

TNO PUBLIC

TNO Energy TransitionWesterduinweg 3
1755 LE Petten
P.O. Box 15
1755 ZG Petten
The Netherlandswww.tno.nl

T +31 88 866 50 65

TNO report**TNO 2020 R10866****Lichteiland Goeree LiDAR measurement
campaign; Instrumentation Report**

Date	11 June 2020
Author(s)	J.P. Verhoef, G. Bergman, P.A. van der Werff
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Summary

In order to better understand the wind conditions at the North Sea for future offshore wind farms a LEOSPHERE WINDCUBE V2 LiDAR was originally installed at the Lichteiland Goeree (LEG) platform in 2014 . This report describes the background of the measurement campaign, the Lichteiland Goeree (LEG) platform itself, the used LiDAR system, data sources and operational aspects. This report is an updated version of earlier released reports and covers the transition from ECN part of TNO to TNO Energy Transition.

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1 Introduction

An import step to achieve the renewable energy targets of the Netherlands is working towards 60GW of offshore wind energy in 2050. The Offshore Wind Energy Act gives the government the option of issuing lots for the development of offshore wind farms. In line with these policy intentions to arrive at 3,500 MW from the first roadmap for offshore wind energy, lots have been issued in the wind energy areas Borssele and the Dutch coast ('Hollandse Kust Noord' (HKN) and 'Hollandse Kust Zuid' (HKZ)).

The commissioning of wind farms within these plots, as described in the Roadmap 2023 (see Figure 1), meets the objective of the Energy Agreement for offshore wind energy, namely approximately 4,450 MW in 2023, Reference [1].

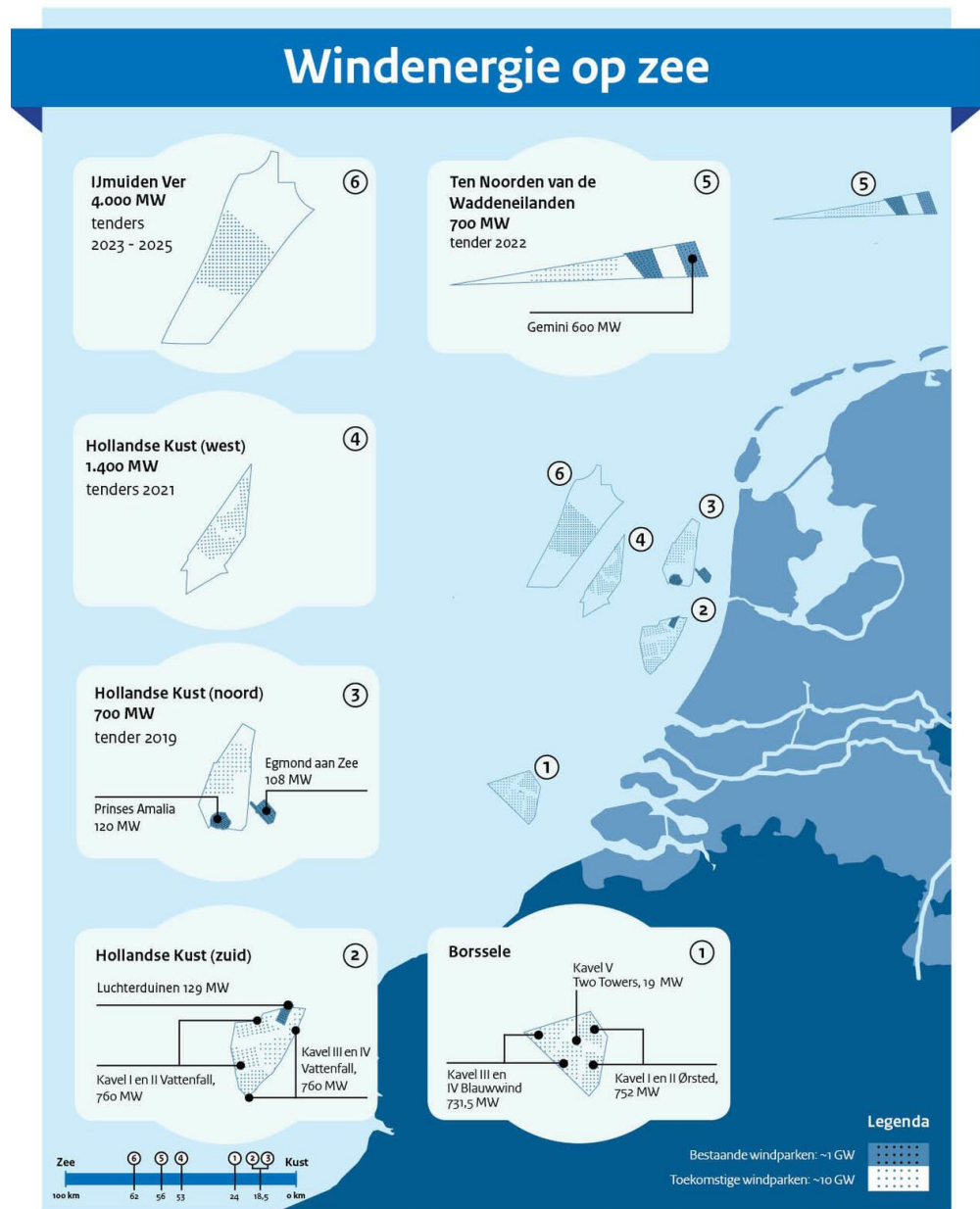


Figure 1 Offshore wind development plans in NL until 2030

To gain more knowledge of the meteorological conditions for the future offshore wind farms, the Dutch Government set up a measurement campaign on strategic points in the designated areas to collect the wind conditions at these locations. This helps developers to make accurate offshore wind farm business plans for the indicated lots. The three running campaigns within the Wind @ Sea – measurement campaign funded by the Dutch Ministry of Economic Affairs and Climate Policy are LiDAR measurements at Lichteiland Goeree (LEG), Europlatform (EPL) and K13-A.

An important measurement campaign, the Meteorological Mast Ijmuiden (MMIJ) measurements, was stopped in 2013. Data collected during this campaign still proves to be of great value and can be retrieved via the Wind @ Sea website, Reference [6]. That measurement campaign, as well as the meteorological mast

measurements at the Offshore Wind farm Egmond aan Zee (OWEZ) and the various floating LiDAR measurements in the Dutch offshore zones (Borssele, Hollandse Kust (Noord, West and South), “Ten Noorden van de Wadden” (TNW) and IJmuiden Ver) provide valuable data.

As part of the Wind @ Sea measurement campaign, TNO started a LiDAR measurement campaign on Lichteiland Goeree in 2014. This report describes the instrumentation for the LEOSPHERE WINDCUBE V2 LiDAR measurement campaign at Lichteiland Goeree (LEG). Chapter 2 describes the platform Lichteiland Goeree (LEG), its location and use. Chapter 3 describes the used instrumentation (eq. LEOSPHERE WINDCUBEv2 LiDAR). Chapter 4 presents the mechanical as well as the electrical installation and gives the important information like measurement heights, North orientation, data format etc. Chapter 5 describes the data handling from measurements to checking and exporting of the generated data. Chapter 6 finally describes the operation and maintenance (O&M) aspects regarding the measurement campaign.

2 Lichteiland Goeree (LEG)

At a distance of about 30 km south-west from Hoek van Holland the platform Lichteiland Goeree (LEG) is situated. The exact location of the platform can be seen in Figure 2.



Figure 2 Location of Lichteiland Goeree

The platform serves as a beacon for ships on the North Sea. Also, meteorological measurements and wave measurements are being performed on the platform. A picture of the platform can be seen in Figure 3.



Figure 3 Lichteiland Goeree (LEG)

Lichteiland Goeree is part of the North Sea Monitoring Network which purpose is to collect up-to-date information on the air and the seawater. This meets the need for data of the meteorological and oceanographic conditions on the North Sea. The

North Sea Monitoring Network consists of several permanent monitoring locations in and around the North Sea. Some of them are in the English section of the North Sea.

Some specific data concerning Lichteiland Goeree are:

RD coordinates 36779, 438793 (Rijksdriehoeksmeting X,Y in meters)
 Degrees 51.92503 , 3.66844 (Notation DD.ddddd°)
 Degrees and Minutes N 51 55.502, E 3 40.106 (Notation DD°MM.mmmm')
 Degrees, minutes & seconds N 51 55 30.1, E 3 40 6.4) (Notation DD°MM'SS.s")

LAT = MSL - 115 cm

NAP = LAT + 92 cm (Hoek van Holland)

LAT = LLWS - 12 cm

References for this information can be found in Reference [2] and Reference [3].

The platform consists of a helicopter deck on a height of 23.54 meter above LLWS (Lowest Low Water Spring) with an accommodation deck below. The floor of this accommodation deck is on 19.00 meter above LLWS, Reference [4] .

A top view of the platform can be seen in Figure 4 while Figure 5 shows the rear view.

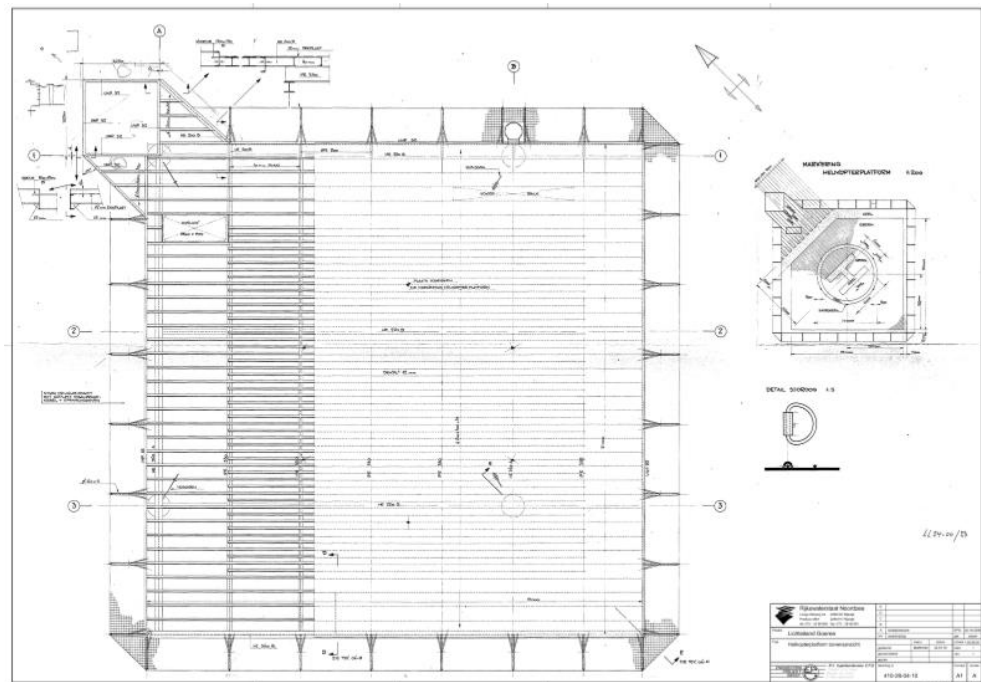


Figure 4 Top view of Lichteiland Goeree

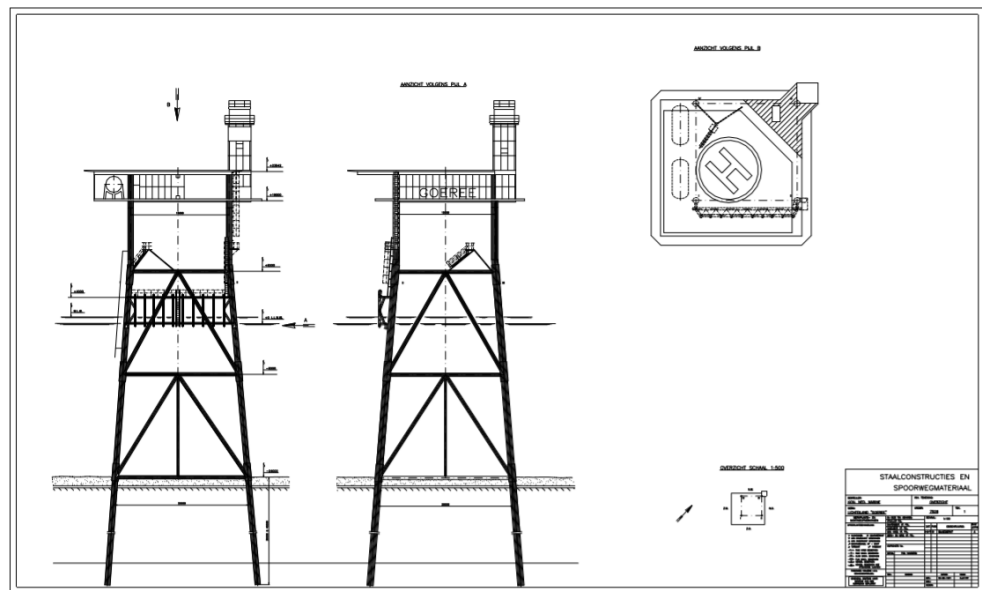


Figure 5 Rear view of Lichteiland Goeree

To perform wind speed measurements on the platform on higher altitudes (up to 220m above sea level), TNO installed a LEOSPHERE WINDCUBE V2 LiDAR on the platform.

Chapter 4 describes the selected measurement heights in more detail.

3 LEOSPHERE WINDCUBE V2 LiDAR

The LEOSPHERE WINDCUBE V2 is a LiDAR instrument used for wind profile measurements which can measure up to 200 meter. The principle of the LiDAR is that it sends infrared pulses into the atmosphere. Four beams are sent successively in four defined directions along a 28° scanning cone. The laser pulses are backscattered by aerosol particles in the air (such as dust, water droplets, aerosol etc.) that move with the wind speed. The collected backscattered light contains information on wind speed and wind direction which can be calculated by using a Doppler induced laser wave length shift, Reference [5]. The LiDAR can measure up to 10 different range gates allowing to measure wind speed and wind direction at 10 different heights.

Figure 6 shows the LEOSPHERE WINDCUBE V2. The specifications of the LEOSPHERE WINDCUBE V2 can be found in Appendix A.

The WINDCUBEv2 is a class 1M laser product and the system should be handled with caution. It is important not to stare directly into the beam with optical instruments like telescopes or binoculars. The laser beam is eye-safe according IEC EN 60825-1, January 2008, see Appendix B.



Figure 6 LEOSPHERE WINDCUBE V2

4 Installation LEOSPHERE WINDCUBE V2 LiDAR

This chapter describes the installation of the LEOSPHERE WINDCUBE V2 LiDAR. The location as well as the mechanical and electrical installation are described, together with the limitations in placement. Furthermore the applied LiDAR settings are given.

4.1 Installation limitations

The installation possibilities of the LiDAR are limited by the following conditions:

- The top of the platform is a helicopter landing. It is not possible to install the LiDAR on top of the platform, as no objects are allowed to protrude above the helicopter platform.
- Next to the helicopter platform, on the North corner of the platform, a lighthouse is present. Unfortunately it is not possible to install the LiDAR close to this lighthouse, as on top of the lighthouse a radar is rotating, which would hinder the laser beam of the LiDAR.

4.2 Installation possibility

The only possible installation location for the LiDAR was the side of the helicopter platform, with enough distance to the lighthouse not to hinder the LiDAR's laser beams. A suitable place for this has been found just beside the cage-ladder on the north-west side of the platform, about 3 meters away from the West corner of the platform. In Figure 7 the position of the LiDAR on the platform is shown.

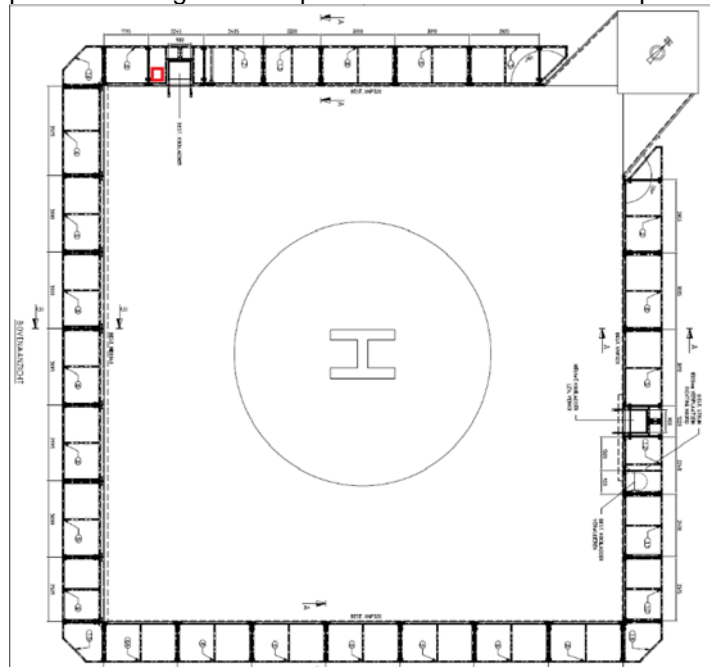


Figure 7 Lichteiland Goeree with location of LiDAR

4.3 Mechanical installation

On 6 October 2014 the first LiDAR has been installed under the helicopter platform. Pictures of the installed LiDAR can be found in Figure 8 and Figure 9.



Figure 8 Installed LiDAR (side view with safety net removed)

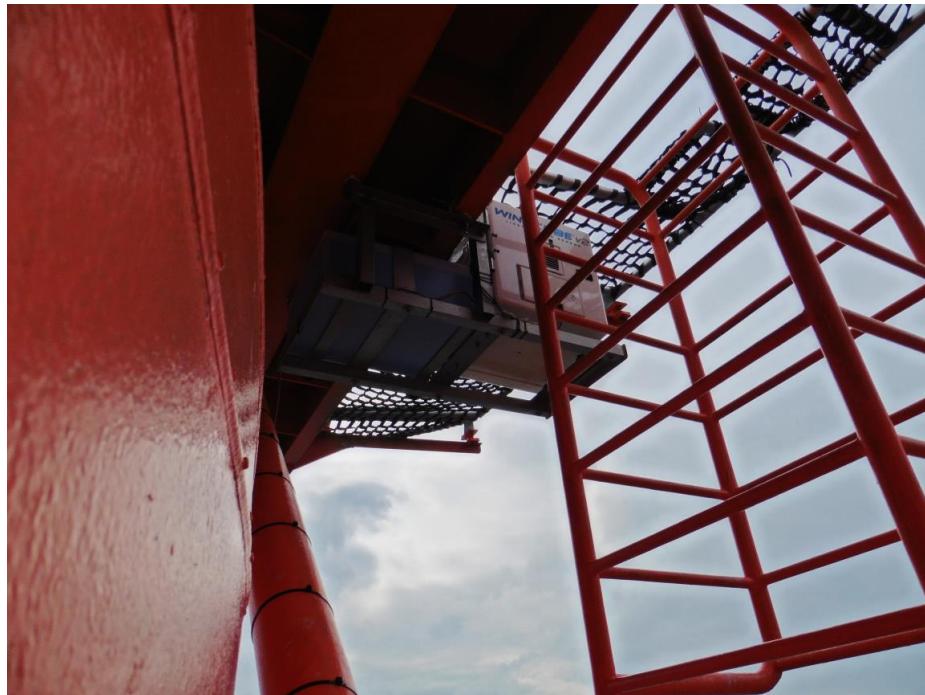


Figure 9 Installed LiDAR (bottom view with safety net installed)

4.4 Orientation of the LiDAR

The LiDAR has been oriented in such a way that the 'North' marker of the LiDAR is on the left side of the LiDAR (pointing away from the lighthouse), see Figure 10. Looking at Figure 7, true north is diagonal to the platform in the north-east direction in the drawing, this results in a directional offset of exact -135° for the LiDAR.

4.5 Safety net adjustment

After the initial LiDAR installation the laser was partly hindered by the safety net above the LiDAR lens. In consultation with Rijkswaterstaat a temporary replacement safety net has been manufactured, with a hole in the safety net just above the LiDAR lens, see Figure 10.

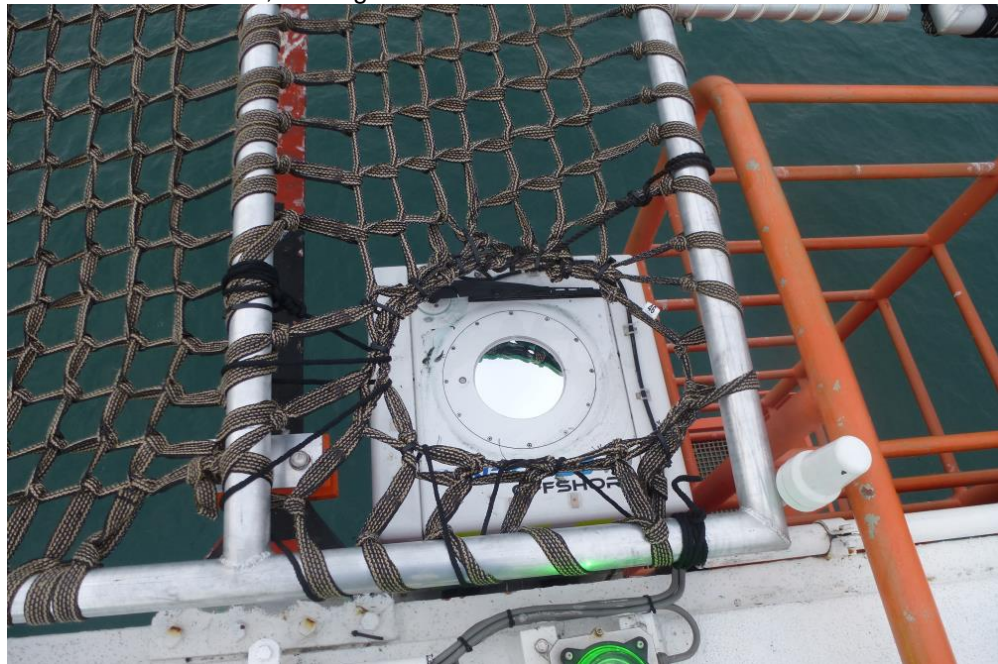


Figure 10 Modified replacement safety net installed

4.6 Electrical installation

4.6.1 *Electrical power*

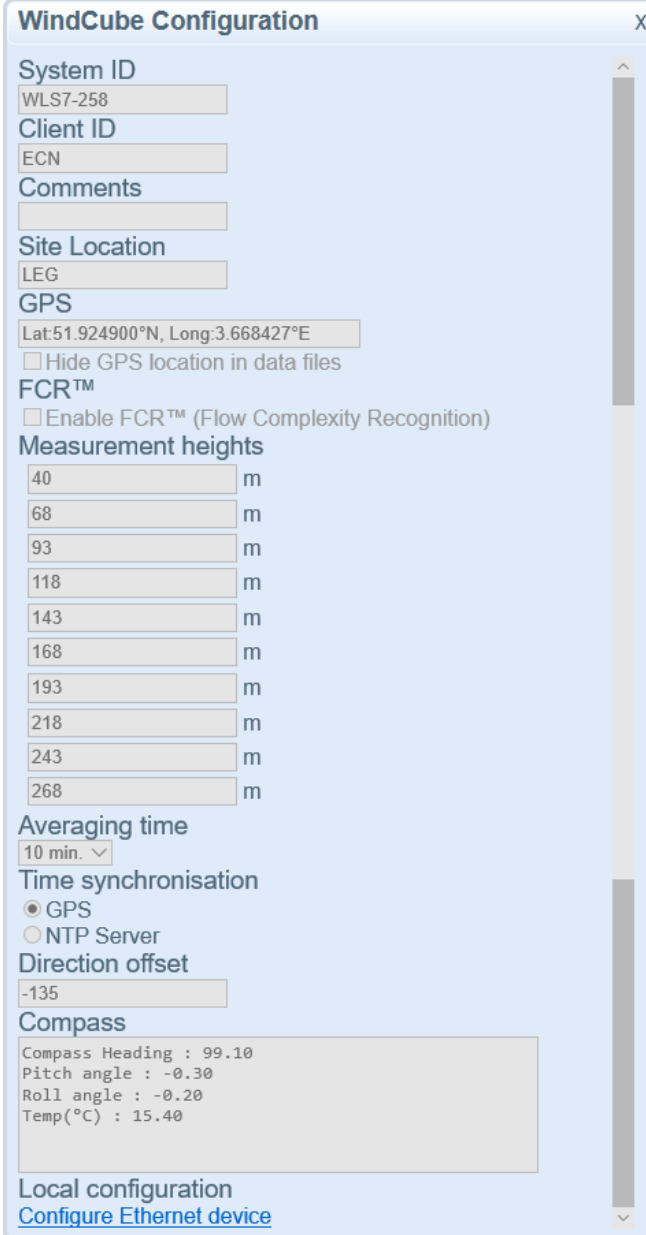
To be able to operate, the LiDAR needs a 24V DC power supply. The power requirements of the LiDAR can be found in Appendix A. From the LiDAR, an electrical cable runs along diagonal brace, attached with tie-wraps (see Figure 9). From the bottom of this tube the cable has been lead through a cable duct and through a hole in the wall to enter the computer room of the platform. In this computer room the power supply AC(230V)-DC(24V) converter is plugged into a 230V AC wall outlet.

4.6.2 *Communication*

Initially a satellite communication equipped LiDAR was installed in 2014. Shortly after, in 2015, a 3G/4G router is installed in the computer room of the platform as 3G network is available at the LEG platform. From this router an Ethernet cable was routed to the LiDAR along the installed power cable.

4.7 LiDAR settings

The settings for the LiDAR are easy to adjust. In the following figure an example of the configuration screen is given.



The screenshot shows the 'WindCube Configuration' window with the following settings:

- System ID:** WLS7-258
- Client ID:** ECN
- Comments:** (empty text box)
- Site Location:** LEG
- GPS:** Lat:51.924900°N, Long:3.668427°E
 - Hide GPS location in data files
- FCR™:**
 - Enable FCR™ (Flow Complexity Recognition)
- Measurement heights:**
 - 40 m
 - 68 m
 - 93 m
 - 118 m
 - 143 m
 - 168 m
 - 193 m
 - 218 m
 - 243 m
 - 268 m
- Averaging time:** 10 min.
- Time synchronisation:**
 - GPS
 - NTP Server
- Direction offset:** -135
- Compass:**
 - Compass Heading : 99.10
 - Pitch angle : -0.30
 - Roll angle : -0.20
 - Temp(°C) : 15.40
- Local configuration:**
 - [Configure Ethernet device](#)

Figure 11 Example of setting screen LiDAR

Additionally a directional offset is applied in the settings to correct the measured wind direction to the North. As described in Chapter 4.4 for the LiDAR at LEG the directional offset is -135° .

4.8 Measuring heights

Based on the height of the LiDAR and the chosen reference level, in this case MSL (Mean Sea Level), the relative measured LiDAR heights are corrected, in their signal names, to the absolute measurement heights related to reference level MSL. Prior to June 2020 the height of the LiDAR was considered to be 23 meter above MSL. However during writing of this report, it was discovered that the 23 meter was based on reference level LLWS. Based on relation of the different reference levels at the LEG location, as described in Chapter 2, the MSL is 1.03 meter higher than LLWS. Therefore the real measuring heights of the LiDAR with the current height configuration to reference level MSL is one meter lower than assumed. From June 2020 onwards the signal names of the height dependent signals have been corrected to the actual measuring heights to MSL. The LiDAR height configuration related to LLWS as well as to MSL is found in Table 1.

Table 1 LiDAR configuration and measurement height to LLWS and MSL

No	LiDAR height configuration	measurement height (LLWS)	measurement height (MSL)
1	40	63	62
2	68	91	90
3	93	116	115
4	118	141	140
5	143	166	165
6	168	191	190
7	193	216	215
8	218	241	240
9	243	266	265
10	268	291	290

5 Data handling

In this chapter we will consider the three TNO data sources / flow as well as the additional available data sources, namely:

- Standard produced LEOSPHERE data files STA (10 minute statistical data) and RTD (1 second data);
- TNO database handling and checking;
- TNO data export via www.WindOpZee.net;
- Additional LEG data from RWS and KNMI.

5.1 LEOSPHERE WINDCUBE V2 LiDAR data files

The LEOSPHERE WINDCUBE V2 LiDAR delivers two data sets: the 10 minute statistical data (STA output file) and the 1 second data (RTD output file)

For each altitude the measurements are grouped in 18 columns, see Figure 12, and each line in the STA file represents the averaged data acquired during the past 10 minutes (for the given date and time).

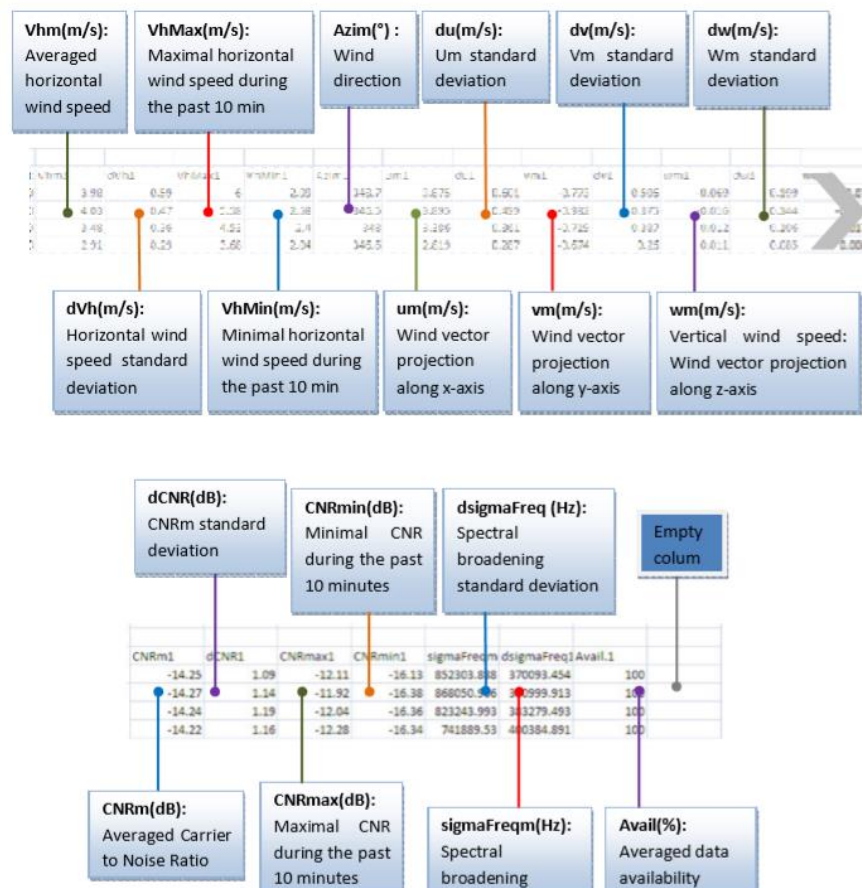


Figure 12 File format WINDCUBE V2 STA file

All the produced STA and RTD data are transferred on a daily bases from each measurement location to the data server at TNO.

The file name is time stamped as described below:

WLS7-XXXX_YYYY_MM_DD_hh_mm_ss

- WLS7-XXXX: WINDCUBEv2 serial number
- YYYY: year of data
- MM: month of data
- DD: day of data
- hh_mm_ss: time of the first registered in file

5.2 TNO –data base

After data transfer the data will be imported into the TNO data base and then the processing starts. The Lead Engineer will evaluate daily the “daily-plot”, see Figure 13, which is automatically created and sent by email. If needed the Lead Engineer can perform a post-validation so that a specific data period is marked as invalid and no longer is visible.

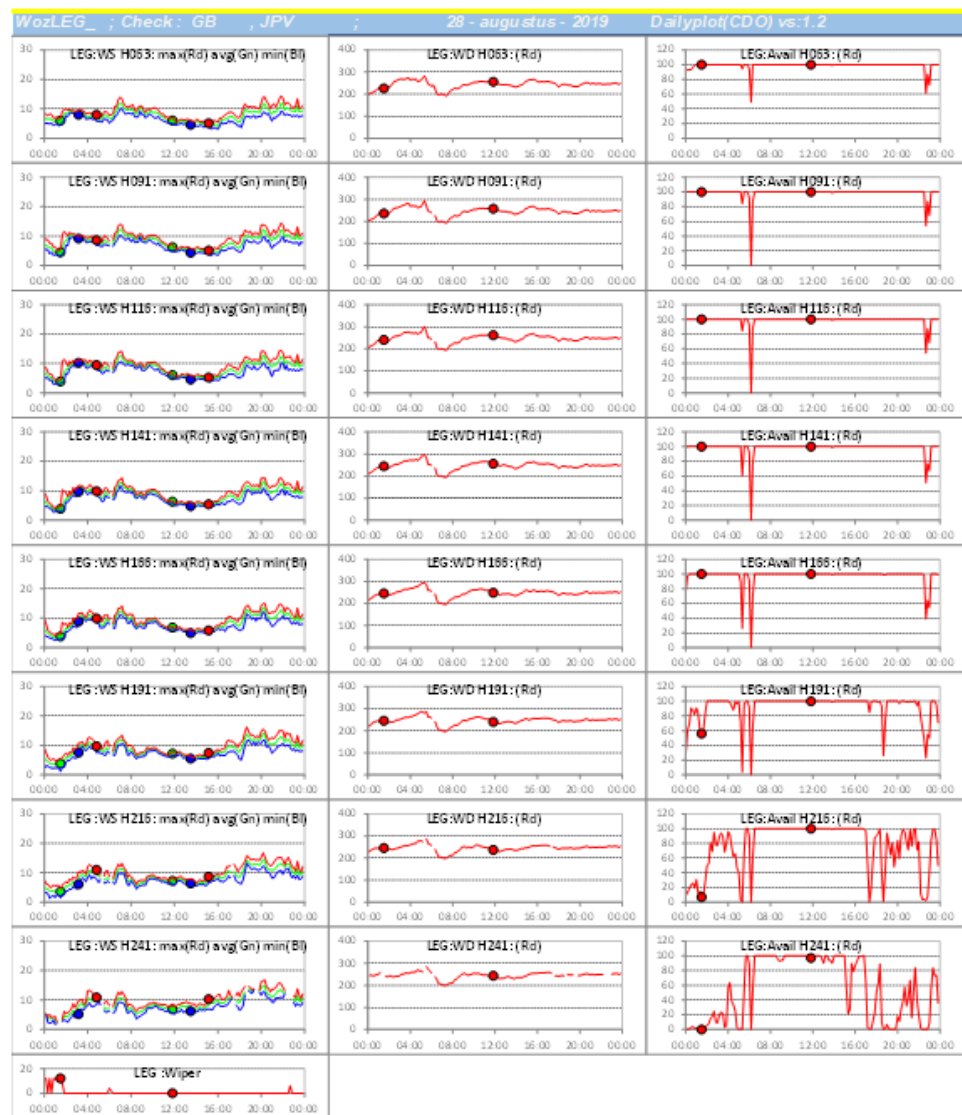


Figure 13 Daily-plot for LEG measurement campaign

5.3 Data export Lichteiland Goeree

TNO makes the 10 minute statistical data available via the www.WindOpZee.net website. Here you can find the historical data of the LiDAR measurement campaign.

The order for export and presentation on the website will be as follows.

LEG-yyyy-mm.CSV for the previous month(s).

After a quarter is completed the monthly files will be replaced by LEG-yyyy-Qx.CSV (where x stands for the actual quarter)

After the year is completed the quarterly files will be replaced by a yearly file like LEG-yyyy.CSV

5.4 Additional data sets

Besides the TNO LiDAR measurements, both KNMI and Rijkswaterstaat also perform measurements on Lichteiland Goeree. Those measurements can be divided in Meteorological Measurements (KNMI) and Oceanographic measurements (Rijkswaterstaat).

Meteorological parameters include:

- Air pressure
- Wind speed / Wind direction
- Air temperature
- Relative humidity
- Visibility

Oceanographic parameters include:

- Water level
- Water temperature
- Wave height

The oceanographic parameters are measured with a Radac WaveGuide Radar F08 free space type which is installed on the jacket construction 8 meter above M.S.L.

The measurements are not carried out by TNO but they are important reference measurements. Together with the LiDAR data the availability and plausibility is checked on a daily basis.

6 Operational and maintenance aspects

The LEOSPHERE WINDCUBE V2 was first installed on October 10th, 2014. According to TNO quality system the LiDAR is replaced every two years and will be serviced every year. All operational aspects with respect to installing and maintaining the LiDAR are recorded in the Logbook.

In the following table, an overview is given of the used LiDAR's and the period that they were operational. It should be noted that before the LiDAR was installed at the LEG platform it was first calibrated at the TNO Ground based RSD Verification Facility, Reference [7], Reference [8] and Reference [9].

Table 2 Overview of applied LiDAR @ LEG

LiDAR	TNO code	Period	Reason for replacement
127	DELI	06-10-2014 to 10-04-2015	Satellite communication
258	DELI	10-04-2015 to 28-09-2015	GSM(communication improved)
127	DELI	28-09-2015 to 05-10-2017	Periodically replacement
577	DELI	05-10-2017 to 24-10-2019	Periodically replacement
258	DELI	24-10-2019 to	

By web interface the LEOSPHERE WINDCUBE V2 can be accessed and the status of components can be monitored, see Figure 14.



Figure 14 Screenshot WINDCUBE V2 web interface

7 References

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A Specifications of the WINDCUBE V2 LiDAR

Specifications

MEASUREMENTS

Range	40m to 200m
Data sampling rate	1s
Number of programmable heights	12
Speed accuracy	0,1m/s
Speed range	0 to +60m/s
Direction accuracy	2°

ELECTRICAL

Power supply	18-32V DC / 93 to 264 VAC 50-60 Hz
Power consumption	45W

ENVIRONMENTAL

Temperature range	-30°C to +45°C / -22 °F to 108°F
Operating humidity	0 .. 100 %RH
Housing classification	IP67
Shocks & vibration	ISTA / FEDEX 6A
Safety	Class 1M IEC/EN 60825-1
Compliance	CE

TRANSPORTATION

Size	System : 543 x 552 x 540 mm Transport case : 685 x 745 x 685 mm
Weight	System : 45 kg Transport case : 21 kg

SOFTWARE/DATA

Data format	ASCII
Data storage	SSD and compact flash (backup storage)
Data transfer	LAN/USB
Standard WINDSOFT™ Software	Configuration & control Real time display Diagnostic
Output data	1s/10min horizontal & vertical wind speed Min & max, direction, SNR Quality factor (data availability) GPS coordinates

Figure A.1 WINDCUBE V2 LiDAR specifications sheet

B Declaration of eye safety compliance



Declaration of Eyesafety compliance

The Wednesday, June 16, 2010
at Orsay, France

I, Alexandre Sauvage, CEO of Leosphere Corporation, hereby testify that the WINDCUBE Lidar technology is compliant with the Laser safety: IEC EN 60825-1, January 2008.

The tests of compliance have successfully been passed at the LNE, Laboratoire national de métrologie et d'essais, LNE-Paris, 1, rue Gaston Boissier, 75724 Paris Cedex 15.

The compliance certification document reference is #L0207508, dated March 19, 2010.

Alexandre SAUVAGE, President



Leosphere SAS au capital de 61752 euros - SIRET : 452 972 649 00019
76 rue Monceau 75006 Paris - 01 81 87 05 00

Figure B.1 WINDCUBE V2 laser declaration of eye safety compliance