Energy Islands – Floating LiDAR Measurements

Final Campaign Report for Lot 1, November 2021 – February 2024

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Client	ENERGINET
Client Address	ENERGINET Eltransmission A/S, Tonne Kjærsvej 65, DK-7000 Fredericia, Denmark
Client Contact	Guillaume Mougin, Kim Parsberg Jakobsen and Gry Schachtschabel

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Contents

List of Figures

List of Tables

Abbreviations

Abbreviation	Definition
CTD	Conductivity, temperature, depth
DD	day of month 2 digits
DGPS	Dual GPS
GNSS	Global Navigation Satellite System
GPS	Global positioning system
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
LiDAR (or lidar)	Light Detection and Ranging
MM	month 2 digits
MSL	Mean Sea Level
MWL	Mean Water Level
NaN (Not a Number)	Label indicating data as invalid/missing
PEP	Project Execution Plan
PPE	Personal Protective Equipment
QHSSE	Quality, Health, Safety, Security and Environment
QA/QC	Quality Assurance / Quality Control
SI	Système International
SWLB	Seawatch Wind Lidar Buoy
SWMini	Seawatch Mini Wave Buoy
UTC	Universal Time Coordinated
WMO	World Meteorological Organization
WS	Seawatch Wavescan buoy
YYYY	year 4 digits

Conventions

Convention	Description
Time	All times are UTC
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 GNSS - relative to true north. Magnetic compass is used for wave and current direction, while GNSS is the main heading source for lidar and Gill wind directions. Compass data is available (stored in the data logger) as backup heading source for lidar wind directions. At Lot 1 the deviation between magnetic and true north is approximately +2.4°E (https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination). In the monthly reports, no corrections for the magnetic declination were applied. For the final dataset (see **Table 4-1**), the magnetic deviation was applied to wave and current directions and **all** direction data are given relative to true north for all parameters. Please note, that this correction was not applied to any wave spectra data or raw data.

Executive Summary

Fugro Norway AS entered into an agreement with ENERGINET, Denmark for the project "Floating LiDAR Measurements Energy Island Offshore Wind Farm - Lot 1-4" for initially 12 months. Lots 1, 2 and 4 were extended for an additional 12 months each. The purpose of the assignment is to provide met ocean data obtained through real time measurements at the two (2) energy islands: Energioe Nordsoen and Energioe Bornholm. The results of the atmospheric and oceanographic measurements should be used for verification of the wind energy potential, as basis for derivation of metocean design parameters and as a supplement to the environmental baseline description.

For Lot 1 the following instruments were deployed: a LiDAR buoy (SWLB WS170 or WS191) together with a bottom mounted Thelma water level sensor and a bottom mounted upward-looking Nortek Signature500 current profiler. The Signature500 was offline and data were downloaded at services and processed thereafter. In addition, a mini wave buoy SWMini071 was deployed at Lot 1 wave buoy location 1.

LiDAR buoy WS170, SWMini buoy SWMini071, and a bottom mounted upward-looking Nortek Signature500 current profiler were on 15 November 2021. On 30 November 2022, an additional SWMini wave buoy (SWMini074) was deployed at Lot 1 wave buoy location 3.

The campaign ended on 15 November 2023. The equipment was not recovered before 26 April 2024 due to unfavourable weather conditions in combination with lack of vessel availability. It was thus agreed to add selected data from the period 15 November 2023 to 24 February 2024 to the dataset and final report.

This final campaign report covers Lot 1 in the North Sea and includes general information of the measurement campaign, configurations, post-processing, quality control, post-processed data availability and data presentations over the period 15 November 2021 to 24 February 2024.

The data availability of the combined dataset for the full 24-month campaign (November 2021 - November 2023) is 84.6 % for wind and 97 % for waves, 65 % for currents, 58 % for water pressure and >97 % for all other parameter groups. The wave data availability from both SWMini buoys is 99%.

1. Introduction

1.1 Energioe Nordsoen project area

The Energioe Nordsoen project area is located approximately 90 km west of Thyborøn, Denmark (**Figure 1-1**). The water depth in the 1100 km^2 in the area varies between 25 m LAT and 50 m LAT (Admiralty Chart). The area was divided into 2 lots: Lot 1 in the north and Lot 2 in the south of the project area. This report summarizes the measurements at Lot 1.

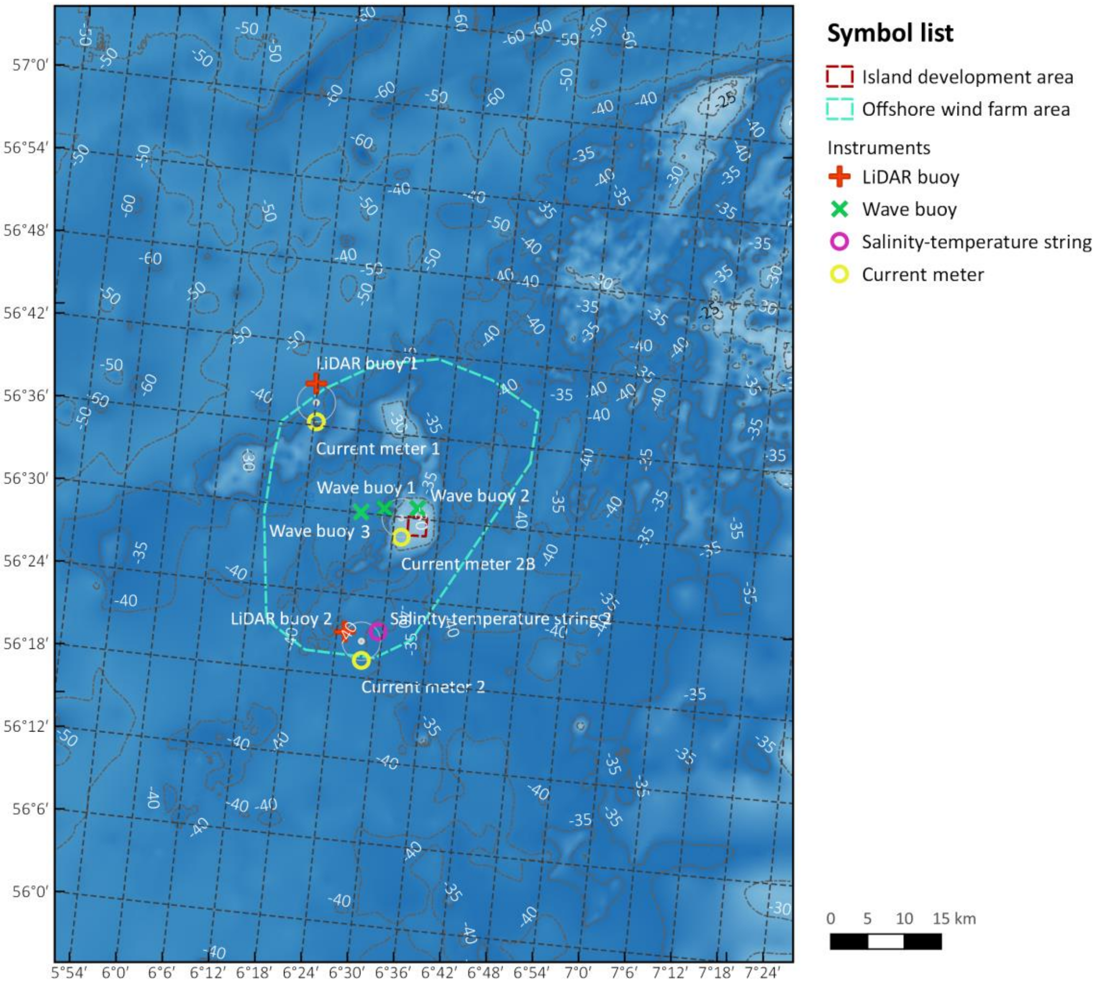


Figure 1-1 Instrument locations in the Energioe Nordsoen project area

The aim of the measurement campaign is to provide a set of continuous meteorological and oceanographic (metocean) data with excellent quality and high availability. The measurement campaign lasted for 12 months, was continued for an additional 12 months and extended by 3 additional months resulting in 27 months of data. The results of the atmospheric and oceanographic measurements are to be used for verification of wind energy potential, as basis for derivation of metocean design parameters and as a supplement to the environmental baseline description.

1.2 Lot 1 equipment, locations, and deployments

At Lot 1 the following instruments were deployed: a LiDAR buoy (SWLB) together with a bottom mounted Thelma water level sensor, and a bottom mounted upward-looking Nortek Signature500 current profiler. In addition, a SEAWATCH mini wave buoy SWMini071 was deployed at Lot 1 wave buoy location 1. On 30 November 2022, an additional SWMini wave buoy (SWMini074) was deployed at Lot 1 wave buoy location 3.

The positions of the bottom mooring weights are listed in **Table 1-1**. As the buoys are free to float around the mooring point within a radius of about 110 m, the actual water depth at the actual position of the buoy varies. The position of the water level sensor is assumed equal to the position of the bottom weight of the associated buoy.

During the campaign, 2 LiDAR buoys were used at Lot 1: WS170 and WS191. The buoys were deployed on the same mooring and swapped as needed. The datasets were concatenated.

The LiDAR buoys and SWMini buoy provided near real-time data that was transmitted to shore every 10 minutes. The Signature500 collected data that was only stored onboard the instrument. This offline data was downloaded at service and reported thereafter.

The campaign ended on 15 November 2023. The equipment was not recovered before 26 April 2024 due to unfavourable weather conditions in combination with lack of vessel availability. It was thus agreed to add selected data from the period 15 November 2023 to 24 February 2024 to the dataset and final report.

All equipment was recovered on 26 April 2024.

Table 1-2 shows a log of the deployments at Lot 1 including start and end times of valid data.

Table 1-1 Equipment locations and water depths

Buoy	Location	Latitude [°N]	Longitude [°E]	Water Depth [m MWL]
LiDAR Buoy 1 (SWLB)	North Sea/Lot 1	56.6280	6.3007	46.4
Wave Buoy 1 (SWMini)	North Sea/Mini 1 (Lot 1)	56.5114	6.5190	27.0
Wave Buoy 3 (SWMini)	North Sea/Mini 3 (Lot 1)	56.5020	6.4337	45.0
Bottom mounted ADCP	North Sea/ADCP Lot 1	56.6272	6.3008	46.0

Table 1-2 Deployments at Lot 1

Deployment	Station	Buoy S. no.	LiDAR #	Start time (UTC)	End time (UTC)	Status
D01-SWLB	Lot 1	WS170	ZX585	2021-11-15 09:30	2022-05-20 07:00	Recovered for service
D02-SWLB	Lot 1	WS191	ZX862	2022-05-20 07:50	2022-12-01 08:10	Recovered for service
D03-SWLB	Lot 1	WS191	ZX862	2022-12-01 14:30	2023-04-22 18:50	Recovered for service
D04-SWLB	Lot 1	WS170	ZX585	2023-04-22 20:10	2023-06-13 09:40	Recovered for service
D05-SWLB	Lot 1	WS191	ZX862	2023-06-13 13:00	2024-02-24 23:50	End of campaign
D01-Mini	Mini 1	SWMini071	-	2021-11-15 11:20	2022-11-30 18:00	Recovered for service
D02-Mini	Mini 1	SWMini071	-	2022-11-30 19:00	2024-02-24 23:50	End of campaign
D03-Mini	Mini 3	SWMini074	-	2022-11-30 19:00	2024-02-24 23:50	End of campaign
D01-ADCPSWLB	ADCP Lot 1	Nortek Signature 500	-	2021-11-15 09:50	2022-10-26 16:00	Recovered for service
D02-ADCPSWLB	ADCP Lot 1	Nortek Signature 500	-	2022-12-01 08:50	2023-09-27 10:00	Recovered for service
D03-ADCPSWLB	ADCP Lot 1	Nortek Signature 500	-	2023-09-27 12:50	2024-02-24 23:50	End of campaign

1.3 SWLB Calibration and Pre-deployment Validation

The LiDAR buoys were pre-validated and passed Best Practice Criteria for all wind speed ranges at all heights [1] [2].

The measurement plan [3] for this campaign includes information on calibration certificates for the other instruments.

1.4 Data collection and reports

1.4.1 SWLB data

Data from the SWLB and SWMini buoys was transmitted to shore in near real-time, quality checked monthly and reported in monthly reports. Fugro also provided motion-compensated estimates of SWLB-measured turbulence intensity in separate work packages.

Table 1-3 lists the monthly reports and the report on TI motion-compensation for this lot.

Table 1-3 List of monthly reports at Lot 1

Year 1	Year 2
C75486-R-001(03)-Monthly Report Lot 1-NovDec2021	C75486-R-013(03)-Monthly Report Lot 1-NovDec22
C75486-R-002(03)-Monthly Report Lot 1-Dec21Jan22	C75486-R-014(02)-Monthly Report Lot 1-Dec22Jan23
C75486-R-003(02)-Monthly Report Lot 1-JanFeb22	C75486-R-015(02)-Monthly Report Lot 1-JanFeb23
C75486-R-004(02)-Monthly Report Lot 1-FebMar22	C75486-R-016(02)-Monthly Report Lot 1-FebMar23
C75486-R-005(03)-Monthly Report Lot 1-MarApr22	C75486-R-017(02)-Monthly Report Lot 1-MarApr23
C75486-R-006(02)-Monthly Report Lot 1-AprMay22	C75486-R-018(03)-Monthly Report Lot 1-AprMay23
C75486-R-007(02)-Monthly Report Lot 1-MayJun22	C75486-R-019(03)-Monthly Report Lot 1-MayJun23
C75486-R-008(04)-Monthly Report Lot 1-JunJul22	C75486-R-020(02)-Monthly Report Lot 1-JunJul23
C75486-R-009(04)-Monthly Report Lot 1-JulAug22	C75486-R-021(02)-Monthly Report Lot 1-JulAug23
C75486-R-010(03)-Monthly Report Lot 1-AugSep22	C75486-R-022(02)-Monthly Report Lot 1-AugSep23
C75486-R-011(03)-Monthly Report Lot 1-SepOct22	C75486-R-023(02)-Monthly Report Lot 1-SepOct23
C75486-R-012(03)-Monthly Report Lot 1-OctNov22	C75486-R-024(02)-Monthly Report Lot 1-OctNov23
C75486-R-004(03)-TI Report Lot 1 & 2 - Campaign data	

1.4.2 ADCP SWLB

The instrument was deployed offline and collected data during 3 deployments. The full 24-month dataset is presented in this report.

1.4.3 Bat sensor

A bat sensor was mounted on the SWLB. The data from this instrument was downloaded during services. The raw data was provided at the end of the campaign. The locations of the bat measurements correspond to the SWLB position data.

2. Activities

2.1 Service and Maintenance Activities

LiDAR buoy WS170 was deployed at Lot 1 on 15 November 2021 at 09:30 UTC together with a bottom mounted Thelma water level sensor and a bottom mounted upward-looking Nortek Signature500 current profiler. SWMini buoy SWMini071 was deployed at Lot 1 wave buoy location 1 on 15 November 2021 at 11:20 UTC.

Water pressure and bottom temperature from the Thelma water level sensor stopped on 12 February 2022.

WS170 started to experience power supply issues due to loss of contact with the fuel cells from 05 April 2022 onwards. The intermittent drops in voltage resulted in temporary shutdowns of the lidar unit from 06 April 2022 00:00 until 10 April 2022. Low power resulted in a permanent shutdown of the lidar unit and loss of all lidar wind data from 10 April 2022 14:50 onwards. Insufficient charging by the solar panels due to bad weather led to a shutdown of all buoy sensors on 13 May 2022.

On 20 May 2022 WS170 was recovered for maintenance and the spare buoy WS191 was deployed on the same mooring on 20 May 2022 07:50 UTC. WS191 did not receive any water pressure data.

On 16 October 2022, the PWS visibility sensor on WS191 stopped working.

On 30 November 2022, SWMini071 was recovered for maintenance, serviced offshore onboard the service vessel, and redeployed on the same day on the same mooring. On 30 November 2022, an additional SW Mini wave buoy (SWMini074) was deployed at Lot 1 wave buoy location 3 at 14:30 UTC.

WS191 was recovered for maintenance on 01 December 2022, serviced offshore onboard the service vessel, and redeployed on the same day on the same mooring. During the service, a new Thelma top modem was installed. Data from the bottom unit was received and stored on the datalogger. The data was post-processed and added to the final dataset.

On 20 December 2022, the Gill wind sensor at 004 m mast height on WS191 stopped working.

A storm on 16 February 2023 affected the lidar on WS191 and the transmitted lidar data did not pass the QC procedures. From 26 February 2023, the lidar only worked erratically. The WS191 buoy was shut off on 14 April 2023 at 12:00 UTC.

WS191 was recovered on 22 April 2023 at 18:50 UTC and replaced by WS170 at 20:10 UTC on the Lot 1 mooring.

On 13 June 2023, WS170 was recovered at 09:40 UTC and, at 13:00 UTC, WS191 was re-deployed on the Lot 1 mooring.

On 22 December 2023, the Vaisala air pressure and air temperature and humidity sensors stopped working after storm *Pia* passed over the area.

On 07 January 2024, the Lidar unit on WS191 was switched off remotely to save power until recovery was possible.

During deployment 1 of the offline ADCP (D01-ADCPSWLB, **Table 1-2**), the current meter stopped recording data in March 2022 resulting in a data gap from 22 March 2022 until 01 December 2022.

All equipment was recovered on 26 April 2024.

2.2 Health, Safety and Environment

No incidents were logged during the campaign.

3. Methods for Post-Processing and Availability Calculations

The general measurement setup, sensors, configurations, and measurement scheme are described in the measurement plan [3].

3.1 SWLB and SWMini buoys

3.1.1 Measurement configurations

Table 3-1 shows the measurement configuration of the SWLB at Lot 1. The data from the SWLB is averaged every 10 minutes. Definitions of wave parameters are given in **Table 3-2**.

Table 3-3 shows the measurement configuration of the SWMini wave buoys at wave buoy location Mini 1 and Mini 3. The data from the SWMini buoys is averaged every 30 minutes.

For each instrument on a SWLB, the measurement processes are set-up individually according to the resolution needed. The measurements are stored in the onboard in-memory database. Selected measurements are averaged over 10 minutes and/or used in internal processes together with other measurements from other sensors:

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

The buoys convert all measurements to physical quantities in SI units. The data are packed for transmission and storage in binary integer numbers using a proprietary compression algorithm, giving sufficient resolution while using minimal storage space. At the receiving end the data are unpacked to physical values in real numbers using the reverse conversion method. This also means that the data in transmission are encrypted.

The monthly reports are based on the 10-minute averages transmitted via satellite. Any gaps in the transmitted data or any data deemed suspicious after the monthly quality checks are performed, are flagged. These gaps and issues are investigated once stored data are available.

10-minute averages stored on the datalogger form the basis of the final campaign dataset. In addition, any data downloaded during a service or at the end of the campaign (pff and raw) are used to investigate gaps in the data set that occurred during the deployment. When necessary and if available (no other instrument issues), the data can be re-processed using raw data and used to fill gaps.

Table 3-1 Configuration of measurements of the Seawatch Wind Lidar buoy at Lot 1

Instrument Type	Sensor Height [m]	Parameter Measured	Sample Height[1] [m]	Sampling Interval [s]	Averaging Period [s]	Burst Interval [s] [2]	Measurement Resolution	Trans-mitted ?
Wavesense 3	0	Heave, pitch, roll, heading	0	0.5	Time series duration: 1024 s	1024	0.1m, 0.2°, 0.2° 0.5°	No
		Sea state parameters[3]	0	600	1024	1024	0.1m, 0.2°, 0.1s	Yes
ZephIR ZX300 Lidar	2	Wind speed and direction at 10 heights and the reference level at 40 m	40[4], 30, 60, 90, 100, 120 150, 180 200, 240, 270	17.4[5]	600	600	0.1m/s 1°	Yes
Gill Windsonic M	4.1	Wind speed and direction	4.1	1	600	600	0.01m/s 1°	Yes
Nortek Aquadopp 600 kHz z-cell	-1	Current speed and direction profile, water temperature (at 1m depth)	-1 -2 … -41	1	600	600	2 cm/s 1° 0.1°C	Yes
Vaisala PTB330A	0.0	Air pressure	0.0	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
MiniPWS (fog)	4.1	Visibility	4.1	600	600	1	0.6 m	Yes
Young Precipitation sensor	4.0	Precipitation	4.0	600	600	60	0.001 mm	Yes
Apogee Pyranometer	4.1	Solar Irradiance	4.1	1	600	600	1 W/m2	Yes
Septentrio DGPS	4.1	Buoy orientation	4.1	5	10	1	0.35°	No

Thelma Biotel TBR700	-45	Bottom water pressure and bottom temperature	-45	1	600	600	0.01m 0.01°C	Yes

Notes

[1] = Height relative to actual sea surface.

[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] = Wave parameters as defined in **Table 3-2**

[4] = The reference level (40 m), which is not configurable.

[5] = 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 internally in the lidar is carried out.

Table 3-2 Definition of wave parameters

Parameter	Unit	Description
hm0	m	Estimate of Hs (significant wave height). Hs is the average of the one third highest waves. $hm0 = 4\sqrt{m0}$ where m0 is the zeroth order moment of the spectrum.
hm0a	m	Estimate of Hs (significant wave height) in the **a** frequency band.*
hm0b	m	Estimate of Hs (significant wave height) in the **b** frequency band.*
hmean**	m	Average height of individual waves.
hmax**	m	Height of the highest individual wave in the sample. Calculated from zero-upcrossing analysis.
hs**	m	Significant wave height, average of the one third highest waves
mdir	°N	Mean spectral wave direction. Computed from spectral analysis.
mdira	°N	Mean spectral wave direction in the **a** frequency band.*
mdirb	°N	Mean spectral wave direction in the **b** frequency band.*
sprtp	°N	Wave spreading at the spectral peak period. Computed from spectral analysis.
thhf	°N	Mean wave direction at the spectral peak period. Computed from spectral analysis.
thtp	°N	High frequency mean wave direction. This is the mean wave direction over the frequency band 0.40 – 0.45 Hz, corresponding to wave periods between 2.2 – 2.5 sec.
tm01	s	Estimate of mean wave period Tz or the average period of the individual waves. Calculated from the spectral moments. tm01 = m0/m1 where mn are the nth order spectral moments.
tm02	s	Estimate of mean wave period Tz or the average period of the individual waves. Calculated from the spectral moments. $tm02 = \sqrt{(m0/m2)}$ where mn are the nth order spectral moments.
tm02a	s	Estimate of mean wave period Tz or the average period of the individual waves in the **a** frequency band.*

Parameter	Unit	Description
tm02b	s	Estimate of mean wave period Tz or the average period of the individual waves in the **b** frequency band.*
tp	s	Period of the spectral peak
thmax**	s	Period of the highest wave. Calculated from the zero-upcrossing analysis.
tz**	s	Average period of individual waves.
ts**	s	Average period of the one third highest waves.
ui	-	Unidirectivity index, an indicator for the unidirectionality of the spectral wave components. If all mean wave directions are propagating in the same direction, ui=1

* Swell and wind sea frequency ranges:

Band "a" (Swell): 0.04 – 0.10 Hz (corresponding to wave periods between 10-25 sec, i. e. long waves)

Band "b" (Wind sea): 0.10 – 0.50 Hz (corresponding to wave periods between 2-10 sec, i. e. short waves)

** zero-upcrossing requires a certain number of "high" wave in the data series to be calculated e.g. 50. Hmax, hs, hmean, tz, ts and thmax thus are usually not calculated if significant wave height is lower than approximately 0.3 m.

Table 3-3 Configuration of measurements of the SWMini wave buoys at Lot 1

Instrument Type	Sensor Height [m]	Parameter Measured	Sample Height[1] [m]	Sampling Interval [s]	Averaging Period [s]	Burst Interval [s] [2]	Measurement Resolution	Trans-mitted ?
Wavesense 3	0	Heave, east position, north position	0	0.5	Time series duration: 1024 s	1024	0.1m, 0.2°, 0.2°	No
		Sea state parameters[3]	0	1800[4]	1024 s	1024	0.1m, 0.2°, 0.1s	Yes

Notes

[1] = Height relative to actual sea surface.

[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.

[3] = Wave parameters as defined in **Table 3-2**

[4] = A new 17-minute measurement cycle is initiated every 30 minutes.

3.1.2 General post-processing and data quality control

The general data flow, post-processing and quality control applied to the data before they are delivered to the client is described in the measurement plan [3].

No 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 the use of data from any external sources.

Post-processed data refers to values that have undergone the following steps:

a. Deployment period, i.e. removing values outside of those times where the system is deployed at the target position (e.g. in transit to/from shore or onshore)

b. Check that data was saved for all 10-min intervals. If not, substitutions of NaN values when all data for a 10-min time step is missing

c. Removing duplicated measurements if all measurements/parameters by one sensor are repeated from one time step to the next

d. Out of range values replaced by NaN (**Table 3-4**)

e. Applying parameter group / instrument specific quality control measures for specific groups outlined below

f. Inspection and assessment (QA/QC) by senior meteorologist/oceanographer

g. Calculate signal and system availability

The QA/QC filter ranges used for each parameter (group) are listed in **Table 3-4**. The filter ranges are based on the valid data ranges of each sensor, the expected environmental conditions at the Lot 1 site, and the manufacturer recommended minimum signal strength for the Aquadopp current profiler.

Table 3-4 QA/QC filter ranges for each parameter

Parameter	Minimum Value	Maximum Value	Unit
Wind speed lidar	0.001	58	m/s
Wind speed Gill	0.001	35	m/s
Direction (**all**)	0	360	°N
Current speed	0	135	cm/s
Current signal strength	36	-	counts
hm0	0	18	m

Parameter	Minimum Value	Maximum Value	Unit
hmax	0	24	m
tp	0.1	23	s
thmax	0.1	23	s
Air humidity	0.01	100	%
Air pressure	905	1100	hPa
Air temperature	-10	35	°C
Water temperature	0.1	30	°C
Water pressure	27.3	57.3	dbar
Visibility	10	6001	m
Precipitation	0	10	mm/10min
Solar irradiance	0	1000	W/m²

3.1.3 Additional data post-processing steps

3.1.3.1 Wind speed and direction

For wind, and additional 180° ambiguity check is done on the 10-minute average LiDAR wind directions using 10-minute average Gill wind direction.

The lidar wind dataset from 01 December 2022 until 22 April 2023 (WS191) was reprocessed in-house from raw 1hz lidar, Septentrio heading data, and Gill wind direction from the parallel Lot 2 deployment (WS181) in order to recover some of the wind measurements in February and March 2023. For this deployment the additional 180° ambiguity check was done using the Lot 2 Gill wind directions.

The lidar wind dataset from 22 April 2023 until 13 June 2023 (WS170) was also reprocessed in-house from stored raw data to recover the wind measurements missing in the monthly reports.

3.1.3.2 Turbulence intensity

The turbulence intensity (TI) supplied in the monthly and final SWLB **WindSpeedDirectionTI.csv* files is estimated from measured standard deviation with a constant factor and influenced by buoy-motion. Here 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*).

Motion-compensated estimates of SWLB-measured turbulence intensity are provided in addition to the above-mentioned dataset. Motion-compensation of turbulence intensity is described in the associated reports [4].

3.1.3.3 Wave data (applied to the full campaign dataset)

Wave spectra are continuously calculated by Fugro's proprietary Neptun wave processing software while the buoys are measuring at sea. However, only the 2 Hz components of motion (SWLB: heave, pitch, roll; SWMini: east, north, heave) and the calculated wave parameters (as given in the **WaveData.csv* and **Wave.csv* files) are stored. Wave spectra are re-calculated in house using Neptun. Calculations of wave parameters done onboard the buoy use the measured data before storing and digitalization. Thereafter data is stored, both raw and calculated. During this storage process, the data is digitalized with a given resolution (i.e. binned). If the stored raw data or memspec files are used to re-calculate the wave parameters, there may be small differences compared to parameters calculated onboard the buoy. The resolution settings are, however, set such that the differences are insignificant.

A set of low frequency wave filters was applied to the following wave parameters (**WaveData.csv* and **Wave.csv* files):

a. If hmax < hm0, hmax is removed.
b. All wave parameters are removed, if hmax/hm0 > 2.3.
   The heave time series is likely contaminated by a disturbance in the form of a single large wave.
c. If tp/tm02 >2.1, tp and thtp are removed and hm0 is set equal to hm0b. If also tm02/tm02b > 2 and hm0b < 0.02, all wave parameters are removed.
d. Any tz < 1 were discarded.

All wave directions (as given in the **WaveData.csv* and **Wave.csv* files) were corrected for magnetic declination and are given relative to true north.

3.1.3.4 Precipitation

Precipitation is measured by a Young Precipitation Gauge that measures rain or snow precipitation without moving parts. Rain or snow collected in the catchment funnel is directed into the measuring chamber. When the maximum fill level (50 mm) is reached, the column is automatically emptied. Column level is sensed by a capacitive probe and converted to a linear voltage signal which is converted back to height in mm by the buoy's datalogger. Raw data are not stored on the instrument.

During the first half of the campaign, the buoy's datalogger processed the precipitation data into accumulated precipitation per 10 minutes. This was used in the first monthly reports. Raw measurements were not stored on the datalogger.

Mid-campaign, the processing on the datalogger was updated to store the raw column height measurements directly. Precipitation was then updated to raw precipitation ("precip_raw mm") and is reported as such. The filter limits changed to -10 mm (no precipitation) – 50 mm. Emptying of the column when the maximum fill level is reached appears as "negative precipitation", i.e., a jump from 50 mm to lower fill levels.

3.1.3.5 Currents

The data at 001 m water depth are measured by a separate set of horizontal transducers, the z-cell. The data was included in the monthly datasets. However, the measurements deviate significantly from the neighbouring bins and appear to be subject to higher uncertainty from dynamic motion near the buoy and the sea surface. For this final dataset, the data in this 001m bin was removed as the measuring principle is different and due to the deviation from the neighbouring bins.

Only depths 02 – 41 m (top-down) were filtered on current speed, current direction, and signal strength. Current speed and direction where signal strength was below the minimum threshold (**Table 3-4**) was removed. For deployment D2, a higher cut-off of 39 counts was used compared to the rest of the deployments. Spikes in current speed at 02 and 03 m depth were removed if the difference in speed compared to the 04 m depth bin was > 6 cm/s.

For deployments D2 and D3, all current data in the 02 – 06 m bins was removed due to faulty data from beam 1.

Marine growth restricted the range of valid data towards the end of the individual deployments. In the bottom half of the profile (below 23 m), any current measurements below any gaps were also removed.

All current directions (as given in the **CurrentData.csv* files) were corrected for magnetic declination and are given relative to true north.

3.1.3.6 Water pressure

Water pressure from month 13 and deployment 5 was recovered, reprocessed from the raw measurements and added to the dataset.

3.1.3.7 Water level

Water level is not measured directly but inferred from measurements of water pressure at the seabed. The Thelma water level sensor is mounted on its own mooring connected to the buoy mooring. The vertical position of the sensor relative to the mean sea level position is obtained from bathymetry data at the deployed coordinates. The pressure sensor head is free floating and assumed to be located at nominally 1-1.5 m above the seabed. This height can vary during a campaign if there are changes to the length of the rope connecting the sensor to its mooring due to either burial of the rope or manual shortening during service visits. In this campaign the nominal sensor height is 1.5 m.

The bottom mounted pressure sensor Thelma 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 air pressure measurement from the buoy is subtracted from the total measured water pressure and an adjustment for the height of the sensor above the seabed is included. The actual height of the water column above the sensor is determined using the hydrostatic equation: $h_w = (P_w - P_a)/(\rho g)$ where h_w is the height of the water column, P_w is the measured total water pressure including an adjustment for the height of the sensor above the seabed, P_a is the measured total air pressure, ρ is the average density of the water (inferred from measured salinity and density at Lot 1, here 1025 m^3/kg), and g is the normal acceleration of gravity.

Water level referenced to MSL is then obtained by removing the mean water depth.

During the campaign, three different Thelma pressure sensors were deployed and the water pressure timeseries (**Figure B-36**) shows that each was deployed with a slightly different length of rope resulting in three different mean sensor heights above the seafloor. The height of each sensor was adjusted by comparing the mean water pressure before and after the service visit. There is some uncertainty (ca. 40%) connected to this adjustment.

3.1.4 Availability calculations

3.1.4.1 Monthly System Availability: One-Month Average

The Floating Lidar System is ready to function according to specifications and to deliver data, taking into account all time stamped data entries in the output data files including flagged data (e.g. by NaNs or 9999s) for the given month.

Note that for the system to be considered "ready", at least one valid data point must be recorded (at any height).

The Monthly Overall System Availability is the number of those time stamped data entries relative to the maximum possible number of (here 10-minute) data entries including periods of maintenance within the respective calendar month.

3.1.4.2 Monthly Post-processed Data Availability: One-Month Average

The Monthly Post-processed Data Availability is the number of those data entries remaining after subtraction of all non-valid entries caused by including but not limited to:

- downtime (due to equipment failure, maintenance, weather, damage, malfunction, theft, or any other events)
- Lidar internal (unseen) filtering (as set by the Lidar manufacturer)
- application of quality filters based on system own parameters

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

3.1.4.3 Post-processed parameter group availability

The monthly post-processed parameter group 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 but excluding 240 and 270 m. 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. Atmospheric pressure: main instrument (Vaisala)

c. Air temperature: main instrument (Vaisala)

d. Air humidity: main instrument (Vaisala)

e. Sea surface temperature: main instrument (Seabird SBE)

f. Wave: Average of wave parameters (10-min frequency), excluding any zero-upcrossing parameters.

g. Current: Average of current speed and direction over the water column.

h. Water level: water pressure for monthly reports.

In the case of multiple (redundant) measurement instruments determining one parameter value, the availability of at least one parameter value is the determining base for the data availability.

Table 3-5 lists the parameters used in the calculations.

3.1.4.4 SWMini availability

For the wave buoy, the availability calculations are done in the same way but based on 30-minute intervals.

The group average of the SWMini wave data is calculated as the average of wave parameters excluding any zero-upcrossing parameters:

hm0 m, hm0a m, hm0b m, mdir deg, mdira deg, mdirb deg, sprtp deg, thhf deg, thtp deg, tm01 s, tm02 s, tm02a s, tm02b s, tp s (30-min frequency)

Table 3-5 Parameter group availability

Parameter group	Parameters
Wind	WindSpeed004m (m/s), WindSpeed030m (m/s), WindSpeed040m (m/s), WindSpeed060m (m/s), WindSpeed090m (m/s), WindSpeed100m (m/s), WindSpeed120m (m/s), WindSpeed150m (m/s), WindSpeed180m (m/s), WindSpeed200m (m/s) WindDir004m (°N), WindDir030m (°N), WindDir040m (°N), WindDir060m (°N), WindDir090m (°N), WindDir100m (°N), WindDir120m (°N), WindDir150m (°N), WindDir180m (°N), WindDir200m (°N)
Atmospheric pressure	AirPressure (hPa)
Air temperature	AirTemperature (°C)
Air humidity	AirHumidity (%)
Sea surface temperature	WaterTempSBE000 (°C) from Seabird SBE
Wave	hm0 (m), hm0a (m), hm0b (m), mdir (°N), mdira (°N), mdirb (°N), sprtp (°N), thhf (°N), thtp (°N), tm01 (s), tm02 (s), tm02a (s), tm02b (s), tp (s)
Current	AqSpd001 (cm/s), AqSpd002 (cm/s), ..., AqSpd041 (cm/s) AqDir001 (°N), AqDir002 (°N), ..., AqDir041 (°N)
Water level	WaterPressure (dbar)

3.2 Upward-facing ADCP

3.2.1 Offline Nortek Signature500 (upward-facing) measurement configuration

A Nortek Signature 500 current profiler was placed on the seafloor near the SWLB on a separate mooring to measure the current profile from bottom to surface. Water depth at the deployment location was ca. 46 m. The current meter was mounted in a floating buoy resulting in a nominal depth of the transducer head at ca. 3 m above the seafloor. Antifouling patches were applied to the transducers.

Table 3-6 shows the measurement configuration of the Nortek Signature500 current meter (Serial# 102860: Nov 2021 - Nov 2022; and 103326: Nov 2022 - Feb 2024) at Lot 1. The noise floor for the transducers of this instrument is 27 dB.

Cell size was set to 1 m with blanking distance of 0.5 m and 51 cells in total. The centre of the first valid cell is therefore nominally 4 m above the seafloor.

There were 3 deployments of the ADCP in total (**Table 1-2**) with short maintenance windows for data download and battery replacements in between.

During deployment 1 of the offline ADCP (D01-ADCPSWLB, **Table 1-2**), the current meter stopped recording data in March 2022 resulting in a data gap from 22 March 2022 until 01 December 2022.

The sensor configuration is given in **Table 3-6**. The raw data from deployment 1 was recorded in UTC+1. Deployments 2 and 3 are in UTC. During deployment 3, the averaging period was extended to 180 s.

For this final dataset, all three deployments are combined and the processed data are delivered in 1 data file.

Table 3-6 Configuration of measurements of the upward facing ADCP

Deploy-ment	Instrument Type	Sensor Height[1] [m]	Parameter Measured	Sample Height[2] [m]	Sampling Interval	Avera-ging Period [s]	Measure-ment Interval [s]	Measure-ment Resolu-tion
1 and 2	Nortek Signature 500	-43	Current speed and direction profile, water temperature and water pressure (at 43 m depth)	-4 -5 -6 … -43	1 Hz, 311 pings	120	600	0.9 cm/s 0.1° 0.1°C

3	Nortek Signature 500	-43	Current speed and direction profile, water temperature and water pressure (at 43 m depth)	-4 -5 -6 … -43	1 Hz, 360 pings	180	600	0.9 cm/s 0.1° 0.1°C

Notes

[1] = Height relative to actual sea surface.

[2] = Height relative to seafloor.

3.2.2 Seawater temperature and water level

The bottom-mounted Nortek Signature 500 also records water temperature at and pressure above the sensor head.

Seawater temperature is used without further processing except for an outlier check, with yielded no exclusions. The measurements are presented in **Section 10.2**.

For the Signature500, there is an uncertainty in the sensor height above the sea floor similar to what is described in **Section 3.1.3.6** since it is deployed on a floating buoy. The nominal height used for the water level calculations is 2.50 m.

The raw water pressure measurements (**Figure B-36**) reveal a change in sensor height above the seafloor after each service visit. For these deployments, the height is adjusted by comparing the mean pressure before and after the service visit. There is some uncertainty (ca. 40%) connected to these adjustments.

Air pressure from the Lot 1 SWLB was used and gaps in air pressure were filled with data from Lot 2 after 22 December 2023.

Water level referenced to MSL is then calculated as described in **Section 3.1.3.6**.

3.2.3 Data post-processing and quality control

Fugro follows the international standard recommendations ISO-19901-1:2015 for the collection and supply of oceanographic data, to verify the proper functioning of the measuring and recording systems and for data quality control procedures.

Standalone ADCP processing follows the required and some recommended steps in the IOOS QUARTOD manual on in-situ current observations [5].

All current data are post-processed from raw data stored on the current meter using the manufacturer's Ocean Contour V2 [6] software and additional python scripts.

All raw data from all 3 deployments was processed using Ocean Contour with the following quality filters:

1. Bin mapping to compensate for tilt, i.e., cell re-positioning to account for differences in the vertical bin-depth, i.e., vertical alignment.

   An excessive tilt check was not implemented.

2. Minimum signal strength of 32 dB: here noise floor (27 dB) + 5 dB.

   This removes data with poor return signal quality.

3. Minimum 50 % correlation between incoming and outgoing beams.

   This also removes data with poor return signal quality.

4. Automatic sidelobe removal threshold: 95%

5. Correction for magnetic declination (+2.4°).

   Current directions are reported relative to true north.

6. Averaging over 1 averaging window per cell to yield 10-minute averages (default for 10-minute averages).

The processed data from each deployment was exported from Ocean Contour in netcdf format and combined using python scripts. The data from D1 was shifted to UTC from UTC+1. Data during the service periods was set to NaN. Current speed and current direction columns were renamed based on sensor height and cell size, upward, starting at 004 m and ending at 044 m. The Ocean Contour data mask (contained in the data files) was applied to the current speed and current directions only. Timestamps were rounded to the nearest 10 min and current speed was converted to cm/s. Bins 41m – 44m were removed by the automatic sidelobe removal (step 4).

The following IOOS QUARTOD tests were implemented:

a. Current speed [0;135] cm/s

b. Current directions [0;360°]

c. Test on extreme changes and outliers in heading, pitch, and roll

d. Vertical velocities (both up1 and up2) were checked for indications of excessive values.

   Some high vertical velocities in uppermost bins (33 – 40 m) were found, and all speed and direction data where the absolute value of the vertical velocity was greater than 16 cm/s were removed.

Data in the near-surface bins may periodically still be affected by sidelobe energy, especially during rougher conditions. This can appear as spikes in the current speed data. Signal strength per beam is part of the data file and can be used to do further analysis and exclusions, if deemed necessary.

3.3 Comments on top-down and bottom-up current data

During the campaign the current speed and direction measurements by the buoy-mounted, downward-facing Aquadopp 600kHz z-cell and the floater-mounted upward-facing Signature500 were compared. It was discovered that the Aquadopp-measured current directions appeared to differ by on average 30 degrees from modelled current directions while the floater-mounted upward-looking Signature agree better with modelled current directions.

Time series of depth-averaged (between 10 – 30 m) Aquadopp against Signature current speed and directions show no constant offset but periods of agreement and periods of larger offsets for both current speeds and directions appearing to correspond to sea state.

Neither the mounting of the Aquadopp, nor magnetic influence, offsets in heading or differences in post-processing explain the differences between the Aquadopp and Signature data. The manufacturer confirmed that both instruments were set up and configured correctly and worked as intended. After checking for mounting, magnetic influence and proper processing, the main remaining issue is additional, unaccounted sources of error in the measurements, specifically motion.

In this project, the surface-buoy mounted Aquadopps experience rapid motion during both high sea states and low sea states (buoy resonance). In addition, there are effects of bubbles, turbulence, non-linear dynamics from flow around and underneath the buoy as well as reflections from the sea surface and/or air when the motion is high. These are not distinguishable in the data. In contrast, the Signatures experience less motion and less non-linear dynamics than the surface-buoy mounted Aquadopps. In addition, the Signatures have more internal QC and more post-processing options, including bin mapping that helps compensate for more motion than just averaging over a given interval.

The deviation between both instruments is strongly correlated with the prevailing sea states. When the sea is calm, both instruments measure the same, both for current speed and direction. When the sea is rough, the Aquadopp measures higher current speeds than the Signature and the Aquadopp current direction contains an offset compared to the current directions from the Signature.

More details are given in two technical notes ([7], [8]).

4. Data files

Table 4-1 lists the final 24-month datafiles. This includes the full SWLB dataset, both SWMini datasets, the QC'd ADCP data and the motion-compensated turbulence intensity data and reports.

Table 4-1 List of final campaign datafiles at Lot 1

Instrument	Filename
SWLB	Energinet_Lot1_SWLB_20240604 November 2021 February 2024 CurrentData.csv Energinet_Lot1_SWLB_20240604 November 2021 February 2024 MetOceanData.csv Energinet_Lot1_SWLB_20240604 November 2021 February 2024 Posdata.csv Energinet_Lot1_SWLB_20240604 November 2021 February 2024 Status.csv Energinet_Lot1_SWLB_20240806 November 2021 February 2024 WaveData.csv Energinet_Lot1_SWLB_20240604 November 2021 February 2024 WindSpeedDirectionTI.csv Energinet_Lot1_SWLB_20240604 November 2021 February 2024 WindStatus.csv Energinet_Lot1_SWLB_20240710 November 2021 February 2024 WaterLevel MSL.csv
SWMini	Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Posdata.csv Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Status.csv Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Wave.csv Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Posdata.csv Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Status.csv Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Wave.csv
ADCP (upward)	Energinet_Lot1_Signature_20240524 November 2021 February 2024.csv Energinet_Lot1_Signature_20240710 November 2021 February 2024 WaterLevel MSL.csv
TI	LOT1_Deployment1_TIdata.csv LOT1_Deployment2_TIdata.csv LOT1_Deployment3_TIdata.csv

Appendix C lists the contents and parameters of each final post-processed datafile listed in **Table 4-1**.

Appendix D gives additional information on any raw data files supplied with this dataset.

5. Data Availabilities

5.1 Issues and gaps affecting the final dataset

Appendix A summarizes events that impact data availability and the descriptions of these gaps as far as these are ascertainable.

The lidar measurements can be influenced by adverse weather conditions (e. g. fog, rain, poor visibility) resulting in low packet counts. Measurements at each height are independent and short gaps at intermediate heights can occur.

There is a gap in the 004m wind measurements between 20 December 2022 and 22 April 2023 as the Gill wind sensor at 004 m mast height on WS191 stopped working.

Two large storms (April 2022 and February – March 2023) affected the lidar units and/or power supply system leading to gaps in the lidar wind data and eventual shut-down. Some lidar wind data in during February and March 2023 was recovered and added to the dataset (ref. **Section 3.1.3.1**). In addition, the lidar wind data from deployment 4 (months 18 and 19) was also recovered. The Lidar unit on WS191 was switched off remotely on 07 January 2024 to save power until recovery was possible.

There is a drop in signal strength of the Aquadopp current meter data below 20 m depth during a part of the campaign and a substantial amount of data below this depth is filtered out. The downward looking profiler is most likely experiencing marine growth restricting the range towards the end of the individual deployments.

The SWLB current dataset was subjected to stricter QC than during the monthly checks resulting in overall lower current data availability (see **Table 5-7**).

There is no water pressure data between March 2022 and November 2022. Water pressure from month 13 and from 13 June 2023 until campaign end was recovered and added to the dataset.

On 22 December 2023, the Vaisala air pressure and air temperature and humidity sensors stopped working after storm *Pia* passed over the area. There are some back-up air pressure and air temperature measurements from the lidar met station between 22 December 2023 and 07 January 2024 that can be used to fill part of this gap. However, these data should be validated against the available measurements prior to substitution.

During deployment 1 of the offline ADCP (D01-ADCPSWLB, **Table 1-2**), the current meter stopped recording data in March 2022 resulting in a data gap from 22 March 2022 until 01 December 2022. Apart from this instrument failure during deployment 1, the offline ADCP at Lot 1 performed well.

SWMini071 stopped recording data on 15 February 2024 due to lack of power.

5.2 Post-processed Data Availability: 24-month and additional period

The final campaign post-processed data availability per parameter for the period 15 November 2021 to 15 November 2023 for the SWLB data is presented in **Table 5-1**. The post-processed data availability per parameter for the additional period 15 November 2023 to 24 February 2024 for the SWLB data is presented in **Table 5-2**. For the wave data from both SWmini buoys, the post-processed data availability per parameter for the period 15 November 2021 to 15 November 2023 is presented in **Table 5-3** and for the additional period 15 November 2023 to 24 February 2024 in **Table 5-4**. For the offline ADCP, the post-processed data availability per parameter for the period 15 November 2021 to 15 November 2023 is presented in **Table 5-5**, and for the additional period 15 November 2023 to 24 February 2024 in **Table 5-6.**

Table 5-1: SWLB 24-month post-processed data availability

Parameter	Availability [%]	Parameter	Availability [%]
WindDir004m deg	82.0	hm0 m	97.4
WindDir030m deg	85.9	hm0a m	97.4
WindDir040m deg	85.9	hm0b m	97.4
WindDir060m deg	85.7	hmax m	97.1
WindDir090m deg	84.8	hmean m	97.3
WindDir100m deg	84.7	hs m	97.3
WindDir120m deg	84.5	mdir deg	97.4
WindDir150m deg	84.2	mdira deg	97.4
WindDir180m deg	84.0	mdirb deg	97.4
WindDir200m deg	83.8	sprtp deg	97.4
WindDir240m deg	83.5	thhf deg	97.4
WindDir270m deg	83.3	thmax s	97.1
WindGust004m m/s	82.0	thtp deg	93.2
WindSpeed004m m/s	82.0	tm01 s	97.4
WindSpeed030m m/s	85.9	tm02 s	97.4
WindSpeed040m m/s	85.9	tm02a s	97.4
WindSpeed060m m/s	85.7	tm02b s	97.4
WindSpeed090m m/s	84.8	tp s	93.2
WindSpeed100m m/s	84.7	tz s	97.4
WindSpeed120m m/s	84.5	ts s	97.3
WindSpeed150m m/s	84.2	AirTemperature C	97.7
WindSpeed180m m/s	84.0	precipitation mm	65.7
WindSpeed200m m/s	83.8	solarIrradiance W/m2	97.8
WindSpeed240m m/s	83.5	thTBRtemperature degC	54.3
WindSpeed270m m/s	83.3	WaterTemp001 degC	97.5

Parameter	Availability [%]	Parameter	Availability [%]
AirHumidity %	97.7	WaterPressure dbar	58.6
AirPressure hPa	97.5	BottomTemperature degC	51.1
AqDir001 deg	0.0	AqSpd001 cm/s	0.0
AqDir002 deg	49.6	AqSpd002 cm/s	49.6
AqDir003 deg	52.4	AqSpd003 cm/s	52.4
AqDir004 deg	52.4	AqSpd004 cm/s	52.4
AqDir005 deg	52.4	AqSpd005 cm/s	52.4
AqDir006 deg	52.4	AqSpd006 cm/s	52.4
AqDir007 deg	97.5	AqSpd007 cm/s	97.5
AqDir008 deg	97.5	AqSpd008 cm/s	97.5
AqDir009 deg	97.4	AqSpd009 cm/s	97.4
AqDir010 deg	97.4	AqSpd010 cm/s	97.4
AqDir011 deg	94.1	AqSpd011 cm/s	94.1
AqDir012 deg	93.8	AqSpd012 cm/s	93.8
AqDir013 deg	94.7	AqSpd013 cm/s	94.7
AqDir014 deg	93.0	AqSpd014 cm/s	93.0
AqDir015 deg	90.9	AqSpd015 cm/s	90.9
AqDir016 deg	88.5	AqSpd016 cm/s	88.5
AqDir017 deg	85.8	AqSpd017 cm/s	85.8
AqDir018 deg	83.1	AqSpd018 cm/s	83.1
AqDir019 deg	80.4	AqSpd019 cm/s	80.4
AqDir020 deg	77.8	AqSpd020 cm/s	77.8
AqDir021 deg	75.3	AqSpd021 cm/s	75.3
AqDir022 deg	72.8	AqSpd022 cm/s	72.8
AqDir023 deg	69.2	AqSpd023 cm/s	69.2
AqDir024 deg	67.0	AqSpd024 cm/s	67.0
AqDir025 deg	65.3	AqSpd025 cm/s	65.3
AqDir026 deg	63.8	AqSpd026 cm/s	63.8
AqDir027 deg	62.4	AqSpd027 cm/s	62.4
AqDir028 deg	61.2	AqSpd028 cm/s	61.2
AqDir029 deg	59.8	AqSpd029 cm/s	59.8
AqDir030 deg	57.8	AqSpd030 cm/s	57.8
AqDir031 deg	55.3	AqSpd031 cm/s	55.3
AqDir032 deg	52.7	AqSpd032 cm/s	52.7
AqDir033 deg	49.8	AqSpd033 cm/s	49.8
AqDir034 deg	46.9	AqSpd034 cm/s	46.9
AqDir035 deg	43.9	AqSpd035 cm/s	43.9

Parameter	Availability [%]	Parameter	Availability [%]
AqDir036 deg	40.8	AqSpd036 cm/s	40.8
AqDir037 deg	38.7	AqSpd037 cm/s	38.7
AqDir038 deg	36.8	AqSpd038 cm/s	36.8
AqDir039 deg	34.5	AqSpd039 cm/s	34.5
AqDir040 deg	32.8	AqSpd040 cm/s	32.8
AqDir041 deg	31.3	AqSpd041 cm/s	31.3

Table 5-2: Additional period (15 November 2023 – 24 February 2024) SWLB post-processed data availability

Parameter	Availability [%]	Parameter	Availability [%]
WindDir004m deg	99.9	hm0 m	99.7
WindDir030m deg	52.0	hm0a m	99.7
WindDir040m deg	52.1	hm0b m	99.7
WindDir060m deg	52.3	hmax m	99.7
WindDir090m deg	52.1	hmean m	99.7
WindDir100m deg	52.1	hs m	99.7
WindDir120m deg	52.1	mdir deg	99.7
WindDir150m deg	52.1	mdira deg	99.7
WindDir180m deg	52.0	mdirb deg	99.7
WindDir200m deg	52.0	sprtp deg	99.7
WindDir240m deg	52.0	thhf deg	99.7
WindDir270m deg	52.0	thmax s	99.7
WindGust004m m/s	99.9	thtp deg	95.9
WindSpeed004m m/s	99.9	tm01 s	99.7
WindSpeed030m m/s	52.0	tm02 s	99.7
WindSpeed040m m/s	52.1	tm02a s	99.7
WindSpeed060m m/s	52.3	tm02b s	99.7
WindSpeed090m m/s	52.1	tp s	95.9
WindSpeed100m m/s	52.1	tz s	99.7
WindSpeed120m m/s	52.1	ts s	99.7
WindSpeed150m m/s	52.1	AirTemperature C	36.0
WindSpeed180m m/s	52.0	precipitation mm	36.0
WindSpeed200m m/s	52.0	solarIrradiance W/m2	100
WindSpeed240m m/s	52.0	thTBRtemperature degC	80.7
WindSpeed270m m/s	52.0	WaterTemp001 degC	100
AirHumidity %	36.0	WaterPressure dbar	99.6
AirPressure hPa	36.0	BottomTemperature degC	79.1

Table 5-3: SWMini buoy 24-month post-processed data availability

Parameter	Lot1_mini (SWMini071) Availability [%]	Lot1_mini3 (SWMini074) Availability [%]
hm0 m	99.9	99.7
hm0a m	99.9	99.7
hm0b m	99.9	99.7
hmax m	99.6	99.4
hmean m	99.9	99.7
hs m	99.9	99.7
mdir deg	99.9	99.7
mdira deg	99.9	99.7
mdirb deg	99.9	99.7
sprtp deg	99.9	99.7
thhf deg	99.9	99.7
thmax s	99.4	99.3
thtp deg	99.9	99.7
tm01 s	99.9	99.7
tm02 s	99.9	99.7
tm02a s	99.9	99.7
tm02b s	99.9	99.7
tp s	96.9	93.3
tz s	99.9	99.7
ts s	99.6	99.7
ui unknown	99.9	99.7

Table 5-4: Additional period (15 November 2023 – 24 February 2024) SWMini buoy post-processed data availability

Parameter	Lot1_mini (SWMini071) Availability [%]	Lot1_mini3 (SWMini074) Availability [%]
hm0 m	90.3	99.9
hm0a m	90.3	99.9
hm0b m	90.3	99.9
hmax m	90.3	99.9
hmean m	90.3	99.9
hs m	90.3	99.9
mdir deg	90.3	99.9
mdira deg	90.3	99.9
mdirb deg	90.3	99.9

Parameter	Lot1_mini (SWMini071) Availability [%]	Lot1_mini3 (SWMini074) Availability [%]
sprtp deg	90.3	99.9
thhf deg	90.3	99.9
thmax s	90.3	99.9
thtp deg	90.3	99.9
tm01 s	90.3	99.9
tm02 s	90.3	99.9
tm02a s	90.3	99.9
tm02b s	90.3	99.9
tp s	87.8	96.4
tz s	90.3	99.9
ts s	90.3	99.9
ui unknown	90.3	99.9

Table 5-5: Signature post-processed data availability during the campaign (November 2021 – November 2023)

Parameter	Availability [%]	Parameter	Availability [%]
Speed004m_cm/s	64.8	SigDir004m_deg	64.8
Speed005m_cm/s	64.8	SigDir005m_deg	64.8
Speed006m_cm/s	64.8	SigDir006m_deg	64.8
Speed007m_cm/s	64.8	SigDir007m_deg	64.8
Speed008m_cm/s	64.8	SigDir008m_deg	64.8
Speed009m_cm/s	64.8	SigDir009m_deg	64.8
Speed010m_cm/s	64.8	SigDir010m_deg	64.8
Speed011m_cm/s	64.8	SigDir011m_deg	64.8
Speed012m_cm/s	64.8	SigDir012m_deg	64.8
Speed013m_cm/s	64.8	SigDir013m_deg	64.8
Speed014m_cm/s	64.8	SigDir014m_deg	64.8
Speed015m_cm/s	64.8	SigDir015m_deg	64.8
Speed016m_cm/s	64.8	SigDir016m_deg	64.8
Speed017m_cm/s	64.8	SigDir017m_deg	64.8
Speed018m_cm/s	64.8	SigDir018m_deg	64.8
Speed019m_cm/s	64.8	SigDir019m_deg	64.8
Speed020m_cm/s	64.8	SigDir020m_deg	64.8
Speed021m_cm/s	64.8	SigDir021m_deg	64.8
Speed022m_cm/s	64.8	SigDir022m_deg	64.8
Speed023m_cm/s	64.8	SigDir023m_deg	64.8
Speed024m_cm/s	64.8	SigDir024m_deg	64.8

Parameter	Availability [%]	Parameter	Availability [%]
Speed025m_cm/s	64.8	SigDir025m_deg	64.8
Speed026m_cm/s	64.8	SigDir026m_deg	64.8
Speed027m_cm/s	64.8	SigDir027m_deg	64.8
Speed028m_cm/s	64.8	SigDir028m_deg	64.8
Speed029m_cm/s	64.8	SigDir029m_deg	64.8
Speed030m_cm/s	64.8	SigDir030m_deg	64.8
Speed031m_cm/s	64.8	SigDir031m_deg	64.8
Speed032m_cm/s	64.8	SigDir032m_deg	64.8
Speed033m_cm/s	64.8	SigDir033m_deg	64.8
Speed034m_cm/s	64.8	SigDir034m_deg	64.8
Speed035m_cm/s	64.8	SigDir035m_deg	64.8
Speed036m_cm/s	64.7	SigDir036m_deg	64.7
Speed037m_cm/s	64.6	SigDir037m_deg	64.6
Speed038m_cm/s	64.3	SigDir038m_deg	64.3
Speed039m_cm/s	64.0	SigDir039m_deg	64.1
Speed040m_cm/s	63.9	SigDir040m_deg	64.1

Table 5-6: Signature post-processed data availability during the additional period (15 November 2023 – 24 February 2024)

Parameter	Availability [%]	Parameter	Availability [%]
Speed004m_cm/s	100	SigDir004m_deg	100
Speed005m_cm/s	100	SigDir005m_deg	100
Speed006m_cm/s	100	SigDir006m_deg	100
Speed007m_cm/s	100	SigDir007m_deg	100
Speed008m_cm/s	100	SigDir008m_deg	100
Speed009m_cm/s	100	SigDir009m_deg	100
Speed010m_cm/s	100	SigDir010m_deg	100
Speed011m_cm/s	100	SigDir011m_deg	100
Speed012m_cm/s	100	SigDir012m_deg	100
Speed013m_cm/s	100	SigDir013m_deg	100
Speed014m_cm/s	100	SigDir014m_deg	100
Speed015m_cm/s	100	SigDir015m_deg	100
Speed016m_cm/s	100	SigDir016m_deg	100
Speed017m_cm/s	100	SigDir017m_deg	100
Speed018m_cm/s	100	SigDir018m_deg	100
Speed019m_cm/s	100	SigDir019m_deg	100
Speed020m_cm/s	100	SigDir020m_deg	100

Parameter	Availability [%]	Parameter	Availability [%]
Speed021m_cm/s	100	SigDir021m_deg	100
Speed022m_cm/s	100	SigDir022m_deg	100
Speed023m_cm/s	100	SigDir023m_deg	100
Speed024m_cm/s	100	SigDir024m_deg	100
Speed025m_cm/s	100	SigDir025m_deg	100
Speed026m_cm/s	100	SigDir026m_deg	100
Speed027m_cm/s	100	SigDir027m_deg	100
Speed028m_cm/s	100	SigDir028m_deg	100
Speed029m_cm/s	100	SigDir029m_deg	100
Speed030m_cm/s	100	SigDir030m_deg	100
Speed031m_cm/s	100	SigDir031m_deg	100
Speed032m_cm/s	100	SigDir032m_deg	100
Speed033m_cm/s	100	SigDir033m_deg	100
Speed034m_cm/s	99.9	SigDir034m_deg	99.9
Speed035m_cm/s	99.8	SigDir035m_deg	99.8
Speed036m_cm/s	99.8	SigDir036m_deg	99.8
Speed037m_cm/s	99.7	SigDir037m_deg	99.7
Speed038m_cm/s	99.6	SigDir038m_deg	99.6
Speed039m_cm/s	99.5	SigDir039m_deg	99.6
Speed040m_cm/s	99.3	SigDir040m_deg	99.5

5.3 Post-processed parameter group availability: 24-month and additional period

The monthly post processed data availability per main parameter group as reported in the monthly reports is compared to the final monthly post-processed group availability and shown in **Table 5-7** through **Table 5-11**. The final, overall, 24-month post-processed parameter group availability for the final dataset is shown in row "F". The post-processed group availability for the additional period is shown in the last row (row "Add").

Any gaps due to satellite transmission/reception issues (e.g. month 18) are filled. There were 2 lidar failures (April 2022 and February – March 2023) that resulted in low lidar wind data availability. Some lidar wind data during these times has been recovered. In addition, the lidar wind data from deployment 4 (months 18 and 19) was also reprocessed and recovered. Water pressure from month 13 and deployment 5 was recovered.

The SWLB current dataset has been subjected to stricter QC than during the monthly checks resulting in overall lower current data availability.

Apart from the instrument failure during deployment 1, the offline ADCP at Lot 1 performed well.

SWMini071 stopped recording data on 15 February 2024 due to lack of power.

Table 5-7: Post-processed parameter group availability (wind, waves, currents) in % for the SWLB data per month: monthly reports, final 24-month dataset and additional period.

#	Reporting Period	Monthly Wind	Final Wind	Monthly Wave	Final Wave	Monthly Current	Final Current
1	NovDec2021	99.4	99.5	100	100	100	96.9
2	Dec2021Jan2022	96.9	96.9	100	99.9	100	90.2
3	JanFeb2022	99.2	99.3	100	100	99.9	97.5
4	FebMar2022	98.2	98.3	100	100	99.3	96.7
5	MarApr2022	73.2	73.1	99.9	99.9	99.0	96.4
6	AprMay2022	9.1	9.3	86.2	86.3	85.1	82.9
7	MayJun2022	83.7	83.7	84.0	84.1	37.8	25.5
8	JunJuly2022	98.6	98.6	100	100	58.2	36.2
9	JulyAug2022	98.2	98.2	100	100	0.0	40.4
10	AugSep2022	100	100	100	99.9	42.7	40.2
11	SepOct2022	100	100	100	100	28.9	26.3
12	OctNov2022	98.7	98.7	100	100	29.1	26.6
13	NovDec2022	98.8	98.9	98.3	98.4	72.8	53.0
14	Dec2022Jan2023	91.5	91.5	99.1	99.2	85.2	82.8
15	JanFeb2023	89.4	89.5	95.6	95.6	83.2	80.7
16	FebMar2023	0.0	30.8	97.9	97.9	82.0	79.5
17	MarApr2023	0.0	0.0	95.3	95.4	67.3	65.0
18	AprMay2023	17.0	70.8	68.2	73.8	60.6	63.3
19	MayJun2023	15.3	98.4	96.1	96.2	82.0	79.4
20	JunJul2023	96.6	96.8	99.2	99.3	82.6	79.9
21	JulAug2023	98.8	98.9	99.6	99.6	78.2	75.7
22	AugSep2023	97.0	97.1	97.6	97.6	73.1	70.6
23	SepOct2023	99.7	99.8	99.6	99.6	39.1	36.6
24	OctNov2023	97.3	97.3	99.8	99.8	34.3	31.9
F	**Nov2021 – Nov2023**	**-**	**84.6**	**-**	**96.8**	**-**	**64.6**
Add	Nov2023 – Feb2024	-	56.9	-	99.2	-	0.0

Table 5-8: Post-processed parameter group availability (met parameters) in % for the SWLB data per month: monthly reports, final 24-month dataset and additional period.

#	Reporting Period	Monthly Atm. Pressure	Final Atm. Pressure	Monthly Air temp.	Final Air temp.	Monthly Air humidity	Final Air humidity
1	NovDec2021	99.6	100	100	100	100	100
2	Dec2021Jan2022	99.5	100	99.8	99.9	99.8	99.9
3	JanFeb2022	98.9	99.9	99.8	99.9	99.8	99.9
4	FebMar2022	98.7	99.8	100	100	100	100
5	MarApr2022	98.3	99.9	99.8	99.9	99.8	99.9
6	AprMay2022	84.2	86.9	91.1	93.3	91.1	93.3
7	MayJun2022	81.5	84.0	84.0	84.1	84.0	84.1
8	JunJuly2022	97.7	99.8	100	100	100	100
9	JulyAug2022	97.8	100	100	100	100	100
10	AugSep2022	97.9	100	100	100	100	100
11	SepOct2022	99.0	100	100	100	100	100
12	OctNov2022	99.3	100	100	100	100	100
13	NovDec2022	97.8	99.0	99.1	99.1	99.1	99.1
14	Dec2022Jan2023	99.6	100	100	100	100	100
15	JanFeb2023	99.3	100	100	100	100	100
16	FebMar2023	95.3	98.9	99.5	99.5	99.5	99.5
17	MarApr2023	95.9	97.1	96.0	96.1	96.0	96.1
18	AprMay2023	68.5	75.1	70.0	75.0	70.0	75.0
19	MayJun2023	97.3	99.6	99.4	99.5	99.4	99.5
20	JunJul2023	97.5	99.9	99.5	99.6	99.5	99.6
21	JulAug2023	97.1	99.8	99.3	99.3	99.3	99.3
22	AugSep2023	99.8	99.9	98.8	98.9	98.8	98.9
23	SepOct2023	100	100	99.9	100	99.9	100
24	OctNov2023	99.8	99.8	99.9	100	99.9	100
F	**Nov2021 – Nov2023**	**-**	**97.5**	**-**	**97.7**	**-**	**97.7**
Add	Nov2023 – Feb2024	-	36.0	-	36.0	-	36.0

Table 5-9: Post-processed parameter group availability (sea surface temperature, water pressure) in % for the SWLB data per month: monthly reports, final 24-month dataset and additional period.

#	Reporting Period	Monthly Sea surf. Temp.	Final Sea surf. Temp.	Monthly Water pressure	Final Water pressure
1	NovDec2021	95.9	100	99.7	99.8
2	Dec2021Jan2022	93.1	100	100	100
3	JanFeb2022	85.9	100	89.3	89.2
4	FebMar2022	100	100	0.0	0.0
5	MarApr2022	99.9	100	0.0	0.0
6	AprMay2022	85.5	85.5	0.0	0.0
7	MayJun2022	84.0	84.1	0.0	0.0
8	JunJuly2022	100	100	0.0	0.0
9	JulyAug2022	100	100	0.0	0.0
10	AugSep2022	100	100	0.0	0.0
11	SepOct2022	100	100	0.0	0.0
12	OctNov2022	100	100	0.0	0.0
13	NovDec2022	99.1	99.1	0.0	45.8
14	Dec2022Jan2023	100	100	100	100
15	JanFeb2023	99.9	100	100	100
16	FebMar2023	100	100	100	100
17	MarApr2023	97.1	97.1	97.1	97.2
18	AprMay2023	70.1	75.2	75.3	75.1
19	MayJun2023	99.5	99.6	73.7	98.1
20	JunJul2023	99.8	100	0.0	100
21	JulAug2023	99.9	100	0.0	100
22	AugSep2023	100	100	0.0	100
23	SepOct2023	99.9	100	0.0	100
24	OctNov2023	100	100	0.0	98.7
F	**Nov2021 – Nov2023**	**-**	**97.5**	**-**	**58.6**
Add	Nov2023 – Feb2024	-	100	-	99.6

Table 5-10: Post-processed parameter group availability for the SWMini buoys in % per month: monthly reports, final 24-month dataset and additional period.

#	Reporting Period	SWMini Monthly Wave	SWMini071 Final Wave	SWMini_3 Monthly Wave	SWMini_074 Final Wave
1	NovDec2021	99.9	100	-	-
2	Dec2021Jan2022	99.9	100	-	-
3	JanFeb2022	99.9	100	-	-
4	FebMar2022	99.9	100	-	-
5	MarApr2022	99.9	100	-	-
6	AprMay2022	99.9	100	-	-
7	MayJun2022	99.9	100	-	-
8	JunJuly2022	99.9	100	-	-
9	JulyAug2022	99.9	100	-	-
10	AugSep2022	99.9	100	-	-
11	SepOct2022	99.9	100	-	-
12	OctNov2022	99.9	100	-	-
13	NovDec2022	99.5	99.8	99.2	99.8
14	Dec2022Jan2023	99.6	99.8	99.6	99.8
15	JanFeb2023	98.0	98.5	98.1	98.7
16	FebMar2023	99.3	99.6	99.2	99.5
17	MarApr2023	99.3	99.5	99.2	99.5
18	AprMay2023	95.3	99.4	95.4	99.3
19	MayJun2023	97.4	97.4	97.1	97.2
20	JunJul2023	99.3	99.5	99.6	99.8
21	JulAug2023	99.8	99.9	99.8	99.8
22	AugSep2023	98.5	98.6	98.5	98.6
23	SepOct2023	99.8	99.8	99.9	99.9
24	OctNov2023	99.8	99.9	99.9	99.9
F	**Nov2021 – Nov2023**	**-**	**99.7**	**-**	**99.2**
Add	Nov2023 – Feb2024	-	90.1	-	99.7

Table 5-11: Post-processed parameter group availability (sea surface temperature, water pressure, current data) in % from the upward-facing for the final dataset per deployment.

#	Reporting Period	Final Sea surf. Temp.	Final Water pressure	Final Current
F	**Nov2021 – Nov2023**	**65.0**	**65.0**	**64.7**
Add	**Nov2023 – Feb2024**	**100**	**100**	**99.9**

6. Uncertainty assessment of the Lidar wind data

The performance verification of WS170 took place between 01 May 2021 and 22 May 2021 at the LEG offshore platform in the Dutch North Sea. This validation was done against a fixed reference Leosphere Windcube v2 lidar. SWLB wind direction data was given based on magnetic compass heading correction [1].

The pre-deployment validation of WS191 took place between 16 February 2022 and 03 March 2022 at Fugro's pre-deployment validation site in Frøya, Norway. This validation was done against a fixed reference ZX lidar. SWLB wind direction data was given based on DGPS heading correction [2].

The validation reports ([1] [2]) contain uncertainty estimations considering the following components: 1. Reference/anemometer uncertainty, 2. Mean deviation of the remote sensor measurements and the reference measurements, 3. Standard uncertainty of the measurement of the remote sensing device, 4. Mounting uncertainty of the remote sensor at the verification test, 5. Uncertainty due to non-homogenous flow, and 6. Uncertainty due to separation distance.

The uncertainty estimations for the FLS verifications were done according to the IEC bin definition. During both performance verifications, the IEC database requirement for the lidar verification of 180 hours between 4 m/s and 16 m/s was met for each comparison height. The additional IEC database requirement of a minimum of 3 data pairs in each 0.5 m/s wind speed bin was fulfilled for each comparison height.

During WS170 performance verification, the maximum 10-minute averaged wind speeds at the reference lidar varied between 21.5 m/s at the lowest comparison level (62 m) and 28.3 m/s at the highest level (240 m). The air temperatures ranged from 4.2 °C to 15.1 °C. The significant wave heights observed were up to 3.82 m. The maximum wave heights observed cover a range up to 6.17 m.

During WS191 performance verification, the maximum 10-minute averaged wind speeds at the reference lidar varied between 26.0 m/s at the lowest comparison level (40 m) and 29.6 m/s at the highest level (250 m). The air temperatures ranged from -3.4 °C to 7.0 °C. The significant wave heights observed were up to 4.67 m. The maximum wave heights observed cover a range up to 7.75 m. The tidal or water levels observed at Mausund, north of Frøya during the measurement campaign varied between -124.5 cm and 130.7 cm over MSL.

For WS170, the overall uncertainty during the pre-deployment validation trial varied between 2.59 % - 5.51 % for wind speeds between 2-16 m/s and 62 - 240 m height.

For WS191, the overall uncertainty during the pre-deployment validation trial varied between 1.60 % - 4.51 % for wind speeds between 2-16 m/s and 40 - 120 m height.

7. Results: Buoy positions

Figure 7-1 shows the position of the buoy throughout the full campaign including the additional period, the nominal anchor position reported in **Table 1-1**, and the ADCP anchor position. **Figure 7-2** and **Figure 7-3** show the positions of the SWMini buoys throughout the campaign. There were no drifts or position changes.

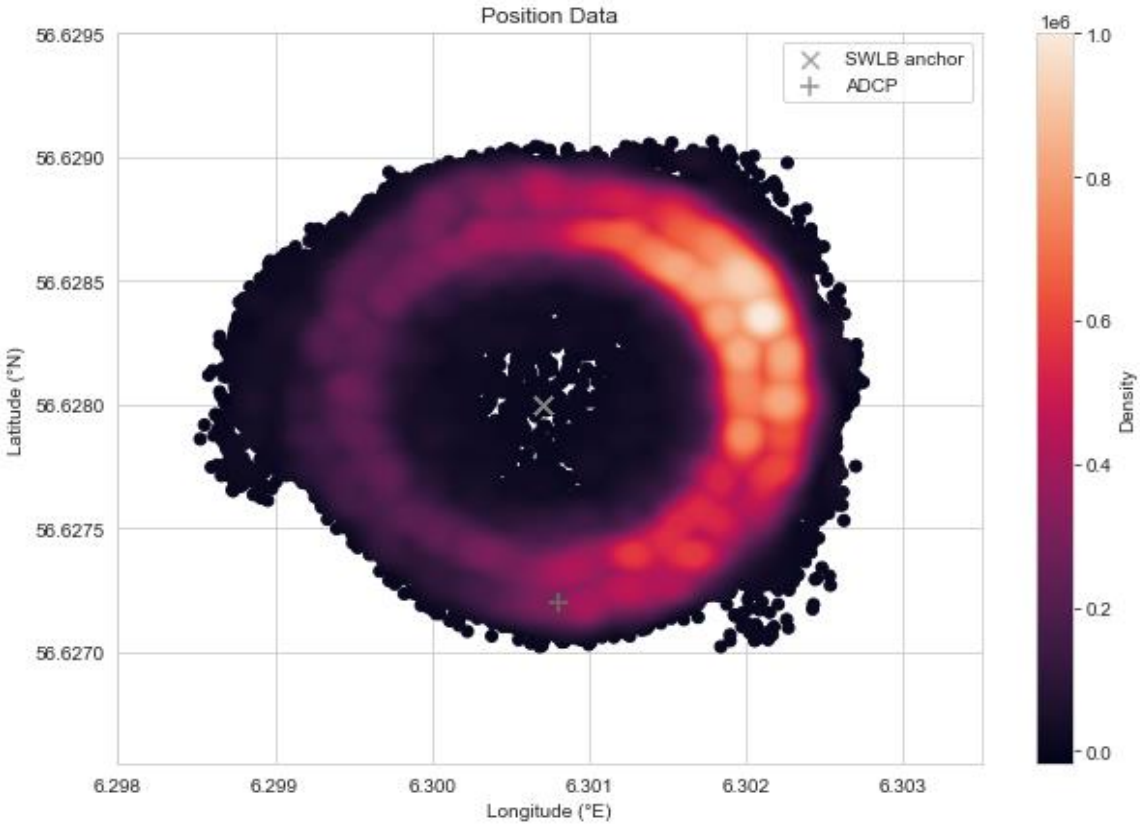


Figure 7-1: Full campaign (including the additional period) SWLB and ADCP position data.

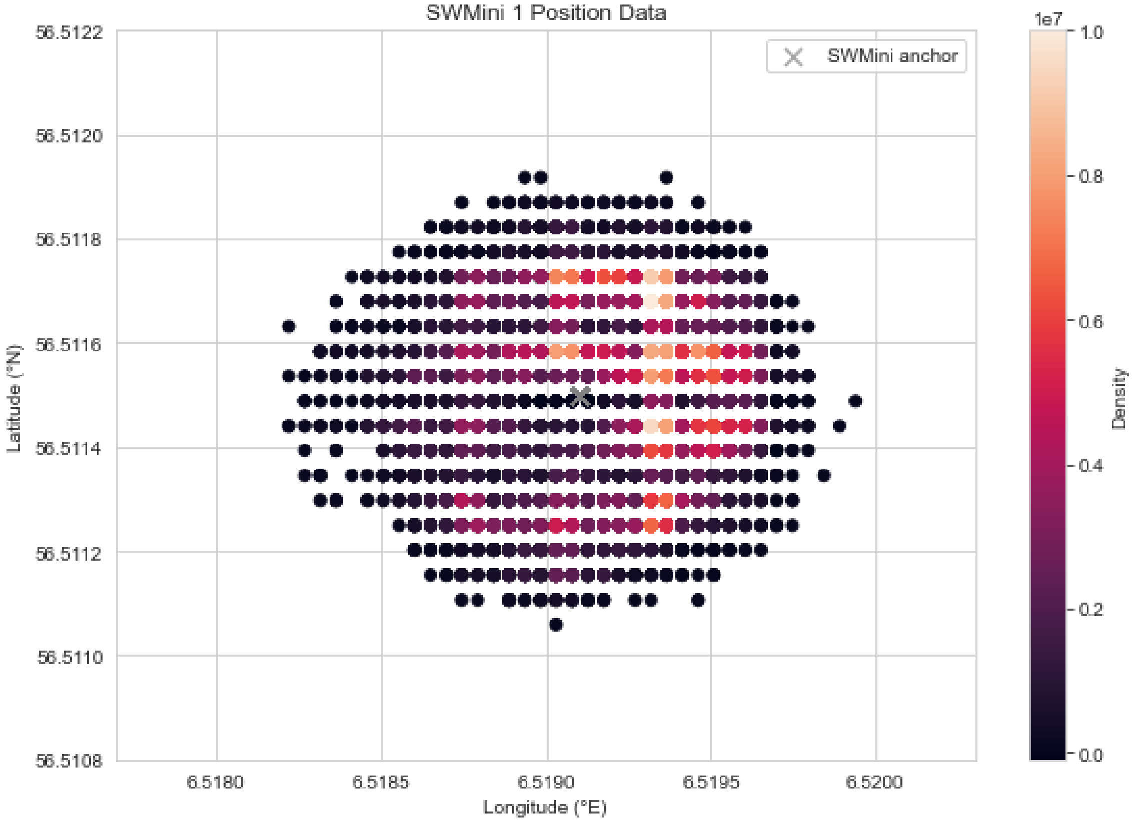


Figure 7-2: Full campaign (including the additional period) SWMini 1 position data.

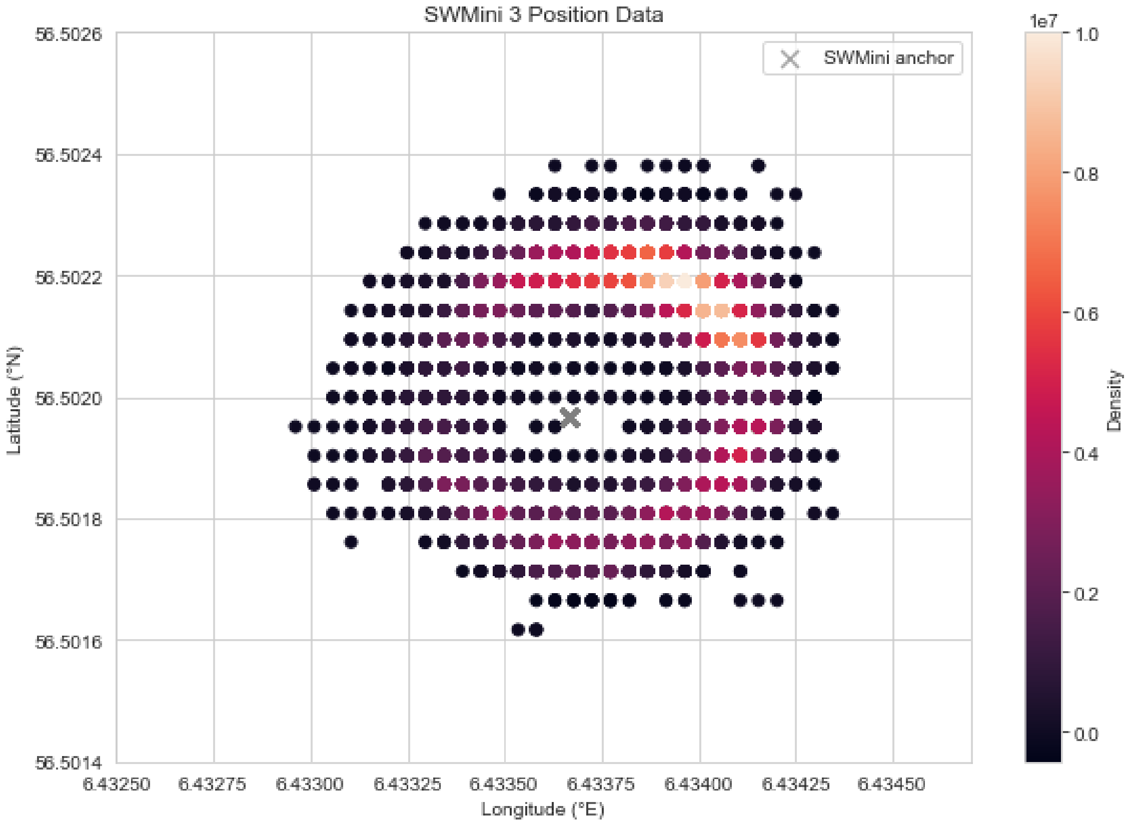


Figure 7-3: Full campaign (including the additional period) SWMini 3 position data.

8. Results: Wind

There were 2 lidar failures (April 2022 and February – March 2023) that resulted in low lidar wind data availability. Some lidar wind data during these times has been recovered and added to the dataset. Measurements were taken between 04 m and 270 m height. During the additional period, the lidar unit on WS191 was switched off remotely on 07 January 2024 to save power until recovery was possible.

Timeseries of wind speed and direction are presented in **Appendix B**.

Table 8-1 summarizes statistics for wind speed over the full campaign including the additional period (Nov 2021 – Feb 2024). **Figure 8-1** shows wind roses at 4 heights (04, 90, 150, and 240 m) and **Figure 8-2** presents the wind speed profile for the full campaign including the additional period.

The highest wind speeds during the 24-months of the campaign were measured on 29 January 2022. The maximum wind speeds during the full campaign including the additional period were measured in December 2023. High wind speeds (> 30 m/s) were also measured in February 2023, October 2023, and January 2024. The dominant wind direction was from northwest and west.

Table 8-1: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2021 – Feb 2024): wind speed

Instrument / Parameter	Height [m]	Standard Deviation [m/s]	Minimum [m/s]	Mean [m/s]	Maximum [m/s]
Gill Windsonic 10min wind speed (WindSpeed004m m/s)	4	4.9	0.5	10.7	34.3
ZephIR Lidar 10min wind speed	30	3.9	0.0	8.4	24.1
	40	4.5	0.5	9.8	31.8
	60	4.6	0.5	10.0	32.3
	90	4.8	0.5	10.4	34.0
	100	5.0	0.5	10.7	35.1
	120	5.0	0.4	10.8	34.6
	150	5.1	0.5	11.0	34.9
	180	5.3	0.5	11.2	34.8
	200	5.4	0.5	11.3	35.9
	240	5.4	0.5	11.4	36.5
	270	5.6	0.5	11.6	37.7

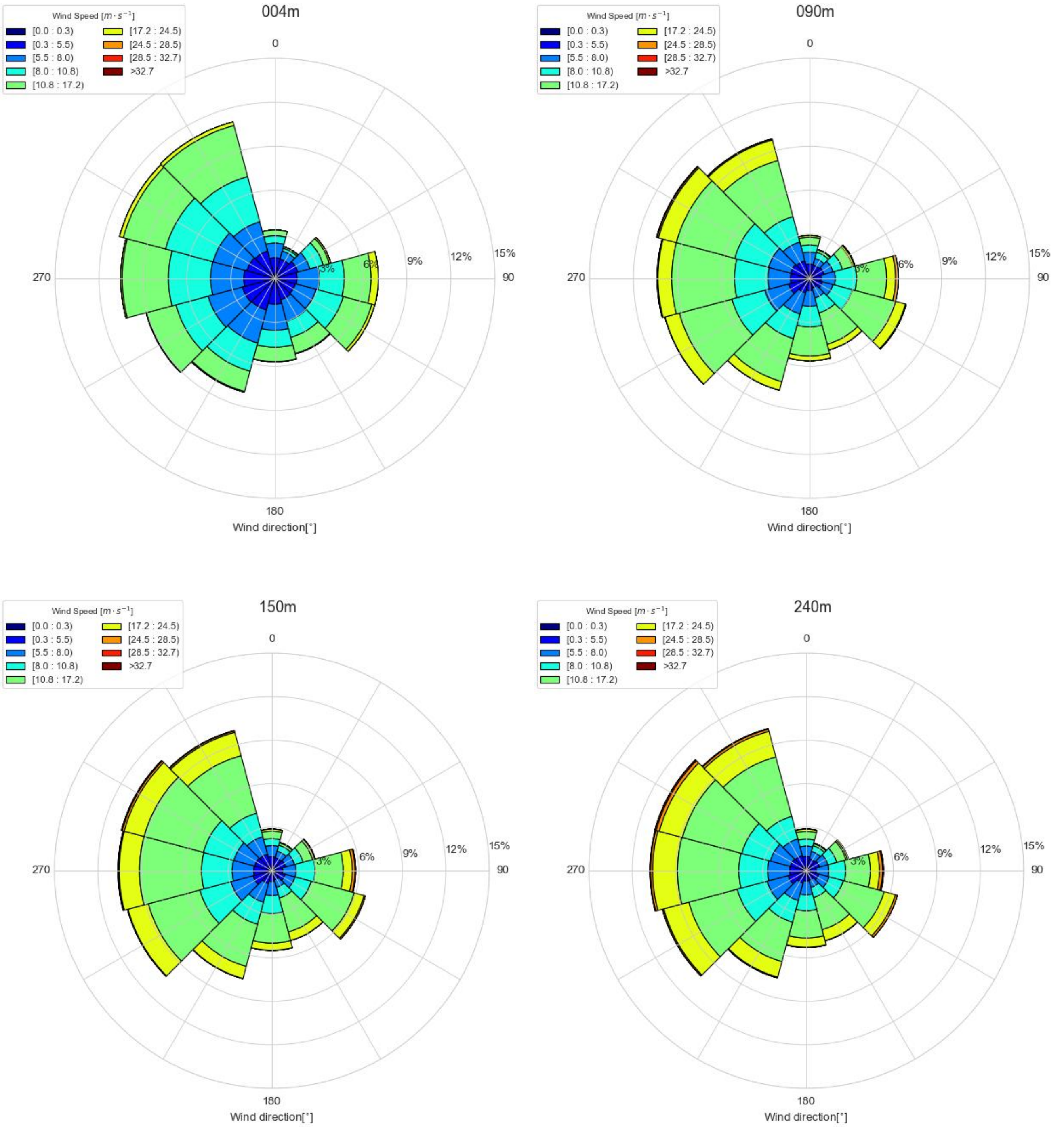


Figure 8-1 Wind roses at 04 m, 90 m, 150 m, and 240 m height for the full campaign including the additional period (Nov 2021 – Feb 2024).

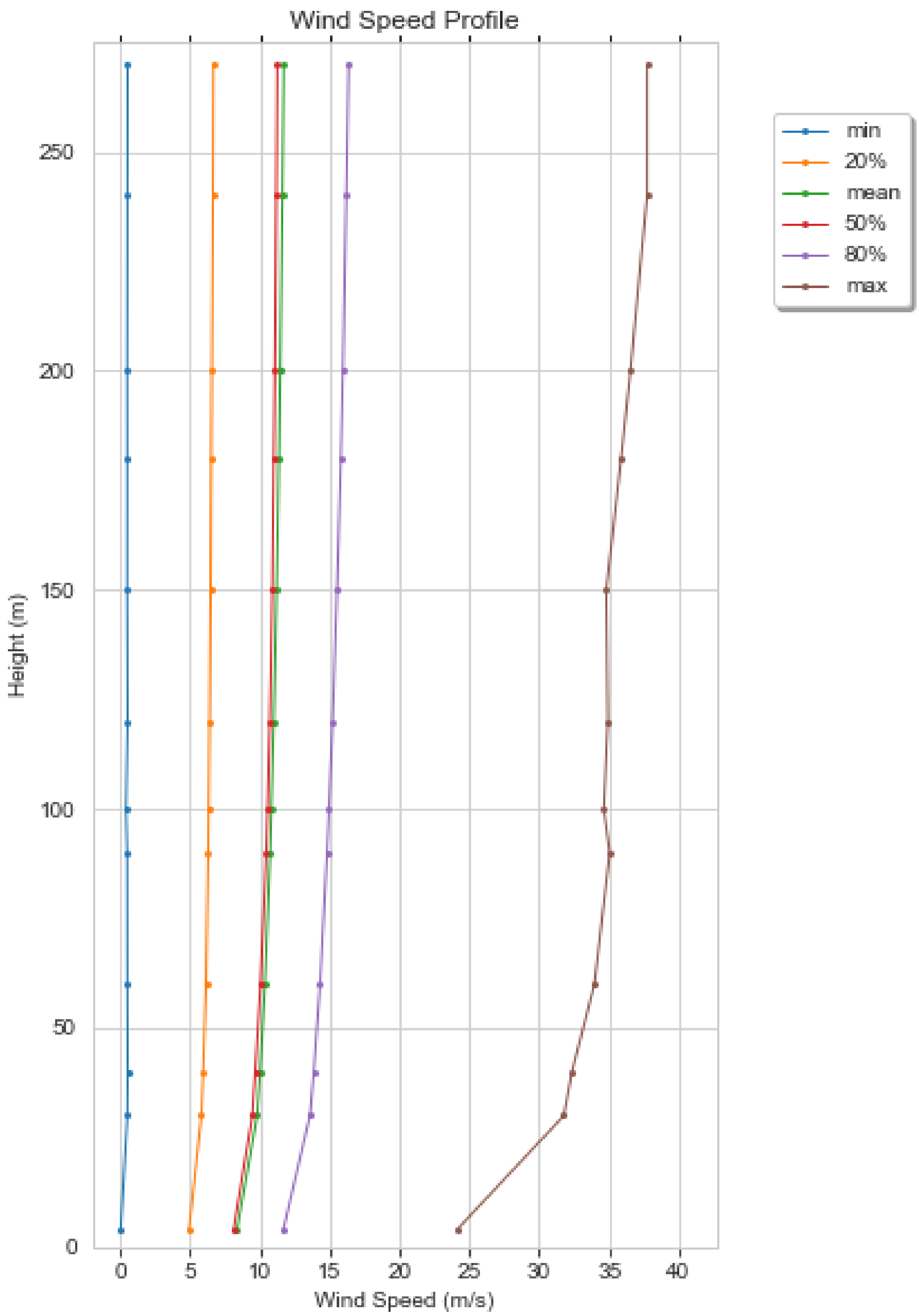


Figure 8-2 Full campaign including the additional period (Nov 2021 – Feb 2024) wind speed profile.

9. Results: Waves

The floating lidar system and SWMini wave buoys performed well and without disruptions during leading to a virtually complete wave dataset.

Timeseries of wave height, period and direction for all 3 buoys are presented in **Appendix 0**.

Figure 9-2 and **Figure 9-2** show wave roses for wave height and direction for the full campaign including the additional period from the SWLB, SWMini 1, and SWMini 3. **Table 9-1**, **Table 9-2**, and **Table 9-3** summarize statistics for wave heights and periods from the SWLB and the SWMini buoys over the full campaign including the additional period (Nov 2021 – Feb 2024, Nov 2022 – Feb 2024 for SWMini 3). **Figure 9-3** and **Figure 9-4** show examples of directional wave spectra for 2 high wave events during the campaign.

All wave directions (as given in the **WaveData*.csv and **Wave*.csv files) were corrected for magnetic declination and are given relative to true north.

The highest wave heights during the campaign (November 2021 – November 2023) were measured in January 2022. High wave heights (hmax > 12 m) were also measured in December 2021, January 2023, February 2023, and October 2023 through February 2024.

The dominant wave directions are from northwest.

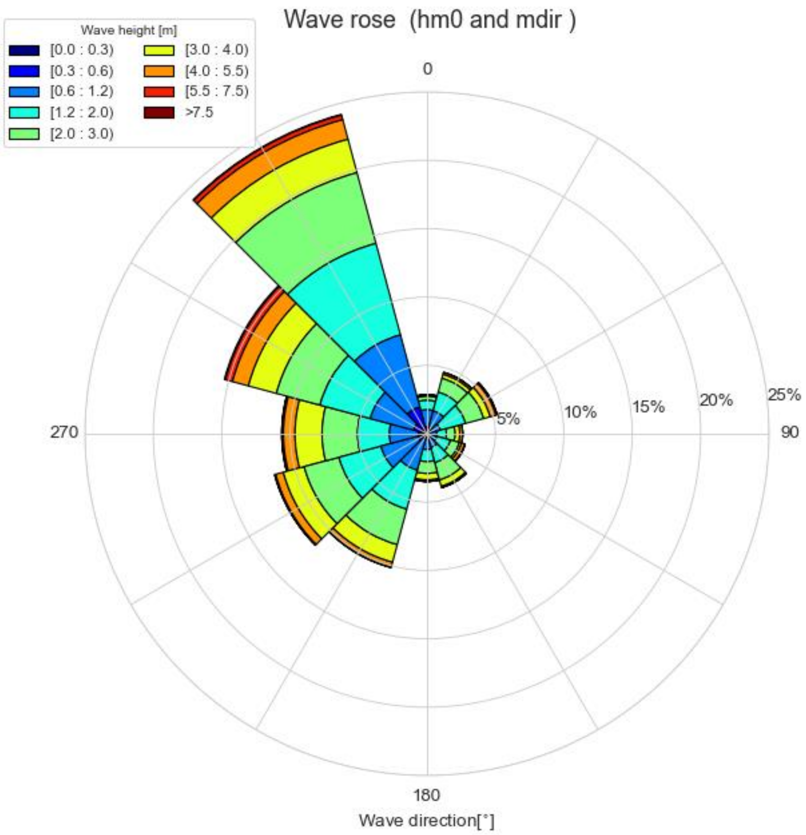
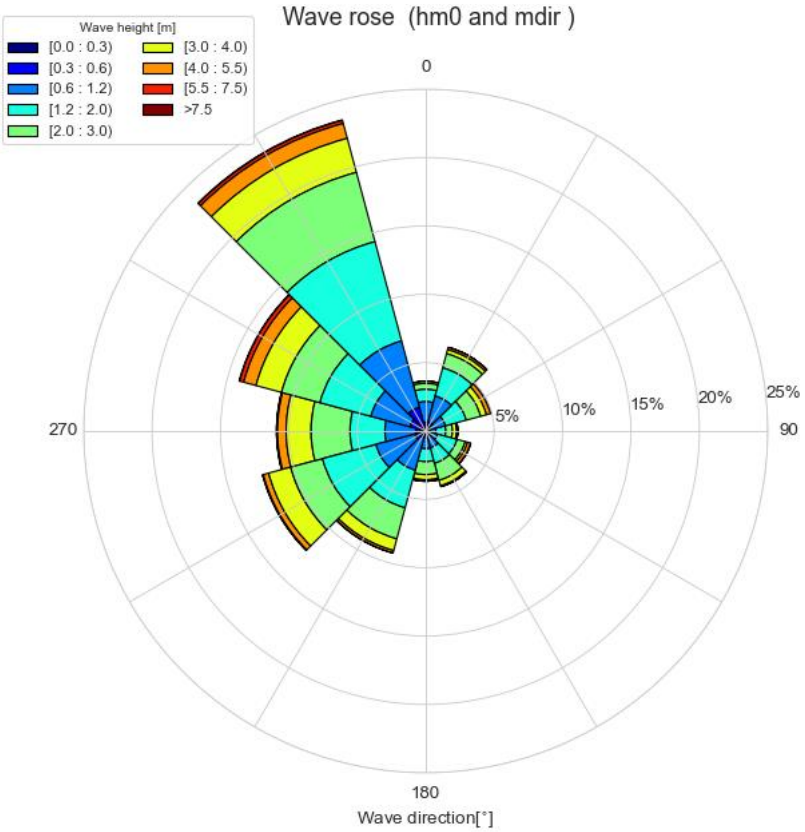


Figure 9-1 Wave rose with wave direction relative to true north (°N) for the full campaign including the additional period (Nov 2021 – Feb 2024) from the SWLB.



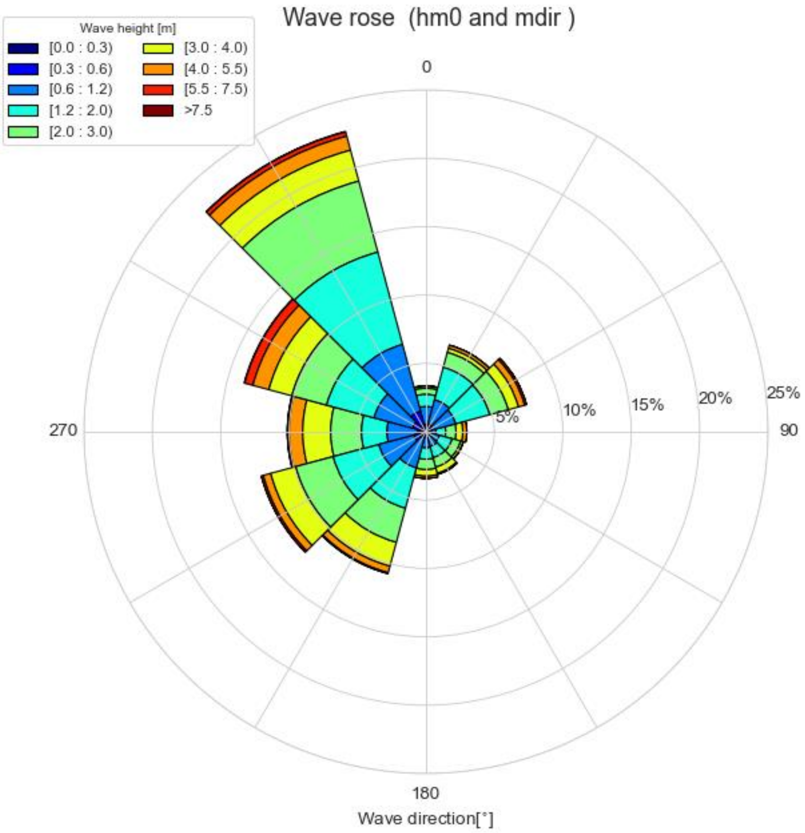


Figure 9-2 Wave roses with wave direction relative to true north (°N) for the full campaign including the additional period (Nov 2021 – Feb 2024) from the SWMini 1 (left) and SWMini 3 (right) buoys.

Table 9-1: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2021 – Feb 2024): SWLB wave parameters.

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
hm0 m	m	0	1.2	0.2	2.0	13.8
hmax m	m	0	1.9	0.3	3.1	17.5
thmax s	s	0	1.9	2.7	6.8	22.9
tm01 s	s	0	1.2	3.0	5.8	20.1
tm02 s	s	0	1.1	2.9	5.3	19.3
tp s	s	0	2.3	2.0	7.6	22.8

Table 9-2: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2021 – Feb 2024): SWMini 1 wave parameters.

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
hm0 m	m	0	1.1	0.1	1.9	9.6
hmax m	m	0	1.8	0.3	2.9	19.0
thmax s	s	0	1.8	2.5	6.5	22.7
tm01 s	s	0	1.1	2.8	5.5	17.0
tm02 s	s	0	1.0	2.7	5.1	15.9
tp s	s	0	2.1	2.1	7.2	22.8

Table 9-3: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2022 – Feb 2024): SWMini 3 wave parameters.

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
hm0 m	m	0	1.2	0.2	2.0	10.0
hmax m	m	0	1.9	0.4	3.1	14.6
thmax s	s	0	1.8	2.6	6.6	19.4
tm01 s	s	0	1.2	2.8	5.6	10.9
tm02 s	s	0	1.1	2.7	5.2	10.2
tp s	s	0	2.0	2.1	7.2	16.8

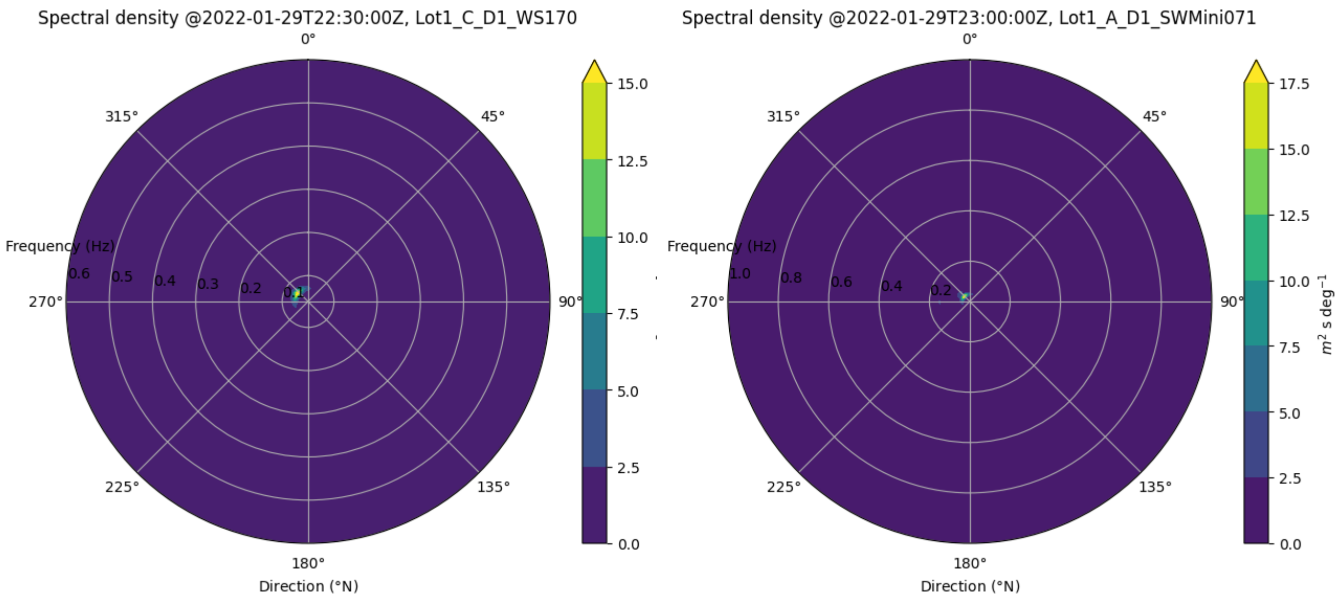
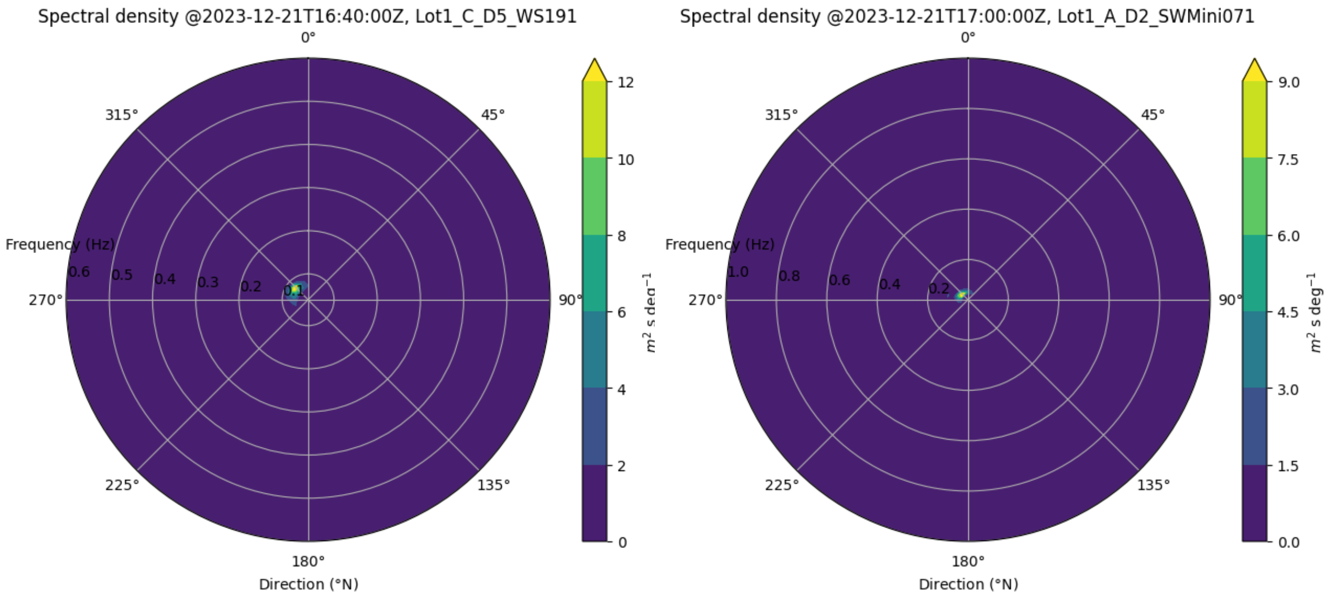


Figure 9-3 Directional wave spectra (MEM spectra m²/s) from 29 January 2022.



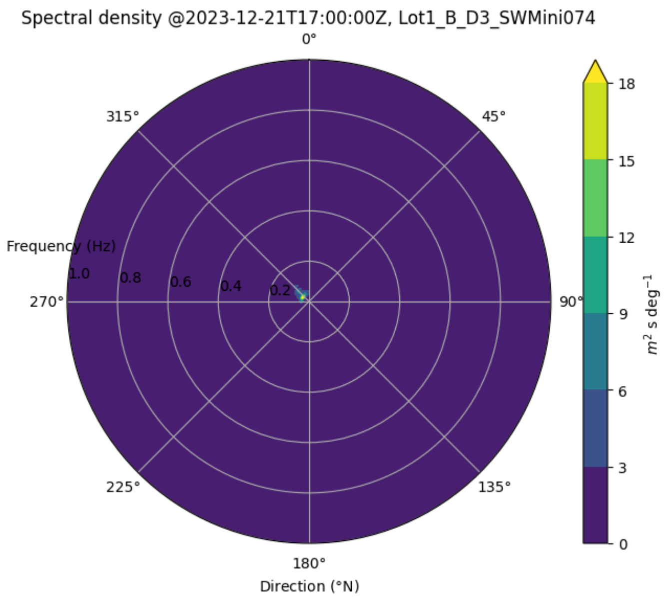


Figure 9-4 Directional wave spectra (MEM spectra m^2/s) from 21 December 2023.

10. Results Metocean

10.1 Met

Timeseries of all atmospheric parameters are presented in **Appendix B.3**.

Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.

Table 10-1 summarizes statistics for the main atmospheric parameters over the full campaign and the additional period until 22 December 2023 when the Vaisala air pressure and air temperature and humidity sensors stopped working after storm *Pia* passed over the area.

Between 15 November 2021 and 24 February 2024, the air temperature varied between -0.8 and 20.4 °C. The air pressure varied between 967.6 and 1050.2 hPa.

The lowest air temperatures were measured in November 2023. The lowest air pressures were measured in February 2022. The highest air temperatures were measured in August 2022. The highest air pressures were measured in March 2022.

Table 10-1: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2021 – Dec 2023): met parameters

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
AirHumidity %	% R.H.	4	9.7	38.3	81.5	99.6
AirPressure hPa	hPa	0.5	12.3	967.6	1012.4	1050.2
AirTemperature C	°C	4	4.4	-0.8	10.3	20.4

10.2 Sea water temperatures

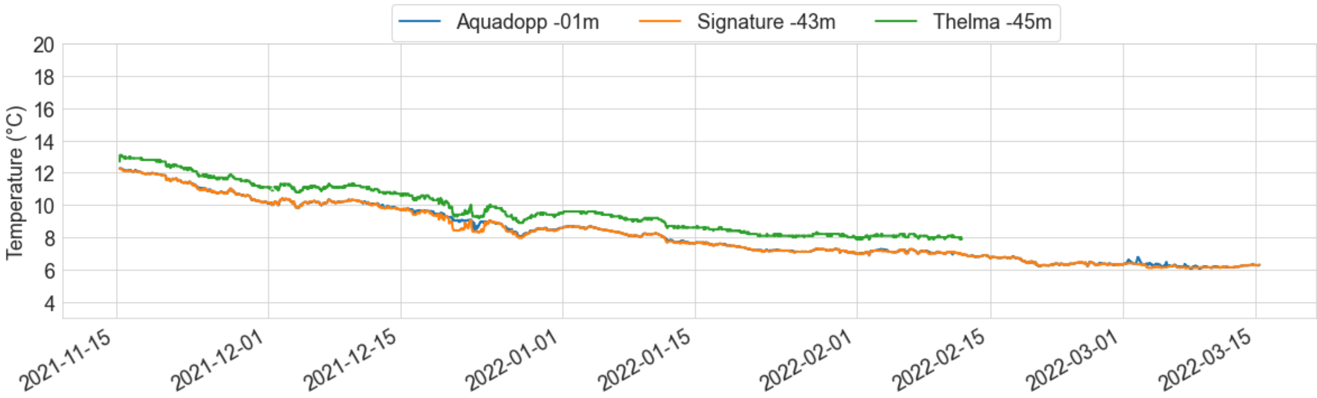
Table 10-2 summarizes statistics for water temperature from all sensors over the full campaign including the additional period. **Figure 10-1** shows 6-monthly timeseries of all seawater temperature data from all sensors.

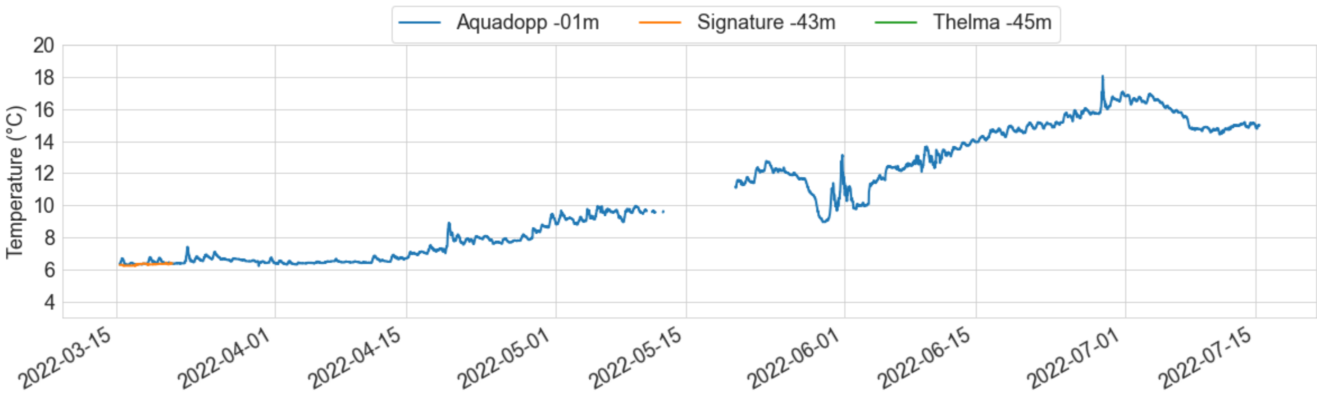
Please note that the statistics cover different periods during the campaign (see **Section 5.1** and **Figure 10-1**).

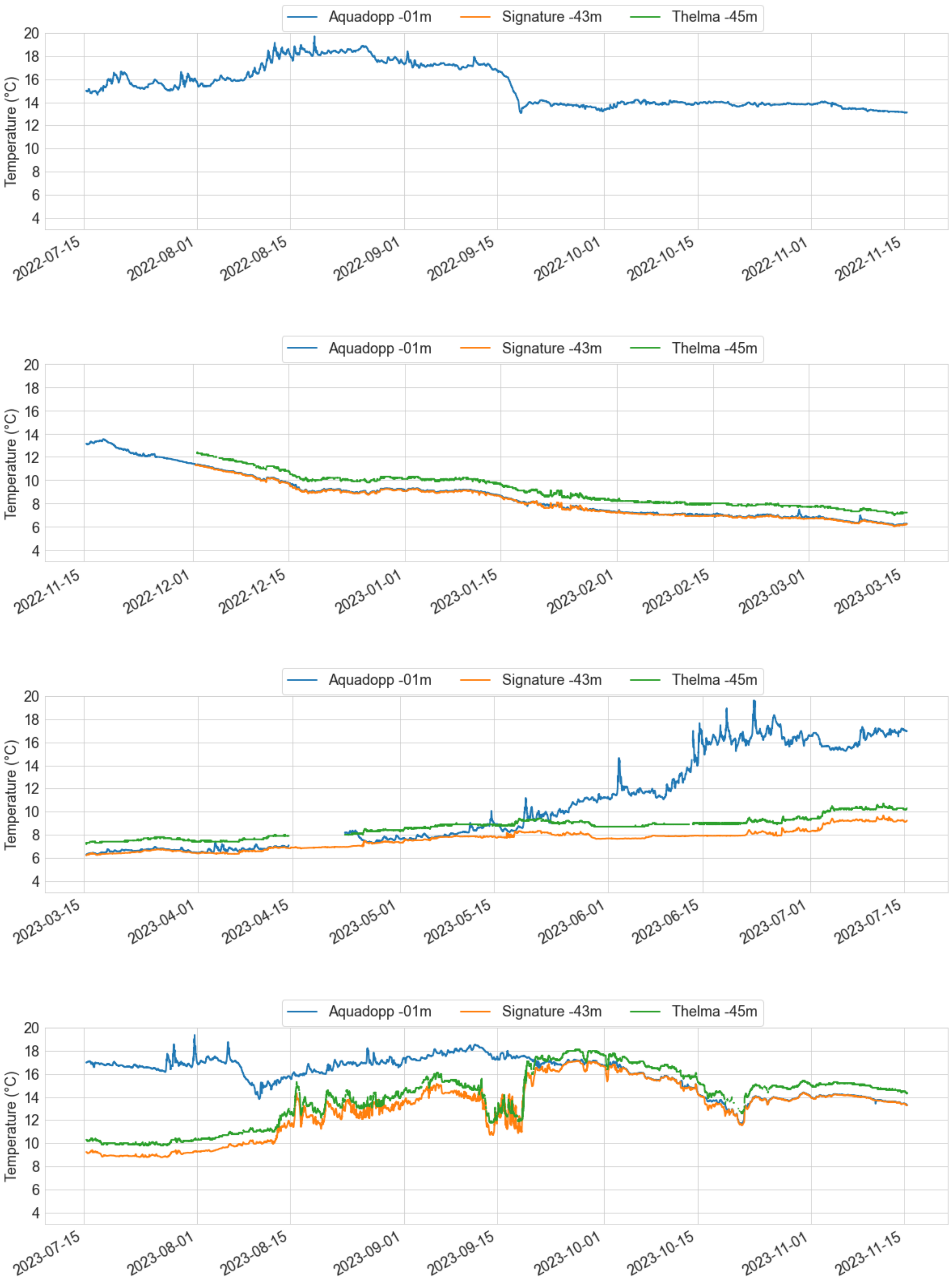
Between 15 November 2021 and 24 February 2023, the sea surface temperature varied between 5.7 and 19.7 °C. The water temperature near the seafloor varied between 6.8 and 18.1 °C. The water column appears well-mixed during the winter and spring seasons and highly stratified during the summer and fall seasons.

Table 10-2: Summary statistics (standard deviation, minimum, mean and maximum) over the full campaign including the additional period (Nov 2021 – Feb 2024): sea water temperatures

Parameter	Height [m]	Standard deviation	Minimum	Mean	Maximum
Sea surface temperature (Aquadopp)	-1	4.0	5.7	11.2	19.7
Bottom Water Temperature (Signature500)	-43	2.7	5.8	9.0	17.1
Bottom Water Temperature (Thelma)	-45	2.6	6.8	10.2	18.1






Aquadopp -01m
Signature -43m
Thelma -45m
Temperature (°C)
2022-07-15
2022-08-01
2022-08-15
2022-09-01
2022-09-15
2022-10-01
2022-10-15
2022-11-01
2022-11-15
2022-12-01
2022-12-15
2023-01-01
2023-01-15
2023-02-01
2023-02-15
2023-03-01
2023-03-15
2023-04-01
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01
2023-07-15
2023-08-01
2023-08-15
2023-09-01
2023-09-15
2023-10-01
2023-10-15
2023-11-01
2023-11-15

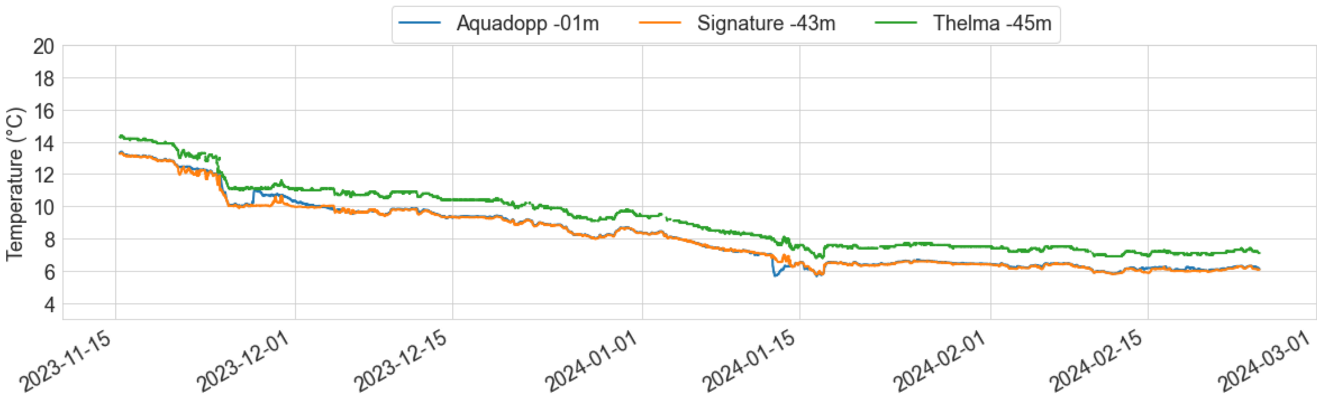


Figure 10-1 Timeseries of all seawater temperature data from all sensors for all depths per 6 months intervals

10.3 Water level

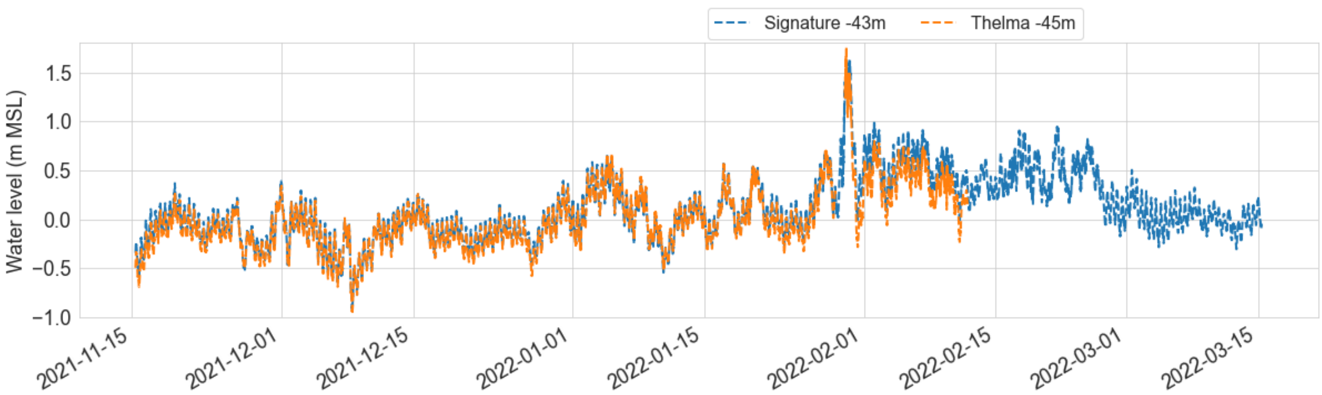
Table 10-3 summarizes statistics for water pressure and water level (ref. MSL) from the Thelma bottom unit and the Signature500 over the full campaign including the additional period. Please note that the averaging periods for the different instruments differ based on available data. **Figure 10-2** shows 6-monthly timeseries of all water level data from all sensors. Given the uncertainties in the sensor heights, the water levels calculated from both the Thelma pressure gauge and the pressure sensor of the Signature500 agree well.

Between 15 Nov 2021 and 24 February 2024, the water pressure varied between -0.97 and 1.76 m MSL.

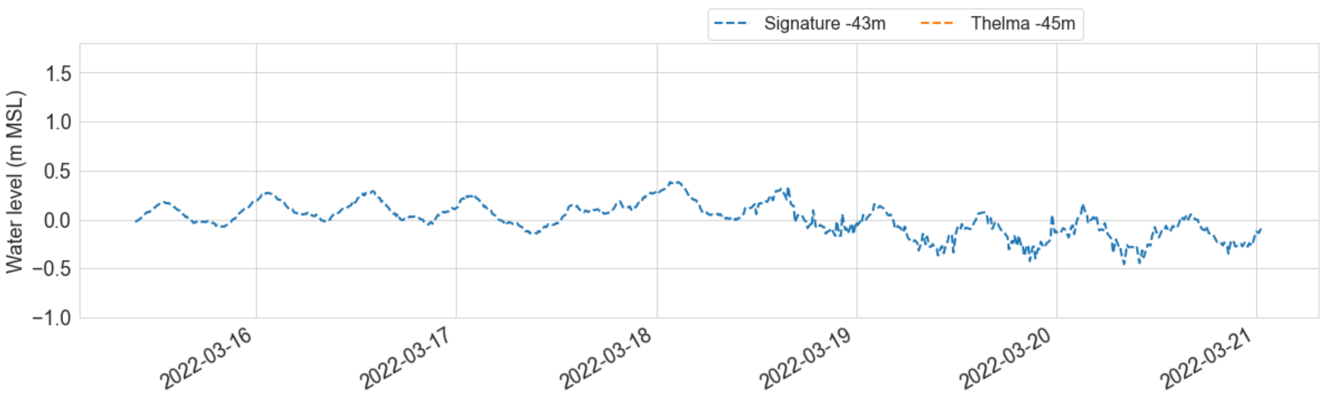
There is no water pressure and water level data between March 2022 and November 2022 (see **Section 5.1**).

Table 10-3: Summary statistics (standard deviation, minimum, mean and maximum): Water pressure and water level (ref. MSL). Please note that the averaging periods for the different instruments differ based on available data.

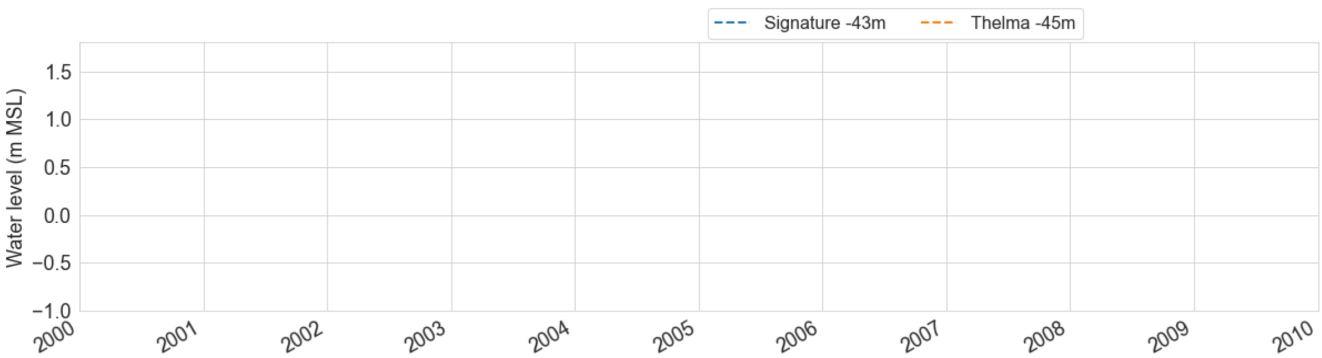
Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
Water pressure (Signature500)	dbar	-43	0.5	43.2	44.1	46.0
Water pressure (Thelma)	dbar	-45	0.2	43.9	45.1	46.8
Water level MSL (Signature500)	m	0	0.26	-0.92	0.12	1.63
Water level MSL (Thelma)	m	0	0.24	-0.97	0.00	1.76



Signature -43m
Thelma -45m
Water level (m MSL)
1.5
1.0
0.5
0.0
−0.5
−1.0
2021-11-15
2021-12-01
2021-12-15
2022-01-01
2022-01-15
2022-02-01
2022-02-15
2022-03-01
2022-03-15



Signature -43m
Thelma -45m
Water level (m MSL)
1.5
1.0
0.5
0.0
−0.5
−1.0
2022-03-16
2022-03-17
2022-03-18
2022-03-19
2022-03-20
2022-03-21



Signature -43m
Thelma -45m
Water level (m MSL)
1.5
1.0
0.5
0.0
−0.5
−1.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Figure 10-2 Timeseries of water level (ref. MSL) per 6 months intervals

11. Results Currents

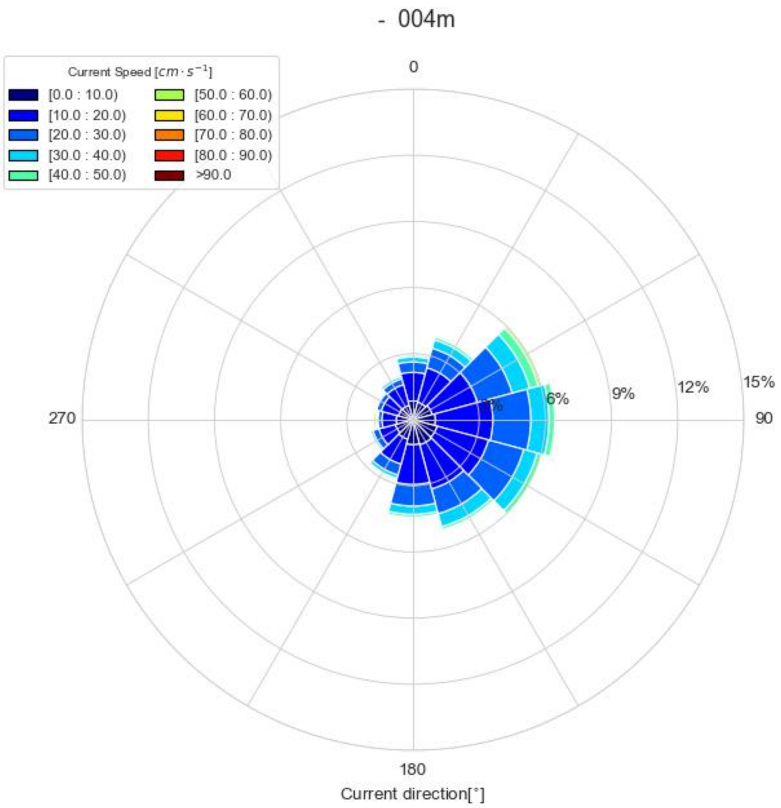
11.1 SWLB Aquadopp

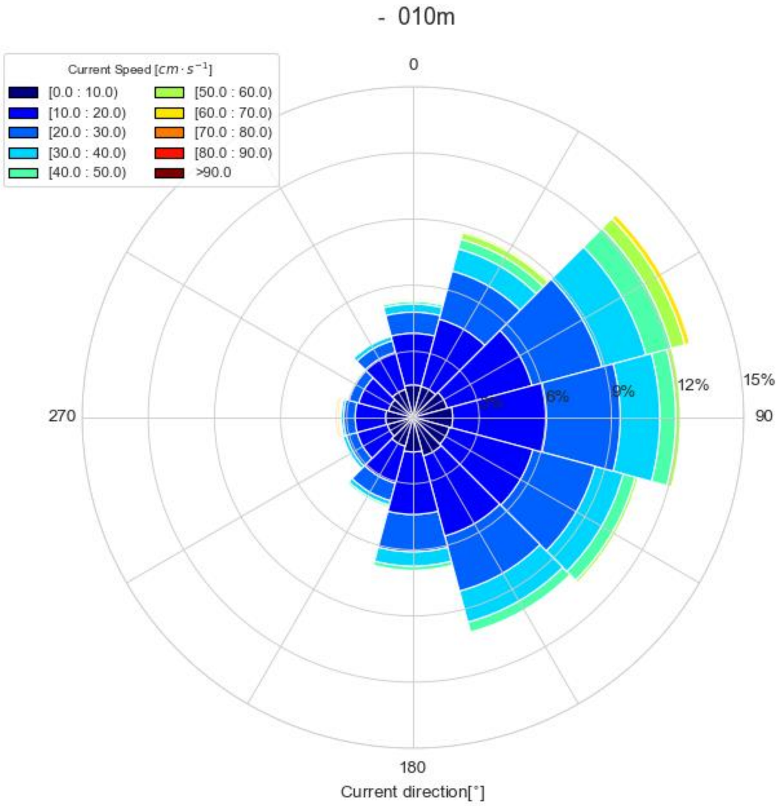
Heatmaps of 6-monthly current speed and direction are presented in **Appendix B.4**.

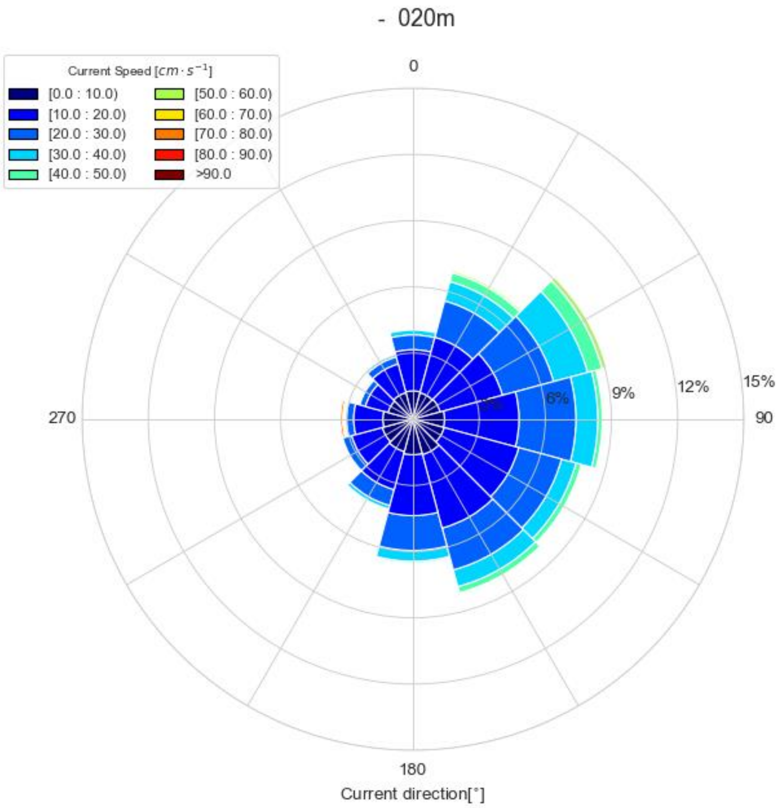
Table 11-1 summarizes statistics for current speed over the full campaign including the additional period. **Figure 11-1** shows current roses at 4 depths below the sea surface (04, 10, 20, and 30 m) and **Figure 11-2** shows the current speed profile for the full campaign including the additional period.

The highest current speeds during the campaign were measured in October 2023. The mean current speeds are generally low (ca. 20 cm/s). The dominant current direction is towards the east.

All current directions (as given in the **CurrentData*.csv files) were corrected for magnetic declination and are given relative to true north.




- 010m
Current Speed [cm·s⁻¹]
[0.0 : 10.0)
[10.0 : 20.0)
[20.0 : 30.0)
[30.0 : 40.0)
[40.0 : 50.0)
[50.0 : 60.0)
[60.0 : 70.0)
[70.0 : 80.0)
[80.0 : 90.0)
>90.0
0
90
180
270
6%
9%
12%
15%
Current direction[°]


- 020m
Current Speed [cm·s⁻¹]
[0.0 : 10.0)
[10.0 : 20.0)
[20.0 : 30.0)
[30.0 : 40.0)
[40.0 : 50.0)
[50.0 : 60.0)
[60.0 : 70.0)
[70.0 : 80.0)
[80.0 : 90.0)
>90.0
0
90
180
270
6%
9%
12%
15%
Current direction[°]

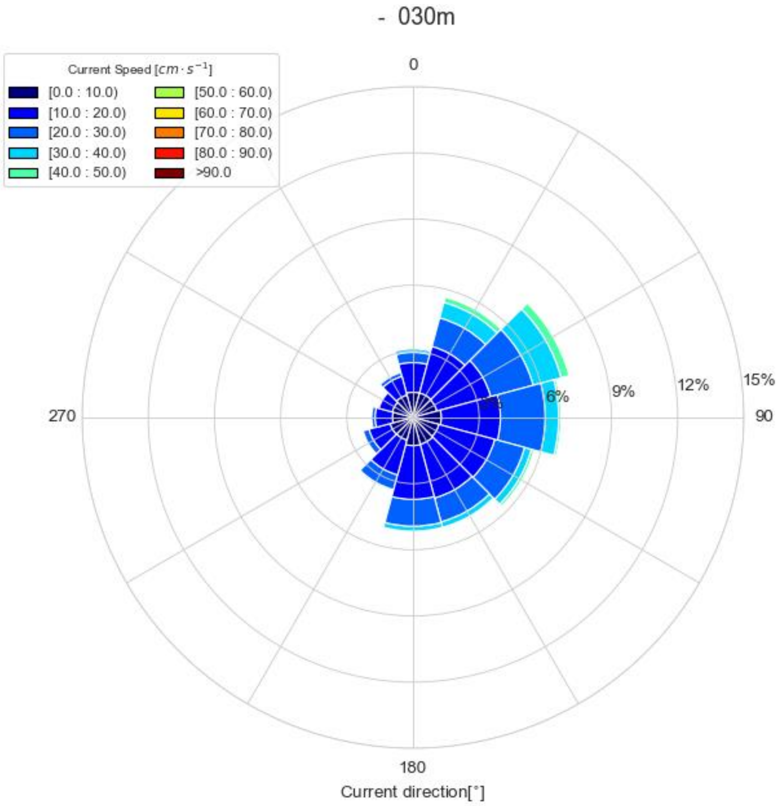


Figure 11-1 Current roses (top-down) at 04 m, 10 m, 20 m, and 30 m depth for the full campaign including the additional period (November 2021 – February 2024).

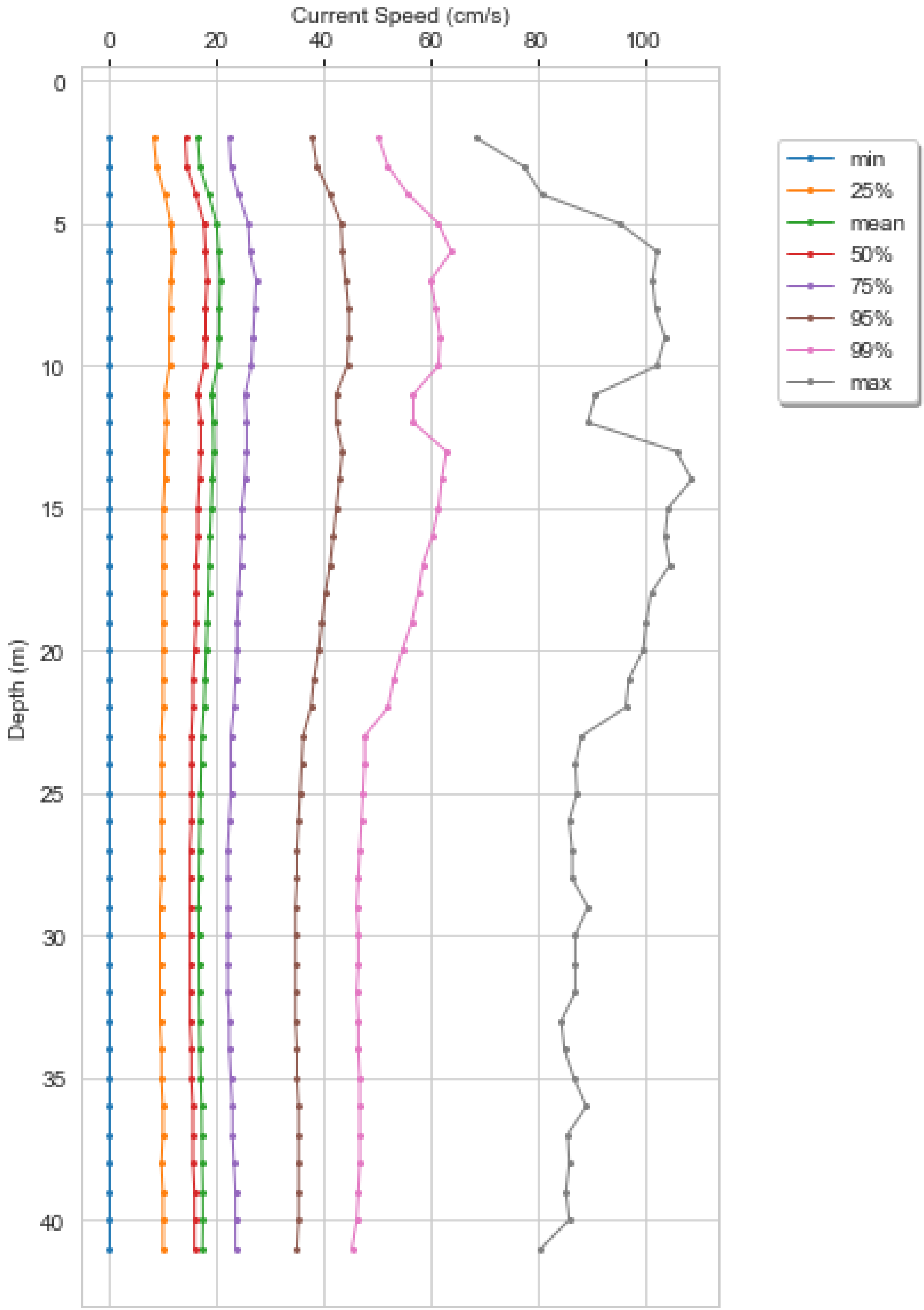


Figure 11-2 Full campaign (November 2021 – February 2024) current speed profile

Table 11-1: 24-month summary statistics (standard deviation, minimum, mean and maximum): current speed

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
AqSpd002	cm/s	-2	10.9	0.2	16.6	68.7
AqSpd003	cm/s	-3	11.2	0.2	17.0	77.5
AqSpd004	cm/s	-4	11.7	0.2	18.7	81.0
AqSpd005	cm/s	-5	12.3	0.2	20.2	95.4
AqSpd006	cm/s	-6	12.5	0.2	20.5	102.5
AqSpd007	cm/s	-7	12.5	0.2	20.8	101.6
AqSpd008	cm/s	-8	12.8	0.2	20.7	102.2
AqSpd009	cm/s	-9	12.8	0.2	20.6	103.9
AqSpd010	cm/s	-10	12.7	0.2	20.3	102.5
AqSpd011	cm/s	-11	12.0	0.2	19.2	91.0
AqSpd012	cm/s	-12	12.0	0.2	19.5	89.5
AqSpd013	cm/s	-13	12.8	0.2	19.6	106.0
AqSpd014	cm/s	-14	12.6	0.2	19.3	108.9
AqSpd015	cm/s	-15	12.5	0.2	19.1	104.5
AqSpd016	cm/s	-16	12.3	0.2	18.9	103.9
AqSpd017	cm/s	-17	12.0	0.2	18.7	104.8
AqSpd018	cm/s	-18	11.8	0.2	18.6	101.3
AqSpd019	cm/s	-19	11.6	0.2	18.4	100.4
AqSpd020	cm/s	-20	11.4	0.2	18.2	99.8
AqSpd021	cm/s	-21	11.2	0.2	18.0	97.2
AqSpd022	cm/s	-22	10.9	0.2	17.8	96.6
AqSpd023	cm/s	-23	10.1	0.2	17.4	88.4
AqSpd024	cm/s	-24	10.0	0.2	17.3	87.2
AqSpd025	cm/s	-25	9.9	0.2	17.2	87.5
AqSpd026	cm/s	-26	9.8	0.2	17.1	86.0
AqSpd027	cm/s	-27	9.8	0.2	16.9	86.6
AqSpd028	cm/s	-28	9.7	0.2	16.9	86.6
AqSpd029	cm/s	-29	9.7	0.2	16.8	89.5
AqSpd030	cm/s	-30	9.7	0.2	16.8	87.2
AqSpd031	cm/s	-31	9.7	0.2	16.8	87.2
AqSpd032	cm/s	-32	9.8	0.2	16.9	87.2
AqSpd033	cm/s	-33	9.8	0.2	17.0	84.5
AqSpd034	cm/s	-34	9.8	0.2	17.1	85.1
AqSpd035	cm/s	-35	9.9	0.2	17.2	86.9
AqSpd036	cm/s	-36	9.9	0.2	17.4	89.2

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
AqSpd037	cm/s	-37	9.9	0.2	17.4	85.7
AqSpd038	cm/s	-38	9.9	0.2	17.5	86.0
AqSpd039	cm/s	-39	9.9	0.2	17.6	85.4
AqSpd040	cm/s	-40	9.9	0.2	17.6	86.0
AqSpd041	cm/s	-41	9.7	0.2	17.5	80.7

11.2 Upward-facing Signature

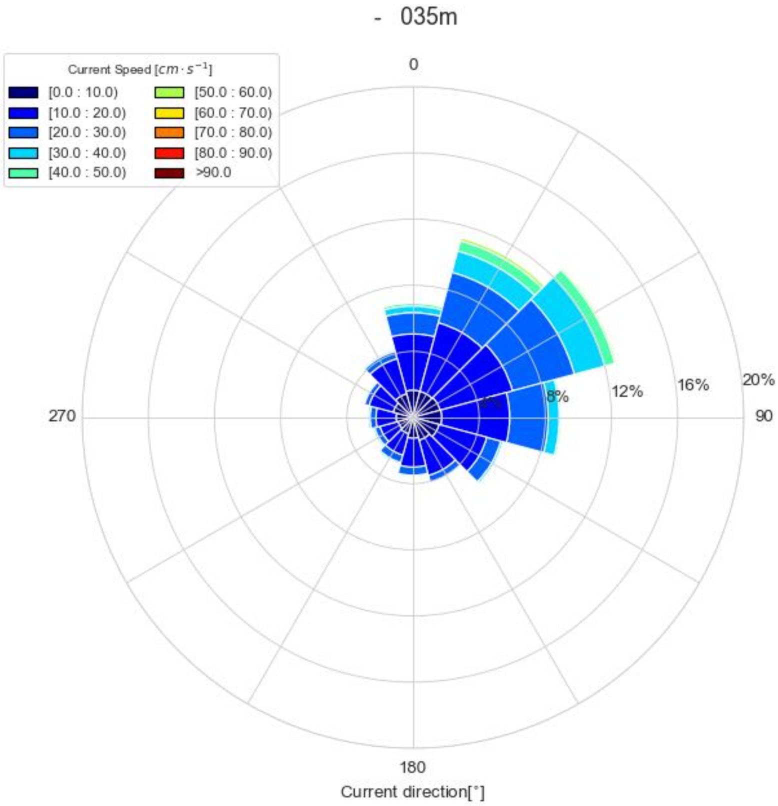
Heatmaps of 6-monthly current speed and direction are presented in **Appendix B.5**.

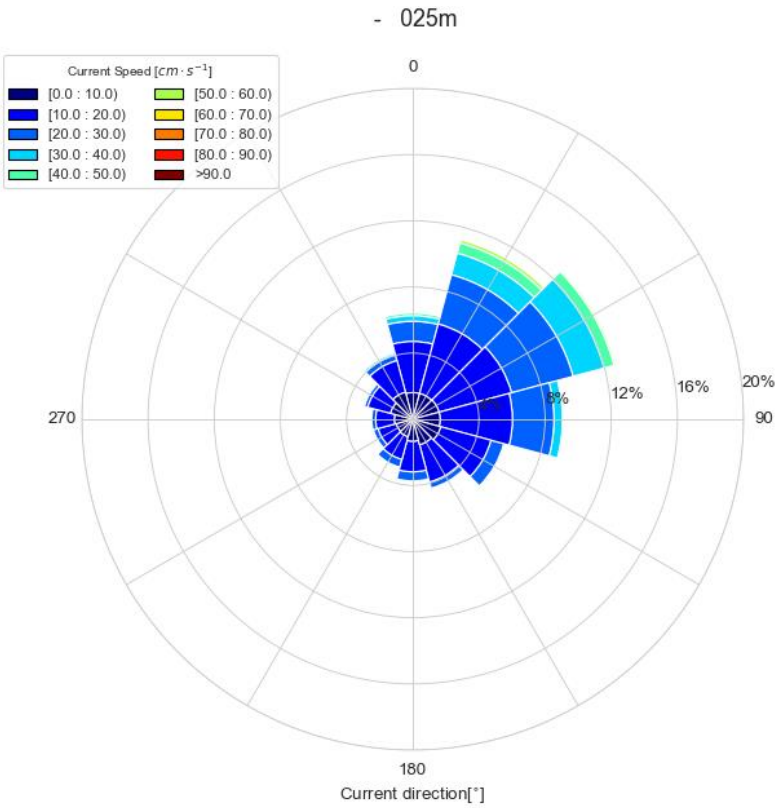
Current roses at 4 depths above the seafloor (35, 25, 15, and 05 m) are shown in **Figure 11-3** for the full campaign including the additional period (November 2021 – February 2024). **Figure 11-4** shows the current speed profile for the full campaign including the additional period.

Table 11-2 summarizes statistics for current speed for the full campaign including the additional period.

The highest current speeds during the full campaign including the additional period were measured in October 2023. The mean current speeds are generally low (ca. 16 cm/s).

All current directions were corrected for magnetic declination and are given relative to true north.


- 035m
Current Speed [$cm \cdot s^{-1}$]
[0.0 : 10.0)
[10.0 : 20.0)
[20.0 : 30.0)
[30.0 : 40.0)
[40.0 : 50.0)
[50.0 : 60.0)
[60.0 : 70.0)
[70.0 : 80.0)
[80.0 : 90.0)
>90.0
0
90
180
270
8%
12%
16%
20%
Current direction[°]


- 025m
Current Speed [$cm \cdot s^{-1}$]
[0.0 : 10.0)
[10.0 : 20.0)
[20.0 : 30.0)
[30.0 : 40.0)
[40.0 : 50.0)
[50.0 : 60.0)
[60.0 : 70.0)
[70.0 : 80.0)
[80.0 : 90.0)
>90.0
0
90
180
270
8%
12%
16%
20%
Current direction[°]

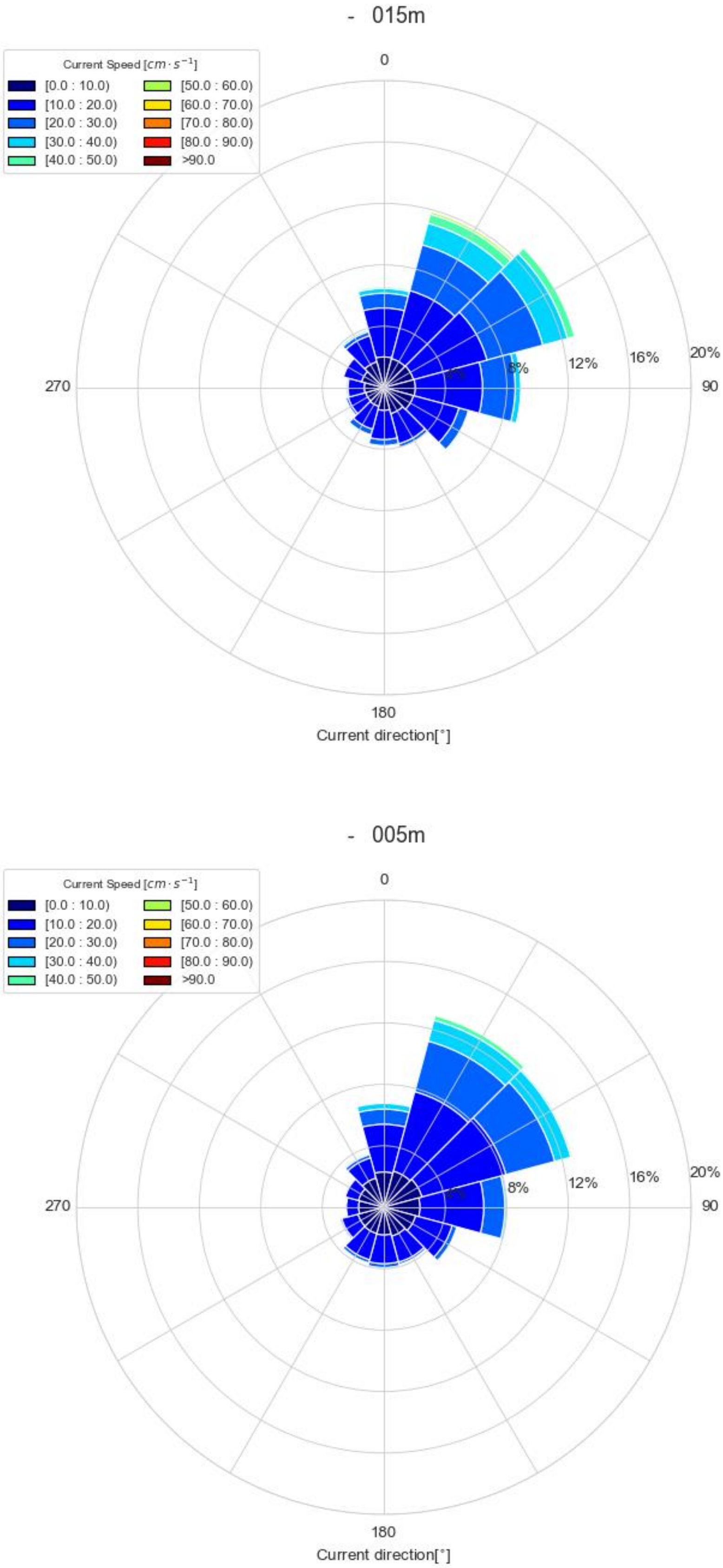


Figure 11-3 Current roses (bottom-up) at 35 m, 25 m, 15 m, and 05 m above the seafloor during the additional period (November 2021 – February 2024).

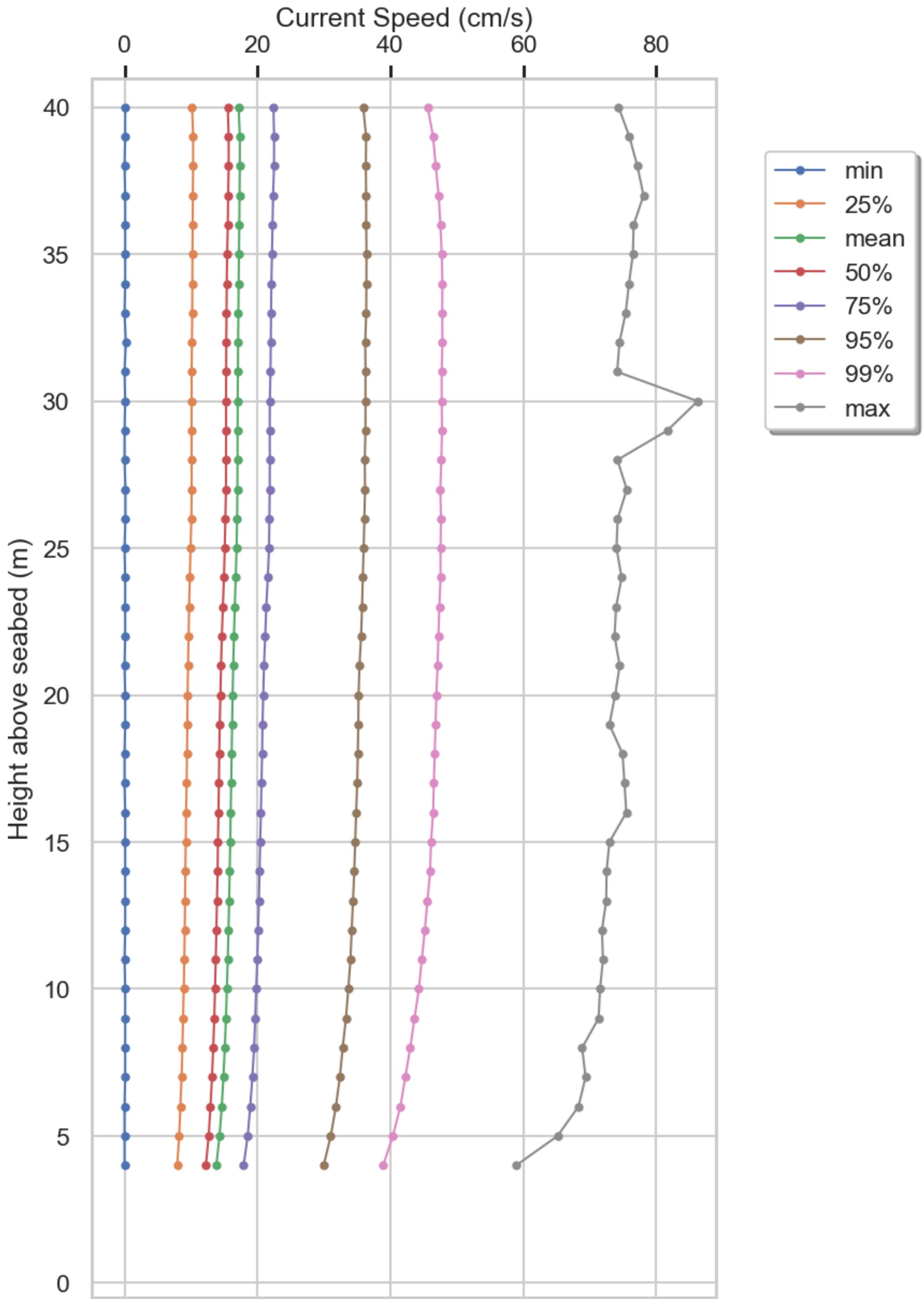


Figure 11-4 Current speed profile during the full campaign including the additional period (November 2021 – February 2024).

Table 11-2: Current speed summary statistics (standard deviation, minimum, mean and maximum) during the full campaign including the additional period (November 2021 – February 2024).

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
Speed004m	cm/s	-4	8.2	0.0	13.8	59.0
Speed005m	cm/s	-5	8.5	0.0	14.3	65.2
Speed006m	cm/s	-6	8.7	0.0	14.6	68.3
Speed007m	cm/s	-7	8.8	0.1	14.9	69.4
Speed008m	cm/s	-8	8.9	0.1	15.1	68.9
Speed009m	cm/s	-9	9.0	0.1	15.3	71.3
Speed010m	cm/s	-10	9.1	0.1	15.4	71.6
Speed011m	cm/s	-11	9.2	0.0	15.5	72.0
Speed012m	cm/s	-12	9.3	0.1	15.6	71.9
Speed013m	cm/s	-13	9.3	0.1	15.7	72.5
Speed014m	cm/s	-14	9.4	0.1	15.8	72.6
Speed015m	cm/s	-15	9.4	0.1	15.9	73.0
Speed016m	cm/s	-16	9.5	0.1	16.0	75.5
Speed017m	cm/s	-17	9.5	0.0	16.1	75.2
Speed018m	cm/s	-18	9.5	0.0	16.1	75.0
Speed019m	cm/s	-19	9.6	0.1	16.2	73.0
Speed020m	cm/s	-20	9.6	0.1	16.3	73.8
Speed021m	cm/s	-21	9.6	0.0	16.4	74.5
Speed022m	cm/s	-22	9.7	0.1	16.5	73.8
Speed023m	cm/s	-23	9.7	0.1	16.6	74.0
Speed024m	cm/s	-24	9.8	0.1	16.7	74.8
Speed025m	cm/s	-25	9.8	0.0	16.9	74.0
Speed026m	cm/s	-26	9.8	0.1	16.9	74.2
Speed027m	cm/s	-27	9.8	0.1	17.0	75.6
Speed028m	cm/s	-28	9.8	0.0	17.0	74.2
Speed029m	cm/s	-29	9.8	0.0	17.0	81.7
Speed030m	cm/s	-30	9.8	0.1	17.0	86.3
Speed031m	cm/s	-31	9.8	0.0	17.1	74.1
Speed032m	cm/s	-32	9.9	0.2	17.1	74.5
Speed033m	cm/s	-33	9.9	0.0	17.1	75.4
Speed034m	cm/s	-34	9.9	0.1	17.2	75.9
Speed035m	cm/s	-35	9.9	0.1	17.2	76.5
Speed036m	cm/s	-36	9.9	0.1	17.3	76.6
Speed037m	cm/s	-37	9.9	0.1	17.3	78.1
Speed038m	cm/s	-38	9.8	0.0	17.3	77.2
Speed039m	cm/s	-39	9.8	0.1	17.4	76.0

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
Speed040m	cm/s	-40	9.7	0.1	17.2	74.4

* Height above the seafloor

12. References

[1] DNVGL, ""WS170 Independent performance verification of Seawatch Wind Lidar Buoy at the LEG offshore platform,"," 10298247-R-1, Rev. A, issue date: 2021-07-09, 2021.

[2] DNVGL, "WS191 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway," Report No.: 10332389-R-4, Rev. A, Date: 2022-04-04, 2022.

[3] Fugro, "SWLB measurements at Energy Islands Project Measurement Plan, All Lots," Fugro, 2022.

[4] Fugro, "Motion correction of turbulence intensity. WP2: North Sea campaign data," C75486-TI1-R-04 03, 20 March 2024.

[5] U.S. Integrated Ocean Observing System, "Manual for Real-Time Quality Control of In-Situ Current Observations Version 2.1 A Guide to Quality Control and Quality Assurance of Acoustic Doppler Current Profiler Observations.," 2019.

[6] Ocean Contour Acoustic Doppler Data Processing Package V 2.1.5, Ocean Illumination Ltd. 2016-2018, 2022.

[7] Fugro, "Technical Note – Deviations between downward-looking and upward-looking current measurements," C75486-TN-001 01, 21 June 2023.

[8] Fugro, "Nortek Aquadopp – Error assessment and correction, Comparison of measurements from two collocated ADCPs," C75 01, 11 August 2023.

Appendix A

Event Logs

Issue Number	Start time	End time	Instru-ment	Parameter	Description
1	2022-02-12 02:10	2022-12-01	Thelma sensors	thSNR dB, thTBRtemperature degC, thTilt deg, BottomTemperature degC, WaterPressure dbar	Data from Thelma sensors missing. Either the bottom sensor or the modem in the keelweight malfunctioned.
2	2022-03-03 09:20	2022-03-03 13:10	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
3	2022-03-04 12:00	2022-03-04 14:10	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
4	2022-03-05 14:40	2022-03-05 15:40	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
5	2022-03-14 16:00	2022-03-15 01:50	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
6	2022-03-15 17:00	2022-03-16 16:40	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
7	2022-03-19 12:00	2022-03-19 17:20	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
8	2022-03-22 09:10	2022-03-24 05:00	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
9	2022-03-25 00:00	2022-03-25 02:00	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
10	2022-03-26 01:40	2022-03-26 07:50	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
11	2022-03-27 02:50	2022-03-27 07:20	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
12	2022-03-30 04:40	2022-03-30 07:10	Lidar	Lidar parameters at intermediate heights	Lidar data partially missing due to low visibility/fog
13	2022-04-06 00:00	2022-04-06 14:40	Lidar	All lidar data	Large gaps from temporary shutdowns of the lidar unit due to insufficient power.
14	2022-04-06 14:50	2022-05-20	Lidar	All lidar data	All lidar data missing. Lidar unit permanently shut down due to insufficient power.
15	2022-03-22	2022-03-25	Aquadopp	AqSpd002m cm/s, Aqdir002m deg	High current speed at 2m depth level during calm conditions.
	2022-03-31	2022-04-02			
16	2022-05-10 12:00	2022-05-13 09:00	Power supply	All SWLB data	Intermediate shutdowns of the SWLB systems due to insufficient power leading to large data gaps.
17	2022-05-13 09:10	2022-05-20	Power supply	All SWLB data	SWLB systems permanently shutdown due to insufficient power. No data collected.
18	2022-05-20	2022-12-01	WS191	All SWLB data	WS191 deployed instead of WS170

Issue Number	Start time	End time	Instru-ment	Parameter	Description
19	2022-05-20	2022-12-01	Aquadopp	All current data	High current speed at 3m depth level during calm conditions. All current data removed pending investigation of instrument and raw data.
20	2022-05-20	2022-12-01	Aquadopp	Current speed profile	Downward-looking current profile seems flat. To be checked against upward-looking Signature500 data.
21	2022-05-20	2022-12-01	Thelma	Water pressure, Bottom temperature, thTBRtemperature	WS191 was deployed without Thelma modem. No data was received.
22	2022-07-15	2022-12-01	WS191 Aquadopp	Current speed profile	High current speed in 2-6m
23	2022-10-16	2022-12-01	WS191 PWS visibility sensor	pws_visibility m	The PWS visibility sensor stopped working and will be replaced during the next service.
24	2022-11-30	2022-11-30	SWMini071	All wave buoy data	The buoy was recovered for data download and maintenance and redeployed.
25	2022-11-30	2024-02-24	SWMini074	All wave buoy data	Deployed at additional location
26	2022-12-01	2022-12-01	WS191	All SWLB data	WS191 was serviced offshore.
27	2022-12-01	2023-04-22	WS191 PWS visibility sensor	pws_visibility m	PWS sensor was not replaced, and visibility data are missing.
28	2022-12-01	2023-04-22	WS191 Aquadopp	Current speed profile	Aquadopp current meter was replaced. High current speeds in 2-6m persist.
29	2022-12-01	2023-04-22	WS191 Thelma	Water pressure, Bottom temperature	During the service, a new top modem was installed. Data from the bottom unit was received and stored on the datalogger. The data has been post-processed and added to this dataset.
30	2022-12-20 05:30 UTC	2023-04-22	WS191 Gill wind sensor	WindDir004m deg; WindGust004m m/s; WindSpeed004m m/s;	The Gill wind sensor stopped working and data from this sensor are missing.
31	2023-02-15 09:30 UTC	2023-04-22	WS191 Lidar	All Lidar data	The storm on 16th February 2023 affected the lidar and the transmitted lidar data did not pass the QC procedures. From 26th February 2023, the lidar only worked erratically. Some raw data are stored on the lidar unit and an attempt to

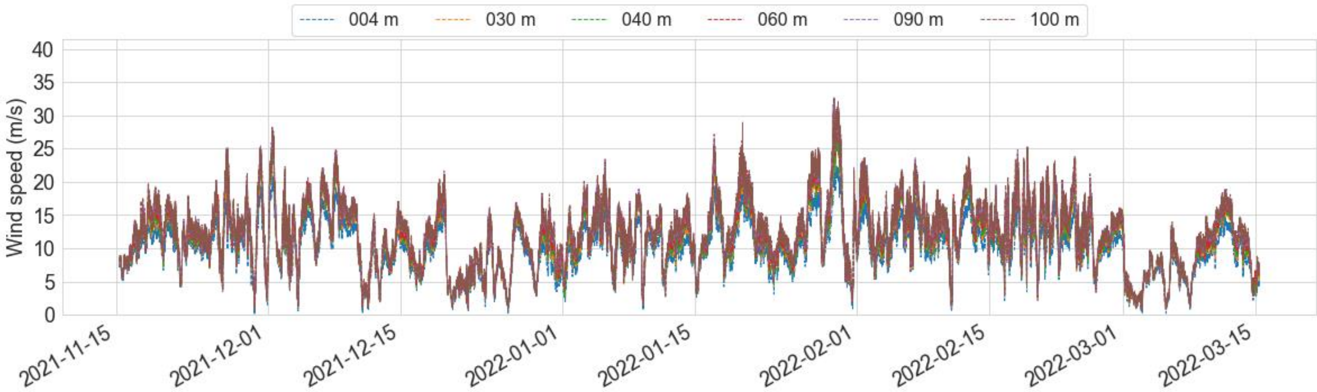
Issue Number	Start time	End time	Instru-ment	Parameter	Description
					recover the data will be made for the final dataset.
32	2023-04-14 12:00 UTC	2023-04-22	WS191	All data	Due to the effects of the storm on 16th February 2023 on the WS191 buoy, the buoy was shut off on 14th April 2023 at 12:00 UTC and all SWLB data are missing from that point onward.
33	2023-04-22	2023-04-22	WS191	All data	WS191 was recovered for maintenance.
34	2023-04-22	ongoing	WS170	All data	WS170 was deployed.
35	2023-04-26	2023-06-13	WS170 Lidar	WS170 Lidar data	There was an interruption in the communication between the lidar unit and the datalogger resulting in the loss of the transmitted 10-min wind data. The raw data was stored and will be re-processed and added to the final dataset.
36	2023-04-22	2023-06-13	WS170 Thelma	Water pressure, Bottom temperature	WS170 received water pressure data from two Thelma bottom sensors and the wrong pressure data were included in the transmitted pff. Water pressure data from the correct raw measurements were stored onboard and downloaded during a service visit in June 2023. The data has been processed into 10-minute averages with the same algorithm as employed on the lidar buoy. The 10-minute averages have been added to the monthly dataset.
37	2023-04-30	2023-05-02	All buoys	All buoy data	In the period 30 April – 2 May 2023, there is reduced data availability of the transmitted data due to data server issues receiving the Iridium satellite messages (pff messages) sent by the buoys. The missing pff messages are stored on the buoys' dataloggers and will be retrieved during the scheduled maintenance activities.
38	2023-06-13	2024-02-24	WS191	All data	WS191 was deployed on the Lot 1 mooring on 2023-06-13 at 13:00.

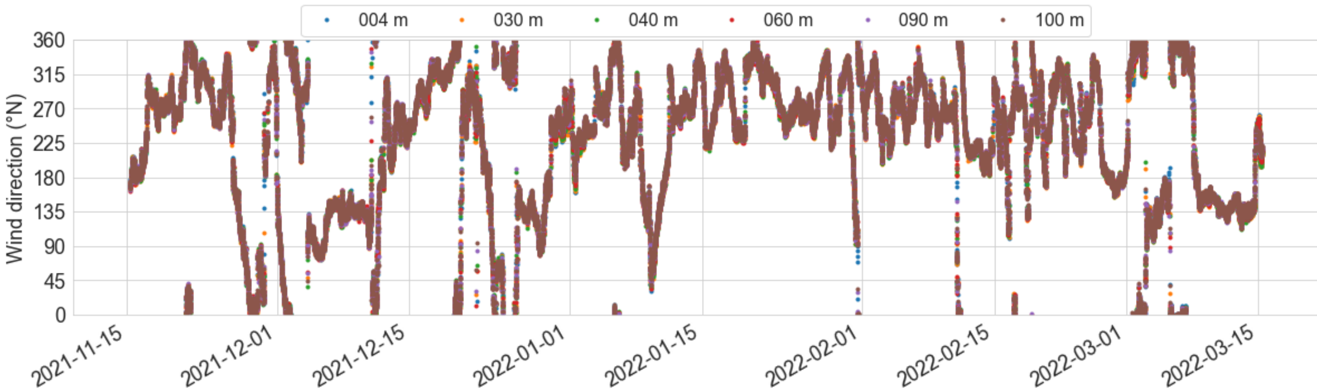
Issue Number	Start time	End time	Instru-ment	Parameter	Description
39	2023-06-13	2024-02-24	WS191 Thelma	Water pressure, Bottom temperature	Bottom sensor data are missing in the transmitted pff. The raw data will be processed and added to the final dataset.
38	2023-07-15	2024-02-24	WS191 Aquadopp	All current speed and direction data	Current data below 15 m depth show signs of deterioration.

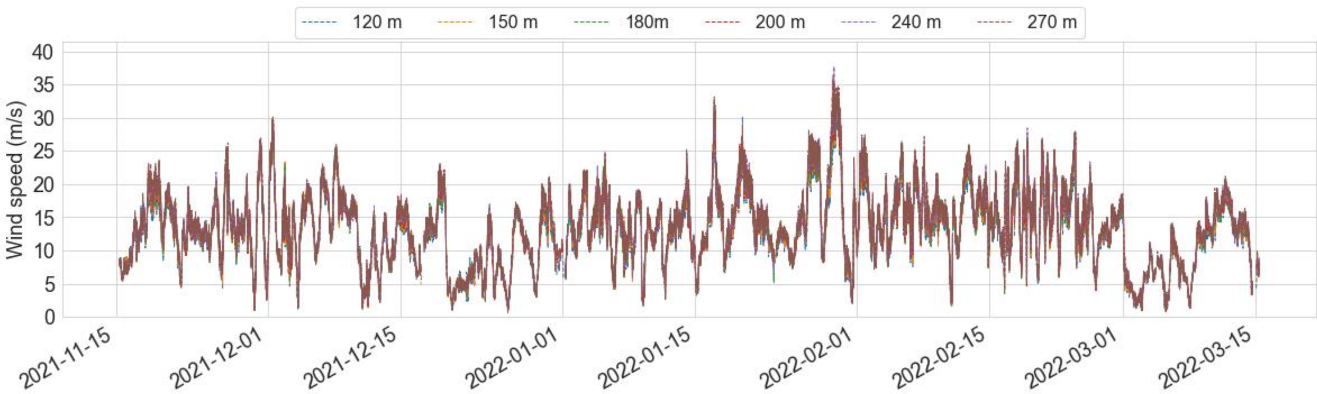
Appendix B

Data presentation

B.1 Wind data


004 m
030 m
040 m
060 m
090 m
100 m
Wind speed (m/s)
2021-11-15
2021-12-01
2021-12-15
2022-01-01
2022-01-15
2022-02-01
2022-02-15
2022-03-01
2022-03-15


004 m
030 m
040 m
060 m
090 m
100 m
Wind direction (°N)
2021-11-15
2021-12-01
2021-12-15
2022-01-01
2022-01-15
2022-02-01
2022-02-15
2022-03-01
2022-03-15


120 m
150 m
180m
200 m
240 m
270 m
Wind speed (m/s)
2021-11-15
2021-12-01
2021-12-15
2022-01-01
2022-01-15
2022-02-01
2022-02-15
2022-03-01
2022-03-15

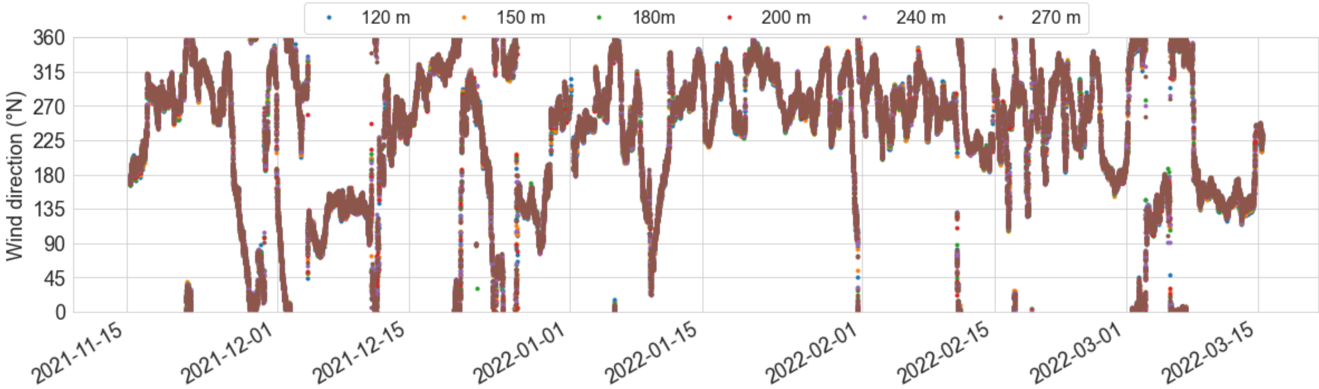
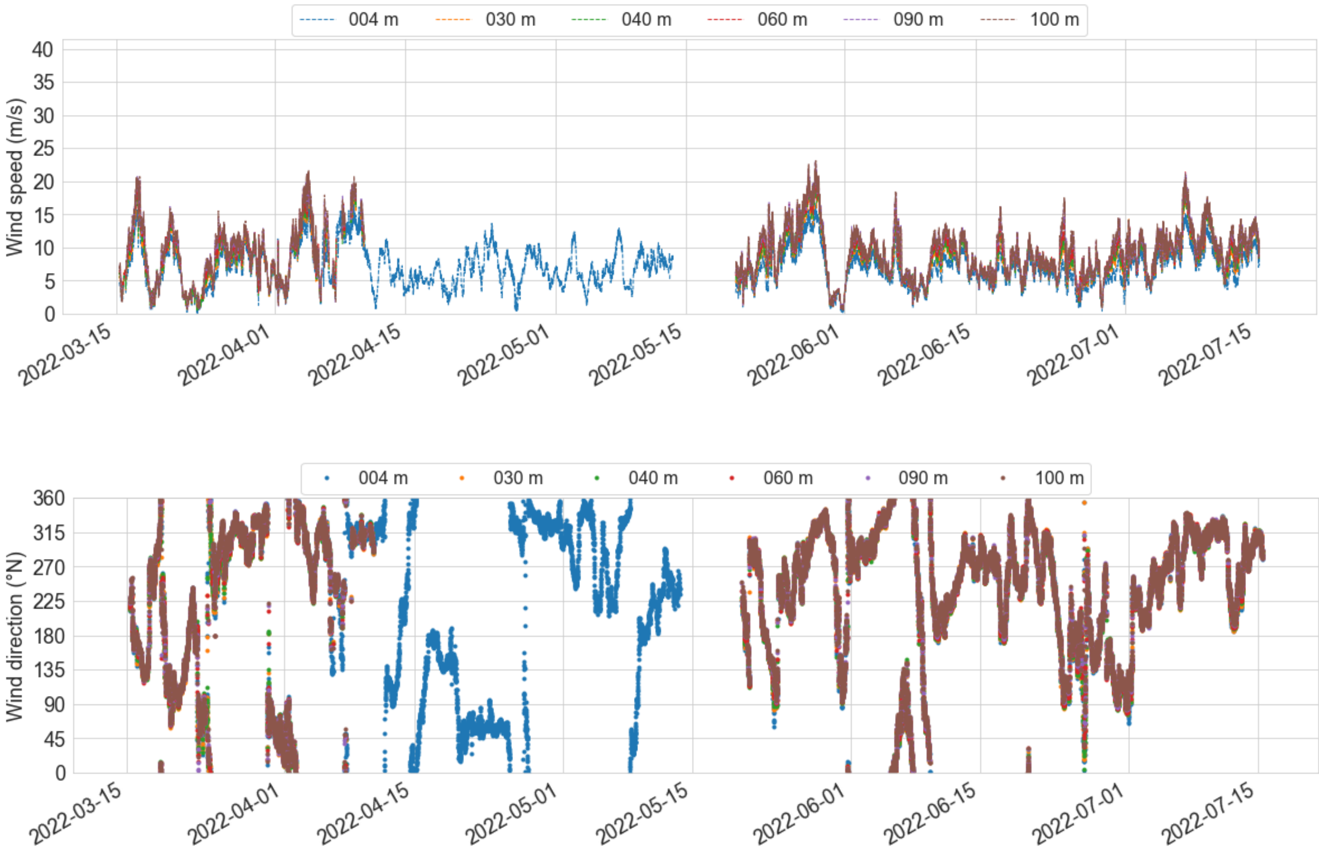


Figure B-1 Timeseries of wind speed and direction from November 2021 until March 2022. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).



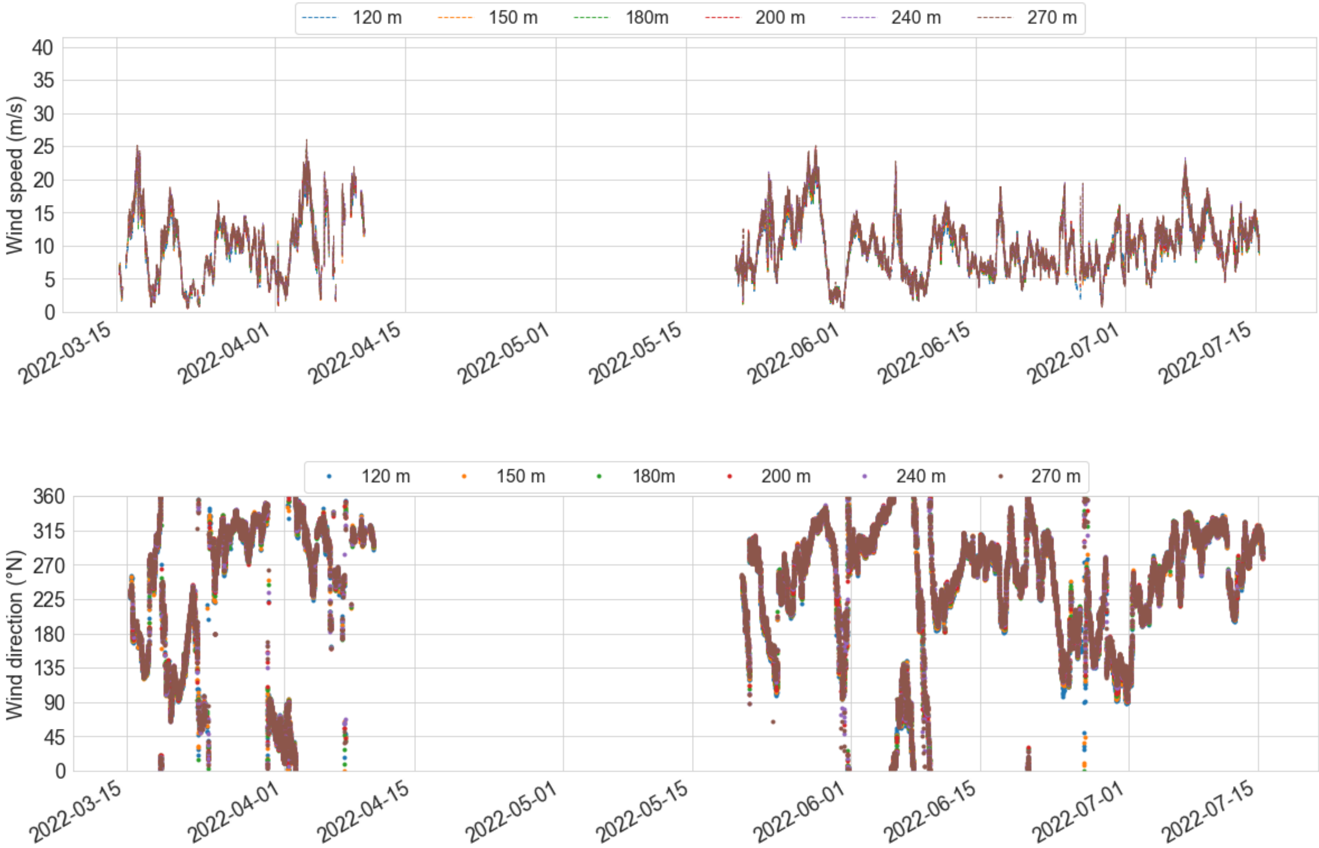
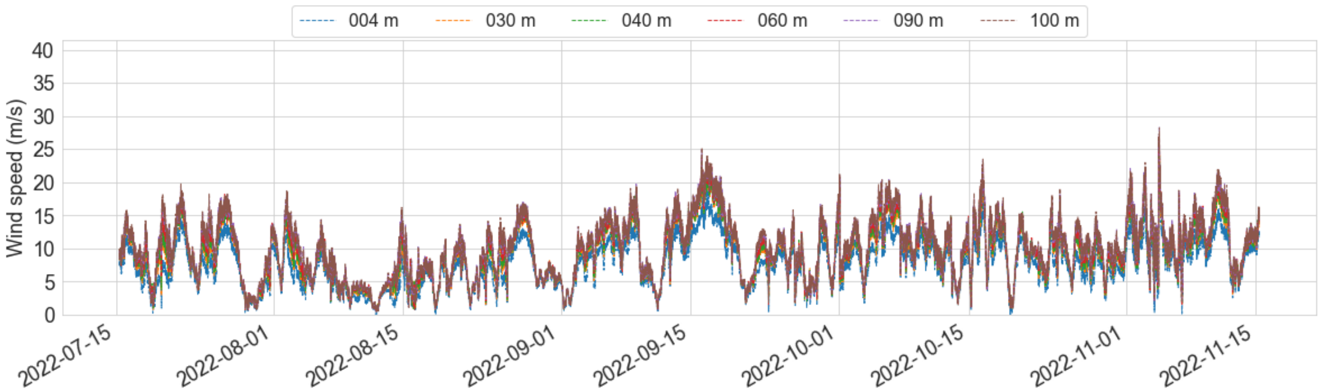


Figure B-2 Timeseries of wind speed and direction from March 2022 until July 2022. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).



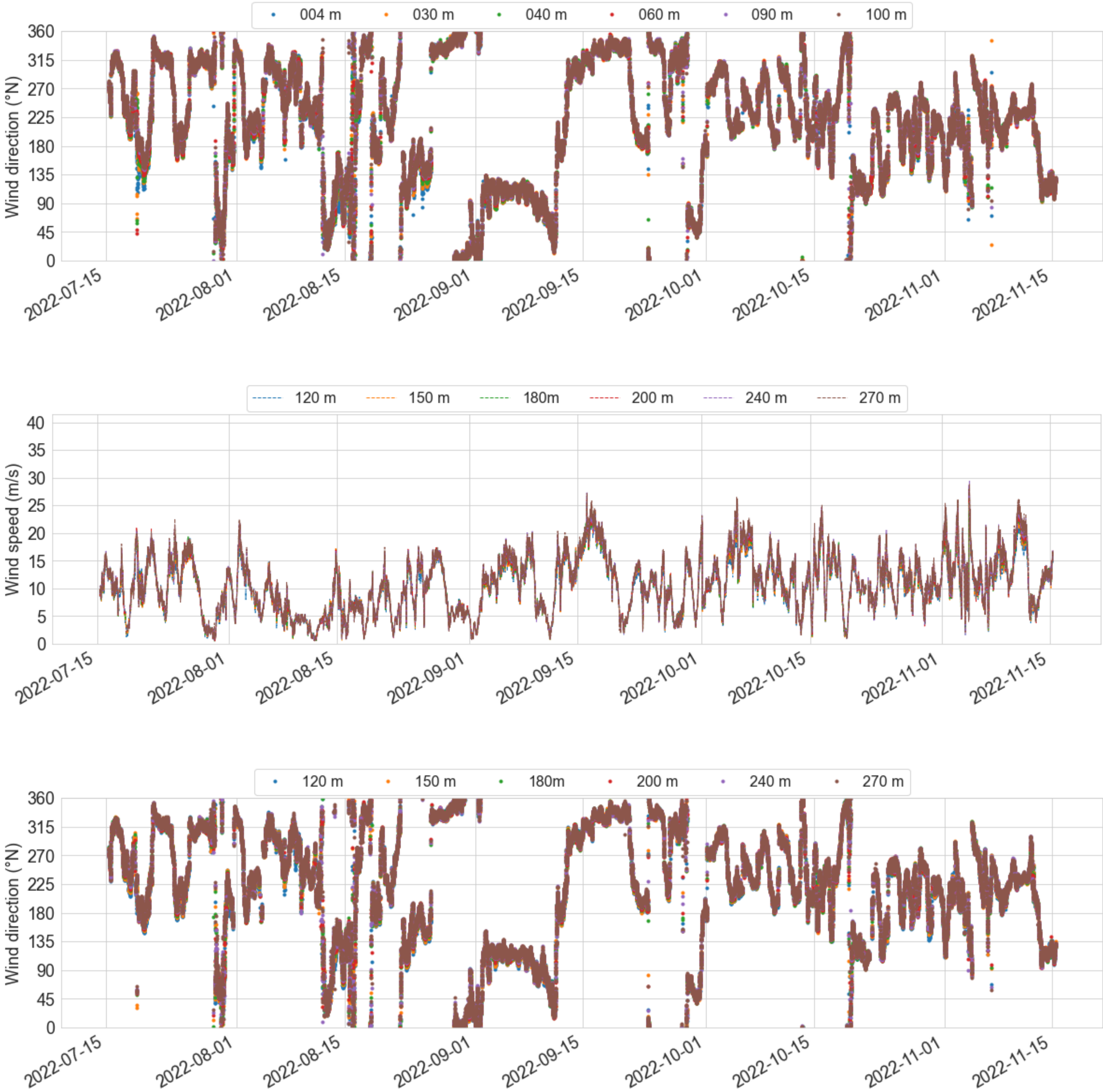
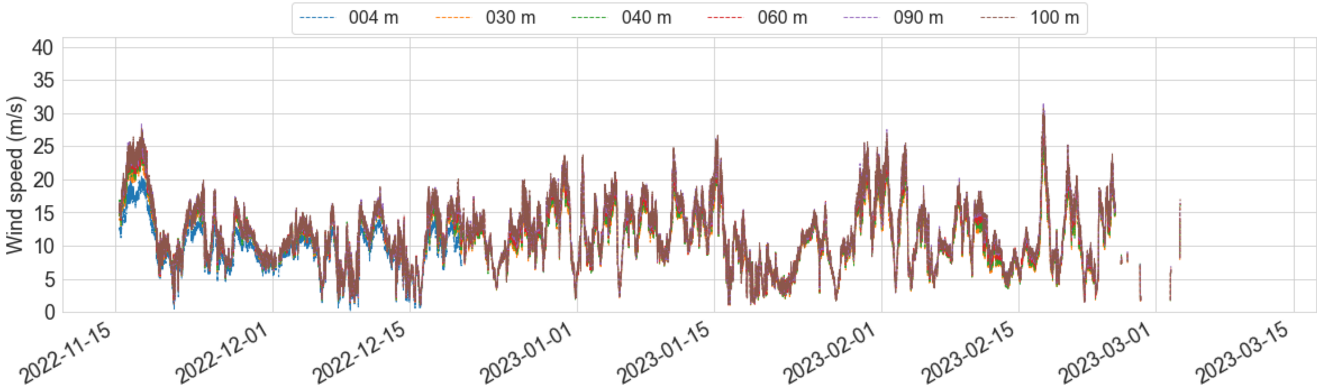
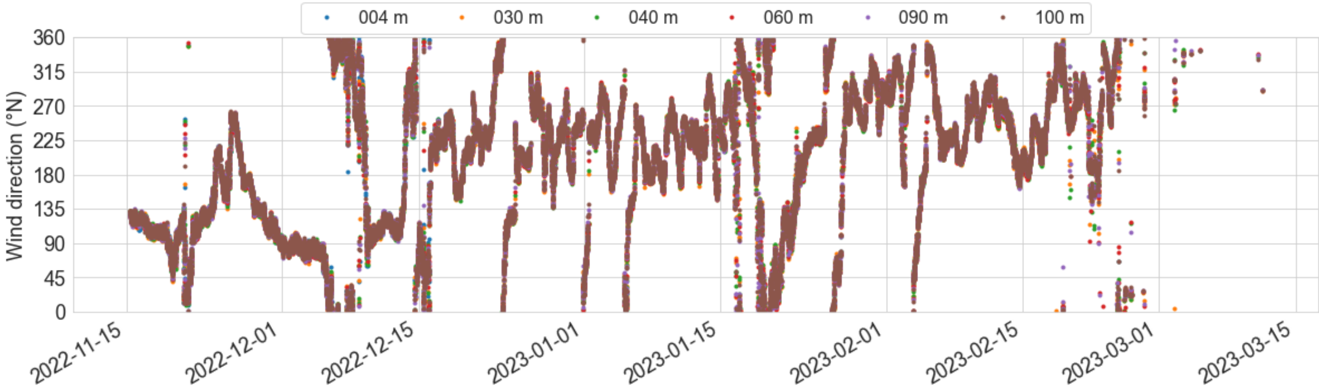
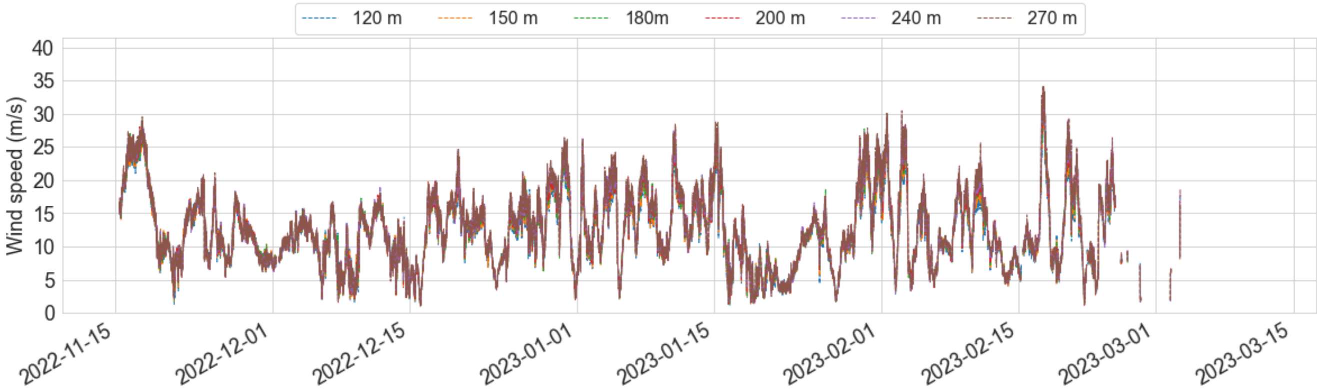


Figure B-3 Timeseries of wind speed and direction from July 2022 until November 2022. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).


004 m
030 m
040 m
060 m
090 m
100 m
Wind speed (m/s)
0
5
10
15
20
25
30
35
40
2022-11-15
2022-12-01
2022-12-15
2023-01-01
2023-01-15
2023-02-01
2023-02-15
2023-03-01
2023-03-15


004 m
030 m
040 m
060 m
090 m
100 m
Wind direction (°N)
0
45
90
135
180
225
270
315
360
2022-11-15
2022-12-01
2022-12-15
2023-01-01
2023-01-15
2023-02-01
2023-02-15
2023-03-01
2023-03-15


120 m
150 m
180m
200 m
240 m
270 m
Wind speed (m/s)
0
5
10
15
20
25
30
35
40
2022-11-15
2022-12-01
2022-12-15
2023-01-01
2023-01-15
2023-02-01
2023-02-15
2023-03-01
2023-03-15

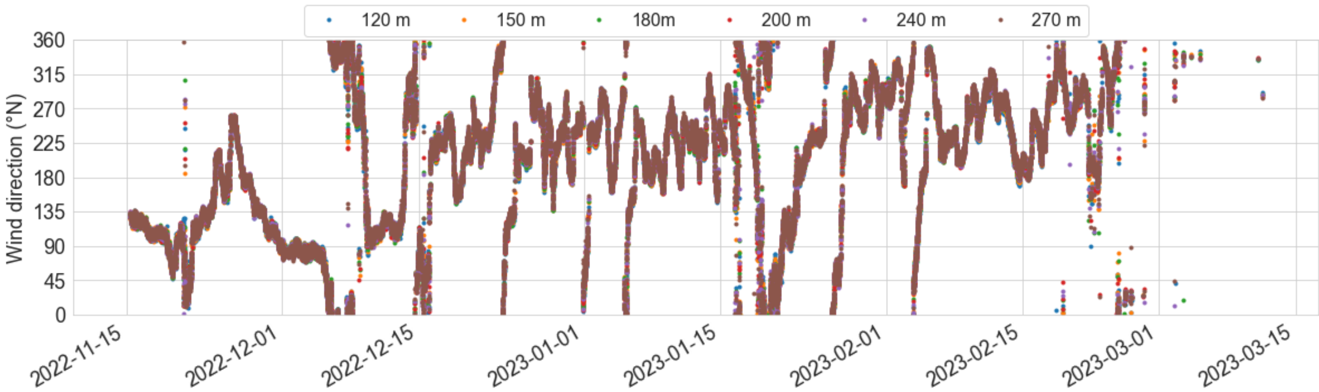
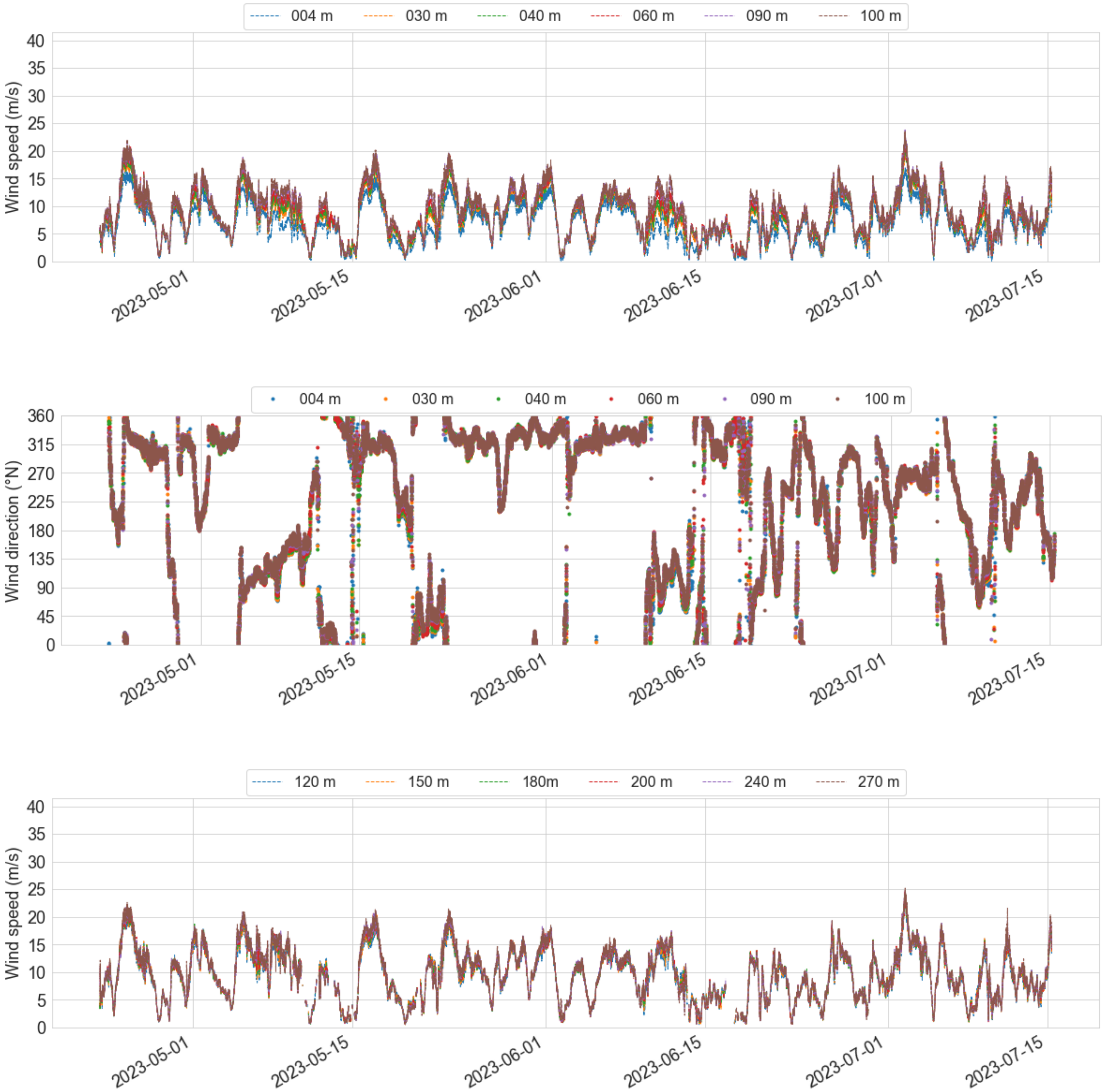

120 m
150 m
180m
200 m
240 m
270 m
Wind direction (°N)
0
45
90
135
180
225
270
315
360
2022-11-15
2022-12-01
2022-12-15
2023-01-01
2023-01-15
2023-02-01
2023-02-15
2023-03-01
2023-03-15

Figure B-4 Timeseries of wind speed and direction from November 2022 until March 2023. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).



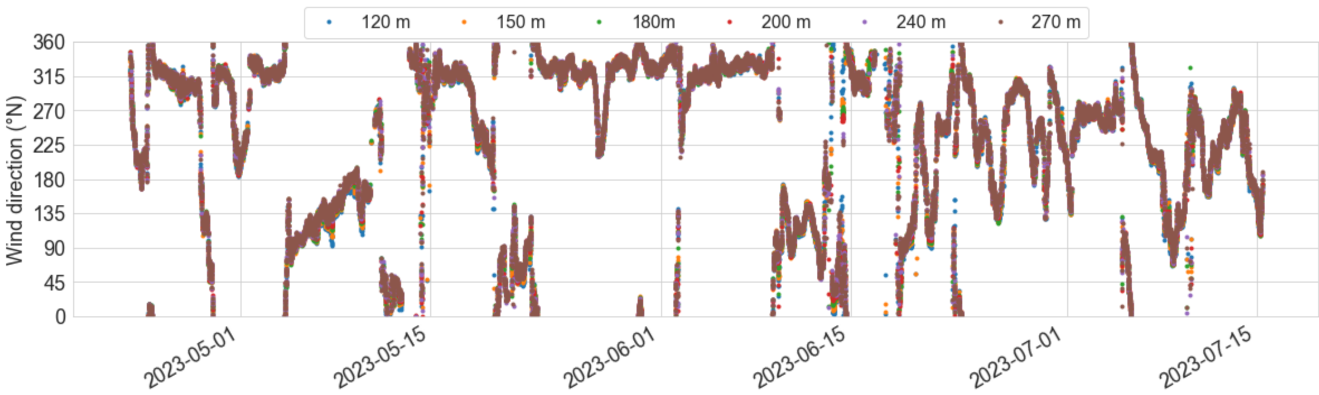
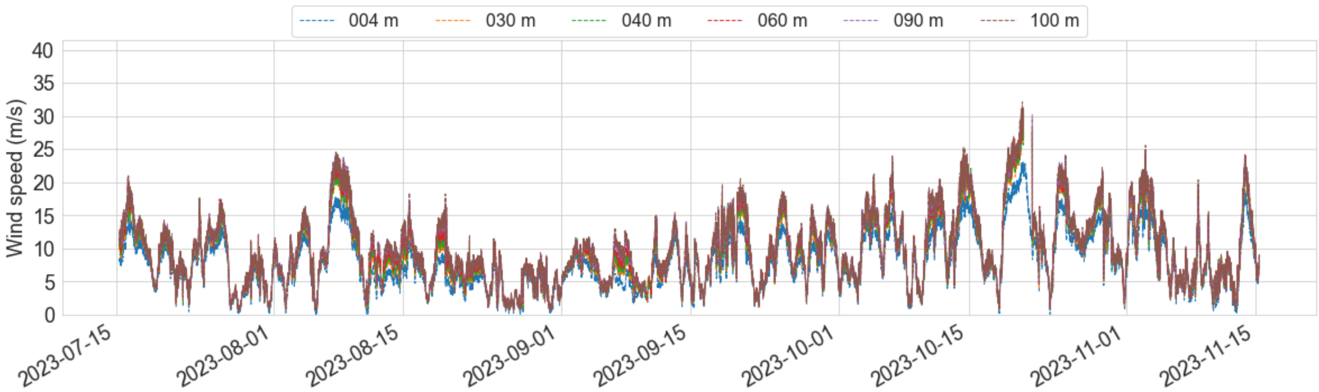
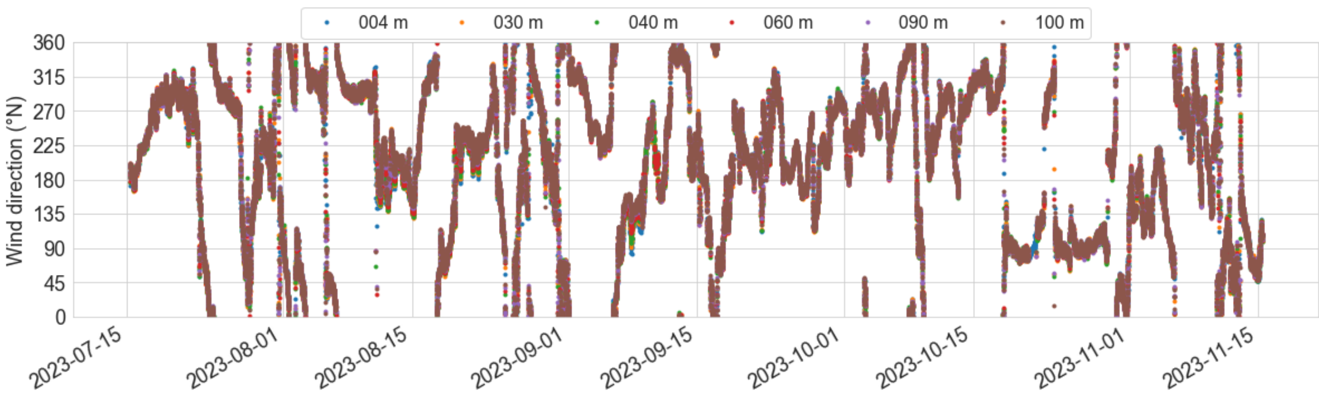


Figure B-5 Timeseries of wind speed and direction from March 2023 until July 2023. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).





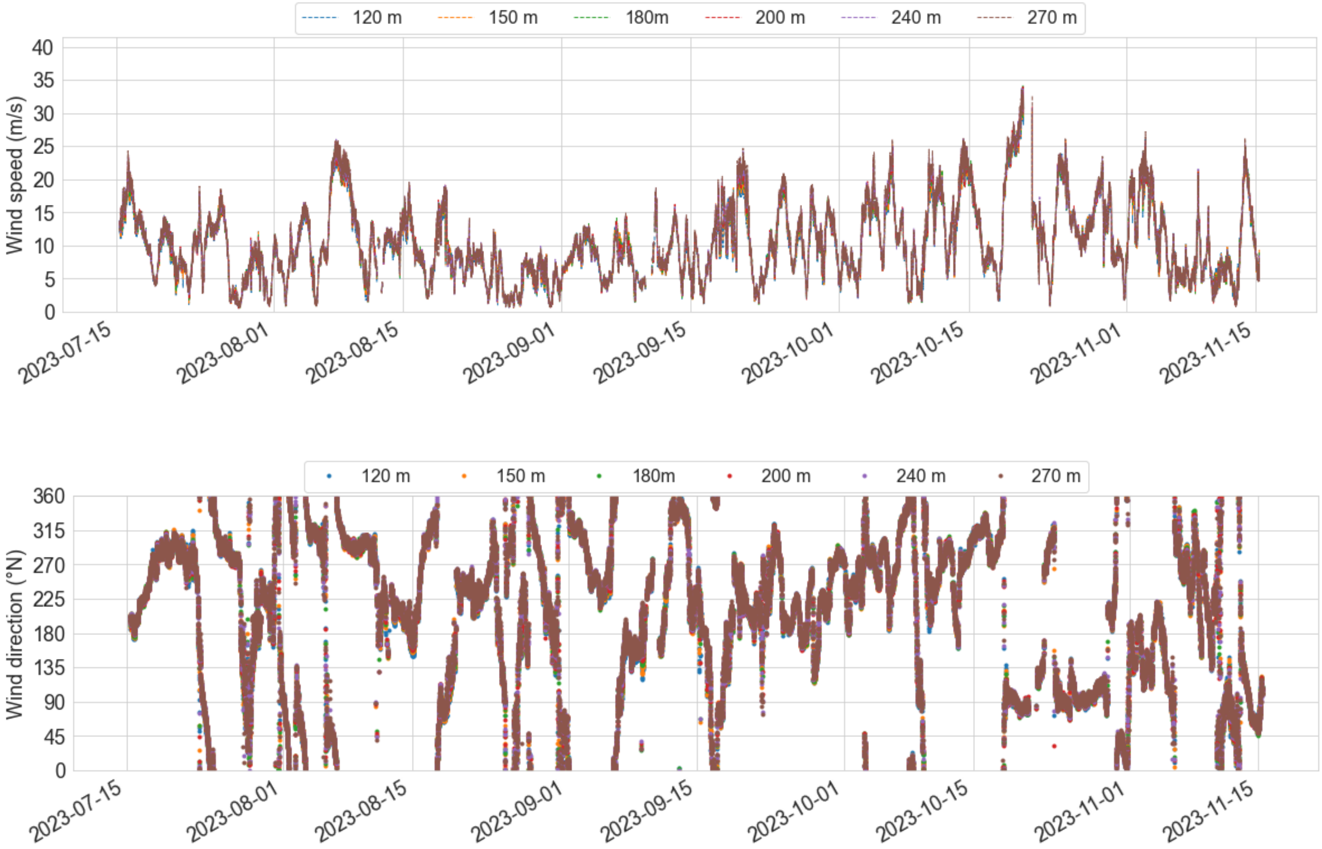
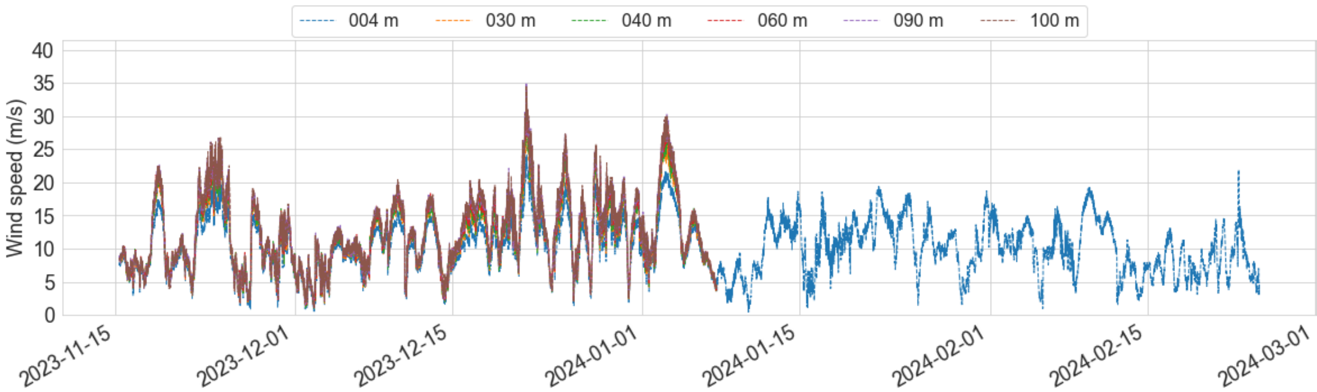


Figure B-6 Timeseries of wind speed and direction from July 2023 until November 2023. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).



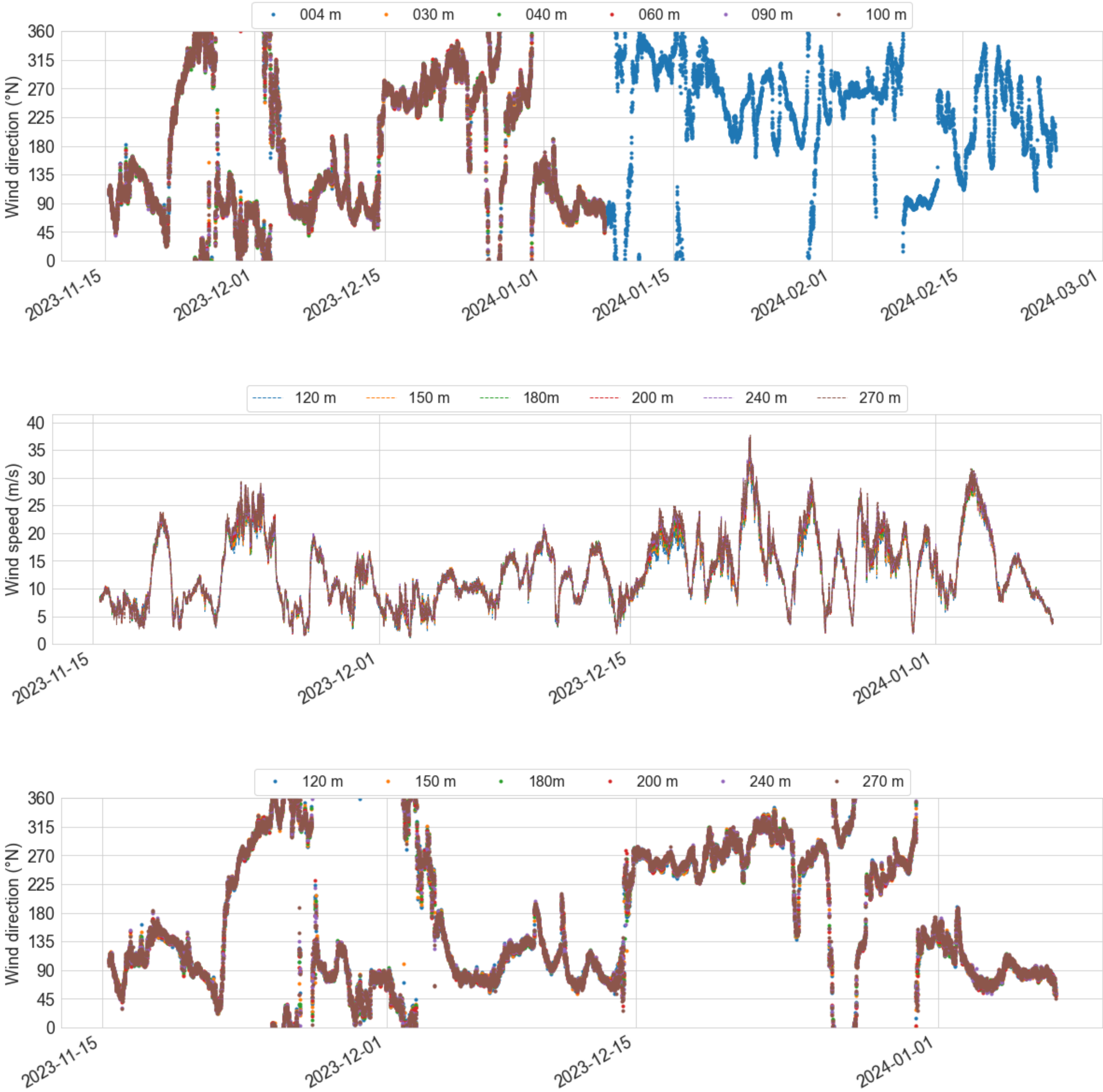


Figure B-7 Timeseries of wind speed and direction from November 2023 until February 2024. Please note that the y-axis for wind direction spans from 0° (bottom line) to 360° (top line).

B.2 Wave data

B.2.1 Wave heights

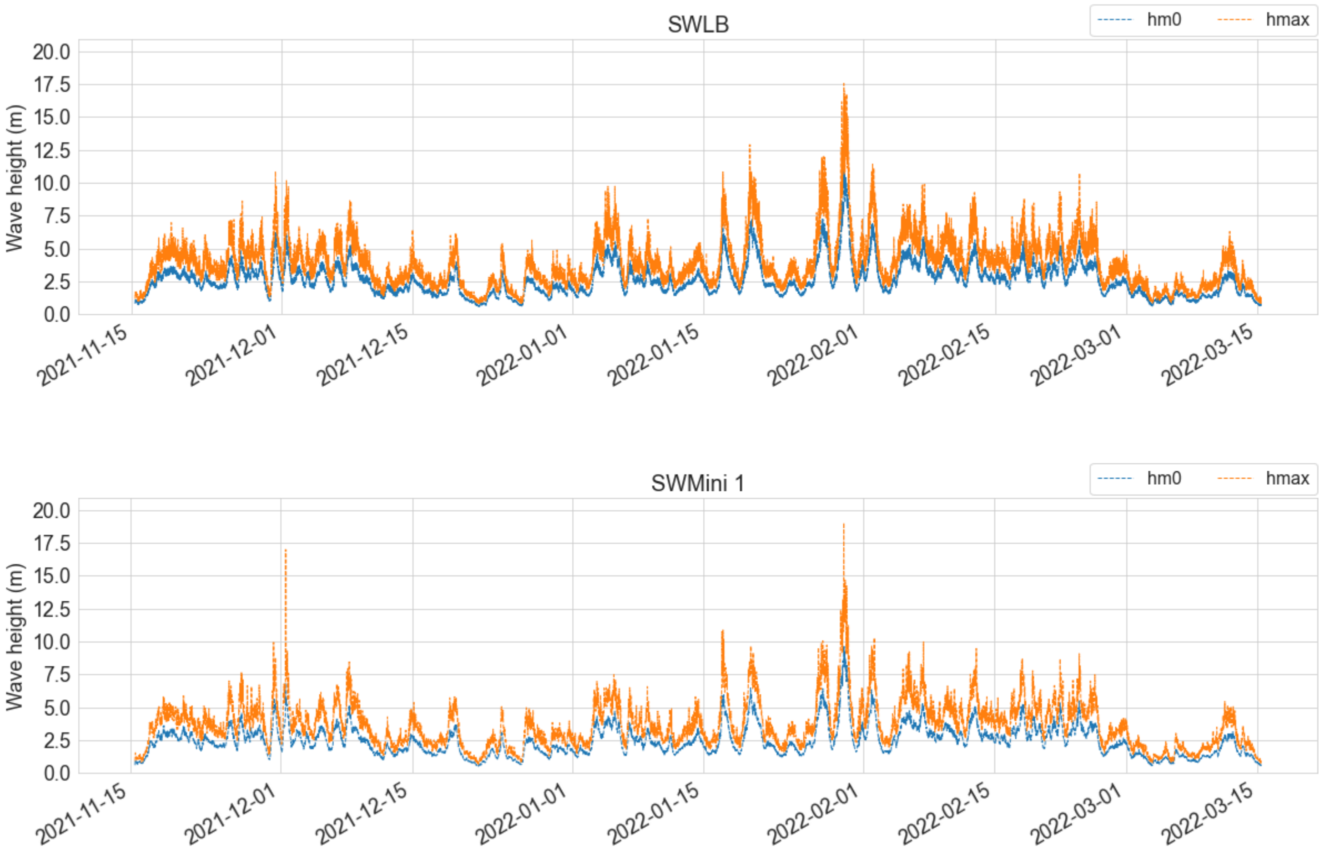
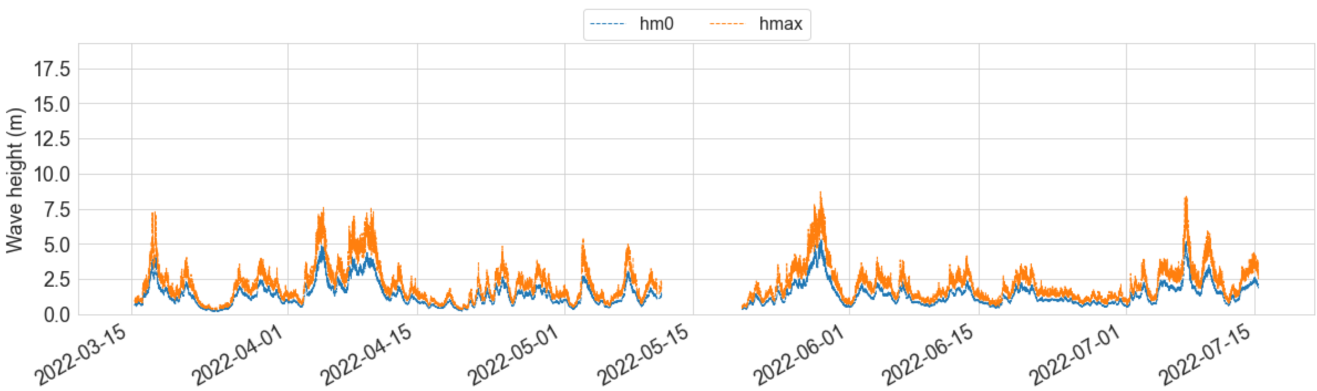


Figure B-8 Timeseries of wave heights from November 2021 until March 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).



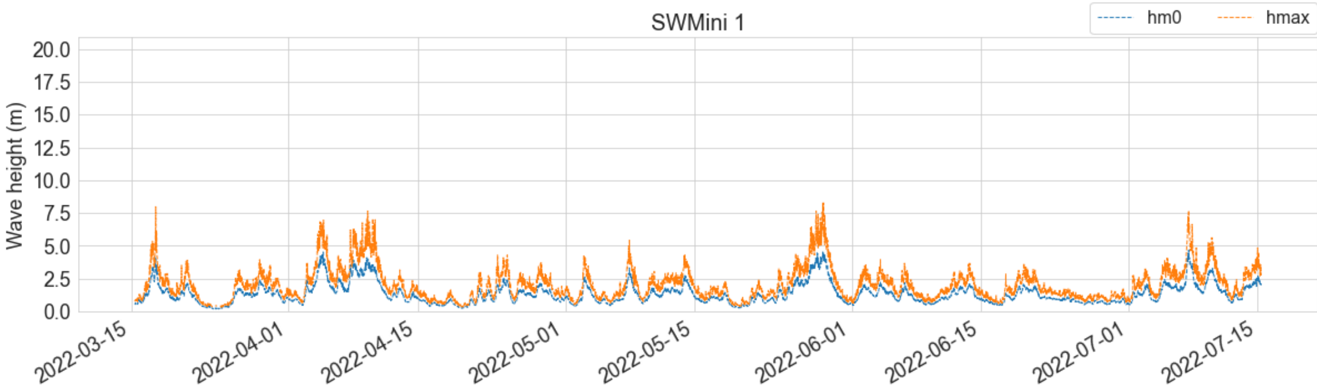


Figure B-9 Timeseries of wave heights from March 2022 until July 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).

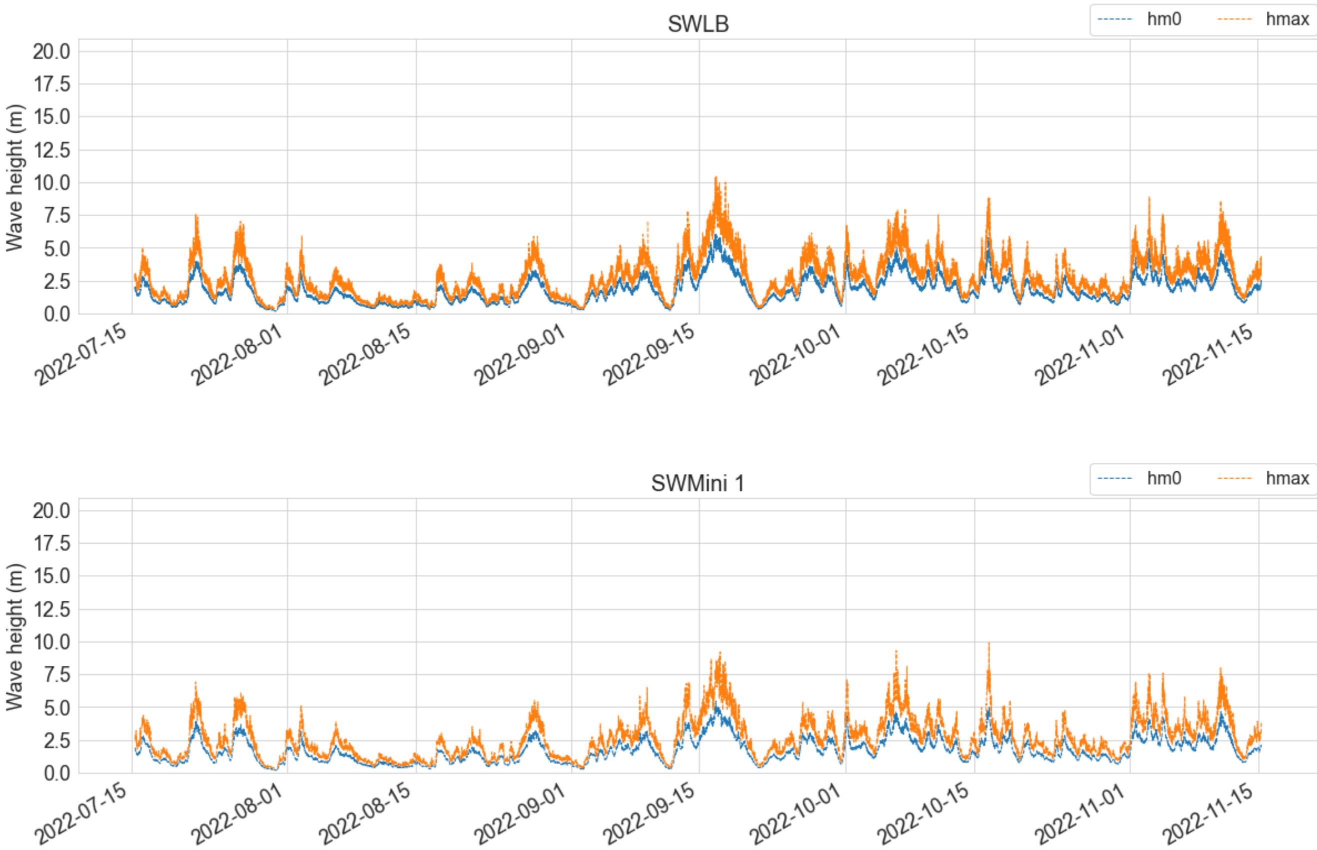


Figure B-10 Timeseries of wave heights from July 2022 until November 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).

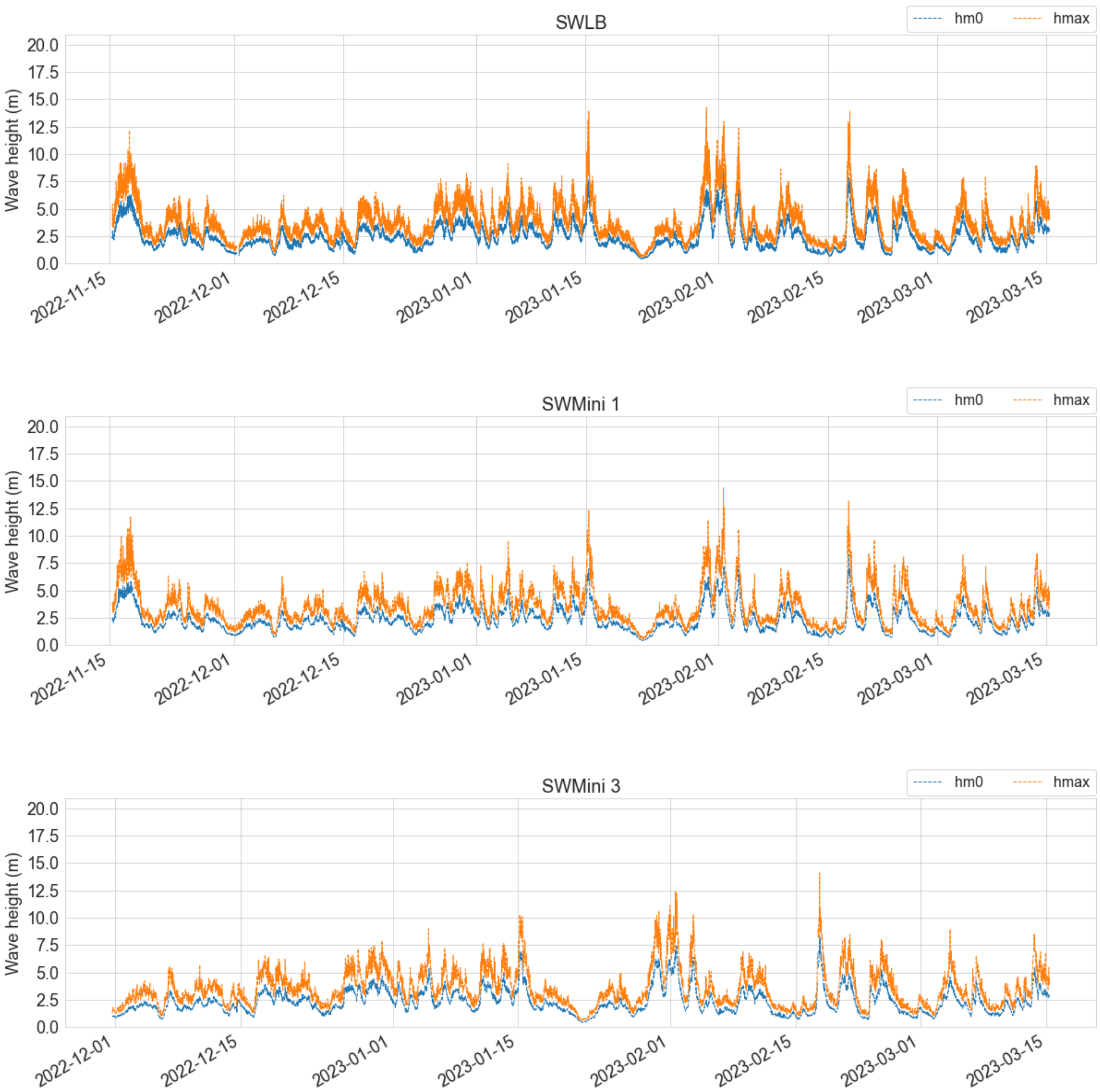


Figure B-11 Timeseries of wave heights from November 2022 until March 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

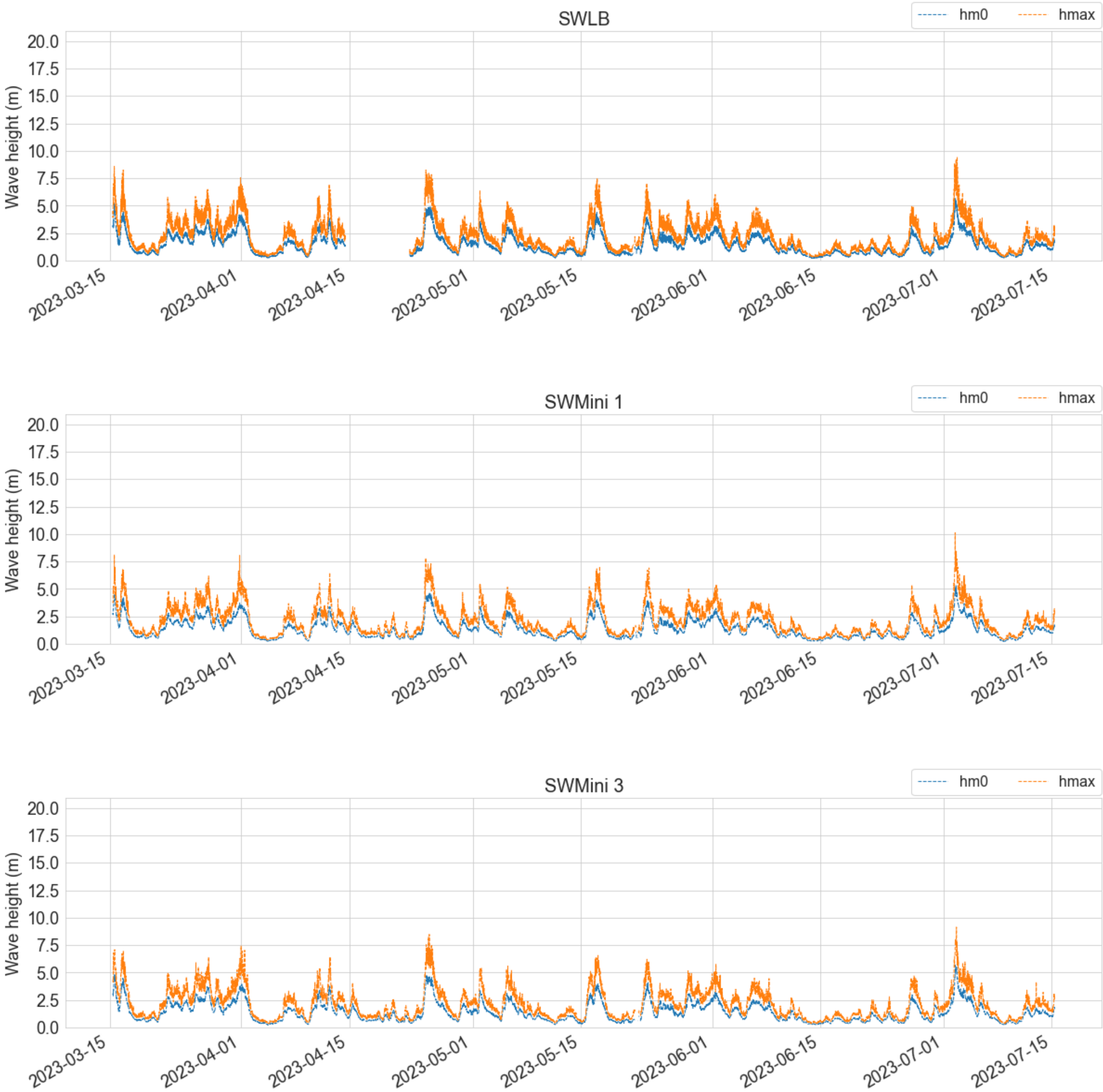


Figure B-12 Timeseries of wave heights from March 2023 until July 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

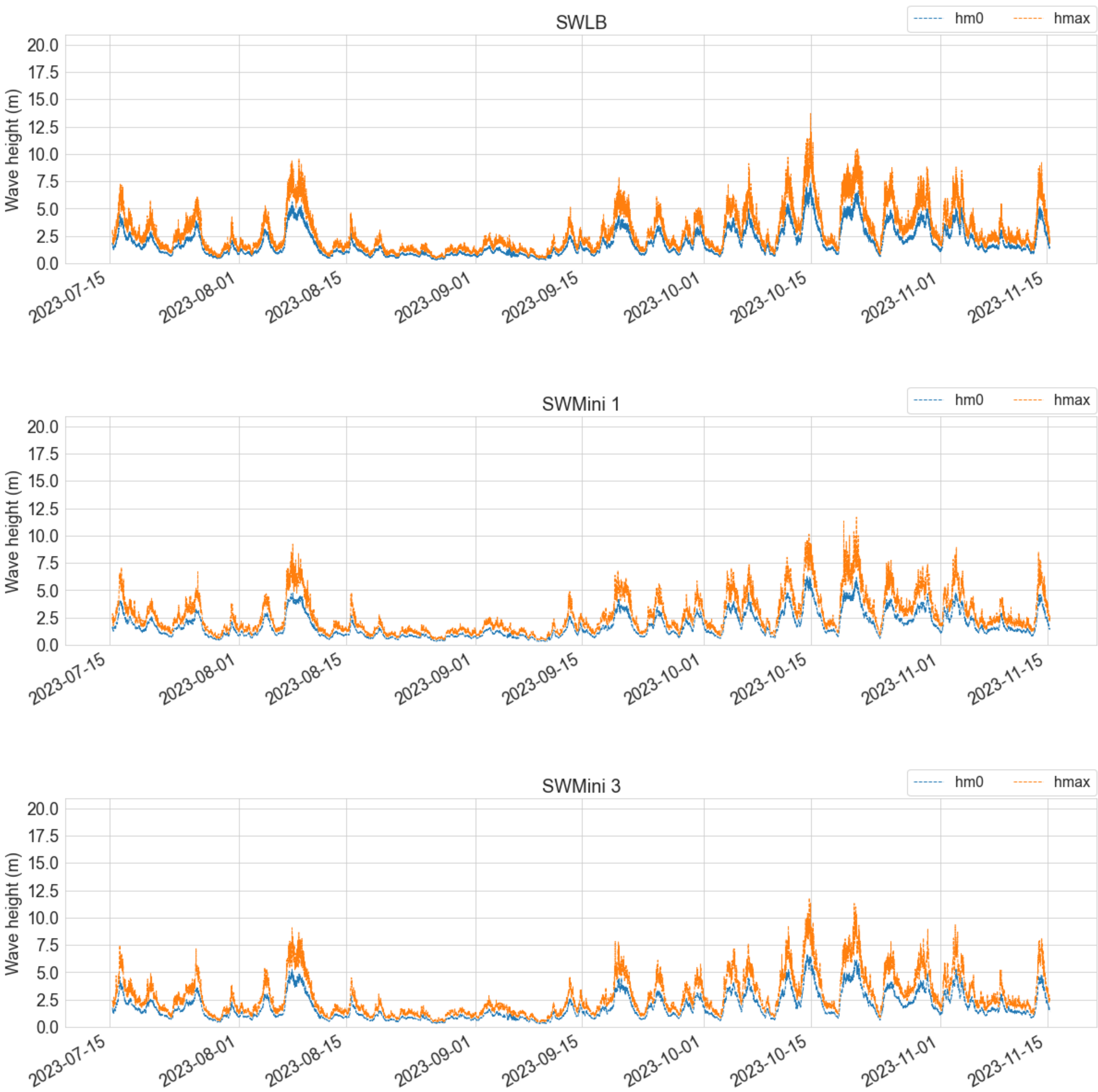


Figure B-13 Timeseries of wave heights from July 2023 until November 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

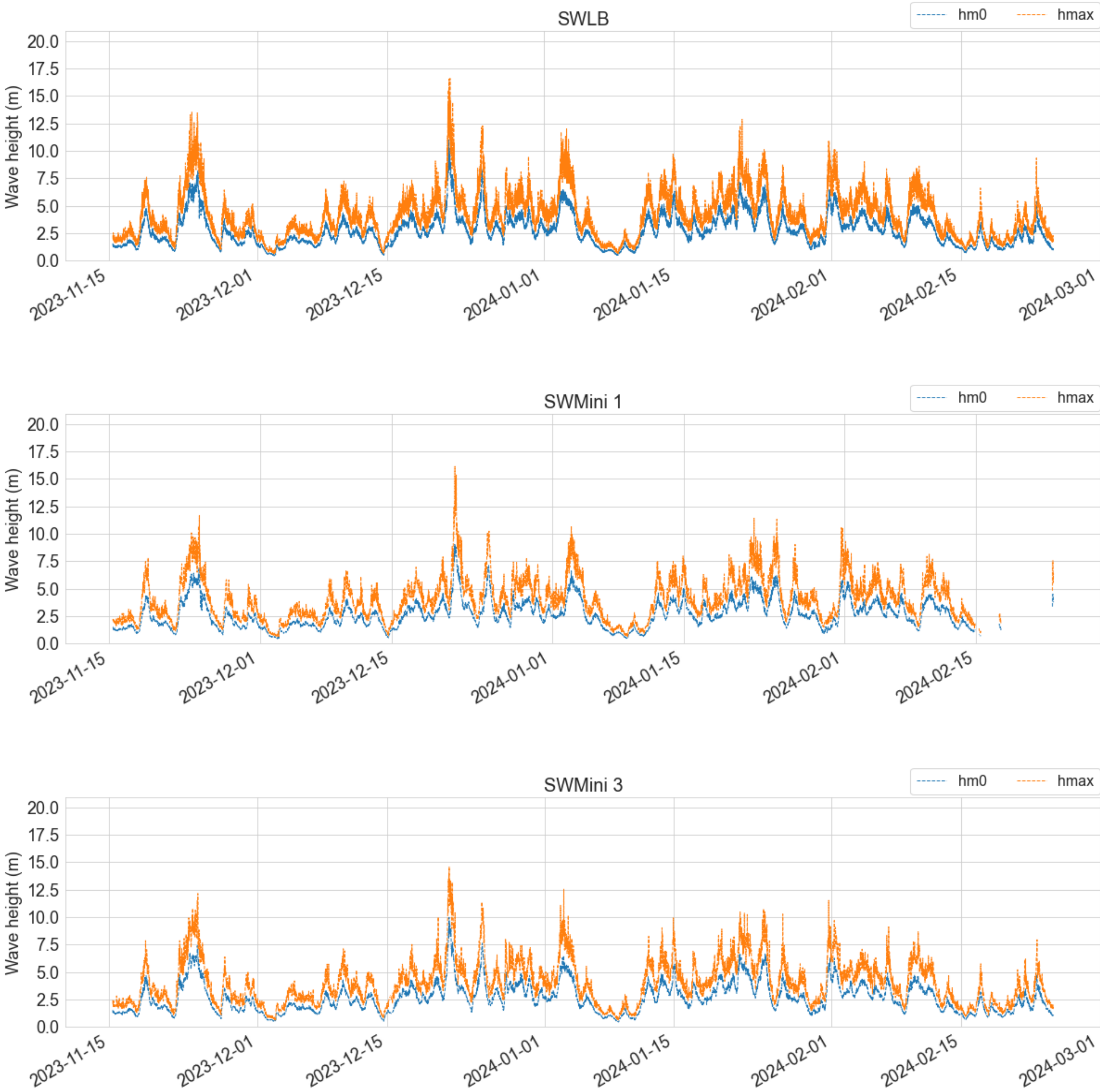


Figure B-14 Timeseries of wave heights from November 2023 until February 2024 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

B.2.2 Wave directions

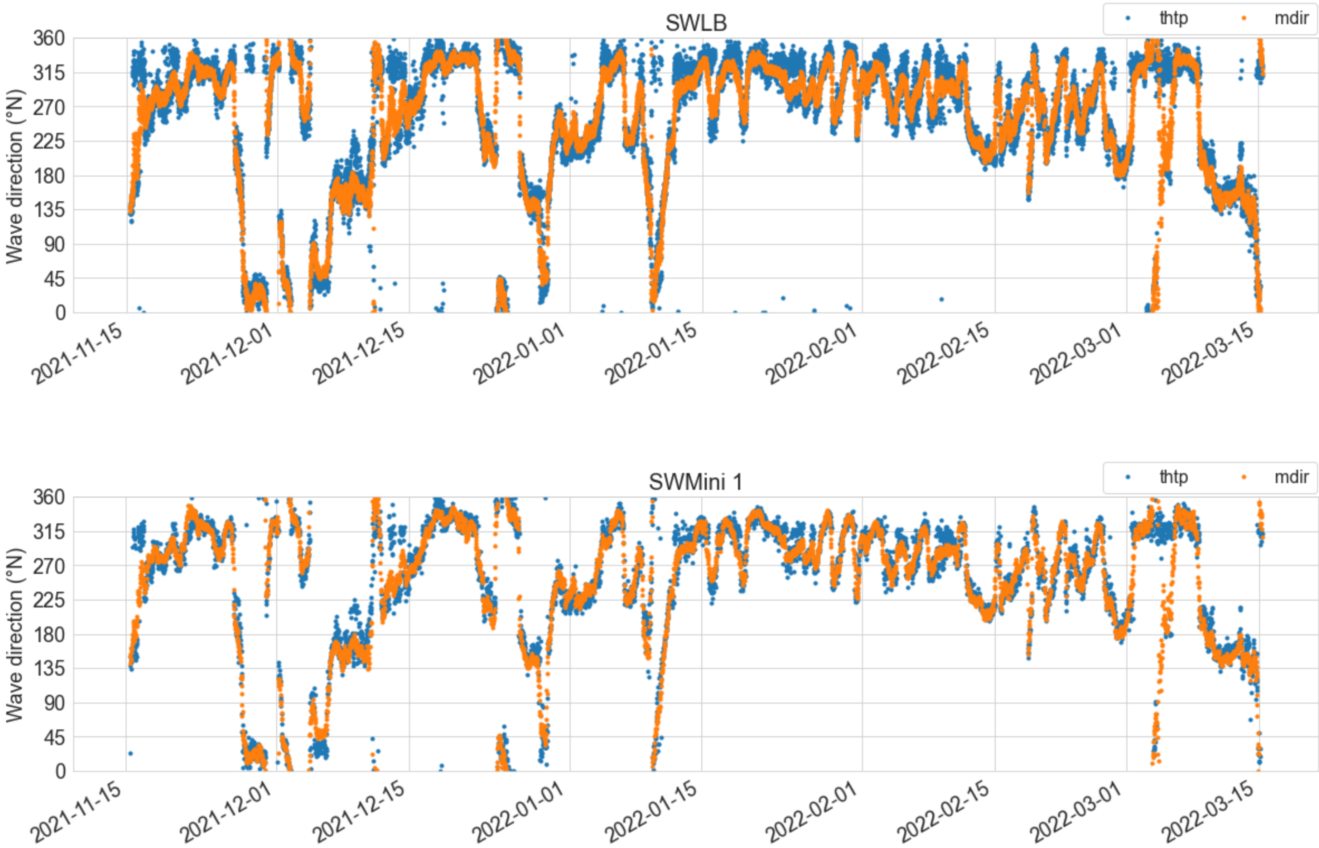
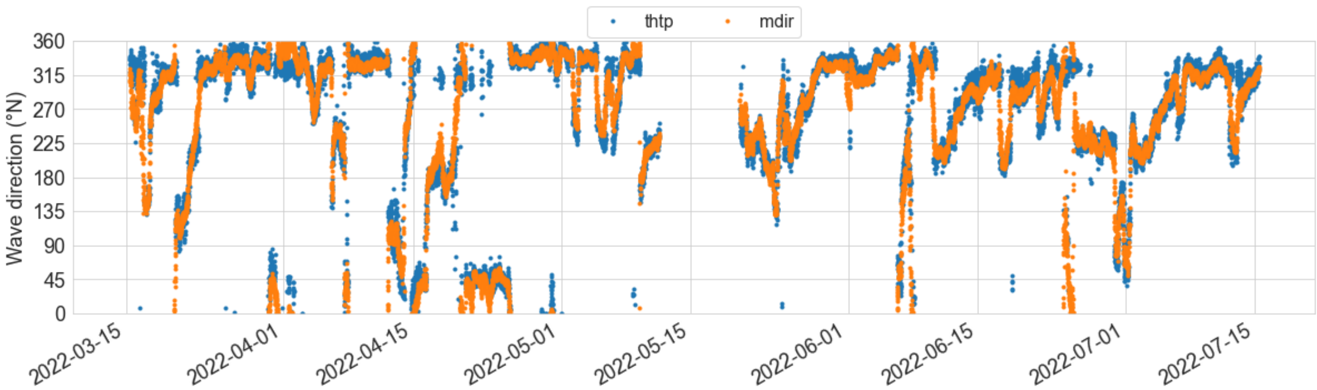


Figure B-15 Timeseries of wave directions from November 2021 until March 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).



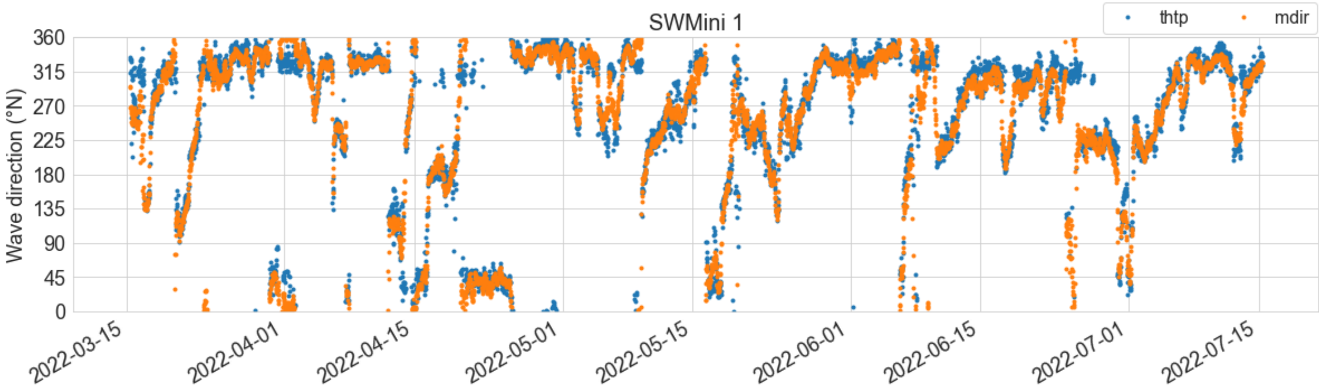


Figure B-16 Timeseries of wave directions from March 2022 until July 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

Figure B-17 Timeseries of wave directions from July 2022 until November 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

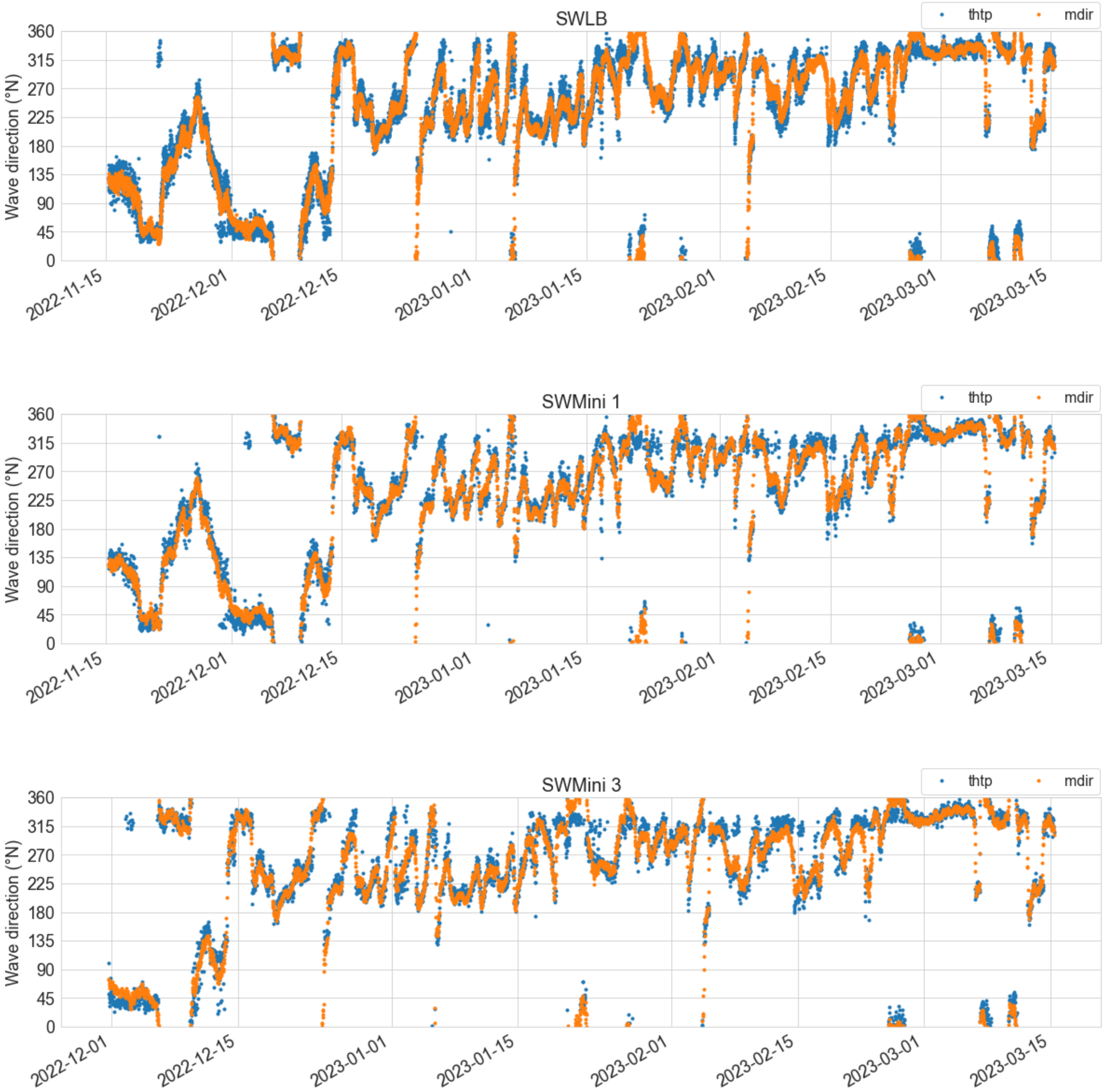


Figure B-18 Timeseries of wave directions from November 2022 until March 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

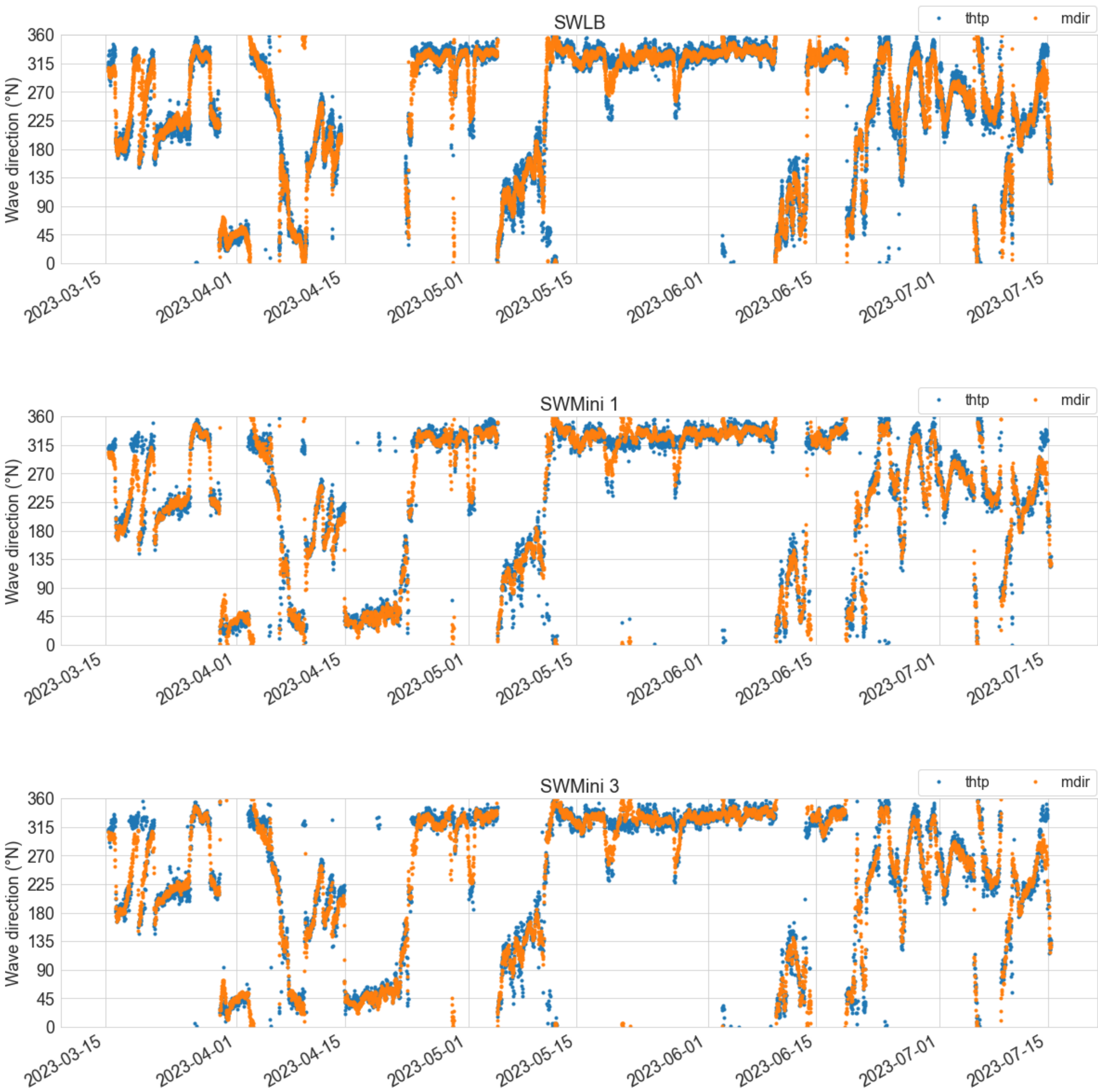


Figure B-19 Timeseries of wave directions from March 2023 until July 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

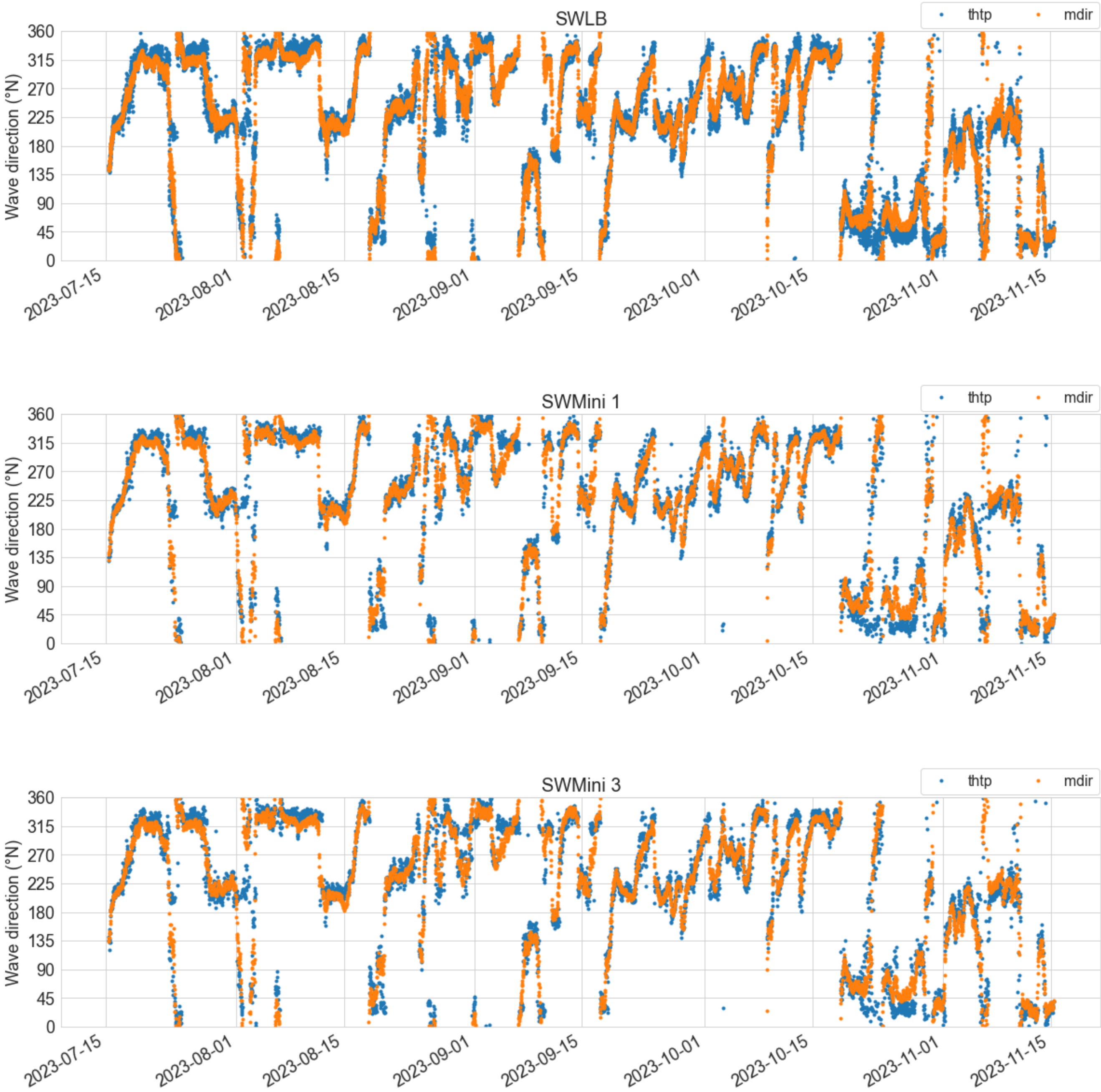


Figure B-20 Timeseries of wave directions from July 2023 until November 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

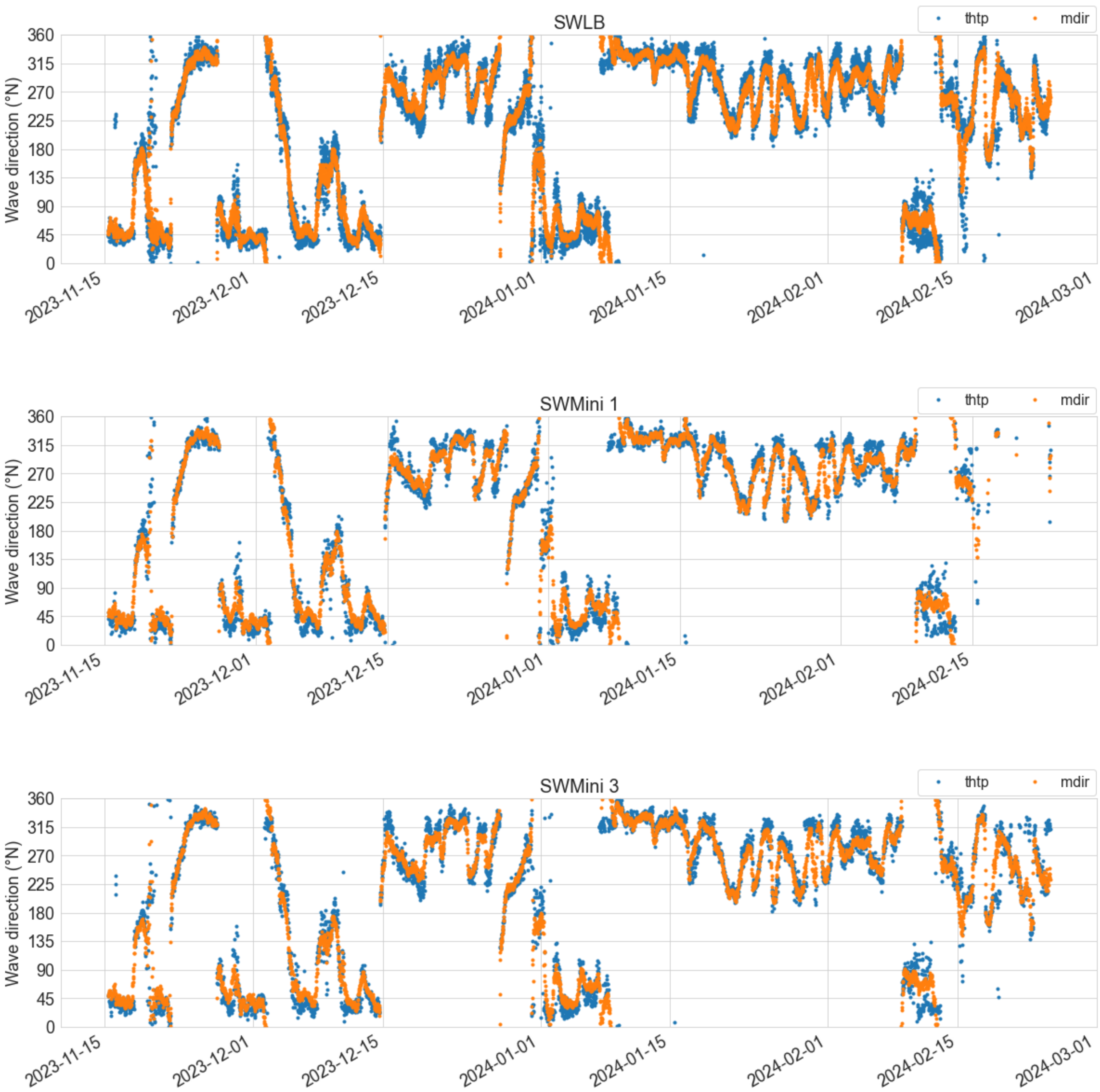
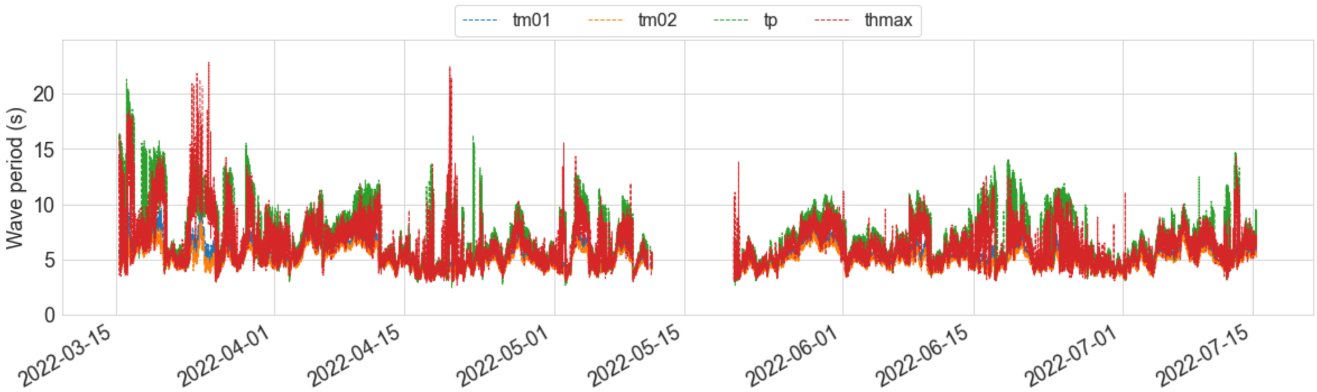


Figure B-21 Timeseries of wave directions from November 2023 until February 2024 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom). Please note that the y-axis for wave direction spans from 0° (bottom line) to 360° (top line).

B.2.3 Wave periods

Figure B-22 Timeseries of wave periods from November 2021 until March 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).



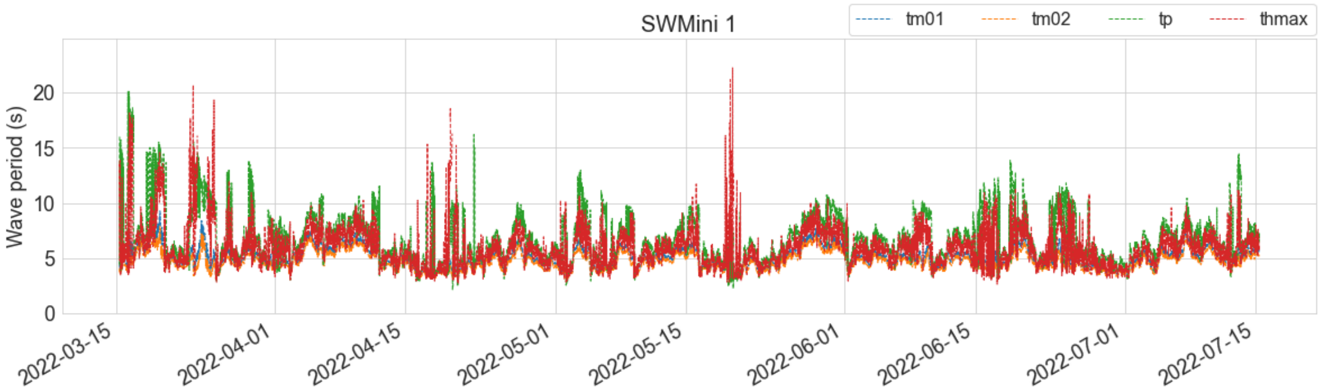


Figure B-23 Timeseries of wave periods from March 2022 until July 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).

Figure B-24 Timeseries of wave periods from July 2022 until November 2022 measured by the SWLB (top) and SWMini wave buoy 1 (bottom).

Figure B-25 Timeseries of wave periods from November 2022 until March 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

Figure B-26 Timeseries of wave periods from March 2023 until July 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

Figure B-27 Timeseries of wave periods from July 2023 until November 2023 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

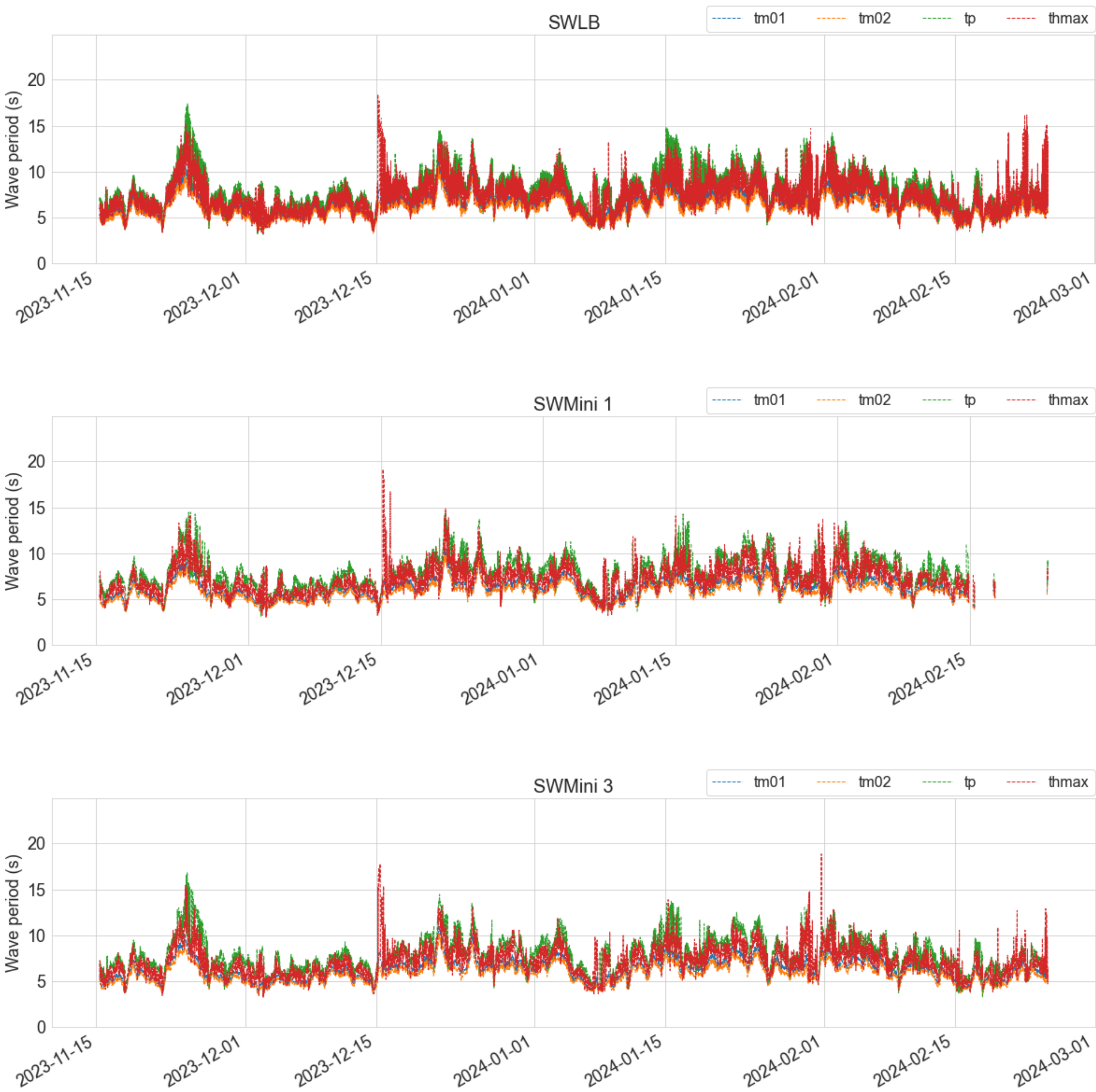
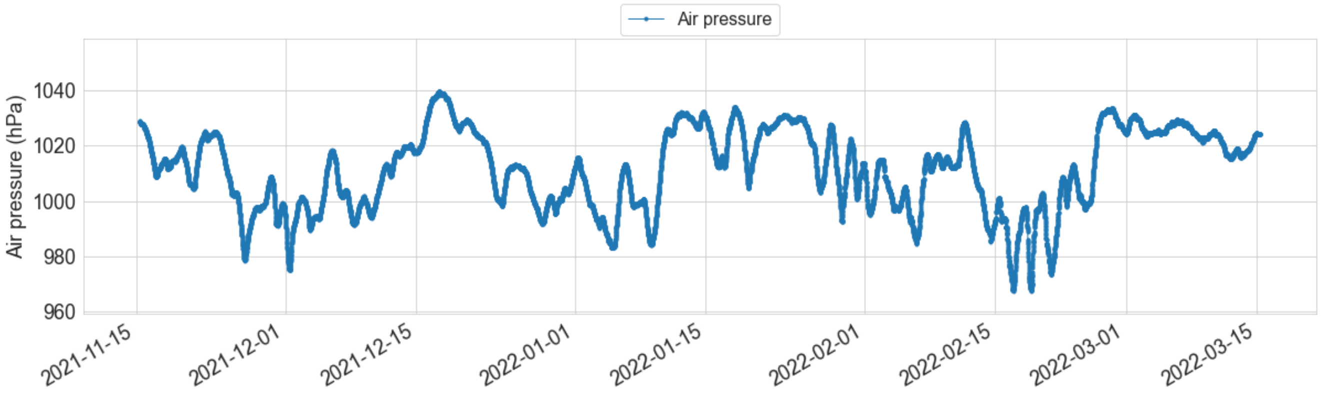
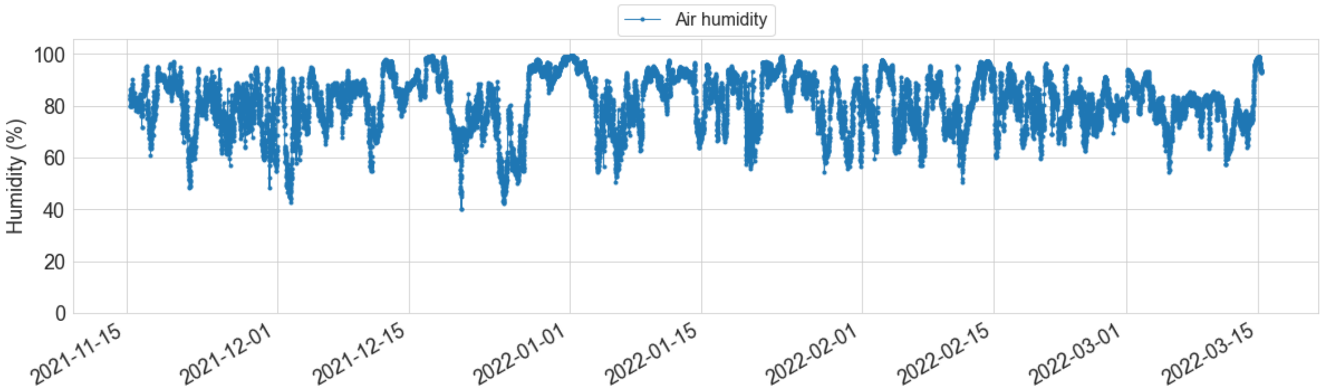
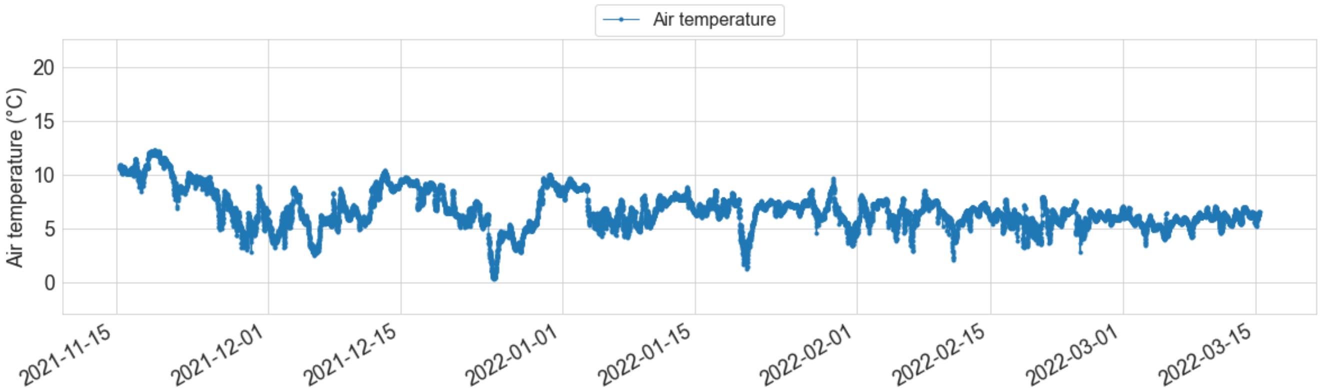


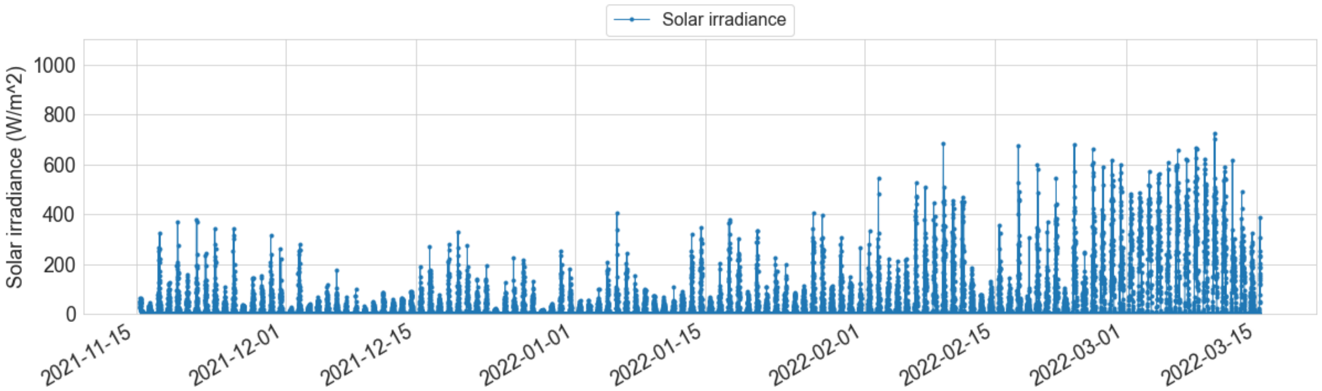
Figure B-28 Timeseries of wave periods from November 2023 until February 2024 measured by the SWLB (top), SWMini wave buoy 1 (middle), and SWMini 3 (bottom).

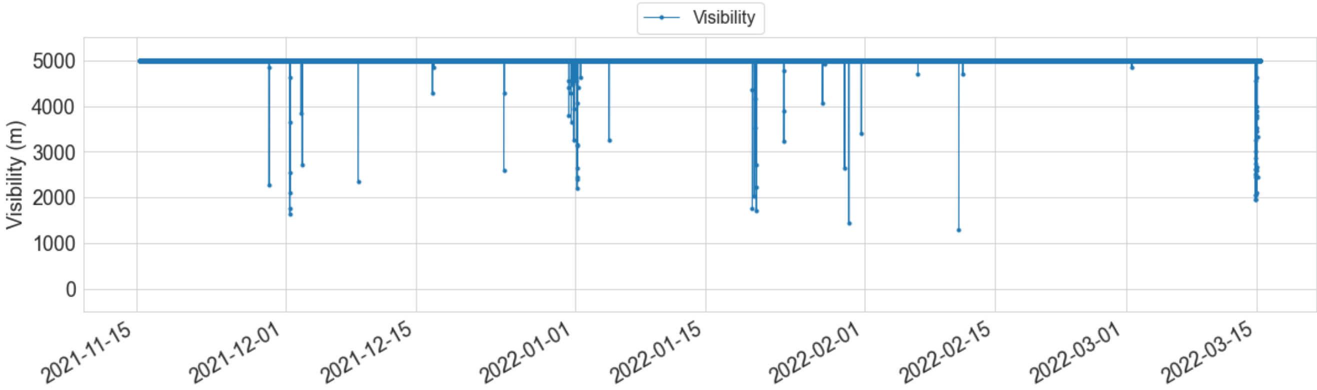
B.3 Metocean data











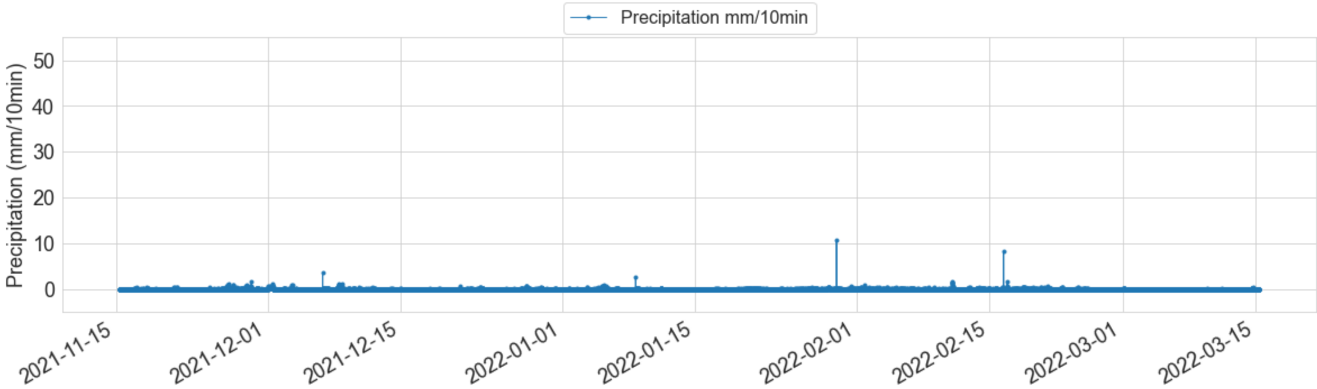
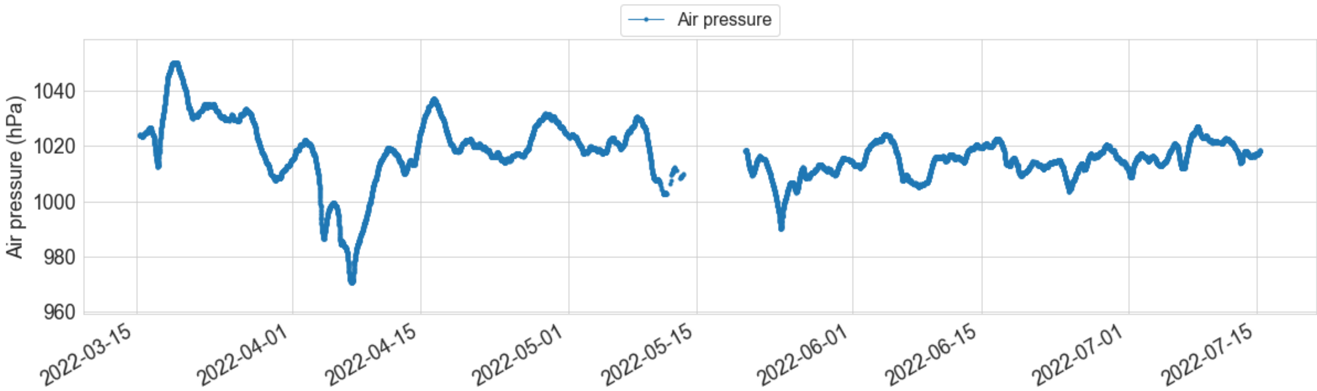
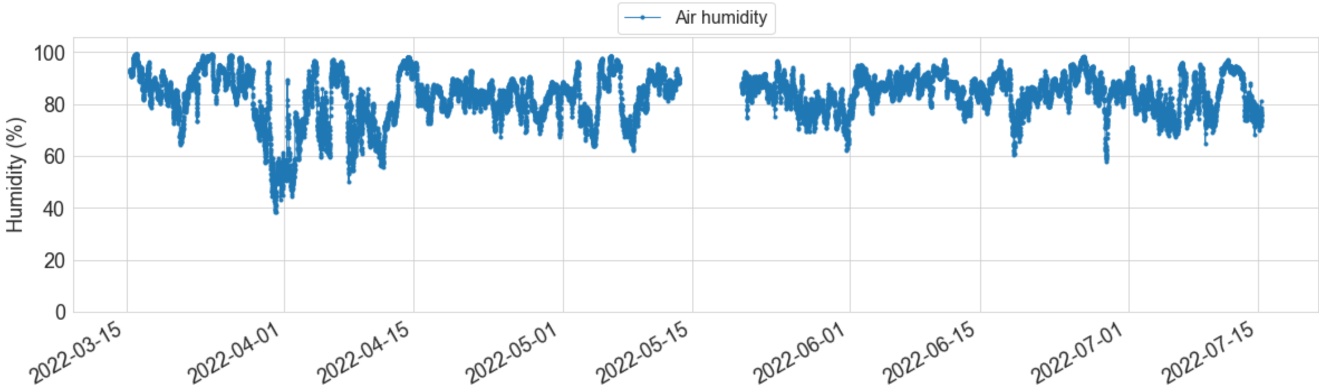
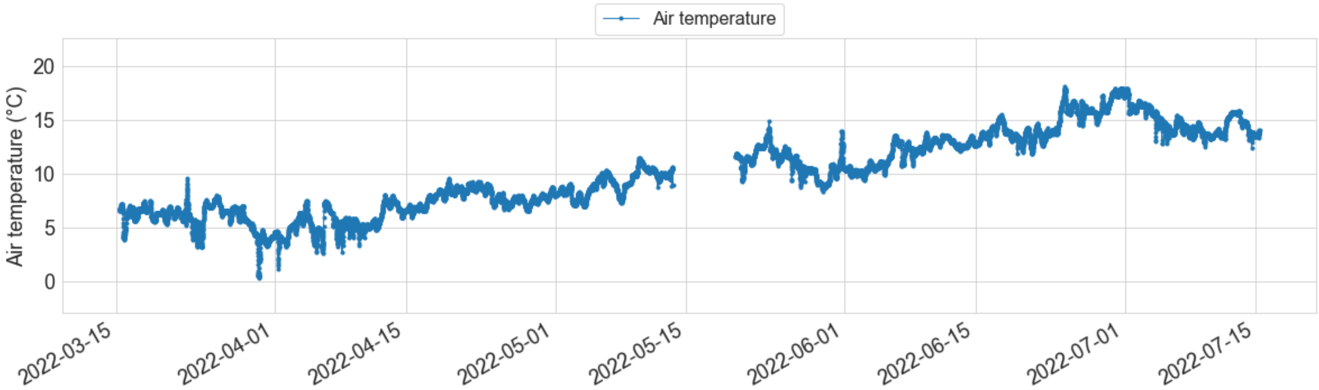
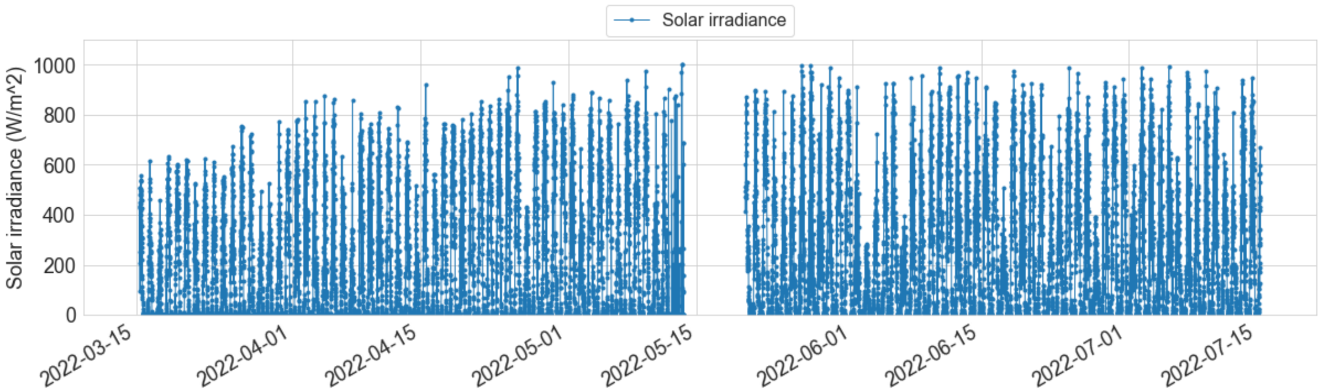


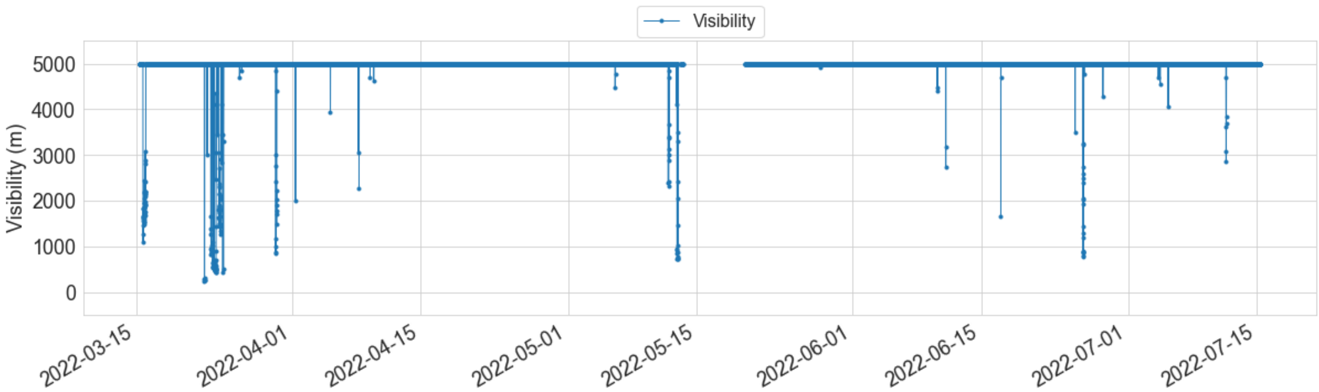
Figure B-29 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from November 2021 until March 2022




Air humidity
Humidity (%)
0
20
40
60
80
100
2022-03-15
2022-04-01
2022-04-15
2022-05-01
2022-05-15
2022-06-01
2022-06-15
2022-07-01
2022-07-15


Air temperature
Air temperature (°C)
0
5
10
15
20
2022-03-15
2022-04-01
2022-04-15
2022-05-01
2022-05-15
2022-06-01
2022-06-15
2022-07-01
2022-07-15


Solar irradiance
Solar irradiance (W/m^2)
0
200
400
600
800
1000
2022-03-15
2022-04-01
2022-04-15
2022-05-01
2022-05-15
2022-06-01
2022-06-15
2022-07-01
2022-07-15


Visibility
Visibility (m)
0
1000
2000
3000
4000
5000
2022-03-15
2022-04-01
2022-04-15
2022-05-01
2022-05-15
2022-06-01
2022-06-15
2022-07-01
2022-07-15

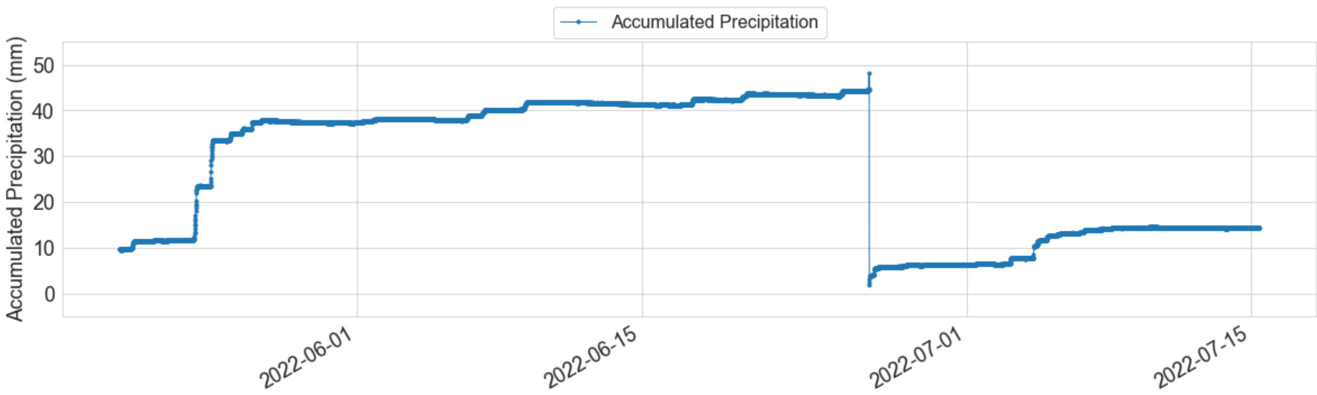
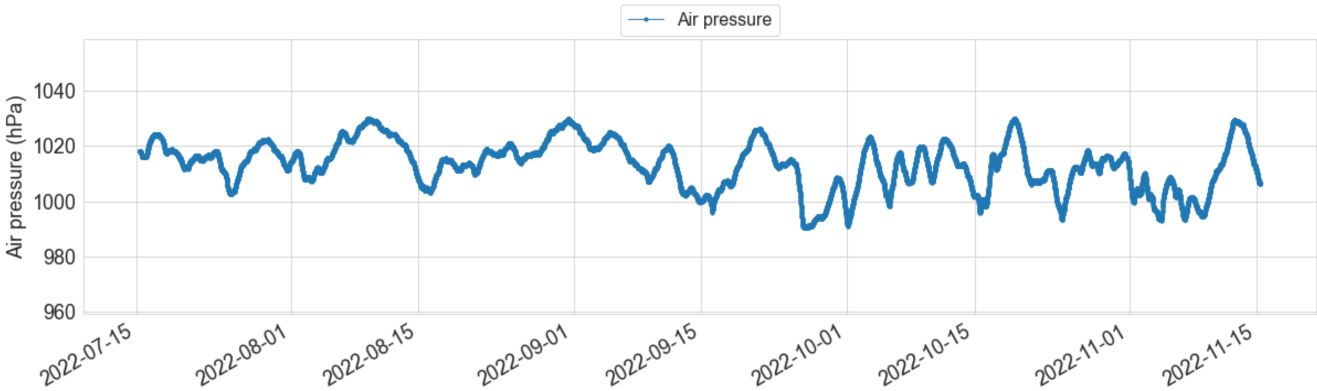
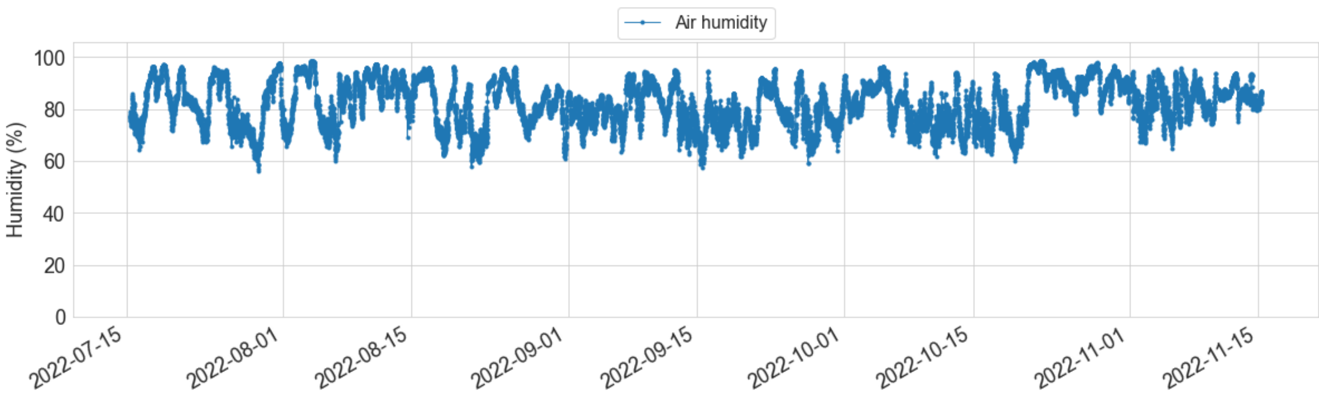
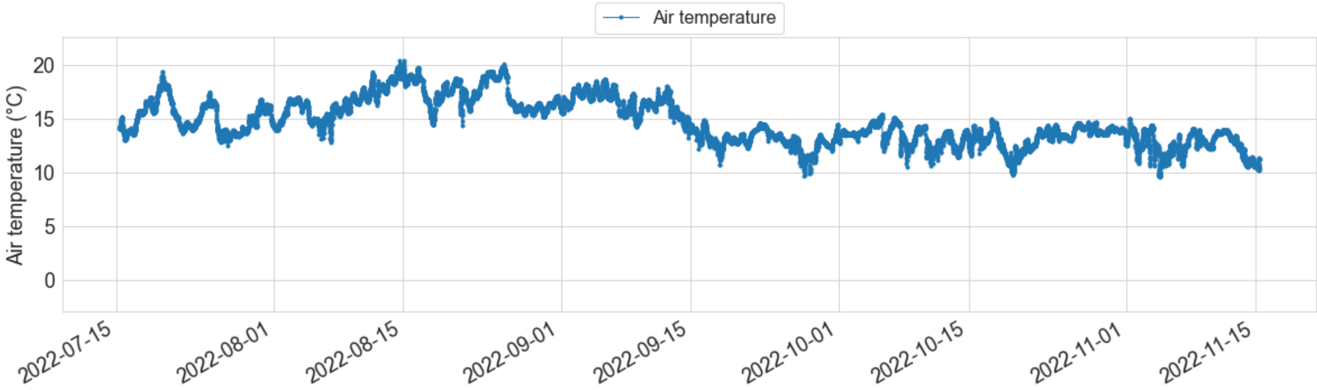


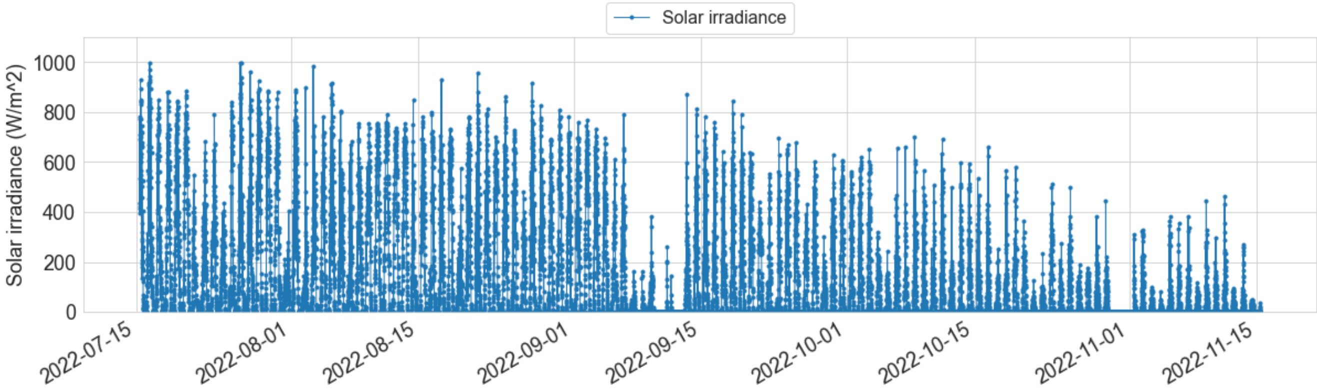
Figure B-30 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from March 2022 until July 2022. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.



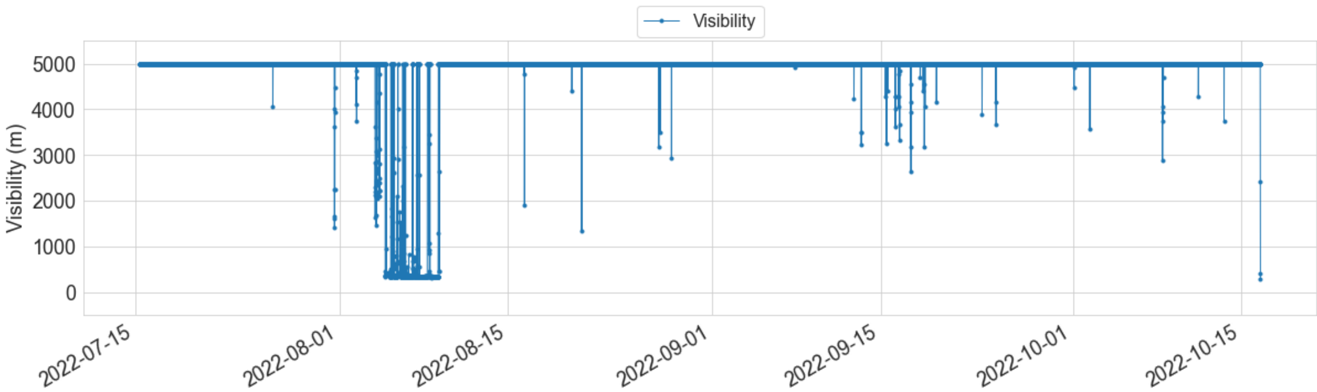




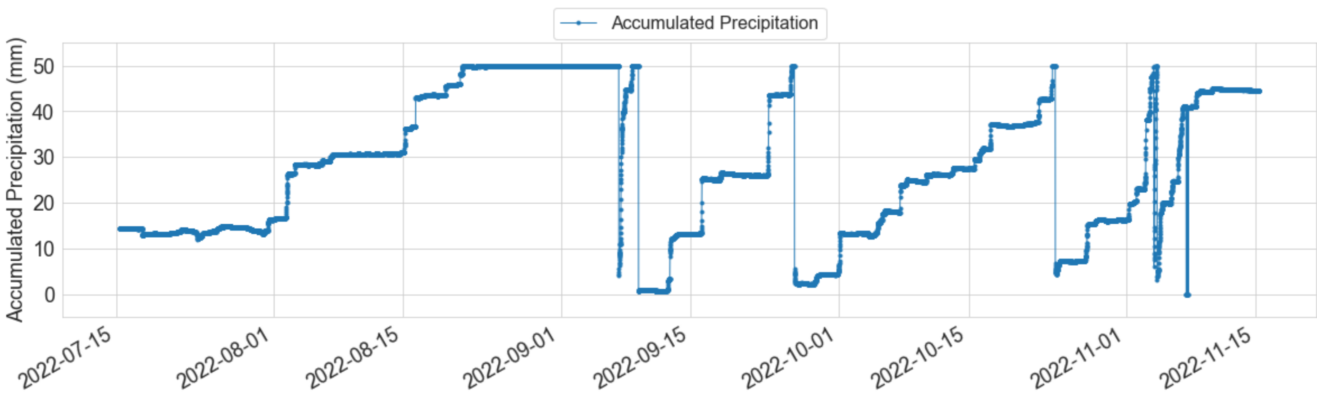
Air temperature
Air temperature (°C)
20
15
10
5
0
2022-07-15
2022-08-01
2022-08-15
2022-09-01
2022-09-15
2022-10-01
2022-10-15
2022-11-01
2022-11-15



Solar irradiance
Solar irradiance (W/m^2)
1000
800
600
400
200
0
2022-07-15
2022-08-01
2022-08-15
2022-09-01
2022-09-15
2022-10-01
2022-10-15
2022-11-01
2022-11-15

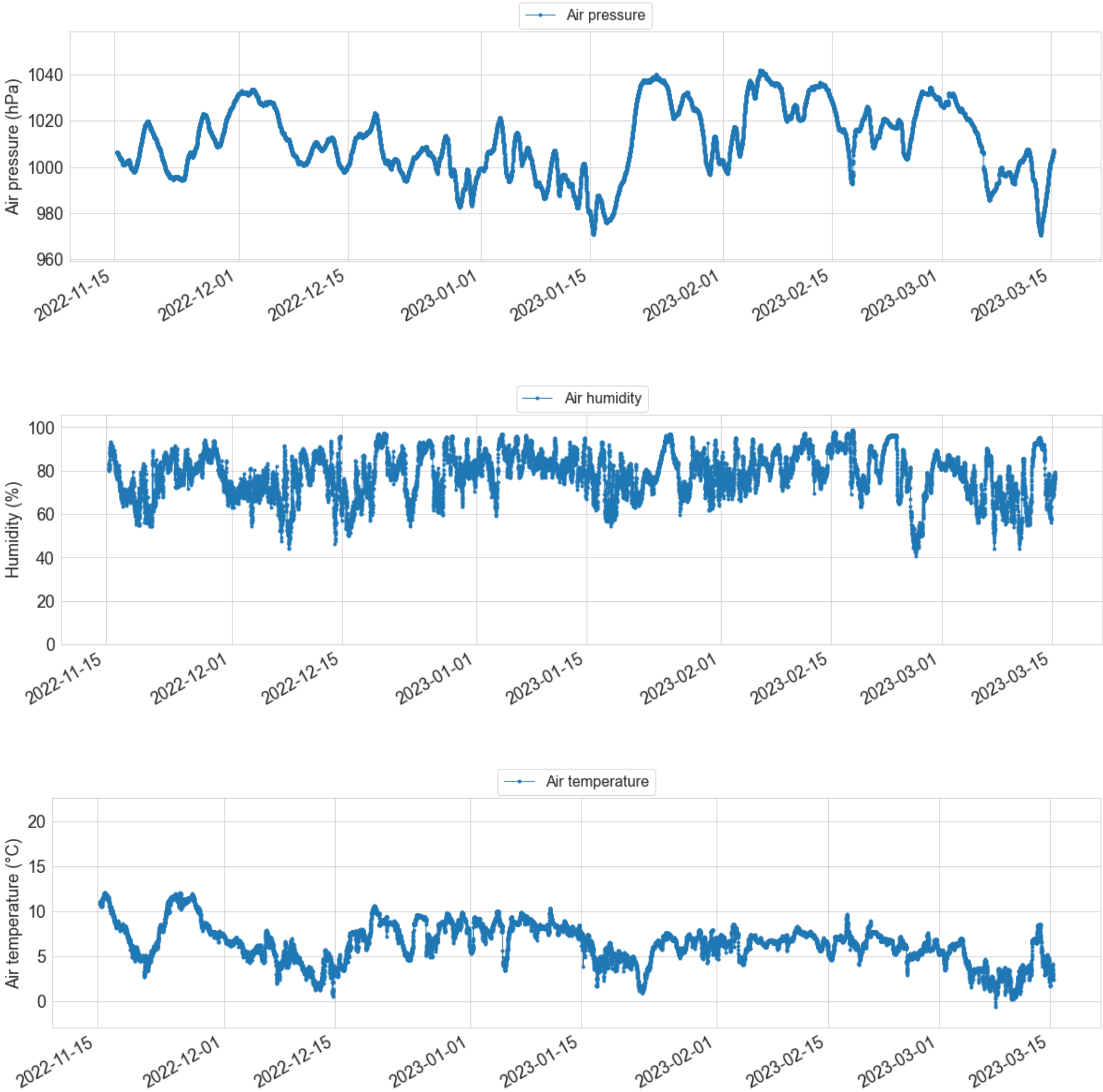


Visibility
Visibility (m)
5000
4000
3000
2000
1000
0
2022-07-15
2022-08-01
2022-08-15
2022-09-01
2022-09-15
2022-10-01
2022-10-15



Accumulated Precipitation
Accumulated Precipitation (mm)
50
40
30
20
10
0
2022-07-15
2022-08-01
2022-08-15
2022-09-01
2022-09-15
2022-10-01
2022-10-15
2022-11-01
2022-11-15

Figure B-31 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from July 2022 until November 2022. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.



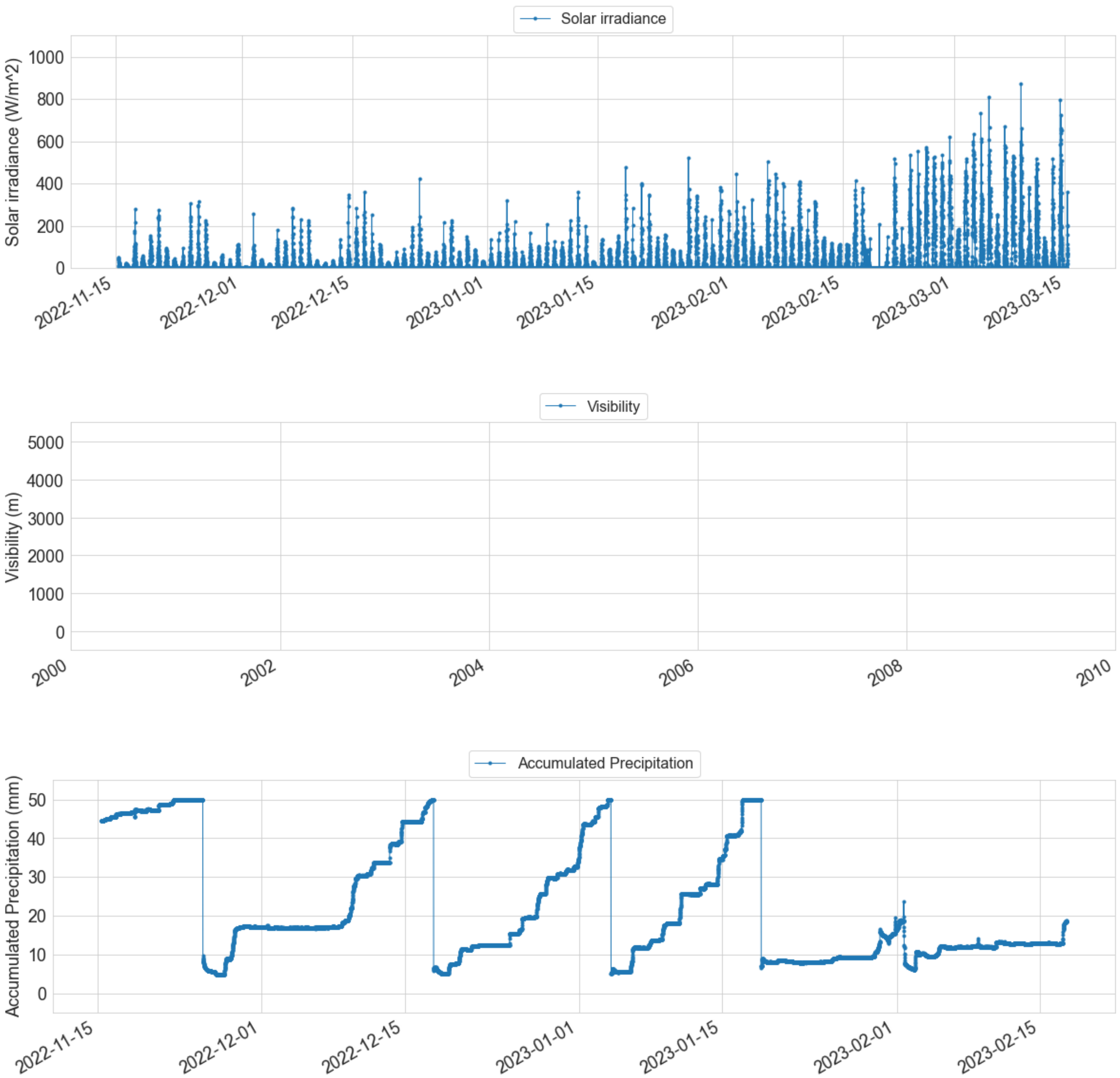
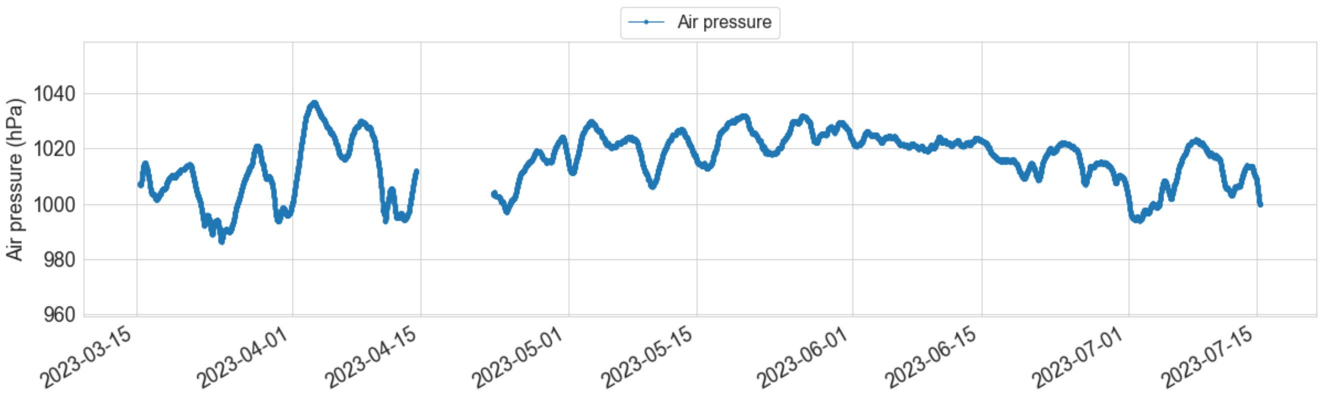
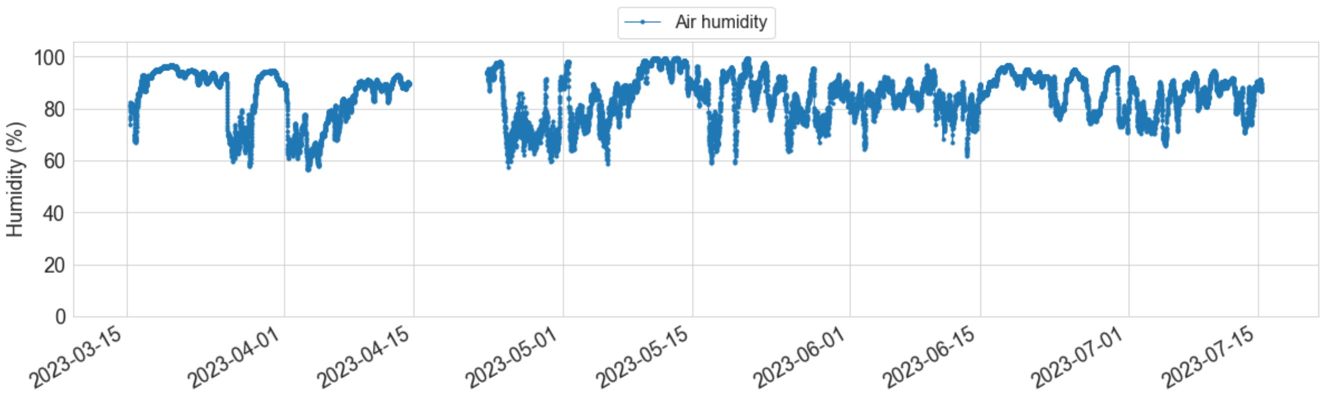
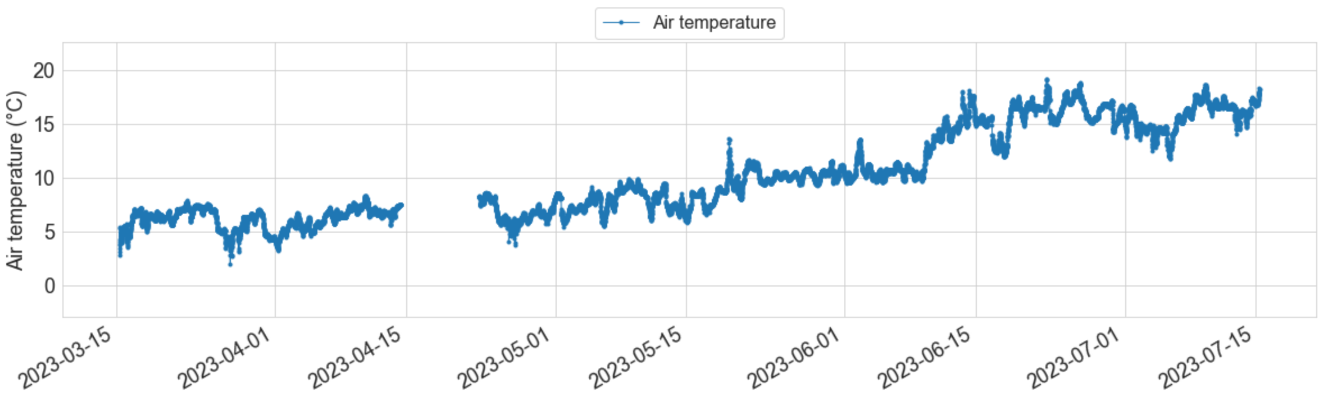
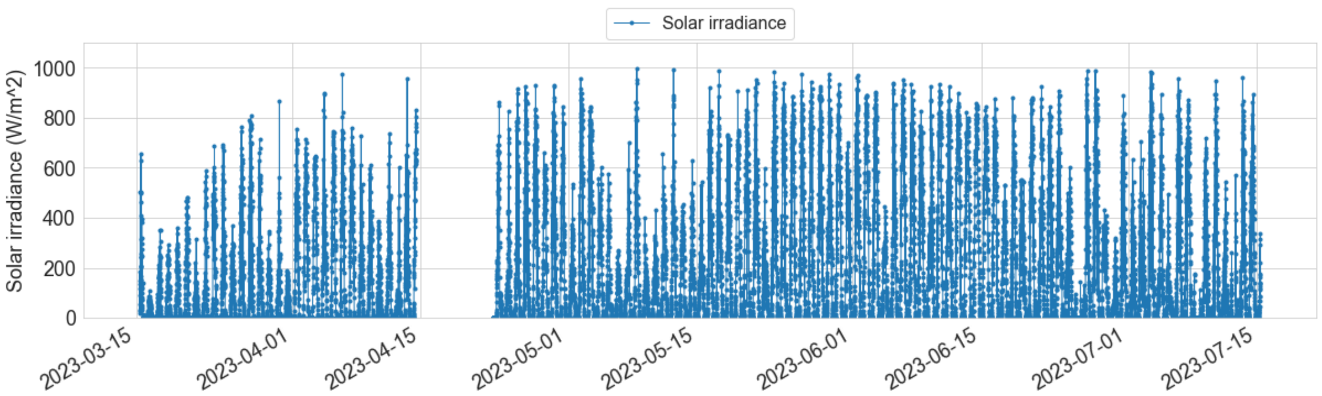


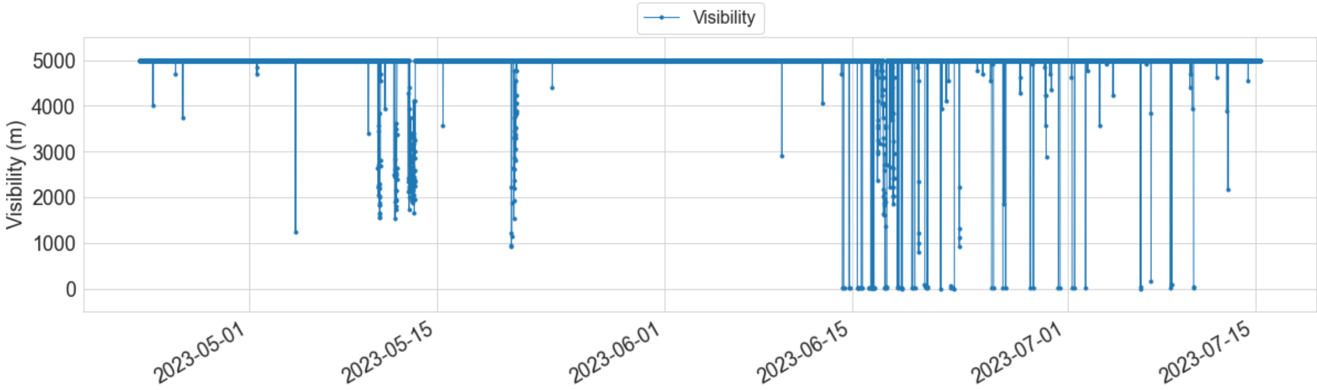
Figure B-32 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from November 2022 until March 2023. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.


Air pressure
Air pressure (hPa)
1040
1020
1000
980
960
2023-03-15
2023-04-01
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01
2023-07-15


Air humidity
Humidity (%)
100
80
60
40
20
0
2023-03-15
2023-04-01
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01
2023-07-15


Air temperature
Air temperature (°C)
20
15
10
5
0
2023-03-15
2023-04-01
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01
2023-07-15


Solar irradiance
Solar irradiance (W/m^2)
1000
800
600
400
200
0
2023-03-15
2023-04-01
2023-04-15
2023-05-01
2023-05-15
2023-06-01
2023-06-15
2023-07-01
2023-07-15



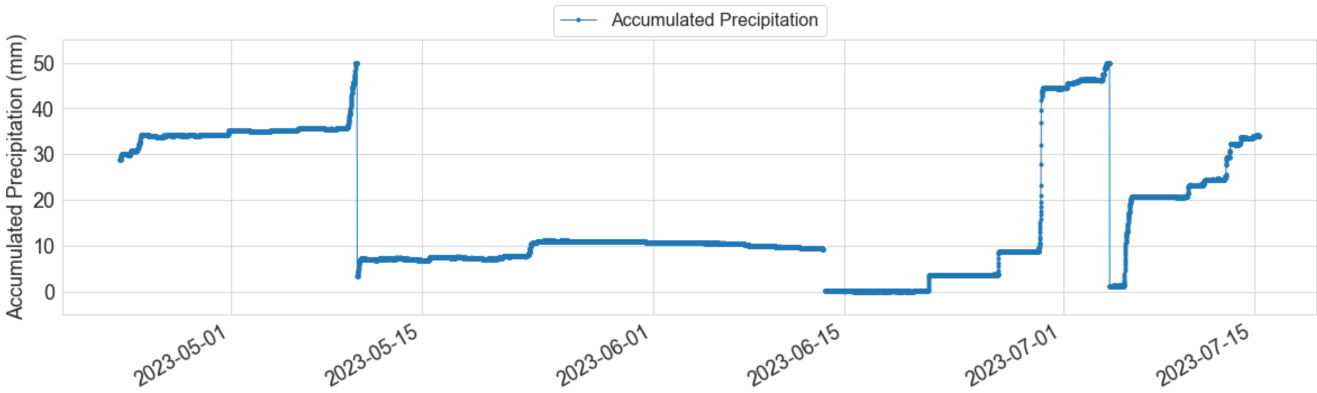
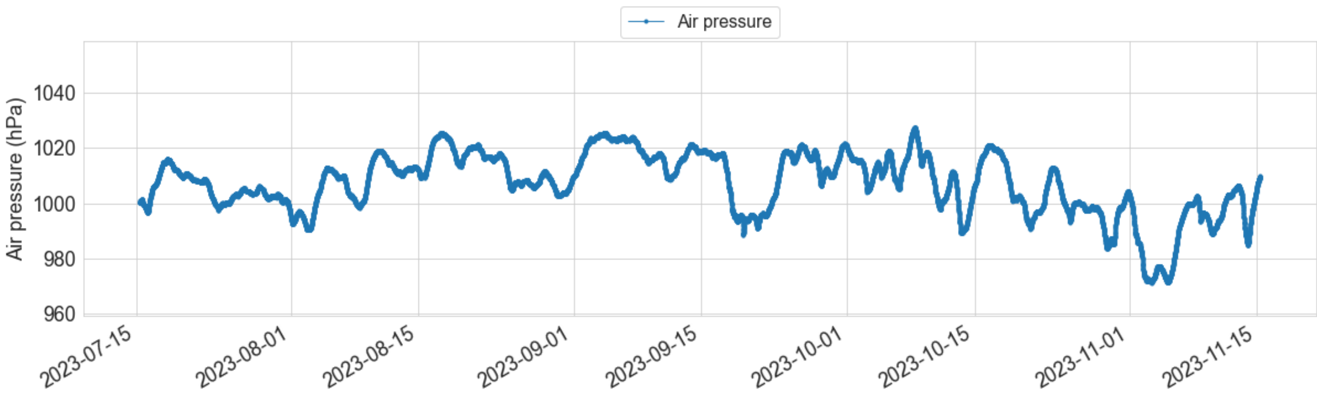
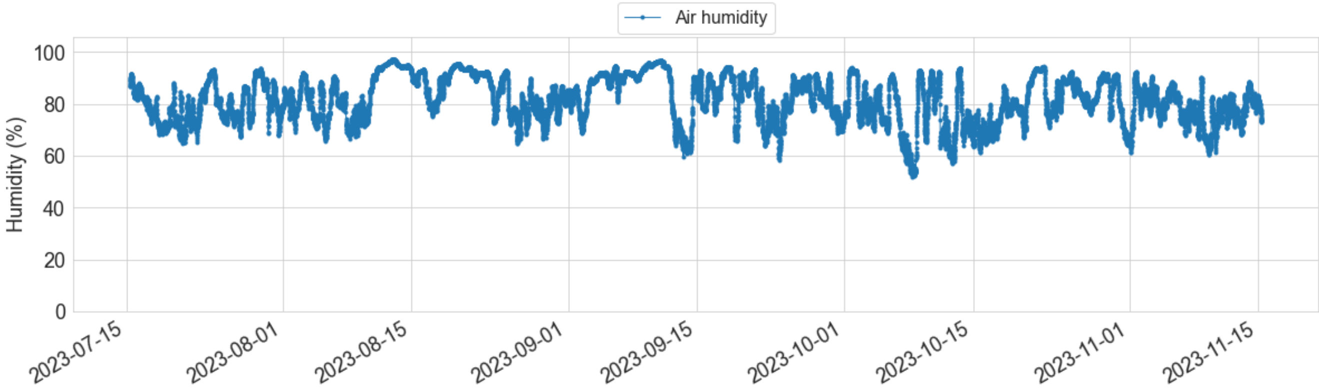
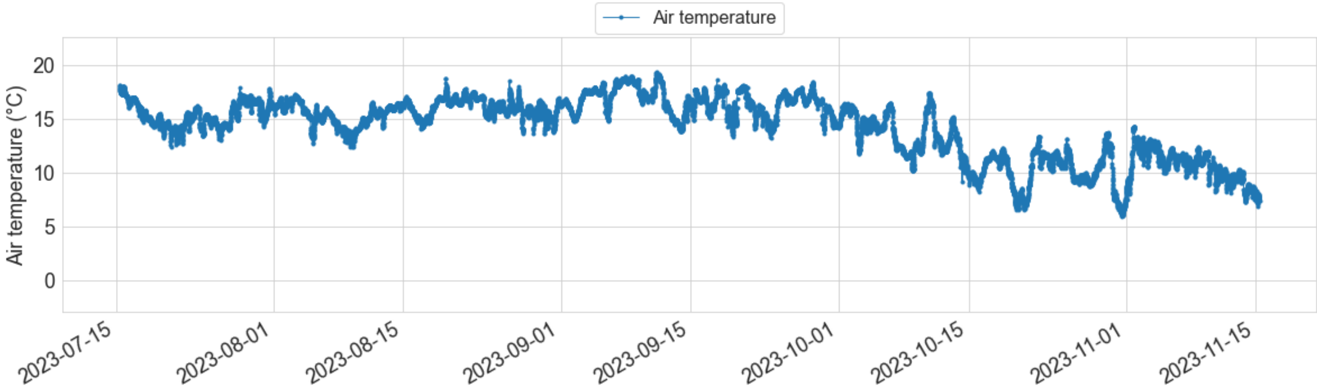
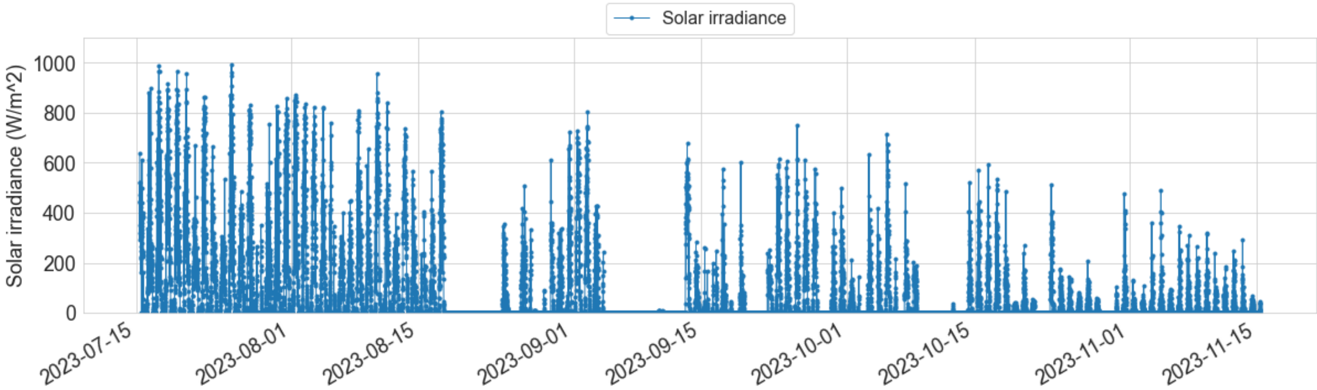


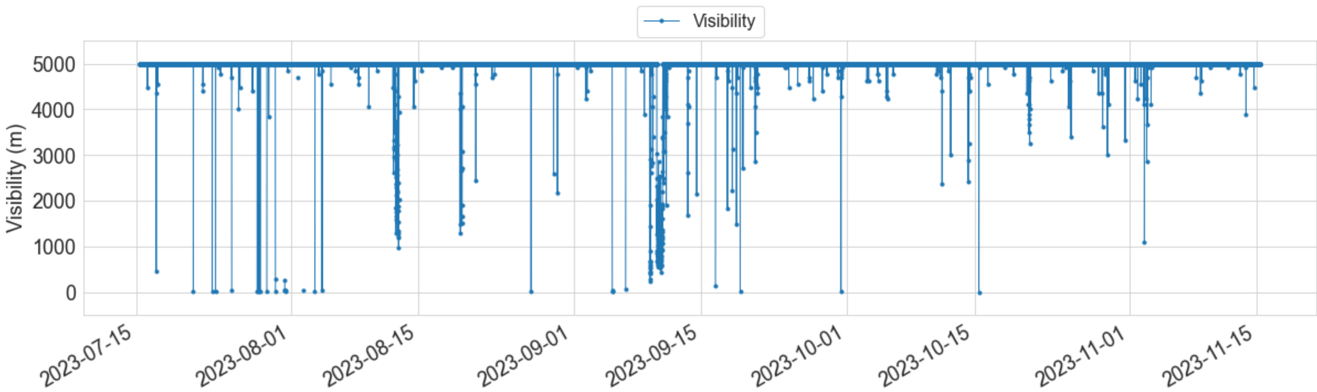
Figure B-33 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from March 2023 until July 2023. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.




Air humidity
Humidity (%)
100
80
60
40
20
0
2023-07-15
2023-08-01
2023-08-15
2023-09-01
2023-09-15
2023-10-01
2023-10-15
2023-11-01
2023-11-15


Air temperature
Air temperature (°C)
20
15
10
5
0
2023-07-15
2023-08-01
2023-08-15
2023-09-01
2023-09-15
2023-10-01
2023-10-15
2023-11-01
2023-11-15


Solar irradiance
Solar irradiance (W/m^2)
1000
800
600
400
200
0
2023-07-15
2023-08-01
2023-08-15
2023-09-01
2023-09-15
2023-10-01
2023-10-15
2023-11-01
2023-11-15


Visibility
Visibility (m)
5000
4000
3000
2000
1000
0
2023-07-15
2023-08-01
2023-08-15
2023-09-01
2023-09-15
2023-10-01
2023-10-15
2023-11-01
2023-11-15

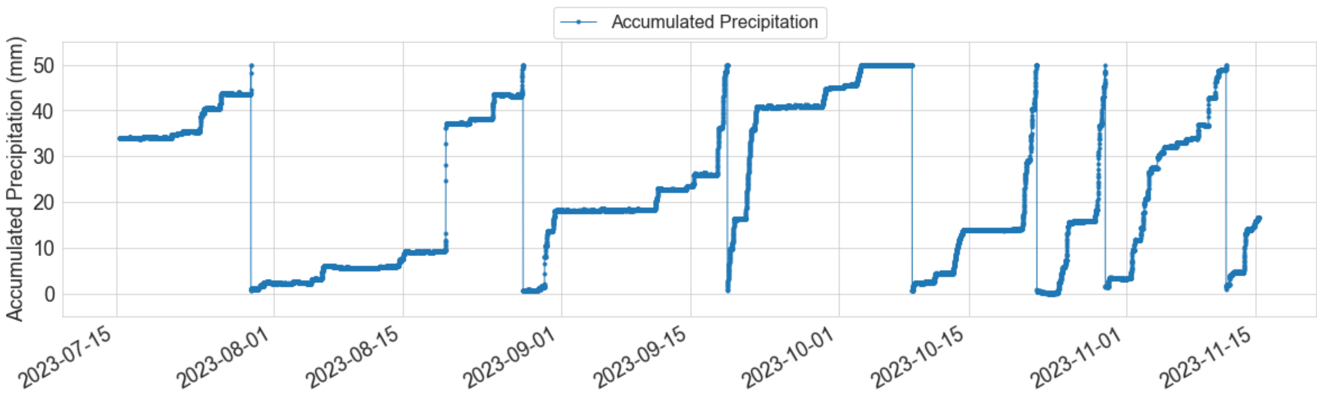
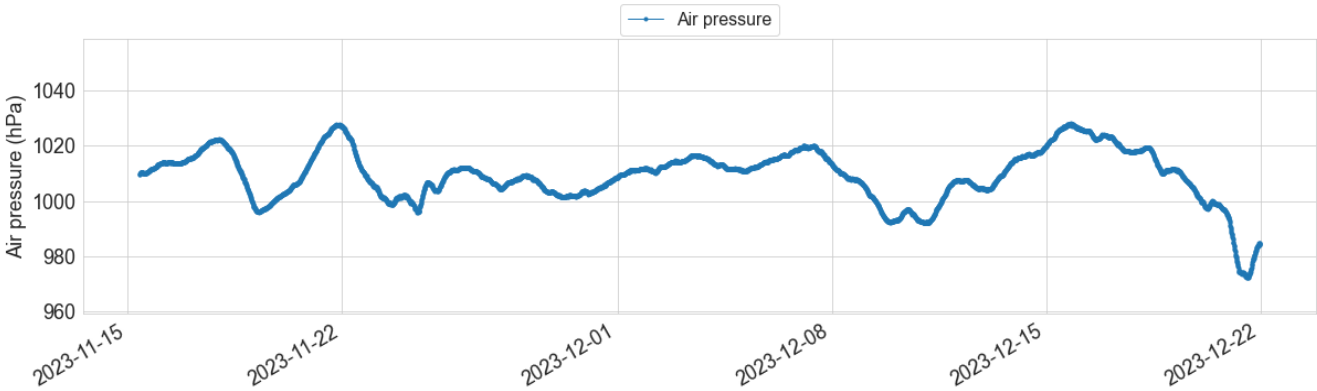
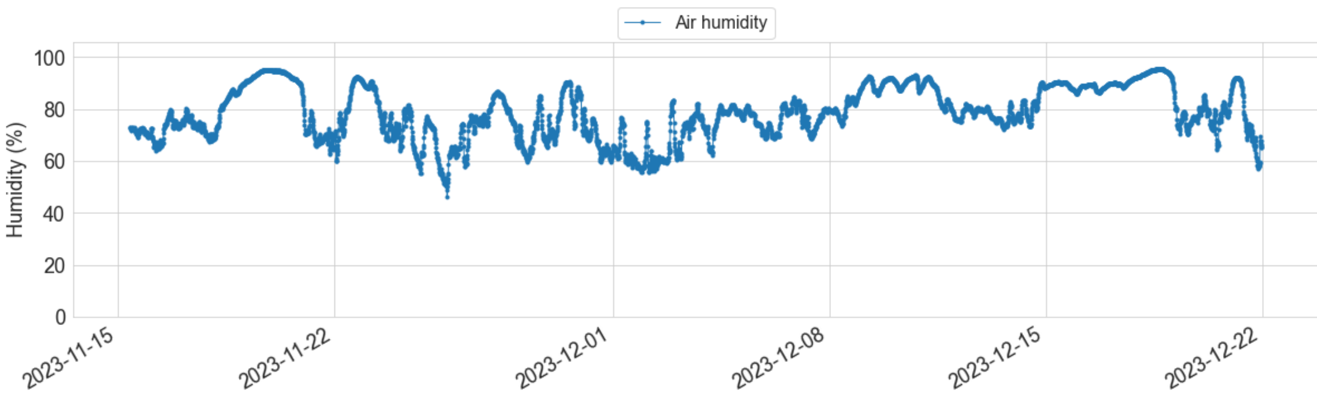
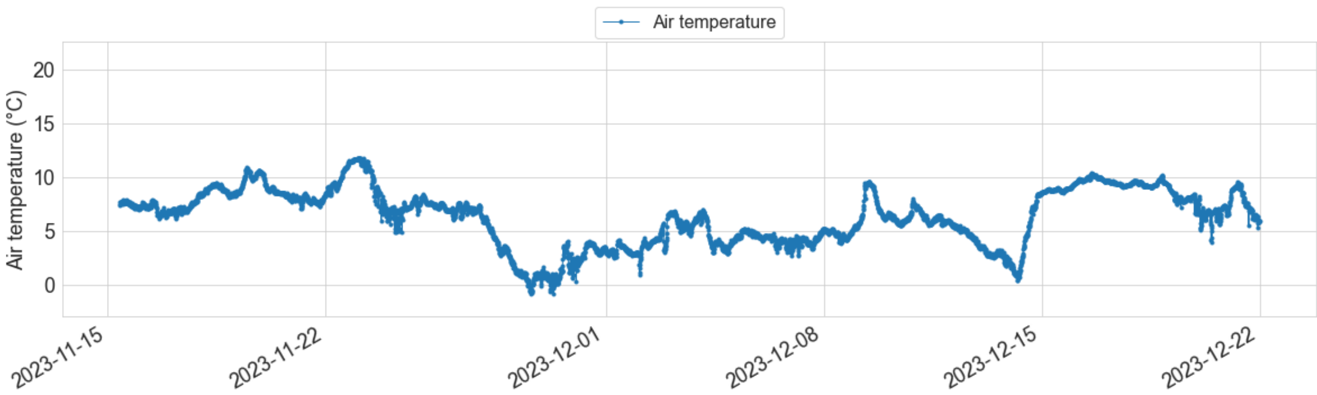
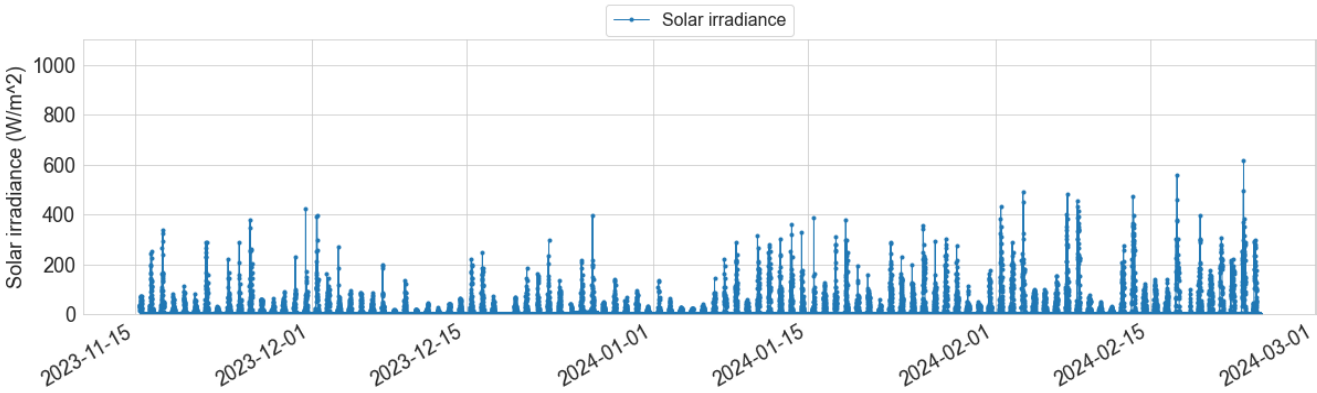


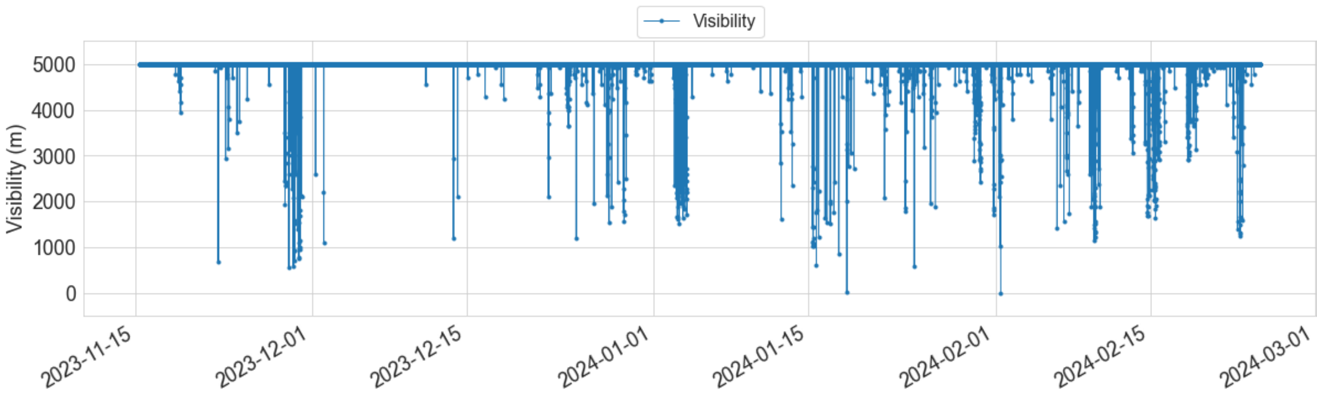
Figure B-34 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from July 2023 until November 2023. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.






Air temperature
Air temperature (°C)
20
15
10
5
0
2023-11-15
2023-11-22
2023-12-01
2023-12-08
2023-12-15
2023-12-22


Solar irradiance
Solar irradiance (W/m^2)
1000
800
600
400
200
0
2023-11-15
2023-12-01
2023-12-15
2024-01-01
2024-01-15
2024-02-01
2024-02-15
2024-03-01


Visibility
Visibility (m)
5000
4000
3000
2000
1000
0
2023-11-15
2023-12-01
2023-12-15
2024-01-01
2024-01-15
2024-02-01
2024-02-15
2024-03-01

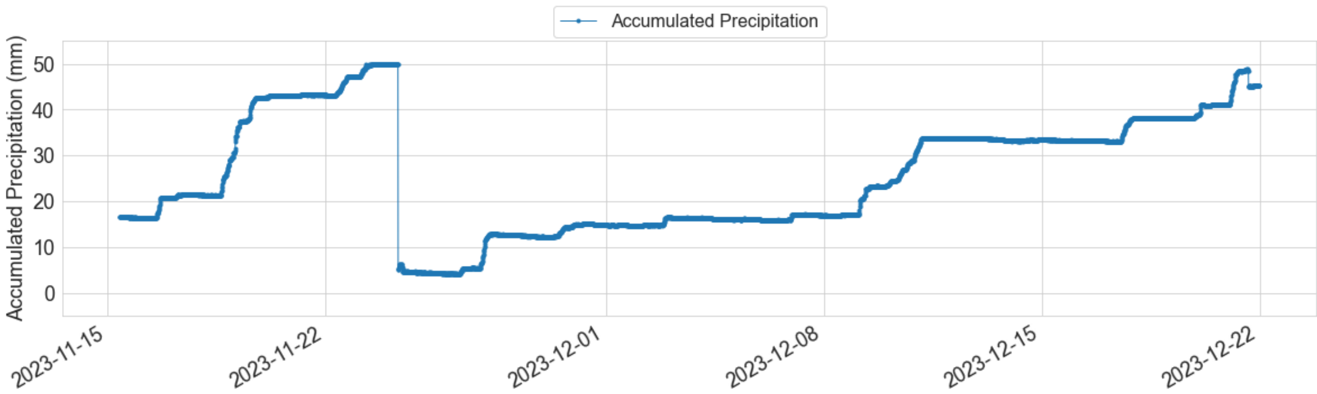
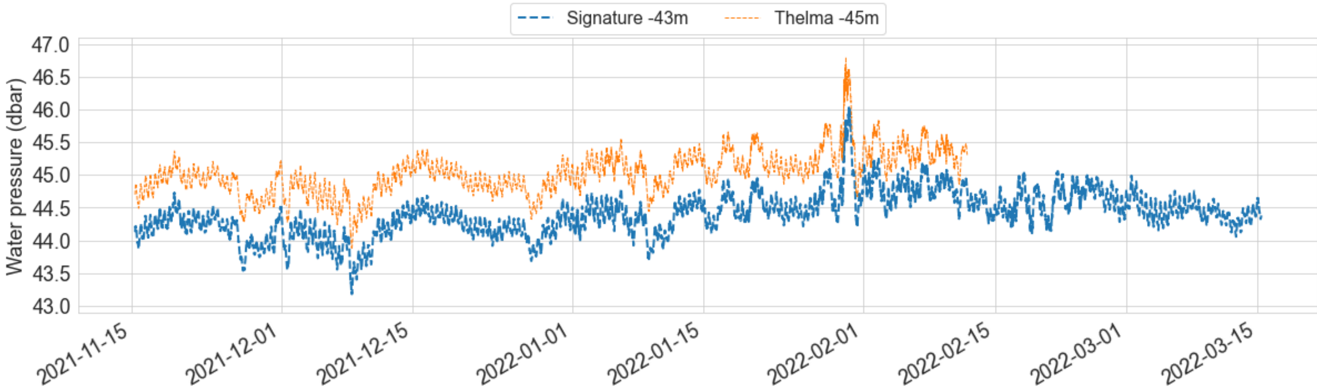
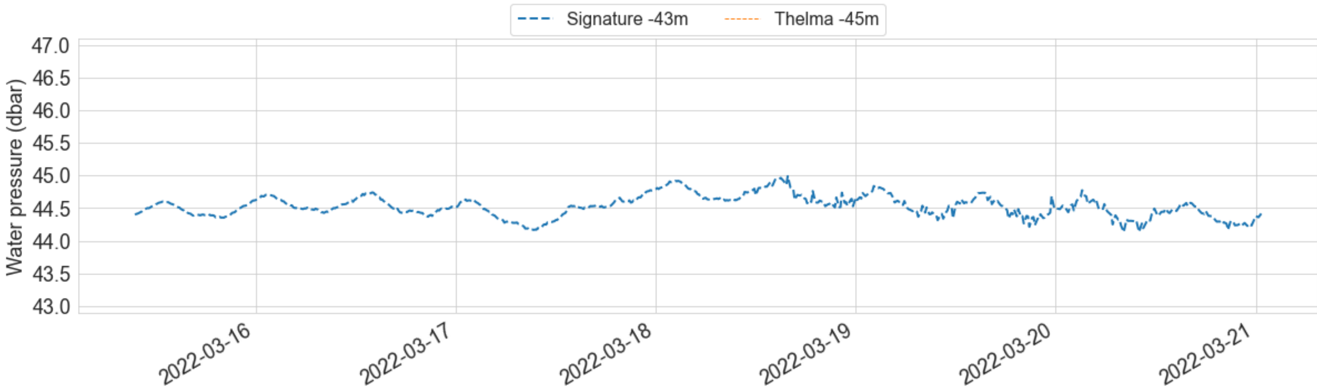
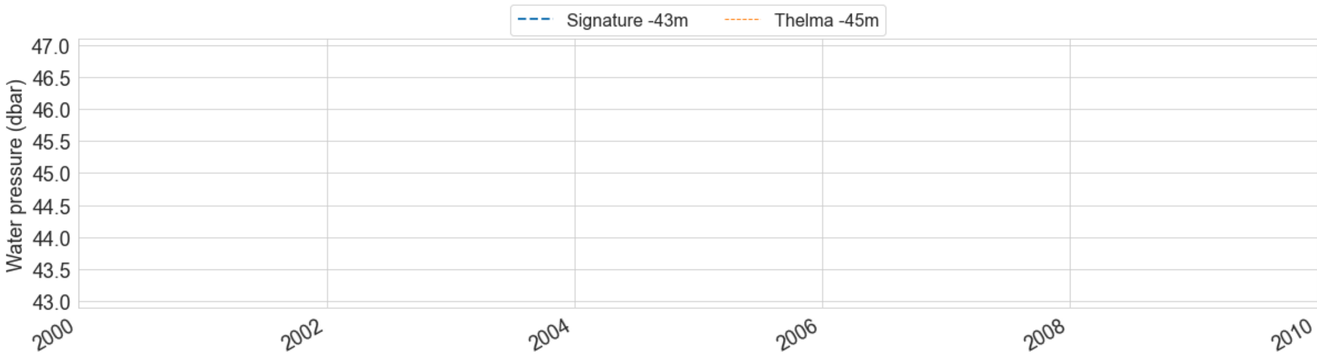

Accumulated Precipitation
Accumulated Precipitation (mm)
50
40
30
20
10
0
2023-11-15
2023-11-22
2023-12-01
2023-12-08
2023-12-15
2023-12-22

Figure B-35 Timeseries of air pressure, air humidity, air temperature, solar irradiance, visibility, and precipitation from November 2023 until February 2024. Please note that for precipitation, a jump from 50 mm to lower fill levels indicates emptying of the column when the maximum fill level is reached.







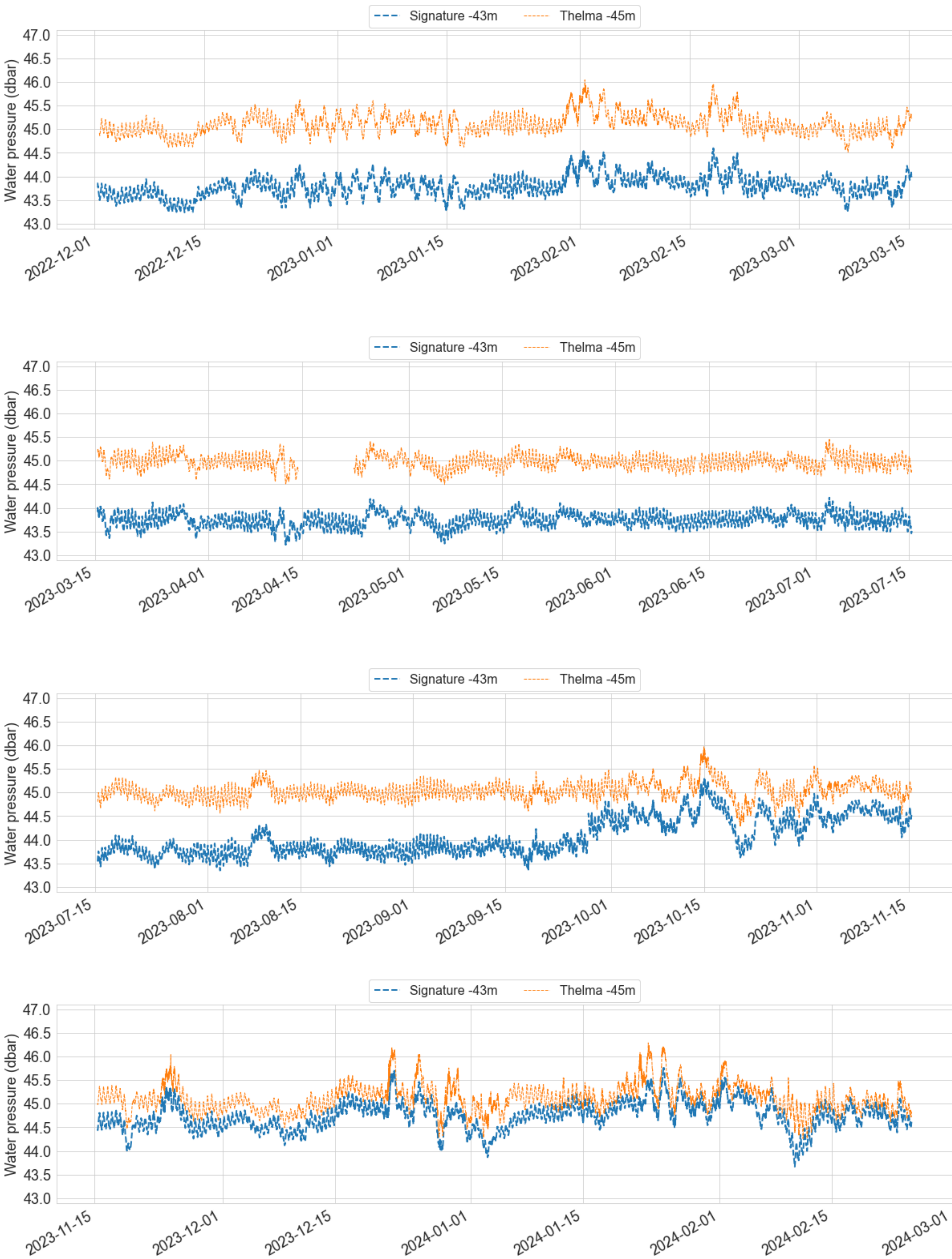


Figure B-36 Timeseries of water pressure in 6-monthly intervals

B.4 Current data (top-down)

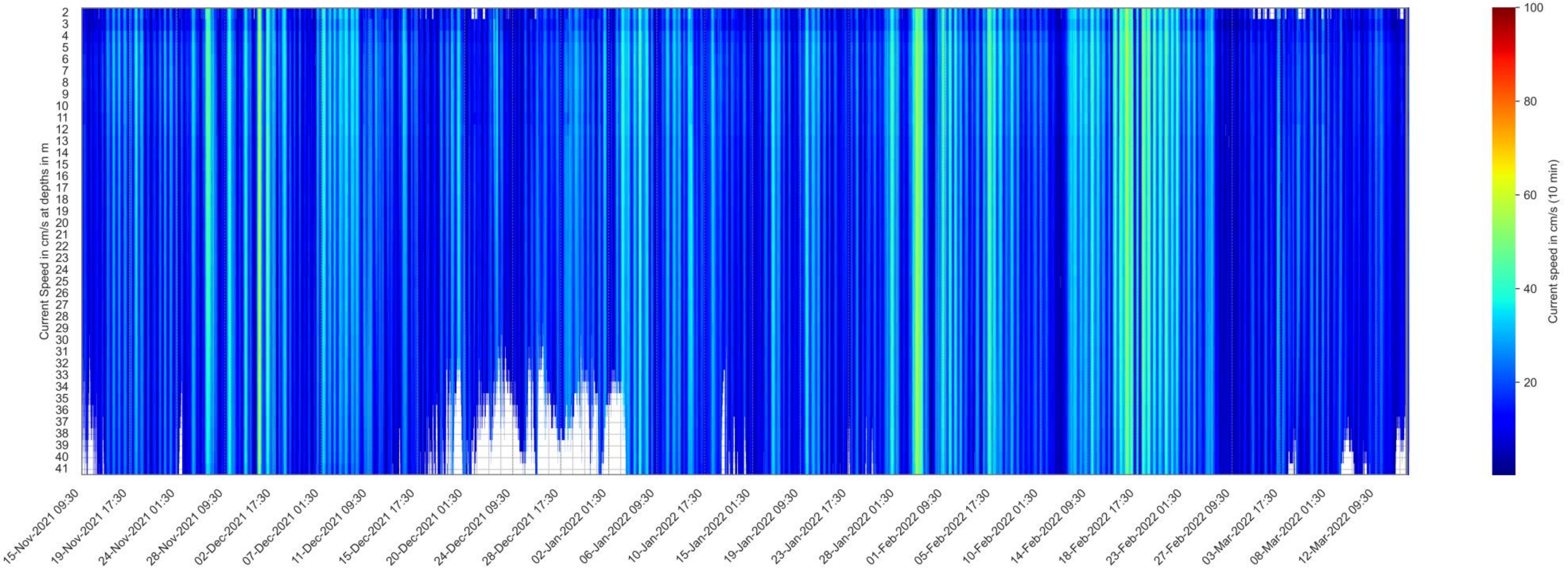


Figure B-37 Heatmap of SWLB (Aquadopp)-measured top-down current speed from November 2021 until March 2022.

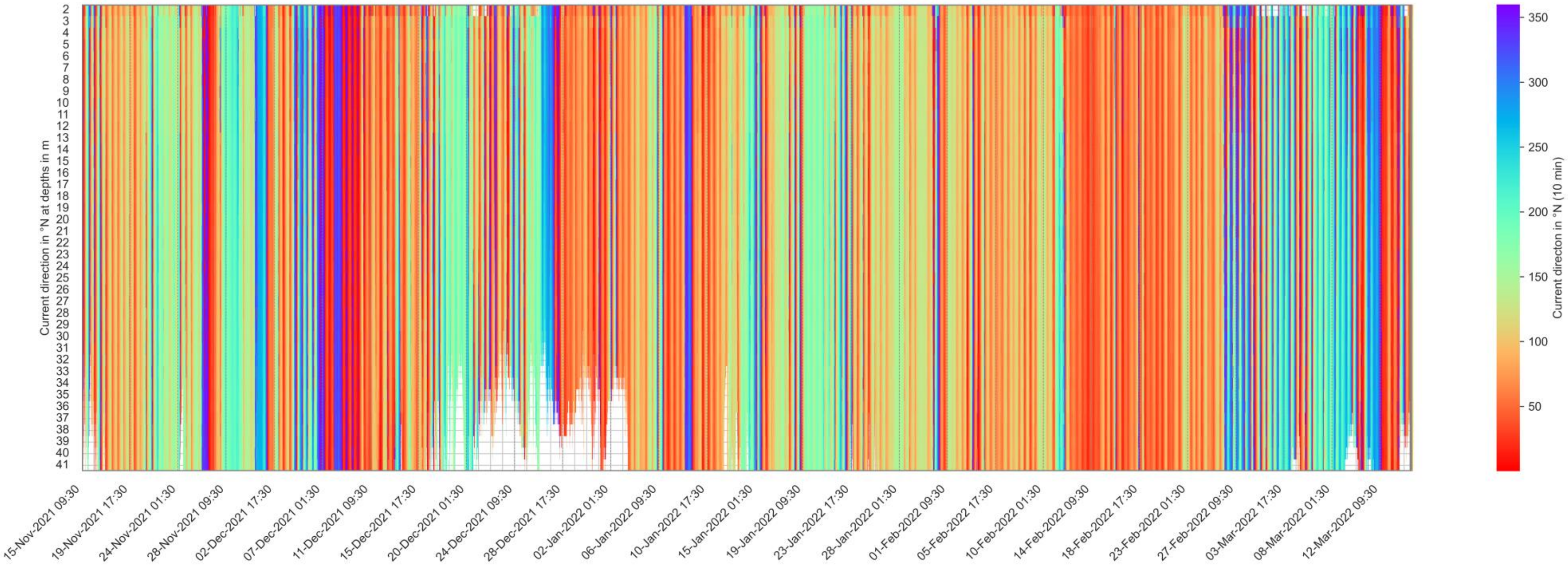


Figure B-38 Heatmap of SWLB (Aquadopp)-measured top-down current direction from November 2021 until March 2022.

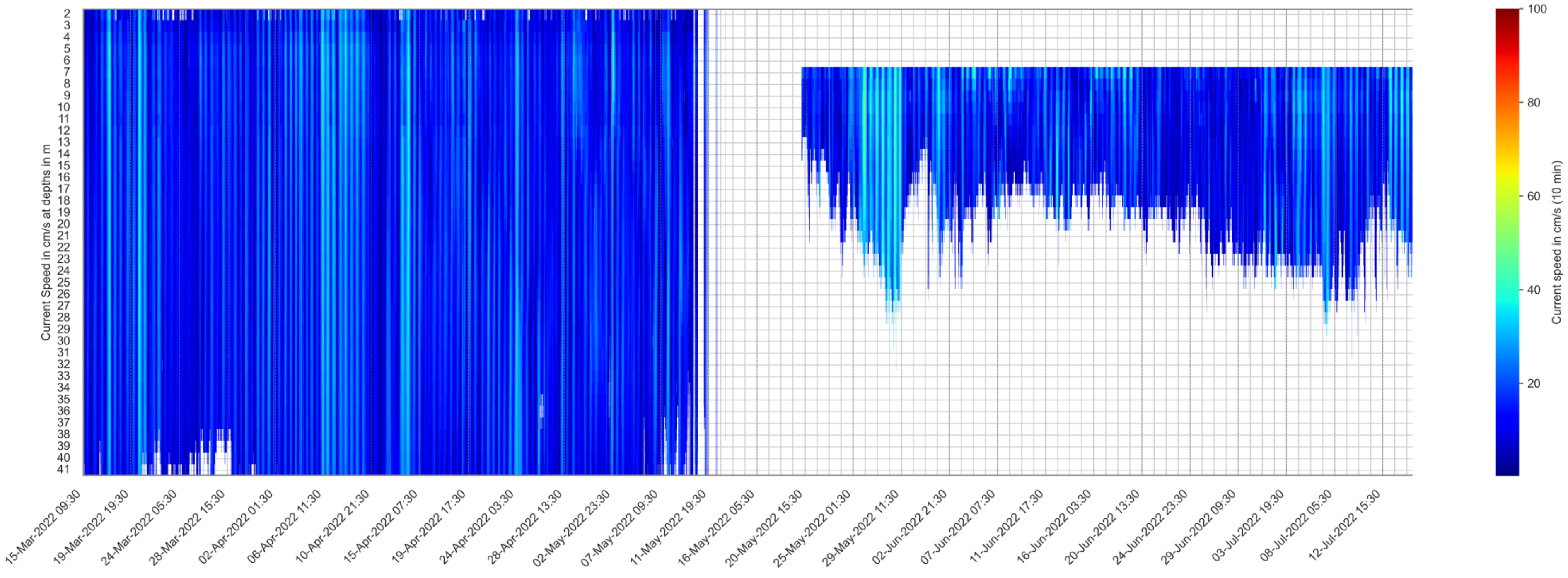


Figure B-39 Heatmap of SWLB (Aquadopp)-measured top-down current speed from March 2022 until July 2022.

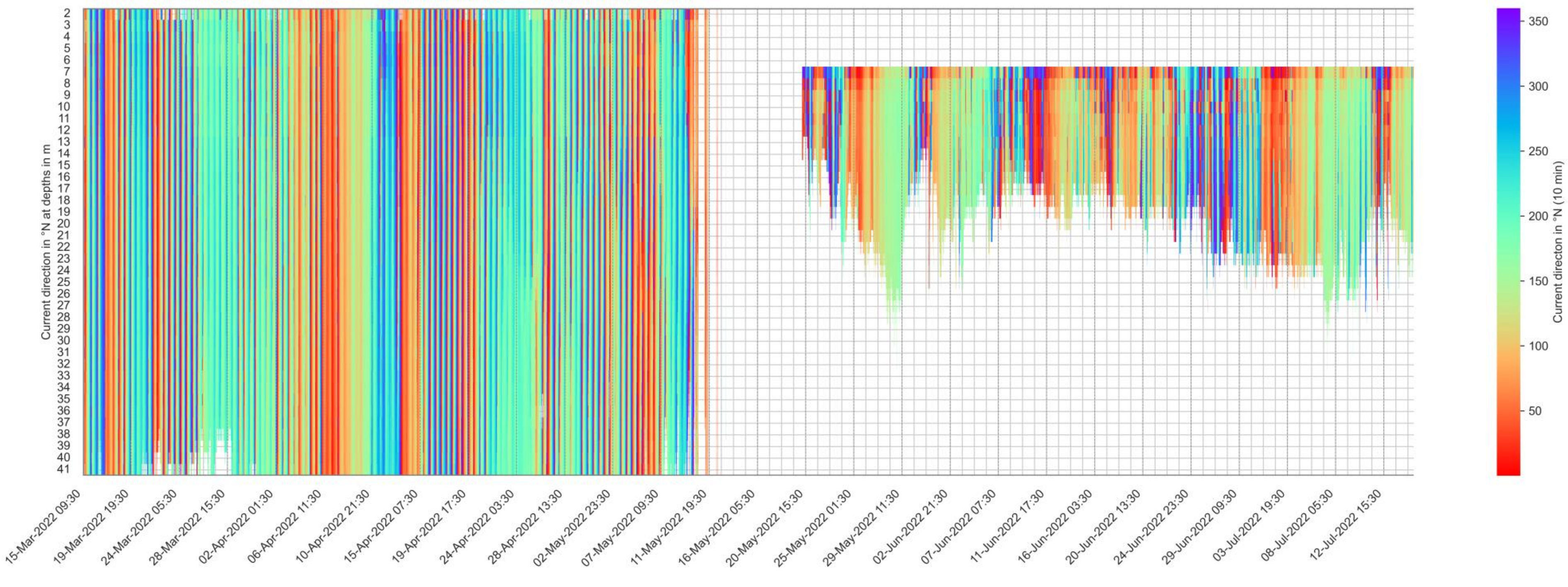


Figure B-40 Heatmap of SWLB (Aquadopp)-measured top-down current direction from March 2022 until July 2022.

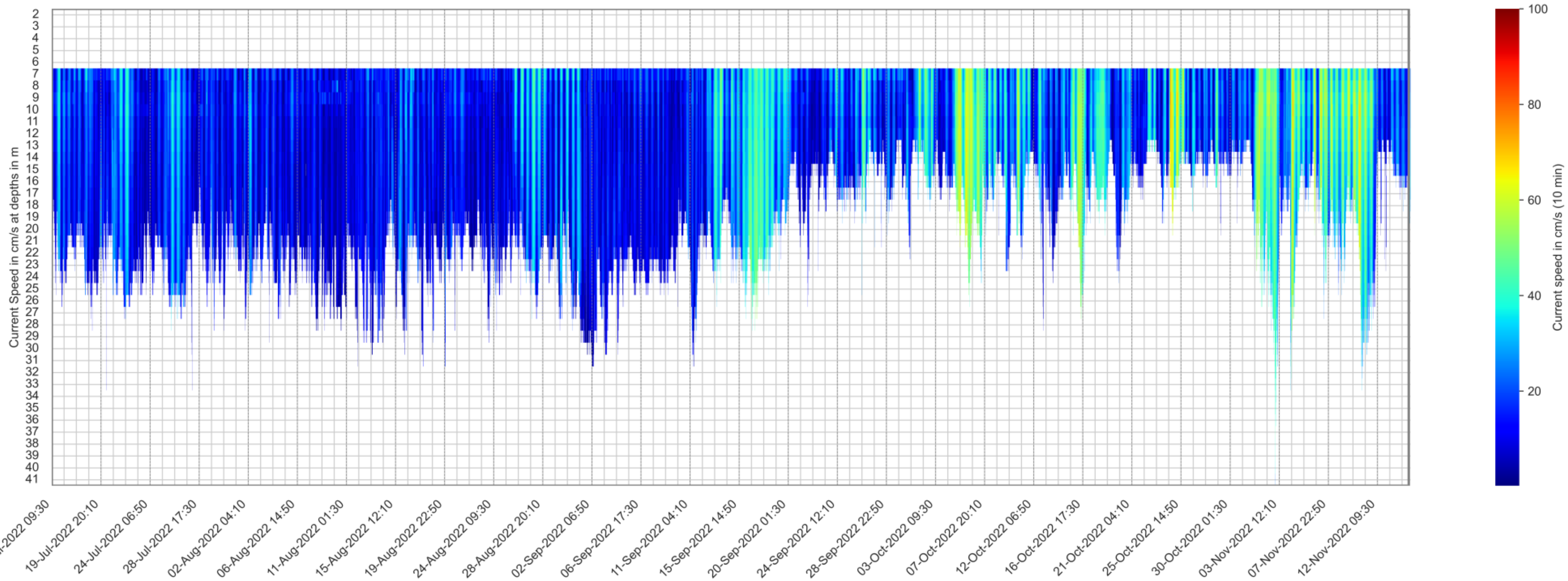


Figure B-41 Heatmap of SWLB (Aquadopp)-measured top-down current speed from July 2022 until November 2022.

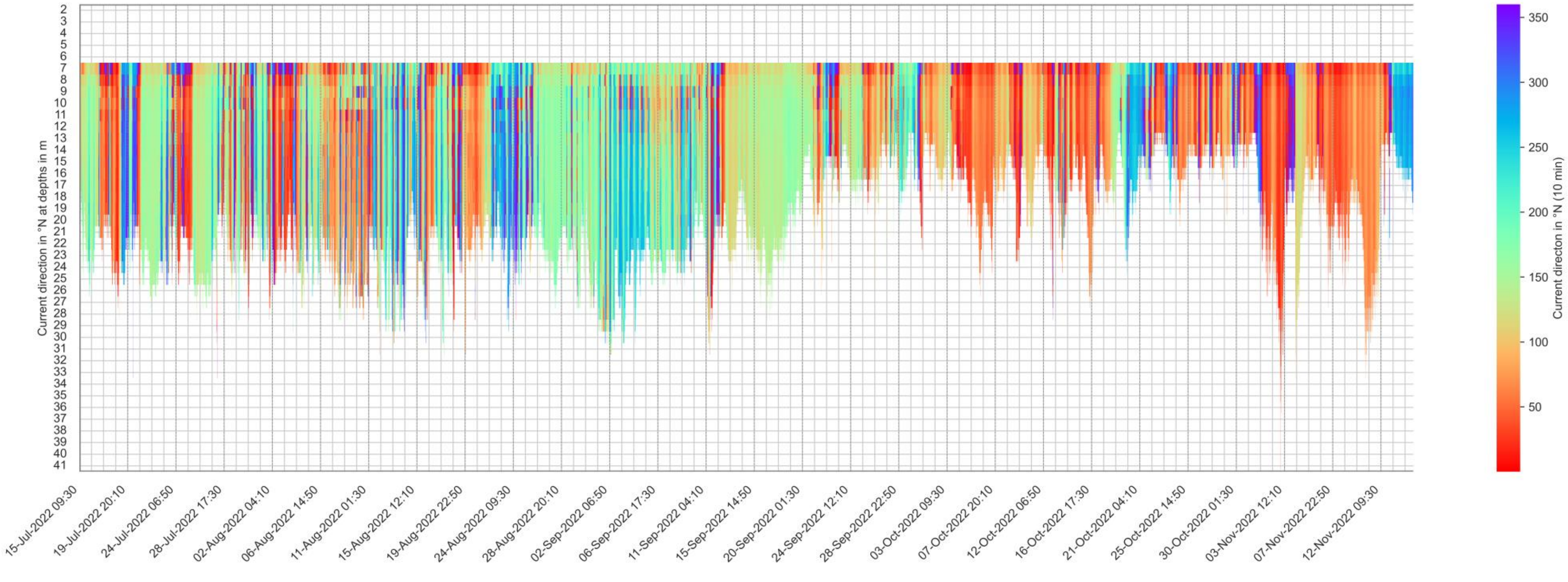


Figure B-42 Heatmap of SWLB (Aquadopp)-measured top-down current direction from July 2022 until November 2022.

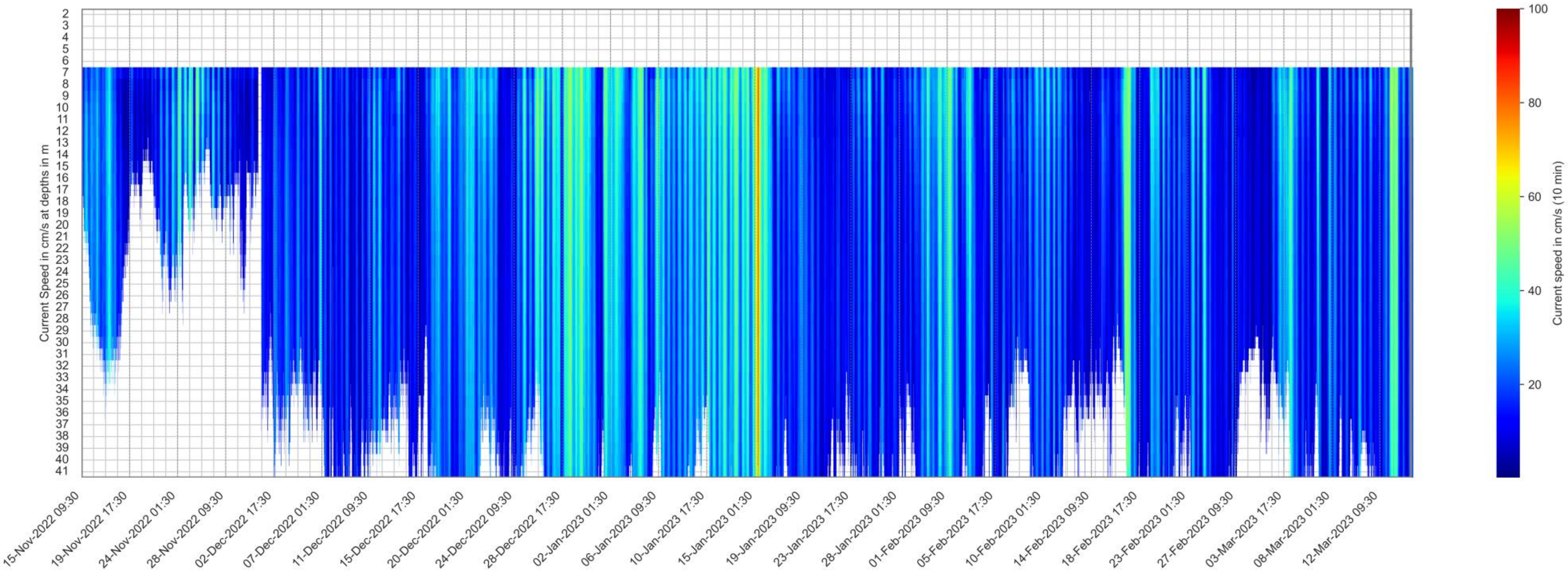


Figure B-43 Heatmap of SWLB (Aquadopp)-measured top-down current speed from November 2022 until March 2023.

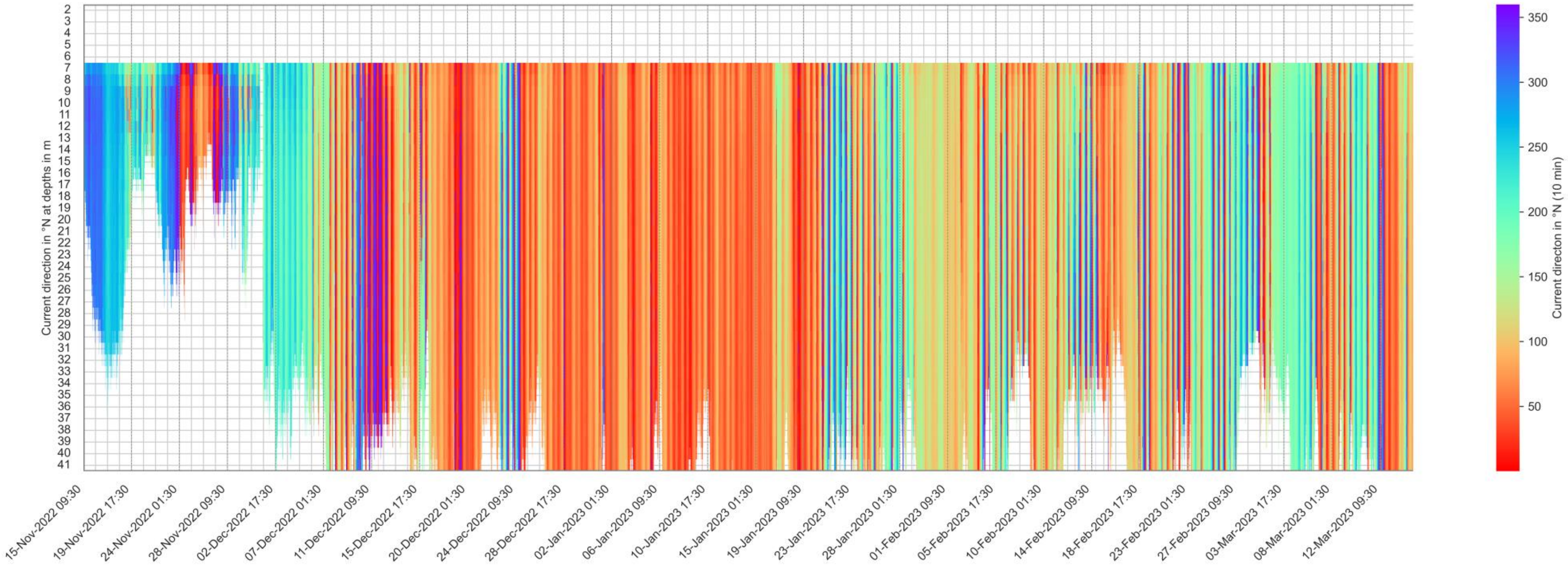


Figure B-44 Heatmap of SWLB (Aquadopp)-measured top-down current direction from November 2022 until March 2023.

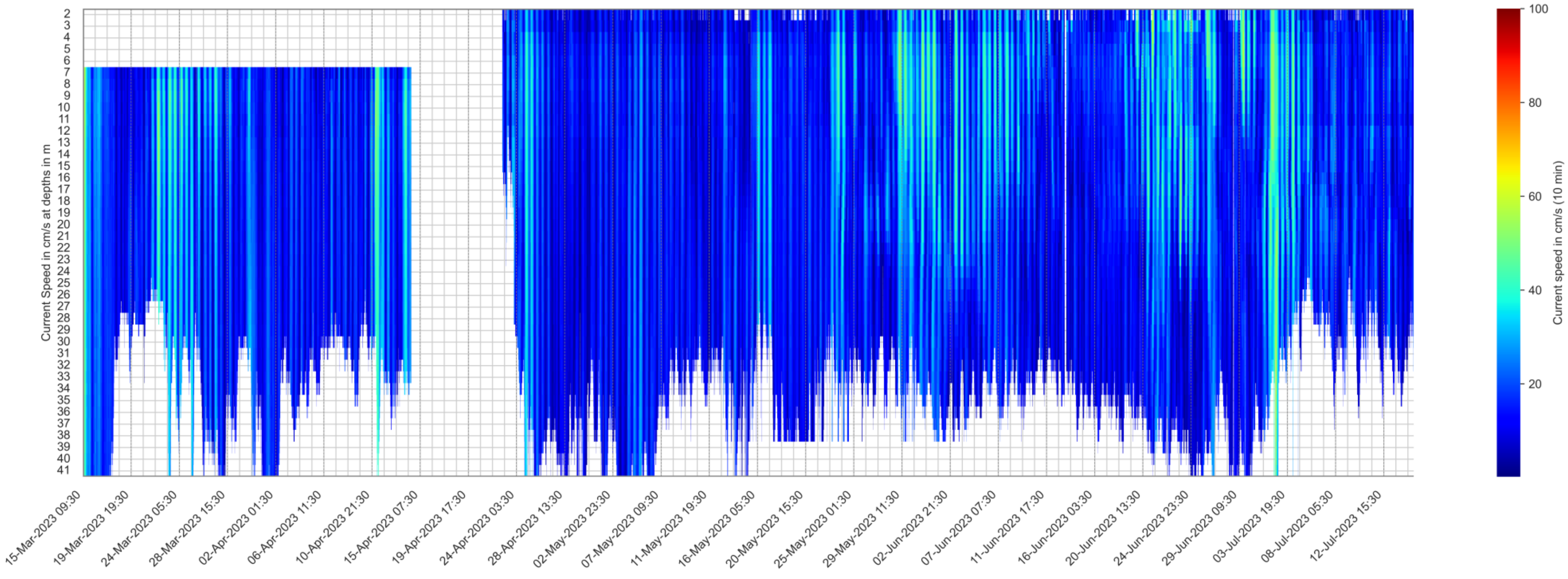


Figure B-45 Heatmap of SWLB (Aquadopp)-measured top-down current speed from March 2023 until July 2023.

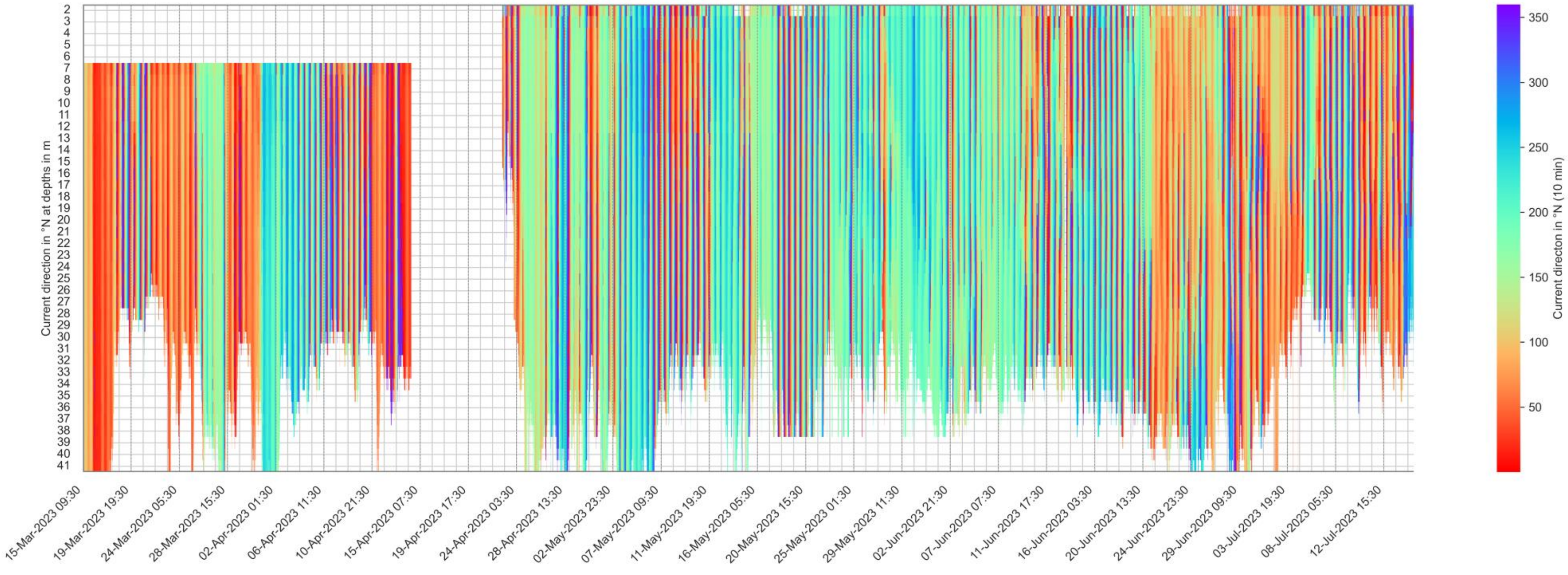


Figure B-46 Heatmap of SWLB (Aquadopp)-measured top-down current direction from March 2023 until July 2023.

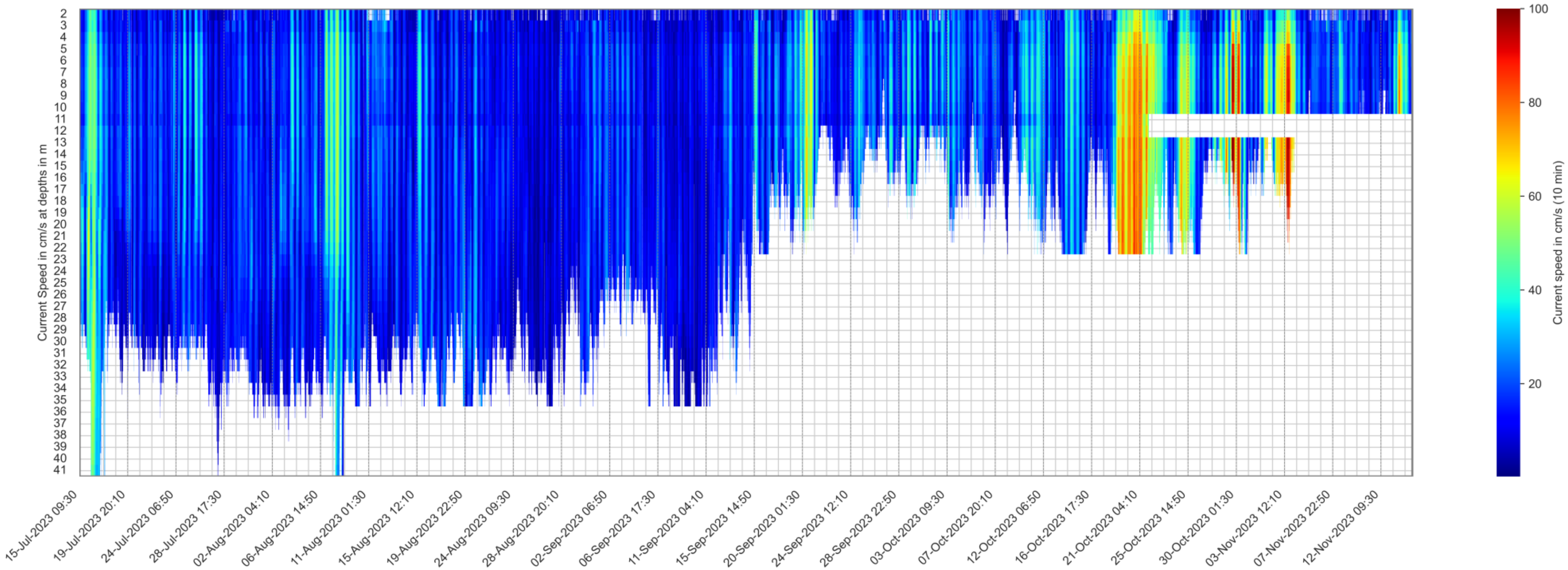


Figure B-47 Heatmap of SWLB (Aquadopp)-measured top-down current speed from July 2023 until November 2023.

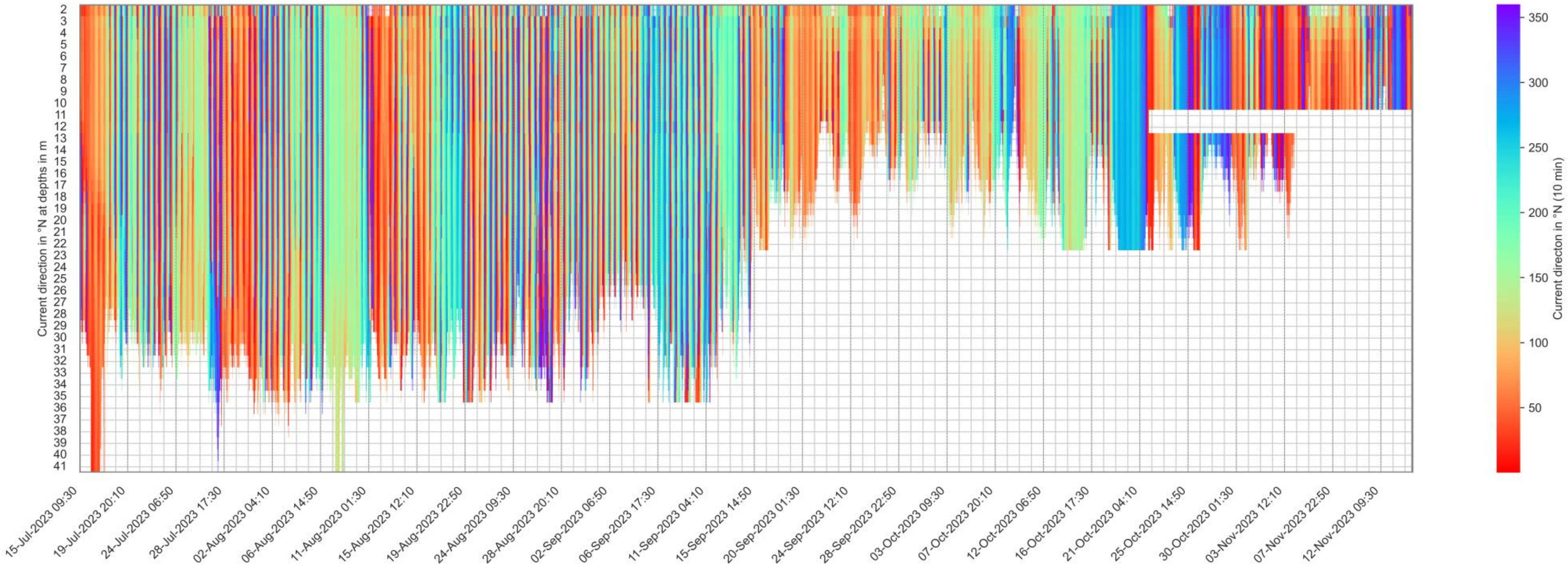


Figure B-48 Heatmap of SWLB (Aquadopp)-measured top-down current direction from July 2023 until November 2023.

B.5 Current data (upward)

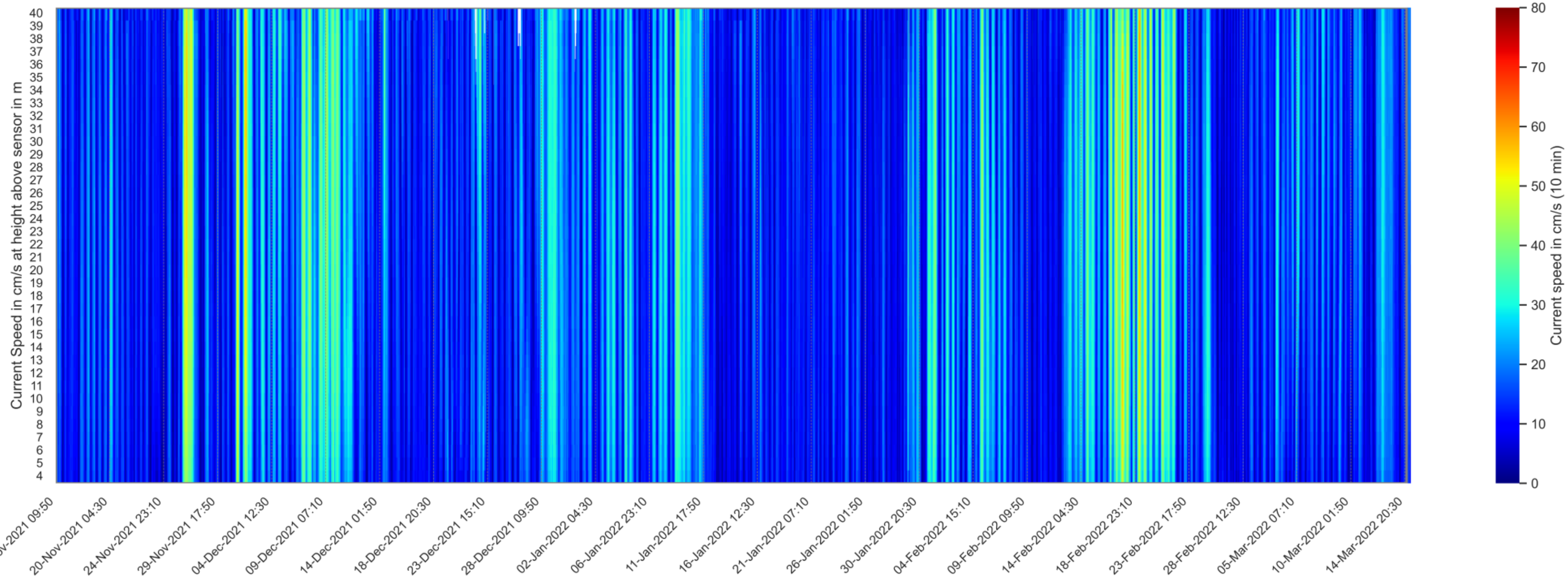


Figure B-49 Heatmap of offline (Signature)-measured bottom-up current speed from November 2021 until March 2022.

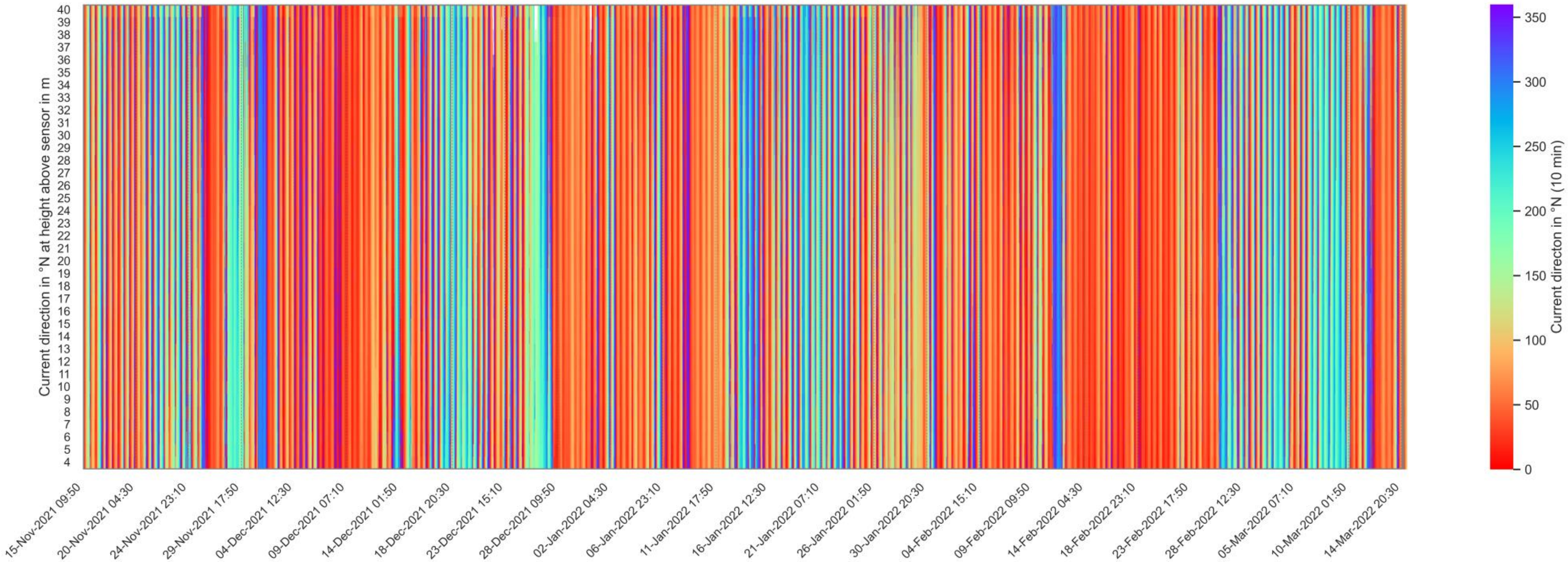


Figure B-50 Heatmap of offline (Signature)-measured bottom-up current direction from November 2021 until March 2022.

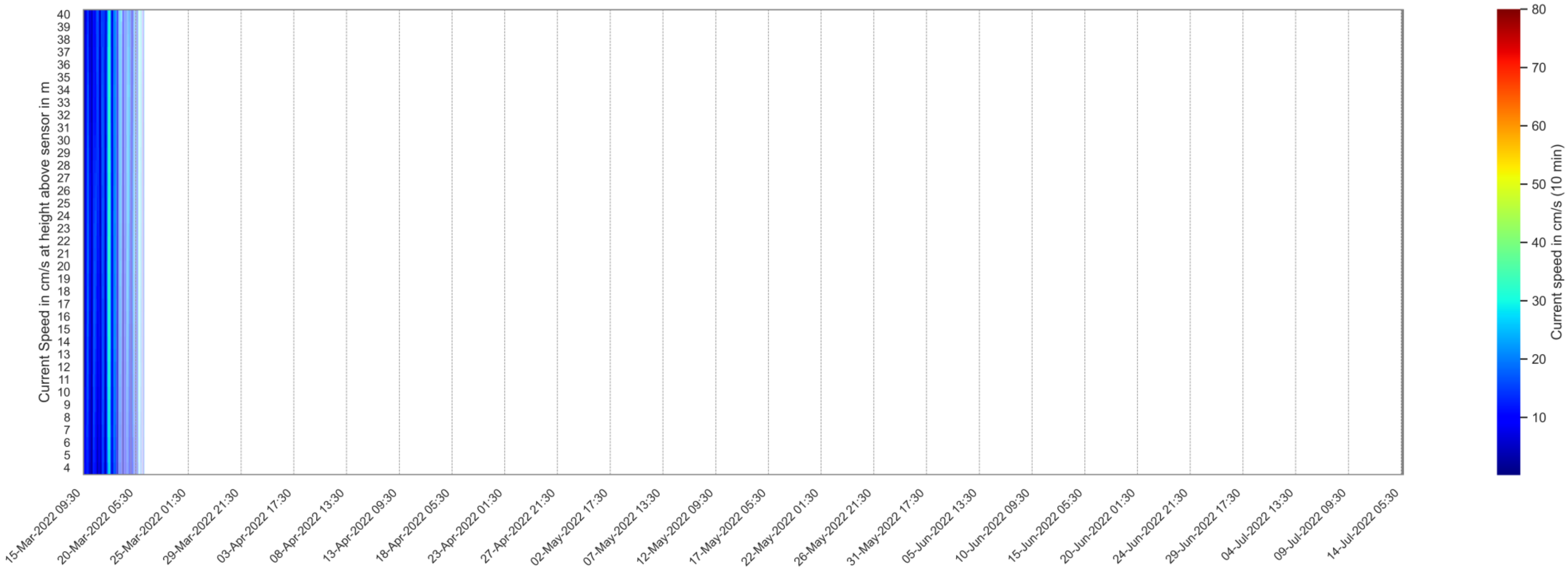


Figure B-51 Heatmap of offline (Signature)-measured bottom-up current speed from March 2022 until June 2022.

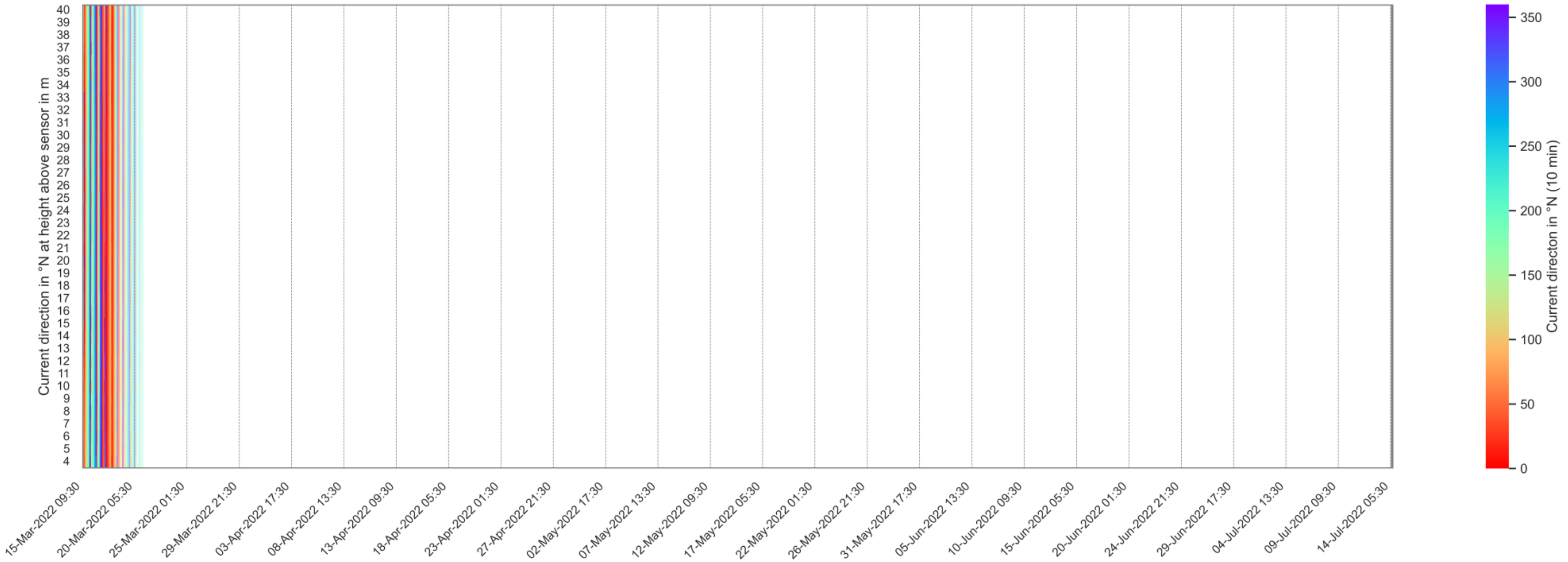


Figure B-52 Heatmap of offline (Signature)-measured bottom-up current direction from March 2022 until June 2022.

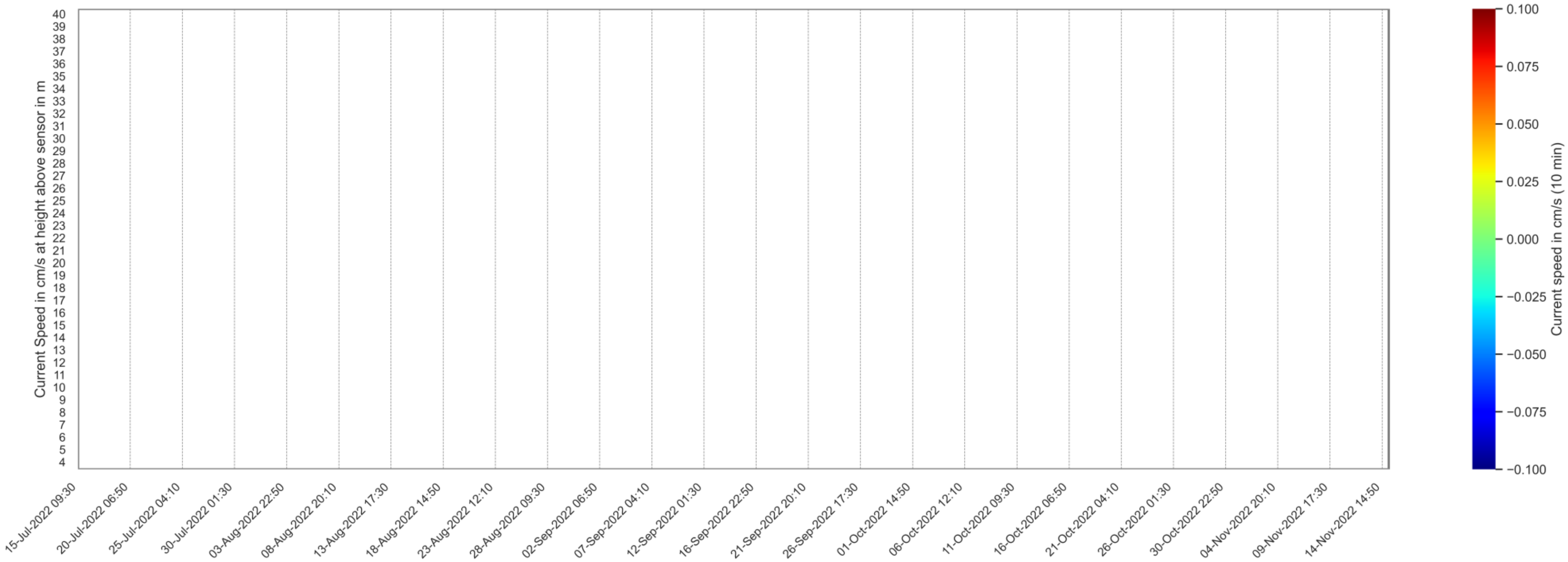


Figure B-53 Heatmap of offline (Signature)-measured bottom-up current speed from June 2022 until December 2022.

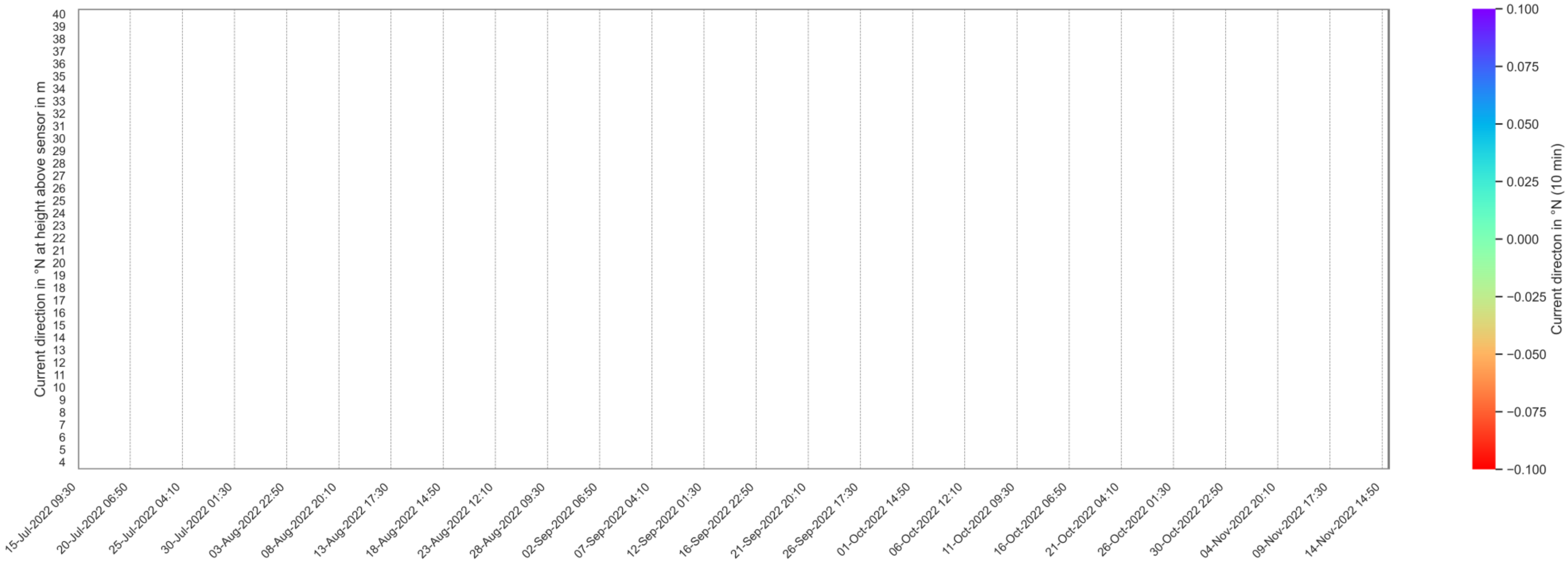


Figure B-54 Heatmap of offline (Signature)-measured bottom-up current direction from June 2022 until December 2022.

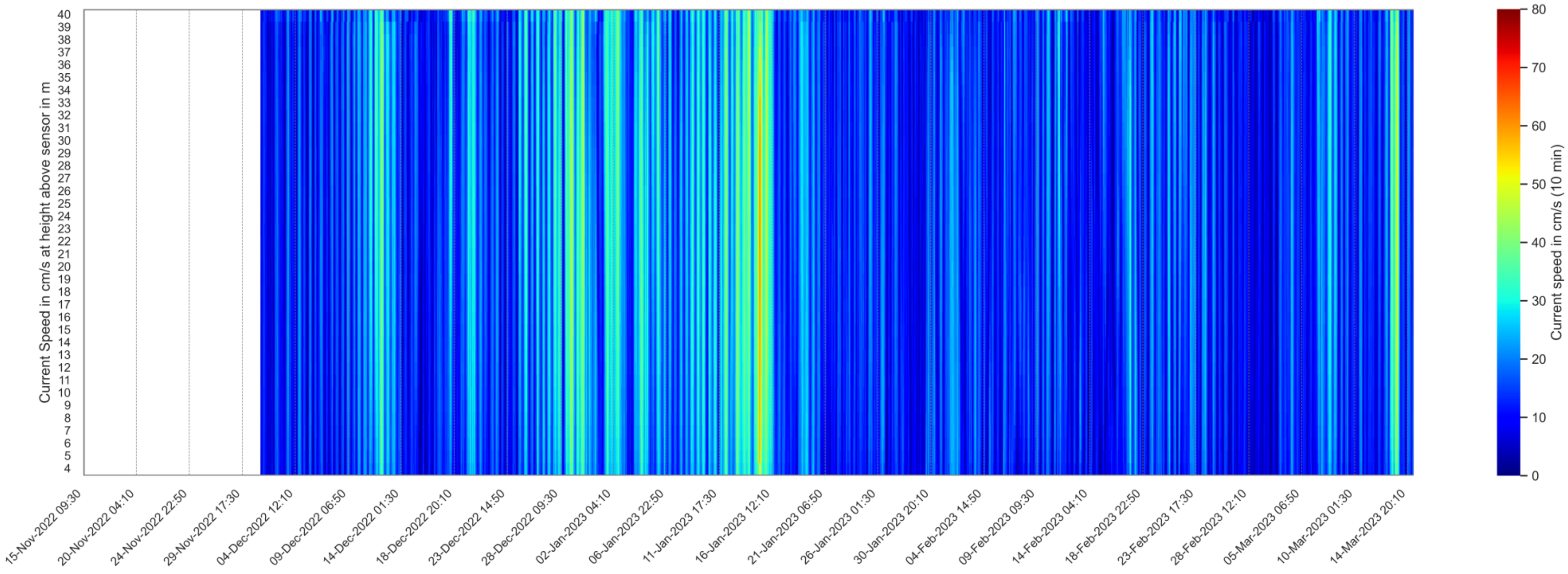


Figure B-55 Heatmap of offline (Signature)-measured bottom-up current speed from December 2022 until March 2023.

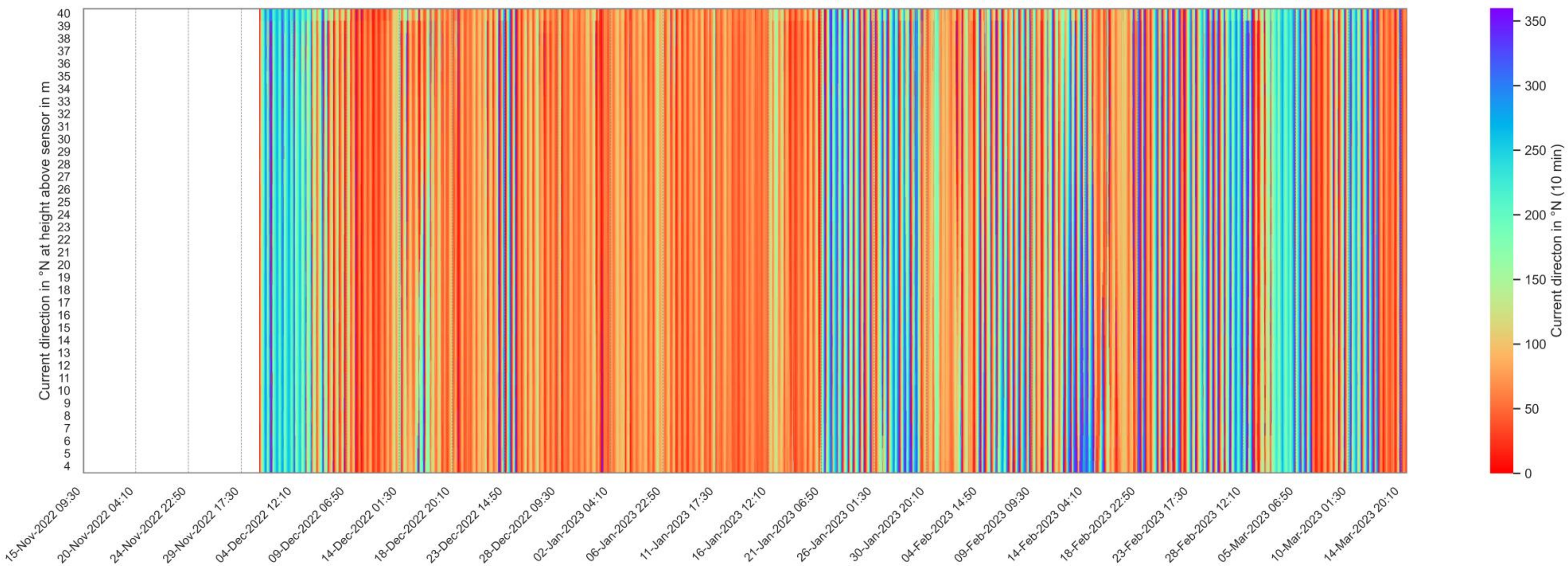


Figure B-56 Heatmap of offline (Signature)-measured bottom-up current direction from December 2022 until March 2023.

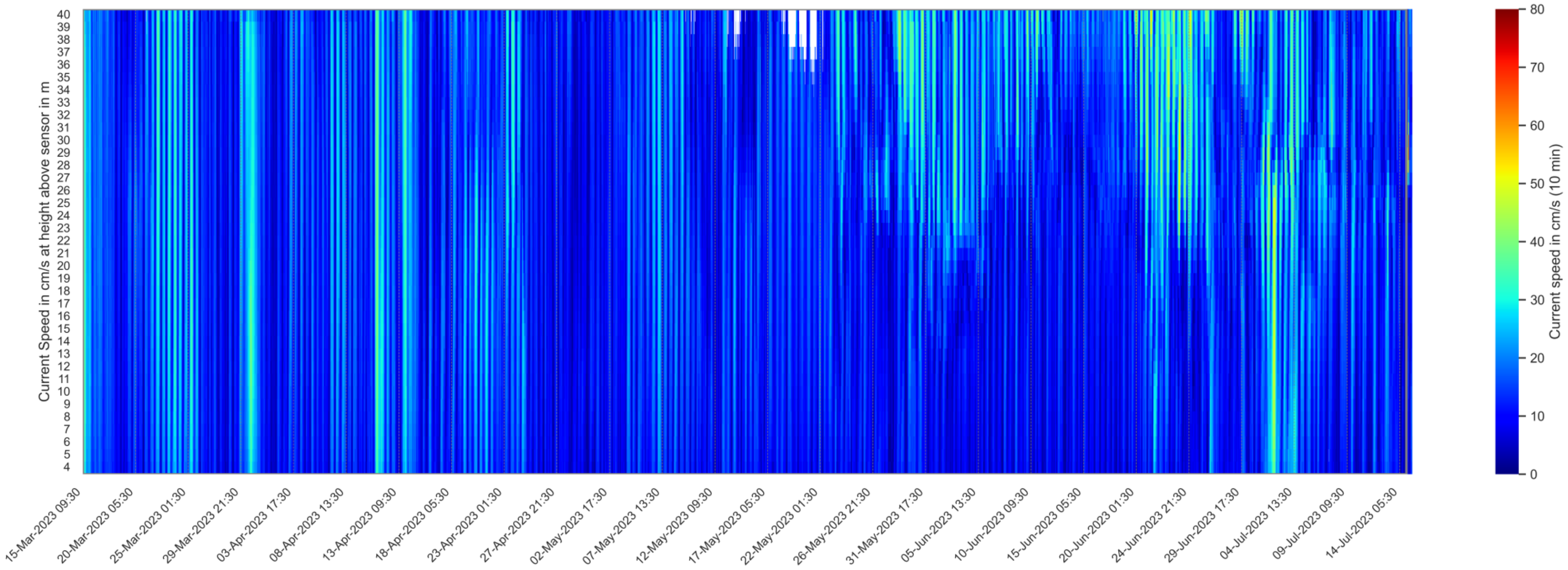


Figure B-57 Heatmap of offline (Signature)-measured bottom-up current speed from March 2023 until July 2023.

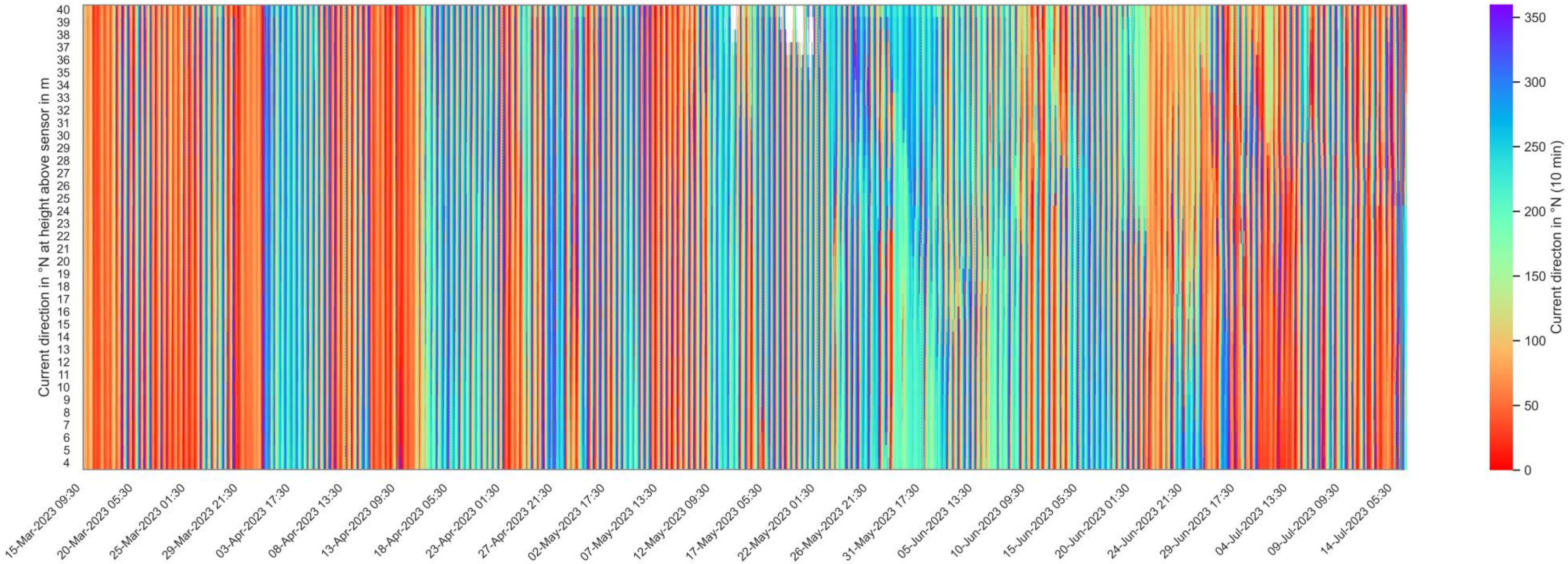


Figure B-58 Heatmap of offline (Signature)-measured bottom-up current direction from March 20223 until July 2023.

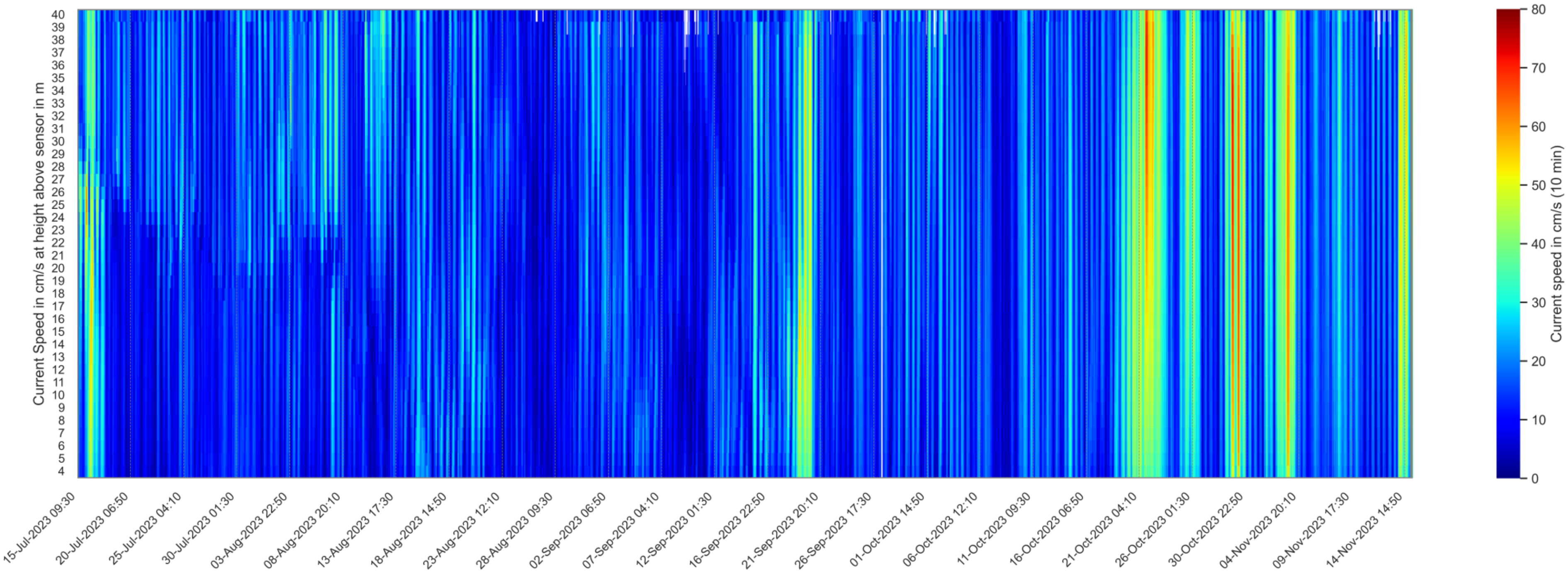


Figure B-59 Heatmap of offline (Signature)-measured bottom-up current speed from July 2023 until November 2023.

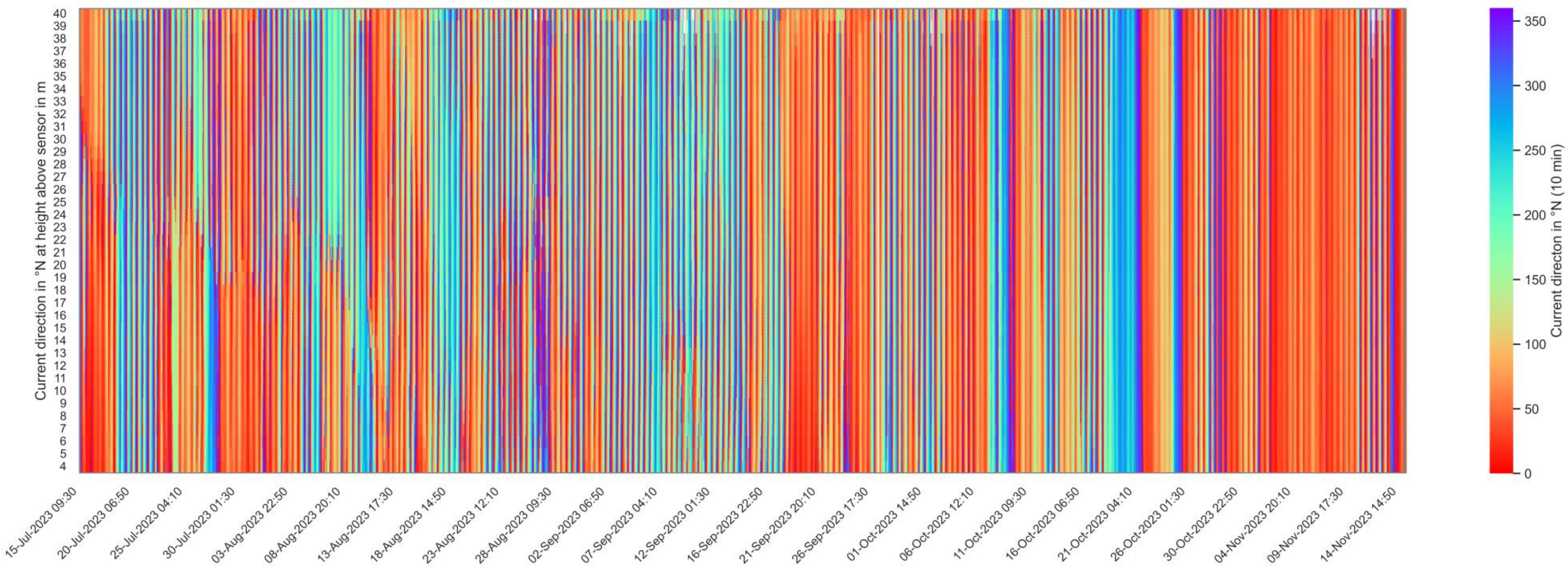


Figure B-60 Heatmap of offline (Signature)-measured bottom-up current direction from July 2023 until November 2023.

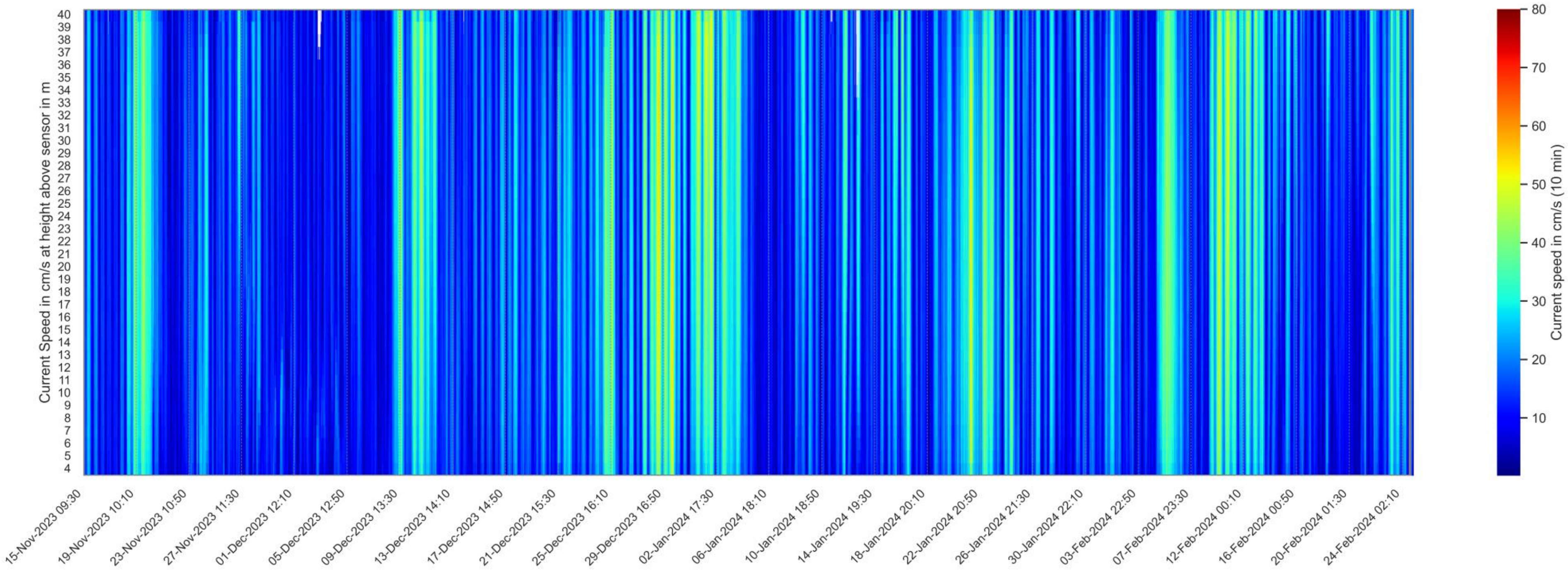


Figure B-61 Heatmap of offline (Signature)-measured bottom-up current speed from July 2023 until November 2023.

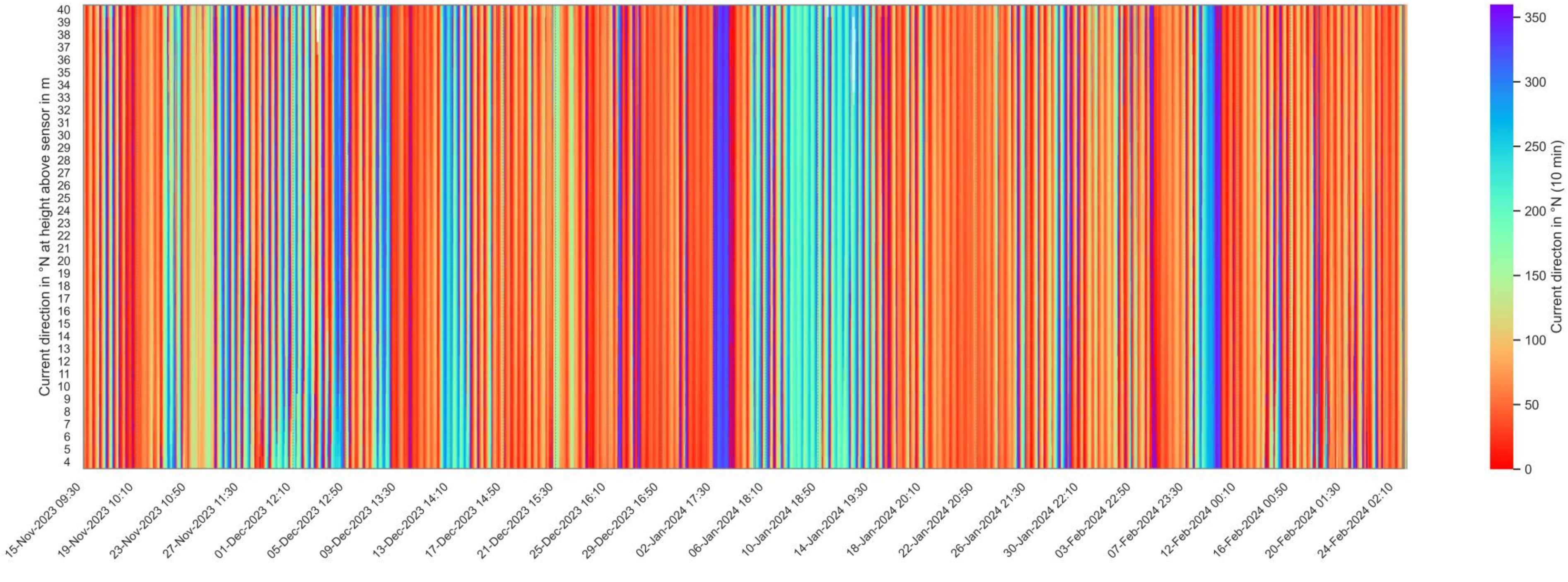


Figure B-62 Heatmap of offline (Signature)-measured bottom-up current direction from November 2023 until February 2024.

Appendix C

Final post-processed file contents

C.1 Energinet_Lot1_SWLB_20240604 November 2021 February 2024 CurrentData.csv

Parameter	Unit	Description
AqDir00xx deg	°N	Aquadopp current direction
AqSpd00xx cm/s	cm/s	Aquadopp current speed
AqAmpxx int	int	Aquadopp signal strength
where xx = 001, … , 041 m corresponding to measurement depth		

C.2 Energinet_Lot4_SWLB_ 20240215 November 2021 November 2023 MetOceanData.csv

Parameter	Unit	Description
AirHumidity %	%	Air humidity, Vaisala HMP155
AirPressure hPa	hPa	Air pressure, Vaisala PTB330
AirTemperature C	°C	Air temperature, Vaisala HMP155
AirPressure_lidar hPa	hPa	Air pressure from lidar met station
AirTemp_lidar C	°C	Air temperature from lidar met station
thSNR dB	dB	Thelma bottom sensor signal strength
thTBRtemperature degC	°C	Thelma modem (keelweight) surface water temperature
thTilt deg	°	Thelma bottom sensor tilt
BottomTemperature degC	°C	Thelma bottom sensor water temperature (near seafloor)
WaterPressure dbar	dbar	Thelma bottom sensor water pressure
precip_raw mm	mm	Accumulated precipitation
solarIrradiance W/m2	W/m2	Solar irradiance
pws_visibility m	m	Visibility in m
pws_WMOcode int	int	Visibility decoded
precipitation mm/10min	mm/10min	Precipitation
WaterTemp001 degC	°C	Aquadopp sea surface temperature
precipitation mm	mm	Accumulated precipitation

C.3 Energinet_Lot1_SWLB_20240604 November 2021 February 2024 Posdata.csv

Parameter	Unit	Description
irLatitude deg	°N	Latitude (position) from the Iridium modem
irLongitude deg	°E	Longitude (position) from the Iridium modem
spLatitude deg	°N	Latitude (position) from the Septentrio DGPS
spLongitude deg	°E	Latitude (position) from the Septentrio DGPS

C.4 Energinet_Lot1_SWLB_20240604 November 2021 February 2024 Status.csv

Parameter	Unit	Description
fcCurrentz A	A	Current produced by fuel cell z**
fcErrorz int	int	Error number from fuel cell z**
fcFuelRemz l	l	Remaining fuel connected to cell z**
fcOpTimez h	h	Operational time of fuel cell z**
fcULFz V	V	Fan voltage of fuel cell z**
leadAhCharged Ah	Ah	Net battery charging by solar panels during last hour
leadAhDischarged Ah	Ah	Energy drawn from batteries during last hour
leadBatteryVoltage V	V	Voltage in the lead acid batteries
lithiumAhDischarged Ah	Ah	Discharge of the lithium batteries during last hour
lithiumBattVoltage V	V	Battery voltage in the lithium batteries
pmuCardNo no	int	Card no in use in the power management unit, 1 or 2
sysUptime unknown	s	Time (in seconds) since last reboot of the buoy
thTBRid unknown	int	ID number of the water level sensor at bottom
** z= 1,2,3,4 = number of fuel cell		

C.5 Energinet_Lot4_SWLB_ 20240424 November 2021 November 2023 WaveData.csv

Parameter	Unit	Description
hm0 m	m	Significant wave height
hm0a m	m	Significant wave height, a-band**
hm0b m	m	Significant wave height, b-band**
hmax m	m	Average height of individual waves***
hmean m	m	Height of the highest individual wave***
hs m	m	Significant wave height, average of the one third highest waves***
mdir deg	°N	Mean spectral wave direction
mdira deg	°N	Mean spectral wave direction, a-band**
mdirb deg	°N	Mean spectral wave direction, b-band**
sprtp deg	°N	Wave spreading at the spectral peak period
thhf deg	°N	Mean wave direction at the spectral peak period
thmax s	s	High frequency mean wave direction
thtp deg	°N	Estimate of mean wave period tz, calculated from spectral moments tm01 = m0/m1
tm01 s	s	Estimate of mean wave period tz, calculated from spectral moments $tm02 = \sqrt{(m0/m2)}$
tm02 s	s	Estimate of tm02 in a-band**
tm02a s	s	Estimate of tm02 in b-band**
tm02b s	s	Period of spectral peak
tp s	s	Period of the highest wave***
tz s	s	Average period of individual waves***
ts s	s	Average period of the one third highest waves***

** Swell and wind sea frequency ranges:

Band “a” (Swell): 0.04 – 0.10 Hz (corresponding to wave periods between 10-25 sec, i. e. long waves)

Band “b” (Wind sea): 0.10 – 0.50 Hz (corresponding to wave periods between 2-10 sec, i. e. short waves)

*** zero-upcrossing requires a certain number of "high" wave in the data series to be calculated e.g. 50. Both hmax and thmax thus are usually not calculated if significant wave height is lower than approximately 0.3 m.

C.6 Energinet_Lot1_SWLB_20240604 November 2021 February 2024 WindSpeedDirectionTI.csv

Parameter	Unit	Description
VerticalWindSpeedxx m/s	m/s	Vertical lidar wind speed 10 min average calculated on buoy
WindDir004m deg	°N	Ultrasonic anemometer wind direction
WindGust004m m/s	m/s	Ultrasonic anemometer wind speed
WindSpeed004m m/s	m/s	Ultrasonic anemometer wind gust speed
WindDirxx deg	°N	Lidar wind direction 10 min average calculated on buoy
WindSpeedxx m/s	m/s	Horizontal lidar wind speed 10 min average calculated on buoy
windMax_horxx m/s	m/s	Maximum horizontal wind speed in 10 min interval
windMin_horxx m/s	m/s	Minimum horizontal wind speed in 10 min interval
turbulence(TI)xx	-	Turbulence intensity*, calculated on buoy
StandardDeviationxx m/s	m/s	Standard Deviation of wind speed in 10 min interval using lidar data

where xx = 30m, … , 270m corresponding to measurement height

* 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. Methods for motion compensation are being developed and corrected data may be calculated in the future. (Z300 MODBUS interface, a user's guide, 19th Dec 2013, issue K, ZephIR Lidar)

C.7 Energinet_Lot1_SWLB_20240604 November 2021 February 2024 WindStatus.csv

Parameter	Unit	Description
liBattteryVoltage unknown	V	Lidar battery voltage
liPODHumidity unknown	%	Lidar pod humidity
liRain unknown	int	Lidar rain count
liMirrorTemp unknown	°C	Lidar mirror temperature
liStatusFlagHi unknown	int	Lidar status flag high bits
liStatusFlagLow unknown	int	Lidar status flag low bits
liInfoFlagHi unknown	int	Lidar info flag high bits
liInfoFlagLow unknown	int	Lidar info flag low bits

liInfoFlag	int	Lidar status flag combined
liStatusFlag	int	Lidar info flag combined
liInfoFlagText	-	Lidar status flag translated to text
liStatusFlagText	-	Lidar info flag translated to text
liPacketCountxx	-	Number of samples for the averaging period
where xx = 30m, … , 270m corresponding to measurement height		

C.8 Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Posdata.csv; Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Posdata.csv

Parameter	Unit	Description
latitude deg	°N	Latitude (position) from the Iridium modem
longitude deg	°E	Longitude (position) from the Iridium modem

C.9 Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Status.csv; Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Status.csv

Parameter	Unit	Description
AhCharged Ah	Ah	Net battery charging by solar panels during last hour
AhDischargedLead Ah	Ah	Energy drawn from batteries during last hour
LeadBatteryVoltage V	V	Voltage in the lead acid batteries
LeadBatteryTemp deg C	°C	Temperature in the lead-acid batteries
AhDischargedLithium Ah	Ah	Discharge of the lithium batteries during last hour
lithiumBattVoltage V	V	Battery voltage in the lithium batteries
CardNo no	int	Card no in use in the power management unit, 1 or 2
uptime unknown	s	Time (in seconds) since last reboot of the buoy
numprocs unknown	int	Number of processes running
load15min unknown	int	15 min load average

C.10 Energinet_Lot1_SWmini_20240619 November 2021 February 2024 Wave.csv; Energinet_Lot1_SWmini_3_20240619 November 2022 February 2024 Wave.csv

Parameter	Unit	Description
hm0 m	m	Significant wave height
hm0a m	m	Significant wave height, a-band**
hm0b m	m	Significant wave height, b-band**
hmax m	m	Average height of individual waves***
hmean m	m	Height of the highest individual wave***
hs m	m	Significant wave height, average of the one third highest waves***
mdir deg	°N	Mean spectral wave direction
mdira deg	°N	Mean spectral wave direction, a-band**
mdirb deg	°N	Mean spectral wave direction, b-band**
sprtp deg	°N	Wave spreading at the spectral peak period
thhf deg	°N	Mean wave direction at the spectral peak period
thmax s	s	High frequency mean wave direction
thtp deg	°N	Estimate of mean wave period tz, calculated from spectral moments tm01 = m0/m1
tm01 s	s	Estimate of mean wave period tz, calculated from spectral moments $tm02 = \sqrt{(m0/m2)}$
tm02 s	s	Estimate of tm02 in a-band**
tm02a s	s	Estimate of tm02 in b-band**
tm02b s	s	Period of spectral peak
tp s	s	Period of the highest wave***
tz s	s	Average period of individual waves***
ts s	s	Average period of the one third highest waves***

** Swell and wind sea frequency ranges:

Band “a” (Swell): 0.04 – 0.10 Hz (corresponding to wave periods between 10-25 sec, i. e. long waves)

Band “b” (Wind sea): 0.10 – 0.50 Hz (corresponding to wave periods between 2-10 sec, i. e. short waves)

*** zero-upcrossing requires a certain number of "high" wave in the data series to be calculated e.g. 50. Both hmax and thmax thus are usually not calculated if significant wave height is lower than approximately 0.3 m.

C.11 Energinet_Lot4_Signature_20240405 November 2021 June 2022.csv

Column header	Unit	Description
Speed004m_cm/s, …, Speed040m_cm/s	cm/s	10-min averaged current speed
SigDir004m_deg, …, SigDir040m_deg	°N	10-min averaged current direction
DataMask_0, …, DataMask_36[1]	int	Data selection mask: non-zero indicates bad data value
BinMapAmp_BeamX_0, …, BinMapAmp_BeamX_36[1]	dB	Beam amplitude (signal-to-noise ration) where X corresponds to beam number 1 through 4
BinMapCor_Beam1_0, …, BinMapCor_Beam1_36[1]	%	Beam correlation (outgoing vs. incoming) where X corresponds to beam number 1 through 4
BinMapVel_East_0, …, BinMapVel_East_36[1]	cm/s	East velocity
BinMapVel_North_0, …, BinMapVel_North_36[1]	cm/s	North velocity
BinMapVel_Up1_0, …, BinMapVel_Up1_36[1]	cm/s	Vertical velocity
BinMapVel_Up2_0, …, BinMapVel_Up2_36[1]	cm/s	Vertical velocity
SpeedOfSound	m/s	Speed of sound during data collection at transducer head
WaterTemperature	°C	Seawater temperature at transducer head
Pressure	dbar	Water pressure measured at transducer head
Heading	°N	Heading
Pitch	°N	Pitch
Roll	°N	Roll
Altimeter_LE	dbar	Altimeter pressure - Leading Edge
Altimeter_AST	dbar	Altimeter pressure - Acoustic Surface Tracking
Altimeter_Pressure	dbar	Altimeter pressure
AltimeterQuality_LE	int	Altimeter Leading Edge quality parameter
AltimeterQuality_AST	int	Altimeter Acoustic Surface Tracking quality parameter
ASTPressureOffset	s	Acoustic Surface Tracking pressure offset
AltimeterStatus	int	Altimeter status

[1] where 0 corresponds to 004m and 36 to 040m

Appendix D

File formats and contents of the raw data files

Energy Islands – Floating LiDAR Measurements

File formats and contents of the raw data files

C75487-RawData-README-001 01 | 2 May 2024

Final

ENERGINET

Document Control

Document Information

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Client Information

Client	ENERGINET
Client Address	ENERGINET Eltransmission A/S, Tonne Kjærsvej 65, DK-7000 Fredericia, Denmark
Client Contact	Guillaume Mougin, Kim Parsberg Jakobsen and Gry Schachtschabel

Revision History

Issue	Date	Status	Comments on Content	Prepared By	Checked By	Approved By
01	24 Apr 2024	Draft	First complete issue	Irene Pathirana	Arve Berg	
02	05 May 2024	Final	Final issue	Irene Pathirana	Arve Berg	Arve Berg

Contents

1. ZX Lidars *.zph

There are two types of data produced by the ZX 300:

- Unaveraged 1 Hz data (wind*.zph)
- Averaged "10 minute" data (Wind10*.zph)

Each day has an associated file of each type resulting in two data files per day. Both data types are contained on the ZX 300's internal storage and can be accessed by the user. Data is compressed by the ZX 300 to save storage space and bandwidth during transmission.

The unaveraged 1 Hz data is used by the SWLB datalogger unit to determine wind speed and direction using the SWLB heading.

The averaged 10-minute data is **not used by the SWLB system**. It is not heading corrected and is only provided for completeness. The user should only use the 1 Hz *.zph data and the QC'd SWLB 10-minute data.

2. Nortek Aquadopp *.prf

The .prf file is the output from the AquaPro software, in binary format.

3. Nortek Signature500 raw data

The .ad2cp file contains all 1 Hz raw current measurements collected by the Signature 500. In addition a configuration file (*.cfg), a deployment setup file (*.deploy) and an internally averaged 10-min file (*.avgd.ad2cp) are supplied. The *.avgd.ad2cp is not used for any post-processing.

4. Thelma Biotel water level sensor *.bin

Data from both the bottom sensor and the top receiver modem are written to file by the SWLB datalogger into daily “thelma-YYYY-MM-DD.bin” files, where YYYY = year, MM = month, DD = day, readable with a text editor.

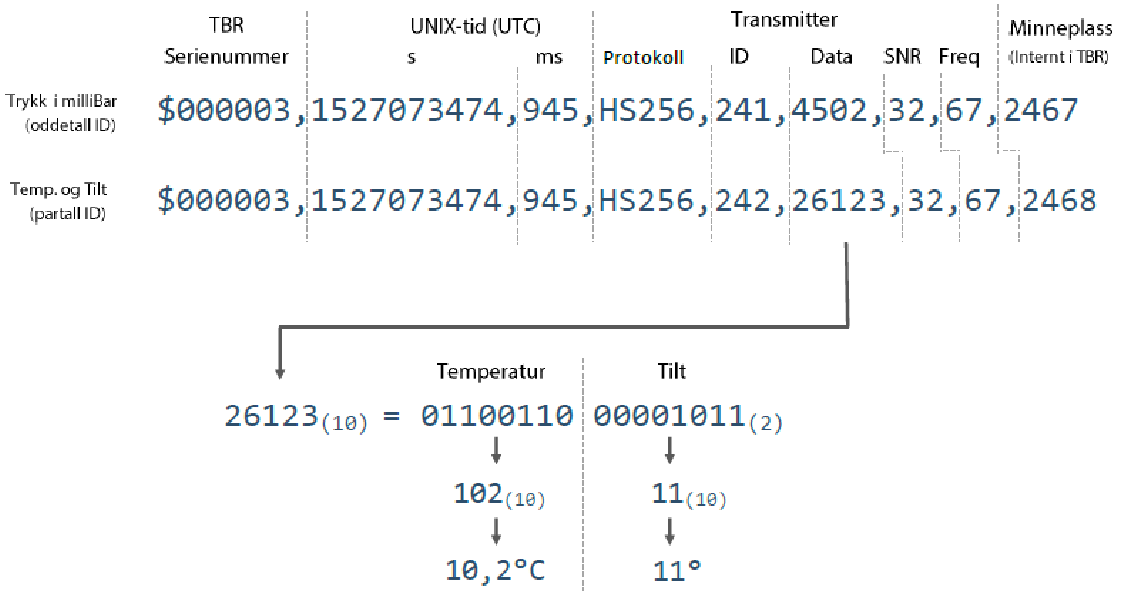
4.1 Tag detections

Bottom sensor data									
1554076846	000924	1554076840	432	HS256	21	3316	38	67	116543
GENITIME	SERIAL	UNIXTIME	MILLIS	PROTO	TAGID	DATA	SNR	FREQ	FLASHENTRY
int	int	int	int	int	int	int	int	int	int
Real time data	TBR serial number	UTC UNIX timestamp (automatically reset to 1. Jan. 2000 when power is off)	millisecond timestamp	code type	tag ID	data	Signal to Noise Ratio	TBR listening frequency - kHz	code running entry number in flash memory
Top Modem data									
1554076801	000924	1554076800	TBR Sensor	132	9	15	67	116542	
int	int	int	int	int	int	int	int	int	
Real time data	TBR serial number	UTC UNIX timestamp (automatically reset to 1. Jan. 2000 when power is off)	code type	Modem Temperature data	Average noise level	Peak noise level	TBR listening frequency - kHz	code running entry number in flash memory	

4.2 Decoding bottom sensor data

Odd TAGID X = total pressure in milliBar

Even TAGID X+1 = bottom temperature and tilt



4.3 Decode top modem data

Temperature = (data -50)/10 -> °C

5. Fugro Wavesense 3 **chpr** (**enh**)

chpr.csv files contain Wavesense 3 compass, heave, pitch, roll raw data from the SWLB buoys as basis to determine the wave parameters. The sensor sampling rate is set to 2Hz.

enh.csv files contain Wavesense 3 east, north, heave raw data from the SWLB buoys as basis to determine the wave parameters. The sensor sampling rate is set to 2Hz.

Compass direction is given in degrees, pitch and roll in radians, heave elevations, east and north positions are given in m.

For each row the timestamp in the first column given represents the start of the sampling of all the time series in that row.

The index in the parameter name, given by [0],[1],...,[2048] is the sample number for the parameter.

Note that there is a 20-minute difference in the timestamps between the raw *chpr* (*enh*) data and the processed, QC'd 10-minute averaged wave data.

6. MEM wave spectra

The directional wave spectra are estimated from the directional Fourier components using the Burg Maximum Entropy method (MEM) [1] . The wave spectra were postprocessed to using the raw compass, heave, pitch and roll data (lidar buoys) or east, north and heave data (wave buoy). There is a 20 min offset between the data in the memspec files and the timeseries.

Spectra are stamped like the time series, rounded back to the beginning of the measuring interval. Parameter records from real rime processing are stamped at the time of recording, which is rounded forward to the end of the recording interval.

Calculations of wave parameters done onboard the buoy use the measured data before storing and digitalization. Thereafter data is stored, both raw and calculated. During this storage process, the data is digitalized with a given resolution (i.e. binned). If the stored raw data or memspec files are used to re-calculate the wave parameters, there may be small differences compared to parameters calculated onboard the buoy. The resolution settings are, however, set such that the differences are insignificant (better than the accuracy).

6.1 Spectra for SW Mini wave buoy

fmin = 0.04; fmax = 1.0; df = 0.01; units = Hz

dirmin =0; dirmax = 360; ddir = 5; units = degrees.

6.2 Spectra for lidar buoy

fmin = 0.04; fmax = 0.6; df = 0.01; units = Hz

dirmin =0; dirmax = 360; ddir = 5; units = degrees.

7. Memspec* file format

The file contains the 2-dimensional directional spectral density S(f, ϴ) [m^2 s deg^{-1}] in addition to other spectral parameters. The directional spectrum is estimated from the directional Fourier components using the Burg Maximum Entropy method (MEM) [1].

The MEMspec data file is a sequential text file containing a sequence of records for each recorded wave time series:

1. ISSUE TIME: The date and time when the analysis was produced.
2. START TIME: The time of the first measurement in the time series of Heave, Pitch, Roll and Compass heading data
3. END TIME: The time of the end of the time series of Heave, Pitch, Roll and Compass heading data
4. LOCATION: Text identifying the location and buoy.
5. direction: Unit for direction data.
6. frequency: Unit for frequency
7. matrix rows: Number of rows (frequencies) in the spectrum matrix.
8. Hm0 m: Spectral estimate of significant wave height in meters for this time series.
9. Tp s: Peak period = $1/f_{Peak}$ where f_{Peak} is the frequency of the maximum spectral energy density within the (omni-directional) wave spectrum S(f).
10. Mdir deg: Mean wave direction in degrees for this time series.
11. spectral density: Unit for spectral density (m^2 s = m^2 Hz-1).
12. a1: $a_1(f)$ = Fourier coefficients a_1 of the directional distribution at frequency f = fmin, ..., fmax.
13. b1: $b_1(f)$ = Fourier coefficients b_1 of the directional distribution at frequency f = fmin, ..., fmax.

14. a2: $a_2(f)$ = Fourier coefficients a_2 of the directional distribution at frequency f = fmin, ..., fmax.

15. b2: $b_2(f)$ = Fourier coefficients b_2 of the directional distribution at frequency f = fmin, ..., fmax.

16. hspec: Omnidirectional spectral energy density S(f) for each frequency f.

17. Directions in degrees for each column in the following directional spectrum matrix.

18. – 18 + <matrix rows> -1: The directional wave spectrum. There is one record for each frequency, f, of the directional spectrum, containing f and then S(f, Θ), for Θ = ΔΘ, ..., 360°.

Then follows the next spectrum data block beginning with “ISSUE TIME”.

8. Seabird CTD raw data

Each SBE 37-IMP-ODO MicroCAT (SBE37SMP-RS485 instrument stores the raw data in *.hex and '.xmlcon files. Each instruments' raw data files (SBE37SMP-RS485_*_DATE.hex and SBE37SMP-RS485_*_DATE.xmlcon) were converted to SBE37SMP-RS485_*_DATE.cnv files (readable with text editors) for each depth, where * indicates the serial numbers for the sensors at the different depths and DATE the filedate.

9. References

[1] A. Lygre and H. E. Krogstad. Maximum entropy estimation of the directional distribution in ocean wave spectra. J. Phys. Oceanogr., 16, 1986.