ECOFYS | WIND TURBINE TESTING SERVICES

# Strategic Advice about Floating LiDAR Campaigns

## Borssele offshore wind farm

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## Borssele offshore wind farm

**Project number: ESMWT16419**

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| Approved: | Erik Holtslag | 10/07/2016 |
| Filename | 20160708_REP_Borssele LiDAR campaign advice_v3.docx | |
| Pages | 19 | |
| Status | Final; for publication at client's discretion | |

| Version | Author | Date | Remarks/Change |
|---|---|---|---|
| 1.0 | D Dhirendra | 14 June 2016 | Draft memo for client review |
| 2.0 | D Dhirendra | 24 June 2016 | Draft memo for client review |
| 3.0 | A Crockford | 8 July 2016 | Final report for publication |

# Executive Summary


Within the Borssele offshore wind farm zone, RVO is performing a wind measurement campaign with two floating LiDARs. The primary objectives of this campaign are determining the wind conditions at site and measuring the Belgium wind farm wake effects. The wake effects are to be quantified by calculating the wind speed ratio between two LiDAR locations.

RVO commissioned Ecofys WTTS to perform an initial analysis on the status of the wind measurements at the Borssele windfarm zone from two floating LiDARs. The goal was to determine whether three months of parallel measurements from two LiDARs is sufficient to calculate horizontal wind speed gradient, and hence whether initial goals for the second floating LiDAR (at location BWFZ Lot 2) are met.

The wind speed gradient between BWFZ Lot 1 and BWFZ Lot 2 has been calculated, showing a significant WSW gradient, attributed to the wake effects of the existing Belgian wind farms.

Based on the results presented in this report, it can be concluded that:

1. The available 3-months of collected data meet the DNV criteria for a short-term campaign, hence Ecofys WTTS concludes that wind data required for calculating the horizontal wind speed gradient between two locations within Borssele windfarm zone is sufficient. Extending the measurement campaign at BWFZ Lot 2 location is not expected to change the gradient results significantly.
2. The objective for placing a second floating LiDAR close to existing Belgian wind farms is fulfilled.

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# 1 Introduction

Within the Borssele offshore wind farm zone, RVO is performing a wind measurement campaign with two floating LiDARs, as shown in the map in Figure 1. The primary objectives of this campaign are determining the wind conditions at site and measuring the Belgium wind farm wake effects

The wake effects are to be quantified by calculating the wind speed ratio between two LiDAR locations. RVO has requested that Ecofys WTTS perform a preliminary analysis of the floating LiDAR wind measurements. The objectives of this initial study are to determine:

i. Whether three months of parallel measurements with two LiDARs is sufficient to calculate horizontal wind speed gradient;
ii. What that wind speed gradient is; and
iii. Whether initial goals for floating LiDAR at the BWFZ Lot 2 position measurement campaign are met and whether the LiDAR can be removed from site.

To accomplish these objectives, the wind speed gradient between the two floating LiDAR positions has been calculated according to industry standards, as detailed further below.

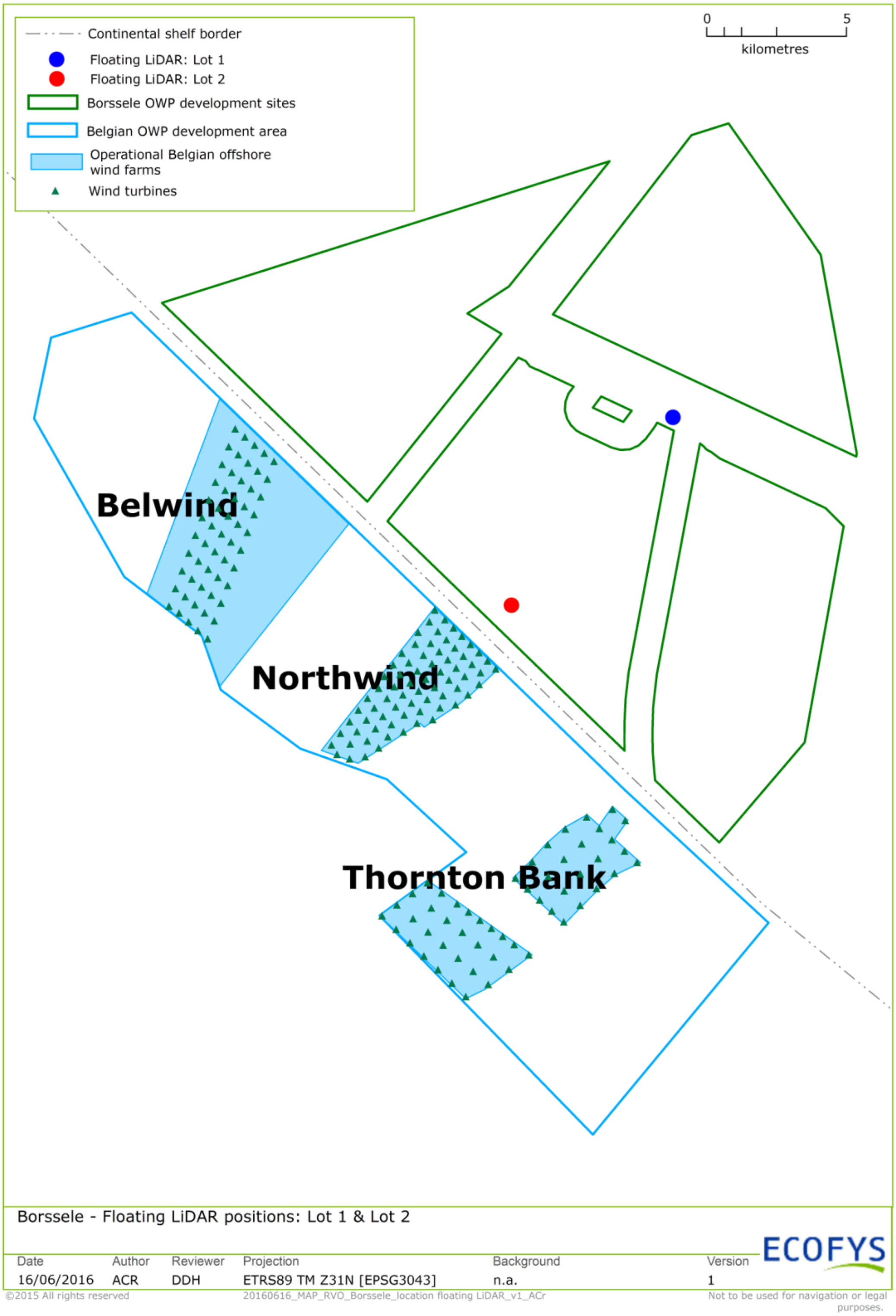


**Figure 1: Location of two floating LiDARs deployed at Borssele wind farm site, and surrounding existing wind farms**

# 2 Measurement campaign detail

The measurement campaigns with both LiDARs are described in the following section. The coordinates of both LiDARs are shown in the table below and in Figure 1. The measurement campaigns of both LiDARs is still ongoing as of the writing of this report, although data was only available up until 15 May 2016.

**Table 1: Location of LiDARs**

| Position id | Latitude | Longitude |
|---|---|---|
| BWFZ Lot 1 | 51° 42.414′ | 3° 02.0771′ |
| BWFZ Lot 2 | 51° 38.778′ | 2° 57.0846′ |

## 2.1 BWFZ Lot 1

The Seawatch Wind LiDAR buoy with serial no. WS149 was first deployed at the Borssele Wind Farm Zone (BWFZ) Lot 1 location in the Dutch sector of the North Sea on 11 June 2015. The type of LiDAR that was installed on this floating buoy is ZephIR 300S. Wind measurements were recorded at 30 m and from 40 m up to 200 m at intervals of 20 m.

The LiDAR on Buoy WS149 stopped working on 26 December 2015 due to a technical problem. The buoy was replaced by the spare buoy WS157 which was deployed on 12 February 2016.

## 2.2 BWFZ Lot 2

The Seawatch Wind LiDAR buoy with serial no. WS156 was deployed at the BWFZ Lot 2 location on 12 February 2016. The LiDAR type is identical to the LiDAR on the Lot 1 buoy, and wind measurements are taken at the same heights.

More information about the campaigns can be found here: http://offshorewind.rvo.nl/studiesborssele

## 2.3 Existing wind farms

There are several planned offshore wind farms in the Belgian territory of the North Sea, to the southwest of the Borssele zone. There will be wake effects from these wind farms which will cause a reduction in wind speed downstream (affecting the future Borssele wind farms). Four of the wind farms are already constructed, as shown in Figure 1 and in the table below.

**Table 2: Existing wind farms**

| Name of wind farm | Wind turbine details |
|---|---|
| Northwind | 72 x Vestas V112-3.0MW @ 71 m hub height |
| Belwind | 55 x Vestas V90-3.0MW @ 72 m hub height |
| Thornton Bank | 48 x Senvion 5M & 6.2M126 @ 94-95 m hub height |
| Belwind pilot project | 1 x Haliade 150-6MW @ 100 m hub height |

# 3 Wind data analysis

This chapter considers the first two objectives of this study:

i. Whether three months of parallel measurements with two LiDARs is sufficient to calculate horizontal wind speed gradient; and
ii. What that wind speed gradient is.

This wind speed gradient calculation has been performed as per the DNV guideline regarding the design of LiDAR wind measurement campaigns (DNV-RP-J101[*]). DNV has defined criteria for quantifying the uncertainty and other metrics for evaluating whether short term measurements meet the goals of a wind resource campaign.

## 3.1 Evaluation of data quality and quantity

Ecofys WTTS performed an initial quality check of the collected data for both LiDARs as per standard practice. A quality check was done to identify records which were affected by equipment malfunction or other anomalies. The floating LiDARs have been recording on the site for an overlapping period since 12 February 2016 and this analysis considers the latest published data, up until 15 May 2016.

The horizontal wind speed gradient between the two LiDARs has been studied for three heights, approximately related to the upper tip height, hub height and lower tip height of a typical offshore wind turbine. Following this assumption, the heights that were considered are 30 m, 100 m and 180 m. The level of 30 m was also the lowest height at which measurements from LiDARs was available.

A critical part of the data collection process is ensuring that enough data has been collected to provide value to the user. The data needs to be representative of site conditions and be useful for reducing the overall uncertainty in a wind farm energy yield assessment.

The DNV guideline provides four criteria for data collection: two general criteria and two direction-bin-specific criteria. The direction-bin specific criteria are to be met in as many direction bins as possible, with at least 50% of the collected data falling into bins fulfilling the criteria. Data in some direction bins may be more variable or there may be very few data points from some directions.

Table 3 shows the four DNV criteria, and the results for the combined datasets for the three considered heights of 30, 100 and 180 m.

[*] DNV, Recommended Practice DNV-RP-J101, "Use of Remote Sensing for Wind Energy Assessments", April 2011

**Table 3: Evaluation of combined datasets for BWFZ Lot 1 and Lot 2 floating LiDARs, according to DNV criteria**

| DNV recommended criteria | 30 m | 100 m | 180 m |
|---|---|---|---|
| **Minimum duration:** *Data collection should proceed for at least 1 month at each measurement location* | 3 months | | |
| **Uncertainty:** *Recommended uncertainty of the direction-weighted metric* of approximately 1%* | 0.50% | 0.45% | 0.32% |
| **Minimum quantity**: *At least 48 hours of validated data should be collected for each wind direction bin* | Met for all wind direction bins | Met for all wind direction bins | Met for all wind direction bins |
| **Range of data:** *At least 12 hours of data should be collected in each of two wind speed bins with range spanning 4 to 16m/s for each wind direction* | Met for 11 of 12 bins (direction bin 5 contains only 6 hours in bin 8-16 m/s) | Met for all bins | Met for all bins |
| **Direction-specific:** *At least 50% of the collected data should fall into bins fulfilling the above criteria* | 96% | 100% | 100% |

Based on Table 3, it is understood that the collected wind data at floating LiDAR fulfils the DNV recommended criteria, hence the available 3 months of data is sufficient to conduct this study.

## 3.2 Wind speed gradient calculation

The wind roses of mean wind speeds are shown in Figure 3 for the three investigated heights of 30, 100 and 180 m. It can be concluded that there is a strong gradient in the WSW-direction (as expected) and that even when considering all wind directions this gradient effect is persistent.

* The metric is the direction-weighted wind speed ratio, according to the definition in the DNV guideline, as explained in Section 3.2

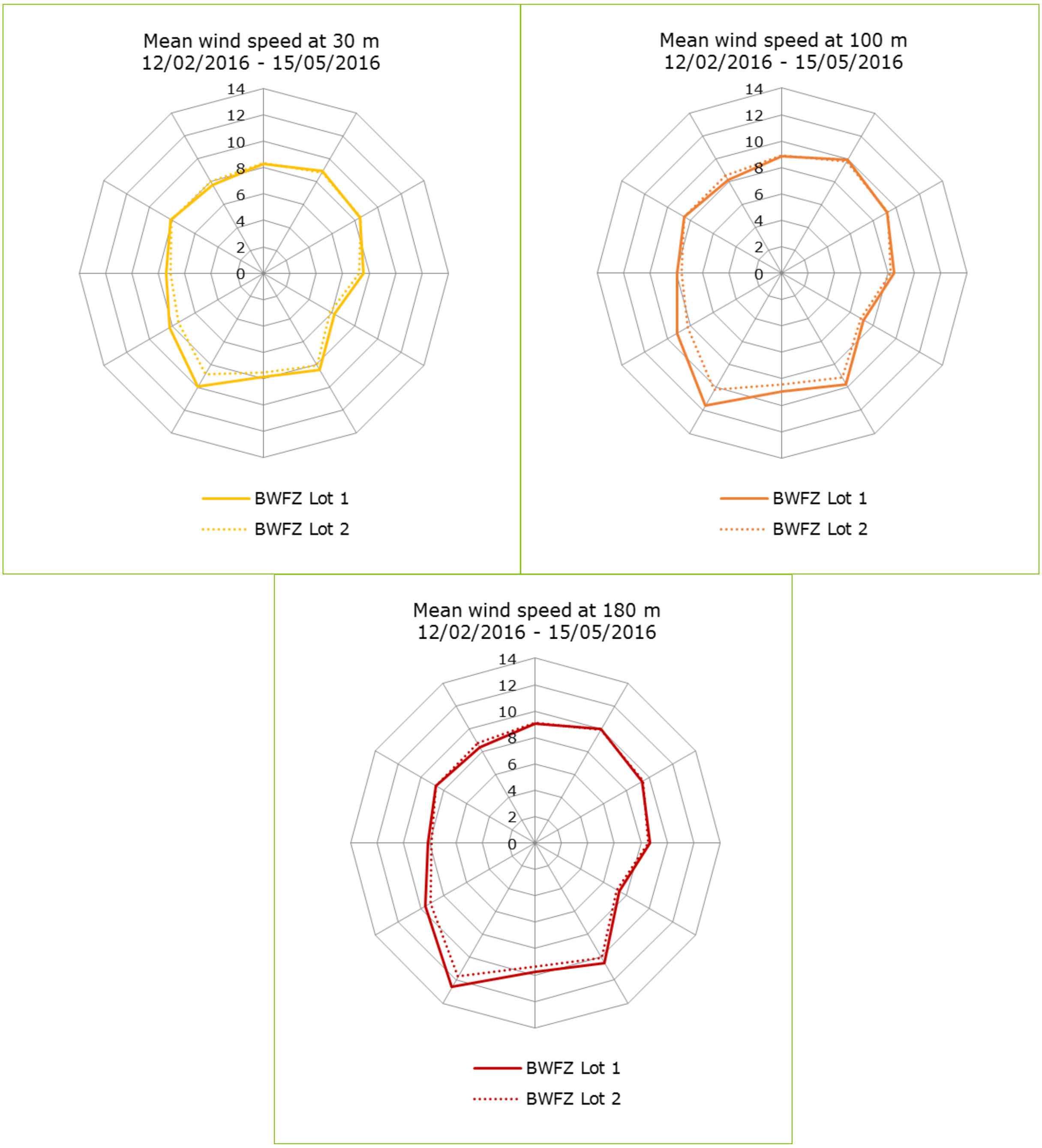


**Figure 2: Wind roses of mean wind speeds measured over 3 months by BWFZ Lot 1 and BWFZ Lot 2 floating LiDARs; there is a strong gradient in the WSW-direction, especially at 100 m, which can be attributed to wake effects from the Belgian wind farms.**

The mean direction-weighted ratio of the 10-minute measured wind speeds of the two LiDARs has been calculated, according to the metric definition in the DNV guideline. This ratio indicates the mean wind speed relation of the BWFZ Lot 2 compared to the BWFZ Lot 1. The mean direction-weighted ratio has been calculated at three different heights over the concurrent time period of 3 months.

To calculate the direction weighted ratio between the two LiDARs, the long term wind direction frequency of the Borssele wind farm zone has been considered, based on a previous Ecofys WTTS study for RVO of the Borssele wind climate.

Below are the tables for three different heights that shows the wind speed ratio in each direction.

**Table 4: Mean wind speed ratio (BWFZ Lot 2/BWFZ Lot 1) for the concurrent time period at 30m**

| Direction sector [°] | Long-term frequency [%] | Mean wind speed ratio at 30 m BWFZ Lot 2/ BWFZ Lot 1 |
|---|---|---|
| 0 | 7.0% | 1.001 |
| 30 | 5.9% | 0.998 |
| 60 | 7.5% | 1.008 |
| 90 | 6.3% | 0.963 |
| 120 | 4.7% | 0.962 |
| 150 | 4.7% | 0.958 |
| 180 | 10.3% | 0.958 |
| 210 | 15.3% | 0.881 |
| 240 | 14.0% | 0.895 |
| 270 | 9.6% | 0.958 |
| 300 | 7.4% | 0.969 |
| 330 | 7.3% | 0.996 |
| **Direction-weighted** | | **0.951** |

**Table 5: Mean wind speed ratio (BWFZ Lot 2/BWFZ Lot 1) for the concurrent time period at 100m**

| Direction sector [°] | Long-term frequency [%] | Mean wind speed ratio at 100 m BWFZ Lot 2/ BWFZ Lot 1 |
|---|---|---|
| 0 | 7.0% | 0.998 |
| 30 | 5.9% | 0.990 |
| 60 | 7.5% | 1.005 |
| 90 | 6.3% | 0.969 |
| 120 | 4.7% | 0.968 |
| 150 | 4.7% | 0.934 |
| 180 | 10.3% | 0.933 |
| 210 | 15.3% | 0.864 |
| 240 | 14.0% | 0.892 |
| 270 | 9.6% | 0.954 |
| 300 | 7.4% | 0.968 |
| 330 | 7.3% | 0.995 |
| **Direction-weighted** | | **0.943** |

**Table 6: Mean wind speed ratio (BWFZ Lot 2/BWFZ Lot 1) for the concurrent time period at 180m**

| Direction sector [°] | Long-term frequency [%] | Mean wind speed ratio at 180 m BWFZ Lot 2/ BWFZ Lot 1 |
|---|---|---|
| 0 | 7.0% | 0.996 |
| 30 | 5.9% | 0.993 |
| 60 | 7.5% | 1.002 |
| 90 | 6.3% | 0.988 |
| 120 | 4.7% | 0.993 |
| 150 | 4.7% | 0.968 |
| 180 | 10.3% | 0.958 |
| 210 | 15.3% | 0.920 |
| 240 | 14.0% | 0.945 |
| 270 | 9.6% | 0.963 |
| 300 | 7.4% | 0.967 |
| 330 | 7.3% | 0.991 |
| **Direction-weighted** | | **0.966** |

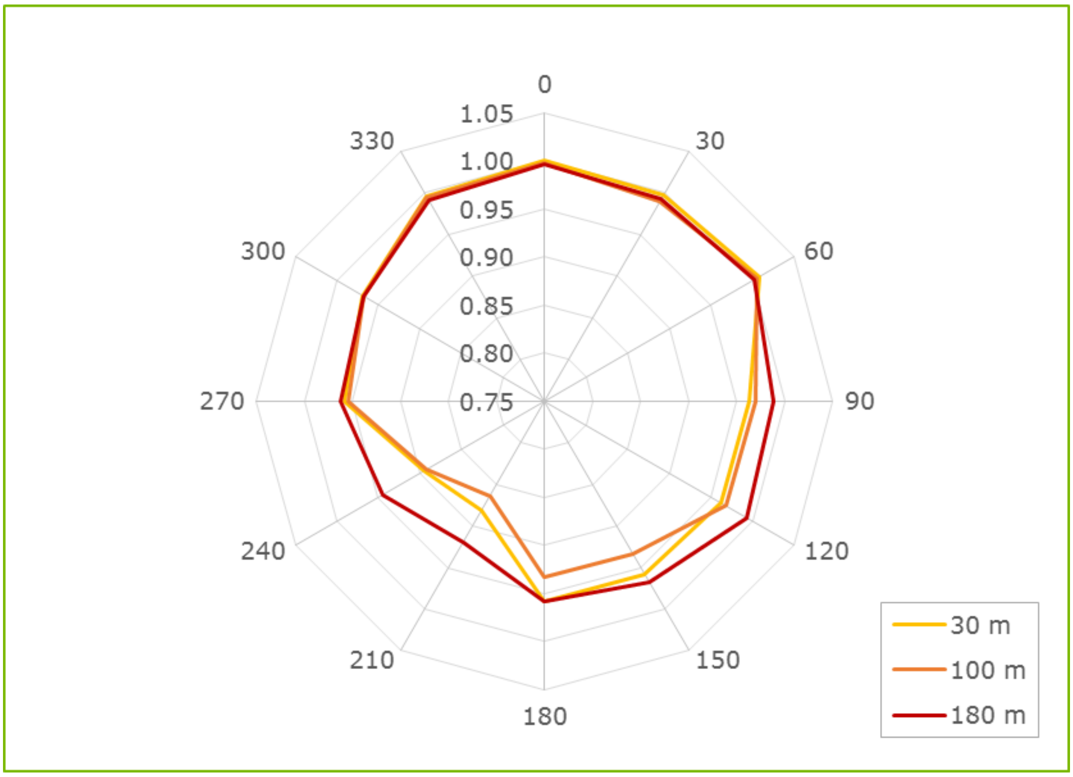


**Figure 3: Wind speed gradient plot in each wind direction, as ratio**

## 3.3 Wind speed profiles

Comparison of wind speed profiles were made for both floating LiDARs in order to see wake effects between BWFZ Lot 1 and BWFZ Lot 2 because of nearby Belgian existing windfarms. The vertical profiles of wind speed were plotted for the WSW direction.

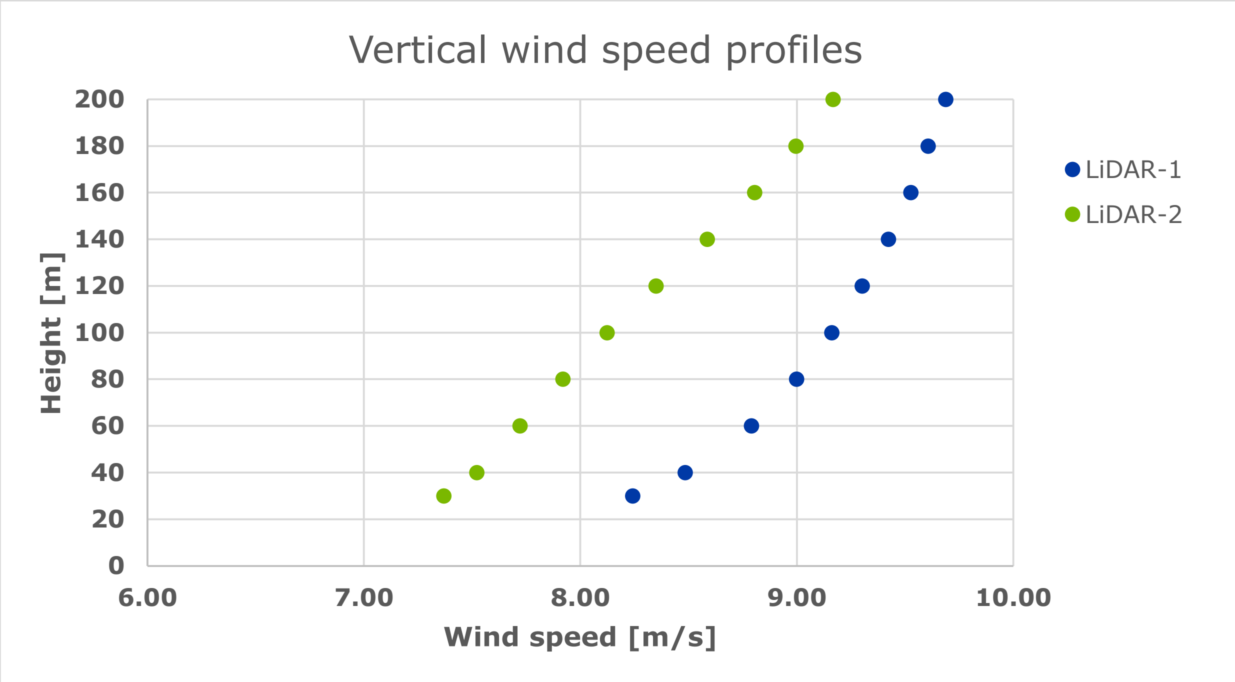


**Figure 4: Vertical wind speed profiles at both LiDAR locations in WSW direction (30dgr bin centered on 240 degree)**

The above figures suggest that, as per expectation, wind speed measurements at the BWFZ Lot 2 location are under strongly reduced wind speed because of nearby Belgian existing windfarms.

It is acknowledged here that the floating LiDARs perform volume averaging measurements. Therefore, wind farm wake effects can only be captured to a certain extent. Yet the results shown here are considered significant.

## 3.4 Uncertainty

LiDARs have found a vast acceptability in the wind industry. They are used for measuring various atmospheric and wind parameters including wind speed and wind direction for several heights. Land based LiDARs are considered as suitable replacement to meteorological met mast. Similarly, floating LiDAR has the potential to replace the meteorological met mast for the measurements.

Both LiDARs are of the type ZephIR 300s on a Fugro SeaWatch buoy. For these two LiDARs, no site-specific uncertainty calculation was performed. There are pre-deployment DNV-GL verification reports, published by RVO (http://offshorewind.rvo.nl/studiesborssele), regarding a verification of a similar type of LiDAR against Meteomast Ijmuiden. In this report, the measurement uncertainty of the wind speed measurements has not been evaluated.

Ecofys WTTS has performed uncertainty estimations for several (non-floating) ZephIR LiDARs, at Test Site Lelystad. Based on the Ecofys WTTS experience, the measurement uncertainty on a ZephIR LiDAR is around 2% at a height of 100m. Since, as of this report writing, there was no other sources available to determine the ZephIR 300s LiDAR uncertainty, this Ecofys WTTS internal expertise was used.

Ecofys WTTS considers that the uncertainty of floating LiDARs will be higher than land based LiDARs. Considering all the relevant parameters affecting floating LiDAR measurements, the uncertainty of floating LiDAR-based wind speeds will be around 3.0%. Please note that this is a high-level estimation of floating LiDAR uncertainty and it is highly recommended to perform uncertainty calculation of floating LiDAR measurements.

Considering the uncertainty of the floating LiDARs, it can be said that there is a significant wind speed gradient between both LiDARs location. Wind speed gradient between two LiDARs (e.g. 13.6% at 100 m for the WSW direction) is significantly higher than the uncertainty bands of the individual LiDAR measurements (~3.0%). It should also be noted that the uncertainty of the relative comparison in wind speeds will be lower than the uncertainty of any absolute measurements, since both measurements are performed with similar types of devices.

# 4 Post-campaign evaluation of goals

This chapter considers the final objective of this study:

i. Whether initial goals for the floating LiDAR at BWFZ Lot 2 position measurement campaign are met and whether the LiDAR can be removed from site.

In addition to the analysis in the previous chapter, Ecofys WTTS also evaluated whether the BWFZ Lot 2 data showed any signs of degraded accuracy during the three-month deployment. As per standard guideline from IEA*: *"once a LiDAR unit has been established as sufficiently accurate (see Section 5.2) there is no clear reason for suspecting that its accuracy will degrade in a systematic manner during the trial in a manner that would compromise the trial results. Therefore it is not normally recommended to perform a post-trial verification check on the LiDAR unit. Circumstances which may result in a decision to perform a post-trial validation are for example if doubt has arisen through an accident or impact affecting the LiDAR during the trial."*

During the measurement period at the BWFZ Lot 2 location, no inconsistencies have been observed in wind data time series and also there have been no reports of any accident that could have affected the BWFZ Lot 2 operation. Therefore, post-verification of the BWFZ Lot 2 LiDAR is not required and under such scenario the pre-deployment verification campaign is considered sufficient.

Based on the analysis in the previous chapter, showing that there has been sufficient data collected to evaluate the wind speed gradient from the BWFZ Lot 1 location, Ecofys WTTS recommends that the measurement campaign of the second LiDAR can be terminated/ceased. The objective of placing a second LiDAR close to existing Belgian windfarms is fulfilled.

* http://www.ieawindtask32.org/wp-content/uploads/2016/04/IEA-StateOfArtFloatingLIDAR-2Feb2016_v1.0.pdf

# 5 Conclusion

RVO commissioned Ecofys WTTS to perform an initial analysis on the status of the wind measurements at the Borssele windfarm zone from two floating LiDARs. The goal was to determine whether three months of parallel measurements from two LiDARs is sufficient to calculate horizontal wind speed gradient, and hence whether initial goals for the second floating LiDAR (at location BWFZ Lot 2) are met.

The wind speed gradient between BWFZ Lot 1 and BWFZ Lot 2 has been calculated, showing a significant WSW gradient, attributed to the wake effects of the existing Belgian wind farms.

Based on the results presented in this report, it can be concluded that:

1. The available 3-months of collected data meet the DNV criteria for a short-term campaign, hence Ecofys WTTS concludes that wind data required for calculating the horizontal wind speed gradient between two locations within Borssele windfarm zone is sufficient. Extending the measurement campaign at BWFZ Lot 2 location is not expected to change the gradient results significantly.
2. The objective for placing a second floating LiDAR close to existing Belgian wind farms is fulfilled.

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