Danish Offshore Wind 2030 – Floating LiDAR Measurements

Final Campaign Report for Kriegers Flak II, 3 September 2023 - 3 September 2024

C75517-R12-KFII 02 | 11 November 2024

ENERGINET

Document Control

Document Information

Project Title	Danish Offshore Wind 2030 – Floating LiDAR Measurements
Document Title	Final Campaign Report for Kriegers Flak II, 3 September 2023 - 3 September 2024
Fugro Project No.	C75517
Fugro Document No.	C75517-R12-KFII
Issue Number	02
Issue Status	Final

Client Information

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Revision History

Issue	Date	Status	Comments on Content	Prepared By	Checked By	Approved By
01	4 November 2024		First issue	Martin Murvold Sungsoo Lim	Sungsoo Lim	Arve Berg
02	11 November 2024		Final	Sungsoo Lim		

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Abbreviations

Abbreviation	Definition
ADCP	Acoustic Doppler Current Profiler
D1, D2	D1: The campaign period by first deployment D2: The campaign period by second deployment (after service)
FLS	Floating Lidar System
GNSS	Global Navigation Satellite System
IEC	International Electrotechnical Commission
KFII	Kriegers Flak II (Project site)
LAT	Lowest Astronomical Tide
LiDAR (or lidar)	Light Detection and Ranging
MSL	Mean Sea Level
MWL	Mean Water Level
NaN (Not a Number)	Label indicating data as invalid/missing
QA/QC	Quality Assurance / Quality Control
SI	Système International
SWLB	Seawatch Wind Lidar Buoy
TI	Turbulent Intensity
UTC	Universal Time Coordinated
WMO	World Meteorological Organization
WS	Seawatch Wavescan buoy (Prefix for some type of Lidar buoy)
DA	Data Availability
FNAS	Fugro Norway AS
ID	Identifier
KFII	Kriegers Flak II

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. The deviation between magnetic and true north is approximately 5.0°(E) for KFII-1-LB/CP and 4.9°(E) for KFII-2-LB/CP station.[1] These deviations apply to magnetic compass heading data; wave and current directions have been corrected accordingly. Please note, that this correction was not applied to any wave spectra data or raw data.

[1] https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination (Accessed on 9 October 2023)

Executive Summary

Fugro Norway AS entered into an agreement with ENERGINET, Denmark for the project "Danish Offshore Wind 2030 – Lot 1-3" for 12 months.

The measurements from the metocean surveys will be used as input to various environmental, metocean, and other studies and analyses to support the project development and design process, including energy yield calculations, site assessment, selection and design of foundation, grid connections, cable corridors, etc.

Lot 2 consists of Kriegers Flak II South and Kriegers Flak II North with one Lidar buoy and one bottom mounted current profiler on the bottom at each location. The two primary buoys allocated for Lot 2 are WS190 and WS172. Both buoys were first deployed on 3 September 2023 at KFII South and KFII North, respectively. WS172 was replaced by SWLB085 on 16 January 2024 and SWLB085 was replaced by SWLB083 on 7 June 2024. WS172 was serviced and deployed at Kriegers Flak II South replacing WS190 on 16 February 2024.

As an extra measurement campaign, the LiDAR buoy WS210 was also allocated and deployed from 1 November 2023 to 14 April 2024 at the site in the easternmost part of the Kriegers Flak II North site to study wake effect from the existing Kriegers Flak wind farm site. This measurement is reported separately.

The LiDAR buoys are online with processed data being transmitted every ten minutes. Unprocessed data from the buoys and the bottom current profilers are downloaded at service and/or at the end of the measurement campaign.

This final report covers Lot 2, Kriegers Flak II and includes general information of measurement campaign, configurations, post-processing, quality control, data availability and data presentations over the period from 3 September 2023 to 3 September 2024. SWLB083 was recovered on 15 September 2024 from Kriegers Flak II North. The rest of equipment from Kriegers Flak II South were recovered on 16 October 2024.

The combined data availability for KFII-1 (WS190 and WS172) is 97.2 % for wind, 100.0% for wave, 81.1% for current (buoy mounted) and >97 % for all other parameter groups, except visibility parameter.

The combined data availability for KFII-2 (WS172, SWLB085 and SWLB083) is 90.7 % for wind, 95.9% for wave, 96.8% for current (buoy mounted) and >95 % for all other parameter groups, except bottom temperature and water pressure and visibility parameters.

1. Introduction

1.1 Kriegers Flak II project area

The Kriegers Flak II project areas consist of a northern and southern part. The northern area is close to 100 km^2, is located nearly 25 km from Rødvig, and has water depths between 20 m and 35 m. The southern area is 75 km^2, is located about 20 km off Møns Cliff, and has water depths between 18 and 42 m. The approximate distance to Rødvig Port is 55 km.

Deployment locations are given in Figure 1.1 and exact positions and water depths for the different buoy locations are given in Table 1.1.

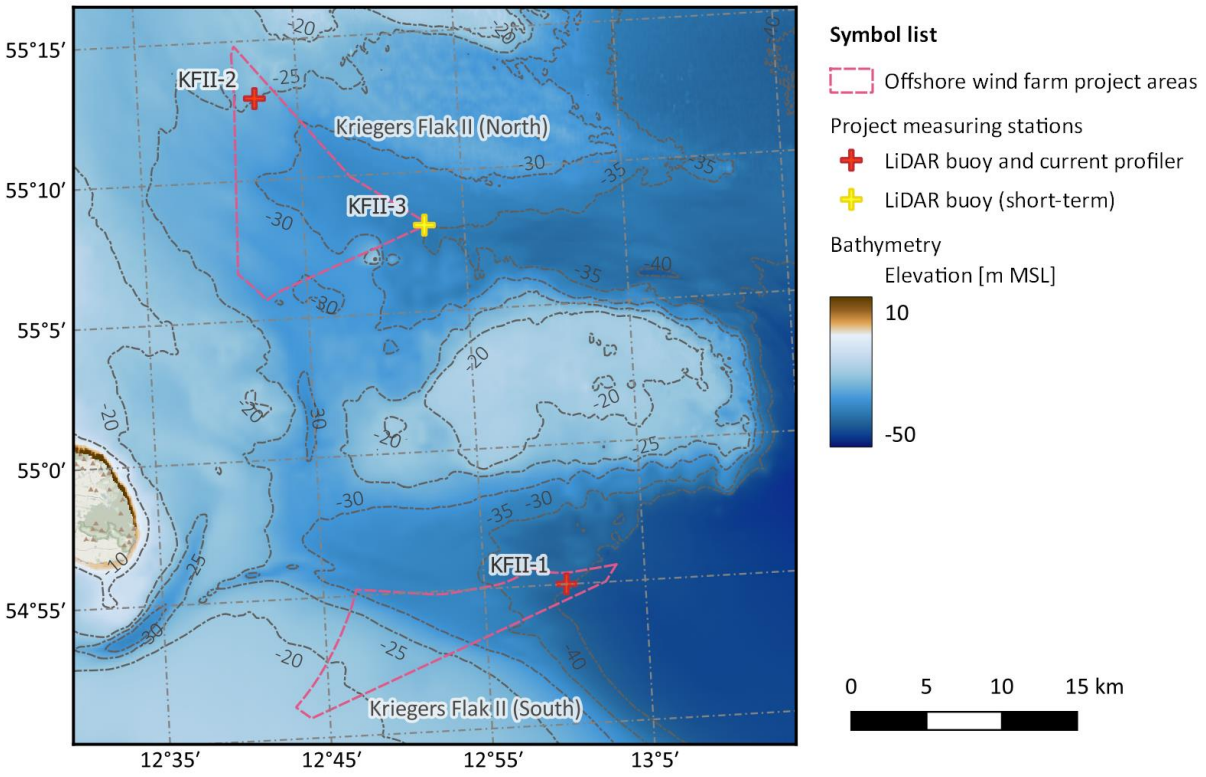


Figure 1.1: Instrument locations at Kriegers Flak II project area.

Table 1.1: Buoy locations and water depths

Station	Area	As laid location (WGS84)		Depth [m]	Type
		Latitude [°N]	Longitude [°E]		
KFII-1-LB	Kriegers Flak II S	54.9168	12.9945	39.7	LiDAR buoy
KFII-1-CP	Kriegers Flak II S	54.9167	12.9939	39.6	Current profiler*
KFII-2-LB	Kriegers Flak II N	55.2156	12.6986	27.2	LiDAR buoy
KFII-2-CP	Kriegers Flak II N	55.2153	12.6992	27.3	Current profiler*

Station	Area	As laid location (WGS84)		Depth [m]	Type
		Latitude [°N]	Longitude [°E]		
KFII-3-LB	Kriegers Flak II N	55.1375	12.8162	32.9	LiDAR buoy†

Note
*Indicates offline instruments
†Short-deployment and reported separately

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 will last 12 months.

1.2 Deployments Kriegers Flak II

Wind LiDAR buoy WS172 and WS190 were deployed at Kriegers Flak II North and South, respectively, on 3 September 2023 together with a bottom mounted water level sensor and a bottom mounted upward-looking current profiler. At Kriegers Flak II North WS172 was replaced by SWLB085 on 16 January 2024 and SWLB085 was replaced by SWLB083 on 7 June 2024. WS172 was serviced with the lidar unit zx757 and deployed at Kriegers Flak II South replacing WS190 on 16 February 2024.

As an extra measurement campaign, the LiDAR buoy WS210 was also allocated and deployed at the site in the easternmost part of KFII-1 site to study wake effect from the existing Kriegers Flak wind farm site. This measurement is reported separately. (Ref. [1])

The LiDAR buoy provides near real-time data that is transmitted to shore every 10 minutes. This report gives an overview of this transmitted data, data availability and activities for the month. Unprocessed data from the buoy and the bottom current profiler are only downloaded at service.

The positions of the bottom mooring weights are listed in Table 1.1. As the buoy is free to float around the mooring point within a radius of about 110 m, the water depth varies slightly with the position of the buoy.

Table 1.2 shows a log of the deployments at Kriegers Flak II.

Table 1.2: Deployments at Kriegers Flak II

Station	ID	LiDAR #	Start time (UTC)	End time (UTC)	Status
KFII-1-LB	WS190	zx809	2023-09-03 16:55	2024-02-16 15:40	end of campaign
	WS172	zx757	2024-02-16 15:40	2024-09-03 16:55	end of campaign
KFII-1-CP	104620	-	2023-09-03 17:20	2024-04-15 10:40	end of campaign

Station	ID	LiDAR #	Start time (UTC)	End time (UTC)	Status
	104503	-	2024-04-15 11:30	2024-09-03 17:20	end of campaign
KFII-2-LB	WS172	zx709	2023-09-03 11:35	2024-01-16 09:00	end of campaign
	SWLB085	zx1915	2024-01-16 09:18	2024-06-07 10:50	end of campaign
	SWLB083	Zx1646	2024-06-07 12:00	2024-09-03 11:35	end of campaign
KFII-2-CP	104621	-	2023-09-03 11:45	2024-04-15 13:35	end of campaign
	104620	-	2024-04-15 13:50	2024-09-03 11:45	end of campaign
KFII-3-LB	WS210	zx1004	2023-11-01 16:07	2024-04-14 03:20	end of campaign

Note
*12-month campaign ended on 3 September 2024. Actual recovery time for SWLB083 was 15 September 2024 16:35 UTC, for WS210 16 September 2024 10:30 UTC and for WS172 16 October 2024 19:30 UTC.

1.3 Calibration and Pre-deployment Validation

The Wind LiDAR buoys WS190, WS172, SWLB083 and SWLB085 have been pre-validated and passed Best Practice Criteria for all wind speed and direction ranges at all heights [2] [3] [4] [5].

The measurement plan [6] for this campaign includes information on calibration certificates for the other instruments.

The LiDAR buoy WS210 was allocated and deployed also for Kriegers Flak project site at a corner of KFII-1 site, Kriegers Flak II North. The pre-deployment validation for this buoy was performed and met Best Practice Criteria for all wind speed and direction ranges at all heights [7].

1.4 Data collection and reports

1.4.1 SWLB data

Data from the LiDAR buoys was transmitted to shore in near real-time, quality checked and reported monthly. Monthly reports gave an overview of the transmitted data, data availability and activities for each month. Table 1.3 lists the monthly reports for this project area. At each service the data from the buoy is downloaded.

Table 1.3: List of monthly reports at Kriegers Flak II (KFII)

Time period	Monthly report
3 September 2023 – 3 October 2023	C75517-R-KFII-M01(04)
3 October 2023 – 3 November 2023	C75517-R-KFII-M02(04)
3 November 2023 – 3 December 2023	C75517-R-KFII-M03(03)
3 December 2023 – 3 January 2024	C75517-R-KFII-M04(03)
3 January 2024 – 3 February 2024	C75517-R-KFII-M05(02)
3 February 2024 – 3 March 2024	C75517-R-KFII-M06(01)
3 March 2024 – 3 April 2024	C75517-R-KFII-M07(01)
3 April 2024 – 3 May 2024	C75517-R-KFII-M08(01)
3 May 2024 – 3 June 2024	C75517-R-KFII-M09(02)
3 June 2024 – 3 July 2024	C75517-R-KFII-M10(03)
3 July 2024 – 3 August 2024	C75517-R-KFII-M11(02)
3 August 2024 – 3 September 2024	C75517-R-KFII-M12(02)

The raw data of buoy mounted current profilers were also collected after the campaign and was checked for this final 12-month report.

1.4.2 Bottom mounted ADCP data

The bottom mounted instruments (Signature500) were deployed at both locations (Table 1.2) and collected data during the 12 months campaign period. The data were downloaded at the end of the measurement campaign. The full 12-month dataset is presented in this report.

2. Activities

2.1 Service and Maintenance Activities

WS172 replaced WS190 at KFII-1-LB station on 16 February 2024. SWLB085 replaced WS172 at KFII-2-LB on 16 January 2024 and SWLB085 was replaced by SWLB083 on 7 June 2024. Serviced bottom current profilers were deployed at KFII-1-LB and KFII-2-LB on 15 April 2024. Details of exact time of deployment and instrument serial numbers are given in Table 1.2.

SWLB083 was recovered on 15 September 2024 from Kriegers Flak II North. The rest of equipment from Kriegers Flak II South were recovered on 16 October 2024 from Kriegers Flak II site.

2.2 Health, Safety and Environment

No incidents were logged during this period.

2.3 Weather Events

High winds combined with storm surge passed by the Lot 2 area from 23 to 24 November 2023.

2.4 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 at the present time.

A gap induced by connection lost or transmission lost can be filled by raw data downloaded either during the service or at the end of campaign.

The lidar measurements can be influenced by adverse weather conditions (e. g. fog, heavy rain, poor visibility) resulting in low packet counts. Measurements at each height are independent and short gaps at intermediate heights can occur. The lidar weather station parameters e.g. air pressure and temperature can be incorrect due to the weather stations are not calibrated for these parameters.

2.4.1 WS190 lidar low input power at KFII-1

WS190 lidar started to stall measuring wind from January 2024. Since 12 February 2024, WS190 lidar was not able to measure wind due to low input power caused by fuel depletion from available fuel chambers. This issue was resolved by buoy swap with WS172 on 16 February 2024.

2.4.2 WS172 lidar ZX709 issue at KFII-2

Since 25 December 2023, the lidar unit ZX709 on WS172 did not measure the wind due to the failure of a lidar part - wedge. WS172 was, after then, paired with the emergency

lidar, ZX757. The issue was resolved by the buoy swap with SWLB085 on 16 January 2024.

2.4.3 SWLB085 Wavesense issue at KFII-2

From 24 May 2024 to 7 June 2024, SWLB085 Wavesense did not measure the integrated instrument data and motion data. Lidar and well mounted ADCP, however, logged the data locally and used for backfill this gap.

- Lidar data ended up with being reprocessed with Septentrio raw heading data but Septentrio also did not measure well the heading source while Wavesense is not working.
- All other gaps except wave and humidity data were backfilled by redundant instrument or raw data saved locally.

2.4.4 Downtime from visibility sensors.

The measured values from the visibility sensor of WS190 at KFII-1-LB was filtered out from 25 October 2023 to 17 February 2024.

The visibility sensor of SWLB085 at KFII-2-LB was not measuring from 28 May 2024 until the buoy was replaced with by SWLB083 in June 2024. SWLB083 did not either measure visibility until the end of campaign in September 2024.

3. Post-Processing and Availability

3.1 Measurement Configurations

3.1.1 SWLB

The general measurement setup, sensors, configurations, and measurement scheme are described in the measurement plan [6]. Table 3.1 shows the measurement configuration of the SWLB. Definitions of wave parameters are given in Table 3.2.

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:

- GNSS 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.
- 10-minute-averaged data of air pressure, air temperature, humidity, precipitation, visibility, and sea surface temperature as well as of the bottom mounted Thelma pressure sensor is calculated for storage every 10 minutes.
- Wave parameters are calculated onboard from motion data and stored every 10 minutes based on 2048 samples in a 1024 second burst.
- Heading information (compass and GNSS) is 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 11 levels in a conical sweep every 17 seconds on average. The LiDAR data are combined with buoy heading information to reference buoy direction to north before calculating the 10-minute-averages.

The buoy converts 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.

Table 3.1: Configuration of measurements of the Seawatch Wind Lidar buoy

Instrument Type	Sensor Height [m]	Parameter Measured	Sample Height[1] [m]	Sampling Interval [s]	Averaging Period [s]	Burst Interval [s] [2]	Measurement Resolution	Transmitted ?
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 ZX300M Lidar	2	Wind speed and direction at 10 heights and the reference level at 40 m	40[4], 12, 80, 100, 130, 150, 170, 190, 220, 260, 300	17.4[5]	600	600	0.1m/s 1°	Yes
Gill Windsonic M (Ancillary anemometer)	4.1	Wind speed and direction	4.1	1	600	600	0.01m/s 1°	Yes
Nortek Signature500 current profiler	-1	Current speed and direction profile, water temperature (at 1m depth)	-3 ... -bottom[6]	1	180	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
Septentrio GNSS	4.1	Buoy orientation	4.1	5	10	1	0.35°	No
Thelma Biotel TBR700	2m above seabed	Bottom water pressure and bottom temperature, Surface temperature	2m above seabed	1	600	600	0.01m 0.01°C	Yes

Instrument Type	Sensor Height [m]	Parameter Measured	Sample Height[1] [m]	Sampling Interval [s]	Averaging Period [s]	Burst Interval [s] [2]	Measurement Resolution	Transmitted ?

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, which is not configurable and referred to as 40.0 Ref.

[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.

[6] = Bottom depths are found in Table 1.1

Table 3.2: Definitions 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	°	Mean spectral wave direction. Computed from spectral analysis.
mdira	°	Mean spectral wave direction in the **a** frequency band.*
mdirb	°	Mean spectral wave direction in the **b** frequency band.*
sprtp	°	Wave spreading at the spectral peak period. Computed from spectral analysis.
thhf	°	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.
thtp	°	Mean wave direction at the spectral peak period. Computed from spectral analysis.
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.

* 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. 25. Hmax, hs, hmean, tz, ts and thmax thus are usually not calculated if significant wave height is lower than approximately 0.3 m.

† The parameters can only be provided from Neptun re-analysis

3.1.2 Bottom mounted current profiler

A Nortek Signature 500 current profiler was placed on the seabed at KFII-1-CP and KFII-2-CP on a separate mooring to measure the current profile upward, from bottom to surface. Figure 3.1 presents the conceptual drawing of the instrument.

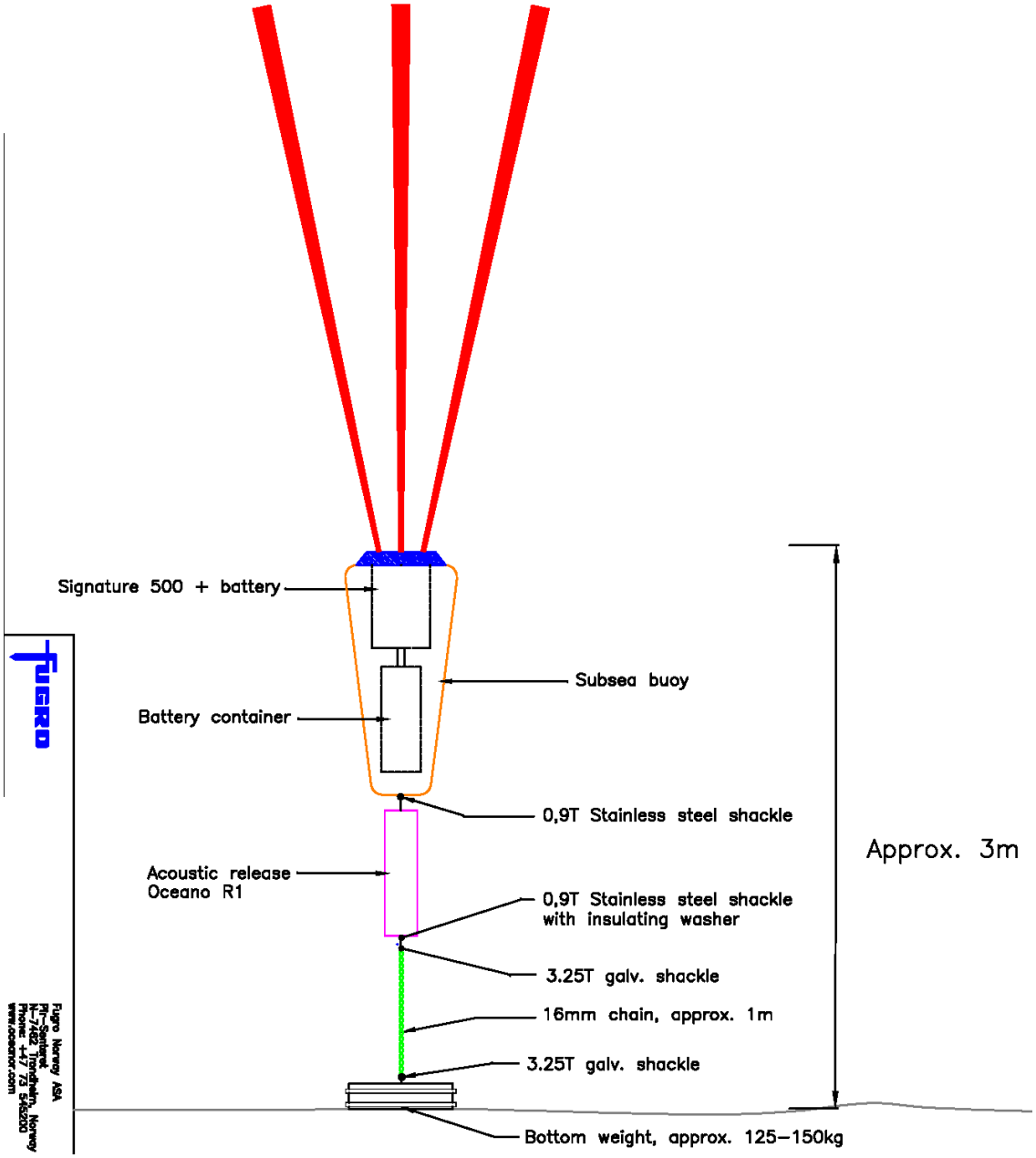


Figure 3.1: Bottom mounted current profiler (Nortek Signature500)

Table 3.4 shows the measurement configuration of the Nortek Signature500 current profiler mounted at KFII-1-CP and KFII-2-CP. The noise floor for these instruments is 27 dB. Table 3.3 describes the height or depths for measurement bins of current profiler instruments.

Table 3.3: Measurement height or depth bin setting for current profilers

	Bottom mounted current profiler	Buoy mounted current profiler	
Instrumnet type	Nortek Signature 500	Nortek Aquadopp 400kHz	Nortek Signature 500
Cell size (m)	1	1	1
Blanking distance (m)	0.5	0.5	0.5
First cell depth or height	4 m above seabed	3 m beneath water surface	3 m beneath water surface
Depth or height bins	5, 6, …34 m above seabed, KFII-1 4, 5, …24 m above seabed, KFII-2	3… 34m beneath water surface, KFII-1 3… 26m beneath water surface, KFII-2	3,….26m beneath water surface, KFII-2
Sensor heights	3 m above seabed	1 m beneath water surface	1 m beneath water surface

The bottom-mounted current profiler also records water temperature at seabed and pressure above the sensor head. There is an uncertainty in the sensor height above the sea floor since it is deployed on a floating buoy. The nominal height of bottom-mounted sensor is 3 m above sea floor (Figure 3.1).

Table 3.4: Configuration of measurements of the upward facing ADCP

Instrument Type	Sensor Height[1] [m]	Parameter Measured	Sample Height[1] [m]	Sampling Interval	Averaging Period [s]	Measure-ment Interval [s]	Measure-ment Resolution
Nortek Signature 500	3m above seabed	Current speed and direction profile, water temperature and water pressure	4, 5, 6, …, d^2	1 Hz, 359 pings	180	600	0.9 cm/s 0.1° 0.1°C

Notes

[1] = Height relative to seafloor.

d^2 = Maximum height above seafloor; see Table 3.3

3.2 SWLB Post-processing

3.2.1 General post-processing and quality control

The general data flow, post-processing and quality control applied to the data is described in the measurement plan [6]. Post-processed data refers to values that have undergone the following steps to increase the post-processed data availability or enhance the data quality.

a. Removal of time windows outside deployment period, for example times when the buoy is on transit.

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 duplicate measurements if all measurements/parameters by one sensor are repeated from one time step to the next

d. Out of range values (Table 3.5) replaced by NaN

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 3.5.

Table 3.5: 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	33	-	dB
hm0	0	18	m
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	23	-	dbar
Visibility	10	5000*	m
Precipitation	0	10	mm/10min

Note
*Maximum visibility is 4000 for MiniOfs, 5000 for pws visibility sensor.

3.2.1.1 Wind speed and direction

For wind, an additional 180° ambiguity check is done on the LiDAR wind directions using Gill direction.

3.2.1.2 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*).

3.2.1.3 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) and the calculated wave parameters (as given in the WaveData files) are stored. Wave spectra are re-calculated inhouse 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.

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

3.2.1.4 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.

3.2.1.5 Currents

Only respective depth bins outlined in Table 3.3 were filtered on current speed, current direction, and signal strength. Current speed and direction where signal strength was below the minimum threshold was removed including any current data in deeper layers.

It is often desirable to neglect data that is near the free surface, e.g. seabed or water surface, due to the possibility of sidelobe interference. Assuming the instrument is installed not too slanted and very close to the surface, the fraction of 0.95 is applied to reject sidelobe effect. The surface is detected by finding the peak in the acoustic return. For example, if the profiler is pointing downward from the water surface, then the peak in amplitude is used to locate the seabed [8].

Both a gradual decrease in signal strength with respect to the distance increase from the instrument head and sidelobe rejection of the current profiler data near the free surface result in a substantial amount of data is filtered out at farther layer bins. In addition, marine growth restricted the range of valid data towards the end of the individual deployments.

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

3.2.1.6 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 pressure sensor head is free floating and assumed to be located at nominally 1.5- 2 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 2 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 approximately equal to the depth in metres. However, to get the proper height of the water column above the sensor, the air pressure measurement from the buoy must be subtracted from the total measured water pressure as simplified in the following:

$$h_w = \frac{P_w - P_a}{\rho g}$$

where h_w is the height of the water column, P_w is the measured total water pressure, P_a is the measured total air pressure, ρ is the density of the water (inferred from measured salinity and temperature), and g is the acceleration of gravity. Since the gravity changes with respect to latitude slightly, the conversion from pressure to depth in this project will employ the formula by UNESCO (1983) (Ref. [9] and [10])

3.2.2 Project specific post-processing criteria

This section outlines any deviations or additions from the general post-processing steps.

3.2.2.1 High thmax filter

At calm seas zero-upcrossing analysis could miss small wave amplitude which may lead to over-estimate tz or thmax values. To disregard these values, the suggested rule can apply to the derived wave statistics:

- thmax/tm02 < 3, Otherwise set thmax, hmax, tz missing

3.3 Upward-facing ADCP

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.

All current data are post-processed from raw data stored on the current meter using the manufacturer's (Ocean Contour V2) [11] software and additional python scripts.

3.3.1 Ocean Contour raw data post-process

All raw data from all 2 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.
2. Minimum signal strength filter, which removes data with poor return signal quality.
3. Minimum correlation check between incoming and outgoing beams, which removes data with poor return signal quality.
4. Automatic sidelobe removal threshold
5. Correction for magnetic declination. 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 was exported from Ocean Contour as netcdf.. 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 4 m (5m at KFII-1-CP) and ending at 34 m and 24 m for KFII-1-CP and KFII-2-CP respectively. 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 35m – 46m (KFII-1-CP) and 25m-35m (KFII-2-CP) were removed by the automatic sidelobe removal (step 4). Current speed and current direction measured values in the bin where they still showed apparent strong influences of sidelobes were partially rejected and removed.

The following settings were also used for Ocean Contour data process:

- Bin mapping applied
- Low SNR threshold: 30 dB (noise floor 27 dB)
- Minimum correlation: 50%
- Sidelobe rejection: 95%, Surface
- Correction for magnetic declination: +5.0° and +4.9° for KFII-1-CP and KFII-2-CP, respectively

3.3.2 IOOS Qartod tests

Standalone ADCP processing follows the required and some recommended steps in the IOOS QARTOD manual on in-situ current observations [12]. The following IOOS QARTOD tests were implemented:

a. Current speed [0;135] cm/s, [0;135] cm/s, [0;135] cm/s for KFII-1-CP and KFII-2-CP, respectively

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 were found, and all speed and direction data where the absolute value of the vertical velocity was greater than 20 cm/s were removed.

Data in the near-surface bins may periodically still be affected by sidelobe energy 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.

4. Data files

Table 4.1 summarizes the contents of each delivered datafile following the post-processing steps outlined in the measurement plan [6].

Table 4.1: Post-processed SWLB data by files

File	Signals
CurrentData	The file contains 10-minute average data calculated on the buoy from the current profiler. All timestamps are set at the end of the averaging period. For all current speed and direction signals currSp(d) and currDir(d), where d = 3,4,5, ..., up to water depth m, the data are checked for out-of-bounds values and signal strength. For timestamps and depths where the speed is outside the accepted range, the speed and direction are set to NaN.
MetOceanData	The file contains 10-minute average data calculated on the buoy from the meteorological and oceanographic sensors. All timestamps are set at the end of the averaging period. Parameters: Air and Water Temperatures, Air Pressure, Humidity from all available sensors, precipitation, visibility, solar irradiance, water pressure, depth, and water level. All data with values outside the accepted range are replaced by NaNs.
PosData	The file contains 10-minute average position data from all available sources. All timestamps are set at the end of the averaging period.
Status	The file contains hourly buoy status data. Parameters: fuel, voltage, battery, error codes.
WaveData	The file contains the wave data at 10-min frequency based on 17 min sampling. Parameters: Parameters: hm0, hm0a, hm0b, hmax, mdir, mdira, mdirb, sprtp, thhf, thmax. Thtp, tm01, tm02, tm02a, tm02b, tp, tz All data with values outside the accepted range are replaced by NaNs.
WindSpeedDirectionTI	The file contains 10-minute averaged wind speed and direction measurements as well as turbulence intensity calculated on the buoy. The signals are all timestamped with the end of the averaging period. All wind measurements must have wind speed and direction values. For timestamps where either the wind speed or direction is outside this range, the speed and direction are set to NaN. To correct for 180 degrees ambiguities in the lidar wind directions, an additional correction with 10-minute average directions from the ancillary anemometer as ground truth has been used. The correction is done automatically using an algorithm checking each height for ambiguous wind directions and flipping it 180 degrees if necessary.
WindStatus	This file contains status information from the lidar unit. Parameters: Packet count, mirror temperature, rain count, battery voltage, POD humidity, status flags, info flags

Table 4.2 lists the final 12-month datafiles. This includes the full SWLB dataset and the quality assessed ADCP data.

Table 4.2 List of final campaign datafiles at Kriegers Flak II (KFII-1 & KFII-2)

Instrument	Filename (KFII-1)	Filename (KFII-2)
SWLB 12-month dataset	**KFII-1-LB_12M_CurrentData.csv** **KFII-1-LB_12M_MetOceanData.csv** **KFII-1-LB_12M_Posdata.csv** **KFII-1-LB_12M_Status.csv** **KFII-1-LB_12M_WaveData.csv** **KFII-1-LB_12M_WindSpeedDirectionTI.csv** **KFII-1-LB_12M_WindStatus.csv**	**KFII-2-LB_12M_CurrentData.csv** **KFII-2-LB_12M_MetOceanData.csv** **KFII-2-LB_12M_Posdata.csv** **KFII-2-LB_12M_Status.csv** **KFII-2-LB_12M_WaveData.csv** **KFII-2-LB_12M_WindSpeedDirectionTI.csv** **KFII-2-LB_12M_WindStatus.csv**
SWLB monthly dataset*	KFII-1-LB_MXX_CurrentData.csv KFII-1-LB_MXX_MetOceanData.csv KFII-1-LB_MXX_Posdata.csv KFII-1-LB_MXX_Status.csv KFII-1-LB_MXX_WaveData.csv KFII-1-LB_MXX_WindSpeedDirectionTI.csv KFII-1-LB_MXX_WindStatus.csv	KFII-2-LB_MXX_CurrentData.csv KFII-2-LB_MXX_MetOceanData.csv KFII-2-LB_MXX_Posdata.csv KFII-2-LB_MXX_Status.csv KFII-2-LB_MXX_WaveData.csv KFII-2-LB_MXX_WindSpeedDirectionTI.csv KFII-2-LB_MXX_WindStatus.csv
Neptun monthly dataset (Re-analysed) *	KFII-1-LB_MXX_chpr_WS190_....csv KFII-1-LB_MXX_memfile_WS190_....txt KFII-1-LB_MXX_wavepar_WS190_....txt KFII-1-LB_MXX_chpr_WS172_....csv KFII-1-LB_MXX_memfile_WS172_....txt KFII-1-LB_MXX_wavepar_WS172_....txt	KFII-2-LB_MXX_chpr_WS172_....csv KFII-2-LB_MXX_memfile_WS172_....txt KFII-2-LB_MXX_wavepar_WS172_....txt KFII-2-LB_MXX_chpr_SWLB085_....csv KFII-2-LB_MXX_memfile_SWLB085_....txt KFII-2-LB_MXX_wavepar_SWLB085_....txt KFII-2-LB_MXX_chpr_SWLB083_....csv KFII-2-LB_MXX_memfile_SWLB083_....txt KFII-2-LB_MXX_wavepar_SWLB083_....txt
ADCP (upward)	**KFII-1-CP_D1_CurrentData_20230903_20240415.csv** **KFII-1-CP_D2_CurrentData_20240415_20240903.csv**	**KFII-2-CP_D1_CurrentData_20230903_20240415.csv** **KFII-2-CP_D2_CurrentData_20240415_20240903.csv**
Water Level & Pressure	**KFII-1-LB_CP_12M_WaterLevel.csv**	**KFII-2-LB_CP_12M_WaterLevel.csv**
Note * XX = 01 to 12; the monthly periods for respective datafiles.		

Appendix D lists the contents and parameters of each final post-processed datafile listed in Table 4.2. Appendix E gives additional information on any raw data files supplied with this dataset.

5. Data Availability

5.1 Availability Calculations

5.1.1 System availability

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 ("available"), at least one valid data point must be recorded (at any height).

The 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 month or a defined period.

5.1.2 Post-processed data availability

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 or a defined period based on the given time interval of 10-minutes.

5.1.3 Post-processed parameter group availability

The post-processed parameter group availability is determined as follows:

a. Wind: Average of the 10-minute averaged post processed data availabilities per measured elevation, speed, and direction up to and including 200 m from the LiDAR but excluding heights above 200 m. The wind data set also include near surface wind speed and direction measured in mast top (4 m height) by the ancillary anemometer.

b. Atmospheric pressure: main instrument (Vaisala) and ancillary instrument (ZX Lidar).

c. Air temperature: main instrument (Vaisala) or ancillary instrument (ZX Lidar).

d. Air humidity: main instrument (Vaisala).

e. Sea surface temperature: main instrument (Signature or Aquadopp) or ancillary instrument (Thelma)

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

g. Current: Average of current speed and direction over the water column, from 3m depth to the depth 28m and 27m for KFII-1-LB and KFII-2-LB stations, respectively.

h. Water level: water pressure either from Thelma bottom pressure transmitter or from Bottom mounted ADCP, which is greater.

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 5.1 lists the parameters used in the calculations.

Table 5.1: Parameter group availability

Parameter group	Parameters	
Wind	WindSpeed004m m/s, WindSpeed012m m/s, WindSpeed040m m/s, WindSpeed080m m/s, WindSpeed100m m/s, WindSpeed130m m/s, WindSpeed150m m/s, WindSpeed170m m/s, WindSpeed190m m/s WindDir004m deg, WindDir012m deg, WindDir040m deg, WindDir080m deg, WindDir100m deg, WindDir130m deg, WindDir150m deg, WindDir170m deg, WindDir190m deg	
Atmospheric pressure	AirPressure hPa (Vaisala) or AirPressure_lidar hPa	
Air temperature	AirTemperature C (Vaisala) or AirTemp_lidar C	
Air humidity	AirHumidity %	
Sea surface temperature	WaterTemp001 degC (Aquadopp) or adcp_temperature deg C (Signature) or thTBRtemperature degC (Thelma)	
Wave	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	
Current	For KFII-1, AqSpd003 cm/s, AqSpd004 cm/s, …, AqSpd034 cm/s, AqDir003 deg, AqDir004 deg, …, AqDir034 deg, For KFII-2, AqSpd003 cm/s, AqSpd004 cm/s, …, AqSpd026 cm/s, AqDir003 deg, AqDir004 deg, …, AqDir026 deg, Or, currSp003 cm/s, currSp004 cm/s, …, currSp026 cm/s, currDir003 deg, currDir004 deg, …, currDir026 deg	
Water level	WaterPressure dbar	WaterPressure dbar or Pressure (from Bottom mounted ADCP)
Current (Bottom mounted ADCP)		For KFII-1, currSp005 cm/s, currSp006 cm/s, …, currSp034 cm/s, currDir005 deg, currDir006 deg, …, currDir034 deg

Parameter group	Parameters	
		For KFII-2, currSp004 cm/s, currSp005 cm/s, …, currSp024 cm/s, currDir004 deg, currDir005 deg, …, currDir024 deg

The final report is based on the 10-minute averages data transmitted via satellite and the downloaded data after recovery of the buoys. Any gaps in the transmitted data or any data deemed suspicious during the monthly quality checks were flagged. These gaps and issues are investigated once stored data are available. The stored data (pff and raw) are downloaded during a service and at the end of the campaign. When necessary and if available (i.e. no other instrument issues), the data can be re-processed using raw data to fill the gaps. 10-minute averages downloaded from the datalogger form the basis of the final campaign dataset.

5.2 12-month Post-processed Data Availability

5.2.1 Data Availability for KFII-1

The final campaign post-processed data availability per parameter from 3 September 2023 to 3 September 2024 is presented in Table 5.2 to Table 5.4.

Table 5.2: KFII-1-LB SWLB (WS190 and WS172) 12-month data availability (data less than 90% marked in red)

Parameter	Availability [%]	Parameter	Availability [%]
WindDir004m deg	99.9	hm0 m	100.0
WindDir012m deg	98.2	hm0a m	95.3
WindDir040m deg	98.3	hm0b m	100.0
WindDir080m deg	97.3	hmax m	85.7
WindDir100m deg	96.6	mdir deg	100.0
WindDir130m deg	96.4	mdira deg	100.0
WindDir150m deg	96.2	mdirb deg	100.0
WindDir170m deg	96.1	sprtp deg	100.0
WindDir190m deg	96.1	thhf deg	100.0
WindDir220m deg	95.9	thmax s	85.7
WindDir260m deg	95.7	thtp deg	100.0
WindDir300m deg	95.5	tm01 s	100.0
WindGust004m m/s	99.9	tm02 s	100.0
WindSpeed004m m/s	99.9	tm02a s	100.0
WindSpeed012m m/s	98.2	tm02b s	100.0

Parameter	Availability [%]	Parameter	Availability [%]
WindSpeed040m m/s	98.3	tp s	100.0
WindSpeed080m m/s	97.3	tz s	85.7
WindSpeed100m m/s	96.6	AirHumidity %	99.8
WindSpeed130m m/s	96.4	AirPressure hPa	99.0
WindSpeed150m m/s	96.2	AirPressure_lidar hPa	98.6
WindSpeed170m m/s	96.1	AirTemperature C	99.8
WindSpeed190m m/s	96.1	thTBRtemperature degC	99.9
WindSpeed220m m/s	95.9	BottomTemperature degC	98.4
WindSpeed260m m/s	95.7	WaterPressure dbar	100.0
WindSpeed300m m/s	95.5	ofsVisibility m / pws_visibility m	99.2
precipitation mm	100.0	WaterTemp001 degC	100.0
AqDir003 deg	100.0	AqSpd003 cm/s	100.0
AqDir004 deg	100.0	AqSpd004 cm/s	100.0
AqDir005 deg	100.0	AqSpd005 cm/s	100.0
AqDir006 deg	100.0	AqSpd006 cm/s	100.0
AqDir007 deg	100.0	AqSpd007 cm/s	100.0
AqDir008 deg	99.9	AqSpd008 cm/s	99.9
AqDir009 deg	99.4	AqSpd009 cm/s	99.4
AqDir010 deg	98.8	AqSpd010 cm/s	98.8
AqDir011 deg	97.9	AqSpd011 cm/s	97.9
AqDir012 deg	96.9	AqSpd012 cm/s	96.9
AqDir013 deg	93.6	AqSpd013 cm/s	93.6
AqDir014 deg	90.9	AqSpd014 cm/s	90.9
AqDir015 deg	88.1	AqSpd015 cm/s	88.1
AqDir016 deg	84.9	AqSpd016 cm/s	84.9
AqDir017 deg	81.9	AqSpd017 cm/s	81.9
AqDir018 deg	79.2	AqSpd018 cm/s	79.2
AqDir019 deg	77.2	AqSpd019 cm/s	77.2
AqDir020 deg	75.3	AqSpd020 cm/s	75.3
AqDir021 deg	73.3	AqSpd021 cm/s	73.3
AqDir022 deg	71.8	AqSpd022 cm/s	71.8
AqDir023 deg	70.2	AqSpd023 cm/s	70.2

Parameter	Availability [%]	Parameter	Availability [%]
AqDir024 deg	69.1	AqSpd024 cm/s	69.1
AqDir025 deg	67.3	AqSpd025 cm/s	67.3
AqDir026 deg	68.1	AqSpd026 cm/s	68.1
AqDir027 deg	66.5	AqSpd027 cm/s	66.5
AqDir028 deg	65.8	AqSpd028 cm/s	65.8
AqDir029 deg	65.1	AqSpd029 cm/s	65.1
AqDir030 deg	63.8	AqSpd030 cm/s	63.8
AqDir031 deg	64.6	AqSpd031 cm/s	64.6
AqDir032 deg	62.9	AqSpd032 cm/s	62.9
AqDir033 deg	62.1	AqSpd033 cm/s	62.1
AqDir034 deg	61.5	AqSpd034 cm/s	61.5

Table 5.3: Signature post-processed data availability during D1 (3 September 2023 – 15 April 2024)

Parameter	Availability [%]	Parameter	Availability [%]
currDir034 deg	98.1	currSp034 cm/s	98.1
currDir033 deg	98.6	currSp033 cm/s	98.6
currDir032 deg	99.2	currSp032 cm/s	99.2
currDir031 deg	99.6	currSp031 cm/s	99.6
currDir030 deg	99.8	currSp030 cm/s	99.8
currDir029 deg	99.9	currSp029 cm/s	99.9
currDir028 deg	99.9	currSp028 cm/s	99.9
currDir027 deg	100.0	currSp027 cm/s	100.0
currDir026 deg	100.0	currSp026 cm/s	100.0
currDir025 deg	100.0	currSp025 cm/s	100.0
currDir024 deg	100.0	currSp024 cm/s	100.0
currDir023 deg	100.0	currSp023 cm/s	100.0
currDir022 deg	100.0	currSp022 cm/s	100.0
currDir021 deg	100.0	currSp021 cm/s	100.0
currDir020 deg	100.0	currSp020 cm/s	100.0
currDir019 deg	100.0	currSp019 cm/s	100.0
currDir018 deg	100.0	currSp018 cm/s	100.0
currDir017 deg	100.0	currSp017 cm/s	100.0
currDir016 deg	100.0	currSp016 cm/s	100.0
currDir015 deg	100.0	currSp015 cm/s	100.0
currDir014 deg	100.0	currSp014 cm/s	100.0

Parameter	Availability [%]	Parameter	Availability [%]
currDir013 deg	100.0	currSp013 cm/s	100.0
currDir012 deg	100.0	currSp012 cm/s	100.0
currDir011 deg	100.0	currSp011 cm/s	100.0
currDir010 deg	100.0	currSp010 cm/s	100.0
currDir009 deg	99.9	currSp009 cm/s	99.9
currDir008 deg	99.9	currSp008 cm/s	99.9
currDir007 deg	99.8	currSp007 cm/s	99.8
currDir006 deg	99.5	currSp006 cm/s	99.5
currDir005 deg	98.6	currSp005 cm/s	98.6

Table 5.4: Signature post-processed data availability during D2 (15 April 2024– 3 September 2024)

Parameter	Availability [%]	Parameter	Availability [%]
currDir034 deg	100	currSp034 cm/s	100
currDir033 deg	100	currSp033 cm/s	100
currDir032 deg	100	currSp032 cm/s	100
currDir031 deg	100	currSp031 cm/s	100
currDir030 deg	100	currSp030 cm/s	100
currDir029 deg	100.0	currSp029 cm/s	100.0
currDir028 deg	100.0	currSp028 cm/s	100.0
currDir027 deg	100.0	currSp027 cm/s	100.0
currDir026 deg	100.0	currSp026 cm/s	100.0
currDir025 deg	100.0	currSp025 cm/s	100.0
currDir024 deg	100	currSp024 cm/s	100
currDir023 deg	100.0	currSp023 cm/s	100.0
currDir022 deg	100.0	currSp022 cm/s	100.0
currDir021 deg	100	currSp021 cm/s	100
currDir020 deg	100	currSp020 cm/s	100
currDir019 deg	100	currSp019 cm/s	100
currDir018 deg	100	currSp018 cm/s	100
currDir017 deg	100	currSp017 cm/s	100
currDir016 deg	100	currSp016 cm/s	100
currDir015 deg	100.0	currSp015 cm/s	100.0
currDir014 deg	100	currSp014 cm/s	100

Parameter	Availability [%]	Parameter	Availability [%]
currDir013 deg	100	currSp013 cm/s	100
currDir012 deg	100	currSp012 cm/s	100
currDir011 deg	100.0	currSp011 cm/s	100.0
currDir010 deg	100.0	currSp010 cm/s	100.0
currDir009 deg	100.0	currSp009 cm/s	100.0
currDir008 deg	100.0	currSp008 cm/s	100.0
currDir007 deg	100.0	currSp007 cm/s	100.0
currDir006 deg	99.9	currSp006 cm/s	99.9
currDir005 deg	99.7	currSp005 cm/s	99.7

5.2.2 Data Availability for KFII-2

The final campaign post-processed data availability per parameter from 3 September 2023 to 3 September 2024 is presented in Table 5.5 to Table 5.7.

Table 5.5: KFII-2-LB SWLB (WS172, SWLB085 and SWLB083) 12-month data availability

Parameter	Availability [%]	Parameter	Availability [%]
WindDir004m deg	96.3	hm0 m	96.4
WindDir012m deg	89.4	hm0a m	90.2
WindDir040m deg	90.0	hm0b m	96.4
WindDir080m deg	88.8	hmax m	78.4
WindDir100m deg	88.2	mdir deg	96.4
WindDir130m deg	87.9	mdira deg	96.4
WindDir150m deg	87.7	mdirb deg	96.4
WindDir170m deg	87.6	sprtp deg	96.4
WindDir190m deg	87.4	thhf deg	96.4
WindDir220m deg	87.3	thmax s	78.4
WindDir260m deg	87.1	thtp deg	96.4
WindDir300m deg	87.0	tm01 s	96.4
WindGust004m m/s	96.3	tm02 s	96.4
WindSpeed004m m/s	96.3	tm02a s	96.4
WindSpeed012m m/s	92.8	tm02b s	96.4
WindSpeed040m m/s	93.4	tp s	96.4
WindSpeed080m m/s	92.2	tz s	78.4
WindSpeed100m m/s	91.5	AirHumidity %	96.3

Parameter	Availability [%]	Parameter	Availability [%]
WindSpeed130m m/s	91.2	AirPressure hPa	95.5
WindSpeed150m m/s	91.0	AirTemperature C	96.3
WindSpeed170m m/s	90.9	AirPressure_lidar hPa	63.1
WindSpeed190m m/s	90.8	AirTemperature_lidar C	93.8
WindSpeed220m m/s	90.7	thTBRtemperature degC	87.7
WindSpeed260m m/s	90.5	BottomTemperature degC	69.8
WindSpeed300m m/s	90.3	WaterPressure dbar	74.7
precipitation mm	96.4	ofsVisibility m / pws_visibility m	96.4
WaterTemp001 degC / adcp_temperature degC	96.4	AqSpd003 / currSp003 cm/s	96.3
AqDir003 / currDir003 deg	96.3	AqSpd004 / currSp004 cm/s	96.3
AqDir004 / currDir004 deg	96.3	AqSpd005 / currSp005 cm/s	96.3
AqDir005 / currDir005 deg	96.3	AqSpd006 / currSp006 cm/s	96.3
AqDir006 / currDir006 deg	96.3	AqSpd007 / currSp007 cm/s	96.2
AqDir007 / currDir007 deg	96.2	AqSpd008 / currSp008 cm/s	96.1
AqDir008 / currDir008 deg	96.1	AqSpd009 / currSp009 cm/s	96.1
AqDir009 / currDir009 deg	96.1	AqSpd010 / currSp010 cm/s	96.1
AqDir010 / currDir010 deg	96.1	AqSpd011 / currSp011 cm/s	96.0
AqDir011 / currDir011 deg	96.0	AqSpd012 / currSp012 cm/s	95.8
AqDir012 / currDir012 deg	95.8	AqSpd013 / currSp013 cm/s	95.5
AqDir013 / currDir013 deg	95.5	AqSpd014 / currSp014 cm/s	95.1
AqDir014 / currDir014 deg	95.1	AqSpd015 / currSp015 cm/s	94.5
AqDir015 / currDir015 deg	94.5	AqSpd016 / currSp016 cm/s	94.0
AqDir016 / currDir016 deg	94.0	AqSpd017 / currSp017 cm/s	92.9
AqDir017 / currDir017 deg	92.9	AqSpd018 / currSp018 cm/s	91.5
AqDir018 / currDir018 deg	91.5	AqSpd019 / currSp019 cm/s	90.0
AqDir019 / currDir019 deg	90.0	AqSpd020 / currSp020 cm/s	88.8
AqDir020 / currDir020 deg	88.8	AqSpd021 / currSp021 cm/s	87.6
AqDir021 / currDir021 deg	87.6	AqSpd022 / currSp022 cm/s	86.7
AqDir022 / currDir022 deg	86.7	AqSpd023 / currSp023 cm/s	86.6
AqDir023 / currDir023 deg	86.6	AqSpd024 / currSp024 cm/s	87.8
AqDir024 / currDir024 deg	87.8	AqSpd025 / currSp025 cm/s	95.9
AqDir025 / currDir025 deg	95.9	AqSpd026 / currSp026 cm/s	90.5

Parameter	Availability [%]	Parameter	Availability [%]
AqDir026 / currDir026 deg	90.5		

Table 5.6: Signature post-processed data availability during D1 (01 September 2023 – 15 April 2024)

Parameter	Availability [%]	Parameter	Availability [%]
currDir024 deg	95.4	currSp024 cm/s	95.4
currDir023 deg	99.9	currSp023 cm/s	99.9
currDir022 deg	100.0	currSp022 cm/s	100.0
currDir021 deg	100.0	currSp021 cm/s	100.0
currDir020 deg	100.0	currSp020 cm/s	100.0
currDir019 deg	100.0	currSp019 cm/s	100.0
currDir018 deg	100.0	currSp018 cm/s	100.0
currDir017 deg	100.0	currSp017 cm/s	100.0
currDir016 deg	100.0	currSp016 cm/s	100.0
currDir015 deg	100.0	currSp015 cm/s	100.0
currDir014 deg	100.0	currSp014 cm/s	100.0
currDir013 deg	100.0	currSp013 cm/s	100.0
currDir012 deg	100.0	currSp012 cm/s	100.0
currDir011 deg	100.0	currSp011 cm/s	100.0
currDir010 deg	100.0	currSp010 cm/s	100.0
currDir009 deg	99.9	currSp009 cm/s	99.9
currDir008 deg	99.9	currSp008 cm/s	99.9
currDir007 deg	99.9	currSp007 cm/s	99.9
currDir006 deg	99.8	currSp006 cm/s	99.8
currDir005 deg	99.5	currSp005 cm/s	99.5
currDir004 deg	98.6	currSp004 cm/s	98.6

Table 5.7: Signature post-processed data availability during D2 (09 May 2024 – 1 September 2024)

Parameter	Availability [%]	Parameter	Availability [%]
currDir023 deg	100.0	currSp023 cm/s	100.0
currDir022 deg	100.0	currSp022 cm/s	100.0
currDir021 deg	100.0	currSp021 cm/s	100.0
currDir020 deg	100.0	currSp020 cm/s	100.0
currDir019 deg	100.0	currSp019 cm/s	100.0

Parameter	Availability [%]	Parameter	Availability [%]
currDir018 deg	100.0	currSp018 cm/s	100.0
currDir017 deg	100	currSp017 cm/s	100
currDir016 deg	100.0	currSp016 cm/s	100.0
currDir015 deg	100	currSp015 cm/s	100
currDir014 deg	.100.0	currSp014 cm/s	100.0
currDir013 deg	100.0	currSp013 cm/s	100.0
currDir012 deg	100.0	currSp012 cm/s	100.0
currDir011 deg	100.0	currSp011 cm/s	100.0
currDir010 deg	100.0	currSp010 cm/s	100.0
currDir009 deg	100.0	currSp009 cm/s	100.0
currDir008 deg	100.0	currSp008 cm/s	100.0
currDir007 deg	100.0	currSp007 cm/s	100.0
currDir006 deg	99.9	currSp006 cm/s	99.9
currDir005 deg	100.0	currSp005 cm/s	100.0
currDir004 deg	99.6	currSp004 cm/s	99.6

5.3 Post-processed parameter group availability

5.3.1 Parameter group availability for KFII-1

The monthly post processed data availabilities (denoted as “draft”) per main parameter group as reported in the monthly reports is compared to the final monthly post-processed group availability (denoted as “final”) and shown in Table 5.8 and Table 5.9.

Table 5.8: Post-processed parameter group availability (wind, met) in % for data per month: monthly reports (draft) and final dataset (KFII-1-LB)

#	Period (KFII-1-LB)	Wind		Atm. Pressure		Air temp.		Air humidity		Sea surf. Temp.	
		Draft	Final	Draft	Final	Draft	Final	Draft	Final	Draft	Final
1	SepOct2023	99.1	99.2	99.8	100	100.0	100	100.0	100	99.9	100
2	OctNov2023	99.6	99.6	100.0	100	100.0	100	100.0	100	100.0	100
3	NovDec2023	98.5	98.6	99.9	100.0	100.0	100	100.0	100	100.0	100
4	Dec2023Jan2024	99.3	99.3	99.9	100	100.0	100	100.0	100	100.0	100
5	JanFeb2024	96.8	96.8	100.0	100	100.0	100	100.0	100	100.0	100
6	FebMar2024	81.8	81.9	96.6	96.6	99.4	99.5	99.4	99.5	99.6	99.7
7	MarApr2024	96.4	96.5	99.2	100	99.3	100	99.3	98.5	99.9	100

#	Period (KFII-1-LB)	Wind		Atm. Pressure		Air temp.		Air humidity		Sea surf. Temp.	
		Draft	Final	Draft	Final	Draft	Final	Draft	Final	Draft	Final
8	AprMay2024	97.5	97.6	99.5	99.9	99.9	100	99.9	100	99.9	100
9	MayJun2024	97.3	97.4	99.9	100	99.9	100	99.9	100	99.9	100
10	JunJul2024	99.3	99.4	99.9	100	99.9	100	99.9	99.9	99.9	100
11	JulAug2024	99.6	99.8	99.6	100	99.7	100	99.7	100	99.7	100
12	AugSep2024	99.9	99.9	99.9	100	99.9	100	99.9	100	99.9	100

Table 5.9: Post-processed parameter group availability (waves, currents and ADCP) in % for data per month: monthly reports and final dataset (KFII-1-LB)

#	Period (KFII-1-LB)	Wave		Current		Water pressure		Current (Bottom mounted)	
		Draft	Final	Draft	Final	Draft	Final	Draft	Final
1	SepOct2023	100.0	99.2	99.9	100.0	100.0	100	-	99.9
2	OctNov2023	100.0	100.0	100.0	98.2	100.0	100	-	99.9
3	NovDec2023	99.8	99.8	69.3	67.8	100.0	100	-	100.0
4	Dec2023Jan2024	100.0	100.0	55.6	52.8	100.0	100	-	99.8
5	JanFeb2024	99.8	99.9	52.3	46.8	100.0	100	-	99.0
6	FebMar2024	99.2	99.3	74.3	71.9	99.6	100	-	99.7
7	MarApr2024	99.6	99.7	99.8	99.8	99.9	100	-	100.0
8	AprMay2024	99.6	99.7	99.9	100.0	99.9	99.8	-	99.9
9	MayJun2024	99.4	99.5	99.9	100.0	99.9	100	-	100.0
10	JunJul2024	99.5	99.6	99.9	100.0	99.9	100	-	100.0
11	JulAug2024	99.0	99.3	98.7	98.1	99.7	100	-	100.0
12	AugSep2024	99.6	99.7	47.7	49.1	99.9	100	-	100.0

5.3.2 Parameter group availability for KFII-2

The monthly post processed data availabilities (denoted as "draft") per main parameter group as reported in the monthly reports is compared to the final monthly post-processed group availability (denoted as "final") and shown in Table 5.10 and Table 5.11.

Table 5.10: Post-processed parameter group availability (wind, met) in % for data per month: monthly reports (draft) and final dataset (KFII-2-LB)

#	Period (KFII-2-LB)	Wind		Atm. Pressure		Air temp.		Air humidity		Sea surf. Temp.	
		Draft	Final	Draft	Final	Draft	Final	Draft	Final	Draft	Final
1	SepOct2023	98.5	98.6	96.9	99.9	99.9	100.0	99.9	100.0	99.9	100
2	OctNov2023	99.4	99.4	98.5	100.0	99.9	100.0	99.9	100.0	99.9	100
3	NovDec2023	98.3	98.3	97.5	100.0	99.9	100.0	99.9	100.0	99.9	100
4	Dec2023Jan2024	71.7	71.8	96.9	97.0	99.5	99.6	99.5	99.6	100.0	100
5	JanFeb2024	61.9	61.9	99.6	99.7	99.9	100.0	99.9	100.0	99.8	100.0
6	FebMar2024	92.8	92.8	99.9	100.0	99.8	100.0	99.8	99.9	99.9	100
7	MarApr2024	96.1	96.2	99.9	100.0	99.9	100.0	99.9	99.7	99.9	100
8	AprMay2024	97.8	97.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
9	MayJun2024	81.6	81.5	100.0	100.0	100.0	100.0	70.7	70.7	70.7	100
10	JunJul2024	92.0	92.1	99.7	99.8	99.7	99.8	86.5	86.6	86.5	99.8
11	JulAug2024	99.1	99.5	99.7	100.0	99.7	100.0	99.7	100.0	99.7	100
12	AugSep2024	99.8	99.9	100.0	100	100.0	100	100.0	100	100.0	100

Table 5.11: Post-processed parameter group availability (waves, currents and ADCP) in % for data per month: monthly reports (draft) and final dataset (KFII-2-LB/CP)

#	Period (KFII-2-LB)	Wave		Current		Water pressure		Current (Bottom mounted)	
		Draft	Final	Draft	Final	Draft	Final	Draft	Final
1	SepOct2023	99.9	99.2	99.9	100	99.9	100.0	-	99.8
2	OctNov2023	99.8	99.9	99.9	100	99.8	100	-	99.4
3	NovDec2023	99.8	99.9	99.9	93.2	99.9	100	-	99.6
4	Dec2023Jan2024	99.9	99.9	100.0	89.3	100.0	100	-	99.6
5	JanFeb2024	99.8	99.8	99.9	91.4	99.8	100	-	99.7
6	FebMar2024	99.4	99.4	100.0	100.0	99.9	100	-	99.8
7	MarApr2024	99.5	99.6	99.8	100.0	99.9	100	-	99.7
8	AprMay2024	99.5	99.5	99.8	100.0	67.1	99.9	-	99.8
9	MayJun2024	70.4	69.7	70.6	98.1	0	100	-	100.0
10	JunJul2024	86.1	86.1	85.3	98.0	0	100	-	99.9
11	JulAug2024	98.8	99.0	98.2	98.9	29.8*	100	-	100.0
12	AugSep2024	99.3	99.3	92.3	93.0	100.0	100	-	99.9

Note
*Only from online sensor. Offline sensor is deemed to work 100%

6. Uncertainty assessment of the Lidar wind data

All lidar buoys used during the campaign passed though pre-deployment validation: WS190-ZX809 (16 Jun – 3 August 2023); WS172-ZX757 (28 Feb – 21 Mar 2023); SWLB085-ZX1915 (1 – 28 August 2023); SWLB083-ZX1646 (7 Jun – 13 July 2023); Pre-deployment validations [2] [3] [4] [5] contains an uncertainty estimation 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 estimation for the FLS verifications was done according to the IEC bin definition. 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.

For WS190, the overall uncertainty during the pre-deployment validation trial varied between 1.50 % - 5.08 % for wind speeds between 4-16 m/s and 40 – 120 m height.

For WS172, the overall uncertainty during the pre-deployment validation trial varied between 1.50 % - 4.14 % for wind speeds between 4-16 m/s and 40 – 120 m height.

For SWLB085, the overall uncertainty during the pre-deployment validation trial varied between 1.53 % - 3.70 % for wind speeds between 4-16 m/s and 40 – 120 m height.

For SWLB083, the overall uncertainty during the pre-deployment validation trial varied between 1.49 % - 4.49 % for wind speeds between 4-16 m/s and 40 – 120 m height.

7. Results of Data measurement at KFII-1

7.1 Buoy position

Figure 7.1 shows the position of the buoy throughout the campaign, the nominal SWLB anchor and bottom mounted ADCP anchor as-laid positions reported in Table 1.2. There were no drifts of positions.

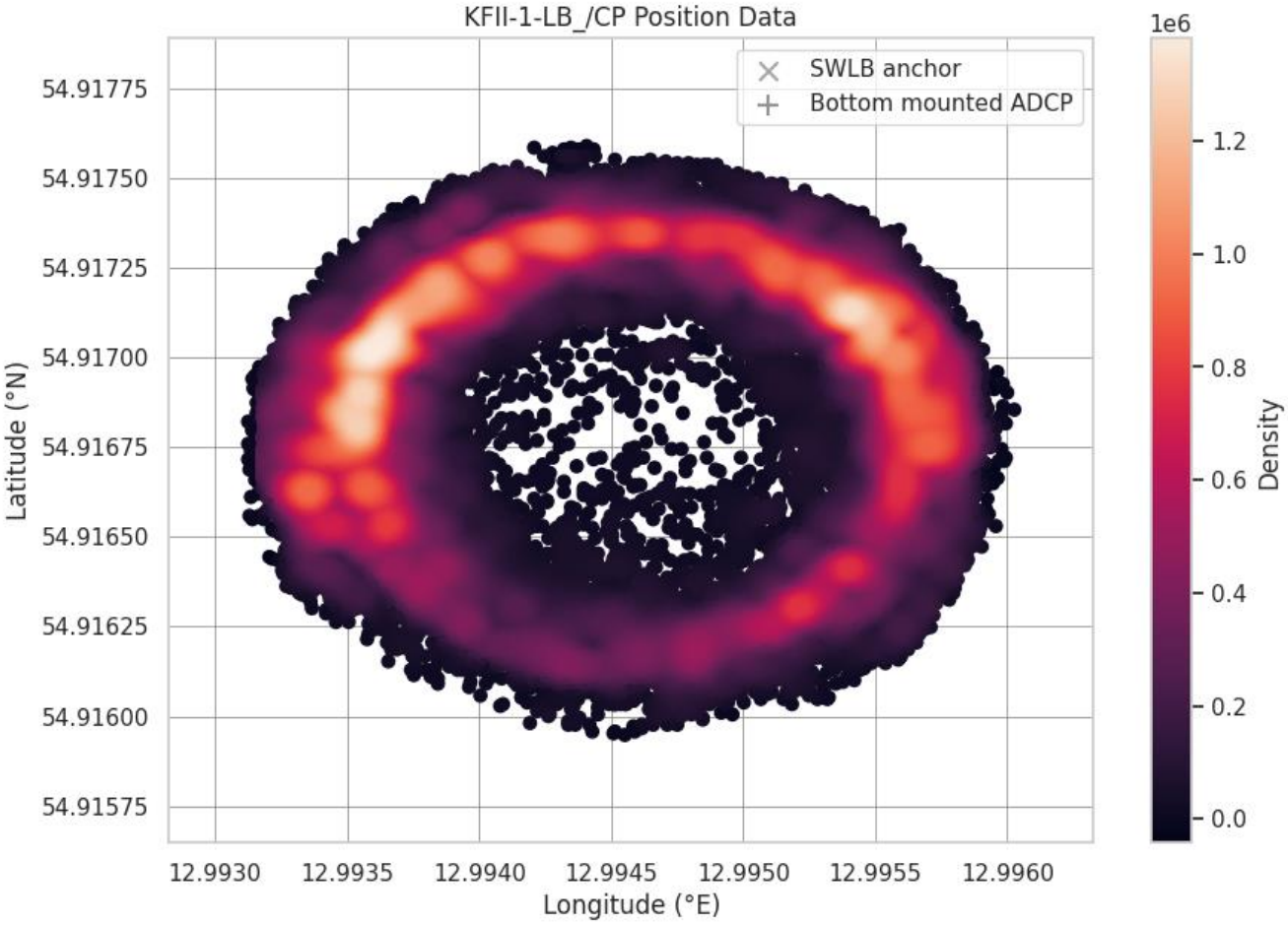


Figure 7.1: Full campaign KFII-1 SWLB and bottom mounted ADCP position data.

7.2 Wind: KFII-1

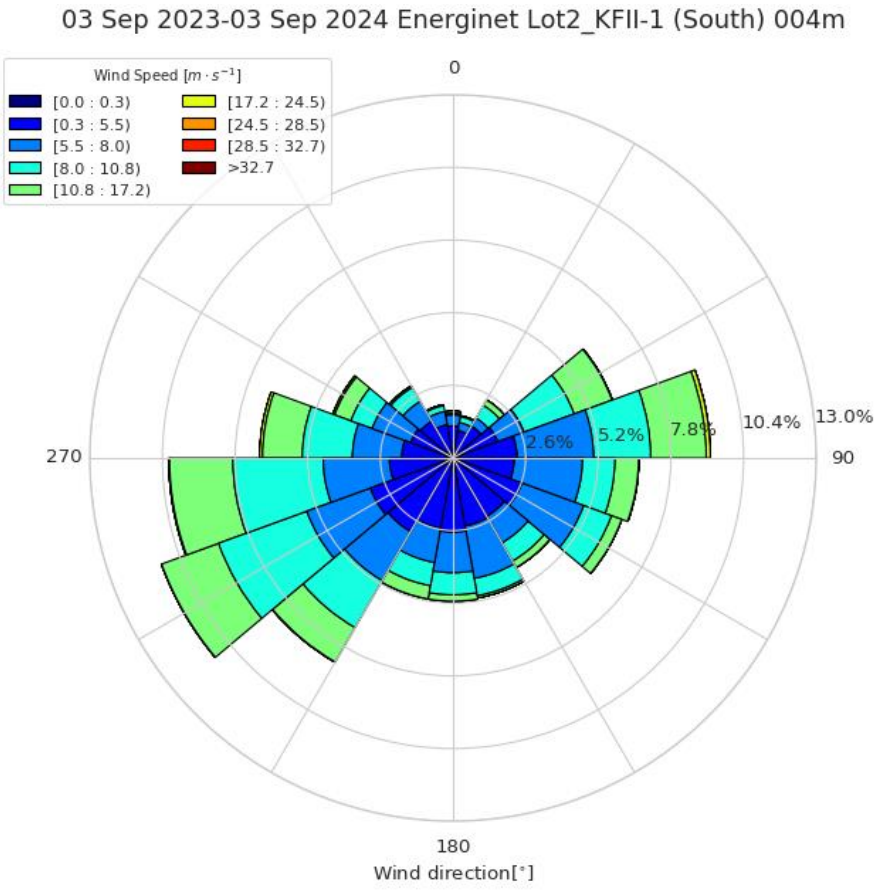
The floating lidar system performed well without disruptions during all 12 months of the campaign. Timeseries of wind speed and direction are presented in Appendix B.

Table 7.1 summarizes statistics for wind speed over the full campaign. Figure 7.2 and Figure 7.3 shows wind roses at 4 heights (4, 100, 170, and 260 m) for all 12 months of data and Figure 7.4 presents the wind speed profile for the full campaign.

The highest wind speeds during the campaign were measured in January 2024. High wind speeds (> 25 m/s) were also measured in October and December 2023. The dominant wind direction was from the south-west and east.

Table 7.1: 12-month summary statistics (standard deviation, minimum, mean and maximum): wind speed at KFII-1

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	3.4	0.0	7.0	21.2
ZephIR Lidar 10min wind speed	12	4.0	0.6	8.0	26.1
	40	4.1	0.5	8.7	27.7
	80	4.5	0.5	9.4	27.5
	100	4.7	0.5	9.7	27.9
	130	4.9	0.5	9.9	28.2
	150	5.1	0.4	10.1	29.6
	170	5.2	0.4	10.2	32.2
	190	5.3	0.5	10.3	35.1
	220	5.4	0.4	10.4	36.3
	260	5.5	0.5	10.5	37.5
	300	5.6	0.5	10.6	39.1



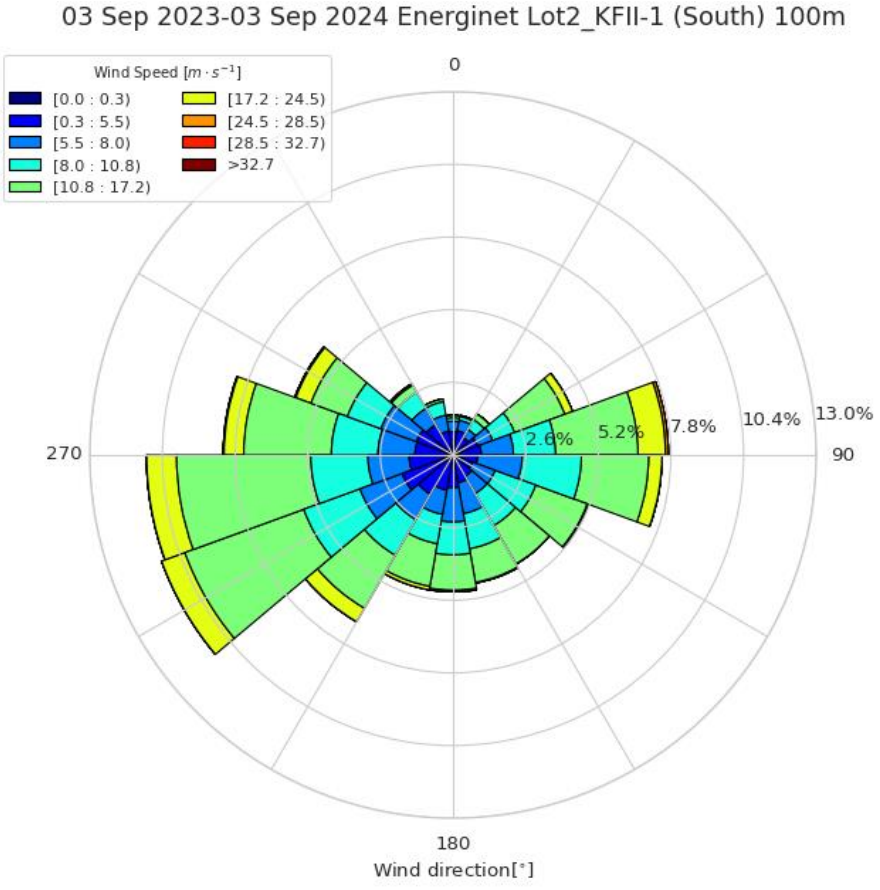
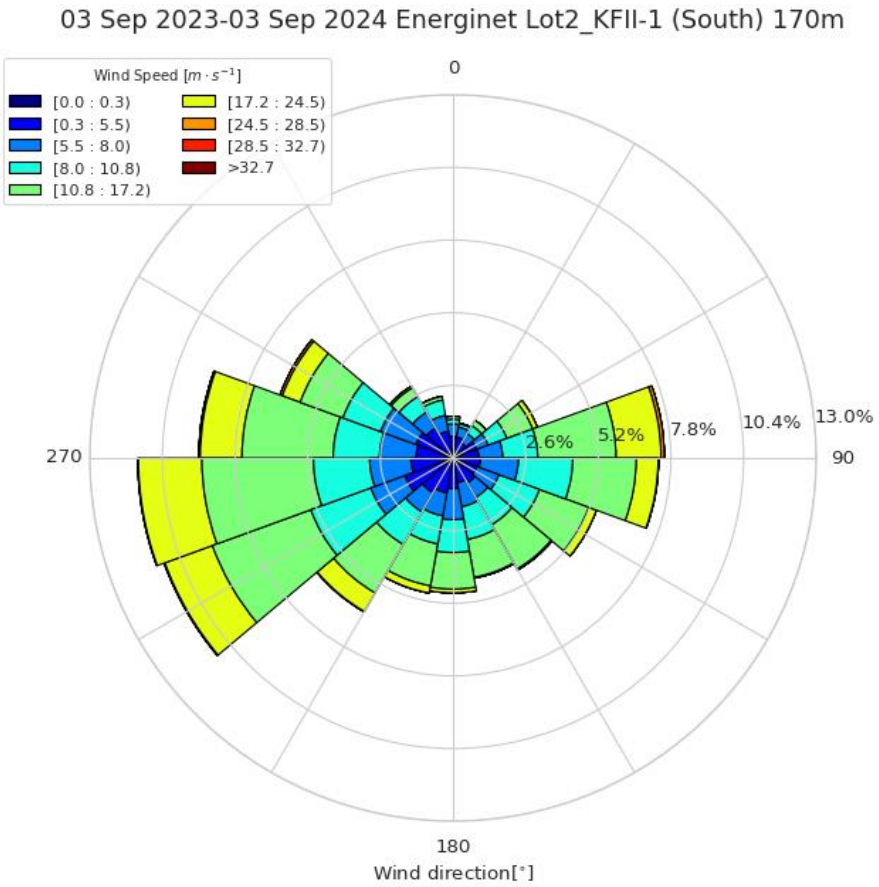


Figure 7.2: Wind roses at 4 m and 100 m height for the full 12 months



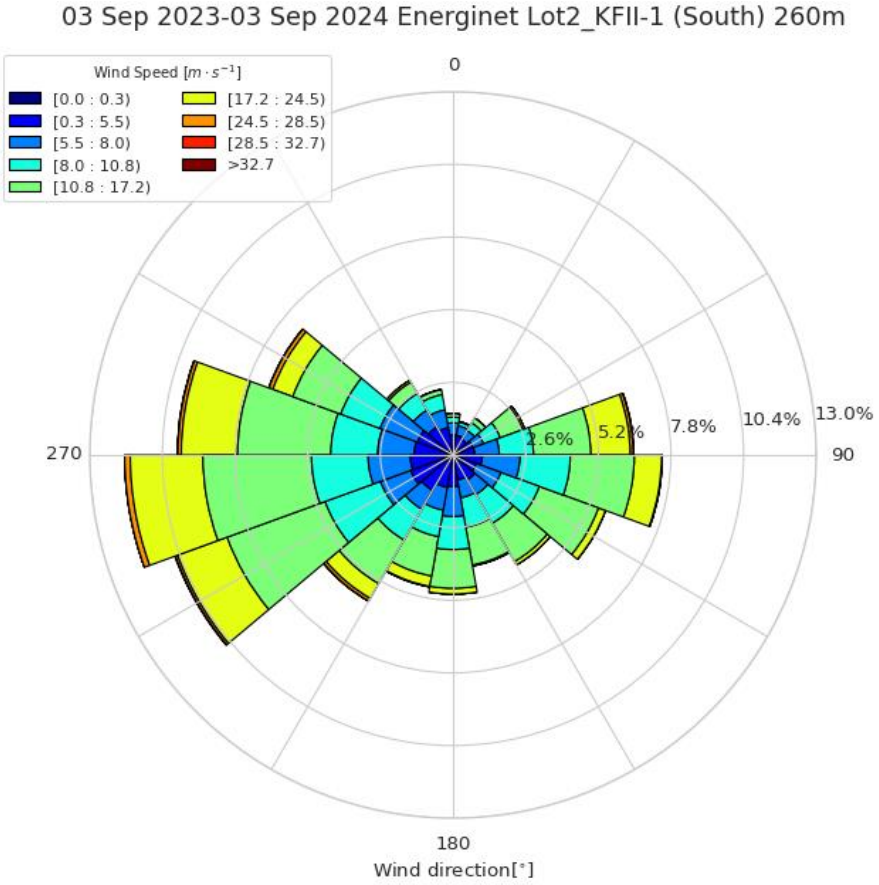


Figure 7.3: Wind roses at 170 m and 260 m height for the full 12 months

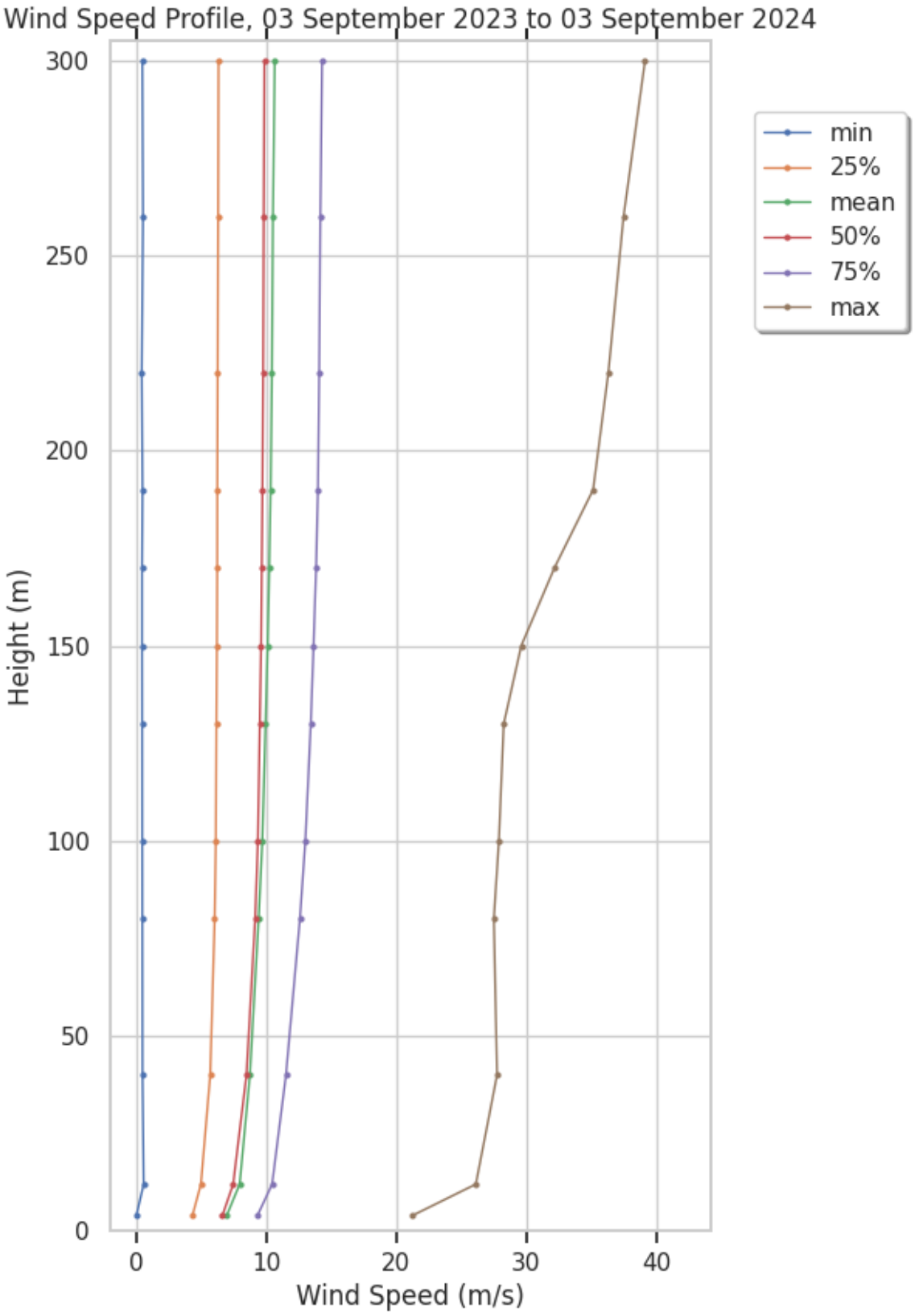


Figure 7.4 : 12-month wind speed profile

7.3 Waves: KFII-1

This chapter includes the results of wave measurement from the SWLB. Timeseries of wave height, period and direction are presented in Appendix B.2

Table 7.2 summarizes statistics for wave heights and periods over the full campaign.

Figure 7.5 shows a wave rose for wave height and mean direction for all 12 months of data. Figure 7.6 and Figure 7.8 show examples of directional wave spectra for 3 high wave events during the campaign.

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

The highest wave heights (hmax > 9 m) during the campaign were measured in October 2023. The dominant wave directions are from the east and south-west.

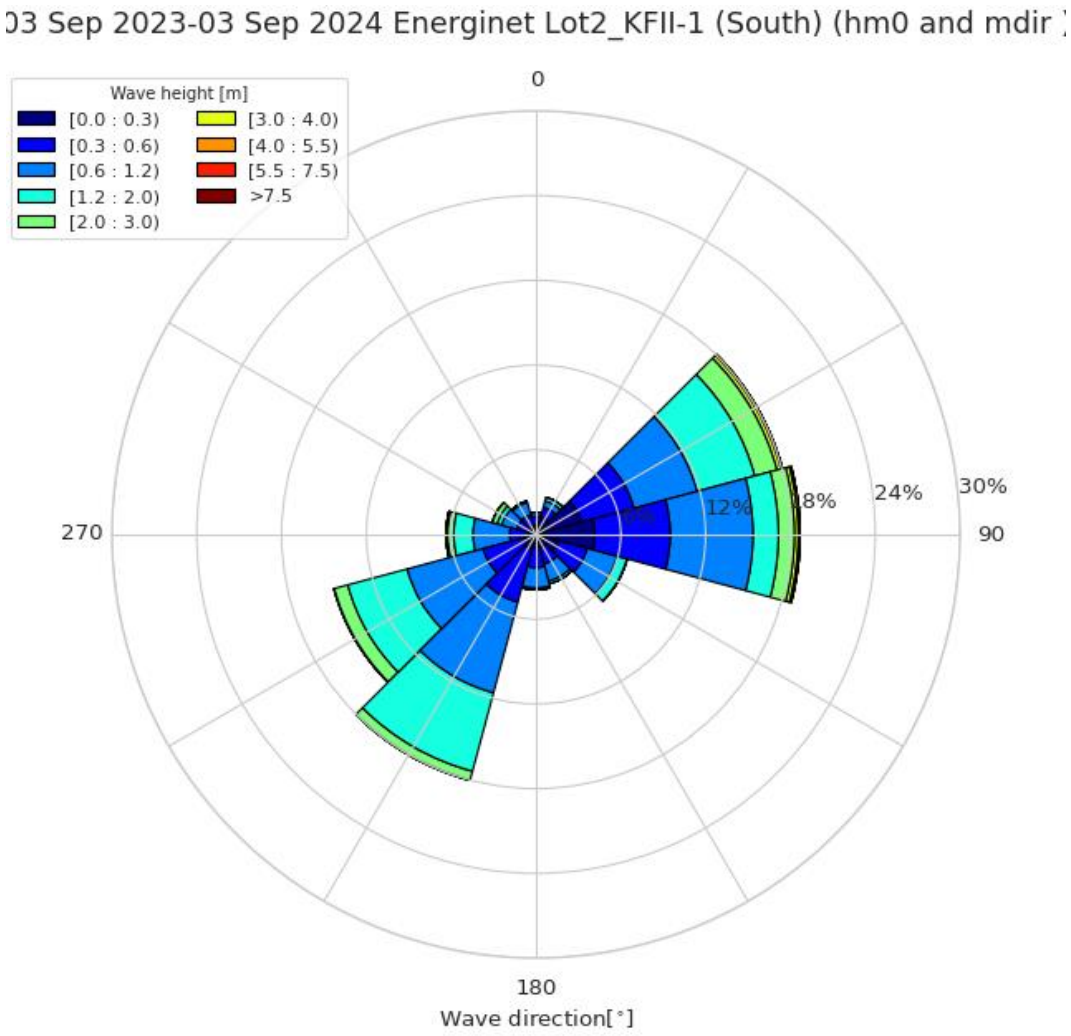
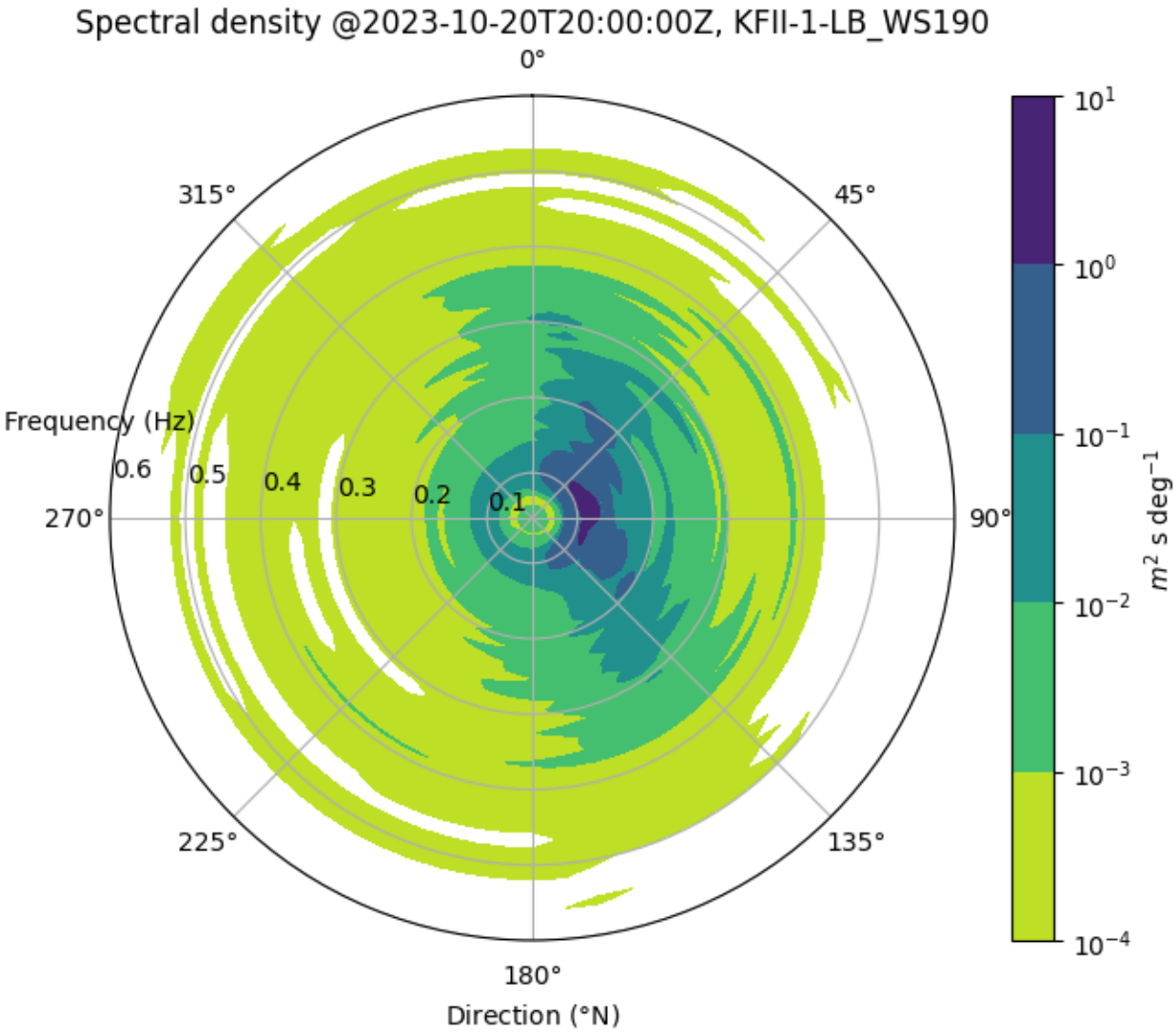


Figure 7.5: 12-month waverose at KFII-1

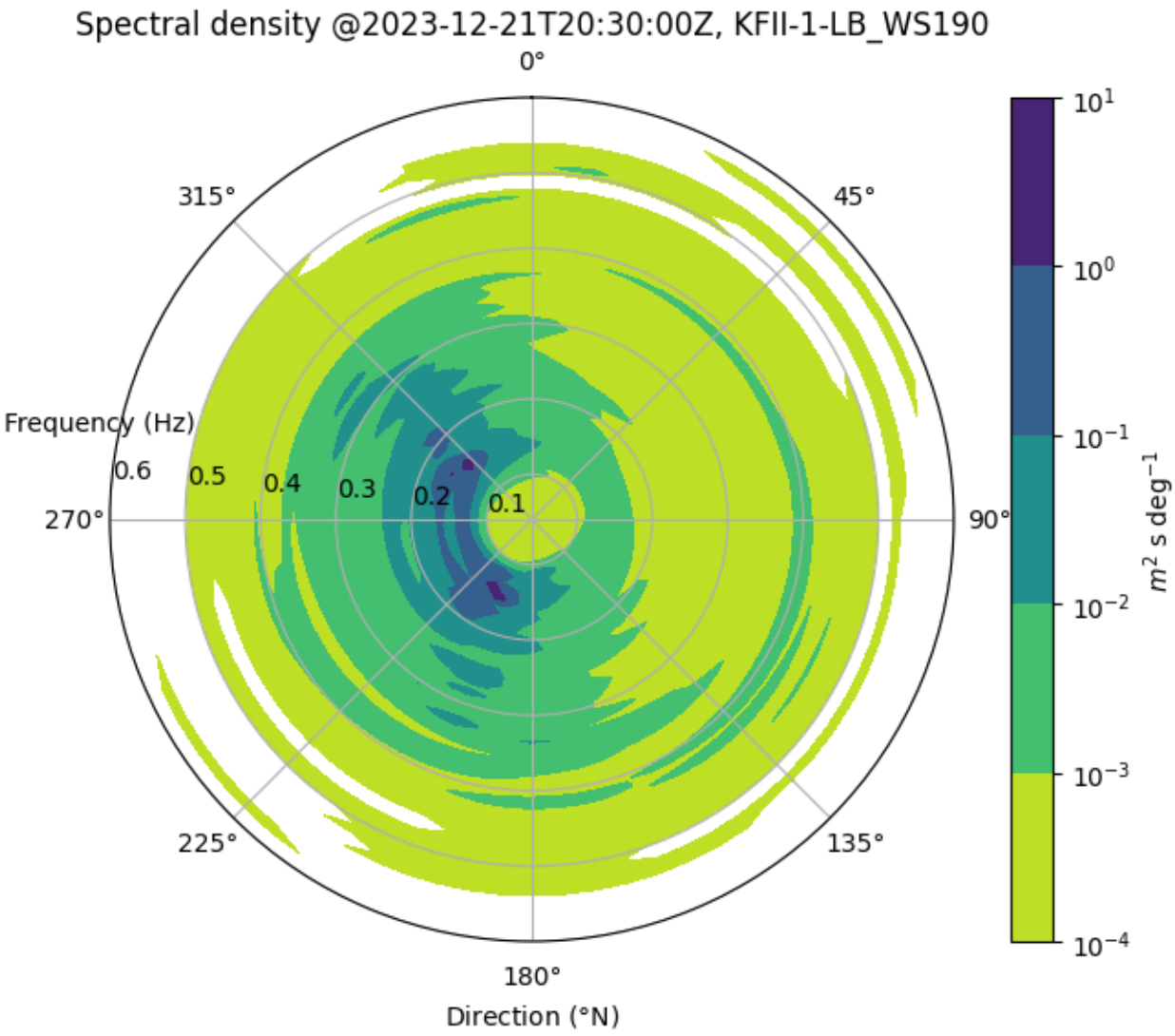
Table 7.2: 12-month summary statistics (standard deviation, minimum, mean and maximum): wave parameters

Parameter	Unit	Standard deviation	Minimum	Mean	Maximum
hm0 m	m	0.7	0.1	0.9	5.7
hmax m	m	1.0	0.3	1.6	11.3
thmax s	s	1.1	2.5	4.4	21.4
tm01 s	s	0.8	2.3	3.8	8.1
tm02 s	s	0.7	2.3	3.6	7.5
tp s	s	1.3	2.0	4.5	10.8
Notes *The height of instrument (Wavesense) is 0m with respect to MWL					



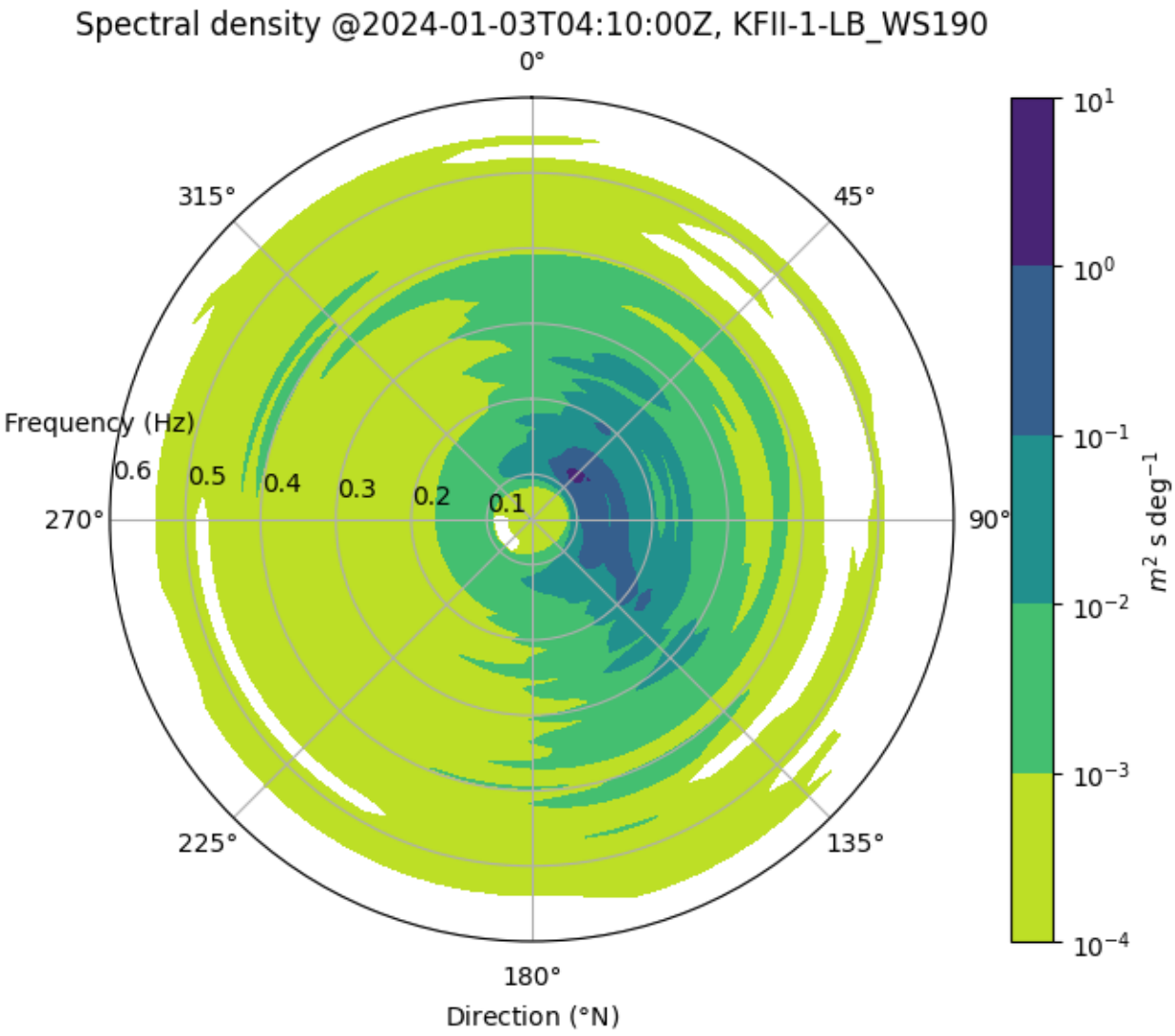
2023-10-20 20:00: hm0 = 5.7 m, hmax=9.9 m tp = 9.0 s mdir = 77.3°

Figure 7.6: Directional wave spectra (MEM spectra m^2/s) from a wave event dated on 20 October 2023.



2023-12-21 20:30: hm0 = 4.3 m, hmax=7.4 m tp = 6.6 s mdir = 243.0°

Figure 7.7: Directional wave spectra (MEM spectra m^2/s) from a wave event dated on 21 December 2023



2024-01-03 04:10: hm0 = 4.4 m, hmax=8.1 m tp = 7.8 s mdir = 70.2°

Figure 7.8: Directional wave spectra (MEM spectra m^2/s) from wave events dated on 3 January 2024

7.4 Metocean Results: KFII-1

7.4.1 Met

Timeseries of all atmospheric parameters are presented in B.3 of Appendix B. 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 7.3 summarizes statistics for the main atmospheric parameters over the full campaign. The lowest air temperature and the lowest air pressure were measured in January 2024. The highest air temperatures were measured in September 2023 and August 2024. The highest air pressures was measured in January 2024.

Table 7.3: 12-month summary statistics of met parameters from 3 September 2023 to 3 September 2024

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
AirHumidity %	% R.H.	4	9.5	37.4	83.5	99.7
AirPressure hPa (PTB330)	hPa	0.5	10.0	967.3	1011.4	1039.8
AirTemperature C (HMP155)	°C	4	6.2	-3.8	10.2	23.5

7.4.2 Sea water temperatures

Table 7.4 summarizes statistics for water temperature from all sensors over the full campaign. Figure 7.9 and Figure 7.10 show timeseries of all seawater temperature data from all sensors.

The water column appears well-mixed during the spring and fall seasons and relatively highly stratified during the summer and winter seasons.

Table 7.4: 12-month summary statistics of sea water temperatures from 3 September 2023 to 3 September 2024

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
Sea surface temperature (Aquadopp)	°C	-1	5.9	3.0	10.6	22.1
Sea surface temperature (Thelma)	°C	-2	5.8	2.8	10.4	20.6
Bottom Water Temperature (Thelma)	°C	2m above seabed	4.0	2.3	9.0	16.9

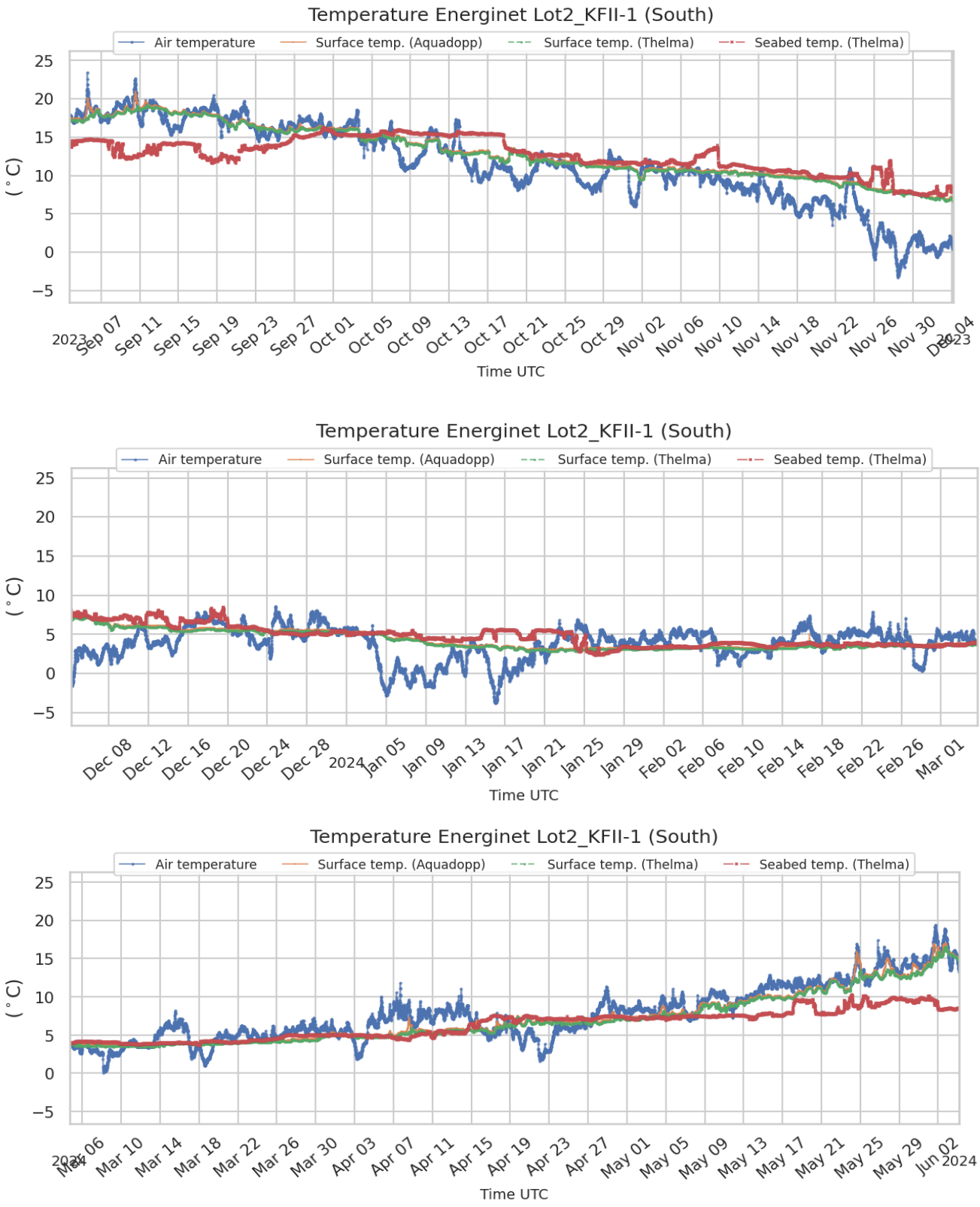


Figure 7.9: Timeseries of all seawater temperature data from all sensors per 3 months intervals (1-3/6)

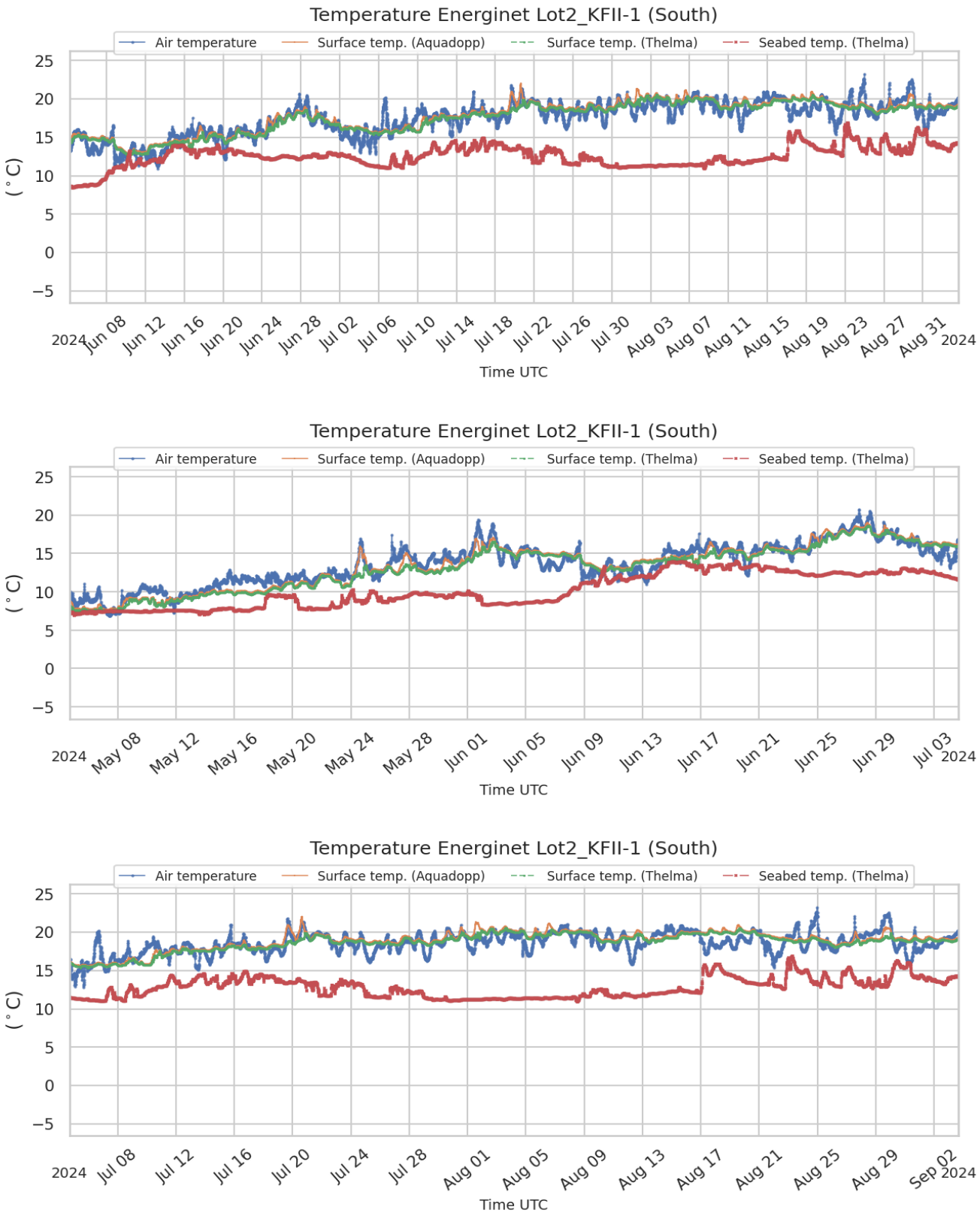


Figure 7.10: Timeseries of all seawater temperature data from all sensors per 3 months intervals (4-6/6)

7.4.3 Water level

Table 7.5 summarizes statistics for water pressure from the Thelma bottom unit and the Signature500 over the full campaign. Figure 7.11 and Figure 7.12 show timeseries of water pressure from both sensors. Given the uncertainties in the sensor heights depending on as-laid locations, two different sensor heights were used for Signature500; 4m for D1 (3 September 2023 to 15 April 2024) and 3m for D2 (15 April 2024 to 3 September 2024). The sensor height of Thelma bottom transmitter is assumed to be 2m. These heights were estimated by a sanity check with two different deployment of Signature instrument and by a validation with other source (Ref. [13]).

Table 7.5: 12-month summary statistics of water pressure from 3 September 2023 to 3 September 2024

Parameter	Unit	Sensor Height [m]	Standard deviation	Minimum†‡	Mean	Maximum
Water pressure (Thelma)	dbar	2.2m above seabed	0.2	38.5	40.1	41.2
Water pressure (Signature500)	dbar	3.4m (D1) and 3.5m (D2) above seabed	0.2	38.4	40.1	41.1
Water level (Thelma)	m	2.2m above seabed	0.2	38.1	39.7	40.9
Water level (Signature500)	m	3.4m (D1) and 3.5m (D2) above seabed	0.2	38.0	39.6	40.8

Notes
†Compared with the water depth (39.6m) to LAT reference from European Marine Observation and Data Network (EMODnet). (https://emodnet.ec.europa.eu/en/bathymetry). Uncertainties in local bathymetry to be taken into consideration for validation of these values.
‡Minimum bound of greater than10 dbar is applied.

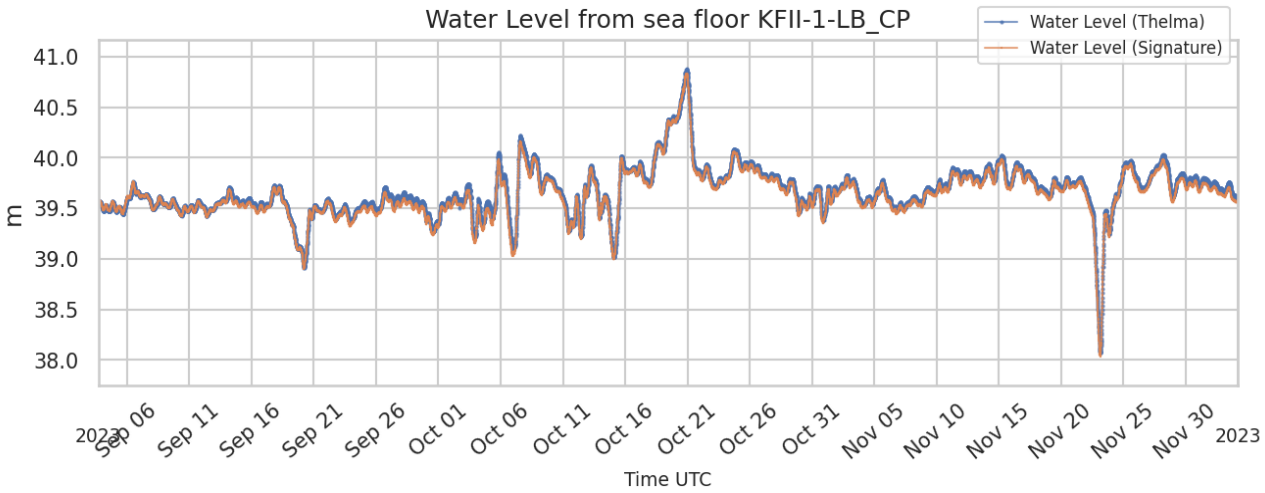


Figure 7.11: Timeseries of water level per 3 months intervals (1/4)

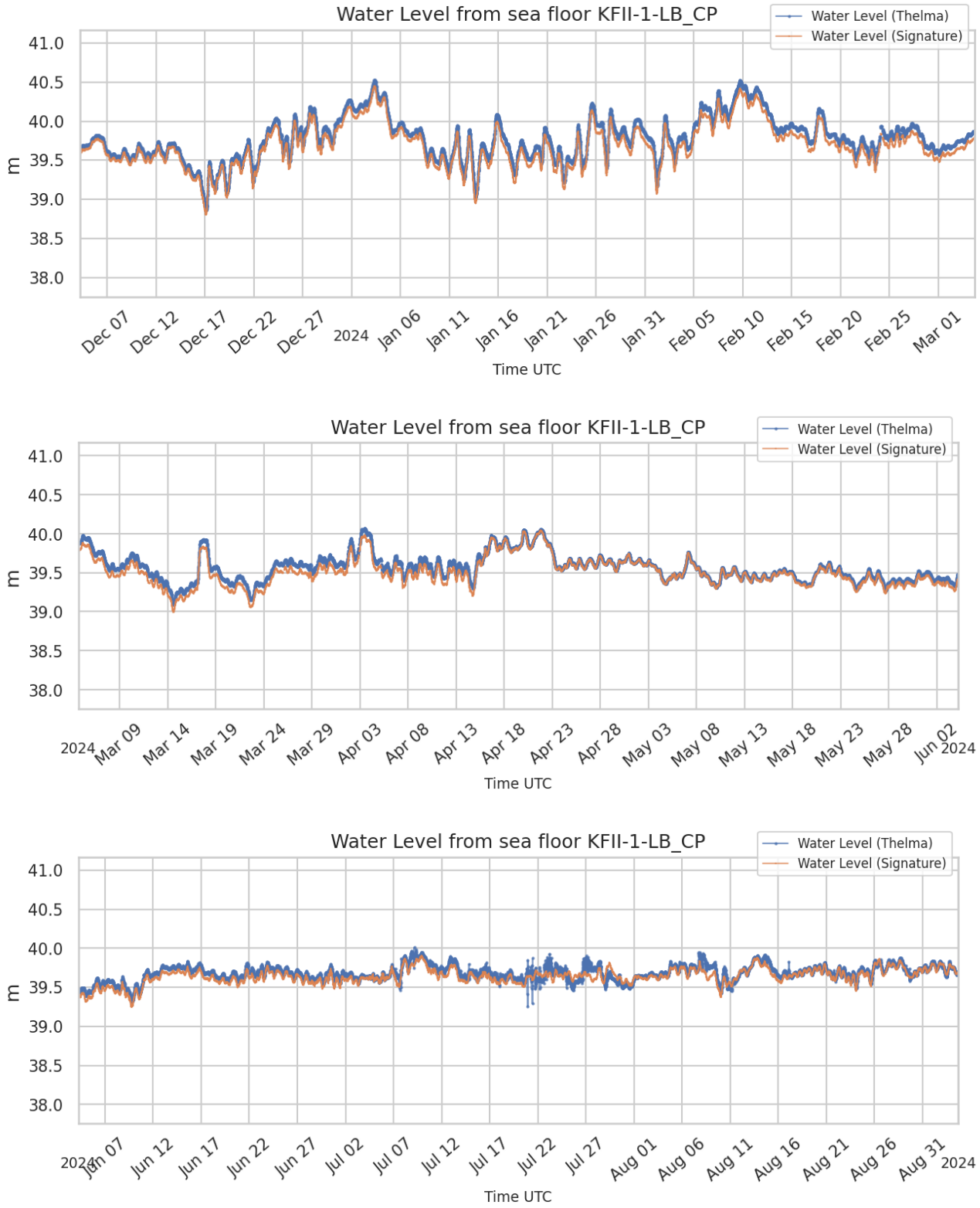


Figure 7.12: Timeseries of water level per 3 months intervals (2-4/4)

7.5 Currents: KFII-1

7.5.1 SWLB ADCP

Heatmaps of current speed and direction are presented in Appendix B.

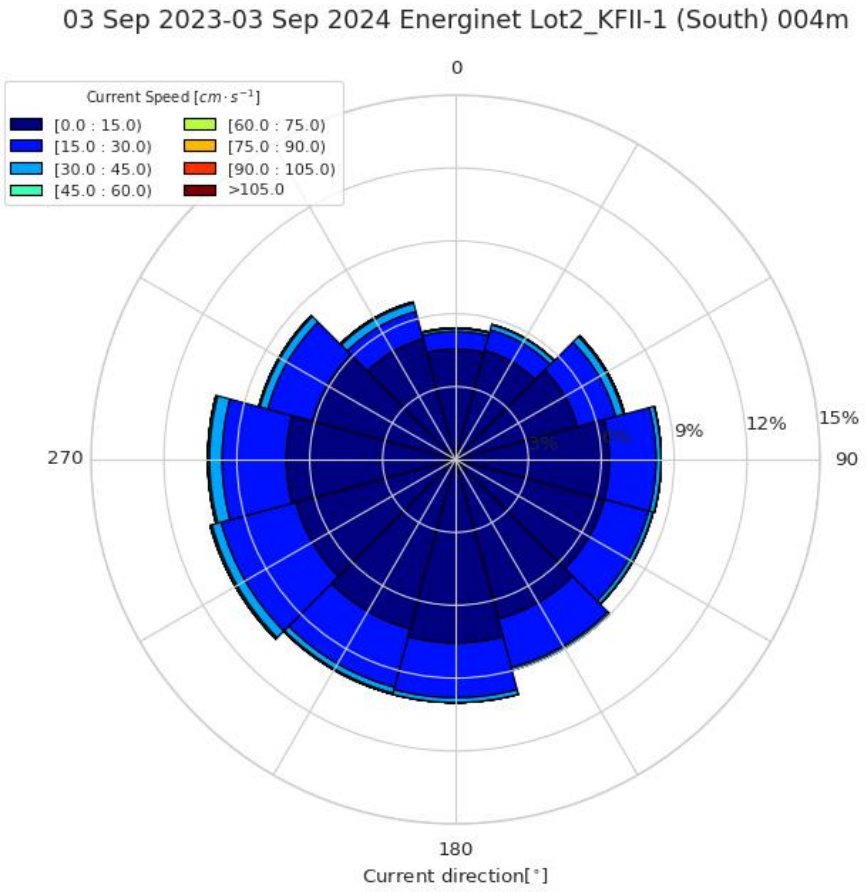
Table 7.6 summarizes statistics for current speed over the full campaign. Figure 7.13 and Figure 7.14 show current roses at 4 depths below the mean sea level (bmsl) (4, 8, 12, and 16 m) for all 12 months of data and Figure 7.15 shows the current speed profile for the full campaign.

The highest current speeds during the campaign were measured in December 2023 and January 2024. All current directions (as given in the CurrentData files) were corrected for magnetic declination and are given relative to true north.

Table 7.6: 12-month summary statistics (standard deviation, minimum, mean and maximum): current speed

Parameter	Unit	Depth bmsl [m]	Standard deviation	Mean	Maximum
AqSpd003	cm/s	-3	11.0	14.0	116.9
AqSpd004	cm/s	-4	8.0	11.9	63.0
AqSpd005	cm/s	-5	8.7	13.0	65.3
AqSpd006	cm/s	-6	9.7	14.4	76.5
AqSpd007	cm/s	-7	10.0	15.0	71.8
AqSpd008	cm/s	-8	10.3	15.1	89.4
AqSpd009	cm/s	-9	10.2	14.8	68.8
AqSpd010	cm/s	-10	10.1	14.5	75.0
AqSpd011	cm/s	-11	9.9	13.9	99.9
AqSpd012	cm/s	-12	9.9	14.3	95.2
AqSpd013	cm/s	-13	10.0	14.1	96.4
AqSpd014	cm/s	-14	9.8	13.7	82.9
AqSpd015	cm/s	-15	9.6	13.5	94.0
AqSpd016	cm/s	-16	9.4	13.2	80.0
AqSpd017	cm/s	-17	9.2	13.0	79.1
AqSpd018	cm/s	-18	9.0	12.7	75.9
AqSpd019	cm/s	-19	8.8	12.5	90.8
AqSpd020	cm/s	-20	8.6	12.3	83.8
AqSpd021	cm/s	-21	8.3	12.0	92.6
AqSpd022	cm/s	-22	8.1	11.8	91.1
AqSpd023	cm/s	-23	7.9	11.8	94.3
AqSpd024	cm/s	-24	7.8	11.7	88.2

Parameter	Unit	Depth bmsl [m]	Standard deviation	Mean	Maximum
AqSpd025	cm/s	-25	7.5	11.4	90.2
AqSpd026	cm/s	-26	7.7	11.4	85.0
AqSpd027	cm/s	-27	7.3	11.3	71.2
AqSpd028	cm/s	-28	7.2	11.2	68.3
AqSpd029	cm/s	-29	7.0	11.0	78.8
AqSpd030	cm/s	-30	6.9	10.8	66.2
AqSpd031	cm/s	-31	6.9	10.7	75.3
AqSpd032	cm/s	-32	6.9	10.7	63.6
AqSpd033	cm/s	-33	6.9	10.6	74.7
AqSpd034	cm/s	-34	7.0	10.7	64.5



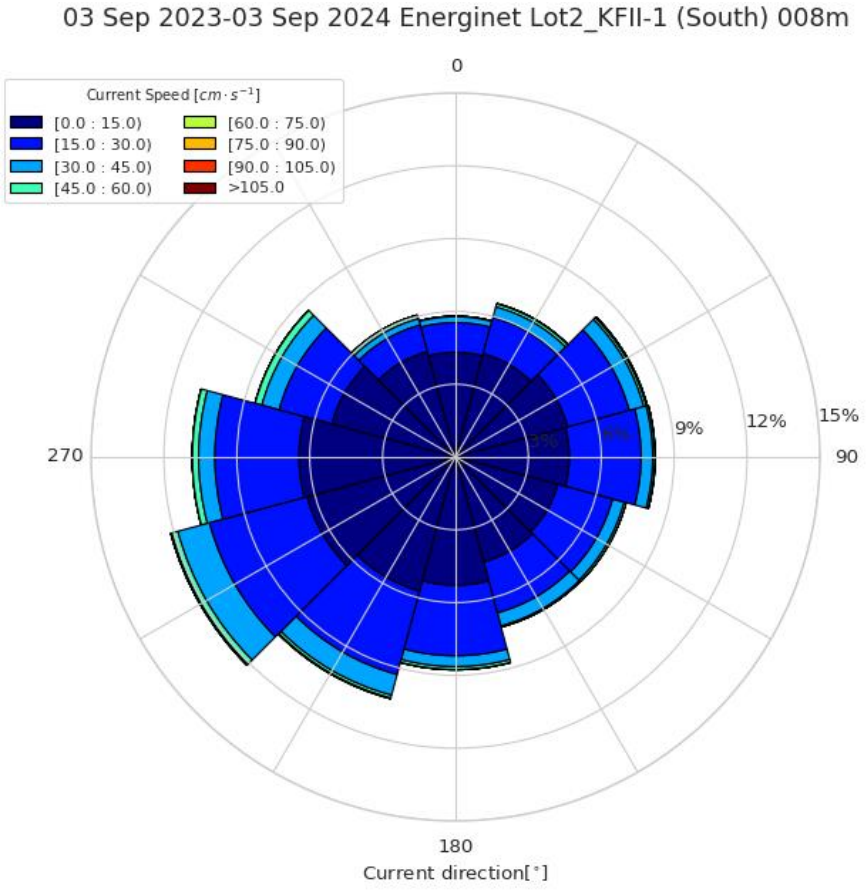
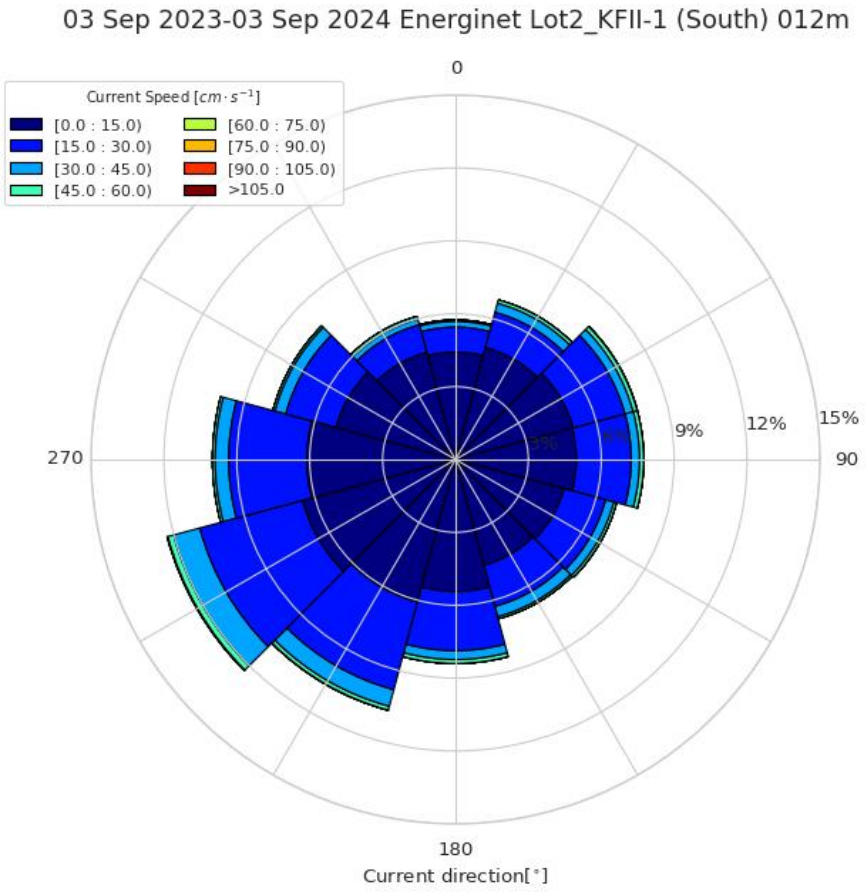


Figure 7.13: Current roses at depths 4 m (top) and 8 m (bottom) for the full 12 months



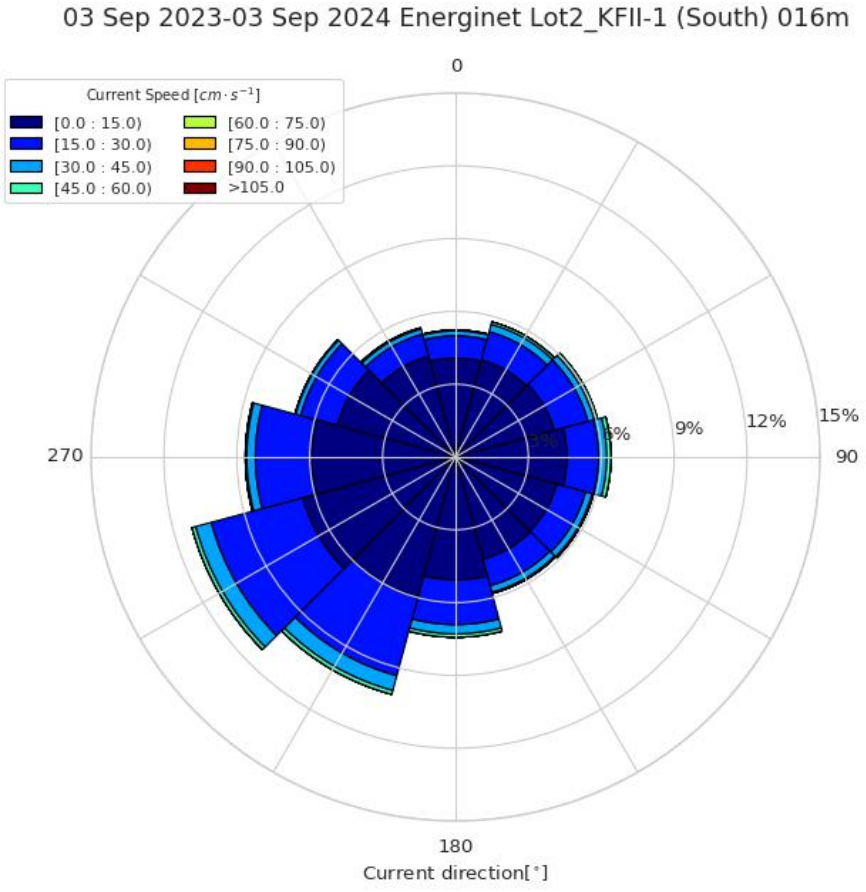


Figure 7.14 Current roses at depths 12 m (top) and 16 m (bottom) for the full 12 months

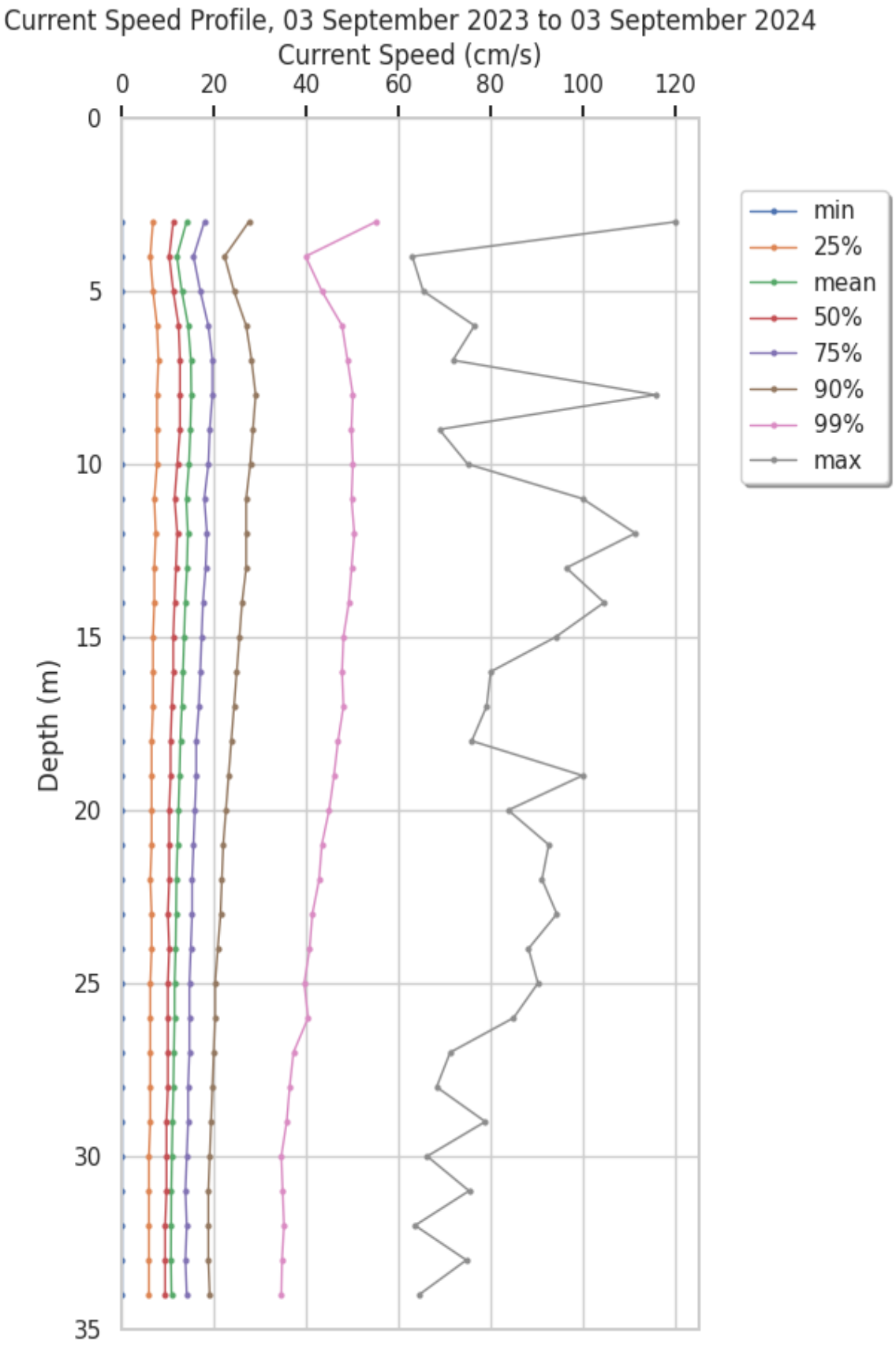


Figure 7.15: 12-month current speed profile

7.5.2 Upward-facing Signature

Heatmaps of current speed and direction are presented in Appendix B.5 . All current directions were corrected for magnetic declination and are given relative to true north.

Table 7.7 and Table 7.8 summarize statistics for current speed over D1 (3 September 2023 – 15 April 2024) and D2 (15 April 2024 – 3 September 2024) respectively. Current roses at four heights above the seafloor (17, 13, 9, and 5 m) are shown in Figure 7.16 through Figure 7.19 while Figure 7.20 and Figure 7.21 show the current speed profiles for D1 and D2, respectively.

The highest current speeds during D1 were measured in October 2023 while the highest current speeds during D2 were measured in April 2024. The mean current speeds are in a range of 12-14 cm/s for D1 and 9-11 cm/s for D2.

Table 7.7: Current speed summary statistics over D1 (3 September 2023 – 15 April 2024).

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp034 cm/s	cm/s	34	9.6	0.1	14.4	81.3
currSp033 cm/s	cm/s	33	9.6	0.2	14.4	81.9
currSp032 cm/s	cm/s	32	9.5	0.2	14.2	81.0
currSp031 cm/s	cm/s	31	9.4	0.0	14.1	79.6
currSp030 cm/s	cm/s	30	9.3	0.1	13.9	78.7
currSp029 cm/s	cm/s	29	9.2	0.1	13.8	76.5
currSp028 cm/s	cm/s	28	9.1	0.1	13.7	73.3
currSp027 cm/s	cm/s	27	9.0	0.1	13.6	70.9
currSp026 cm/s	cm/s	26	8.9	0.0	13.6	70.1
currSp025 cm/s	cm/s	25	8.8	0.0	13.5	70.0
currSp024 cm/s	cm/s	24	8.6	0.0	13.4	69.8
currSp023 cm/s	cm/s	23	8.5	0.1	13.3	68.6
currSp022 cm/s	cm/s	22	8.4	0.1	13.1	67.5
currSp021 cm/s	cm/s	21	8.3	0.0	12.9	66.4
currSp020 cm/s	cm/s	20	8.1	0.0	12.8	65.3
currSp019 cm/s	cm/s	19	8.0	0.0	12.6	63.2
currSp018 cm/s	cm/s	18	7.9	0.0	12.5	61.8
currSp017 cm/s	cm/s	17	7.9	0.1	12.4	61.3
currSp016 cm/s	cm/s	16	7.9	0.0	12.3	62.4
currSp015 cm/s	cm/s	15	8.0	0.0	12.3	61.9
currSp014 cm/s	cm/s	14	8.2	0.0	12.3	63.1
currSp013 cm/s	cm/s	13	8.4	0.1	12.3	64.5
currSp012 cm/s	cm/s	12	8.6	0.1	12.2	71.8
currSp011 cm/s	cm/s	11	8.7	0.0	12.1	79.7
currSp010 cm/s	cm/s	10	8.9	0.1	12.1	89.9

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp009 cm/s	cm/s	9	9.0	0.1	12.0	96.4
currSp008 cm/s	cm/s	8	9.2	0.1	12.1	94.6
currSp007 cm/s	cm/s	7	9.4	0.1	12.2	89.9
currSp006 cm/s	cm/s	6	9.9	0.0	12.4	76.6
currSp005 cm/s	cm/s	5	10.3	0.1	13.0	75.6
Note * Height above the seafloor						

Table 7.8: Current speed summary statistics over D2 (15 April 2024 – 3 September 2024).

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp034 cm/s	cm/s	34	7.0	0.1	11.4	51.6
currSp033 cm/s	cm/s	33	6.9	0.0	11.2	47.0
currSp032 cm/s	cm/s	32	6.8	0.1	11.1	46.0
currSp031 cm/s	cm/s	31	6.8	0.1	10.9	45.8
currSp030 cm/s	cm/s	30	6.7	0.1	10.7	43.9
currSp029 cm/s	cm/s	29	6.6	0.0	10.5	42.8
currSp028 cm/s	cm/s	28	6.5	0.0	10.4	43.3
currSp027 cm/s	cm/s	27	6.5	0.1	10.3	43.8
currSp026 cm/s	cm/s	26	6.4	0.1	10.3	44.6
currSp025 cm/s	cm/s	25	6.2	0.1	10.3	43.6
currSp024 cm/s	cm/s	24	6.1	0.1	10.3	42.7
currSp023 cm/s	cm/s	23	6.0	0.1	10.4	41.0
currSp022 cm/s	cm/s	22	5.9	0.1	10.4	38.7
currSp021 cm/s	cm/s	21	6.0	0.1	10.4	38.4
currSp020 cm/s	cm/s	20	6.0	0.1	10.4	39.9
currSp019 cm/s	cm/s	19	6.0	0.1	10.2	40.7
currSp018 cm/s	cm/s	18	6.0	0.1	10.0	42.5
currSp017 cm/s	cm/s	17	6.0	0.0	9.9	43.8
currSp016 cm/s	cm/s	16	5.9	0.1	9.8	42.4
currSp015 cm/s	cm/s	15	5.9	0.0	9.7	41.3
currSp014 cm/s	cm/s	14	5.8	0.1	9.6	42.4
currSp013 cm/s	cm/s	13	5.7	0.0	9.6	44.0
currSp012 cm/s	cm/s	12	5.7	0.1	9.5	41.4
currSp011 cm/s	cm/s	11	5.6	0.0	9.4	36.7
currSp010 cm/s	cm/s	10	5.5	0.1	9.4	33.9
currSp009 cm/s	cm/s	9	5.4	0.1	9.3	38.5

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp008 cm/s	cm/s	8	5.3	0.1	9.2	42.0
currSp007 cm/s	cm/s	7	5.2	0.0	9.1	43.8
currSp006 cm/s	cm/s	6	5.2	0.0	9.0	36.7
currSp005 cm/s	cm/s	5	5.4	0.0	9.1	39.2

Note
* Height above the seafloor

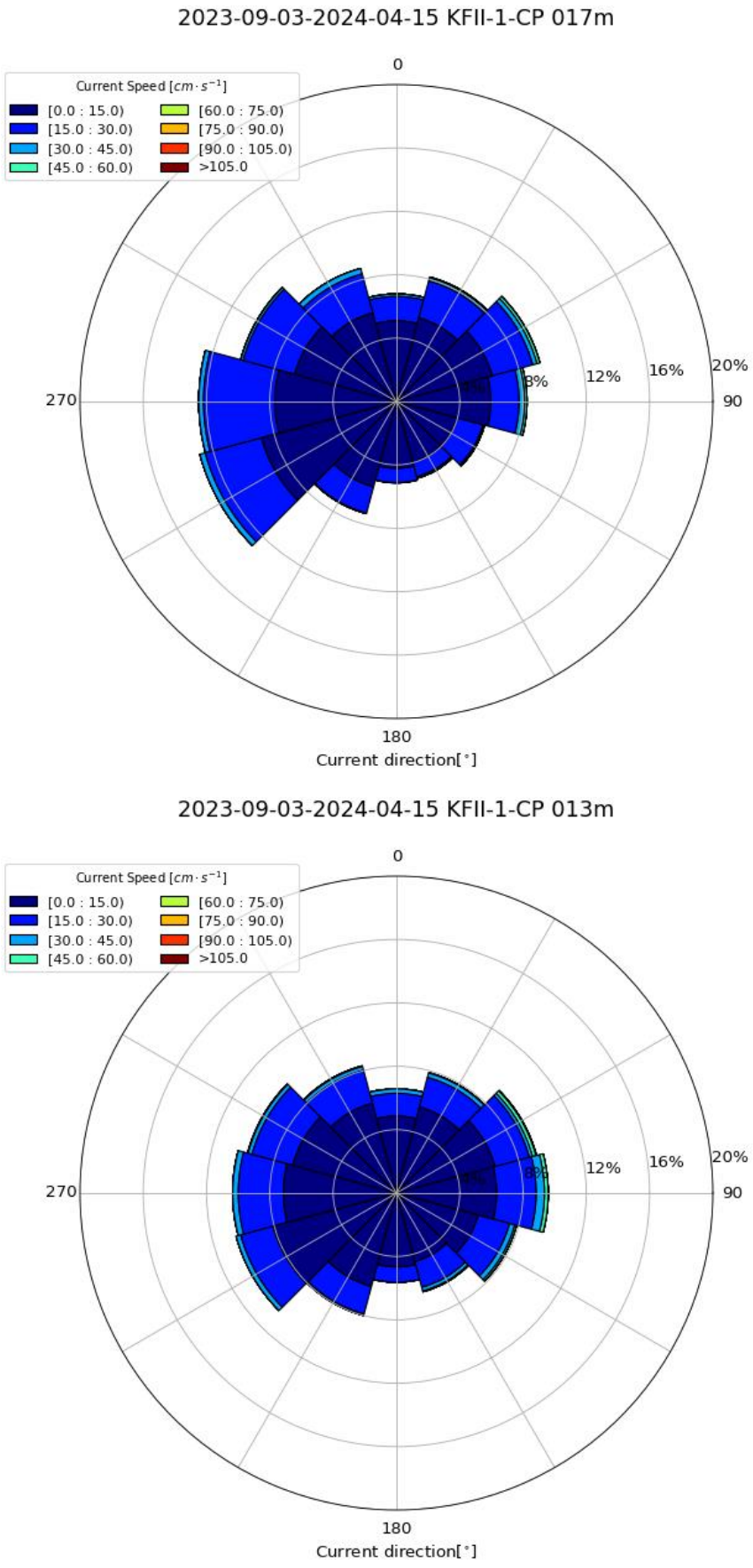


Figure 7.16 Current speed profile at heights 17m (top) and 13m (bottom) during D1 (3 September 2023 – 15 April 2024). Note that heights are given relative to the seafloor.

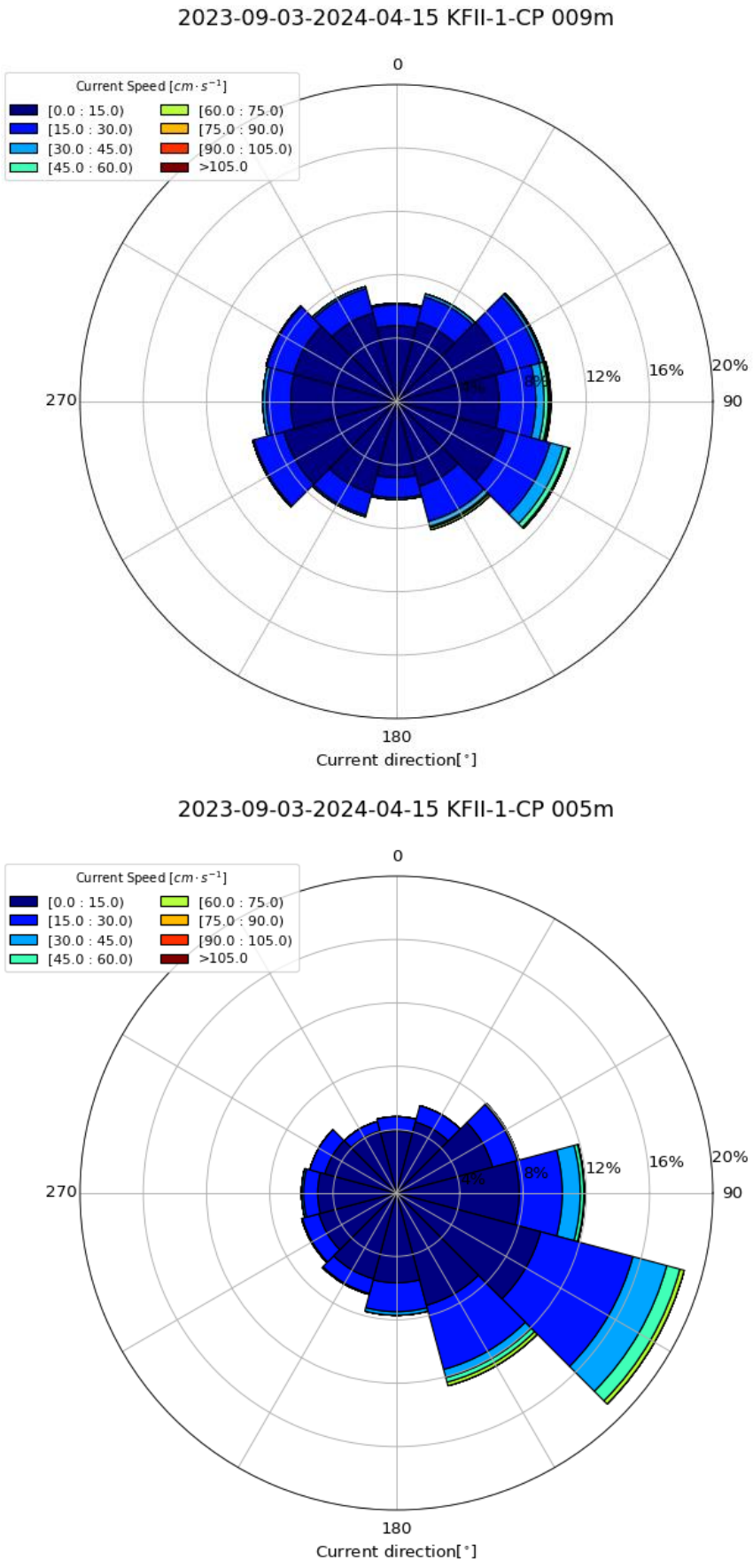


Figure 7.17 Current speed profile at heights 9m (top) and 5m (bottom) during D1 (3 September 2023 – 15 April 2024). Note that heights are given relative to the seafloor.

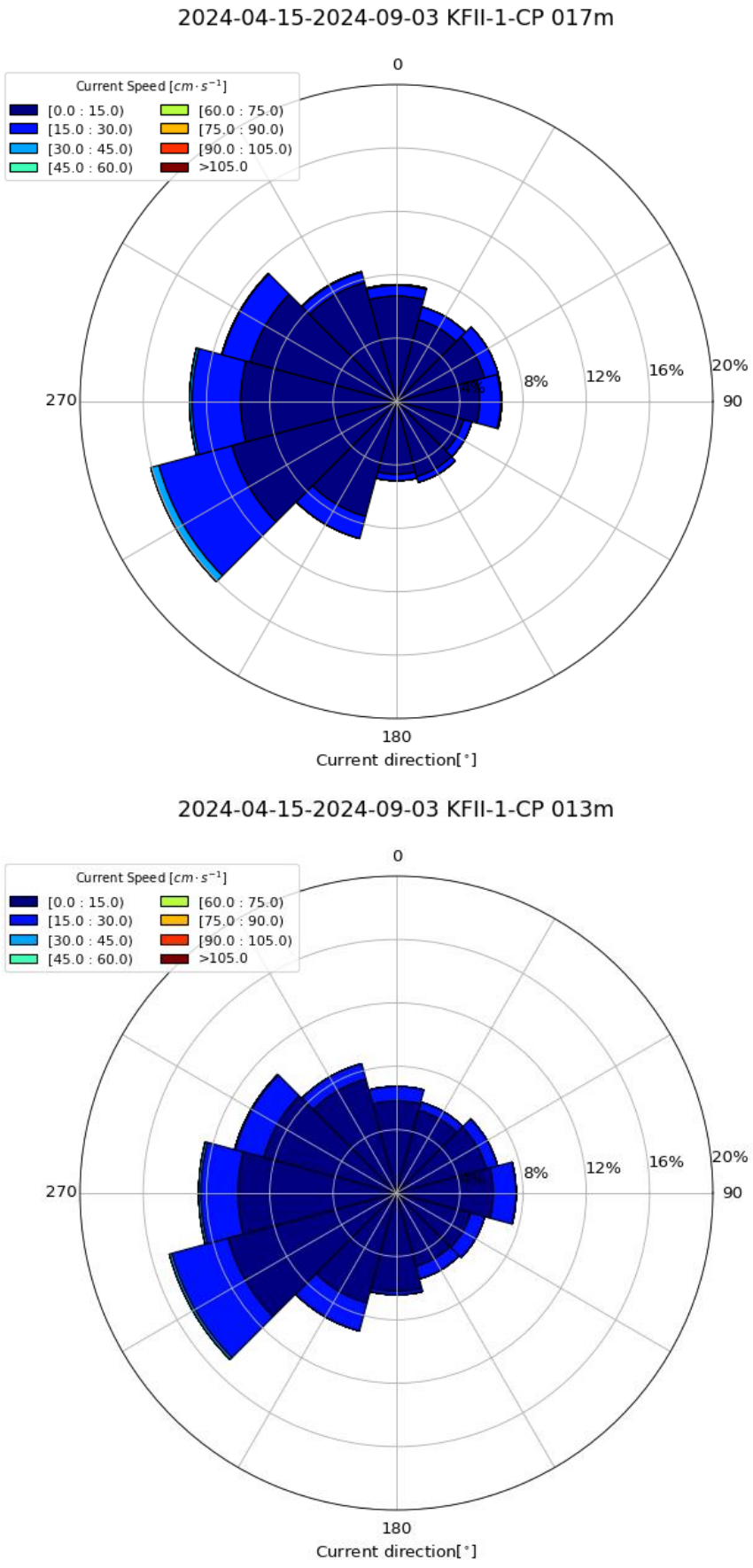


Figure 7.18 Current speed profile at heights 17m (top) and 13m (bottom) during D2 (15 April 2024 – 3 September 2024). Note that heights are given relative to the seafloor.

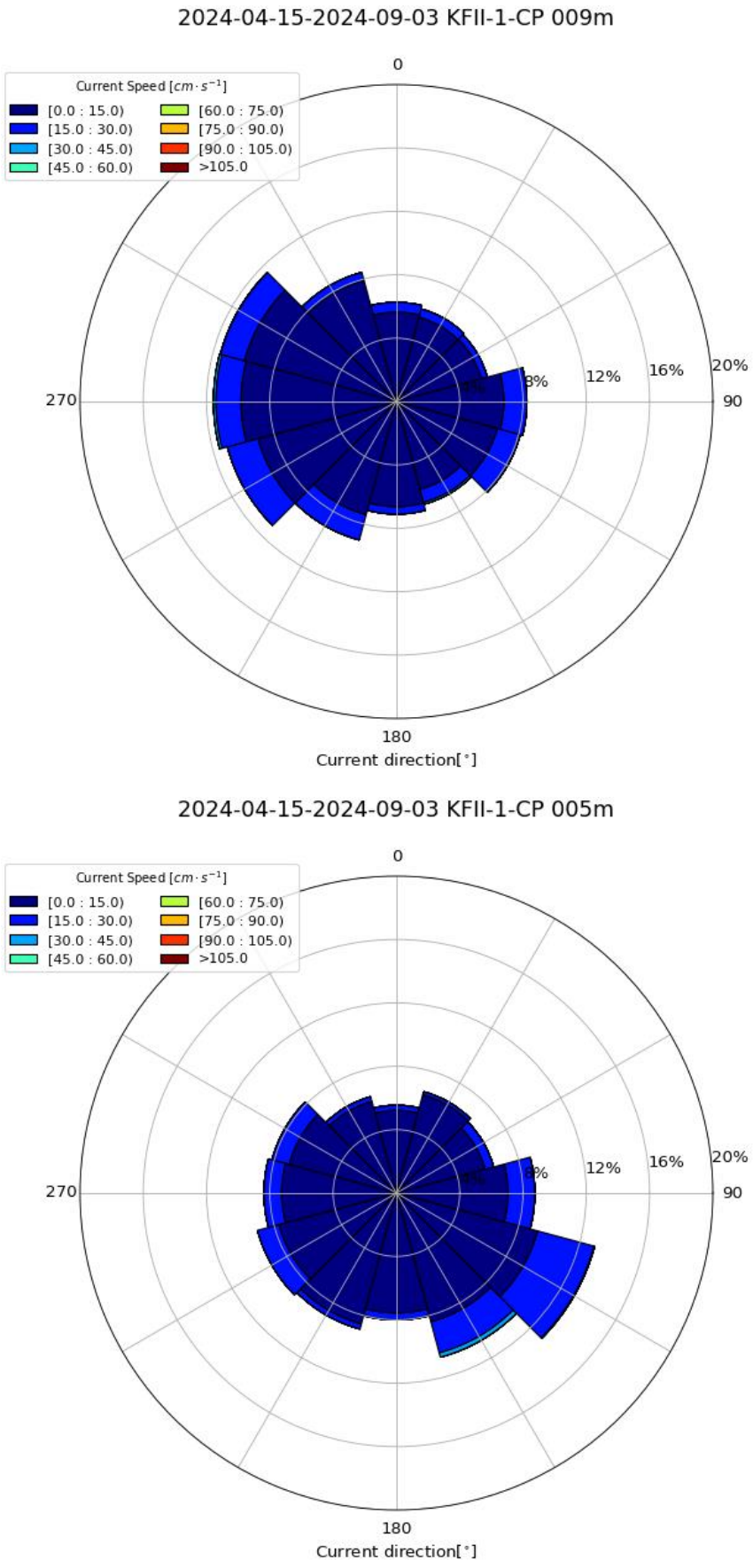


Figure 7.19 Current speed profile at heights 9m (top) and 5m (bottom) during D2 (15 April 2024 – 3 September 2024). Note that heights are given relative to the seafloor.

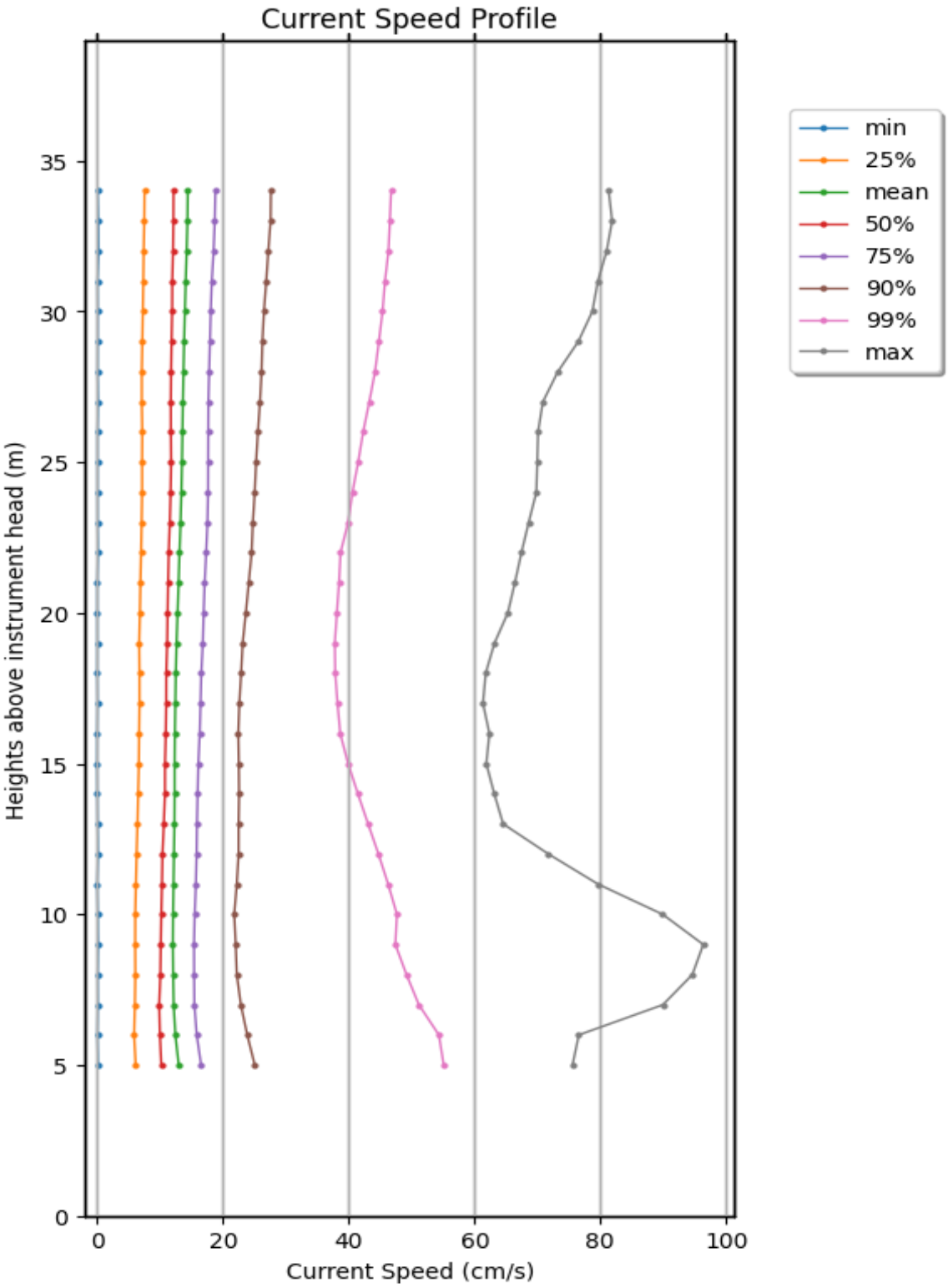


Figure 7.20: KFII-1-CP current speed profile for D1 (3 September 2023 – 15 April 2024)

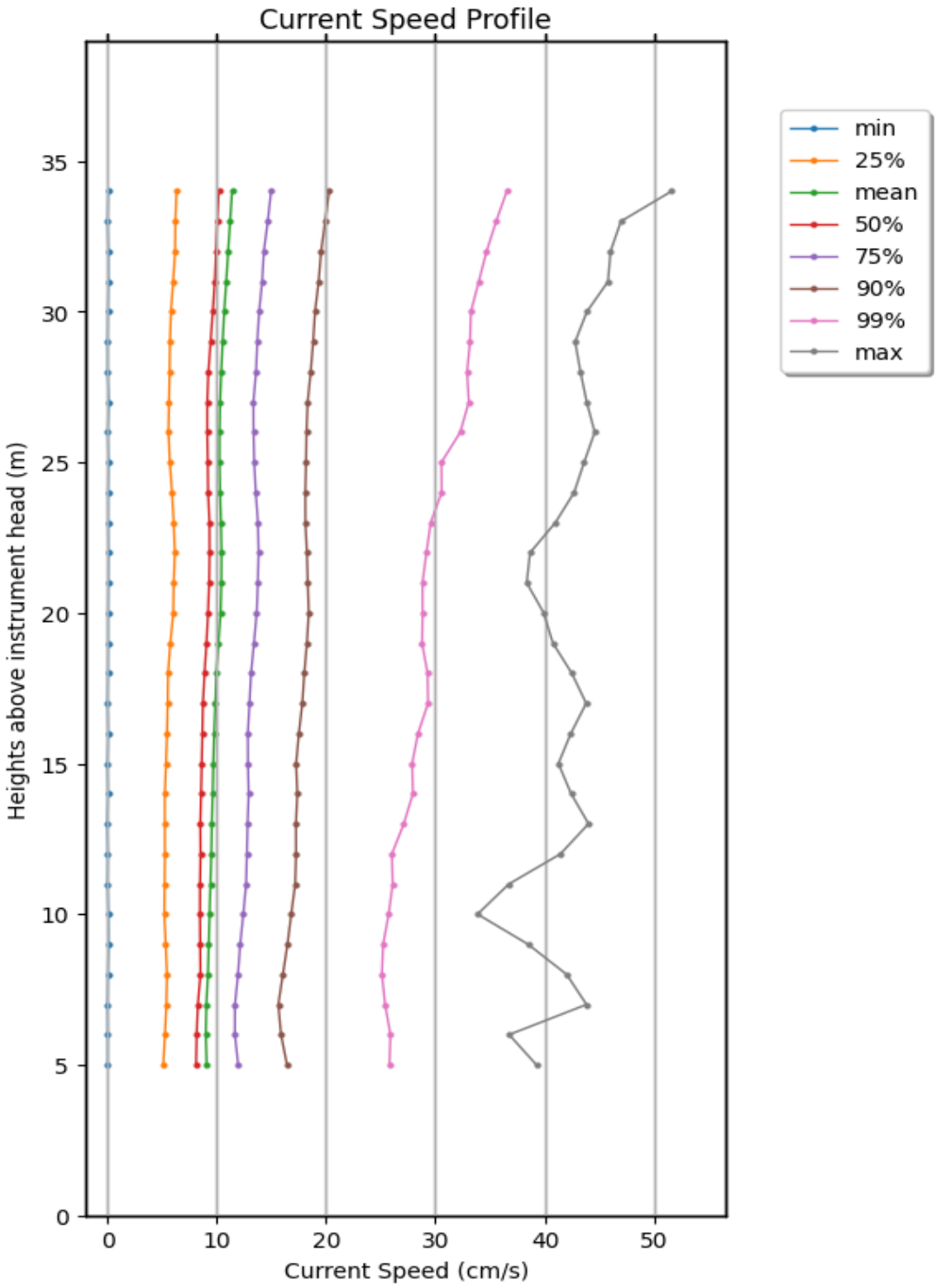


Figure 7.21: KFII-1-CP current speed profile for D2 (15 April 2024-3 September 2024)

8. Results of Data measurement at KFII-2

8.1 Buoy position

Figure 7.1 shows the position of the buoy throughout the campaign, the nominal SWLB anchor and bottom mounted ADCP anchor as-laid positions reported in Table 1.2. There were no drifts of positions.

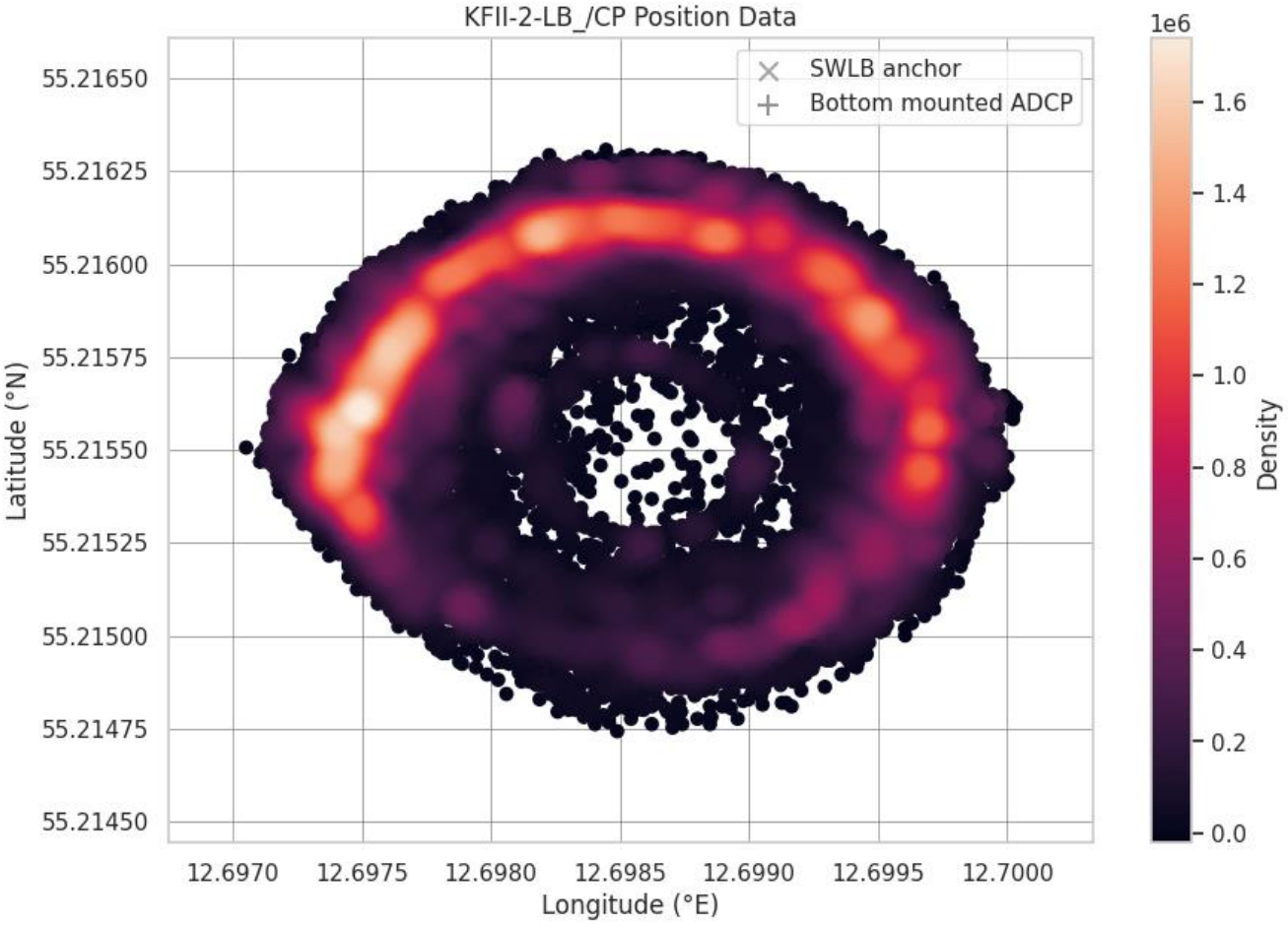


Figure 8.1: Full campaign SWLB and bottom mounted ADCP position data.

8.2 Wind: KFII-2

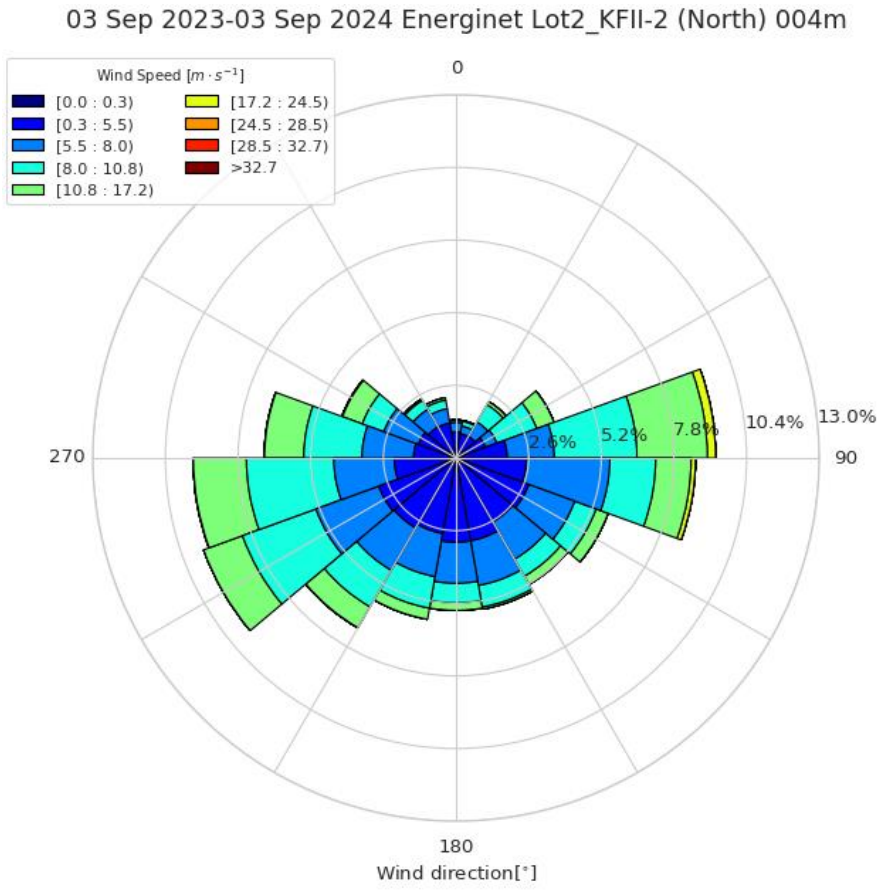
The floating lidar system performed well during the 12 months of the campaign. Timeseries of wind speed and direction are presented in Appendix C.

Table 8.1 summarizes statistics for wind speed over the full campaign. Figure 8.3 shows wind roses at 4 heights (4, 100, 170, and 260 m) for all 12 months of data and Figure 8.4 presents the wind speed profile for the full campaign.

The highest wind speeds during the campaign were measured in January 2024. High wind speeds (> 30 m/s) were also measured in October 2023. The dominant wind direction is from the east and south-west.

Table 8.1: 12-month summary statistics (standard deviation, minimum, mean and maximum): 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	3.2	0.1	6.4	17.0
ZephIR Lidar 10min wind speed	12	3.4	0.5	7.1	18.8
	40	3.9	0.6	8.4	21.3
	80	4.5	0.4	9.3	23.6
	100	4.8	0.5	9.6	25.0
	130	5.0	0.4	9.9	26.7
	150	5.1	0.4	10.1	27.4
	170	5.2	0.4	10.2	28.3
	190	5.3	0.5	10.3	29.6
	220	5.4	0.4	10.4	34.7
	260	5.5	0.5	10.5	36.0
	300	5.6	0.5	10.6	36.6



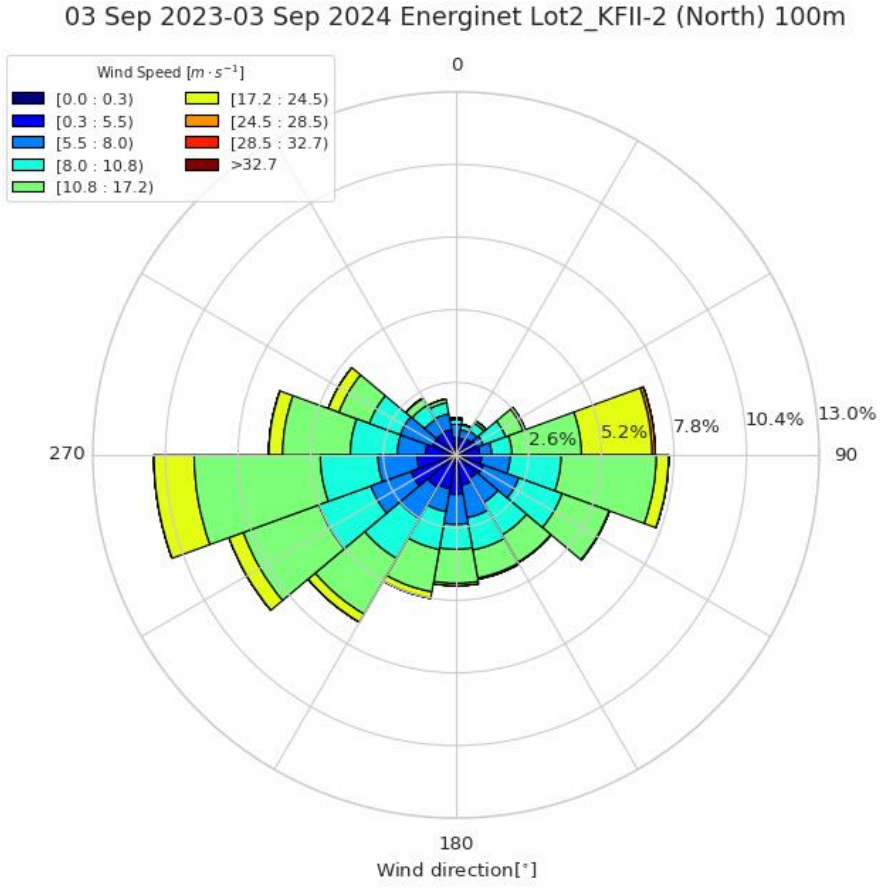
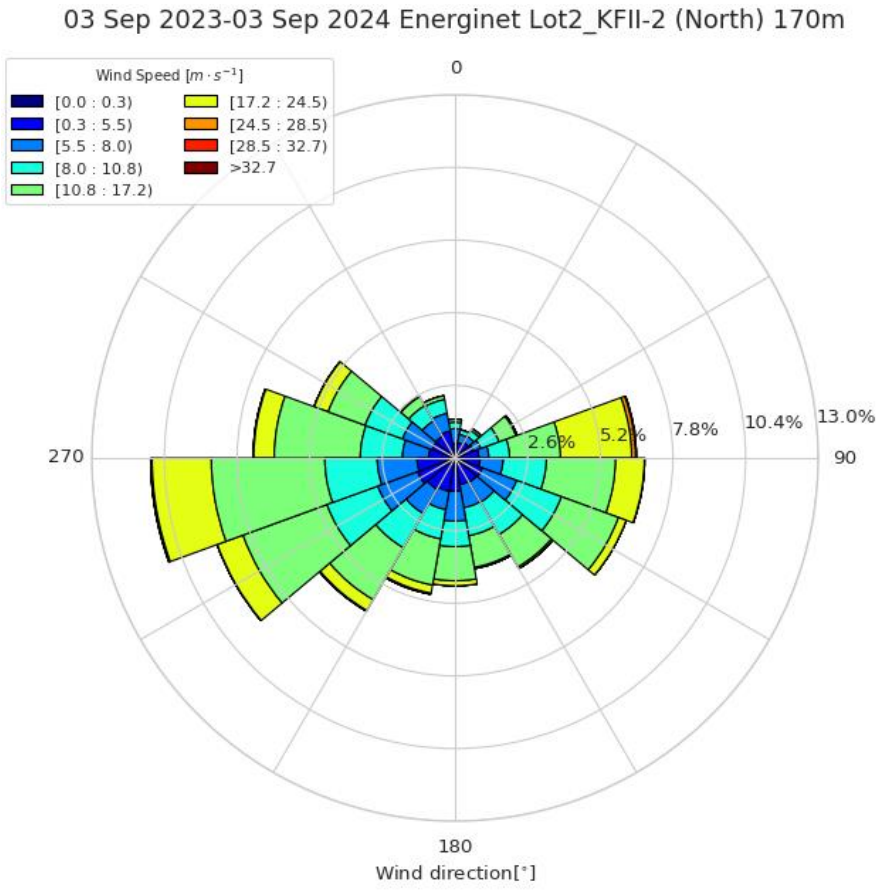


Figure 8.2 : Wind roses at 4 m and 100 m height for the full 12 months



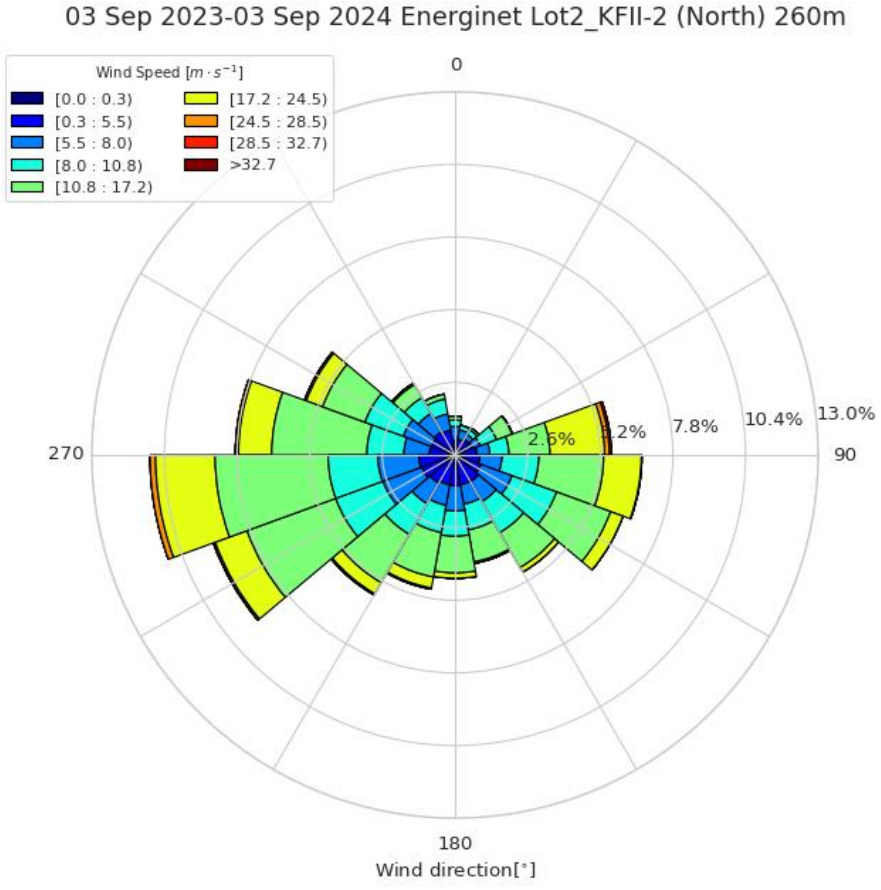


Figure 8.3 : Wind roses at 170 m, and 260 m height for the full 12 months

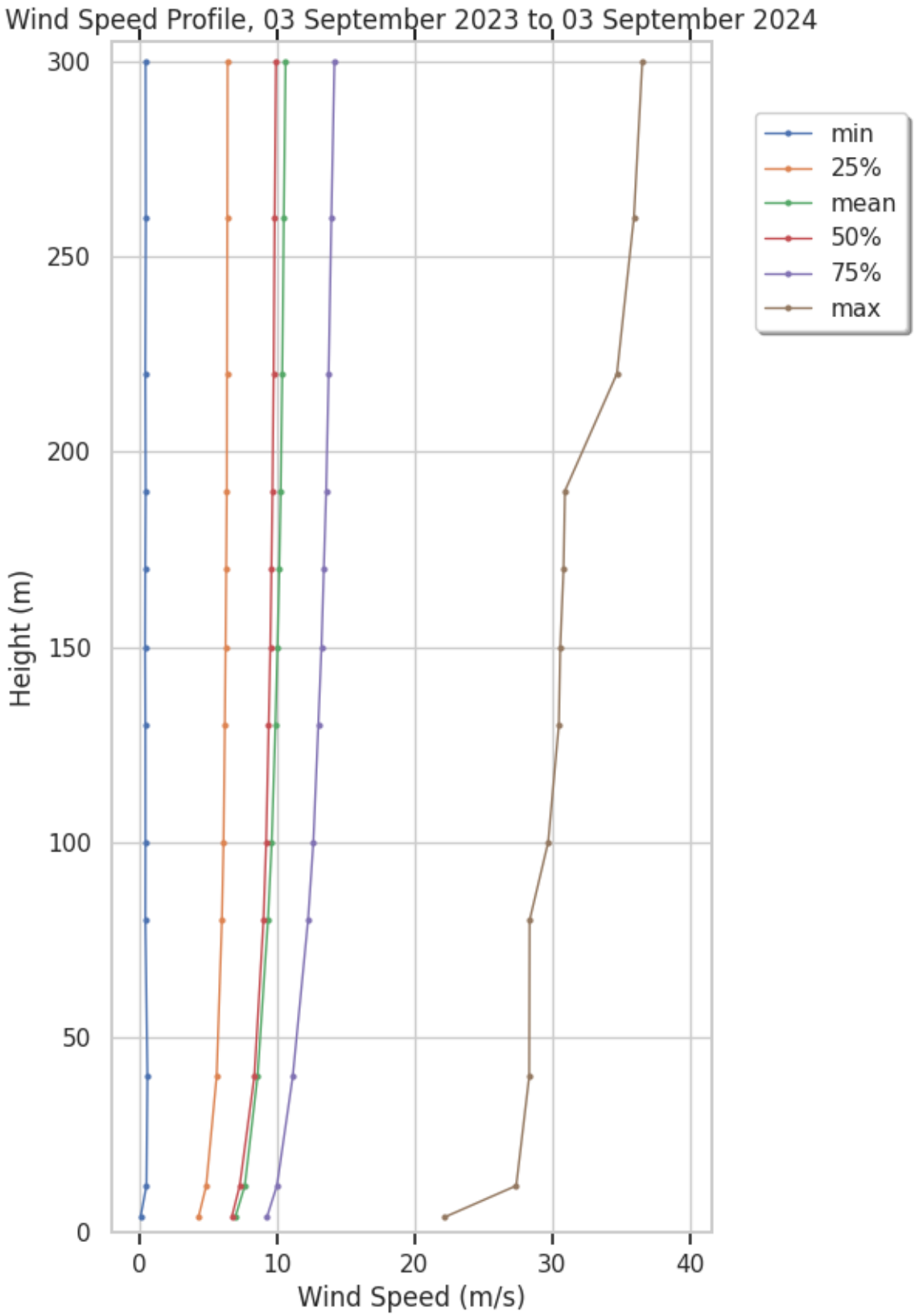


Figure 8.4 : 12-month wind speed profile

8.3 Waves: KFII-2

This chapter includes the results of wave measurement from the SWLB. Timeseries of wave height, period and direction are presented in Appendix C.

Table 8.2 summarizes statistics for wave heights and periods over the full campaign. Figure 8.5 shows a wave rose for wave height and mean direction for all 12 months of data. Figure 8.6, Figure 8.7 and Figure 8.8 show examples of directional wave spectra for 3 high wave events during the campaign.

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

The highest wave heights (hmax > 7.0 m) during the campaign were measured in October 2023. The dominant wave directions are from the east.

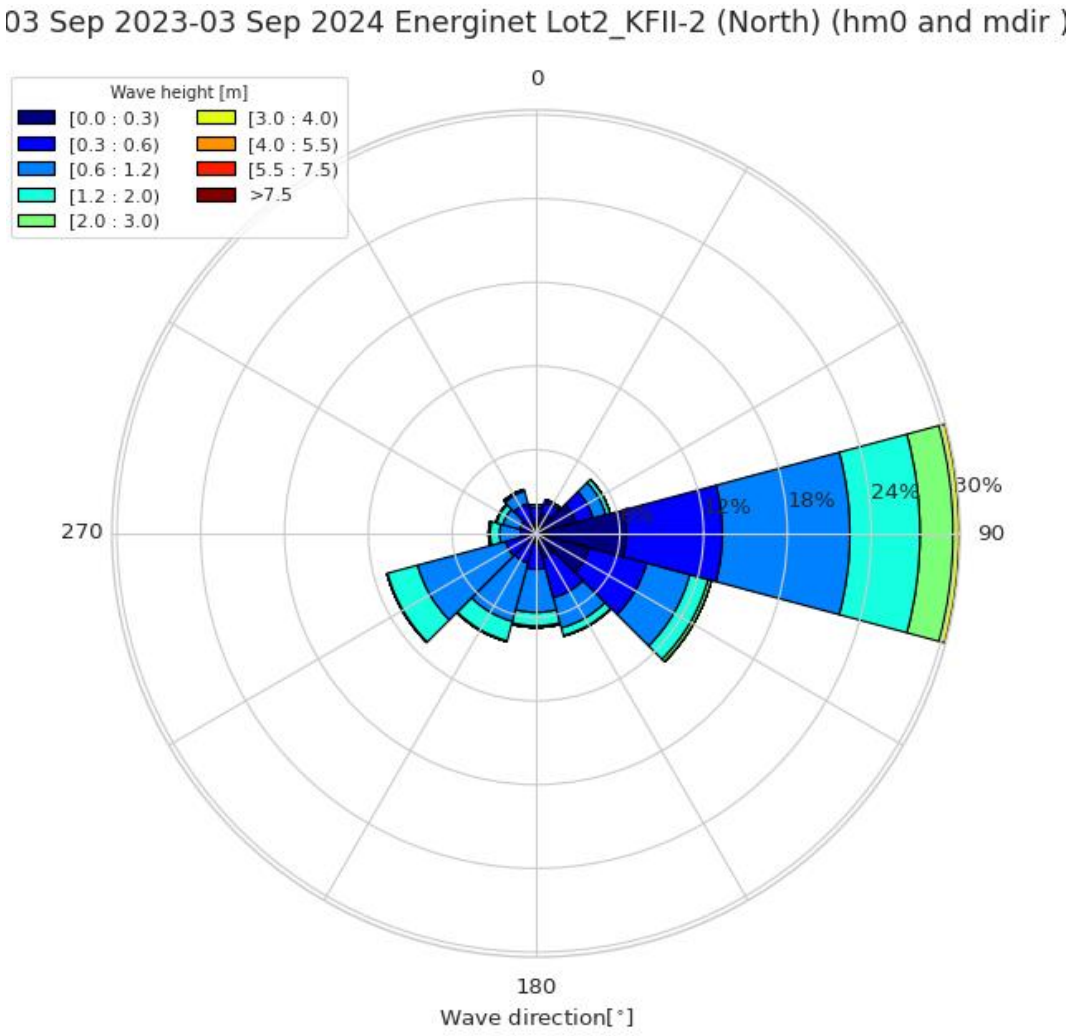
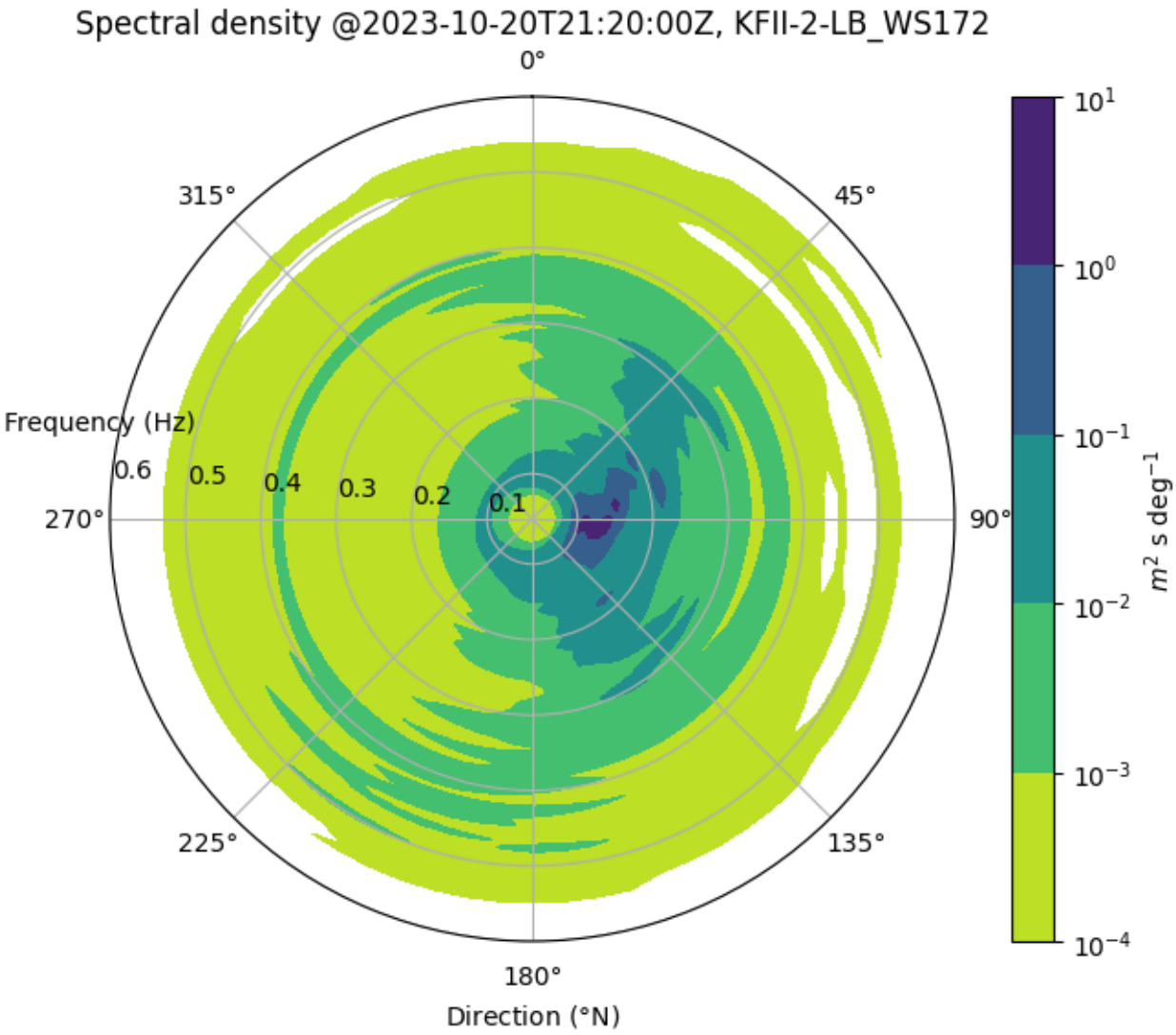


Figure 8.5: 12-month waverose

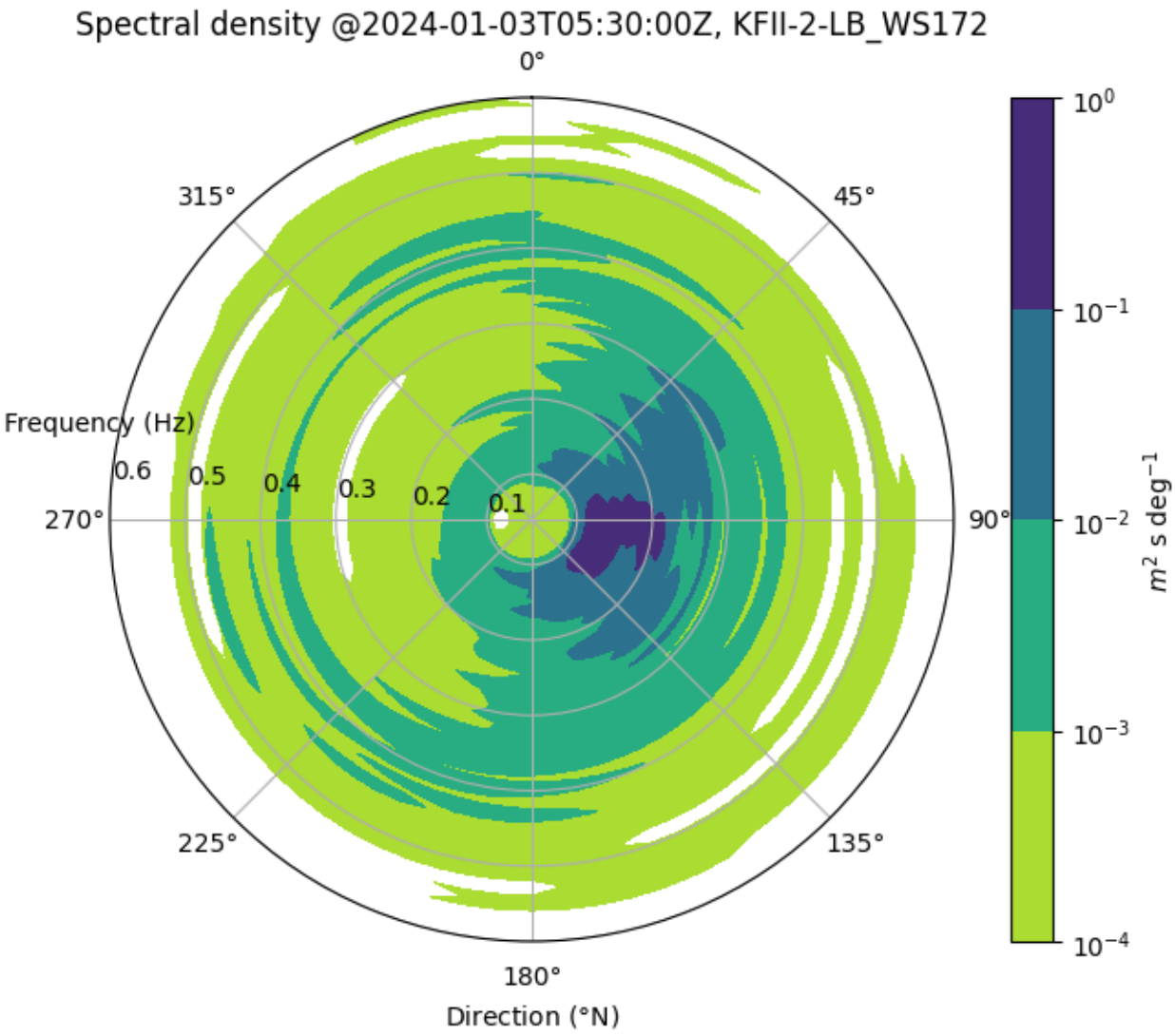
Table 8.2: 12-month summary statistics (standard deviation, minimum, mean and maximum): wave parameters

Parameter	Unit	Standard deviation	Minimum	Mean	Maximum
hm0 m	m	0.6	0.1	0.8	4.5
hmax m	m	0.9	0.3	1.4	7.3
thmax s	s	1.1	2.4	4.1	12.9
tm01 s	s	0.7	2.3	3.5	7.2
tm02 s	s	0.6	2.3	3.4	6.8
tp s	s	1.3	2.0	4.2	11.4
Notes *The height of instrument (Wavesense) is 0m with respect to MWL					



2023-10-20 21:20: hm0 = 4.5 m, hmax=7.0 m tp = 9.0 s mdir = 92.1°

Figure 8.6: Directional wave spectra (MEM spectra m^2/s) from a wave event dated on 20 October 2023



2024-01-03 05:30: hm0 = 3.6 m, hmax=5.1 m tp = 7.9 s mdir = 96.3°°

Figure 8.7: Directional wave spectra (MEM spectra m²/s) from a wave event dated on 3 January 2024

2024-02-09 18:30: hm0 = 3.2 m, hmax=4.3 m tp = 7.0 s mdir = 87.9°

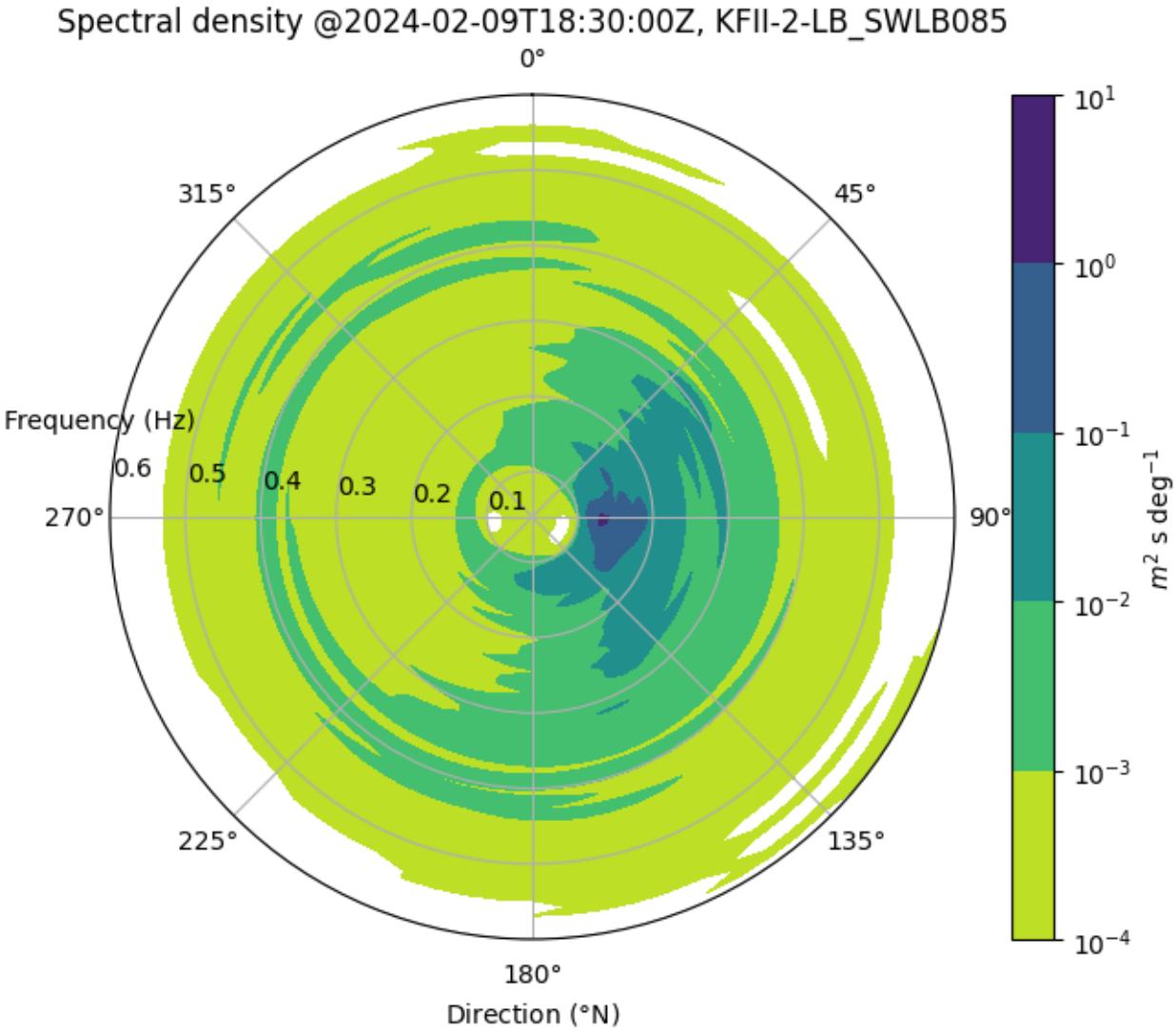


Figure 8.8: Directional wave spectra (MEM spectra m^2/s) from wave events dated on 9 February 2024

8.4 Metocean Results: KFII-2

8.4.1 Met

Timeseries of all atmospheric parameters are presented in C.3 of Appendix C. Table 8.3 summarizes statistics for the main atmospheric parameters over the full campaign. The lowest air temperature was measured in November 2023 and the lowest air pressures was measured in December 2023. The highest air temperature was measured in July 2024 and the highest air pressure were measured in September 2023.

Table 8.3: 12-month summary statistics of met parameters from 3 September 2023 to 3 September 2024

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
AirHumidity %	% R.H.	4	9.4	37.2	84.4	98.8
AirPressure hPa (PTB330)	hPa	0.5	9.6	976.2	1012.1	1034.7
AirTemperature C (HMP155)	°C	4	6.3	-4.6	10.5	24.2

8.4.2 Sea water temperatures

Table 8.4 summarizes statistics for water temperature from all sensors over the full campaign. Figure 8.9 and Figure 8.10 show timeseries of all seawater temperature data from all sensors.

Table 8.4: 12-month summary statistics of sea water temperatures from 3 September 2023 to 3 September 2024

Parameter	Unit	Height [m]	Standard deviation	Minimum	Mean	Maximum
Sea surface temperature (Thelma)	°C	-2	6.1	1.9	10.2	20.5
Sea surface temperature (Signature, SWLB085/SWLB083)	°C	1	6.5	2.1	10.2	23.8
Sea surface temperature (Aquadopp, WS172)	°C	1	4.8	3.0	10.3	20.7
Bottom Water Temperature (Thelma)	°C	2m above seabed	4.6	1.9	8.3	18.8

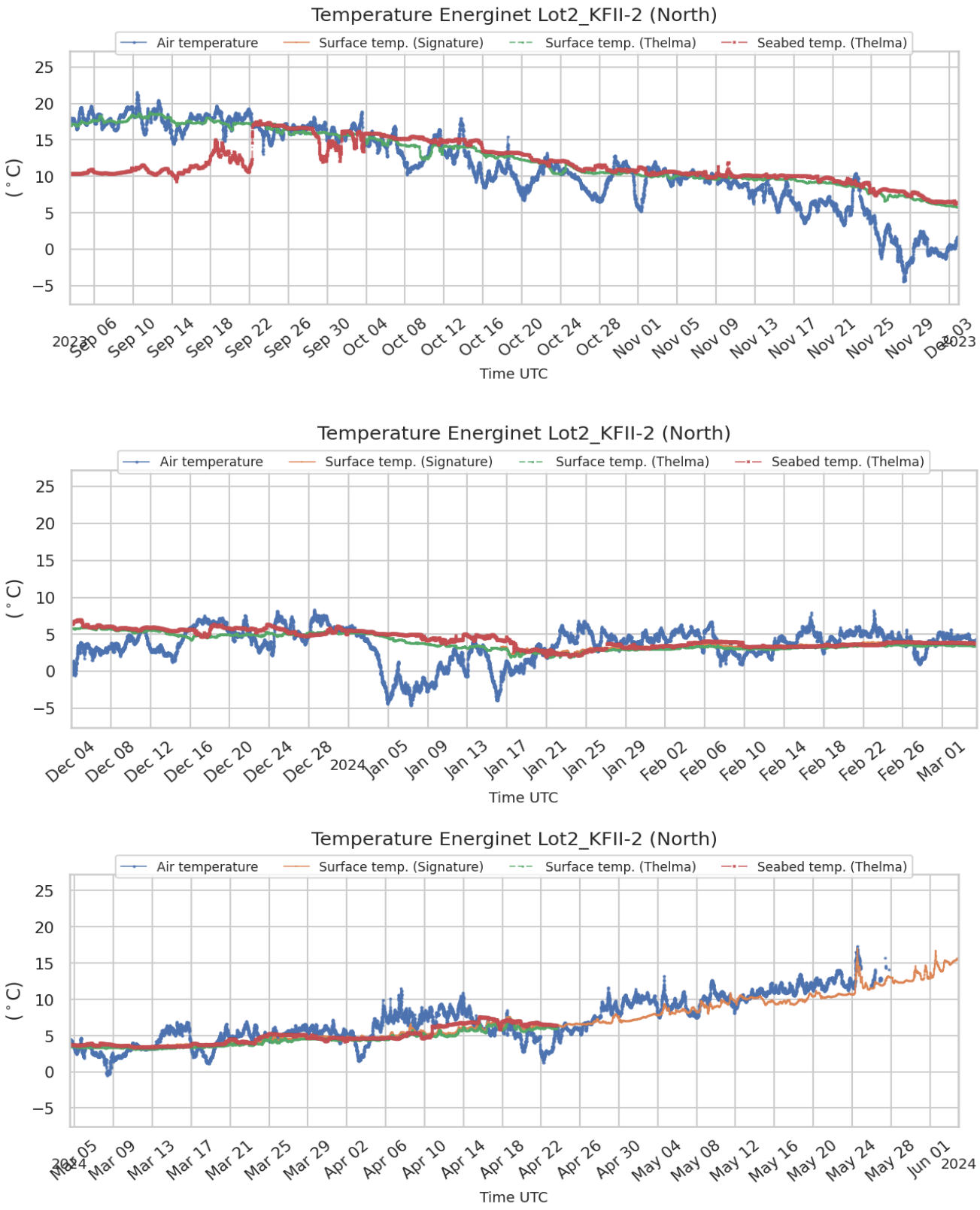


Figure 8.9: Timeseries of all seawater temperature data from all sensors per 3 months intervals (1-3/4)

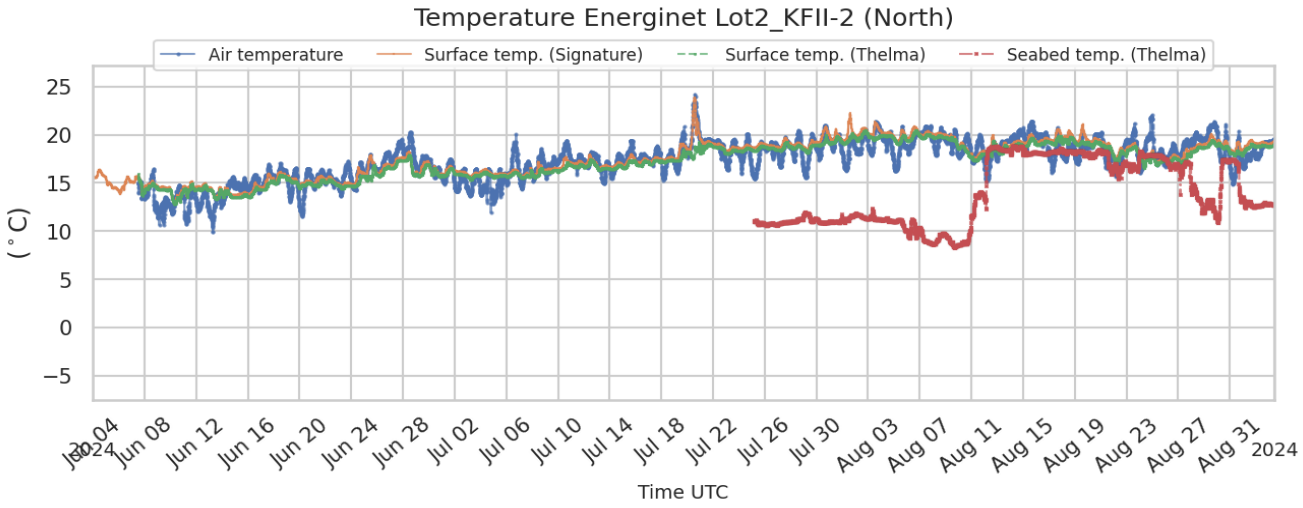


Figure 8.10: Timeseries of all seawater temperature data from all sensors per 3 months intervals (4/4)

8.4.3 Water level

Table 8.5 summarizes statistics for water pressure from the bottom-mounted CP over the full campaign period. Figure 8.11 and Figure 8.12 show timeseries of water pressure from the sensor. Given the uncertainties in the sensor heights depending on as-laid locations, two different sensor heights were used for Signature500; 3m for D1 (3 September 2023 to 15 April 2024) and 3m for D2 (15 April 2024 to 3 September 2024). These heights were estimated by a sanity check with two different deployment of Signature instrument and by a validation with other source (Ref. [13]).

Table 8.5: 12-month summary statistics of water pressure from 3 September 2023 to 3 September 2024

Parameter	Unit	Sensor Height [m]	Standard deviation	Minimum†‡	Mean	Maximum
Water pressure (Thelma)	dbar	2 m above seabed	0.3	25.9	27.7	28.8
Water pressure (Signature500)	dbar	3m (D1) and 3.2m (D2) above seabed	0.2	25.7	27.4	28.6
Water level (Thelma)	m	2m above seabed	0.3	25.4	27.3	28.5
Water level (Signature500)	m	3m (D1) and 3.2m (D2) above seabed	0.3	25.3	27.1	28.3

Notes
†Compared with the water depth (27.3m) to LAT reference from European Marine Observation and Data Network (EMODnet). (https://emodnet.ec.europa.eu/en/bathymetry). Uncertainties in local bathymetry to be taken into consideration for validation of these values.
‡Minimum bound of greater than10 dbar is applied.

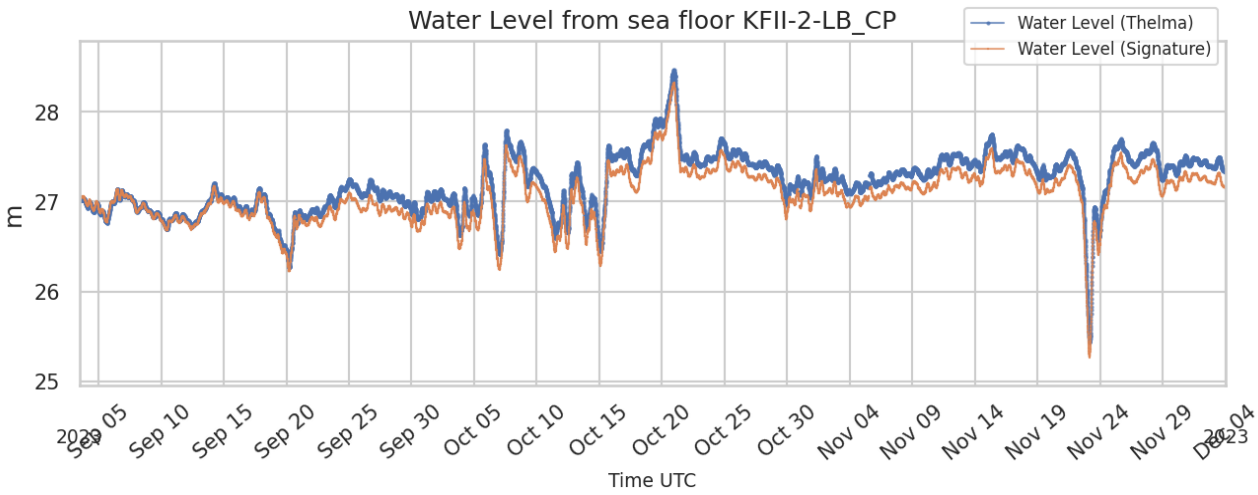


Figure 8.11: Timeseries of water level per 3 months intervals (1/4)

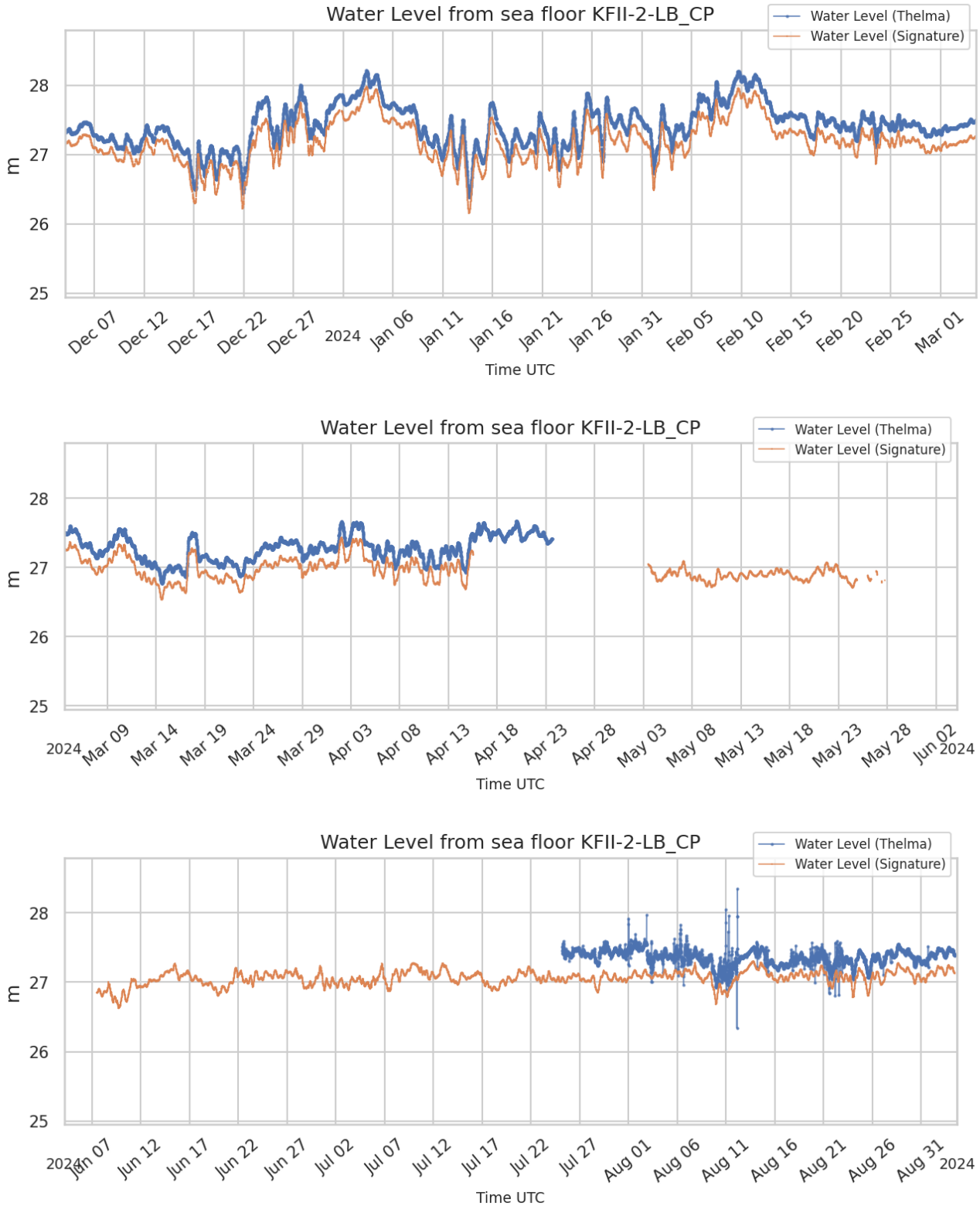


Figure 8.12: Timeseries of water level per 3 months intervals (2-4/4)

8.5 Currents: KFII-2

8.5.1 SWLB ADCP

Heatmaps of current speed and direction are presented in C.4.

Table 8.6 and Table 8.7 summarizes statistics for current speed over the full campaign. Figure 8.13 shows the current speed profile for the campaign period and Figure 8.14 shows current roses at 4 depths below the mean sea level (bmsl) (4, 8, 12, and 16 m) for all 12 months of data.

The highest current speeds during the campaign were measured in October and December 2023 and also in February and March 2024. The mean current speeds are around 7.5-19.5 cm/s for all depth bins.

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

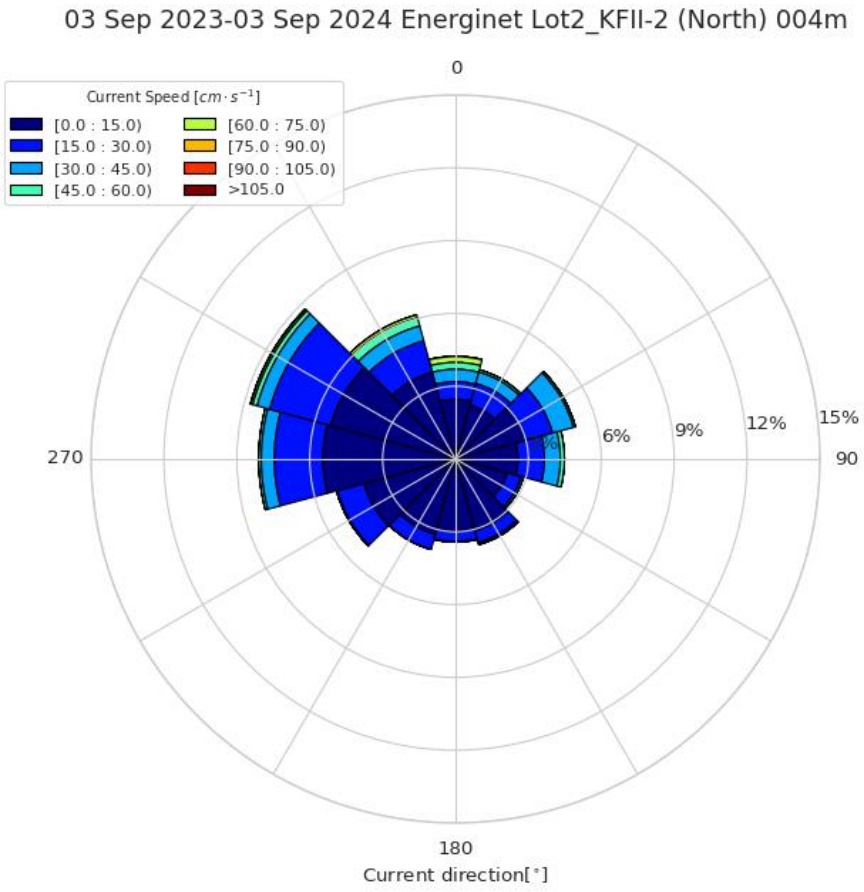
Table 8.6: 12-month summary statistics (standard deviation, minimum, mean and maximum): current speed Signature

Parameter	Unit	Depth bmsl [m]	Data count (10min)	Standard deviation	Mean	Maximum
currSp003	cm/s	-3	31350	11.7	14.7	82.5
currSp004	cm/s	-4	31338	11.7	14.4	87.5
currSp005	cm/s	-5	31338	11.7	14.4	87.5
currSp006	cm/s	-6	31310	11.7	14.2	85.7
currSp007	cm/s	-7	31272	11.3	13.8	84.5
currSp008	cm/s	-8	31235	11.1	13.5	85.4
currSp009	cm/s	-9	31210	10.9	13.2	87.2
currSp010	cm/s	-10	31202	10.7	13.0	87.5
currSp011	cm/s	-11	31150	10.7	13.0	98.6
currSp012	cm/s	-12	31081	10.6	13.0	99.5
currSp013	cm/s	-13	31017	10.3	12.8	122.2
currSp014	cm/s	-14	30948	10.0	12.6	78.1
currSp015	cm/s	-15	30883	9.6	12.4	94.2
currSp016	cm/s	-16	30814	9.2	12.2	56.9
currSp017	cm/s	-17	30709	8.9	12.0	113.9
currSp018	cm/s	-18	30608	8.6	11.8	82.2
currSp019	cm/s	-19	30443	8.3	11.7	61.6
currSp020	cm/s	-20	30310	8.1	11.5	52.5
currSp021	cm/s	-21	30165	7.9	11.2	81.9

Parameter	Unit	Depth bmsl [m]	Data count (10min)	Standard deviation	Mean	Maximum
currSp022	cm/s	-22	30084	7.6	10.8	63.4
currSp023	cm/s	-23	30241	7.0	9.7	101.3
currSp024	cm/s	-24	30988	5.7	7.4	84.5
currSp025	cm/s	-25	31141	3.5	5.0	62.2
currSp026	cm/s	-26	30670	3.5	5.9	46.0

Table 8.7: 12-month summary statistics (standard deviation, minimum, mean and maximum): current speed Aquadopp

Parameter	Unit	Depth bmsl [m]	Data count (10min)	Standard deviation	Mean	Maximum
AqSpd003	cm/s	-3	19422	13.1	16.4	109.6
AqSpd004	cm/s	-4	19422	13.9	18.0	114.3
AqSpd005	cm/s	-5	19422	14.1	19.3	115.1
AqSpd006	cm/s	-6	19422	14.0	19.4	109.3
AqSpd007	cm/s	-7	19422	13.7	19.2	109.9
AqSpd008	cm/s	-8	19422	13.2	18.4	104.6
AqSpd009	cm/s	-9	19422	12.6	17.8	98.7
AqSpd010	cm/s	-10	19422	12.1	16.5	95.8
AqSpd011	cm/s	-11	19422	11.7	16.7	93.5
AqSpd012	cm/s	-12	19340	11.2	16.1	94.0
AqSpd013	cm/s	-13	19160	10.8	15.3	90.2
AqSpd014	cm/s	-14	18947	10.4	14.9	90.2
AqSpd015	cm/s	-15	18705	10.1	14.4	89.6
AqSpd016	cm/s	-16	18275	9.8	14.1	85.3
AqSpd017	cm/s	-17	17618	9.4	13.7	83.2
AqSpd018	cm/s	-18	16992	9.2	13.5	80.0
AqSpd019	cm/s	-19	16477	9.1	13.3	73.5
AqSpd020	cm/s	-20	15993	9.1	13.1	68.3
AqSpd021	cm/s	-21	15611	9.2	13.0	63.9
AqSpd022	cm/s	-22	15378	9.6	13.2	68.8
AqSpd023	cm/s	-23	15264	9.7	13.3	70.9
AqSpd024	cm/s	-24	19422	8.2	12.0	69.7
AqSpd025	cm/s	-25	17050	5.1	8.2	37.8
AqSpd026	cm/s	-26	19422	13.1	16.4	109.6



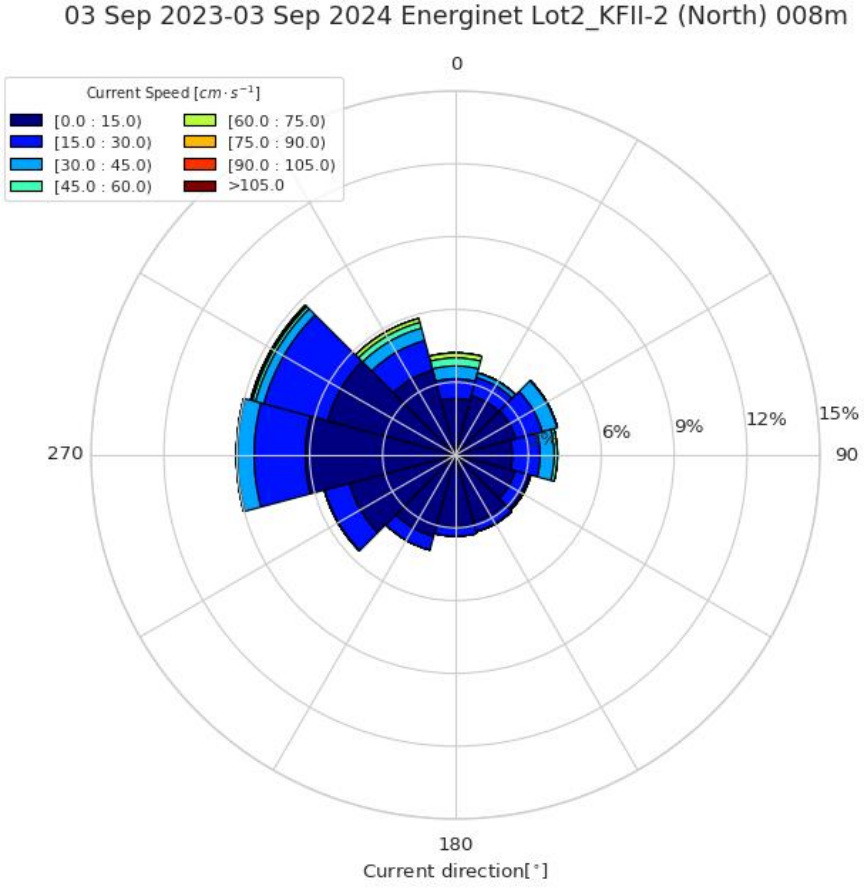
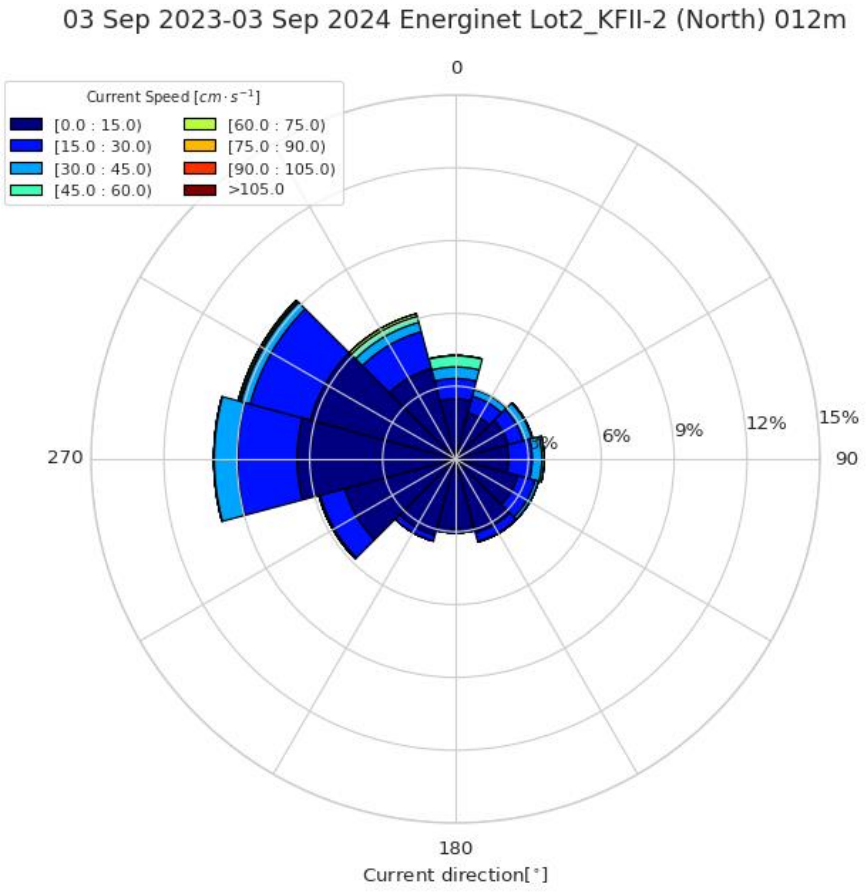


Figure 8.13: Current roses at depths 4 m (top) and 8 m (bottom) for the full 12 months



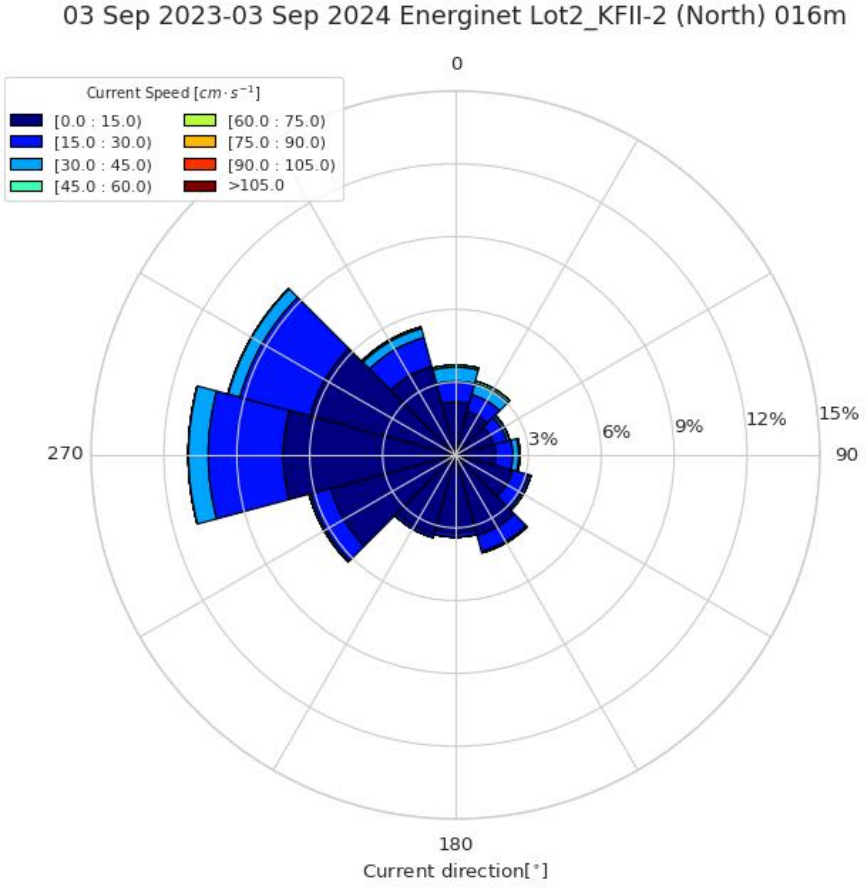


Figure 8.14 Current roses at depths 12 m (top) and 16 m (bottom) for the full 12 months

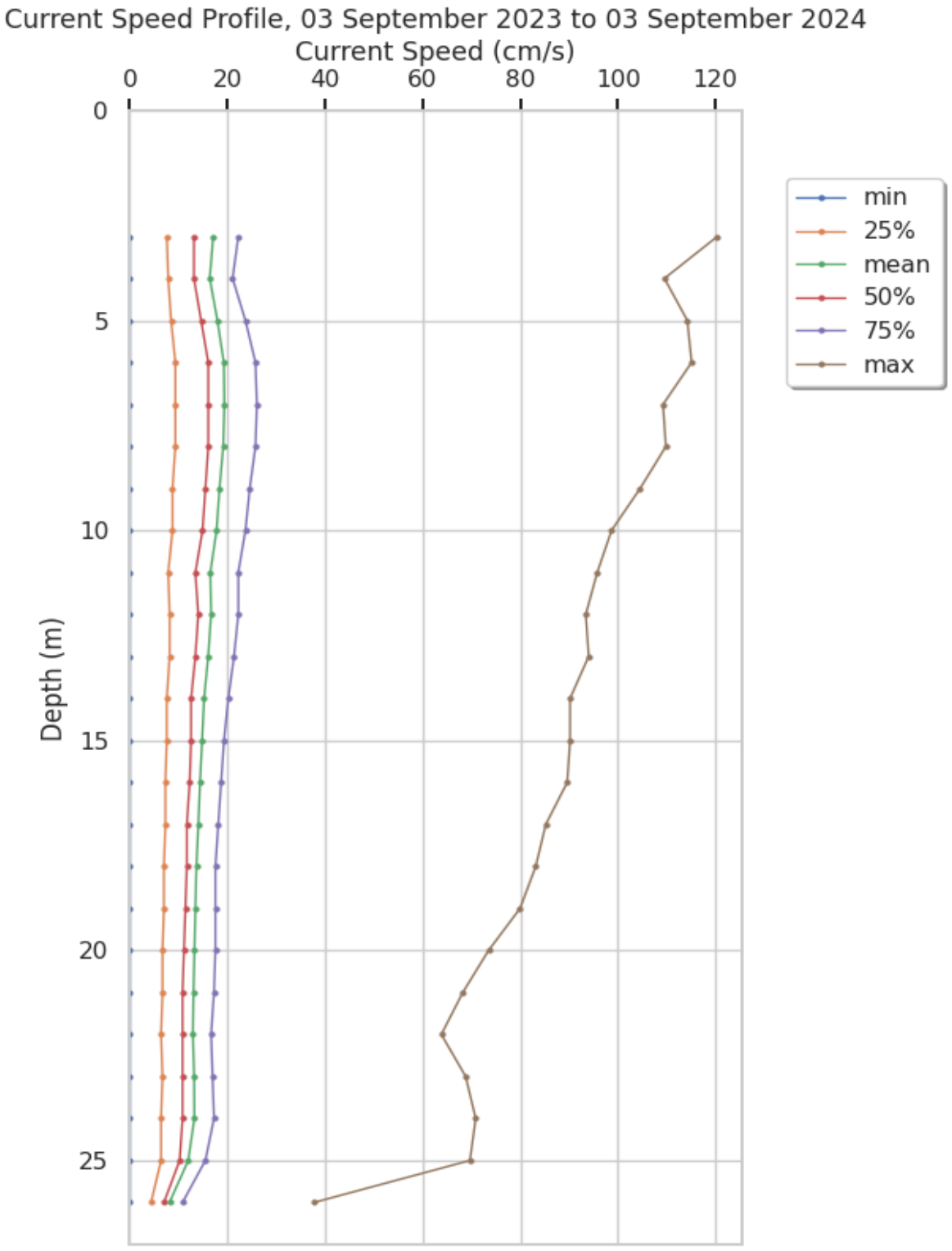


Figure 8.15: Full-3.5 month current speed profile(Aquadopp 400kHz, 3 September 2023 – 16 January 2024)

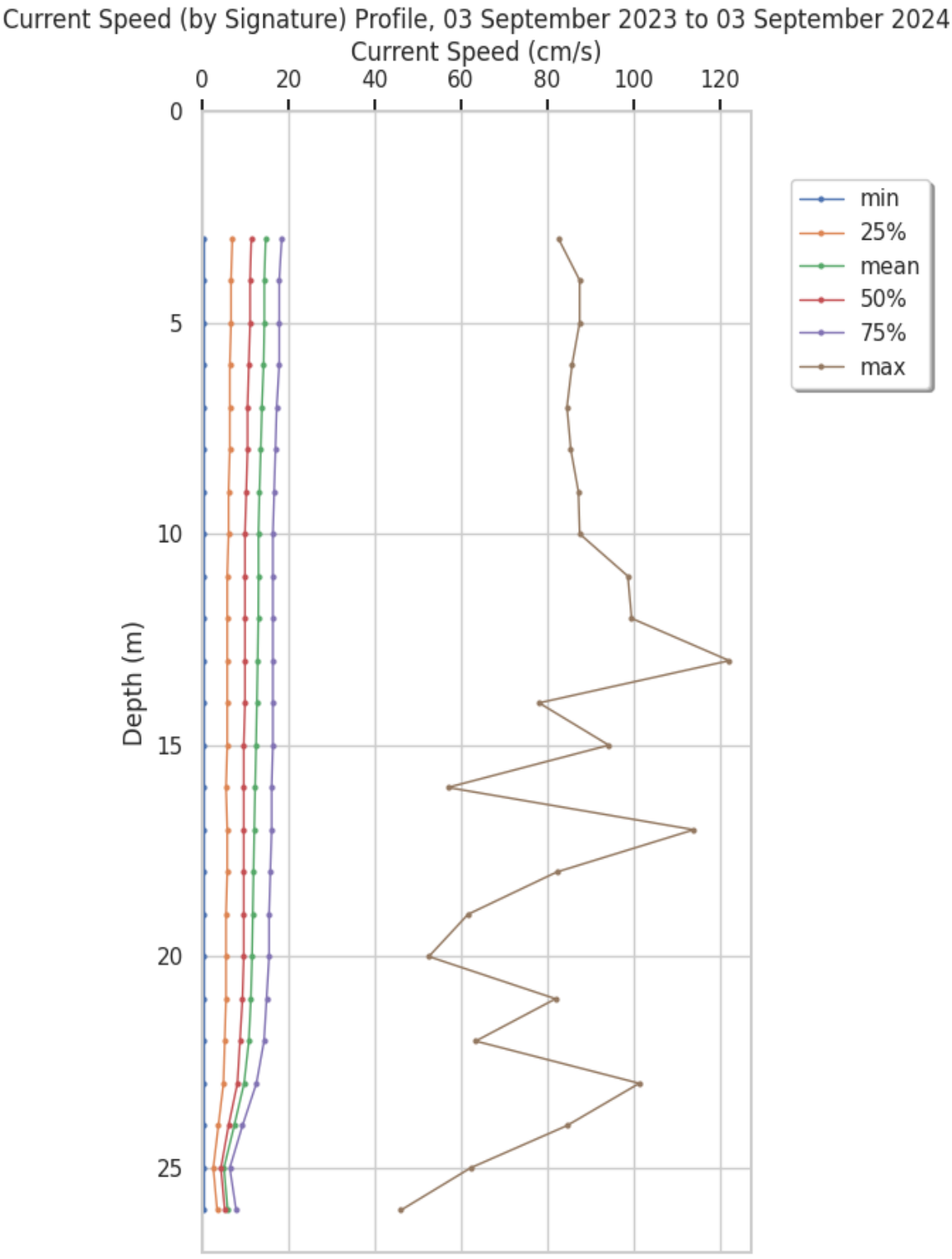


Figure 8.16: Full 8.5-months current speed profile (Signature500, 16 January 2024 – 3 September 2024)

8.5.2 Upward-facing Signature

Heatmaps of current speed and direction are presented in C.5

Table 8.8 and Table 8.9 summarize statistics for current speed over D1 (3 September 2023 – 15 April 2024) and D2 (15 April 2024 – 3 September 2024) respectively. Current roses at four heights above the seafloor (17, 13, 9, and 5 m) are shown in Figure 8.17 through Figure 8.20. Figure 8.21 and Figure 8.22 show the current speed profiles for D1 and D2, respectively.

The highest current speeds during D1 were measured in October 2023 at the nearest bin to the surface, while the highest current speeds during D2 were measured in June 2024 at the nearest bin to the surface. The mean current speeds are in range 9-17 cm/s for all depth bins.

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

Table 8.8: Current speed summary statistics over D1 (3 September 2023 – 15 April 2024).

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp024	cm/s	24	11.9	0.2	16.4	94.2
currSp023	cm/s	23	12.9	0.0	16.3	105.8
currSp022	cm/s	22	12.8	0.1	16.1	99.1
currSp021	cm/s	21	12.6	0.1	15.8	97.4
currSp020	cm/s	20	12.3	0.0	15.5	94.6
currSp019	cm/s	19	12.1	0.0	15.1	92.0
currSp018	cm/s	18	11.9	0.1	14.8	88.0
currSp017	cm/s	17	11.5	0.1	14.5	87.2
currSp016	cm/s	16	11.2	0.1	14.1	87.9
currSp015	cm/s	15	10.9	0.0	13.8	88.9
currSp014	cm/s	14	10.5	0.0	13.4	90.2
currSp013	cm/s	13	10.2	0.1	13.1	91.8
currSp012	cm/s	12	9.9	0.1	12.8	93.9
currSp011	cm/s	11	9.6	0.1	12.6	92.5
currSp010	cm/s	10	9.3	0.0	12.4	88.0
currSp009	cm/s	9	9.0	0.1	12.1	85.8
currSp008	cm/s	8	8.7	0.1	11.9	82.6
currSp007	cm/s	7	8.6	0.0	11.7	71.4
currSp006	cm/s	6	8.6	0.1	11.5	63.5
currSp005	cm/s	5	8.7	0.0	11.3	67.2
currSp004	cm/s	4	8.6	0.1	11.1	65.8

Note
* Height above the seafloor

Table 8.9: Current speed summary statistics over D2 (15 April 2024 – 3 September 2024).

Parameter	Unit	Height [m]*	Standard deviation	Minimum	Mean	Maximum
currSp024	cm/s	24	11.7	0.1	13.7	79.7
currSp023	cm/s	23	11.7	0.0	13.3	77.3
currSp022	cm/s	22	11.4	0.0	12.9	75.2
currSp021	cm/s	21	11.0	0.1	12.5	73.1
currSp020	cm/s	20	10.6	0.1	12.1	71.2
currSp019	cm/s	19	10.3	0.1	11.7	71.4
currSp018	cm/s	18	10.1	0.1	11.5	72.5
currSp017	cm/s	17	9.9	0.1	11.3	73.2
currSp016	cm/s	16	9.7	0.1	11.1	70.4
currSp015	cm/s	15	9.4	0.1	11.1	64.7
currSp014	cm/s	14	9.3	0.1	11.1	59.4
currSp013	cm/s	13	9.2	0.1	11.1	56.9
currSp012	cm/s	12	8.9	0.1	11.0	55.3
currSp011	cm/s	11	8.6	0.1	10.9	54.0
currSp010	cm/s	10	8.3	0.1	10.7	54.2
currSp009	cm/s	9	8.0	0.0	10.6	55.5
currSp008	cm/s	8	7.8	0.0	10.5	58.7
currSp007	cm/s	7	7.7	0.0	10.4	52.1
currSp006	cm/s	6	7.7	0.1	10.3	44.7
currSp005	cm/s	5	7.4	0.1	9.9	49.2
currSp004	cm/s	4	11.7	0.1	13.7	79.7

Note
* Height above the seafloor

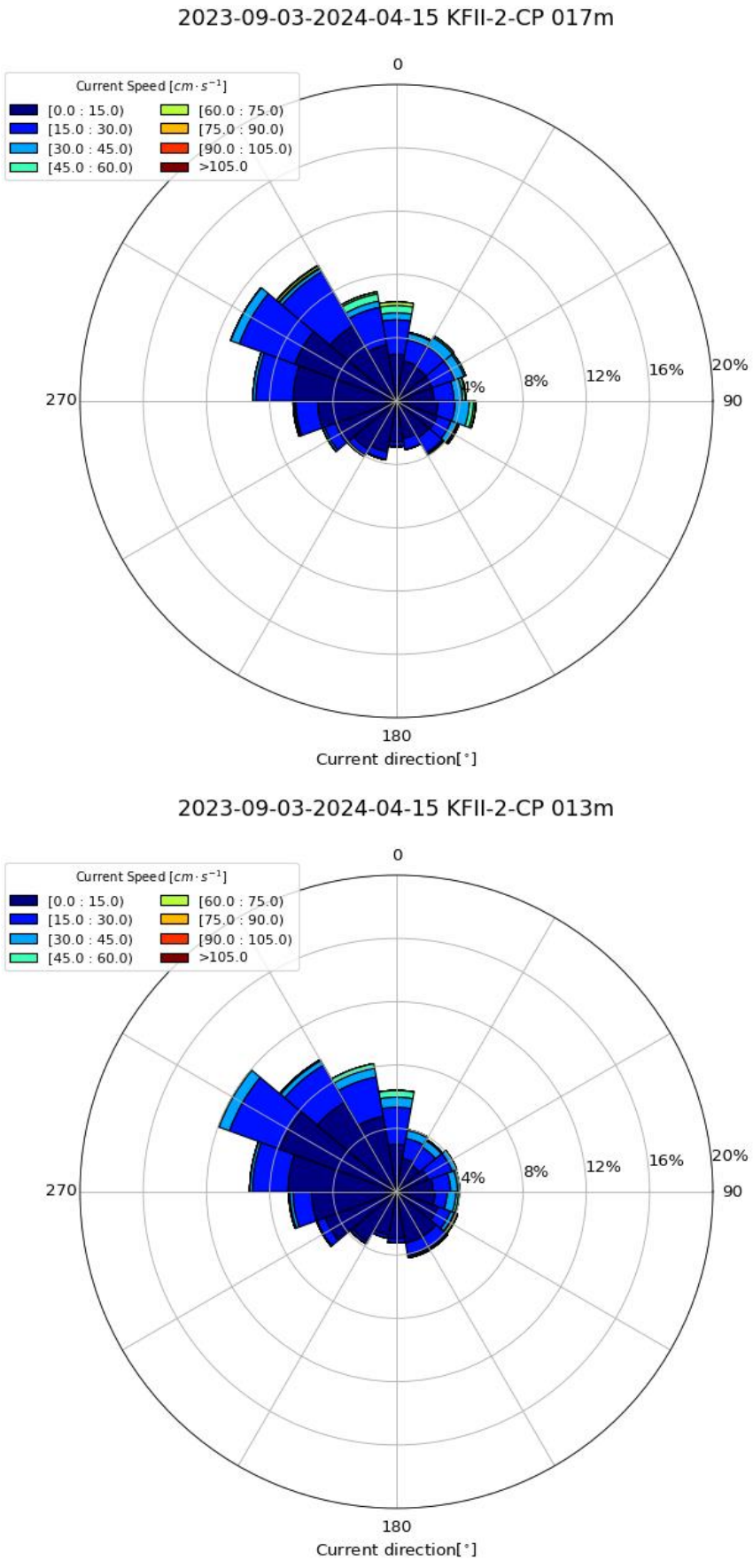


Figure 8.17 Current speed profile at heights 17m (top) and 13m (bottom) during D1 (3 September 2023 – 15 April 2024). Note that heights are given relative to the seafloor.

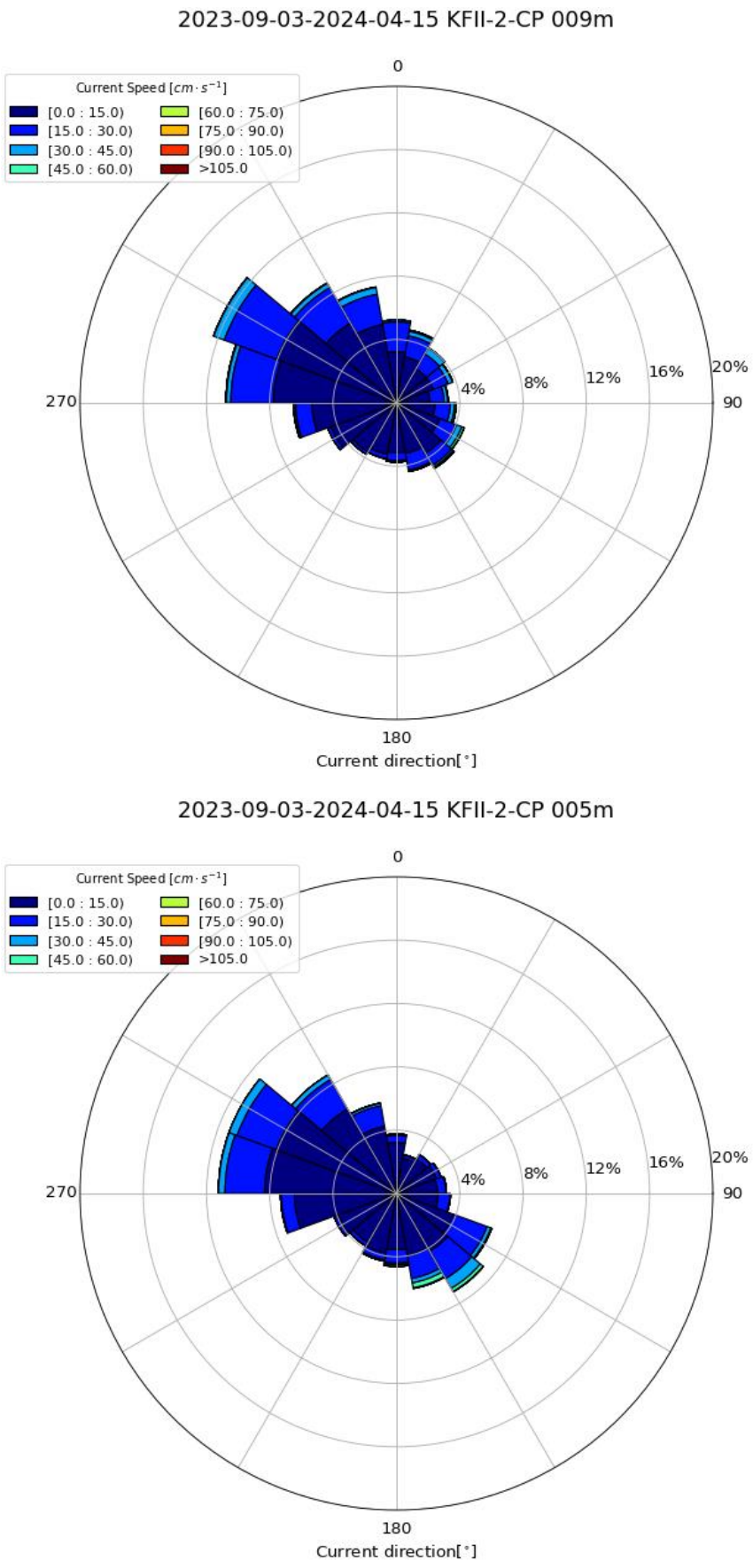


Figure 8.18 Current speed profile at heights 9m (top) and 5m (bottom) during D1 (3 September 2023 – 15 April 2024). Note that heights are given relative to the seafloor.

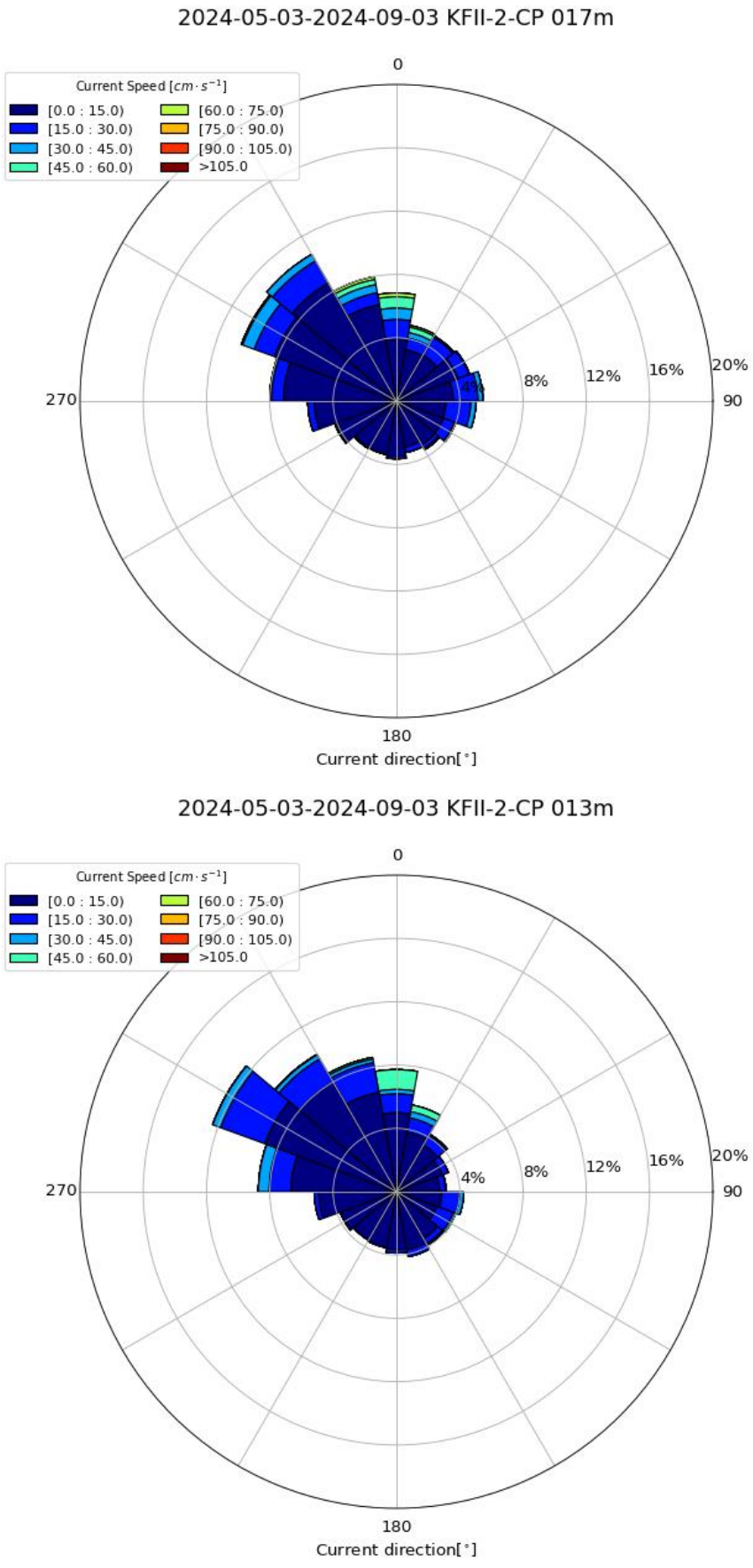


Figure 8.19 Current speed profile at heights 17m (top) and 13m (bottom) during D2 (15 April 2024 – 3 September 2024). Note that heights are given relative to the seafloor.

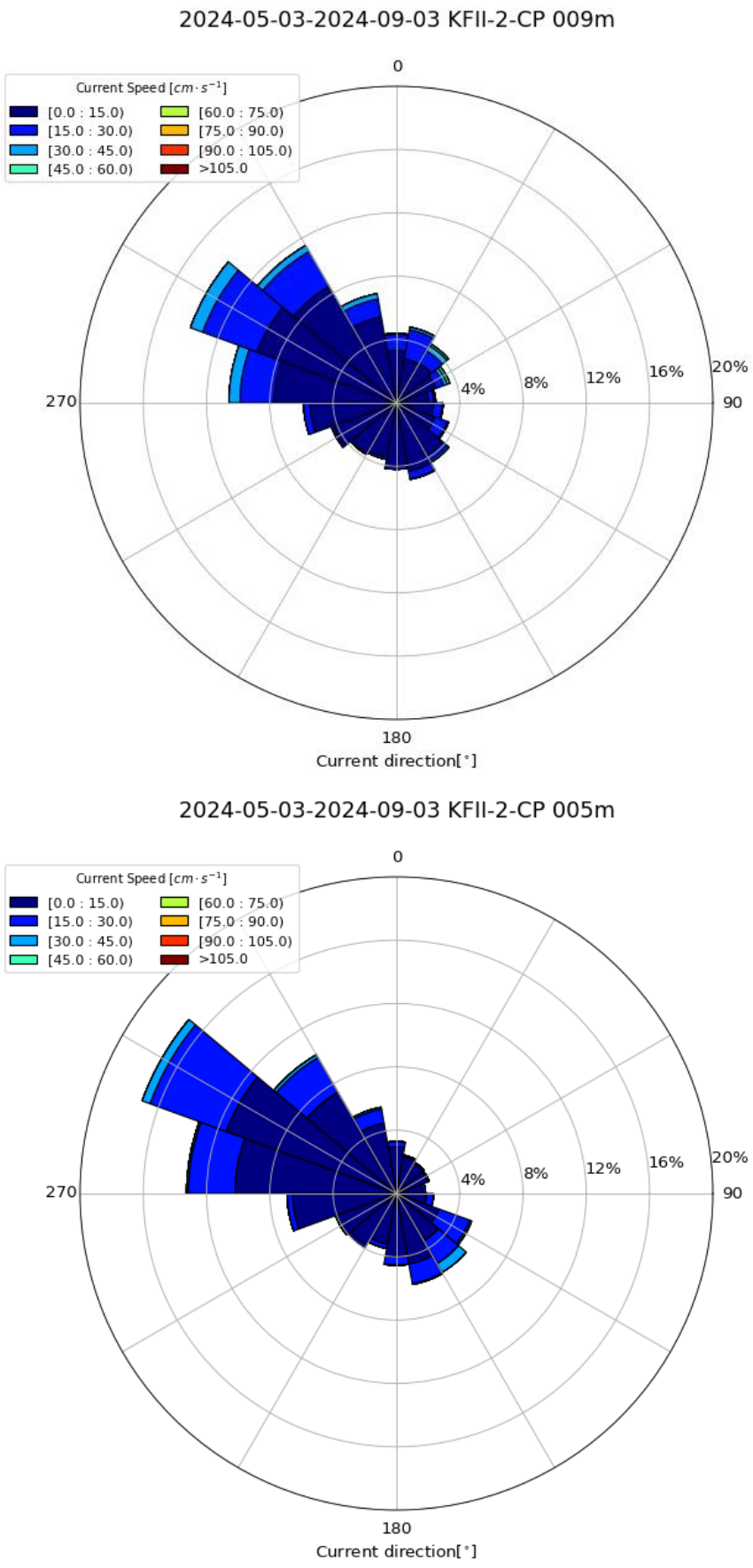


Figure 8.20 Current speed profile at heights 9m (top) and 5m (bottom) during D2 (15 April 2024 – 3 September 2024). Note that heights are given relative to the seafloor.

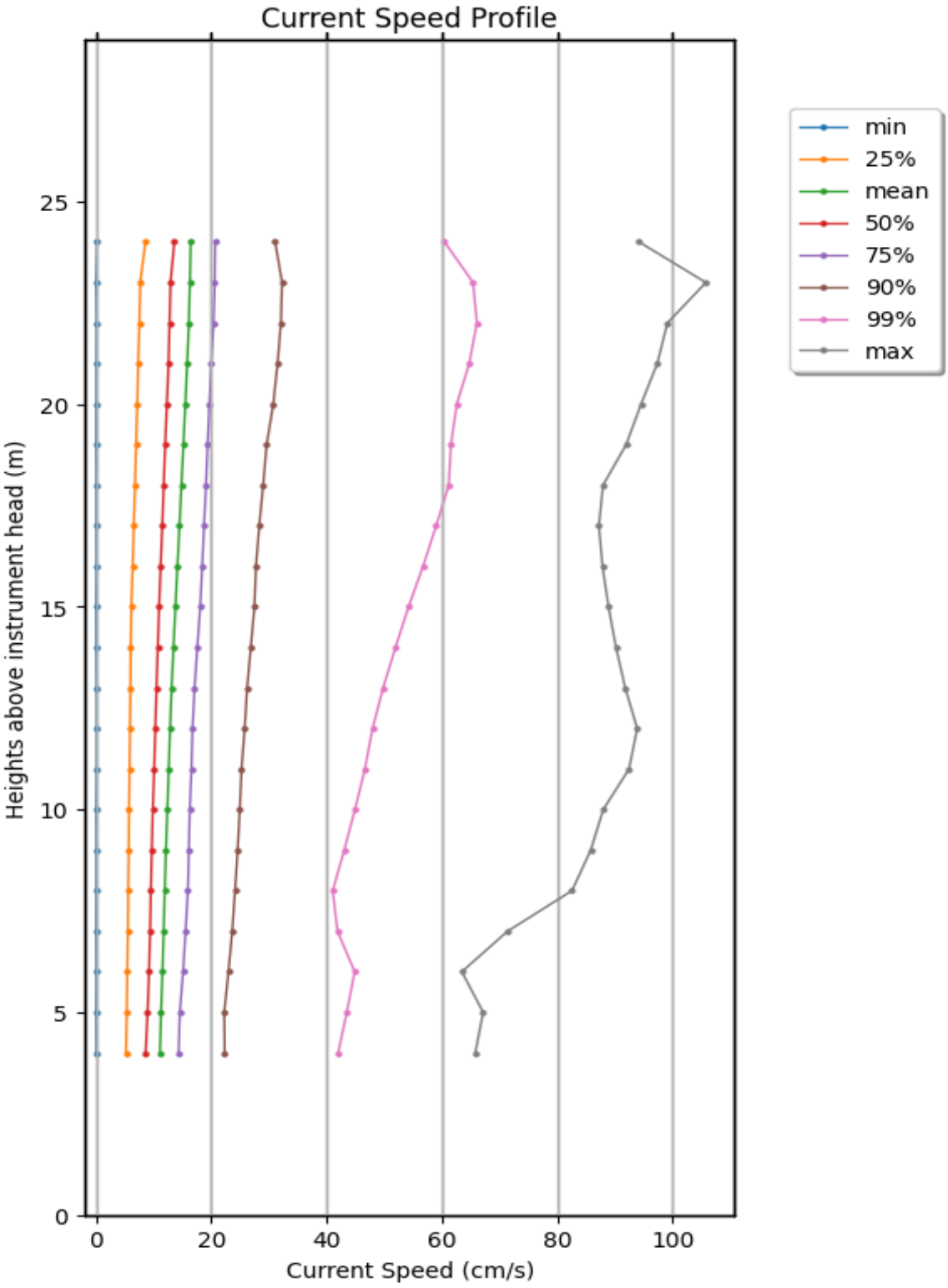


Figure 8.21: KFII-2-CP current speed profile for D1 (3 September 2023 – 15 April 2024)

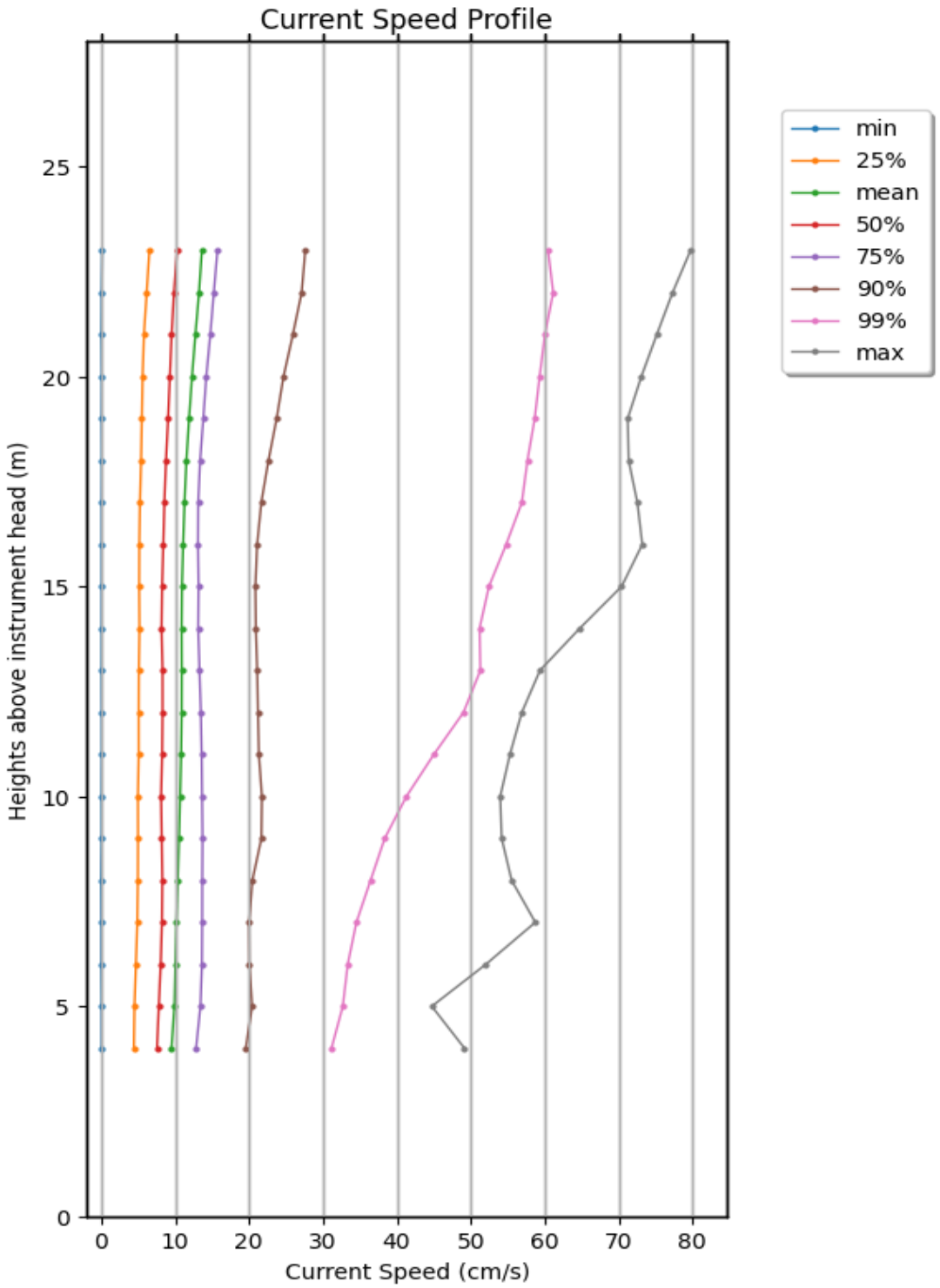


Figure 8.22: KFII-2-CP current speed profile for D2 (15 April 2024-3 September 2024)

9. References

[1] Fugro Norway AS, "Final Report for Kriegers Flak II (KFII-3), 1 November 2023 - 14 April 2024, C75517-R6-KFII3-001 (01), 28 October 2024," 2024.

[2] DNVGL, "Assessment of the Fugro Seawatch Wind LiDAR Buoy WS 190 Pre-Deployment Validation at Frøya, Norway," 10129033-R-10, Rev. B, issue date: 2019-11-28, 2019.

[3] DNVGL, "WS172 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway," 10422674-R-6, Rev. B, issue date: 2023-08-25, 2023.

[4] DNV, ""SWLB083 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway", 10422674-R-14, Rev.A. 2023-07-28," 2023.

[5] DNV, ""SWLB085 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway", 10422674-R-18, Rev.A. 2023-10-09".

[6] Fugro, "Project Measurement Plan, All Lots (SWLB measurements - Danish Offshore Wind 2030)," Fugro, 2023.

[7] DNVGL, "WS210 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway," 10422674-R-7, Rev.B, issue date: 2023-09-01, 2023.

[8] Nortek, *Surge Help Guide,* "*Current Data Quality Control*".

[9] UNESCO 1983, "*Algorithms for computation of fundamental properties of seawater*", Unesco technical papers in marine science 44.

[10] *Python-seawater (the package uses the formulas from UNESCO 1981 and UNESCO 1983 (EOS-80)). Retrieved from https://pythonhosted.org/seawater/eos80.html.*

[11] Ocean Contour Acoustic Doppler Data Processing Package V 2.1.5, R2272, Ocean Illumination Ltd. 2016-2018, 2022.

[12] 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.

[13] European Commision, *European Marine Observation and Data Network (EMODnet), (https://emodnet.ec.europa.eu/geoviewer/).*

[14] DNVGL, "WS199 Independent performance verification of Seawatch Wind Lidar Buoy at Frøya, Norway," 10422674-R-11, Rev. B, issue date: 2023-07-13, 2023.

Appendix A

Event Logs

A.1 KFII-1

Issue number	Start time	End time	Instrument	Parameter	Description
1	10/09/2023 23:10	11/09/2023 01:00	Lidar	80-300m	Partial QC filter due to bad weather
2	04/01/2024 12:10	04/01/2024 13:00	Lidar	All parameters	Partial QC filter due to bad weather
3	31/01/2024 21:20	31/01/2024 22:00	Lidar	All parameters	Partial QC filter due to bad weather
4	01/02/2024 02:10	01/02/2024 03:00	Lidar	All parameters	Partial QC filter due to bad weather
5	01/02/2024 10:10	01/02/2024 11:00	Lidar	All parameters	Partial QC filter due to bad weather
6	12/02/2024 04:10	16/02/2024 16:50	Lidar	All parameters	Lidar low input power
7	27/02/2024 07:20	27/02/2024 08:00	Lidar	80-300m	Partial QC filter due to bad weather
8	27/02/2024 13:10	27/02/2024 13:50	Lidar	100-300m	Partial QC filter due to bad weather
9	02/03/2024 10:10	02/03/2024 11:00	Lidar	80-300m	Partial QC filter due to bad weather
10	02/03/2024 12:10	02/03/2024 14:00	Lidar	80-300m	Partial QC filter due to bad weather
11	02/03/2024 15:10	02/03/2024 16:00	Lidar	80-300m	Partial QC filter due to bad weather
12	20/03/2024 22:10	21/03/2024 00:00	Lidar	80-300m	Partial QC filter due to bad weather
13	01/04/2024 08:10	01/04/2024 09:00	Lidar	80-300m	Partial QC filter due to bad weather
14	08/04/2024 17:10	08/04/2024 20:00	Lidar	80-300m	Partial QC filter due to bad weather
15	08/04/2024 21:10	08/04/2024 23:00	Lidar	80-300m	Partial QC filter due to bad weather
16	04/05/2024 07:20	04/05/2024 09:00	Lidar	80-300m	Partial QC filter due to bad weather
17	11/05/2024 13:10	11/05/2024 13:50	Lidar	80-300m	Partial QC filter due to bad weather
18	11/05/2024 18:20	11/05/2024 20:00	Lidar	80-300m	Partial QC filter due to bad weather
19	25/05/2024 14:20	25/05/2024 15:00	Lidar	80-300m	Partial QC filter due to bad weather

Issue number	Start time	End time	Instrument	Parameter	Description
20	25/05/2024 21:10	25/05/2024 21:50	Lidar	80-300m	Partial QC filter due to bad weather
21	28/06/2024 04:10	28/06/2024 06:00	Lidar	80-300m	Partial QC filter due to bad weather
22	04/09/2023 21:40	04/09/2023 23:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
23	05/09/2023 05:10	05/09/2023 06:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
24	05/09/2023 07:50	05/09/2023 09:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
25	05/09/2023 21:50	06/09/2023 06:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
26	09/09/2023 20:50	09/09/2023 22:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
27	10/09/2023 00:00	10/09/2023 01:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
28	10/09/2023 05:10	10/09/2023 07:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
29	10/09/2023 09:30	10/09/2023 11:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
30	11/09/2023 01:50	11/09/2023 04:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
31	11/09/2023 08:40	11/09/2023 10:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
32	11/09/2023 11:20	11/09/2023 13:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
33	12/09/2023 03:10	12/09/2023 04:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
34	27/09/2023 16:00	27/09/2023 18:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
35	29/09/2023 00:20	29/09/2023 02:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
36	02/10/2023 22:20	03/10/2023 00:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
37	08/10/2023 20:40	08/10/2023 23:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
38	21/10/2023 23:50	22/10/2023 05:40	Thelma	Bottom Temperature	Values out of bound

Issue number	Start time	End time	Instrument	Parameter	Description
39	22/10/2023 06:00	22/10/2023 10:00	Pws visibility sensor	Visibility	Outliers
40	22/10/2023 12:30	23/10/2023 01:20	Pws visibility sensor	Visibility	Outliers
41	23/10/2023 02:40	24/10/2023 00:10	Pws visibility sensor	Visibility	Outliers
42	24/10/2023 04:30	25/10/2023 00:10	Pws visibility sensor	Visibility	Outliers
43	12/11/2023 03:30	12/11/2023 05:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
44	12/11/2023 18:40	12/11/2023 20:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
45	12/11/2023 22:50	13/11/2023 01:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
46	09/01/2024 20:50	09/01/2024 23:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
47	30/01/2024 00:30	30/01/2024 02:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
48	01/02/2024 01:40	01/02/2024 03:20	Lidar	Air Pressure / Air Temperature	Duplicate values
49	01/02/2024 09:30	01/02/2024 11:10	Lidar	Air Pressure / Air Temperature	Duplicate values
50	12/02/2024 03:40	14/02/2024 20:10	Lidar	Air Pressure / Air Temperature	Duplicate values
51	15/02/2024 17:20	15/02/2024 19:00	Lidar	Air Pressure / Air Temperature	Duplicate values
52	15/02/2024 17:20	15/02/2024 19:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
53	16/02/2024 02:30	16/02/2024 16:50	Lidar	Air Pressure / Air Temperature	Duplicate values
54	16/02/2024 15:10	16/02/2024 16:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
55	24/02/2024 00:20	24/02/2024 07:10	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
56	29/02/2024 23:10	01/03/2024 01:40	Vaisala PTB330	Air Pressure	Duplicate values
57	03/03/2024 05:20	03/03/2024 07:10	Vaisala HMP155	Air Humidity / Air Temperature	Duplicate values

Issue number	Start time	End time	Instrument	Parameter	Description
58	12/03/2024 04:10	12/03/2024 06:00	Vaisala PTB330	Air Pressure	Duplicate values
59	13/03/2024 00:20	13/03/2024 02:40	Vaisala HMP155	Air Humidity / Air Temperature	Duplicate values
60	20/03/2024 18:30	20/03/2024 21:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
61	25/03/2024 08:20	25/03/2024 10:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
62	25/03/2024 12:30	25/03/2024 14:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
63	30/03/2024 04:20	30/03/2024 06:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
64	08/04/2024 11:10	08/04/2024 13:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
65	08/04/2024 19:30	09/04/2024 00:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
66	03/05/2024 02:20	03/05/2024 04:30	Vaisala PTB330	Air Pressure	Duplicate values
67	04/05/2024 14:40	04/05/2024 16:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
68	04/05/2024 23:10	05/05/2024 00:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
69	08/05/2024 19:10	08/05/2024 21:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
70	09/05/2024 02:00	09/05/2024 05:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
71	11/05/2024 11:30	11/05/2024 13:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
72	24/05/2024 20:40	24/05/2024 22:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
73	29/05/2024 00:40	29/05/2024 02:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
74	04/06/2024 16:00	04/06/2024 17:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
75	04/06/2024 20:10	05/06/2024 00:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
76	18/06/2024 01:00	18/06/2024 04:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
77	18/06/2024 07:50	18/06/2024 09:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
78	18/06/2024 17:40	18/06/2024 19:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
79	19/06/2024 01:40	19/06/2024 04:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
80	24/06/2024 16:20	24/06/2024 21:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
81	25/06/2024 01:20	25/06/2024 03:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
82	08/07/2024 22:50	09/07/2024 01:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
83	11/07/2024 03:20	11/07/2024 05:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
84	12/07/2024 04:10	12/07/2024 06:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
85	16/07/2024 01:20	16/07/2024 03:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
86	19/07/2024 19:40	20/07/2024 05:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
87	21/07/2024 03:00	21/07/2024 05:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
88	25/07/2024 23:20	26/07/2024 01:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
89	30/07/2024 03:30	30/07/2024 10:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
90	30/07/2024 14:20	30/07/2024 16:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
91	01/08/2024 10:50	01/08/2024 13:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
92	01/08/2024 22:10	01/08/2024 23:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
93	02/08/2024 07:30	02/08/2024 10:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
94	04/08/2024 06:50	04/08/2024 08:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
95	12/08/2024 23:20	13/08/2024 01:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
96	27/08/2024 10:30	27/08/2024 13:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
97	30/08/2024 21:40	31/08/2024 00:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
Note Gaps less than or equal to consecutive 30 minutes were excluded from lidar data gap. For other parameters, gaps less than consecutive 100 minutes were excluded.					

A.2 KFII-2

Issue number	Start time	End time	Instrument	Parameter	Description
1	08/09/2023 01:10	08/09/2023 12:00	Lidar	100-300m	Partial QC filter due to bad weather
2	24/12/2023 22:10	16/01/2024 09:20	Lidar	All parameters	Partial QC filter due to bad weather
3	14/02/2024 17:10	15/02/2024 03:00	Lidar	12m, 80-300m	Partial QC filter due to bad weather
4	15/02/2024 12:20	15/02/2024 13:00	Lidar	12m, 100-300m	Partial QC filter due to bad weather
5	15/02/2024 21:20	15/02/2024 22:00	Lidar	12m, 80-300m	Partial QC filter due to bad weather
6	16/02/2024 02:10	16/02/2024 04:00	Lidar	80-300m	Partial QC filter due to bad weather
7	27/02/2024 14:10	27/02/2024 16:00	Lidar	80-300m	Partial QC filter due to bad weather
8	01/03/2024 12:10	01/03/2024 14:00	Lidar	80-300m	Partial QC filter due to bad weather
9	02/03/2024 09:10	02/03/2024 17:00	Lidar	80-300m	Partial QC filter due to bad weather
10	13/03/2024 11:10	13/03/2024 13:00	Lidar	80-300m	Partial QC filter due to bad weather
11	14/03/2024 01:10	14/03/2024 02:00	Lidar	80-300m	Partial QC filter due to bad weather
12	20/03/2024 21:10	21/03/2024 01:00	Lidar	80-300m	Partial QC filter due to bad weather
13	01/04/2024 04:10	01/04/2024 06:00	Lidar	80-300m	Partial QC filter due to bad weather

Issue number	Start time	End time	Instrument	Parameter	Description
14	04/04/2024 12:10	04/04/2024 14:00	Lidar	80-300m	Partial QC filter due to bad weather
15	08/04/2024 22:20	09/04/2024 02:00	Lidar	12m, 80-300m	Partial QC filter due to bad weather
16	26/05/2024 08:30	27/05/2024 00:00	Lidar	All parameters	Partial QC filter due to bad weather
17	07/06/2024 11:00	07/06/2024 12:00	Lidar	All parameters	Partial QC filter due to bad weather
18	03/09/2023 19:20	03/09/2023 21:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
19	04/09/2023 17:40	04/09/2023 20:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
19	05/09/2023 01:20	05/09/2023 07:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
20	05/09/2023 18:00	05/09/2023 20:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
21	06/09/2023 08:50	06/09/2023 10:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
22	10/09/2023 07:50	10/09/2023 09:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
23	26/09/2023 11:10	26/09/2023 17:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
24	08/10/2023 18:10	08/10/2023 23:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
25	09/10/2023 11:50	09/10/2023 16:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
26	18/10/2023 17:10	18/10/2023 19:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
27	24/10/2023 02:10	24/10/2023 04:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
28	03/11/2023 18:40	03/11/2023 21:00	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
29	08/11/2023 02:20	08/11/2023 04:00	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
30	11/11/2023 13:10	11/11/2023 15:00	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
31	12/11/2023 20:10	12/11/2023 21:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
32	27/11/2023 04:50	27/11/2023 06:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
33	09/12/2023 12:40	09/12/2023 16:30	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
34	11/12/2023 06:00	11/12/2023 07:40	Vaisala HMP155	Air Humidity / Air Temperature	Duplicate values
35	24/12/2023 22:00	27/12/2023 15:10	Lidar	Air Pressure / Air Temperature	Duplicate values
36	27/12/2023 18:20	02/01/2024 01:00	Lidar	Air Pressure / Air Temperature	Duplicate values
37	31/12/2023 15:00	31/12/2023 20:20	Vaisala PTB330	Air Pressure (hpa)	Duplicate values
38	02/01/2024 04:40	03/01/2024 01:10	Lidar	Air Pressure / Air Temperature	Duplicate values
39	03/01/2024 05:40	09/01/2024 11:20	Lidar	Air Pressure / Air Temperature	Duplicate values
40	09/01/2024 19:50	09/01/2024 22:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
41	09/01/2024 19:50	16/01/2024 05:10	Lidar	Air Pressure / Air Temperature	Duplicate values
42	16/01/2024 09:50	16/01/2024 13:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
43	31/01/2024 12:10	31/01/2024 14:20	Thelma	Bottom Temperature	Values out of bound
44	15/02/2024 13:10	15/02/2024 15:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
45	18/02/2024 00:10	18/02/2024 02:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
46	25/03/2024 16:10	25/03/2024 17:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
47	26/03/2024 02:40	26/03/2024 04:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
48	30/03/2024 03:00	30/03/2024 04:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
49	01/04/2024 02:40	01/04/2024 08:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
50	08/04/2024 11:40	08/04/2024 13:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
51	08/04/2024 19:40	08/04/2024 22:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
52	18/04/2024 10:50	18/04/2024 12:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
53	23/04/2024 15:00	24/05/2024 16:40	Thelma	All parameters	Duplicate values
54	24/05/2024 21:20	25/07/2024 05:30	Thelma	Bottom Temperature / Water Pressure	Values out of bound
55	29/04/2024 13:00	29/04/2024 16:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
56	04/05/2024 15:50	05/05/2024 04:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
57	05/05/2024 08:30	05/05/2024 10:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
58	08/05/2024 11:20	09/05/2024 07:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
59	09/05/2024 20:40	09/05/2024 23:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
60	10/05/2024 23:10	11/05/2024 11:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
61	11/05/2024 19:30	14/05/2024 19:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
62	20/05/2024 00:30	20/05/2024 05:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
63	24/05/2024 05:10	24/05/2024 16:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
64	24/05/2024 21:20	25/05/2024 23:20	Wavesense/ Geni datalogger	Wave parameters / Humidity	Wavesense/Geni system error, Other data was backfilled by local data storage
65	26/05/2024 08:40	07/06/2024 11:00	Wavesense/ Geni datalogger	Wave parameters / Humidity	Wavesense/Geni system error, Other data was backfilled by local data storage
66	20/06/2024 23:40	21/06/2024 08:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
67	24/06/2024 09:40	25/06/2024 07:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
68	27/06/2024 22:50	29/06/2024 21:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
69	01/07/2024 07:50	01/07/2024 09:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
70	01/07/2024 15:50	07/07/2024 21:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
71	07/07/2024 21:40	08/07/2024 04:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
72	11/07/2024 05:20	11/07/2024 17:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
73	12/07/2024 09:00	12/07/2024 10:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
74	19/07/2024 08:40	19/07/2024 10:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
75	19/07/2024 22:50	20/07/2024 22:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
76	23/07/2024 09:00	23/07/2024 22:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
77	29/07/2024 20:50	30/07/2024 09:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
78	30/07/2024 22:20	31/07/2024 01:50	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
79	31/07/2024 23:10	01/08/2024 02:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
80	01/08/2024 06:00	01/08/2024 12:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
81	02/08/2024 08:20	02/08/2024 16:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
82	06/08/2024 02:10	06/08/2024 13:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
83	17/08/2024 13:40	17/08/2024 17:10	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
84	18/08/2024 01:50	18/08/2024 04:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
85	18/08/2024 14:10	18/08/2024 17:00	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
86	19/08/2024 12:00	19/08/2024 13:40	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
87	19/08/2024 23:10	20/08/2024 01:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Issue number	Start time	End time	Instrument	Parameter	Description
88	27/08/2024 11:10	27/08/2024 13:20	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes
89	01/09/2024 02:40	01/09/2024 04:30	Wavesense	Hmax/thmax	Zero crossing parameter missing due to small amplitudes

Note
Gaps less than or equal to consecutive 30 minutes were excluded from lidar data gap. For other parameters, gaps less than consecutive 100 minutes were excluded.

Appendix B

Data presentation: KFII-1

B.1 Wind data

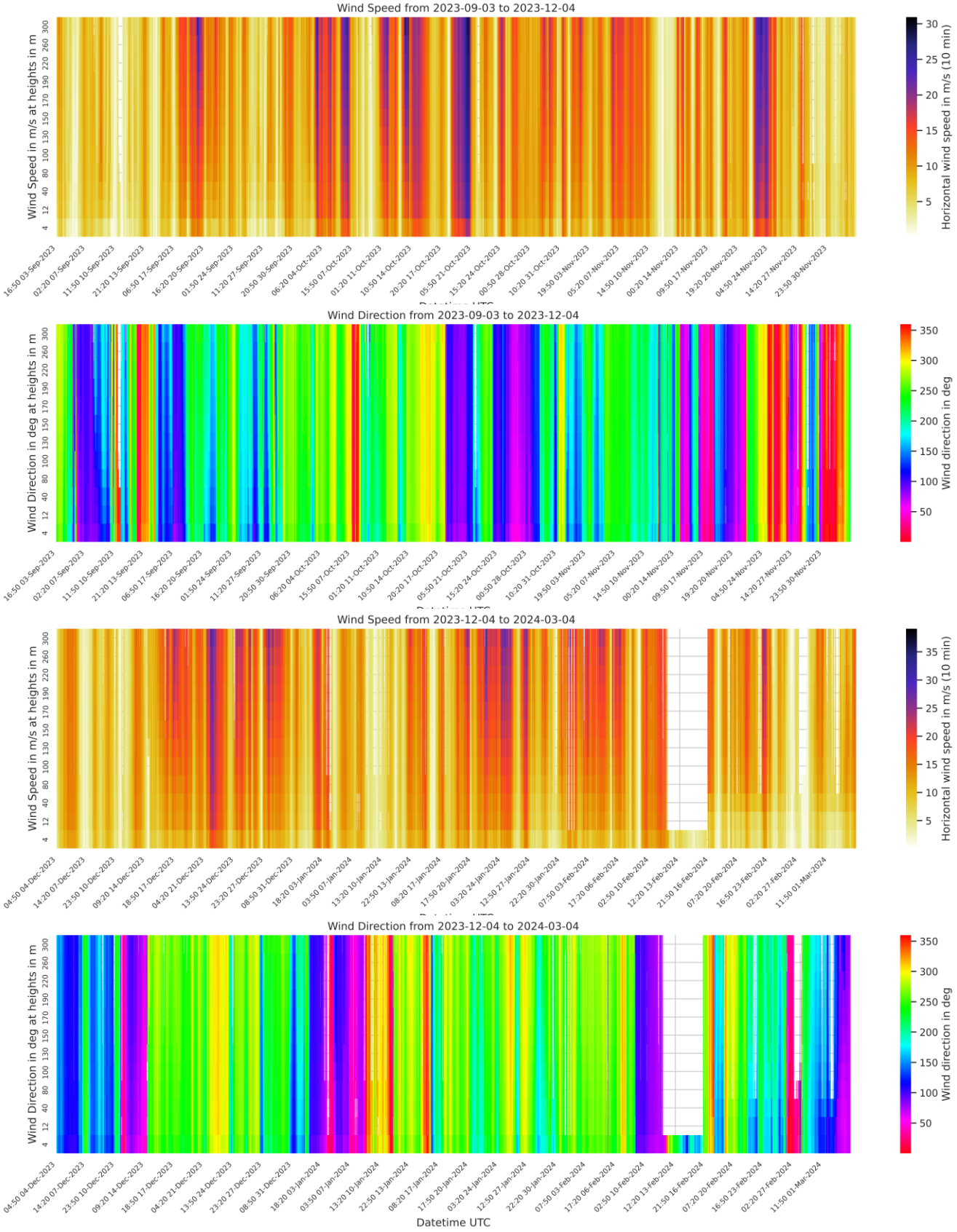


Figure B.1: Heatmaps of wind speed and direction from 3 September 2023 to 3 March 2024

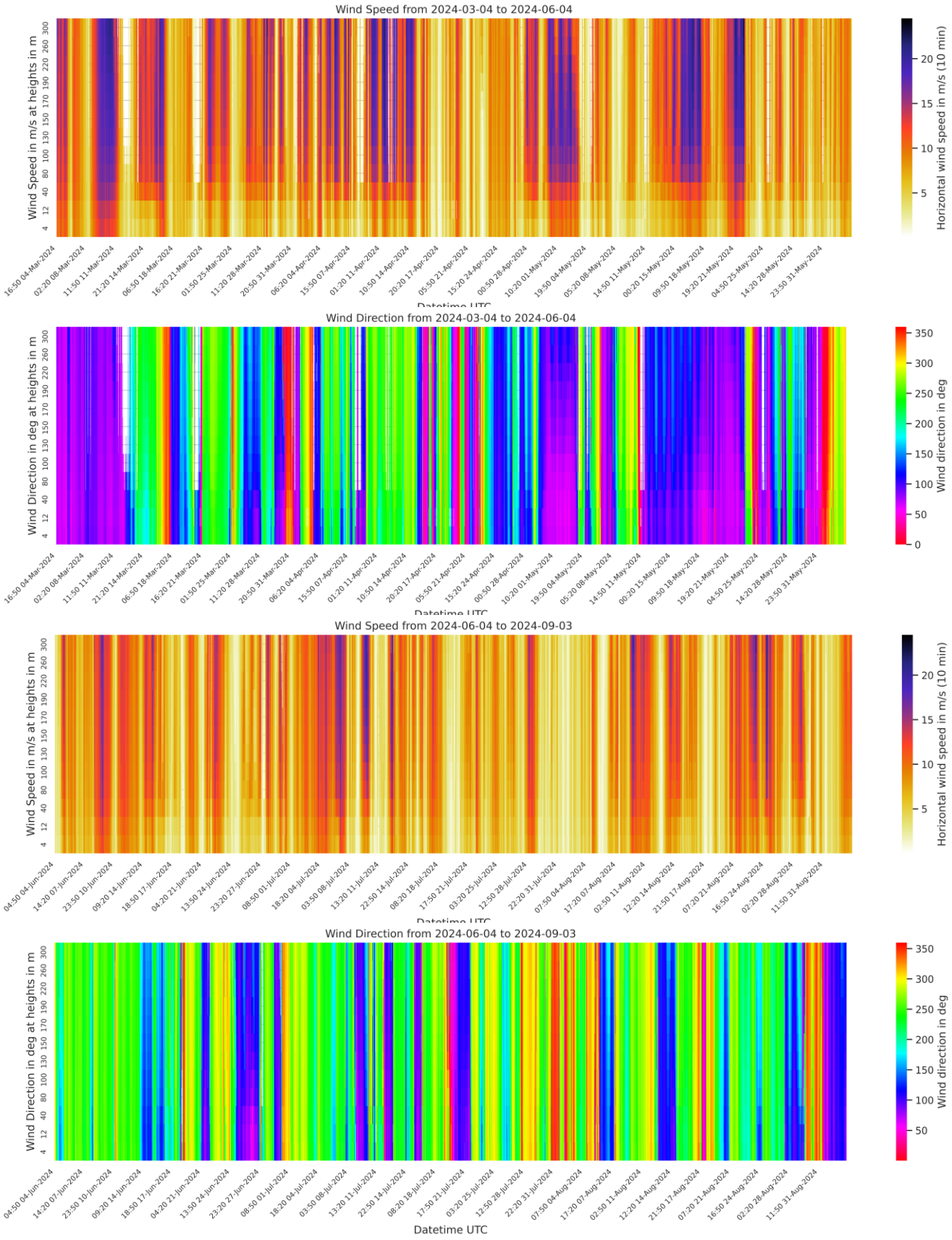


Figure B.2: Heatmaps of wind speed and direction from 3 March 2024 to 3 September 2024

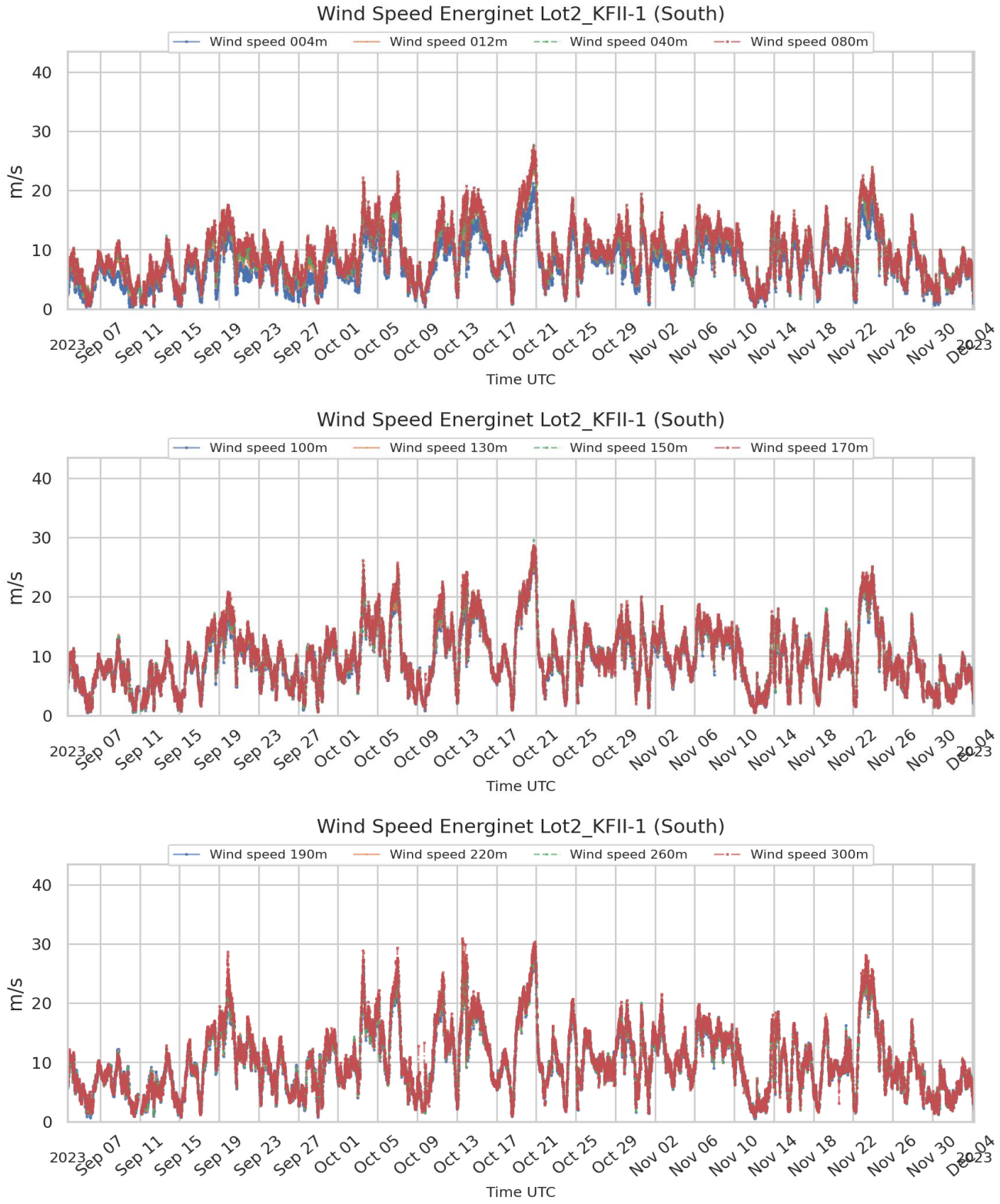


Figure B.3: Timeseries of wind speed from 3 September 2023 to 4 December 2023

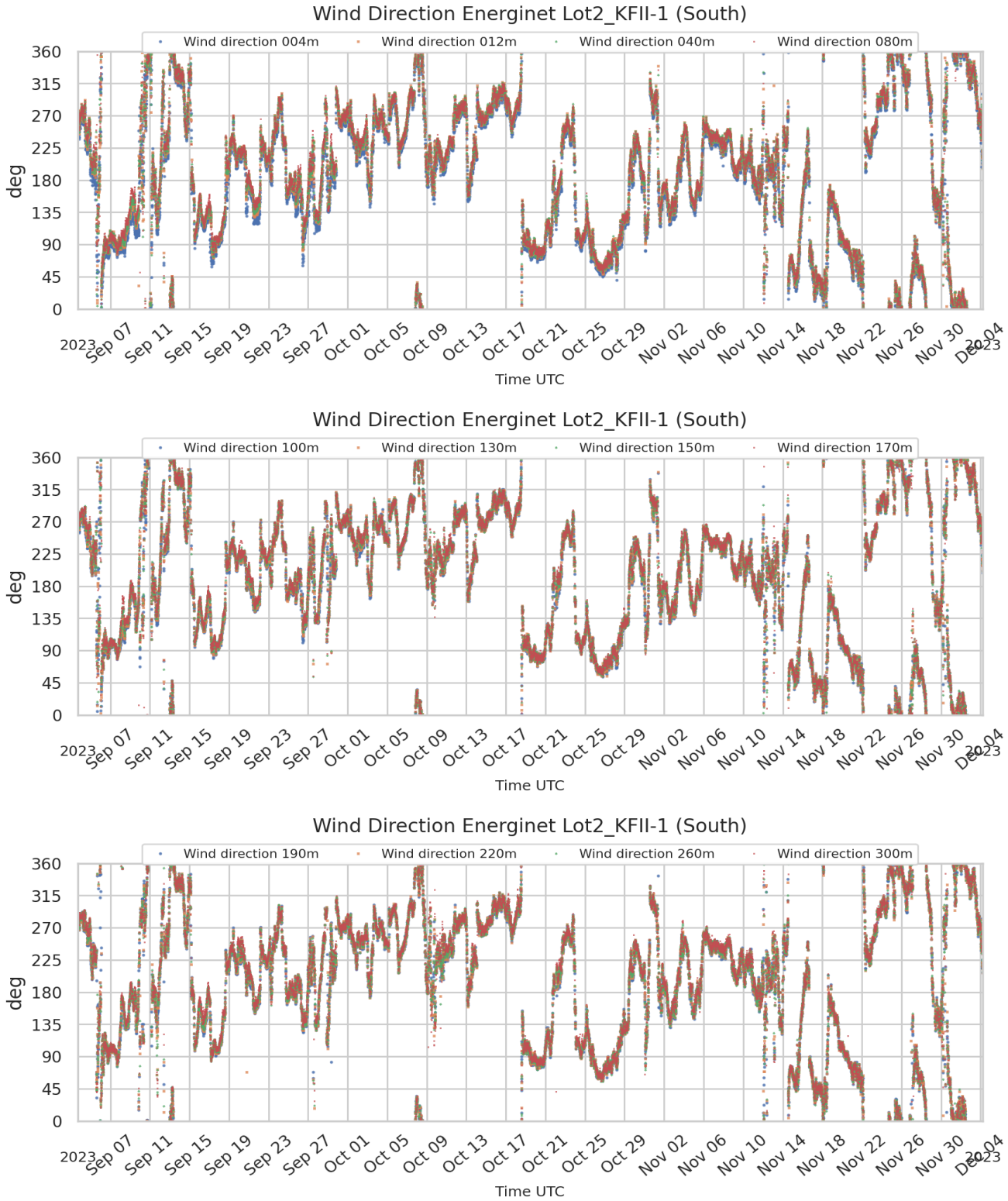


Figure B.4: Timeseries of wind direction from 3 September 2023 to 4 December 2023

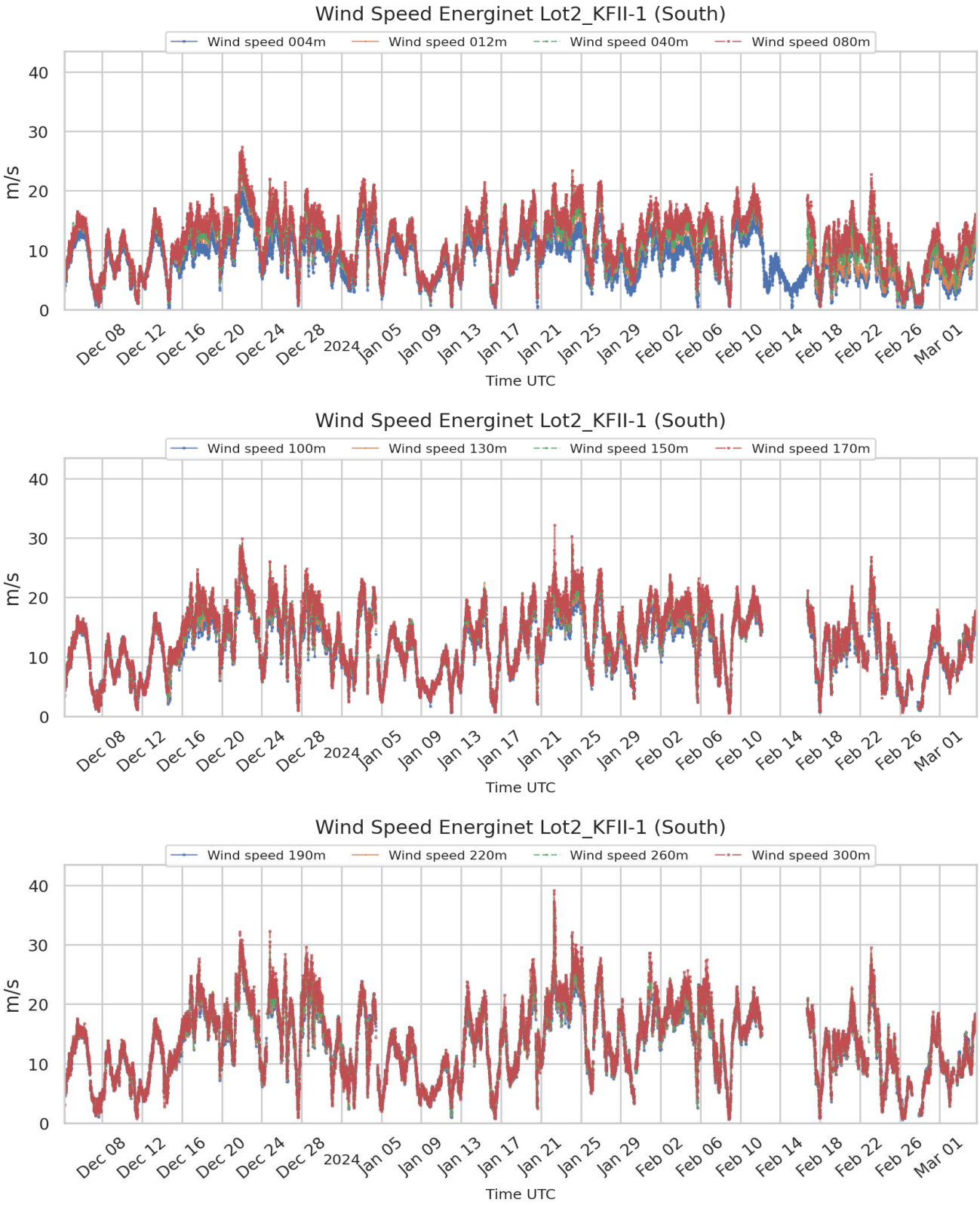


Figure B.5: Timeseries of wind speed from 4 December 2023 to 3 March 2024

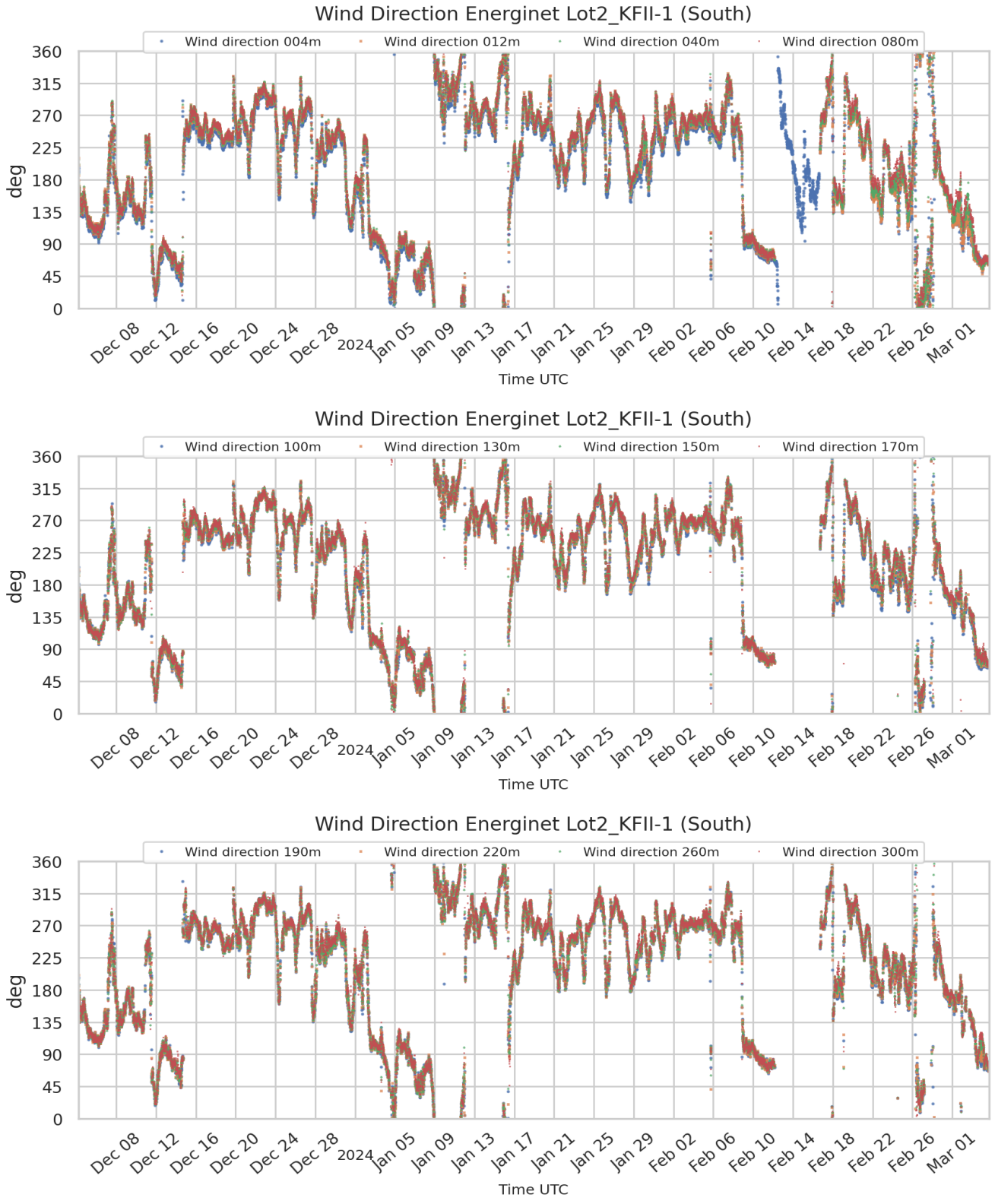


Figure B.6: Timeseries of wind direction from 4 December 2023 to 3 March 2024

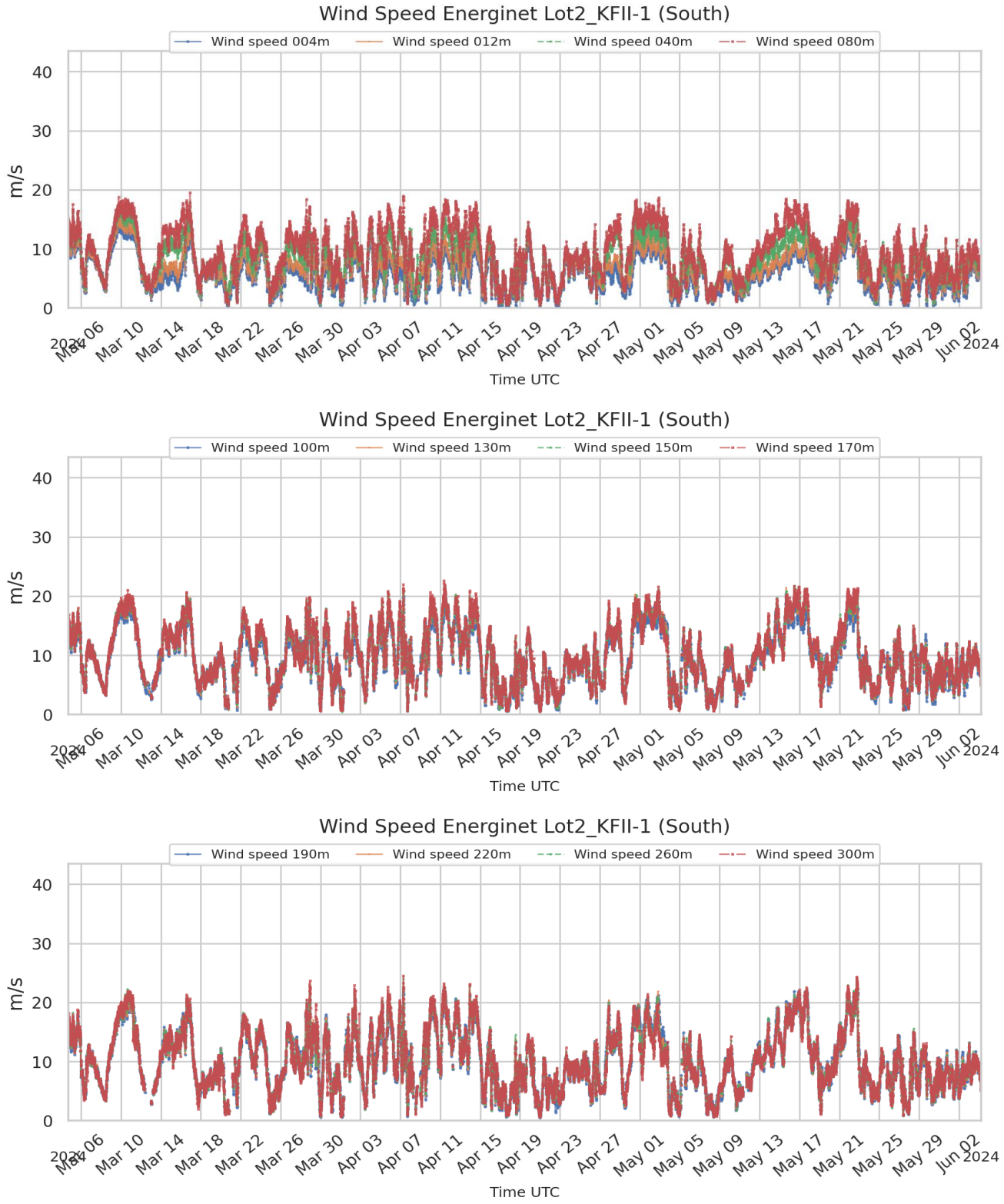


Figure B.7: Timeseries of wind speed from 3 March 2024 to 3 June 2024

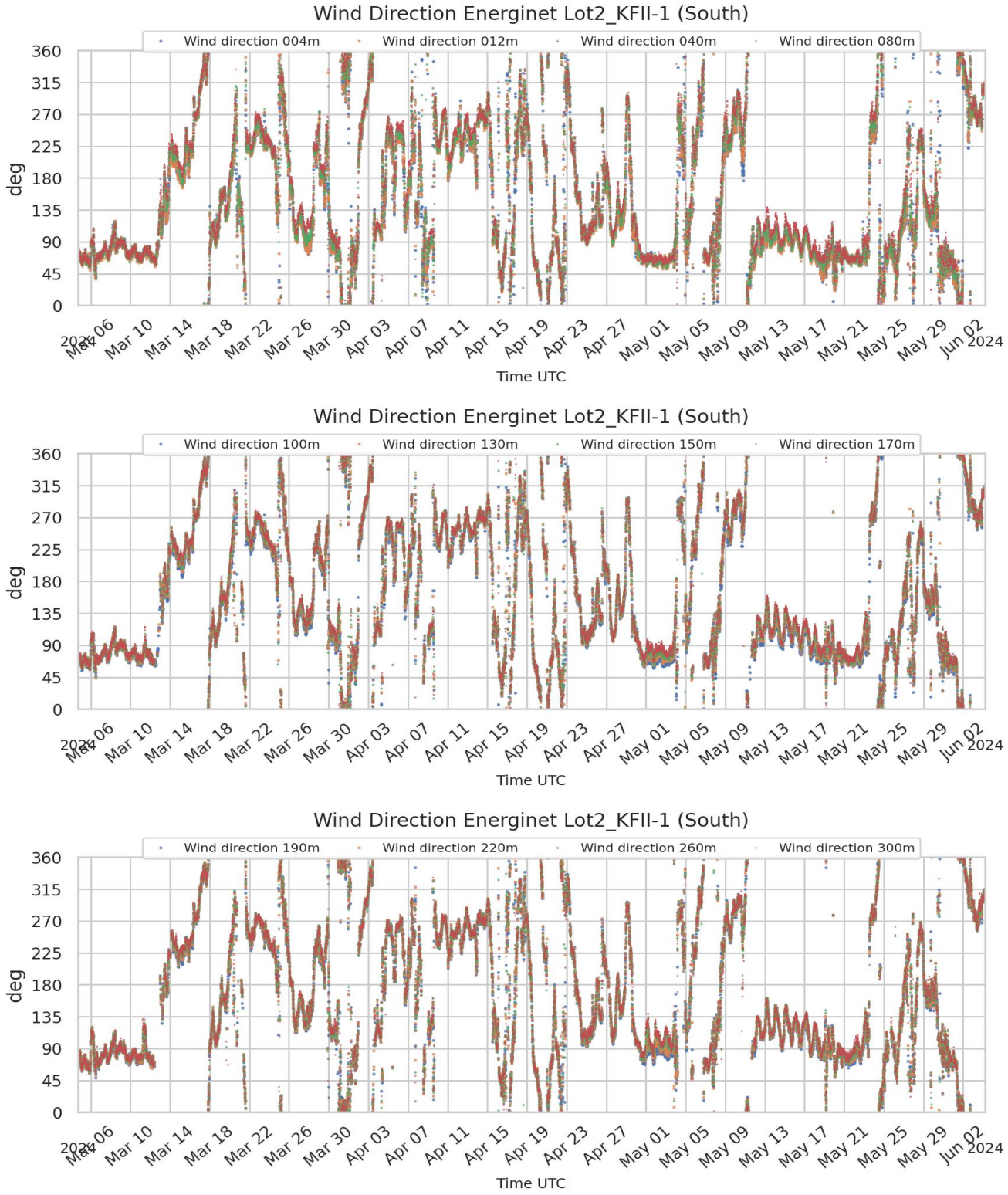


Figure B.8: Timeseries of wind direction from 3 March 2024 to 3 June 2024

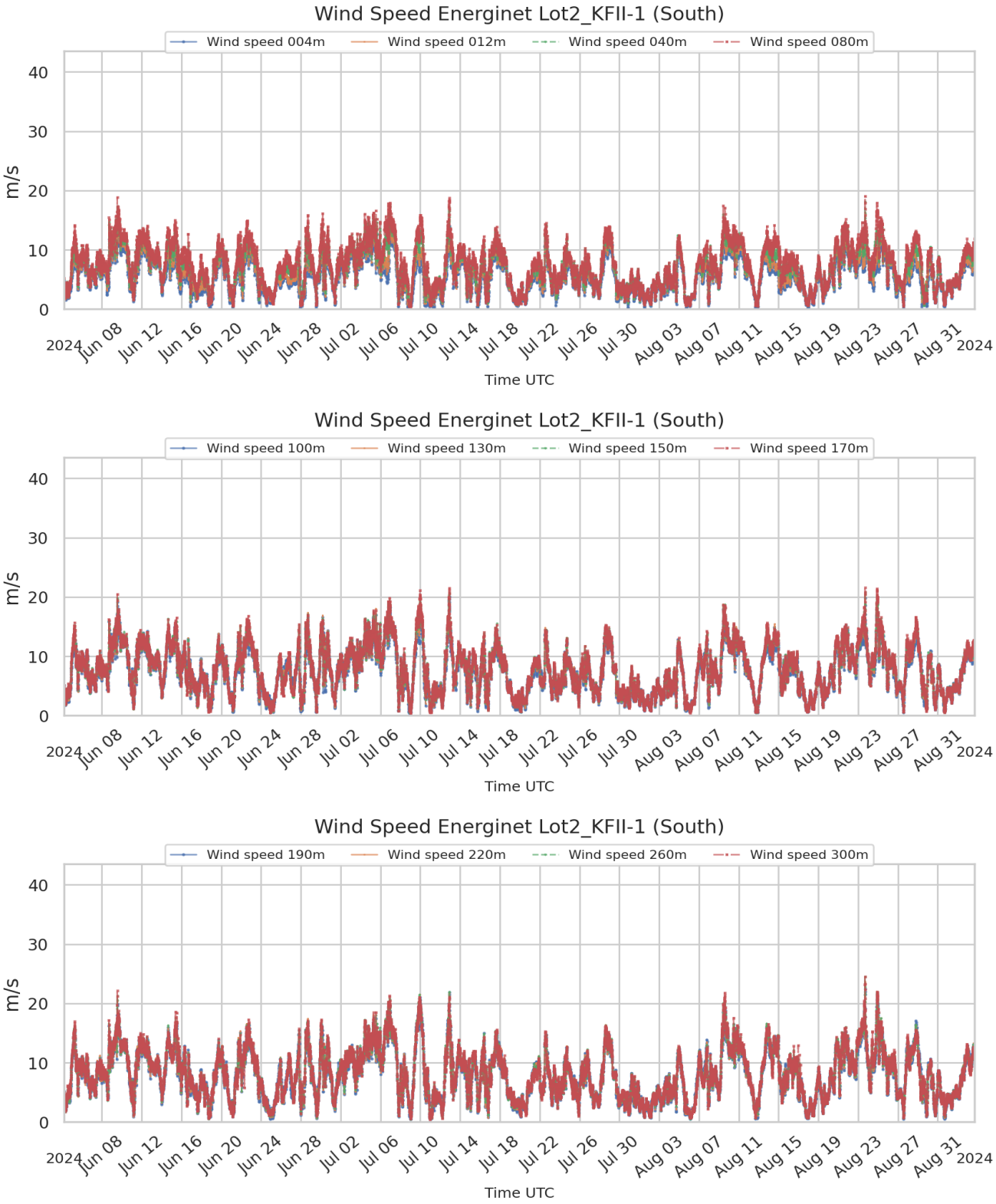


Figure B.9: Timeseries of wind speed from 3 June 2024 to 3 September 2024

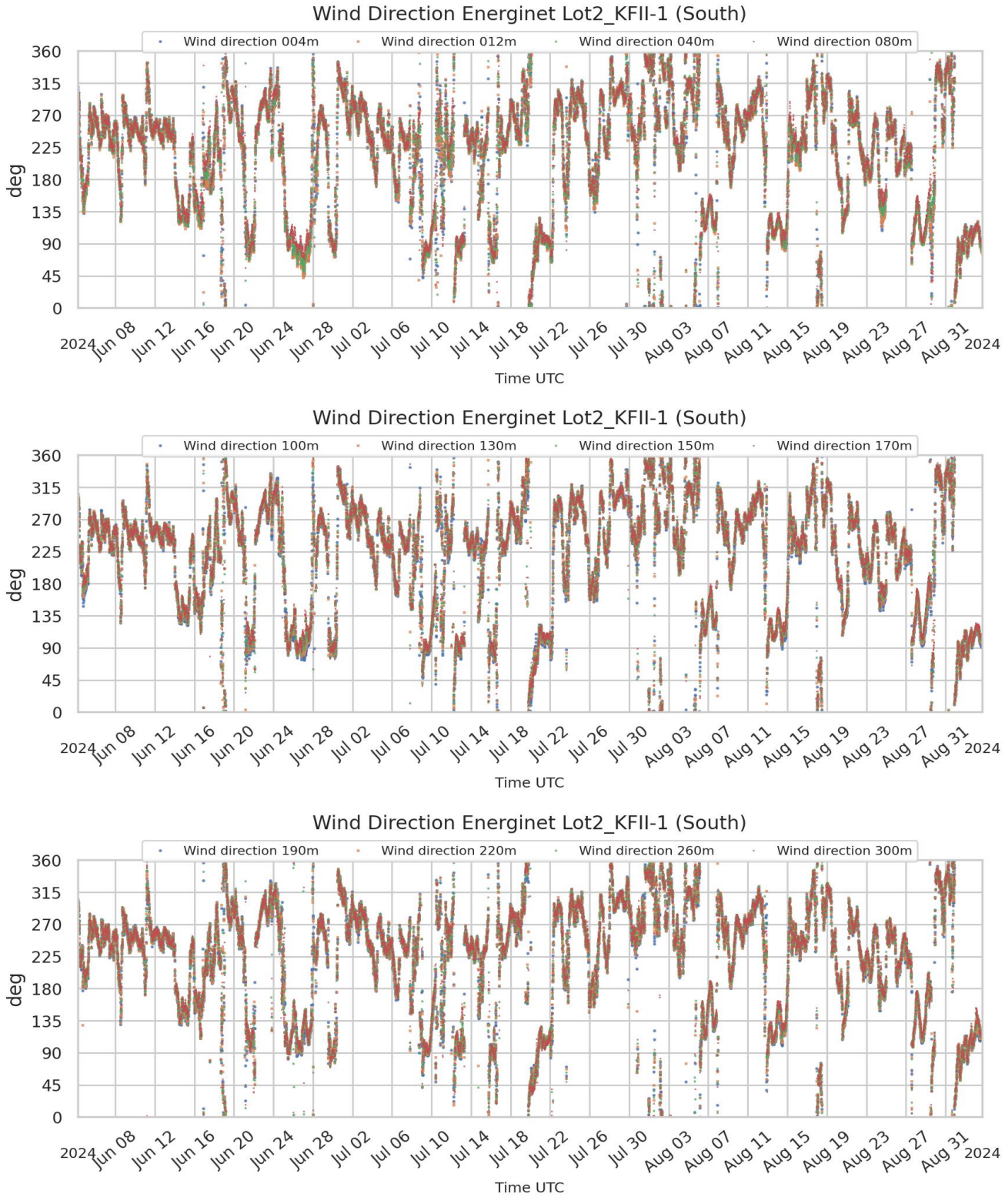


Figure B.10: Timeseries of wind direction from 3 June 2024 to 3 September 2024

B.2 Wave data

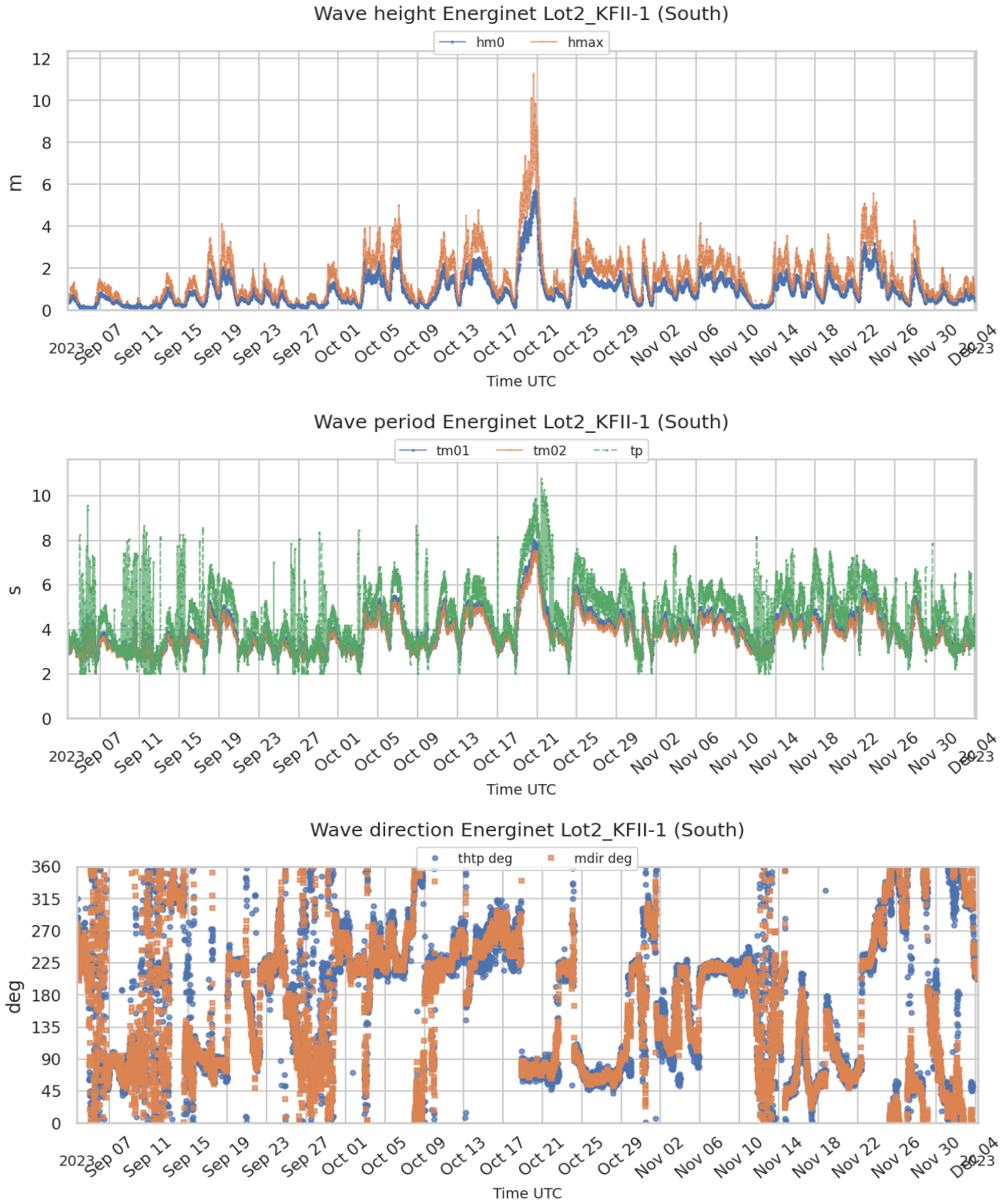


Figure B.11: Timeseries of wave heights, wave periods, and wave direction from 3 September 2023 to 4 December 2023

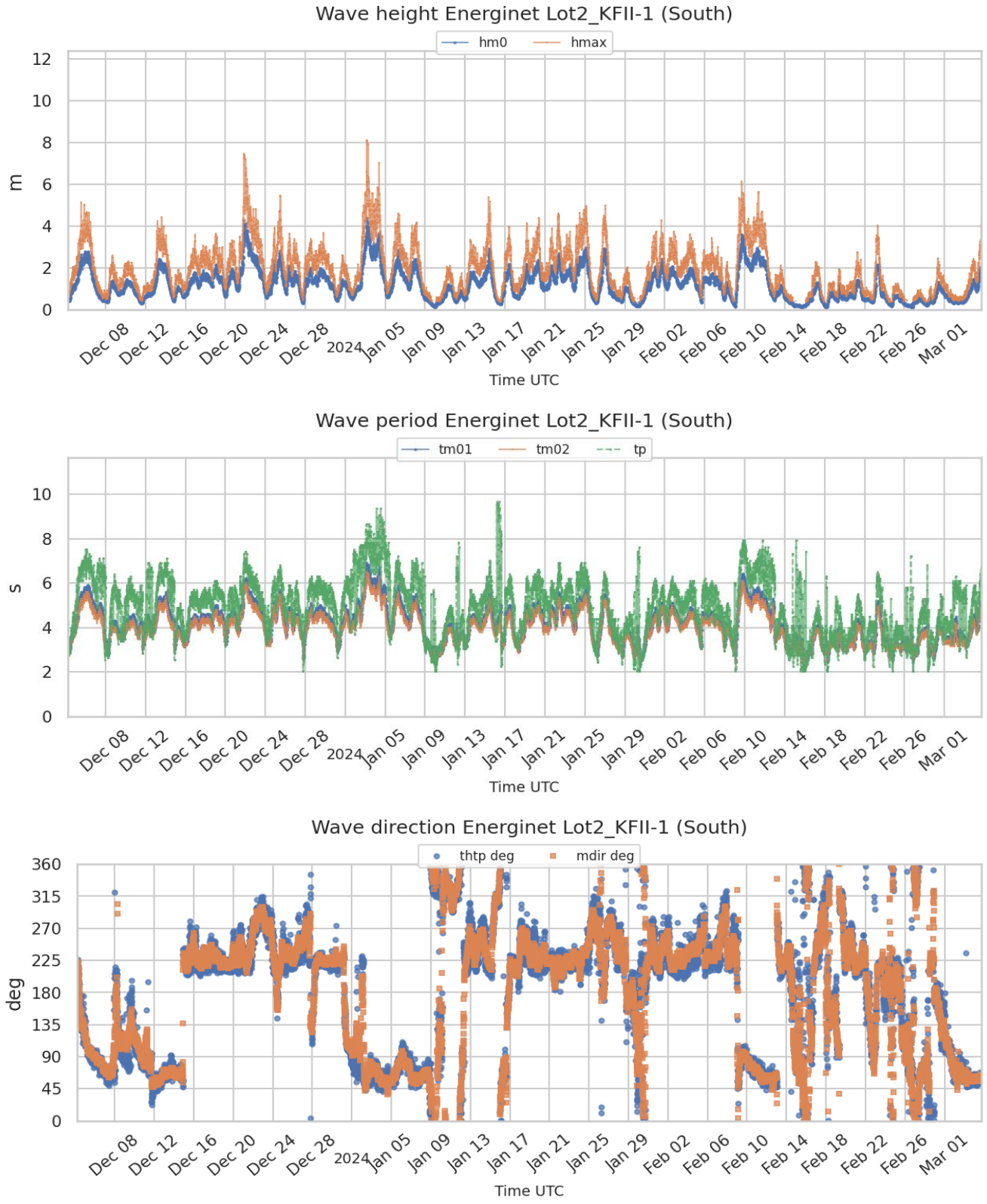


Figure B.12: Timeseries of wave heights, wave periods, and wave direction from 4 December to 3 March 2024

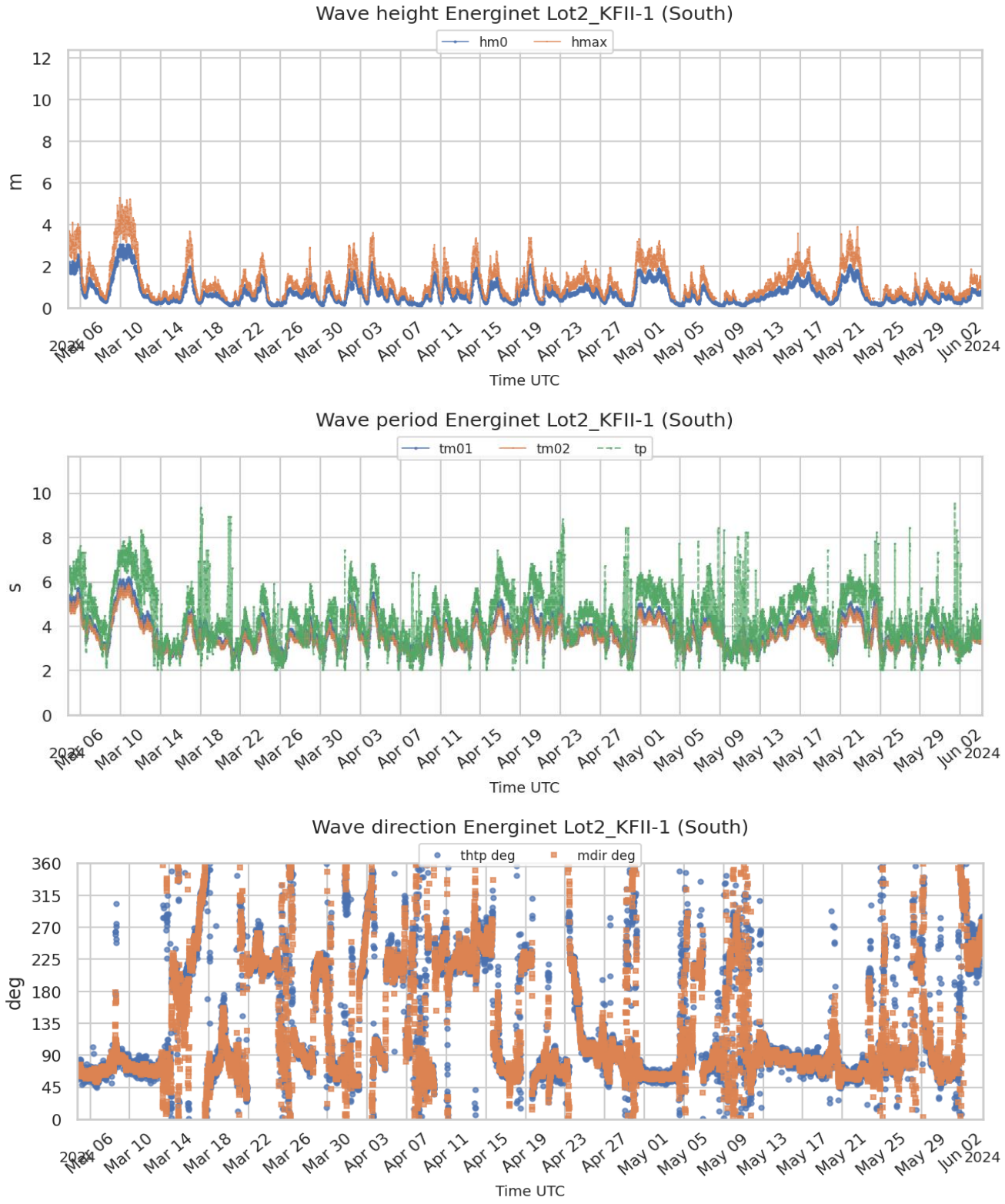


Figure B.13: Timeseries of wave heights, wave periods, and wave direction from 3 March 2024 to 3 June 2024

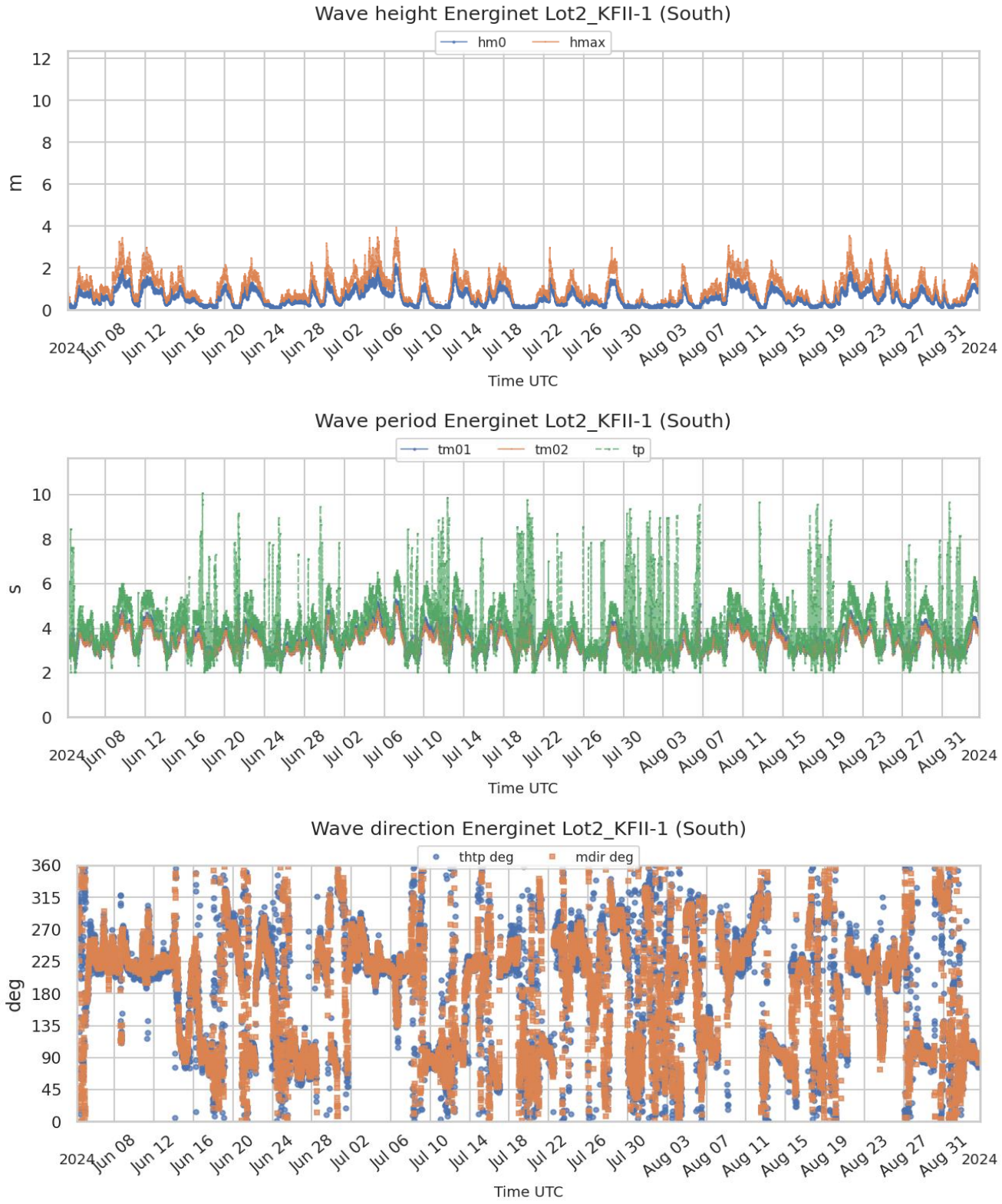


Figure B.14: Timeseries of wave heights, wave periods, and wave direction from 3 June 2024 to 3 September 2024

B.3 Metocean data

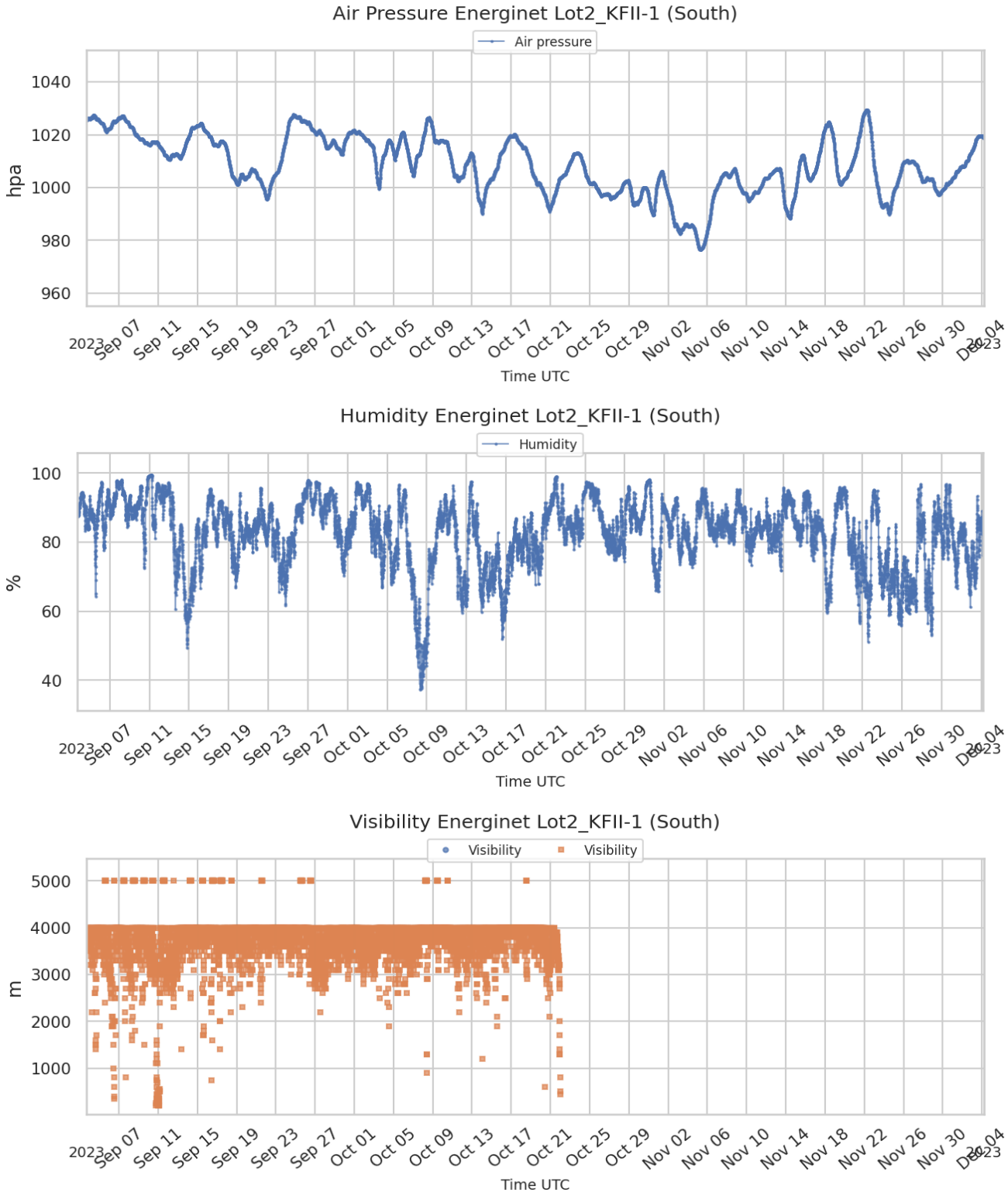


Figure B.15: Timeseries of air pressure, humidity and visibility from 3 September 2023 to 4 December 2023

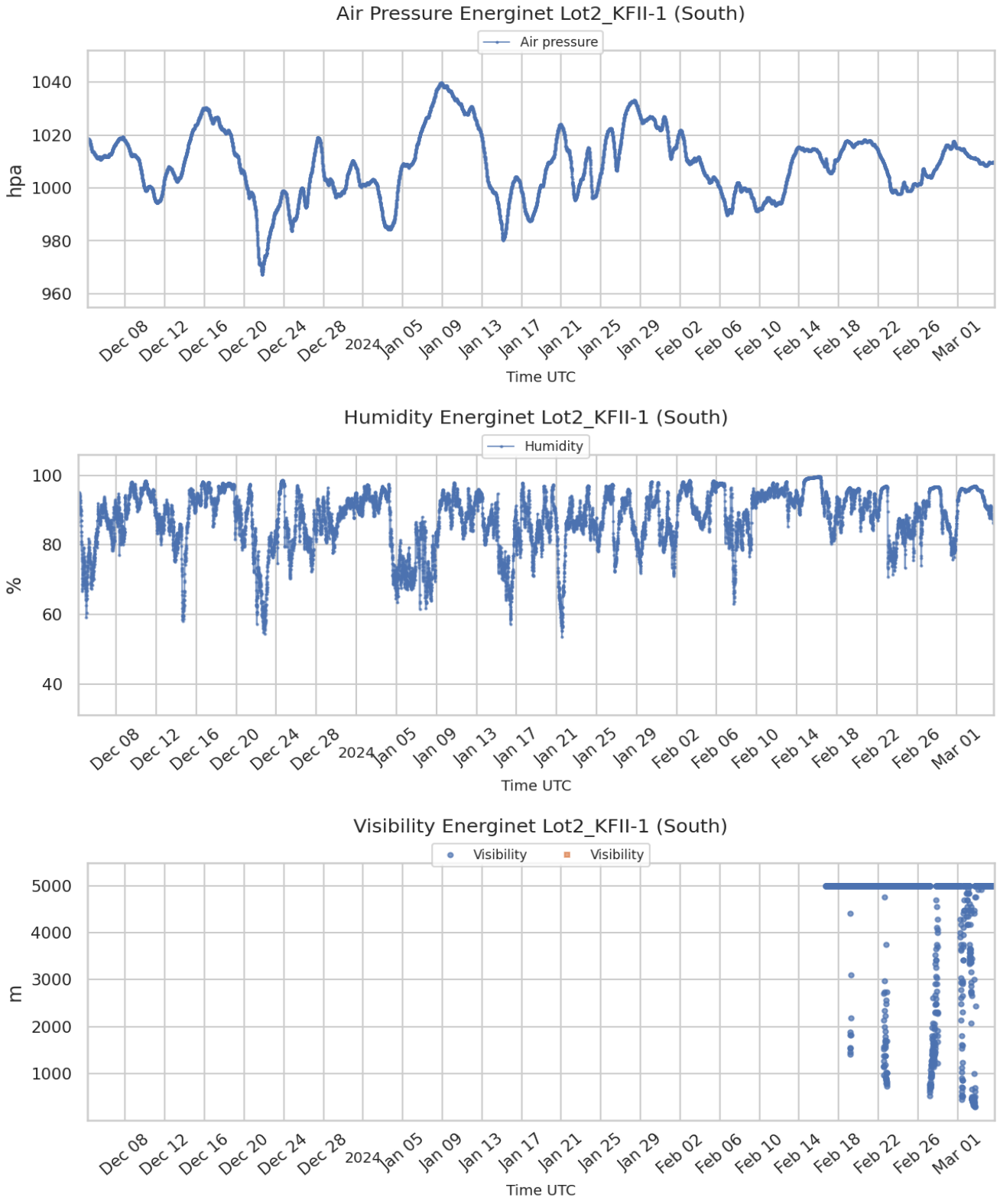


Figure B.16: Timeseries of air pressure, humidity and visibility from 4 December 2023 to 3 March 2024

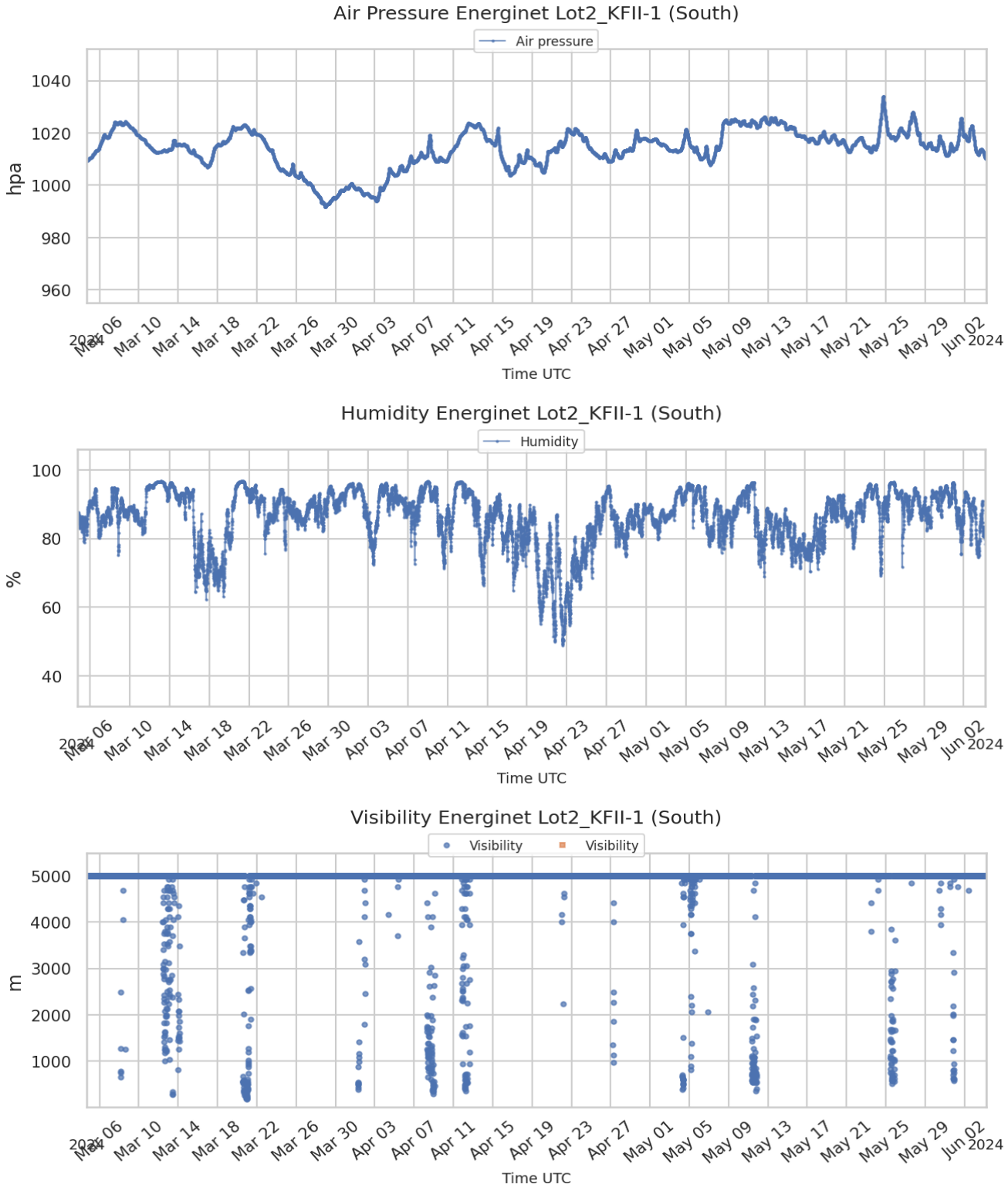


Figure B.17: Timeseries of air pressure, humidity and visibility from 3 March 2024 to 3 June 2024

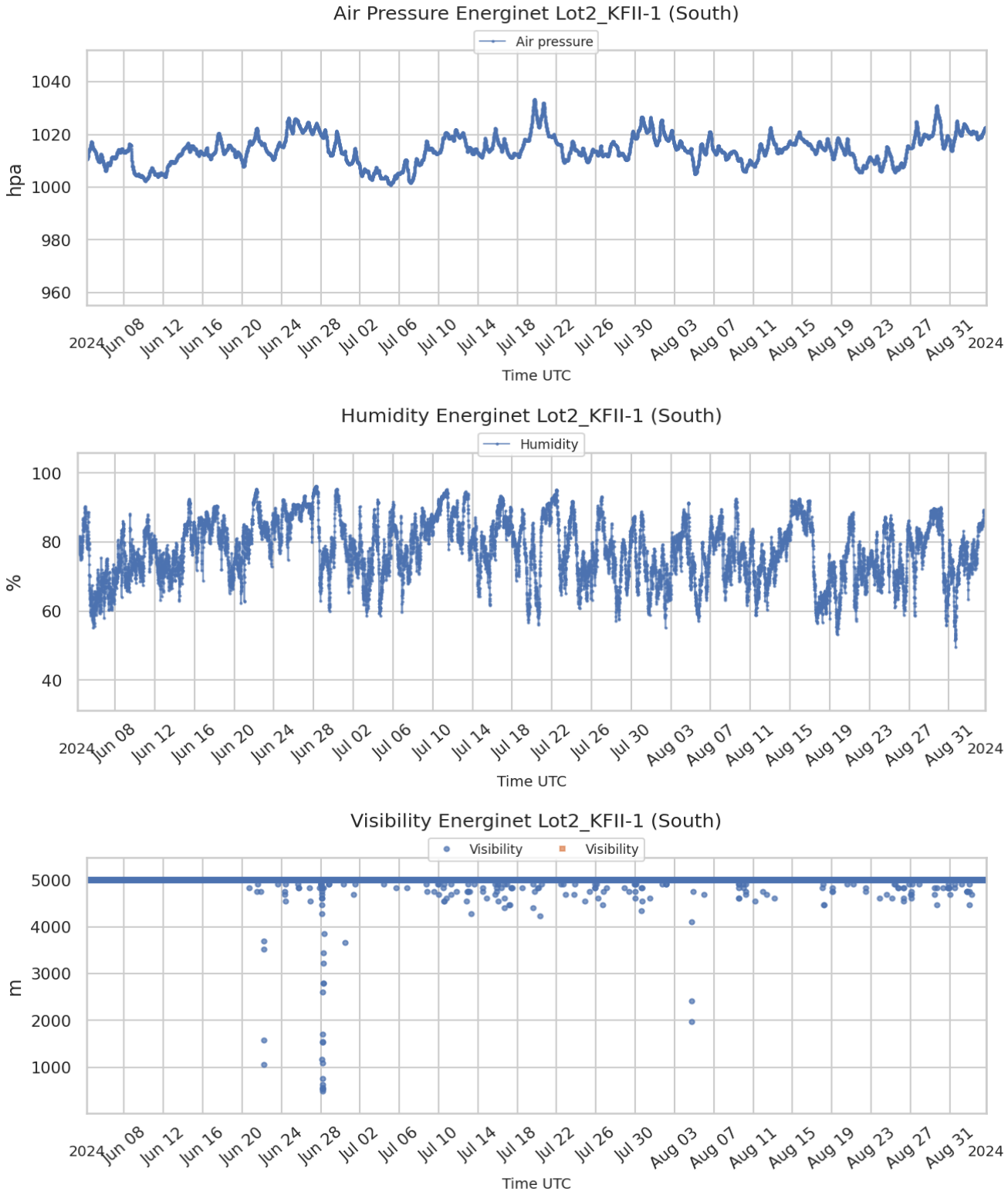


Figure B.18: Timeseries of air pressure, humidity and visibility from 3 June 2024 to 3 September 2024

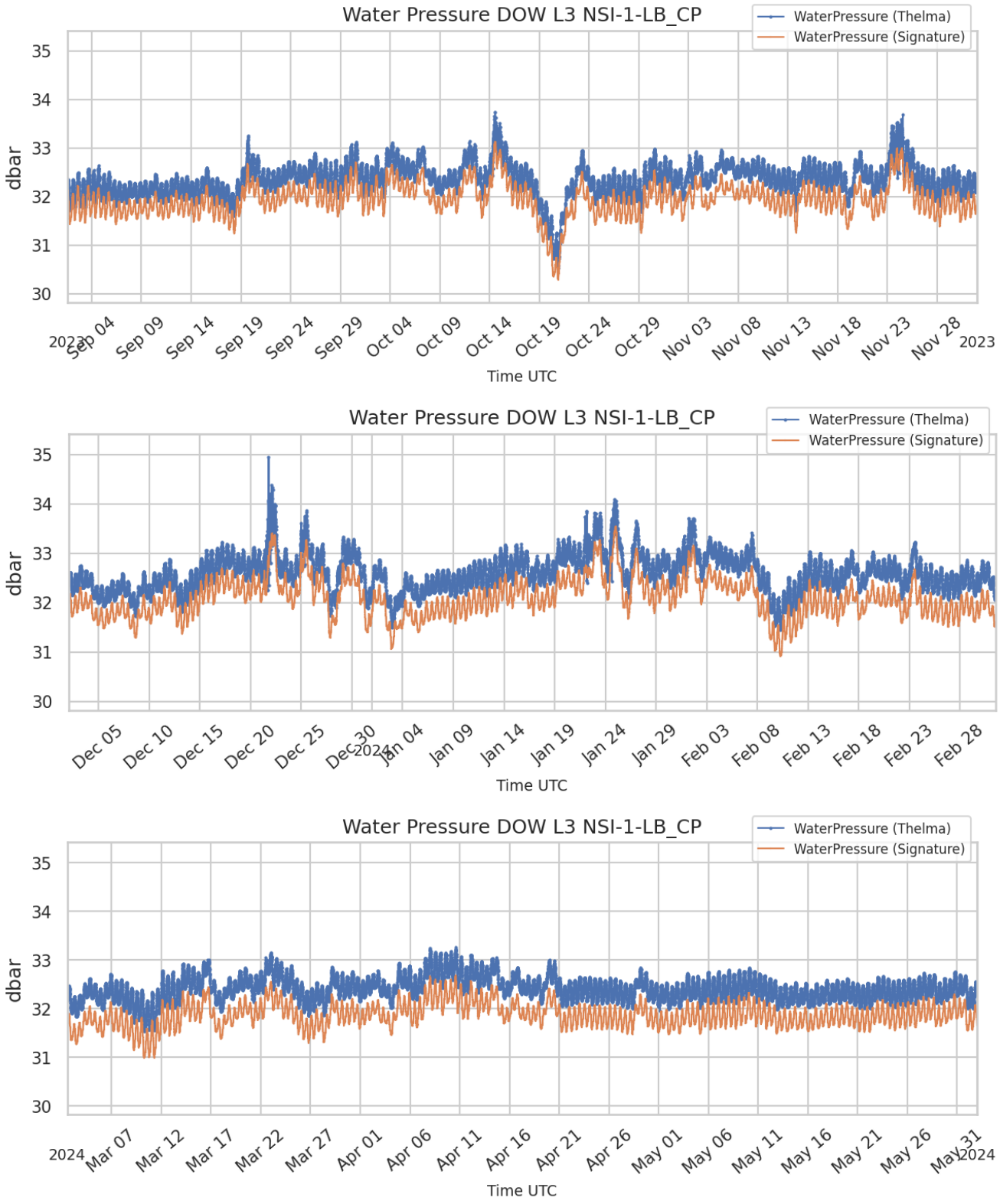


Figure B.19: Timeseries water pressure from 3 September 2023 to 2 June 2024

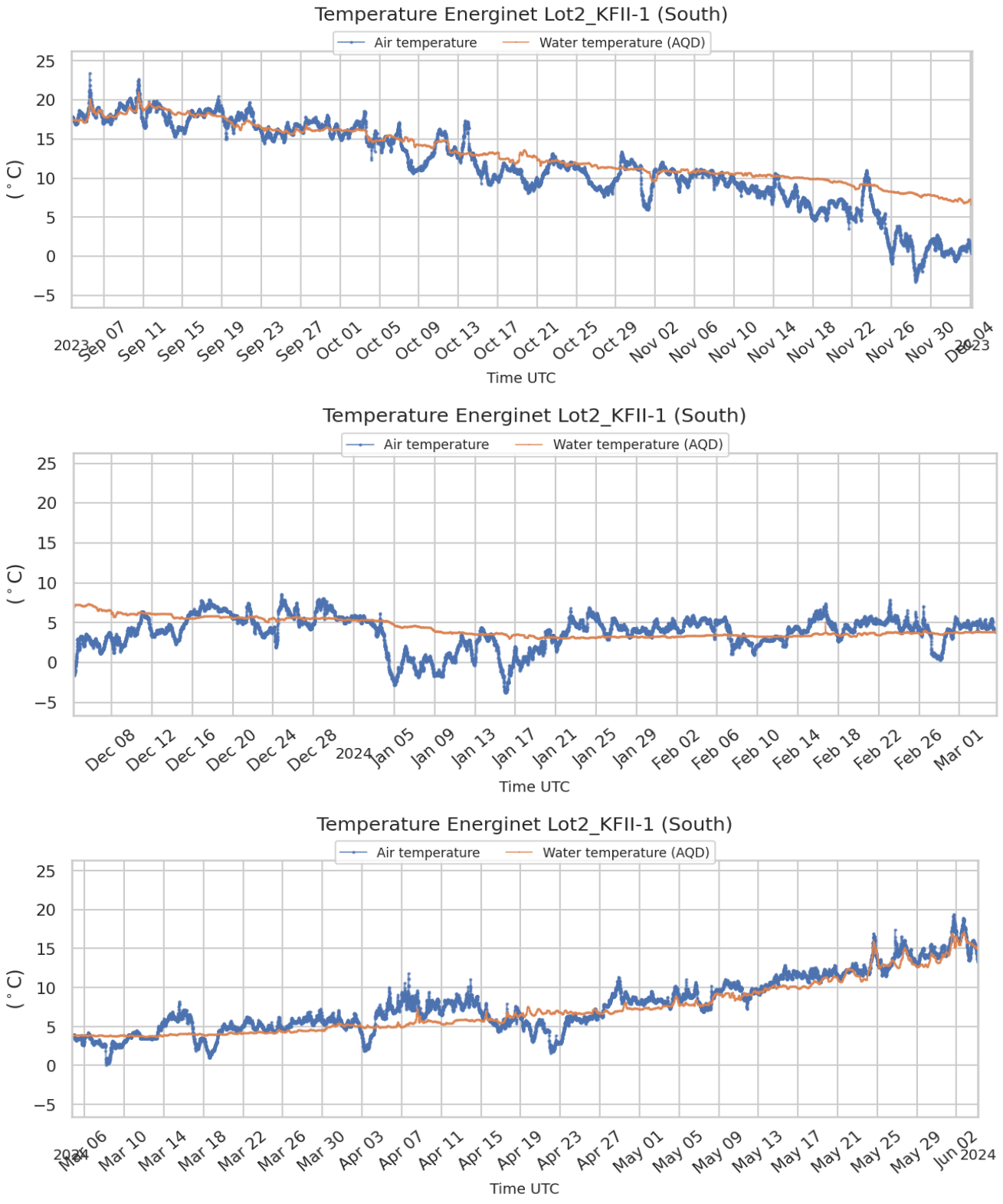


Figure B.20: Timeseries of air temperature and surface water temperature from 3 September 2023 to 2 June 2024

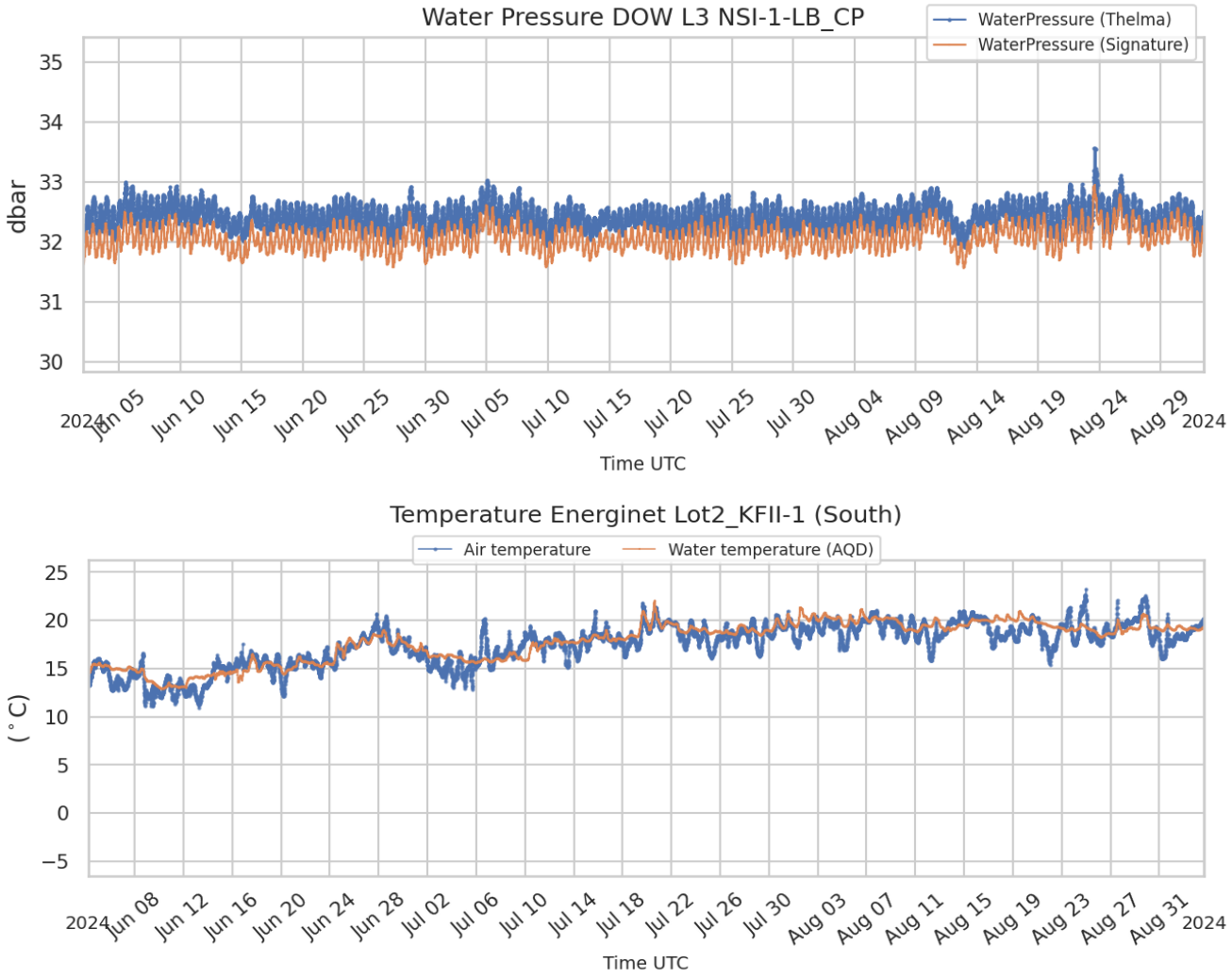


Figure B.21: Timeseries of water pressure, air temperature and surface water temperature from 3 June 2024 to 3 September 2024

B.4 Current data (top-down)

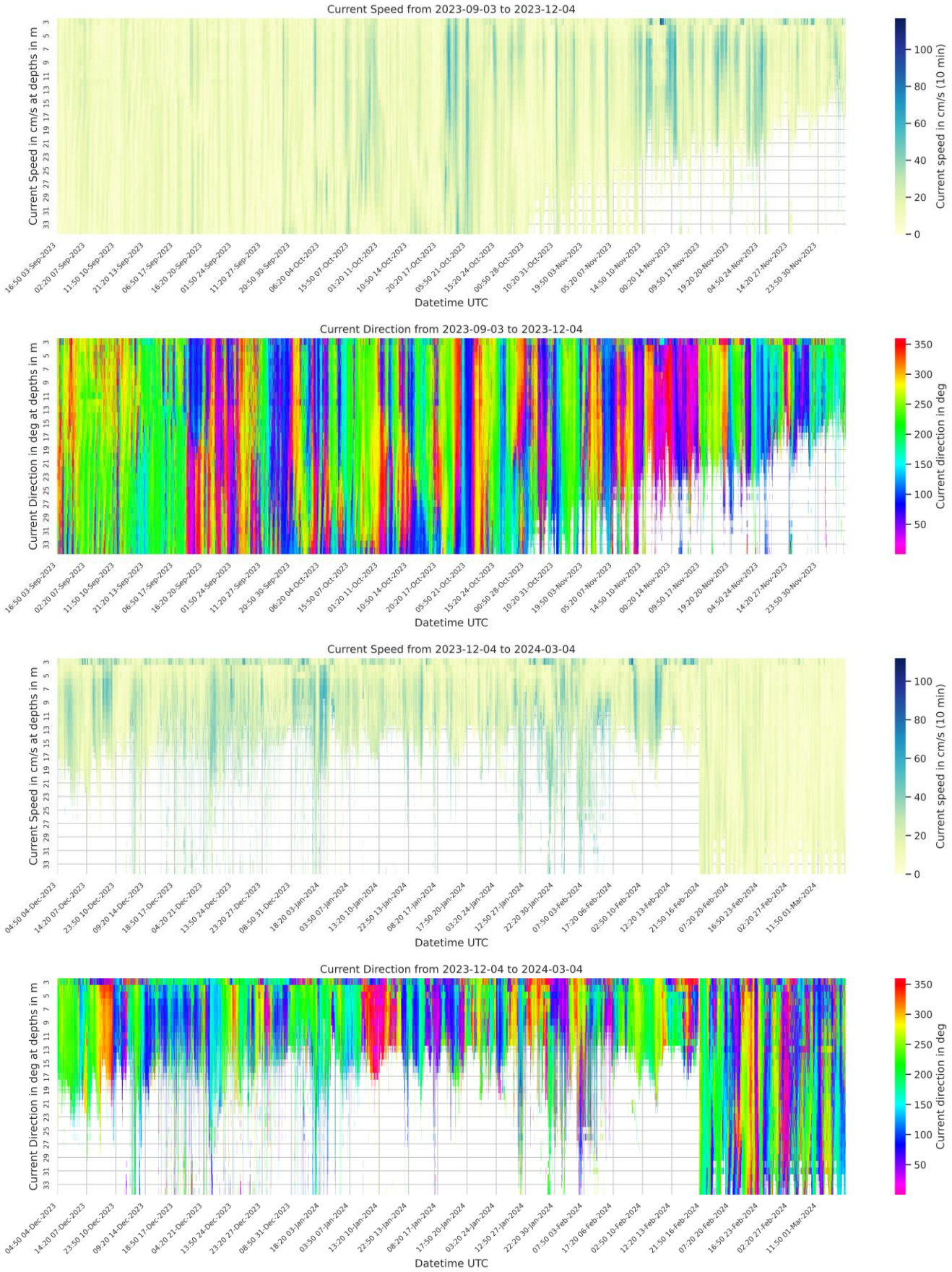


Figure B.22: Heatmaps of current speed and direction from 3 September 2023 to 3 March 2024

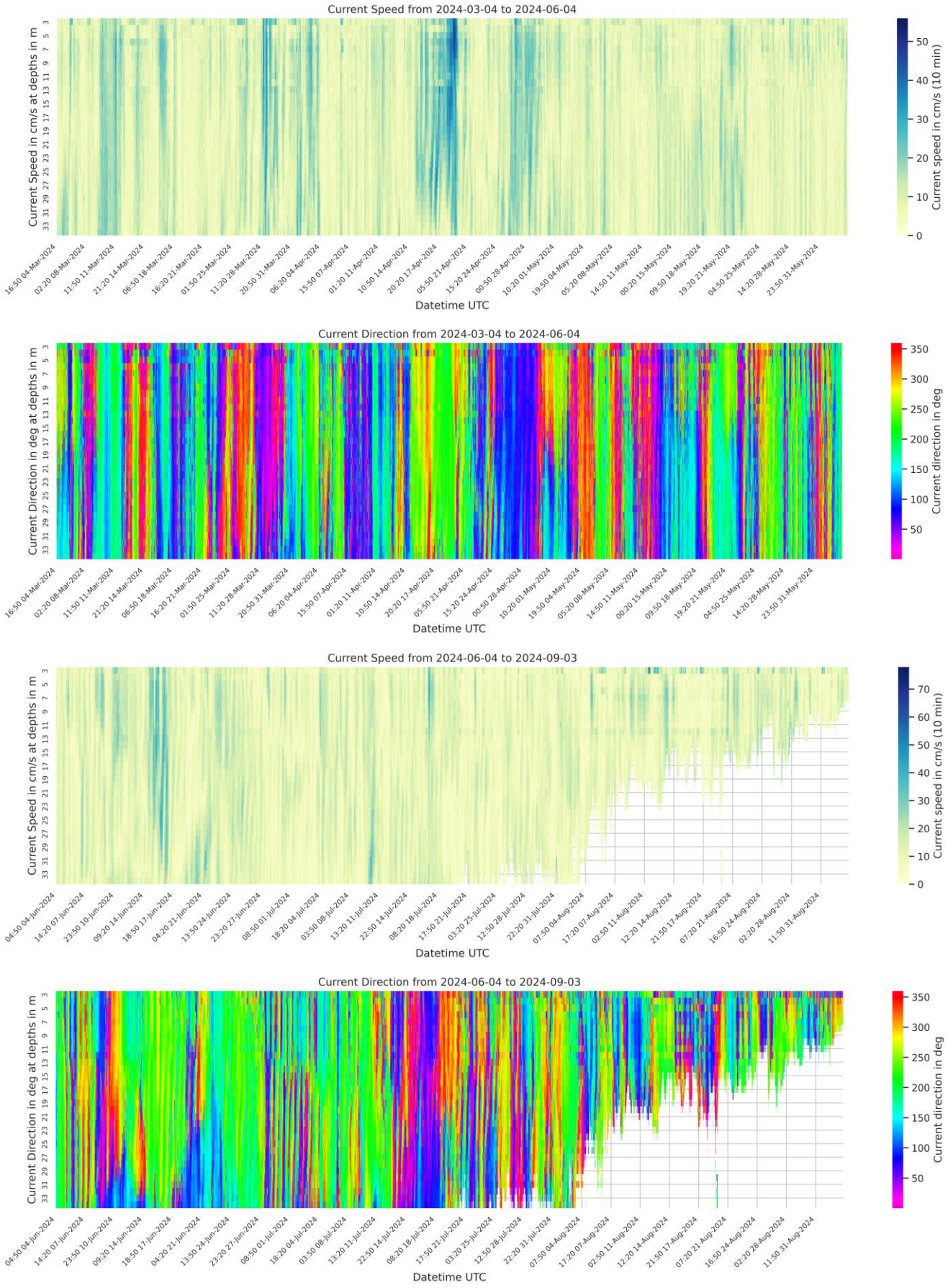


Figure B.23: Heatmaps of current speed and direction from 3 March 2024 to 3 September 2024

B.5 Current data (upward)

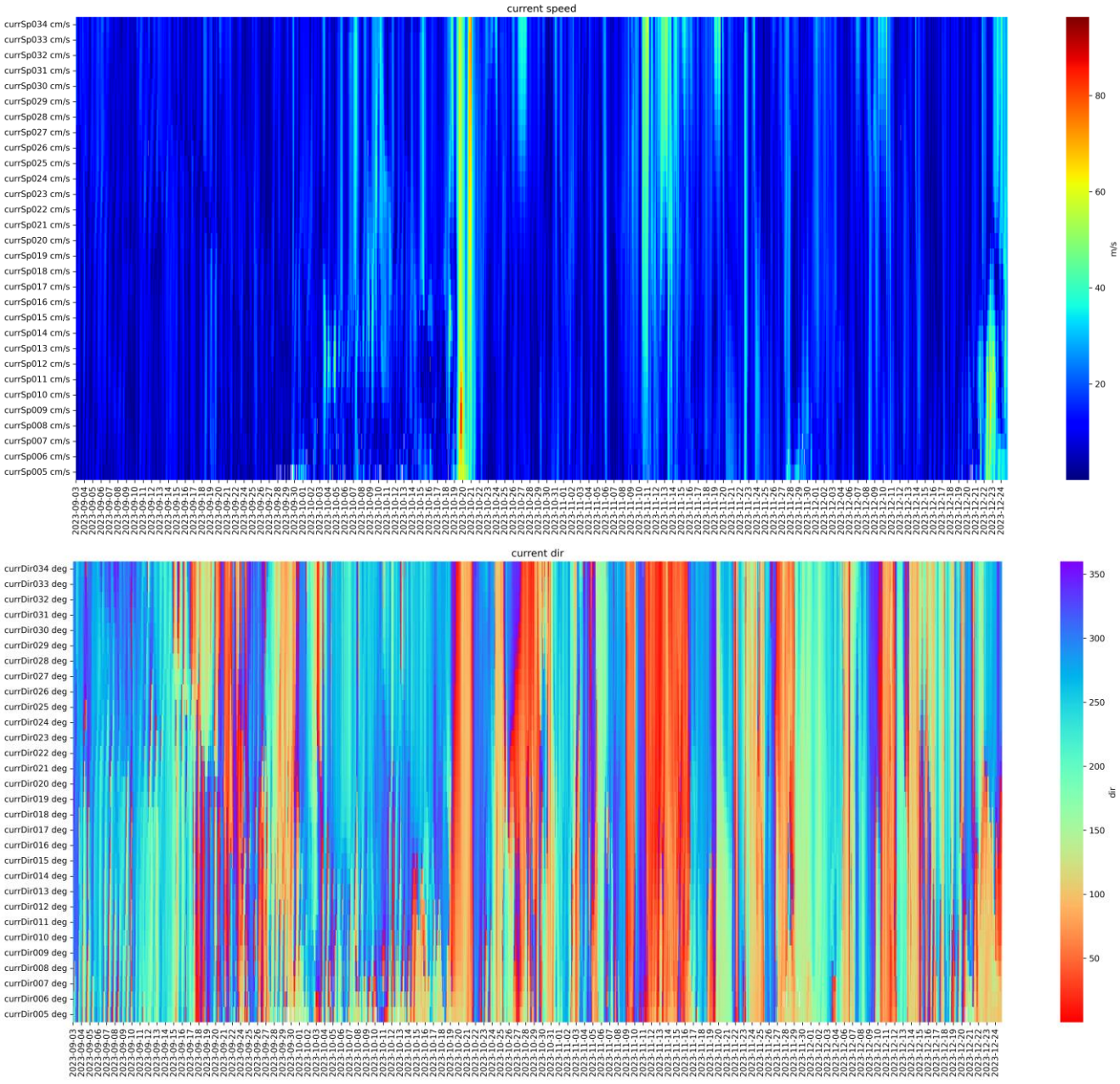


Figure B.24: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 3 September 2023 to 25 December 2023 (D1) (1/2).

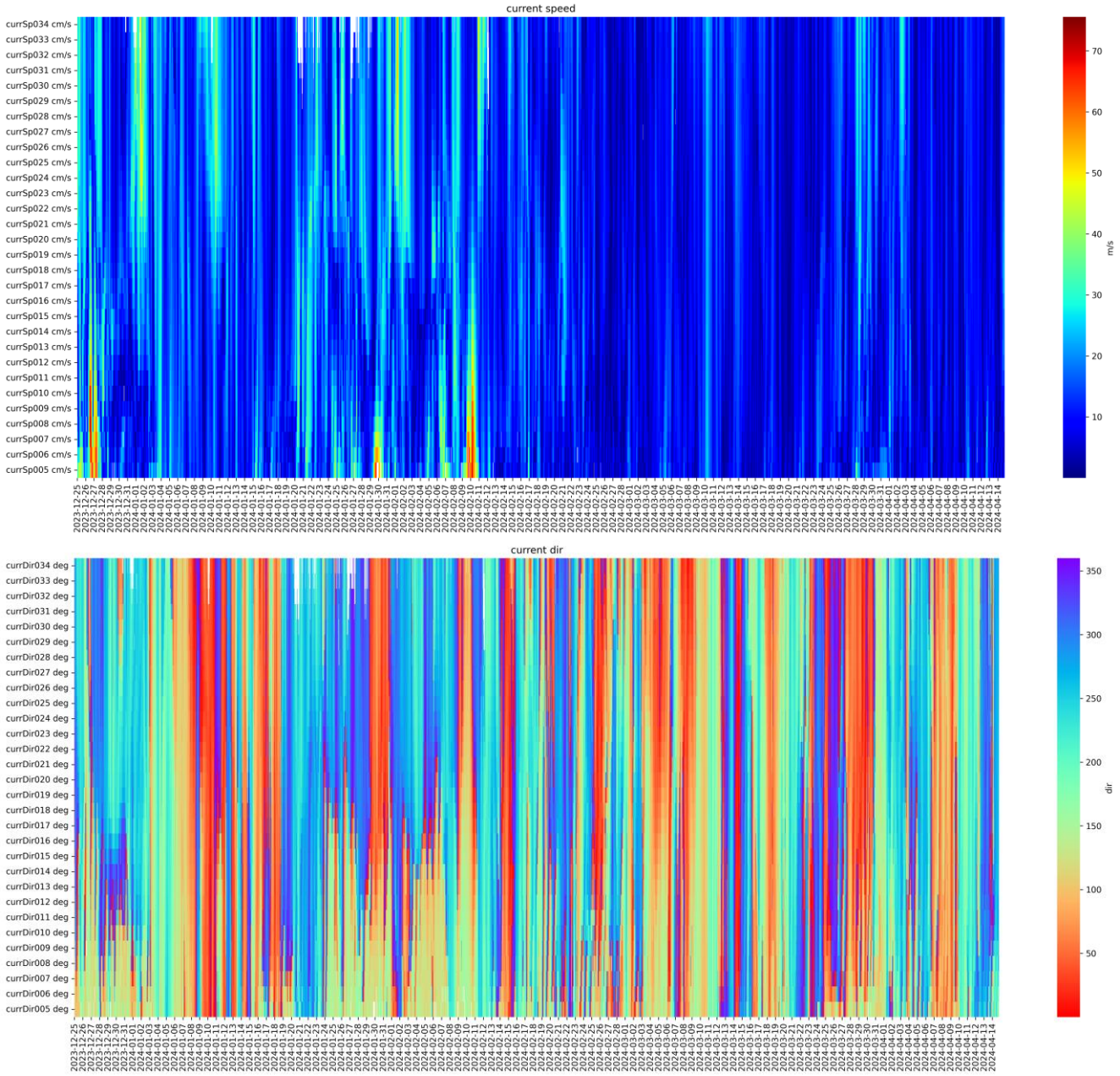


Figure B.25: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 25 December 2023 to 15 April 2024 (D1) (2/2).

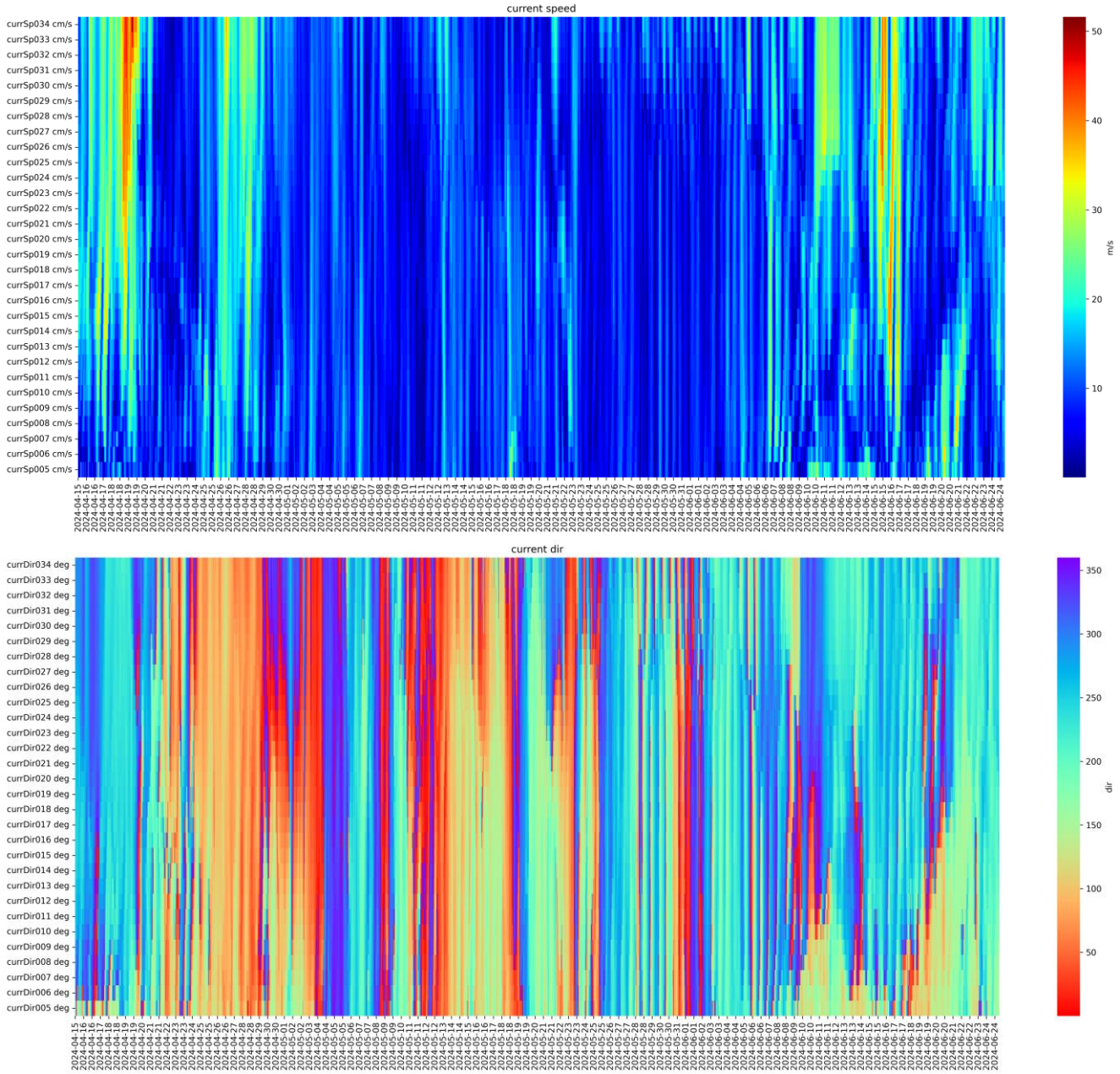


Figure B.26: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 15 April 2024 to 24 June 2024 (D2) (1/2).

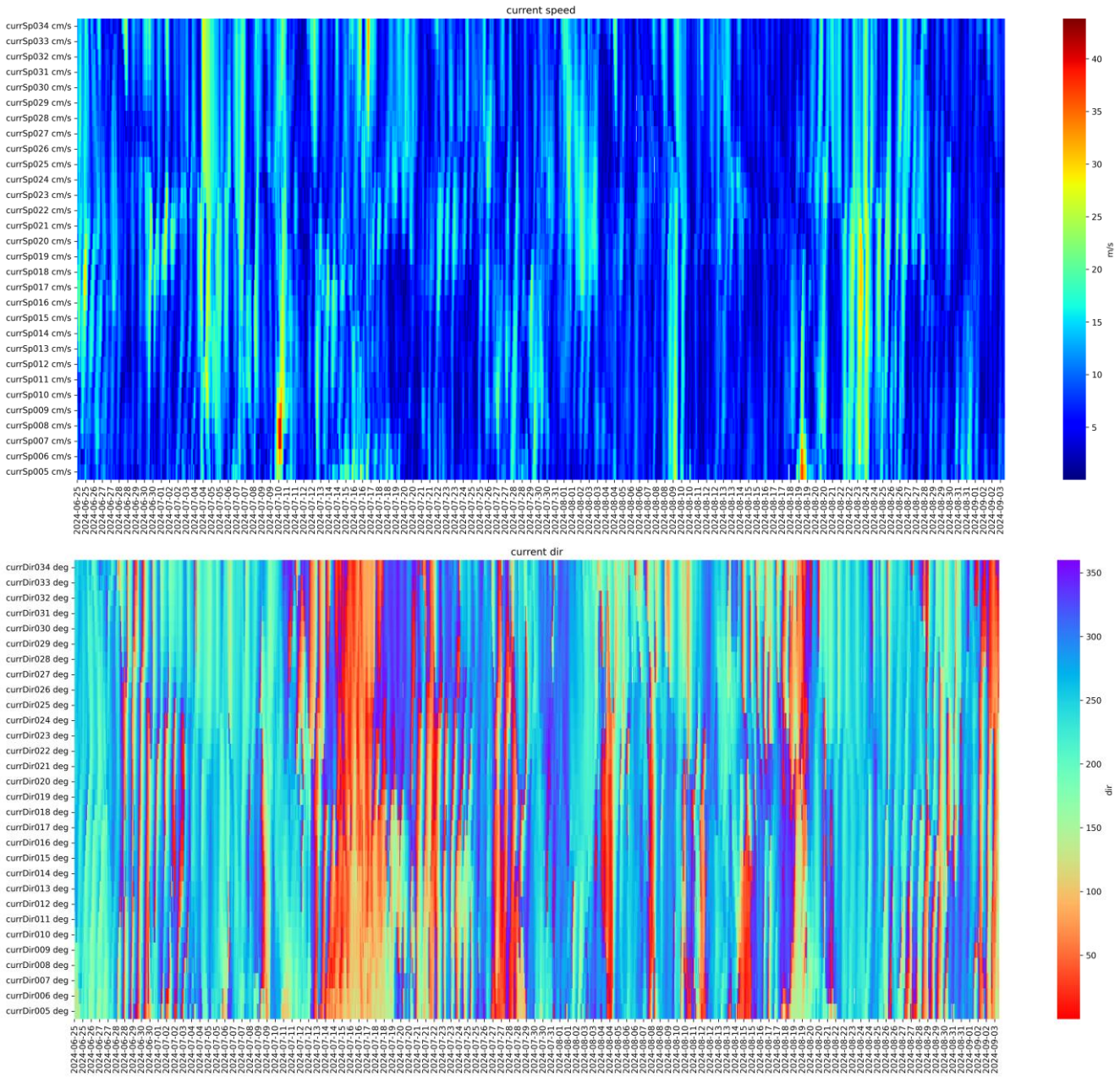


Figure B.27: Heatmap of offline (Signature)-measured bottom-up current speed and direction from direction from 24 June 2024 to 3 September 2024 (D2) (2/2).

Appendix C

Data presentation: KFII-2

C.1 Wind data

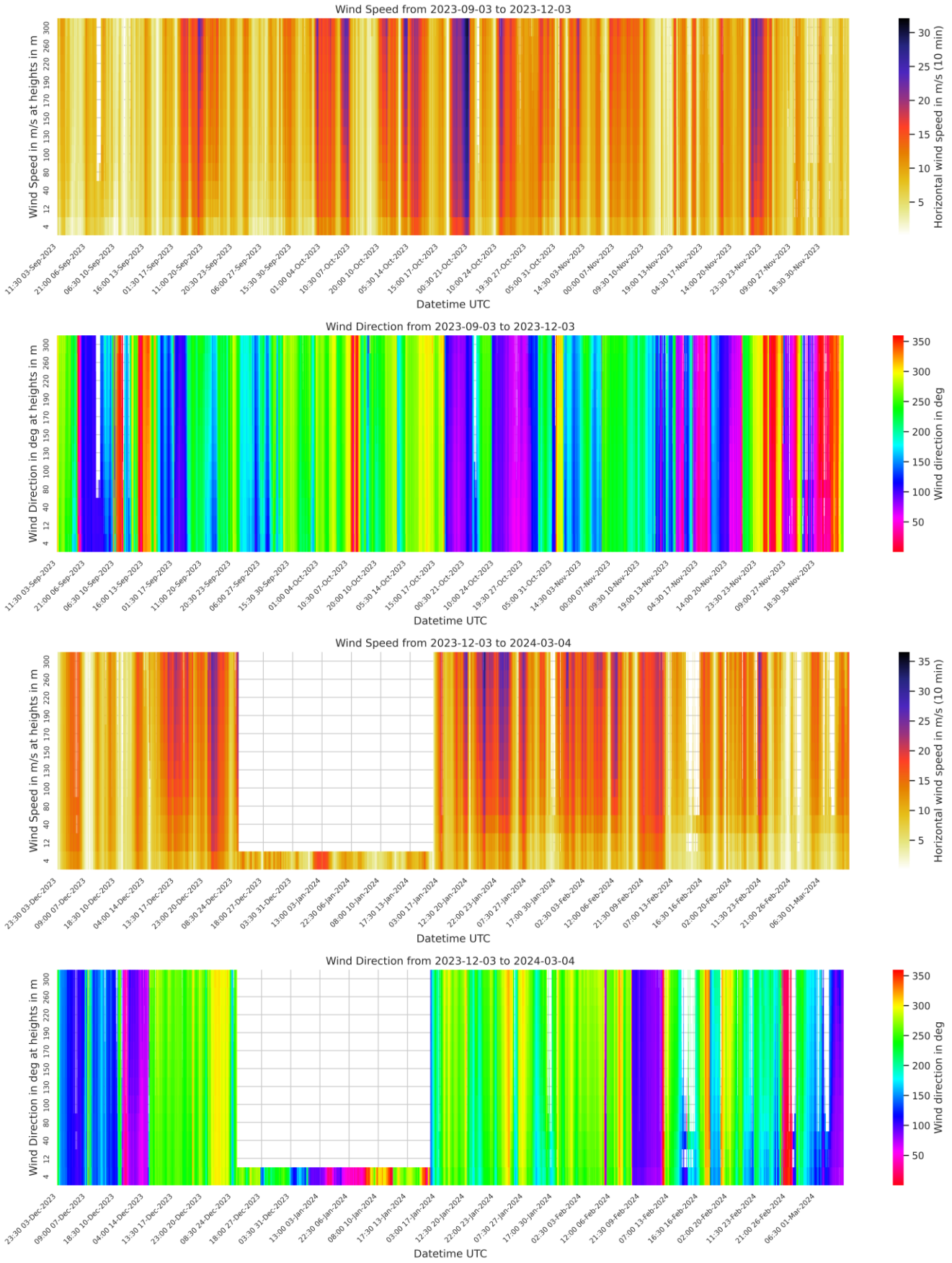


Figure C.1: Heatmaps of wind speed and direction from 3 September 2023 to 3 March 2024

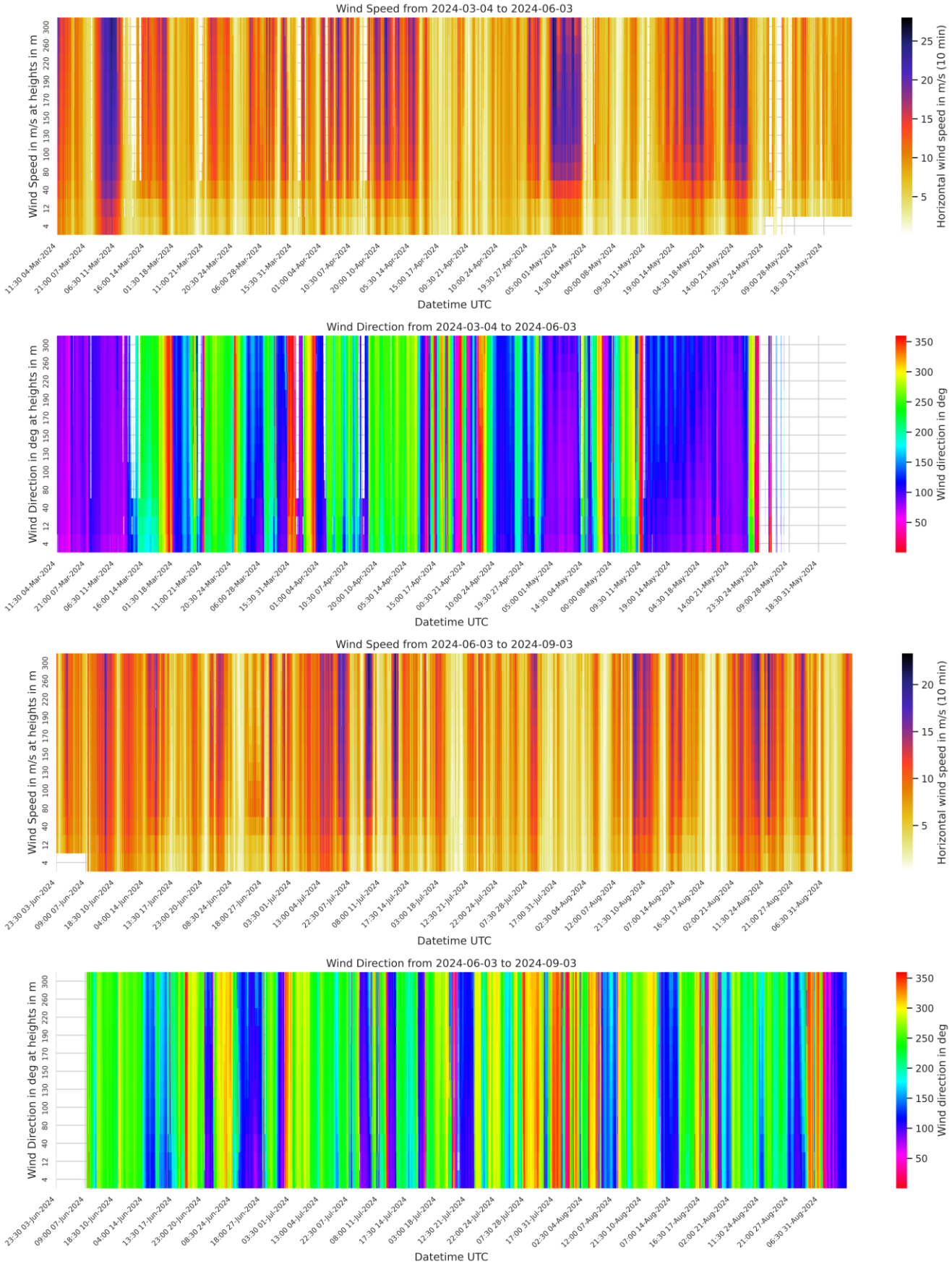


Figure C.2: Heatmaps of wind speed and direction from 3 March 2024 to 3 September 2024

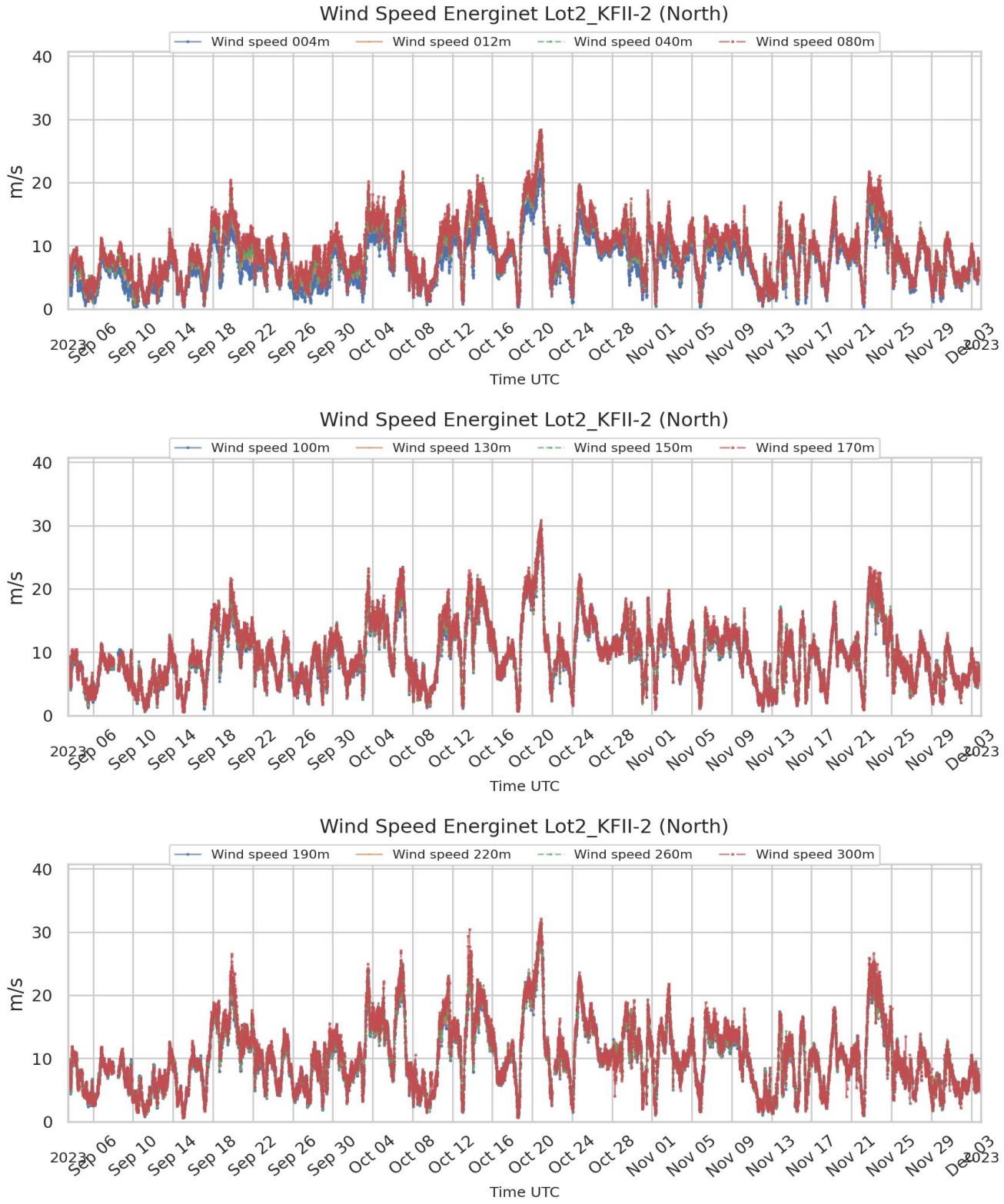


Figure C.3: Timeseries of wind speed from 3 September 2023 to 3 December 2023

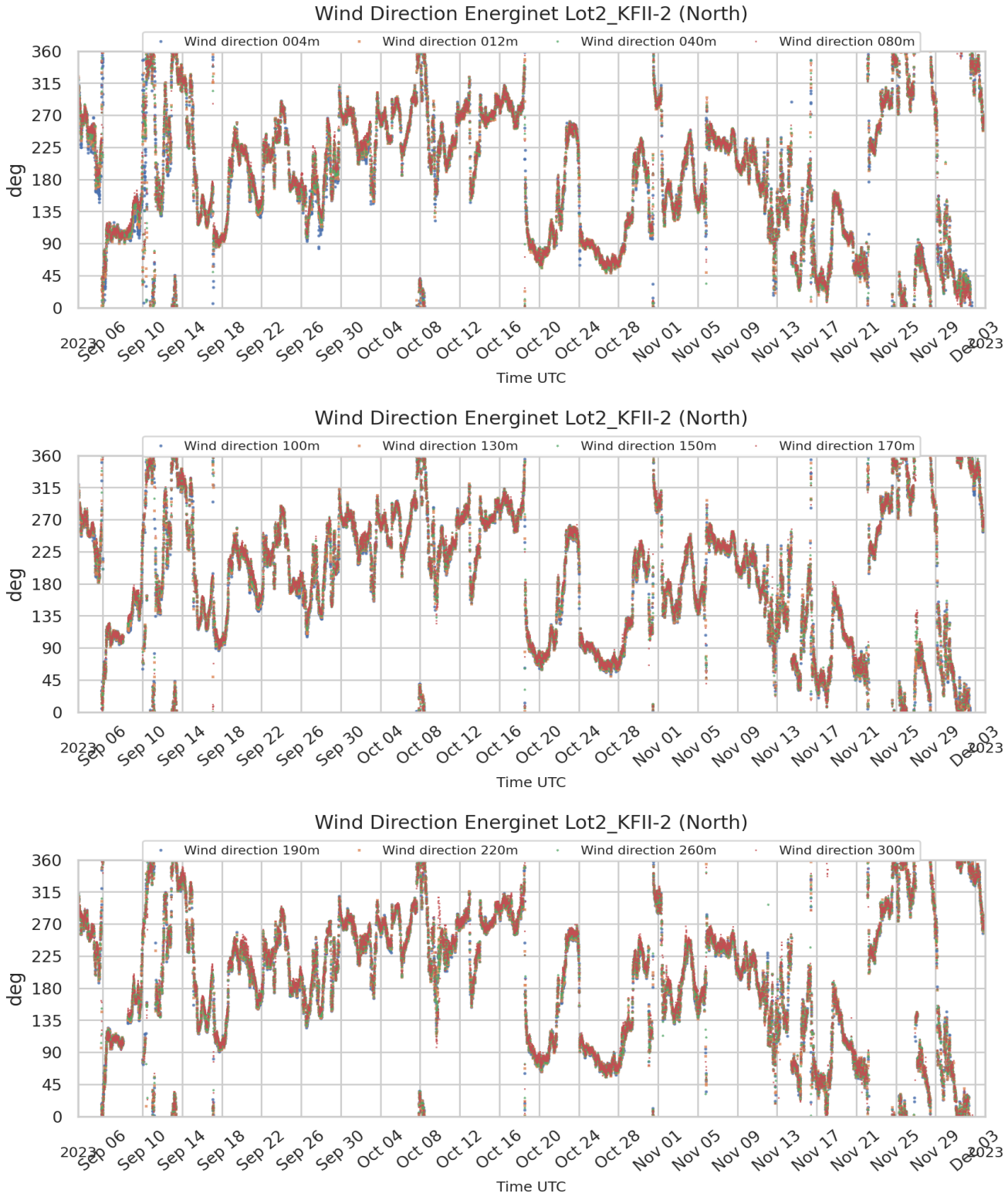


Figure C.4: Timeseries of wind direction from 3 September 2023 to 3 December 2023

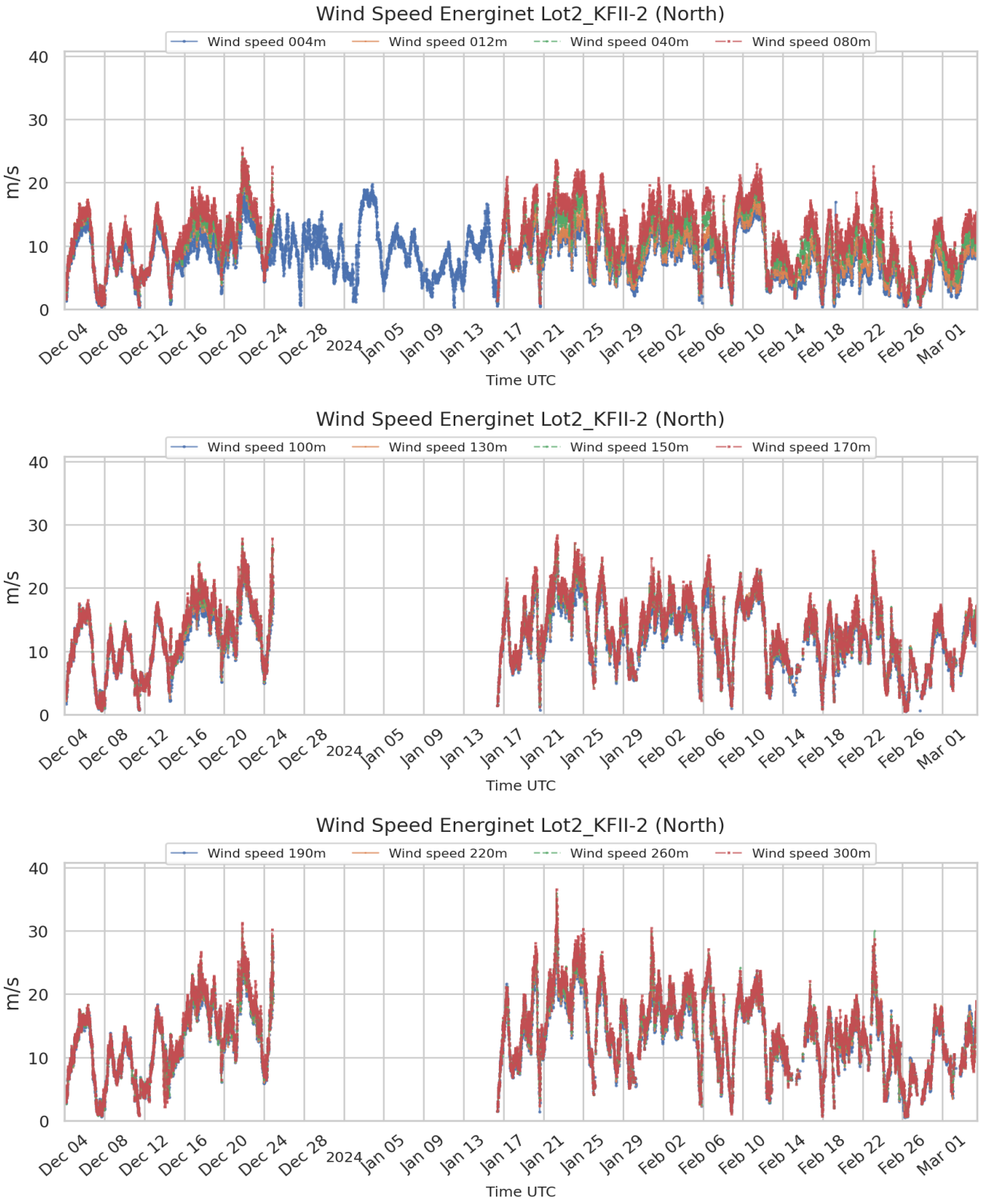


Figure C.5: Timeseries of wind speed from 3 December 2023 to 3 March 2024

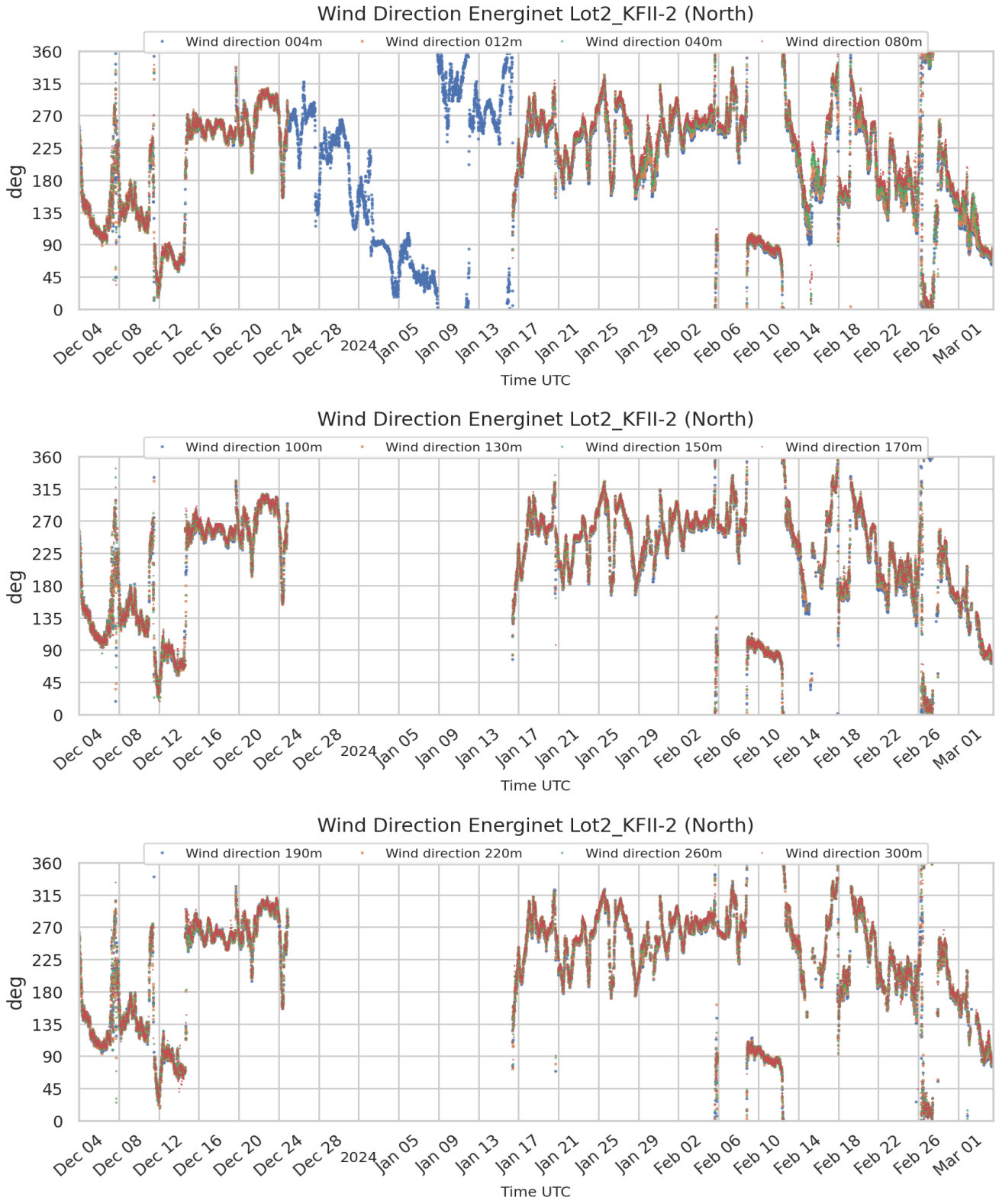


Figure C.6: Timeseries of wind direction from 3 December 2023 to 3 March 2024

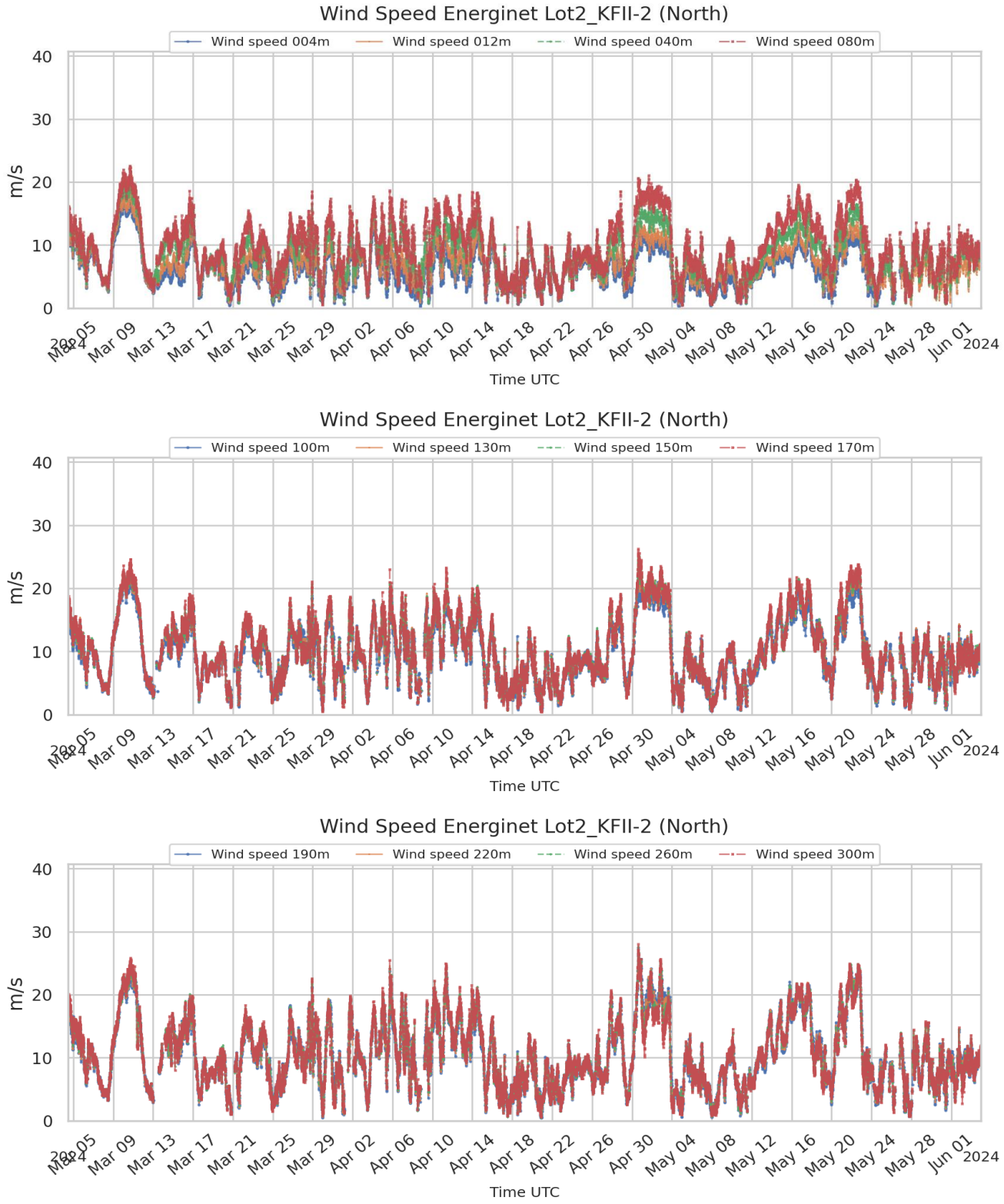


Figure C.7: Timeseries of wind speed from 3 March 2024 to 3 June 2024

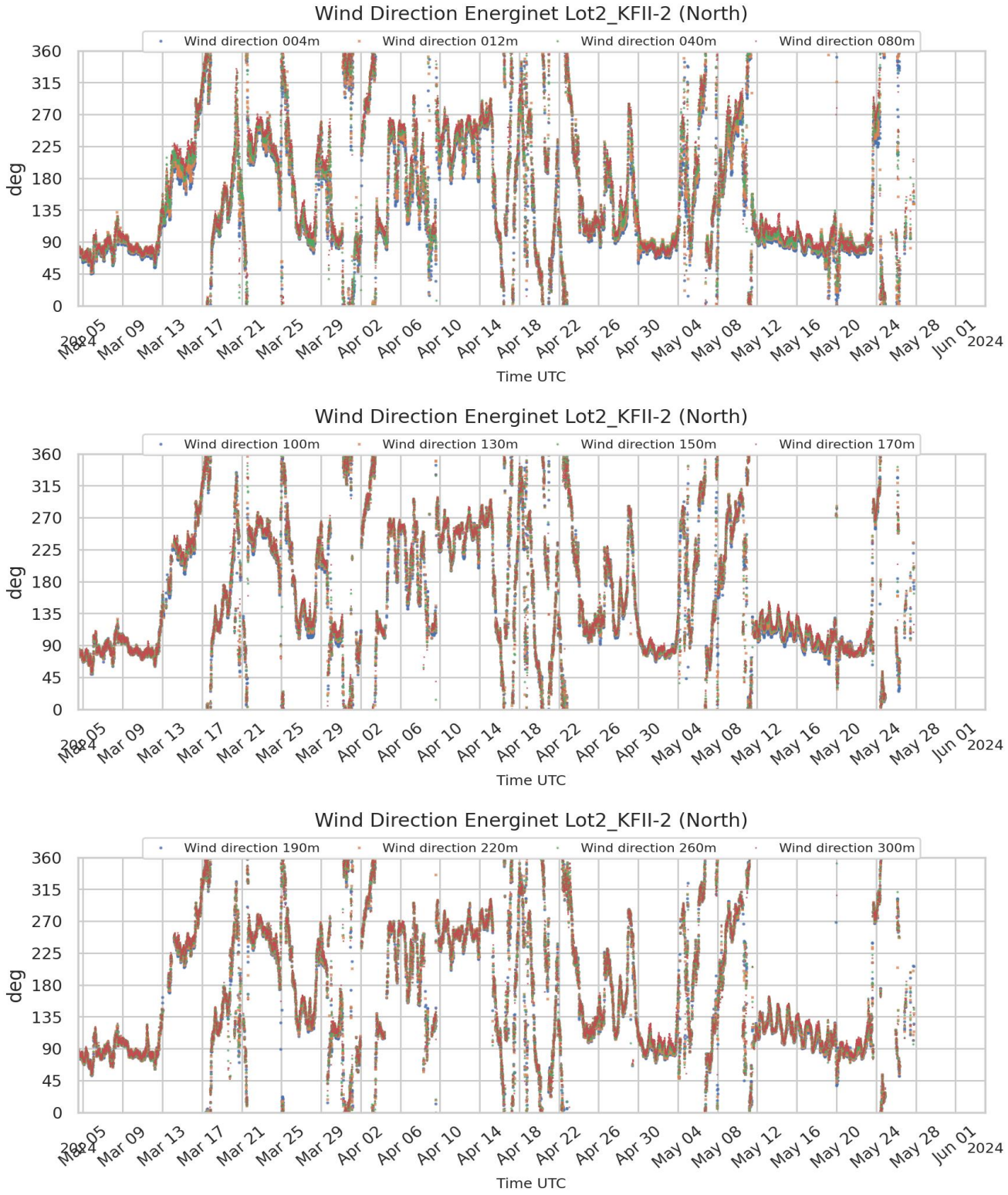


Figure C.8: Timeseries of wind direction from 3 March 2024 to 3 June 2024

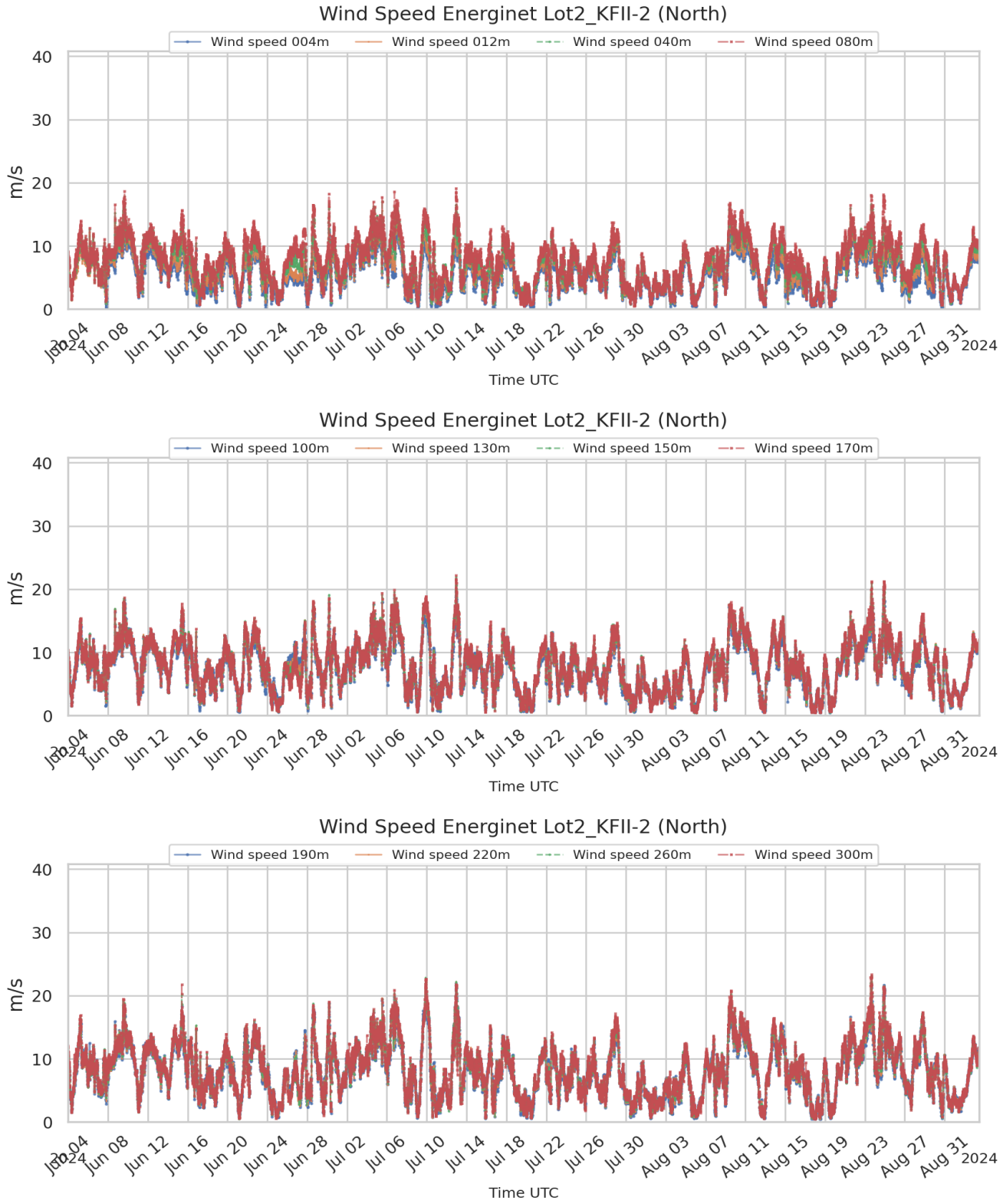
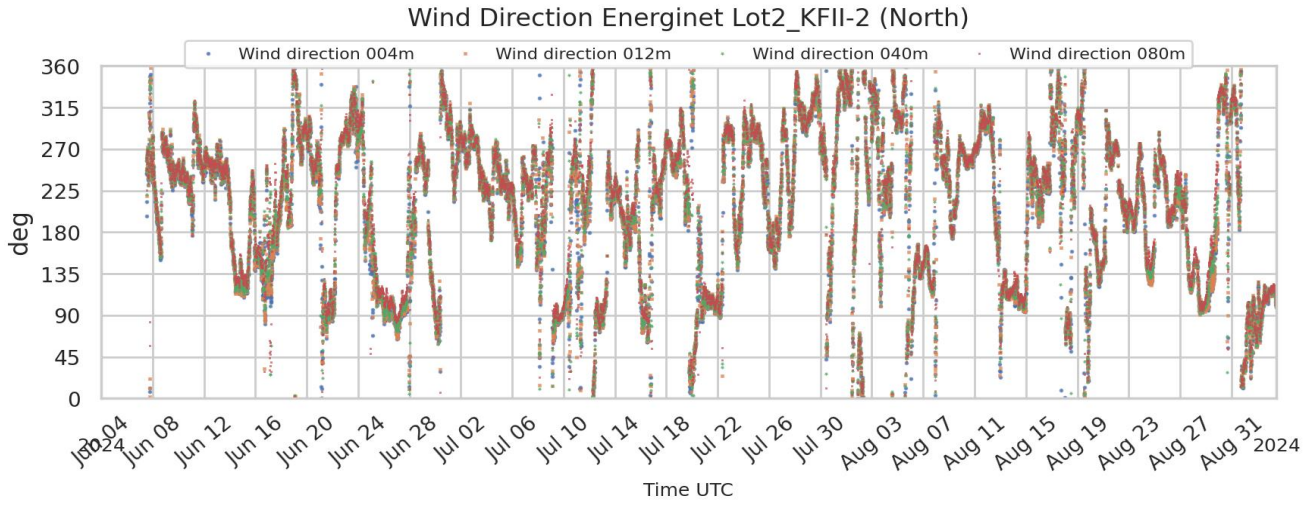
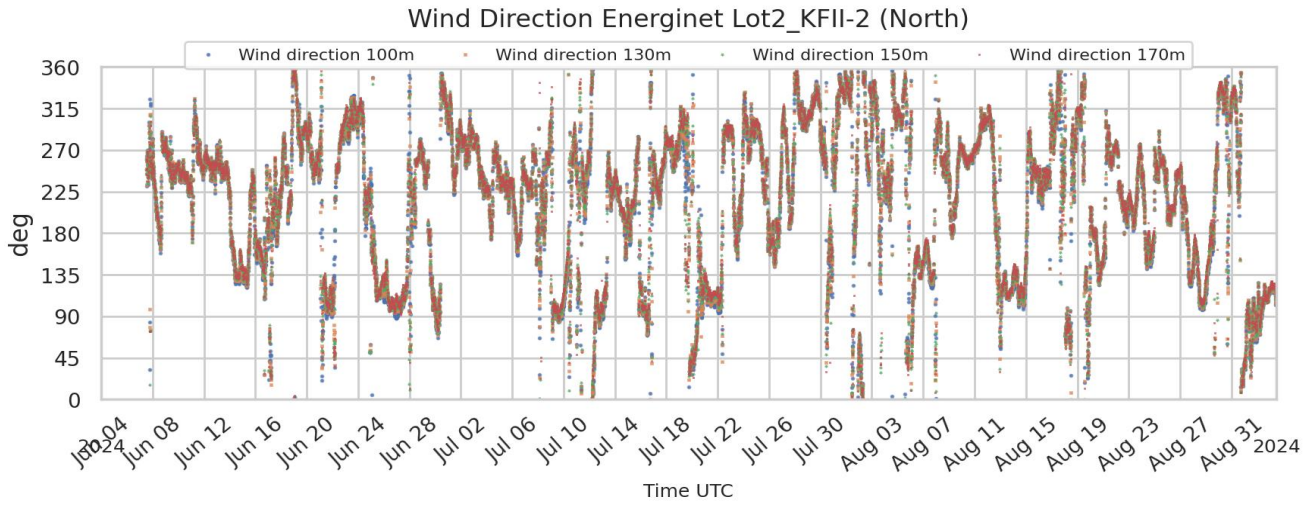


Figure C.9: Timeseries of wind speed from 3 June 2024 to 3 September 2024





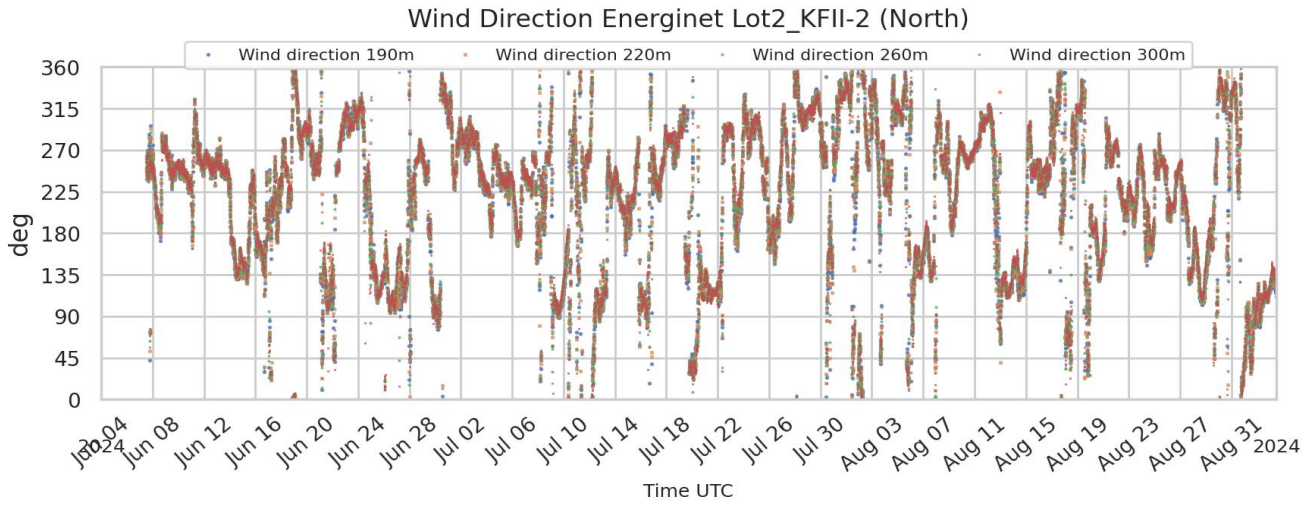


Figure C.10: Timeseries of wind direction from 3 June 2024 to 3 September 2024

C.2 Wave data

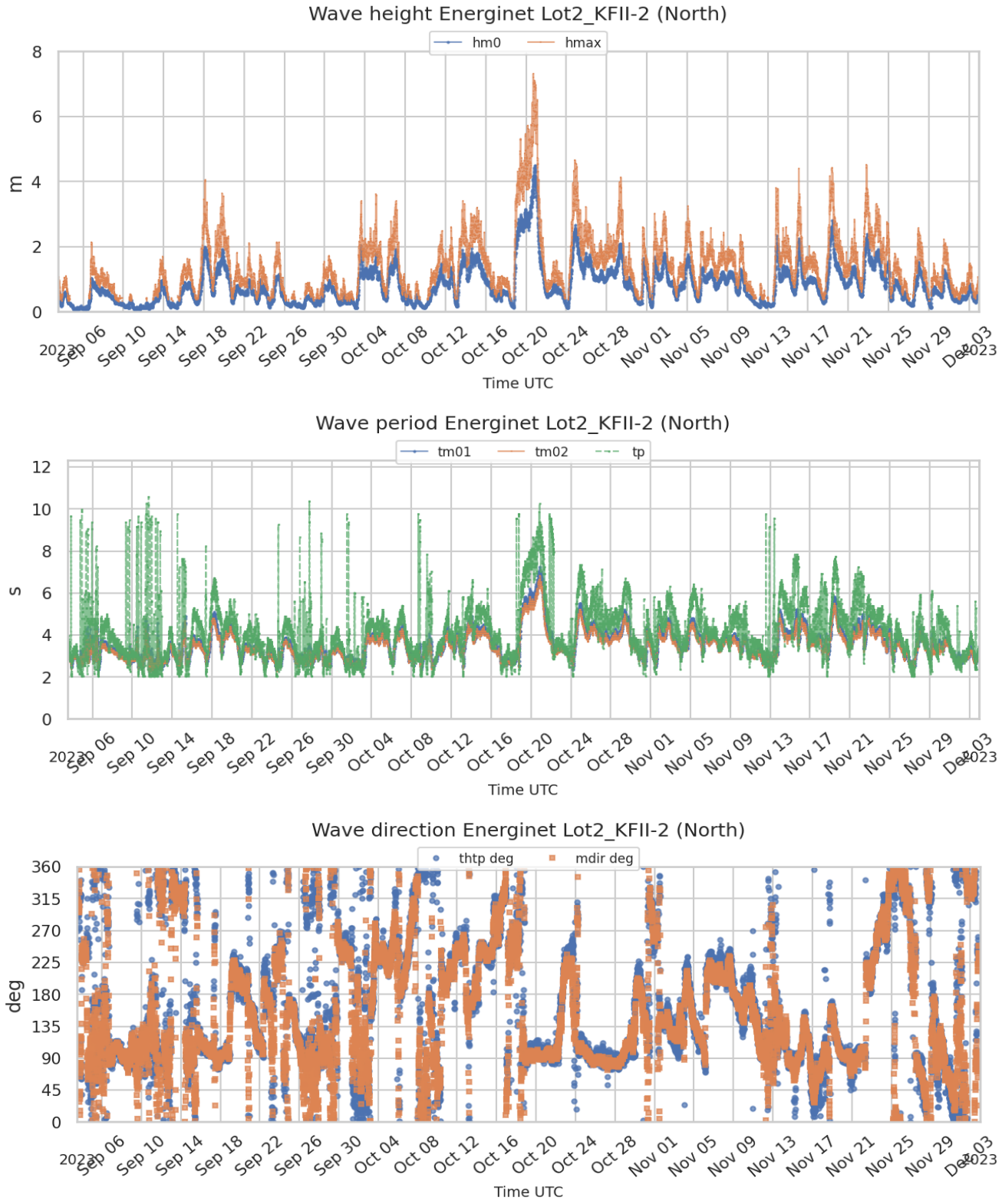


Figure C.11: Timeseries of wave heights, wave periods, and wave direction from 3 September 2023 to 3 December 2023

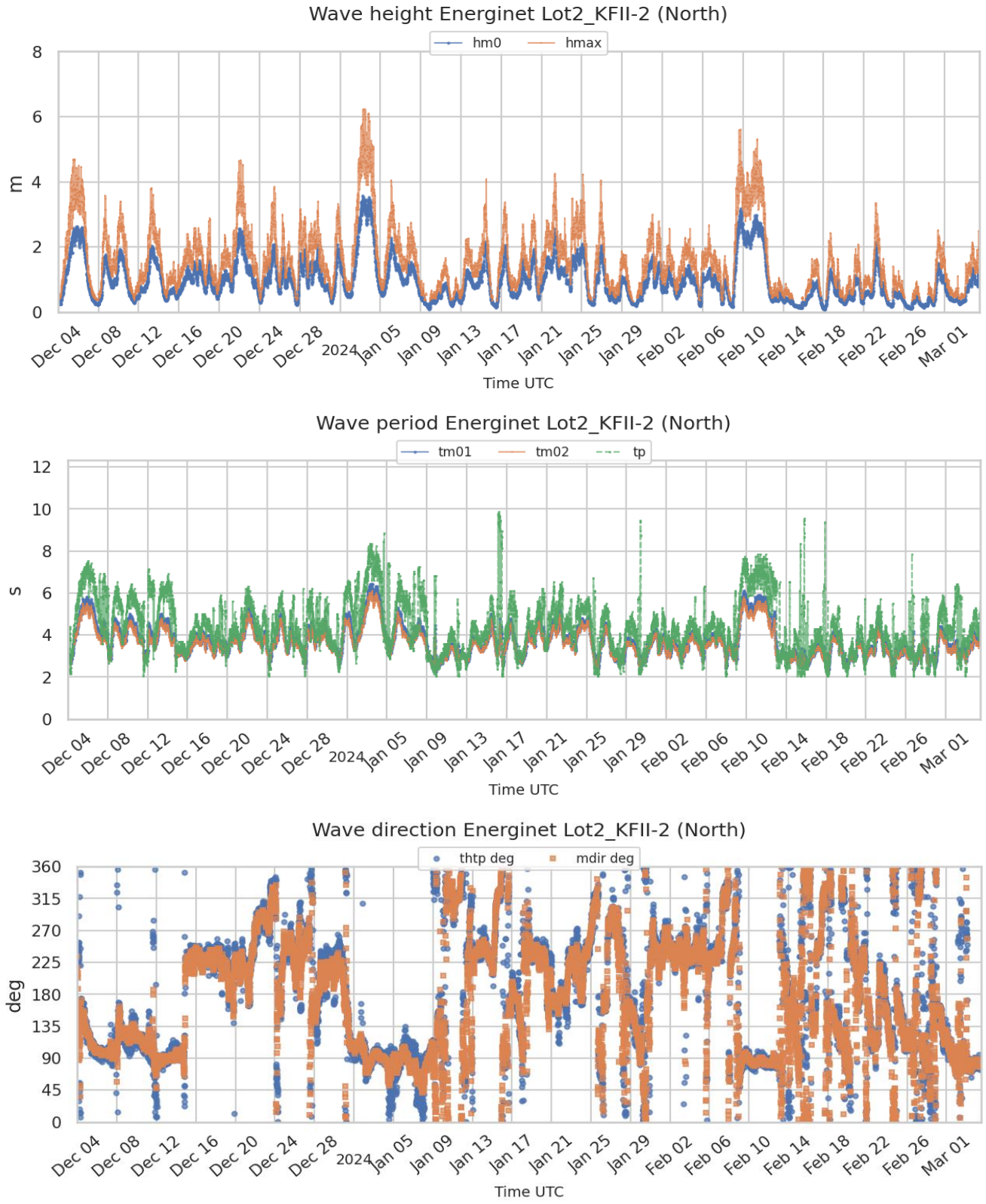


Figure C.12: Timeseries of wave heights, wave periods, and wave direction from 3 December 2023 to 3 March 2024

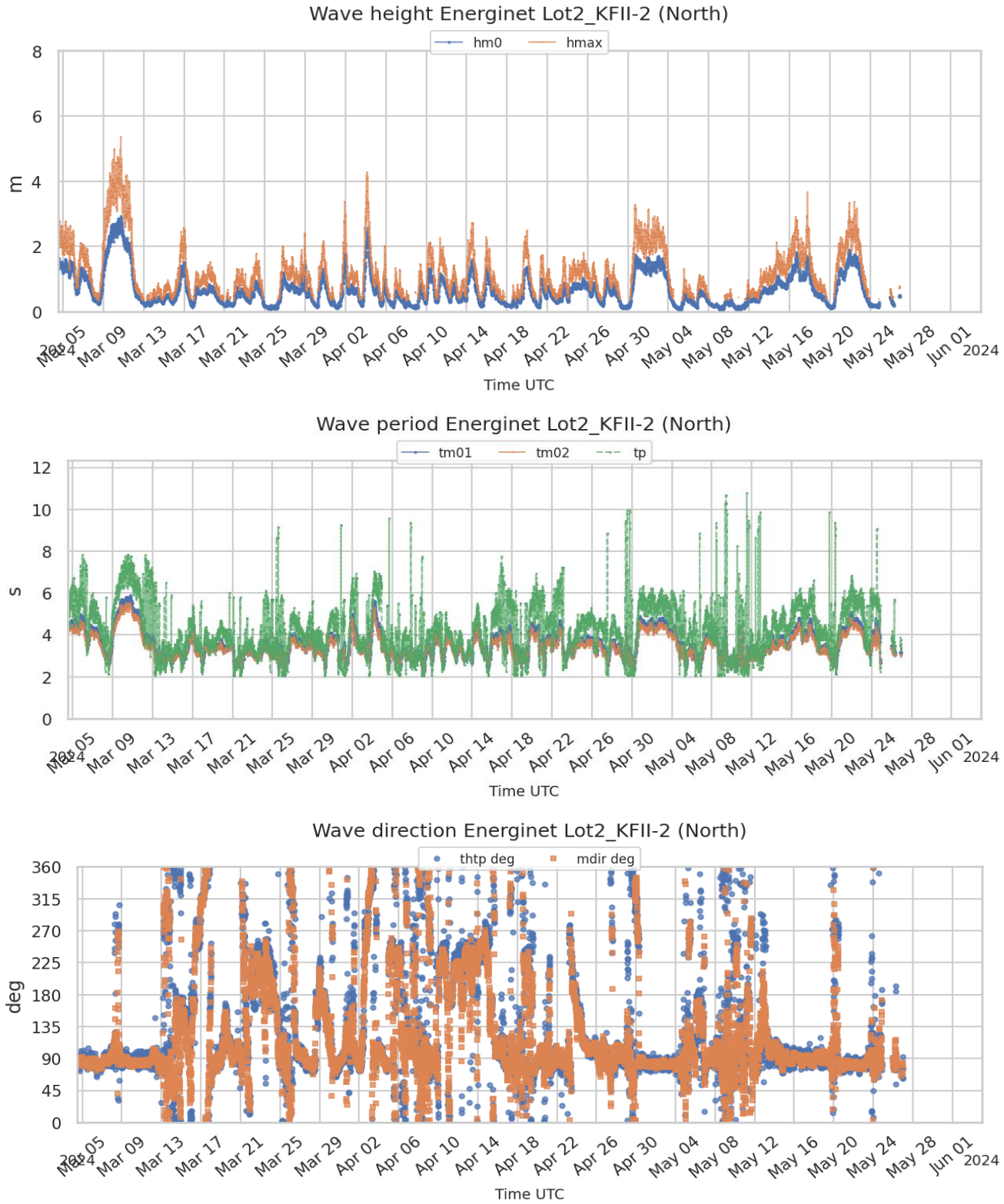


Figure C.13: Timeseries of wave heights, wave periods, and wave direction from 3 March 2024 to 3 June 2024

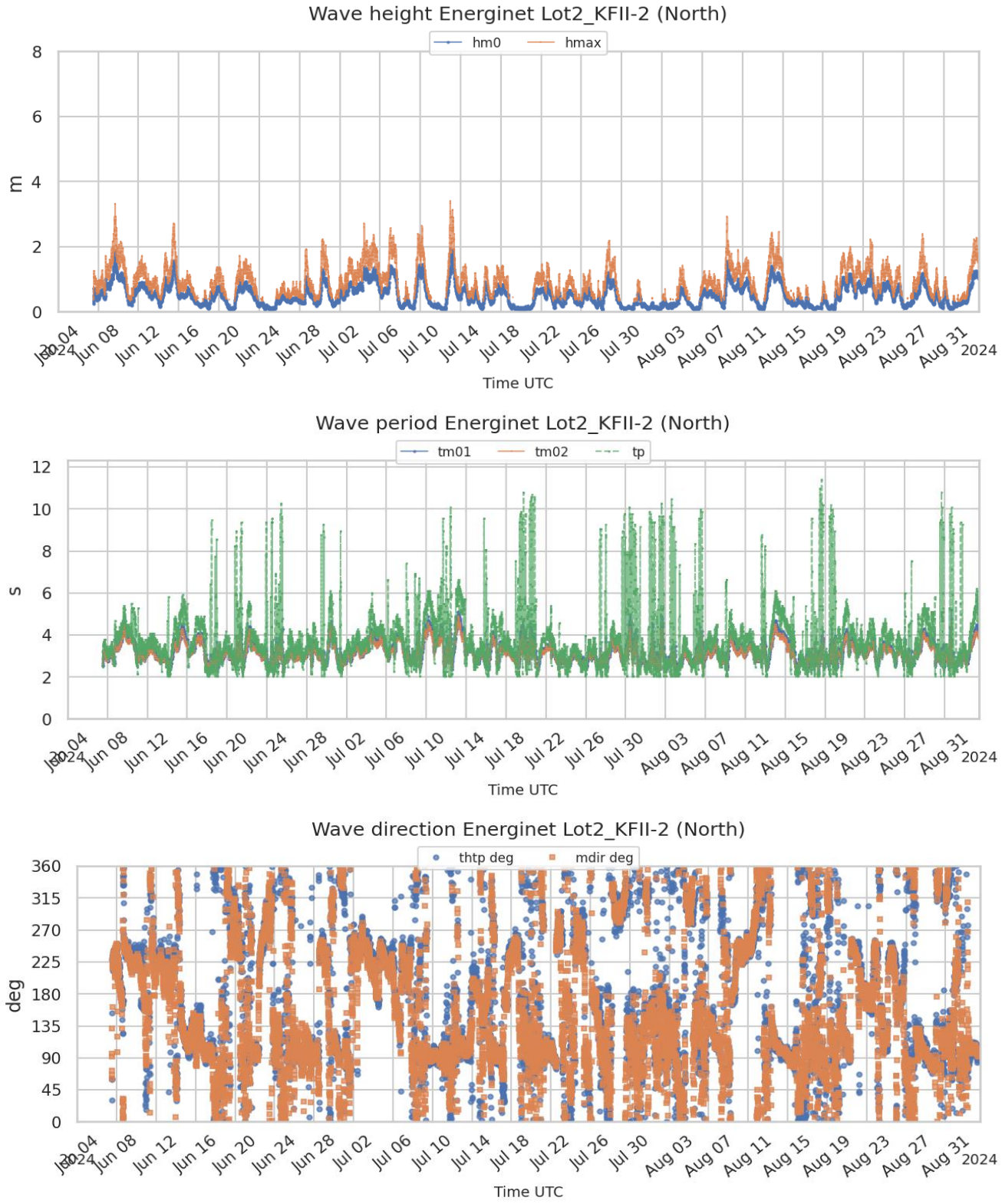


Figure C.14: Timeseries of wave heights, wave periods, and wave direction from 3 June 2024 to 3 September 2024

C.3 Metocean data

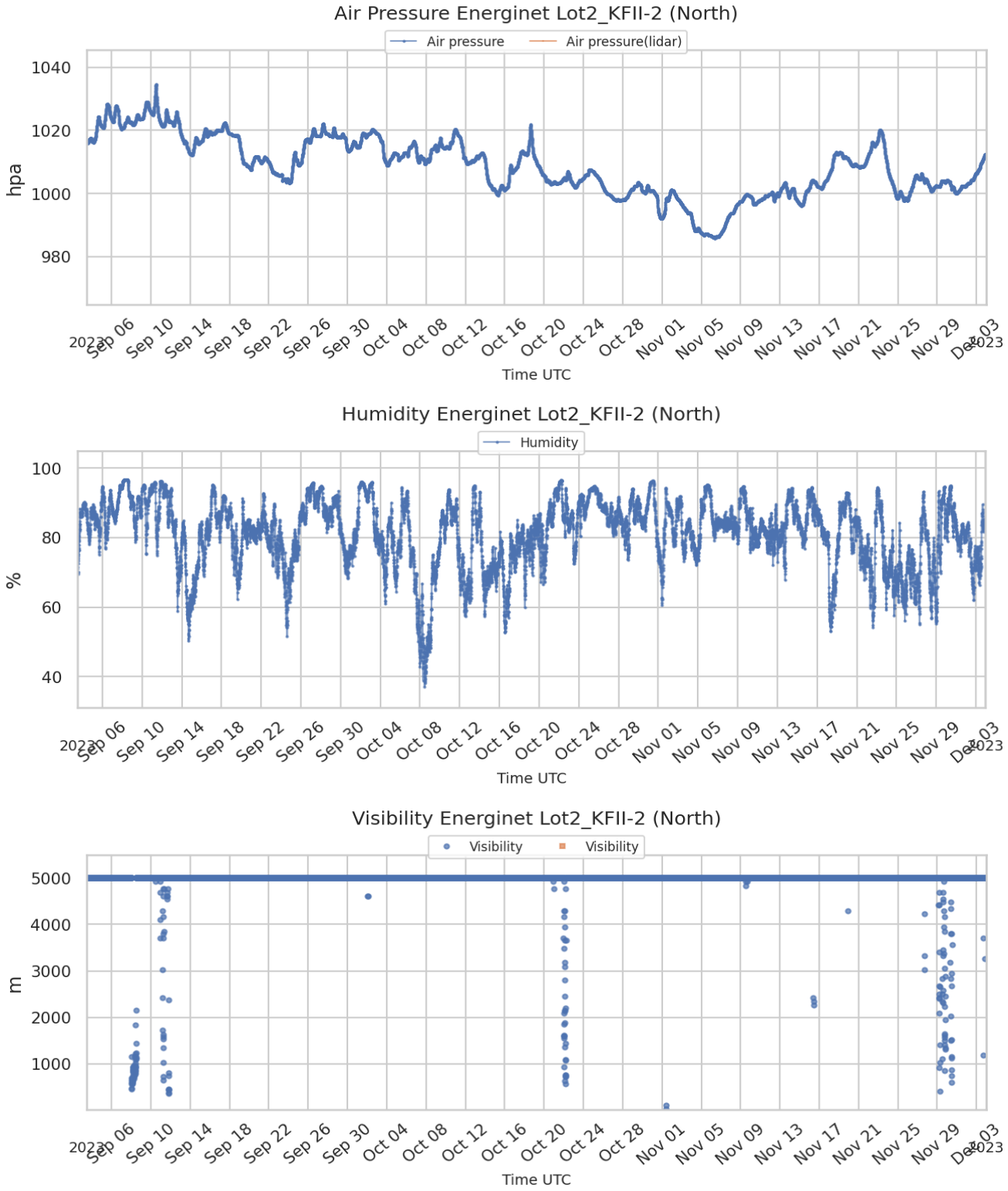


Figure C.15: Timeseries of air pressure, humidity and visibility from 3 September 2023 to 3 December 2023

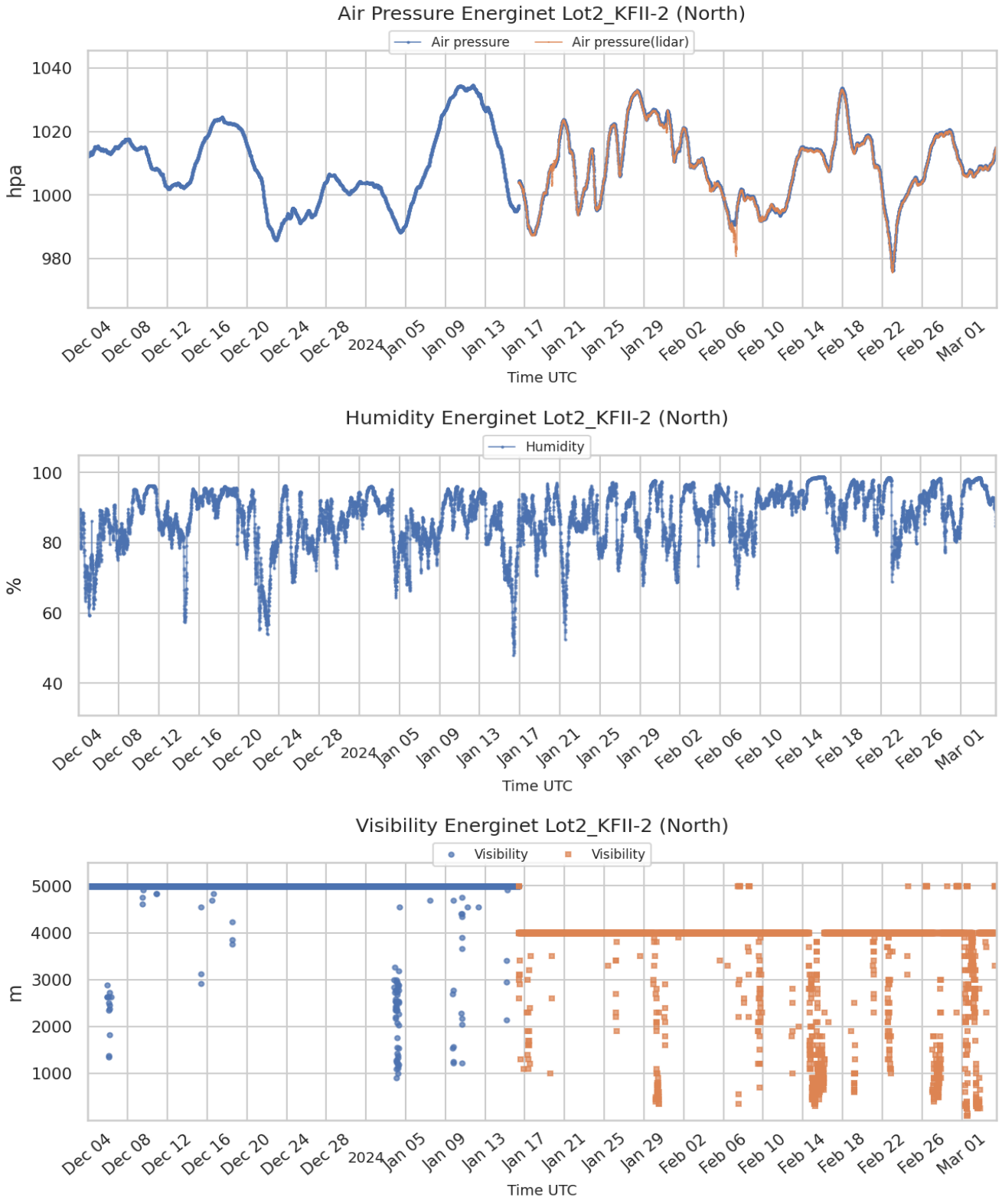


Figure C.16: Timeseries of air pressure, humidity and visibility from 3 December 2023 to 3 March 2024

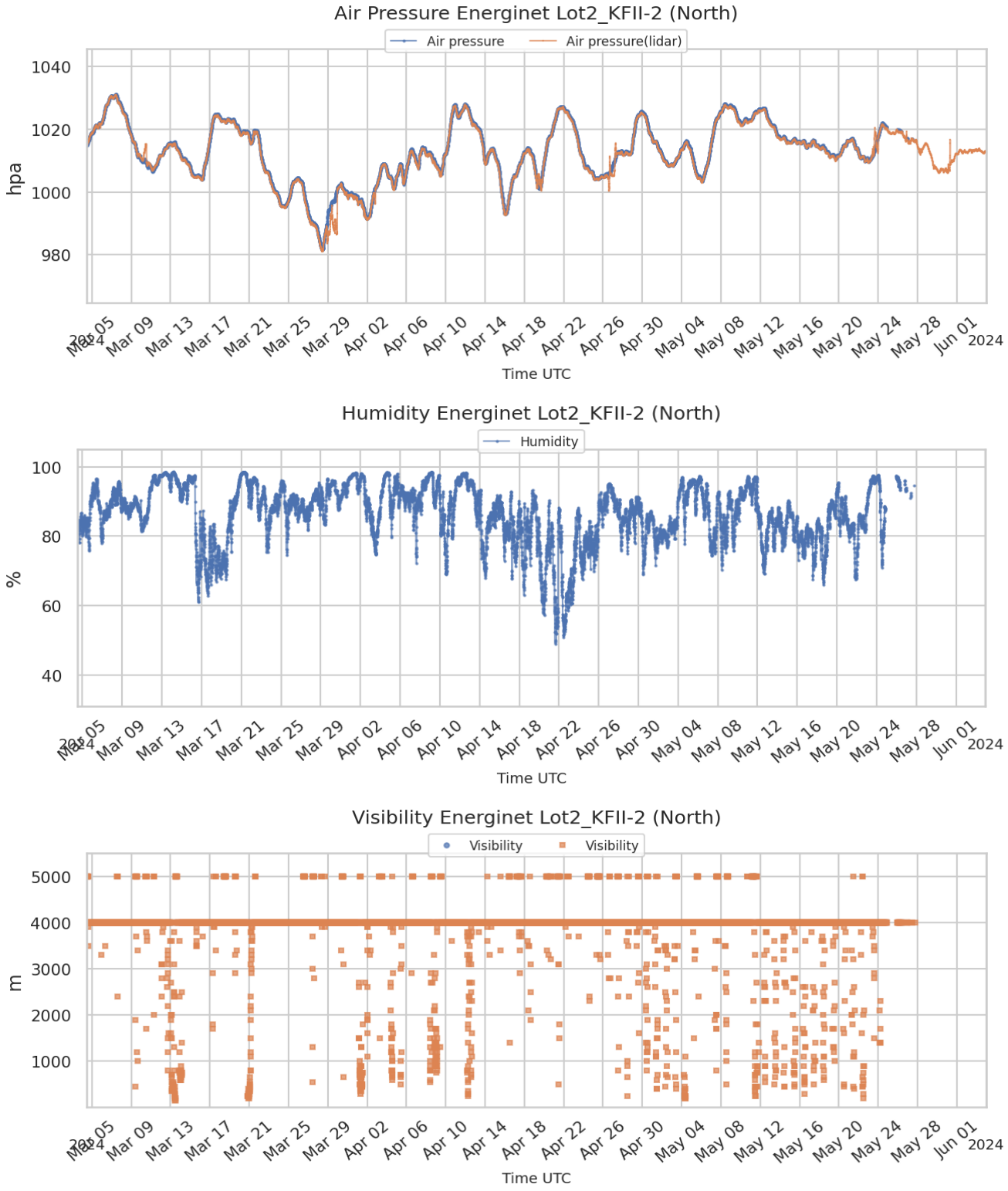


Figure C.17: Timeseries of air pressure, humidity and visibility from 3 March 2024 to 3 June 2024

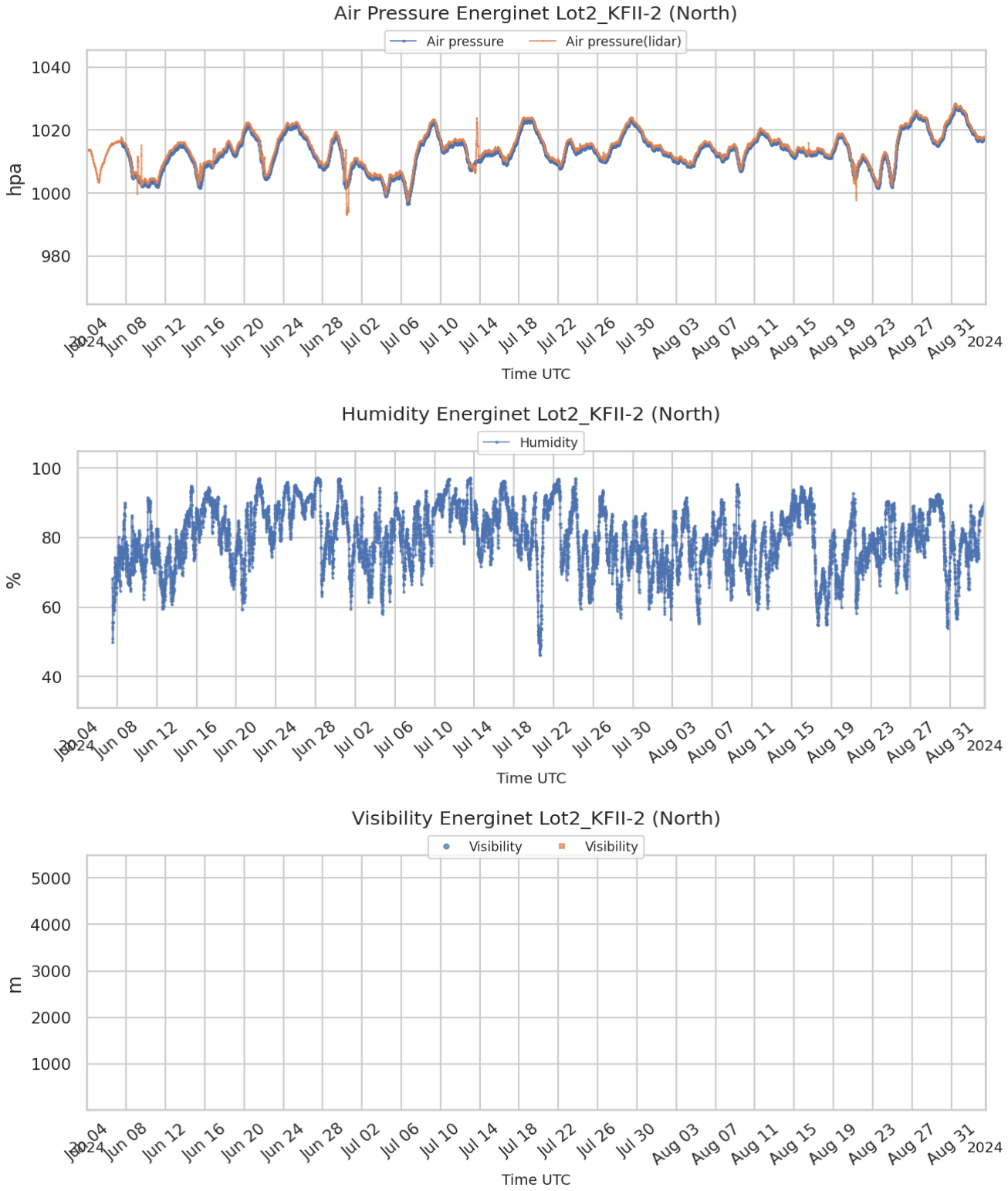


Figure C.18: Timeseries of air pressure, humidity and visibility from 3 June 2024 to 3 September 2024

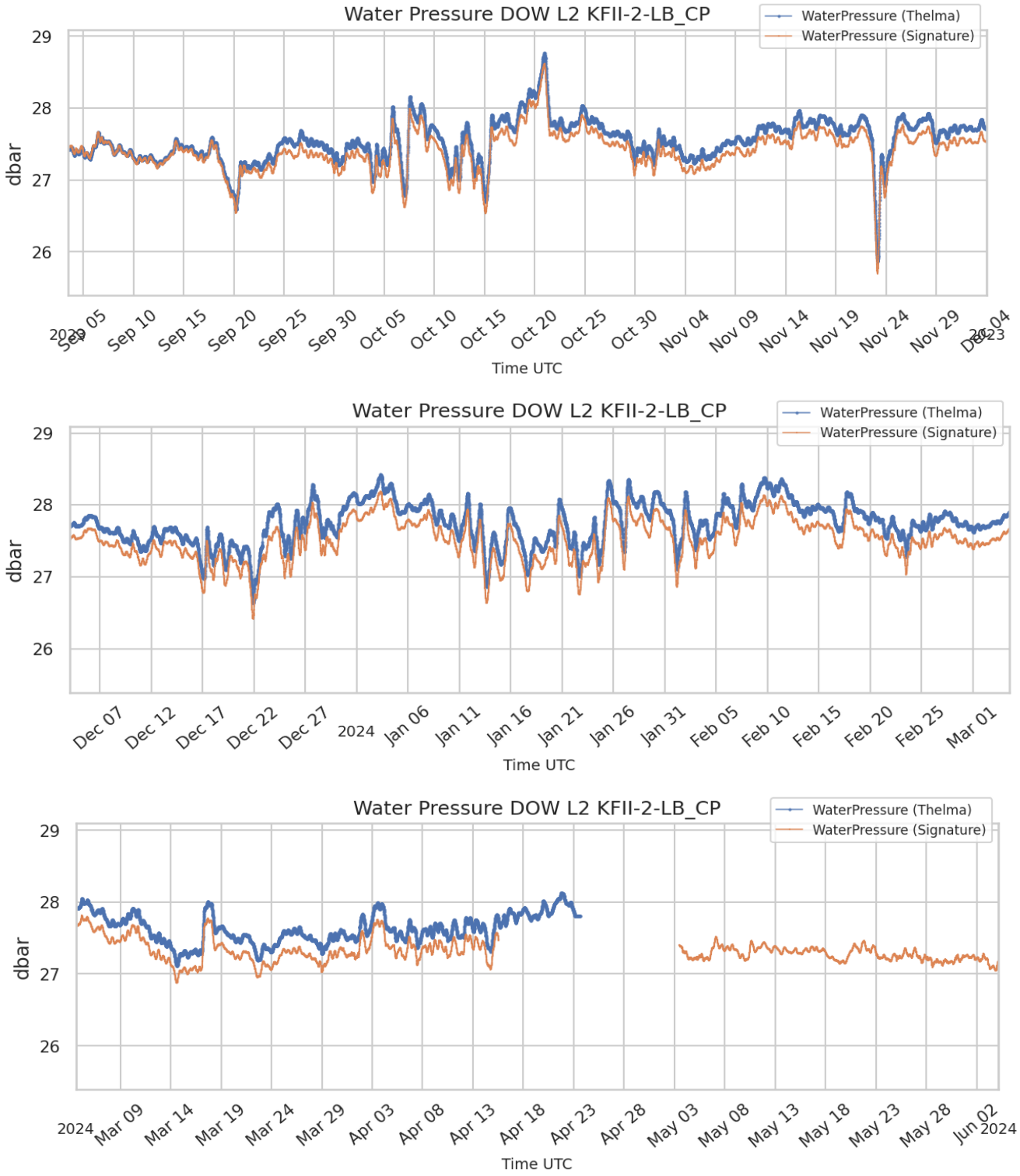


Figure C.19: Timeseries of water pressure from 3 September 2023 to 3 June 2024

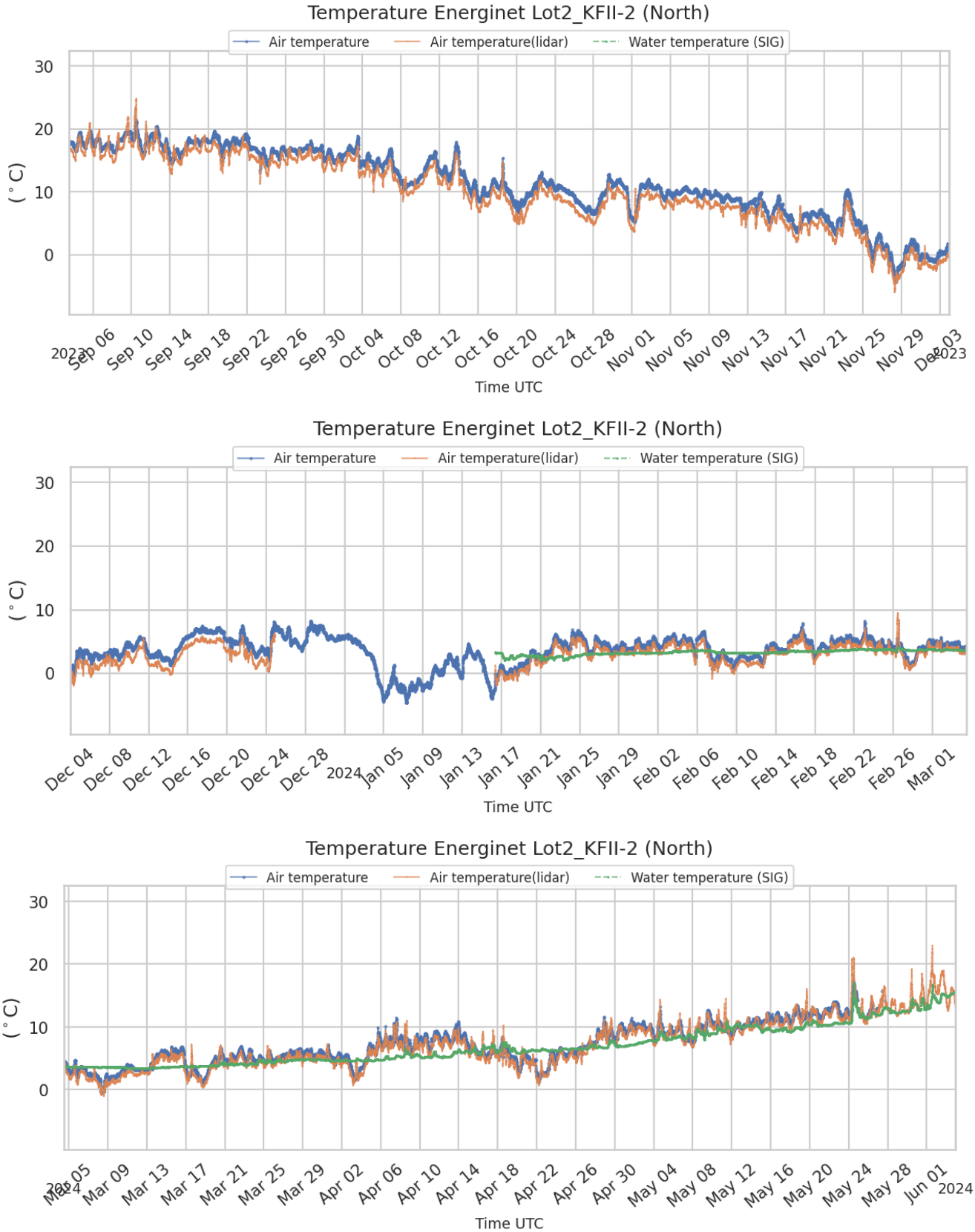


Figure C.20: Timeseries of water pressure, air temperature and surface water temperature from 3 September 2023 to 3 June 2024

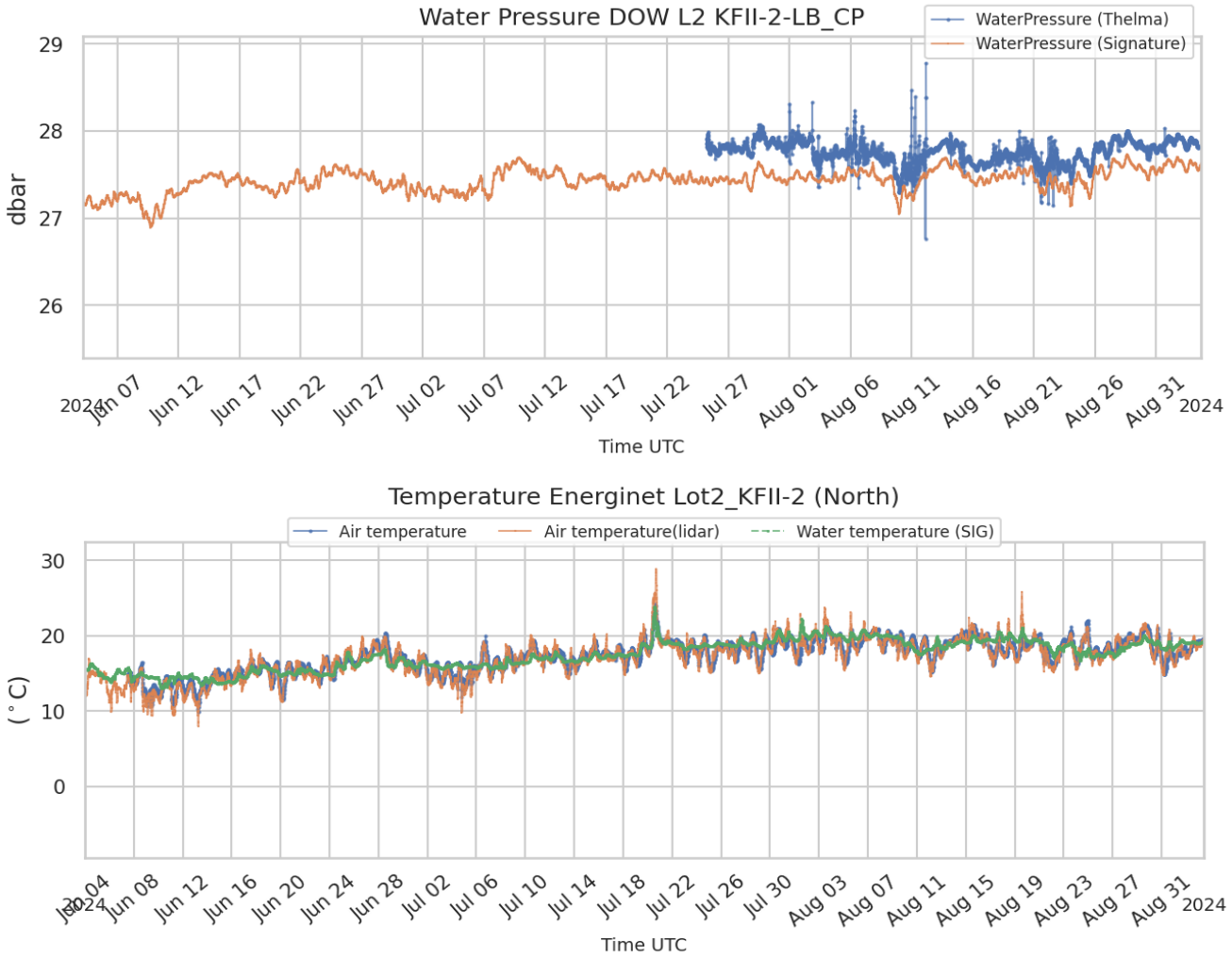


Figure C.21: Timeseries of accumulated precipitation, water pressure, air temperature and surface water temperature from 3 June 2024 to 3 September 2024

C.4 Current data (top-down)

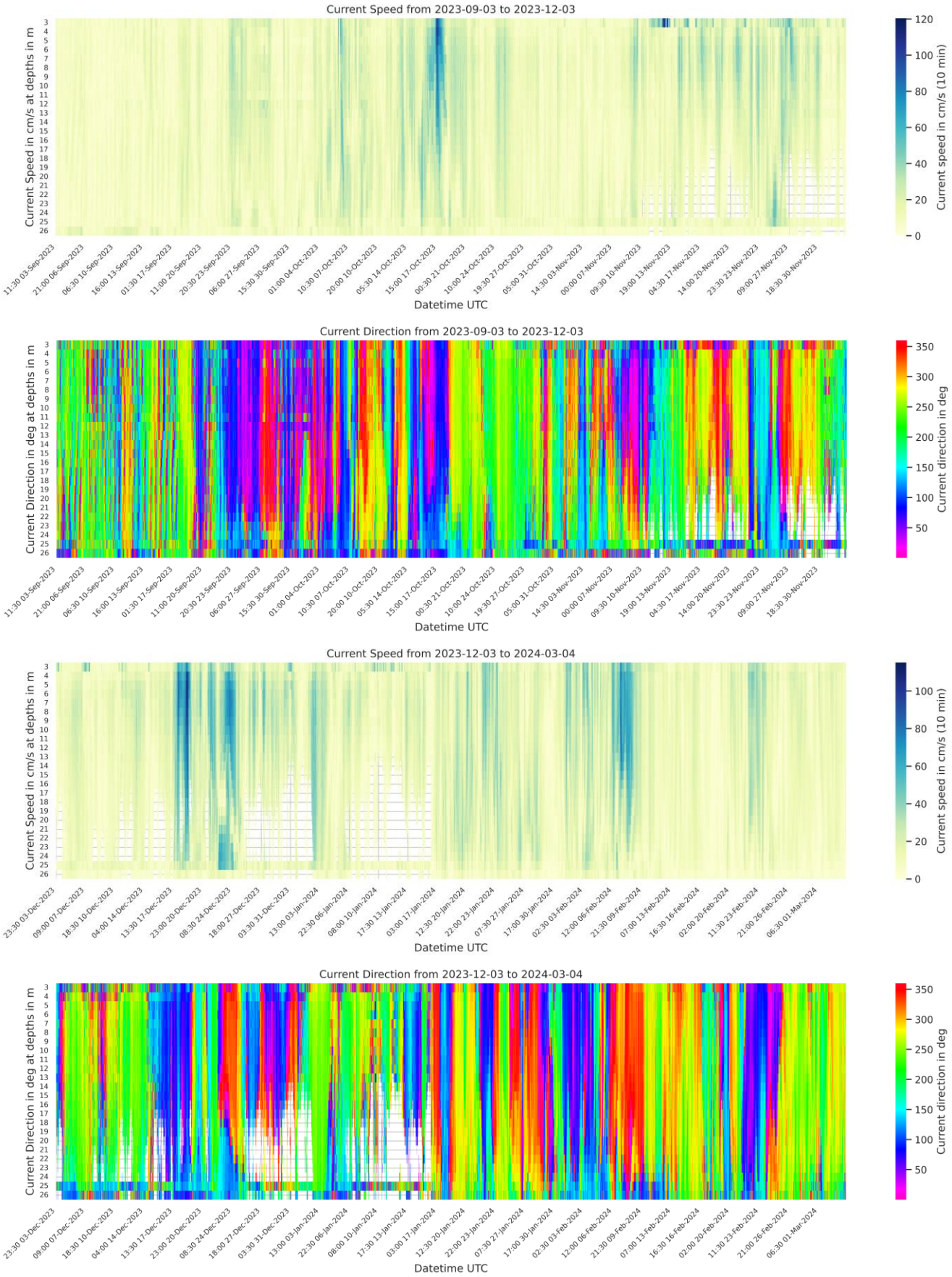


Figure C.22: Heatmaps of current speed and direction from 3 September 2023 to 3 March 2024

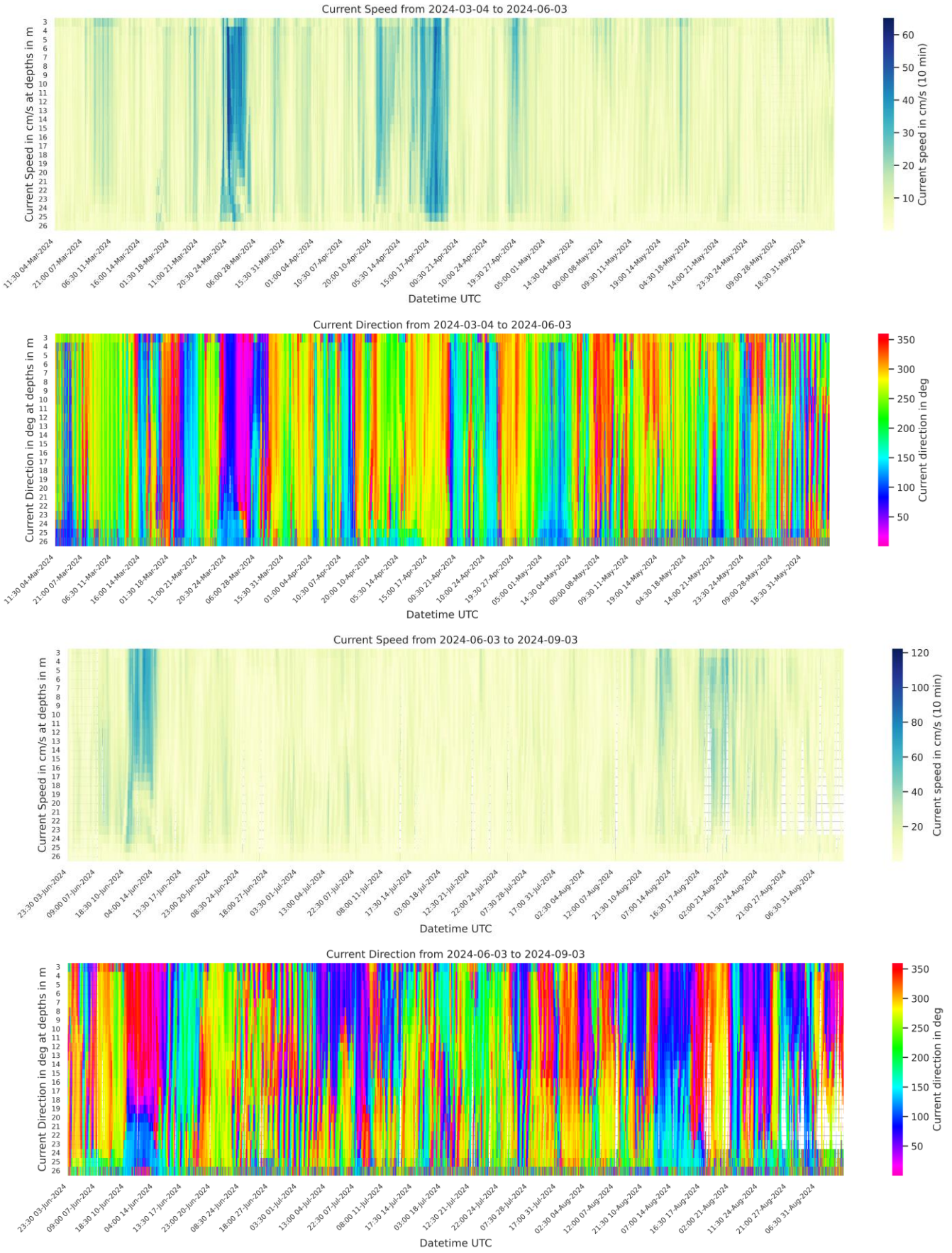


Figure C.23: Heatmaps of current speed and direction from 3 March 2024 to 3 September 2024

C.5 Current data (upward)

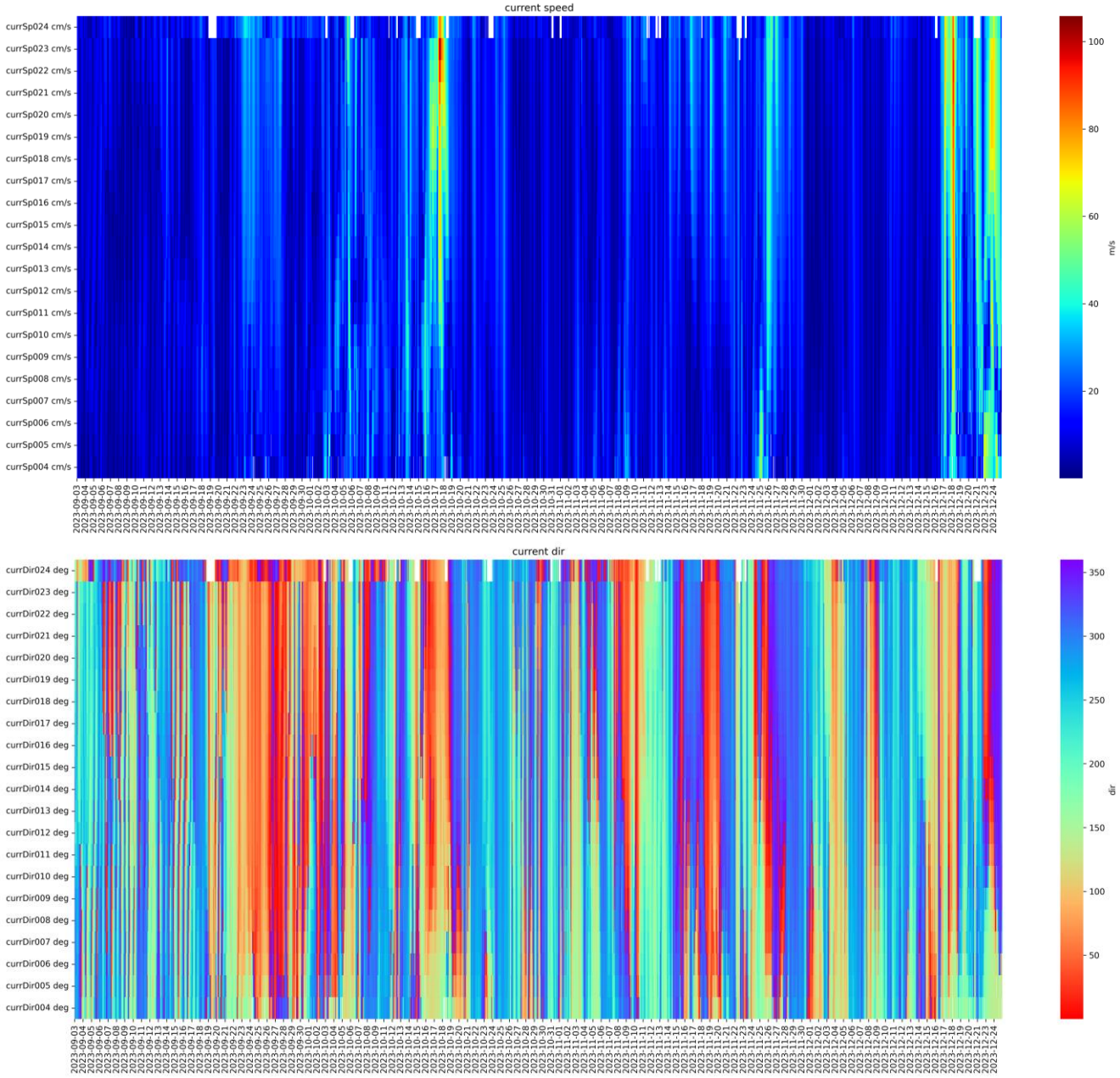


Figure C.24: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 3 September 2023 to 24 December 2023 (D1) (1/2).

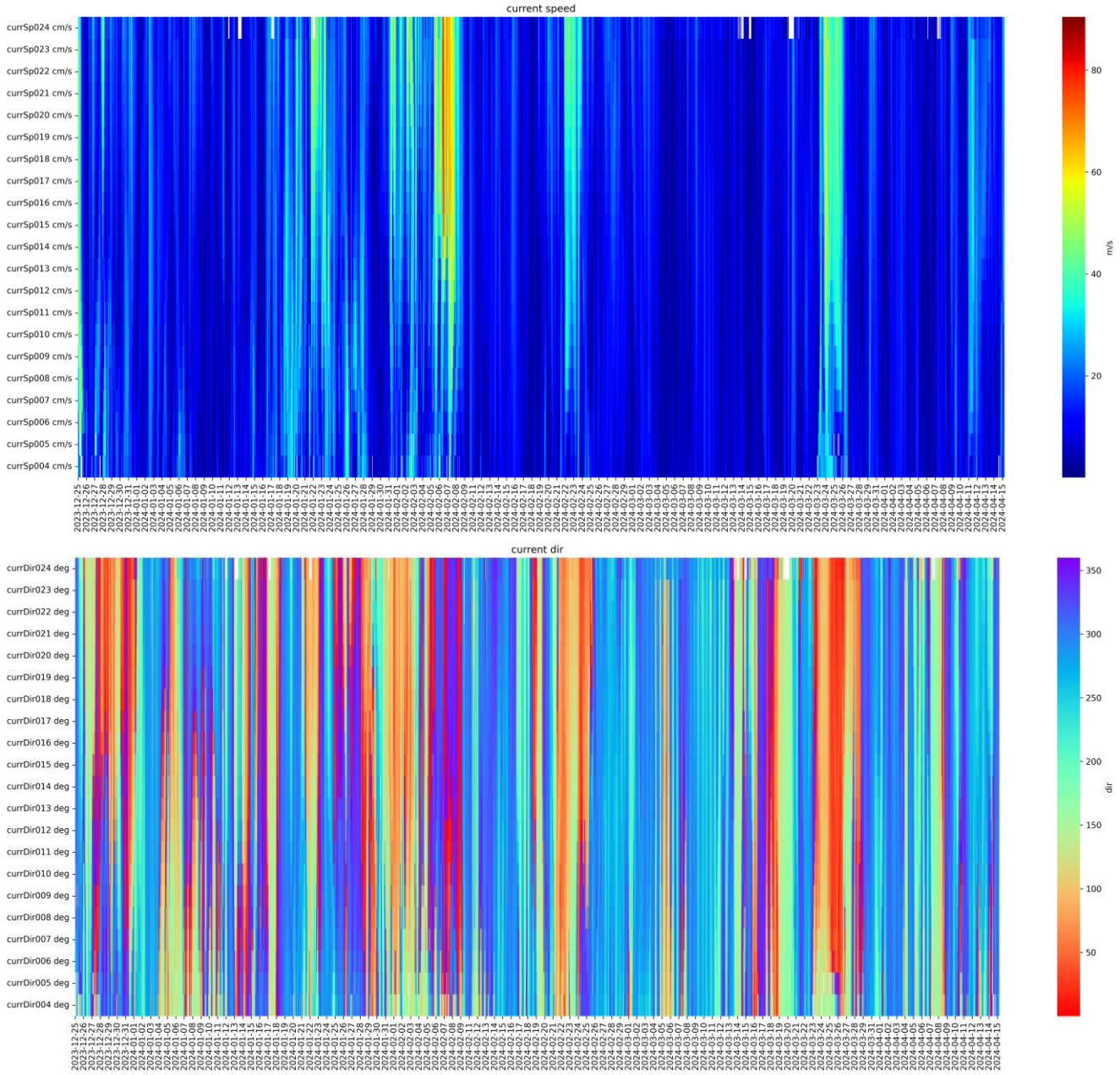


Figure C.25: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 24 December 2023 to 15 April 2024 (D1) (2/2).

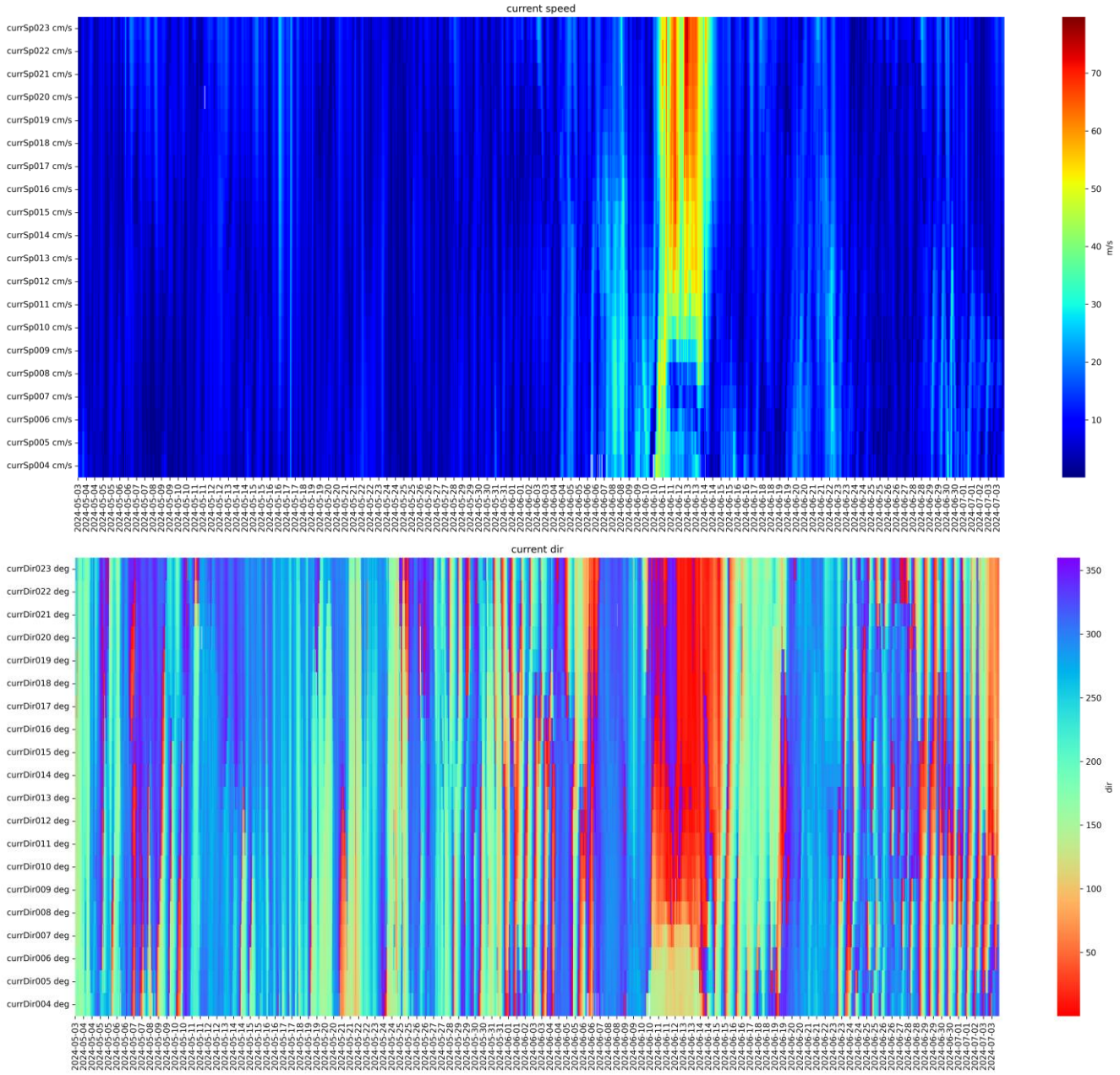


Figure C.26: Heatmap of offline (Signature)-measured bottom-up current speed and direction from 15 April 2024 to 4 July 2024 (D2) (1/2).

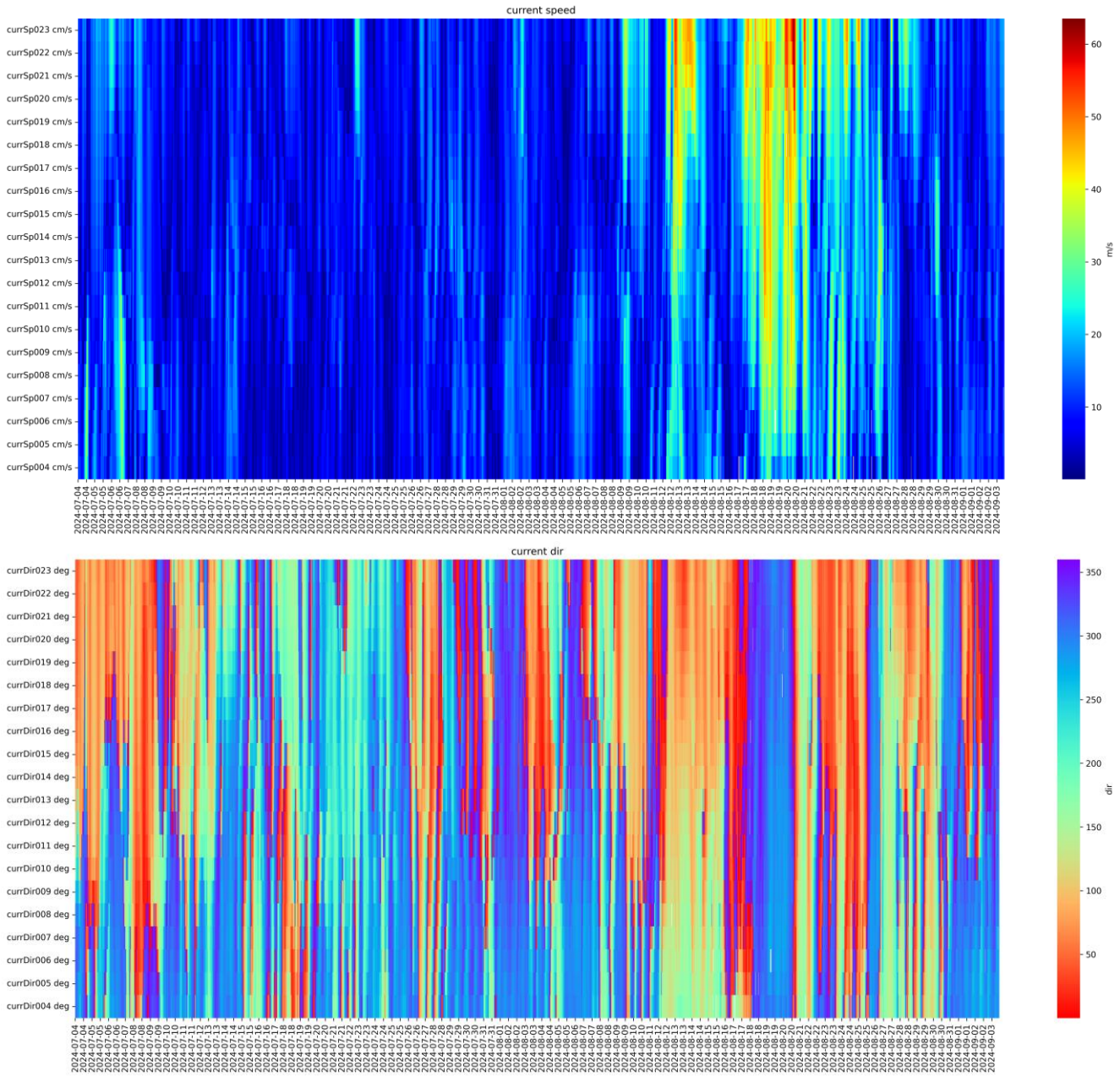


Figure C.27: Heatmap of offline (Signature)-measured bottom-up current speed and direction from direction from 4 July 2024 to 3 September 2024 (D2) (2/2).

Appendix D

Final post-processed file contents

D.1 KFII-1*-LB_12M_CurrentData.csv

Parameter	Unit	Description
currDir00xx deg	°N	Signature current direction
currSp00xx cm/s	cm/s	Signature current speed
echoIntxx int	int	Signature signal strength

where xx = 001, … , 017 m corresponding to measurement depth
1* = same data format for KFII-1-LB and KFII-2-LB

D.2 KFII-1*-LB_12M_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
pws_visibility m	m	Visibility in m
precipitation mm	mm	Accumulated precipitation

1* = same data format for KFII-1-LB and KFII-2-LB

D.3 KFII-1*-LB_12M_Posdata.csv

Parameter	Unit	Description
spLatitude deg	°N	Latitude (position) from the Septentrio GNSS
spLongitude deg	°E	Latitude (position) from the Septentrio GNSS

1* = same data format for KFII-1-LB and KFII-2-LB

D.4 KFII-1*-LB_12M_Status.csv

Parameter	Unit	Description

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
1* = same data format for KFII-1-LB and KFII-2-LB

D.5 KFII-1*-LB_12M_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	Height of the highest individual wave***
hmean m	m	Average height of individual waves***
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	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.
thmax s	s	Period of the highest wave***
thtp deg	°N	Mean wave direction at the spectral peak period

Parameter	Unit	Description
tm01 s	s	Estimate of mean wave period tz, calculated from spectral moments tm01 = m0/m1
tm02 s	s	Estimate of mean wave period tz, calculated from spectral moments $tm02 = \sqrt{(m0/m2)}$
tm02a s	s	Estimate of tm02 in a-band**
tm02b s	s	Estimate of tm02 in b-band**
tp s	s	Period of spectral peak
tz s	s	Average period of individual waves***
ts s	s	Average period of the one third highest waves***

1* = same data format for KFIII-1-LB and KFIII-2-LB
** 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.

D.6 KFII-1*-LB_12M_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 = 12m, … , 300m corresponding to measurement height
* Turbulence Intensity (TI) is defined as: (σ/u¯) / C where σ is the standard deviation and 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)

1* = same data format for KFII-1-LB and KFII-2-LB

D.7 KFII-1*-LB_12M_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
liPacketCountxx	-	Number of samples for the averaging period

where xx = 12m, … , 300m corresponding to measurement height
1* = same data format for KFII-1-LB and KFII-2-LB

D.8 KFII-1*-CP_D*_CurrentData_20230903[x1]_20240415[x2].csv

Column header	Unit	Description
currSp005m_cm/s, …, currSp034m_cm/s	cm/s	10-min averaged current speed
currDir005m_deg, …, currDir034m_deg	°N	10-min averaged current direction
DataMask_2, …, DataMask_31[1]	int	Data selection mask: non-zero indicates bad data value
BinMapAmp_BeamX_2, …, BinMapAmp_BeamX_31[1]	dB	Beam amplitude (signal-to-noise ration) where X corresponds to beam number 1 through 4
BinMapCor_Beam1_2, …, BinMapCor_Beam1_31[1]	%	Beam correlation (outgoing vs. incoming) where X corresponds to beam number 1 through 4
BinMapVel_East_2, …, BinMapVel_East_31[1]	cm/s	East velocity
BinMapVel_North_2, …, BinMapVel_North_31[1]	cm/s	North velocity
BinMapVel_Up1_2, …, BinMapVel_Up1_31[1]	cm/s	Vertical velocity
BinMapVel_Up2_2, …, BinMapVel_Up2_31[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

Column header	Unit	Description
Heading	°N	Heading
Pitch	°N	Pitch
Roll	°N	Roll

[1] where 1 corresponds to 004m, At KFII-2-CP, the binned from 4m to 24m, which correspond to 1 to 21 in bin numbers.
In file name:
1* = same data format for KFII-1-LB and KFII-2-LB
D* = D1 and D2 signifying downloaded data intervals (before and after service)
^{X1}, ^{X2} =start date and end date of interval D*

D.9 KFII-1*-LB_CP_12M_WaterLevel.csv

Column header	Unit	Description
WaterPressure dbar	dbar	Water pressure measured from Thelma pressure transmitter
Pressure	dbar	Water pressure measured from Signature500
WaterLevel_th m	m	Water level calculated from Thelma measured pressure data
WaterLevel_sig m	m	Water level calculated from Signature measured pressure data

1* = same data format for KFII-1-LB and KFII-2-LB

Appendix E

File formats and contents of the raw data files

Danish Offshore Wind 2030 – Floating LiDAR Measurements

File formats and contents of the raw data files

C75517-RawData-README-001 01 | 30 October 2024

Final

ENERGINET

Document Control

Document Information

Project Title	Danish Offshore Wind 2030 – Floating LiDAR Measurements
Document Title	File formats and contents of the raw data files
Fugro Project No.	C75517
Fugro Document No.	C75517-RawData-README-001
Issue Number	01
Issue Status	Final

Client Information

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Revision History

Issue	Date	Status	Comments on Content	Prepared By	Checked By	Approved By
01	30 October 2024	Final	First complete issue	Sungsoo Lim	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.

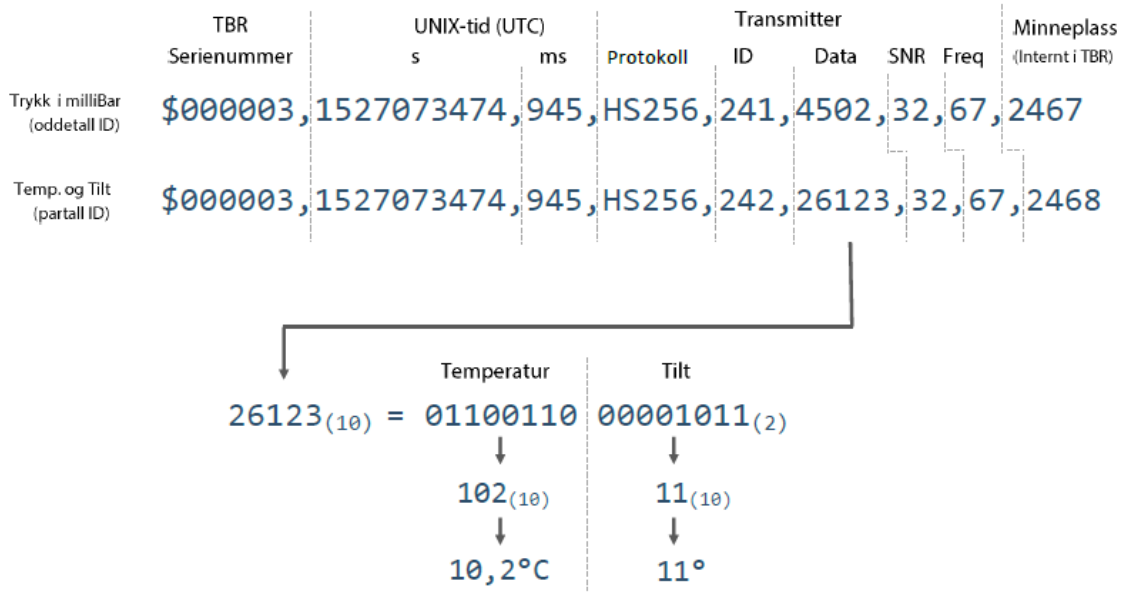
4.1 Tag detections

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.

See below snipet of Geni code for pitch and roll angles

tmp = sinf(out.roll[i])*cosf(out.pitch[i]); //sine of the angle to the horizontal plane. Note that order of lines are important for calculation/processing

out.roll[i] = tmp;

out.pitch[i] = -sinf(out.pitch[i]);

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 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.