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TNO report

TNO 2020 R10868

**K13-a LiDAR measurement campaign;
Instrumentation Report**

TNO Energy Transition

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Date	29 September 2020
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Copy no	
No. of copies	
Number of pages	24 (incl. appendices)
Number of appendices	
Sponsor	Ministry of Economic Affairs and Climate Policy
Project name	2020 Wind conditions @ North Sea
Project number	060.42447

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Summary

In order to better understand the wind conditions at the North Sea for future offshore wind farms a ZX Lidars ZX300M LiDAR was installed at the K13-a platform of Wintershall Noordzee B.V. in 2016. This report describes the background of the measurement campaign, the platform itself, the used LiDAR system, data sources and operational aspects. The measurement data is available via the www.WindOpZee.net website Reference [2]. This report is an updated version of earlier released reports and covers the transition from *ECN part of TNO* to *TNO Energy Transition*.

Contents

	Summary	2
1	Introduction.....	4
2	Platform K13-a	6
3	ZX Lidars ZX300M.....	10
4	Installation ZX Lidars ZX300M LiDAR.....	11
4.1	Installation limitation	11
4.2	Installation possibilities	11
4.3	Mechanical installation.....	11
4.4	Electrical installation	12
4.5	Orientation of the LiDAR.....	13
4.6	Obstacles	13
4.7	LiDAR settings	13
5	Data handling	15
5.1	ZX Lidars ZX300M data files	15
5.2	TNO data base	15
5.3	Data export K13-a.....	16
5.4	Additional data sets	17
5.5	Wind direction correction	18
6	Operation and maintenance aspects.....	19
7	References	20

1 Introduction

An important step to achieve the renewable energy targets in the Netherlands is working towards 60GW offshore wind energy by 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 3,5 GW 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))(Figure 1).

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, a portfolio of 4,5 GW by 2023 and 11.5 GW by 2030 Reference [1].

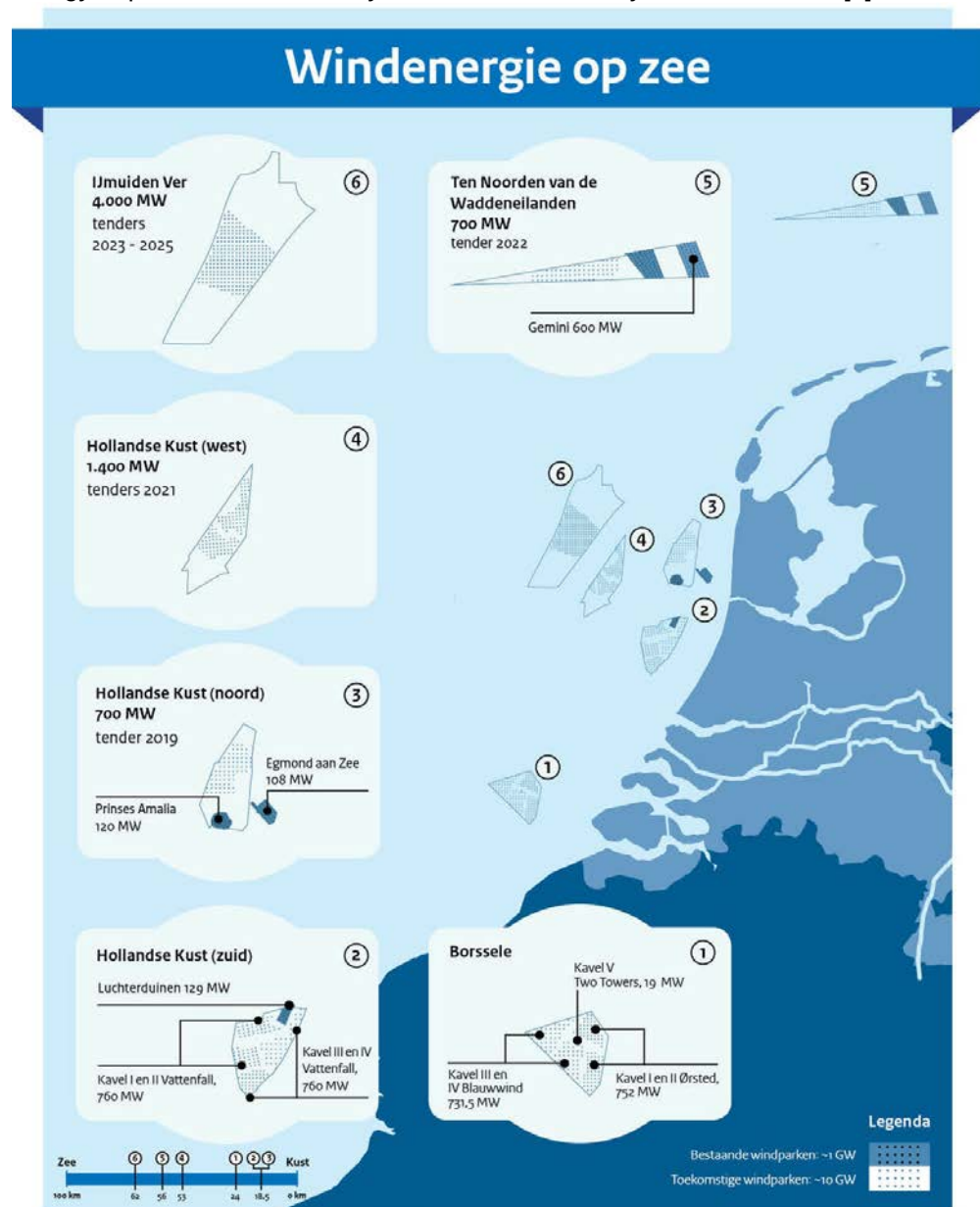


Figure 1 Offshore wind development plans in NL until 2030

To gain more knowledge about the meteorological conditions for the future offshore wind farms, the Dutch Government has set up a network of measurement campaigns at strategic locations in the designated areas aiming at collecting and determining the wind conditions. This helps developers to make accurate offshore wind farm business cases. So far, there are three running campaigns within the Wind@Sea – measurement program funded by the Dutch Ministry of Economic Affairs and Climate Policy are LiDAR measurements at Lichteiland Goeree (LEG), Europlatform (EPL) and K13-a (www.windopzee.net).

Within the 10 years of experience on measurement campaigns run by the wind energy department of TNO it is worthwhile to mention the Meteorological Mast IJmuiden (MMIJ) that measured meteorological quantities from November 2011 until March 2016. This dataset proves to be of great value for both WRA studies as well as general meteorological studies and can be retrieved via the Wind@Sea website Reference [2] . Additionally, 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) as well as IJmuiden Ver) render the *Wind Op Zee* program valuable for application in the energy sector.

As part of the Wind @ Sea measurement program; this report describes the instrumentation phase of the TNO LiDAR measurement campaign at K13-a, which started in 2016. The report is structured as follows: Chapter 2 describes the platform K13-a, its location and use. Chapter 3 describes the used instrumentation (eq. ZX Lidars ZX300M 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 Platform K13-a

The K13-a offshore platform owned by Wintershall Noordzee B.V. is located northwest of Den Helder, 101 kilometres from the coast, see Figure 2. The platform serves as a production platform for natural gas. Since November 2016 wind measurements are carried out by TNO using a platform-mounted ZX 300M wind LiDAR Figure 6 (~35 m above MSL). The platform is part of the North Sea Monitoring Network consisting of several permanent monitoring locations.



Figure 2 Locations of TNO offshore LiDAR measurements

The platform serves as a measurement station for oceanographic (Rijkswaterstaat) and meteorological (KNMI) measurements. An aerial picture of the platform can be seen in Figure 3.



Figure 3 Aerial view of the K13-a platform

Some specific data concerning the K13-a are:

Coordinates:	N53.217860° E3.218500° / 53°13'4.3"N 3°13'6.6"E
Water depth:	28 meter
Heading platform north:	325° relative to true North

A top view and side view drawing of the K13-a platform can be seen in Figure 4 and Figure 5.

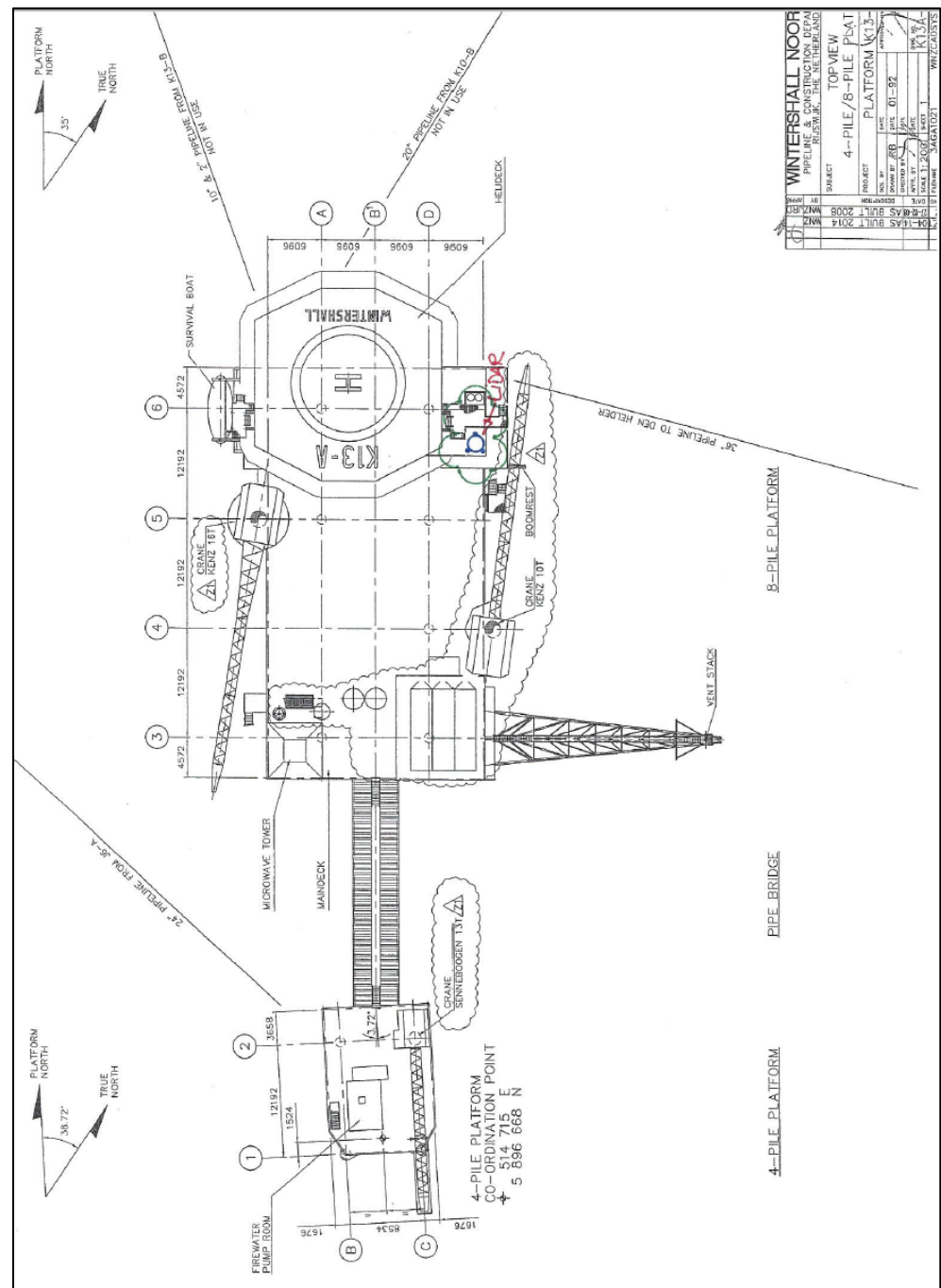


Figure 4 Top view of the K13-a platform (platform north pointing upwards)

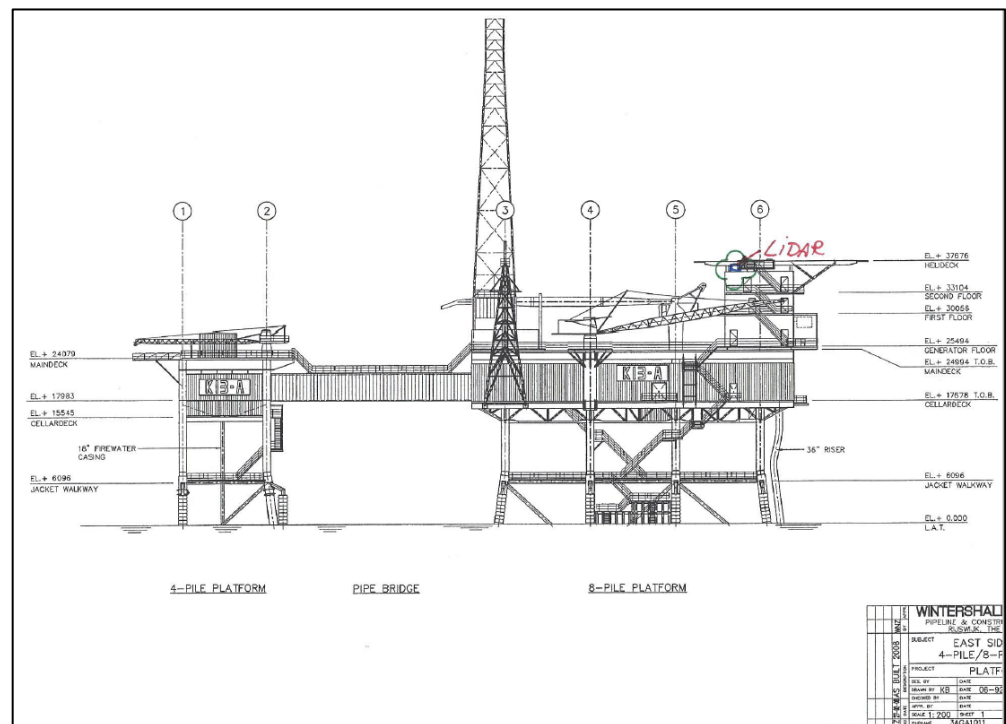


Figure 5 East Side view of the K13a platform

3 ZX Lidars ZX300M

The ZX Lidars Z300M LiDAR consists of a tripod-shaped housing, with dimensions of ca. 90 x 90 x 90 cm. The inclined top of the housing contains the lens through which the laser beam is projected upwards.

A picture of the system can be seen in Figure 6.



Figure 6 ZX Lidars ZX300M LiDAR

The laser beam of this LiDAR points up with an angle of 30 degrees with respect to the vertical, and sweeps to describe full circles, as can be seen in Figure 10.

4 Installation ZX Lidars ZX300M LiDAR

4.1 Installation limitation

The installation of the LiDAR is limited by the fact that the top of the platform is a helicopter landing area, which makes it impossible to install the LiDAR on top of the platform, as no objects are allowed to protrude above the helicopter deck.

4.2 Installation possibilities

Just below the helicopter deck at the east side the lidar is installed on top of the accommodation building, see Figure 5.

The helicopter deck height: 37.675 meter LAT

LiDAR platform height: 36.190 meter LAT, 35.130 MSL

At this location the top of the LiDAR is below the helicopter deck and installed high enough to have a clear view, see Figure 8.

4.3 Mechanical installation

The LiDAR is mounted on top of the accommodation building with six bolts on three hard plastic mounting blocks. The three blocks are mounted to the platform with three bolts and made watertight using Sikaflex, see Figure 7.

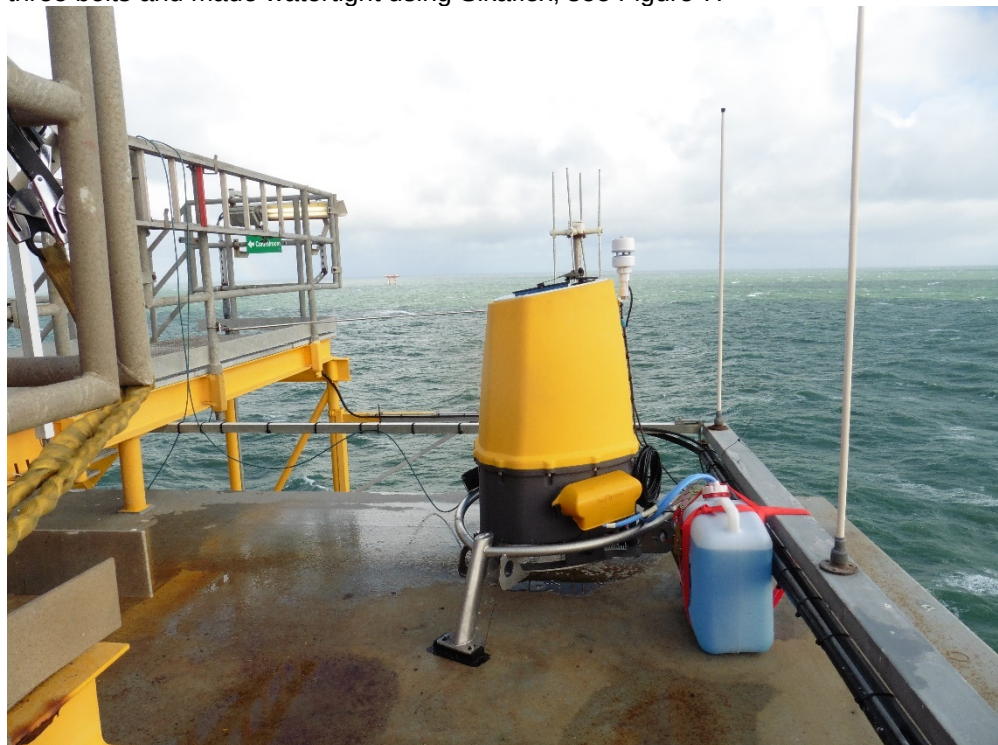


Figure 7 ZX300M mounted on top of the accommodation building at K13-a

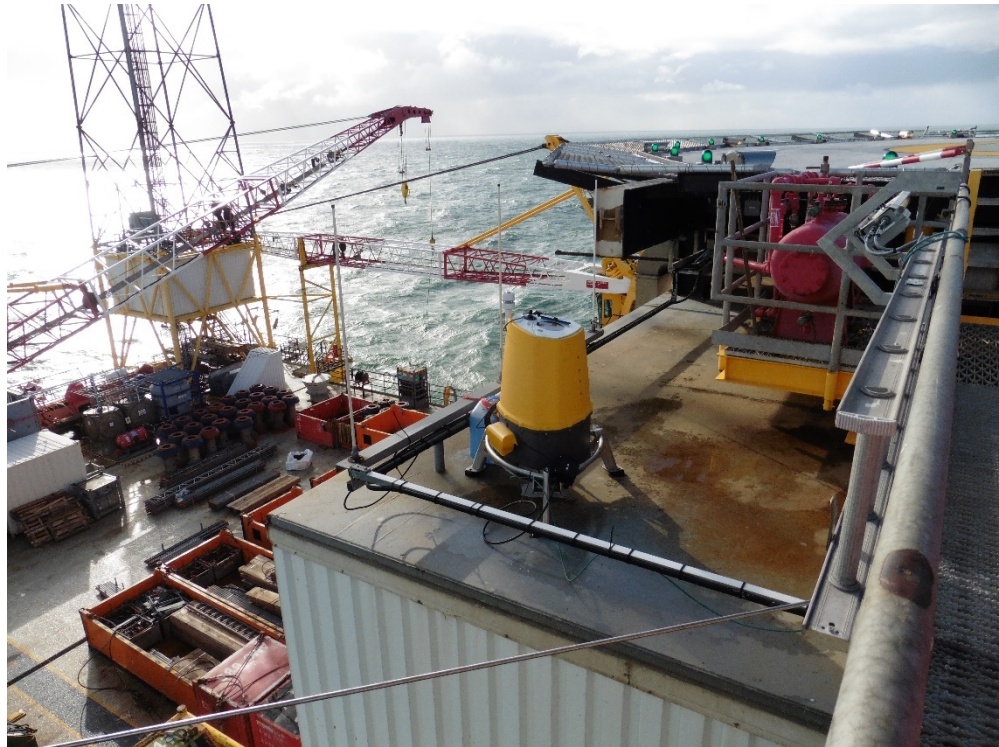


Figure 8 ZX300M LIDAR platform just below the helicopter deck

4.4 Electrical installation

4.4.1 *Power supply*

To be able to operate, the LiDAR needs a 12VDC power supply. The power requirements of the LiDAR in standard climate conditions is 69 Watt, see Appendix B.

From the Lidar a power cable is guided to the computer room, where the LiDAR power AC(230V)-DC(12V) transformer is located and plugged into an 230VAC socket.

4.4.2 *Communication*

To be able to transfer the data measured by the LiDAR to TNO, a laptop is installed in the computer room, located close to the LiDAR. The laptop is connected to the internet by local wireless network and satellite connection, see Figure 9.

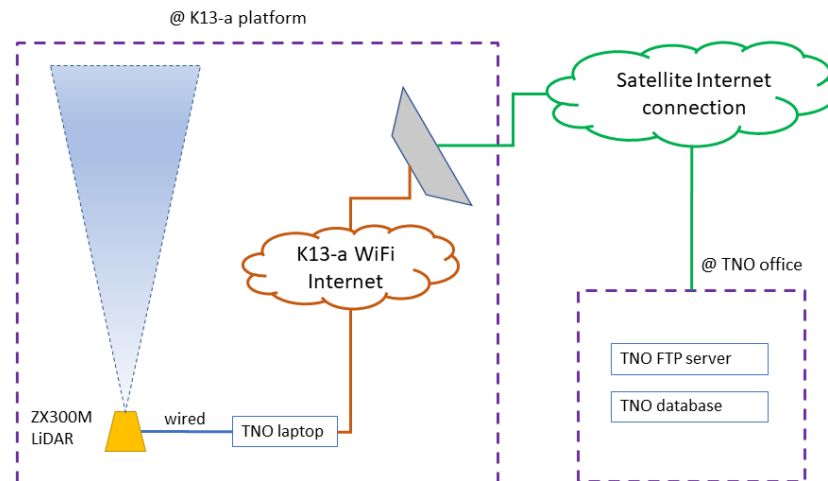


Figure 9 K13-a LiDAR campaign network layout

4.5 Orientation of the LiDAR

The LiDAR has been installed with the 'North' marker of the LiDAR pointing towards the platform North. As seen in Figure 4 the platform North is orientated 35 degrees west of true north. Therefore a $360-35=325$ degrees bearing is configured in the LiDAR settings, see Figure 10.

4.6 Obstacles

The ZX300M LiDAR is installed just below the helicopter deck on a platform to the side of the helicopter deck, see Figure 4 and Figure 8, therefore the LiDAR experiences free sight for the complete scan circle of the LiDAR beam with an opening angle of 30 degree to the vertical. The meteo station of the LiDAR however experiences the blockage effect of the platform. This results in periods with a 180 degrees offset as explained in Chapter 5.5.

4.7 LiDAR settings

4.7.1 Measuring heights

We have chosen to configure the measurement heights (MSL) at the K13-a platform the same as the heights measured at the Lichteiland Goeree platform, which in turn are based on the meteorological mast (MMIJ) measurement height configuration, mentioned in chapter 1.

The lens of the LiDAR is around 36 meters above sea level (MSL). The measuring heights as configured in the LiDAR can be seen in Figure 10 and Table 1 gives the corresponding measurement heights above MSL as well.

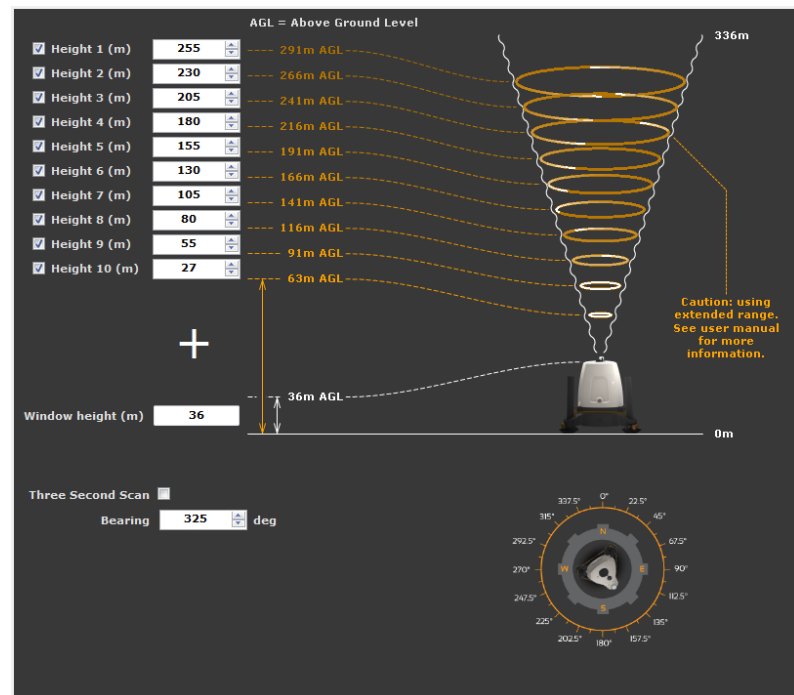


Figure 10 Height configuration of the ZX300M LiDAR

Table 1 LiDAR configuration and measurement height to MSL

No	LiDAR height configuration	measurement height to MSL
	[m]	[m]
1	27	63
2	55	91
3	80	116
4	105	141
5	130	166
6	155	191
7	180	216
8	205	241
9	230	266
10	255	291

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 ZX Lidars ZX300M data files, 10-minute statistical data and 1-second data;
- TNO database handling, checking, correction and filtering;
- TNO data export via www.WindOpZee.net;
- Additional LEG data from RWS and KNMI.

5.1 ZX Lidars ZX300M data files

The ZX300M LiDAR delivers data files in binary (ZPH) format. To process the data you need to convert the binary format to a readable format like CSV or create software which can read the binary format. Conversion to a readable format can be done using the manufacturers software called Waltz or the conversion tool ZPH2CSV.

Two different files are created by the LiDAR on a daily basis, one file with the 10-minute statistical data, recognised from the prefix "Wind10_" and one file with the 1-second data with prefix "Wind_". Every second one configured height is measured so the actual scan rate in Hertz is 1 divided by the number of heights configured.

The complete filename is build up as described below:

Wind10_"ID"@Yyyy_Mmm_Ddd.ZPH (Wind_"ID"... in case of 1-second data file)

- "ID": ZX Lidars ZX300 serial number
- yyyy: year of data
- mm: month of data
- dd: day of data

For an overview of the outputted signals see Appendix A.

All the produced ZPH files are transferred on a daily base to the data server at TNO.

5.2 TNO data base

After data transfer, the data is imported into the TNO data base and then the following processing starts. TNO will evaluate the "daily-plot", see Figure 11, which is automatically created and distributed via email. If needed the TNO can perform a post-validation on the data in the database so that a specific data period is marked as invalid and is no longer visible.

In the database an automated wind direction correction is active as well, as explained in Paragraph 5.5.

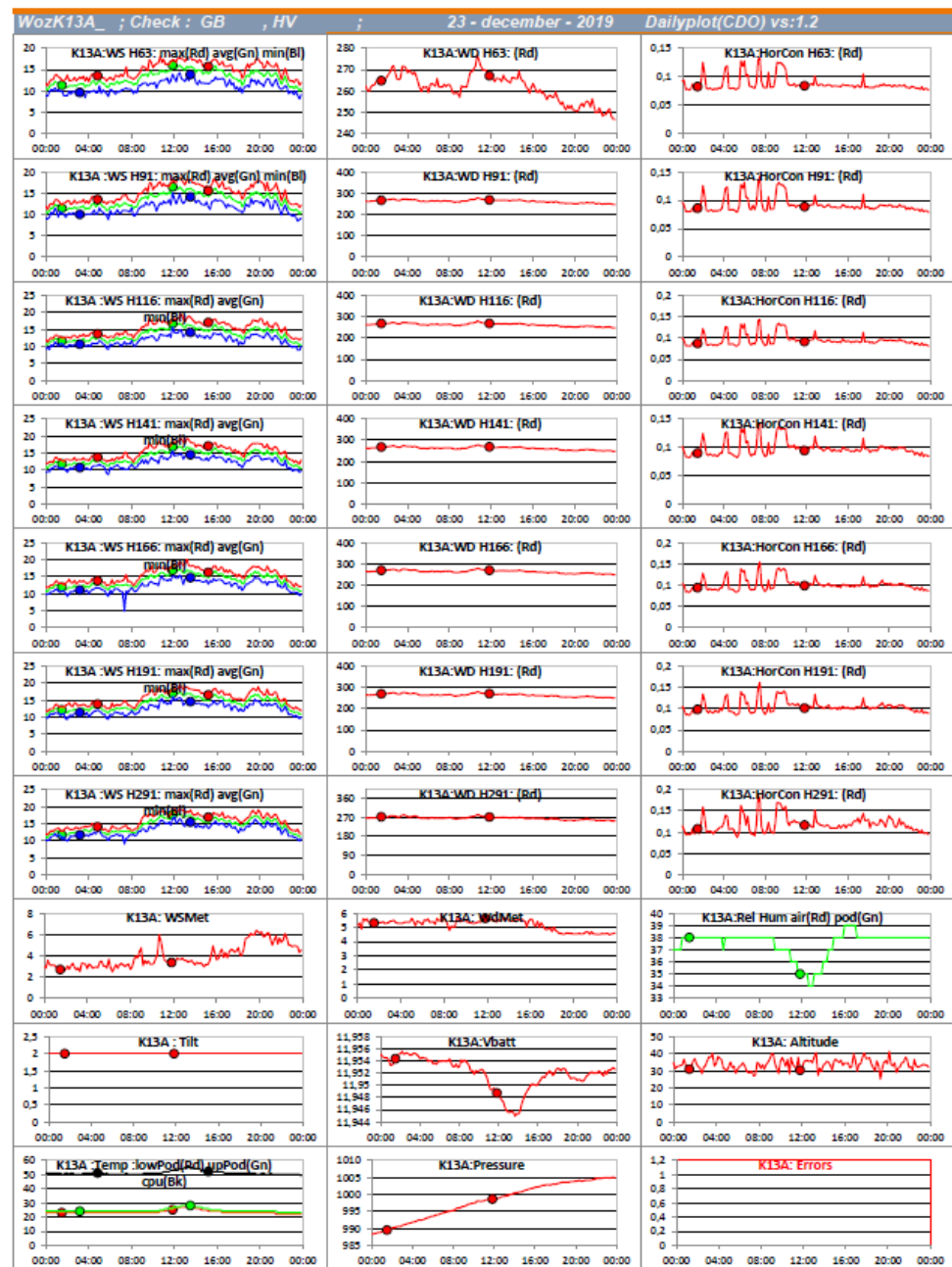


Figure 11 Daily plot example for the K13-a measurement campaign

5.3 Data export K13-a

TNO makes the 10-minute statistical data available via the www.WindOpZee.net website Reference [2] . 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:
K13a-yyyy-mm.CSV for the previous month(s).

After a quarter is completed the monthly files will be replaced by:
K13a-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:
K13a-yyyy.CSV

5.4 Additional data sets

Besides the TNO LiDAR measurements, both KNMI and Rijkswaterstaat also perform measurements on K13-a. Those measurements can be divided into Meteorological Measurements (KNMI), Reference [4] and Oceanographic measurements (Rijkswaterstaat), Reference [5].

Meteorological parameters include:

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

Oceanographic parameters include:

- Water level
- Water temperature
- Wave height
- Wave period

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.

5.5 Wind direction correction

The ZX300M is based on the continuous wave technology. It changes focus point for every measurement height and per height it takes about 1 second to complete one 360 degree scan. Depending on the configured heights, it can take between 10 and 15 seconds to complete the measurements of all configured heights. Using the doppler shift in the backscattered data the wind speed can be determined but the direction of the doppler shift cannot be determined, which can result in a 180 degree shift. For this the ZX300M is equipped with an sonic anemometer mounted at a pole at the side of the LiDAR used as a reference wind direction. However when installed at the side of a platform like the LiDAR at the K13-a platform, the sonic wind direction measurement is highly disturbed. This results in periods where the wind direction determination of the LiDAR fails and the wind direction is shifted 180 degrees.

This 180 degrees shift of course can only be identified by having a secondary wind direction signal for comparison, which is available in the additional K13-a platform data set from KNMI. In short the correction is done as follows:

- Take the difference of the two wind direction timeseries;
- Remove solitary spikes from this difference signal;
- Identify the periods where the ZX300M wind direction is clearly reversed;
- These periods can be extended under certain circumstances.

The complete description of the wind direction correction method is found in Appendix C.

6 Operation and maintenance aspects

The ZX Lidars ZX300M was first installed on November 1th, 2016. Before the installation, the LiDAR was calibrated at the TNO LiDAR calibration facility Reference [3].

As defined by TNO's ISO17025:2017 quality system, the LiDAR should be replaced every two years and serviced every year. All operational aspects with respect to installing and maintaining the LiDAR are recorded in the Logbook. Wintershall personnel, oil and gas company working at the platform, supports monitoring and control of the LiDAR.

Using the manufacturers software Waltz we can connect to the LiDAR at K13-a and the status of components can be monitored, see Figure 12.

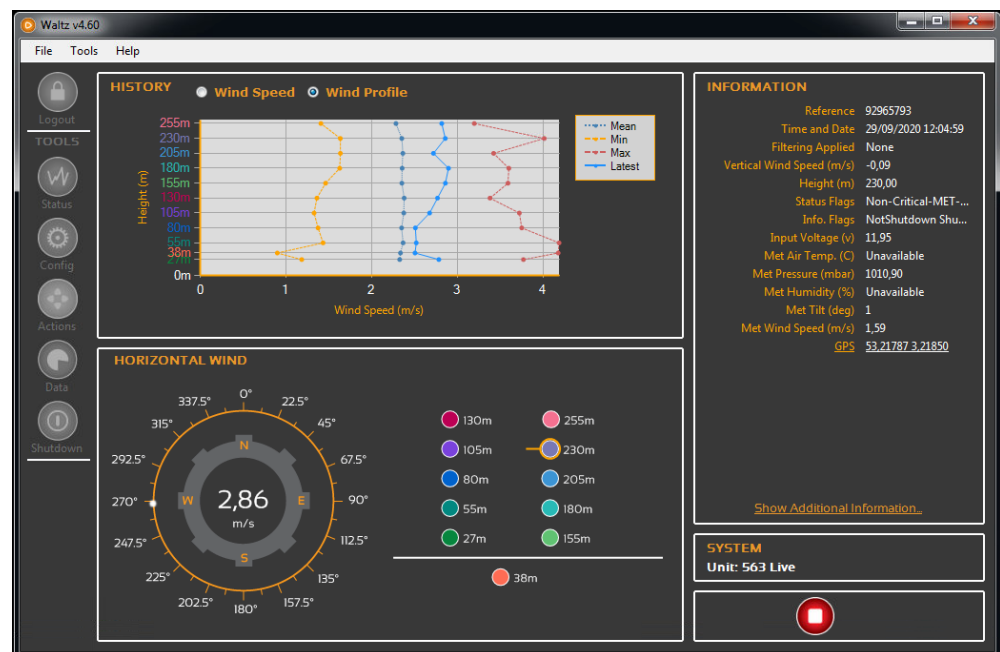


Figure 12 Screenshot of ZX Lidars software Waltz

7 References

- [1] Kamerbrief routekaart windenergy op zee 2030, Den Haag, Kamerbrief 27 maart 2019, kenmerk DGETM-E2020/17177527
- [2] <https://www.WindOpZee.net>
- [3] TNO ground based RSD Verification Facility at EWTW
Gerben Bergman and Hans Verhoef, ECN – Wind Energy
TNO 2020 R10781, June 2020
- [4] <https://data.knmi.nl/>
- [5] <https://noos.matroos.rws.nl/>

A Signal list K13-a ZX300M LiDAR

Name	Location	Short name (Signal name)	Sensor	Unit	installed	Freq (Hz)	Campaign
LIDAR, ZX300M							
Battery Voltage	K13a	K13a_VBat	ZXLidars ZX300M	V	TNO	stat	Wind@Sea
Max temperature inside Lidar		K13a_LowPodTemp		deg C			
Min temperature inside Lidar		K13a_UpPodTemp		deg C			
CPU temperature in Lidar		K13a_Tcpu		deg C			
Relative humidity inside Lidar		K13a_Hpod		%			
Lidar bearing		K13a_Bearing		deg			
Lidar tilt angle		K13a_Tilt		deg			
Air temperature at Lidar position		K13a_Tair2		deg C			
Air pressure at Lidar position		K13a_Pair2		hPa			
Relative humidity at Lidar position		K13a_Hair2		%			
Wind speed measured by Lidar meteo station		K13a_WsMet		m/s			
Wind direction measured by Lidar meteo station		K13a_WdMet		deg			
Precipitation measured by Lidar meteo station		K13a_Rain		%			
Measuring height		K13a_Altitude		m/s			
External supply voltage		K13a_VGen		V			
Error flags		K13a_ErrorFlagsZP300		-			
GPS Lat.		K13a_ZPHS_GPSDataFloatLatitude		-			
GPS Lon.		K13a_ZPHS_GPSDataFloatLongitude		-			
For every measuring height (m):		xxx : 63, 91, 116, 141, 166, 191, 216, 241, 266, 291					
Horizontal wind speed average	K13a	K13a_Hxxx_WsHor_avg	ZXLidars ZX300M	-	TNO	stat	Wind@Sea
Horizontal wind speed std deviation		K13a_Hxxx_WsHor_std		-			
Horizontal wind speed minimum		K13a_Hxxx_WsHor_min		-			
Horizontal wind speed maximum		K13a_Hxxx_WsHor_max		deg			
Vertical wind speed average		K13a_Hxxx_WsVer_avg		m/s			
Wind direction		K13a_Hxxx_Wd		m/s			
Signal to noise ration		K13a_Hxxx_BackScatter		m/s			
HorizontalConfidence		K13a_Hxxx_HorizontalConfidence		m/s			
Data package valid or invalid (only time series)		K13a_Hxxx_DataValidity		m/s			
# packets in fit		K13a_Hxxx_npackets		-			
# measuring points		K13a_Hxxx_npts		-			
# missed points		K13a_Hxxx_Missed					
# packets in fit		K13a_Hxxx_npackets					
CS, diagnostic use only		K13a_Hxxx_CS					

Figure 13 Signal list K13-a ZX300M LiDAR

B Specifications of the ZX Lidars ZX300M LiDAR

ZX 300M – Offshore wind Lidar Specifications

Measurements

Range	10 - 200 metres (Lidar measurement) 0 - 10 metres (onboard met weather station)
Probe length	± 0.07 metres @ 10 metres ± 7.70 metres @ 100 metres
Heights measured	10 User configurable 1 Additional met weather station measurement
Sampling rate	50Hz (up to 50 measurement points every second)
Averaging rate	True 1-second averaging 10 Minute averaging
Accuracy wind speed	0.1 m/s*
Direction variation	< 0.5°
Range	< 1 m/s to 80 m/s

Products

Service Interval	36 months from new
Size	805 x 845 x 966mm
Weight	53.4kg
IP Rating	IP 67
Power consumption	69W
Power Input	12V
Temperature range	-40 + 50C
Warranty	3 years
Maintenance	No annual maintenance or calibration in this period

Figure B.14 ZX Lidars ZX300M LiDAR specifications

C Wind direction correction method ZX300M LiDAR

Short description:

- Take the difference of the two wind direction timeseries.
- Remove solitary spikes from this difference signal.
- Identify the periods where the ZX300M wind direction is clearly reversed.
- These periods can be extended under certain circumstances

Assumptions:

- Only 180 wind direction offsets are to be corrected;
- $WD_{corrected} = WD_{measured} + \text{Offset}$ | Offset is 0° or Offset = 180° ;
- The offset can only change at the start of 10 minute time frame;
- Wind direction is only reliable measured above a wind speed of 1 m/s;
- The offset changes occur longer then 20 minutes;
- Reference platform wind vane data available (KNMI).

Method:

1. Extract the wind direction and wind speed data from the LiDAR at the lowest measuring height;
2. Acquire the wind direction data from the reference data source (KNMI);
3. Remove (set to NaN) all samples from the LiDAR time series where the wind speed > 100 m/s;
4. Calculate the wind direction difference between Lidar and reference time series and take care of the north gap;
5. Derive 2 signals (timeseries): A and B
 A: True; if wind speed is > 1 m/s and |wind direction difference| < $30^\circ \rightarrow$ Offset = 0°
 B: True; if wind speed is > 1 m/s and $150^\circ < | \text{wind direction difference} | < 210^\circ \rightarrow$ Offset = 180°
 In this way the timeseries is divided into intervals ('sure' intervals) where it is sure whether the signal is switched or not switched, the intervals in between are the 'unsure' intervals. In a more mathematical way 'sure' interval mean signal A or signal B is true , 'unsure' interval mean signal A and signal B are both false;
6. Remove spikes from signal B.(remove solitary true or false values);
7. Intervals where signal B is true are investigated and extended as long as: |wind direction difference| > 90° , solitary missing data points are skipped. In this way the 'sure' intervals where the signal is switched, can grow into the 'unsure' intervals until it is more likely that the signal is 'not switched';
8. In case two adjacent intervals where B is true are separated by a period where the wind direction difference signal was missing, the two intervals are combined to one;
9. The moments where the Offset changes from 0° to 180° and reverse are found there where signal B shows rising or falling edges.