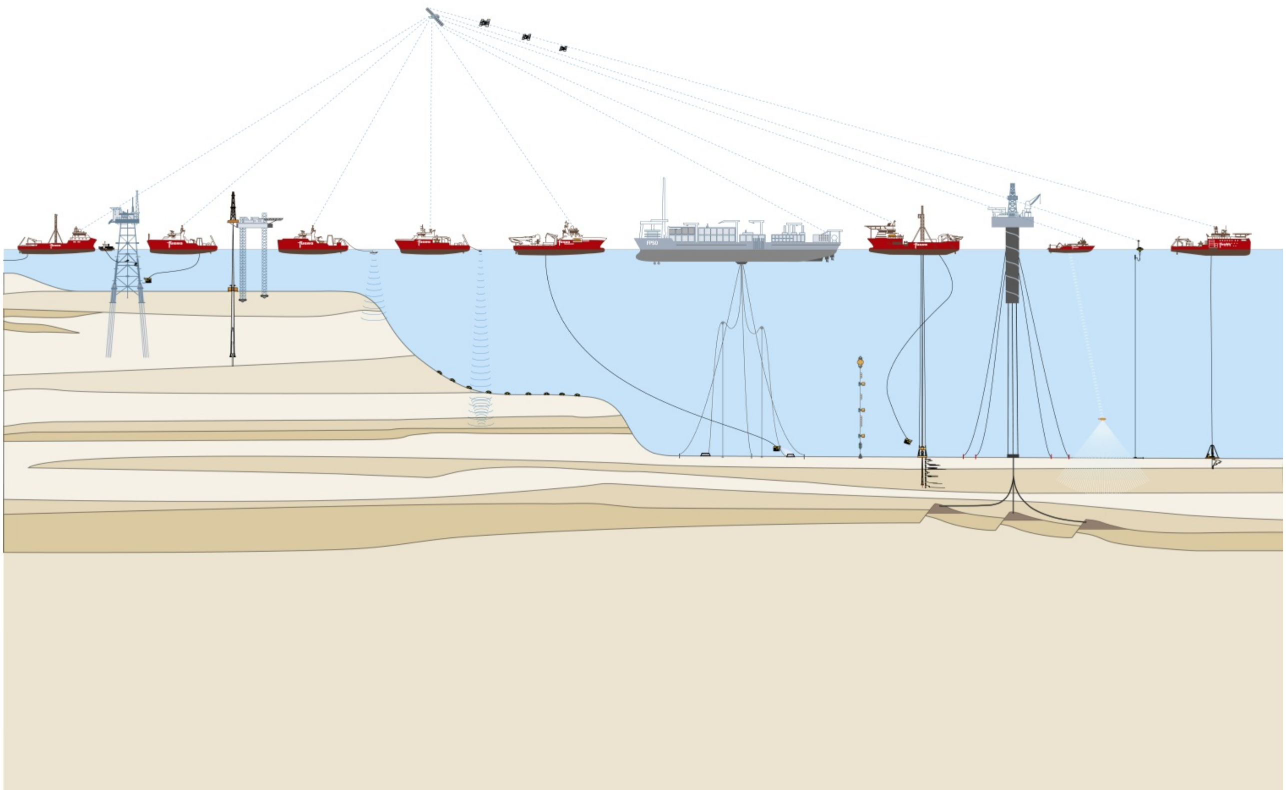
Supply of Meteorological and Oceanographic data at Ten Noorden van de Waddeneilanden

Monthly Data Report: October 2019

Fugro Document No: C75433_MDR04_F

29 January 2020

THE NETHERLANDS ENTERPRISE AGENCY (RVO.nl)



Supply of Meteorological and Oceanographic data at Ten Noorden van de Waddeneilanden: C75433_MDR04_F					
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1	07.01.2020	Arve Berg			Draft report for client review.
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Signed:	Arve Berg	Irene Pathirana	Arve Berg

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SUMMARY

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

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.

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 SWLBs and with nearby references. Deltares as an independent institute is subcontracted by Fugro to perform the data validation performing an independent analysis of the monthly performance of the measurement campaign. The Deltares validation report [1] is provided as an accompanying report.

This monthly report summarizes the activities and data recorded during October 2019 and presents time series plots and data availability statistics of the collected data based on satellite transmitted data.

The data availability of LiDAR buoy WS190 at TNWA is high, in the range 96-99 % for all parameters during October 2019, except for LiDAR wind speeds and direction (79 %) and water level (0 %). The water level sensor failed right after deployment in June. Spare was not available. A new sensor will be deployed at next service.

The data availability of LiDAR buoy WS191 at TNWB is high, in the range 96-99 % for all parameters during October 2019, except for LiDAR wind speeds and direction (0 %). Lidar data is expected to be stored internally in the Lidar and will be downloaded and reprosessed after service.

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

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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 compass - relative to magnetic north, or DGPS - relative to true north. Magnetic compass is used for wind directions from Gill, waves and currents, while DGPS is the main heading source for LiDAR wind directions. Compass is available (stored in the data logger) as backup/fallback for Lidar wind direction.

At TNW the deviation between magnetic and true north is approximately 1.7°.

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

1. INTRODUCTION

Fugro has been contracted by RVO.nl 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 starting point assumptions given to Fugro by RVO.nl detail the extent of the TNW Wind Farm Zone given in Figure 1.1 and in Figure 1.2. In addition, two recommended areas for positioning the systems in the south-eastern sector of the wind farm zone were provided.

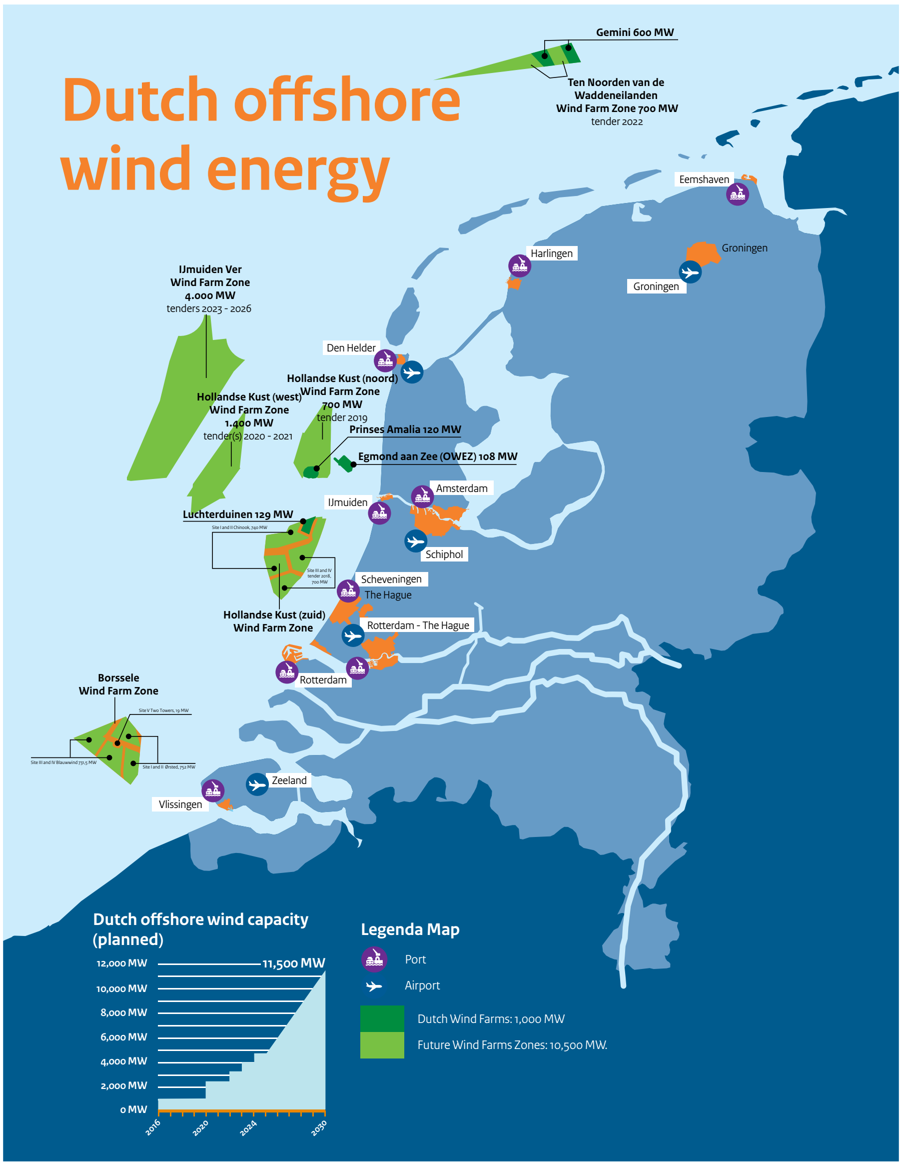


Figure 1.1: Map of the TNW Wind Farm Zone

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 SWLB is 3rd party type validated by the accredited institution DNVGL to be in the pre-commercial stage according to Carbon Trust's requirements [2] over a six-month trial [3]. That trial took place in 2014 at the now decommissioned RWE met mast in Dutch waters 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 [4]. 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 [3] before the start of the TNW field measurement campaign. The performance of the systems was independently verified by DNVGL 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. The validation site has also been 3rd party evaluated by DNVGL [5] 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 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 transmitted data is used as the primary dataset for the monthly report. If a maintenance visit is performed, a downloaded data set can be used in the monthly report. Table 1.2 indicates if downloaded or transmitted data are used in this report. At the end of the measurement campaign downloaded datasets for the full measurement periods are provided.

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 perform the field validation performing an independent analysis of the monthly performance of the measurement campaign. The Deltares validation report [1] is provided as an accompanying report.

The water depths relative to LAT for this region are based on data from a detailed bathymetric survey by Fugro commissioned by RVO.nl. As the buoys are free to float around the mooring point within a radius of about 110 m, the actual water depths at the actual positions of the buoy vary.

The present positions of the bottom mooring weights are listed in Table 1.1 and shown in Figure 1.2. The position of the water level sensor (WLS) is assumed equal to the position of the bottom weight of the associated buoy.

This report presents a summary of measurement results at TNWA and TNWB during October 2019 and presents time series plots of the measurements for the time intervals indicated in Table 1.2.

These data sets are named "TNW_20191219_Fugro_MetOcean Buoys_TNWA October 2019" and "TNW_20191219_Fugro_MetOcean Buoys_TNWB October 2019", and consist of the published data files listed in Table 1.3. The contents of the data files are described in Section 4.1. Signal lists for each file are given in Table 4.3 - Table 4.6.

The time reference used in this report is UTC.

Table 1.1: Positions (ETRS89/UTM zone 31N) of the LiDAR buoys at TNW during October 2019

Station	Buoy	Longitude (E)	Latitude (N)	Easting (m)	Northing (m)	Water depth (m MSL)	Date Deployed (UTC)	Date Recovered (UTC)
TNWA	WS190	5° 33.014'	54° 01.089'	667077	5988551	∼ 36	2019-06-19 04:45	
TNWB	WS191	5° 32.988'	54° 01.306'	667034	5988952	∼ 36	2019-06-19 06:00	

Table 1.2: Time periods of transmitted and downloaded data used in this monthly report from the two SWLB at TNW during 1 – 31 October 2019

Station	Buoy S.no.	Start time (UTC)	End time (UTC)	Transmitted or downloaded
TNWA	WS190	2019.10.01 00:00	2019.10.31 23:50	Transmitted
TNWB	WS191	2019.10.01 00:00	2019.10.31 23:50	Transmitted

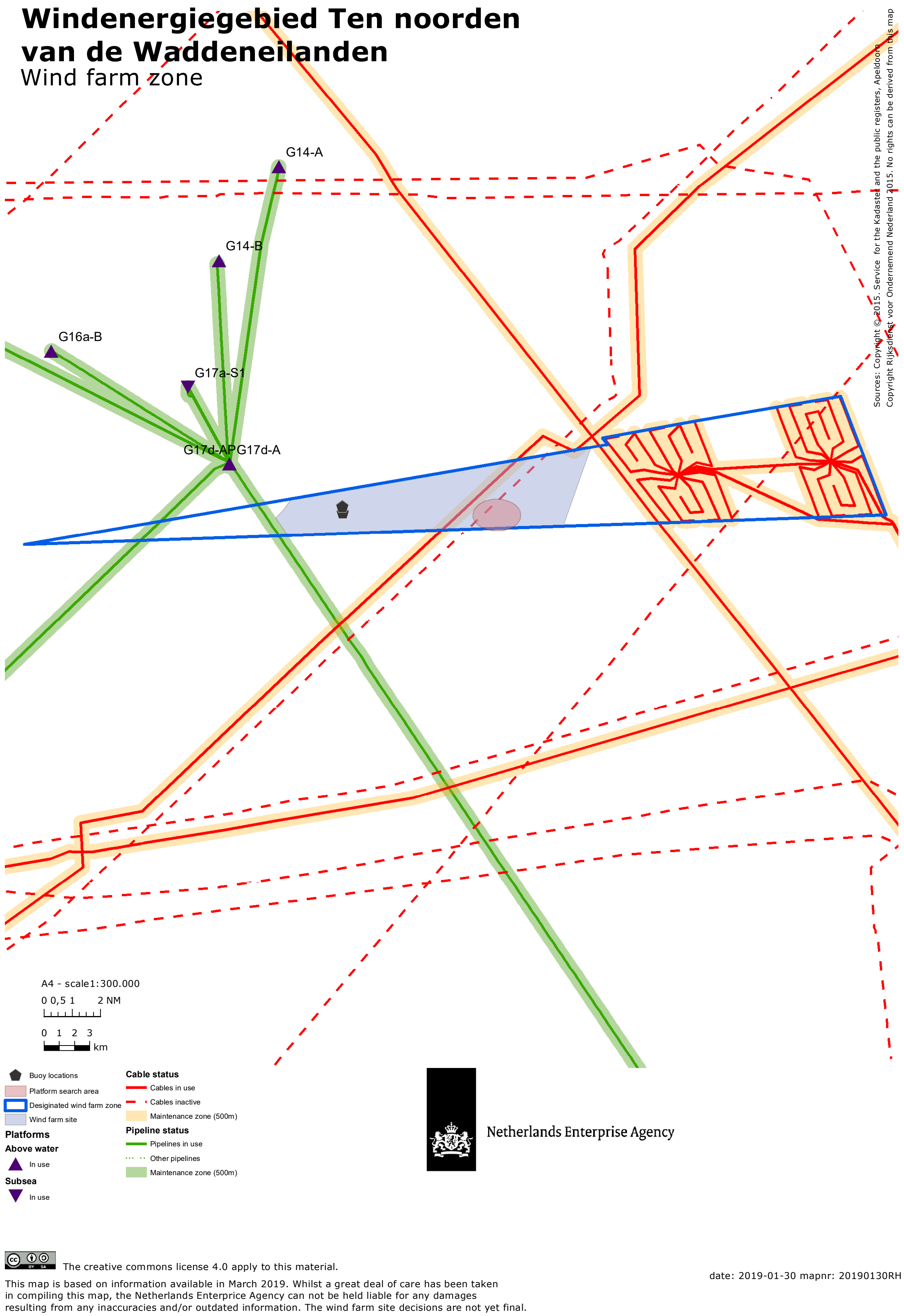


Figure 1.2: Map showing the buoy locations.

Table 1.3: Data files that make up the complete set of data presented in this report.

TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 MetCurrentDataStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 MetCurrentDataStatFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 WaveDataStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 WaveDataStatFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 WindResourceSpeedDirectionStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 WindResourceTIVeerShearInflow_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 WindResourceStatusFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 StatusData_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWA October 2019 PosData_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 MetCurrentDataStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 MetCurrentDataStatFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 WaveDataStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 WaveDataStatFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 WindResourceSpeedDirectionStat_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 WindResourceTIVeerShearInflow_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 WindResourceStatusFlags_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 StatusData_F.csv
TNW_20191219_Fugro_MetOcean Buoys TNWB October 2019 PosData_F.csv

2. SUMMARY OF ACTIVITIES

2.1 Summary of service and maintenance activities

The buoys were deployed successfully on 19th June (WS190 and WS191) 2019, except for the water level sensor at TNWA.

2.2 Health, Safety and Environment

There were no HSE related incidents during the deployments or any other activity related to this project during October 2019.

2.3 Event log

Any system issues that arise during the campaign, actions taken and consequences to the monthly dataset are briefly described in Table 2.1.

Table 2.1: Event Log.

Station	Buoy	Time Interval		Instrument	Parameter	Description
		From	Until			
TNWA	WS190	2019-06-19 04:45	ongoing	Water level sensor	Water level, bottom temperature	Water level sensor failed right after deployment. No spare was available.
TNWB	WS191	2019-09-12 06:00	ongoing	Lidar	wind speed, wind direction, turbulence	Communication between Lidar and buoy data logger stopped working
TNWB	WS191	2019-09-15	ongoing	Water level sensor	water pressure	Sensor seems to have moved to a deeper position

3. Instrumentation and measurement configuration

3.1 Summary of instrumentation and measurement scheme

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

- Wavesense 3 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 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 3.1 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 3.2, which include the moorings for the WLSs.

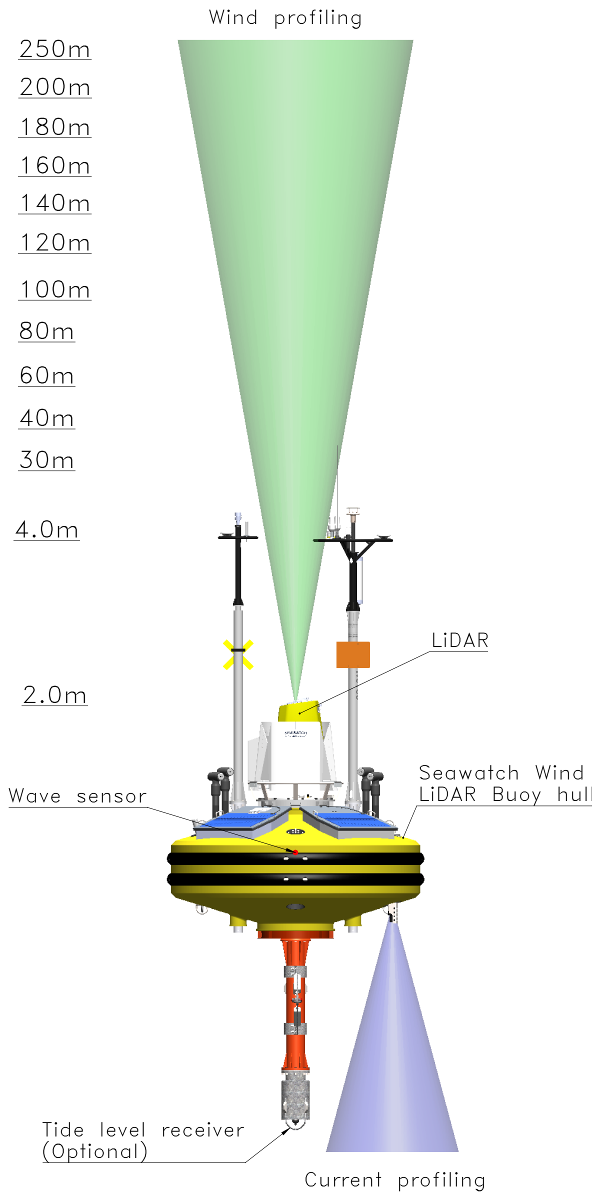


Figure 3.1: Illustration of the wind and current profile measurements from the LiDAR buoy. Heights ref. sea surface

The measurement setup is detailed in Table 3.1.
Details of sensor types and serial numbers can be found in Appendix A, Table 1 and Table 2.

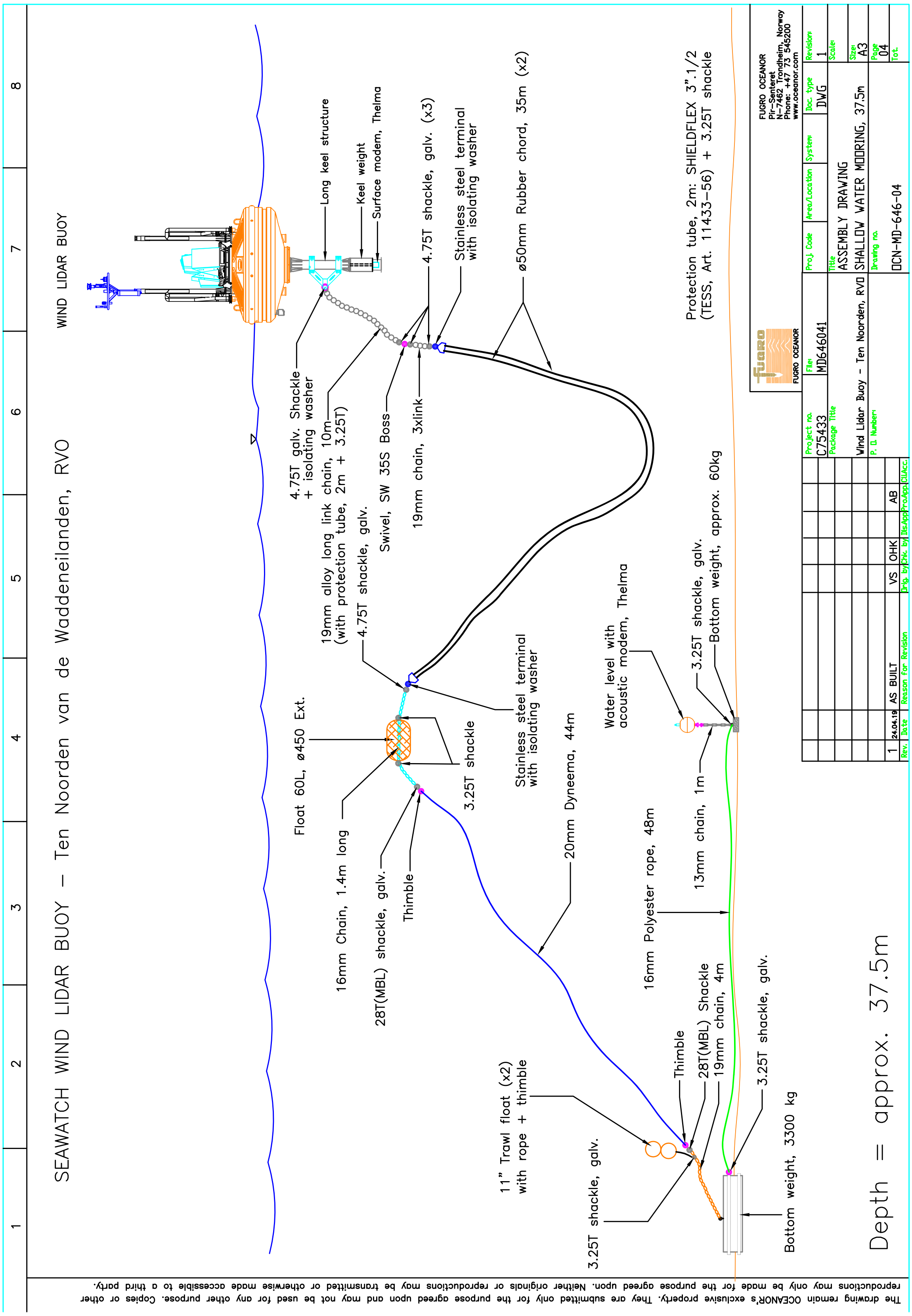


Figure 3.2: Mooring design for the SWLB at TNW (same for both stations)

Table 3.1: 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)	Measure-ment reso-lution	Trans-mitted?
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 4.3)	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.

3.2 Measurement principles

3.2.1 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. Heading information is 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 approximately 1.7°.

3.2.2 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 Wavesense 3 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 4.4 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 Fourier analysis. The measurements are taken continuously and the processing windows overlap.

Maximum wave height, hmax, is calculated by "zero upcrossing" and require 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.

3.2.3 Wind

There are two types of wind sensors on the LiDAR buoy: *Gill Windsonic* and *ZephIR ZX300 LiDAR*. The drawing in Figure 3.1 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. In the SWLB Wavesense 3 processing unit, each 1 s sample is processed by an algorithm which fuses data from other sensors to produce the 10-minute averages. 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 the 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 Lidar is equipped with a met. station that include 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 is thus not impacting the LiDAR wind measurements.

At TNW, wind directions from both SWLB were pre-deployment validated using DGPS as heading source.

3.2.4 Current measurements

The *AquaDopp current profiler* is mounted in the buoy hull with the acoustic head immediately below the hull. 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.

There are signal-noice info stored internally in the current profiler. These are a part of the raw data which will be available after downloading raw data at services. For the monthly reports transmitted data without such signal-noice information is used.

3.2.5 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.

3.2.6 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.

3.2.7 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. 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.

When a long data serie is collected, it will be possible to correlate the measurement with other water level observations and models to establish reference to MSL or LAT. This will be a part of the final campaign report.

3.2.8 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 is not available, 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.

3.2.9 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.

4. Post-processing and availability of data from the LiDAR buoy

This chapter outlines the processing steps applied to the data before they are delivered to RVO.nl. No tampering or modifications have been 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.

The buoy converts all measurements to physical quantities in SI units. 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. The data are packed for simultaneous transmission and storage in binary integer numbers using a proprietary compression algorithm, giving sufficient digital resolution while using minimal storage space. The digitization resolution is given in Table 4.3 - Table 4.6. The digitization resolution is higher than the actual measurement resolution ensuring lossless compression. At the receiving end the data are unpacked to physical values in real numbers using the reverse conversion method. The dataset presented in this report is therefore binned according to the digitization resolution. The application of the compression algorithm also means that the data in transmission are encrypted.

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 4.1)
5. Spike removal (typically a magnitude of standard deviation)
6. Additional 180-degree ambiguity check on LiDAR wind data
7. Derivation of wind veer and wind shear from the underlying measured physical quantities in post-processing
8. Inspection and assessment by senior meteorologist/oceanographer

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 automatically 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.

All filenames have prefixes 'TNW_YYYYMMDD_Fugro_MetOcean Buoys TNWX Month YYYY', where YYYYMMDD is used as a reference for the date of creation of the file.

Table 4.1: 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	°
Inflow Angle	-15	15	°
Current speed	0	135	cm/s
Hm0	0	18	m
Hmax	0	18	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 (TNWA)	35	41	dbar
Water pressure (TNWB)	35	41	dbar

Table 4.2: 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 4.1) found and removed	item 4
OutlierFound	Spike/outlier found and removed	item 5
Flipped180Degrees	180 ° ambiguity found and wind direction flipped 180°	item 6

4.1 Post processing done in each delivered data file

File: *MetCurrentDataStat*

Signals: See Table 4.3.

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

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

Met parameters Air and Water Temperatures, Air Pressure, Humidity, Water Pressure, from all available sensors.

All data with values outside the accepted range (Table 4.1) are replaced by NaNs. Water Pressure is given in dbar (pressure above seafloor).

File: *MetCurrentDataStatFlags*

This file contains the filter flags (see Table 4.2) for the data in Table 4.3 indicating where duplicates or out-of-bounds values were encountered and removed.

File: *WaveDataStat*

Signals: See Table 4.3. Wave parameters are explained in more detail in Table 4.4

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

The following signals derived from the wave spectra are checked for consecutive duplicates and out-of-bounds as described above:

['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']

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 4.2) for the data in Table 4.3 indicating where duplicates or out-of-bounds values were encountered and removed.

File: *WindResourceSpeedDirectionStat*

Signals: See Table 4.5

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 (Table 4.1), 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: *WindResourceTIVeerShearInflow*

Signals: See Table 4.6

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

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

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 (Table 4.1).

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

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.

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

No further processing is done on the signals here.

File: *WindResourceStatusFlags*

This file contains LiDAR package count, rain count and the processing (filter) flags (see Table 4.2) indicating where duplicate or out-of-bounds values were removed.

File: *LiDARInfoStatusFlags*

This file contains the LiDAR info and status flags.

File: *StatusData*

Signals: Household parameters.

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

File: *PosData*

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

This file contains hourly values of buoy position according to the GPS sources.

Table 4.3: *WaveCurrentDataStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1)]	Digitization Resolution	Configured range
AirHumidity	%	4	Air humidity	Vaisala HMP155	B	0.107422	0, 110
AirPressure	hPa	0	Air pressure	Vaisala PTB330	B	0.0976563	900, 1100
AirTemperature	°C	4	Air temperature	Vaisala HMP155	B	0.0537109	-15, 40
AirPressure _lidar	hPa	2	Air pressure from LiDAR met station	ZephIR	B	0.0976563	900,1100
AirTemp _lidar	°C	2	Air temperature from LiDAR met station	ZephIR	B	0.0537109	-15,40
AqDir00xx[2)]	deg	-3 ... -36	Current direction	Aquadopp	B	0.176758	0, 360
AqSpd00xx[2)]	cm/s	-3 ... -36	Current speed	Aquadopp	B	0.293945	0, 300
WaterTemp0001	°C	-1	Surface water temperature	Aquadopp	B	0.0078125	-2, 30
Bottom Temperature	°C	1 m a.s.f.	Water temperature	Thelma	B	0.000946045	-5, 26
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	0.0196289	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

Table 4.3: *WaveCurrentDataStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1)]	Digitization Resolution	Configured range
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
WaterPressure	dbar	Mooring depth	Pressure of water column from mooring point.	Thelma	B	0.0012207	0, 160
thTBR id			sensor ID	Thelma	B		
thTBR temperature	°C	-2.5	Water temperature of Thelma top modem	Thelma	B	0.00610352	-15,45
thTilt	°	1 m a.s.f.	Tilt of bottom sensor	Thelma	B	0.703125	0,180
thSNR	dB	1 m a.s.f.	Signal-to-noise ratio of bottom sensor	Thelma	B	0.703125	0,90

[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 Section 4.1.
[2)] xx = 04, ..., 30 corresponding to measurement height, see Table 3.1
[3)] Swell and wind sea frequency ranges:
Band "a" (Swell): 0.04 - 0.10 Hz
Band "b" (Wind sea): 0.10 - 0.50 Hz

Table 4.4: 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
m0, m1, m2, m4, m-1, m-2		Moments of the spectrum about the origin: $\int f^k S(f)df$ where $S(f)$ is the spectral density and the wave frequency, f, is in the range 0.04 - 0.50 Hz
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
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")

Table 4.4: Definitions of wave parameters presented in this report

Symbol	Unit	Description
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 4.5: *WindResourceSpeedDirectionTIStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1]	Digitization Resolution	Configured range
WindDir004m	deg	4	Ultrasonic anemometer wind direction	Gill anemometer	B	0.353516	0, 360
WindSpeed004m	m/s	4	Ultrasonic anemometer wind speed	Gill anemometer	B	0.0595703	0, 60
WindGust004m	m/s	4	Ultrasonic anemometer wind gust speed	Gill anemometer	B	0.0595703	0, 60
WindDirxx[2]	deg	30 ... 200 250	LiDAR wind direction 10 min average using LiDAR data	ZephIR LiDAR	D	0.0883789	0, 360
WindSpeedxx[2]	m/s	30 ... 200 250	Horizontal LiDAR wind speed 10 min average using LiDAR data	ZephIR LiDAR	D	0.0595703	0, 60
VerticalWindSpeedxx[2]	m/s	30 ... 200 250	Vertical LiDAR wind speed 10 min average using LiDAR data	ZephIR LiDAR	D	0.0292969	-15, 15

[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 Section 4.1.

[2] **xx** = 30, ..., 200, 250 corresponding to measurement height, see Table 3.1

Table 4.6: *WindResourceInflowAnglesStat* signals

Signal name	Unit	Height (m)	Description	Sensor	Proc. Code[1]	Digitization Resolution	Configured range
Standard Deviation xx[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 xx[2]	None	30 ... 200 250	Turbulence Intensity;[3] using LiDAR data	ZephIR LiDAR	B	0.0012207	0, 20
Inflow angle xx[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	0.0595703	-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	0.0595703	-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 Section 4.1.

[2] xx = 30, ..., 200, 250 index corresponding to measurement height, see Table 3.1

[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)

4.2 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).

For calculation of Data Availability, 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 system's own parameters, defined in Section 4.1.

The *Monthly Post-processed Data Availability* is calculated by the remaining data entries divided 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 Buoy A and Buoy B. However, the two buoys are deployed for redundancy reasons, so it is possible to increase data availability for a certain parameter by combining the data of the 2 buoys.

5. Results

5.1 Signal and System Availabilities

In the following section, data availability for the current month is presented and discussed. Comparisons are also made for the campaign up to to current month.

Note on gaps in the SWLB dataset:

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.
- 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, summarized in the gaps tables at the end of the following sections discussing data availability per buoy/station (Section 5.1.1, Section 5.1.2), or individually addressed in the data presentation sections (Section 5.2.1, Section 5.3.1).

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 is due to transmission gaps from the bottom sensor to the buoy and post-processing as detailed in Section 4.1.

5.1.1 Buoy Station TNWA

Buoy WS190 at TNWA delivered data for all parameters with a data availability in the range 96-99 % during October 2019, except for LiDAR wind speeds and direction (79 %) and water level (0 %). The water level sensor failed right after deployment. Spare was not available. A new sensor will be deployed at next service.

The heading reference for wind direction for WS190 is Differential GPS (DGPS) (true north).

The monthly post-processed data availability per main system is presented in Table 5.1. In addition the monthly post-processed signal availability as defined in Section 4.2 is presented in Table 5.2. The data presented for this location are from satellite transmitted data.

Gaps in the monthly datasets are marked with flags in the data files containing "Flags" in the file name, see Table 1.3. In the present month there are quite many gaps in the Lidar data and it is not practical to define all such periods in this report.

Table 5.1: Post-processed data availability in % per main data sets for the campaign up to and including the current month at TNWA.

Month	Wind	Waves	Currents	Air Pressure	Temperature	Water Level
June-July 2019 (19.06-31.07)	73.6	100	96.4	100	96.3	0
August 2019	81.8	99.9	96.4	100	96.8	0
September 2019	70.0	99.8	96.4	99.9	97.6	0
October 2019	81.1	99.9	96.3	99.9	97.6	0

Maximum wave height, hmax, is calculated by "zero upcrossing" and require 50 "high" waves in 17 min to be calculated. This means that hmax will not be calculated when significant wave height, hm0, is less than approximately 0.3 m. This is the reason why the availability for maximum wave height and period of maximum wave height is lower than the availability for other wave parameters in this period.

Table 5.2: Signal Availability in % per parameter for the campaign up to and including the current month at TNWA.

Parameter	June-July 2019	August 2019	September 2019	October 2019
WindDir004m deg	99.6	99.6	99.7	99.7
WindDir030m deg	73.8	80	67	79.2
WindDir040m deg	73.9	80	67	79.2
WindDir060m deg	73.8	80	67	79.2
WindDir080m deg	73.6	80	67	79.2
WindDir100m deg	73.6	80	67	79.2
WindDir120m deg	73.5	80	67	79.2
WindDir140m deg	73.5	80	67	79.2
WindDir160m deg	73.5	80	67	79.2
WindDir180m deg	73.4	80	67	79.2
WindDir200m deg	73.4	79.9	67	79.2
WindDir250m deg	73.1	79.9	67	79.2
WindGust004m m/s	99.6	99.6	99.7	99.7
WindSpeed004m m/s	99.6	99.6	99.7	99.7
WindSpeed030m m/s	73.8	80	67	79.2
WindSpeed040m m/s	73.9	80	67	79.2
WindSpeed060m m/s	73.8	80	67	79.2
WindSpeed080m m/s	73.6	80	67	79.2
WindSpeed100m m/s	73.6	80	67	79.2
WindSpeed120m m/s	73.5	80	67	79.2
WindSpeed140m m/s	73.5	80	67	79.2
WindSpeed160m m/s	73.5	80	67	79.2
WindSpeed180m m/s	73.4	80	67	79.2
WindSpeed200m m/s	73.4	79.9	67	79.2
WindSpeed250m m/s	73.1	79.9	67	79.2
AqDir003 deg	96.4	96.4	96.4	96.3
AqDir004 deg	96.4	96.4	96.4	96.3
AqDir005 deg	96.4	96.4	96.4	96.3
AqDir006 deg	96.4	96.4	96.4	96.3
AqDir007 deg	96.4	96.4	96.4	96.3
AqDir008 deg	96.4	96.4	96.4	96.3
AqDir009 deg	96.4	96.4	96.4	96.3
AqDir010 deg	96.4	96.4	96.4	96.3
AqDir011 deg	96.4	96.4	96.4	96.3
AqDir012 deg	96.4	96.4	96.4	96.3
AqDir013 deg	96.4	96.4	96.4	96.3
AqDir014 deg	96.4	96.4	96.4	96.3
AqDir015 deg	96.4	96.4	96.4	96.3
AqDir016 deg	96.4	96.4	96.4	96.3
AqDir017 deg	96.4	96.4	96.4	96.3
AqDir018 deg	96.4	96.4	96.4	96.3

Table 5.2: Signal Availability in % per parameter for the campaign up to and including the current month at TNWA.

Parameter	June-July 2019	August 2019	September 2019	October 2019
AqDir019 deg	96.4	96.4	96.4	96.3
AqDir020 deg	96.4	96.4	96.4	96.3
AqDir021 deg	96.4	96.4	96.4	96.3
AqDir022 deg	96.4	96.4	96.4	96.3
AqDir023 deg	96.4	96.4	96.4	96.3
AqDir024 deg	96.4	96.4	96.4	96.3
AqDir025 deg	96.4	96.4	96.4	96.3
AqDir026 deg	96.4	96.4	96.4	96.3
AqDir027 deg	96.4	96.4	96.4	96.3
AqDir028 deg	96.4	96.4	96.4	96.3
AqDir029 deg	96.4	96.4	96.4	96.3
AqDir030 deg	96.4	96.4	96.4	96.3
AqDir031 deg	96.4	96.4	96.4	96.3
AqDir032 deg	96.4	96.4	96.4	96.3
AqDir033 deg	96.4	96.4	96.4	96.3
AqDir034 deg	96.4	96.4	96.4	96.3
AqDir035 deg	96.4	96.4	96.4	96.3
AqDir036 deg	96.4	96.4	96.4	96.3
AqDir037 deg	96.4	96.4	96.4	96.3
AqSpd003 cm/s	96.4	96.4	96.4	96.3
AqSpd004 cm/s	96.4	96.4	96.4	96.3
AqSpd005 cm/s	96.4	96.4	96.4	96.3
AqSpd006 cm/s	96.4	96.4	96.4	96.3
AqSpd007 cm/s	96.4	96.4	96.4	96.3
AqSpd008 cm/s	96.4	96.4	96.4	96.3
AqSpd009 cm/s	96.4	96.4	96.4	96.3
AqSpd010 cm/s	96.4	96.4	96.4	96.3
AqSpd011 cm/s	96.4	96.4	96.4	96.3
AqSpd012 cm/s	96.4	96.4	96.4	96.3
AqSpd013 cm/s	96.4	96.4	96.4	96.3
AqSpd014 cm/s	96.4	96.4	96.4	96.3
AqSpd015 cm/s	96.4	96.4	96.4	96.3
AqSpd016 cm/s	96.4	96.4	96.4	96.3
AqSpd017 cm/s	96.4	96.4	96.4	96.3
AqSpd018 cm/s	96.4	96.4	96.4	96.3
AqSpd019 cm/s	96.4	96.4	96.4	96.3
AqSpd020 cm/s	96.4	96.4	96.4	96.3
AqSpd021 cm/s	96.4	96.4	96.4	96.3
AqSpd022 cm/s	96.4	96.4	96.4	96.3
AqSpd023 cm/s	96.4	96.4	96.4	96.3
AqSpd024 cm/s	96.4	96.4	96.4	96.3

Table 5.2: Signal Availability in % per parameter for the campaign up to and including the current month at TNWA.

Parameter	June-July 2019	August 2019	September 2019	October 2019
AqSpd025 cm/s	96.4	96.4	96.4	96.3
AqSpd026 cm/s	96.4	96.4	96.4	96.3
AqSpd027 cm/s	96.4	96.4	96.4	96.3
AqSpd028 cm/s	96.4	96.4	96.4	96.3
AqSpd029 cm/s	96.4	96.4	96.4	96.3
AqSpd030 cm/s	96.4	96.4	96.4	96.3
AqSpd031 cm/s	96.4	96.4	96.4	96.3
AqSpd032 cm/s	96.4	96.4	96.4	96.3
AqSpd033 cm/s	96.4	96.4	96.4	96.3
AqSpd034 cm/s	96.4	96.4	96.4	96.3
AqSpd035 cm/s	96.4	96.4	96.4	96.3
AqSpd036 cm/s	96.4	96.4	96.4	96.3
AqSpd037 cm/s	96.4	96.4	96.4	96.3
hm0 m	100	99.9	99.8	99.9
hm0a m	100	99.9	99.8	99.9
hm0b m	100	99.9	99.8	99.9
hmax m	95.9	93.4	99.8	99.9
mdir deg	100	99.9	99.8	99.9
mdira deg	100	99.9	99.8	99.9
mdirb deg	100	99.9	99.8	99.9
sprtp deg	100	99.9	99.8	99.9
thhf deg	100	99.9	99.8	99.9
thmax s	95.9	93.4	99.8	99.9
thtp deg	100	99.9	99.8	99.9
tm01 s	100	99.9	99.8	99.9
tm02 s	100	99.9	99.8	99.9
tm02a s	100	99.9	99.8	99.9
tm02b s	100	99.9	99.8	99.9
tp s	100	99.9	99.8	99.9
AirPressure hPa	100	100	99.9	99.9
AirTemperature C	96.2	97.4	98.7	98.8
AirHumidity %	96.2	97.4	98.8	98.8
WaterTemp001 degC	96.4	96.3	96.4	96.3

5.1.2 Buoy Station TNWB

Buoy WS191 at TNWB delivered data for all parameters with a data availability in the range 96-99 % during October 2019, except for wind (0 %). The buoy data logger lost communication with the the Lidar on the 12th of September and it was not possible to restore it remotely.

The heading source for the wind direction data on WS191 is DGPS (relative to true north).

The monthly post-processed data availability per main system is presented in Table 5.3. In addition the monthly post-processed signal availability as defined in Section 4.2 is presented in Table 5.4. The data presented for this location are from satellite transmitted data.

Gaps in the monthly datasets are marked with flags in the data files containing "Flags" in the file name, see Table 1.3. On the 12th of September the buoy data logger lost communication with the Lidar. Several attempts were made to restore its functionality by sending reboot commands through satellite but without success. There are thus no transmitted Lidar data after 12th of September. From the system data we can however see that the power consumtion indicate that the Lidar is running and it has thus most likely collecting data that can be downloaded at next service.

Table 5.3: Post-processed data availability in % per main data sets for the campaign up to and including the current month at TNWB.

Month	Wind	Waves	Currents	Air Pressure	Temperature	Water Level
June-July 2019 (19.06-31.07)	77.3	99.9	100	99.9	98.2	95.9
August 2019	81.1	99.9	99.9	100	98.6	96.1
September 2019	42.4	99.8	99.9	100	99.4	96.0
October 2019	0.0	99.9	99.9	99.9	99.3	96.0

Maximum wave height, hmax, is calculated by "zero upcrossing" and require 50 "high" waves in 17 min to be calculated. This means that hmax will not be calculated when significant wave height, hm0, is less than approximately 0.3 m. This is the reason why the availability for maximum wave and period of maximum wave height is lower than the availability for other wave parameters in this period.

Table 5.4: Signal Availability in % per parameter for the campaign up to and including the current month at TNWB.

Parameter	June-July 2019	August 2019	September 2019	October 2019
WindDir004m deg	99.7	99.6	99.7	99.6
WindDir030m deg	77.5	79.3	36.7	0
WindDir040m deg	77.7	79.3	36.7	0
WindDir060m deg	77.7	79.3	36.7	0
WindDir080m deg	77.3	79.3	36.7	0
WindDir100m deg	77.2	79.3	36.6	0
WindDir120m deg	77.2	79.3	36.7	0
WindDir140m deg	77.1	79.3	36.7	0
WindDir160m deg	77.1	79.3	36.7	0
WindDir180m deg	77.1	79.3	36.7	0
WindDir200m deg	77.1	79.3	36.7	0
WindDir250m deg	76.7	79.1	36.7	0
WindGust004m m/s	99.7	99.6	99.7	99.6
WindSpeed004m m/s	99.7	99.6	99.7	99.6
WindSpeed030m m/s	77.5	79.3	36.7	0
WindSpeed040m m/s	77.7	79.3	36.7	0
WindSpeed060m m/s	77.7	79.3	36.7	0
WindSpeed080m m/s	77.3	79.3	36.7	0
WindSpeed100m m/s	77.2	79.3	36.6	0
WindSpeed120m m/s	77.2	79.3	36.7	0
WindSpeed140m m/s	77.1	79.3	36.7	0
WindSpeed160m m/s	77.1	79.3	36.7	0
WindSpeed180m m/s	77.1	79.3	36.7	0
WindSpeed200m m/s	77.1	79.3	36.7	0
WindSpeed250m m/s	76.7	79.1	36.7	0
AqDir003 deg	100	99.9	99.9	99.9
AqDir004 deg	100	99.9	99.9	99.9
AqDir005 deg	100	99.9	99.9	99.9
AqDir006 deg	99.9	99.9	99.8	99.9
AqDir007 deg	100	99.9	99.9	99.9
AqDir008 deg	100	99.8	99.9	99.9
AqDir009 deg	99.9	99.9	99.9	99.9
AqDir010 deg	100	99.9	99.9	99.9
AqDir011 deg	100	99.9	99.9	99.9
AqDir012 deg	100	99.9	99.9	99.9
AqDir013 deg	100	99.9	99.9	99.9
AqDir014 deg	100	99.9	99.9	99.9
AqDir015 deg	100	99.8	99.9	99.9
AqDir016 deg	100	99.9	99.9	99.9
AqDir017 deg	100	99.9	99.9	99.9
AqDir018 deg	100	99.9	99.9	99.9

Table 5.4: Signal Availability in % per parameter for the campaign up to and including the current month at TNWB.

Parameter	June-July 2019	August 2019	September 2019	October 2019
AqDir019 deg	100	99.8	99.9	99.9
AqDir020 deg	100	99.9	99.9	99.9
AqDir021 deg	100	99.9	99.9	99.9
AqDir022 deg	100	99.8	99.9	99.9
AqDir023 deg	100	99.9	99.9	99.9
AqDir024 deg	100	99.9	99.9	99.9
AqDir025 deg	100	99.9	99.9	99.9
AqDir026 deg	100	99.9	99.9	99.9
AqDir027 deg	100	99.9	99.9	99.9
AqDir028 deg	100	99.9	99.9	99.9
AqDir029 deg	100	99.9	99.9	99.9
AqDir030 deg	100	99.9	99.9	99.9
AqDir031 deg	100	99.9	99.9	99.9
AqDir032 deg	100	99.9	99.9	99.9
AqDir033 deg	100	99.9	99.9	99.9
AqDir034 deg	100	99.9	99.9	99.9
AqDir035 deg	100	99.9	99.9	99.9
AqDir036 deg	100	99.8	99.9	99.9
AqDir037 deg	99.9	99.8	99.9	99.9
AqSpd003 cm/s	100	99.9	99.9	99.9
AqSpd004 cm/s	100	99.9	99.9	99.9
AqSpd005 cm/s	100	99.9	99.9	99.9
AqSpd006 cm/s	99.9	99.9	99.8	99.9
AqSpd007 cm/s	100	99.9	99.9	99.9
AqSpd008 cm/s	100	99.8	99.9	99.9
AqSpd009 cm/s	99.9	99.9	99.9	99.9
AqSpd010 cm/s	100	99.9	99.9	99.9
AqSpd011 cm/s	100	99.9	99.9	99.9
AqSpd012 cm/s	100	99.9	99.9	99.9
AqSpd013 cm/s	100	99.9	99.9	99.9
AqSpd014 cm/s	100	99.9	99.9	99.9
AqSpd015 cm/s	100	99.8	99.9	99.9
AqSpd016 cm/s	100	99.9	99.9	99.9
AqSpd017 cm/s	100	99.9	99.9	99.9
AqSpd018 cm/s	100	99.9	99.9	99.9
AqSpd019 cm/s	100	99.8	99.9	99.9
AqSpd020 cm/s	100	99.9	99.9	99.9
AqSpd021 cm/s	100	99.9	99.9	99.9
AqSpd022 cm/s	100	99.8	99.9	99.9
AqSpd023 cm/s	100	99.9	99.9	99.9
AqSpd024 cm/s	100	99.9	99.9	99.9

Table 5.4: Signal Availability in % per parameter for the campaign up to and including the current month at TNWB.

Parameter	June-July 2019	August 2019	September 2019	October 2019
AqSpd025 cm/s	100	99.9	99.9	99.9
AqSpd026 cm/s	100	99.9	99.9	99.9
AqSpd027 cm/s	100	99.9	99.9	99.9
AqSpd028 cm/s	100	99.9	99.9	99.9
AqSpd029 cm/s	100	99.9	99.9	99.9
AqSpd030 cm/s	100	99.9	99.9	99.9
AqSpd031 cm/s	100	99.9	99.9	99.9
AqSpd032 cm/s	100	99.9	99.9	99.9
AqSpd033 cm/s	100	99.9	99.9	99.9
AqSpd034 cm/s	100	99.9	99.9	99.9
AqSpd035 cm/s	100	99.9	99.9	99.9
AqSpd036 cm/s	100	99.8	99.9	99.9
AqSpd037 cm/s	99.9	99.8	99.9	99.9
hm0 m	99.9	99.9	99.8	99.9
hm0a m	99.9	99.9	99.8	99.9
hm0b m	99.9	99.9	99.8	99.9
hmax m	96.2	93.9	99.8	99.9
mdir deg	99.9	99.9	99.8	99.9
mdira deg	99.9	99.9	99.8	99.9
mdirb deg	99.9	99.9	99.8	99.9
sprtp deg	99.9	99.9	99.8	99.9
thhf deg	99.9	99.9	99.8	99.9
thmax s	96.2	93.9	99.8	99.9
thtp deg	99.9	99.9	99.8	99.9
tm01 s	99.9	99.9	99.8	99.9
tm02 s	99.9	99.9	99.8	99.9
tm02a s	99.9	99.9	99.8	99.9
tm02b s	99.9	99.9	99.8	99.9
tp s	99.9	99.9	99.8	99.9
AirPressure hPa	99.9	100	100	99.9
AirTemperature C	96.4	97.4	98.8	98.7
AirHumidity %	96.4	97.4	98.8	98.7
WaterTemp001 degC	99.9	99.8	99.9	99.8
WaterPressure dbar	95.9	96.1	96	96
BottomTemperature degC	94.7	95.1	94.9	94.9

5.2 Presentation of the received data

5.2.1 Buoy Station TNWA

The following presentations show data from buoy WS190 at TNWA for October 2019. The data in this report is based on satellite transmitted data.

5.2.1.1 Meteorological data

Plots of air pressure, air temperature and sea surface temperature data are presented in Figure 5.1 - Figure 5.4. The sensors performed well in this period.

The air temperature varied from 8.4 to 16.8 °C with an average value of 13.2 °C. The sea surface temperature was in the range 14.0 – 16.8 °C with an average of 15.3 °C. The air pressure varied from 996 to 1031 hPa.

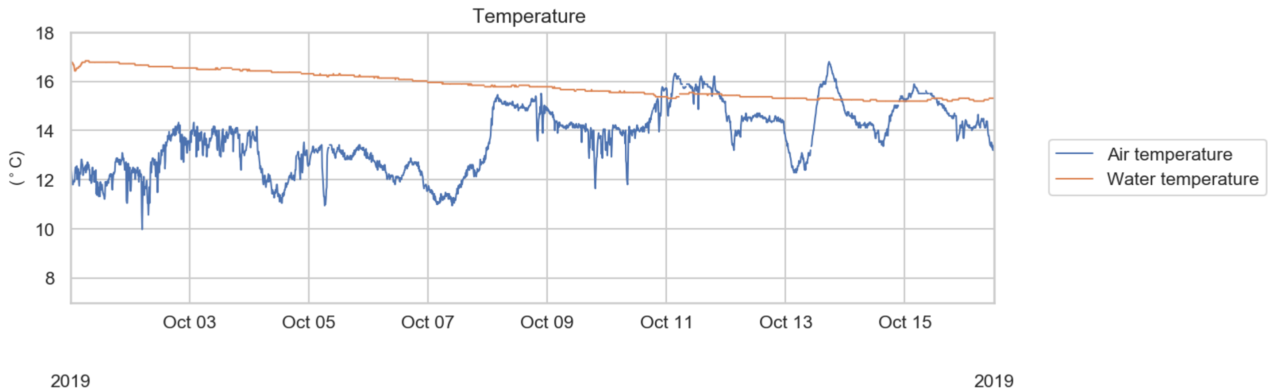


Figure 5.1: Air and sea surface temperature at TNWA, 1 – 15 October 2019

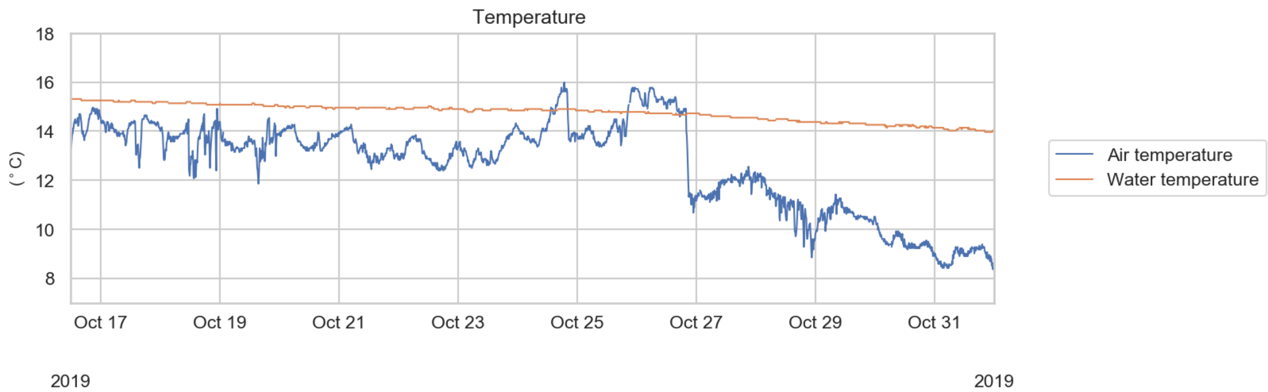


Figure 5.2: Air and sea surface temperature at TNWA, 16 – 31 October 2019

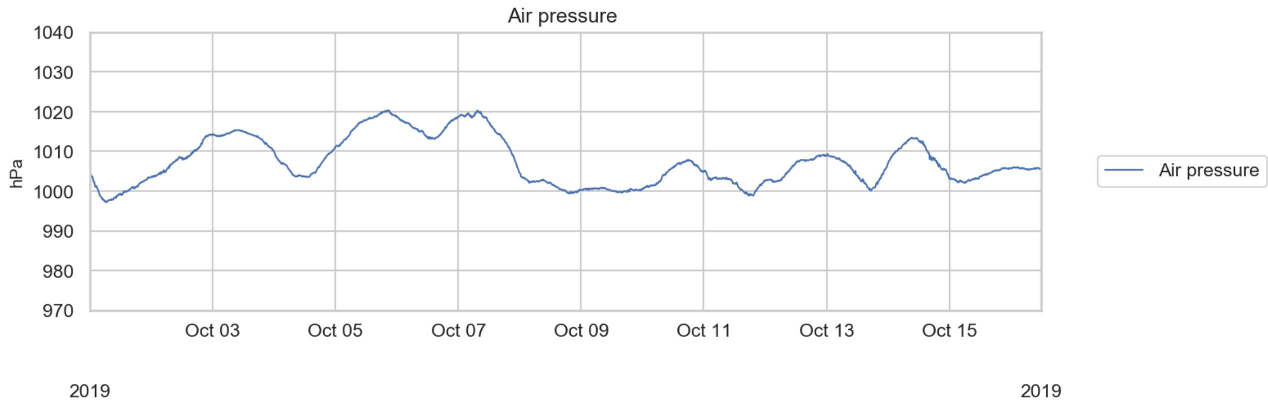


Figure 5.3: Air pressure at TNWA, 1 – 15 October 2019

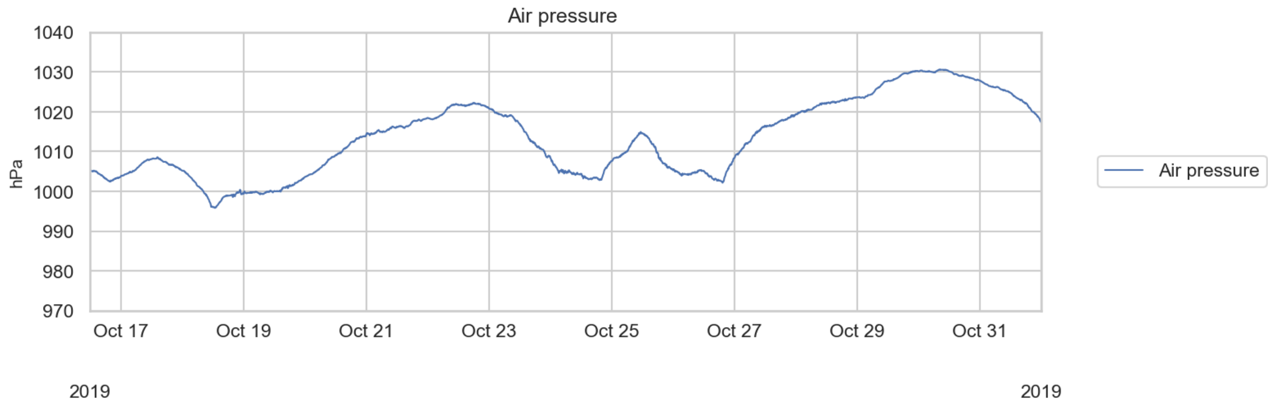


Figure 5.4: Air pressure at TNWA, 16 – 31 October 2019

5.2.1.2 Wave data

Plots of wave height, period and direction are presented in Figure 5.5 and Figure 5.6. The sensor has performed well with a high data availability.

The highest significant wave height (hm0) measured in this period was 4.4 m from a south-westerly direction (∼ 230°) on 26 October at 04:00. The highest single wave of the record with hmax = 8.9 m during this period was observed on 26 October at 06:20.

In October the availability for Hmax was high. 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.

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.

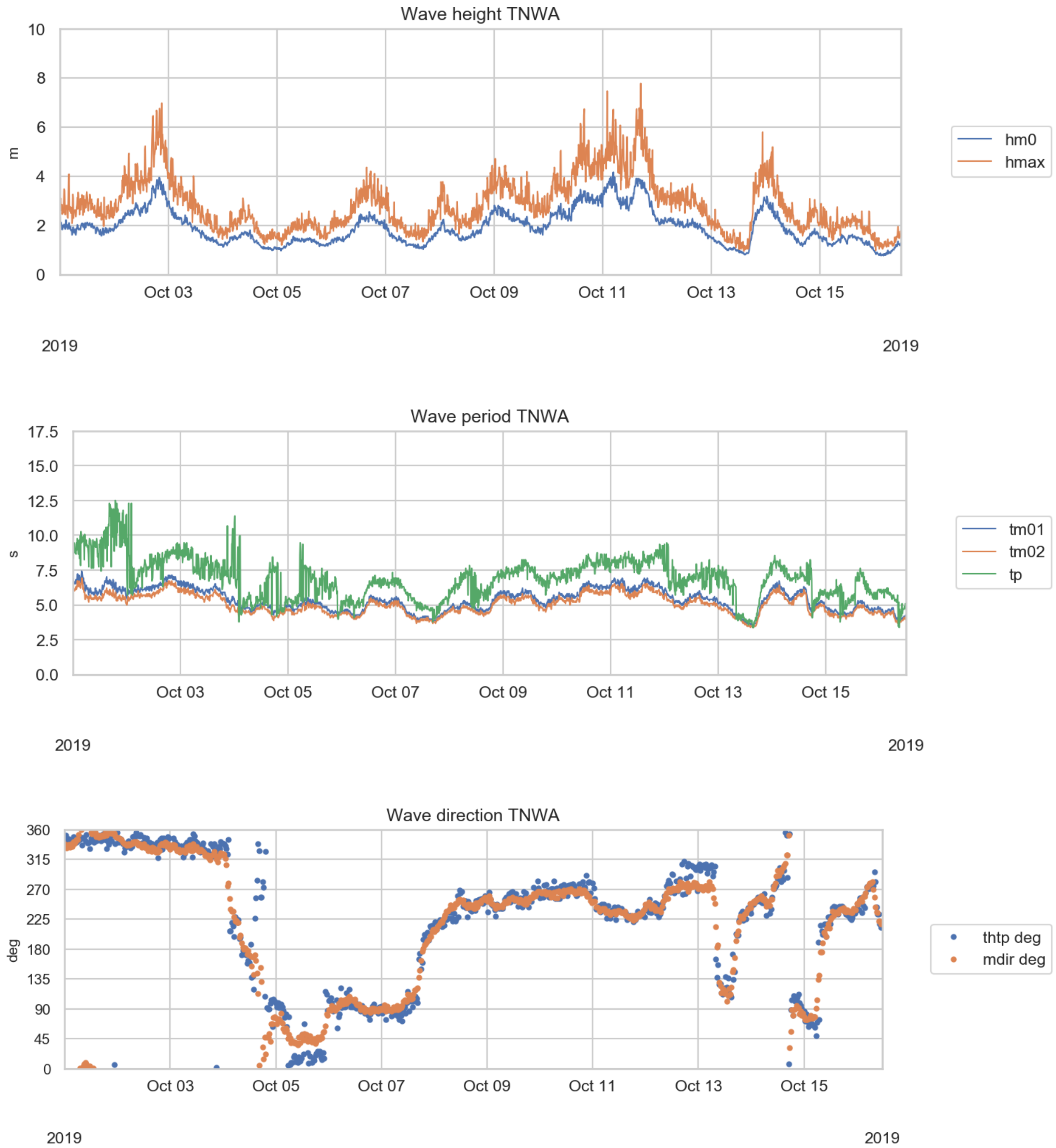


Figure 5.5: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWA, 1 – 15 October 2019.

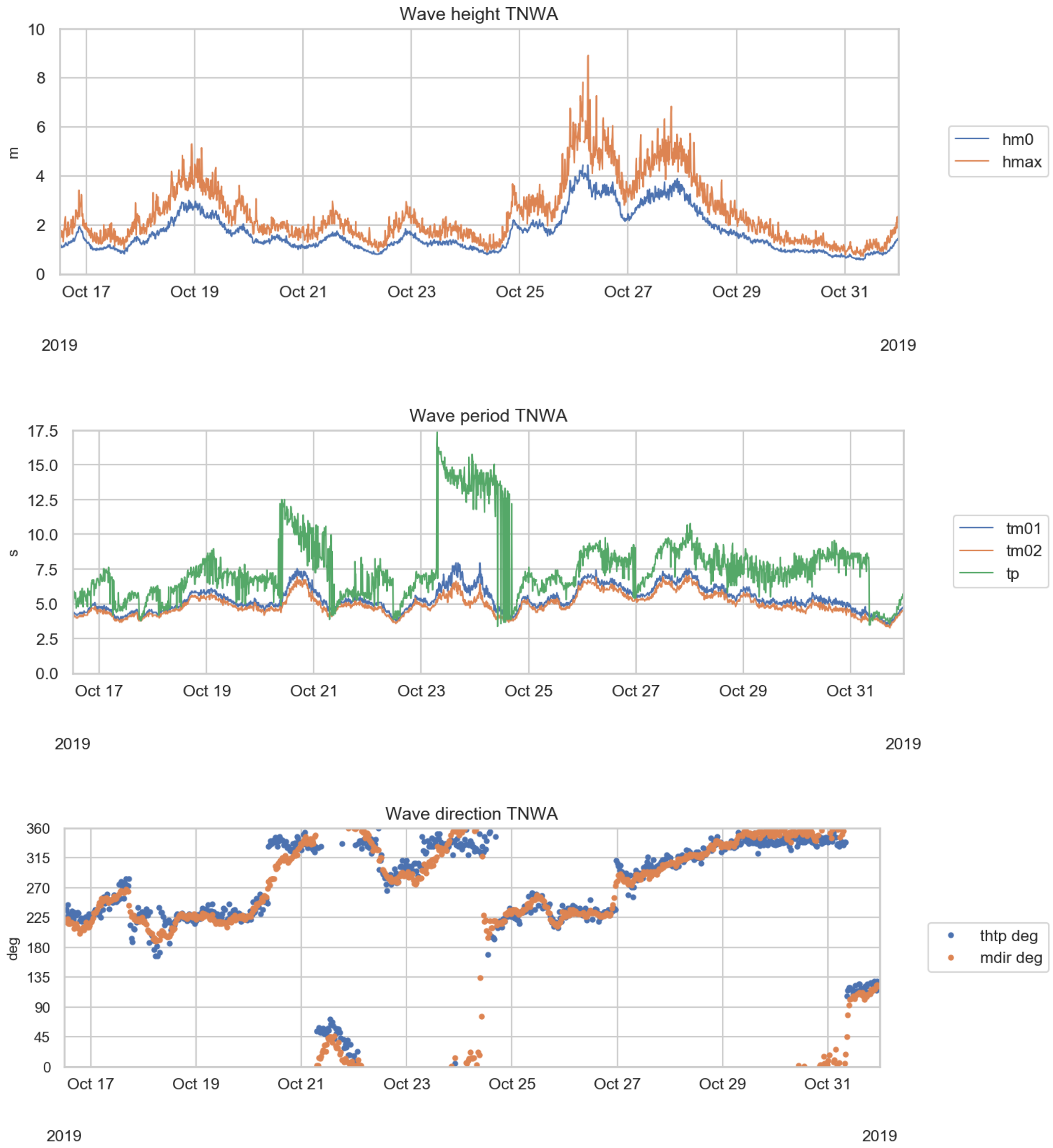


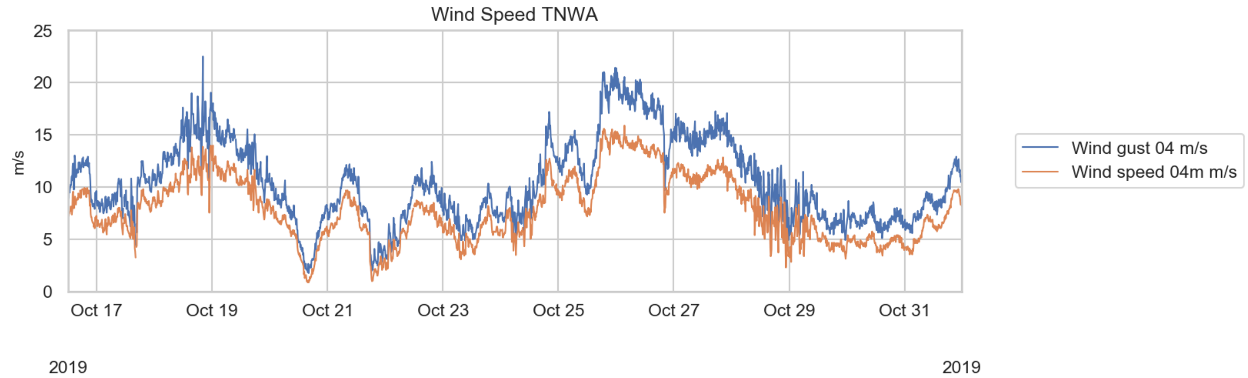
Figure 5.6: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWA, 16 – 31 October 2019.

5.2.1.3 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 5.7 and Figure 5.8.

The data return of this sensor is high with 10 min mean wind speeds up to 15.9 m/s and gusts up to 22.5 m/s. The maximum wind speed and gust were measured on 26 October at 03:30 and on 18 October 20:10 respectively. The average wind speed at mast top height was 8.2 m/s.

Figure 5.7: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWA, 1 – 15 October 2019.



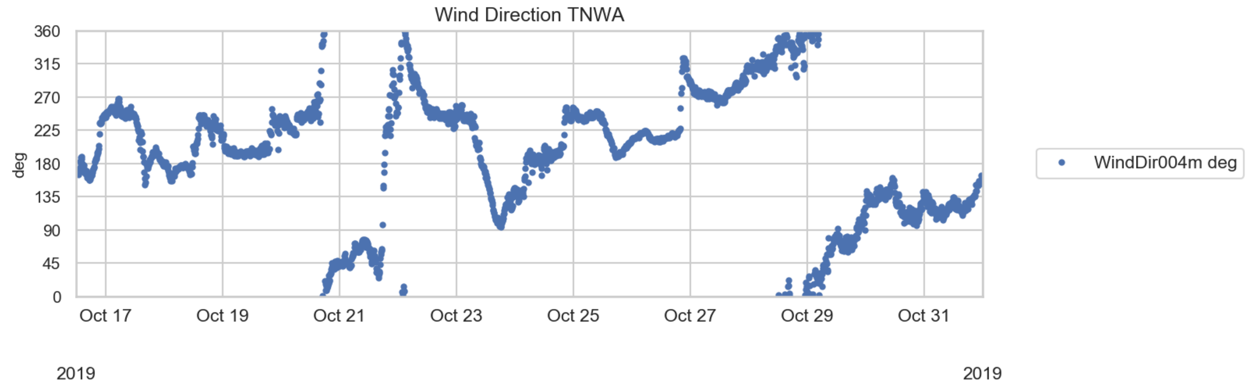
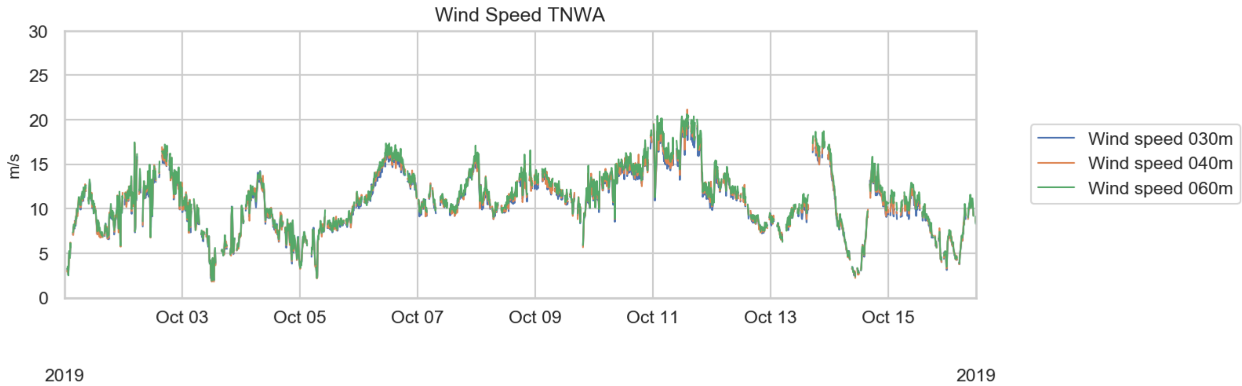


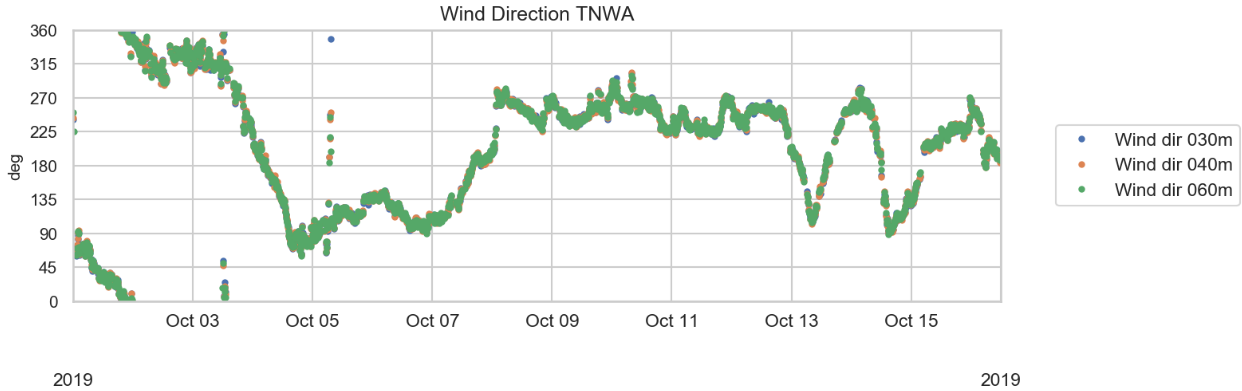
Figure 5.8: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWA, 16 – 31 October 2019.

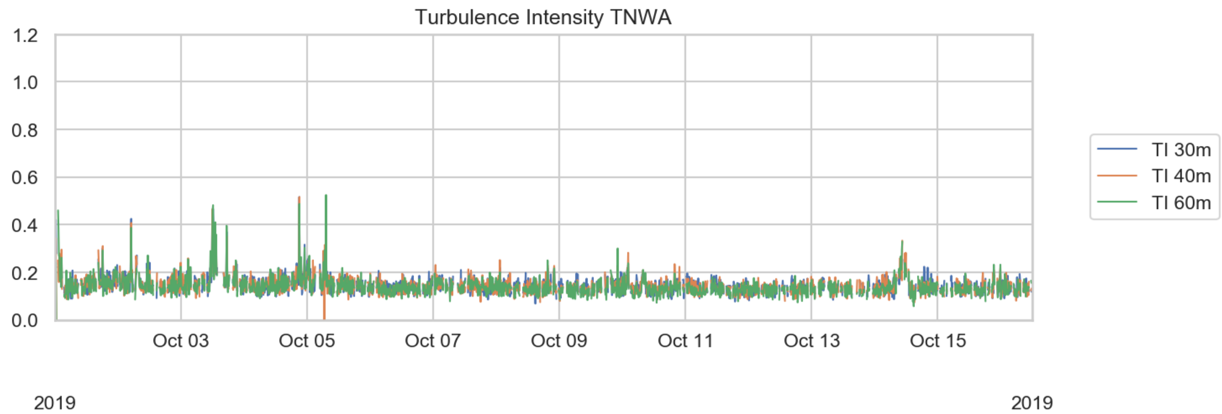
Plots of wind profile data from the LiDAR are presented in Figure 5.9 - Figure 5.16 showing the 10-min. mean wind for each individual level. Plots of the derived parameters Inflow Angle and Turbulence Intensity are also presented.

The highest horizontal 10-minute mean wind speed measured in the profile during October 2019 varies from 21.8 m/s at 30 m to 29.9 m/s at 250 m above the surface. The maximum wind speed at 30 m was measured on 25 October 2019 at 23:40, and the maximum at 250 m on 25 October at 21:50.

Turbulence intensity is transmitted separately from the wind speed measurements, as mentioned in Section 5.1.1 when discussing data availability. The transmission is more susceptible to transmission problems and power supply issues because the turbulence intensity file is the last one transmitted.







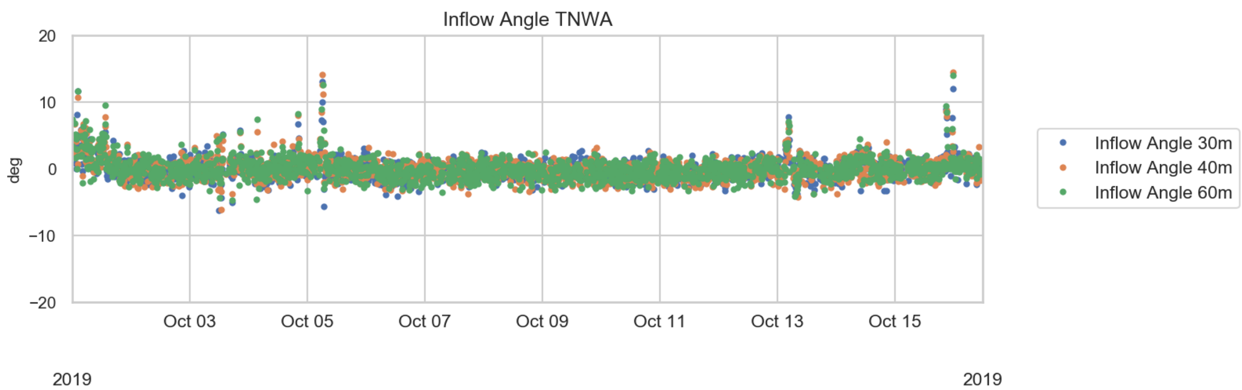
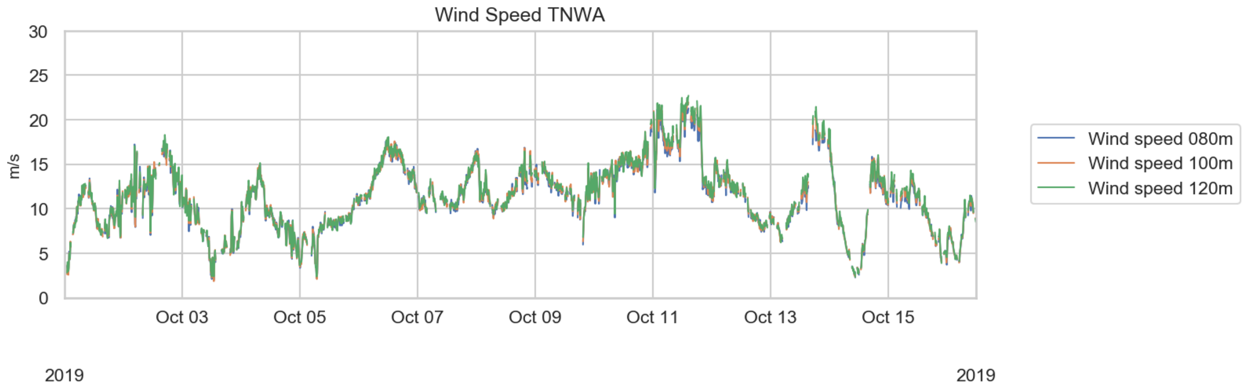
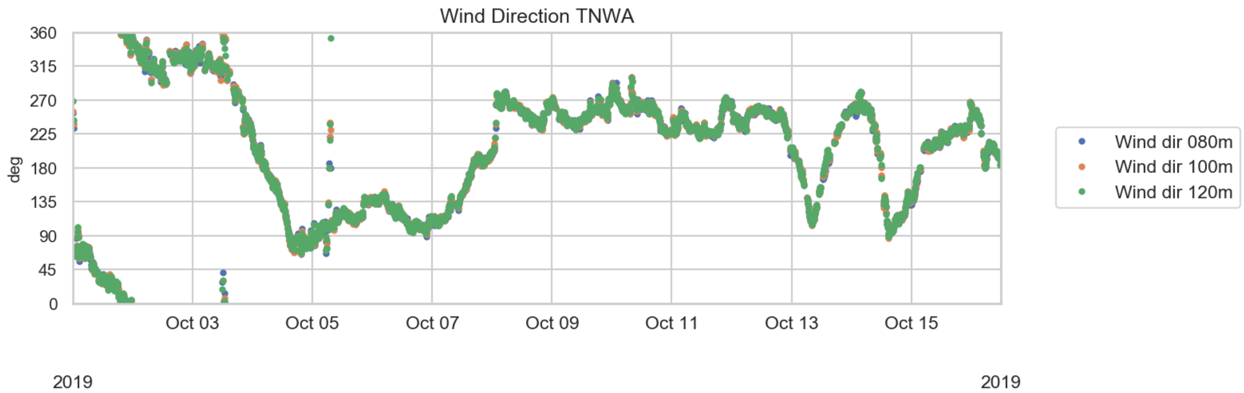
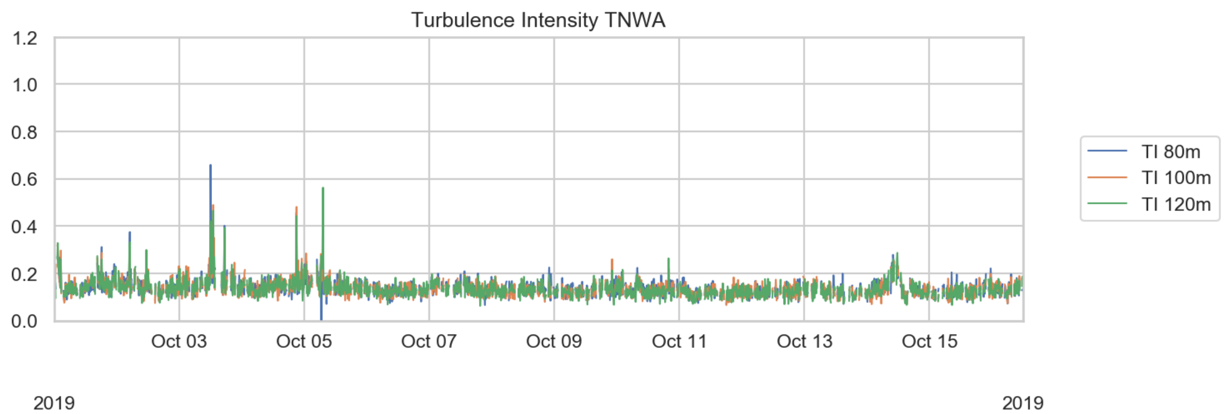


Figure 5.9: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWA, 1 – 15 October 2019.
From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.







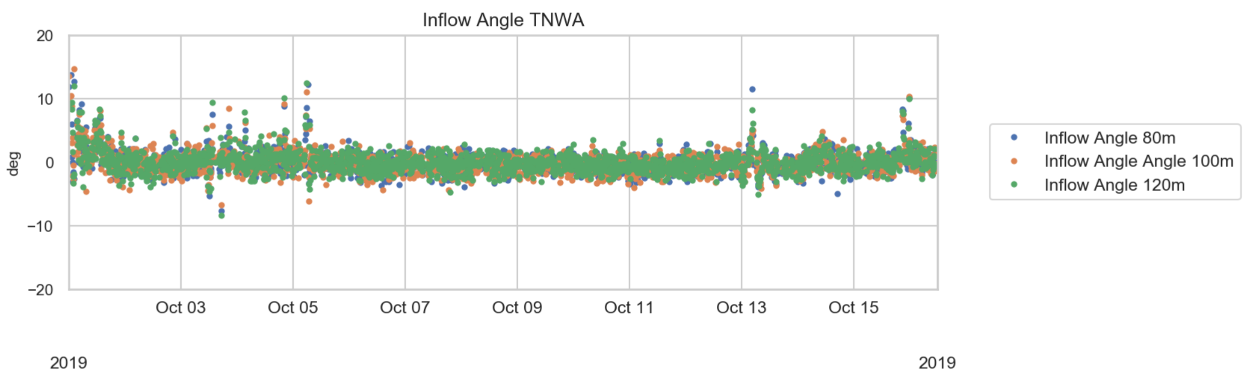


Figure 5.10: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA, 1 – 15 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

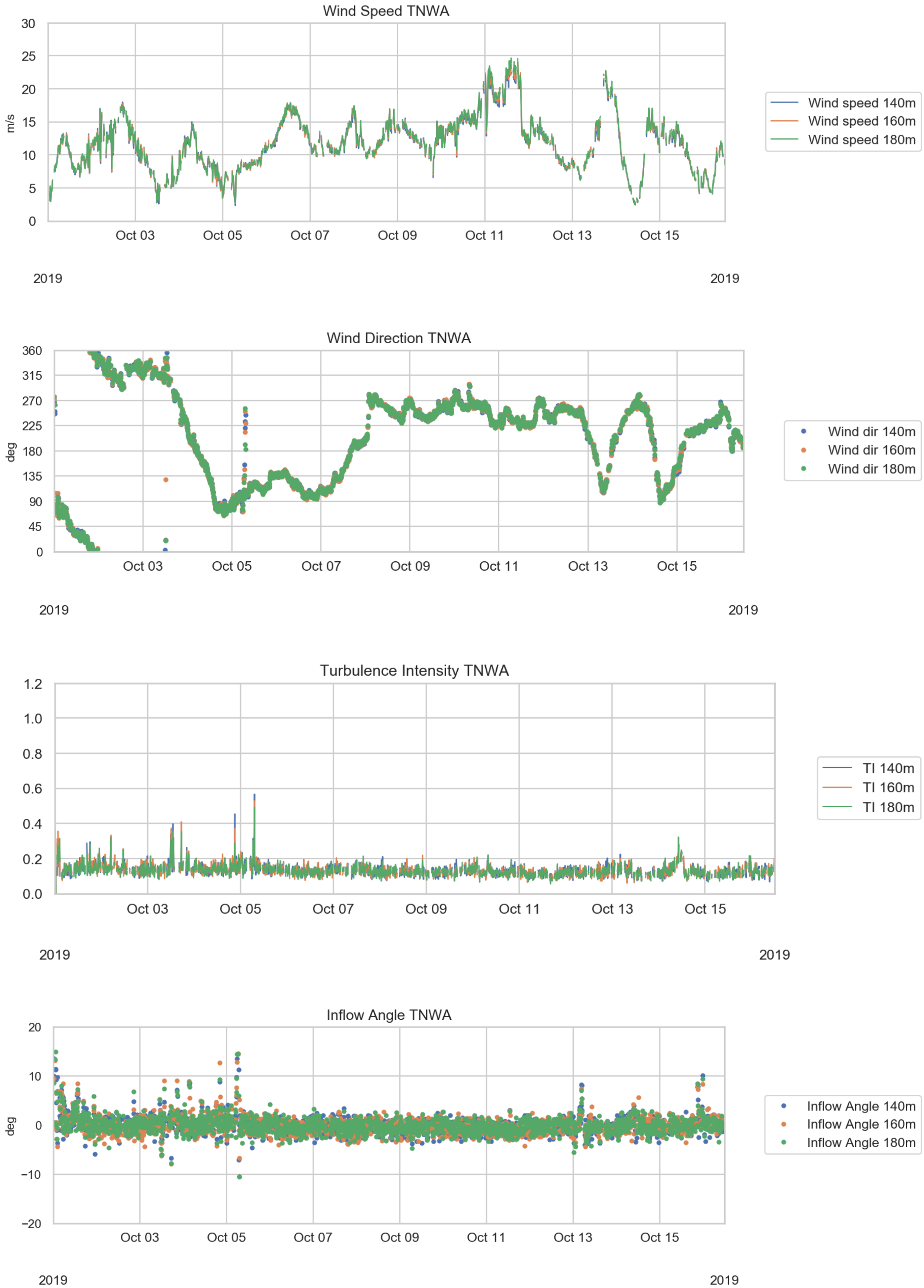


Figure 5.11: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA, 1 – 15 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

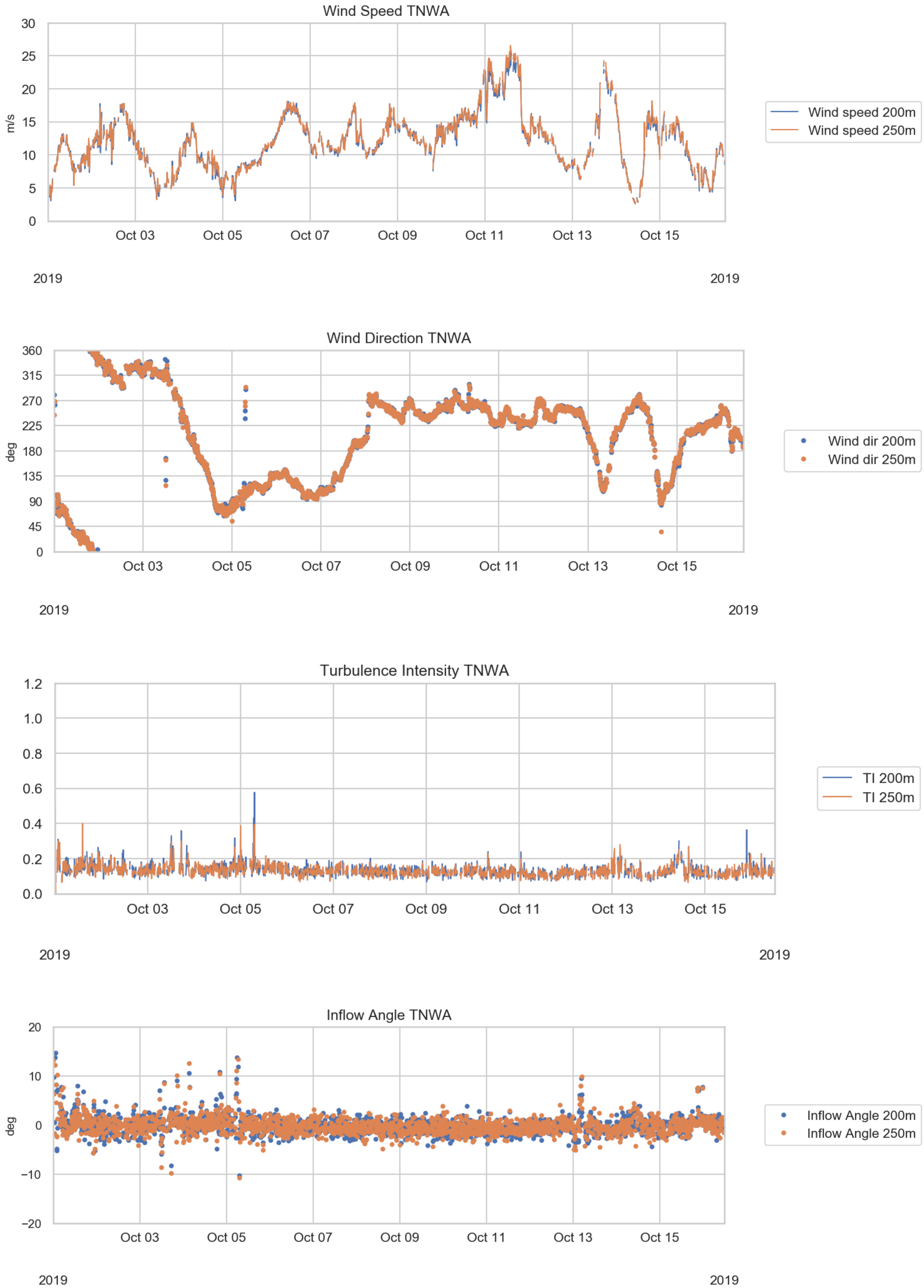


Figure 5.12: Plots of wind profile data, 200, 250 m a.s.l., at TNWA, 1 – 15 October 2019. From top to bottom: Wind, speed, Wind direction, Turbulence Intensity, and Inflow Angle.

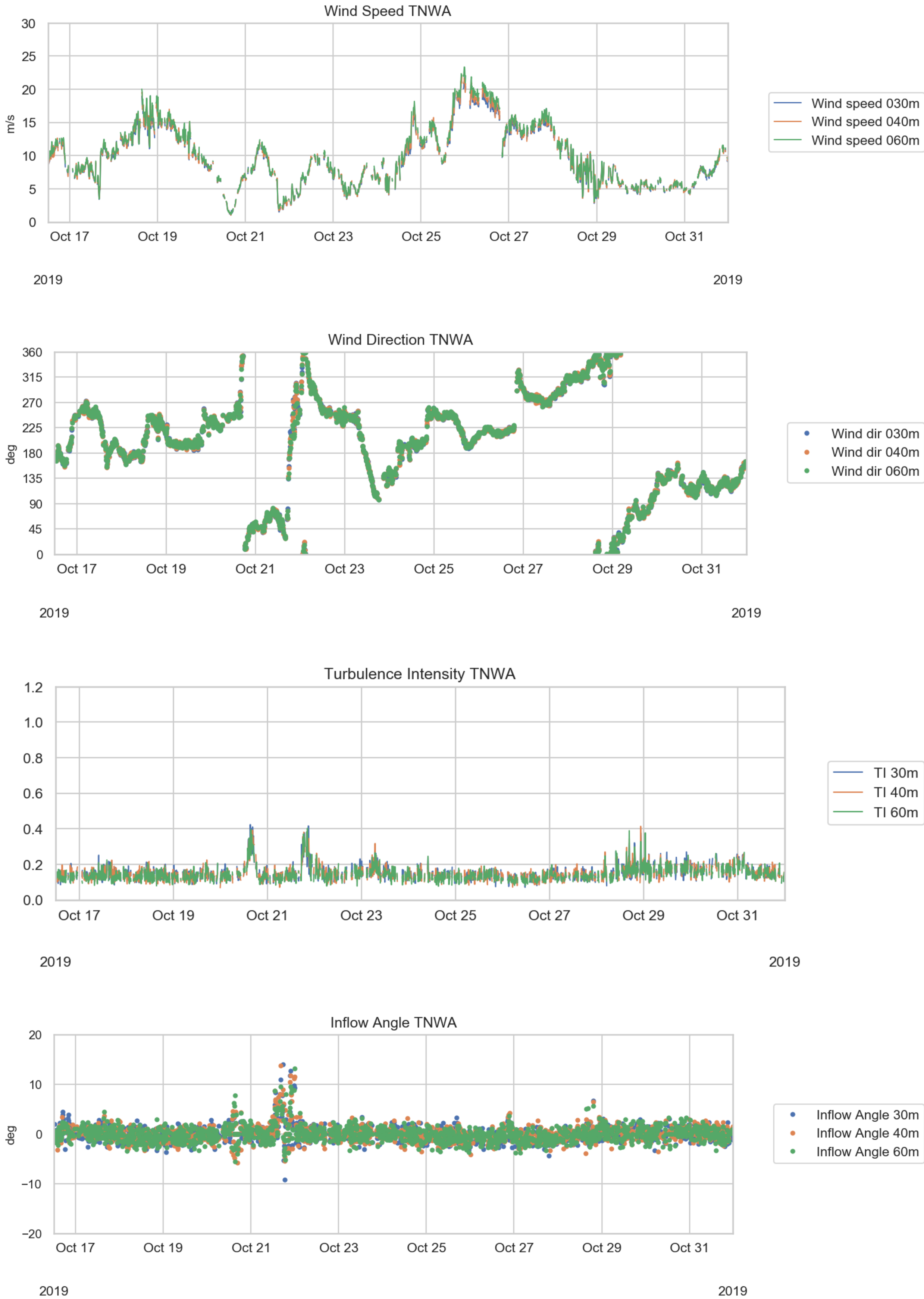


Figure 5.13: Plots of wind profile data, 30, 40, 60 m a.s.l., at TNWA, 16 – 31 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

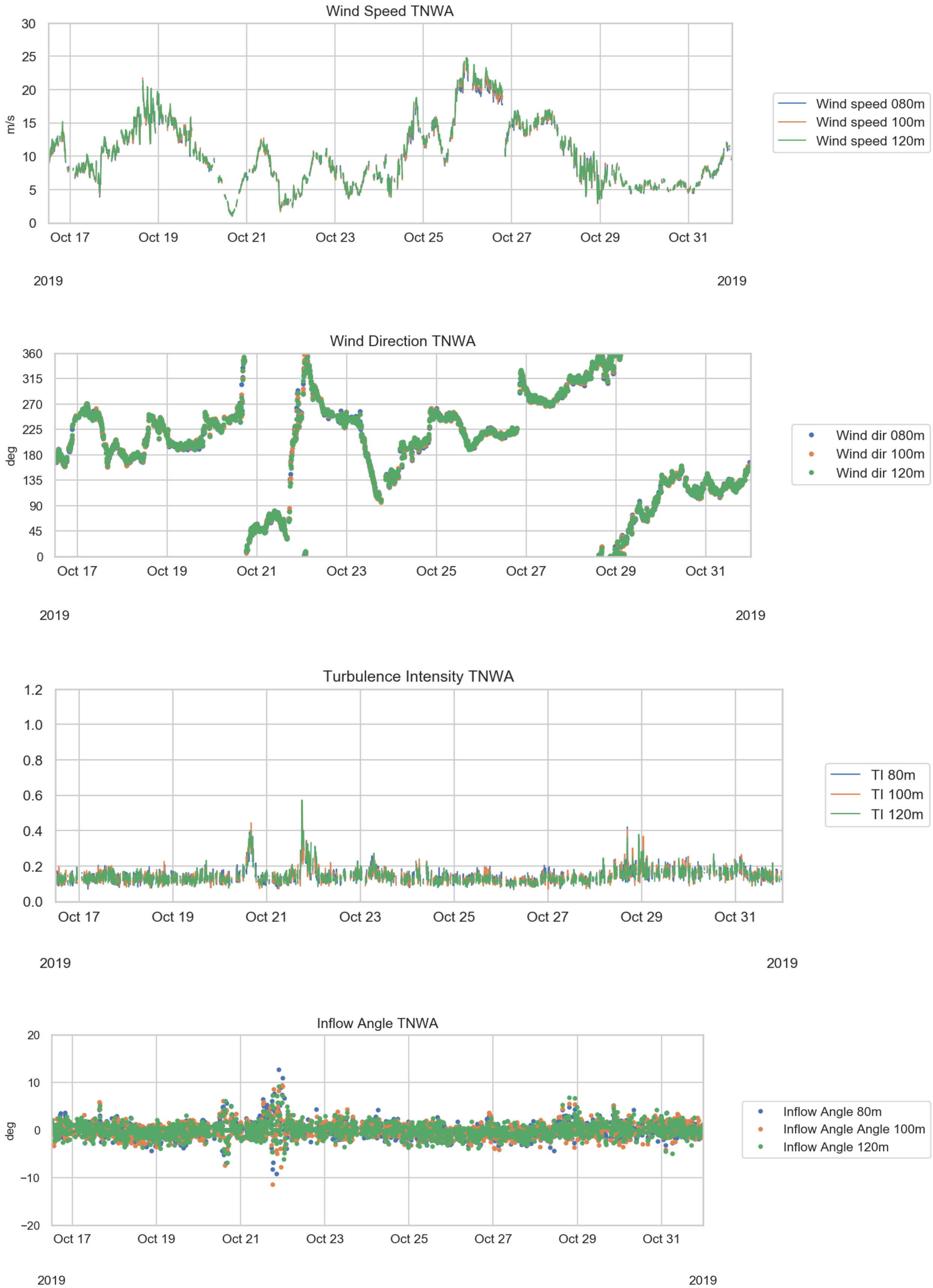


Figure 5.14: Plots of wind profile data, 80, 100, 120 m a.s.l., at TNWA, 16 – 31 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

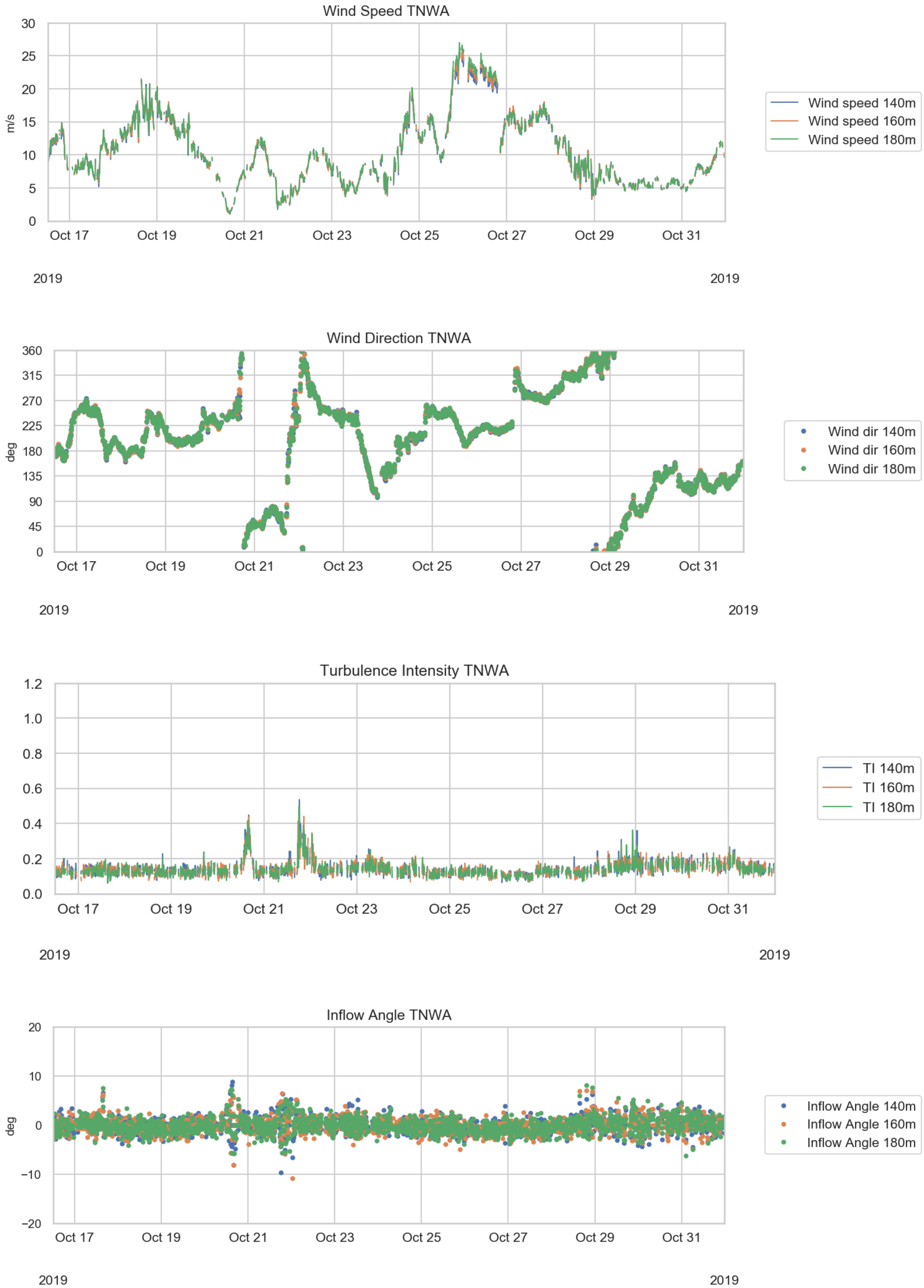


Figure 5.15: Plots of wind profile data, 140, 160, 180 m a.s.l., at TNWA, 16 – 31 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

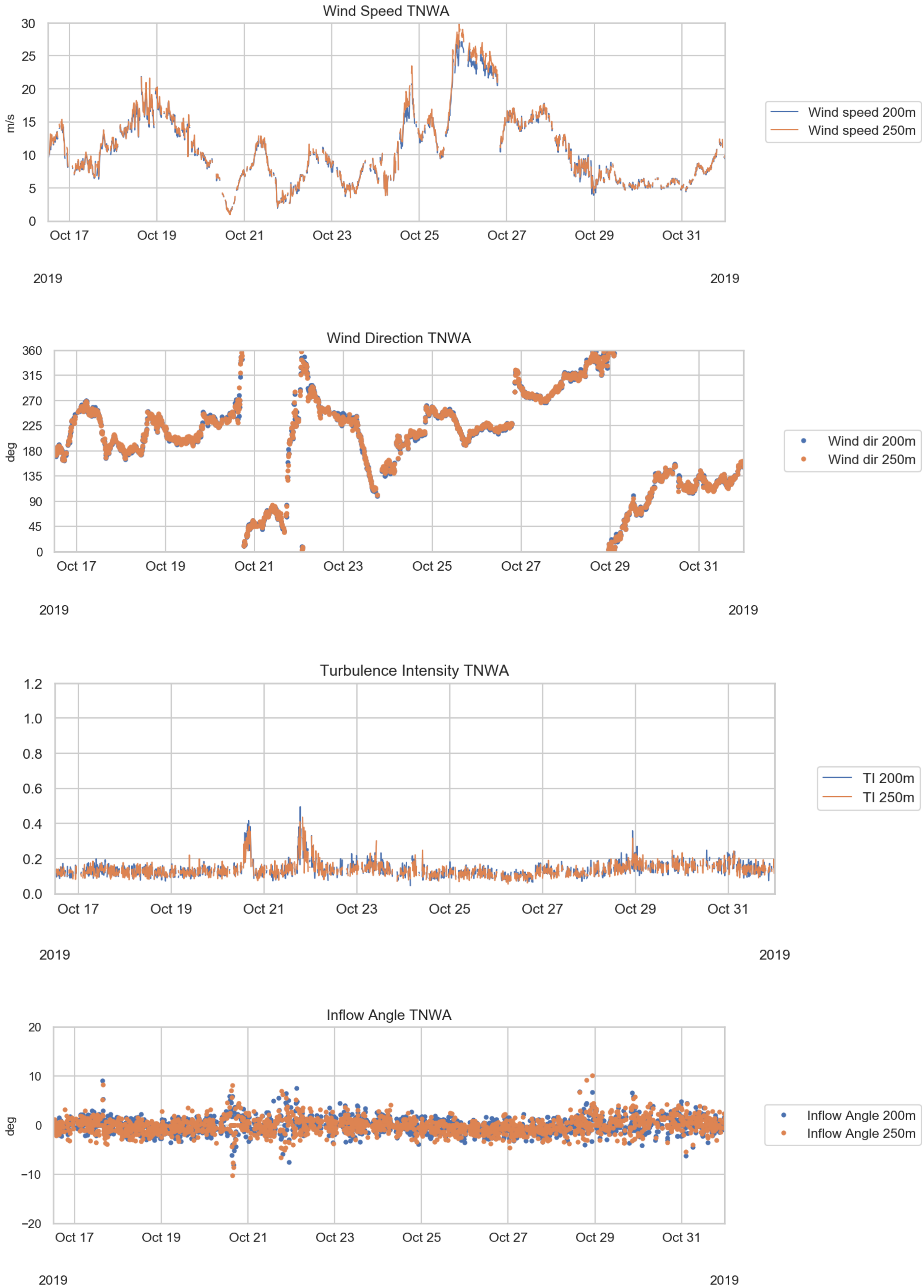


Figure 5.16: Plots of wind profile data, 200, 250 m a.s.l., at TNWA, 16 – 31 October 2019. From top to bottom: Wind speed, Wind direction, Turbulence Intensity, and Inflow Angle.

5.2.1.4 Current velocity profile data

Plots of the current velocity profile time series are presented in Figure 5.17 - Figure 5.33.

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 82 cm/s at 3-7 m depth to 75 cm/s at 25 m depth. The average current speed in the profile varies with depth from 31 cm/s at 4-9 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. When raw data is downloaded the signal to noice ratio especially for the measurements near bottom can be checked to determine which measurements are valid.

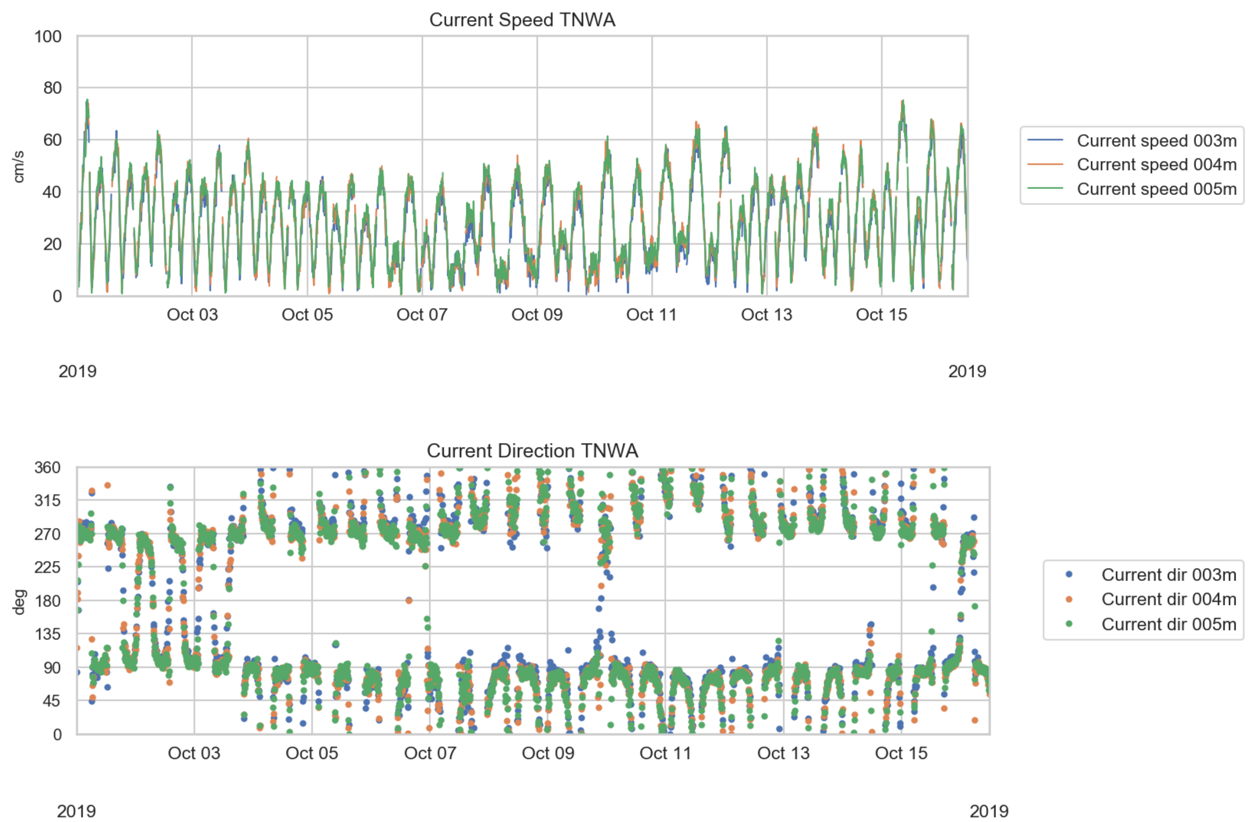


Figure 5.17: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWA, 1 – 15 October 2019.

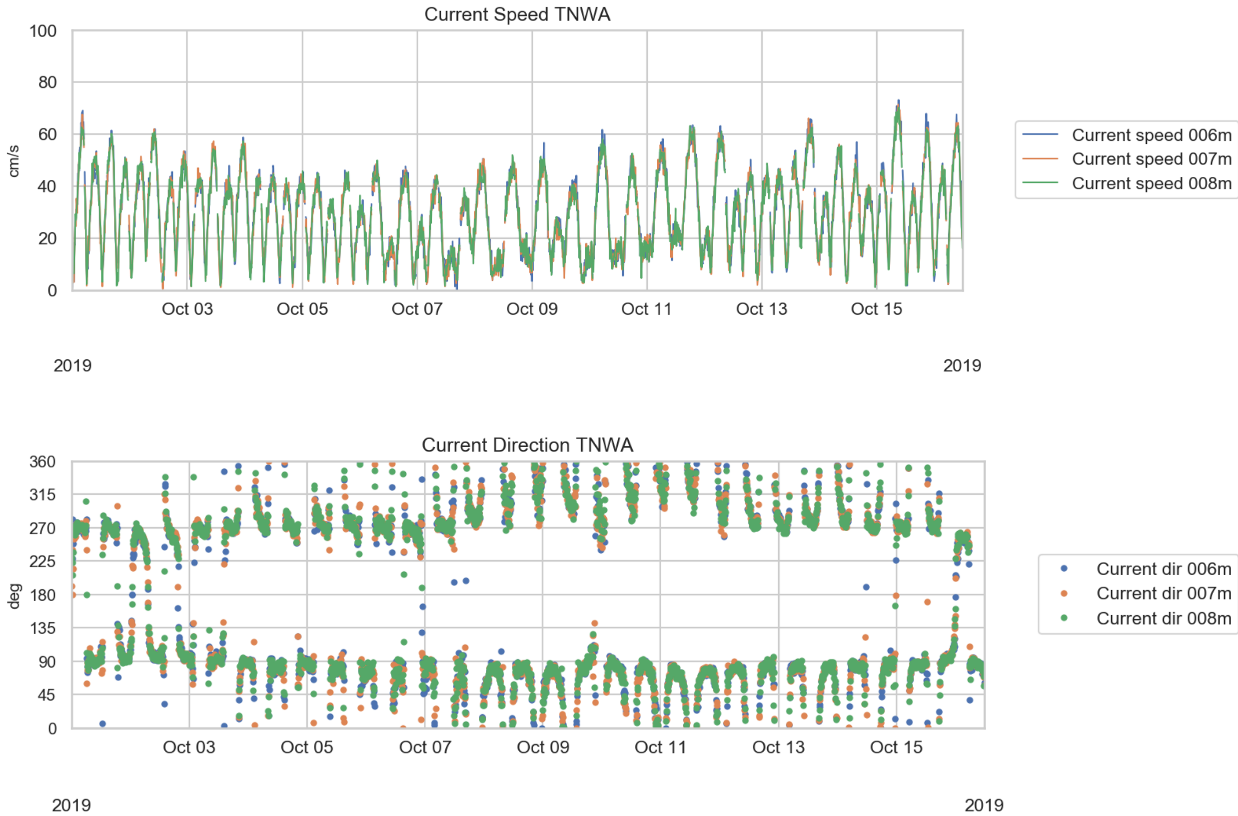


Figure 5.18: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWA, 1 – 15 October 2019.

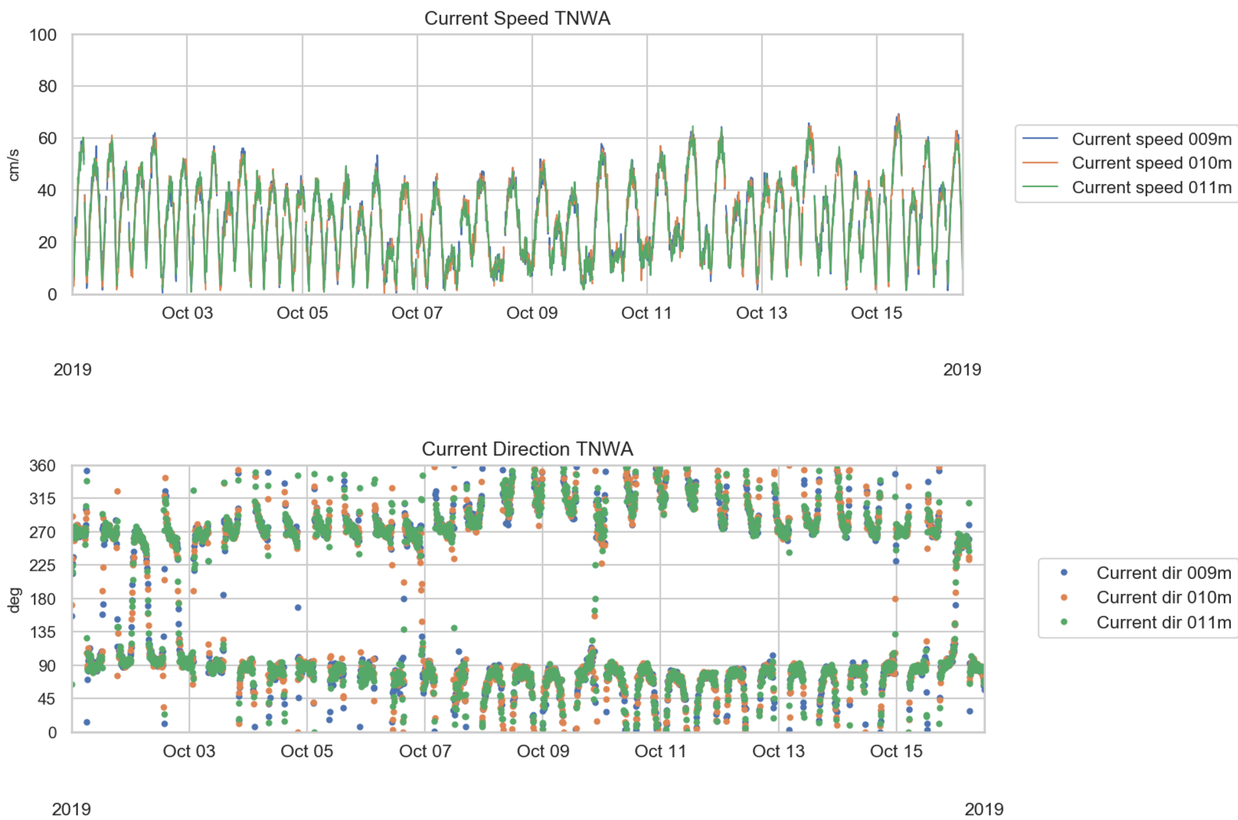


Figure 5.19: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWA, 1 – 15 October 2019.

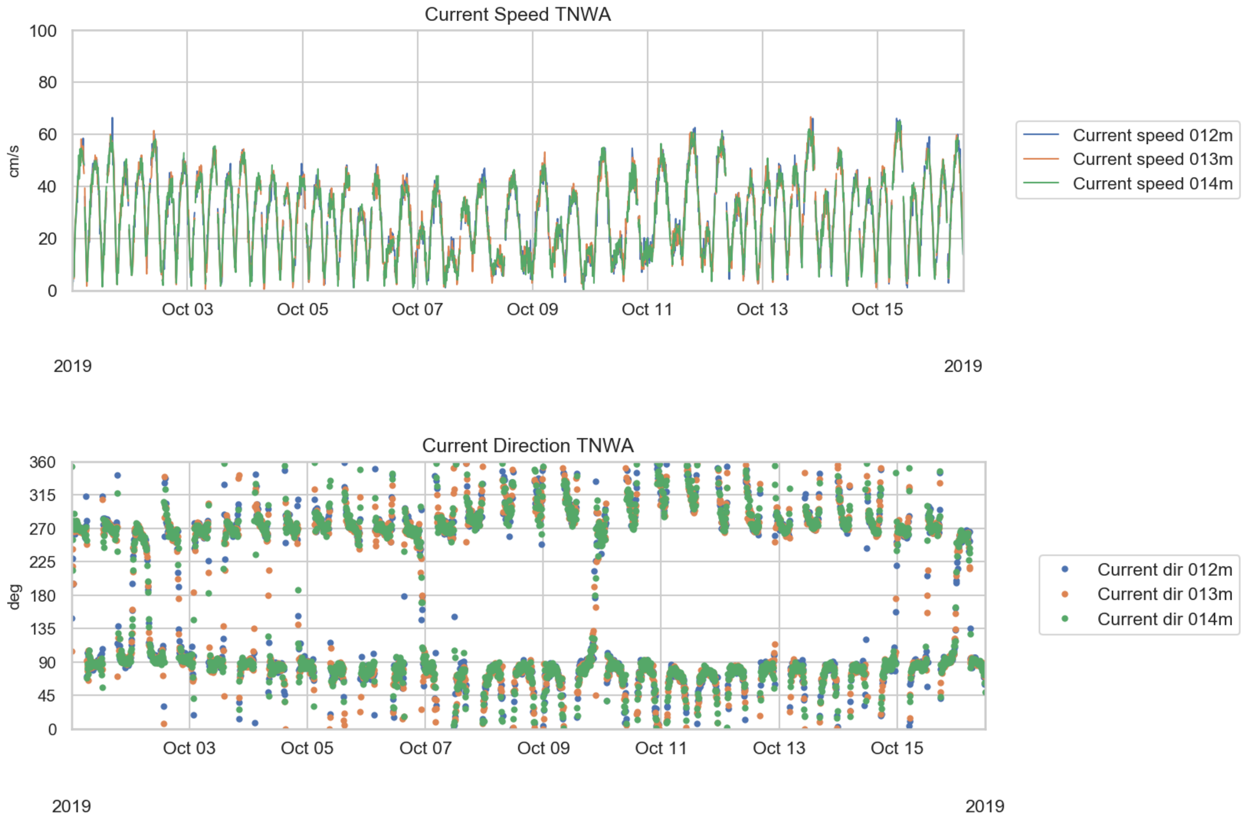


Figure 5.20: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWA, 1 – 15 October 2019.

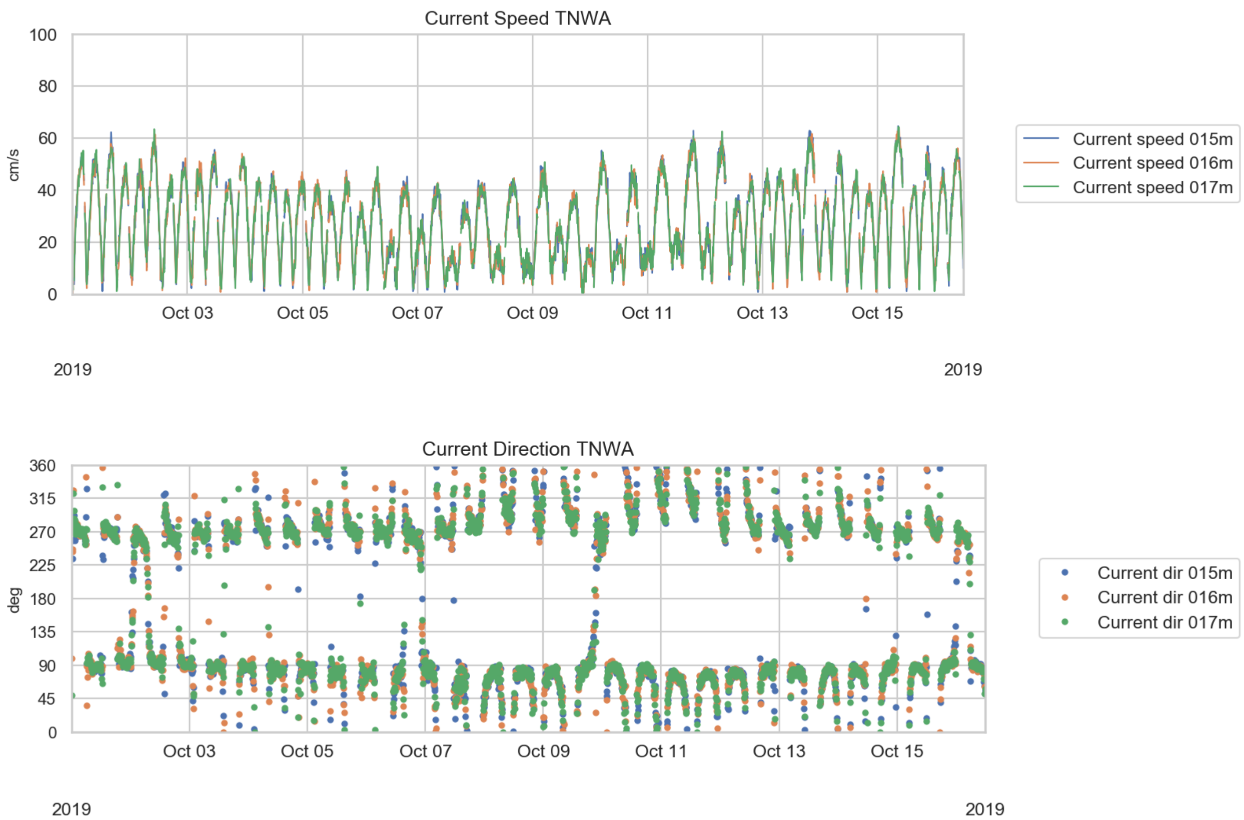


Figure 5.21: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWA, 1 – 15 October 2019.

Figure 5.22: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWA, 1 – 15 October 2019.

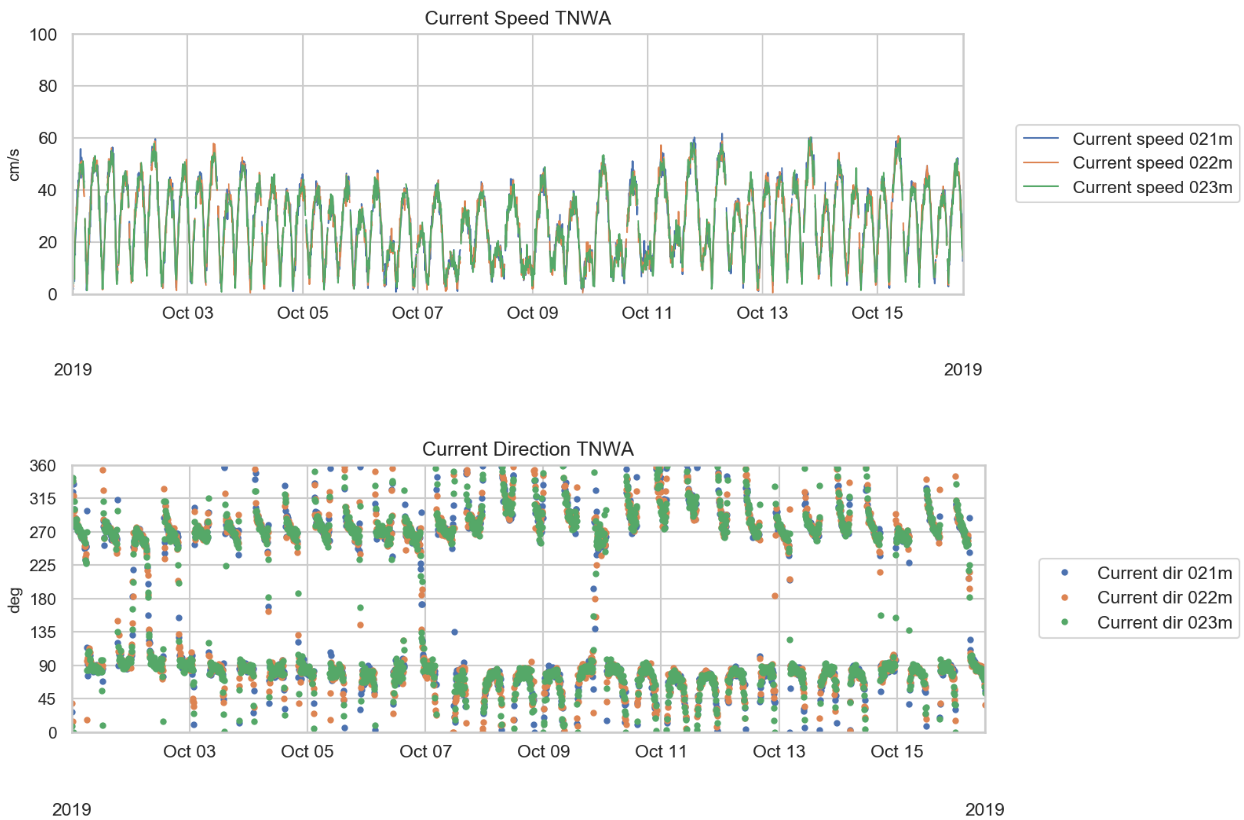


Figure 5.23: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWA, 1 – 15 October 2019.

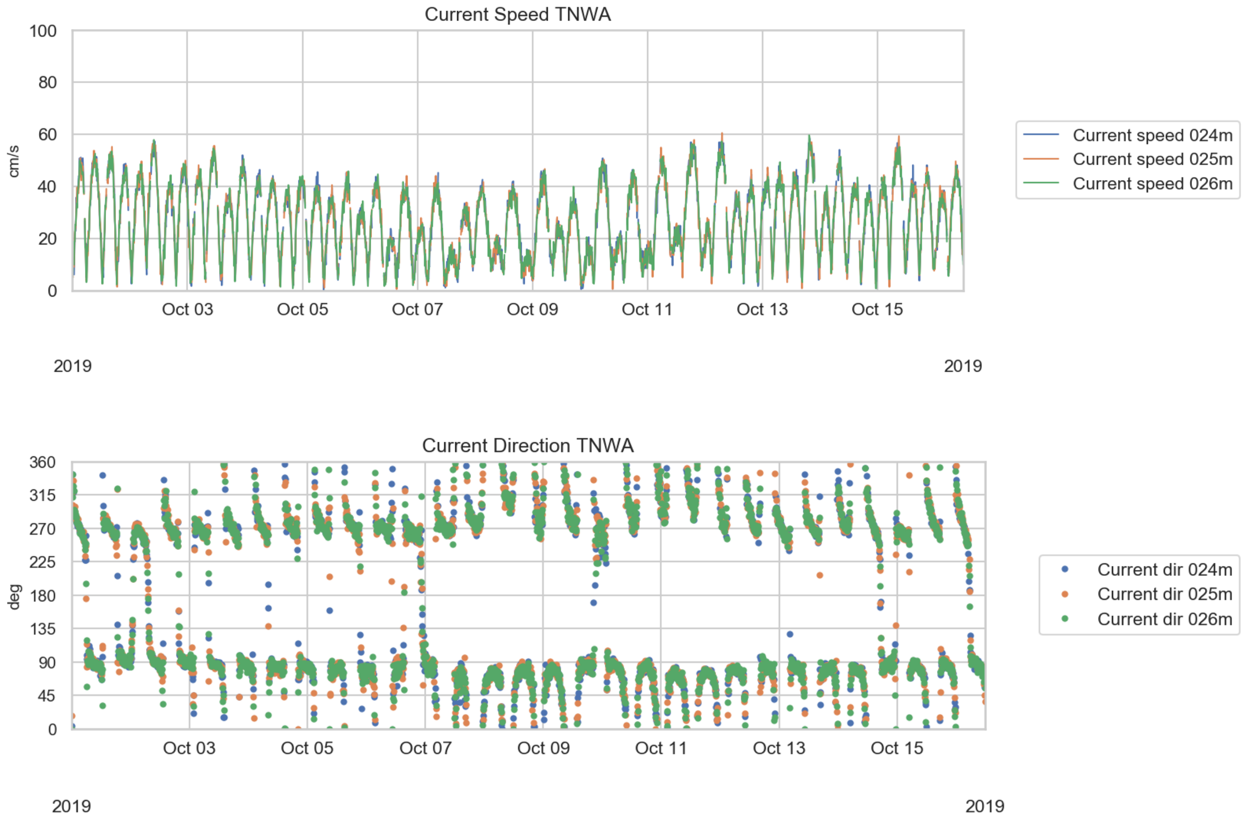


Figure 5.24: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWA, 1 – 15 October 2019.

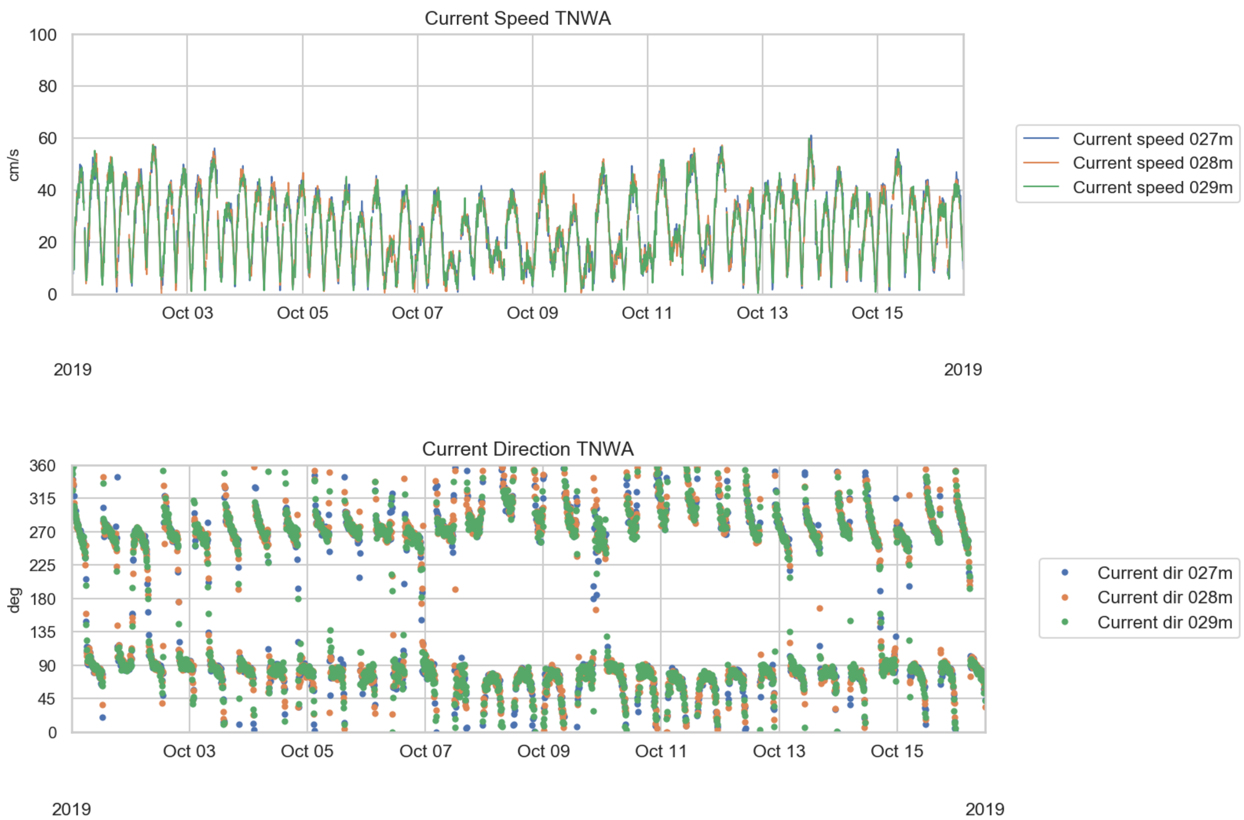


Figure 5.25: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWA, 1 – 15 October 2019.

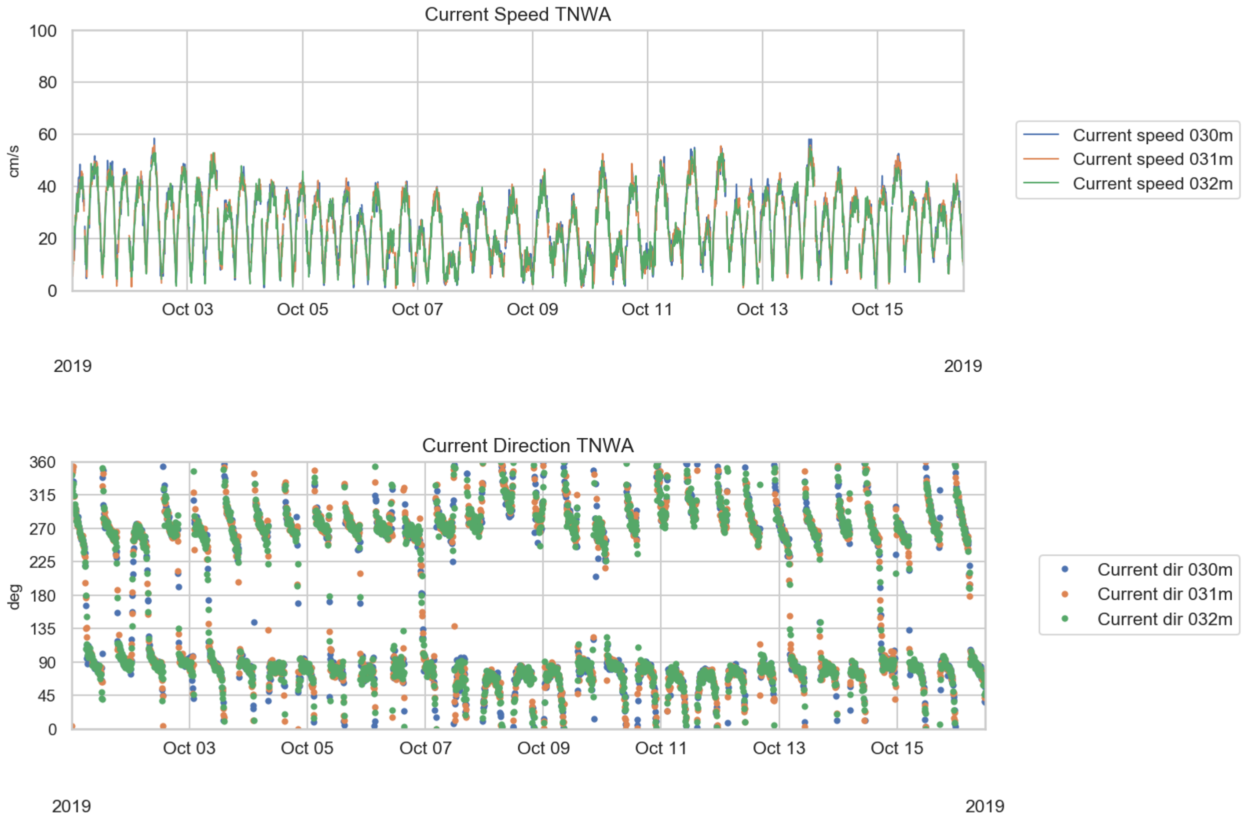


Figure 5.26: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWA, 1 – 15 October 2019.

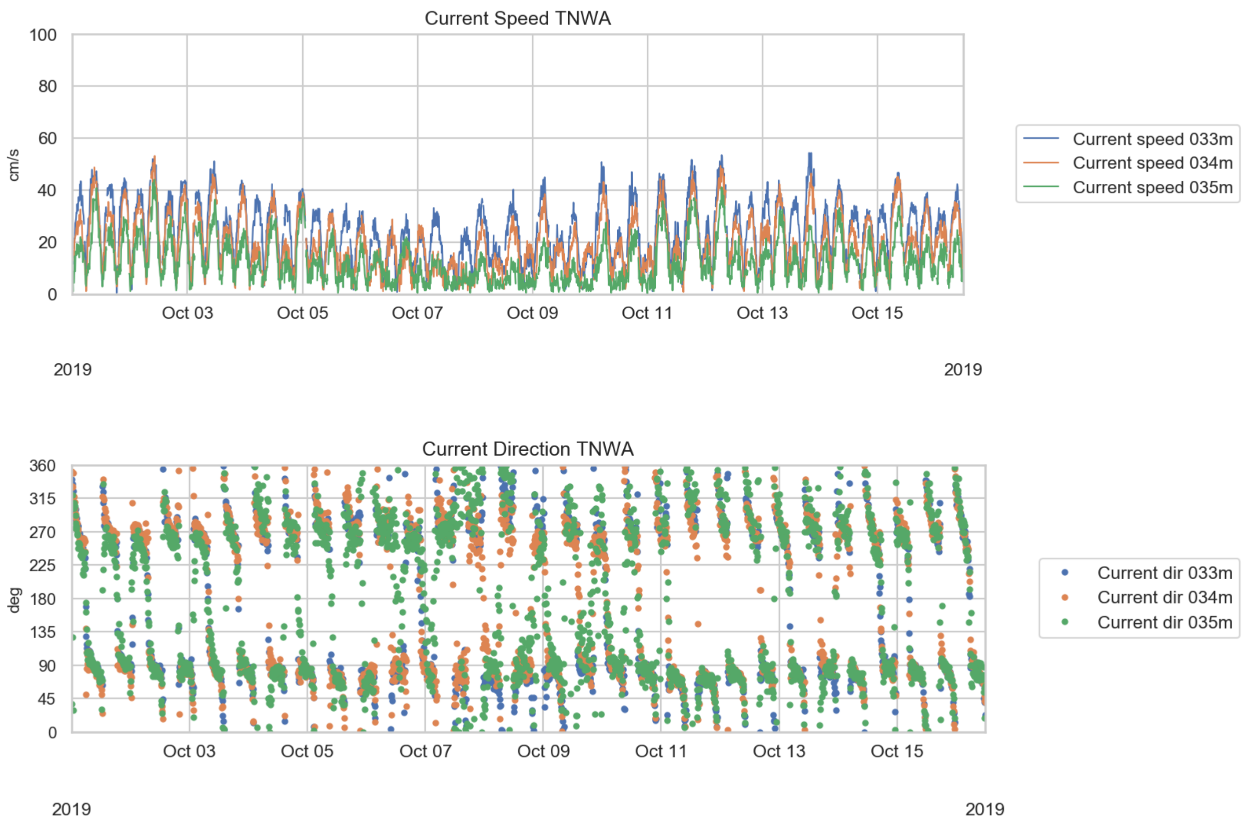


Figure 5.27: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWA, 1 – 15 October 2019.

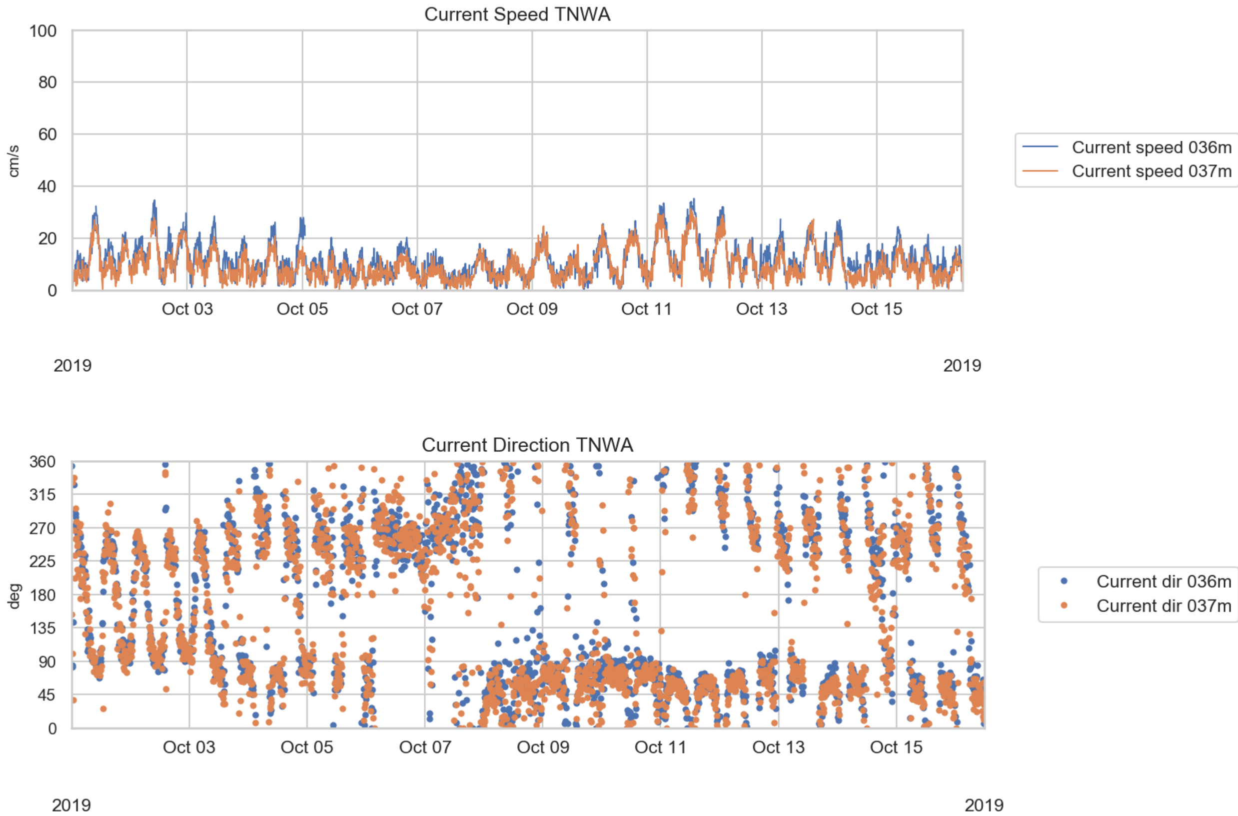


Figure 5.28: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWA, 1 – 15 October 2019.

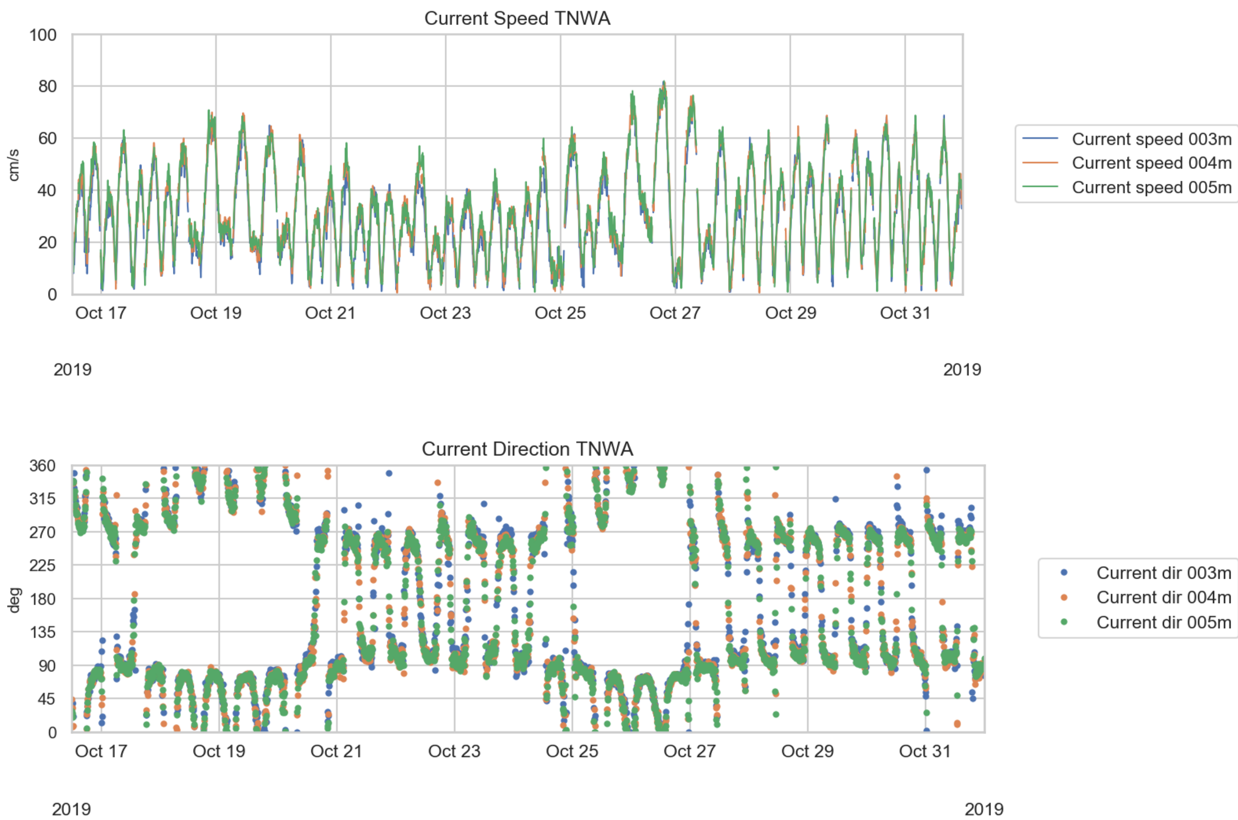


Figure 5.29: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWA, 16 – 31 October 2019.

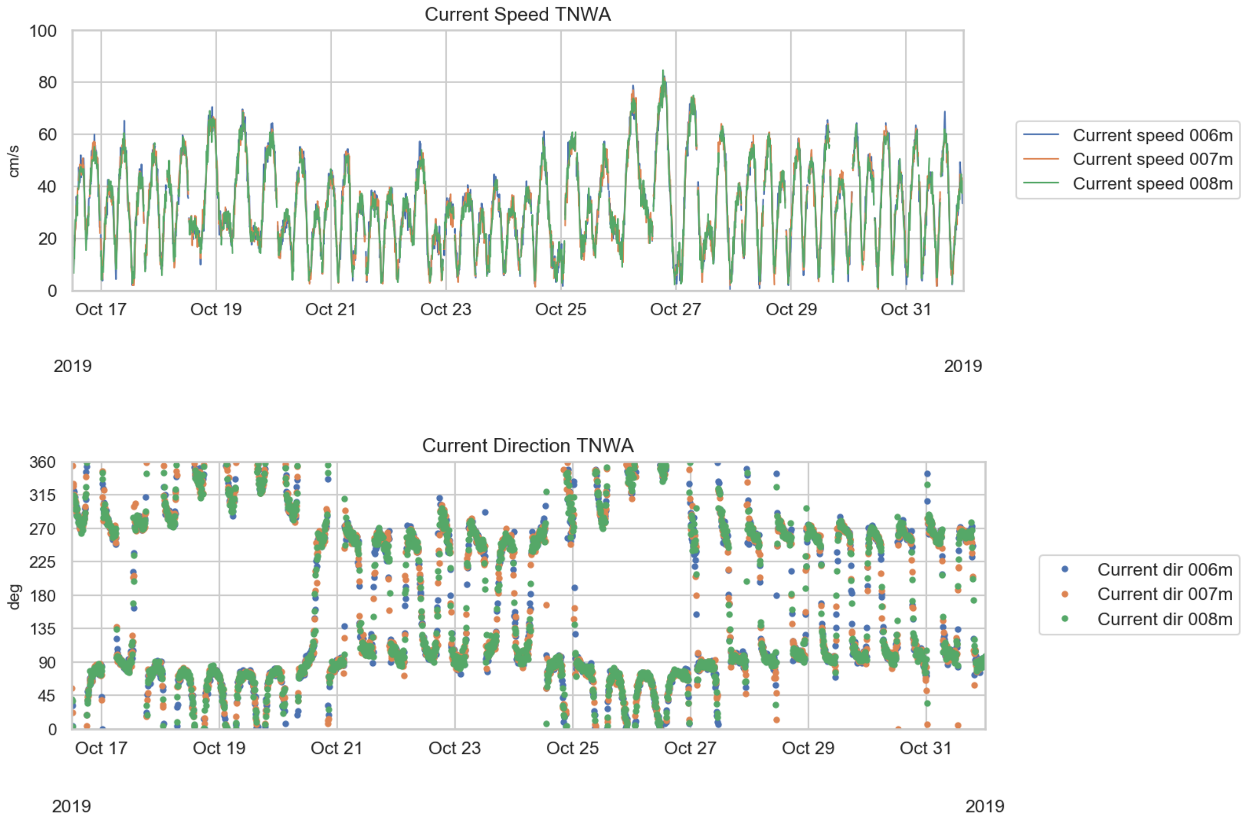


Figure 5.30: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWA, 16 – 31 October 2019.

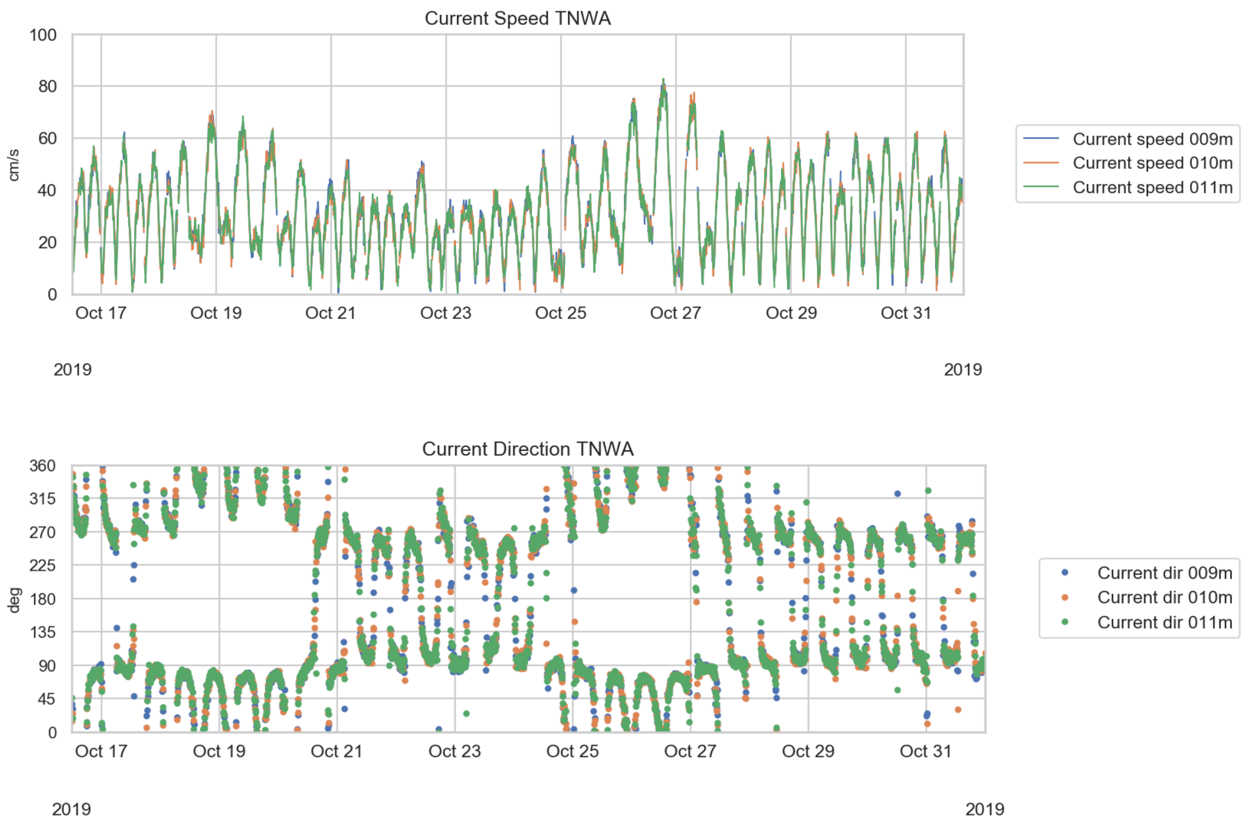


Figure 5.31: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWA, 16 – 31 October 2019.

Figure 5.32: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWA, 16 – 31 October 2019.

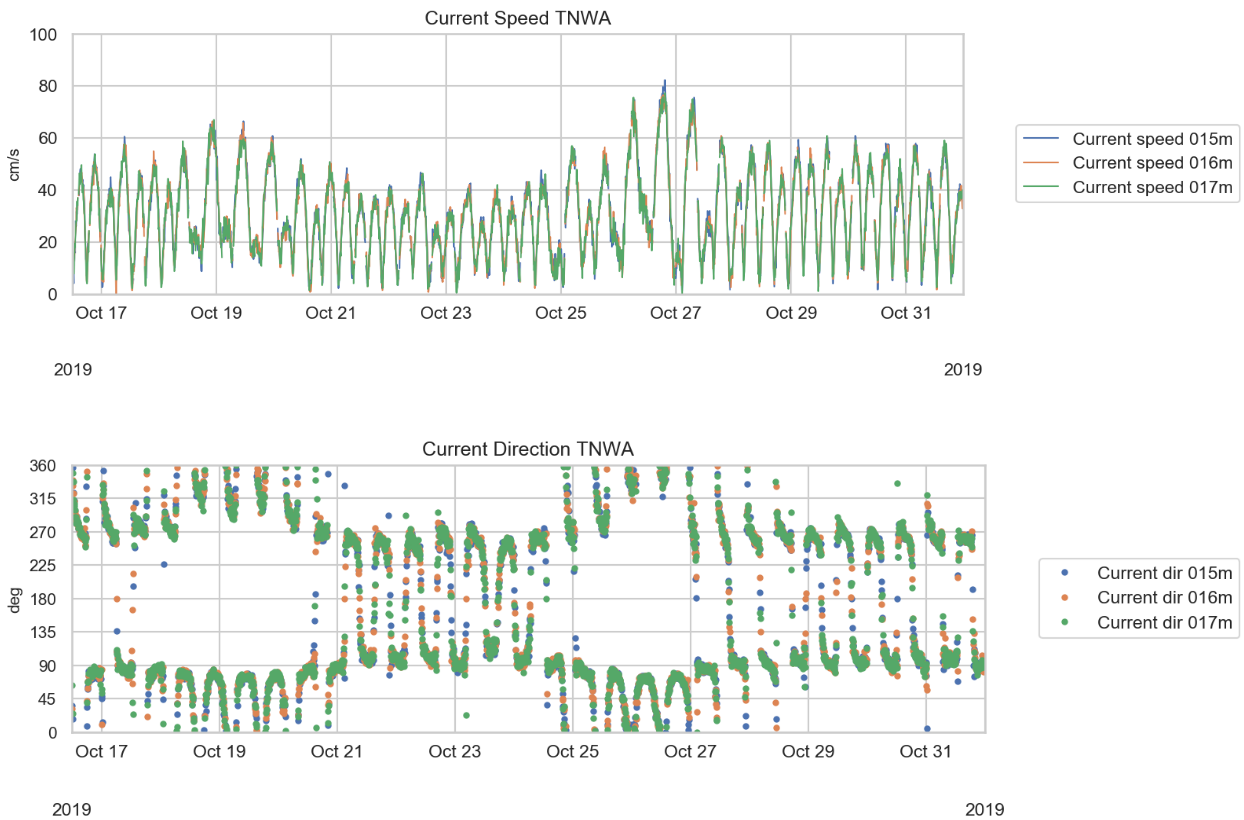


Figure 5.33: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWA, 16 – 31 October 2019.

Figure 5.34: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWA, 16 – 31 October 2019.

Figure 5.35: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWA, 16 – 31 October 2019.

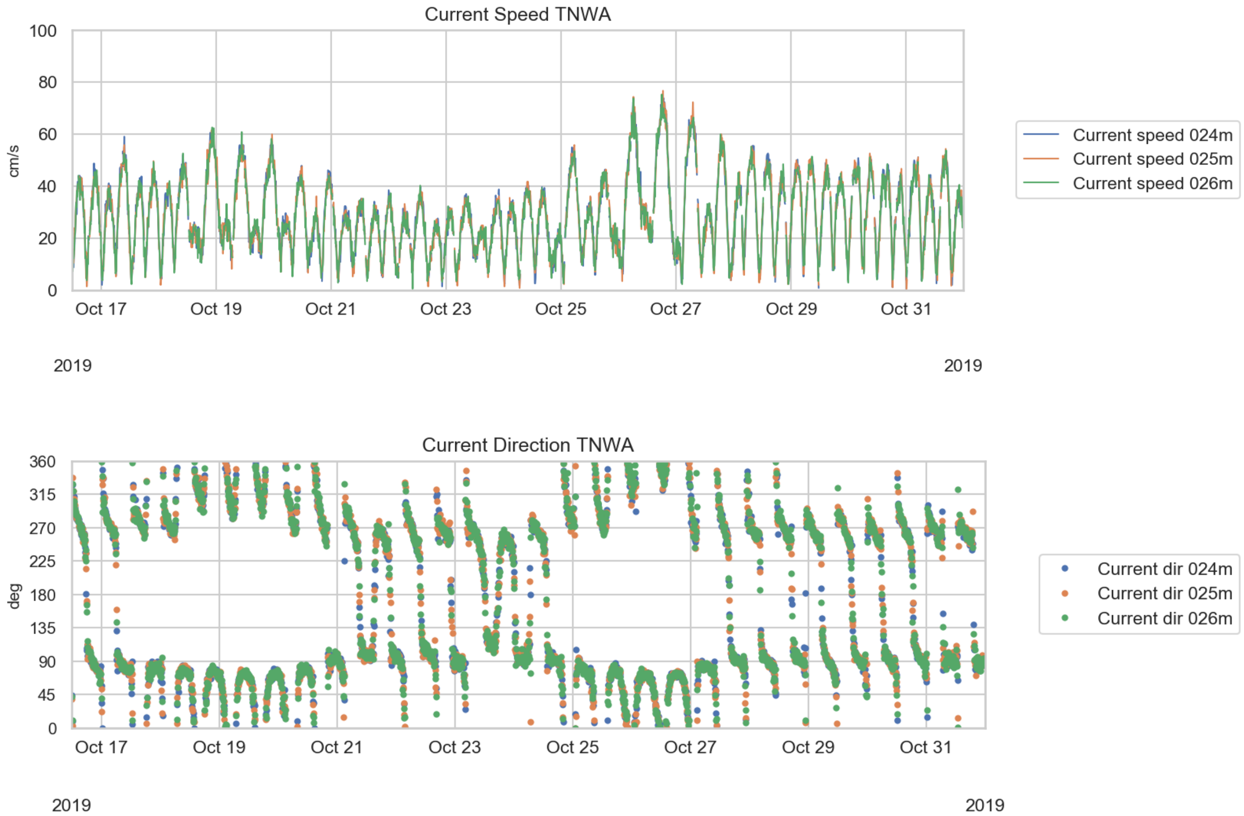


Figure 5.36: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWA, 16 – 31 October 2019.

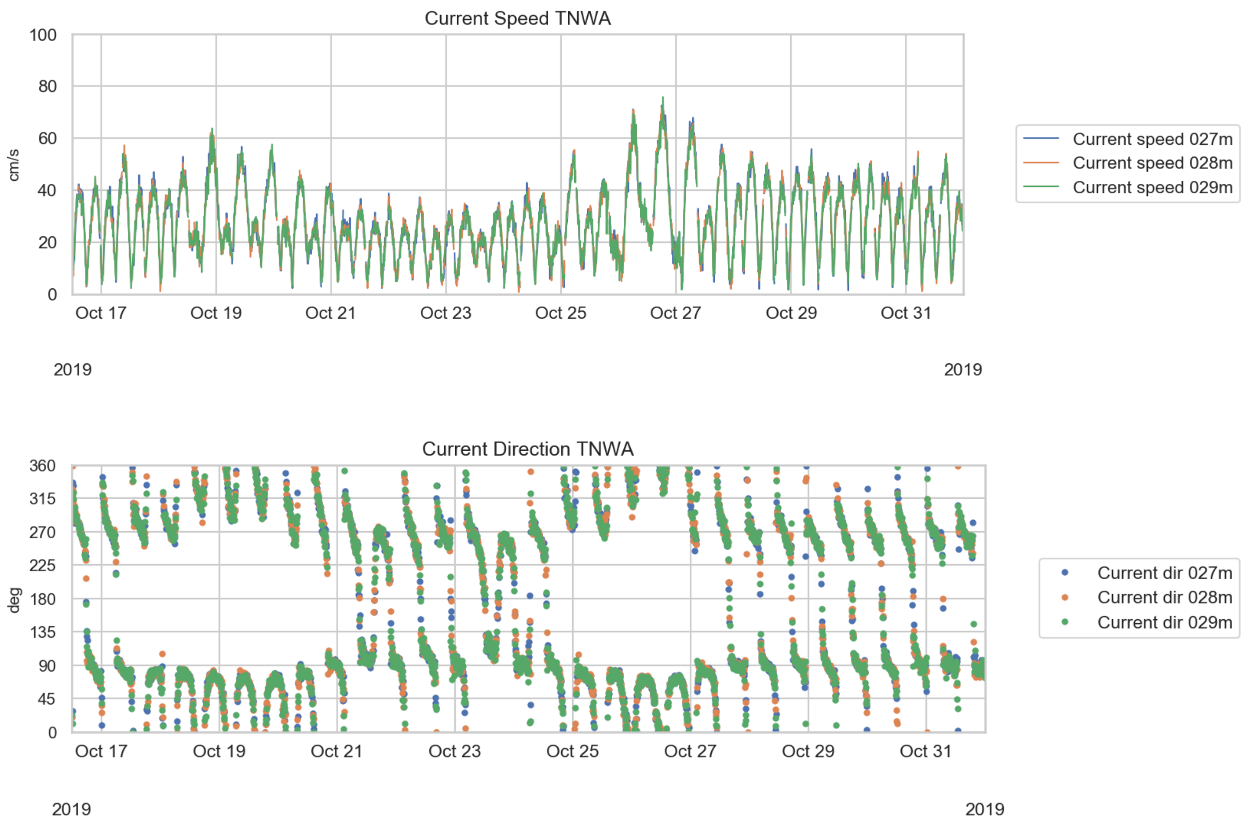


Figure 5.37: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWA, 16 – 31 October 2019.

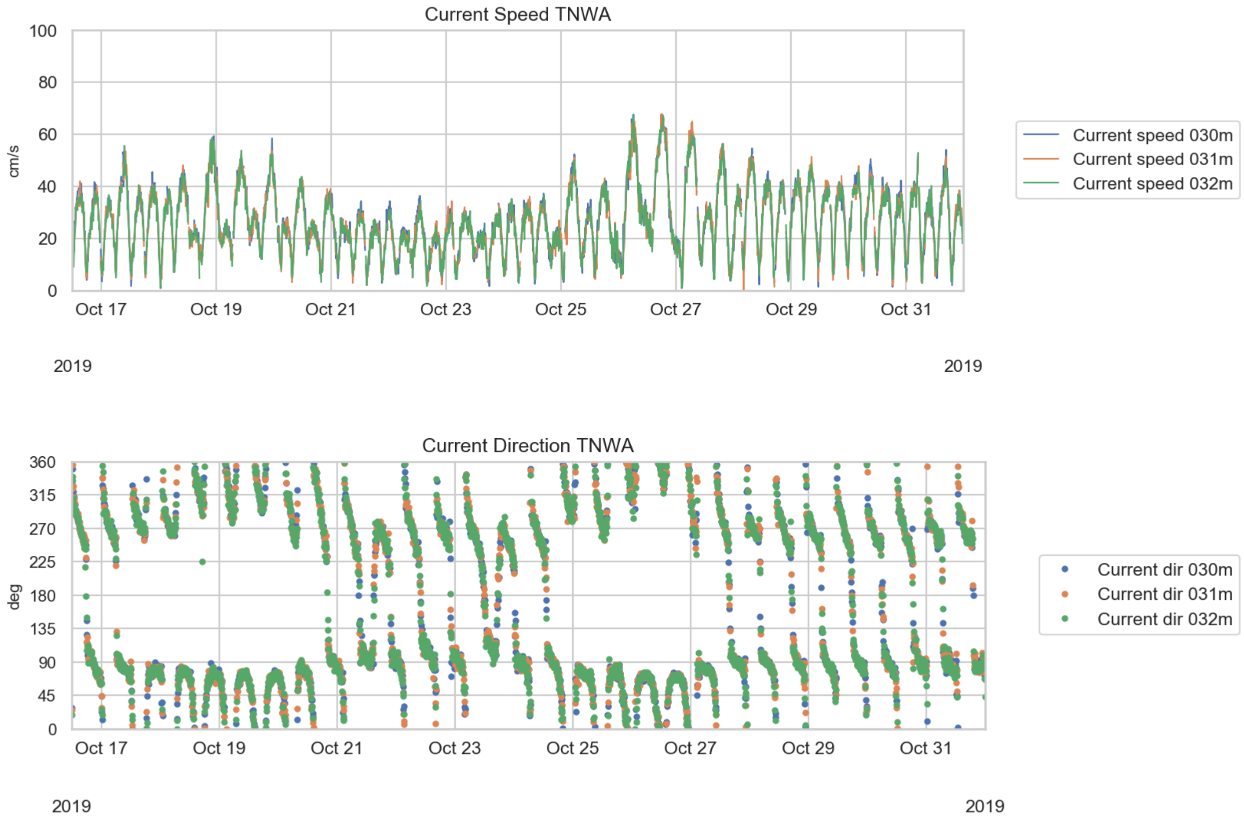


Figure 5.38: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWA, 16 – 31 October 2019.

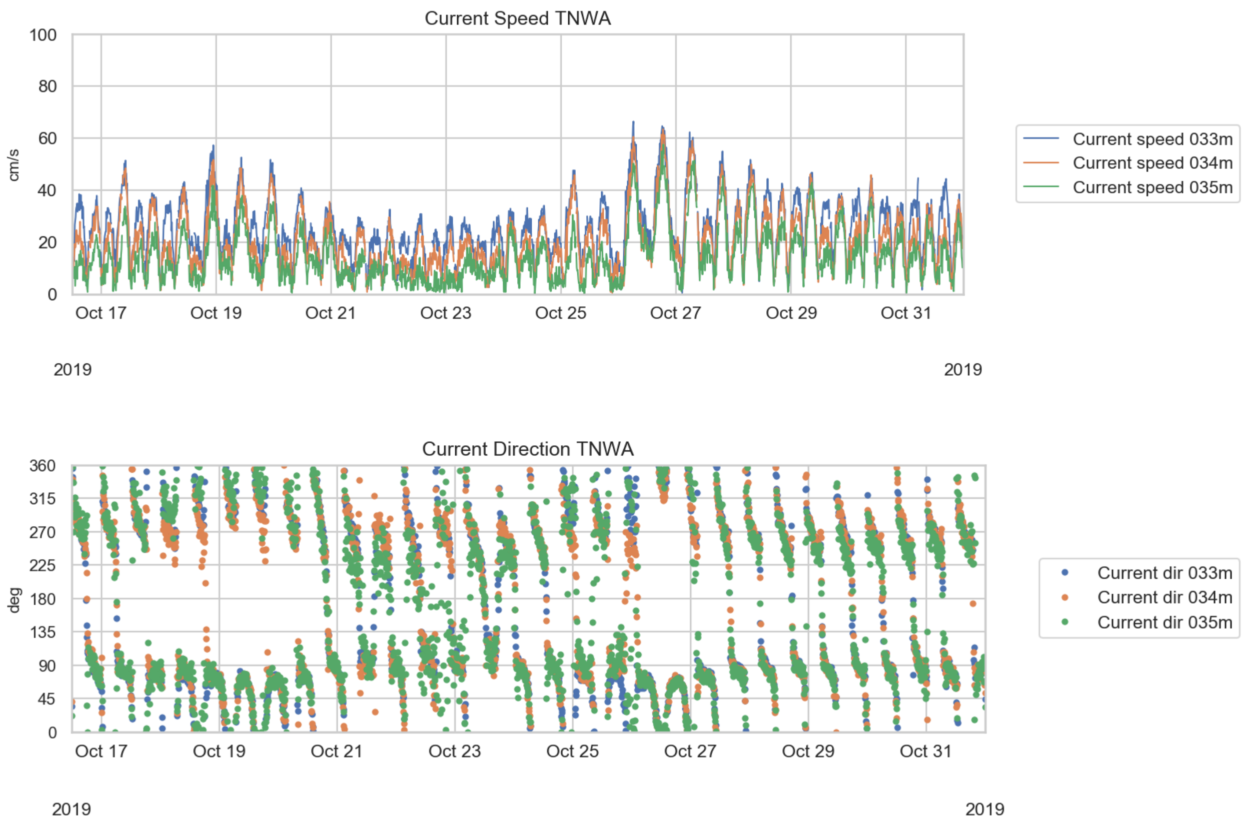


Figure 5.39: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWA, 16 – 31 October 2019.

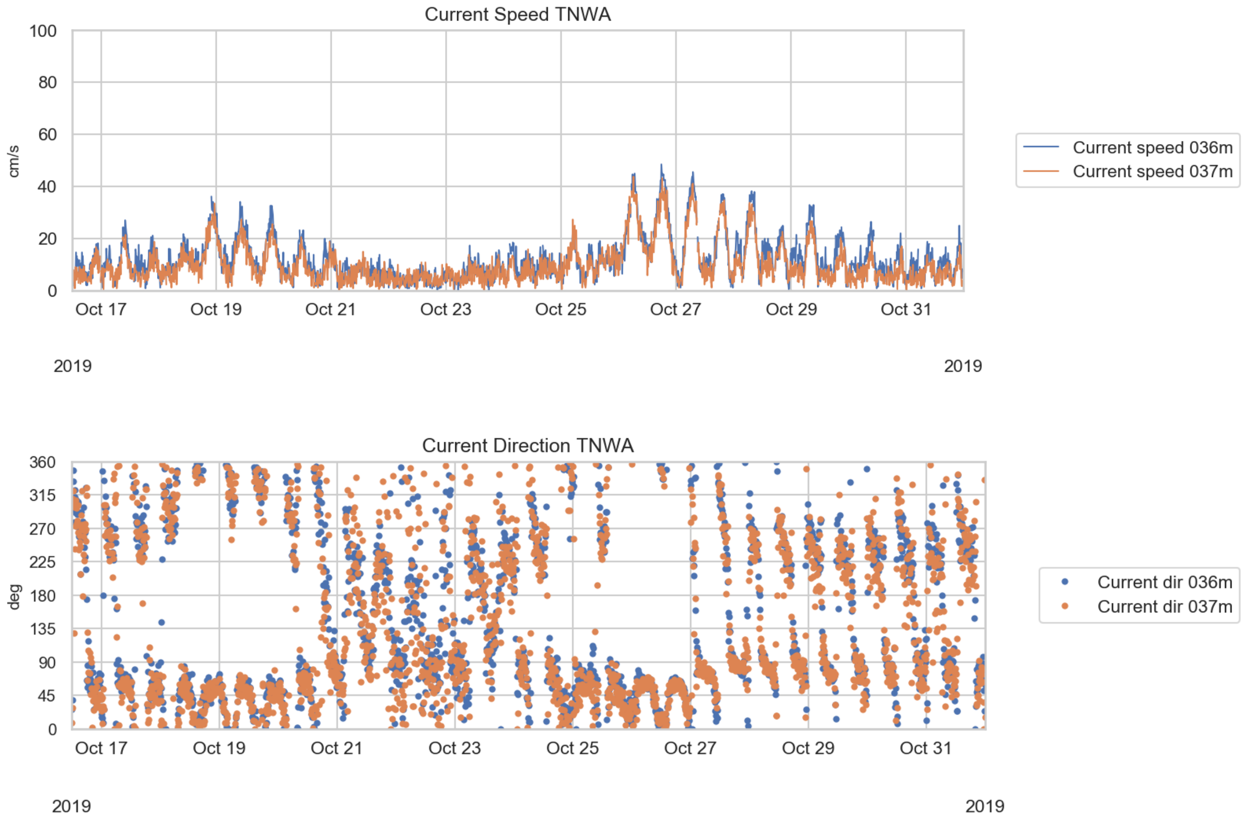


Figure 5.40: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWA, 16 – 31 October 2019.

5.2.1.5 Water pressure and bottom temperature data

Water level and bottom temperature data are not available at TNWA during October 2019. The sensor failed right after deployment. Spare was not available. The sensor had worked fine during testing on land before deployment.

A new water level sensor will be deployed at next service.

5.3 Presentation of the received data

5.3.1 Buoy Station TNWB

The following presentations show data from buoy WS191 at TNWB for October 2019. The data in this report is based on satellite transmitted data.

5.3.1.1 Meteorological data

Plots of air pressure, air temperature and sea surface temperature data are presented in Figure 5.41 - Figure 5.44. The sensors performed well in this period.

The air temperature varied from 8.3 to 16.8 °C with an average value of 13.2 °C. The sea surface temperature was in the range 14.0 – 16.8 °C with an average of 15.3 °C. The air pressure varied from 997 to 1031 hPa.

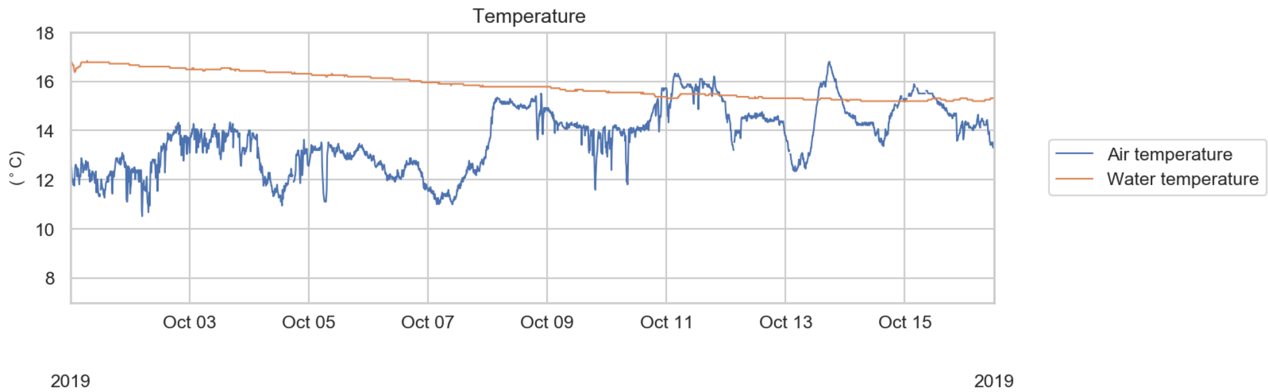


Figure 5.41: Air and sea surface temperature, 1 – 15 October 2019

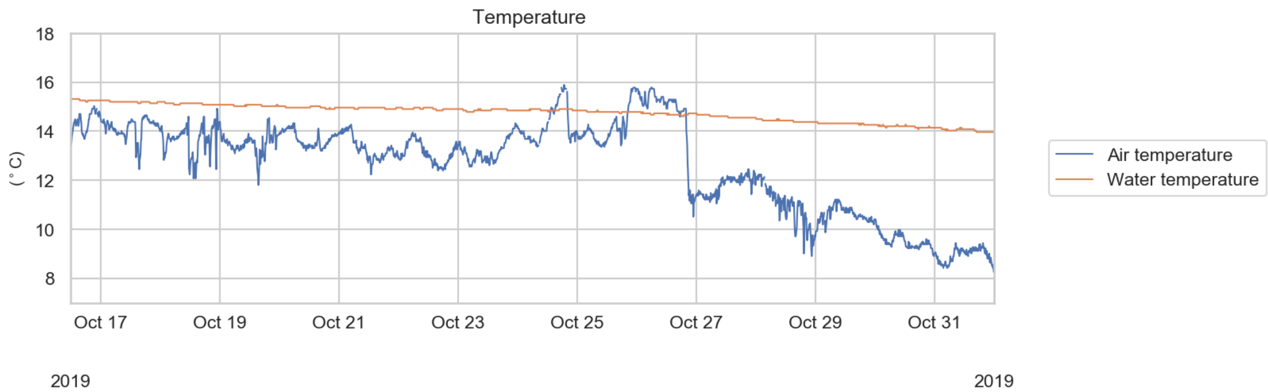


Figure 5.42: Air and sea surface temperature at TNWB, 16 – 31 October 2019

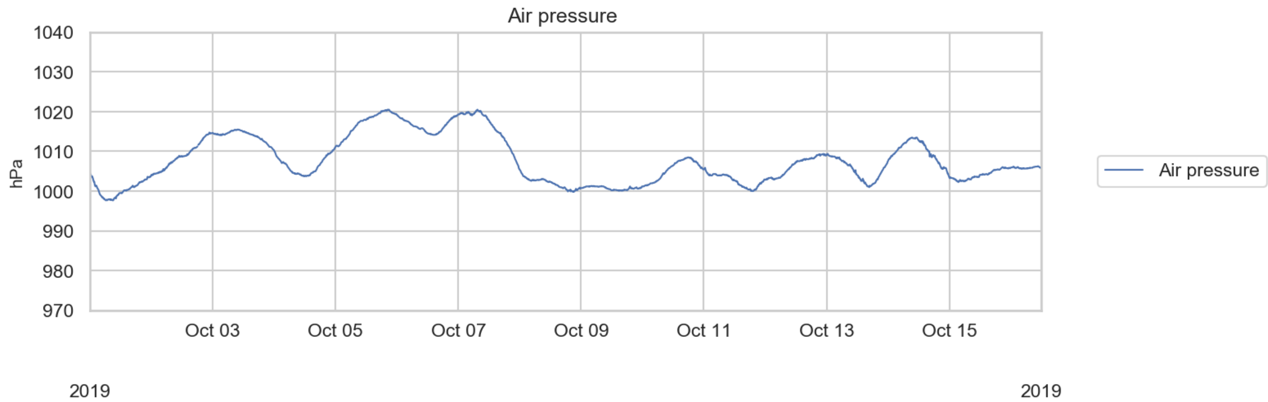


Figure 5.43: Air pressure at TNWB, 1 – 15 October 2019

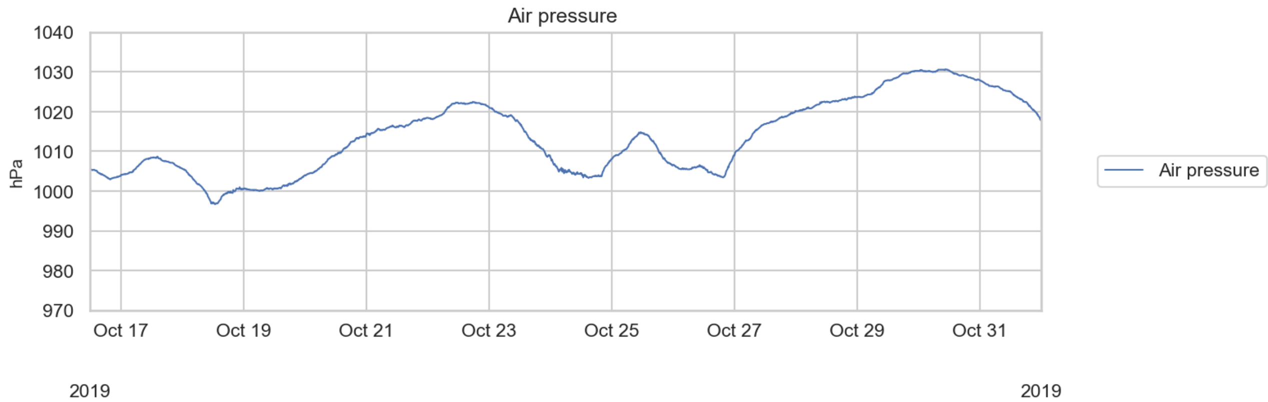


Figure 5.44: Air pressure at TNWB, 16 – 31 October 2019

5.3.1.2 Wave data

Plots of wave height, period and direction are presented in Figure 5.45 and Figure 5.46. The sensor has performed well with a high data availability.

The highest significant wave height (hm0) measured in this period was 4.4 m from a south-westerly direction ($\sim$ 230°) on 26 October at 02:50. The highest single wave of the record with hmax = 7.2 m during this period was observed on 26 October at 00:40. The buoy measured south-westerly wind ($\sim$ 220°) with a speed of 14-15 m/s at 4 m height before the wave height maximum.

In October the availability for Hmax was high. 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.

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.

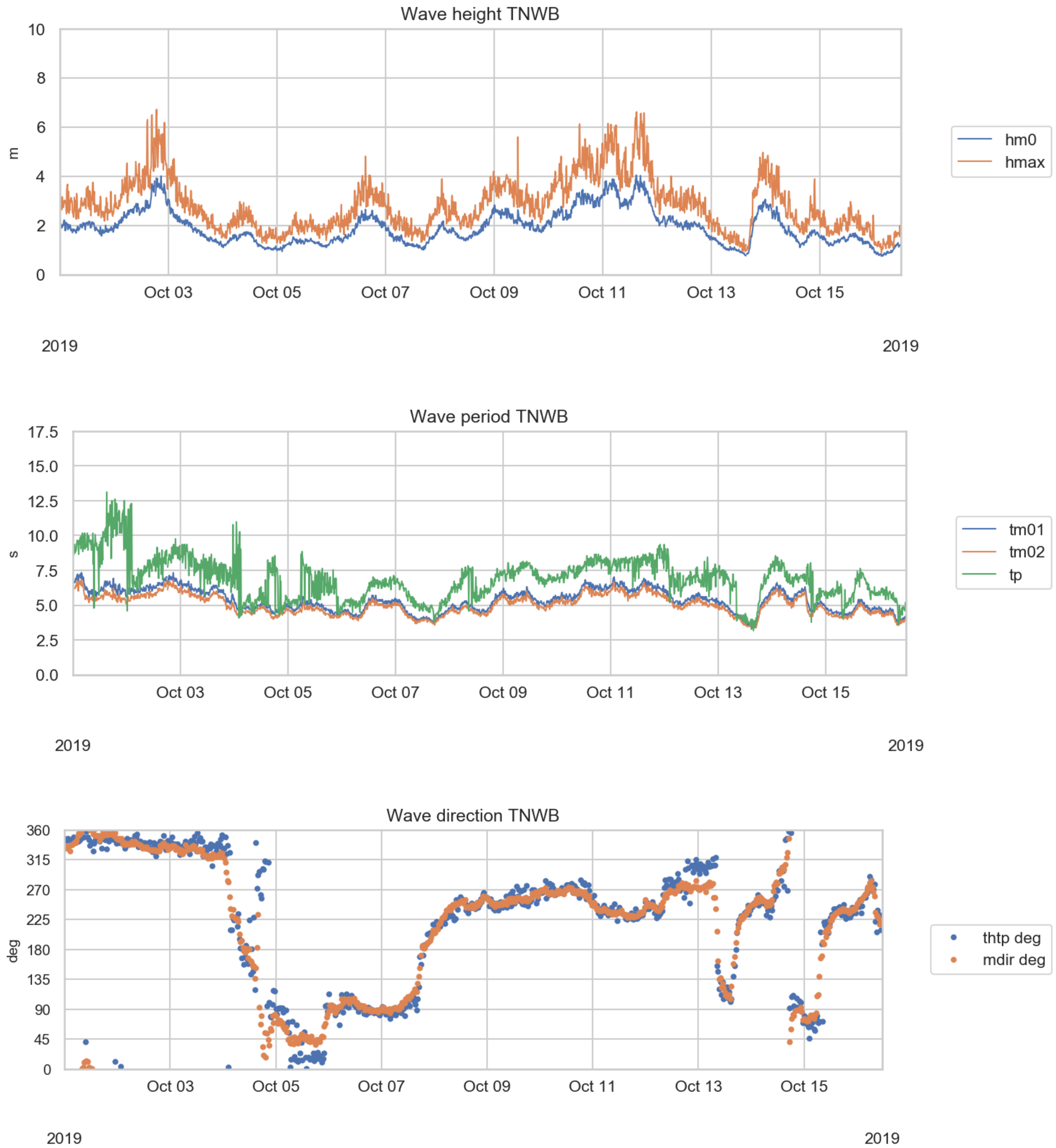


Figure 5.45: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWB, 1 – 15 October 2019.

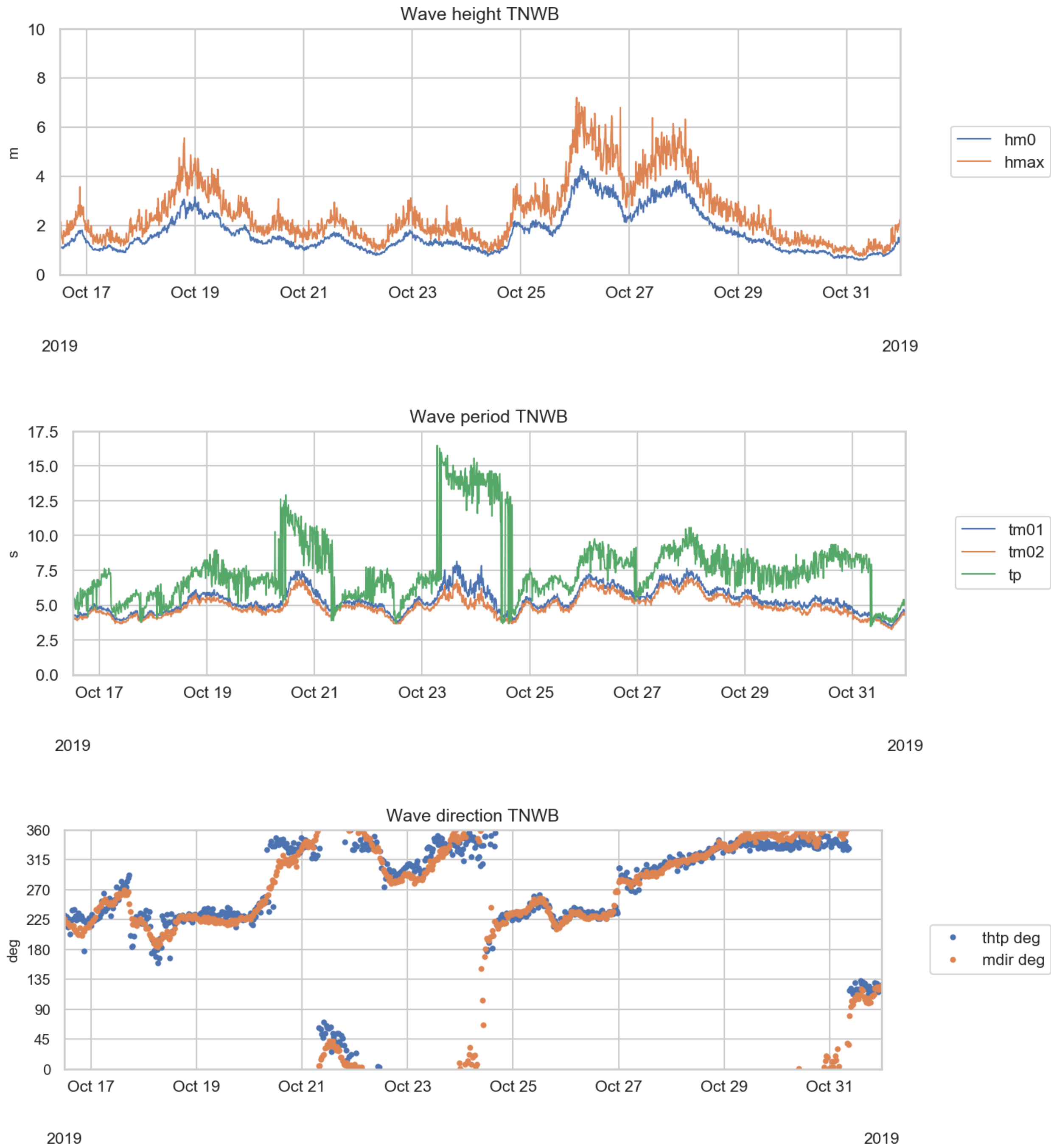


Figure 5.46: Time series plots of wave height (Hm0 and Hmax) (upper panel), wave period (Tm01, Tm02 and Tp) (second panel), and wave direction (ThTp and Mdir) (lower panel) at TNWB, 16 – 31 October 2019.

5.3.1.3 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 5.47 and Figure 5.48.

The data return of this sensor is high with 10 min mean wind speeds up to 16.8 m/s and gusts up to 23.4 m/s. The maximum wind speed and gust were measured on 25 October at 23:10 and on 25 October 21:50 respectively. The average wind speed at mast top height was 8.6 m/s.

Figure 5.47: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWB, 1 – 15 October 2019.

Figure 5.48: Plots of wind speed and gust (upper), and wind direction (lower) at 4 m a.s.l., at TNWB, 16 – 31 October 2019.

Lidar data after 12 September are not transmitted. Data will be downloaded at first service and the report will then be updated with the availability numbers and plots of the downloaded wind data.

5.3.1.4 Current velocity profile data

Plots of the current velocity profile time series are presented in Figure 5.49 - Figure 5.65.

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 81 cm/s at 4-9 m depth to 75 cm/s at 25 m depth. The average current speed in the profile varies with depth from 31 cm/s at 6-8 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. When raw data is downloaded the signal to noice ratio especially for the measurements near bottom can be checked to determine which measurements are valid.

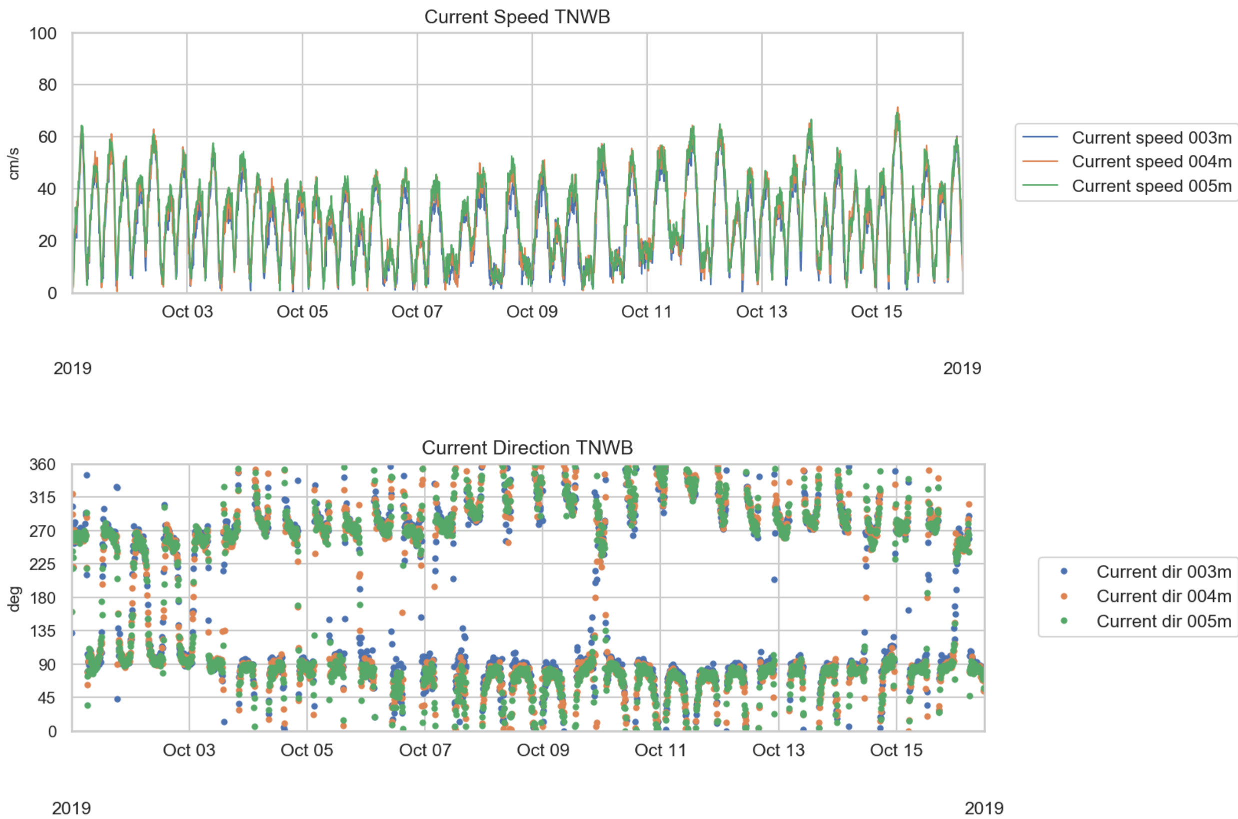


Figure 5.49: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWB, 1 – 15 October 2019.

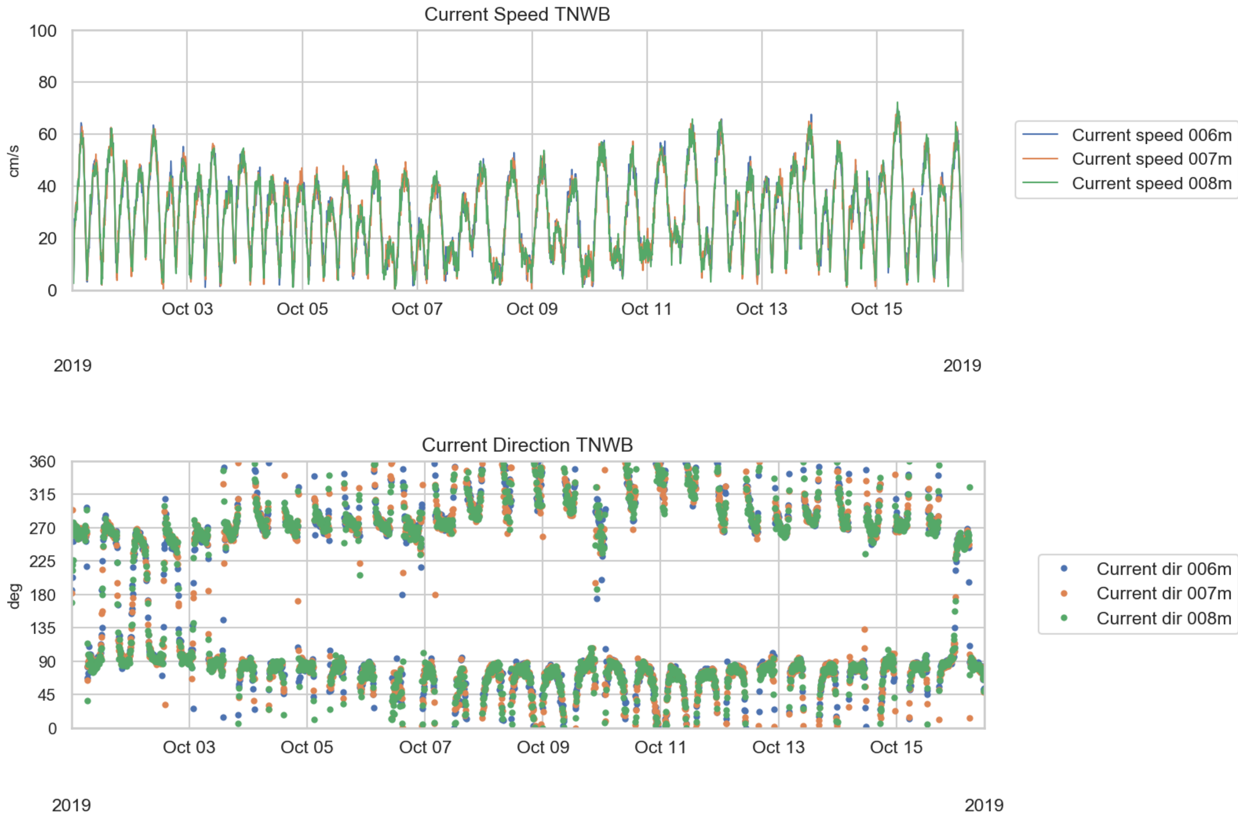


Figure 5.50: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWB, 1 – 15 October 2019.

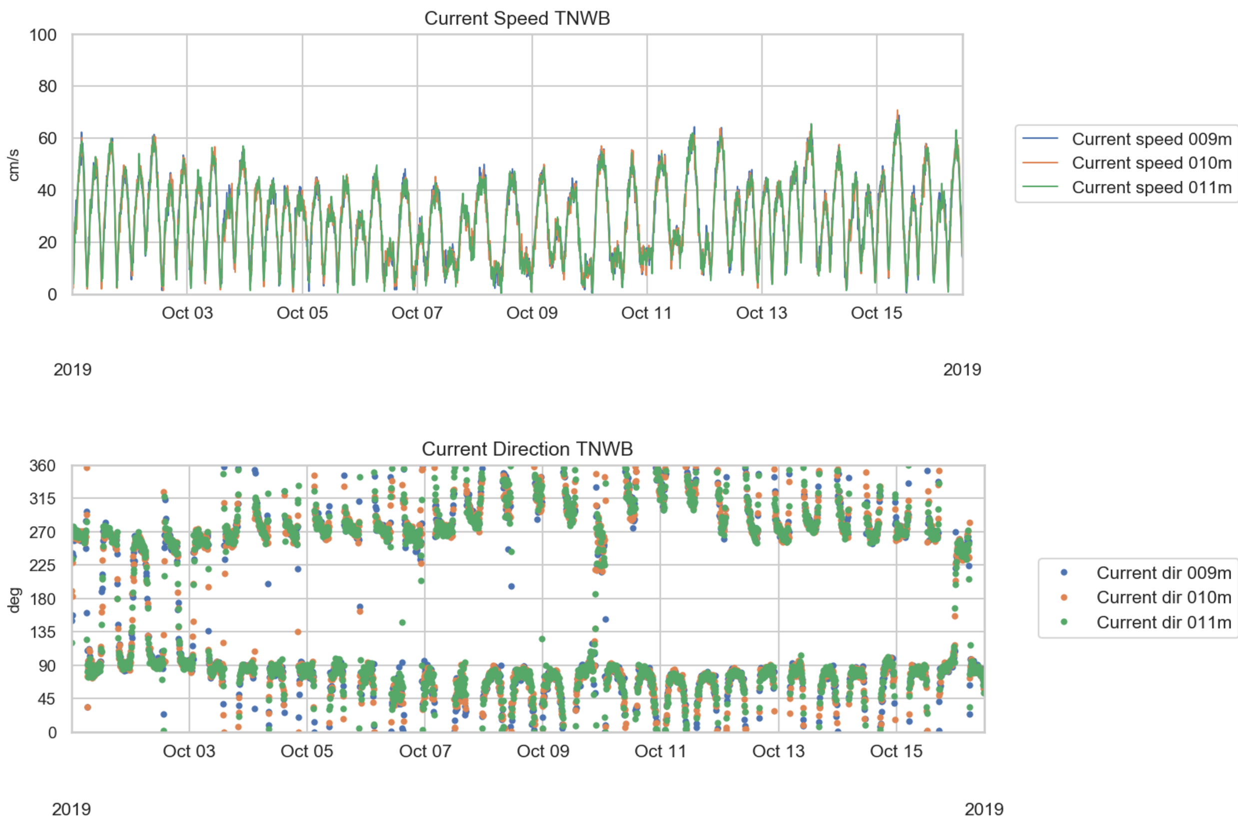


Figure 5.51: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWB, 1 – 15 October 2019.

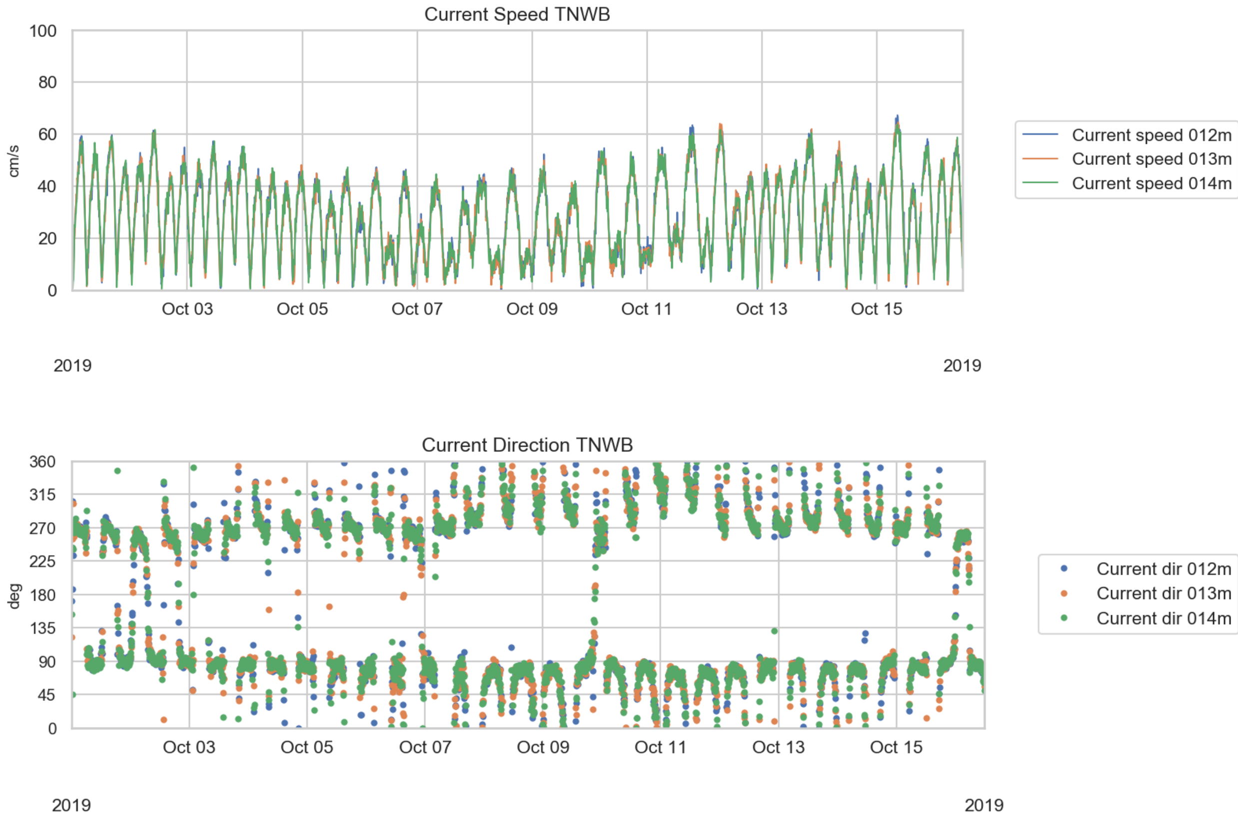


Figure 5.52: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWB, 1 – 15 October 2019.

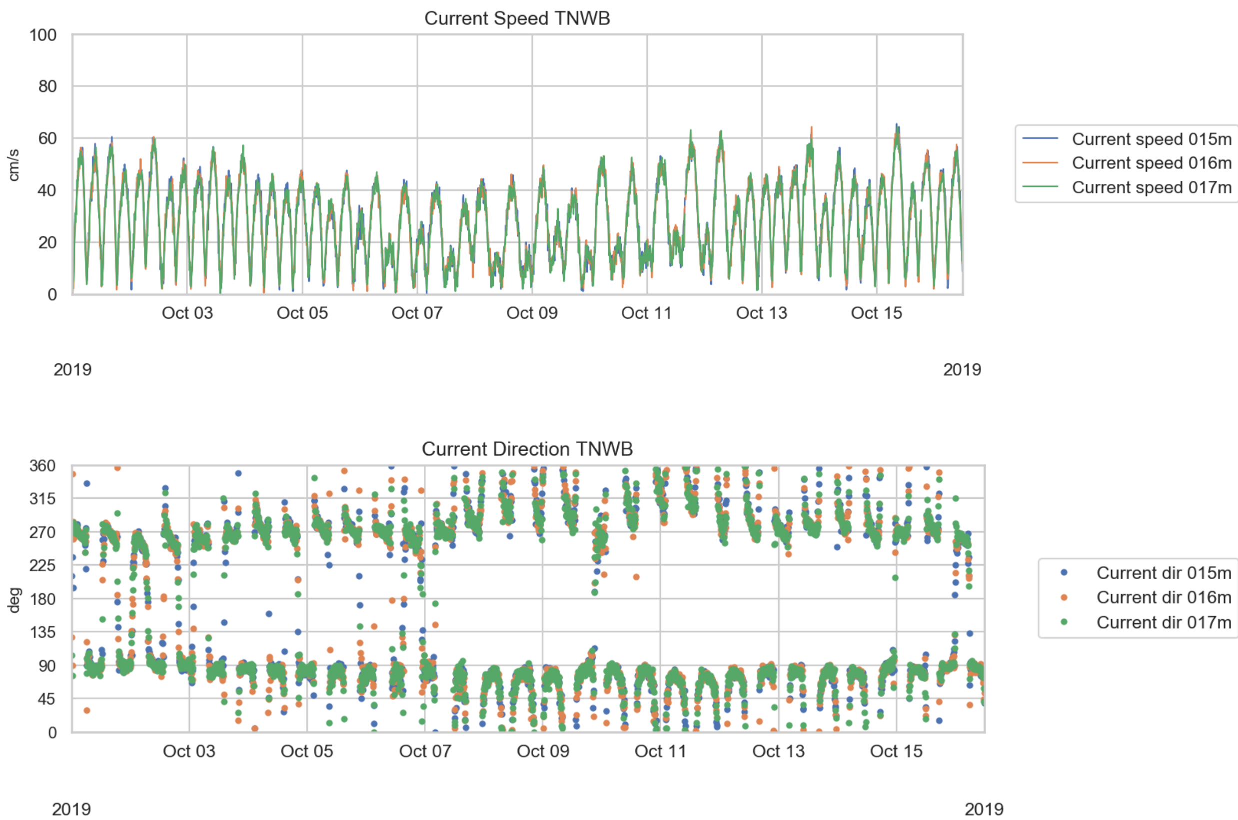


Figure 5.53: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWB, 1 – 15 October 2019.

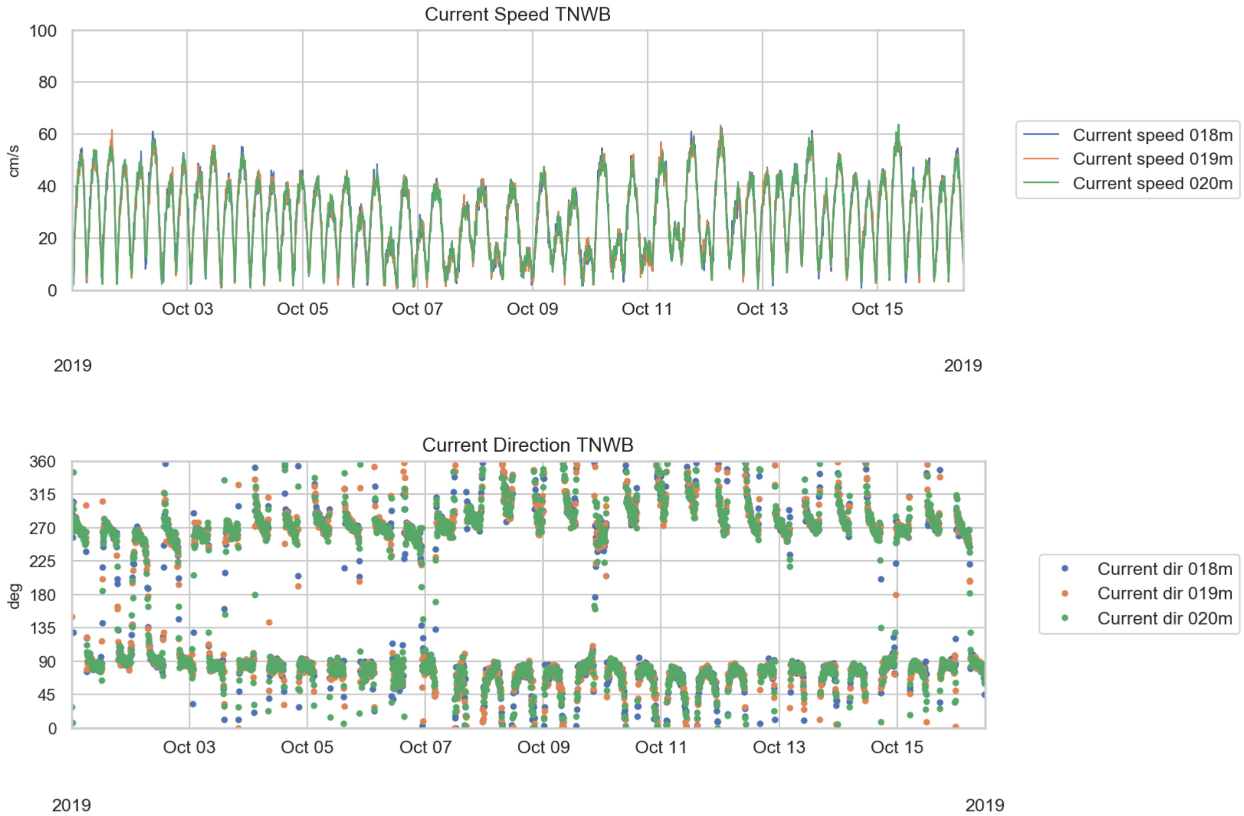


Figure 5.54: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWB, 1 – 15 October 2019.

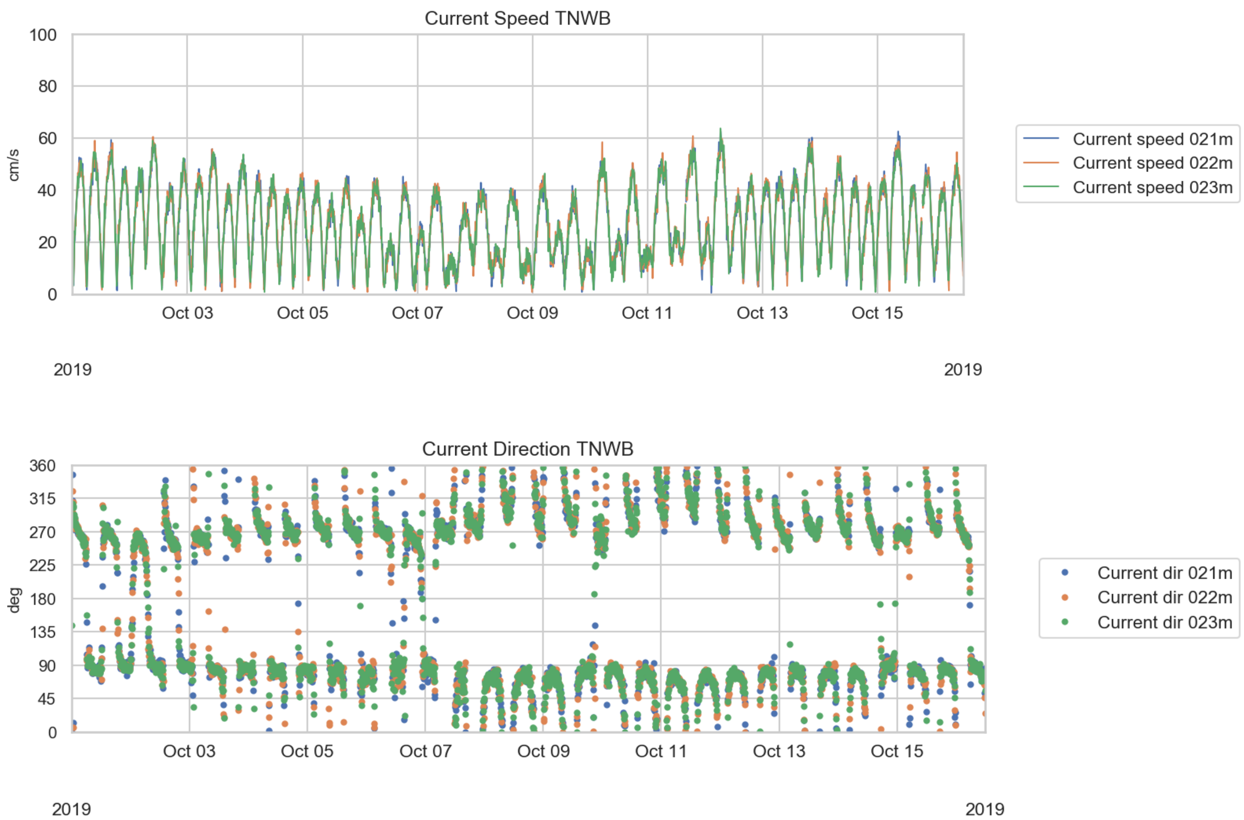


Figure 5.55: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWB, 1 – 15 October 2019.

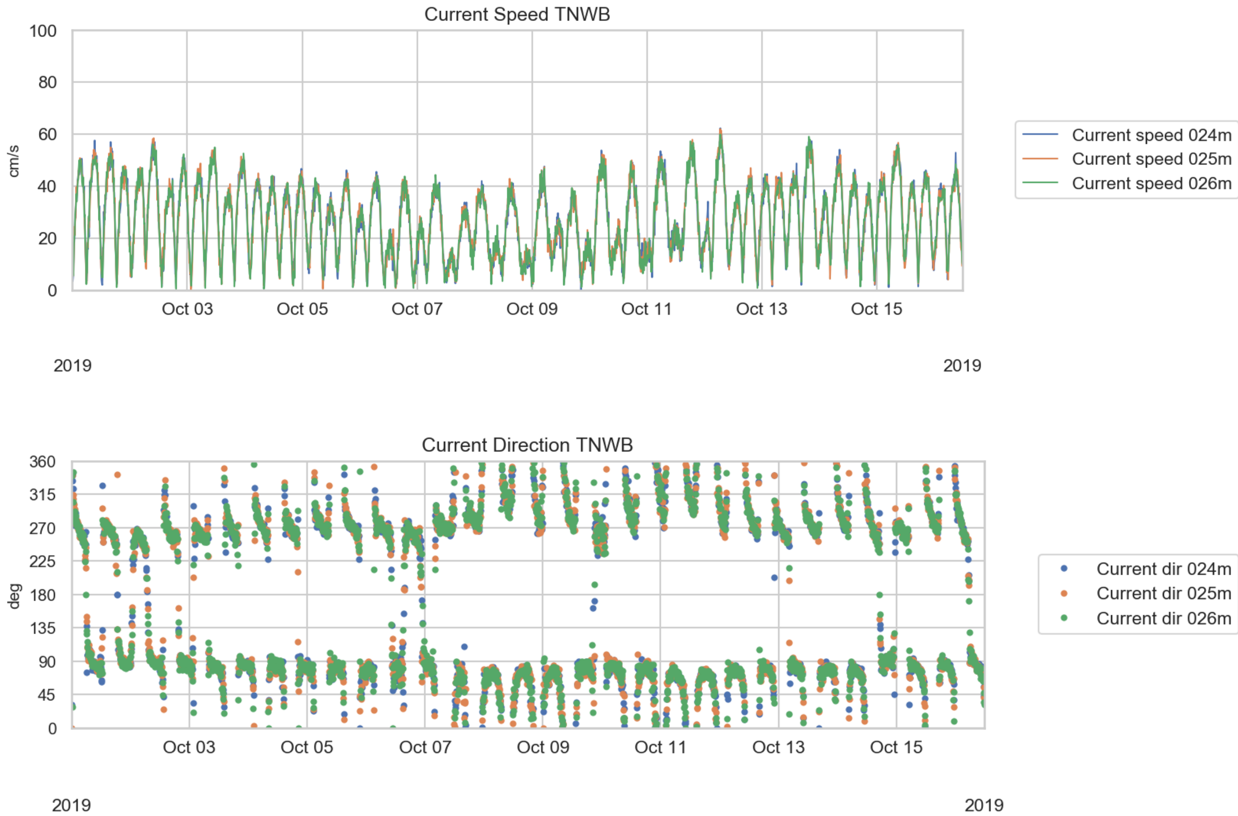


Figure 5.56: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWB, 1 – 15 October 2019.

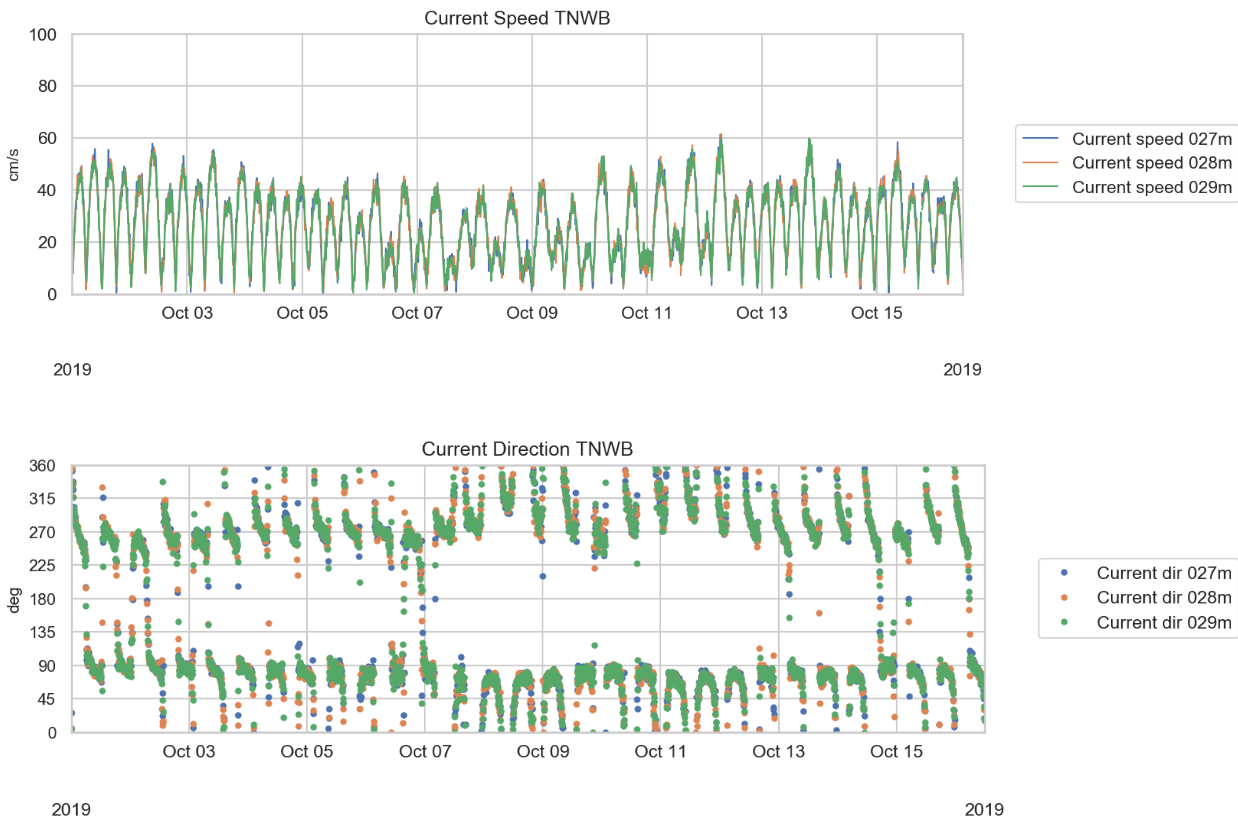


Figure 5.57: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWB, 1 – 15 October 2019.

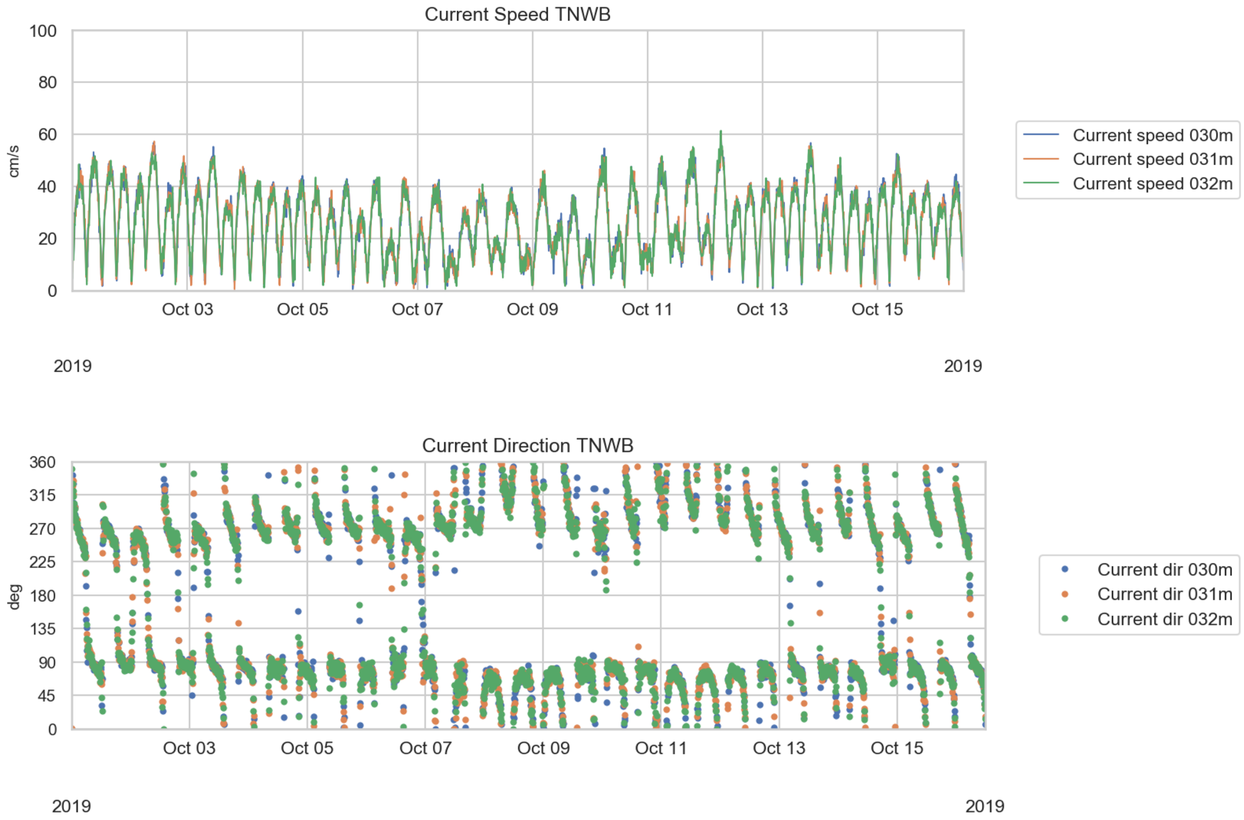


Figure 5.58: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWB, 1 – 15 October 2019.

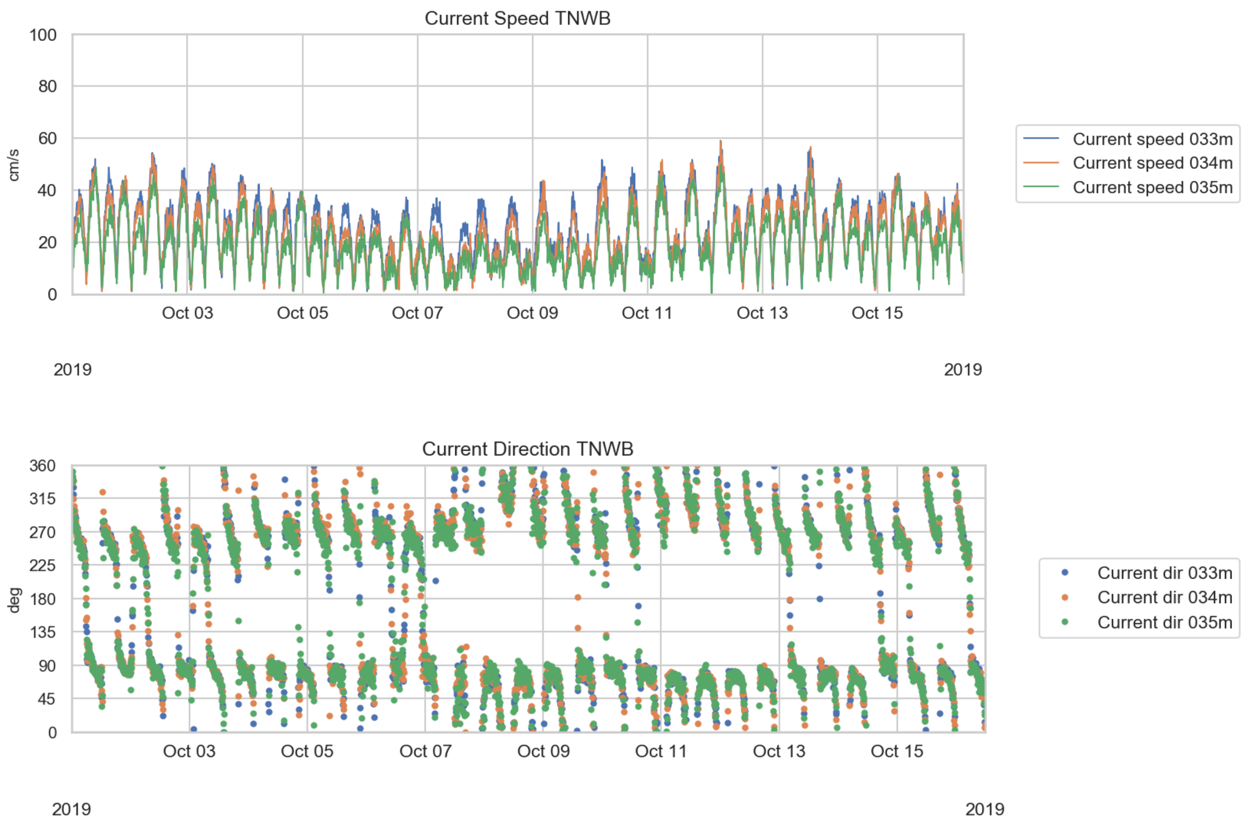


Figure 5.59: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWB, 1 – 15 October 2019.

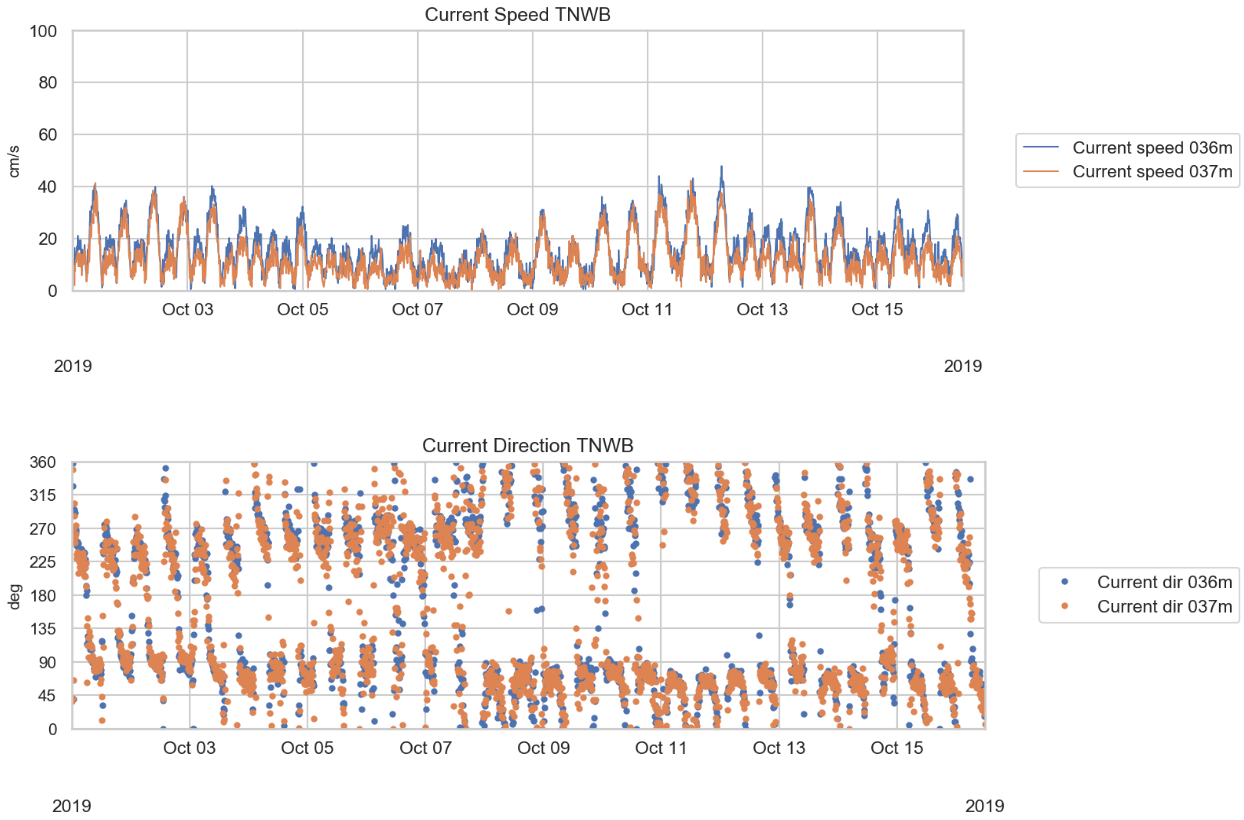


Figure 5.60: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWB, 1 – 15 October 2019.

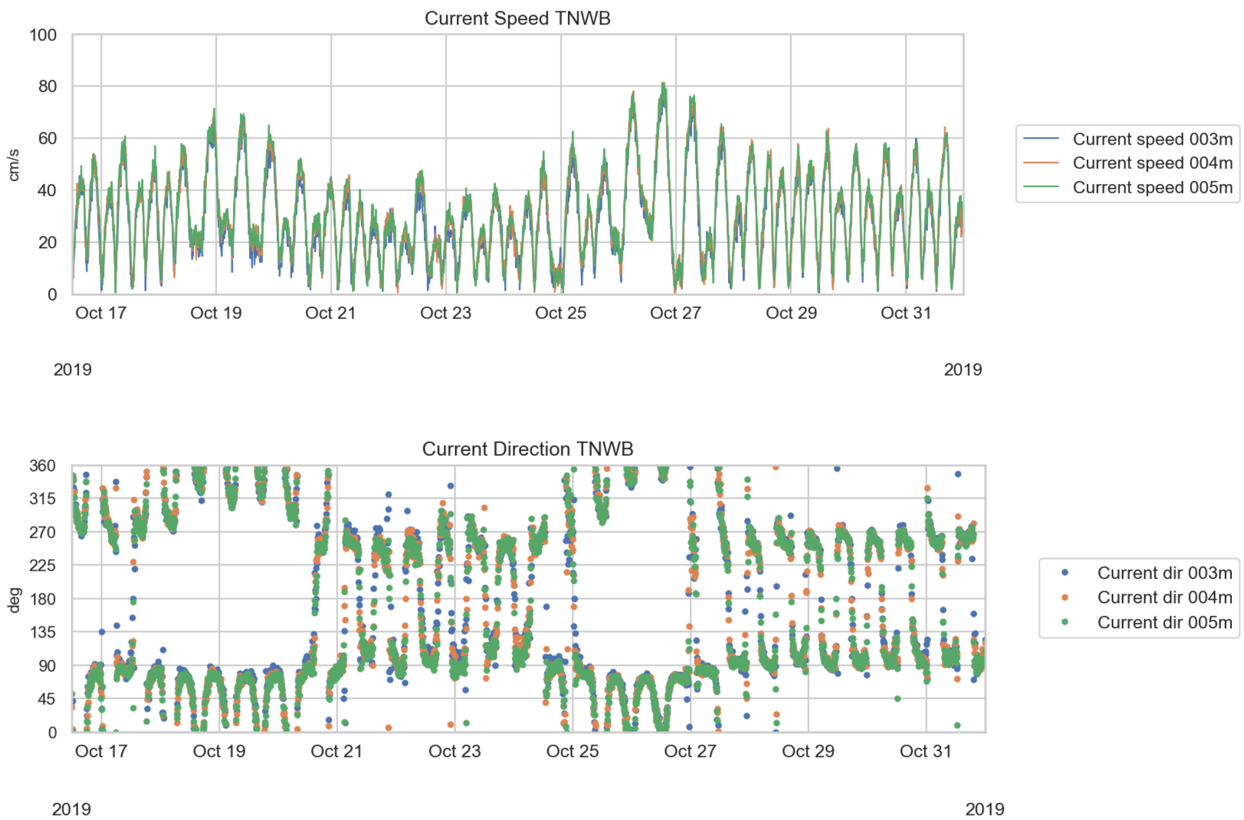


Figure 5.61: Current speed (upper) and direction (lower panel), 3 - 5 m depth, at TNWB, 16 – 31 October 2019.

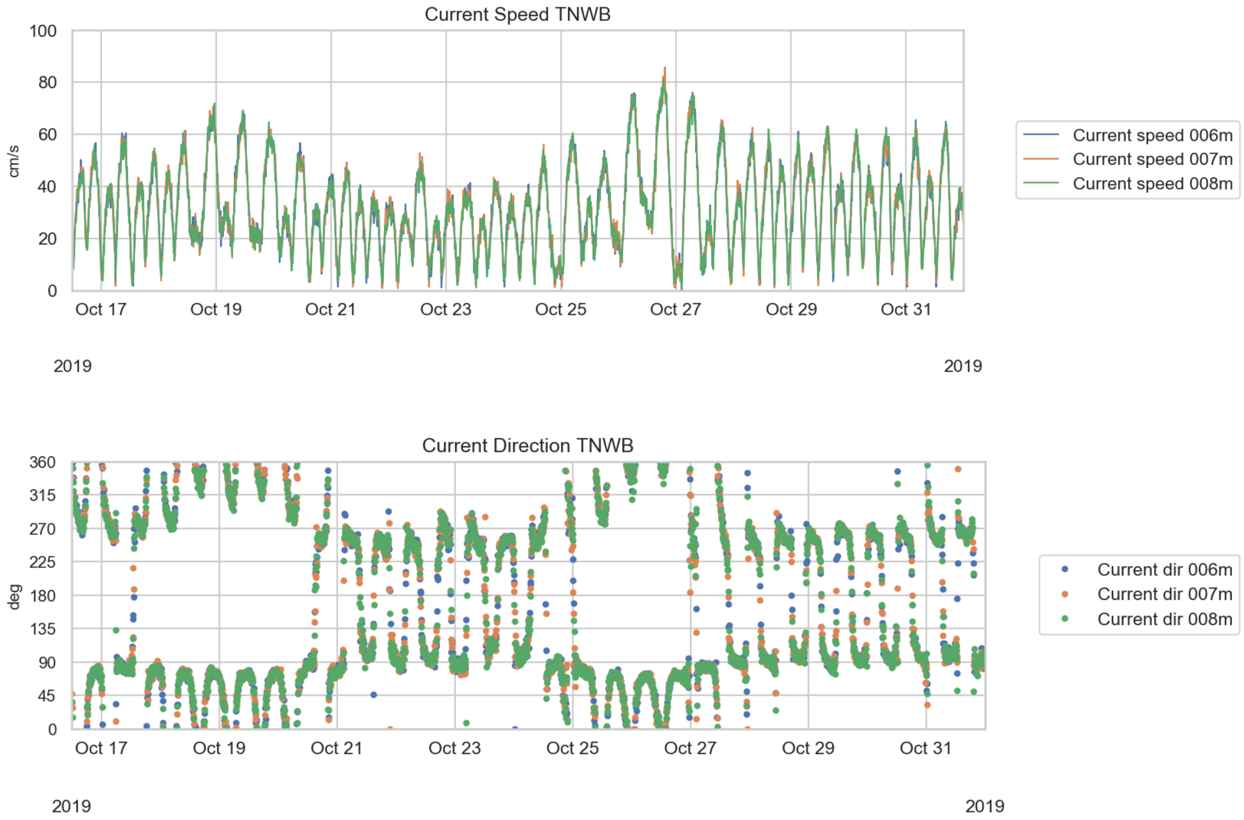


Figure 5.62: Current speed (upper) and direction (lower panel), 6 - 8 m depth, at TNWB, 16 – 31 October 2019.

Figure 5.63: Current speed (upper) and direction (lower panel), 9 - 11 m depth, at TNWB, 16 – 31 October 2019.

Figure 5.64: Current speed (upper) and direction (lower panel), 12 - 14 m depth, at TNWB, 16 – 31 October 2019.

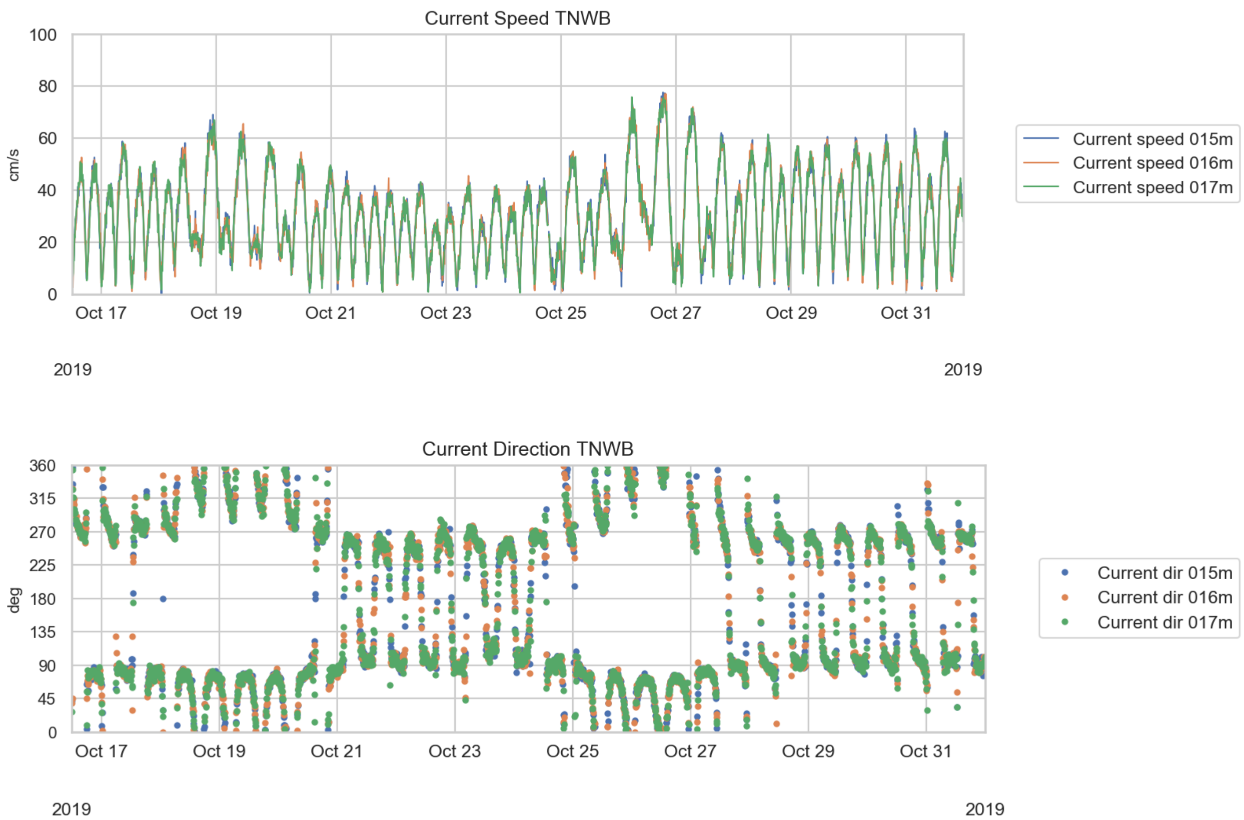


Figure 5.65: Current speed (upper) and direction (lower panel), 15 - 17 m depth, at TNWB, 16 – 31 October 2019.

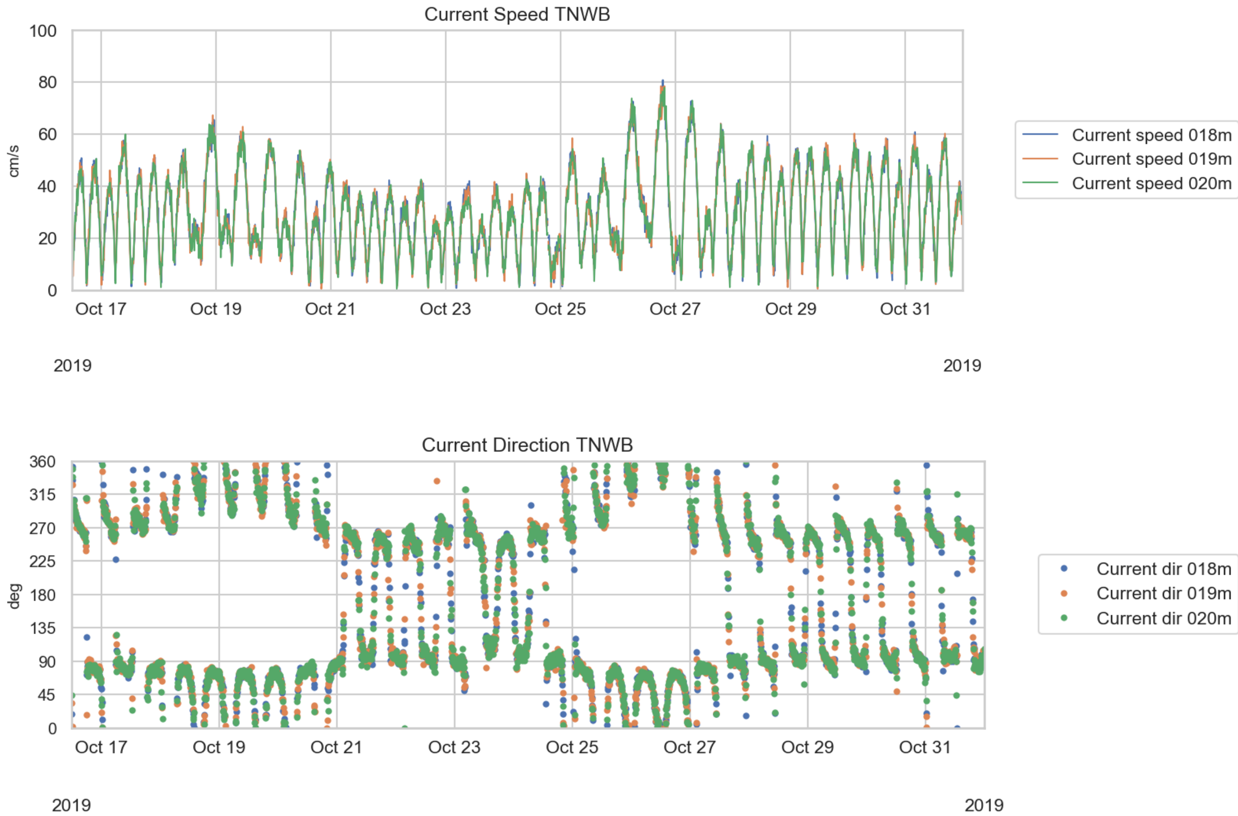


Figure 5.66: Current speed (upper) and direction (lower panel), 18 - 20 m depth, at TNWB, 16 – 31 October 2019.

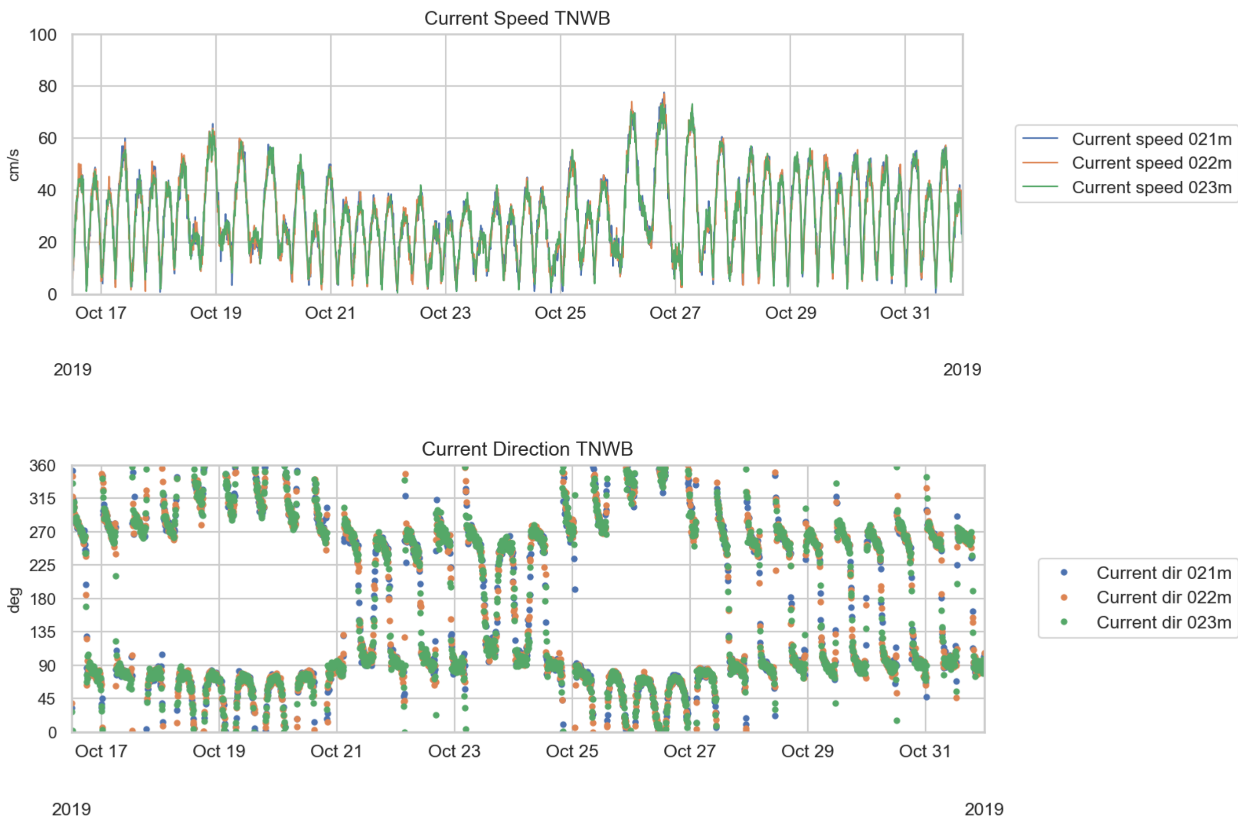


Figure 5.67: Current speed (upper) and direction (lower panel), 21 - 23 m depth, at TNWB, 16 – 31 October 2019.

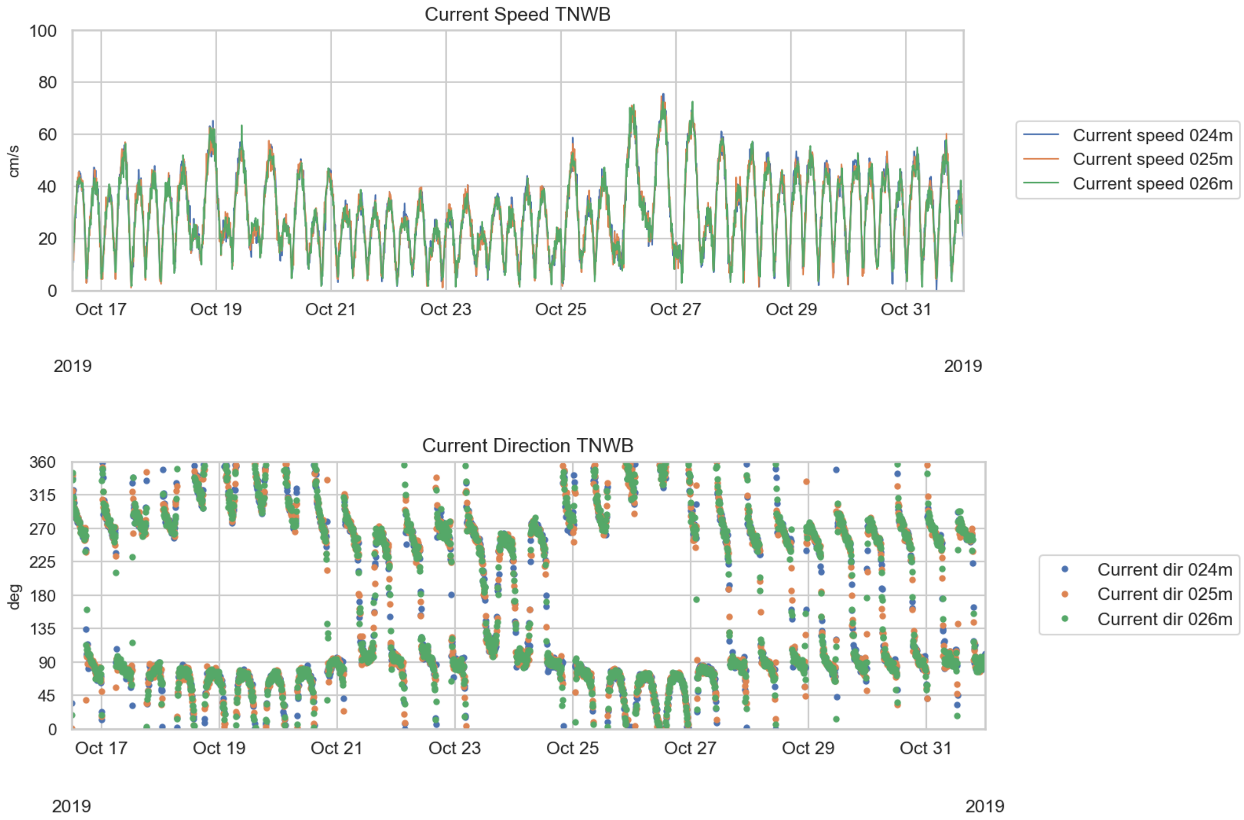


Figure 5.68: Current speed (upper) and direction (lower panel), 24 - 26 m depth, at TNWB, 16 – 31 October 2019.

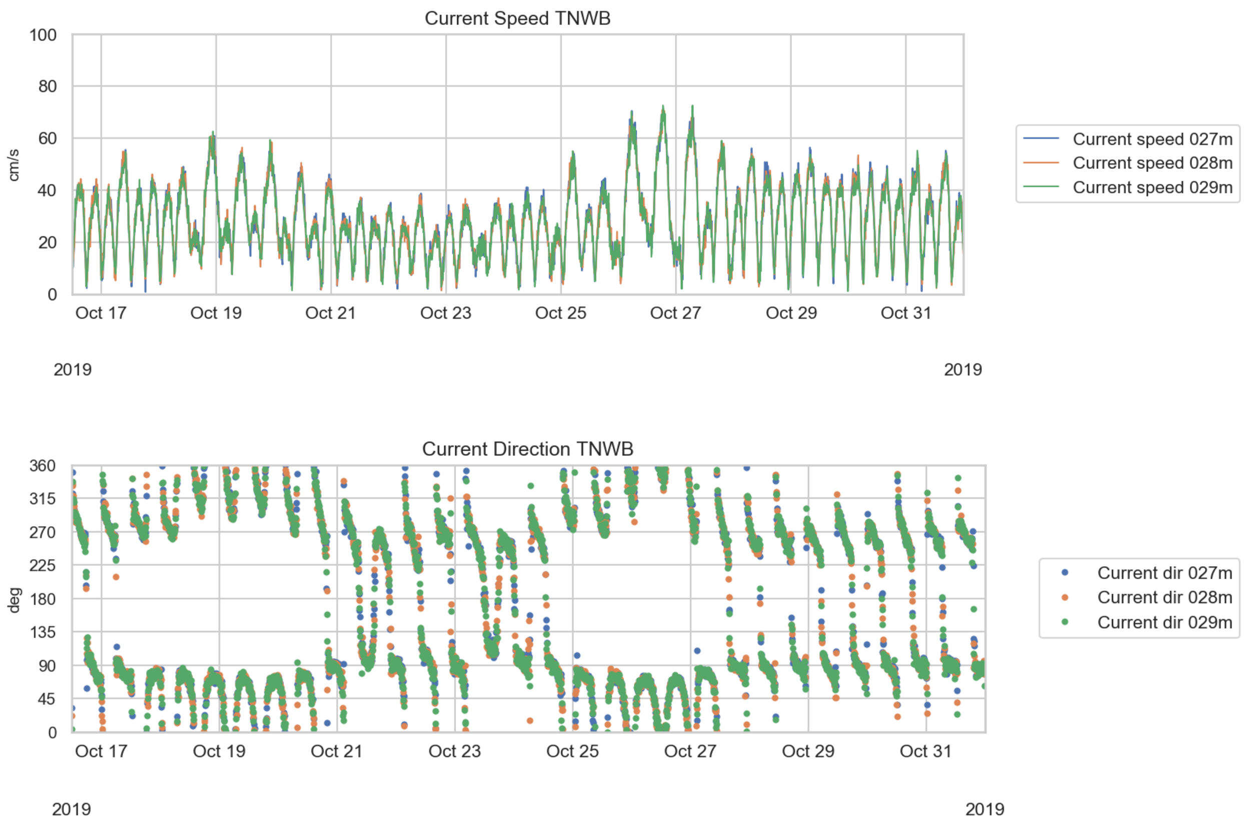


Figure 5.69: Current speed (upper) and direction (lower panel), 27 - 29 m depth, at TNWB, 16 – 31 October 2019.

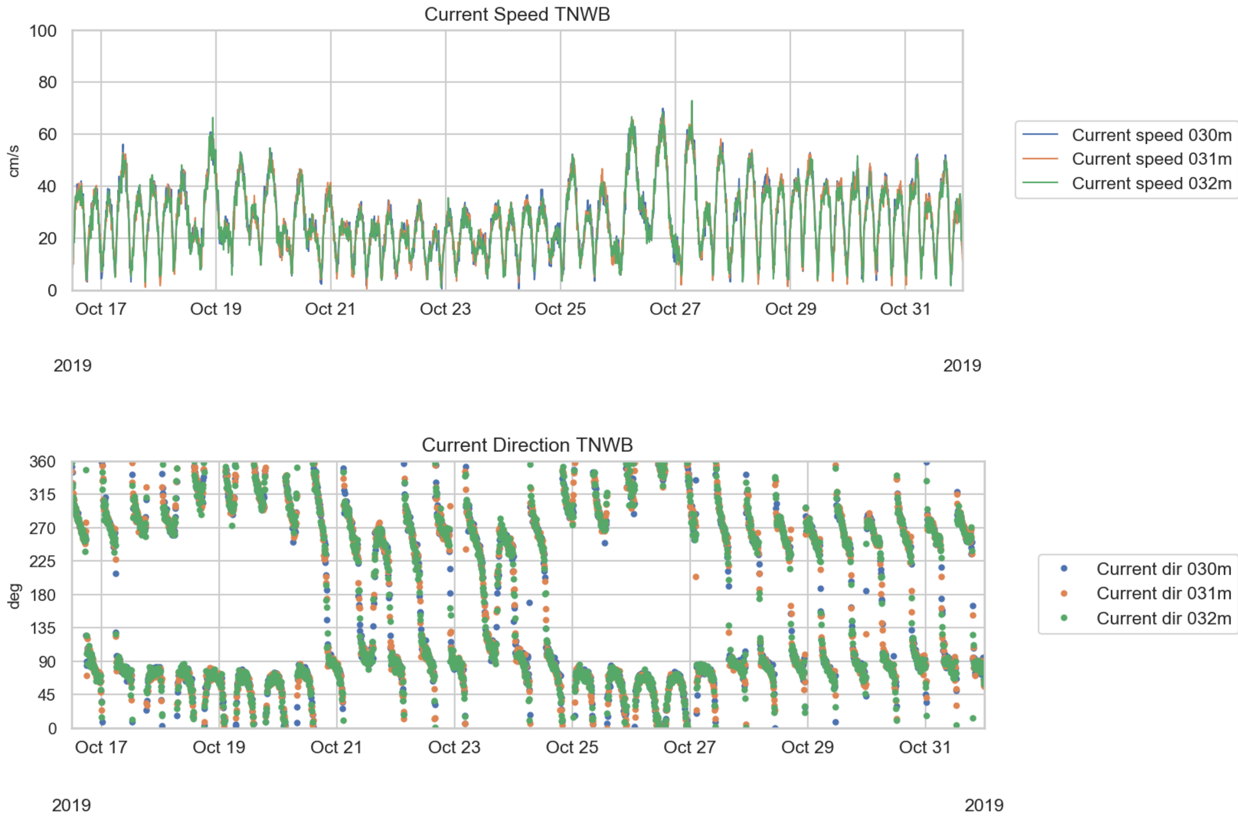


Figure 5.70: Current speed (upper) and direction (lower panel), 30 - 32 m depth, at TNWB, 16 – 31 October 2019.

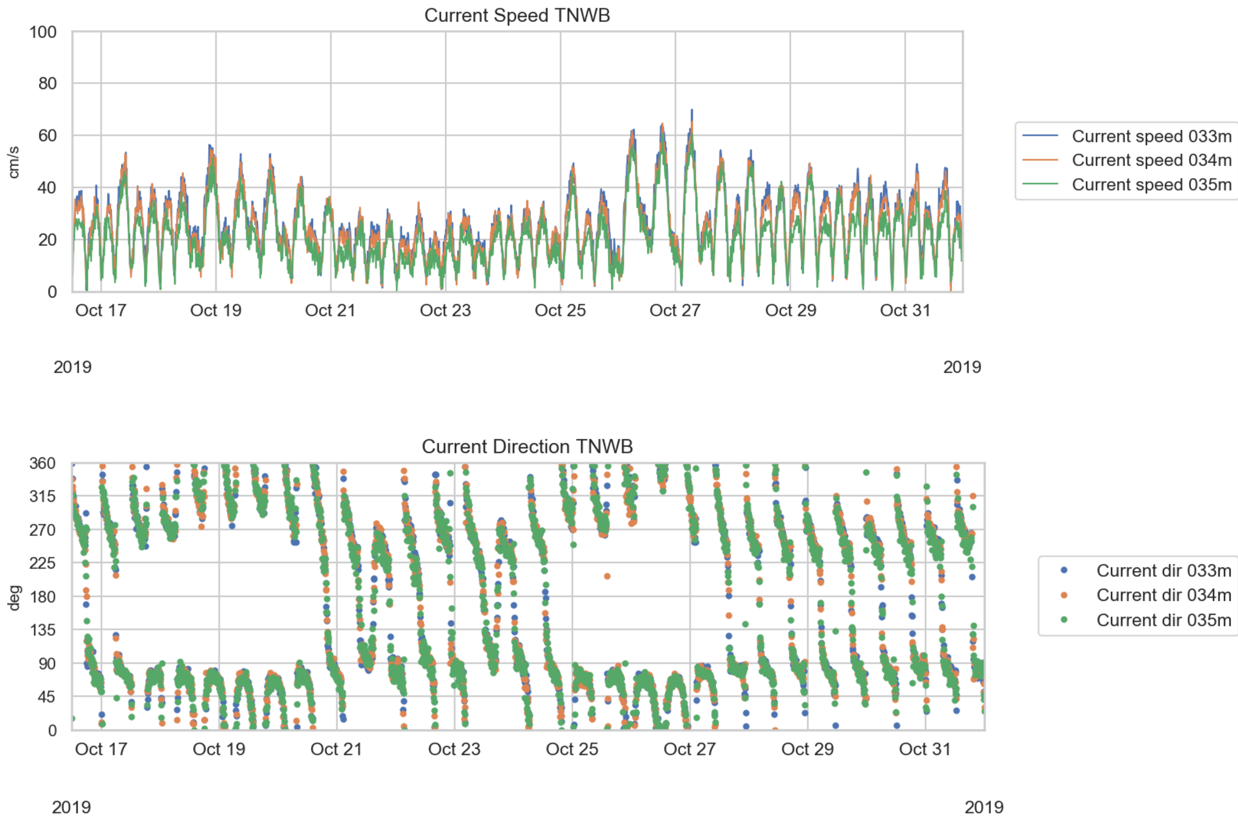


Figure 5.71: Current speed (upper) and direction (lower panel), 33 - 35 m depth, at TNWB, 16 – 31 October 2019.

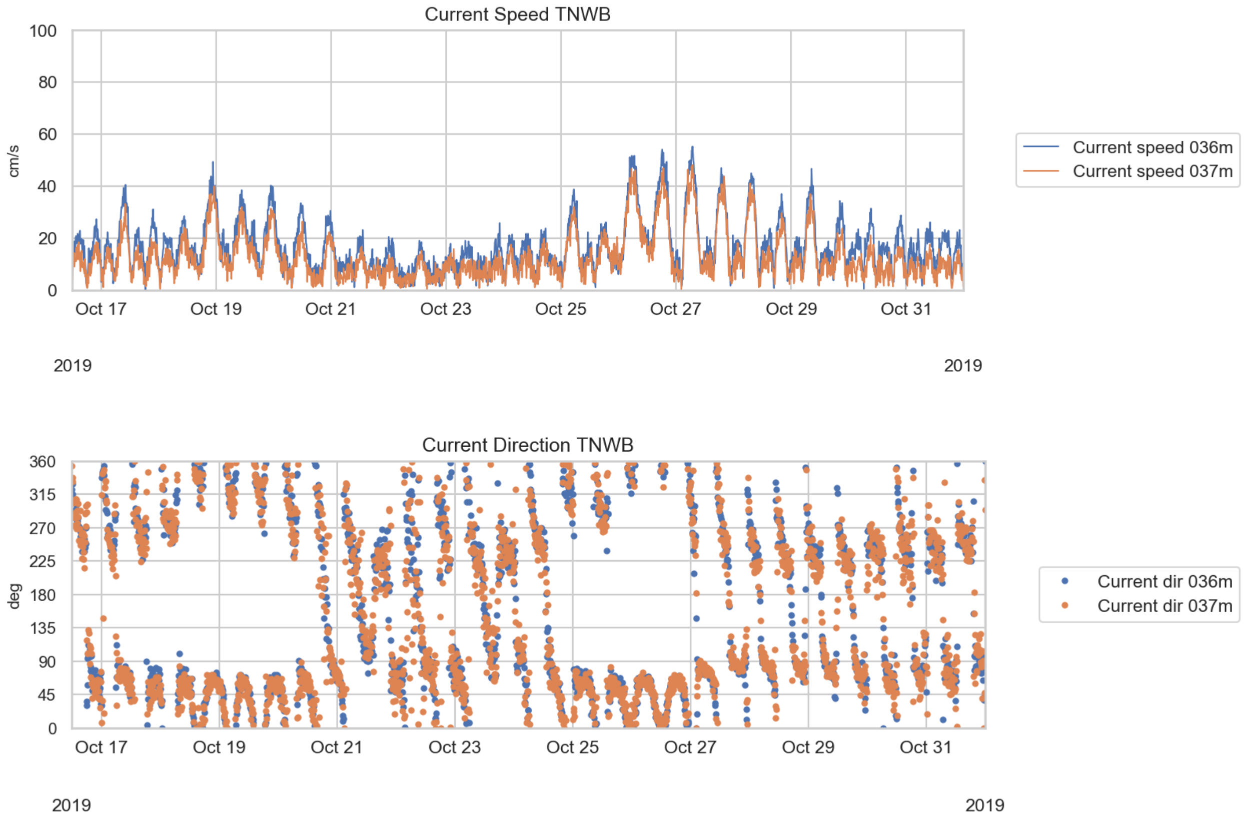


Figure 5.72: Current speed (upper) and direction (lower panel), 36 - 37 m depth, at TNWB, 16 – 31 October 2019.

5.3.1.5 Water pressure and bottom temperature data

Water pressure and bottom temperature data are presented in Figure 5.73 - Figure 5.76.
The water pressure data are not referenced to MSL or LAT.

The water pressure at bottom varies from 38.00 to 40.34 dBar with an average of 39.28 dBar in October.

In mid September the water level sensor seems to have moved to a deeper point, for details see September report. In October the water level sensor seems to have been stable.

The bottom temperature varied from 13.9 to 16.8 °C, with a mean temperature of 15.3 °C. The stepwise behaviour of the plot is due to the resolution of the data.

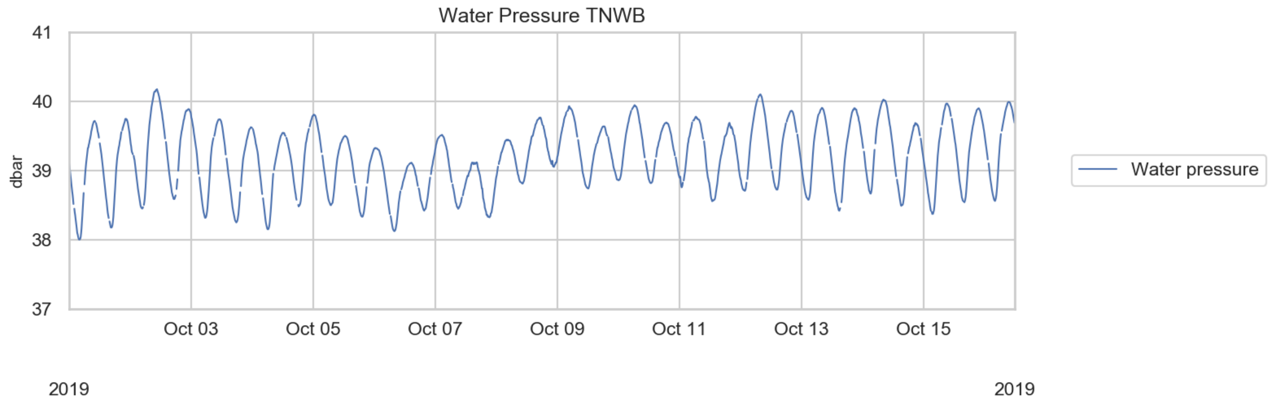


Figure 5.73: Water pressure at TNWB, 1 – 15 October 2019

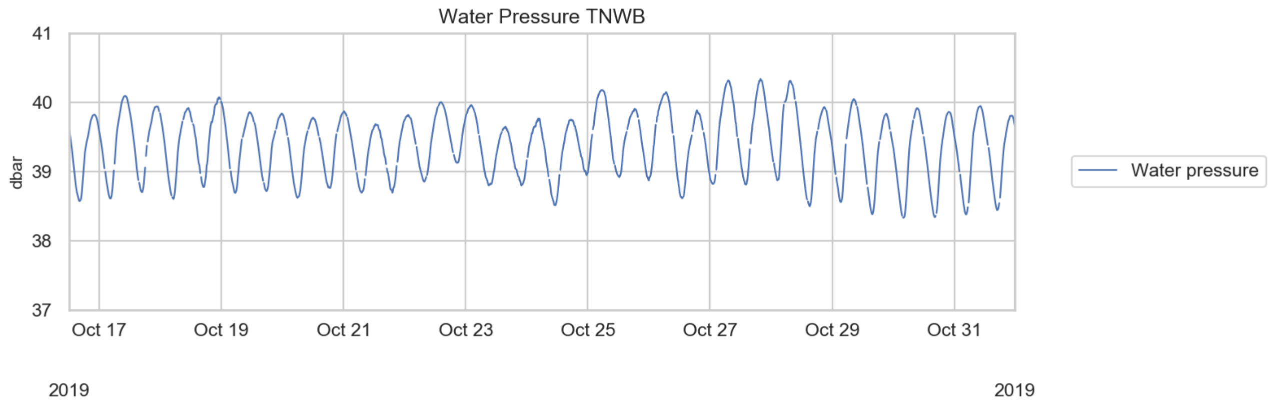


Figure 5.74: Water pressure at TNWB, 16 – 31 October 2019

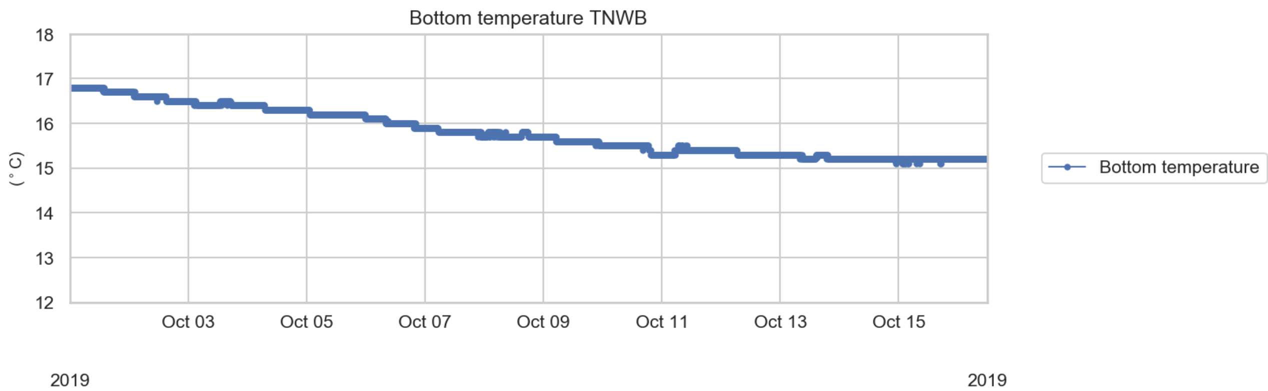


Figure 5.75: Bottom temperature at TNWB, 1 – 15 October 2019

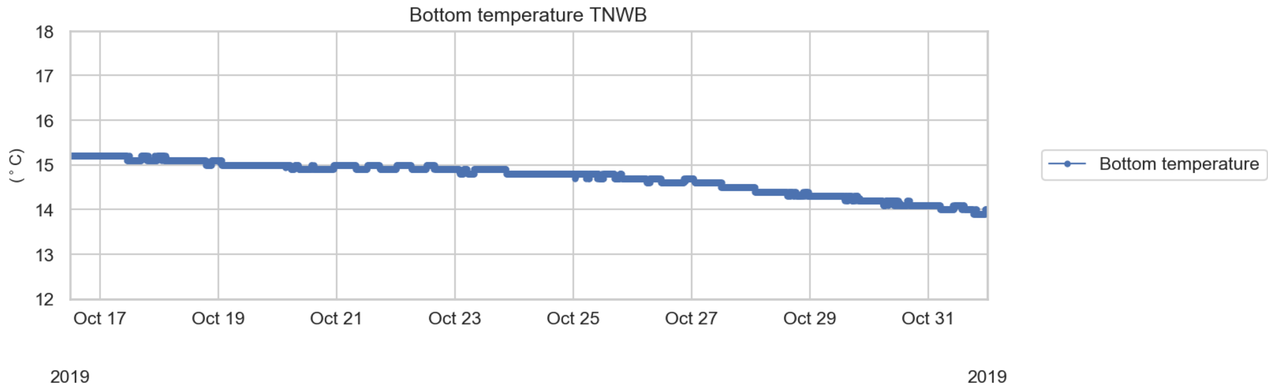


Figure 5.76: Bottom temperature at TNWB, 16 – 31 October 2019

6. Concluding Remarks

The data from the SWLBs at Ten Noorden van de Waddeneilanden for October 2019 presented in the previous sections show that the buoys have delivered measurements for most parameters in accordance with the objective of high availability.

The data availability of LiDAR buoy WS190 at TNWA is high, in the range 96-99 % for all parameters during October 2019, except for LiDAR wind speeds and direction (79 %) and water level (0 %).

The data availability of LiDAR buoy WS191 at TNWB is high, in the range 96-99 % for all parameters during October 2019, except for LiDAR wind speeds and direction (0 %).

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

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[1] Deltares. Ten Noorden van de Waddeneilanden Field Measurement Campaign. Validation Report - October 2019. Tech. Rep. 11203488-002-HYE-0003, Version 2.0, January 29, 2020, Final, S. Caires, 2020.

[2] OWA. Carbon Trust Offshore Wind Accelerator roadmap for the commercial acceptance of floating LIDAR technology. Tech. Rep. CTC819 Version 1.0, 21 December 2013, OWA, 2013.

[3] DNVGL. Assessment of the Fugro/Oceanor Seawatch Floating Lidar Verification at RWE IJmuiden Met Mast. Tech. Rep. GLGH-4257 13 10378-R-0003, Rev. B, issue date 2015-01-30, DNV GL, 2015.

[4] Natural Power. Floating lidar validation analysis, seawatch wind lidar buoy. Tech. Rep. ref. no. 1124607/D, Natural Power, 2015.

[5] DNVGL. Assessment of the Fugro OCEANOR Seawatch Wind LiDAR Buoy Pre-Deployment Validation on Frøya, Norway. Tech. Rep. GLGH-4257 13 10378-R-0004, Rev. A, issue date 2015-03-31, DNV GL, 2015.

Appendix A: Buoy instrumentation logs

TNWA

Table 1: WS190 buoy deployment records.

SWLB	**WS190**			
Instrument	**Serial Number**	**Time Deployed** From	Until	**Reason**
PMU	436	2019-06-19 04:45		
Wavesense	366	2019-06-19 04:45		
DGPS AsteRx4	181013	2019-06-19 04:45		
Septentrio	AsteRx: 87	2019-06-19 04:45		
Compass	1047491	2019-06-19 04:45		
LiDAR	ZX843M	2019-06-19 04:45		
Gill Windsonic	18320036	2019-06-19 04:45		
Nortek	AQP 9721	2019-06-19 04:45		
Aquadopp	AQD 15088	2019-06-19 04:45		
Vaisala PTB	P4120802	2019-06-19 04:45		
Vailsala HMP	P1730331	2019-06-19 04:45		
Thelma	562	2019-06-19 04:45		
Buoy Tracker XEOS	680	2019-06-19 04:45		

TNWB

Table 2: WS191 buoy deployment records.

SWLB	**WS191**			
Instrument	**Serial Number**	**Time Deployed**		**Reason**
		From	Until	
PMU	437	2019-06-19 06:00		
Wavesense	371	2019-06-19 06:00		
DGPS AsteRx4	181014	2019-06-19 06:00		
Septentrio	AsteRx: 88	2019-06-19 06:00		
Compass	1047474	2019-06-19 06:00		
LiDAR	ZX862M	2019-06-19 06:00		
Gill Windsonic	19060137	2019-06-19 06:00		
Nortek	AQP 9744	2019-06-19 06:00		
Aquadopp	AQD 14707	2019-06-19 06:00		
Vaisala PTB	P4120800	2019-06-19 06:00		
Vaisala HMP	P4050599	2019-06-19 06:00		
Thelma	926	2019-06-19 06:00		
Buoy Tracker XEOS	771	2019-06-19 06:00		

Appendix B: Buoy deployment sheets

DEPLOYMENT SHEET

Project Name:	**TNW**		
Project no:	C75433	Latitude:	N54 degrees 01.089`
Station name:	TNWA	Longitude:	E5 degrees 33.014’
WS buoy no:	WS190	Approx. depth:	36 m
		Buoy marking:	Ten Noorden van de Waddeneilanden (TNW)
Reason for deployment: Start of campaign			

Buoy module/sensor	**Serial number/ID**
PMU	436
Wavesense 3 data logger	366
Septentrio	181013
Compass	1047491
ZephIR LiDAR	ZX843M
Gill Windsonic	18320036
Nortek current profiler 600kHz	AQP 9721 AQD 15088
Vaisala PTB330	P4120802
Vaisala HMP155 air temperature/humidity	P1730331
Thelma Bottom Unit	562
Buoy Tracker XEOS	680

DEPLOYMENT HISTORY

	YEAR	MONTH	DATE	UTC
First measurement in position	2019	June	19	04:45

Comments:

Recovery vessel:	Deployment vessel: Barney
Recovered by:	Deployed by: I. Stenstad & L. Fogelin

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DEPLOYMENT SHEET

Project Name:	**TNW**		
Project no:	C75433	Latitude:	N54 degrees 01.306`
Station name:	TNWB	Longitude:	E5 degrees 32.988'
WS buoy no:	WS191	Approx. depth:	36 m
		Buoy marking:	Ten Noorden van de Waddeneilanden (TNW)
Reason for deployment: Start of campaign			

Buoy module/sensor	**Serial number/ID**
PMU	437
Wavesense 3 data logger	371
Septentrio	88
Compass	1047474
ZephIR LiDAR	ZX862M
Gill Windsonic	19060137
Nortek current profiler 600kHz	AQP 9744 AQD 14707
Vaisala PTB330	P4120800
Vaisala HMP155 air temperature/humidity	P4050599
Thelma Bottom Unit	926
Buoy Tracker XEOS	771

DEPLOYMENT HISTORY

	YEAR	**MONTH**	**DATE**	**UTC**
First measurement in position	2019	June	19	06:00

Comments:

Recovery vessel:	Deployment vessel: Barney
Recovered by:	Deployed by: I. Stenstad & L. Fogelin

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