwd})	0.981	0.987	0.981	0.992
Mean offset (OFF_{mwd})	-4.93	-6.82	-3.07	0.43

Wind Lidar buoys – pre-deployment validation results

For Mean Offset (OFF_{mwd}) accuracy for wind direction (WD) has been a significantly improved from buoy WS156 till buoy WS158. This has been achieved by using a compass of better quality.





Correlation of Lidar buoy and Land Lidar for 100 m height for buoy WS158

All reports are made public at RVO's website: http://offshorewind.rvo.nl/

Netherlands Enterprise Agency

Metocean Camp. - Reports Pos. 1

- Data & Validation report Period 13 - Fugro
- Data & Validation report Period 12 - Fugro
- Data & Validation report Period 11 - Fugro
- Data & Validation report Period 10 - Fugro
- Data & Validation report - Additional periods
- Data & Validation report Period 9 - Fugro
- Data & Validation report Period 8 - Fugro
- Data & Validation report Period 7 - Fugro
- Data & Validation report Period 6 - Fugro
- Data & Validation report Period 5 - Fugro
- Data & Validation report Period 4 - Fugro
- Data & Validation report Period 3 - Fugro
- Data & Validation report Period 2 - Fugro
- Data & Validation report Period 1 - Fugro

Metocean Camp. - Data Position 1

- Data position 1 - period 13 - Fugro
- Data position 1 - period 12 - Fugro
- Data position 1 - period 11 - Fugro
- Data position 1 - period 10 - Fugro
- Data position 1 - Additional period B
- Data position 1 - Additional period A
- Data position 1 - period 9 - Fugro
- Data position 1 - period 8 - Fugro
- Data position 1 - period 7 - Fugro
- Data position 1 - period 6 - Fugro
- Data position 1 - period 5 - Fugro
- Data position 1 - period 4 - Fugro
- Data position 1 - period 3 - Fugro
- Data position 1 - period 2 - Fugro
- Data position 1 - period 1 - Fugro

Validation Reports & Signal List

- Uncertainty Assessment - Ecofys
- Pre-Deployment Validation Report WS157
- Pre-Deployment Validation Report WS156
- Pre-Deployment Validation Report WS149
- Trial Campaign Validation Report - DNV GL
- Signal list Metocean data - Fugro

Metocean Camp. - Reports Pos. 2

- Data & Validation report Period 5 - Fugro
- Data & Validation report Period 4 - Fugro
- Data & Validation report Period 3 - Fugro
- Data & Validation report Period 2 - Fugro
- Data & Validation report Period 1 - Fugro

Metocean Camp. - Data Position 2

- Data position 2 - period 5 - Fugro
- Data position 2 - period 4 - Fugro
- Data position 2 - period 3 - Fugro
- Data position 2 - period 2 - Fugro
- Data position 2 - period 1 - Fugro

Borssele Wind Farm Zone, RVO 2015 - *Ongoing*

Borssele Wind farm survey and Northwind wake effects study

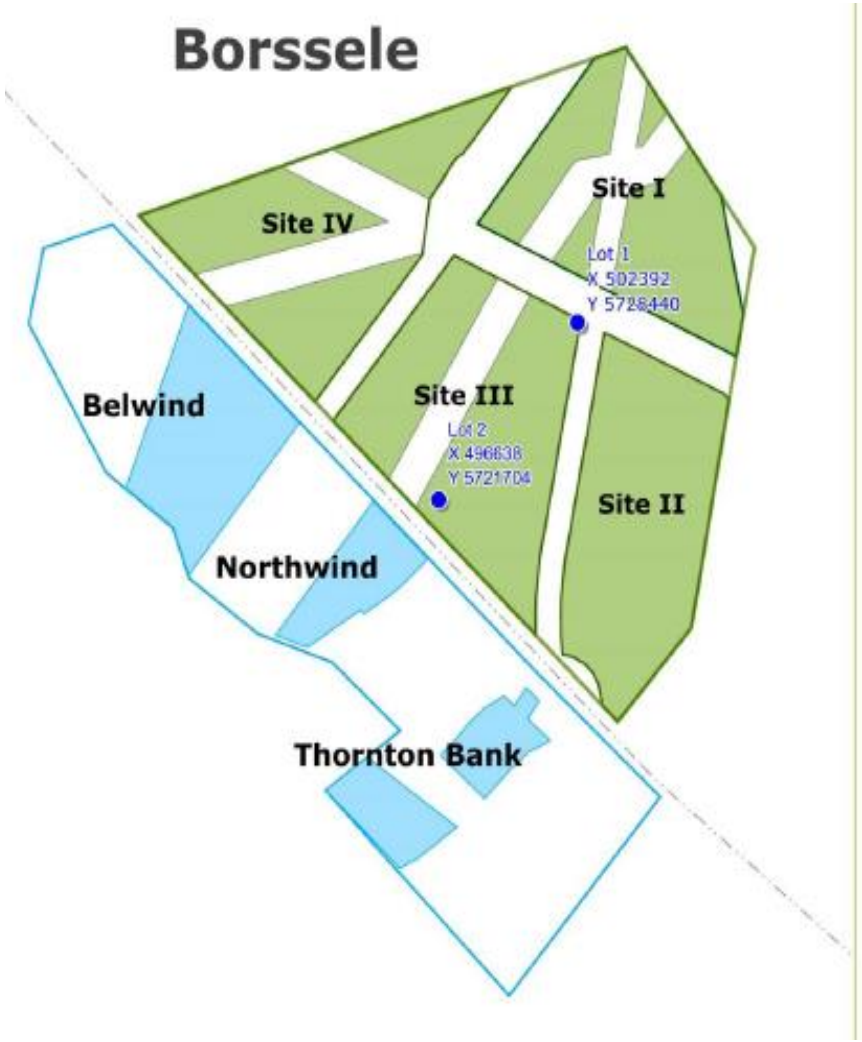
1 SW Wind Lidar buoy deployed June 2015 (Lot 1) and 1 SW Wind Lidar buoy deployed February 2016 (Lot 2)

Parameters:

- Mooring at 30 m water depth
- Wave height, period and direction
- Current profile (30 m) and water temperature
- Wind speed and direction
- Wind speed and direction profile
- Air pressure
- Air humidity and temperature
- Water level (tide)

Wind observations:

Wind speed and direction, turbulence intensity, inflow angle and wind shear/veer

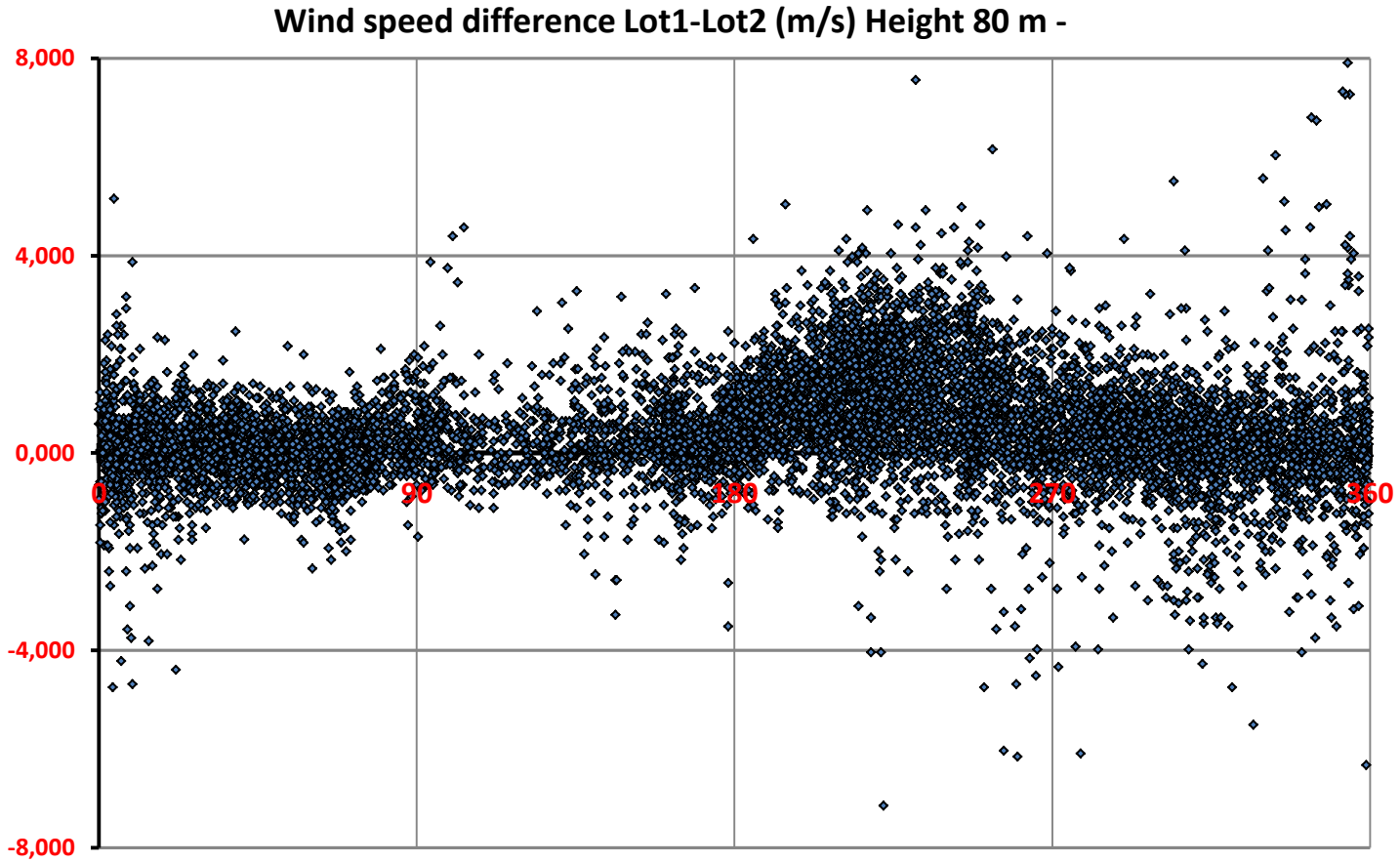


Environmental conditions experienced at Borssele Wind farm

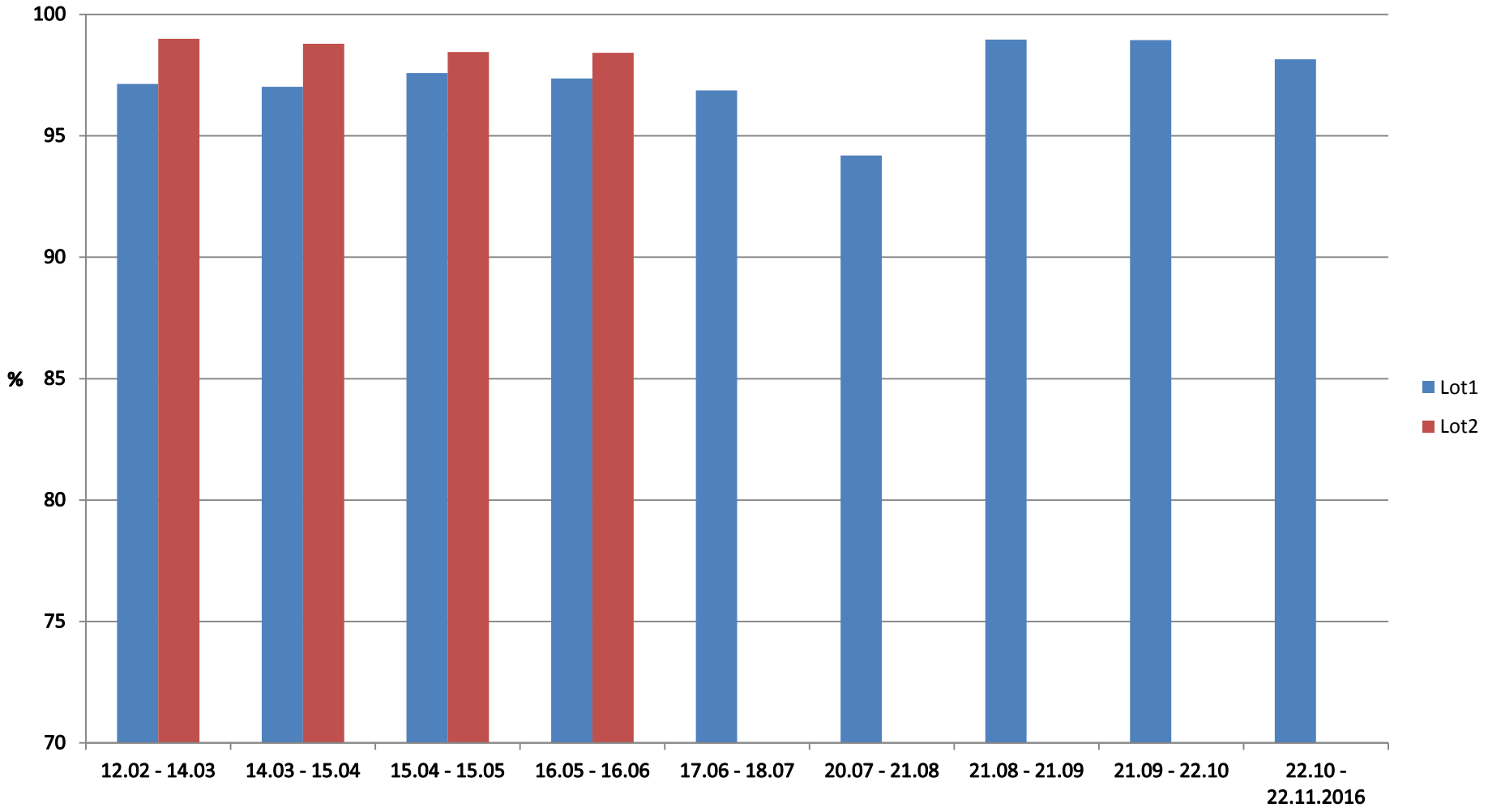
Parameter		Value	
Highest Significant Wave height	m	6.48	14th Jan 2016
Max wave height	m	10.6	20th Nov 2016
Highest 10 min Average Wind speed (30 m)	m/s	28.9	20th Nov 2016
Highest 10 min Average Wind speed (200 m)	m/s	32.3	20th Nov 2016

Preliminary Results wake effects study

Wind speed at Lot 2 lower and turbulence higher than at Lot 1 for direction between 180º (south) and 300º (west-northwest) - wind speed at Lot 1 is 1-2 m/s, or 5-10 % higher than at Lot 2



Availability – Transmitted Data (wind speed and direction)



Borssele – Data Validation

Wind

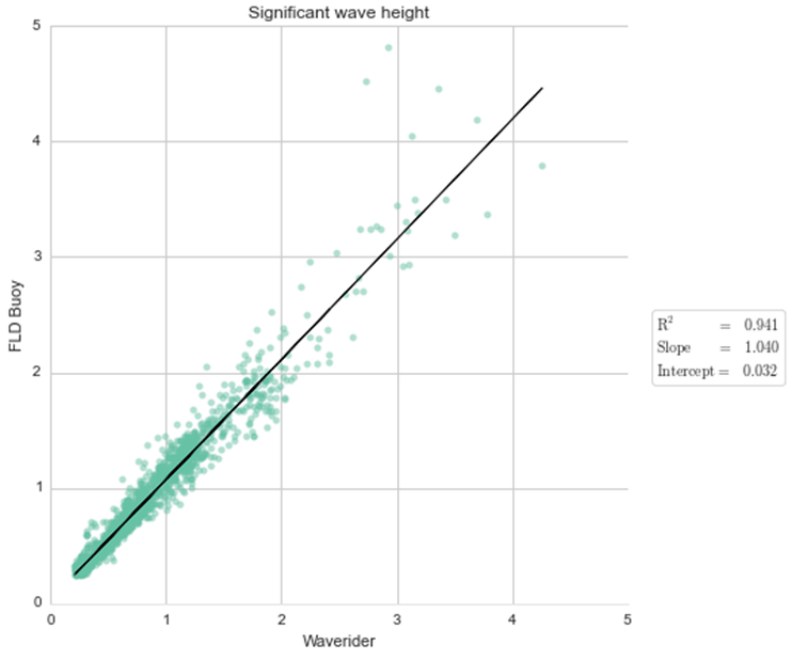
- wind measurements validated against the platform at Vlakte van de Raan
- Wind speed - KNMI cup-anemometer
- Wind direction - KNMI wind vane.
- 27.6 km from Wind Lidar buoy
- 12 km from the nearest shore

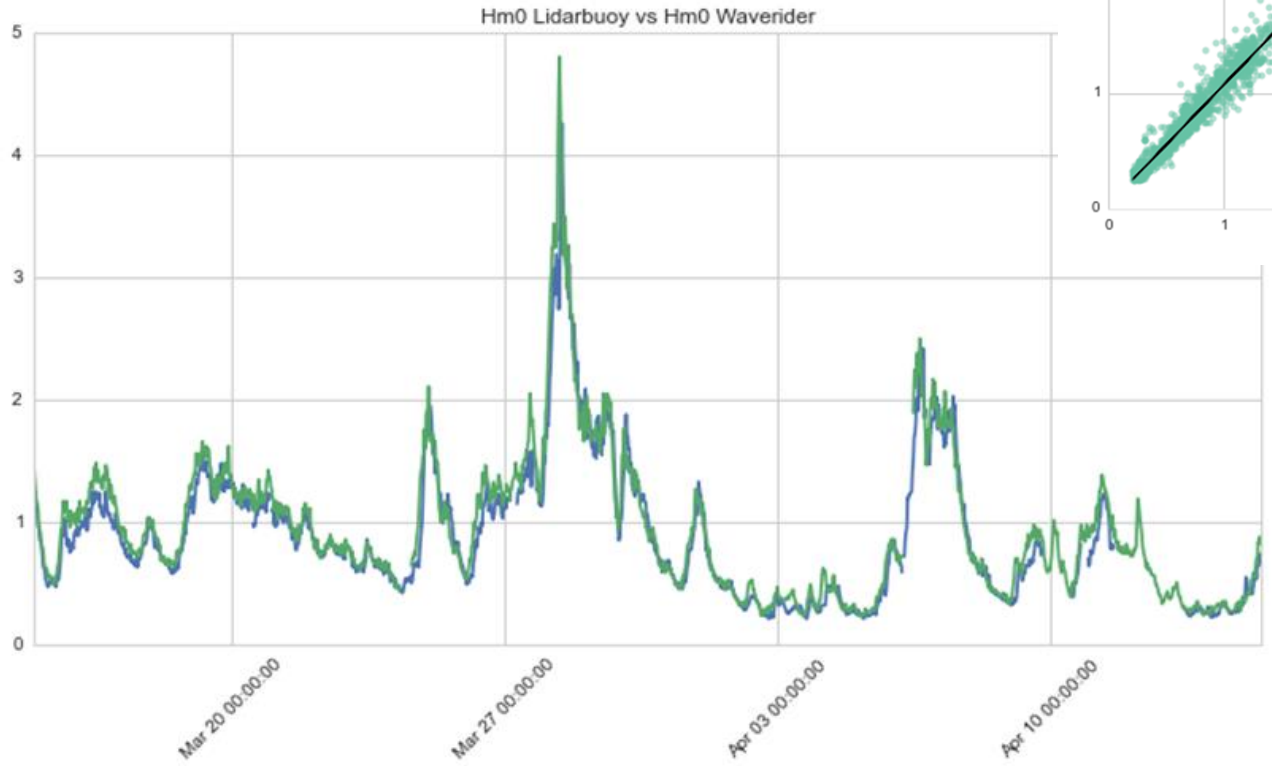
Waves

- wave measurements validated against buoy at Schouwenbank
- directional (“2D”) Datawell Waverider buoy
- 19.3 km from Wind Lidar buoy
- 22.0 km from nearest shore

Borssele – Data Validation - Example

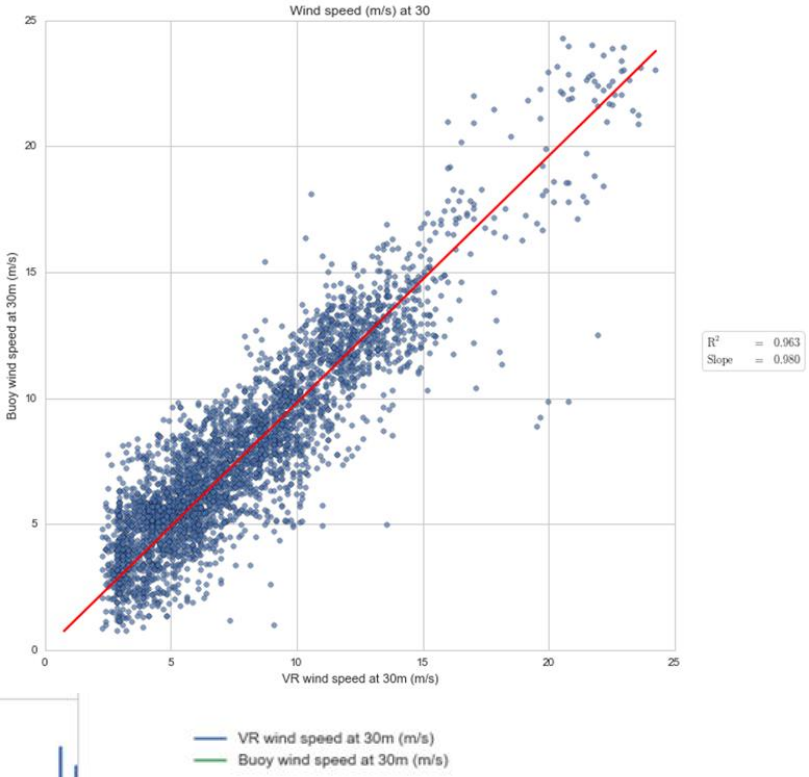
Time series and scatter plot of significant **wave height (Hm0)** from the Lidar buoy (green curve) and the Schouwenbank Waverider buoy (blue)

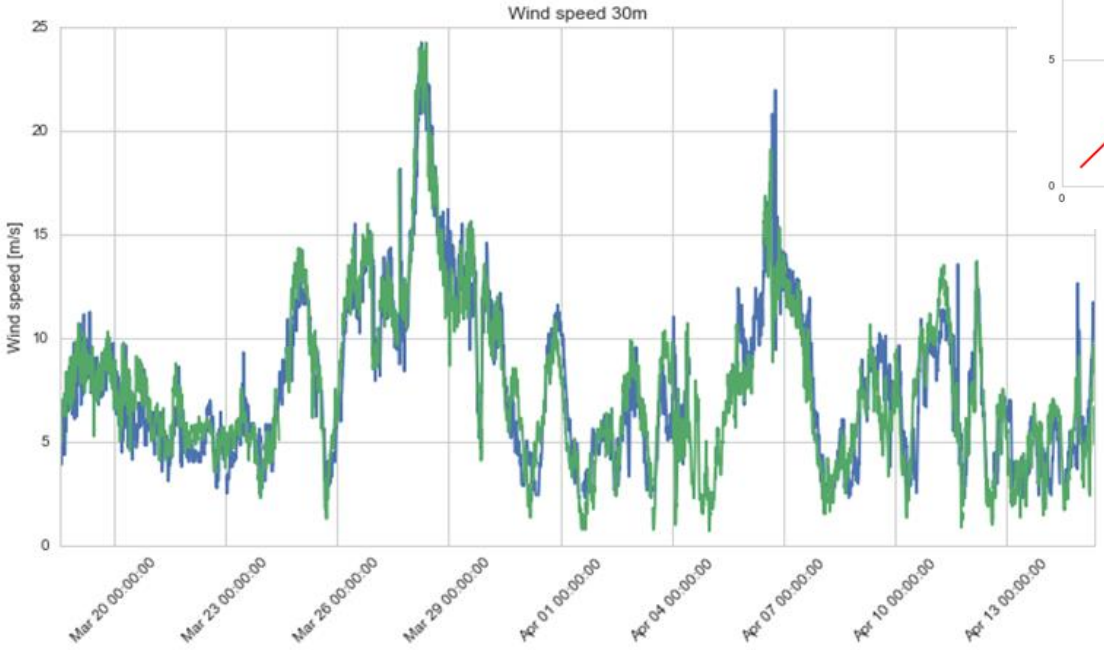




Borssele – Data Validation - Example

Wind speed time serie and scatter at 30 m above sea level measured by the Lidar buoy (green curve) compared to wind speed at Vlakte van de Raan adjusted to 30 m (blue)





Hollandse Kust Wind Farm Zone, RVO - 2016 - *Ongoing*

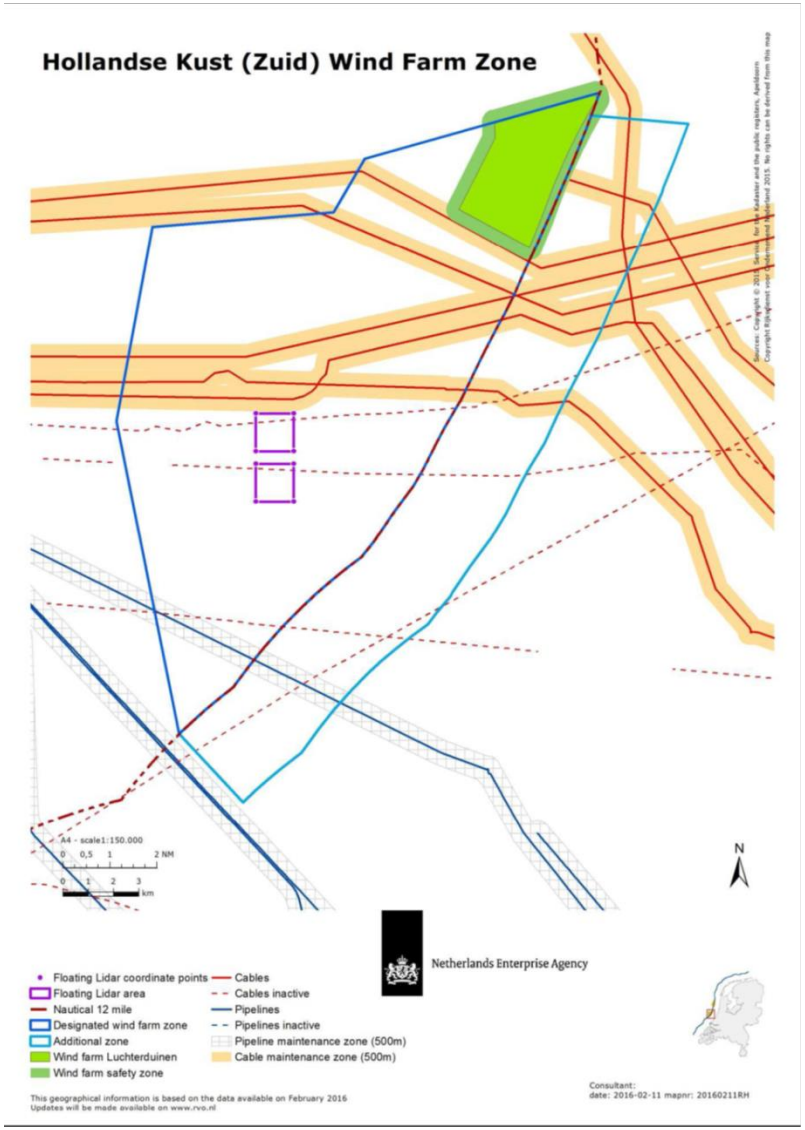
2 SW Wind Lidar buoys deployed June 2016

Parameters:

- Mooring at 23 m water depth
- Wave height, period and direction
- Current profile (22 m) and water temperature
- Wind speed and direction
- Wind speed and direction profile
- Air pressure
- Air humidity and temperature
- Water level (tide)

Wind observations

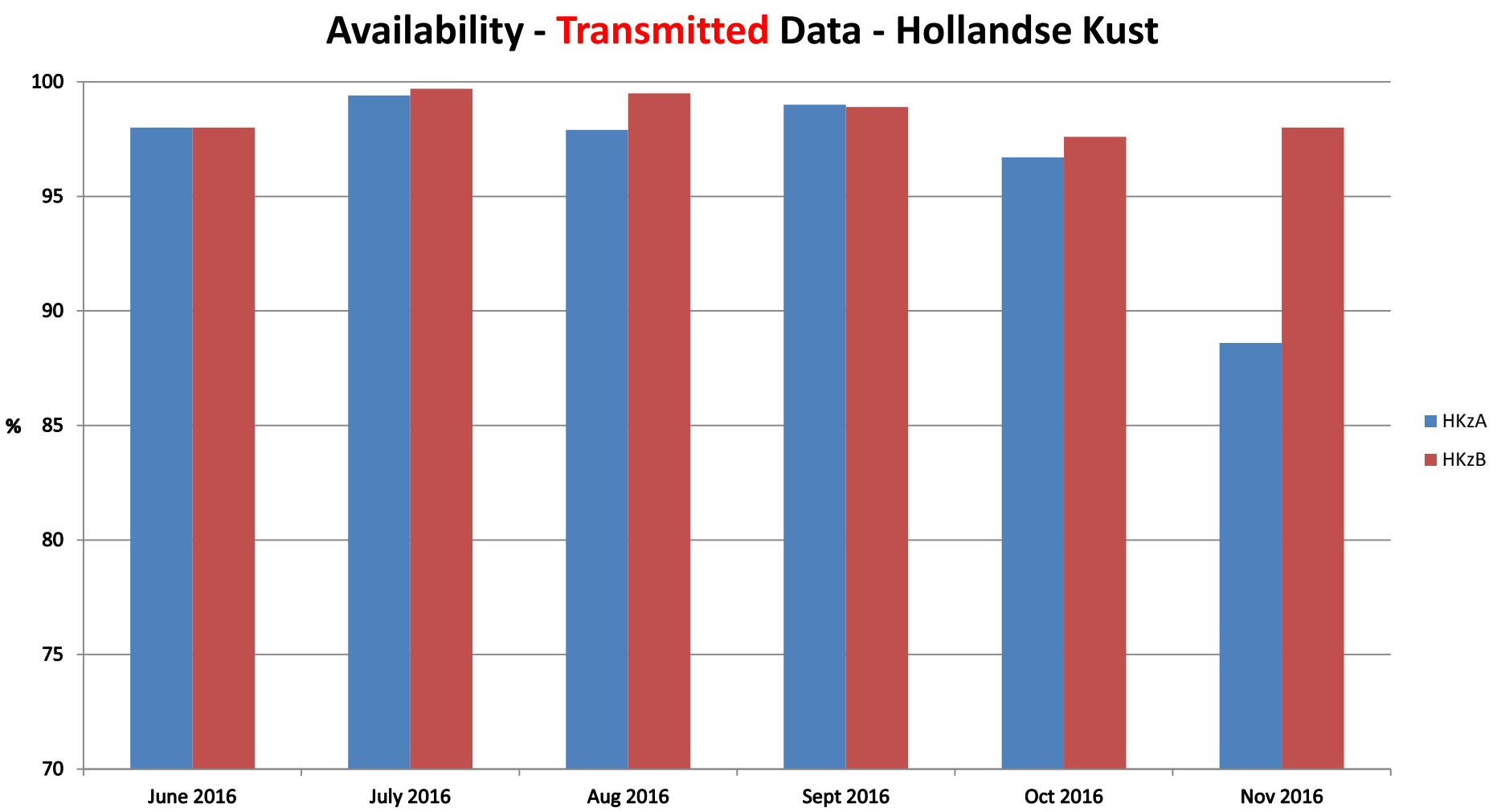
Wind speed and direction, turbulence intensity, inflow angle and wind shear/veer



Environmental conditions experienced at Hollandse Kust Wind Farm Zone

Parameter		Value	
Highest Significant Wave height	m	5.20	20th Nov2016
Max wave height	m	7.74	20th Nov 2016
Highest 10 min Average Wind speed (30 m)	m/s	29.1	20th Nov 2016
Highest 10 min Average Wind speed (200 m)	m/s	33.7	20th Nov 2016

Hollandse Kust Wind Farm Zone, RVO - 2016 - *Ongoing*



Hollandse Kust – Data Validation (2 nearby buoys)

Measurements validated against the platform at Lichteiland Goeree (LEG), EuroPlatform (EPL) and IJmuiden

EPL

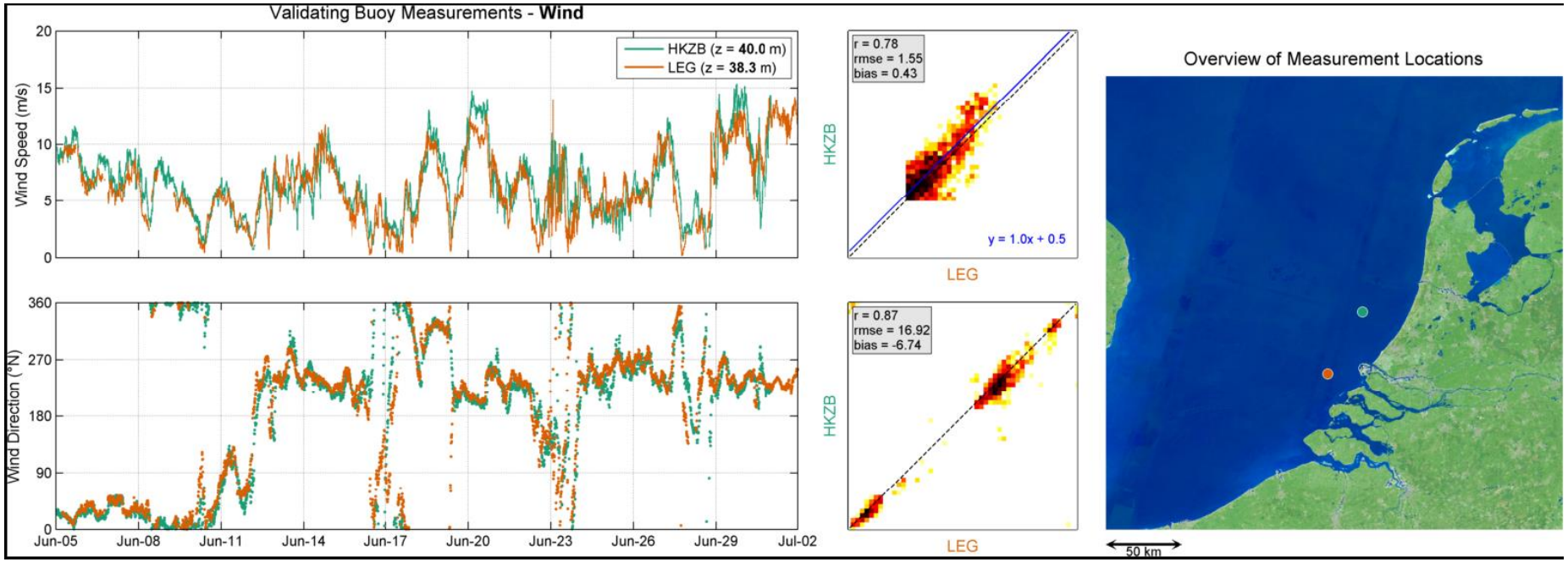
LEG

Measurements from the two buoys compared against each other –

distance between the buoys ~2 km

Hollandse Kust – Data Validation Example (Deltares)

Validation of HKZB wind with LEG (June 2016 period)
Left panel: timeseries.
Middle panel: Density scatter, with the darker colours indicating more data density.



Hollandse Kust - Double measurements (Deltares)

Statistical comparison between two nearby LiDAR buoy

	Wind Speed			Wind Direction		
Elevation (m)	r^2 (-)	Bias (m/s)	Symmetrical Slope (-)	r^2 (-)	Bias (°N)	Filtered Points (%)
4	0.97	0.11	1.01	0.98	2.3	2.7
30	0.97	-0.02	1.00	0.97	0.9	1.4
40	0.98	-0.02	1.00	0.97	1.1	1.5
60	0.98	-0.02	1.00	0.98	1.0	2.4
80	0.98	-0.01	1.00	0.97	0.6	3.2
100	0.98	-0.03	0.99	0.97	0.2	3.3
120	0.98	-0.03	1.00	0.97	0.1	3.3
140	0.98	-0.02	1.00	0.96	-0.2	4.0
160	0.98	-0.03	0.99	0.95	-0.4	4.5
180	0.98	-0.03	0.99	0.95	-0.2	5.3
200	0.98	-0.02	1.00	0.94	-0.5	6.3

Hollandse Kust - Double measurements (Deltares)

Summary:

- The agreement between the LiDAR buoys and the wind and wave observations from fixed platforms is relatively high, especially when considering the closest locations, LEG, EPL and IJmuiden.
- Comparisons between the HKZA and HKZB LiDAR wind velocities at all levels show low bias, good wind speed correlations and slopes close to 1
- wind direction correlations also close to 1 at the lower levels, but slightly lower at higher levels.
- The validation of the temperature, air pressure, water level and current data also show an excellent agreement between the HKZ observations and other observations,
- in the case of currents and water levels also excellent agreement with model results.

The overall conclusion of the validation is that the quality of the HKZA and HKZB data is high and the dataset trustworthy.

Operational Experience

Operations Borssele 2016:

- 2 deployments (Feb)
- 1 recovery (July)
- 2 swapping (July and Dec)

Operations HKz 2016:

- 2 deployments (June)
- 2 swappings (Nov)
- 1 buoy drifting (catching and re-deployment

Experience:

- Spare buoy available important for achieving high data availability
- Deployment of 2 buoys at same cruise worked fine
- Swapping of 2 buoys at the same cruise is difficult (impossible) because 4 buoys are involved
  (require much larger and more expensive vessel)
- All operations performed with sea state Hs $\leq$ 1 m
- No injuries
- Few and minor damage on equipment

LESSONS LEARNED

LIDAR (Z300):

Salt Water Ingress through Wiper Seal

SOLUTION:

- Apply grease to sealing ring,
- proper tightening

LESSONS LEARNED

LIDAR (Z300):

Met station failure (old 150-series type)

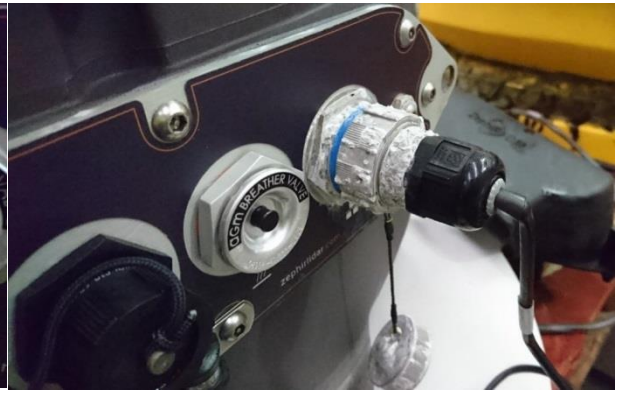
SOLUTION:

- Upgrade to new 200-series type (without humidity sensor water ingress weakness)

LESSONS LEARNED

LIDAR (Z300):

Connector corrosion



SOLUTION:

- Replace with marine grade alloy
- In future only use marine grade connectors
- Marine version launched by Zephir Nov 2015 (after start of Borssele)

LESSONS LEARNED

LIDAR (Z300):

On/off button corrosion (caused Lidar power failure)

SOLUTION:

- On/off button removed/bypassed
- Hole sealed

LESSONS LEARNED

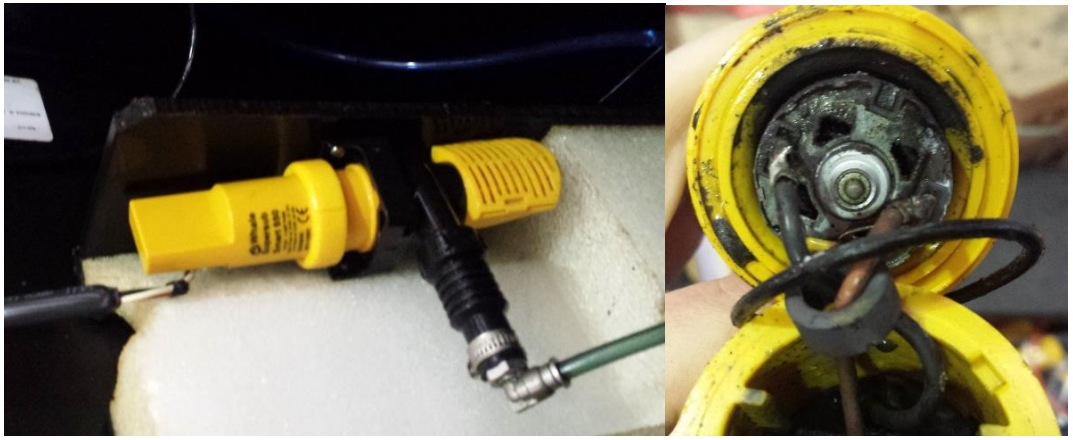
Corrosion on fuel cell cables and connectors

SOLUTION:

- Replacing corroded connectors at service
- Seal non-IP connectors with rubber seal

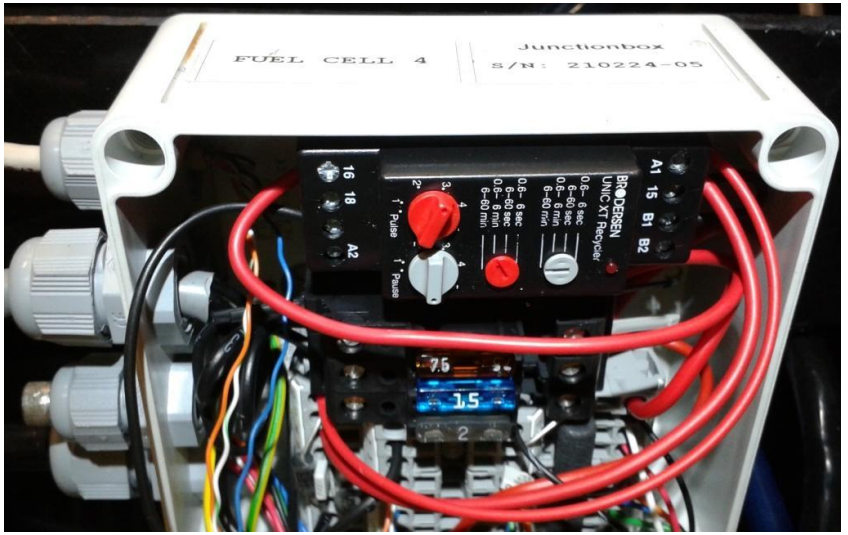
LESSONS LEARNED

Dry-running bilge pumps



SOLUTION:

- Installation improved
- Timer added
- Change to better pump



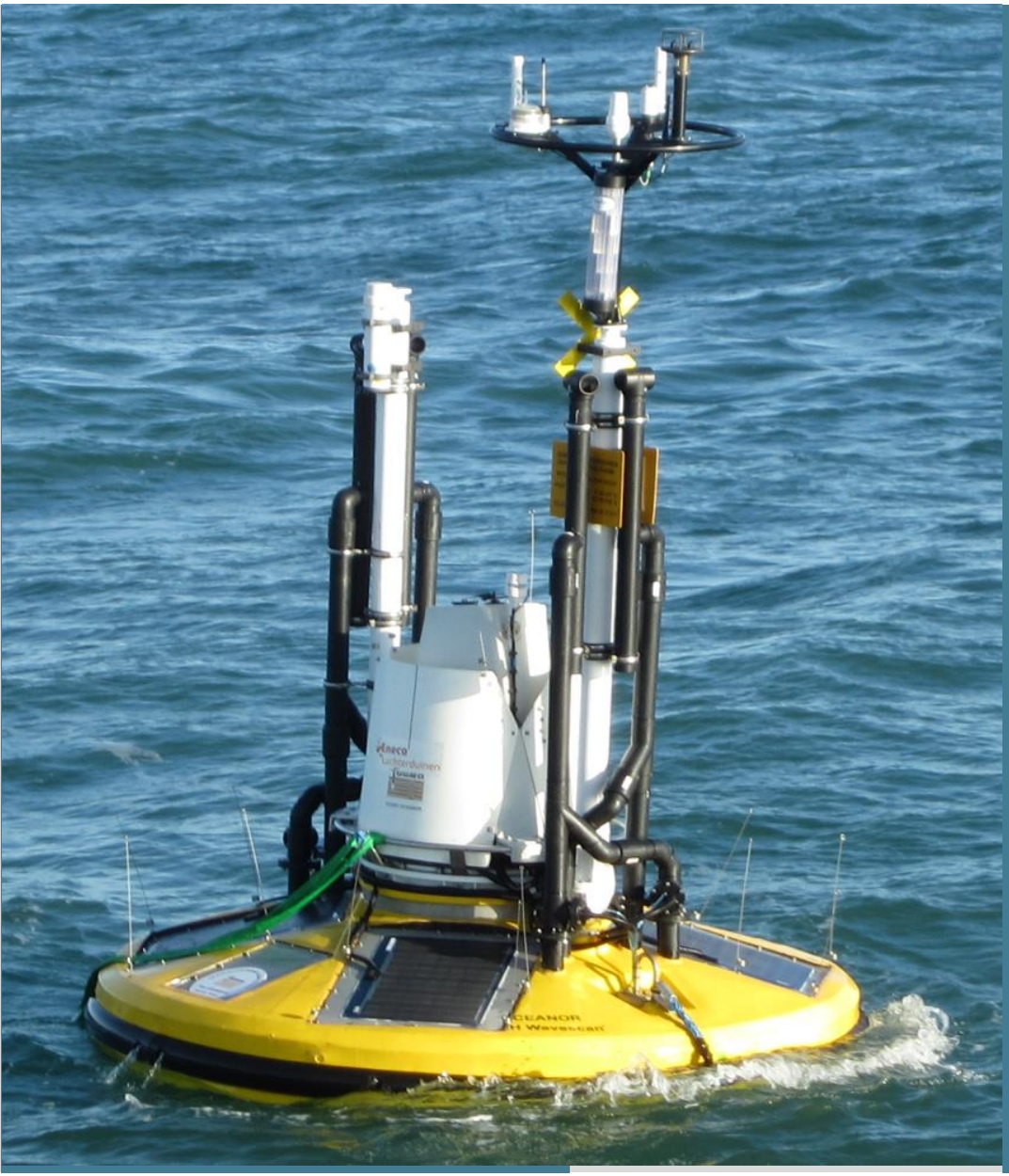
RISK ASSESSMENT - METHOD

					Likelihood				
Hazard severity	Reputation	Assets	Environment	People	**A– Very unlikely** (a freak combination of factors required for incident to result)	**B – Unlikely** (a rare combination of factors would be required for an incident to result	**C - Possible** (could happen when additional factors are present but otherwise unlikely to occur)	**D – Likely** (not certain to happen but an additional factor may result in an accident)	**E – Very Likely** (almost inevitable that an incident would result)
1.Slight	Slight Impact	1- Slight damage, less than €25000	Little or no actual or potential for damage.	1 – Slight health effect/injury (First Aid)	**A1**	**B1**	**C1**	**D1**	**E1**
2.Minor	Limited Impact	2 – Minor damage, €25,000 – 100,000	Within site boundary, short term impact recoverable by the work site	2 – Minor health effect/ injury (RWC MTO)	**A2**	**B2**	**C2**	**D2**	**E2**
3.Major	Considerable Impact	3 – Major damage, €100,000 – 500,000	Beyond the site boundary unlikely to last beyond 1 month. Recovery may require external aid.	3 – Major health effect/ injury (DAWC	**A3**	**B3**	**C3**	**D3**	**E3**
4.Severe	National Impact	4 – Severe damage, €500,000 – 1,000,000	Beyond the site boundary unlikely to last beyond 12 months. Recovery requires external aid.	4 – Permanent Total Disability or single fatality	**A4**	**B4**	**C4**	**D4**	**E4**
5.Catastrophic	International Impact	5 – Extensive damage, greater than €1,000,000	Massive uncontrolled release with significant impact extending well beyond the site boundary.	5 – Multiple serious injuries or fatalities	**A5**	**B5**	**C5**	**D5**	**E5**

Green (Low)	Manage for continuous improvement. May be acceptable; however, review task to see if risk can be reduced further.
Yellow (Medium)	Incorporate Risk Reduction measures. Task should only proceed with appropriate management authorisation after consultation with specialist personnel and assessment team. Where possible, the task should be redefined to take account of the hazards involved or the risk should be reduced further prior to task commencement.
Red (High)	Intolerable. Task must not proceed. It should be redefined or further control measures put in place to reduce risk. The controls should be re-assessed for adequacy prior to task commencement.

RISK ASSESSMENT

Event	Description/Consequence	Likelihood of occurence	Severity for total system	Mitigating measures	Likelihood of occurence	Severity for total system
Dry-running bilge pumps	Pump wears out, fuel cell exposure to salt water. (4 independent systems.) Time for service and refuelling will come sooner.	**C**	**2**	Installation improved, timer added. In future change to better pump	**A**	**2**
Seized/corroded exhaust pump	Higher exhaust pressure. Damage on fuel cell. (4 independent systems.) Time for service and refuelling will come sooner.	**C**	**2**	Housing redesigned **without** pump	**A**	**1**
Corrosion on fuel cell cables and connectors (RJ45)	Corrosion on RJ45 connectors. In worst case fuel cells can stop working. (4 independent systems.) Time for service and refuelling will come sooner.	**B**	**2**	Seal non-IP connectors with liquid rubber. Corroded connectors replaced when buoy is serviced.	**A**	**2**
Fuel cell error messages/failure	Error messages appears indicating that over time fuel cells can stop working. (4 independent systems.) Time for service and refuelling will come sooner.	**C**	**2**	Fuel cells having error messages are replaced when buoy is serviced. Work time is logged and fuel cells are sent for service before service intervals expires	**B**	**2**
Z300 On/off button corrosion	Lidar permanently switches to on or off position. If locked in off, Lidar stops.	**E**	**5**	On/off button removed/bypassed, hole sealed	**A**	**1**
Z300 Salt water ingress through wiper seal	Salt water droplets ingress. Can damage the Lidar electronics	**C**	**3**	Apply grease to sealing ring, check for no damage, proper tightening.	**B**	**2**
Z300 Old type connector corrosion	Old type connectors stuck to chassis	**E**	**1**	Monitor corrosion progress, replace with marine grade alloy when possible. In future only use marine grade connectors.	**A**	**1**
Z300 Old type(150-series) Met station failure	Water ingress in met station. Lidar met. station failure. (Additional met. sensors on buoy used as backup)	**D**	**2**	Upgrade to new type met station(200-series)	**B**	**2**



Thank you for your time

Arve Berg
Fugro OCEANOR

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