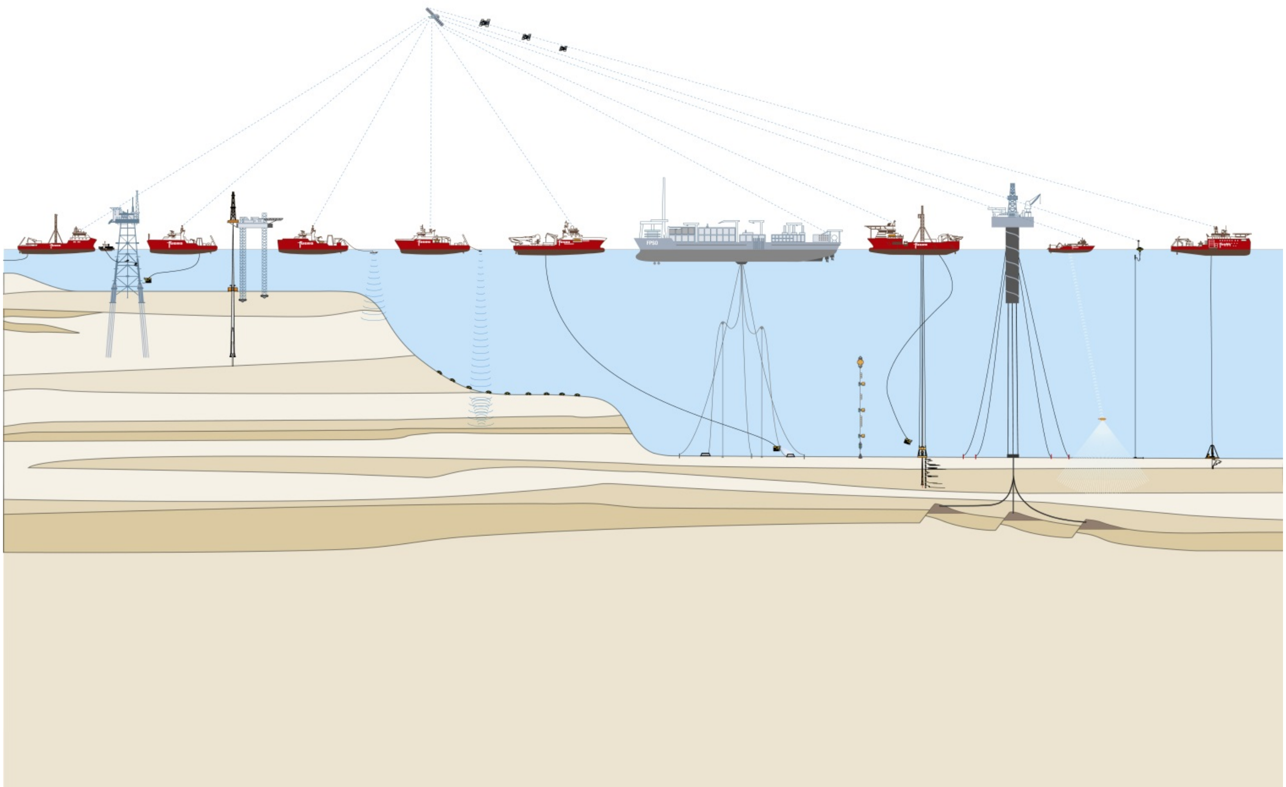
Supply of Meteorological and Oceanographic data at Ten noorden van de Waddeneilanden

Monthly Data Report: January 2021

Fugro Document No: C75433_MDR19_F

19 April 2021

THE NETHERLANDS ENTERPRISE AGENCY (RVO)



Supply of Meteorological and Oceanographic data at Ten noorden van de Waddeneilanden: C75433_MDR19_F					
Rev	**Date**	**Originator**	**Checked**	**Approved**	**Issue Purpose**
1	06.04.2021	Irene Pathirana	Arve Berg		Draft report for client review.
2	16.04.2021	Irene Pathirana	Arve Berg		Updated report for client review.
F	19.04.2021	Irene Pathirana	Arve Berg	Arve Berg	Final report.

Rev F– 19 April 2021	Originator	Checked	Approved
Signed:	Irene Pathirana	Arve Berg	Arve Berg

This report is not to be used for contractual or engineering purposes unless the above is signed where indicated by both the originator of the report and the checker/approver and the report is designated ‘FINAL’.

EXECUTIVE SUMMARY

Fugro has been contracted by RVO to supply meteorological and oceanographic measurement data at Ten noorden van de Waddeneilanden (TNW) Wind Farm Zone (WFZ).

It is the aim of the measurement campaign to provide two sets of continuous meteorological and oceanographic (metocean) data including wind profiles at Ten noorden van de Waddeneilanden with excellent quality and high availability.

Data validation of the on-going measurement campaign is performed each month by comparing the measurements between the two SEAWATCH Wind LiDAR Buoys (SWLB) and with nearby references. Deltares as an independent institute is subcontracted by Fugro to carry out the field validation by conducting an independent analysis of the monthly performance of the measurement campaign. The Deltares validation report [1] is provided as an accompanying report.

Two Seawatch Wind LiDAR Buoys (SWLB) were deployed at the TNW location. The first buoy was deployed at TNWA on 19th June 2019 and the second buoy was deployed at TNWB also on 19th June 2019. Both systems were deployed with an accompanying bottom mounted tide gauge and temperature sensor with an acoustic communication link to the buoy.

The buoys (WS190 and WS191) were successfully recovered on the 22nd of January 2020. At the same day WS170 was successfully deployed at TNWA using the same mooring as for WS190. WS170 had previously been used as spare buoy for the HKW project [2].

From mid-March 2020 service and maintenance operations were restricted by government measures to mitigate the Corona virus pandemic. On the 11th of April 2020 a third party vessel crew recovered WS170 and re-deployed WS190 and WS191 without any Fugro engineer onboard. Support was given remotely. On the 24th of June 2020 another third party vessel crew recovered WS191 and deployed WS170 without any Fugro engineer onboard. Support was given remotely. On the 22nd of July 2020 another third party vessel crew recovered WS190 and deployed WS191 without any Fugro engineer onboard. Support was given remotely. On the 14nd of September 2020 a third party vessel crew recovered WS170 and deployed WS190 without any Fugro engineer onboard. Support was given remotely.

On 25th of October 2020, WS190 moored at TNWB began to drift at mid-day during a storm and was recovered with heavy damage during an emergency operation 12 hours later. There is no data from WS190 at TNWB after 25th of October 2020 11:20 UTC. On the 10nd of November 2020 a third party vessel crew deployed WS156 at the TNWB location without any Fugro engineer onboard. Support was given remotely. WS156 is a first-generation SWLB without DGPS heading that was designated as a spare-buoy for this project.

On 30th of December 2020, WS191 moored at TNWA began to drift at 11:30 UTC and was recovered with heavy damage during an emergency operation on 31 December 2020. As far as can be ascertained, the WS191 buoy did not sustain damages in the lead up or during the drifting incident but during the rescue operation and the data is considered valid until the start of the drift, i.e. until 2020-12-30 11:30 UTC. The TNWA location, however, became unusable for the remainder of the campaign due to parts of the mooring left on the seafloor. A new location TNWA-2 east of of TNWA was then chosen.

SWLB WS199, a newly-built and pre-validated buoy of the same type as WS190 and WS191 (with DGPS heading), was introduced to the campaign and deployed at station TNWA-2 on 16th of January 2021.

The WS156 buoy was successfully recovered on the 25th of January 2021. On the same day, WS187, a buoy previously used during the HKW campaign, was successfully deployed at TNWB.

This monthly report summarizes the activities and data recorded during January 2021 and presents time series plots and data availability statistics of the collected data at TNW based on downloaded data from both WS199 at TNWA-2 and WS156 and WS187 at TNWB. Raw data has to-date not yet been reprocessed.

The data availability of WS199 at TNWA-2 during January 2021 is > 50 % for all parameters except for water level (46 %). The low availability is due to no buoy deployed at TNWA-2 in the first half of January 2021. During the 2nd half of January 2021, buoy WS199 provided nearly complete data coverage. The availability of WS199 corresponds to > 99 % (> 91 % for water level) for the time that the buoy was deployed in January 2021.

The data availability of LiDAR buoys WS156 and WS187 at TNWB is > 98 % for all parameters during January 2021, except for water level (8 %) and current speed and direction (21 %). Water level and current speed and direction are only available from WS187. The current profiler of WS156 started giving suspicious data in November 2020 and all current speed and direction data is under investigation and was removed from this month's dataset. There was no water level sensor at TNWB during the deployment of WS156.

The data collected from the buoys showed good data quality as concluded in the data validation report [1].

DEFINITIONS AND ABBREVIATIONS

Convention of directions:
Directions are given in degrees (°) increasing clockwise from North. For wind and waves the direction is defined as incoming: 0° means wind/waves from the North, 90° from the East etc. For current velocity, the vector or flow direction is used: 0° means current flowing toward the North, 90° toward the East etc. The directions are subject to the source of heading, which is either relative to magnetic north if a magnetic compass is used (wind directions from Gill, LiDAR if compass is used, waves, currents) or relative to true north if DGPS is the main heading source (LiDAR wind directions if DGPS is used).

At TNW the deviation between magnetic and true north is $\leq 1°$. This difference is negligible if directions determined with two different heading sources are compared.

Time: All times refer to UTC.

Abbreviations:

a.s.f.	above sea floor
DD	day of month 2 digits
LAT	Lowest Astronomical Tide
MM	month 2 digits
Month	Month as text
MSL	Mean Sea Level
NaN	Not-a-Number
SWLB	Seawatch Wind LiDAR Buoy
TI	Turbulence Intensity
UTC	Universal Time Coordinated
WLS	Water level sensor
X	A or B to separate TNWA and TNWB
YYYY	year 4 digits

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1. INTRODUCTION

Fugro has been contracted by RVO to supply meteorological and oceanographic measurement data at the Ten noorden van de Waddeneilanden (TNW) Wind Farm Zone (WFZ) in the Dutch sector of the southern North Sea. The goal of the measurement campaign is to provide a 24-month continuous wind profile and metocean data set. It is expected that the data will allow stakeholders to carry out more accurate calculations of the annual energy yield and improve/validate metocean models that have been made as input for the overall wind farm design. Furthermore, it is expected that the resulting accurate wind and metocean data will lead to a lower uncertainty and therefore lower cost of capital in the business case for an offshore wind farm.

The extent of the TNW Wind Farm Zone is shown in Figure 1.1.

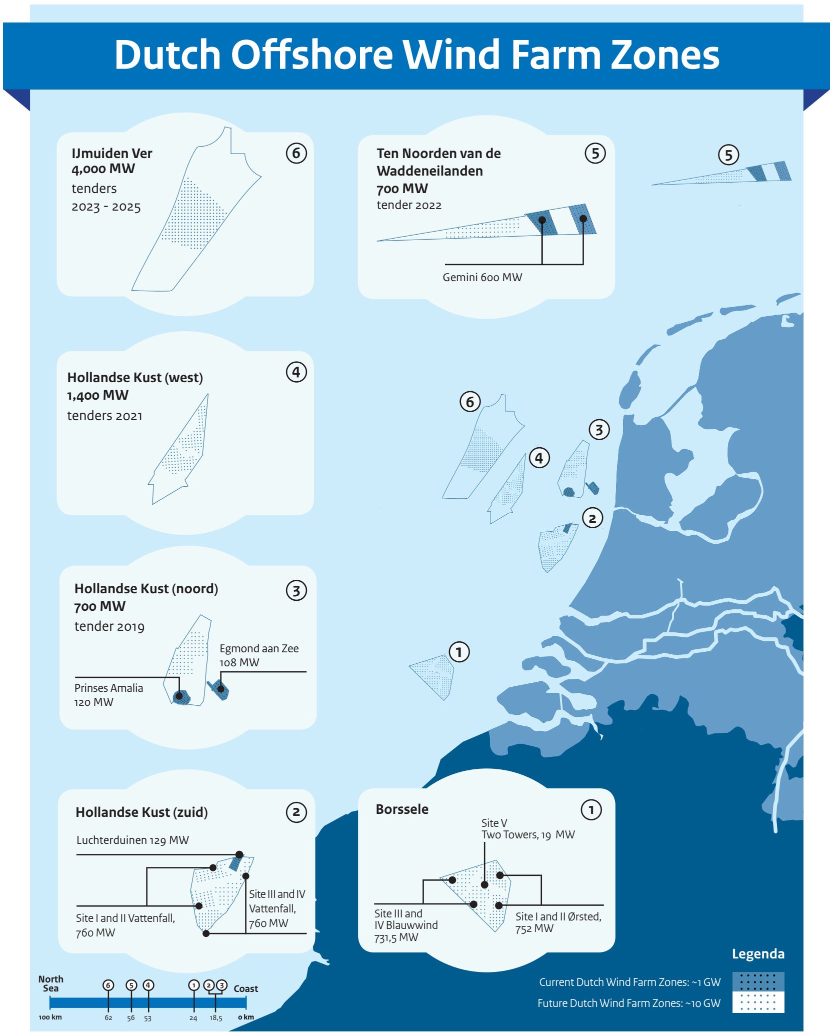

Figure 1.1: Map of the Dutch offshore wind farm zones in the North Sea including the TNW Wind Farm Zone.

Two independent Seawatch Wind LiDAR buoys with serial nos. WS190 and WS191 were deployed at the Ten noorden van de Waddeneilanden locations TNWA and TNWB, respectively, in the Dutch North Sea.

The positions of the bottom mooring weights are listed in Table 1.1. The water depths relative to LAT for this region are based on data from a detailed bathymetric survey by Fugro commissioned by RVO. As the buoys are free to float around the mooring point within a radius of about 110 m, the actual water depth at the actual position of the buoy varies. The position of the WLS is assumed equal to the position of the bottom weight of the associated buoy.

The TNWA station became unusable after 30th December 2020 due to parts of the mooring left on the seafloor after WS191 drifted. Therefore, a new station TNWA-2 east of of TNWA was introduced.

Table 1.1: Positions (ETRS89/UTM zone 31N) of the LiDAR buoys at TNW

Station	Longitude (E)	Latitude (N)	Easting (m)	Northing (m)	Water depth (m MSL)
TNWA	5° 33.014’	54° 01.089’	667077	5988551	∼ 36
TNWA-2	5° 33.8302’	54° 01.0932’	667968	5988591	∼ 38
TNWB	5° 32.988’	54° 01.306’	667034	5988952	∼ 36

The two SWLBs provide a redundant arrangement of instrumentation for the measurement campaign in particular in order to safeguard against data loss. Data measured at each buoy is packed into a digital package that is simultaneously stored on the buoy and transmitted via satellite to allow for near real-time operations checks, maintenance scheduling and monthly reporting. The SWLBs transmit data in near real-time to Fugro for continuous monitoring of the performance as well as monthly reporting. The transmitted data is used as the primary dataset for the monthly report. If the transmitted data is of lower availability (e.g. due to missed satellite transmissions) and a visit is performed at a later time, a recovered data set is provided at the end of the campaign. Table 3.1 indicates if downloaded or transmitted data are used in this report.

Data validation of the on-going measurement campaign is performed each month by comparing the measurements between the two SWLBs and with nearby references. Deltares as an independent institute is subcontracted by Fugro to carry out the data validation by conducting an independent analysis of the monthly performance of the measurement campaign. The Deltares validation report [1] is provided as an accompanying report.

2. SUMMARY OF ACTIVITIES

2.1 Summary of service and maintenance activities

The buoys (WS190 and WS191) were deployed successfully on the 19th of June 2019. However, communication with the WLS failed right after deployment at TNWA.

The buoys (WS190 and WS191) were successfully recovered on the 22nd of January 2020. At the same day WS170 was successfully deployed at TNWA using the same mooring as for WS190. WS170 had previously been used as spare buoy for the HKW project [2].

From mid-March 2020 service and maintenance operations were restricted by government measures to mitigate the Corona virus pandemic. Offshore operations have been done by third party vessel crew only without any Fugro engineer onboard.

The WS170 buoy was successfully recovered on the 11th of April 2020. At the same day WS190 and WS191 were successfully deployed at TNWA and TNWB respectively.

The WS191 buoy was successfully recovered on the 24th of June 2020. At the same day WS170 was successfully deployed at TNWB.

The WS190 buoy was successfully recovered on the 22nd of July 2020. At the same day WS191 was successfully deployed at TNWA.

The WS170 buoy was successfully recovered on the 14th of September 2020. At the same day WS190 was successfully deployed at TNWB.

On 25th of October 2020, WS190 moored at TNWB began to drift at 11:20 UTC during a storm and was recovered with heavy damage during an emergency operation 12 hours later.

The WS156 buoy was successfully deployed at TNWB on the 10th of November 2020.

On 30th of December 2020, WS191 moored at TNWA began to drift at 11:30 UTC and was recovered with heavy damage during an emergency operation on 31st December 2020. As far as can be ascertained, the WS191 buoy did not sustain damages in the lead up or during the drifting incident but during the rescue operation and the data is considered valid until the start of the drift at 2020-12-30 11:30 UTC.

January 2021:
The TNWA station became unusable for the remainder of the campaign due to parts of the mooring left on the seafloor. Therefore, SWLB WS199, a newly-built and pre-validated buoy of the same type as WS190 and WS191, was introduced to the campaign and deployed at station TNWA-2 (east of of TNWA), on 16th of January 2021.

The WS156 buoy was successfully recovered on the 25th of January 2021. On the same day, WS187, a buoy previously used during the HKW campaign, was successfully deployed at TNWB.

2.2 Health, Safety and Environment

There were no HSE related incidents during the deployment of WS199, recovery of WS156 and deployment of WS187 or any other activity related to this project during January 2021.

3. Deployments

3.1 Analysis period

Key information for the current month is summarized in Table 3.1.

Table 3.1: Analysis period

Start Date	2021-01-01 00:00
End Date	2021-01-31 23:50
Number of time steps (10 min intervals)	4464
Type of data: TNWA-2 - WS199	transmitted
Type of data: TNWB - WS156	downloaded
WS187	downloaded

Note that at the time of writing this report buoys WS156 and WS187 were recovered and buoy-produced downloaded pff data was available for use in this report.

3.2 Overview

Data described in this report is produced from the active deployment listed in Table 3.2. Details about the deployments can be found in the corresponding monthly reports. The position of the buoy during 01 - 31 January 2021 is shown in Figure 3.1.

Appendix B: Issues and Solutions contains a log of all system issues during the campaign, actions taken and consequences during the TNW campaign.

Table 3.2: Deployments (Depl.) at TNW

Depl. No.	Station	Buoy S.no.	Depth (m)	Status	Start Time (UTC)	End Time (UTC)
1	TNWA	WS190	36	Ended due to maintenance	2019-06-19 04:45	2020-01-22 08:30
2	TNWB	WS191	36	Ended due to maintenance	2019-06-19 06:00	2020-01-22 10:10
3	TNWA	WS170	36	Ended due to maintenance	2020-01-22 09:30	2020-04-11 06:50
4	TNWB	WS191	36	Ended due to maintenance	2020-04-11 06:10	2020-06-24 06:50
5	TNWA	WS190	36	Ended due to maintenance	2020-04-11 07:00	2020-07-22 17:00
6	TNWB	WS170	36	Ended due to maintenance	2020-06-24 06:50	2020-09-14 18:00
7	TNWA	WS191	36	Ended due to drifting	2020-07-22 18:30	2020-12-30 11:30
8	TNWB	WS190	36	Ended due to drifting	2020-09-14 22:00	2020-10-25 11:20
9	TNWB	WS156	36	Ended due to maintenance	2020-11-10 07:40	2021-01-25 09:10
10	TNWA-2	WS199	36	ongoing	2021-01-16 08:40	
9	TNWB	WS187	36	ongoing	2021-01-25 10:20	

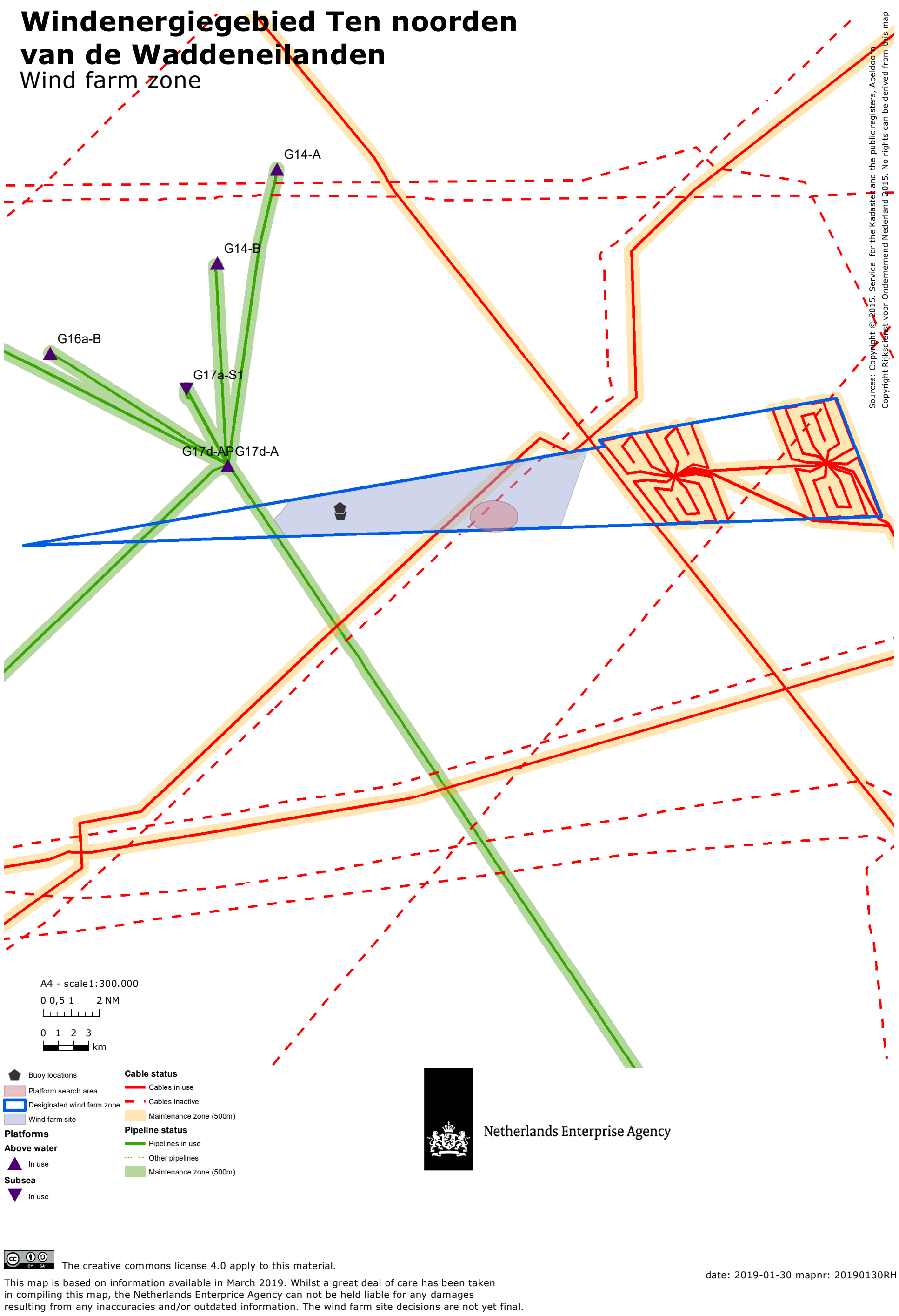

Figure 3.1: Map showing the buoy locations.

3.3 Notes on Data Gaps

Gaps in the buoy datasets may occur due to several potential reasons:

- Buoy re-boot due to power supply issues or external re-boot commands leading to missing data due sensor downtimes, potential sensor spin-up before new measurements are taken, sensor-datalogger communication lags. *Note:* Buoy re-boots can lead to data gaps of varying duration for different sensors.
- Single sensor re-boots leading to missing data of that sensor (e.g. LiDAR re-boots due to a defective met station).
- Only error values from a sensor, no valid data leading to gaps in monthly dataset.
- Not enough samples for a 10-min average or low signal-to-noise ratio (sensor dependent) leading to gaps for particular parameters. *Note:* This can affect individual measurement heights/depths within a set of parameters from a single sensor.
- Gaps due to missed satellite transmissions (not sent by buoy, not received in office, etc). This is indicated in the respective "Flags" files.
- Power (voltage) supply to a single sensor, f ex to Lidar, too low for proper functioning.
- Filtering applied in post-processing. These gaps are explained in the respective "Flags" files.

As far as reasons for data gaps are apparent, known and verified, they are indicated either in the dataset-accompanying "Flags" files, addressed in the following sections discussing data availability per buoy/station (Section 4.3), or individually addressed in the data presentation sections (Appendix F: Figures).

The number and duration of data gaps as well as the verified reasons given can be different between the 2 buoys.

However, there may still be unexplained gaps in the monthly datasets. Each sensor performs internal quality checks before measurements are "considered" valid and made available for further use. The reasons for disqualifying a measurement at this stage are not stored or relayed by all sensors. In addition, weather (storms, rain, fog, too clean air/water) can also affect data quality and lead to gaps in the dataset, however, any discussion of this is purely speculative.

LiDAR packet count, as well as minimum and maximum wind in a 10-minute interval may have different gaps and data availability from wind speed and direction because they are transmitted in separate transmissions. Any gaps due to satellite transmission issues can be corrected when internally stored data is downloaded (at service).

The LiDAR info and status flags are grabbed from ZephIR raw data alongside 1 Hz speed and direction values. The last sample in each 10 min interval for each height is stored and can be retrieved. These are considered “housekeeping” parameters and are only transmitted 1x/hour. They are not intended for detailed QC but are considered for troubleshooting.

Lower availability for water level and bottom temperature are likely due to transmission gaps from the bottom sensor to the buoy and post-processing as detailed in Appendix E: Data processing chain.

Appendix B: Issues and Solutions gives a summary of all issues and events related to instruments affecting data availability.

3.4 Incidents

On the 10nd of November 2020 a third party vessel crew deployed WS156 at the TNWB location without any Fugro engineer onboard. Support was given remotely.

WS156 is a first-generation SWLB without DGPS system onboard that was designated as a spare-buoy for this campaign. The LiDAR wind directions are given with compass heading.

- The iridium antenna failed right after deployment resulting in loss of position data and no transmitted data during the deployment of WS156. XEOS tracker data confirmed that the buoy stayed moored on location during the whole deployment until it was recovered.
- The buoy was deployed without a water level sensor leading to no water level and bottom temperature data.
- The current profiler started giving suspicious data after the first 2 weeks of the deployment in November 2020 and throughout December 2020. All current speed and direction data from this buoy are under investigation at the time of writing this report. All current speed and direction data were removed until the ongoing investigation is concluded.

4. Data

4.1 Data files

Table 4.1 below provides a list of the data provided related to this monthly report collected by Fugro as part of the survey campaign. Details about the contents of each data file are given in Appendix D.

The data were processed with the following version of the processing script: TNW_Year2_2.
A LAT conversion constant of -35.3 is applied to the data from WS199 and WS187.
Thereafter, all tests laid out in Appendix E: Data processing chain were applied to data from all buoys in the same order.

Table 4.1: Data files that make up the TNW set of data presented in this report.

TNWA <id>	**TNW_20210329_Fugro_MetOcean Buoys TNWA January 2021**
Item	**File**
Current Data	<id> CurrentDataStat_F.csv
Current Data Flags	<id> CurrentDataStatFlags_F.csv
Met Data	<id> MetDataStat_F.csv
Met Data Flags	<id> MetDataStatFlags_F.csv
Position Data	<id> PosData_F.csv
Status Data	<id> StatusData_F.csv
Supplementary Data	<id> SupplementaryData_F.csv
Wave Data	<id> WaveDataStat_F.csv
Wave Data Flags	<id> WaveDataStatFlags_F.csv
Wind Data	<id> WindResourceSpeedDirectionStat_F.csv
Wind Data Flags	<id> WindResourceStatusFlags_F.csv
TI Veer Shear	<id> WindResourceTIVeerShearInflow_F.csv
Signal Availability	<id> Signal_Availability_F.csv
LiDAR Info & Status Flags	<id> LiDARInfoStatusFlags_F.csv
TNWB <id>	**TNW_20210329_Fugro_MetOcean Buoys TNWB January 2021**
Item	**File**
Current Data	<id> CurrentDataStat_F.csv
Current Data Flags	<id> CurrentDataStatFlags_F.csv
Met Data	<id> MetDataStat_F.csv
Met Data Flags	<met> MetDataStatFlags_F.csv
Position Data	<id> PosData_F.csv
Status Data	<id> StatusData_F.csv
Supplementary Data	<id> SupplementaryData_F.csv
Wave Data	<id> WaveDataStat_F.csv
Wave Data Flags	<id> WaveDataStatFlags_F.csv
Wind Data	<id> WindResourceSpeedDirectionStat_F.csv
Wind Data Flags	<id> WindResourceStatusFlags_F.csv
TI Veer Shear	<id> WindResourceTIVeerShearInflow_F.csv
Signal Availability	<id> Signal_Availability_F.csv
LiDAR Info & Status Flags	<id> LiDARInfoStatusFlags_F.csv

4.2 Data presentation

A statistical summary of the collected data is given in Table 4.2 - Table 4.5 and in Figure 4.1. Time series for all measured and derived quantities are presented in Appendix F: Figures.

Plots of 10-min. mean horizontal wind speed and direction for 3 heights (30 m, 100 m, 250 m) from the floating LiDAR are presented in Figure 4.2 for TNWA-2 and Figure 4.3 for TNWB as examples of this month's dataset.

At TNWA-2 and TNWB, the highest horizontal 10-minute mean wind speed measured in the profile during January 2021 varies from 9.5 m/s at 30 m to 11.4 m/s at 250 m above the surface. At TNWA-2, the maximum wind speed at 30 m (23.9 m/s) was measured on 21 January 2021 at 08:00, and the maximum at 250 m (30.6 m/s) on 21 January at 04:40. At TNWB, the maximum wind speed at 30 m (24.8 m/s) was measured on 21 January 2021 at 07:40, and the maximum at 250 m (35.2 m/s) on 21 January at 02:10.

Table 4.2: Average and maximum measured values of wind speeds in the period 01 - 31 January 2021 at TNWA-2: 10 min mean and gust from the Gill sensor at 4 m height, 10 min mean speeds at 12 levels from the LiDAR. (Heights referred to the sea surface.)

Instrument	Parameter	Height (m)	Average (m/s)	Maximum (m/s)
Gill Windsonic	10 min mean wind speed	4	8.42	18.0
	3-second gust	4	11.20	24.6
ZephIR LiDAR	10 min mean wind speed	30	9.96	23.9
		40	10.14	25.1
		60	10.42	25.4
		80	10.55	25.9
		100	10.68	26.2
		120	10.82	26.2
		140	10.95	26.8
		160	11.05	27.6
		180	11.14	28.0
		200	11.22	28.4
		250	11.41	30.6

Table 4.3: Minimum, average and maximum measured values of meteorological data, wave data and sea surface temperature (at 1 m depth) at TNWA-2 in the period 01 - 31 January 2021.

Parameter	Unit	Height (m)	Minimum	Average	Maximum
Air Pressure	hPa	0.5	974.90	1001.03	1023.05
Air Temperature	°C	4.0	1.49	5.34	9.12
Humidity	% R.H.	4.0	54.14	79.56	97.97
hm0	m	0.0	0.65	1.97	5.81
hmax	m	0.0	0.80	2.88	10.31
thmax	s	0.0	2.96	7.12	12.30
tm01	s	0.0	3.27	5.75	8.45
tm02	s	0.0	3.06	5.31	7.53
tp	s	0.0	2.96	7.90	14.84
Water Temperature	°C	-1.0	7.07	7.49	7.97
Water Level	m LAT	-36.0	0.39	1.66	2.50

Table 4.4: Average and maximum measured values of wind speeds in the period 01 - 31 January 2021 at TNWB: 10 min mean and gust from the Gill sensor at 4 m height, 10 min mean speeds at 12 levels from the LiDAR. (Heights referred to the sea surface.)

Instrument	Parameter	Height (m)	Average (m/s)	Maximum (m/s)
Gill Windsonic	10 min mean wind speed	4	8.21	18.6
	3-second gust	4	10.84	25.8
ZephIR LiDAR	10 min mean wind speed	30	9.51	24.8
		40	9.65	24.5
		60	9.88	25.7
		80	9.99	27.1
		100	10.10	28.2
		120	10.22	26.6
		140	10.33	27.6
		160	10.41	27.9
		180	10.49	28.2
		200	10.57	28.9
		250	10.71	35.2

Table 4.5: Minimum, average and maximum measured values of meteorological data, wave data and sea surface temperature (at 1 m depth) at TNWB in the period 01 - 31 January 2021.

Parameter	Unit	Height (m)	Minimum	Average	Maximum
Air Pressure	hPa	0.5	973.44	1008.62	1029.69
Air Temperature	°C	4.0	1.22	5.39	9.22
Humidity	% R.H.	4.0	51.67	76.44	100.98
hm0	m	0.0	0.43	1.96	6.00
hmax	m	0.0	0.55	2.87	13.86
thmax	s	0.0	3.27	7.11	17.59
tm01	s	0.0	3.16	5.76	11.70
tm02	s	0.0	2.96	5.31	9.46
tp	s	0.0	2.45	7.98	17.99
Water Temperature	°C	-1.0	7.05	8.07	9.54
Water Level	m LAT	-36.0	0.91	1.80	2.54

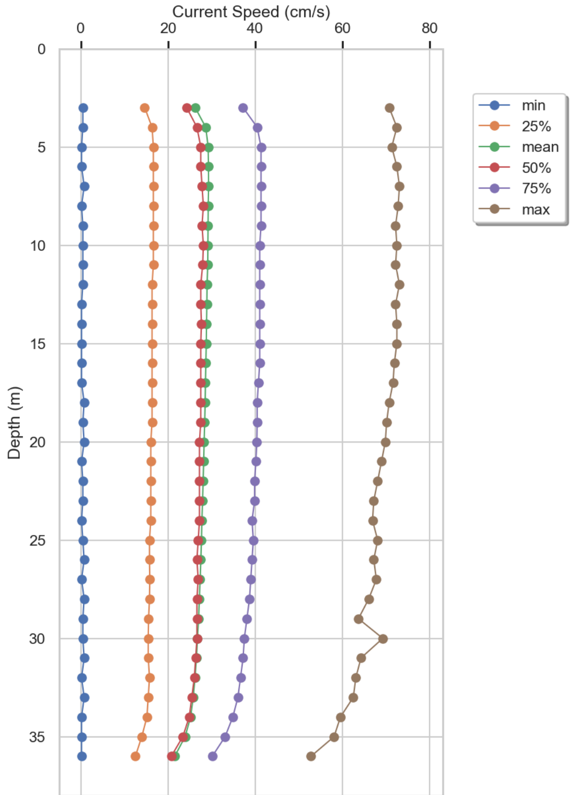

Figure 4.1: Current profile (average, minimum, 25 % percentile, median, 75 % percentile and maximum) at TNWA-2

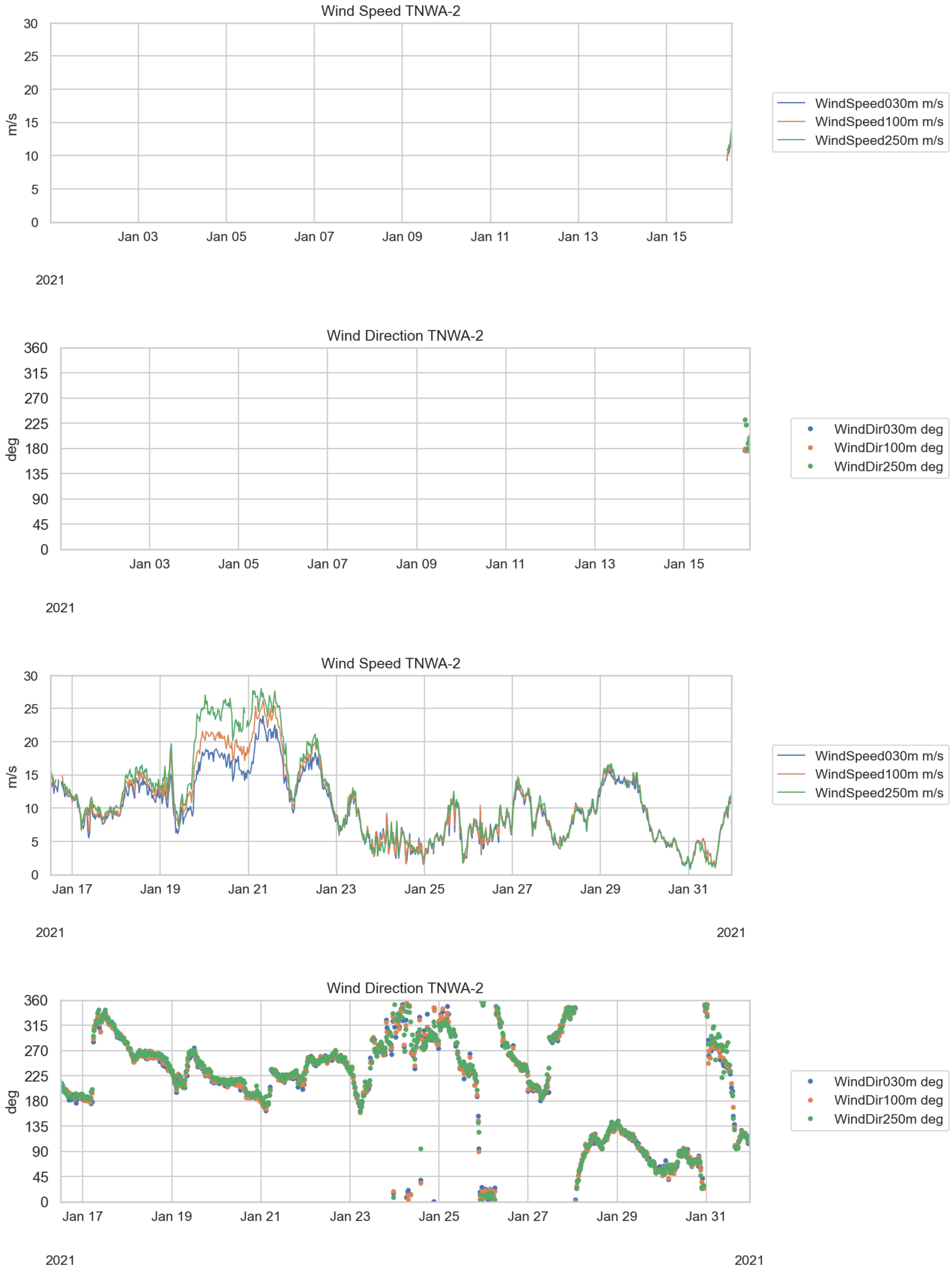

Figure 4.2: 10-min. mean horizontal wind speed and direction for 3 heights (30 m, 100 m, 250 m) from the floating LiDAR at TNWA-2, for the period 01 - 16 January 2021 (top panels) and 16 – 31 January 2021 (bottom panels).

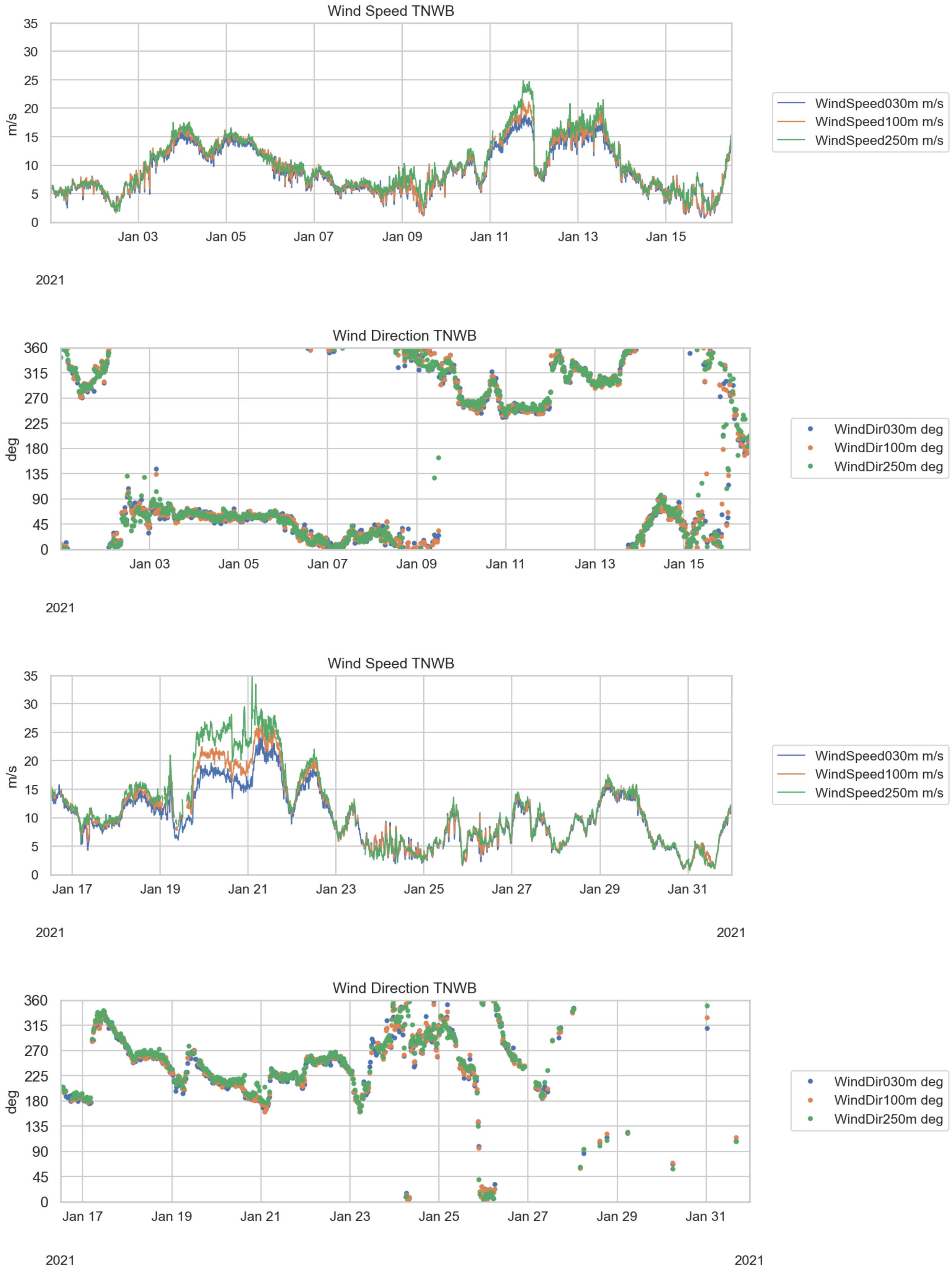

Figure 4.3: 10-min. mean horizontal wind speed and direction for 3 heights (30 m, 100 m, 250 m) from the floating LiDAR at TNWB, for the period 01 - 16 January 2021 (top panels) and 16 – 31 January 2021 (bottom panels).

4.3 Availability

Table 4.6 below shows the post-processed data availability for each parameter group. The procedure to compute the post-processed signal and system availability is described in Appendix E and the availability per parameter per buoy per location is shown in Figure 4.4 and Figure 4.5.

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.
The system availability at TNWA-2 corresponds to >99 % for all parameters except for water level (91 %) from deployment until the end of the month.

At TNWB water level and current speed and direction are only available from WS187. There was no water level sensor at TNWB during the deployment of WS156. The current profiler of WS156 started giving suspicious data in November 2020 and all current speed and direction data is under investigation. The data was removed from this month's dataset until the ongoing investigation is concluded.

Table 4.6: Post-processed data availability in % per main system at TNWA and TNWA-2. Note that the number of valid records varies between wind parameters. Given are the minimum and maximum number of records.

Month	Parameter group	Number of time steps	Number of valid records	Percentage of valid records
July 2020	Wind	4464	[2475 - 4452]	59.5
	Waves	4464	4454	99.8
	Water level	4464	3841	86.0
	Currents	4464	4456	99.8
	Air Pressure	4464	4454	99.8
	Temperature	4464	4341	98.5
Aug 2020	Wind	4464	[4405 - 4458]	99.1
	Waves	4464	4460	99.9
	Water level	4464	3098	69.4
	Currents	4464	4458	99.9
	Air Pressure	4464	4460	99.9
	Temperature	4464	4299	98.1
Sept 2020	Wind	4320	[4156 - 4316]	97.1
	Waves	4320	4319	100.0
	Water level	4320	2530	58.6
	Currents	4320	4314	99.9
	Air Pressure	4320	4319	100.0
	Temperature	4320	4186	98.4
Oct 2020	Wind	4464	[4386 - 4462]	98.6
	Waves	4464	4464	100.0
	Water level	4464	2256	50.5
	Currents	4464	4463	100.0
	Air Pressure	4464	4464	100.0
	Temperature	4464	[4385 - 4463]	99.1
Nov 2020	Wind	4320	[3752 - 4318]	75.7
	Waves	4320	4320	100.0
	Water level	4320	699	16.2
	Currents	4320	4320	100.0
	Air Pressure	4320	4320	100.0
	Temperature	4320	[4235 - 4320]	99.0
Dec 2020	Wind	4464	[3515 - 4243]	45.4
	Waves	4464	4245	95.1
	Water level	4464	0	0
	Currents	4464	4245	95.1
	Air Pressure	4464	4245	95.1
	Temperature	4464	[4133 - 4245]	93.8
Jan 2021	Wind	4464	[2219 - 2250]	50.0
	Waves	4464	2252	50.4
	Water level	4464	2060	46.1

Table 4.6: Post-processed data availability in % per main system at TNWA and TNWA-2. Note that the number of valid records varies between wind parameters. Given are the minimum and maximum number of records.

Month	Parameter group	Number of time steps	Number of valid records	Percentage of valid records
	Currents	4464	2250	50.4
	Air Pressure	4464	2252	50.4
	Temperature	4464	[2217 - 2250]	50.0

Table 4.7: Post-processed data availability in % per main system at TNWB. Note that the number of valid records varies between wind parameters. Given are the minimum and maximum number of records.

Month	Parameter group	Number of time steps	Number of valid records	Percentage of valid records
July 2020	Wind	4464	[4227 - 4460]	99.1
	Waves	4464	4462	100
	Water level	4464	0	0
	Currents	4464	4463	100
	Air Pressure	4464	4462	100
	Temperature	4464	4365	98.9
Aug 2020	Wind	4464	[4394 - 4462]	98.7
	Waves	4464	4464	100
	Water level	4464	0	0
	Currents	4464	[4462 - 4464]	100
	Air Pressure	4464	4464	100
	Temperature	4464	4296	98.1
Sept 2020	Wind	4320	[3880 - 4293]	91.2
	Waves	4320	4297	99.5
	Water level	4320	0	0
	Currents	4320	4297	99.5
	Air Pressure	4320	4297	99.5
	Temperature	4320	4177	98.1
Oct 2020	Wind	4464	[2787 - 3522]	64.0
	Waves	4464	3524	78.9
	Water level	4464	0	0
	Currents	4464	3524	78.9
	Air Pressure	4464	3524	78.9
	Temperature	4464	[3476 - 3524]	78.4
Nov 2020	Wind	4320	[2903 - 2977]	68.0
	Waves	4320	2978	68.9
	Water level	4320	0	0
	Currents	4320	[1975 - 2978]	45.8
	Air Pressure	4320	2978	68.9
	Temperature	4320	[2904 - 2978]	68.1
Dec 2020	Wind	4464	[4408 - 4462]	99.3
	Waves	4464	4464	100
	Water level	4464	0	0
	Currents	4464	0	0
	Air Pressure	4464	4464	100
	Temperature	4464	[4356 - 4462]	98.8
Jan 2021	Wind	4464	[4341 - 4456]	91.5
	Waves	4464	4458	99.9
	Water level	4464	358	8.0
	Currents	4464	946	21.2

Table 4.7: Post-processed data availability in % per main system at TNWB. Note that the number of valid records varies between wind parameters. Given are the minimum and maximum number of records.

Month	Parameter group	Number of time steps	Number of valid records	Percentage of valid records
	Air Pressure	4464	4458	99.9
	Temperature	4464	[4407 - 4457]	99.2

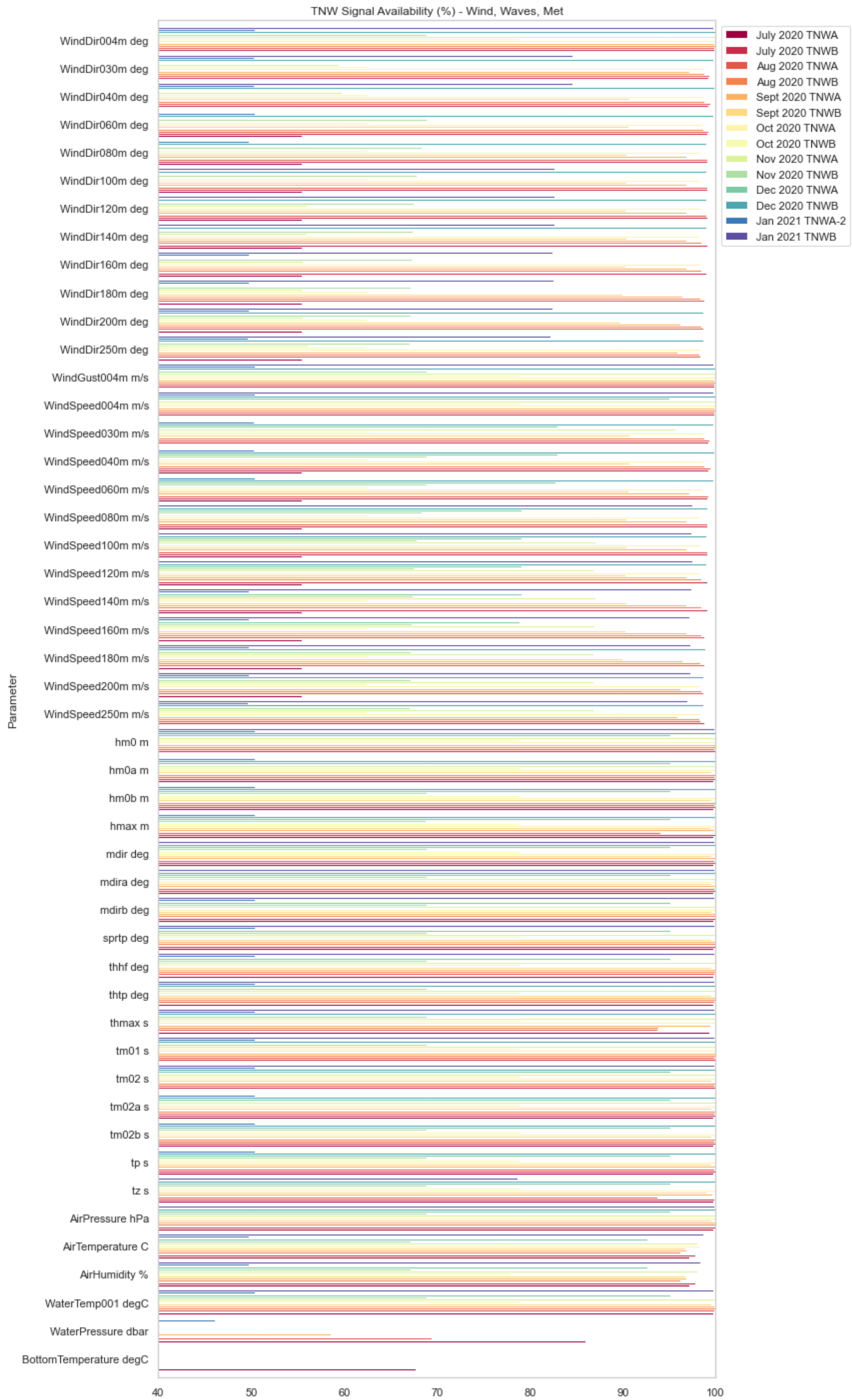

Figure 4.4: Signal Availability (%) wind, waves and met data at TNW during campaign year 2 up to and including January 2021.

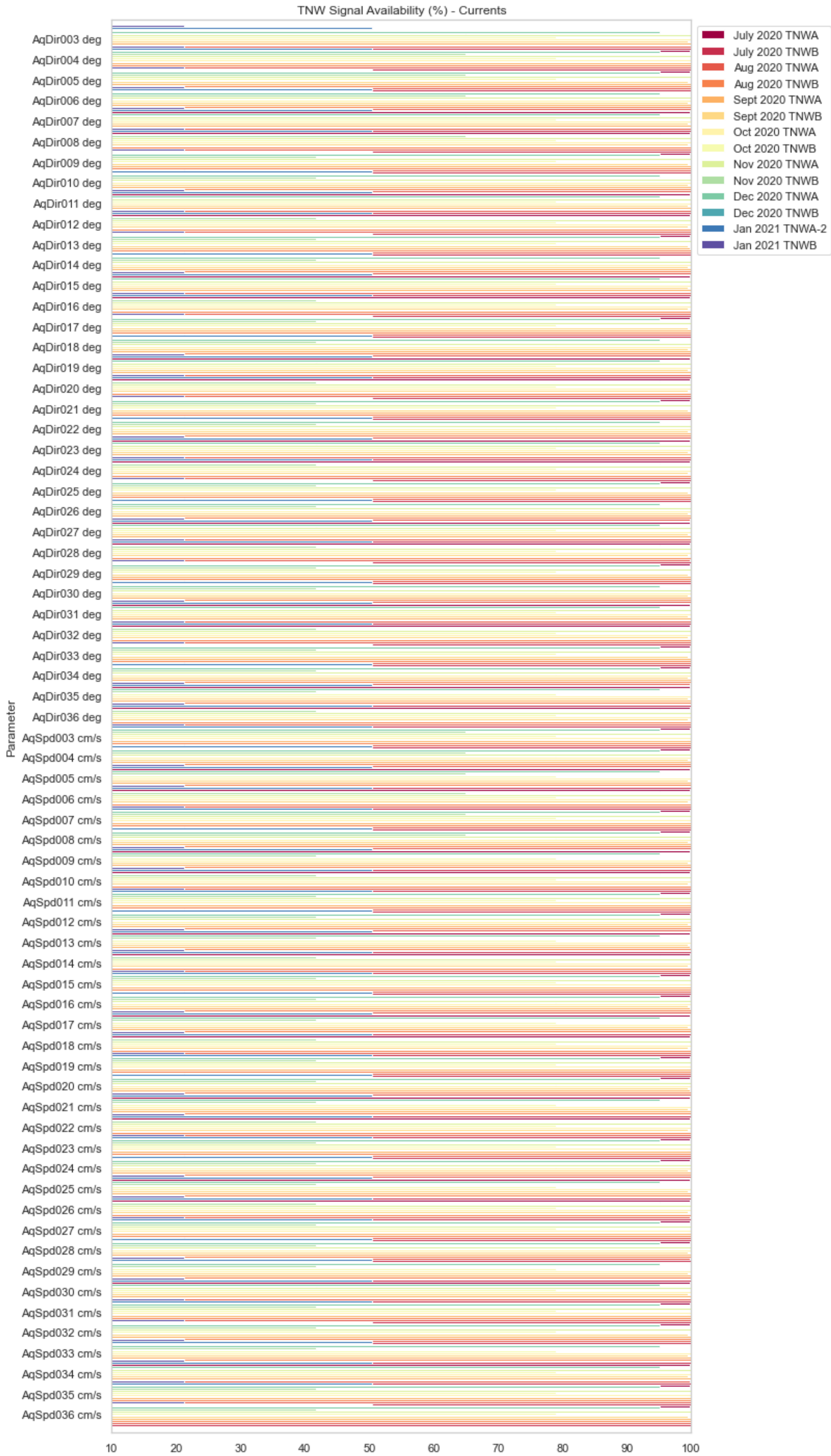

Figure 4.5: Signal Availability (%) currents at TNW during campaign year 2 up to and including January 2021.

5. Outliers

5.1 Remarkable events and/or storms during this period

In January 2021 there were 3 periods with maximum wind speeds well over 18 m/s. One named storm *Christoph* passed over the TNW area on 19th - 21st of January 2021:

- 11th: maximum wind speeds of 15.1 m/s at 4 m height, 24.9 m/s at 250 m
- 12th-13th: maximum wind speeds of 15.3 m/s at 4 m height, 21.5 m/s at 250 m
- 19th - 21st: maximum wind speeds of 18.6 m/s at 4 m height, 35.2 m/s at 250 m, storm *Christoph*

5.2 System errors

Any additional system errors not covered in the data flag files are listed in Table 5.1 and Table 5.2.

There are some flag messages such as "out of bounds" from filtering and "missed transmission" in the present dataset. These flags result from the processing done according to Appendix E: Data processing chain. There are no unexplained data gaps in the present dataset.

There are no info or status flags from the LiDAR unit on WS191 indicating any problems.

From 2021-01-16 18:00, the LiDAR InfoFlags from WS156 contain *SystemNotShutdownCleanly*. The associated status flags are *FullyOperational*. There are a number of short data gaps at intermediate heights due to fog not listed below.

Table 5.1: Additional system errors and gaps >1 hour in the wind dataset at TNWA-2.

Start time UTC	Duration	Dataset	Likely reason
23.01.2021 13:10	1 hours 20 min	250m	Fog
24.01.2021 11:30	1 hours 00 min	140m	Fog
26.01.2021 06:40	1 hours 00 min	40m 100m	Fog
26.01.2021 16:00	1 hours 10 min	30m 250m	Fog
28.01.2021 06:30	1 hours 30 min	60m 120m	Fog
30.01.2021 04:30	1 hours 00 min	30m 160m 250m	Fog
31.01.2021 01:30	1 hours 30 min	80m	Fog
31.01.2021 03:10	1 hours 00 min	60m 120m 140m 250m	Fog
31.01.2021 09:20	1 hours 20 min	120m	Fog

Table 5.2: Additional system errors and gaps >1 hour in the wind dataset at TNWB.

Start time UTC	Duration	Dataset	Likely reason
01.01.2021 05:00	1 hours 20 min	40m 60m	Fog
01.01.2021 07:30	1 hours 20 min	40m 80m 160m	Fog
01.01.2021 12:30	1 hours 30 min	40m	Fog

Table 5.2: Additional system errors and gaps >1 hour in the wind dataset at TNWB.

Start time UTC	Duration	Dataset	Likely reason
01.01.2021 23:10	1 hours 20 min	100m	Fog
02.01.2021 01:10	1 hours 00 min	60m	Fog
02.01.2021 03:00	1 hours 30 min	30m	Fog
02.01.2021 05:20	1 hours 00 min	80m	Fog
02.01.2021 08:40	1 hours 00 min	160m	Fog
02.01.2021 11:10	2 hours 00 min	60m	Fog
02.01.2021 17:20	1 hours 00 min	120m	Fog
02.01.2021 22:30	2 hours 00 min	160m	Fog
07.01.2021 06:00	1 hours 20 min	180m	Fog
08.01.2021 07:30	1 hours 10 min	30m 80m 140m 180m 250m	Fog
08.01.2021 11:00	1 hours 20 min	160m	Fog
08.01.2021 20:30	1 hours 20 min	30m	Fog
09.01.2021 12:20	1 hours 20 min	40m 200m	Fog
09.01.2021 18:40	1 hours 10 min	40m	Fog
10.01.2021 15:20	1 hours 20 min	40m 140m	Fog
10.01.2021 17:20	1 hours 00 min	100m	Fog
12.01.2021 03:10	1 hours 00 min	60m 180m	Fog
14.01.2021 08:30	1 hours 20 min	40m	Fog
14.01.2021 10:00	1 hours 50 min	40m	Fog
14.01.2021 15:40	1 hours 10 min	200m	Fog
15.01.2021 12:40	1 hours 00 min	40m 120m 160m 180m 200m	Fog
15.01.2021 13:50	1 hours 00 min	120m	Fog
15.01.2021 16:00	1 hours 20 min	30m	Fog
15.01.2021 20:40	1 hours 40 min	160m	Fog
15.01.2021 22:30	1 hours 00 min	30m 80m 160m	Fog
15.01.2021 23:40	1 hours 10 min	80m	Fog
17.01.2021 14:50	1 hours 50 min	160m 200m	Fog
23.01.2021 00:50	1 hours 10 min	60m	Fog
23.01.2021 13:10	1 hours 10 min	80-250m	Fog
23.01.2021 18:00	1 hours 10 min	40m 160m	Fog
23.01.2021 19:20	1 hours 10 min	80m	Fog
23.01.2021 21:10	1 hours 00 min	30m 180m	Fog
24.01.2021 01:10	1 hours 00 min	40m 120m 180m 200m	Fog
24.01.2021 04:20	1 hours 10 min	40m	Fog
24.01.2021 11:00	2 hours 00 min	40m 60m 180m	Fog
24.01.2021 15:50	1 hours 10 min	80m	Fog
24.01.2021 18:50	1 hours 20 min	Some data missing	
24.01.2021 20:40	2 hours 10 min	80m	Fog

Table 5.2: Additional system errors and gaps >1 hour in the wind dataset at TNWB.

Start time UTC	Duration	Dataset	Likely reason
25.01.2021 09:20	1 hours 00 min	all LiDAR data missing	Buoy swap
25.01.2021 20:40	1 hours 00 min	120m	Fog
26.01.2021 21:10	1 hours 00 min	160m 180m	Fog
26.01.2021 22:20	5 hours 40 min	all LiDAR data missing	
27.01.2021 11:20	1 hours 40 min	all LiDAR data missing	
27.01.2021 13:10	2 hours 40 min	all LiDAR data missing	
27.01.2021 16:50	7 hours 10 min	all LiDAR data missing	
28.01.2021 00:10	3 hours 50 min	60m	Fog
28.01.2021 04:10	1 hours 50 min	LiDAR wind direction data missing	Heading missing
28.01.2021 06:20	8 hours 10 min	LiDAR wind direction data missing	Heading missing
28.01.2021 14:50	3 hours 40 min	LiDAR wind direction data missing	Heading missing
28.01.2021 18:50	10 hours 50 min	LiDAR wind direction data missing	Heading missing
29.01.2021 05:50	2 hours 20 min	LiDAR wind direction data missing	Heading missing
29.01.2021 08:20	1 hours 00 min	LiDAR wind direction data missing	Heading missing
29.01.2021 13:00	3 hours 30 min	LiDAR wind direction data missing	Heading missing
29.01.2021 16:50	13 hours 10 min	LiDAR wind direction data missing	Heading missing
30.01.2021 06:10	18 hours 40 min	60m	Fog
31.01.2021 01:00	15 hours 10 min	LiDAR wind direction data missing	Heading missing
31.01.2021 16:20	7 hours 40 min	160m	Fog

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Appendix A: Instrumentation overview per buoy

Table A.1: Instrumentation overview WS190.

SWLB	**WS190**			
Instrument	**Serial Number**	**Time installed**		**Reason**
		From	Until	
Design Version	2.2	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
PMU	436	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Wavesense	366	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
DGPS AsteRx4	181013	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Septentrio	AsteRx: 87	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Compass	1047491	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
LiDAR	ZX843M	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting *
LiDAR firmware	2.2020	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Gill Windsonic	18320036	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Nortek	AQP 9721	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Aquadopp	AQD 15088	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Vaisala PTB	P4120802	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Vailsala HMP	P1730331	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Thelma	562	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Buoy Tracker XEOS	680	2020-09-14 22:00	2020-10-25 11:20	ended due to drifting
Pre-Deployment Reference	[3]			

* Laser failure after 2020-07-13. Laser replaced like-for-like by supplier. Service report available [4].

Table A.2: Instrumentation overview WS191.

SWLB	**WS191**			
Instrument	**Serial Number**	**Time installed**		**Reason**
		From	Until	
Design Version	2.2	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
PMU	437	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Wavesense	371	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
DGPS AsteRx4	181014	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Septentrio	AsteRx: 88	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Compass	1047474	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
LiDAR	ZX862M	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
LiDAR firmware	2.2020	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Gill Windsonic	19060137	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Nortek	AQP 9744	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Aquadopp	AQD 14707	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Vaisala PTB	P4120800	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Vaisala HMP	P4050599	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Thelma	926	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Buoy Tracker XEOS	771	2020-07-22 18:30	2020-12-30 11:30	ended due to drifting
Pre-Deployment Reference	[5]			

Table A.3: Instrumentation overview WS170.

SWLB	**WS170**			
Instrument	**Serial Number**	**Time installed** From	Until	**Reason**
Design Version	2.1	2019-06-01	2020-09-14 18:00	recovered for service
PMU	393	2019-06-01	2020-09-14 18:00	recovered for service
Wavesense	336	2019-06-01	2020-09-14 18:00	recovered for service
DGPS AsteRx4	181009	2019-06-01	2020-09-14 18:00	recovered for service
Septentrio	S/N 1810012	2019-08-06	2020-09-14 18:00	recovered for service
Compass	1045891	2019-06-01	2020-09-14 18:00	recovered for service
LiDAR	ZX585M	2019-06-01	2020-09-14 18:00	recovered for service
LiDAR firmware	2.2020	2019-06-01	2020-09-14 18:00	recovered for service
Gill Windsonic	18320033	2019-06-01	2020-09-14 18:00	recovered for service
Nortek	AQP 6692	2019-06-01	2019-11-25	Biofouling.
Aquadopp	AQD 13700	2019-06-01	2019-11-25	Biofouling.
	AQP 8644	2019-11-25	2020-09-14 18:00	recovered for service
	AQD 13597	2019-11-25	2020-09-14 18:00	recovered for service
Vaisala PTB	M5220804	2019-06-01	2020-09-14 18:00	recovered for service
Vaisala HMP	P4050602 2018	2019-06-01	2020-09-14 18:00	recovered for service
Thelma	75	2019-09-19	2020-09-14 18:00	recovered for service
Buoy Tracker XEOS	359	2019-06-01	2020-09-14 18:00	recovered for service
Pre-Deployment Reference	[2]			

Table A.4: Instrumentation overview WS156.

SWLB	**WS156**			
Instrument	**Serial Number**	**Time installed** From	Until	**Reason**
Design Version	1.1	2020-11-10 07:40	2021-01-25 09:10	recovered for service
PMU	346	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Wavesense	279	2020-11-10 07:40	2021-01-25 09:10	recovered for service
DGPS AsteRx4	-			
Septentrio	-			
Compass	1039696	2020-11-10 07:40	2021-01-25 09:10	recovered for service
LiDAR	ZX501M	2020-11-10 07:40	2021-01-25 09:10	recovered for service
LiDAR firmware	2.2020	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Gill Windsonic	17500028	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Nortek	AQP9721	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Aquadopp	AQD15088	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Vaisala PTB	K2740014	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Vaisala HMP	M1750933	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Thelma	-			
Buoy Tracker XEOS	321075	2020-11-10 07:40	2021-01-25 09:10	recovered for service
Pre-Deployment Reference	[5]			

Table A.5: Instrumentation overview WS199.

SWLB	**WS191**			
Instrument	**Serial Number**	**Time installed** From	Until	**Reason**
Design Version	2.2	2021-01-16 08:40		
PMU	454	2021-01-16 08:40		
Wavesense	387	2021-01-16 08:40		
DGPS AsteRx4 Septentrio	18493046948	2021-01-16 08:40		
Compass	1032118	2021-01-16 08:40		
LiDAR	ZX898M	2021-01-16 08:40		
LiDAR firmware	2.2020	2021-01-16 08:40		
Gill Windsonic	20120006	2021-01-16 08:40		
Nortek	AQP8492	2021-01-16 08:40		
Aquadopp	AQD13914	2021-01-16 08:40		
Vaisala PTB	R1820357	2021-01-16 08:40		
Vaisala HMP	S4310172	2021-01-16 08:40		
Thelma	1096	2021-01-16 08:40		
Buoy Tracker XEOS	834	2021-01-16 08:40		
Pre-Deployment Reference	[6]			

Table A.6: Instrumentation overview WS187.

SWLB	WS187			
Instrument	**Serial Number**	**Time installed** From	Until	**Reason**
Design Version	2.2	2021-01-25 10:20		
PMU	432	2021-01-25 10:20		
Wavesense	370	2021-01-25 10:20		
DGPS AsteRx4	SN: 181008	2021-01-25 10:20		Both antenna cables replaced in November 2019
Septentrio	AsteRx:3034681	2021-01-25 10:20		
Compass	1047495	2021-01-25 10:20		
LiDAR	ZX818M	2021-01-25 10:20		LiDAR met station replaced in November 2019
LiDAR firmware	2.2020	2021-01-25 10:20		
Gill Windsonic	18320062	2021-01-25 10:20		
Nortek	AQP 9363	2021-01-25 10:20		
Aquadopp	AQD 14604	2021-01-25 10:20		
Vaisala PTB	N5230736	2021-01-25 10:20		
Vailsala HMP	P1730335	2021-01-25 10:20		
Thelma	921	2021-01-25 10:20		
Buoy Tracker XEOS	682	2021-01-25 10:20		
Pre-Deployment Reference	[7]			

DEPLOYMENT/RECOVERY SHEET

Project Name:	**TNW**		
Project no:	C75433	Latitude:	N54 degrees 01.0932`
Station name:	TNWA-2	Longitude:	E5 degrees 33.8302`
WS buoy no:	WS199	Approx. depth:	36 m
		Buoy marking:	Ten noorden van de Waddeneilanden (TNW)
Reason for deployment: Swap for maintenance			

Buoy module/sensor	**Serial number/ID**
PMU	454
Wavesense 3 data logger	387
Septentrio	18493046948
Compass	1032118
ZephIR LiDAR	898
Gill Windsonic	20120006
Nortek current profiler 600kHz	AQP 8492 AQD 13914
Vaisala PTB330	R1820357
Vaisala HMP155 air temperature/humidity	S4310172
Thelma	1096
Buoy Tracker XEOS	834

DEPLOYMENT HISTORY

	YEAR	MONTH	DATE	UTC
First measurement in position	2021	January	16	08:40
Last measurement in position				

Comments:

Recovery vessel:	Deployment vessel: Mustang
Recovered by:	Deployed by: Vessel crew

DEPLOYMENT/RECOVERY SHEET

Project Name:	**TNW**		
Project no:	C75433	Latitude:	N54 degrees 01.306`
Station name:	TNWB	Longitude:	E5 degrees 32.988
WS buoy no:	WS156	Approx. depth:	36 m
		Buoy marking:	Ten noorden van de Waddeneilanden (TNW)
Reason for deployment: Swap for maintenance			

Buoy module/sensor	**Serial number/ID**
PMU	346
Wavesense 3 data logger	279
Septentrio	-
Compass	1039696
ZephIR LiDAR	501
Gill Windsonic	17500028
Nortek current profiler 600kHz	AQP9721 AQD15088
Vaisala PTB330	K2740014
Vaisala HMP155 air temperature/humidity	M1750933
Thelma Bottom Unit	-
Buoy Tracker XEOS	321075

DEPLOYMENT HISTORY

	YEAR	MONTH	DATE	UTC
First measurement in position	2020	November	10	07:40
Last measurement in position	2021	January	25	09:10

Comments:
1st generation (single-hull) spare buoy, no DGPS

Recovery vessel:	Bever	Deployment vessel:	Zwerver II
Recovered by:	Vessel crew	Deployed by:	Vessel crew

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Appendix B: Issues and Solutions

Table B.1: System issues.

Instrument	Parameter	Status	Issues	1st notice of issue UTC
TNWA				
WS190	Water level, bottom temperature	Data missing	Water level sensor failed right after deployment. No spare was available.	2019-06-19 04:45
WS190	LiDAR wind speed, wind direction, turbulence	Data gaps	In December 2019 the communication between the Lidar and the buoy data logger was functioning intermittently with frequent data gaps and on the 28 December no more data was received from the Lidar.	2019-12-01 06.00
WS190	All	Maintenance	Buoy recovered for service.	2020-01-22 08.30
WS170	All	Only 1 buoy active	Deployment of WS170 as a spare buoy on the mooring of WS190.	2020-01-22 09.30
WS170	Air temperature, humidity	Data missing	Buoy was most likely hit by a freak wave. As a consequence the air temperature and humidity sensor and 3 of 4 fuel cells stopped working.	2020-02-09 16.20
WS170	LiDAR wind speed, wind direction, turbulence	Fuel shortage	The only fuel cell working after 9 February, had comsumed all its fuel. Due to this the Lidar stopped.	2020-03-26
WS170	All	Maintenance	Buoy recovered for service.	2020-04-11 06.50
WS190	All	Active	Deployment of WS190.	2020-04-11 07.00
WS190	LiDAR wind speed, wind direction, turbulence	Laser fault	Laser stopped emitting. No data produced after 2020-07-13.	2020-07-13 15.00
WS190	All	Maintenance	Buoy recovered for service. LiDAR unit sent to supplier for repair. Laser replaced.	2020-07-22 17.00
WS191	All	Active	Deployment of WS191.	2020-07-22 18.30
WS191	LiDAR wind direction	Data missing	WS191 experienced loss of DGPS headings after 8th of December 2020. LiDAR wind data will be reprocessed for the 24M dataset.	November 2020.

Table B.1: System issues.

Instrument	Parameter	Status	Issues	1st notice of issue UTC
WS191	LiDAR wind speed	Data gaps	WS191 experienced intermittent gaps in LiDAR wind speed data for unknown reasons. This is under investigation and LiDAR wind data will be reprocessed for the 24M dataset.	December 2020.
WS191	All	Drifting	Buoy drifted and damaged during rescue operation.	2020-12-30 11.30
TNWB				
WS191	LiDAR wind speed, wind direction, turbulence	Data gaps	Communication between Lidar and buoy data logger stopped working. Data was stored internally in the Lidar and could be downloaded at service in January 2020. In December the Lidar worked intermittently until it stopped on the 22 December.	2019-09-12 06:00
WS191	Water level, bottom temperature	Jump in data	Sensor seems to have moved to a deeper position.	2019-09-15 19.30
WS191	All	Maintenance	Buoy recovered for service.	2020-01-22 10.10
WS191	All	Active	Buoy re-deployed after service.	2020-04-11 06.10
WS191	All	Maintenance	Buoy recovered for service.	2020-06-24 06.50
WS170	All	Active	Deployment of WS170 as a spare buoy on the mooring of WS191.	2020-06-24 07.50
WS170	Water level, bottom temperature	Data gaps	No water level data transmitted.	2020-06-24 07.50
WS170	All	Maintenance	Buoy recovered for service.	2020-09-14 18.00
WS190	All	Active	Buoy re-deployed after service.	2020-09-14 22.00
WS190	Water level, bottom temperature	Data gaps	No water level data transmitted.	2020-09-14 22.00

Table B.1: System issues.

Instrument	Parameter	Status	Issues	1st notice of issue UTC
WS190	All	Drifting	Buoy drifted likely due to the rubber cord of the upper part of the mooring being pulled out of the terminal near the subsurface float.	2020-10-25 11.20
WS156	All	Active	Buoy deployed as spare-buoy.	2020-11-10 07.30
WS156	LiDAR wind direction	Compass	Buoy without DGPS system. LiDAR wind direction calculated using compass heading.	2020-11-10 07.30
WS156	Water level	No data	Buoy deployed without water level sensor.	2020-11-10 07.30
WS156	Current speed and direction	Data missing	Current meter started giving suspicious data. Under investigation.	2020-11-23 23.50

Appendix C: Instrumentation

Each buoy is a Seawatch Wind LiDAR Buoy based on the original Seawatch Wavescan buoy design with the following sensors and main equipment:

- Wavesense3 3-directional wave sensor
- ZephIR ZX300 CW LiDAR
- Gill Windsonic M acoustic wind sensor
- Nortek Aquadopp 600kHz current profiler
- Vaisala PTB330A air pressure sensor
- Vaisala HMP155 air temperature and humidity sensor
- DualGPS Septentrio position tracking
- Acoustic receiver for Thelma TBR700 water pressure sensor

The LiDARs used in this project are marinized versions of the ZX300 LiDAR type.

An independent Thelma (TBR 700) water pressure/level sensor (WLS) is located on the sea floor connected to the buoy mooring via a line. The pressure sensor transmits data to the buoy via an acoustic link.

The LiDAR is equipped with a met station that also measures air temperature and pressure. These measurements are given in the dataset as supporting data only (calibration not verified).

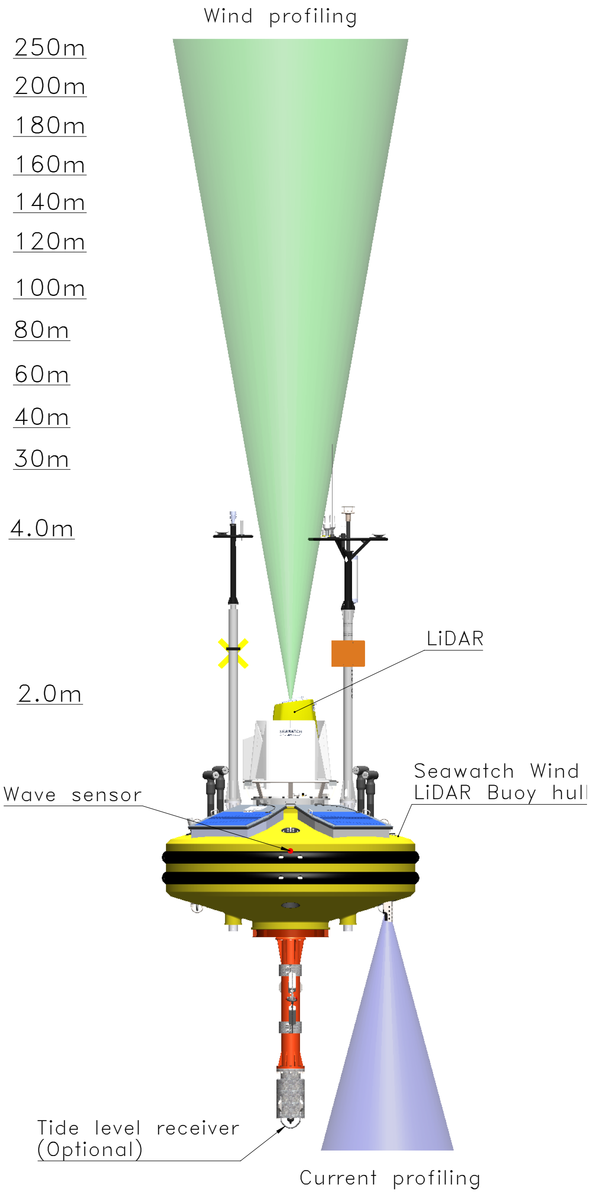


Figure C.1: Illustration of the wind and current profile measurements from the LiDAR buoy. Heights ref. sea surface

Figure C.1 shows the basic shape of the buoy illustrating the principle for wind and current profile measurements. The drawing shows the location of the sensors, and illustrates the LiDAR and current profiler beams. The buoys are deployed with moorings as shown in Figure C.2, which include the moorings for the WLSs.

The measurement setup is detailed in Table C.1. Details of sensor types and serial numbers can be found in Appendix A: Instrumentation overview per buoy.

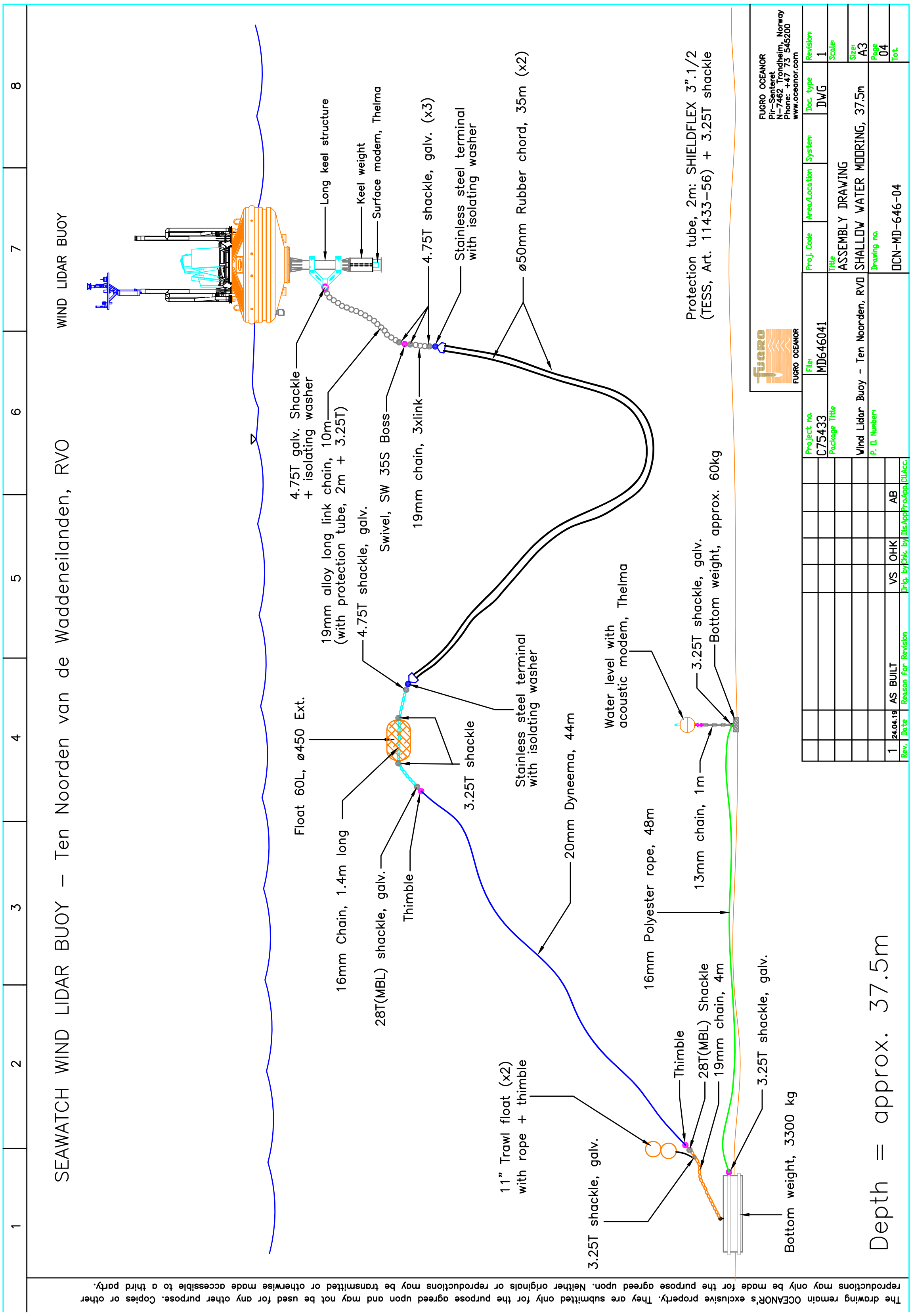


Figure C.2: Mooring design for the SWLB at TNW (same for both stations)

Table C.1: Configuration of measurements by the Seawatch Wind LiDAR buoys at TNW

Instrument type	Sensor height[1] (m)	Parameter measured	Sample height[1] (m)	Sampling interval (s)	Averaging period (s)	Burst interval[2] (s)	Sensor resolution	Transmitted?
Wavesense 3	0	Heave, pitch, roll, heading	0	1	Time series duration: 1024 s	600	0.1m 0.2° 0.2° 0.5°	No
		Sea state parameters (See Table D.3)	0	600	1024	600		Yes
ZephIR ZX300 LiDAR	2	Wind speed and direction at 10 heights (The 11th level, the so-called reference level which is not configurable, is located at 40 m and referred to as 40.0 Ref.)	30 40.0 ref 60 80 100 120 140 160 180 200 250	17.4 s[3]	600	600	0.1 m/s 1°	Yes
Gill Windsonic M	4	Wind speed, wind direction	4	1	600	600	0.01 m/s, 1°	Yes
Nortek Aquadopp	-1	Current speed and direction profile, water temperature (at 1 m depth)	TNWA: -3, -4, ..., -37 (35 levels) TNWB: -3, -4, ..., -37 (35 levels)	1	600	600	2 cm/s 1° 0.1 °C	Yes
Vaisala PTB330A	0.5	Air pressure	0.5	30	60	600	0.05 hPa	Yes
Vaisala HMP155	4.1	Air temperature Air humidity	4.1	5	60	600	0.1 °C 1 %	Yes
Thelma WLS	Sea floor	Water pressure Bottom Water Temperature	TNWA -36 TNWB -36	1	600	600	0.5 mbar 0.1 °C	Yes

[1] Height relative to actual sea surface. The depth of the WLS is an approximate number.
[2] A burst of measurements is the raw data time series used to calculate the average parameters. The burst interval is the time from the beginning of one burst to the beginning of the next burst, and equal to the interval between writing of raw data to disk and transmissions. Note that wave bursts overlap by 424 s.
[3] This is the approximate time between the beginning of one sweep of the profile and the next one; the interval may vary slightly. The ZephIR sweeps one level at a time beginning at the lowest one. After the top level has been swept, it uses some time for calculations and re-focusing back to the lowest level for a new sweep. A minimum of 9 samples per height must be measured in the 10-minute interval in order to produce wind speed and direction, and derived parameters thereof. This applies after signal-noise filtering intenally in the LiDAR is carried out.

Appendix D: Metadata provided parameters

D.1 File contents

File: *CurrentDataStat*

Signals: See Table D.1.

The file contains 10-minute average data from the current meter and the lowest signal strength (AqAmp in dB) per measurement among the 3 beams. All timestamps are set at the end of the averaging period.

For all current speed signals AqSpd(d), where d = 3,4,5,..., 37 m, the transmitted data are checked for consecutive duplicates, out-of-bounds values and signal strength above a set threshold as described in Table E.2. For timestamps and depths where the speed is outside the accepted range, the speed and direction are set to NaN.

File: *CurrentDataStatFlags*

Signals: Filter flags on current data as described in Table E.2.

File: *MetDataStat*

Signals: See Table D.2.

The file contains 10-minute average data calculated on the buoy from the meteorological and bottom sensors. All timestamps are set at the end of the averaging period.

All data with values outside the accepted range (Table E.1) are marked as NaN. Water pressure is given in dbar (pressure above seafloor), water level in m and referenced to LAT.

File: *MetDataStatFlags*

This file contains the filter flags (see Table E.2) for the data in Table D.1.

File: *PosData*

Signals: Geographical Latitude and Longitude in Degrees with 6 decimals plus flags.

This file contains hourly values of buoy position according to the GPS sources (Iridium and Septentrion).

File: *StatusData*

Signals: Household parameters.

This file contains hourly values of various buoy household parameters that are used to check buoy functionality.

File: *SupplementaryData*

Signals: Additional parameters.

This file contains additional Thelma data (SNR, modem temperature, etc) and LiDAR met station and other LiDAR functionality parameters plus flags. The data in this file are provided to supplement the dataset.

File: *WaveDataStat*

Signals: See Table D.3. Wave parameters are explained in more detail in Table D.4

The file contains the wave data at 10-min frequency based on 17 min sampling.

Wave data The following signals derived from the wave spectra are checked:

['hm0 m', 'hm0a m', 'hm0b m', 'hmax m', 'mdir deg', 'mdira deg', 'mdirb deg', 'sprtp deg', 'thhf deg', 'thmax s', 'thtp deg', 'tm01 s', 'tm02 s', 'tm02a s', 'tm02b s', 'tp s', 'tz s'] for consecutive duplicates and out-of-bounds as described above.

If hm0 is found out-of-bounds, all wave parameters (as indicated above) are set to NaN.

File: *WaveDataStatFlags*

This file contains the filter flags (see Table E.2) for the data in Table D.1 indicating where duplicates or out-of-bounds values were encountered and removed.

File: *WindResourceSpeedDirectionStat*

Signals: See Table D.5

The file contains 10-minute averaged wind measurements (wind speed, direction, minimum and maximum horizontal wind speed in 10-min period). The signals are all timestamped with the end of the averaging period.

All wind measurements are checked for consecutive duplicates and out-of-bounds as described above.

For timestamps where the wind speed or direction is found outside the accepted range, all measured wind parameters are set to NaN.

To correct for 180 degrees ambiguities in the LiDAR wind directions, an additional correction with 10-minute average directions from the Gill wind sensor as ground truth has been used. The correction is done automatically using an algorithm checking each height for ambiguous wind directions and flipping it 180 degrees if necessary.

File: *WindResourceStatusFlags*

This file contains LiDAR info and status flags, heading count, package count and rain count.

This file also contains the processing (filter) flags indicating where duplicate or out-of-bounds values were removed.

File: *WindResourceTIVeerShearInflow*

Signals: See Table D.6

This file contains the inflow angles in degrees, standard deviations and turbulence intensities using data from the ZephIR unit.

This file also contains wind veer and shear statistics calculated from the already processed LiDAR wind directions and speeds in the *WindResourceSpeedDirectionStat* file.

The inflow angles are calculated as the angle between the 10-minute average horizontal and vertical components.

Turbulence Intensity (TI) is defined as: $(\sigma/\bar{u})/C$ where σ is the standard deviation and $\bar{u}$ is the mean of the wind speed for a 10-min period. $C = 0.95$ is a constant needed to convert the scan-averaged LiDAR measurement to the point-measurements of a cup anemometer. Note that this definition frequently gives relatively high values in situations with low but variable wind speed. Note also that TI is not compensated for the motion of the buoy, which is a source of increased standard deviation in the measurements, and TI is therefore over-estimated compared to what would be obtained from a LiDAR on a fixed platform. (Z300 MODBUS interface, a user's guide, 19th Dec 2013, issue K, ZephIR Lidar).

Wind shear is calculated as the difference in wind speed per meter between the height levels indicated by the parameter name: $\Delta U/\Delta z = (U_N - U_{N-1})/(z - z_{N-1})$ where U indicates wind speed, z = height, N = height level. Positive values indicate wind speed increasing with height.

Wind veer is the difference in direction between the two levels divided by the height difference, positive if direction rotates counter-clockwise going upward.

The standard deviation, turbulence and inflow angles are set to NaN for the same timestamps and heights where the wind speeds are set to NaN.

Inflow angles are also checked for out-of-bounds values.

No further processing is done on the signals here.

Detailed analysis of derived quantities should always be done using the dataset as a whole and using an appropriate formula of choice.

File: *Signal_Availability*

Signals: Signal availability.

This file contains signal availabilities in % per main parameter.

File: *LiDARInfoStatusFlags*

Signals: LiDAR Info and Status Flags as text.

This file contains LiDAR info and status flags translated to text.

D.2 Signal Tables

Table D.1: *CurrentDataStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1]	Resolution	Configured range
AqDir00xx[2]	deg	-3 ... -36	Current direction	Aquadopp	B	0.176758	-1, 361
AqSpd00xx[2]	cm/s	-3 ... -36	Current speed	Aquadopp	B	0.293945	0, 300
AqAmpxx[2]	dB	-3 ... -36	Signal amplitude	Aquadopp	B	1	0, 128

[1] **Proc. code:** Code describing the level of processing applied to data after receipt from the buoy:
B: Data are presented as delivered by the buoy.
D: Data presented are derived from post-processing as described in Appendix E: Data processing chain.
[2] xx = 04, ..., 36 corresponding to measurement height, see Table C.1

Table D.2: *MetDataStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1]	Resolution	Configured range
AirHumidity	%	4	Air humidity	Vaisala HMP155	B	0.107422	0, 110
AirPressure	hPa	0	Air pressure	Vaisala PTB330	B	0.097656	900, 1100
AirTemperature	°C	4	Air temperature	Vaisala HMP155	B	0.0537109	-15, 40
WaterTemp001	°C	-1	Surface water temperature	Aquadopp	B	0.0380859	-4, 35
Bottom Temperature	°C	1 m a.s.f.	Water temperature	Thelma	B	0.00976563	-5, 35
WaterPressure	dbar	Mooring depth	Pressure of water column from mooring point.	Thelma	B	0.0012207	0, 160

[1] **Proc. code:** Code describing the level of processing applied to data after receipt from the buoy:
B: Data are presented as delivered by the buoy.
D: Data presented are derived from post-processing as described in Appendix E: Data processing chain.

Table D.3: *WaveDataStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1)]	Resolution	Configured range
hm0	m	0	Estimate of Hs (significant wave height).	Wavesense	B	0.0196289	0, 20
hm0a[3)]	m	0	Estimate of Hs of swell[3)]	Wavesense	B	0.0196289	0, 20
hm0b[3)]	m	0	Estimate of Hs of wind sea[3)]	Wavesense	B	0.0196289	0, 20
hmax	m	0	Height of the highest wave in the record.	Wavesense	B	0.0293945	0, 30
mdir	deg	0	Mean spectral wave direction.	Wavesense	B	0.707031	0, 360
mdira[3)]	deg	0	Mean spectral wave direction of swell[3)]	Wavesense	B	0.707031	0, 360
mdirb[3)]	deg	0	Mean spectral wave direction of wind sea[3)]	Wavesense	B	0.707031	0, 360
sprtp	deg	0	Wave spreading at the spectral peak.	Wavesense	B	0.351563	0, 90
thhf	deg	0	High frequency mean wave direction	Wavesense	B	0.707031	0, 360
thmax	s	0	Period of the highest individual wave in the sample.	Wavesense	B	0.101563	0, 25
thtp	deg	0	Estimate of mean wave direction at the spectral peak.	Wavesense	B	0.707031	0, 360
tm01	s	0	Estimate of mean wave period	Wavesense	B	0.101563	0, 25
tm02	s	0	Estimate of mean wave period	Wavesense	B	0.101563	0, 25
tm02a[3)]	s	0	Estimate of mean wave period of swell[3)]	Wavesense	B	0.101563	10, 25
tm02b[3)]	s	0	Estimate of mean wave period of wind sea[3)]	Wavesense	B	0.101563	2, 10
tp	s	0	Period of the spectral peak	Wavesense	B	0.101563	0, 25
tz	s	0	Average period of individual waves	Wavesense	B	0.101563	0, 25

[1)] **Proc. code:** Code describing the level of processing applied to data after receipt from the buoy:
B: Data are presented as delivered by the buoy.
D: Data presented are derived from post-processing as described in Appendix E: Data processing chain.
[3)] Wave frequency ranges:
Band "a" (low frequency): 0.04 - 0.10 Hz
Band "b" (high frequency): 0.10 - 0.50 Hz

Table D.4: Definitions of wave parameters presented in this report

Symbol	Unit	Description
H	m	Individual wave height
Hmax	m	$= Max(H)$: Height of the highest individual wave in the sample, measured from crest to trough in m
Hm0	m	Estimate of significant wave height, hs, $hm0 = 4\sqrt{m0}$ in m
Tp	s	Period of spectral peak $= {}^{1}/_{f_p}$. The frequency/period with the highest energy in s
Tz	s	Average period of individual waves (from zero upcrossing)
Tm01	s	Estimate of the average wave period; $Tm01 = m0/m1$ in s
Tm02	s	Another estimate of the average wave period; $Tm02 = \sqrt{\frac{m0}{m2}}$
ThTp	°	Mean wave direction at the spectral peak in deg ("The direction of the most energetic waves")
Mdir	°	Wave direction averaged over the whole spectrum
Hm0a, Hm0b	m	Estimates of Hs for frequency bands "a" ([0.04 Hz, 0.1 Hz]) and "b" ([0.1 Hz, 0.5 Hz]), as Hm0, but with the moments calculated by integration over the respective frequency bands
Tm02a, Tm02b	s	Estimate of mean wave periods in s calculated for frequency bands "a" and "b"
Mdira, mdirb	°	Estimate of mean wave direction in deg calculated for frequency bands "a" and "b" Directions are given in degrees clockwise from north, giving the direction the waves come from (0°from north, 90°from east, etc.)

Table D.5: *WindResourceSpeedDirectionTIStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1)]	Resolution	Configured range
WindDir004m	deg	4	Ultrasonic anemometer wind direction	Gill anemometer	B	0.353516	-1, 361
WindSpeed004m	m/s	4	Ultrasonic anemometer wind speed	Gill anemometer	B	0.00744629	-1, 60
WindGust004m	m/s	4	Ultrasonic anemometer wind gust speed	Gill anemometer	B	0.00744629	-1, 60
WindDirxxm[2)]	deg	30 ... 200 250	LiDAR wind direction 10 min average using LiDAR data	ZephIR LiDAR	D	0.0883789	-1, 361
WindSpeedxxm[2)]	m/s	30 ... 200 250	LiDAR wind speed 10 min average using LiDAR data	ZephIR LiDAR	D	0.00744629	-1, 60
VerticalWindSpeedxxm[2)]	m/s	30 ... 200 250	Vertical LiDAR wind speed 10 min average using LiDAR data	ZephIR LiDAR	D	0.0244141	-25, 25

1) **Proc. code:** Code describing the level of processing applied to data after receipt from the buoy:
B: Data are presented as delivered by the buoy.
D: Data presented are derived from post-processing as described in Appendix E: Data processing chain.
2) **xx** = 30, ..., 200, 250 corresponding to measurement height, see Table C.1

Table D.6: ***WindResourceInflowAnglesStat*** **signals**

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1)]	Resolution	Configured range
Standard Deviation xxm[2)]	m/s	30 ... 200 250	Standard Deviation of wind speed in 10 min interval using LiDAR data	ZephIR LiDAR	B	0.0012207	0, 60
TI xxm[2)]	None	30 ... 200 250	Turbulence Intensity,[3)] using LiDAR data	ZephIR LiDAR	B	0.0012207	0, 20
Inflow angle xxm[2)]	deg	30 ... 200 250	The Inflow Angle (IA) is the angle of the wind vector relative to the horizontal, calculated from 10 minute averages. IA is positive if the wind vector has an upward directed vertical component.	ZephIR LiDAR	B	0.0883789	-40 ,40
Wind Veer [index][2)]	deg/m	[index][2)]	Difference in direction between adjacent measurement heights per m	ZephIR LiDAR	D	0.0883789	-60, 60
Wind Shear [index][2)]	[(m/s)/m]	[index][2)]	Difference in speed between adjacent measurement heights per m	ZephIR LiDAR	D	0.00744629	-20, 20

1) **Proc. code:** Code describing the level of processing applied to data after receipt from the buoy:
B: Data are presented as delivered by the buoy.
D: Data presented are derived from post-processing as described in Appendix E: Data processing chain.

2) xx = 30, ..., 200, 250 m index corresponding to measurement height, see Table C.1

3) **Turbulence Intensity (TI)** is defined as: $(\sigma/\bar{u})/C$ where σ is the standard deviation and $\bar{u}$ is the mean of the wind speed for a 10-min period. $C = 0.95$ is a constant needed to convert the scan-averaged LiDAR measurement to the point-measurements of a cup anemometer. Note that this definition frequently gives relatively high values in situations with low but variable wind speed. Note also that TI is not compensated for the motion of the buoy, which is a source of increased standard deviation in the measurements, and TI is therefore over-estimated compared to what would be obtained from a LiDAR on a fixed platform. (Z300 MODBUS interface, a user's guide, 19th Dec 2013, issue K, ZephIR Lidar)

Appendix E: Data processing chain

This chapter outlines the data flow, measurement principles for each instrument, processing steps applied to the data before they are delivered to RVO and validation and quality control procedures.

E.1 Data flow

For each instrument on a SWLB, the measurement processes are set-up individually according to the resolution needed. The measurements are stored in the onboard in-memory database and, every 10 minutes, packed into encrypted messages and stored:

- GPS position and current data (Aquadopp-produced 10-minute-averages) are delivered by these instruments every 10 minutes for storage. No further treatment of either data is done on board.
- Air pressure, temperature, and humidity measurements as well as data from the bottom mounted Thelma pressure sensor are stored in the internal memory database at their respective measurement rates. 10-minute-averages are calculated for storage every 10 minutes.
- Wave parameters are calculated onboard from raw data as described in Section E.2.2 and stored every 10 minutes.
- Heading information (compass and DGPS) and data from the Gill sensor are continuously stored at 1 Hz and averaged for each 10-minute interval. In addition these measurements are also made available in real time for the LiDAR processes and used as described in Section E.2.3.
- The LiDAR unit measures at 1 Hz. The LiDAR data are combined with buoy heading information to reference buoy direction to north before calculating the 10-minute-averages. Averaging over 10 minutes also serves as motion correction.

The buoy converts all measurements to physical quantities in SI units. Every 10 minutes the data are timestamped and packed for simultaneous transmission and storage in binary integer numbers using a proprietary compression algorithm (pff), giving sufficient digital resolution while using minimal storage space. The digitization resolution is given in Table D.1 - Table D.6. The digitization resolution is higher than the actual measurement resolution ensuring lossless compression. The data are stored in several pff messages to further minimize filesize.

Each SWLB is set up with unique telemetry message identifiers. Together with deployment records, timestamps and position data, the datasets for each of the buoys/stations in this campaign are be kept separate and are unique.

Data measured at each buoy is simultaneously both stored locally and transmitted via satellite to allow for near real-time operations checks, maintenance scheduling and monthly reporting. At the receiving end the data are unpacked to physical values in real numbers using the reverse conversion method. The application of the compression algorithm also means that the data in transmission are encrypted. The dataset presented in this report is therefore binned according to the digitization resolution.

When a buoy is serviced, the following stored data are downloaded:
- stored pff messages
- raw data stored on the buoy
- raw data stored on the major instruments

Monthly reports are based on satellite transmitted 10-minute averages stored in the pff messages. Any data downloaded during a service is used to investigate gaps in the data set that occurred during the deployment. When necessary and if available (no other instrument issues), these data can be re-processed to fill gaps.

E.2 Measurement principles

E.2.1 Heading sources

There are two main heading sources on each SWLB: the magnetic compass and the DGPS system. The compass gives direction relative to magnetic north, while the DGPS system gives direction relative to true north. For wind direction, the Gill sensor uses the compass as heading source, while for the LiDAR wind directions the DGPS system is the main heading source. However, wind directions from the LiDAR can also be given using the magnetic compass as heading source if the DGPS system is unavailable. Raw 1 Hz heading data are stored on disk as backup/fallback.

In addition the Wavesense and Aquadopp each have a built-in compass that is used as heading source to align the wave and current directions respectively (both relative to magnetic north).

Note that at TNW, the magnetic deviation between magnetic and true north is ≤ 1 ° and thus negligible.

E.2.2 Waves

The wave measurements are based on the fact that the discus shaped buoy will respond to the waves by following the height and slope of the waves, so that the wave motion can be interpreted as the motion of the sea surface. The Wavesense3 wave sensor employs accelerometers, rotation sensors and a compass to calculate the position, velocities and rotations of the buoy in all directions in space. From these data the spectra of wave height and direction are calculated, and the parameters of wave height, period and direction listed in Table D.4 are calculated.

The wave parameters are based on a time series of 1024 1Hz values, i.e. 17 minutes (1024 s $\approx$ 17 min). When the acquisition is complete, the analysis phase starts using FFT (Fast Fourier Transform) algorithms. Wave bursts overlap by 424 s, i.e. data is collected for 1024 s, but data is analyzed and written to file every 600 s. Approximately 25 minutes in total are needed for a full measurement cycle, including "heat-up", 17 min sampling and time to run FFT analysis. The measurements are taken continuously and the processing windows overlap.

Maximum wave height, hmax, and the period of the highest individual wave, thmax, are calculated by "zero upcrossing" analysis and requires 50 "high" waves in 17 min. This means that hmax will not be calculated when significant wave height, hm0, is less than approximately 0.3 m.

In addition to the 10-minute wave parameters, raw 1 Hz compass, heave, pitch and roll data are stored on disk as backup.

E.2.3 Wind

There are two types of wind sensors on the LiDAR buoy: *Gill Windsonic* and *ZephIR ZX300 LiDAR*. The drawing in Figure C.1 shows the location of these sensors, and illustrates the LiDAR beams. Heights indicate the levels of the LiDAR optical window (2 m), the height of the Gill sensor (4 m), and the lowest and highest possible LiDAR profile levels, all relative to the sea surface.

The *Gill Windsonic* is an ultrasonic wind sensor measuring the wind along the two horizontal axes defined by the sensor transmitting and receiving elements. The travel time difference of ultrasound emitted in opposite directions along the two perpendicular axes is used to calculate the wind speed components along those axes. From the components the wind speed and direction relative to the instrument's x-axis is computed. Then the wind direction relative to magnetic North is calculated using the measurement of buoy heading from the buoy's compass. An important function of the Gill Windsonic sensor is to be a reference for wind direction as the LiDAR is known for its 180 ° ambiguity.

The *ZephIR LiDAR* is a Continuous Wave (CW) LiDAR system. The continuous beam emitted from the window at the top of the LiDAR is slanted at an angle from the vertical and rotates with a period of 1 second around the central axis to continually scan a cone in the air. The return is focused to a particular elevation using an optical focus stage and samples individual line of sight points around the circle. The magnitude of the Doppler shift of the backscattered individual line of sight samples is used to reconstruct the 1 second wind field at a particular elevation.

The LiDAR focuses each of the 10 selected elevations in sequence sampling the wind profile. Before going back to another profile, the LiDAR spends some time doing other tasks, such as looking for precipitation, fog and cloud base, and measuring at the reference height of 38 m above the laser. The effective interval between each profile is about 17 s.

The profiles collected at 17 s intervals are averaged to give a time series of 10-minute average horizontal and vertical wind which are stored on the LiDAR unit but not used by the SWLB system. The SWLB Wavesense 3 processing unit, takes the raw 1 Hz LiDAR data and uses data from other sensors to produce the 10-minute averages relative to north. From the components the wind speed and direction relative to the instrument's x-axis are computed. Then the wind direction is calculated using the measurement of buoy heading from Septentrio DGPS. Wind directions are also checked in real-time against the data from the Gill wind sensor to resolve the 180° ambiguity in the results due to the ambiguity in the magnitude of the Doppler shift. The 1 Hz data from the LiDAR are also stored on disk independently of the the LiDAR unit as double backup.

Averaging over 10 minutes also serves as motion correction.

The LiDAR is equipped with a met. station that includes a compass. This is however not used as primary source for resolving the 180° ambiguity of the LiDAR, but is available as fallback/backup. Any errors in the met station thus do not impact the LiDAR wind measurements except for instances where the LiDAR unit is restarted.

E.2.4 Current measurements

The *AquaDopp current profiler* is mounted in the buoy hull with the acoustic head immediately below the hull facing vertically downward. The three slanted transducers emit sound pulses forming 3 acoustic beams at an angle from the vertical. The Doppler shift of sound echoed from particles such as plankton in the water is used to calculate the current velocity component along the beam. The vertical and horizontal velocity components are then calculated, and a large number of pulses are used to calculate the 10-minute average current velocity.

Signal-to-noise information is stored internally in the current profiler and from mid-2019 also stored in the data logger.

E.2.5 Air temperature and humidity

The Vaisala HMP155 measures air temperature and humidity using a state of the art HUMICAP® 180R humidity sensor element and a fast temperature probe. The mounting of the sensor in a protective housing on the mast top sensor carrier ensures that the sensor is exposed to free air and yet shielded from cooling and heating due to solar and diffuse radiation.

Air temperature is also recorded by the LiDAR met station. The LiDAR met station is placed in the top of the second mast. It is, however, not equipped with a shield like the main sensor. The data from this sensor is thus expected to be of lower quality that the main temperature sensor and is provided as supporting data. Calibrations of the LiDAR met station sensors are not verified.

E.2.6 Air pressure

The Vaisala pressure sensor PTB330A inside the buoy includes Vaisala's top class BAROCAP® pressure sensing technology. The sensor is exposed to the pressure of the open air through a diffusor head on the mast which removes the pressure reducing effect of the wind from the air pressure measurement.

Air pressure is also recorded by the LiDAR met station. The data from this sensor is expected to be of lower quality than the main air pressure sensor and is provided as supporting data. Calibrations of the LiDAR met station sensors are not verified.

E.2.7 Water level

Water level is inferred from measurements of water pressure at the seabed. The bottom mounted pressure sensor gives out an approximate value of water level as the actual pressure in dbar minus 10 dbar which is then approximately equal to the depth in metres. However, to get the proper height of the water column above the sensor, the air pressure measurement from the buoy must be subtracted from the total measured water pressure as follows:

$$h_w = (P_w - P_a)/\rho g \tag{1}$$

where h_w is the height of the water column, P_w is the measured total water pressure, P_a is the measured total air pressure, ρ is the average density of the water (1025.7 kg/m^3) according to average temperature and salinity data from this area stored by ICES (International Council for the Exploration of the Sea), and g is the normal acceleration of gravity.
Water level referenced to LAT is then:

$$wl = h_w + LAT \tag{2}$$

where LAT is a site specific constant to convert to LAT.

The vertical position of the sensor relative to the mean sea level position is obtained from bathymetry data at the deployed coordinates, as shown in Table 1.1. The pressure sensor head is assumed to be located 1.00 m above the seabed.

E.2.8 Water temperature

Water temperature is recorded by 2 main instruments at 2 different water depths: the NORTEK Aquadopp Current profiler (~1 m depth) and the Thelma bottom sensor (seabed).

The water temperature sensor in the NORTEK Aquadopp is used as the main water temperature sensor. This sensor is placed in a "well" on the buoy and is thus measuring the water temperature right under the buoy hull, i.e. ~1 m below the water surface.

Bottom water temperature near the seabed is measured by the Thelma bottom sensor at nominally 1 m above the seafloor. Calibration certificates for this temperature sensor are not available and the data is thus provided as supporting data.

In addition, there is a temperature sensor in the top (acoustic) modem for the water level sensor. This modem is placed inside the keel weight, i.e. ~2 m below the surface. Due to different depths the water temperature will not be the same, especially on calm, warm days when the water is heated from the surface and on calm, cold days with clear sky when the water is cooled from surface.

E.2.9 Buoy position (GPS)

Coordinate positions with latitudes and longitudes are measured by two systems on the LiDAR buoy, the Iridium GPS and the Septentrio GPS. The latitudes and longitudes recorded from these two systems are compared to verify the positioning of the buoy.

In addition, the position measurements from the LiDAR met station are also provided as supporting data. This sensor is however showing slow response.

E.3 Post-processing

No tampering or modifications are applied to increase the post-processed availability or enhance the data quality. In post-processing the system integrity is maintained. Post-processing is limited to use of data from the system itself, not depending on use of data from any external sources.

Post-processed data are those values following the steps below. Post-processing is therefore limited to qualifying those quantities by:

1. Indexing along the time axis with additions of NaN values when a transmission time step is missing
2. Deployment period, i. e. removing values outside of those times where the system is deployed at the target position (e.g. in transit while towing)
3. Removing duplicated transmissions (if **all** measurements/parameters by one sensor are repeated from one time step to the next, the duplicated values are removed)
4. Removing out of range values (e.g degrees above 360) and replacement by NaN (see Table E.1)
5. Spike removal (typically a magnitude of standard deviation)
6. Removing current data below a signal strength threshold (see Table E.1)
7. Additional 180-degree ambiguity check on LiDAR wind data
8. Additional wave filter looking for hm0 > hmax and if true, hmax=Nan.
9. Inspection and assessment (QA/QC) by senior meteorologist/oceanographer

Wind veer and wind shear are derived from the underlying measured physical quantities in post-processing.

Note: Single duplicated values present in the processed dataset are most likely due to measurement resolution, digital binning and/or slow changing physical processes (e.g. water temperature). E.g. if any one of the components of the wind vector (horizontal, vertical or direction) has changed, then all of them must have been updated since they are stored atomically by the same process and are compressed into the same pff-telegram. If the horizontal component then is repeated twice, it must be because it fell in the same digital step. This can happen during stable conditions.

Note: Note also that LiDAR packet count, minimum and maximum wind in a 10-minute interval are transmitted/store separately from wind speed and direction and may have different availabilities in case of missed transmissions.

Table E.1: QA/QC filter ranges for each parameter

Parameter	min	max	Unit
Wind speed LiDAR	0.001	58	m/s
Wind speed Gill	0.001	35	m/s
Direction (all)	0	360	°
LiDAR Packet count	10	40	packets
Inflow Angle	-15	15	°
Current speed	0	135	cm/s
Currents AqAmp	27	128	dB
Hm0	0	18	m
Hmax	0	24	m
Tp	0.1	23	s
Thmax	0.01	23	s
Air humidity	0	100	%
Air pressure	905	1100	hPa
Air temperature	-10	30	°C
Water temperature	0	25	°C
Water pressure	30	40	dbar

Table E.2: QA/QC filter flags indication which filter was applied (and data points replaced by NaN) for each parameter (with reference to the processing given in the list above).

Flag	Action	Filter reference
MissedTransmission	Satellite transmission not received, row of NaNs	item 1
DuplicateToNaN	Duplicated set of values from 1 sensor found and removed	item 3
OutOfBounds	Value out of valid range (Table E.1) found and removed	item 4
OutlierFound	Spike/outlier found and removed	item 5
Flipped180Degrees	180 ° ambiguity found and wind direction flipped 180°	item 7
low signal strength	signal strength below threshold and value removed	item 4

Note: Flipped values are marked in the files *WindResourcesStatusFlags*. Fugro can, however, not guarantee that all ambiguous 180 ° data are flagged.

E.4 Quality control

Fugro follows the international standard recommendations ISO-19901-1:2015 for the collection and supply of oceanographic data, in general:

- To verify the proper functioning of the measuring and recording systems.
- Qualified personnel conduct the observations, selection, installation, checking and maintenance of the equipment.
- For data quality control procedures.

Data are first checked for gaps, instrument and buoy operation issues and timestamp and compass alignment as well as duplicated values indicating potential instrument or data logger issues. Data plots are prepared during post-processing showing the original data set and the effect of the post-processing filters applied. In general all the measured parameters are expected to vary over time, more or less depending on the parameter. In addition the sensors represent parameters that are dynamic and variations in one parameter are typically coupled to variations in one or several other parameters.

The quality control steps are divided into the following categories:

1. Buoy operation:
    - “Household” parameters, i.e. power supply (fuel cells, batteries, power consumption by instrument), error logs, and position data are used to assess the function of the buoy.
    - Any reboots and power supply issues leading to loss of data are identified here.
    - Buoy position is checked to verify the buoy stayed in position during the deployment.
    - Info and status flags from the ZephIR LiDAR unit are stored as part of the household parameters and are used to track the functionality of the LiDAR unit.

2. Variation of single parameters:
    - Some degree of variation is expected. Duplicated values and missing data are indications for instrument operation issues.
    - The measured data are checked against ongoing weather conditions. Reasonable agreement with the nearest weather observations is expected.
    - For currents the diurnal and semidiurnal variations due to the tides should be observed.

3. Variation of related parameters:
    - Humidity and air temperature are expected to increase in rain and fog.
    - The wave period will generally increase with increasing wave heights.
    - Correlation between speed and direction at adjacent levels for both wind and currents is expected.
    - Reasonable agreement between Gill and LiDAR measurements is expected.
    - The gust (from Gill sensor) should be 10-40 % higher than the wind speed.
    - Wind against waves (e.g. high waves during high winds, low winds with long swells, wind from offshore expect correlation between increasing wind speed and wave height).

4. Variation between buoys:
    - Taking variations between the buoys due to location/distance/water depth into account.
    - Air pressure should be very similar.
    - Temperature (both in air and water) should not differ by more than 2-3 ° C.
    - Wind speed and direction should be correlated.

After internal QA done by Fugro during post-processing, the dataset is given to Deltares for validation. Deltares first checks for consistency within the dataset, data files and whether any outliers are present and provides feedback.

If any issues are identified by Deltares, these are checked again by Fugro and dealt with in one of the following ways:

1. If a dataset formality (header lines, file name inconsistency, corrupted file) is identified: the file error is corrected.
2. Status data is checked to determine any buoy operating problems (eg voltage) at the time of the issue in question. Additional parameters are examined to check for packing/saving inconsistencies. Issue is then either determined real and left in dataset and noted for discussion or deemed operating problem and removed with flag files updated accordingly.
3. If an outlier is found: filtering is double-checked, other related parameters and status data are checked. If deemed filter failure, outlier is removed and filter flags are updated. Otherwise outlier is kept in dataset and noted for discussion.

If data points are removed, an updated dataset is issued to Deltares to use in the validation.

Deltares proceeds then with the validation of the data set as described in [1].

E.5 Calculations of data availability from the SWLB

Data availability in this report is given per signal as to show data entries per time series and per system (wind, waves, currents, air pressure, air temperature, water level).

The *Monthly Post-processed Data Availability per signal* for each deployment is calculated by dividing the number of data entries remaining after subtraction of all non-valid entries caused by including but not limited to:

- downtime (due to equipment failure, maintenance, severe weather, damage, malfunction, theft, or any other events),
- any system filtering resulting in data rejection, flagged and defined,
- application of quality filters based on the system's own parameters, defined in Appendix E: Data processing chain.

by the maximum possible number of 10-minute data entries within the respective calendar month based on the given time interval of 10-minutes.

The *Monthly Post-processed System Data Availability* is determined as follows:

a. Wind: Average of the 10-minute averaged Monthly post processed data availabilities per measured elevation, speed and direction up to and including 200 m from the LiDAR. The wind data set also include near surface wind speed and direction, i.e. wind measured in mast top (4 m height) by the Gill Windsonic sensor.
b. Wave: Average of wave parameters (10-min frequency), excluding hmax and thmax.
c. Current: Average of current speed and direction over the water column.

d. Water level: Thelma.
e. Atmospheric pressure: Vaisala.
f. Temperature: Average of air and sea surface temperature.

Note: In the case of multiple (redundant) measurement instruments determining one parameter value, the availability of at least one parameter value determines the data availability.

Signal and system availability are given for each buoy separately. The data files presented do not combine data from the buoys. However, the buoys are deployed for redundancy reasons, so it is possible to increase data availability for wind and meteorological parameters by combining data from buoys measuring in parallel.

Appendix F: Figures

F.1 Buoy Station TNWA-2

The following presentations show data from buoy WS199 at TNWA-2 for the period 01 - 31 January 2021. The data in this report is based on downloaded data from WS199.

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.

F.1.1 Meteorological data TNWA-2

Plots of air pressure, air temperature and sea surface temperature data are presented in Figure F.1 - Figure F.4. The sensors performed well in this period.

The air temperature varied from 1.4 to 9.1°C with an average value of 5.3°C. The sea surface temperature was in the range 7.1 – 8.0°C with an average of 7.5°C. The air pressure varied from 975 to 1023 hPa.

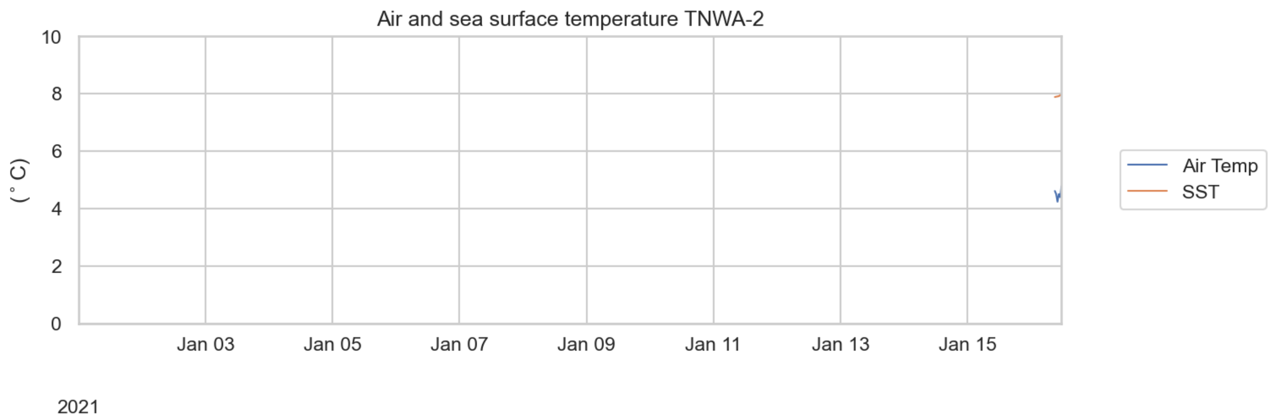


Figure F.1: Air and sea surface temperature at TNWA-2, 01 - 16 January 2021

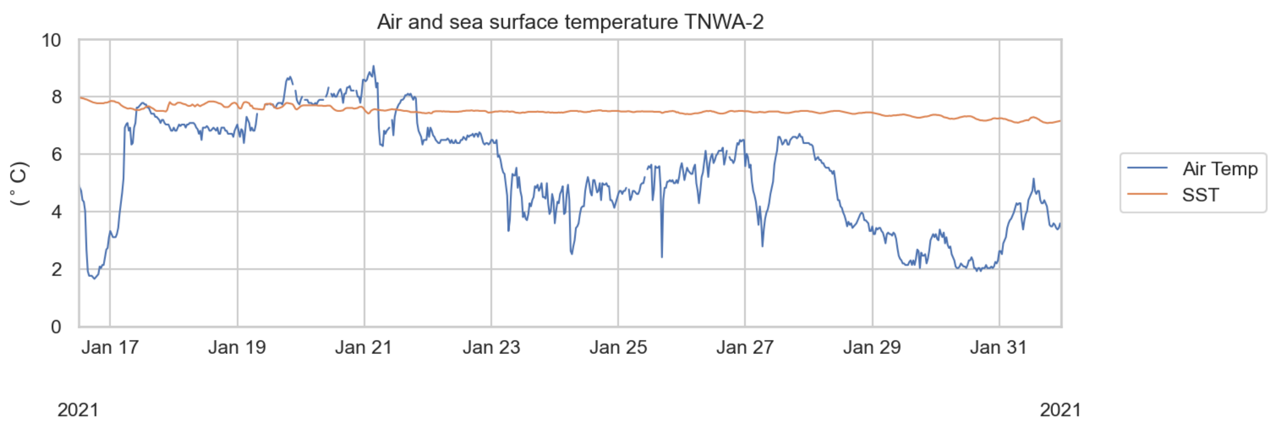


Figure F.2: Air and sea surface temperature at TNWA-2, 16 - 31 January 2021

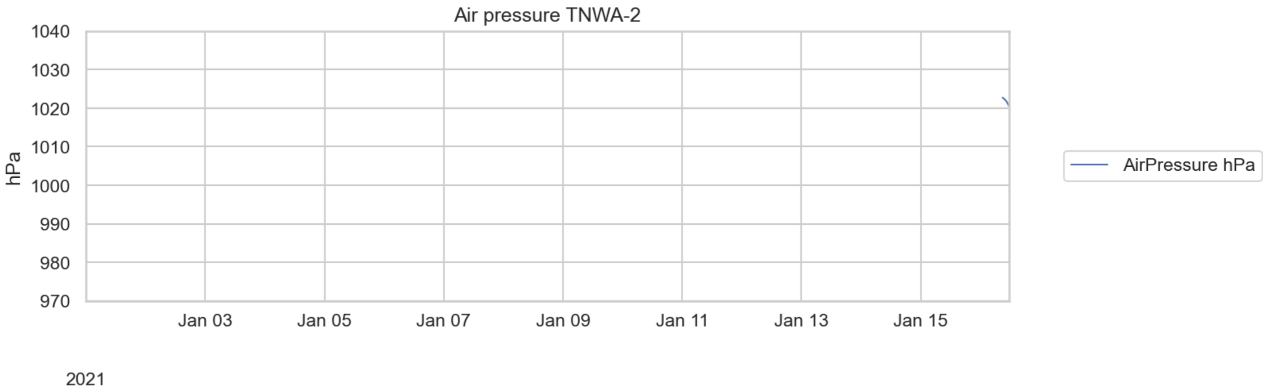


Figure F.3: Air pressure at TNWA-2, 01 - 16 January 2021

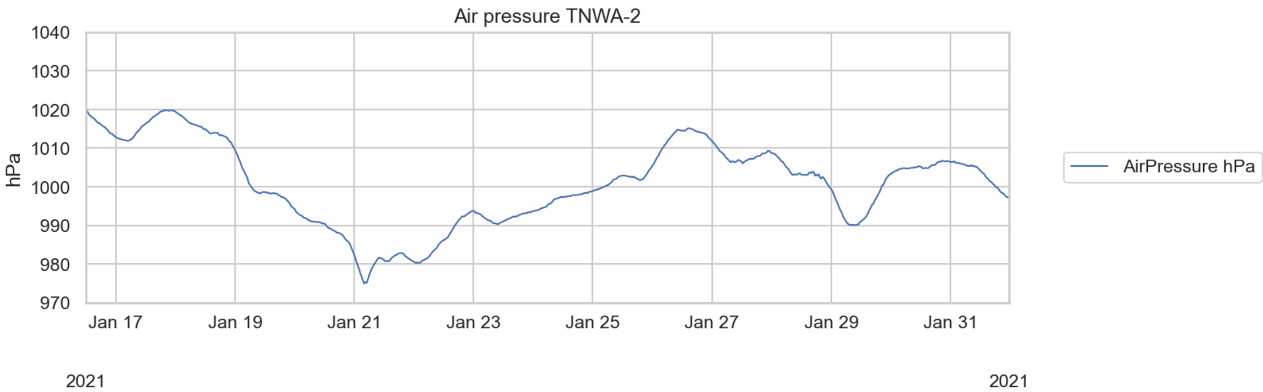


Figure F.4: Air pressure at TNWA-2, 16 - 31 January 2021

F.1.2 Wave data

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.

Plots of wave height, period and direction are presented in Figure F.5 and Figure F.6. The sensor has performed well with a high data availability.

The highest significant wave height (hm0) measured in this period was 5.8 m from a south-westerly direction ($\sim$ 243°) on 21 January at 13:30. The highest single wave of the record with hmax = 10.3 m during this period was observed on 21 January at 12:50. The buoy measured south-westerly wind ($\sim$ 217°) with a speed of 16.0 m/s at 4 m height 30 min before the wave height maximum.

Hmax is calculated from zero-upcrossing analysis requiring a certain number of high enough waves (> 50 "high" waves in 17 min) for a valid calculation.

The variations in wave height agree well with the wind speeds. The average wave period parameters Tm01 and Tm02 show semidiurnal variations which can be explained by the shift in frequency when the waves are travelling along with or opposing the current direction, since the tidal current direction varies in a semi-diurnal pattern. Peaks in Tp, the spectral peak period, during times of low hm0 indicate calm conditions. During times of low winds, there are few short-period wind sea waves and the wave spectrum is dominated by long-period swell leading to higher Tp values.

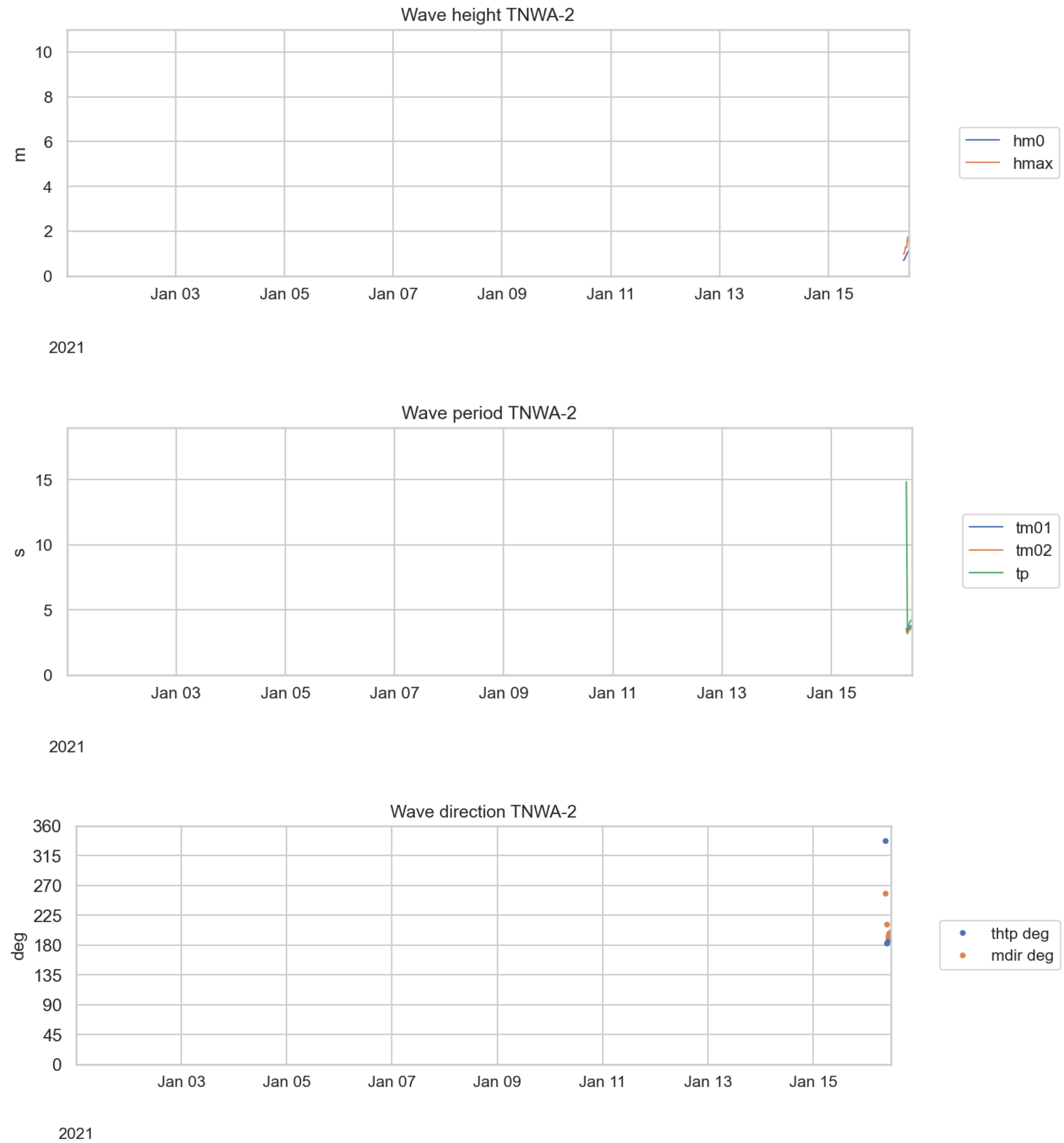
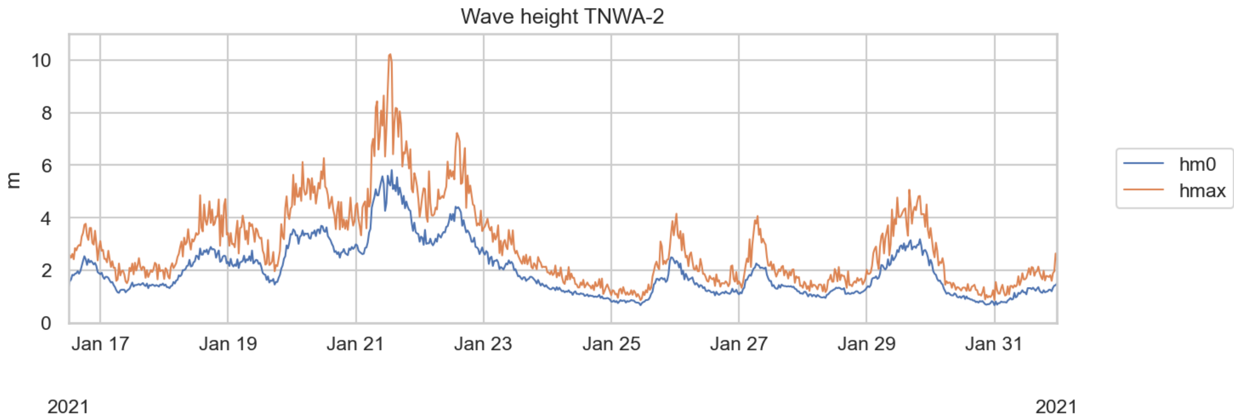
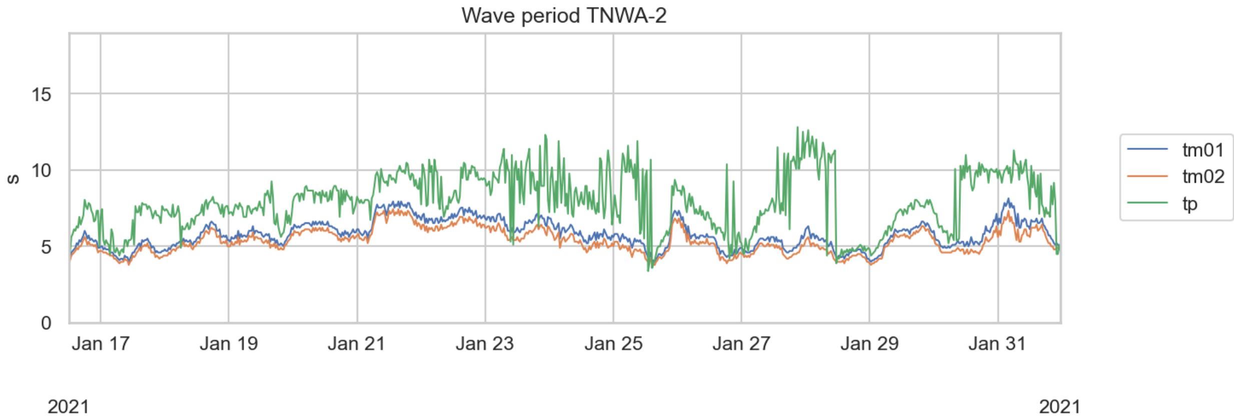


Figure F.5: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWA-2, 01 - 16 January 2021.





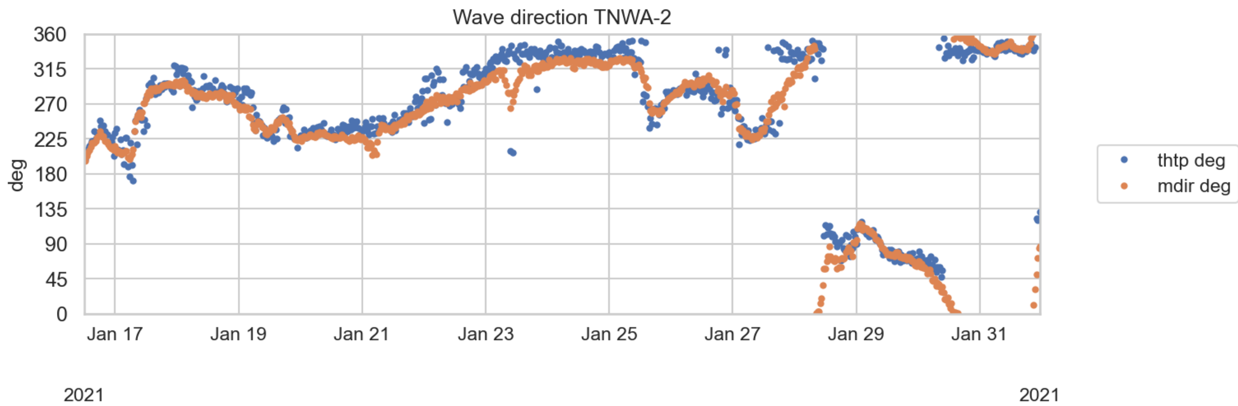


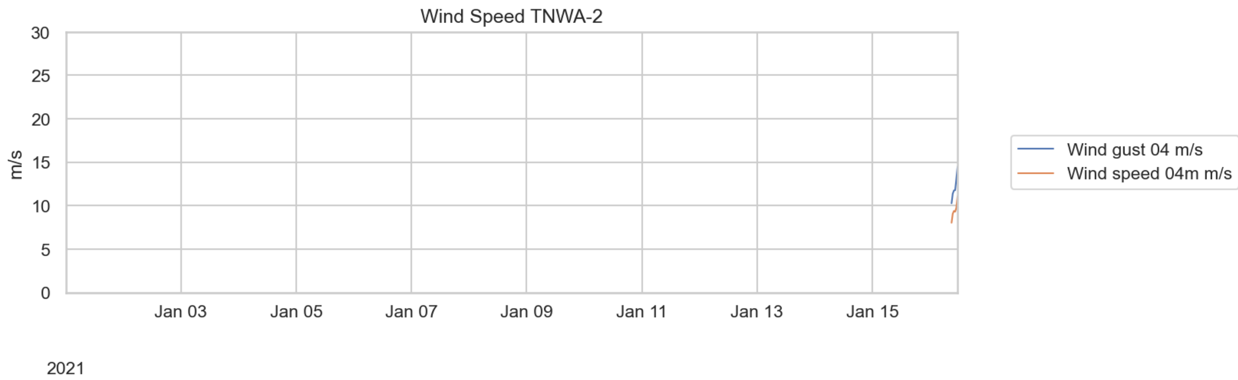
Figure F.6: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWA-2, 16 – 31 January 2021.

F.1.3 Wind profile data

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.

Plots of wind speed and direction data from the Gill wind sensor mounted at 4 m height on the buoy mast are presented in Figure F.7 and Figure F.8.

The data return of this sensor is high with 10 min mean wind speeds up to 18.0 m/s and gusts up to 24.6 m/s. The maximum wind speed was measured on 21 January at 08:00 and the maximum gust was measured on 21 January at 12:40. The average wind speed at mast top height was 8.4 m/s.



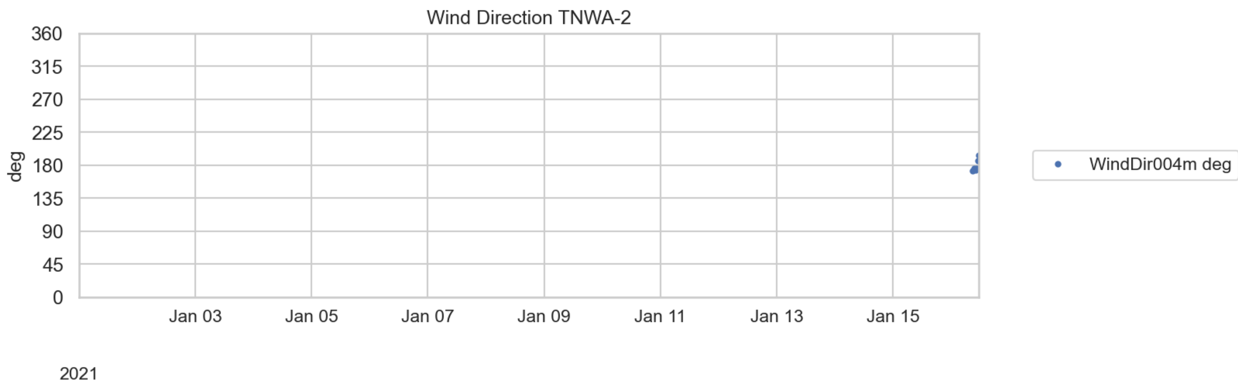


Figure F.7: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWA-2, 01 - 16 January 2021.

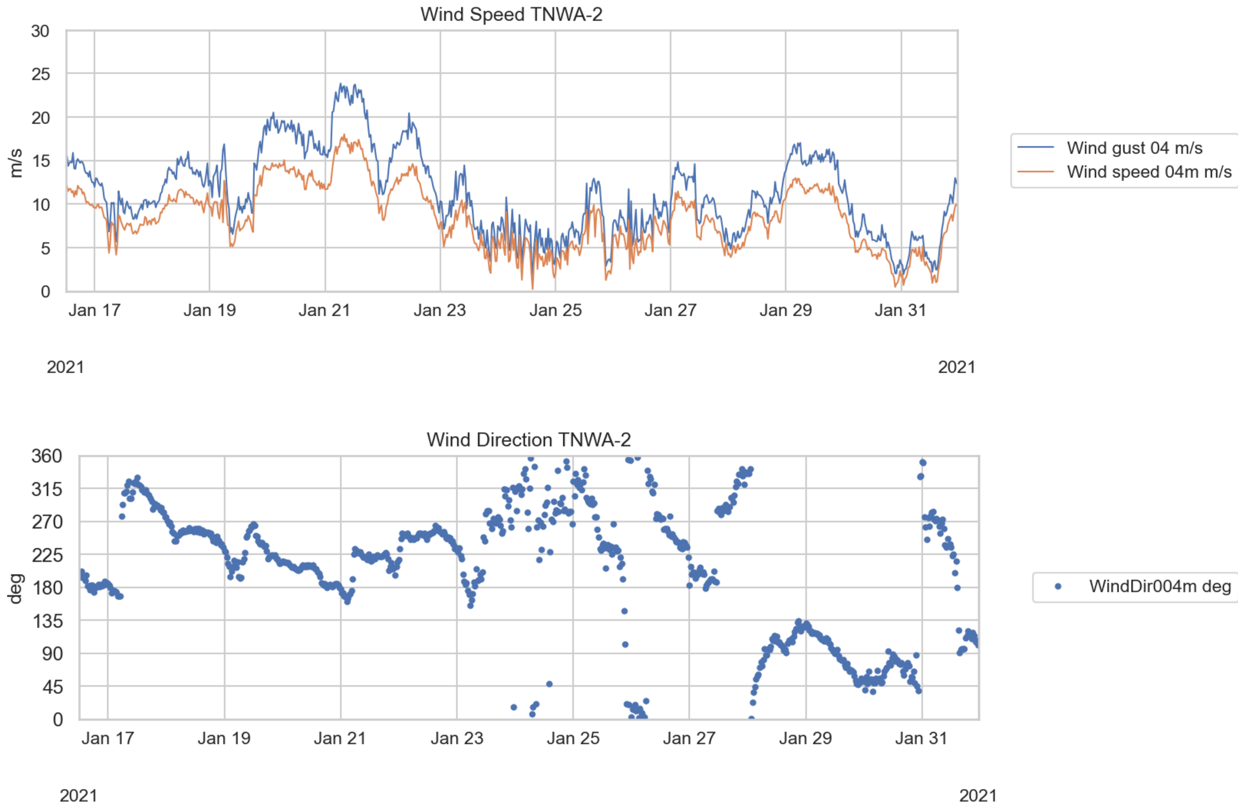


Figure F.8: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWA-2, 16 - 31 January 2021.

Plots of wind profile data from the LiDAR are presented in Figure F.9 - Figure F.24 showing the 10-min. mean wind for each individual level. Plots of the derived parameters Inflow Angle, Turbulence Intensity and wind shear are also presented.

The highest horizontal 10-minute mean wind speed measured in the profile during 01 - 31 January 2021 varies from 10.0 m/s at 30 m to 11.4 m/s at 250 m above the surface. The maximum wind speed at 30 m (23.9 m/s) was measured on 21 January 2021 at 08:00, and the maximum at 250 m (30.6 m/s) on 21 January at 04:40.

Note: TI is in general overestimated, see Table D.1. Detailed analysis of derived quantities (i.e. TI, wind shear, etc.) should always be done using the dataset as a whole and using an appropriate formula of choice.
In addition, turbulence intensity is transmitted separately from the wind speed measurements, as mentioned in Appendix E: Data processing chain. The transmission method is more susceptible to transmission problems and power supply issues. Possible long (several hours) gaps in the TI record generally correspond to scheduled buoy re-boots and affect the TI transmissions more than the other parameters.

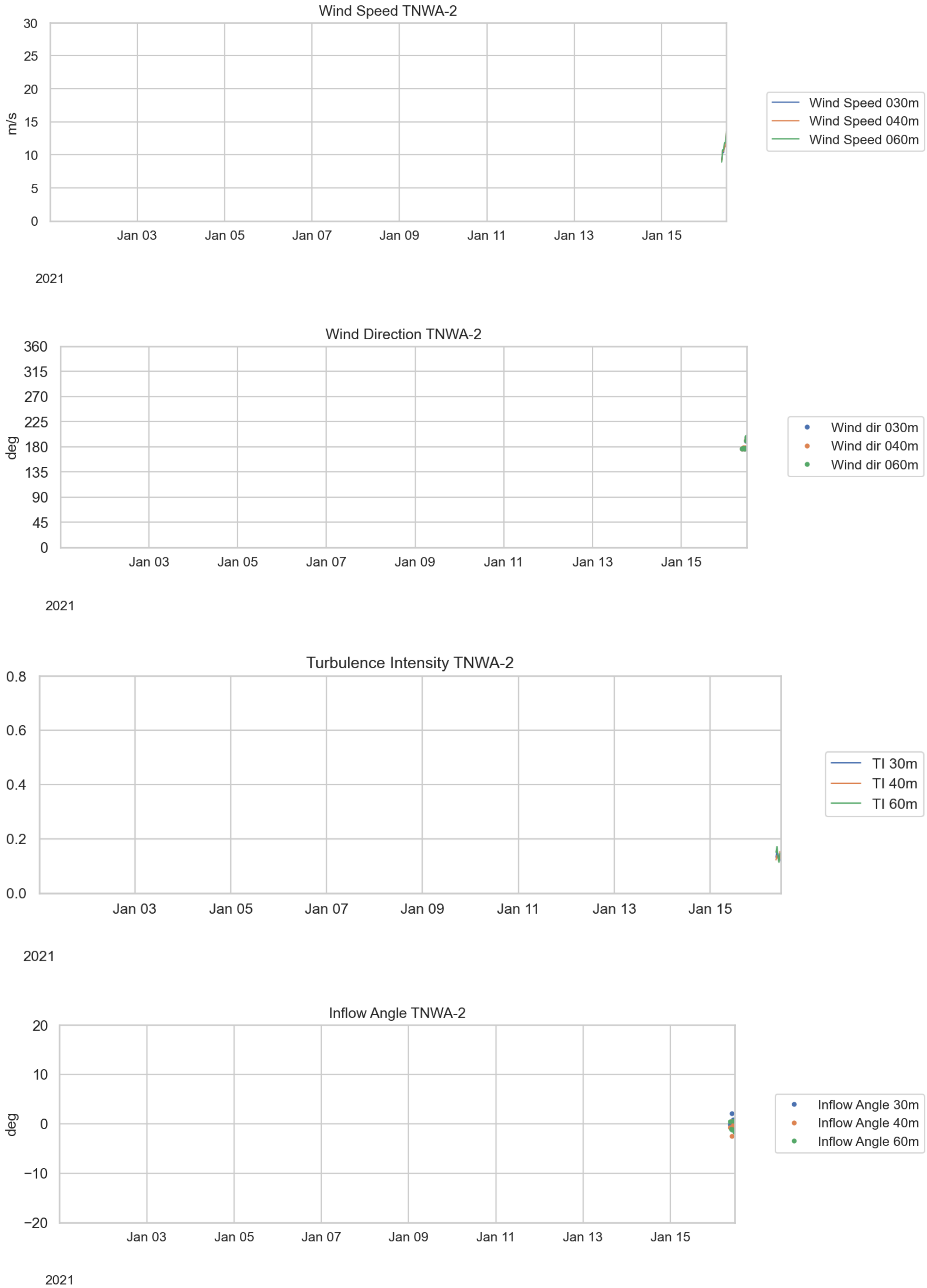


**Figure F.9: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWA-2, 01 - 16 January 2021.
From top to bottom: Wind speed, Wind direction, Turbulence Intensity, Inflow Angle.**

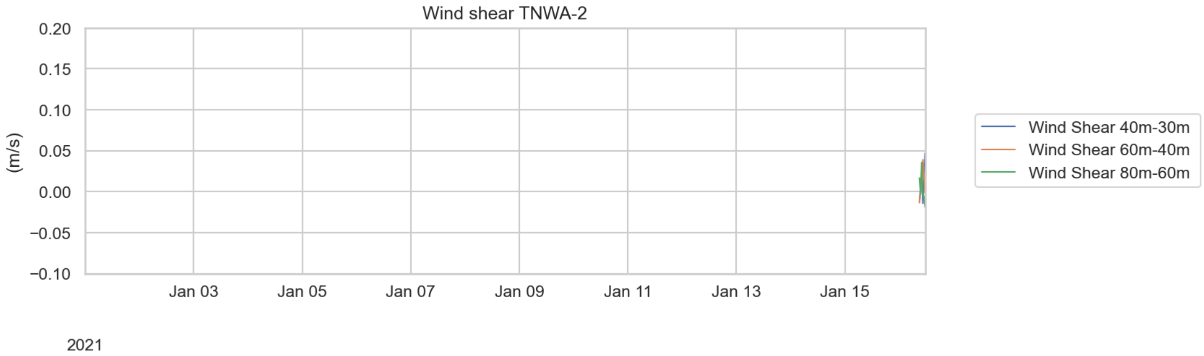


Figure F.10: Plot of wind shear, 30, 40, 60 m a.s.l., at TNWA-2, 01 - 16 January 2021.

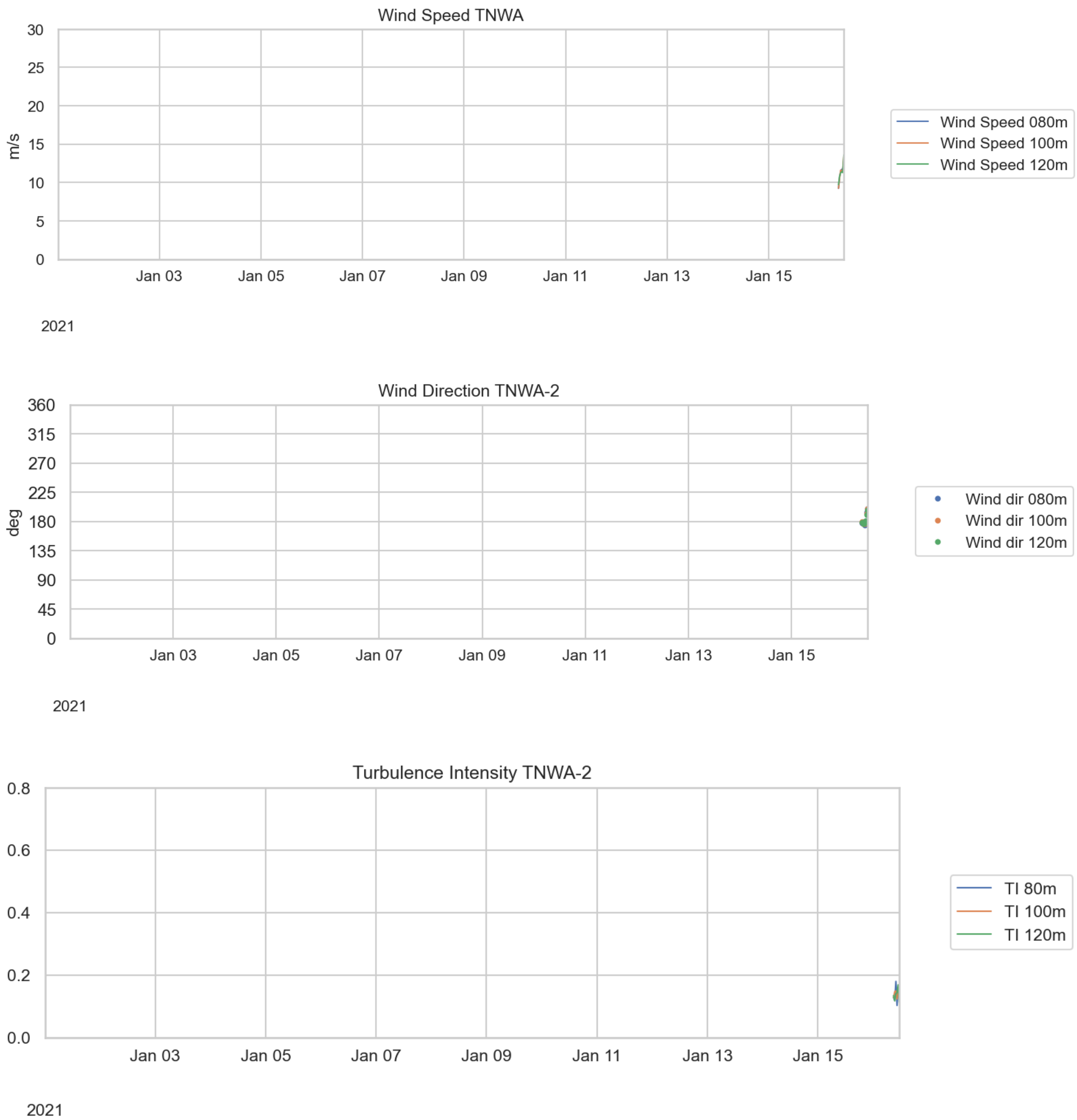
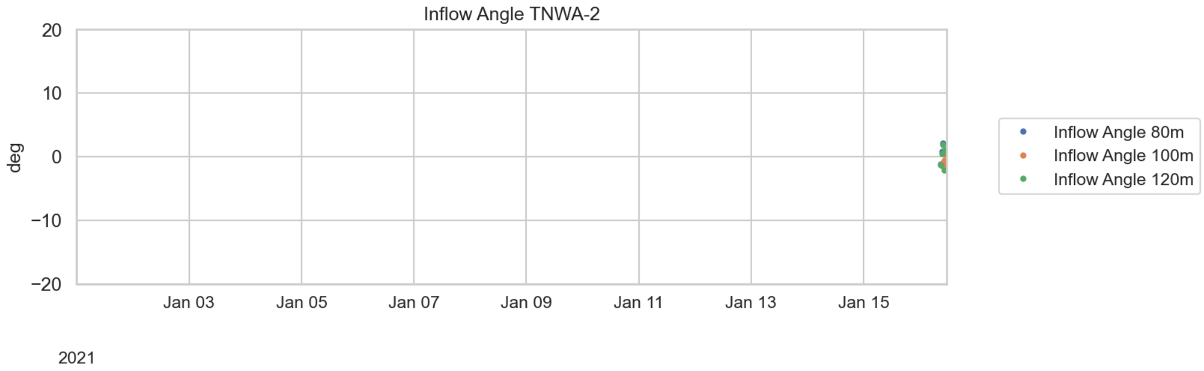


Figure F.11: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA-2, 01 - 16 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity.



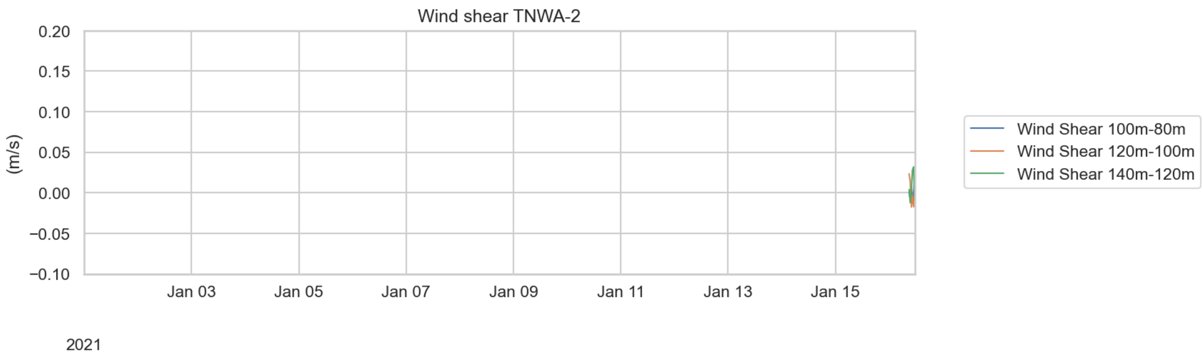
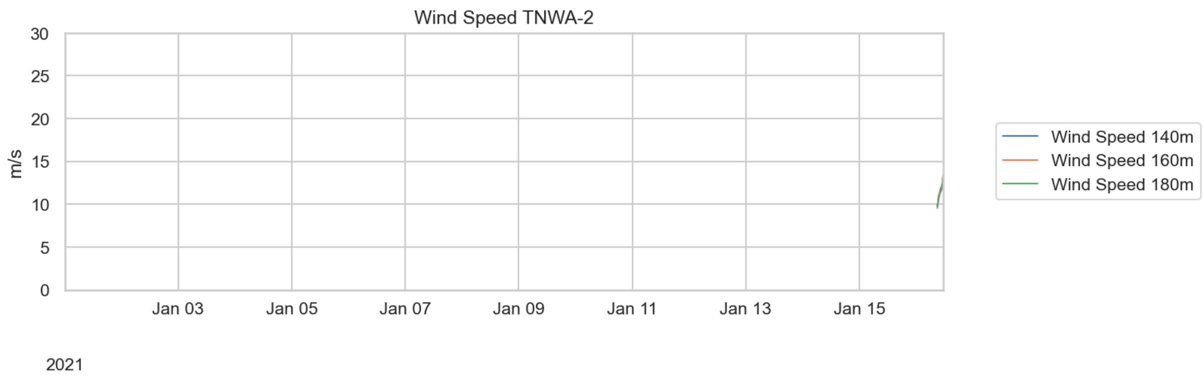


Figure F.12: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA-2, 01 - 16 January 2021. From top to bottom: Inflow Angle and wind shear.



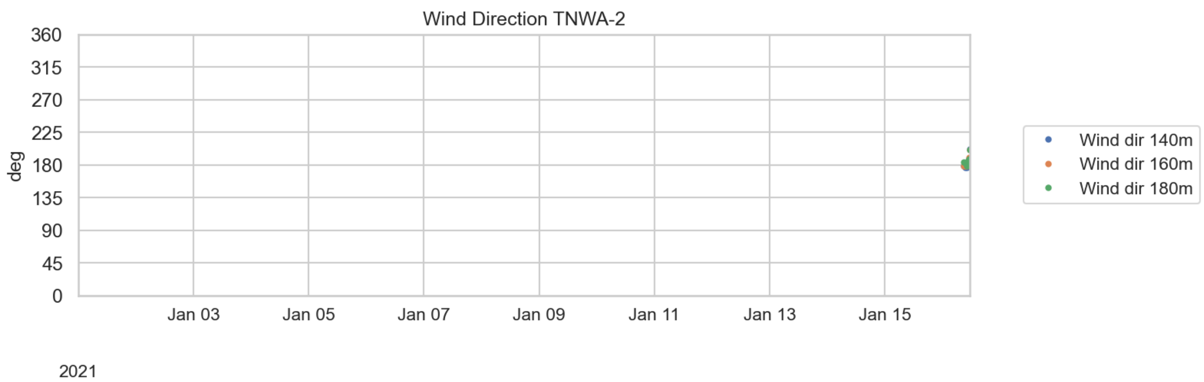


Figure F.13: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA-2, 01 - 16 January 2021. From top to bottom: Wind speed, Wind direction.

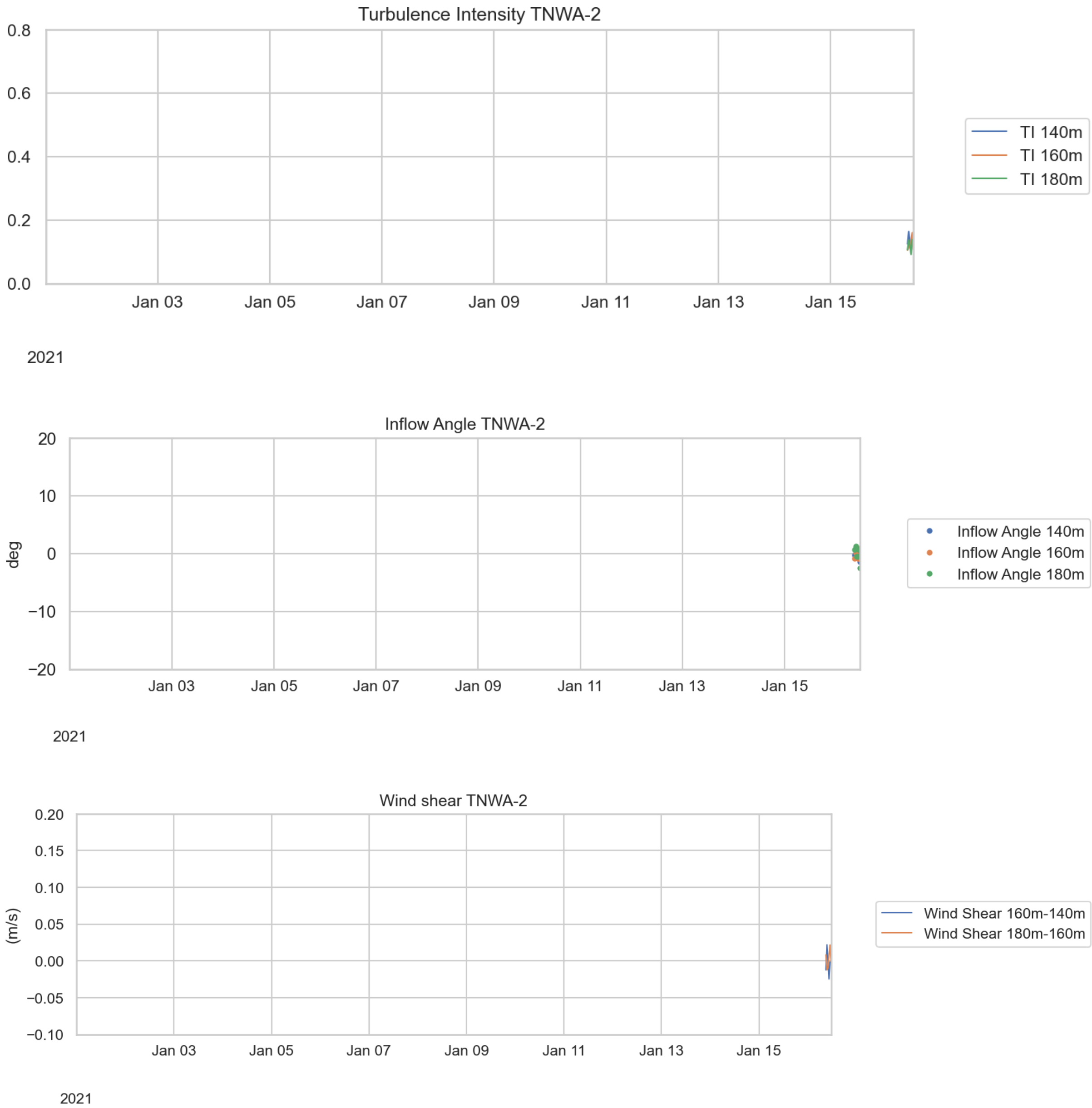


Figure F.14: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA-2, 01 - 16 January 2021. From top to bottom: Turbulence Intensity, Inflow Angle and wind shear.

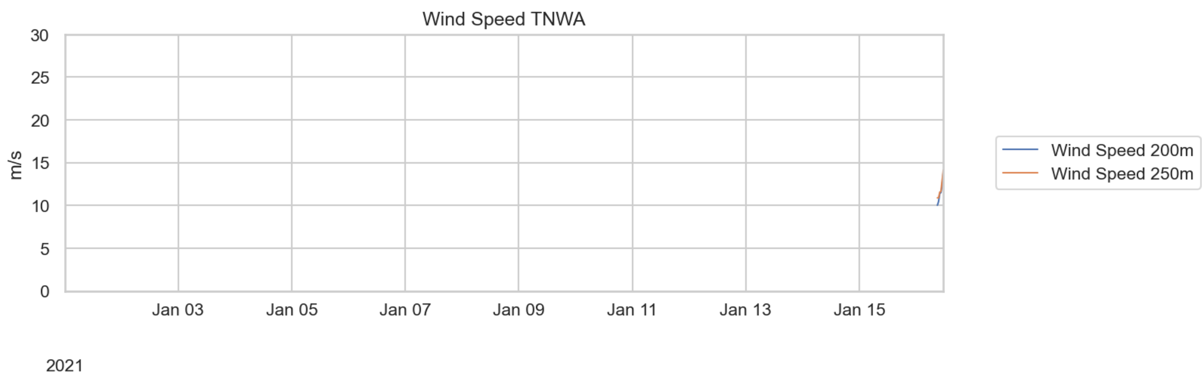
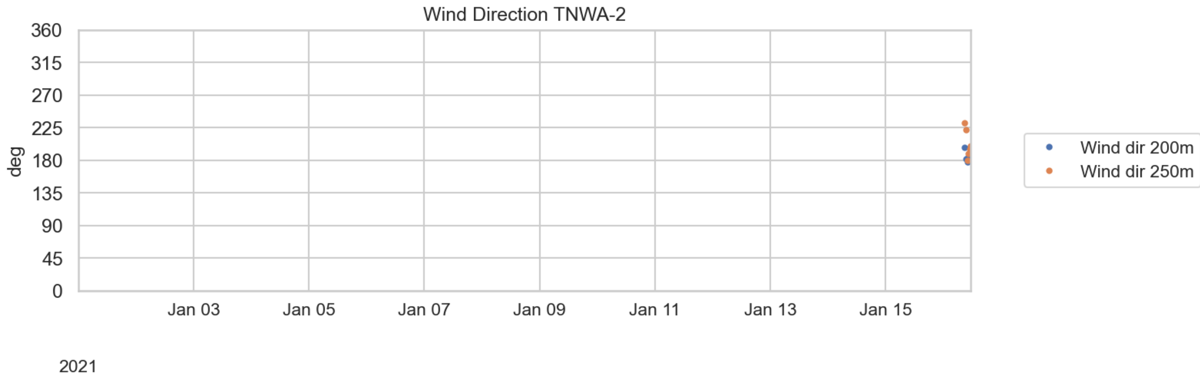
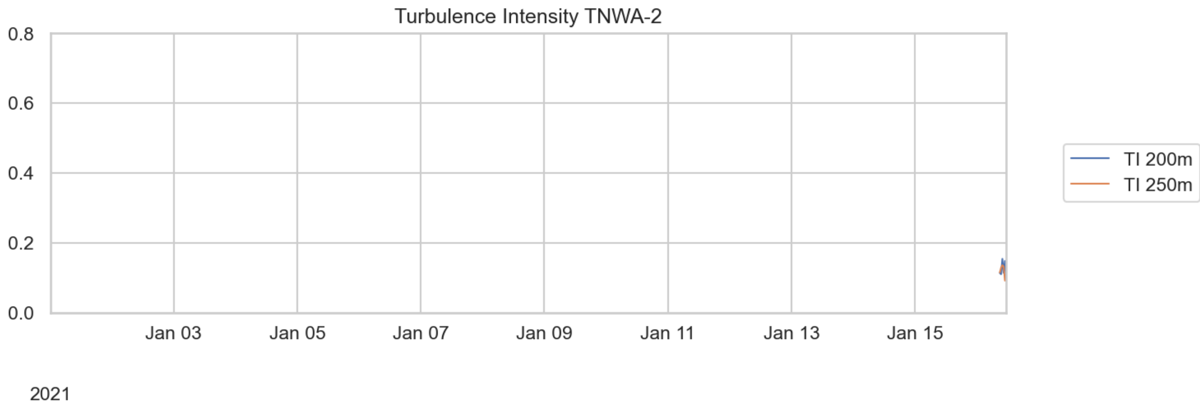
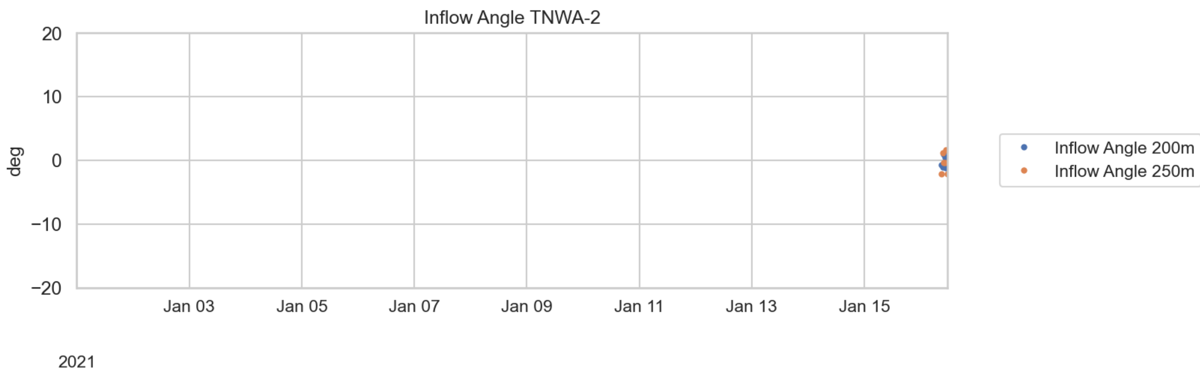


Figure F.15: Plot of wind speed, 200, 250 m a.s.l., at TNWA-2, 01 - 16 January 2021.







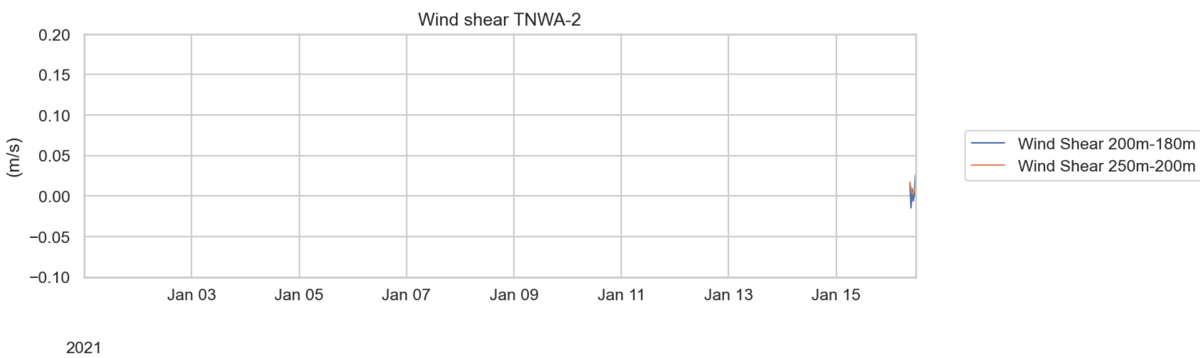


Figure F.16: Plots of wind profile data, 200, 250 m a.s.l., at TNWA-2, 01 - 16 January 2021. From top to bottom: Wind direction, Turbulence Intensity, Inflow Angle and wind shear.

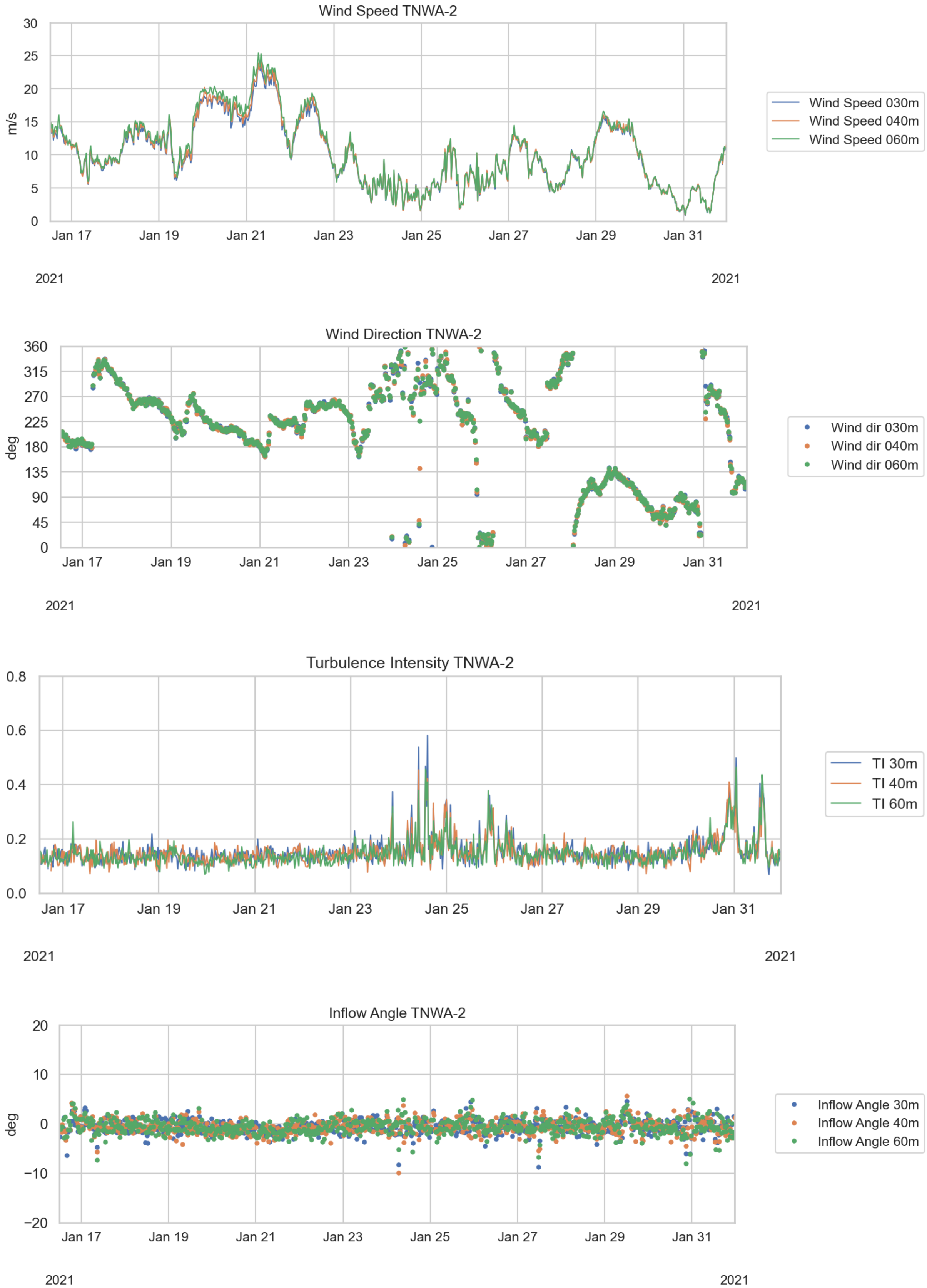


Figure F.17: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWA-2, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, Inflow Angle.

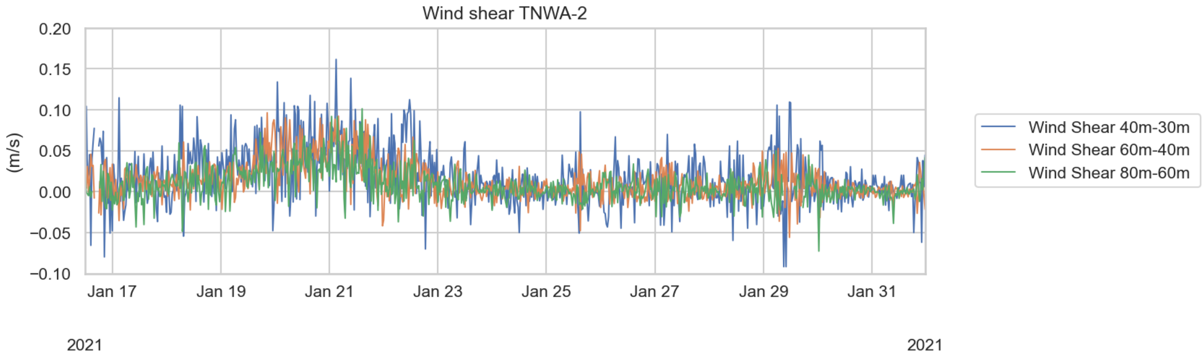


Figure F.18: Plot of wind shear, 30, 40, 60 m a.s.l., at TNWA-2, 16 - 31 January 2021.

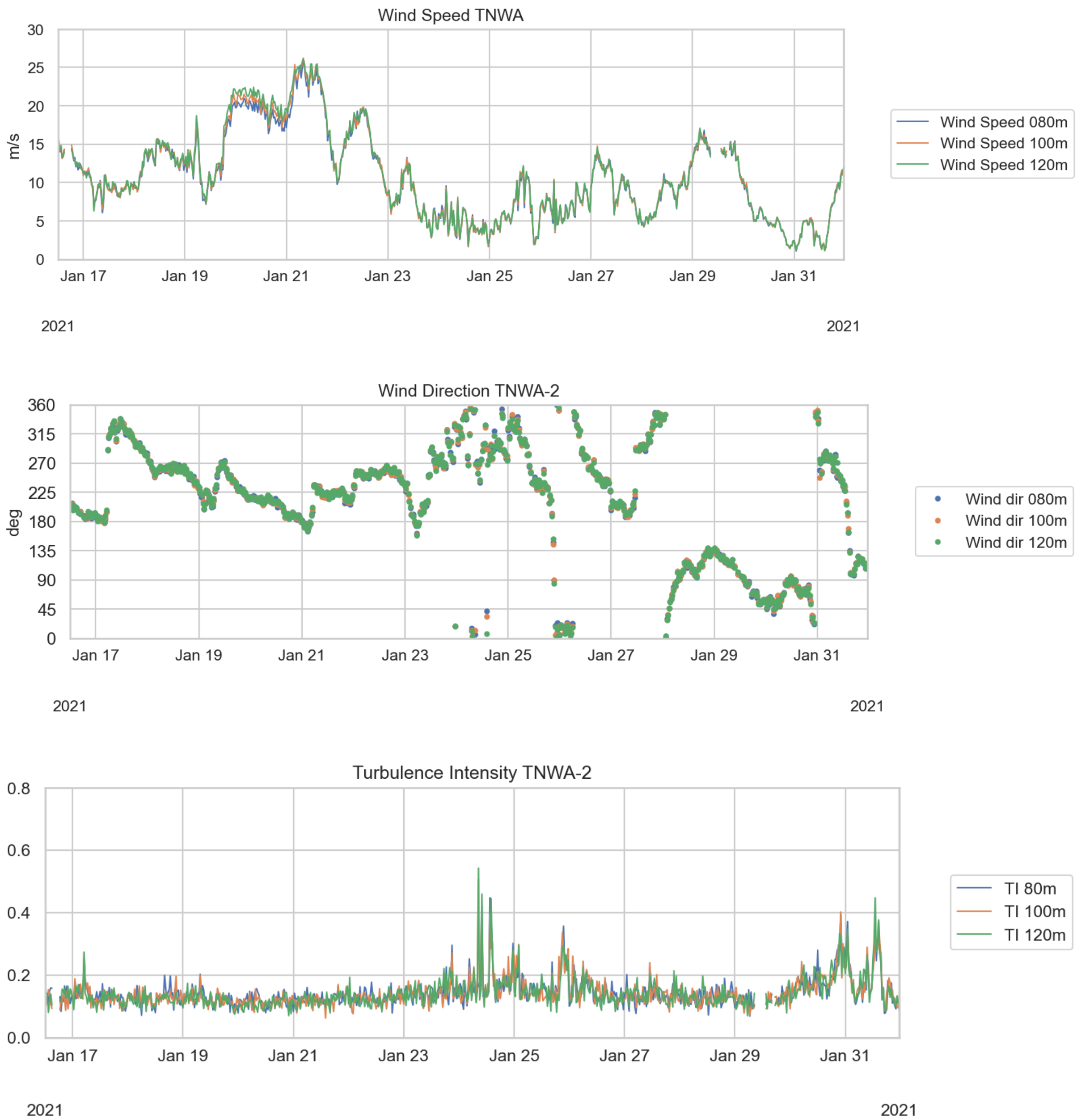


Figure F.19: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA-2, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity.

Figure F.20: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA-2, 16 - 31 January 2021. From top to bottom: Inflow Angle and wind shear.

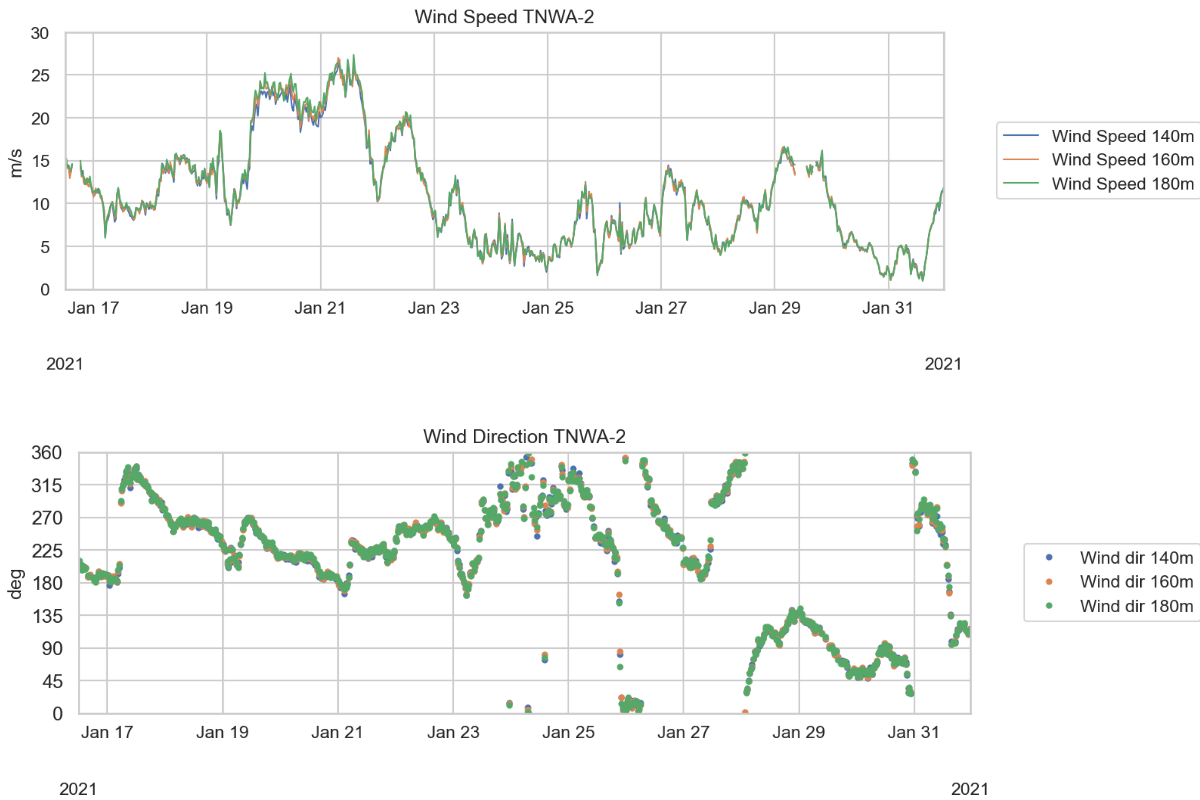


Figure F.21: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA-2, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction.

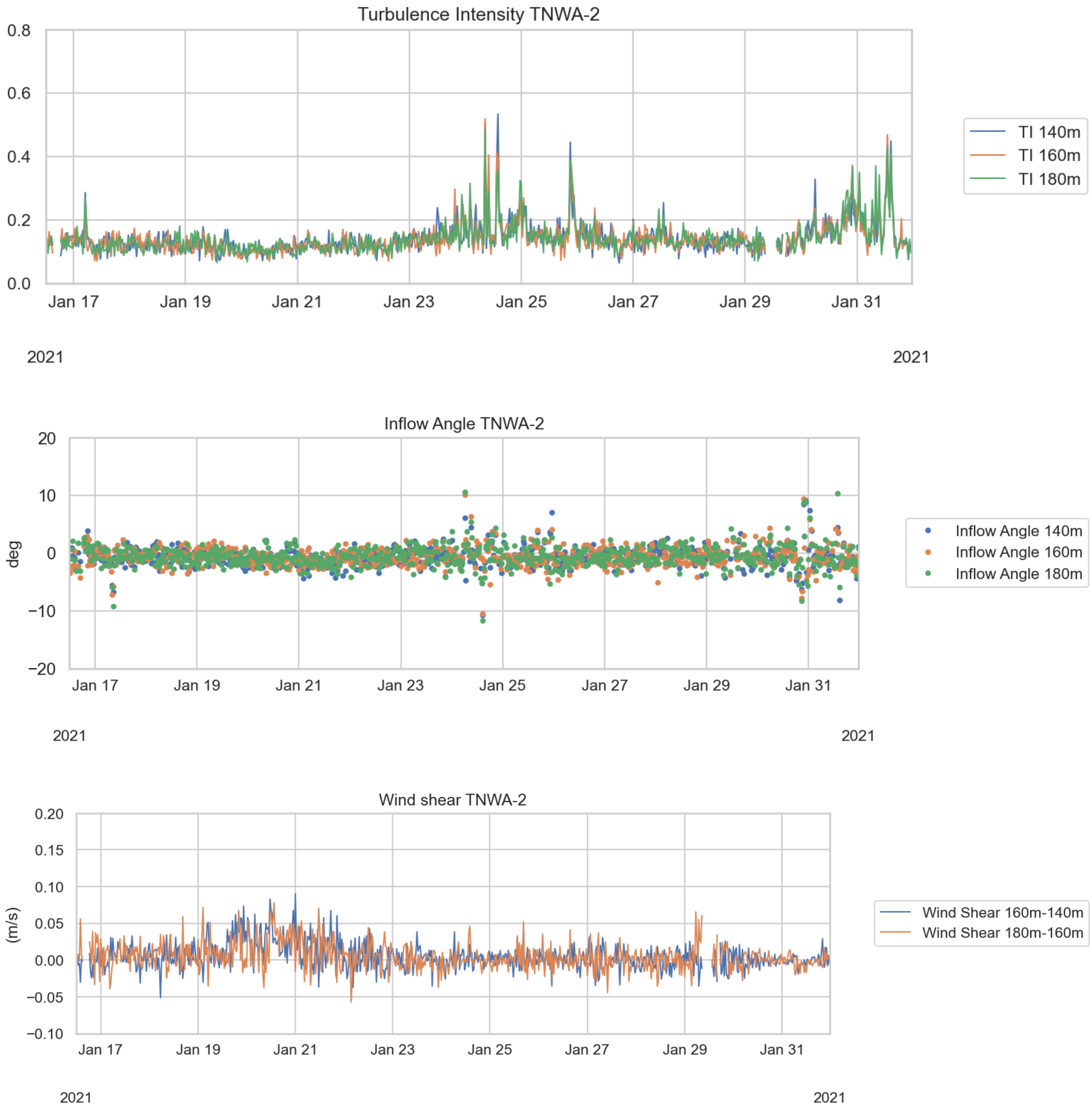


Figure F.22: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA-2, 16 - 31 January 2021. From top to bottom: Turbulence Intensity, Inflow Angle and wind shear.

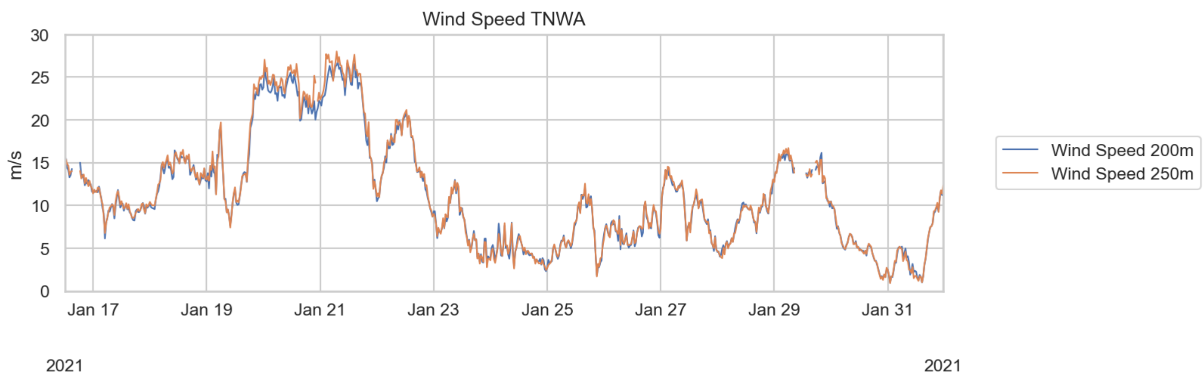


Figure F.23: Plot of wind speed data, 140, 160, 180 m a.s.l., at TNWA-2, 16 - 31 January 2021.

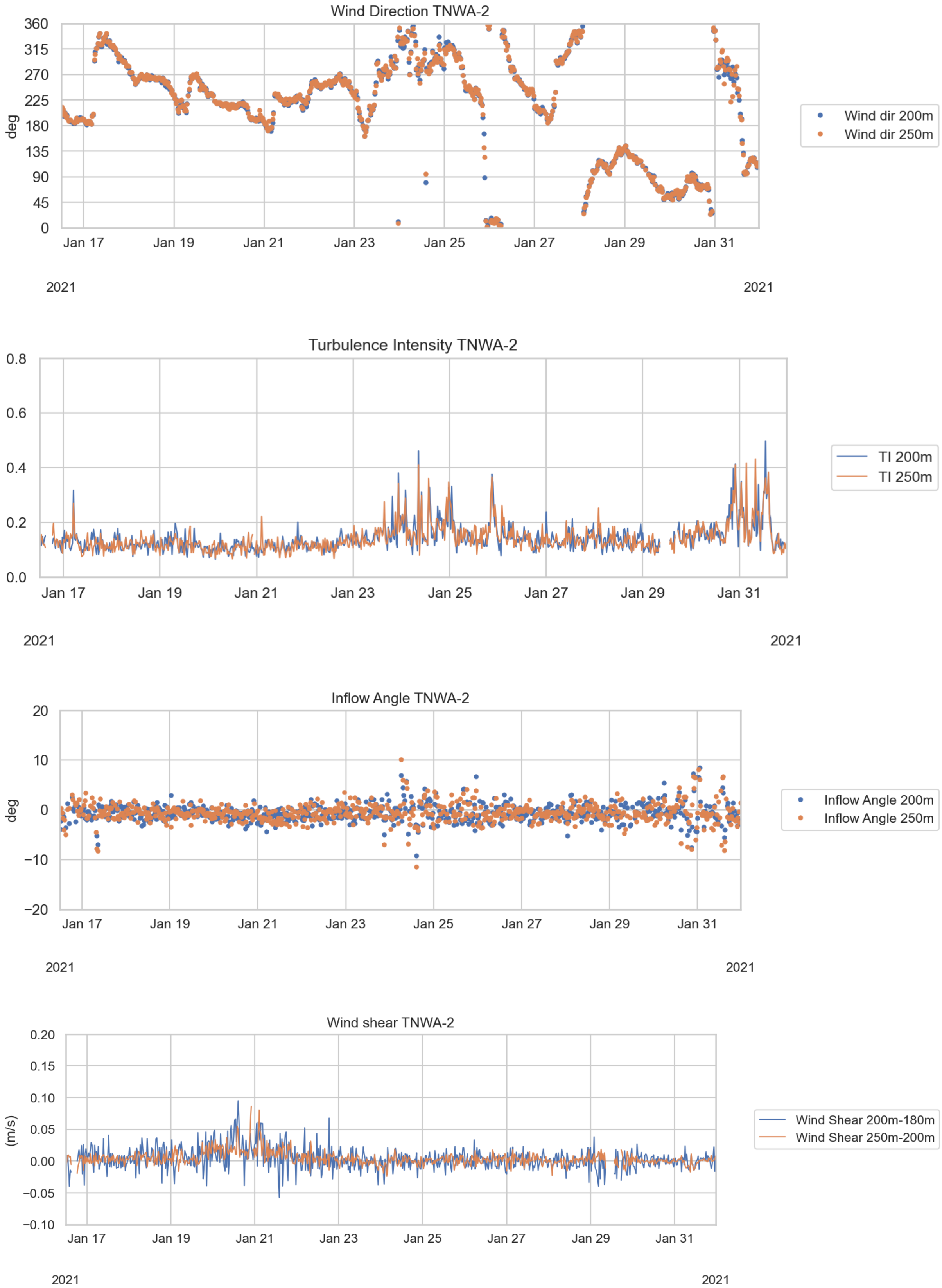


Figure F.24: Plots of wind profile data, 200, 250 m a.s.l., at TNWA-2, 16 - 31 January 2021.
From top to bottom: Wind direction, Turbulence Intensity, Inflow Angle and wind shear.

F.1.4 Current velocity profile data

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.
Plots of the current velocity profile time series are presented in Figure F.25 - Figure F.43.

As expected for this location the current velocity data show a consistent semi-diurnal tidal current pattern. The current vector is completing two rotations of the tidal ellipse per day, between north and south-west. The data availability is high and the data appear inconspicuous.

The maximum observed current speed varies between 70-73 cm/s at 3-7 m depth to 68 cm/s at 25 m depth. The average current speed in the profile varies with depth from 26-29 cm/s at 3-7 m to 28 cm/s at 25 m depth. The lowest depths (35 - 37 m) are shown here but are to be used with caution since seafloor effects have not been taken into account.

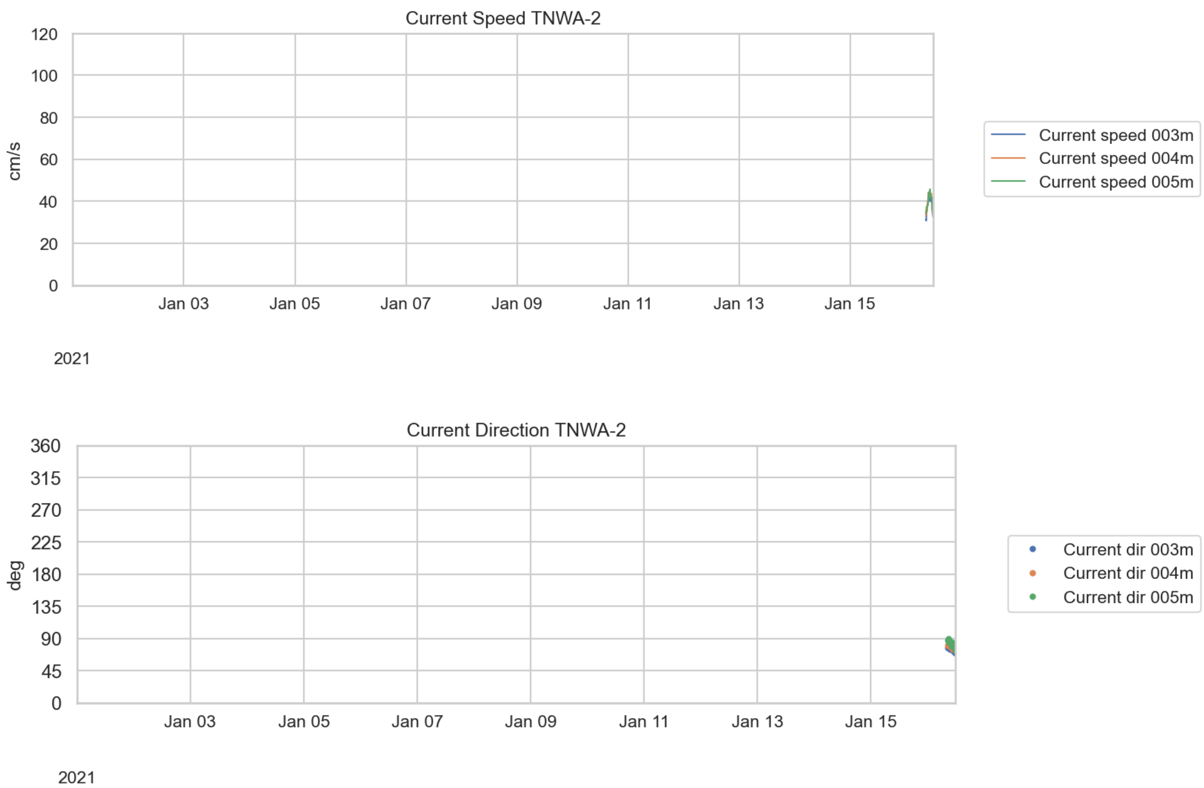


Figure F.25: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWA-2, 01 - 16 January 2021.

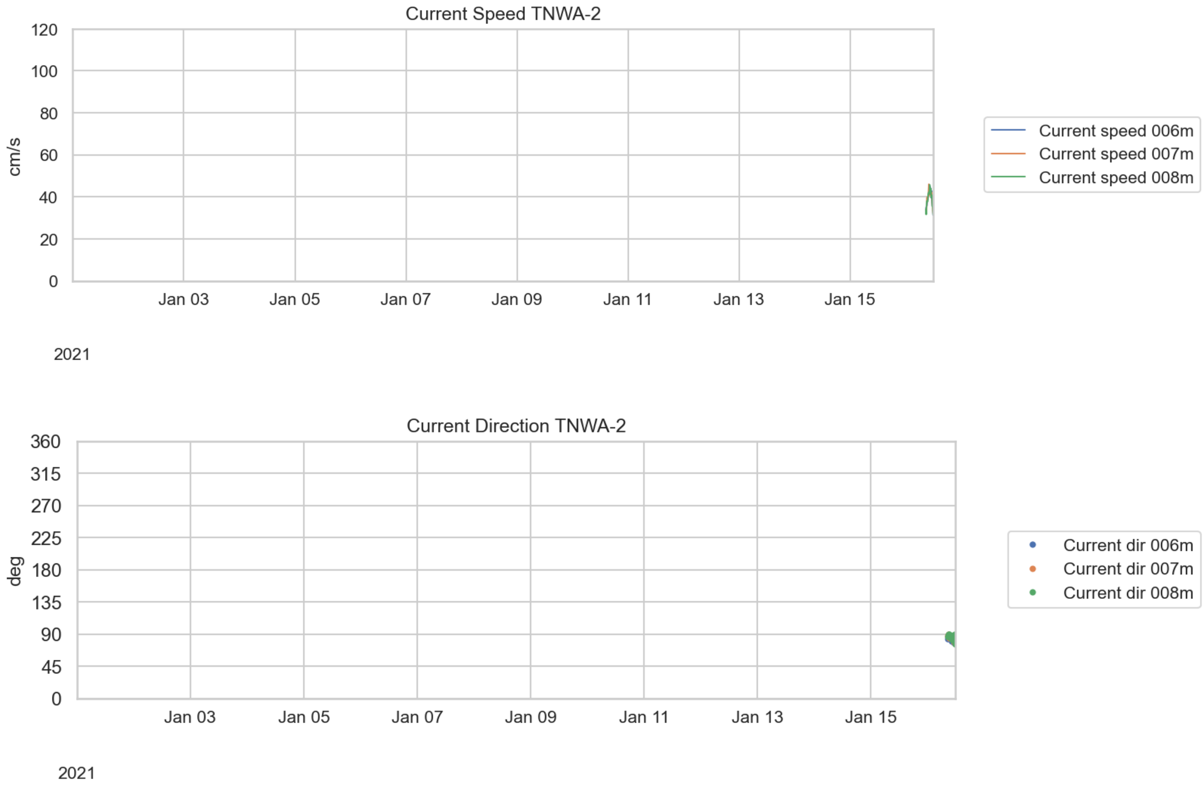


Figure F.26: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWA-2, 01 - 16 January 2021.

Figure F.27: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWA-2, 01 - 16 January 2021.

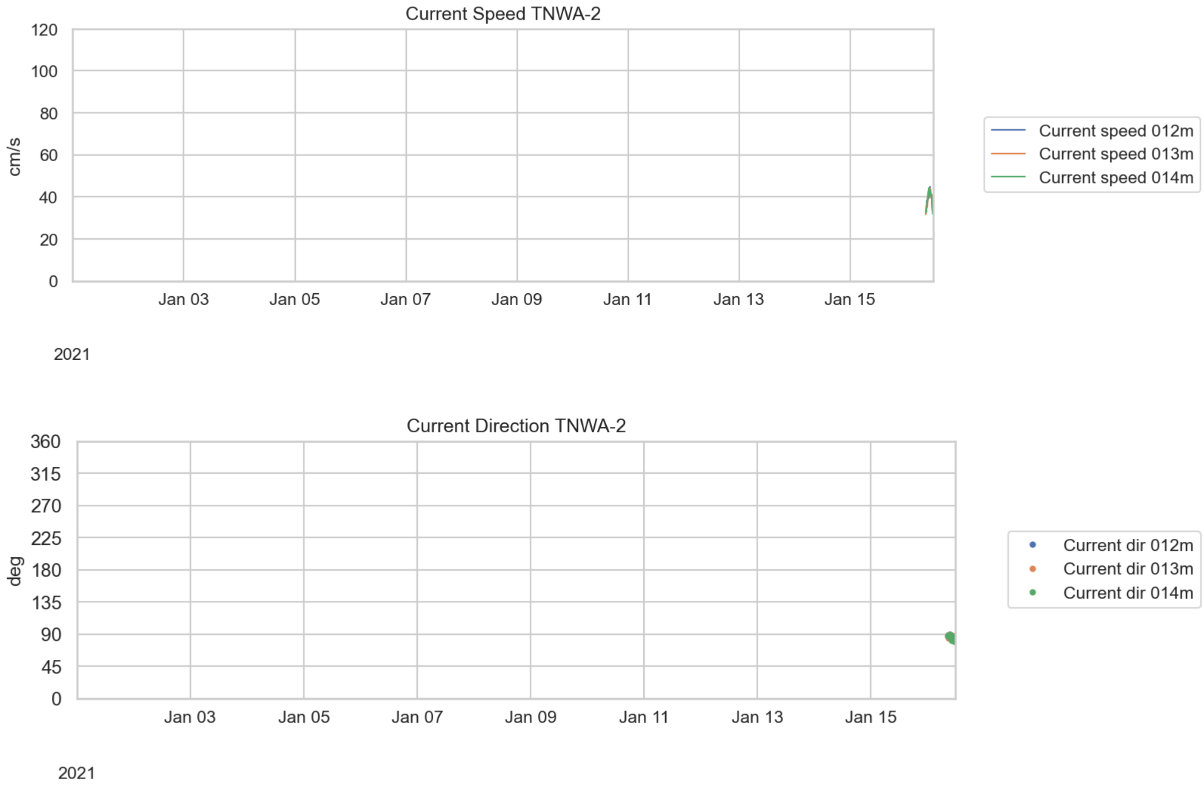


Figure F.28: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWA-2, 01 - 16 January 2021.

Figure F.29: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWA-2, 01 - 16 January 2021.

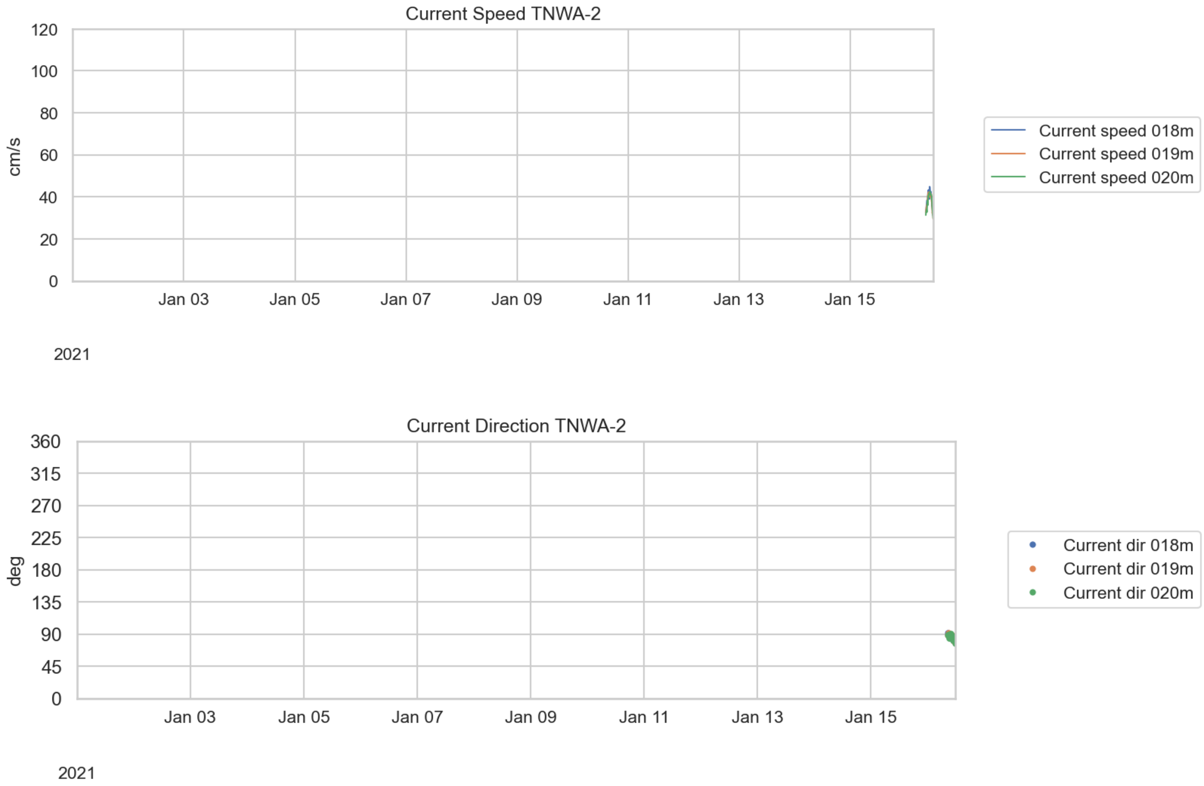


Figure F.30: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWA-2, 01 - 16 January 2021.

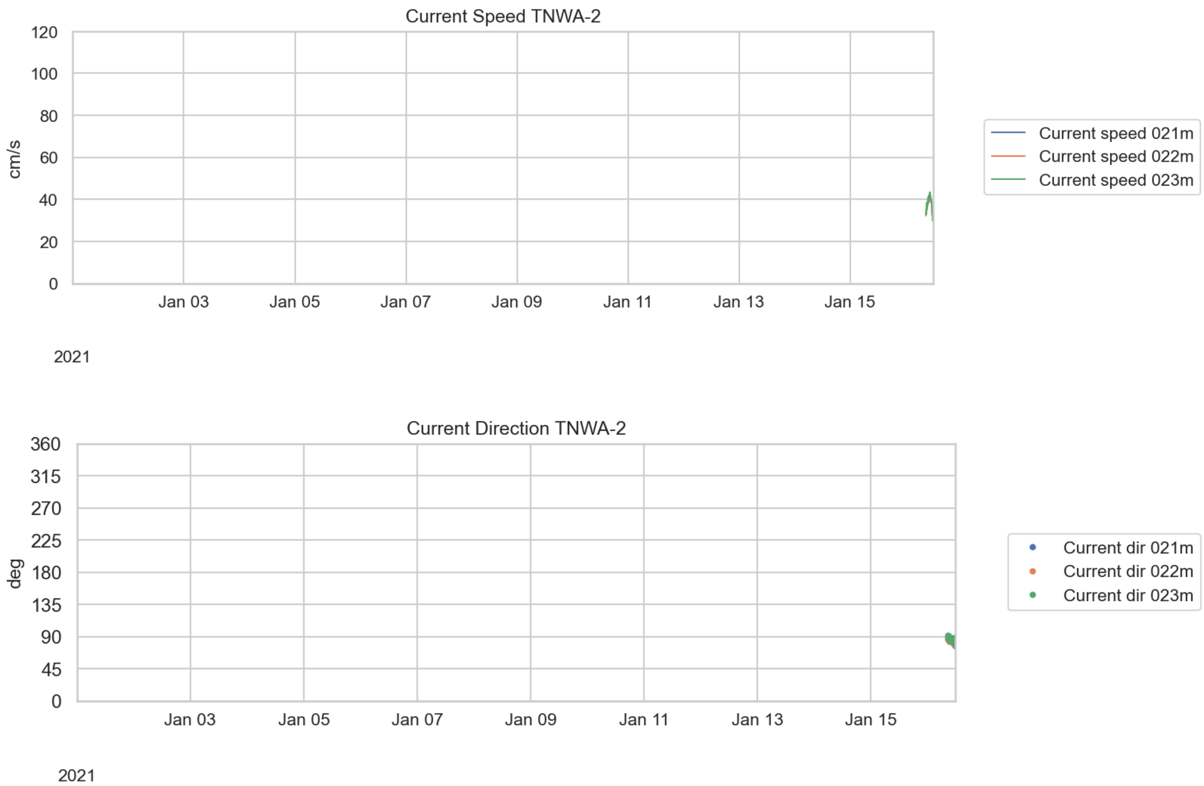


Figure F.31: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWA-2, 01 - 16 January 2021.

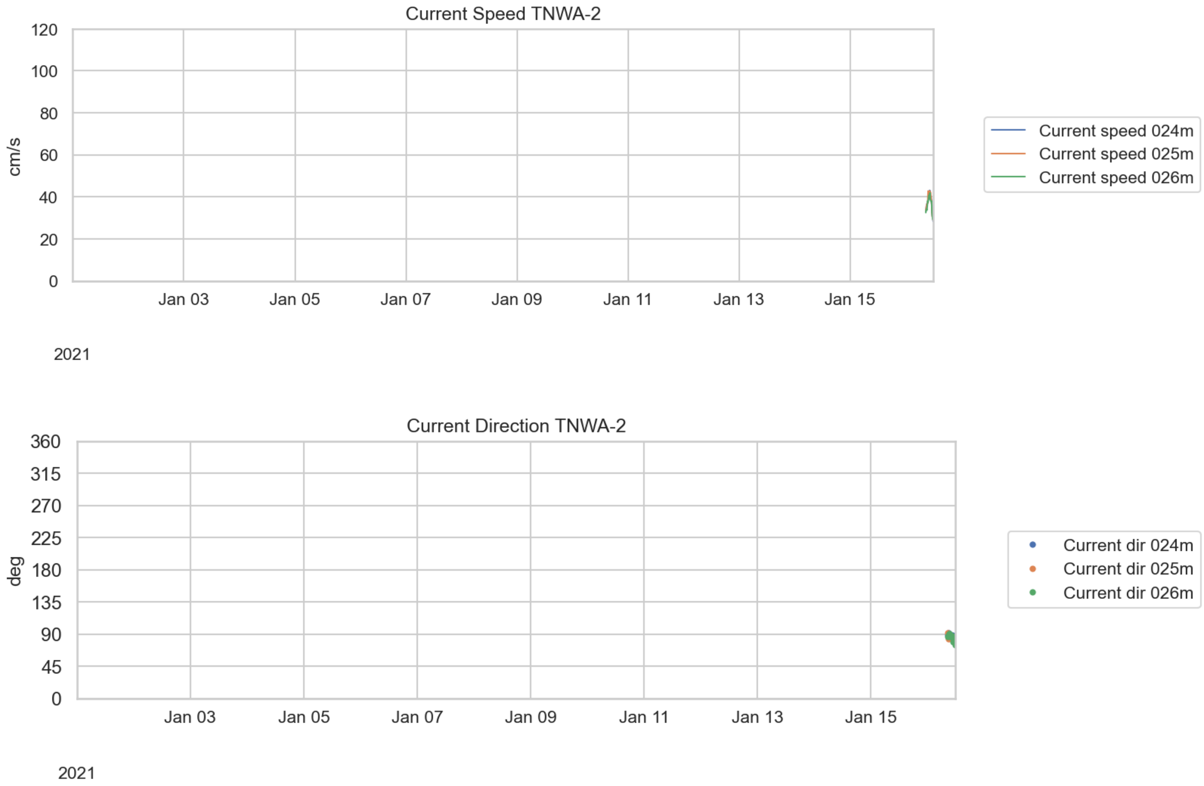


Figure F.32: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWA-2, 01 - 16 January 2021.

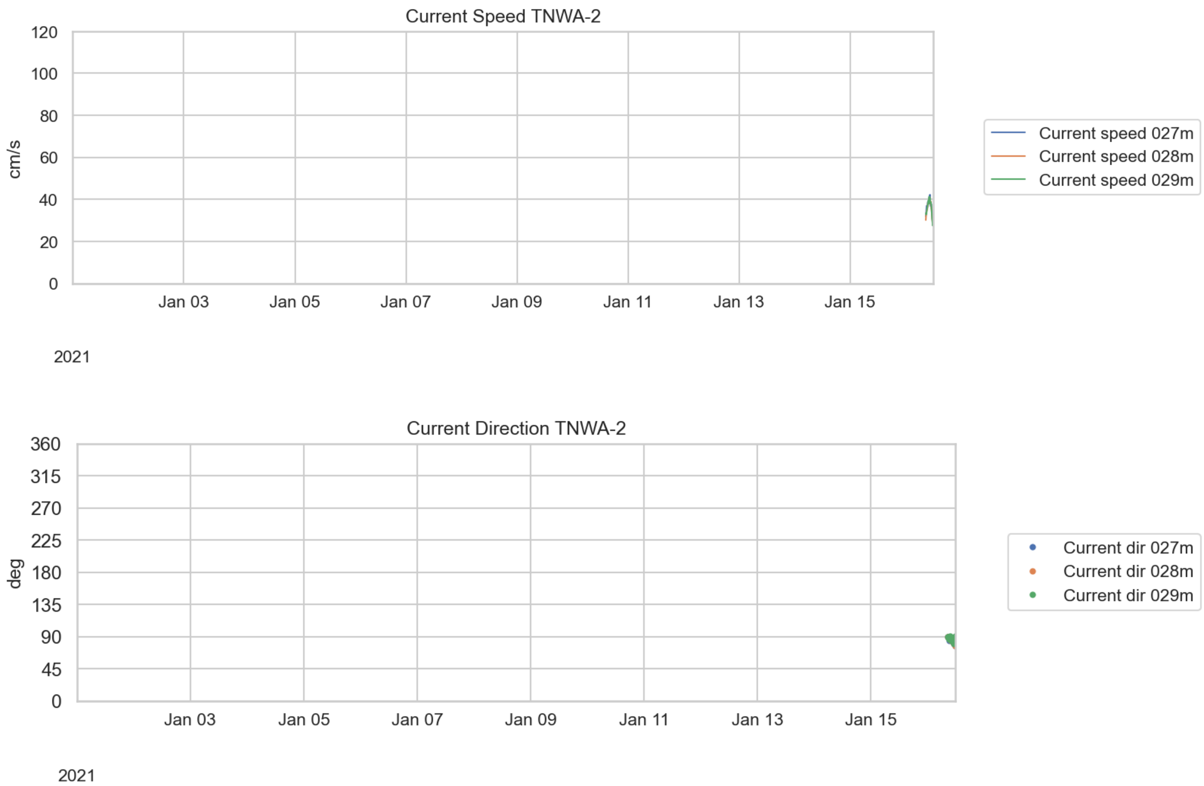


Figure F.33: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWA-2, 01 - 16 January 2021.

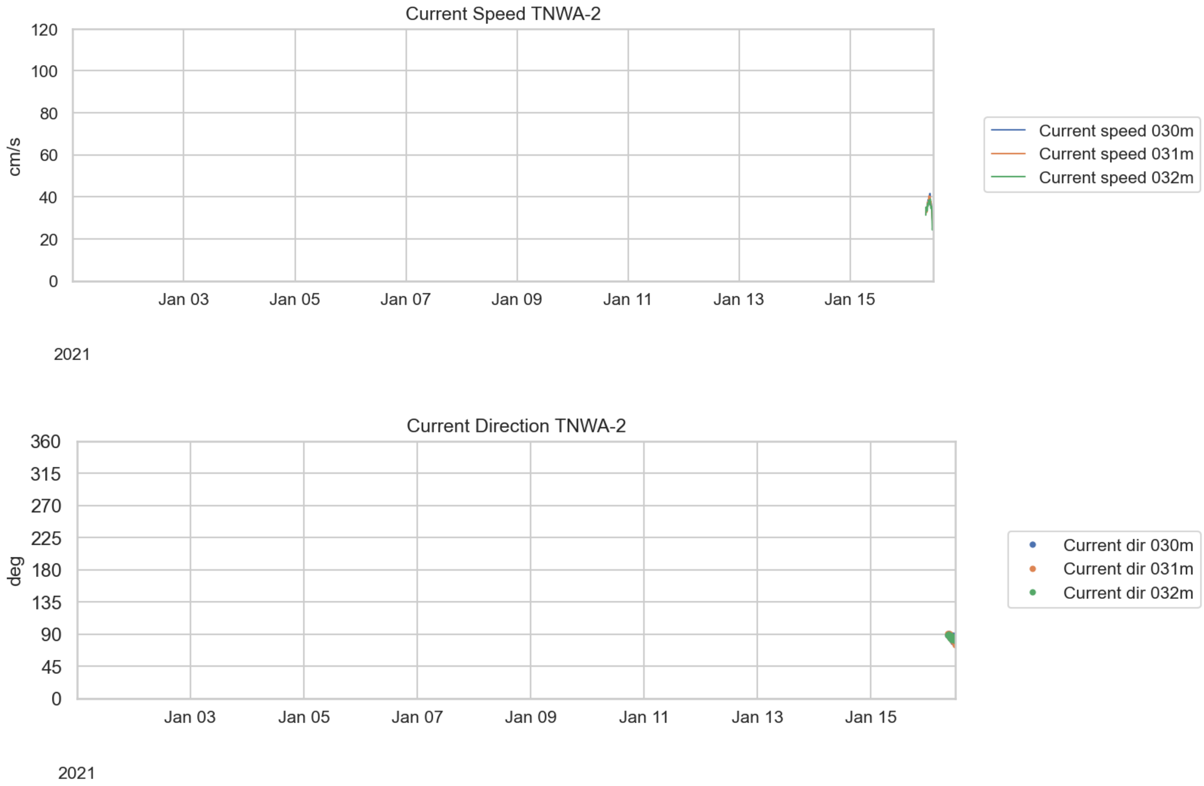


Figure F.34: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWA-2, 01 - 16 January 2021.

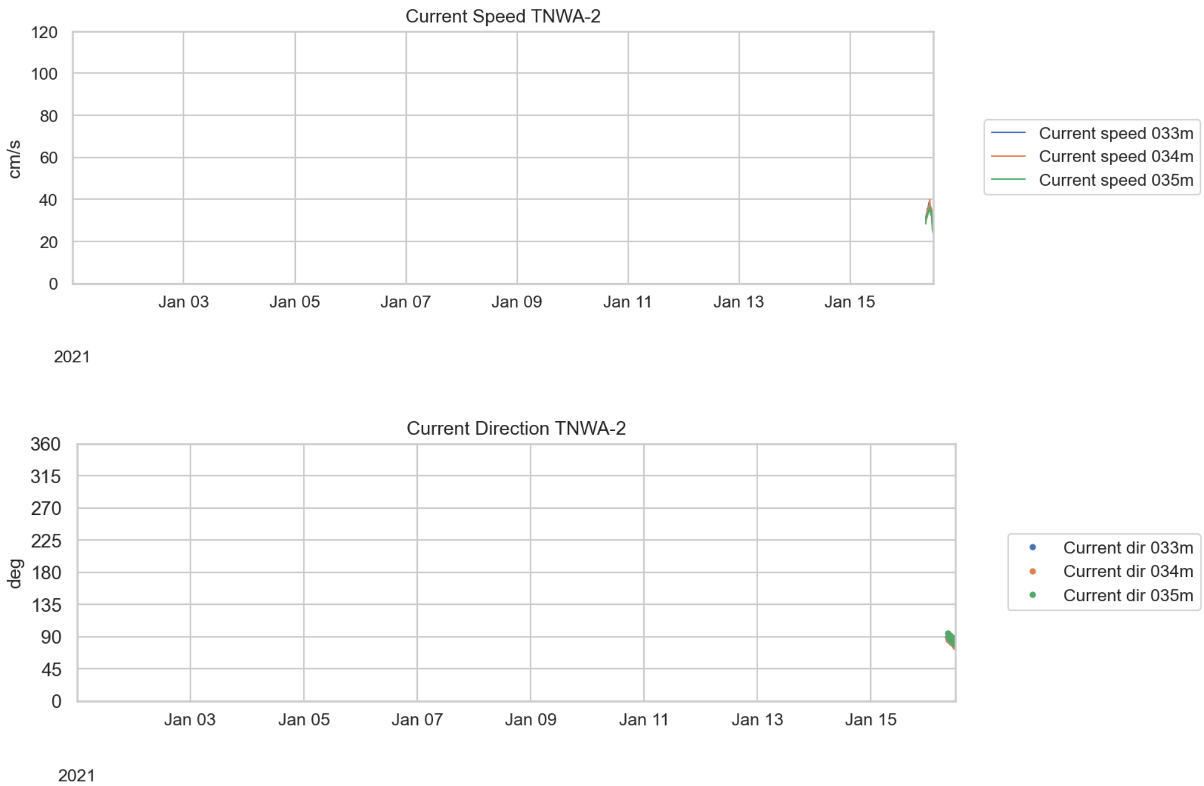


Figure F.35: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWA-2, 01 - 16 January 2021.

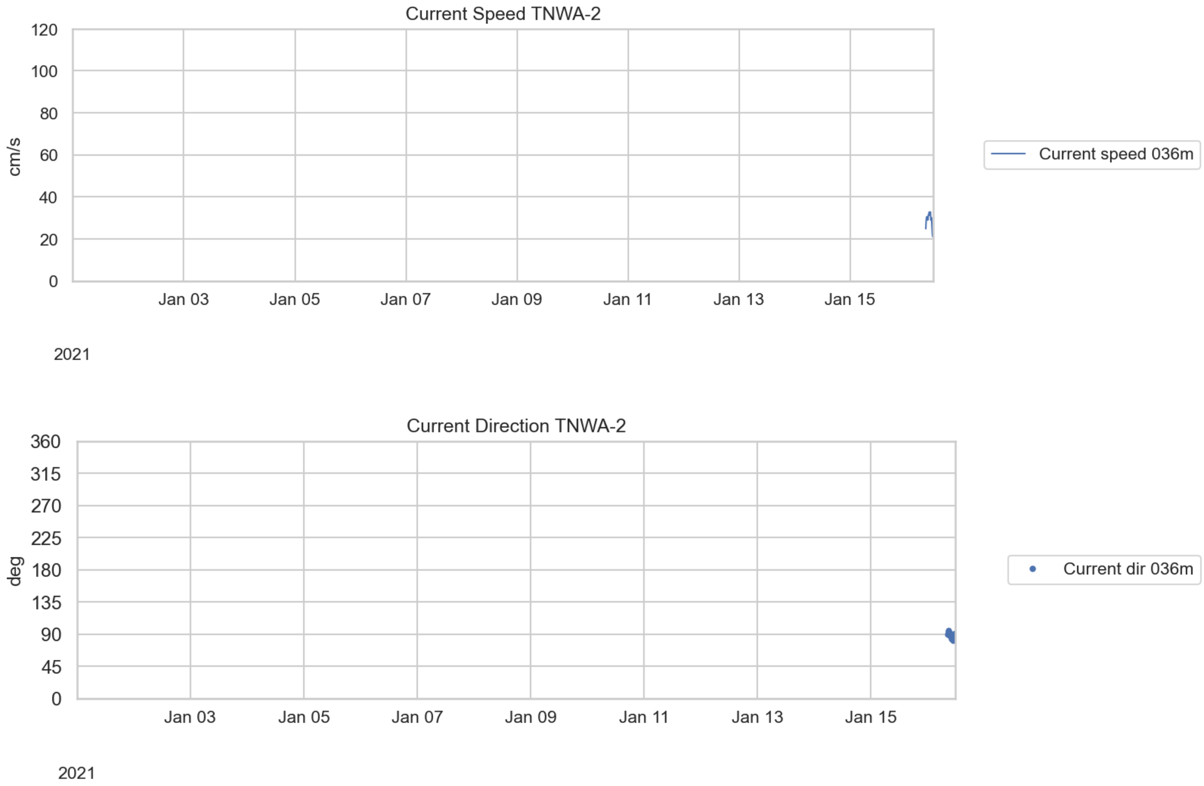


Figure F.36: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWA-2, 01 - 16 January 2021.

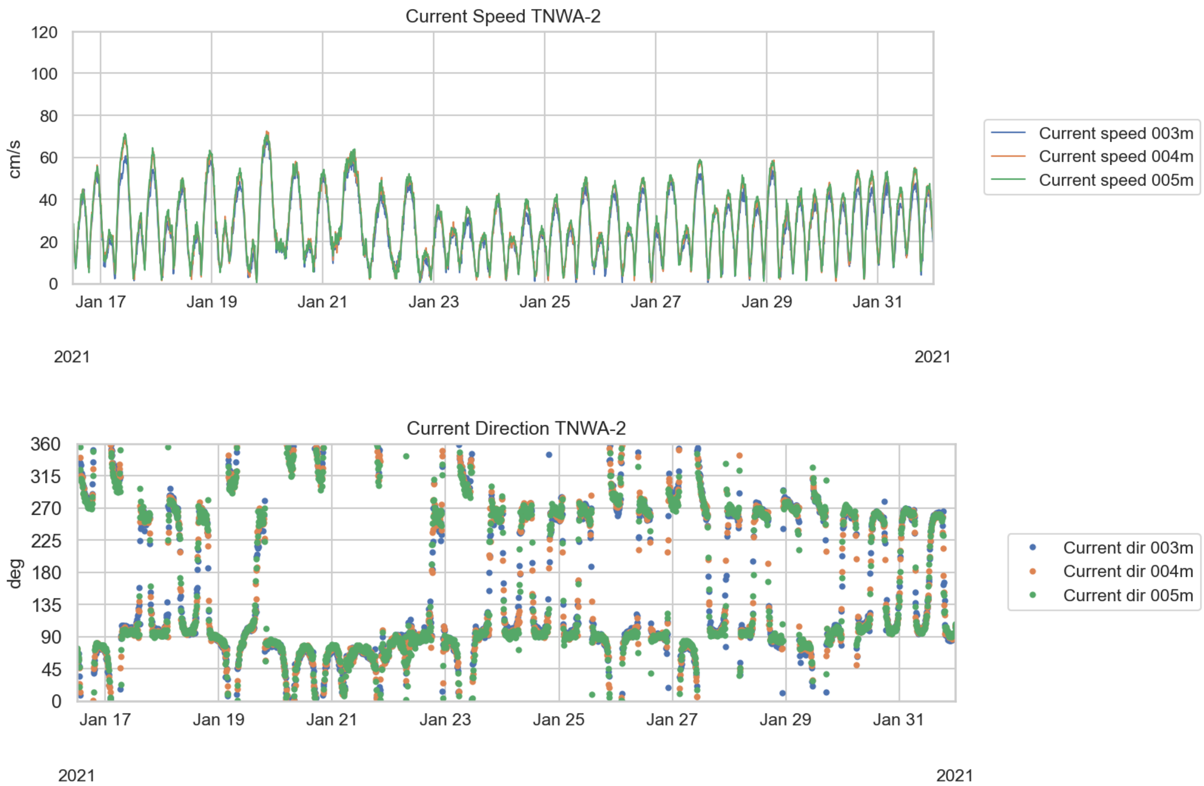


Figure F.37: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWA-2, 16 - 31 January 2021.

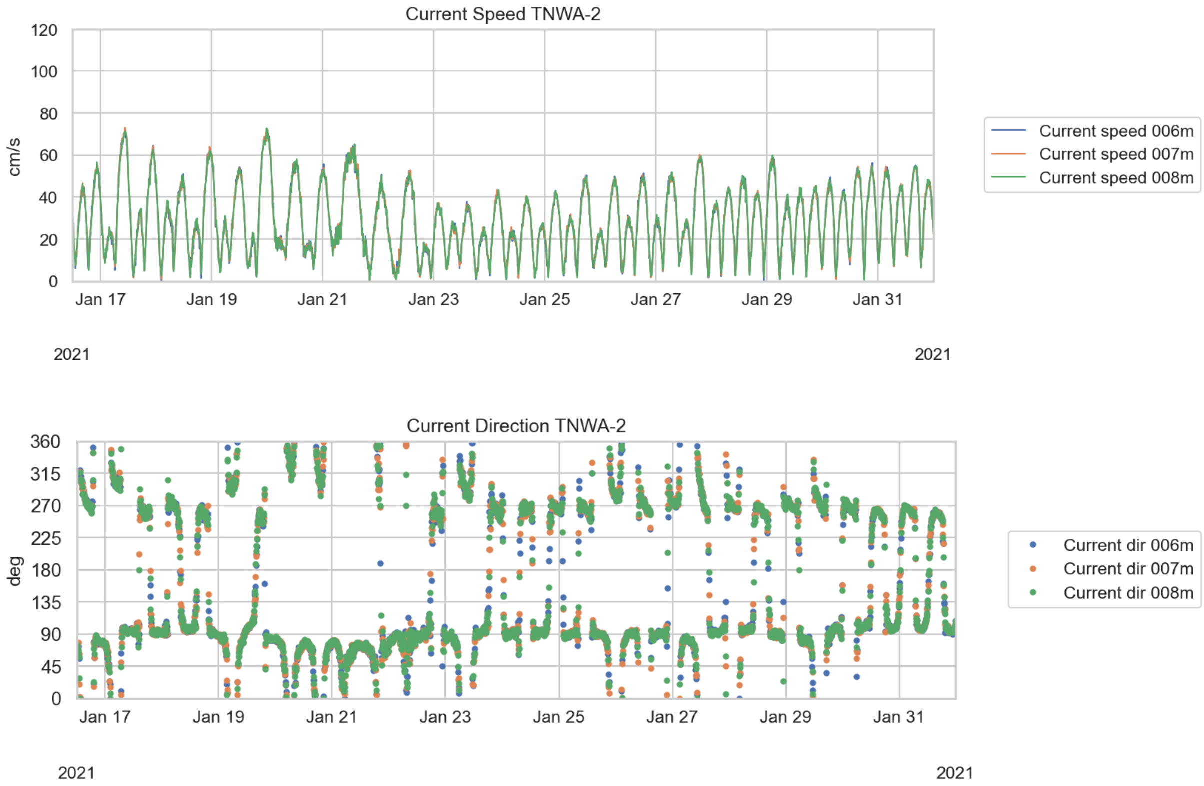


Figure F.38: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWA-2, 16 - 31 January 2021.

Figure F.39: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWA-2, 16 - 31 January 2021.

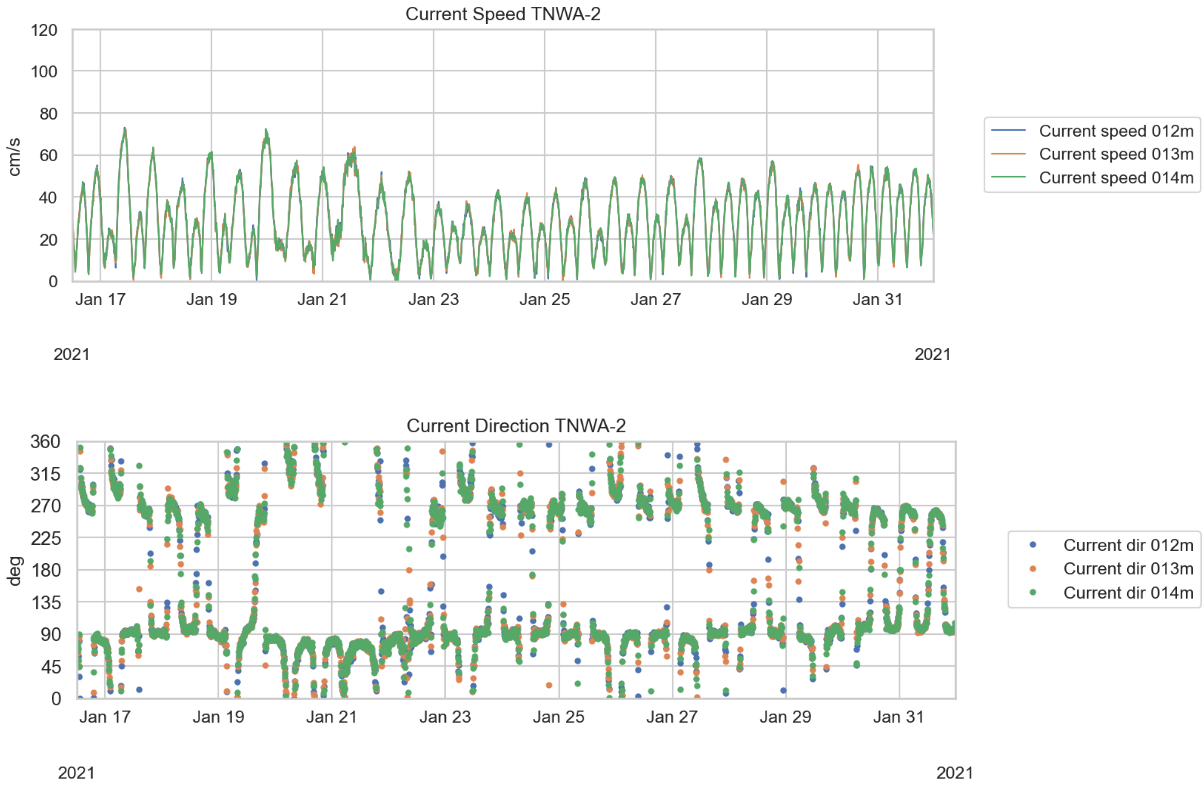


Figure F.40: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWA-2, 16 - 31 January 2021.

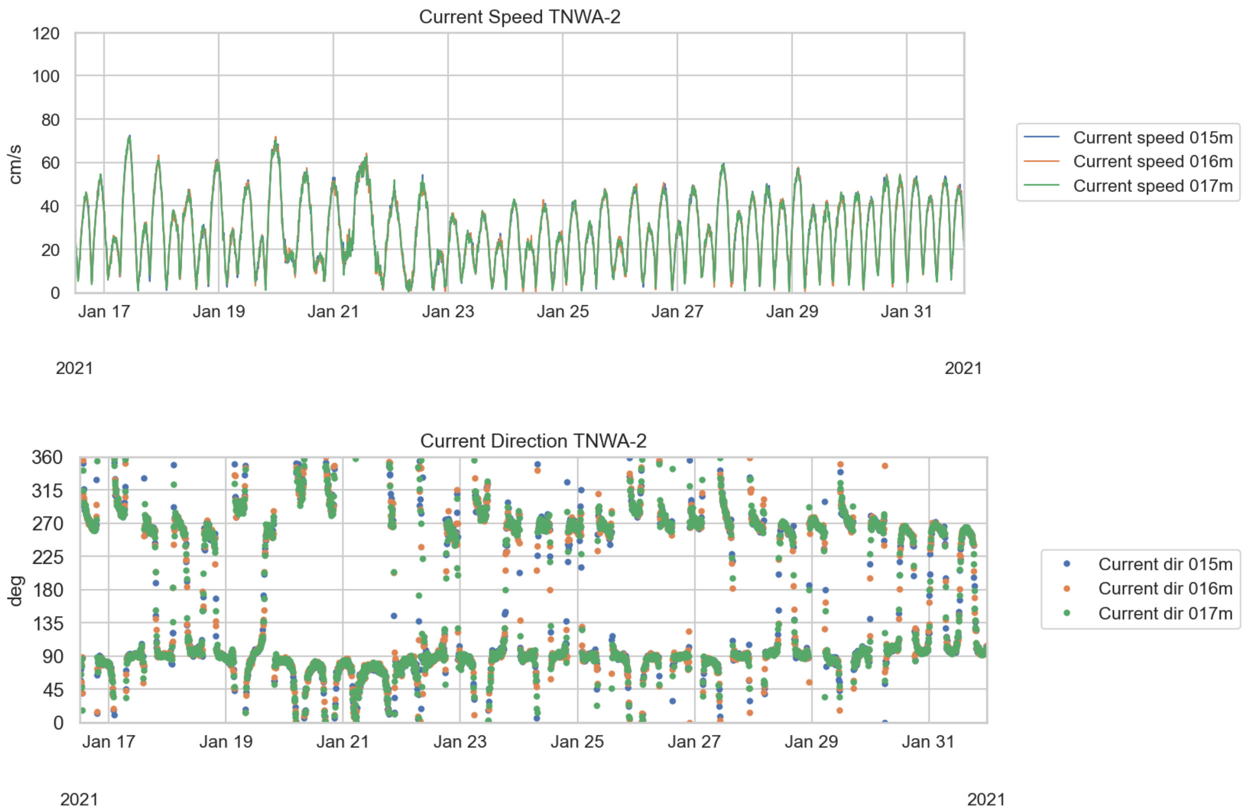


Figure F.41: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWA-2, 16 - 31 January 2021.

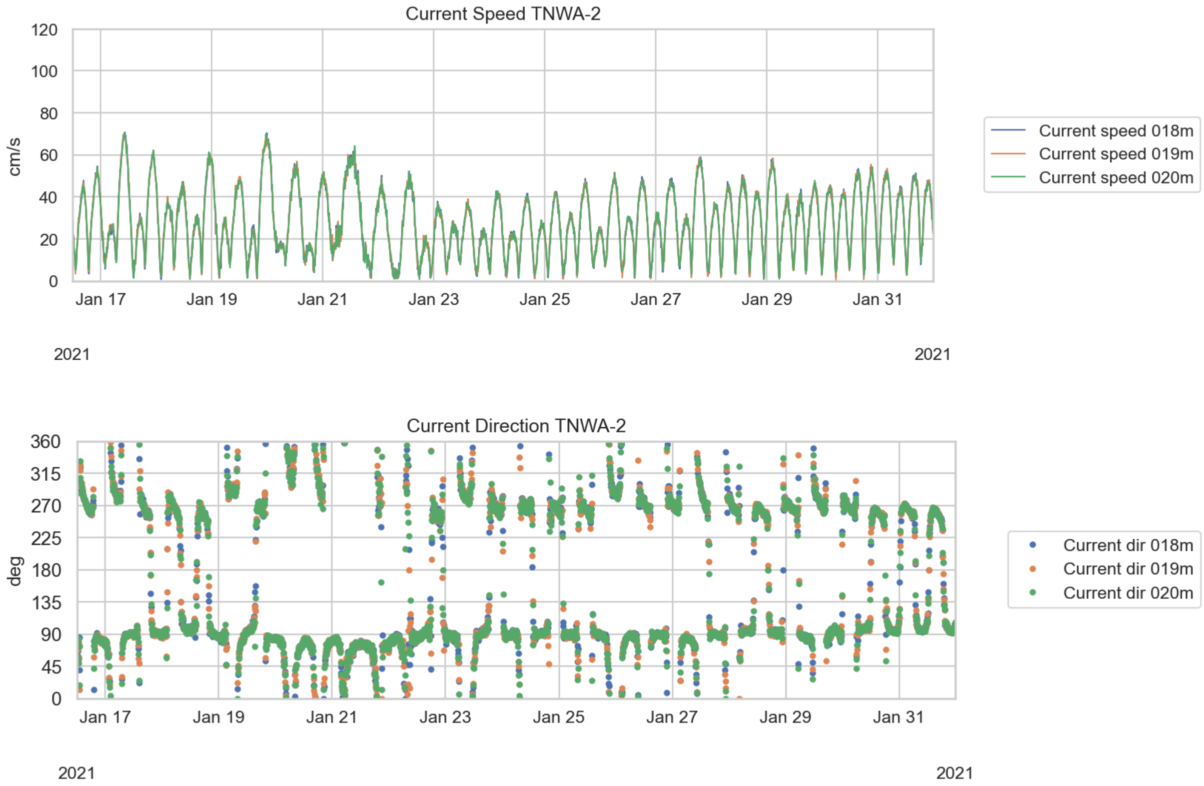


Figure F.42: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWA-2, 16 - 31 January 2021.

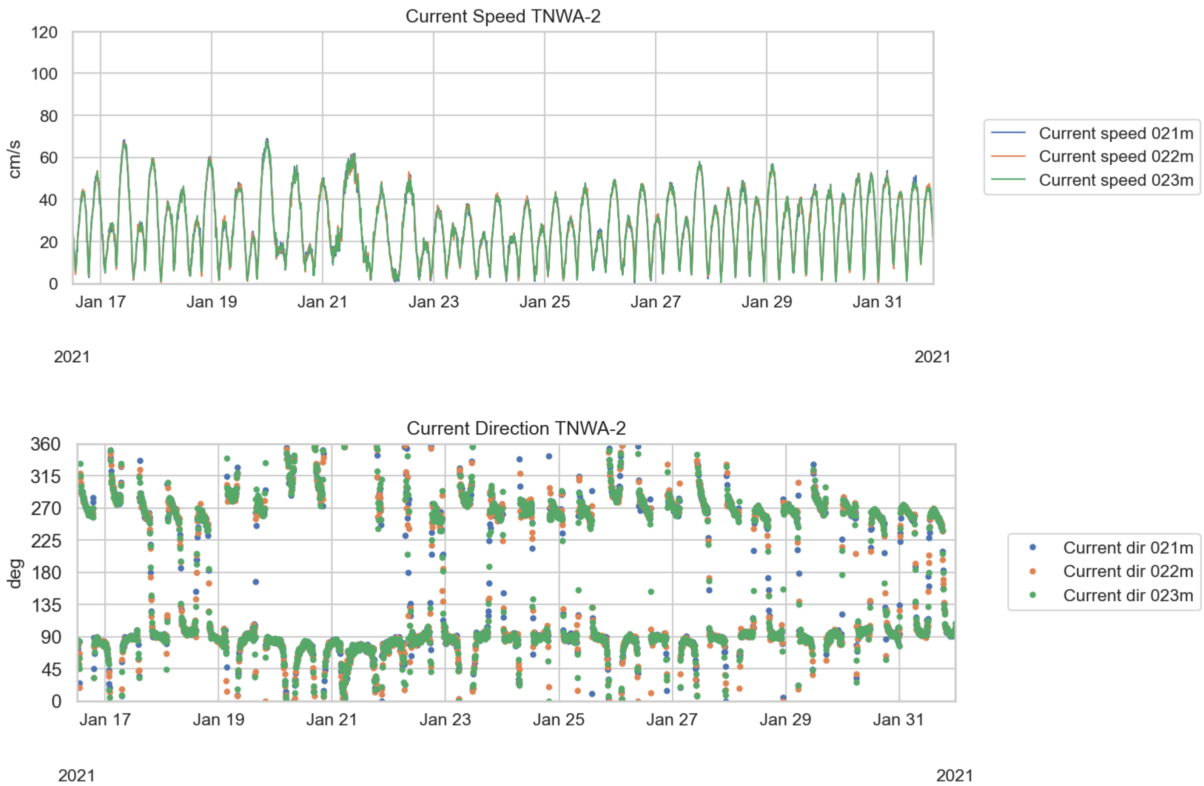


Figure F.43: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWA-2, 16 - 31 January 2021.

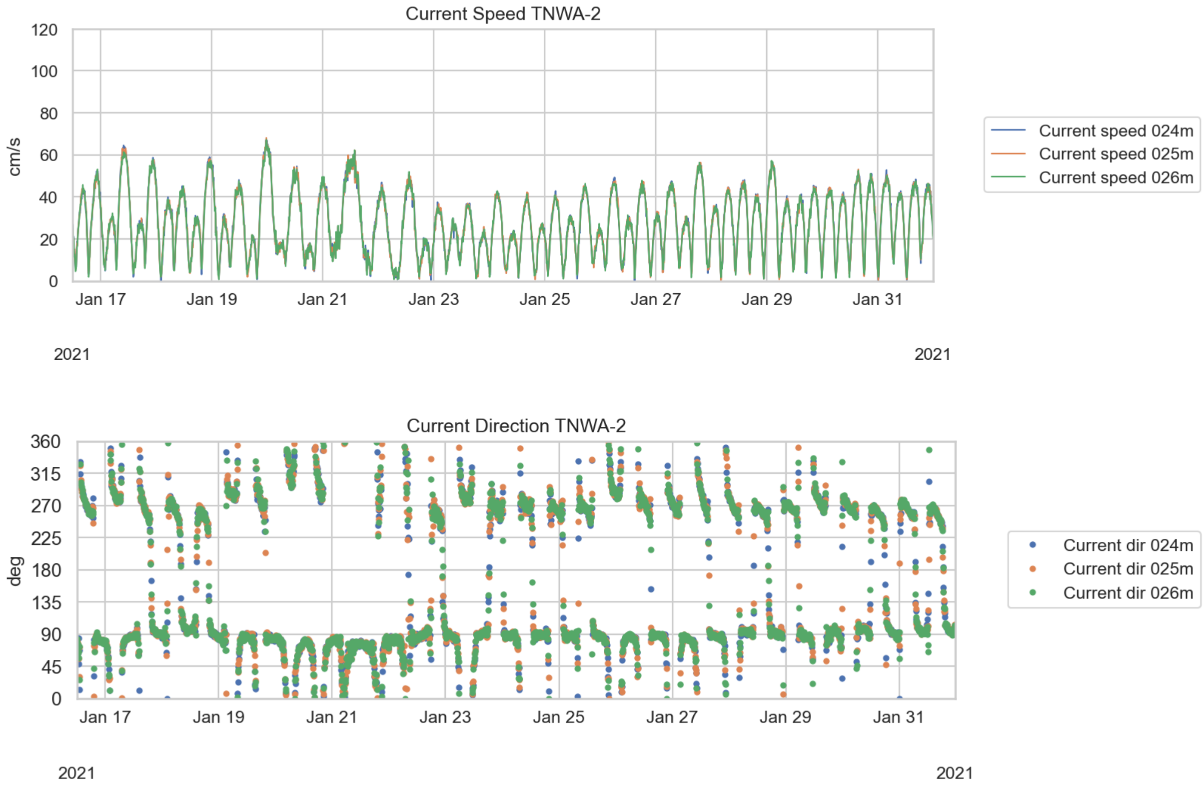


Figure F.44: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWA-2, 16 - 31 January 2021.

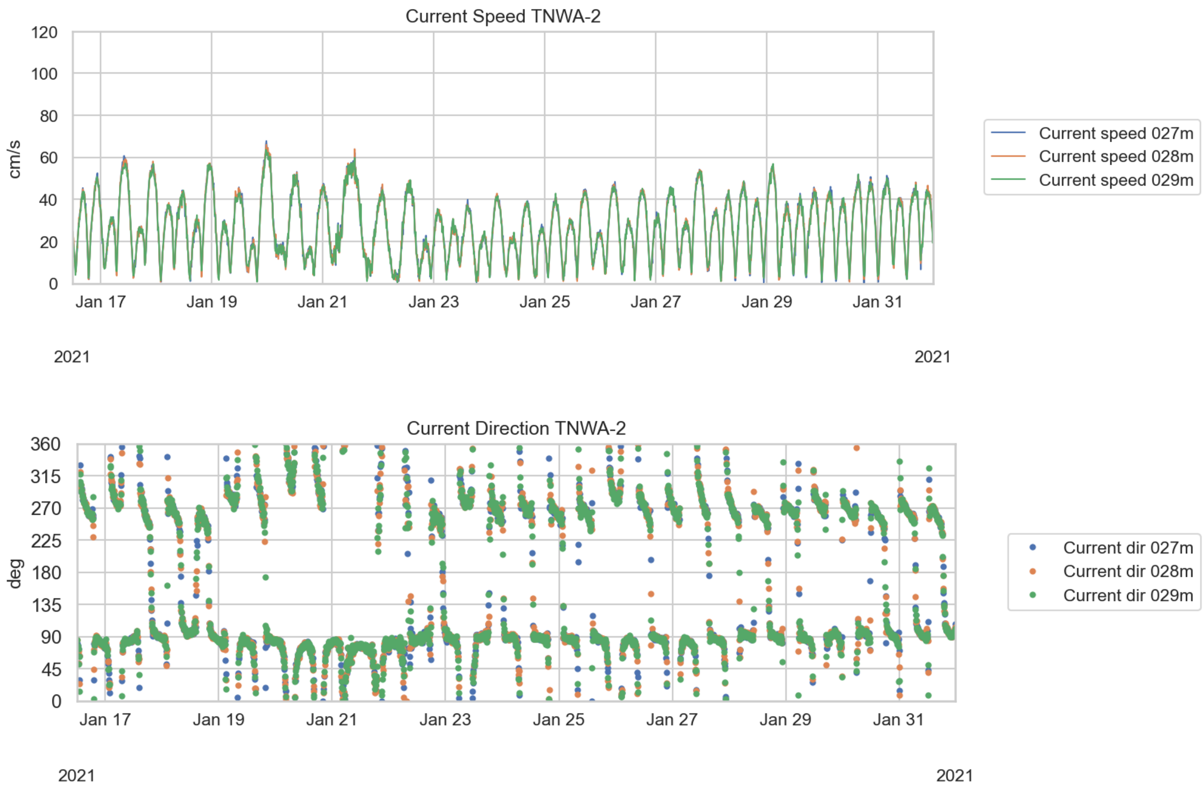


Figure F.45: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWA-2, 16 - 31 January 2021.

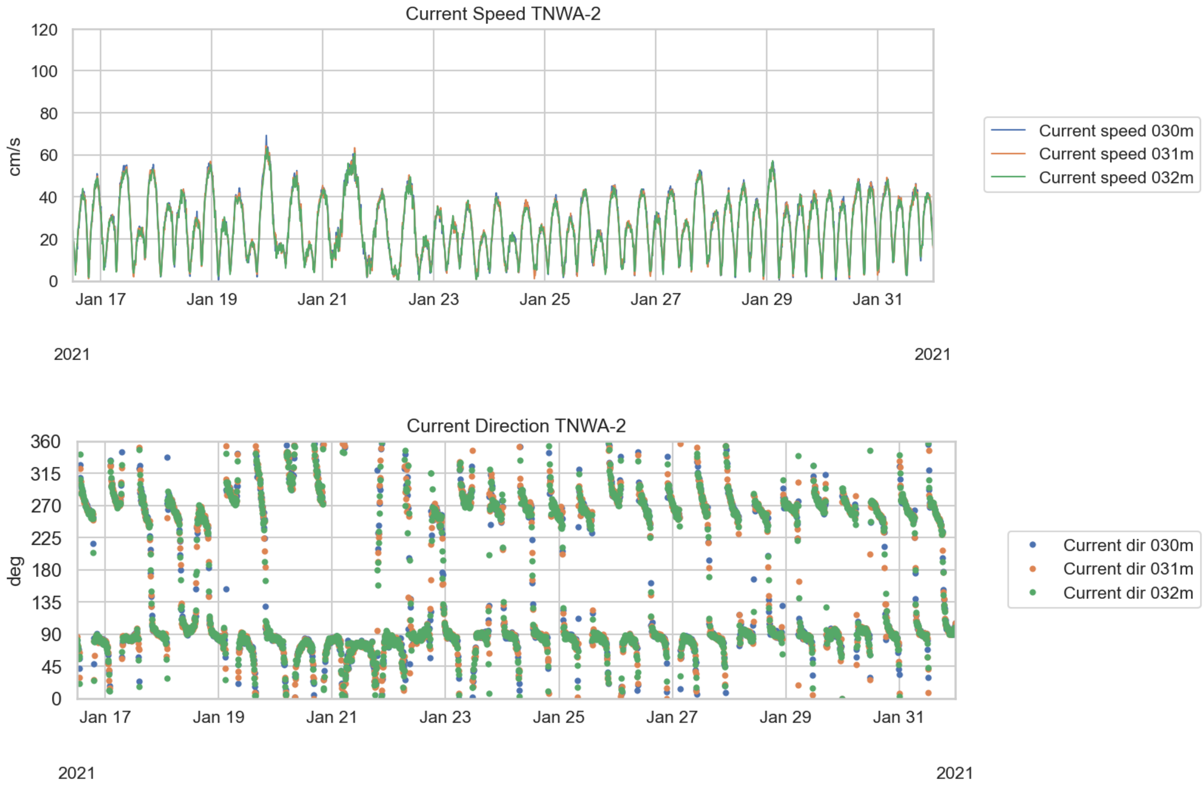


Figure F.46: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWA-2, 16 - 31 January 2021.

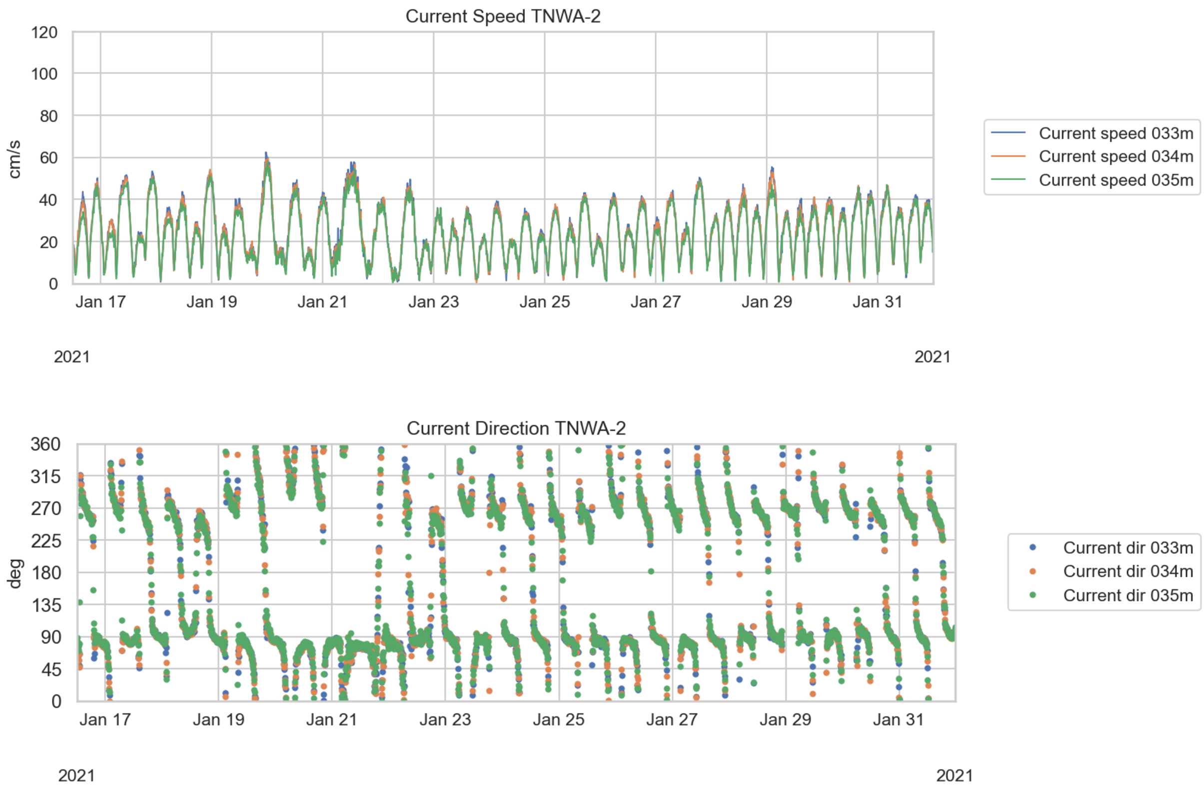
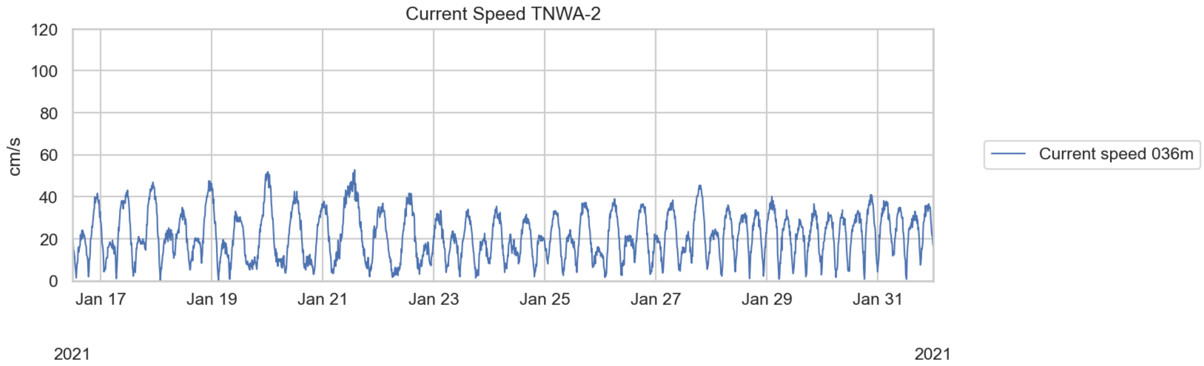


Figure F.47: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWA-2, 16 - 31 January 2021.



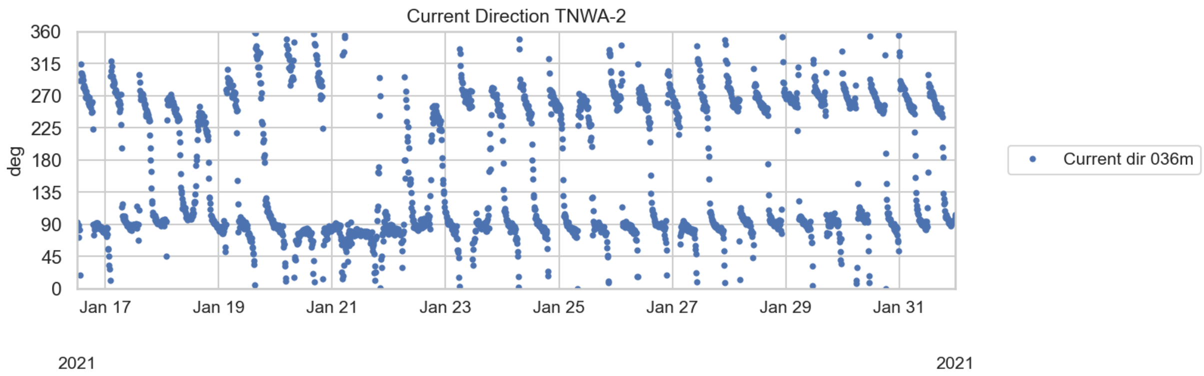


Figure F.48: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWA-2, 16 - 31 January 2021.

F.1.5 Water pressure and bottom temperature data

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.
Water level (ref. LAT) and bottom temperature data are presented in Figure F.49 - Figure F.51.
Note that the conversion to water level is preliminary and will be updated at the end of the campaign.
The total water pressure data are corrected for atmospheric pressure.
The difference between the minimum and maximum water level is 2.1 m. The mean value is 1.7 m.

The bottom temperature varied from 7.5 to 8.2 °C, with a mean temperature of 7.8 °C. The stepwise behaviour of the plot is due to the resolution of the data.

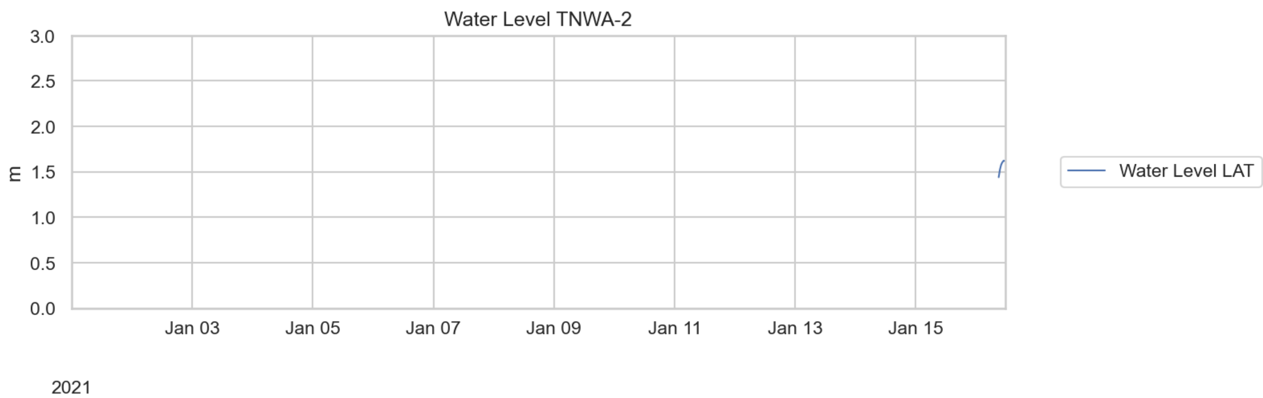


Figure F.49: Water level (m LAT) at TNWA-2, 01 - 16 January 2021

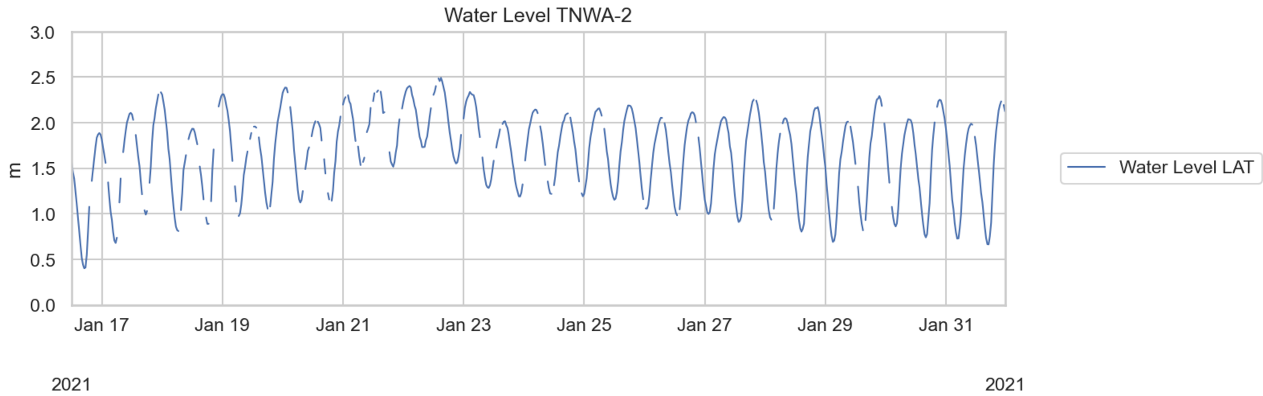


Figure F.50: Water level (m LAT) at TNWA-2, 16 - 31 January 2021

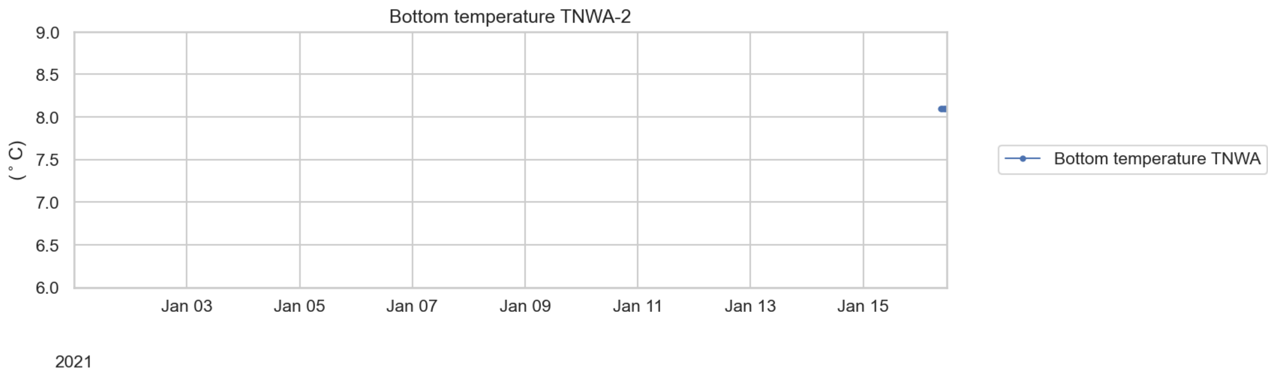


Figure F.51: Bottom temperature at TNWA-2, 01 - 16 January 2021

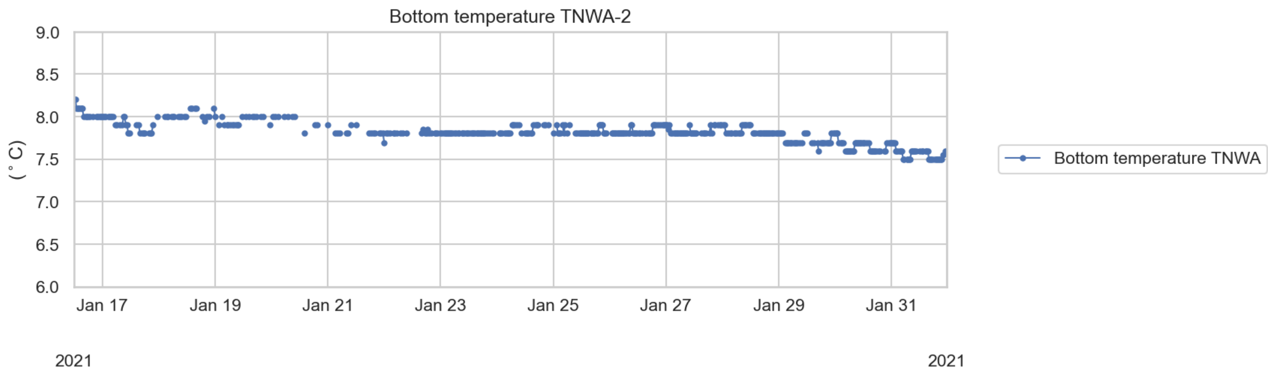


Figure F.52: Bottom temperature at TNWA-2, 16 - 31 January 2021

F.2 Signal Availability for TNWA

Please note that the reason for the data gap in the first half of the month is that there was no buoy at this location until WS199 was deployed on 16th of January 2021.

Table F.1: Signal Availability (%) at TNWA and TNWA-2 during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
WindDir004m deg	99.7	99.9	99.9	100	100	95	50.40
WindDir030m deg	55.5	99.3	97.2	98.7	59.4	0.7	50.30
WindDir040m deg	55.5	99.4	97.3	98.7	59.8	0.5	50.30
WindDir060m deg	55.5	99.2	97.2	98.6	59.5	0.8	50.40
WindDir080m deg	55.4	99.1	96.9	98.4	55.7	0.6	49.80
WindDir100m deg	55.5	99.1	96.9	98.4	56.2	0.6	49.70
WindDir120m deg	55.5	99	96.9	98.3	56	0.6	49.80
WindDir140m deg	55.5	98.9	96.9	98.4	56	0.6	49.80
WindDir160m deg	55.5	98.8	96.8	98.3	55.6	0.6	49.70
WindDir180m deg	55.5	98.8	96.4	98.3	55.4	0.5	49.70
WindDir200m deg	55.5	98.7	96.2	98.3	55.6	0.5	49.70
WindDir250m deg	55.4	98.3	95.9	98.3	56.1	0.5	49.60
WindGust004m m/s	99.7	99.9	99.9	100	100	95	50.40
WindSpeed004m m/s	99.7	99.9	99.9	100	100	95	50.40
WindSpeed030m m/s	55.5	99.3	97.2	98.7	95.7	83	50.30
WindSpeed040m m/s	55.5	99.4	97.3	98.7	96	83	50.30
WindSpeed060m m/s	55.5	99.2	97.2	98.6	95.9	82.8	50.40
WindSpeed080m m/s	55.4	99.1	96.9	98.4	86.8	79.1	49.80
WindSpeed100m m/s	55.5	99.1	96.9	98.4	87.1	79.1	49.70
WindSpeed120m m/s	55.5	99	96.9	98.3	86.9	79.1	49.80
WindSpeed140m m/s	55.5	98.9	96.9	98.4	87.1	79.1	49.80
WindSpeed160m m/s	55.5	98.8	96.8	98.3	87	78.9	49.70
WindSpeed180m m/s	55.5	98.8	96.4	98.3	86.8	79	49.70
WindSpeed200m m/s	55.5	98.7	96.2	98.3	86.9	78.7	49.70
WindSpeed250m m/s	55.4	98.3	95.9	98.3	86.9	78.6	49.60
AqDir003 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir004 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir005 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir006 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir007 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir008 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir009 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir010 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir011 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir012 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir013 deg	99.8	99.9	99.8	100	100	95.1	50.40
AqDir014 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir015 deg	99.8	99.9	99.9	100	100	95.1	50.40

Table F.1: Signal Availability (%) at TNWA and TNWA-2 during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
AqDir016 deg	99.8	99.9	99.8	100	100	95.1	50.40
AqDir017 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir018 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir019 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir020 deg	99.8	99.9	99.8	100	100	95.1	50.40
AqDir021 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir022 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir023 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir024 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir025 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir026 deg	99.8	99.8	99.9	100	100	95.1	50.40
AqDir027 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir028 deg	99.8	99.8	99.9	100	100	95.1	50.40
AqDir029 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir030 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir031 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir032 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir033 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir034 deg	99.8	99.8	99.9	100	100	95.1	50.40
AqDir035 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqDir036 deg	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd003 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd004 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd005 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd006 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd007 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd008 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd009 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd010 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd011 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd012 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd013 cm/s	99.8	99.9	99.8	100	100	95.1	50.40
AqSpd014 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd015 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd016 cm/s	99.8	99.9	99.8	100	100	95.1	50.40
AqSpd017 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd018 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd019 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd020 cm/s	99.8	99.9	99.8	100	100	95.1	50.40
AqSpd021 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd022 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd023 cm/s	99.8	99.9	99.9	100	100	95.1	50.40

Table F.1: Signal Availability (%) at TNWA and TNWA-2 during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
AqSpd024 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd025 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd026 cm/s	99.8	99.8	99.9	100	100	95.1	50.40
AqSpd027 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd028 cm/s	99.8	99.8	99.9	100	100	95.1	50.40
AqSpd029 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd030 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd031 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd032 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd033 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
AqSpd034 cm/s	99.8	99.8	99.9	100	100	95.1	50.40
AqSpd035 cm/s	99.8	99.9	99.9	100	100	95.1	50.40
hm0 m	99.8	99.9	100	100	100	95.1	50.40
hm0a m	99.8	99.9	100	100	100	95.1	50.40
hm0b m	99.8	99.9	100	100	100	95.1	50.40
hmax m	99.8	94	99.9	100	99.9	95.1	50.40
mdir deg	99.8	99.9	100	100	100	95.1	50.40
mdira deg	99.8	99.9	100	100	100	95.1	50.40
mdirb deg	99.8	99.9	100	100	100	95.1	50.40
sprtp deg	99.8	99.9	100	100	100	95.1	50.40
thhf deg	99.8	99.9	100	100	100	95.1	50.40
thtp deg	99.8	99.9	100	100	100	95.1	50.40
thmax s	99.3	93.7	99.4	100	100	95.1	50.40
tm01 s	99.8	99.9	100	100	100	95.1	50.40
tm02 s	99.8	99.9	100	100	100	95.1	50.40
tm02a s	99.8	99.9	100	100	100	95.1	50.40
tm02b s	99.8	99.9	100	100	100	95.1	50.40
tp s	99.8	99.9	100	100	100	95.1	50.40
tz s	99.7	93.7	99.6	100	100	95.1	50.40
AirPressure hPa	99.8	99.9	100	100	100	95.1	50.40
AirTemperature C	97.2	96.3	96.9	98.2	98	92.6	49.70
AirHumidity %	97.2	96.3	96.9	98.2	98	92.6	49.70
WaterTemp001 degC	99.8	99.9	99.9	100	100	95.1	50.40
WaterPressure dbar	86	69.4	58.6	50.5	16.2	0	46.10
BottomTemperature degC	67.7	16.1	12.9	9.5	3.9	0	31.20

F.3 Buoy Station TNWB

The following presentations show data from buoys WS156 and WS187 at TNWB for the period 01 - 31 January 2021. The data in this report is based on downloaded data.

F.3.1 Meteorological data TNWB

Plots of air pressure, air temperature and sea surface temperature data are presented in Figure F.53 - Figure F.56. The sensors performed well in this period.

The air temperature varied from 1.2 to 9.2°C with an average value of 5.4°C. The sea surface temperature was in the range 7.0 – 9.5°C with an average of 8.1°C. The air pressure varied from 973 to 1030 hPa.

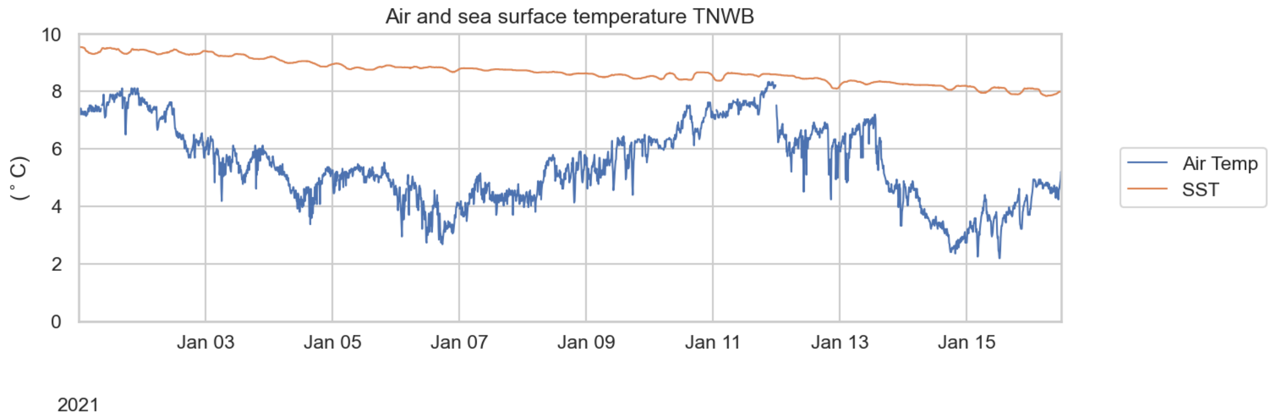


Figure F.53: Air and sea surface temperature at TNWB, 01 - 16 January 2021

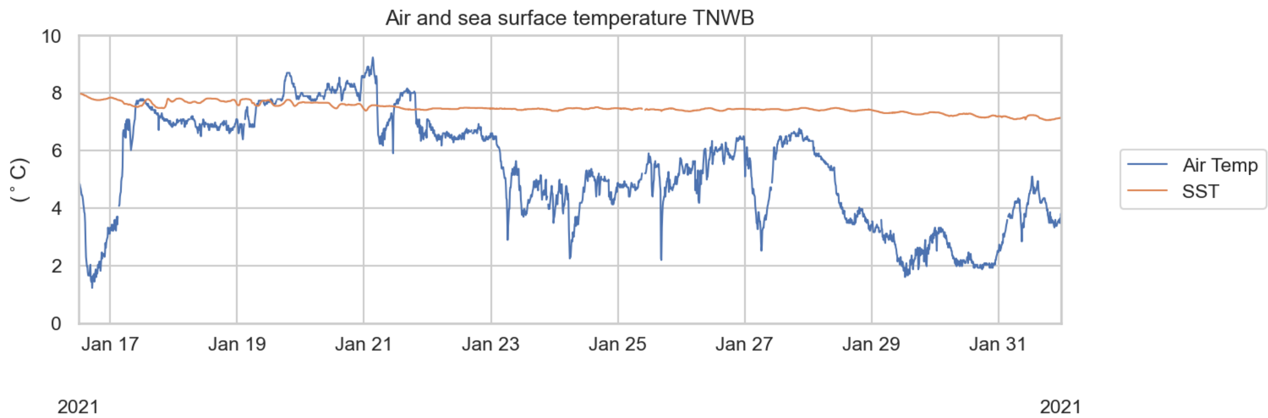


Figure F.54: Air and sea surface temperature at TNWB, 16 - 31 January 2021

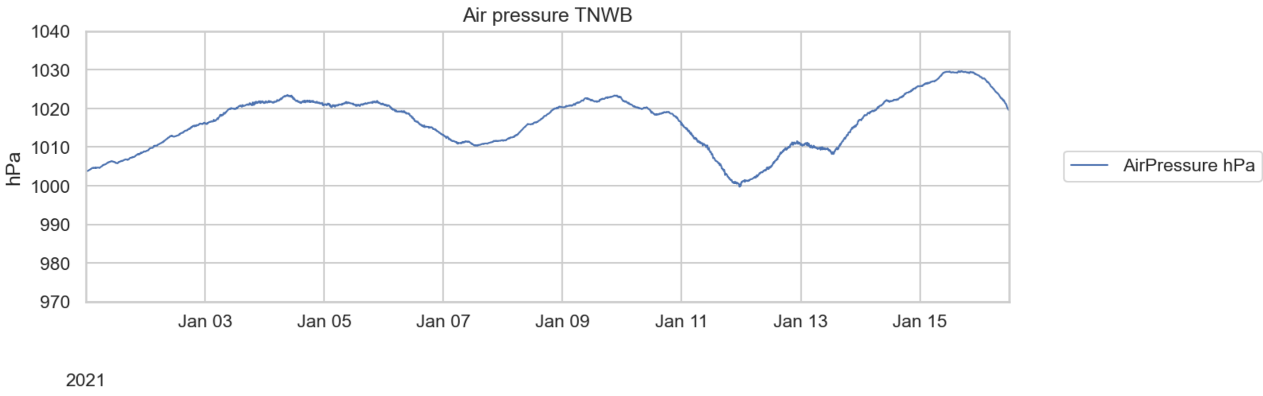


Figure F.55: Air pressure at TNWB, 01 - 16 January 2021

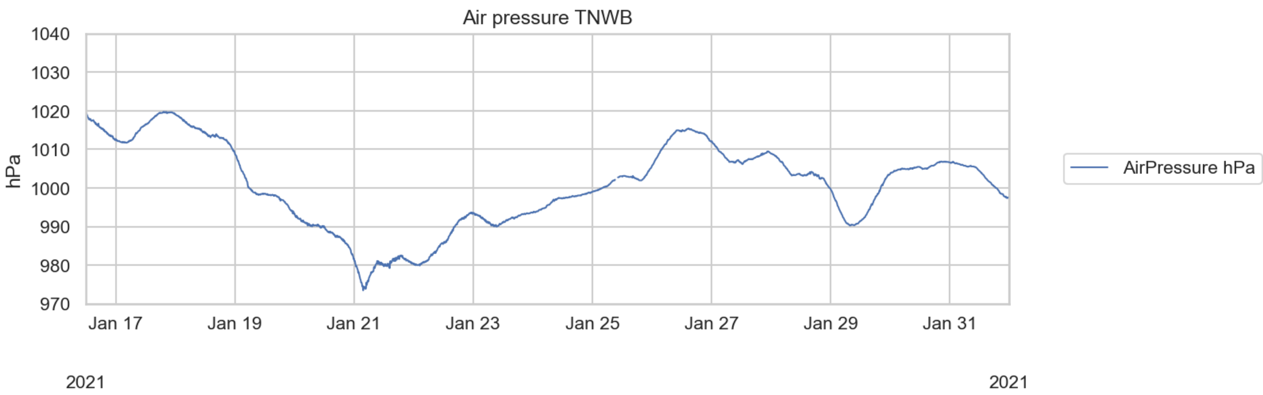


Figure F.56: Air pressure at TNWB, 16 - 31 January 2021

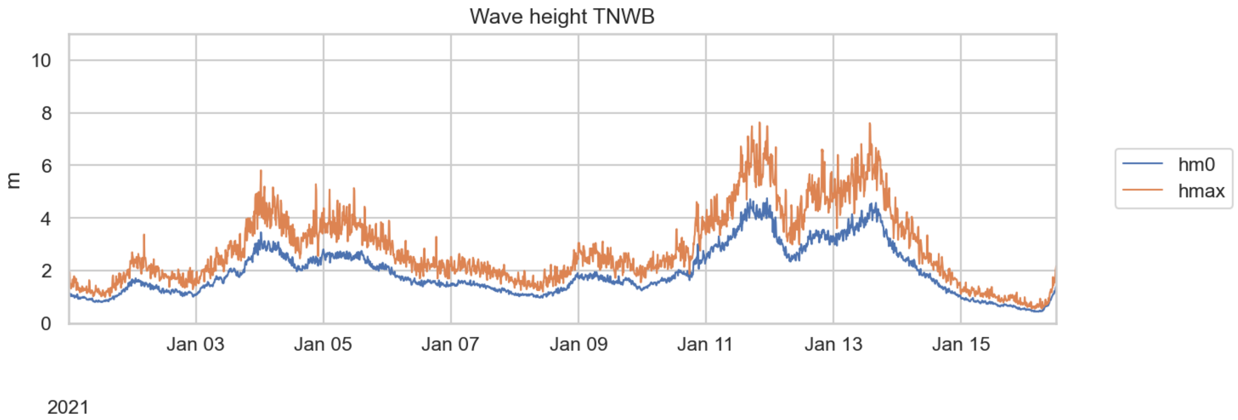
F.3.2 Wave data

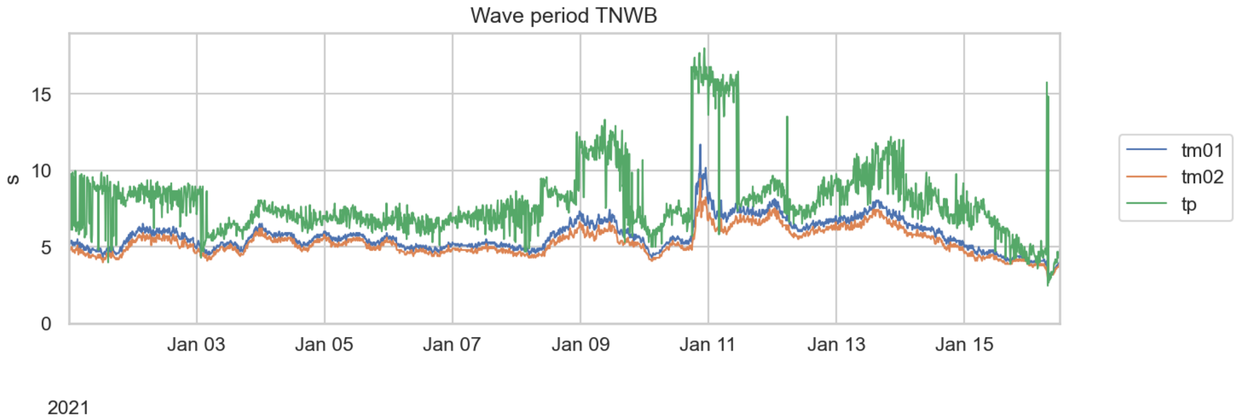
Plots of wave height, period and direction are presented in Figure F.57 and Figure F.58. The sensor has performed well with a high data availability.

The highest significant wave height (hm0) measured in this period was 6.0 m from a south-westerly direction (∼ 248°) on 21 January at 15:40. The highest single wave of the record with hmax = 13.9 m during this period was observed on 21 January at 13:50. The buoy measured south-westerly wind (∼ 229°) with a speed of 16.7 m/s at 4 m height 30 min before the wave height maximum.

Hmax is calculated from zero-upcrossing analysis requiring a certain number of high enough waves (> 50 "high" waves in 17 min) for a valid calculation.

The variations in wave height agree well with the wind speeds. The average wave period parameters Tm01 and Tm02 show semidiurnal variations which can be explained by the shift in frequency when the waves are travelling along with or opposing the current direction, since the tidal current direction varies in a semi-diurnal pattern. Peaks in Tp, the spectral peak period, during times of low hm0 indicate calm conditions. During times of low winds, there are few short-period wind sea waves and the wave spectrum is dominated by long-period swell leading to higher Tp values.





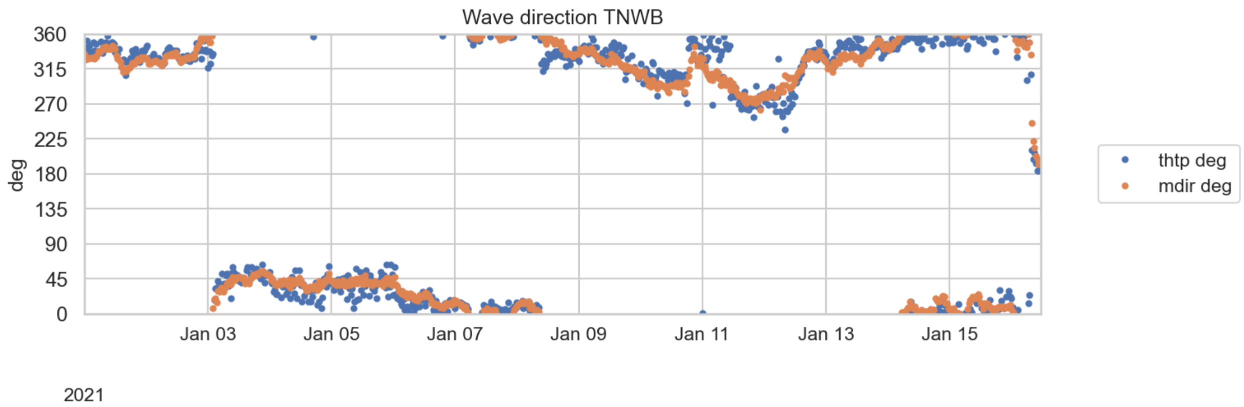


Figure F.57: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWB, 01 - 16 January 2021.

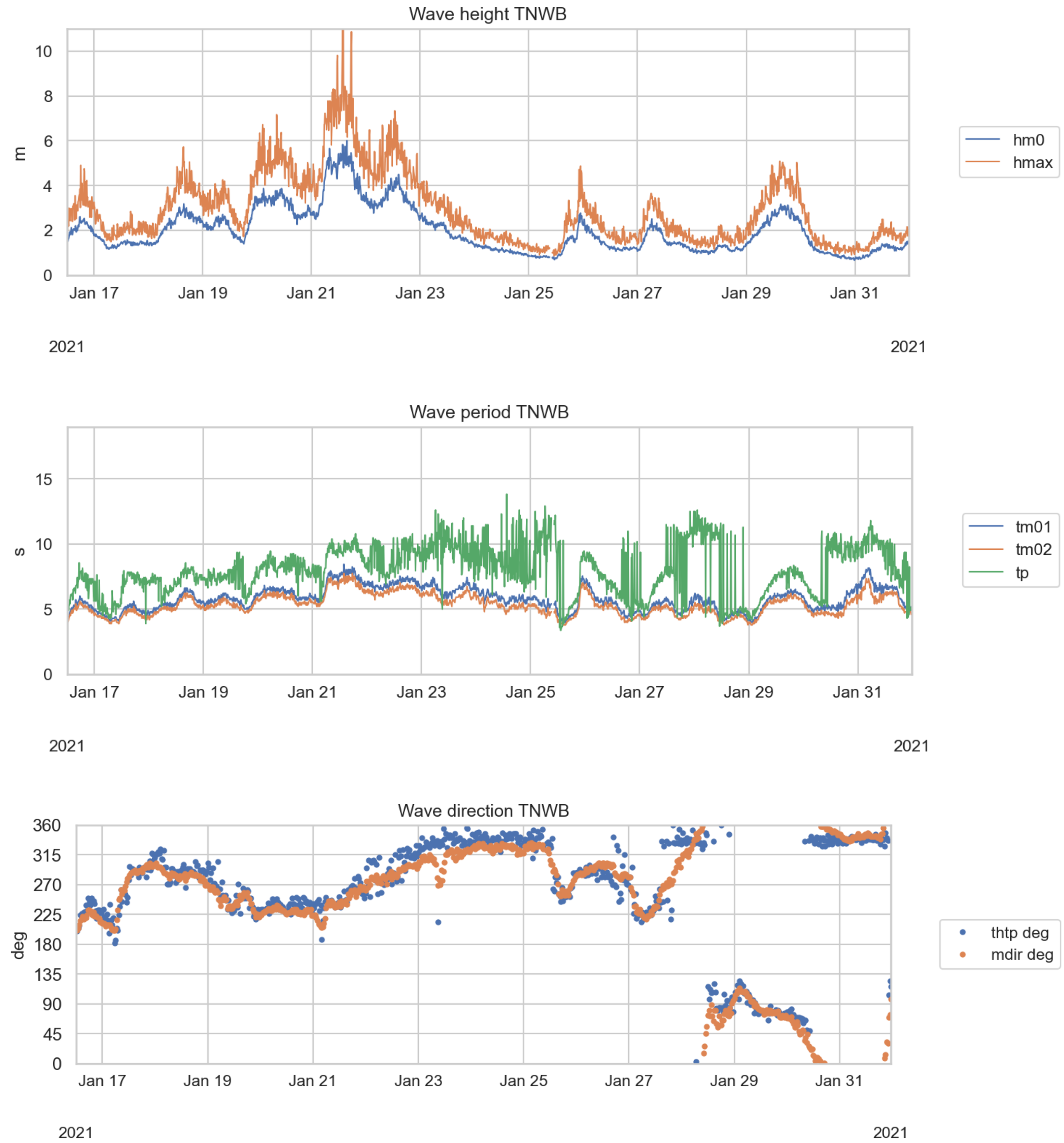


Figure F.58: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWB, 16 – 31 January 2021.

F.3.3 Wind profile data

Plots of wind speed and direction data from the Gill wind sensor mounted at 4 m height on the buoy mast are presented in Figure F.59 and Figure F.60.

The data return of this sensor is high with 10 min mean wind speeds up to 18.6 m/s and gusts up to 25.8 m/s. The maximum wind speed was measured on 21 January at 07:40 and gust were measured on 21 January at 07:00. The average wind speed at mast top height was 8.2 m/s.

Figure F.59: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWB, 01 - 16 January 2021.

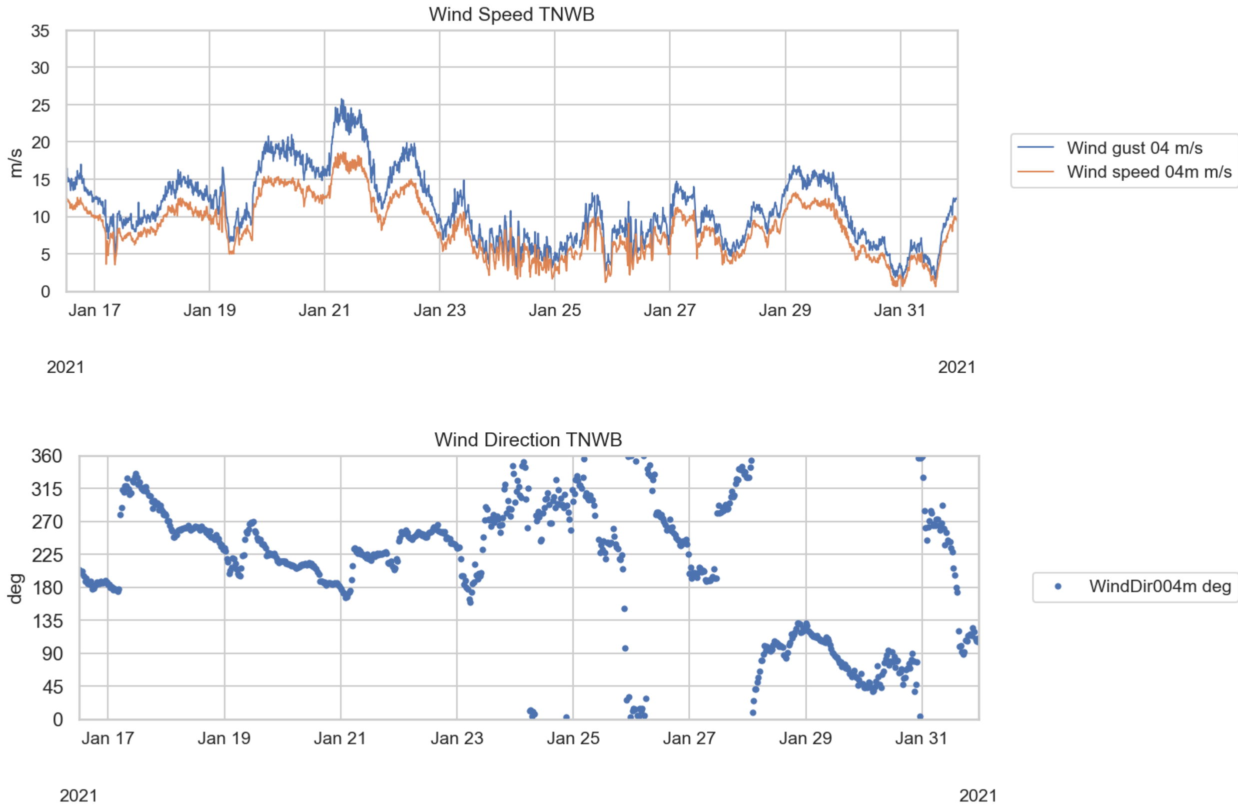


Figure F.60: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWB, 16 - 31 January 2021.

Plots of wind profile data from the LiDAR are presented in Figure F.61 - Figure F.75 showing the 10-min. mean wind for each individual level. Plots of the derived parameters Inflow Angle, Turbulence Intensity and wind shear are also presented.

The highest horizontal 10-minute mean wind speed measured in the profile during 01 - 31 January 2021 varies from 9.5 m/s at 30 m to 10.7 m/s at 250 m above the surface. The maximum wind speed at 30 m (24.8 m/s) was measured on 21 January 2021 at 07:40, and the maximum at 250 m (35.2 m/s) on 21 January at 02:10.

Note: TI is in general overestimated, see Table D.1. Detailed analysis of derived quantities (i.e. TI, wind shear, etc.) should always be done using the dataset as a whole and using an appropriate formula of choice.
In addition, turbulence intensity is transmitted separately from the wind speed measurements, as mentioned in Appendix E: Data processing chain. The transmission method is more susceptible to transmission problems and power supply issues. Possible long (several hours) gaps in the TI record generally correspond to scheduled buoy re-boots and affect the TI transmissions more than the other parameters.

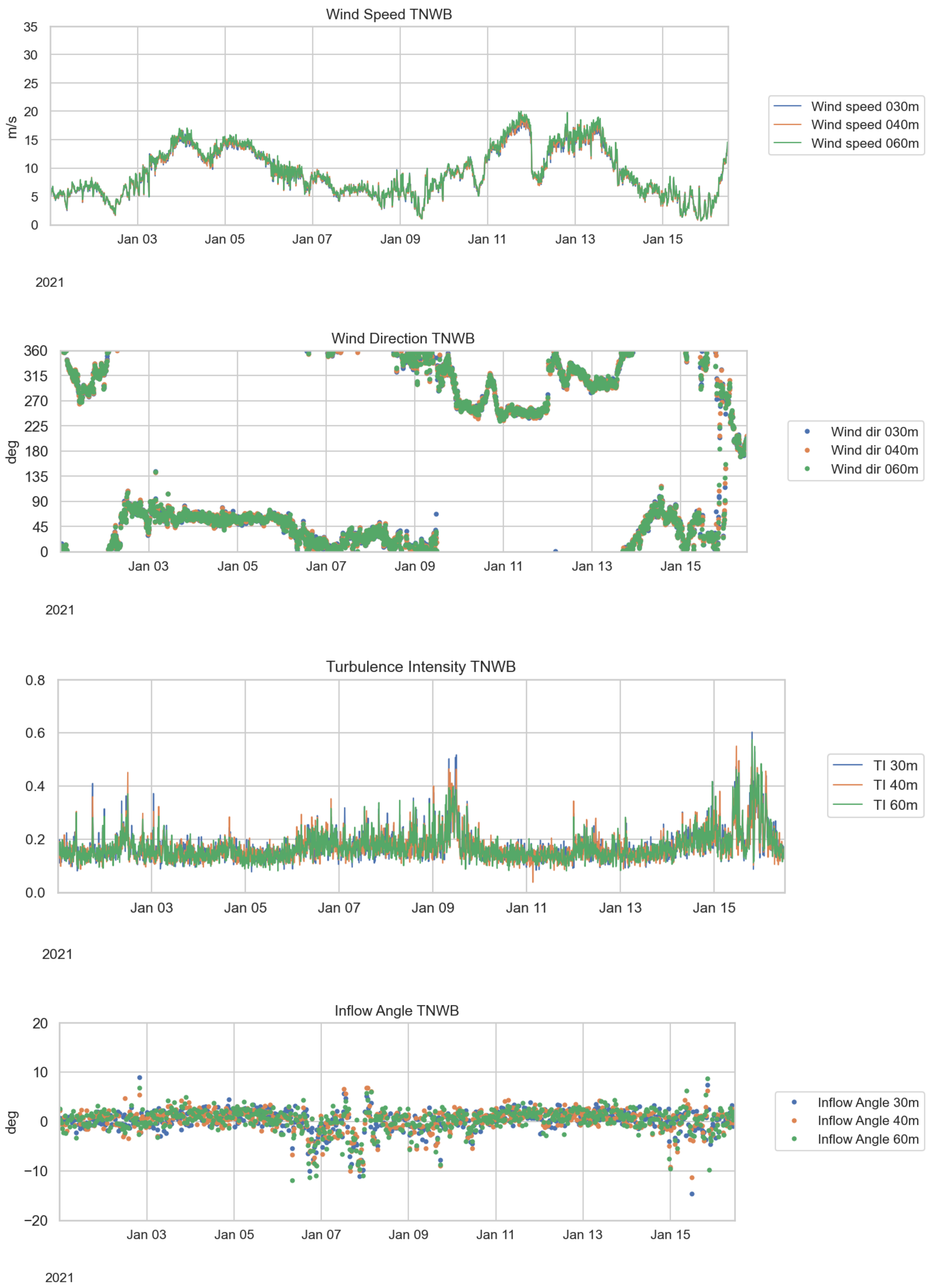


Figure F.61: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWB, 01 - 16 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, Inflow Angle.

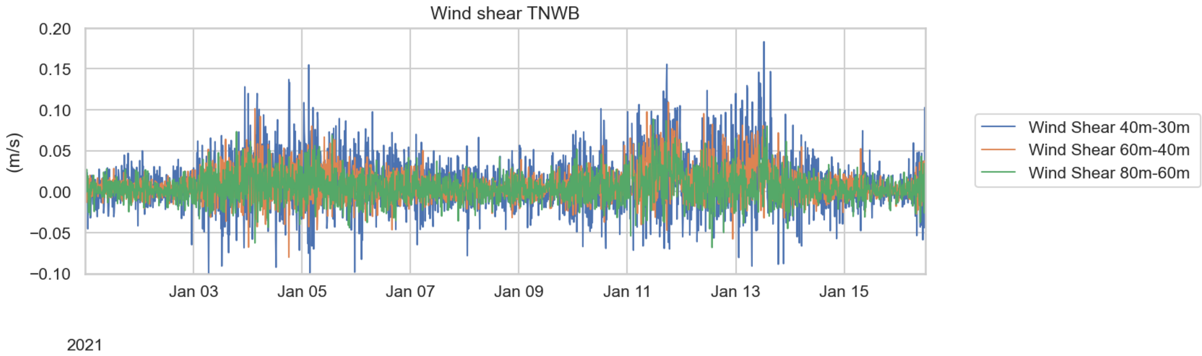


Figure F.62: Plot of wind shear data, 30, 40, 60 m a.s.l., at TNWB, 01 - 16 January 2021.

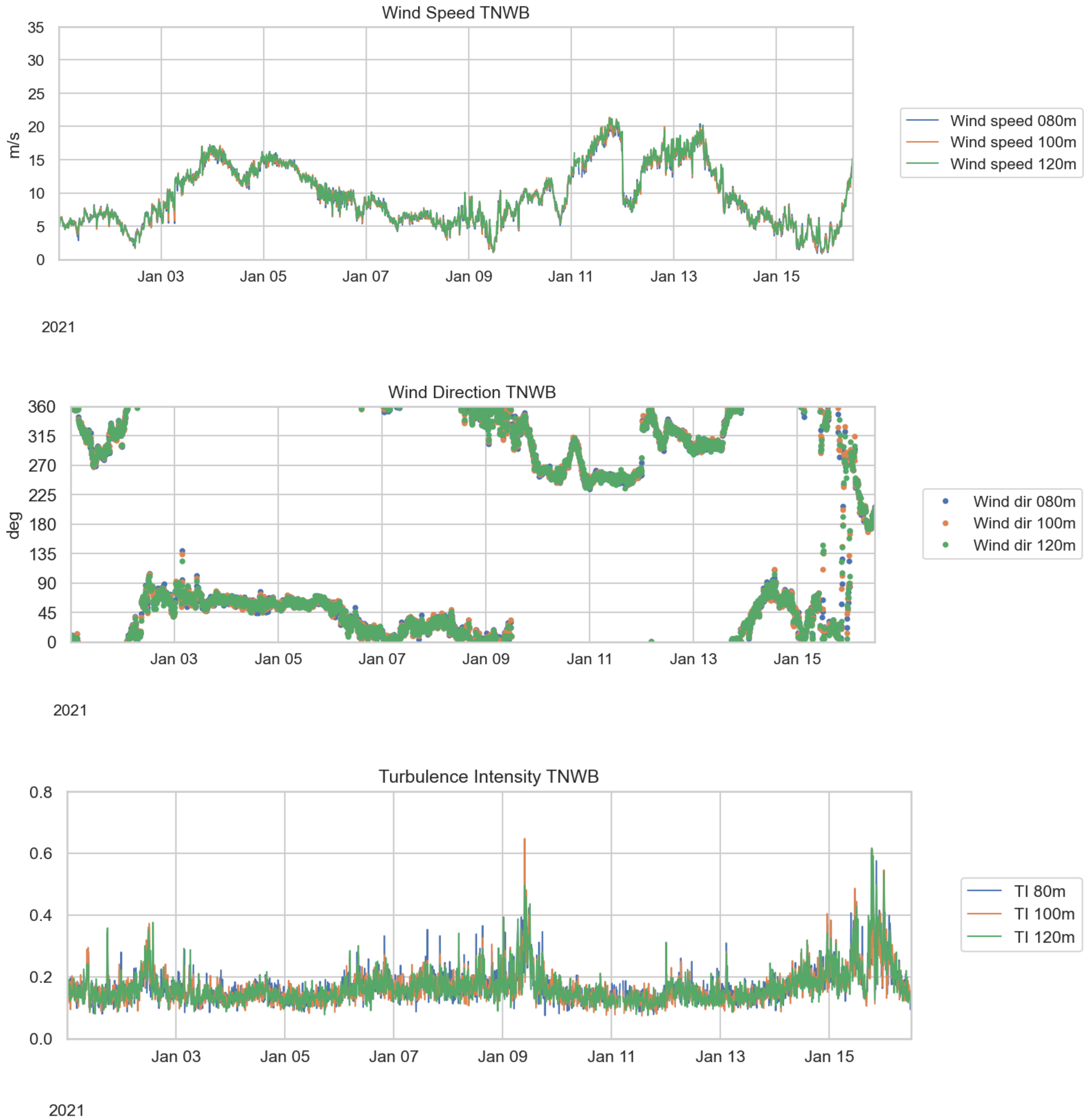
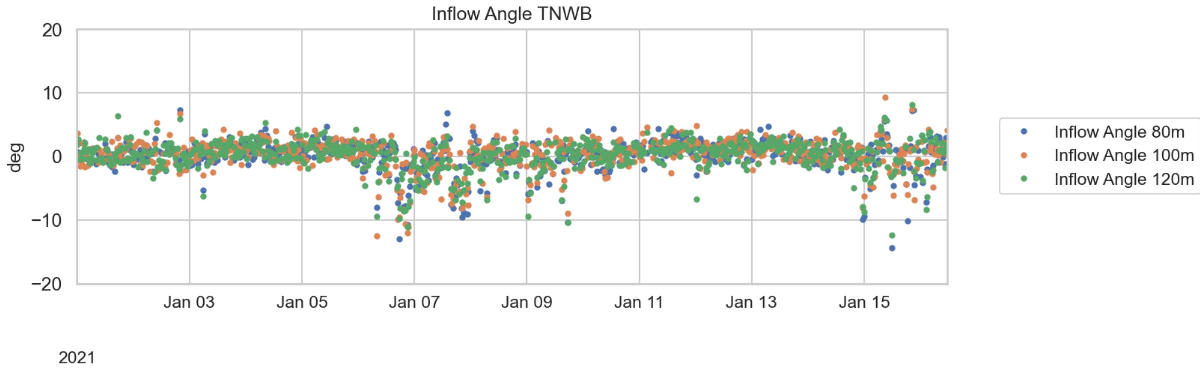


Figure F.63: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWB, 01 - 16 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity.



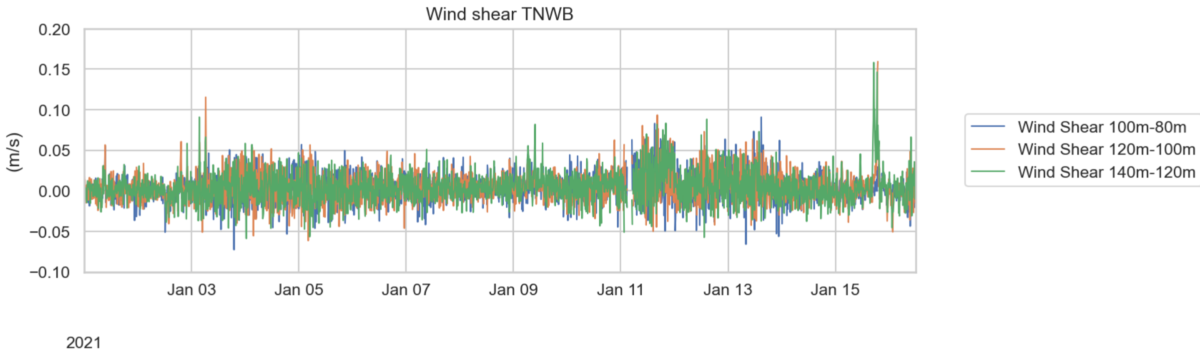
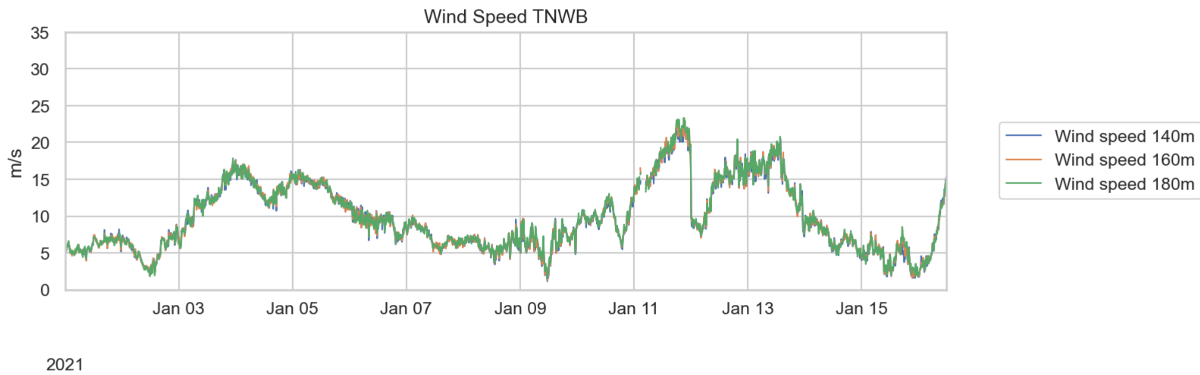


Figure F.64: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWB, 01 - 16 January 2021. From top to bottom: Inflow Angle and wind shear.



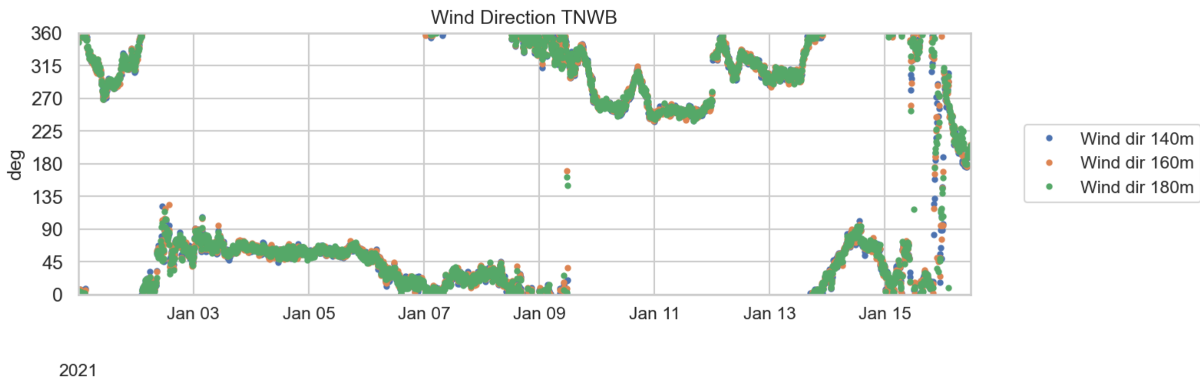
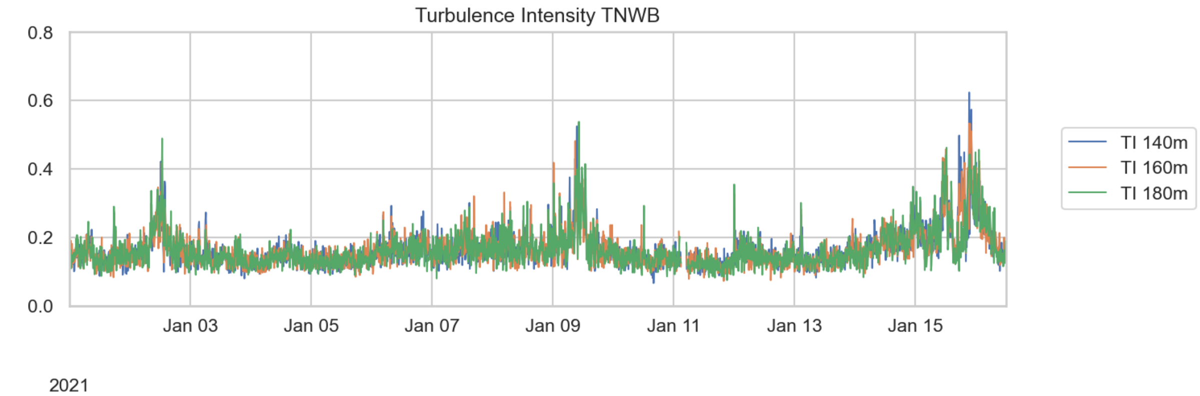
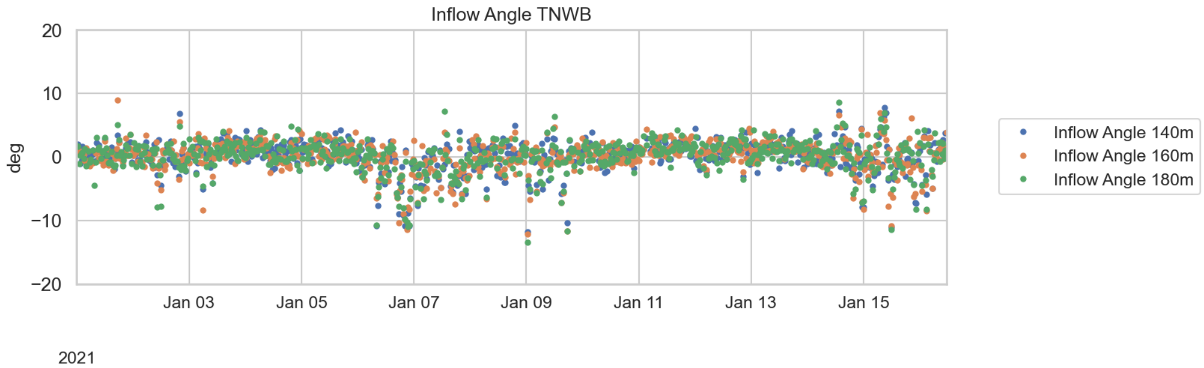


Figure F.65: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWB, 01 - 16 January 2021. From top to bottom: Wind speed, Wind direction.





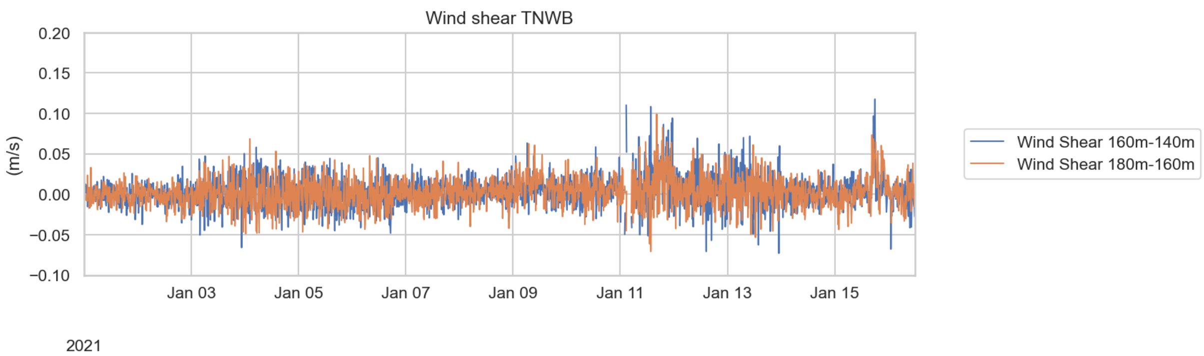


Figure F.66: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWB, 01 - 16 January 2021. From top to bottom: Turbulence Intensity, Inflow Angle and wind shear.

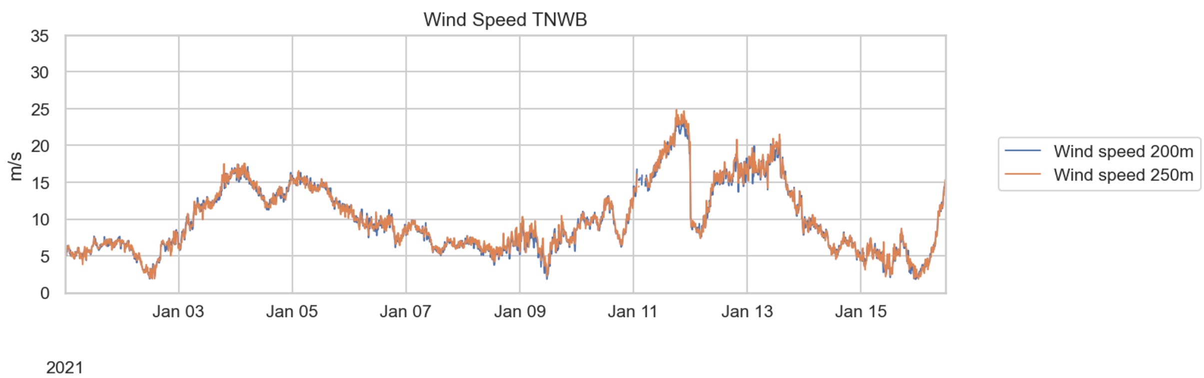
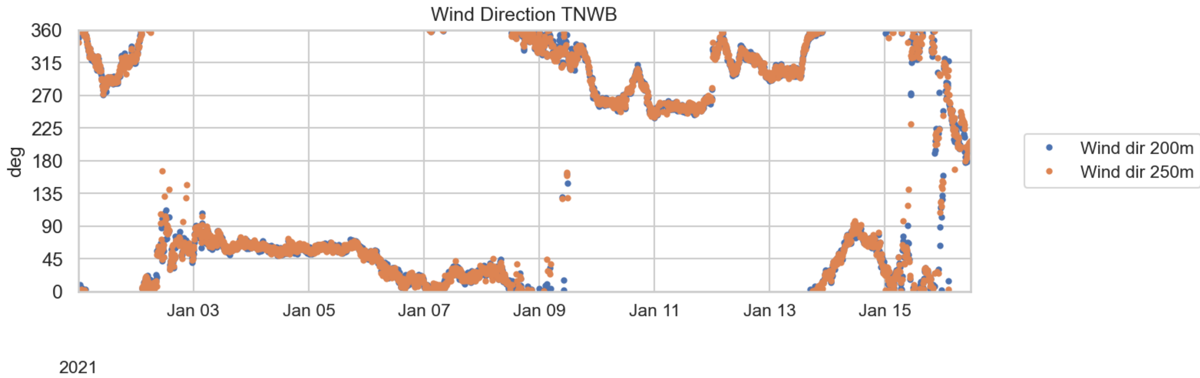
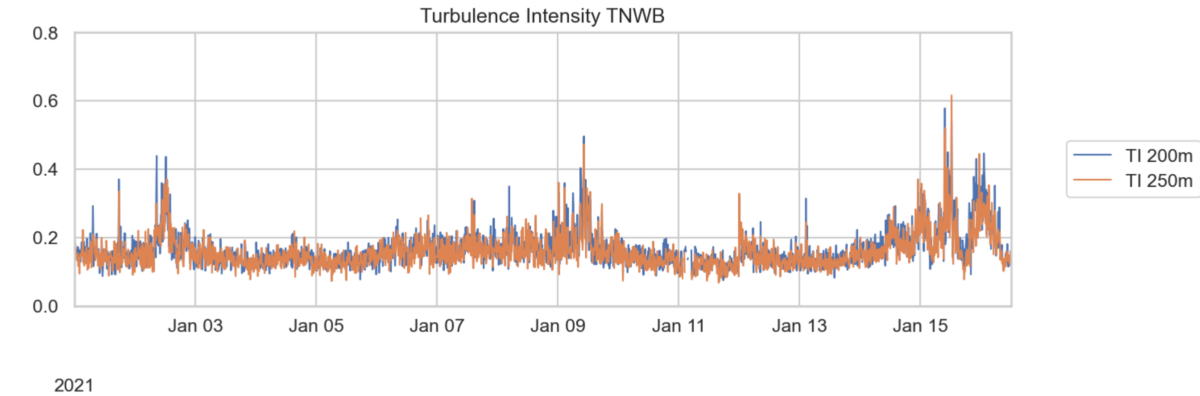
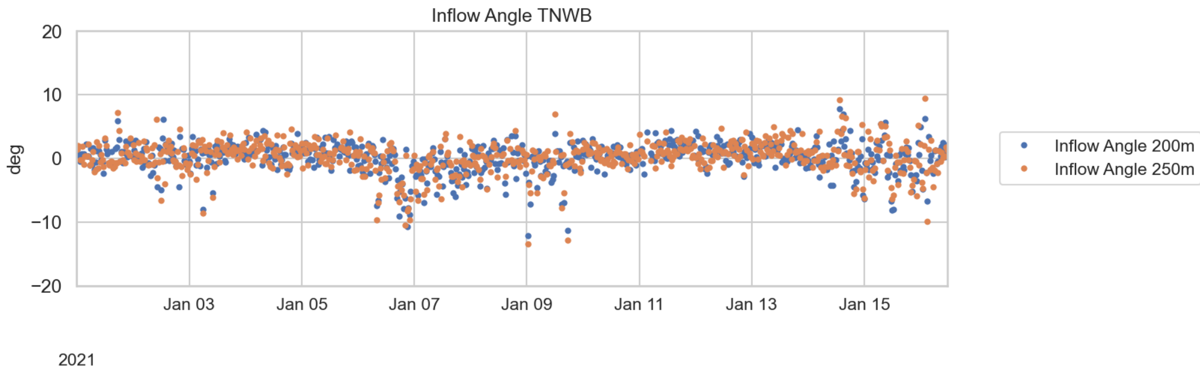


Figure F.67: Plot of wind speed data, 200, 250 m a.s.l., at TNWB, 01 - 16 January 2021.







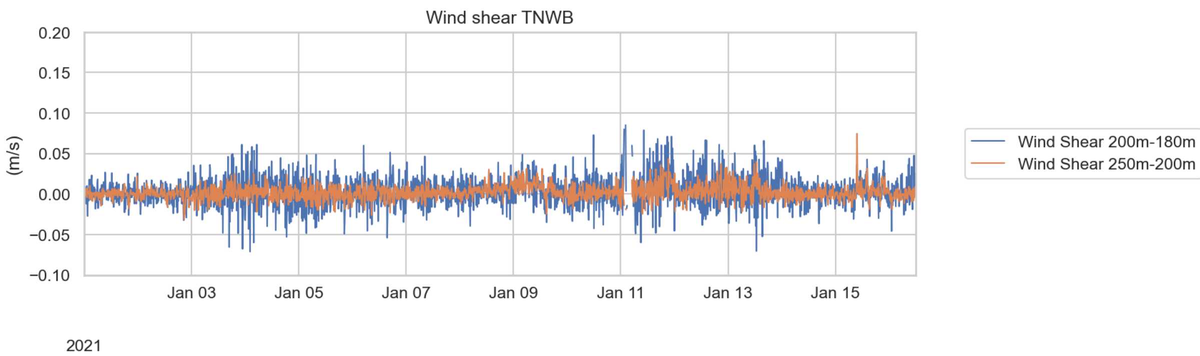


**Figure F.68: Plots of wind profile data, 200, 250 m a.s.l., at TNWB, 01 - 16 January 2021.
From top to bottom: Wind direction, Turbulence Intensity, Inflow Angle and wind shear.**

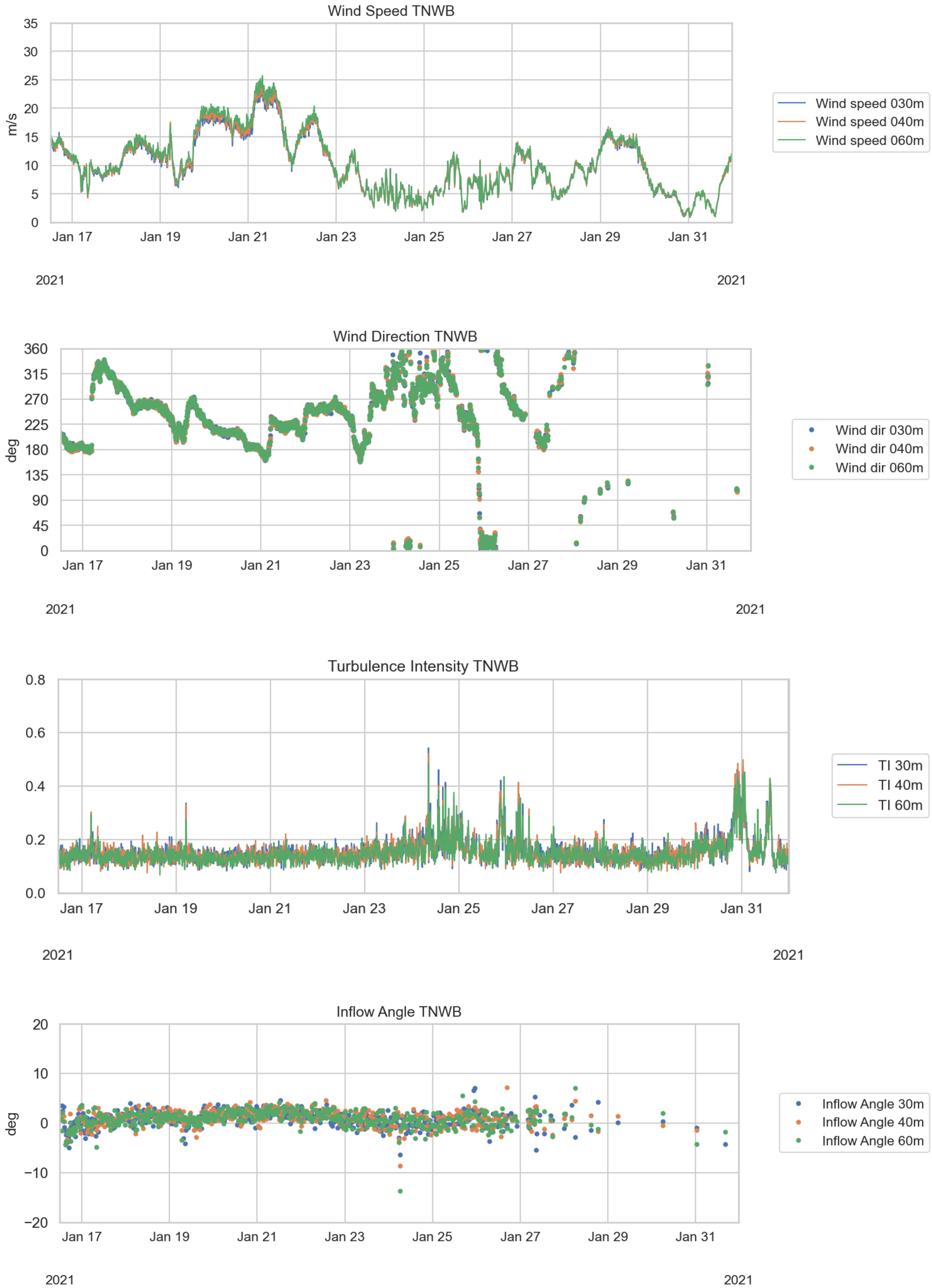


Figure F.69: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWB, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, Inflow Angle.

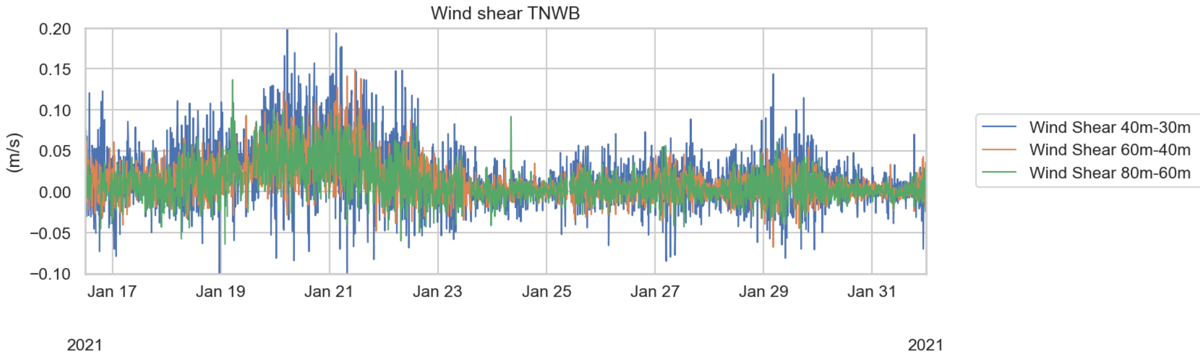


Figure F.70: Plots of wind shear data, 30, 40, 60 m a.s.l., at TNWB, 16 - 31 January 2021.

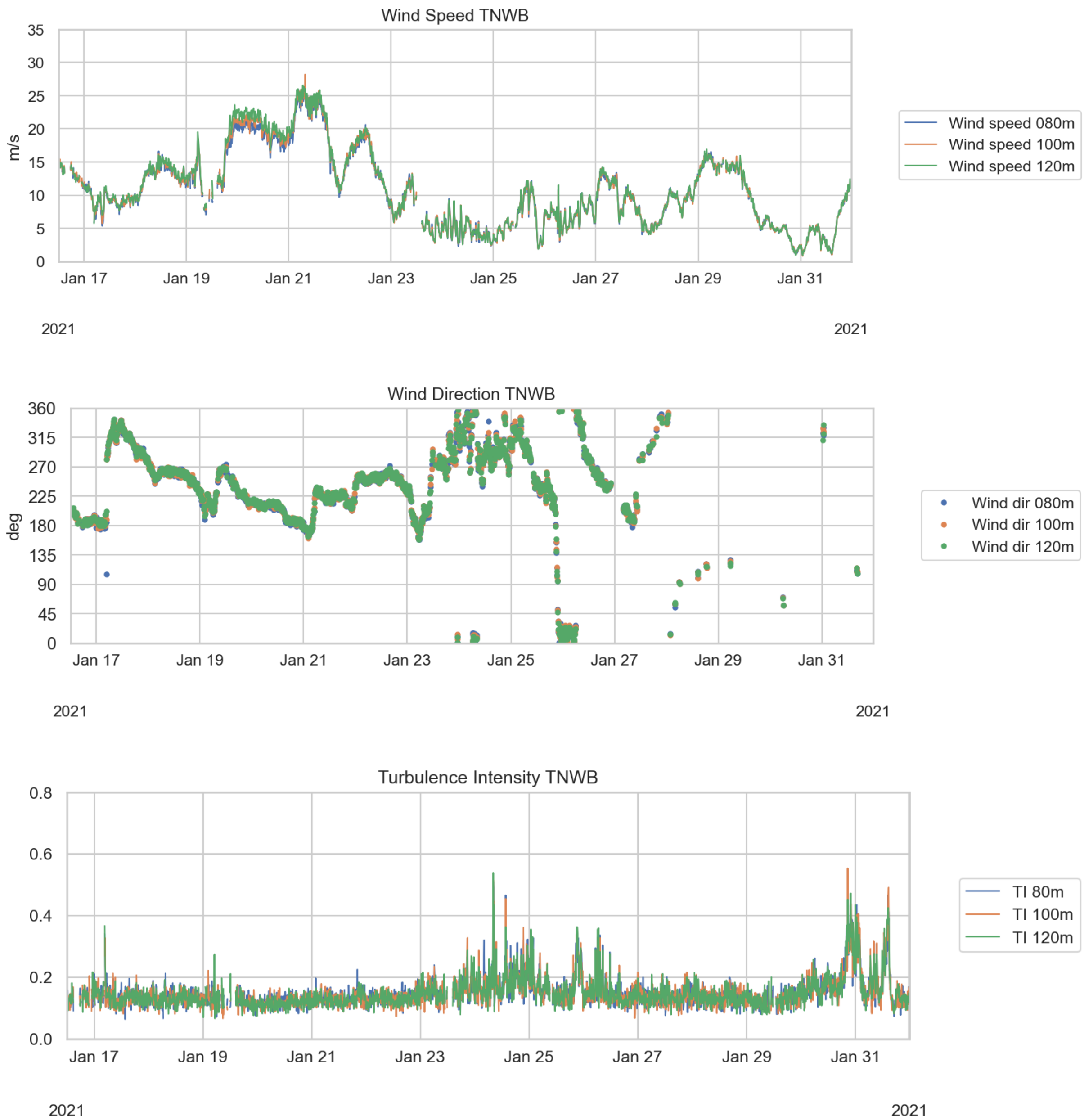


Figure F.71: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWB, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction, Turbulence Intensity.

Figure F.72: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWB, 16 - 31 January 2021. From top to bottom: Inflow Angle and wind shear.

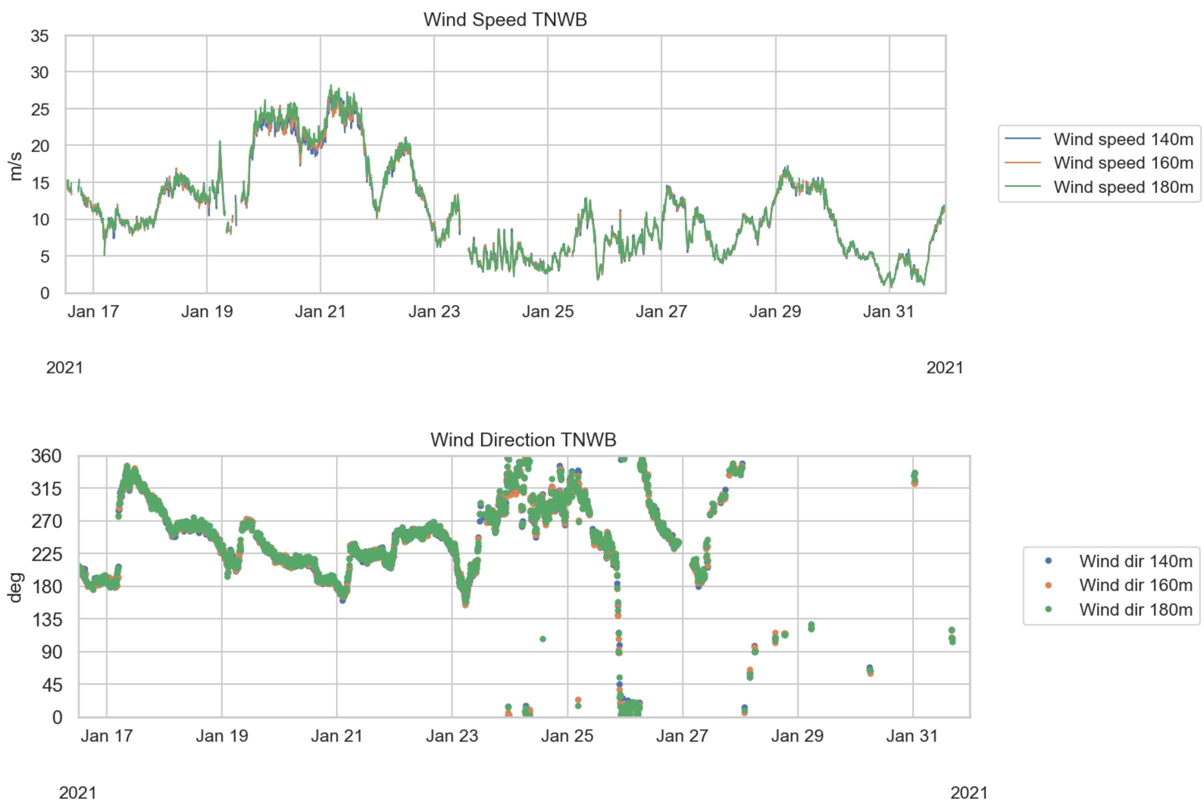


Figure F.73: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWB, 16 - 31 January 2021. From top to bottom: Wind speed, Wind direction.

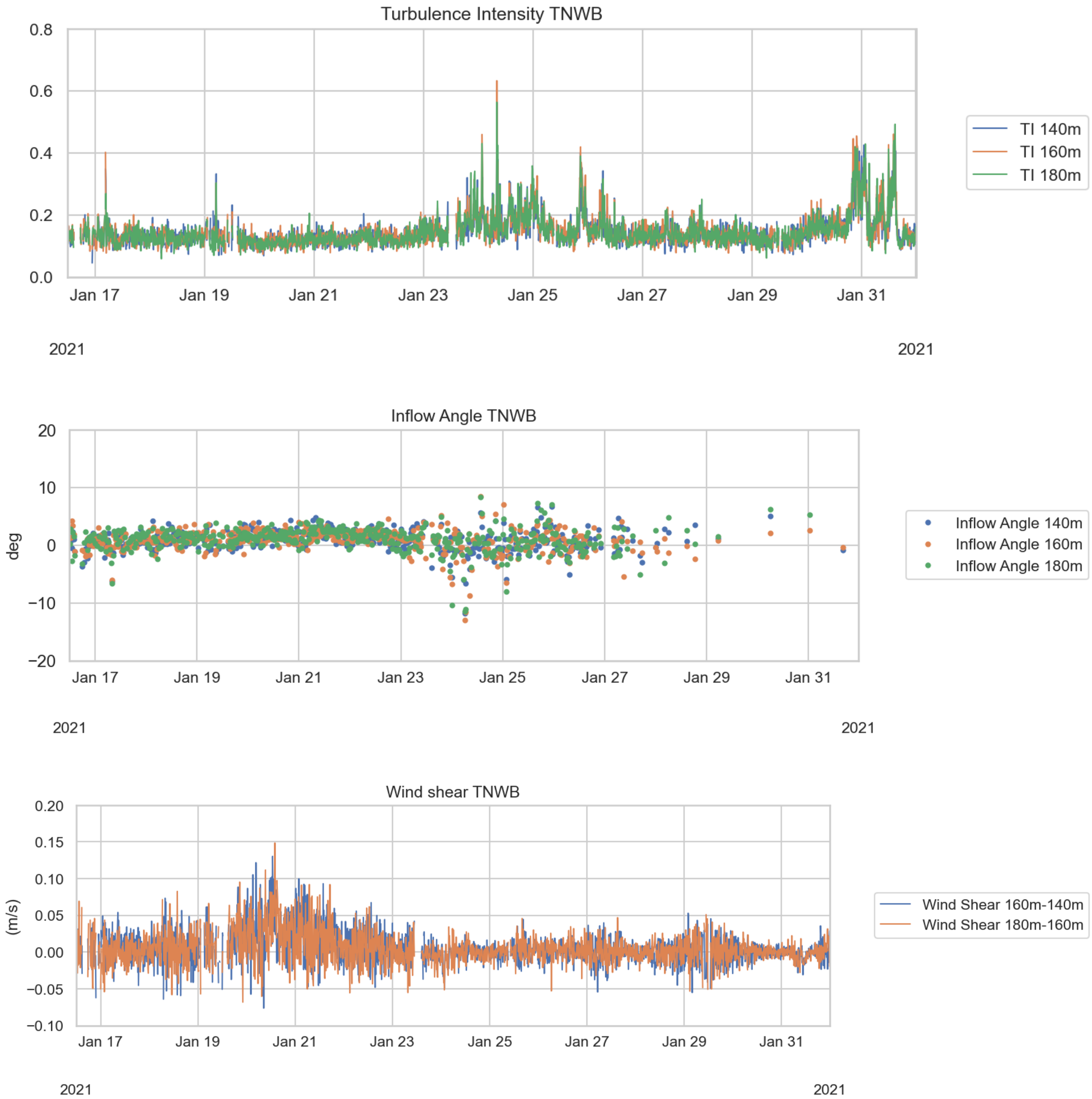


Figure F.74: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWB, 16 - 31 January 2021. From top to bottom: Turbulence Intensity, Inflow Angle and wind shear.

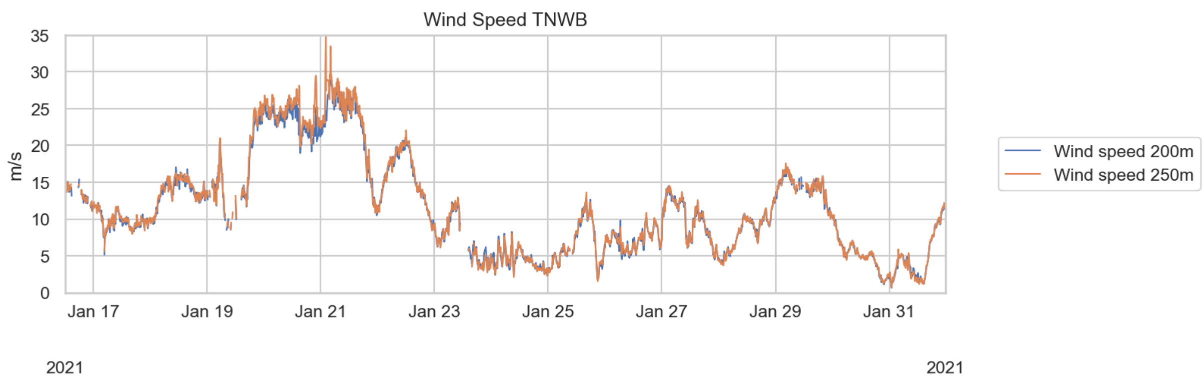


Figure F.75: Plot of wind speed data, 200, 250 m a.s.l., at TNWB, 16 - 31 January 2021.

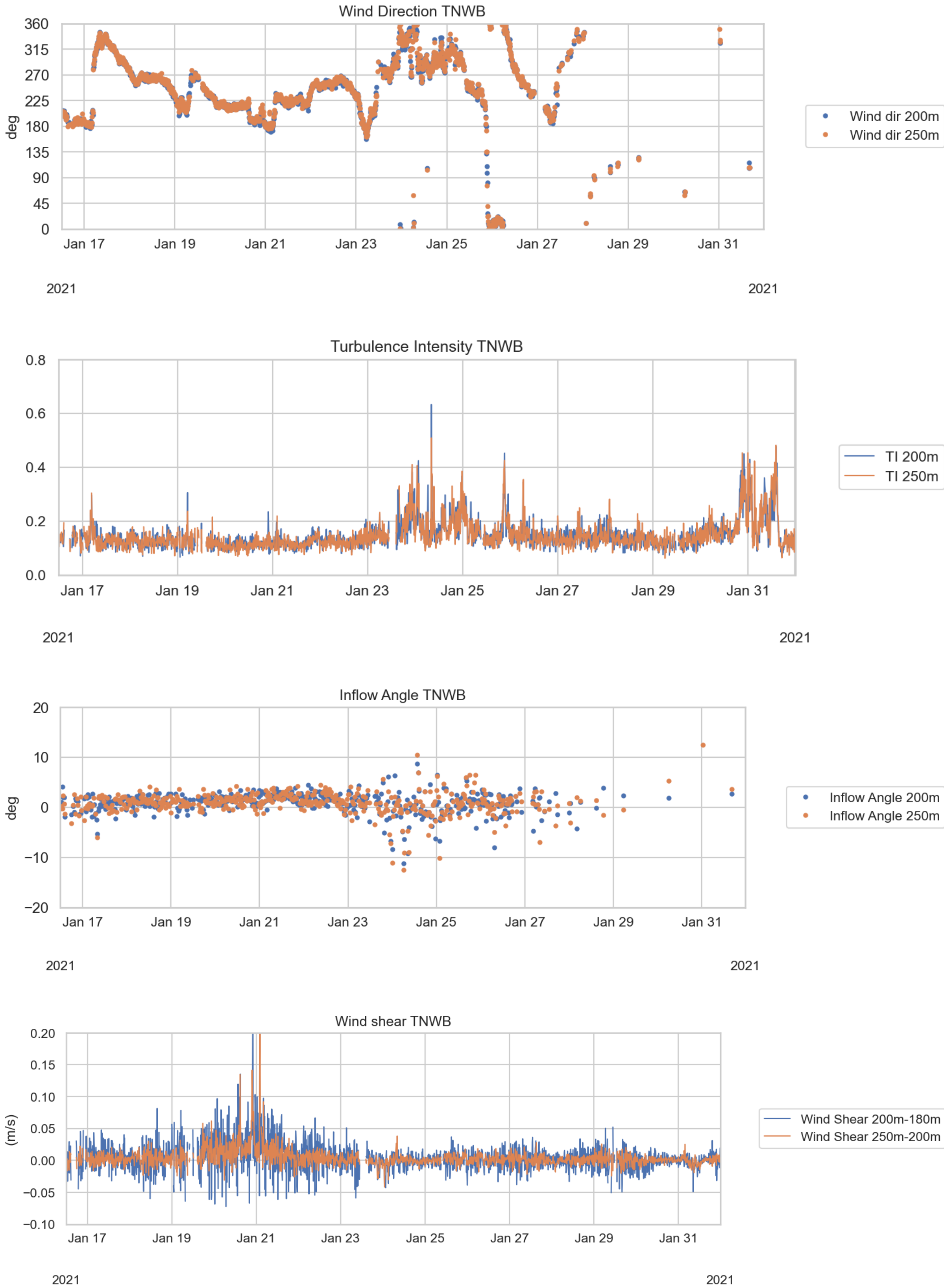


**Figure F.76: Plots of wind profile data, 200, 250 m a.s.l., at TNWB, 16 - 31 January 2021.
From top to bottom: Wind direction, Turbulence Intensity, Inflow Angle and wind shear.**

F.3.4 Current velocity profile data

Plots of the current velocity profile time series are presented in Figure F.77 - Figure F.83.

As expected for this location the current velocity data show a consistent semi-diurnal tidal current pattern. The current vector is completing two rotations of the tidal ellipse per day, between north and south-west. The data availability is high and the data appear inconspicuous.

The maximum observed current speed varies between 58-60 cm/s at 3-7 m depth to 56 cm/s at 25 m depth. The average current speed in the profile varies with depth from 29-31 cm/s at 3-7 m to 29 cm/s at 25 m depth. The lowest depths (35 - 37 m) are shown here but are to be used with caution since seafloor effects have not been taken into account.

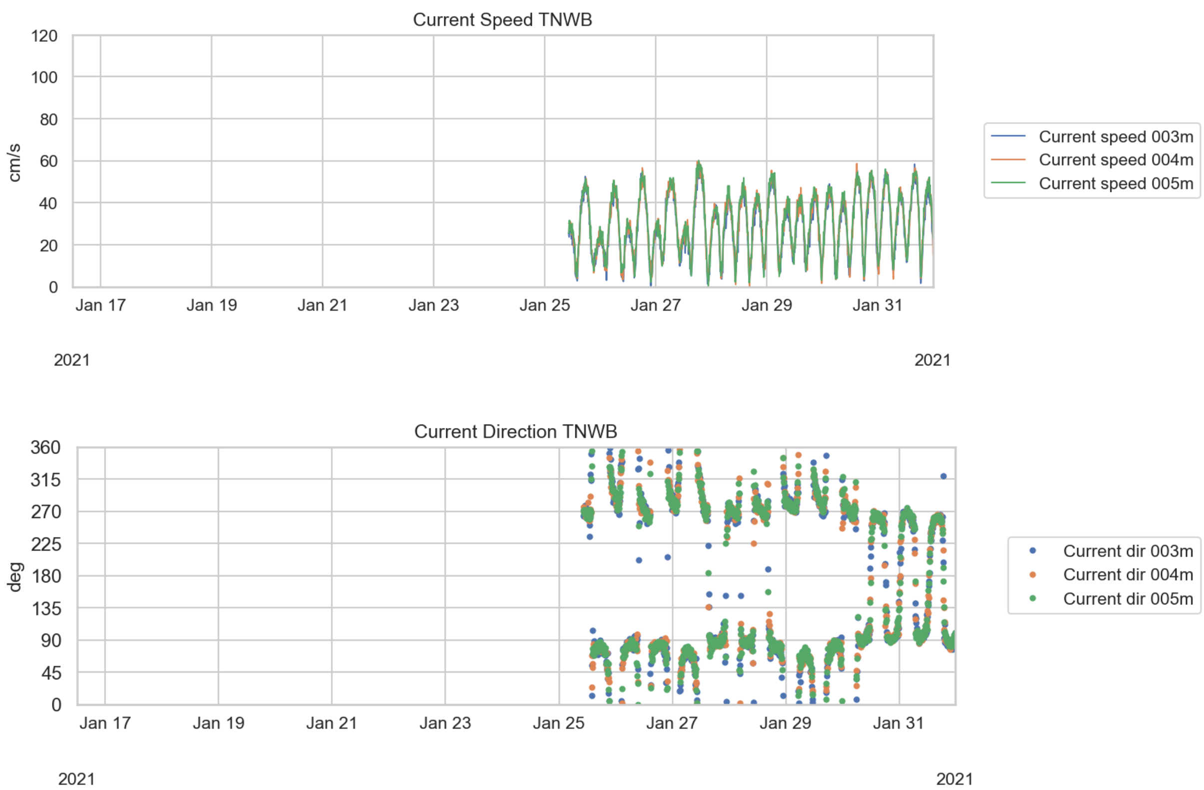


Figure F.77: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWB, 16 - 31 January 2021.

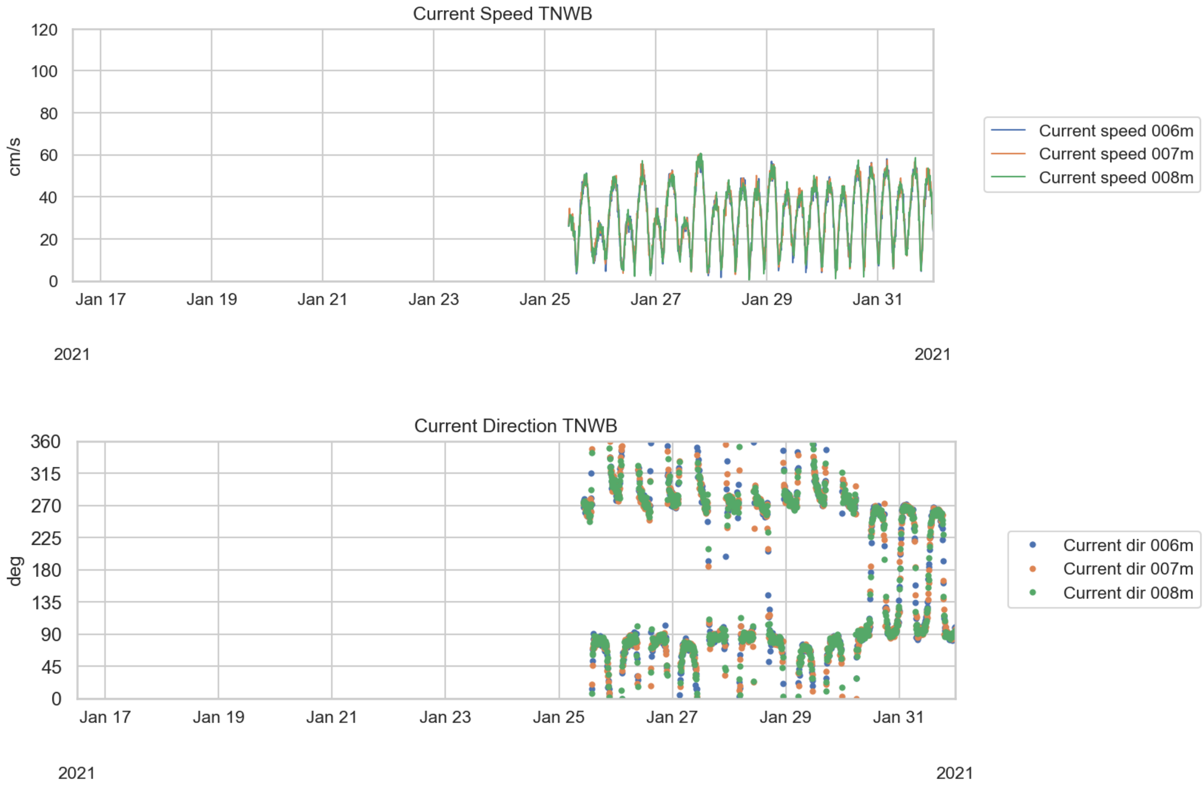


Figure F.78: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWB, 16 - 31 January 2021.

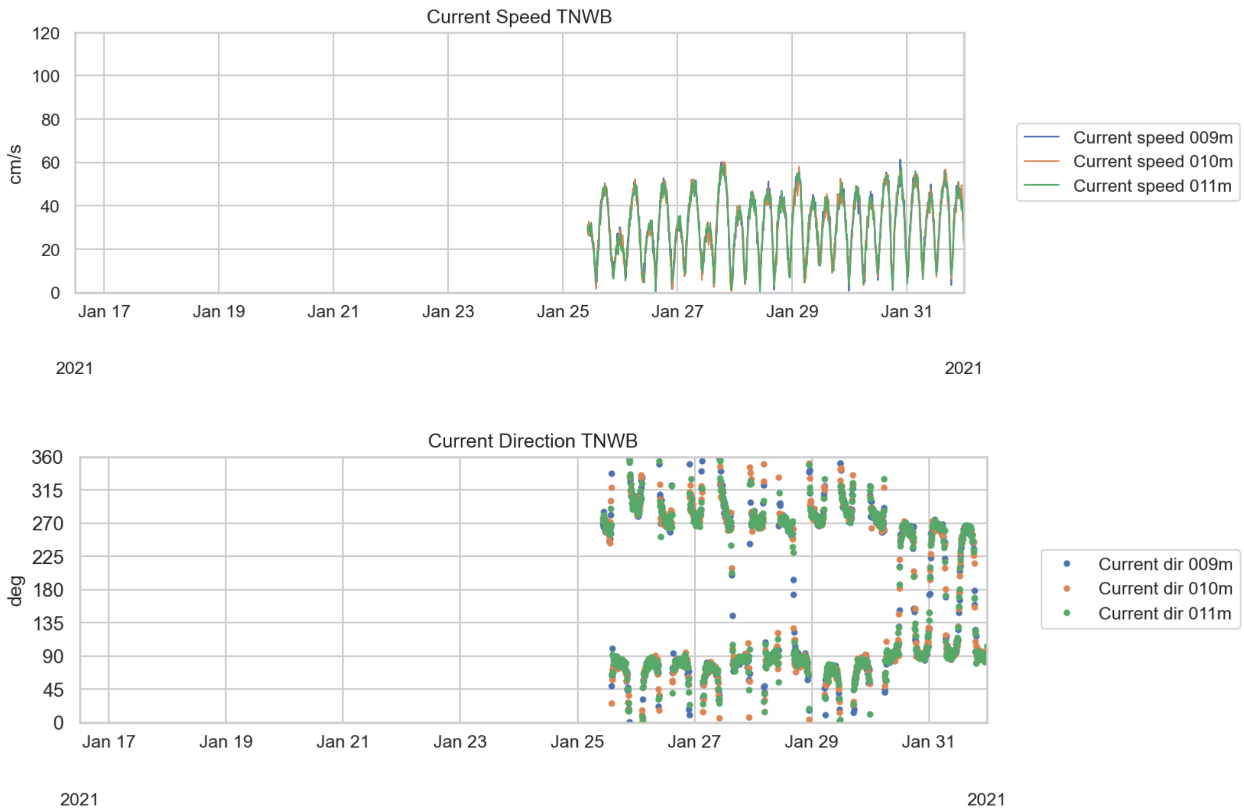


Figure F.79: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWB, 16 - 31 January 2021.

Figure F.80: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWB, 16 - 31 January 2021.

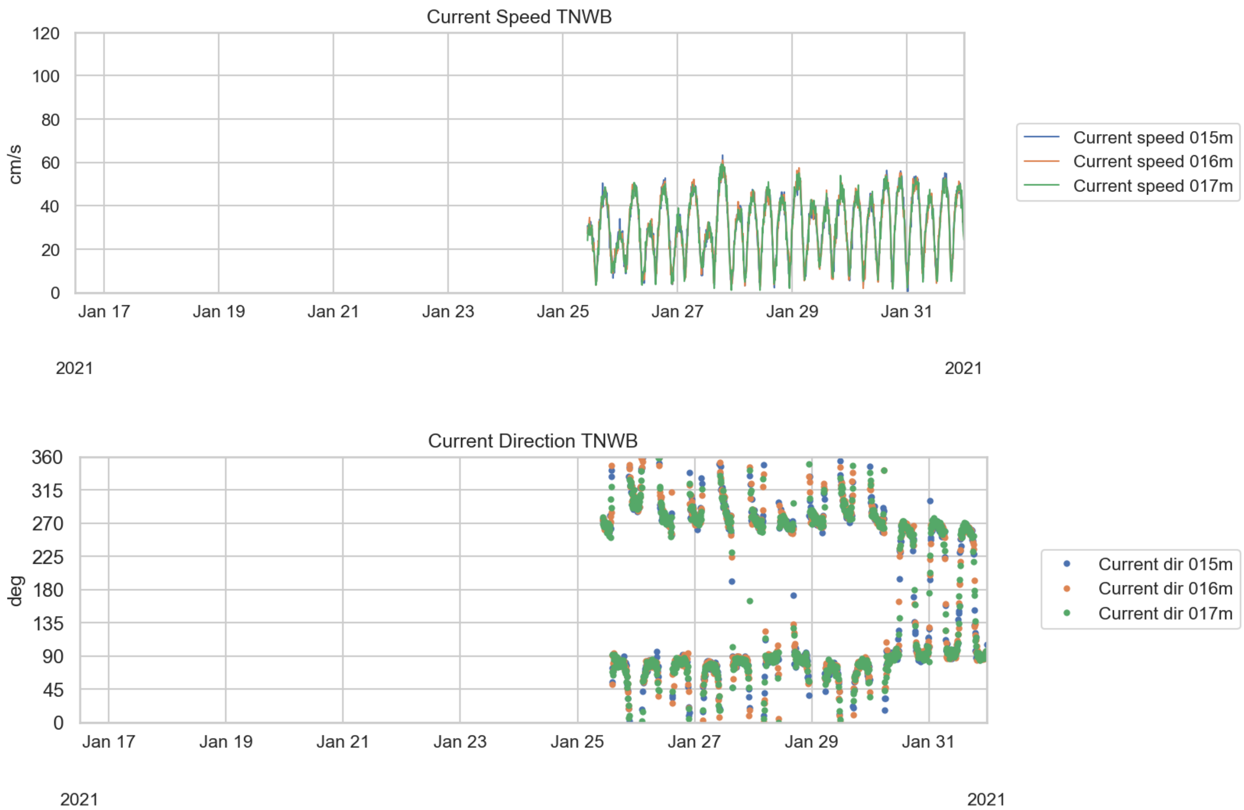


Figure F.81: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWB, 16 - 31 January 2021.

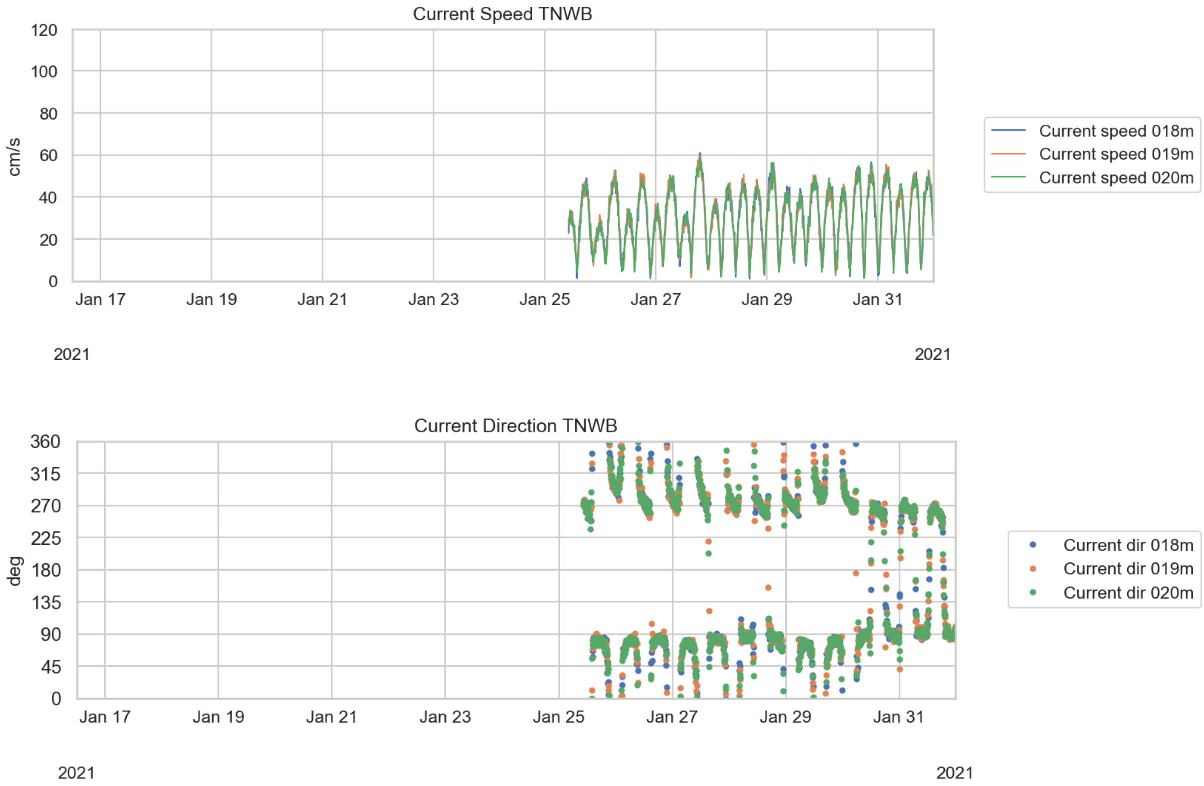


Figure F.82: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWB, 16 - 31 January 2021.

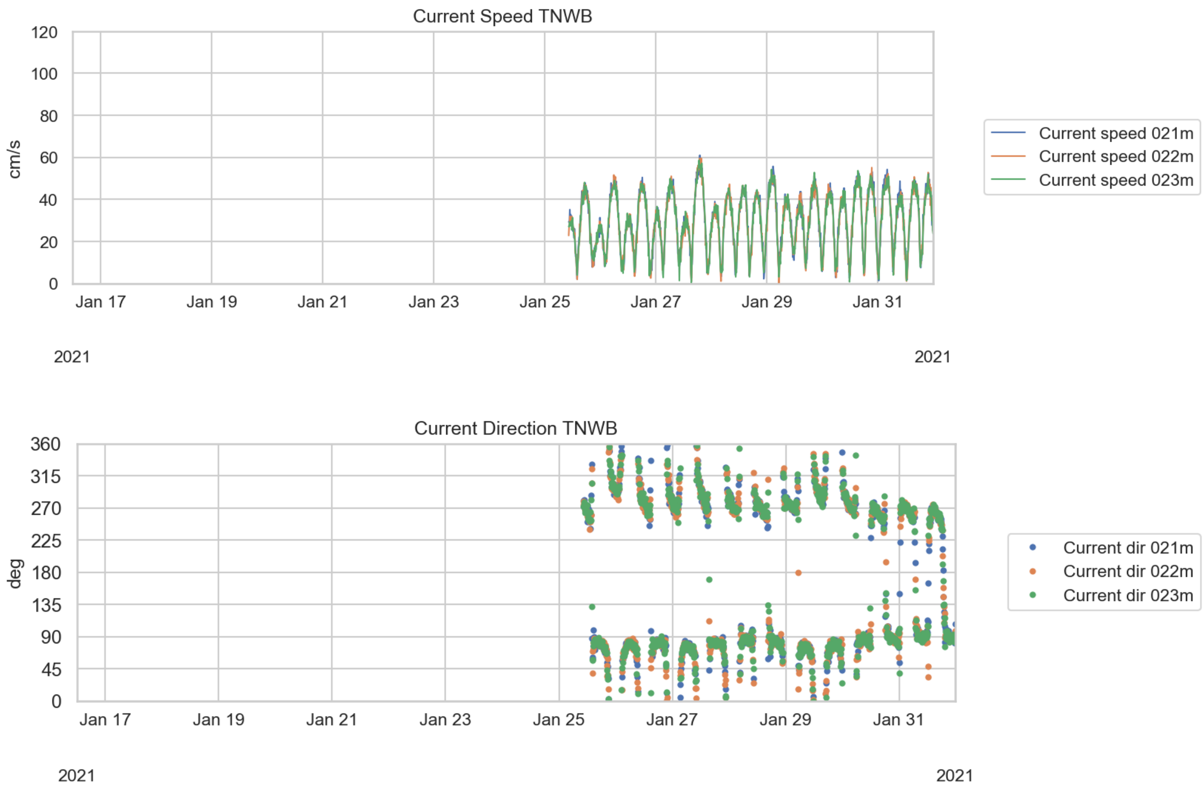


Figure F.83: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWB, 16 - 31 January 2021.

Figure F.84: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWB, 16 - 31 January 2021.

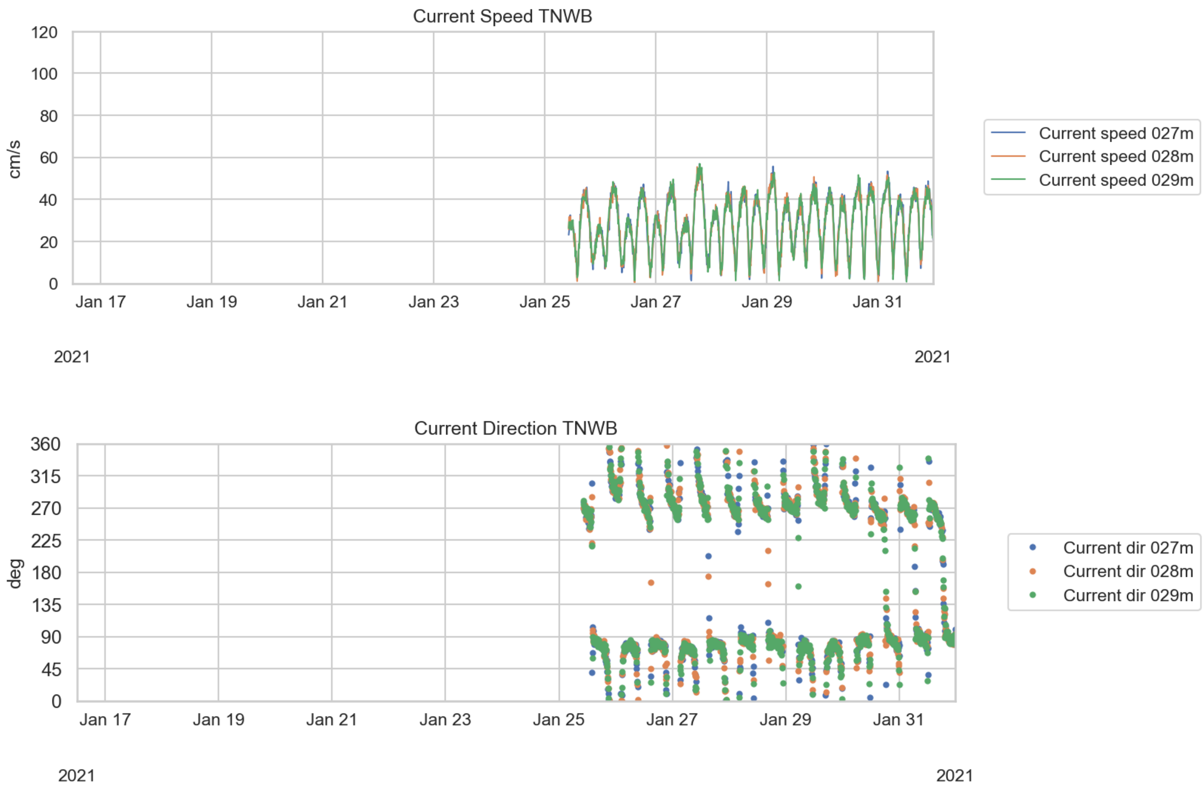


Figure F.85: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWB, 16 - 31 January 2021.

Figure F.86: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWB, 16 - 31 January 2021.

Figure F.87: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWB, 16 - 31 January 2021.

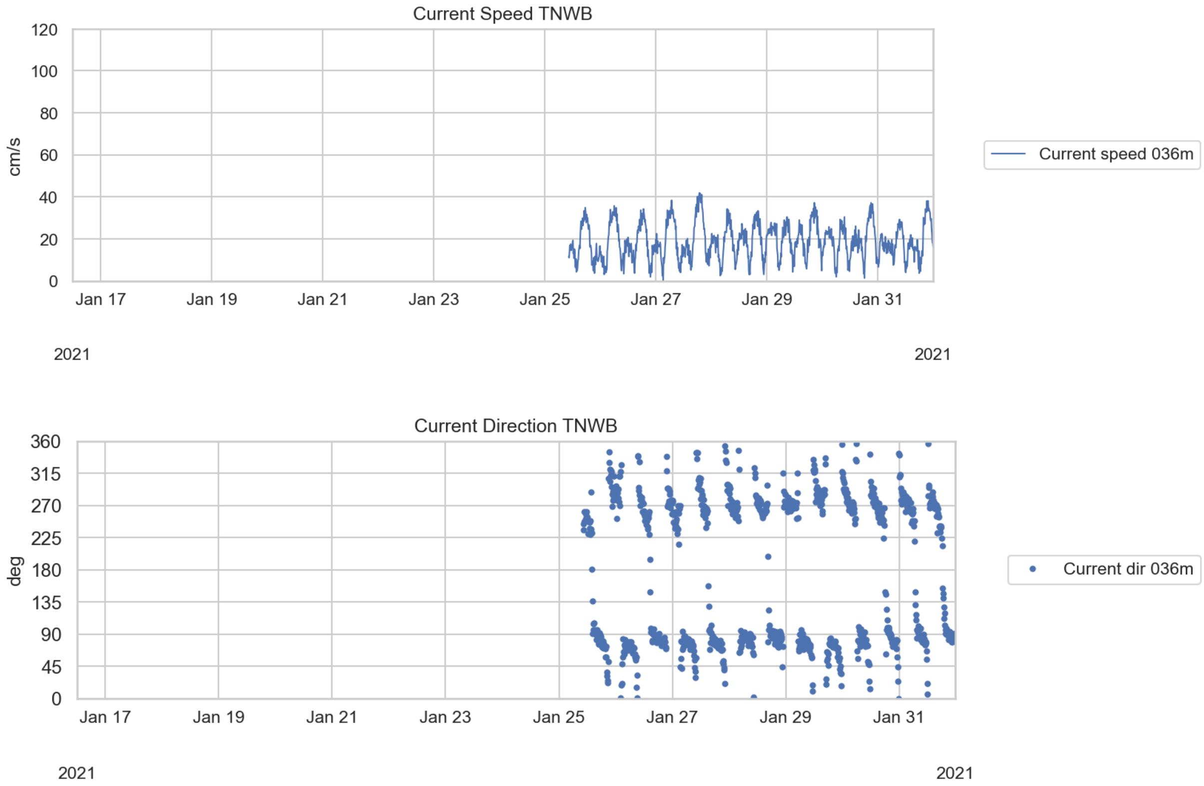


Figure F.88: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWB, 16 - 31 January 2021.

F.3.5 Water pressure and bottom temperature data

Water level (ref. LAT) and bottom temperature data are presented in Figure F.89 - Figure F.90.
Note that the conversion to water level is preliminary and will be updated at the end of the campaign.
The total water pressure data are corrected for atmospheric pressure.
The difference between the minimum and maximum water level is 1.63 m. The mean value is 1.8 m.

The bottom temperature varied from 7.6 to 8.0 °C, with a mean temperature of 7.8 °C. The stepwise behaviour of the plot is due to the resolution of the data.

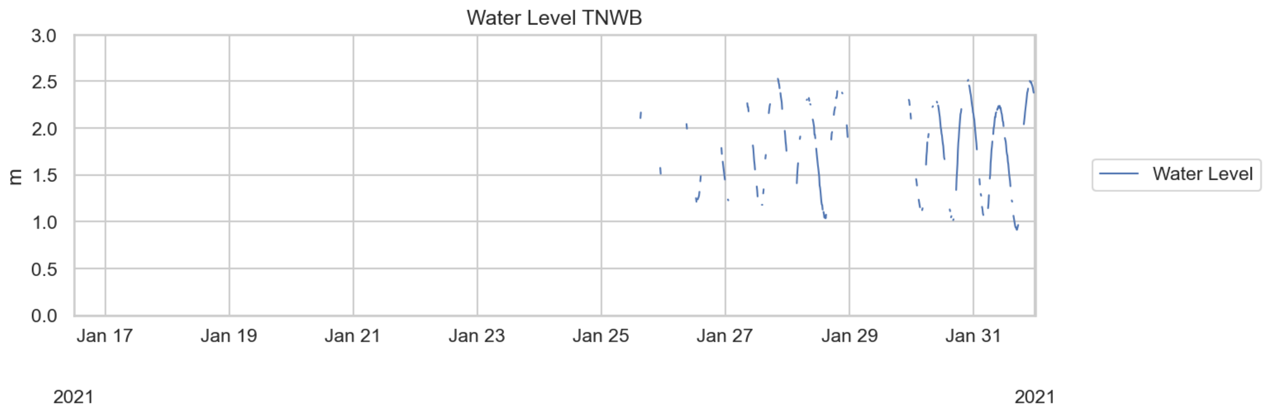


Figure F.89: Water level (m LAT) at TNWB, 16 - 31 January 2021

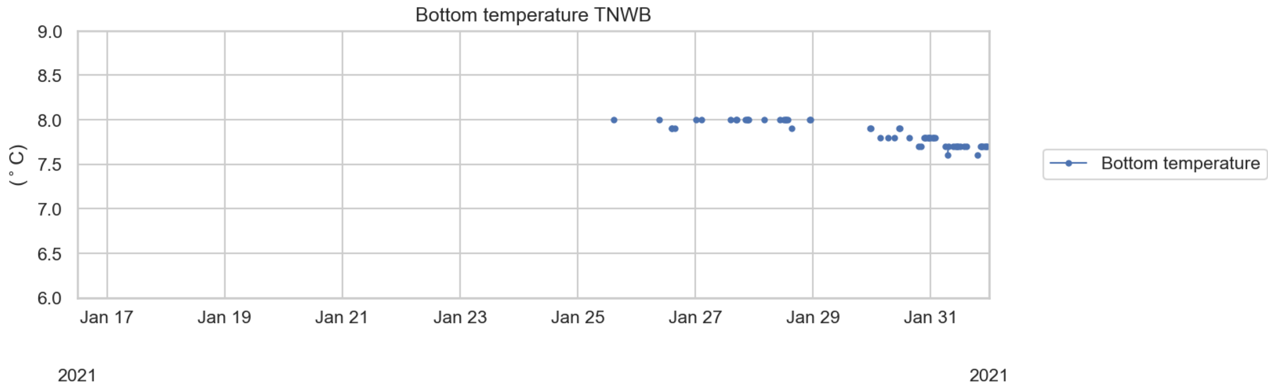


Figure F.90: Bottom temperature at TNWB, 16 - 31 January 2021

F.4 Signal Availability for TNWB

There was no water level sensor at TNWB during the deployment of WS156. The current profiler of WS156 started giving suspicious data in November 2020 and all current speed and direction data is under investigation. The data was removed from this month's dataset until the ongoing investigation is concluded.

Table F.2: Signal Availability (%) at TNWB during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
WindDir004m deg	99.9	100	99.4	78.9	68.9	100	99.80
WindDir030m deg	99.2	98.8	90.7	62.5	68.9	99.8	84.60
WindDir040m deg	99.2	98.8	90.7	62.5	68.9	99.9	84.60
WindDir060m deg	99.1	98.7	90.6	62.5	68.9	99.8	84.60
WindDir080m deg	99.1	98.7	90.4	62.5	68.4	99	82.70
WindDir100m deg	99.1	98.6	90.4	62.5	67.8	99	82.60
WindDir120m deg	99.1	98.5	90.3	62.5	67.5	99	82.60
WindDir140m deg	99.1	98.5	90.4	62.5	67.4	99	82.60
WindDir160m deg	99	98.5	90.3	62.5	67.3	98.9	82.40
WindDir180m deg	99	98.4	90	62.5	67.2	98.9	82.50
WindDir200m deg	98.7	98.5	89.8	62.4	67.2	98.7	82.40
WindDir250m deg	98.8	98.2	89.5	62.4	67.1	98.7	82.20
WindGust004m m/s	99.9	100	99.4	78.9	68.9	100	99.80
WindSpeed004m m/s	99.9	100	99.4	78.9	68.9	100	99.80
WindSpeed030m m/s	99.2	98.8	90.7	62.5	68.9	99.8	99.80
WindSpeed040m m/s	99.2	98.8	90.7	62.5	68.9	99.9	99.80
WindSpeed060m m/s	99.1	98.7	90.6	62.5	68.9	99.8	99.80
WindSpeed080m m/s	99.1	98.7	90.4	62.5	68.4	99.1	97.50
WindSpeed100m m/s	99.1	98.6	90.4	62.5	67.8	99	97.40
WindSpeed120m m/s	99.1	98.5	90.3	62.5	67.5	99	97.50
WindSpeed140m m/s	99.1	98.5	90.4	62.5	67.4	99	97.40
WindSpeed160m m/s	99	98.5	90.3	62.5	67.3	98.9	97.20
WindSpeed180m m/s	99	98.4	90	62.5	67.2	98.9	97.30
WindSpeed200m m/s	98.7	98.5	89.8	62.4	67.2	98.7	97.30
WindSpeed250m m/s	98.8	98.2	89.5	62.4	67.1	98.7	97.00
AqDir003 deg	100	100	99.5	78.9	65	0	21.20
AqDir004 deg	100	100	99.5	78.9	65	0	21.20
AqDir005 deg	100	100	99.5	78.9	65	0	21.20
AqDir006 deg	100	100	99.5	78.9	65	0	21.20
AqDir007 deg	100	100	99.5	78.9	65	0	21.20
AqDir008 deg	100	100	99.5	78.9	65	0	21.20
AqDir009 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir010 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir011 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir012 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir013 deg	100	100	99.5	78.9	41.7	0	21.20

Table F.2: Signal Availability (%) at TNWB during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
AqDir014 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir015 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir016 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir017 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir018 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir019 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir020 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir021 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir022 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir023 deg	100	100	99.4	78.9	41.7	0	21.20
AqDir024 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir025 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir026 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir027 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir028 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir029 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir030 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir031 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir032 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir033 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir034 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir035 deg	100	100	99.5	78.9	41.7	0	21.20
AqDir036 deg	100	100	99.5	78.9	41.7	0	21.20
AqSpd003 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd004 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd005 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd006 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd007 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd008 cm/s	100	100	99.5	78.9	65	0	21.20
AqSpd009 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd010 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd011 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd012 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd013 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd014 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd015 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd016 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd017 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd018 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd019 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd020 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd021 cm/s	100	100	99.5	78.9	41.7	0	21.20

Table F.2: Signal Availability (%) at TNWB during year 2 up to and including January 2021.

Parameter	July 2020 %	Aug 2020 %	Sept 2020	Oct 2020	Nov 2020	Dec 2020	Jan 2021
AqSpd022 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd023 cm/s	100	100	99.4	78.9	41.7	0	21.20
AqSpd024 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd025 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd026 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd027 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd028 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd029 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd030 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd031 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd032 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd033 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd034 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd035 cm/s	100	100	99.5	78.9	41.7	0	21.20
AqSpd036 cm/s	100	100	99.5	78.9	41.7	0	21.20
hm0 m	100	100	99.5	78.9	68.9	100	99.90
hm0a m	100	100	99.5	78.9	68.9	100	99.90
hm0b m	100	100	99.5	78.9	68.9	100	99.90
hmax m	100	94.3	99.4	78.9	68.8	100	99.90
mdir deg	100	100	99.5	78.9	68.9	100	99.90
mdira deg	100	100	99.5	78.9	68.9	100	99.90
mdirb deg	100	100	99.5	78.9	68.9	100	99.90
sprtp deg	100	100	99.5	78.9	68.9	100	99.90
thhf deg	100	100	99.5	78.9	68.9	100	99.90
thtp deg	100	100	99.5	78.9	68.9	100	99.90
thmax s	99.7	93.8	99	78.9	68.9	100	99.90
tm01 s	100	100	99.5	78.9	68.9	100	99.90
tm02 s	100	100	99.5	78.9	68.9	100	99.90
tm02a s	100	100	99.5	78.9	68.9	100	99.90
tm02b s	100	100	99.5	78.9	68.9	100	99.90
tp s	100	100	99.5	78.9	68.9	100	99.90
tz s	99.9	93.8	99	78.9	68.9	100	78.70
AirPressure hPa	100	100	99.5	78.9	68.9	100	99.90
AirTemperature C	97.8	96.2	96.7	77.9	67.2	97.6	98.70
AirHumidity %	97.8	96.2	96.7	77.9	67.2	97.6	98.30
WaterTemp001 degC	100	100	99.5	78.9	68.9	100	99.80
WaterPressure dbar	0	0	0	0	0	0	8.00
BottomTemperature degC	0	0	0	0	0	0	1.30

Appendix G: Validation

G.1 Pre-deployment validation

The SWLB is 3rd party type validated by the accredited institution DNVGL to be in the pre-commercial stage according to Carbon Trust's requirements [8] over a six-month trial [9]. That trial took place in 2014 at the now decommissioned RWE met mast in Dutch with overall post-processed data availability of > 97 %. The Best Practice criteria for the KPIs for "Mean Wind Speed – Slope and Coefficient of Determination", "Mean Wind Direction – Slope, Coefficient of Determination and Offset" were passed indicating the capability of capturing wind directions at high accuracy. A similar six-month trial was conducted at the East Anglia One met mast in 2015 as part of the Carbon Trust programme, with the performance independently verified by Natural Power [10]. All wind speed KPI's exceeded the best practise limits, as well as most wind direction KPI's (minimum practice for wind direction offset at the top two measurement heights).

In addition, the specific systems used in the TNW campaign were validated in a pre-deployment validation campaign according to [9] before the start of the TNW field measurement campaign. The performance of the systems was independently verified by DNV GL to reproduce accurate wind speed and direction across a range of wind and sea states against a land reference. The pre-deployment validation campaign took place at the Fugro validation site at the island of Frøya, Norway, [3] and [5]. The validation site has also been 3rd party evaluated by DNVGL [11] as suitable for the purpose of validating systems like the SWLB. Wind directions from both SWLB WS190 and SWLB WS191 were pre-deployment validated using DGPS (true north) as heading reference.

The 3rd SWLB WS170 (DGPS heading) was in situ validated at the Hollandse Kust (west) Wind Farm Zone (HKWWFZ) metocean campagin site HKWC from 16th June 2019 - 11th August 2019 against WS187 (compass heading) at HKWA and WS188 (DGPS heading) at HKWB. For all wind direction KPIs the Best Practice criterion was passed at all heights. For all wind speed comparisons the Best Practice criteria for the KPI "Mean Wind Speed – Slope" were passed at all heights. Comparing WS170 vs. WS188, the best practice acceptance criterion for the KPI "Mean Wind Speed – Coefficient of Determination" was passed at all heights and wind speed ranges [2].

G.2 Monthly validation

The dataset is validated on a monthly basis and a validation report [1] accompanies the monthly data report.

The validation is carried out by quantifying the agreement between the TNW data and data from other reliable sources (anemometer, LiDAR, numerical models, etc) at fixed North Sea reference stations (no temporary campaigns). For current and wind measurements their respective vertical profiles are also assessed. All comparisons are presented as timeseries and further validated via direct scatter plots for quantifying statistical correspondence between the datasets. The error statistics are computed differently whether a linear or circular (directional) variable is considered. When dealing with circular data, each observation is considered as unit vector, and it requires vector addition rather than ordinary (or scalar) addition to compute the average of angles, the so-called mean direction.

A detailed description of the validation method and data sources used can be found in [1].