Energy Island Baltic Sea

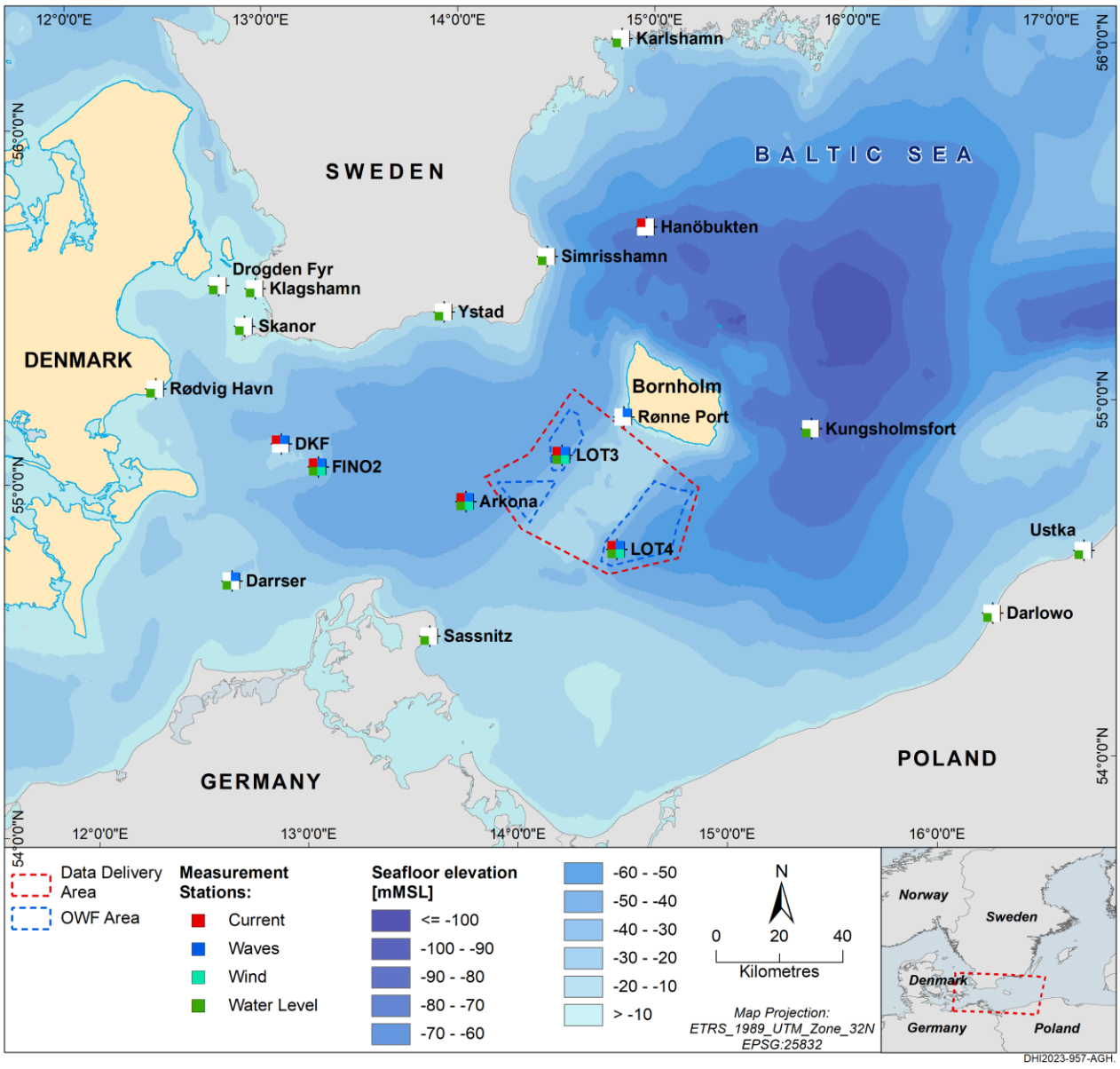
Metocean Assessment

Part C: Data Basis Reverification

Note
IO Number 4500092960

2024-07-04

Prepared for Energinet Eltransmission A/S



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Prepared for: Energinet Eltransmission A/S
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Nomenclature

Variable	Abbreviation	Unit
Atmosphere		
Wind speed @ 10 m height	WS_{10}	m/s
Wind direction @ 10 m height	WD_{10}	°N (clockwise from)
Air pressure @ mean sea level	P_{MSL}	hPa
Air temperature @ 2 m height	$T_{air,2m}$	°C
Relative humidity @ 2 m height	RH_{2m}	-
Ocean		
Water level	WL	mMSL
Current speed	CS	m/s
Current direction	CD	°N (clockwise to)
Water temperature	T_{sea}	°C
Water Salinity	Salinity	PSU
Waves		
Significant wave height	H_{m0}	m
Peak wave period	T_p	s
Mean wave period	T_{01}	s
Zero-crossing wave period	T_{02}	s
Peak wave direction	PWD	°N (clockwise from)
Mean wave direction	MWD	°N (clockwise from)
Direction standard deviation	DSD	°

Definitions	
Coordinate System	WGS84 EPSG 4326 (unless specified differently)
Direction	Clockwise from North Wind: °N coming from Current: °N going to Waves: °N coming from
Time	Times are relative to UTC
Vertical Datum	MSL (unless specified differently)

Abbreviations	
2D	2-dimensional
3D	3-dimensional
ADCP	Acoustic Doppler Current Profiler
AME	Mean Absolute difference
CC	Cross Correlation
DEA	Danish Energy Agency
DNV	Det Norske Veritas
DNVGL	Det Norske Veritas Germanischer Lloyd
ECMWF	European Centre for Medium-Range Weather Forecasts
EIBS	Energy Island Baltic Sea
ERA5	ECMWF Re-analysis v5
EV	Explained variance
FEED	Front-End Engineering Design
HD	Hydrodynamic
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
mMSL	Metres above Mean Sea Level
MSL	Mean Sea Level
NORA3	3 km NOrwegian ReAnalysis atmospheric dataset
OWF	Offshore Wind Farm
PR	Peak to Peak Ratio
PSU	Practical Salinity Unit
QQ	Quantile-quantile
RMSE	Root-mean-square difference
SI	Scatter Index
SW	Spectral Wave
UTC	Coordinated Universal Time
WGS84	World Geodetic System 1984

Revision

Version	Date	Revision log
Draft 0.1	13 June 2024	Draft version for client review
Final 1.0	4 July 2024	Final version including comments from client

Executive Summary

Energinet Eltransmission A/S (Energinet) commissioned DHI A/S (DHI) to carry out a metocean study that shall serve as a basis for Front-End Engineering and Design (FEED) of two offshore wind farms named Bornholm I and Bornholm II, being part of Energy Island Baltic Sea (EIBS). The offshore wind farms will be located southwest of the island Bornholm in the Baltic Sea.

The results of the metocean study consist of three reports: a metocean data basis report (Part A), a metocean data analysis report (Part B), and a hindcast revalidation note (this note). Additionally, a metocean hindcast database is provided.

In this revalidation note, measurements unavailable to the metocean study for Part A and Part B are compared to the models used as the basis for Part A and Part B. The purpose of this note is thus to check if these new measurements will change the design conditions presented in Part B.

The note provides a revalidation of the following parameters: wind, wave, current, water level, seawater temperature and salinity.

The conclusion is that the revalidation of all the parameters mentioned does not change any of the conclusions made in the Part A report [1] nor any of the design conditions presented in the Part B report [2].

It should be noted that both reports (the Part A report and the Part B report) have been certified (see [3] and [4]), as have the metocean measurements collected and used for this study (see [5]).

1 Introduction

This study provides detailed metocean conditions to use in the Front-End Engineering and Design (FEED) of two offshore wind farms named Bornholm I and Bornholm II, being part of Energy Island Baltic Sea (EIBS). The offshore wind farms are to be located southwest of the island Bornholm in the Baltic Sea. The study consists of three reports: a metocean data basis (Part A) [1], a metocean data analysis (Part B) [2], and a hindcast revalidation note, which is the present note. Additionally, a metocean hindcast database is provided.

Energinet Eltransmission A/S (Energinet) was instructed by the Danish Energy Agency (DEA) to initiate site investigations, including a metocean assessment, for offshore wind farms in an area to the southwest of Bornholm in the Baltic Sea. Following this, Energinet commissioned DHI A/S (DHI) to provide a detailed metocean site condition assessment for use in FEED as described in "CONSULTANCY CONTRACT REGARDING SITE METOCEAN CONDITIONS ASSESSMENT FOR OFFSHORE WIND FARMS – BALTIC SEA" signed on 7 March 2023.

The study consists of several deliverables:

- Part A: Description and Verification of Data Basis (report) [1], that has been certified [3]
- Part B: Data Analyses and Results (report) [2], that has been certified [4]
- Long-term hindcast data (digital time series)
- Measurement data (digital time series)
- Part C: Data Basis Reverification (this note)

The study refers to the following standard practices and guidelines:

- DNV-RP-C205 [6]
- IEC 61400-3-1 [7]

The metocean measurements used for this study has also been certified [5].

2 Overview of Additional Measurements

This section describes the additional measurements campaign, which includes wind, wave, water level and current measurements.

The coverage of the data received for the revalidation note and the data used in report [1] is presented in Figure 2.1. Based on the temporal coverage presented in Figure 2.1, the revalidation was carried out for new wind, wave, current, water level, temperature, and salinity at LOT4, and current at LOT3 not previously received. Further details on the data used for the revalidation are available in Table 2.1 to Table 2.5.

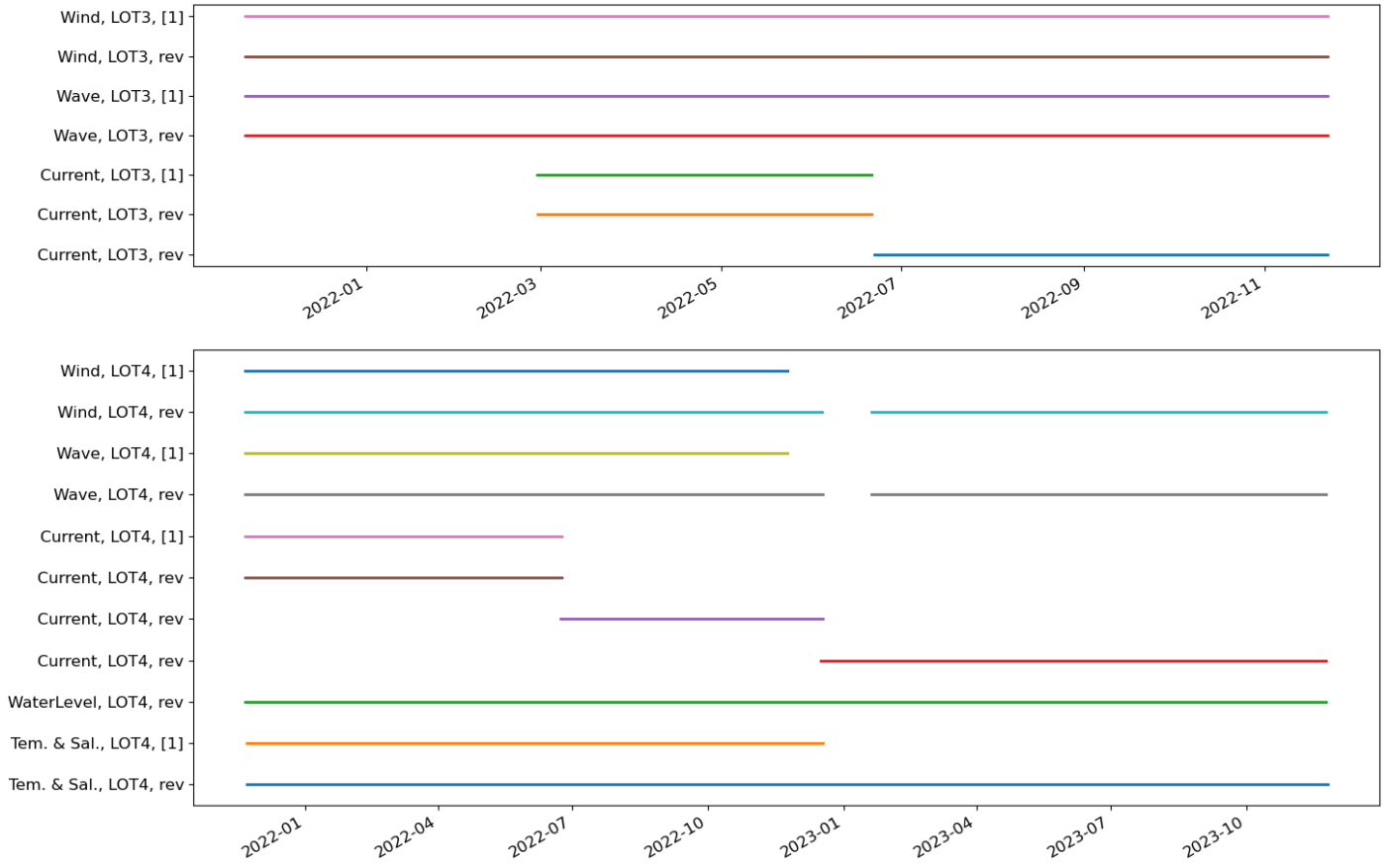

Figure 2.1 Coverage period of measurement campaign of LOT3 and LOT4
[1]: “Measurements from data report [1]”;
rev: “Measurement data received for the revalidation note”.

Table 2.1 Details of additional wind measurement

Station Name	Longitude [°E]	Latitude [°N]	Measurement Height [mMSL]	Data coverage (new period)	Data coverage (full period)	Instrument	Owner / Surveyor
LOT4	14.5882	54.7170	4 (Anemometer) 30, 40, 60, 90, 100, 120, 150, 180, 200, 240, 270 (LiDAR)	2022-11-24 – 2023-11-22	2021-11-21 – 2023-11-22	Anemometer: Gill Windsonic M LiDAR: ZephIR ZX300	Energinet / Fugro

Table 2.2 Details of additional wave measurement

Station Name	Longitude [°E]	Latitude [°N]	Depth [mMSL]	Data coverage (new period)	Data coverage (full period)	Instrument	Owner / Surveyor
LOT4	14.5882	54.7170	42.3	2022-11-21 – 2023-11-22	2021-11-22 – 2023-11-22	Wavesense 3	Energinet / Fugro

Table 2.3 Details of additional water level measurements

Station Name	Longitude [°E]	Latitude [°N]	Depth [mMSL]	Data coverage (new period)	Data coverage (full period)	Instrument	Owner / Surveyor
LOT4	14.5882	54.7170	42.3	2022-12-01 – 2023-11-22	2021-11-22 – 2023-11-22	Nortek Signature 500	Energinet / Fugro

Table 2.4 Details of additional current measurements

Station Name	Longitude [°E]	Latitude [°N]	Depth [mMSL]	Data coverage (new period)	Data coverage (full period)	Levels	Instrument	Owner / Surveyor
LOT3	14.3556	54.9948	39.8		2022-02-28 – 2022-06-20	1 m intervals in range 4 m to 37 m above seabed	Nortek Signature 500	Energinet / Fugro
				2022-06-22 – 2022-11-21	2022-06-22 – 2022-11-21	2 m intervals in range 4 m to 34 m above seabed		
LOT4	14.5882	54.7170	42.3		2021-11-22 – 2022-06-22	1 m intervals in range 4 m to 39 m above seabed	Nortek Signature 500	Energinet / Fugro
				2022-06-24 – 2022-12-16	2022-06-24 – 2022-12-16	2 m intervals in range 4 m to 36 m above seabed		
				2022-12-17 – 2023-11-22	2022-12-17 – 2023-11-22	1 m intervals in range 4 m to 39 m above seabed		

Table 2.5 Details of additional temperature and salinity measurements

Station Name	Longitude [°E]	Latitude [°N]	Depth [mMSL]	Data coverage (new period)	Data coverage (full period)	Levels	Instrument	Owner / Surveyor
LOT4	14.5882	54.7170	42.3	2022-11-24 – 2023-11-22	2021-11-22 – 2023-11-22	Temperature and salinity at 9 m, 18 m, 25 m, and 33 m	Seabird STB CTD	Energinet / Fugro
LOT4	14.5882	54.7170	42.3	2022-11-24 – 2023-11-22	2021-11-22 – 2023-11-22	Surface temperature	LiDAR buoy (SWLB)	Energinet / Fugro

3 Wind Revalidation

This section summarises the modelled versus the measured wind speed and direction. Modelled wind parameters are based on the NORA3 model (Section 3.3.1 of [1]) with coverage extended to November 22, 2023 (end of measurement campaign).

Figure 3.1 compares the time series and scatter plots of wind speed during the new campaign period, the old campaign period, and the full coverage of the campaign period. The wind rose comparison is presented in Figure 3.2.

Table 3.1 provides the validation statistics of the new and full campaign periods. The validation during the new campaign period is consistent with the previous validation [1], regarding both magnitude and direction. It can be summarized that the NORA3 wind has a high correlation with local measurements. Thus, no further adjustment is needed for the wind-related sections in [1] and [2].

Table 3.1 Statistics of wind validation (wind speed)

	LOT4 (new period)	LOT4 (full period)
N	7496	16148
MEAN	7.39	7.47
BIAS	-0.17	-0.13
AME	0.94	0.95
RMSE	1.23	1.25
SI	0.16	0.16
EV	0.89	0.88
CC	0.94	0.94
PR	0.99	0.99
QQ fit	1.00x-0.16	1.01x-0.19

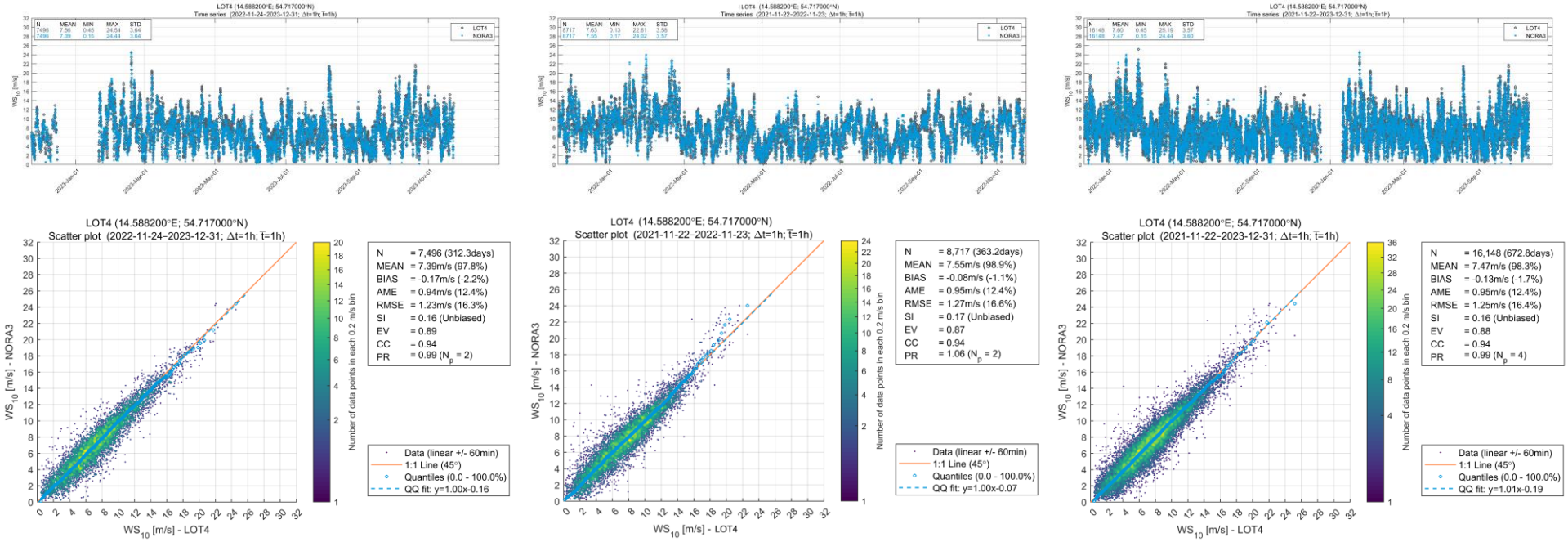

Figure 3.1 Comparison of measured and modelled wind speed at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

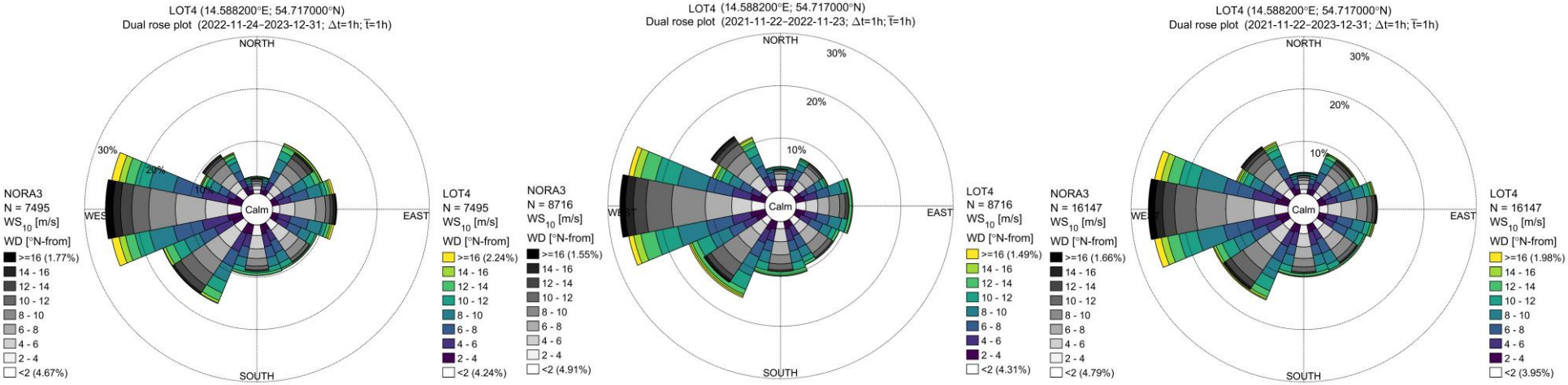

Figure 3.2 Comparison of measured and modelled wind rose at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

4 Wave Revalidation

This section summarises the modelled versus the measured wave parameters (H_{m0}, T_p, T_{01}, T_{02}, MWD). Modelled wave parameters are based on the SW_{EIBS} model (Section 6.6 of [1]) with coverage extended to November 22, 2023 (end of measurement campaign).

Figure 4.1, Figure 4.3, Figure 4.4, and Figure 4.5 show the comparison of the time series and scatter plots of wave parameters (H_{m0}, T_p, T_{01}, T_{02}, respectively) during the new campaign period, old campaign period, and the full coverage of the campaign period. The wave rose comparison is presented in Figure 4.2.

Table 4.1 to Table 4.4 provide the validation statistics for the new and full campaign periods. The validation during the new campaign period is consistent with the previous validation [1], regarding both magnitude and direction. In summary, the SW_{EIBS} model also agrees well with the local measurements for the new period. Thus, no further adjustment is needed for the wave-related sections in [1] and [2].

Table 4.1 Statistics of wave validation (H_{m0})

	LOT4 (new period)	LOT4 (full period)
N	7871	16548
MEAN	0.93	0.94
BIAS	0.04	0.04
AME	0.11	0.11
RMSE	0.16	0.15
SI	0.17	0.16
EV	0.95	0.95
CC	0.98	0.98
PR	0.98	0.98
QQ fit	1.02+0.02	1.04+0.00

Table 4.2 Statistics of wave validation ($T_{p,}$ for H_{m0} > 0.5 m)

	LOT4 (new period)	LOT4 (full period)
N	5005	10860
MEAN	5.26	5.23
BIAS	0.12	0.11
AME	0.36	0.35
RMSE	0.59	0.57
SI	0.11	0.11
EV	0.77	0.75
CC	0.89	0.88
PR	1.05	1.08
QQ fit	1.04-0.08	1.04-0.08

Table 4.3 Statistics of wave validation ($T_{01,}$ for H_{m0} > 0.5 m)

	LOT4 (new period)	LOT4 (full period)
N	5005	10860
MEAN	4.41	4.39
BIAS	0.19	0.18
AME	0.25	0.24
RMSE	0.31	0.30
SI	0.06	0.06
EV	0.89	0.89
CC	0.95	0.95
PR	0.98	1.01
QQ fit	1.04+0.05	1.04+0.03

Table 4.4 Statistics of wave validation ($T_{02,}$ for H_{m0} > 0.5 m)

	LOT4 (new period)	LOT4 (full period)
N	5005	10860
MEAN	4.21	4.19
BIAS	0.17	0.16
AME	0.23	0.22
RMSE	0.28	0.27
SI	0.06	0.05
EV	0.89	0.88
CC	0.95	0.94
PR	0.97	1.00
QQ fit	1.03+0.06	1.02+0.06

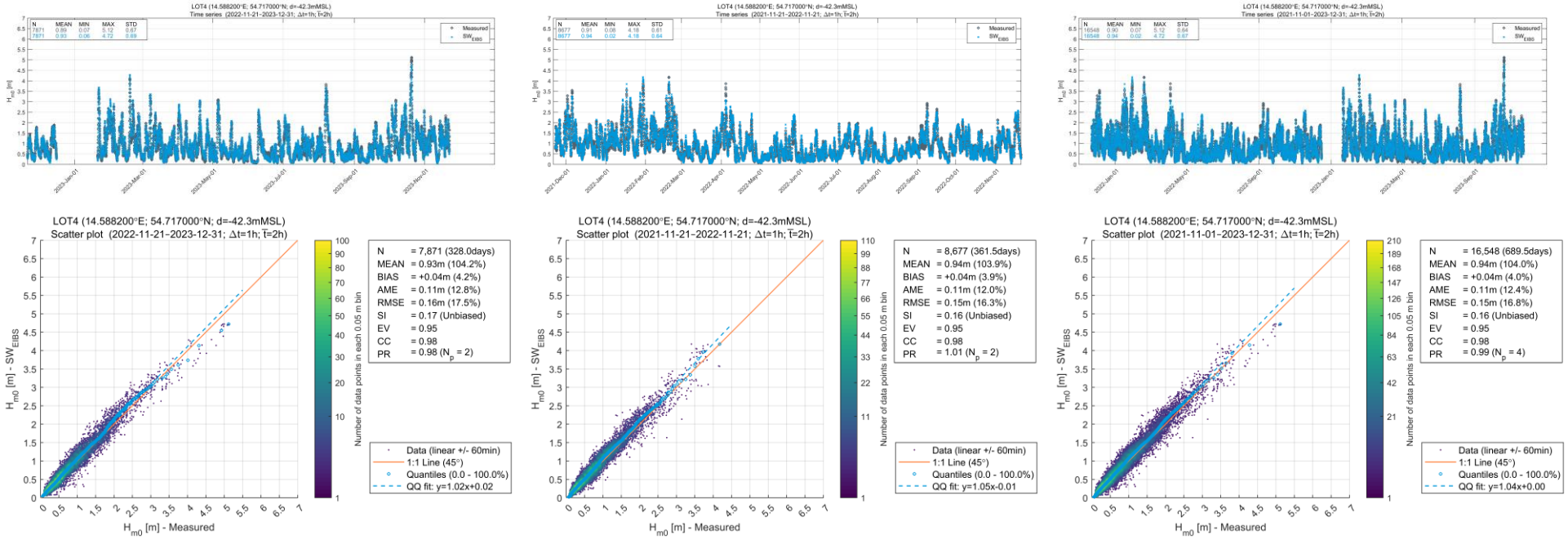

Figure 4.1 Comparison of measured and modelled H_{m0} at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

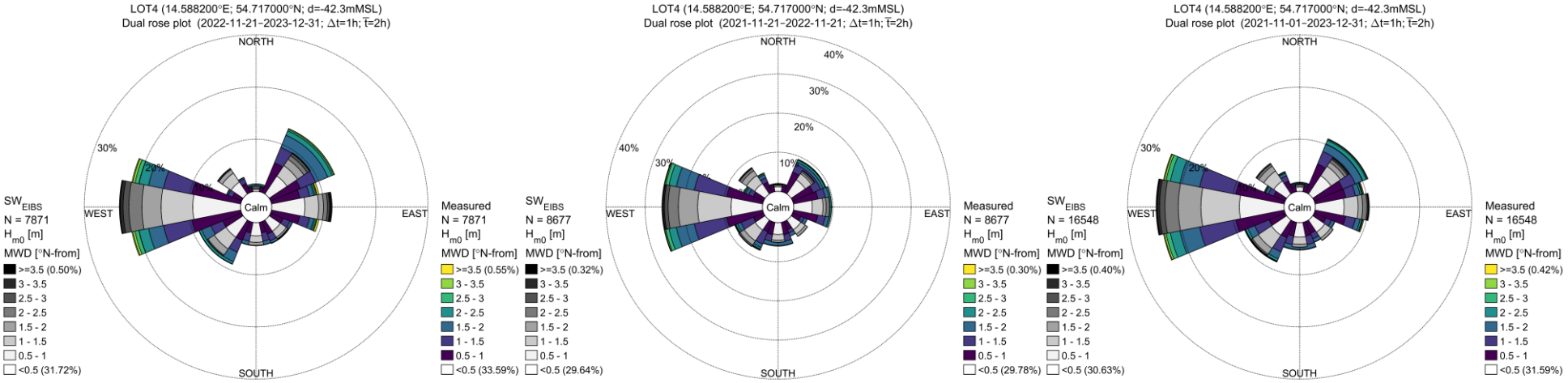

Figure 4.2 Comparison of measured and modelled wave rose at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

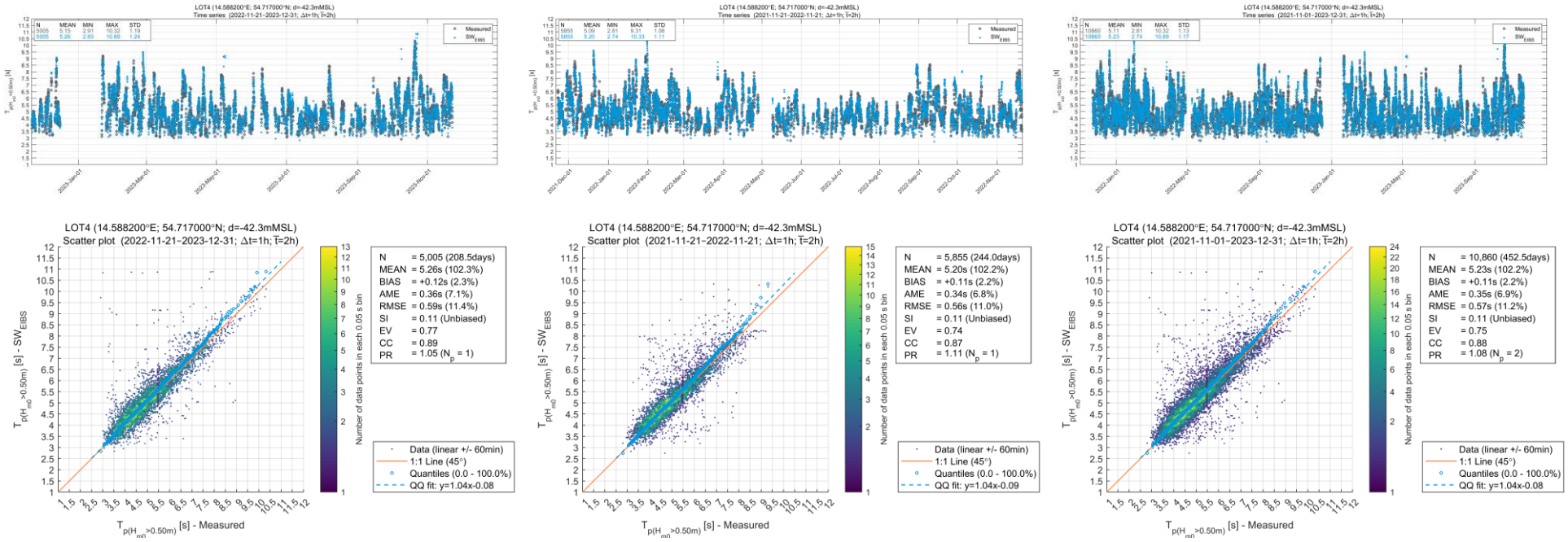

Figure 4.3 Comparison of measured and modelled T_p at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries, Bottom: Rose plots.

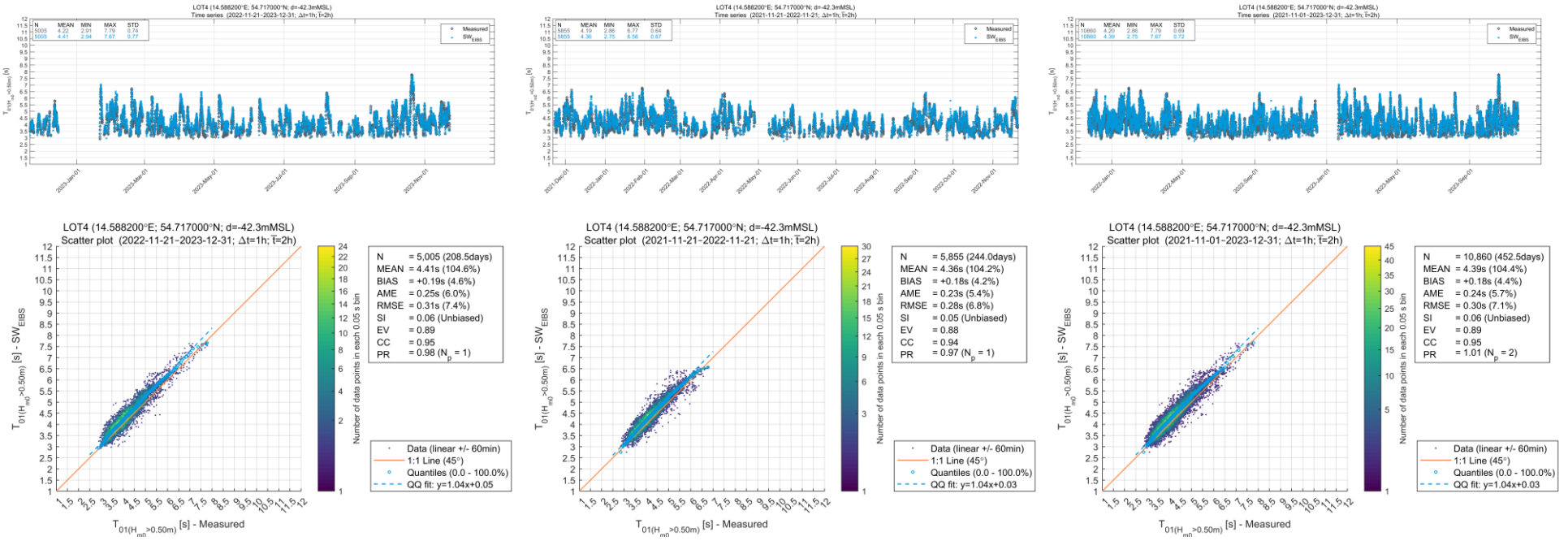

Figure 4.4 Comparison of measured and modelled T_{01} at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

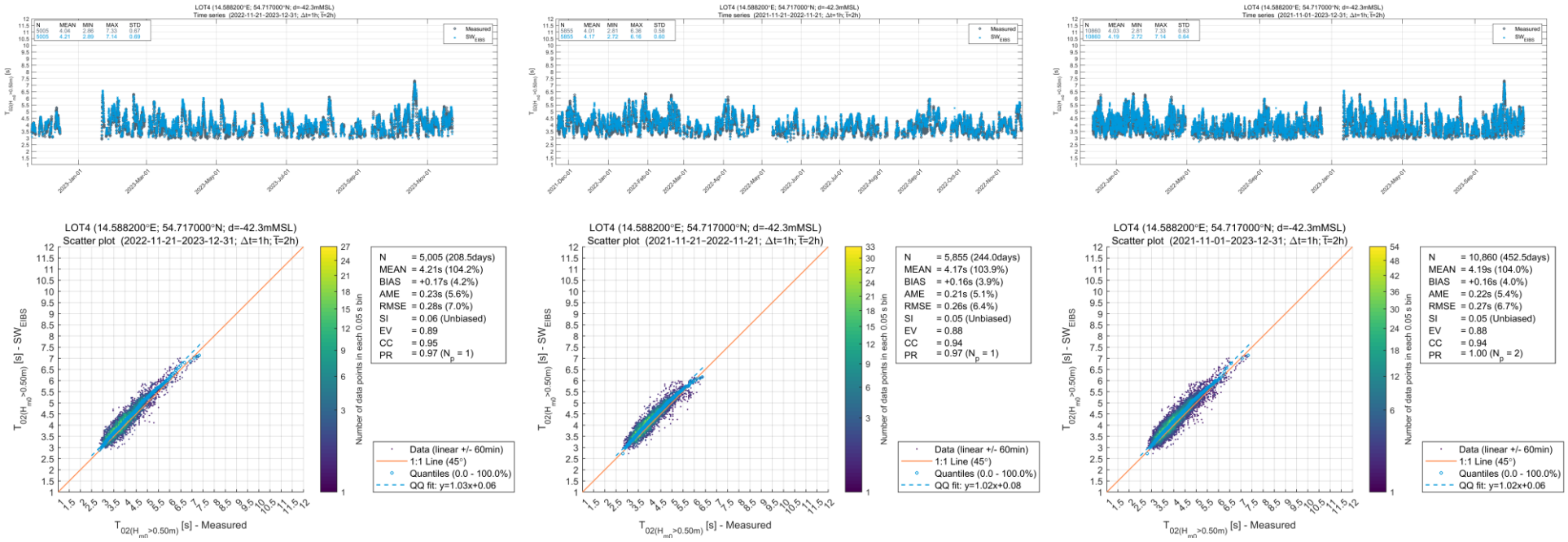

Figure 4.5 Comparison of measured and modelled T_{02} at LOT4

Left: "New measurements", Middle: "Measurements from data report [1]" and, Right: "Measurements from data report [1] and new measurements". Top: Timeseries plots, Bottom: Scatter plots.

5 Water Level Revalidation

This section summarises the modelled versus the measured water level. Modelled water levels are based on the $HD_{NE\text{-}ERA5}$ model (Section 4.3.1 of [1]) with coverage extended to November 22, 2023 (end of measurement campaign).

Figure 5.1 compares the time series and scatter plots of water levels during the new campaign period, the old campaign period, and the full coverage of the campaign period.

Table 5.1 provides the validation statistics for the new and full campaign periods. The validation during the new campaign period is consistent with the previous validation [1]. This indicates a high correlation between the $HD_{NE\text{-}ERA5}$ model and local measurements. Therefore, no further adjustments are required for the water level-related sections in [1] and [2].

Table 5.1 Statistics of water level validation

	LOT4 (new period)	LOT4 (full period)
N	16897	34726
MEAN	-0.00	-0.00
BIAS	-0.00	-0.00
AME	0.03	0.02
RMSE	0.03	0.03
SI	0.25	0.22
EV	0.96	0.97
CC	0.98	0.99
PR	0.87	0.90
QQ fit	0.97x-0.0	0.98x-0.0

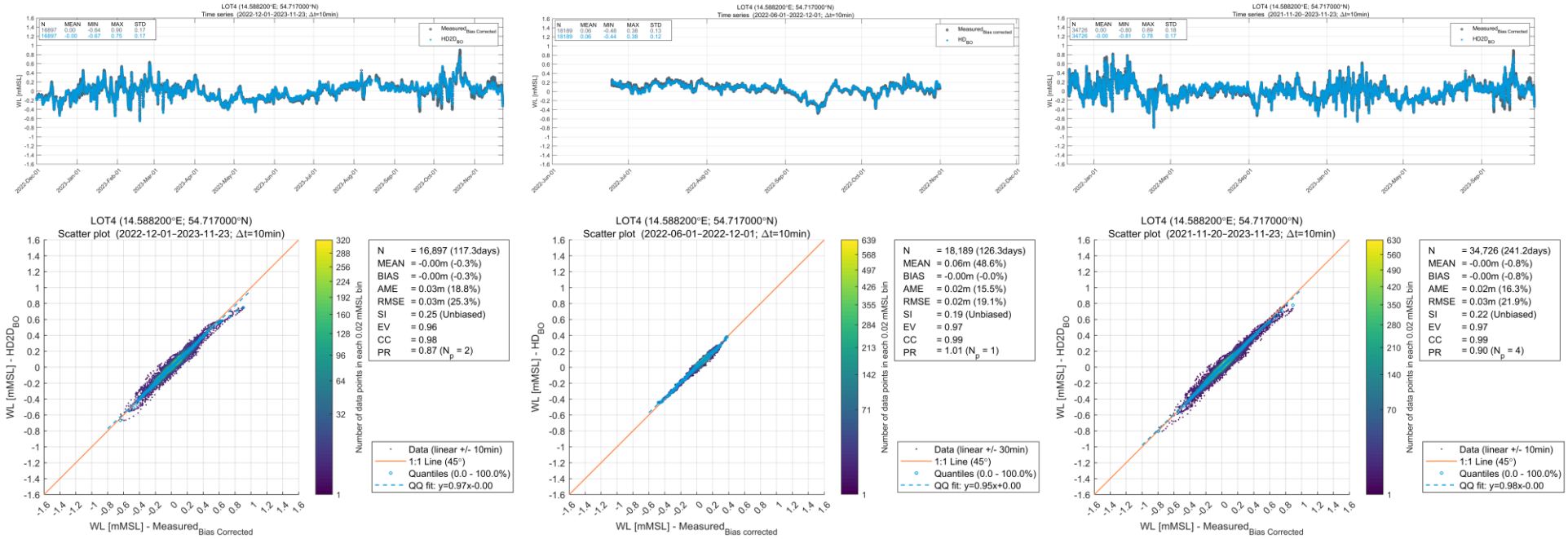

Figure 5.1 Comparison of measured and modelled water level at LOT4
Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

6 Current Revalidation

This section summarises the modelled versus the measured current speed and direction. Modelled current speed and direction parameters are based on the HD_{EIBS} model (Section 5.4 of [1]) with coverage extended to November 22, 2023 (end of measurement campaign).

Figure 6.1, Figure 6.3, Figure 6.5, and Figure 6.7 show the comparison of the time series and scatter plots of current speed (at 10 m and 32 m depth) during the new campaign period, the old campaign period, and the full coverage of the campaign period. The current rose comparison, at 10 m and 32 m depth, is presented in Figure 6.2, Figure 6.4, Figure 6.6, and Figure 6.8.

Table 6.1 and Table 6.2 provide the validation statistics for the new and full campaign periods.

During November 2022, ADCP observations of currents indicate very high currents, especially at LOT 3, both at surface and mid-depth. These current events are not well reflected in the current modelling. We have inspected the basic model results to find an indication of why.

The period around November 19 is characterized by winds from NE and a strong current towards SW, basically following the slopes of the Rønne Banke. The ADCP shows a peak at 50cm/s, going SW at 10m and 30cm/s at 26m. The model shows currents towards SW and SSW along the slope at about 25cm/s at 10m and less than 20cm/s in the deeper part of the water column (see Figure 6.9 and Figure 6.10). A possible explanation for the discrepancy in flow pattern is that the flow resistance (in the model) along the slope is relatively large due to the z-layers (giving s staircase bottom), which will be especially prominent for along-slope flows, thus dampening south-westward currents. During the autumn of 2022, observations show 6 peak current events with south-westerly currents.

This non-conservative prediction of LOT3 peak currents during the autumn season does affect the general QQ-fit such that extreme currents estimates may be adjusted by 20% in the development area (see Figure 6.1 through Figure 6.8). However, this adjustment has already been considered in the design conditions for current in [2] where post-calibration scaling factors, as shown in Table 6.3, are provided.

In summary, no further adjustments are needed for the current related sections in [1] and [2].

Table 6.1 Statistics of current validation at -10m depth

	LOT3 (new period)	LOT3 (full period)	LOT4 (new period)	LOT4 (full period)
N	10908	27031	73750	97621
MEAN	0.09	0.09	0.07	0.07
BIAS	-0.04	-0.03	-0.02	-0.02
AME	0.07	0.06	0.05	0.05
RMSE	0.09	0.08	0.07	0.06
SI	0.60	0.66	0.66	0.65
EV	-0.27	-0.40	-0.17	-0.12
CC	0.18	0.13	0.34	0.36
PR	0.57	0.59	0.82	0.80
QQ fit	0.72x-0.00	0.77x-0.00	0.86x-0.01	0.84x-0.01

Table 6.2 Statistics of current validation at -32m depth

	LOT3 (new period)	LOT3 (full period)	LOT4 (new period)	LOT4 (full period)
N	10909	27032	73577	98429
MEAN	0.08	0.08	0.07	0.07
BIAS	-0.06	-0.03	-0.02	-0.02
AME	0.08	0.06	0.04	0.04
RMSE	0.10	0.08	0.06	0.06
SI	0.63	0.68	0.64	0.64
EV	-0.15	-0.11	-0.11	-0.08
CC	0.20	0.28	0.34	0.36
PR	0.74	0.69	0.64	0.66
QQ fit	0.63x-0.01	0.71x+0.00	0.80x-0.00	0.81x-0.00

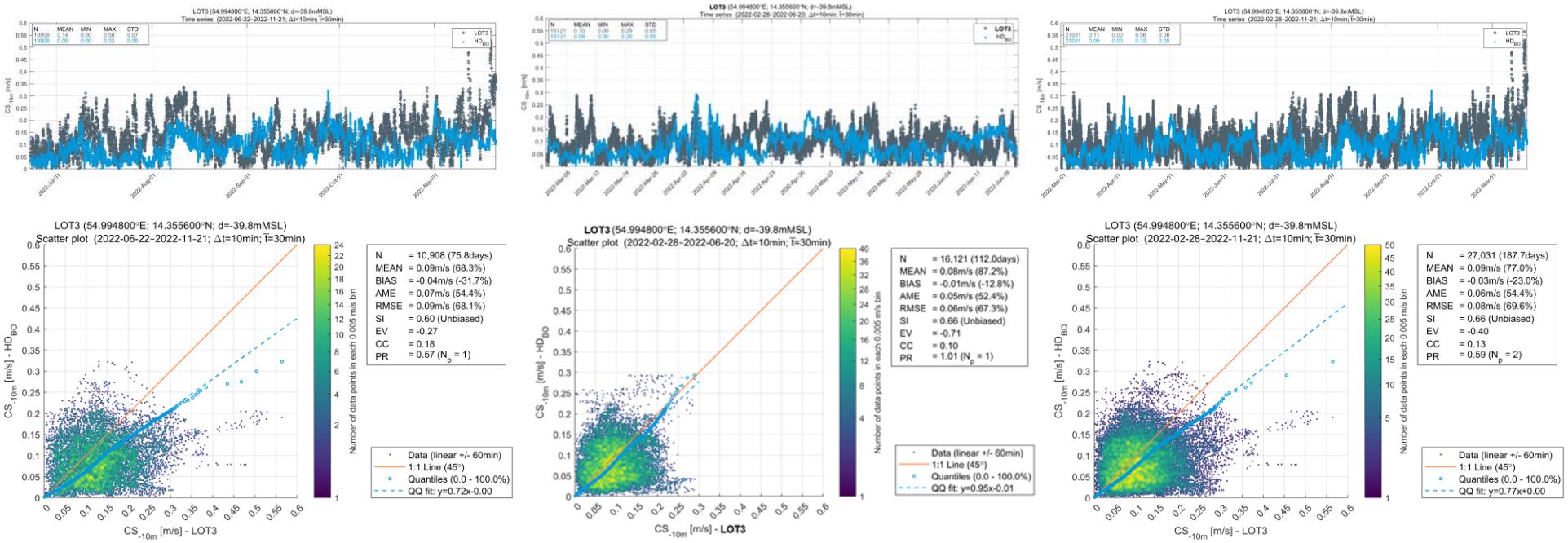

Figure 6.1 Comparison of measured and modelled current speed at LOT3, 10 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

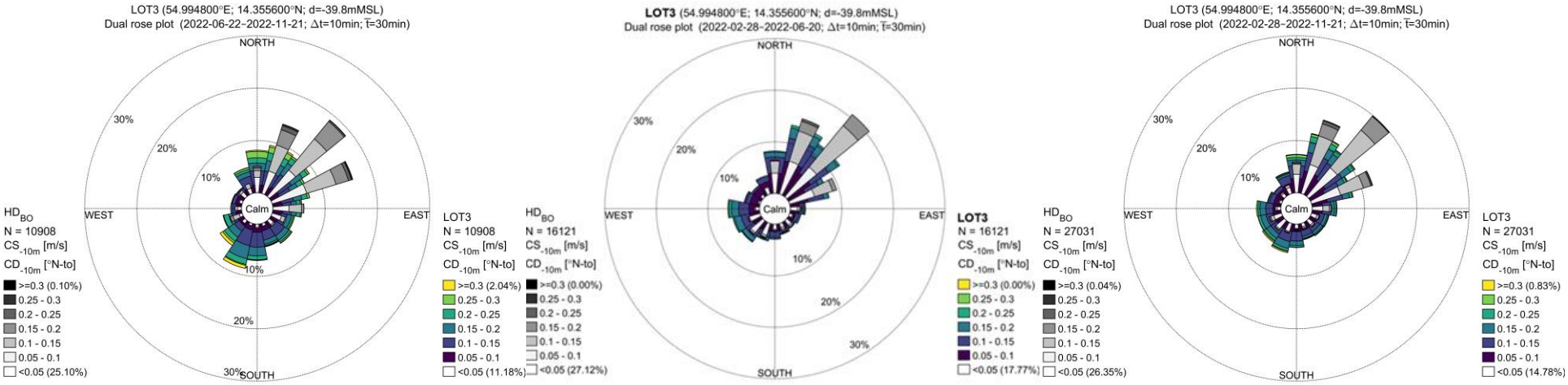

Figure 6.2 Comparison of measured and modelled current rose at LOT3, 10 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

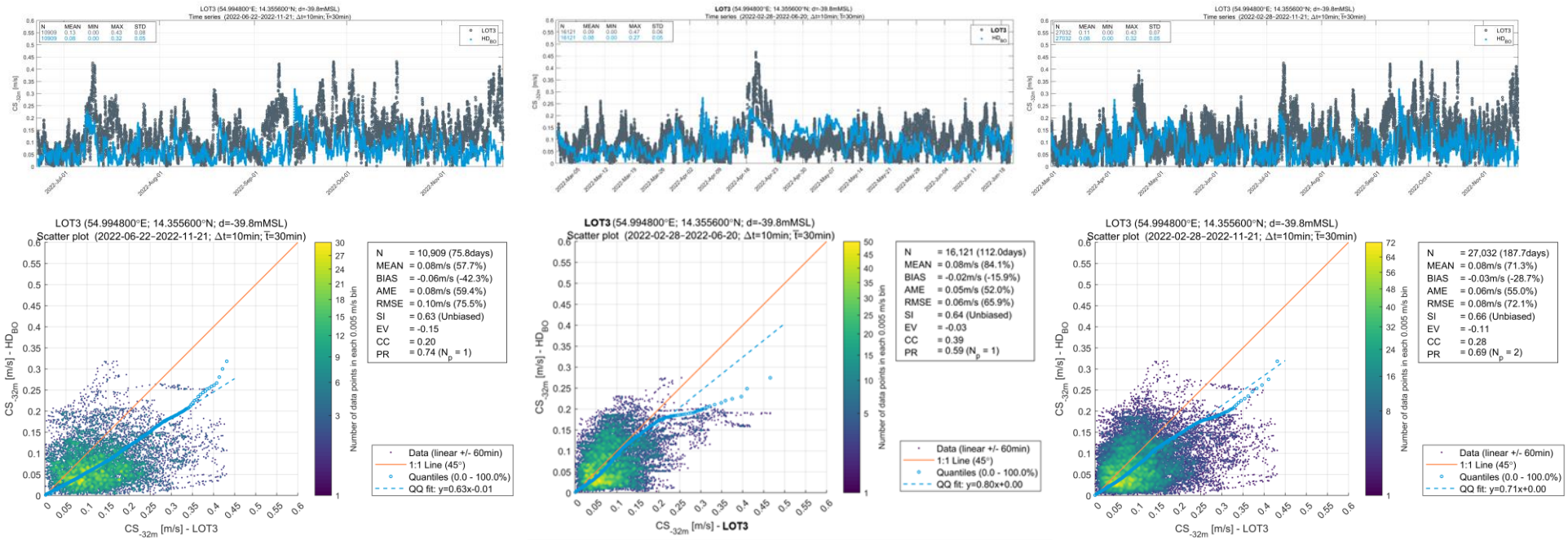

Figure 6.3 Comparison of measured and modelled current speed at LOT3, 32 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries, Bottom: Rose plots.

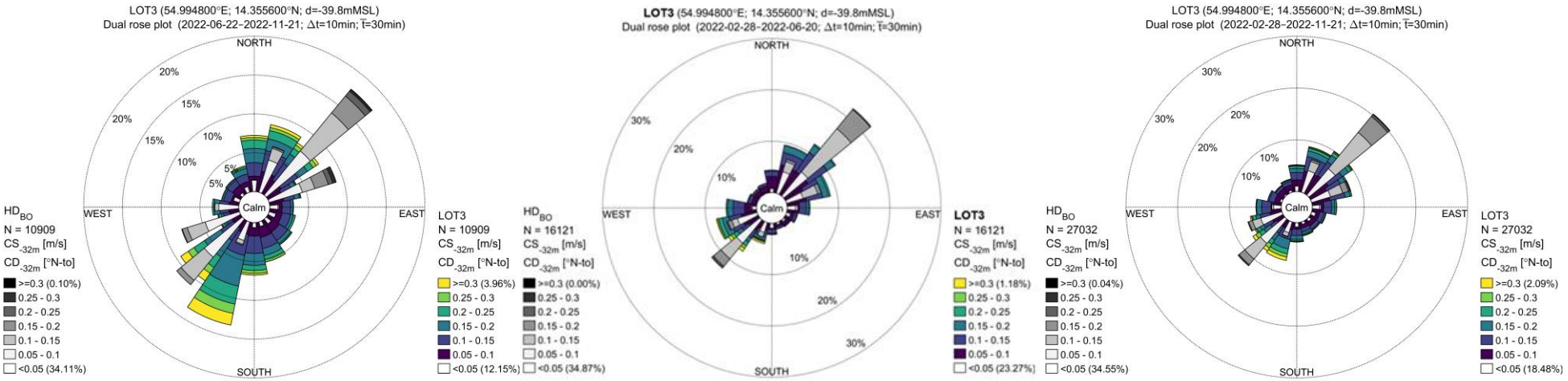

Figure 6.4 Comparison of measured and modelled current rose at LOT3, 32 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

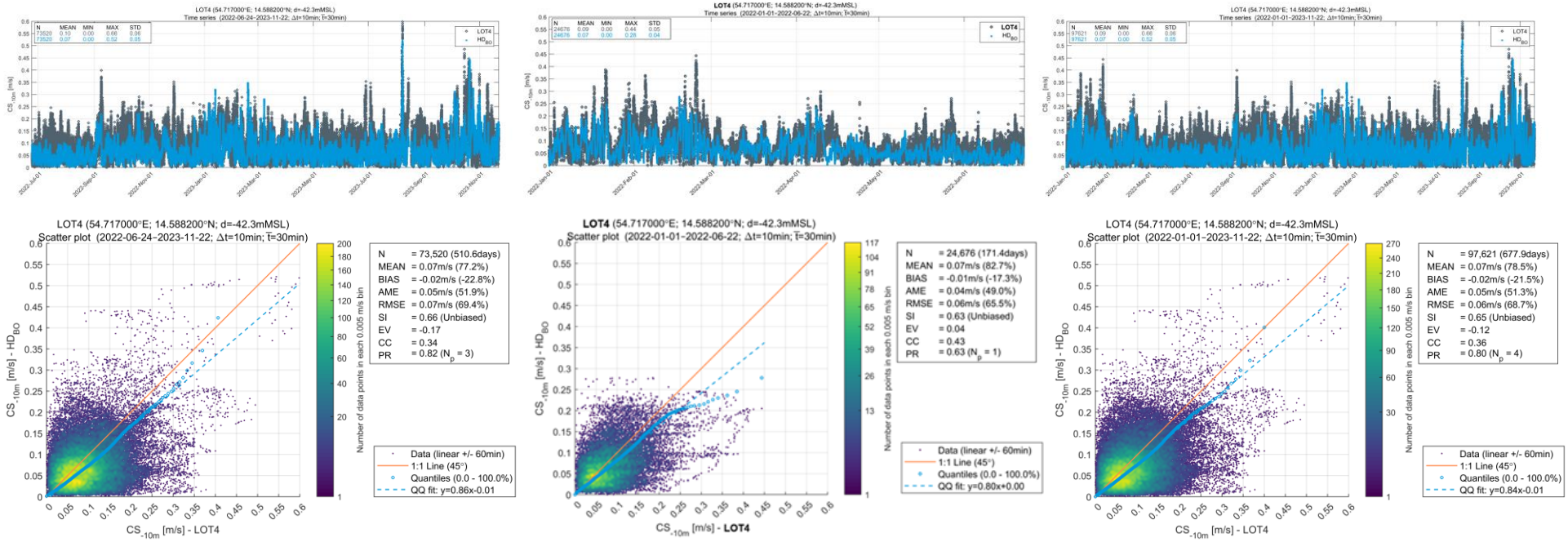

Figure 6.5 Comparison of measured and modelled current speed at LOT4, 10 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots

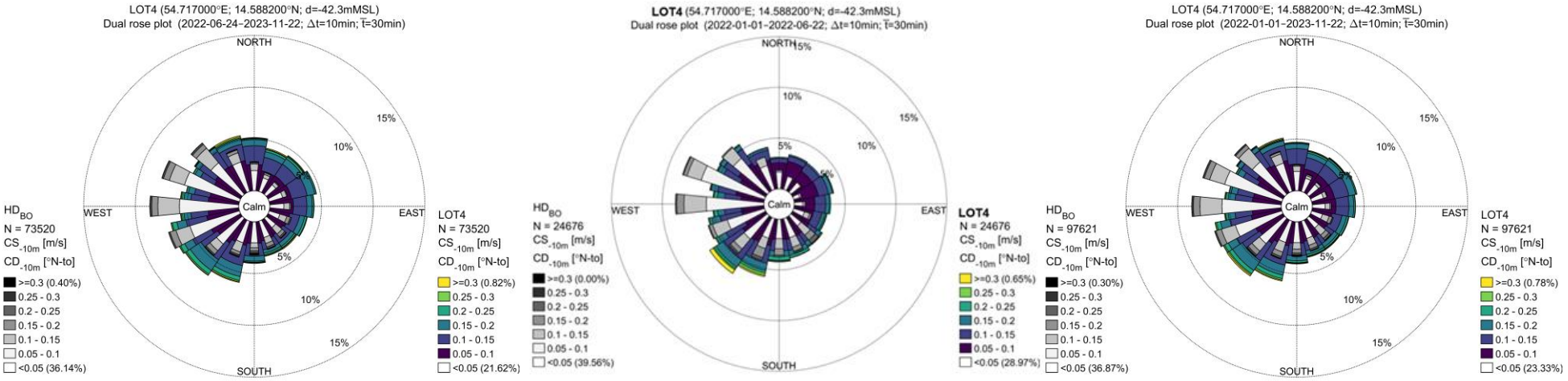

Figure 6.6 Comparison of measured and modelled current rose at LOT4, 10 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

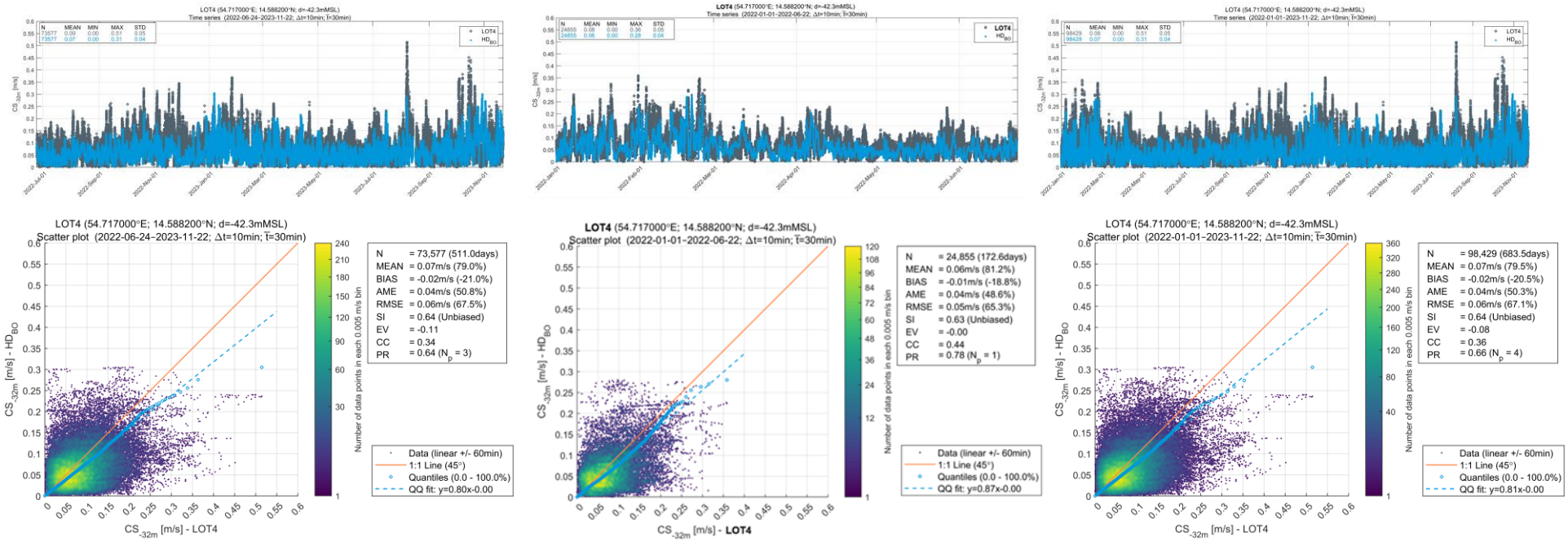

Figure 6.7 Comparison of measured and modelled current speed at LOT4, 32 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries, Bottom: Rose plots.

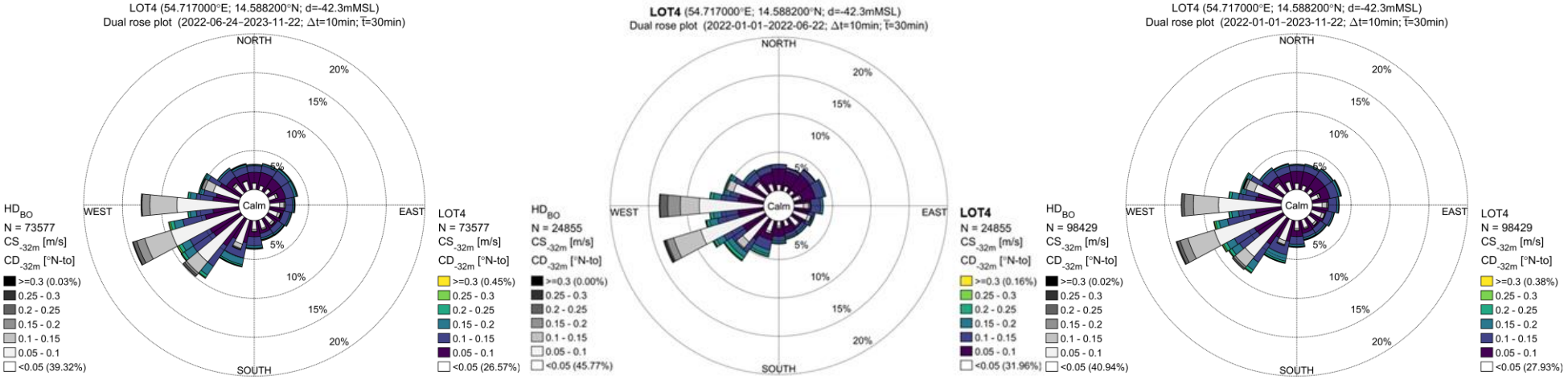

Figure 6.8 Comparison of measured and modelled current rose at LOT4, 32 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

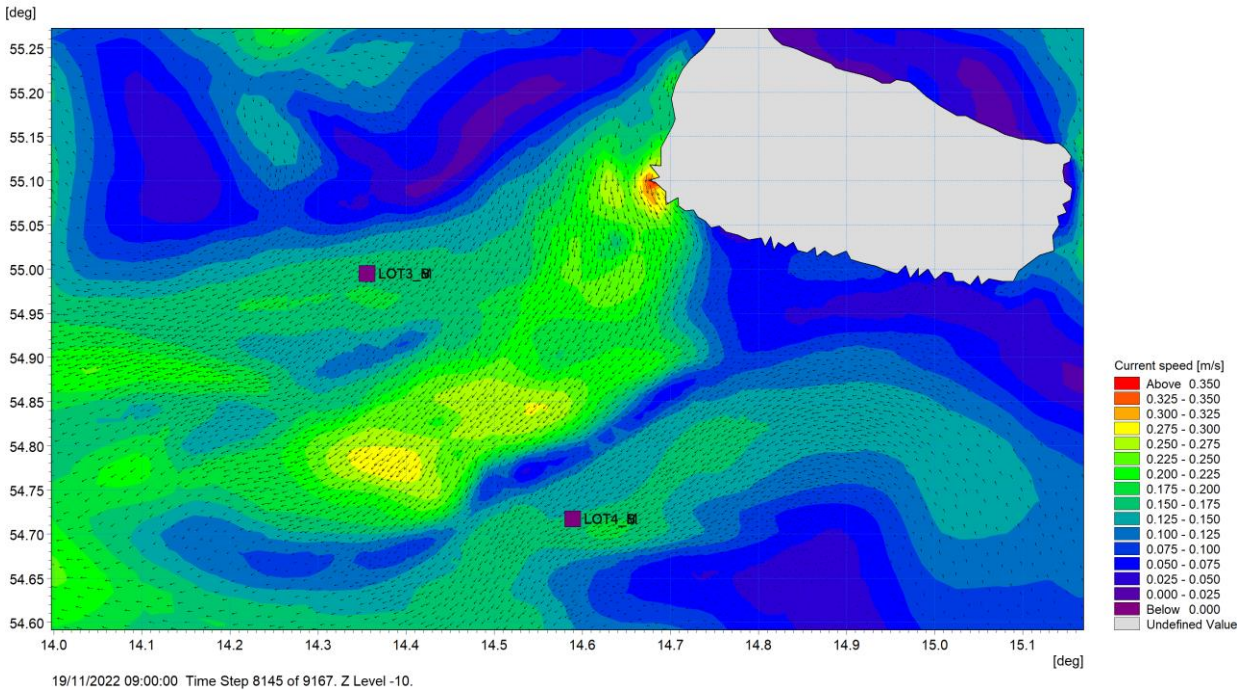

Figure 6.9 Modelled currents at -10 m depth

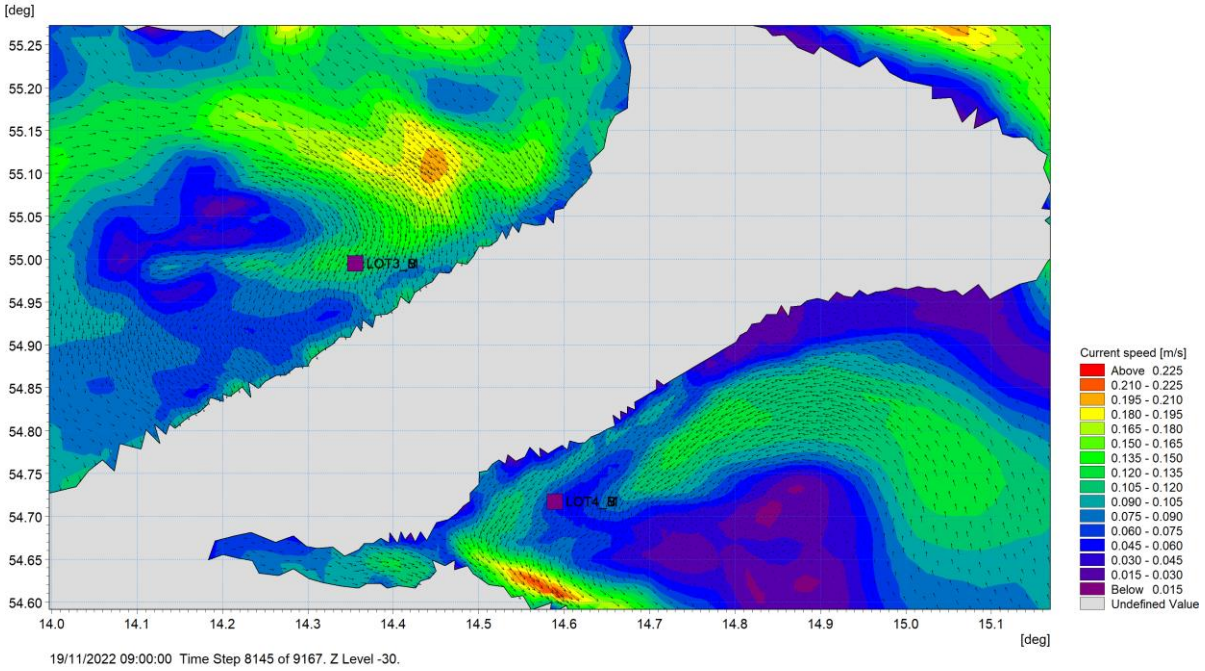

Figure 6.10 Modelled currents at -30 m depth (with Rønne Banke shown in grey)

Table 6.3 Post-calibration scaling factors for current speeds (from [2])

Depth	Factor
Surface	1.0
Mid-depth	1.25
Near-bed	1.1

7 Temperature and Salinity Revalidation

This section summarises of the modelled versus the measured temperature and salinity. Modelled temperature and salinity are based on the HD_{EIBS} model (Section 5.4 of [1]) with coverage extended to November 22, 2023 (end of measurement campaign).

Figure 7.1 compares the time series and scatter plots of near-surface temperature during the new campaign period, the old campaign period, and the full coverage of the campaign period. The temperature timeseries comparison plot at 9 m, 18 m, 25 m, and 33 m depths is presented in Figure 7.2. The salinity time series comparison plot at 25 m depth is presented in Figure 7.3.

Overall, the temperature and salinity validation during the new campaign period align with the previous validation [1]. The HD_{EIBS} model continues to demonstrate strong agreement with local measurements, indicating no further adjustments are necessary for the temperature and salinity-related sections in [1] and [2].

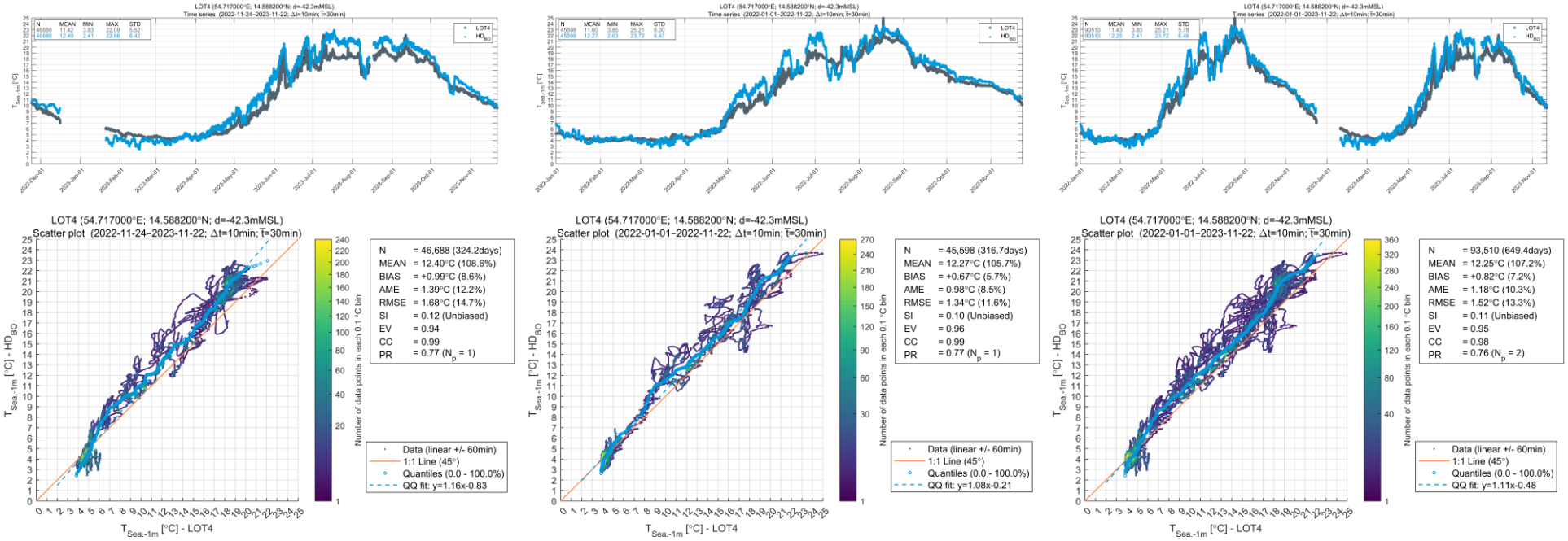

Figure 7.1 Comparison of measured and modelled water temperature at LOT4, surface

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. Top: Timeseries plots, Bottom: Scatter plots.

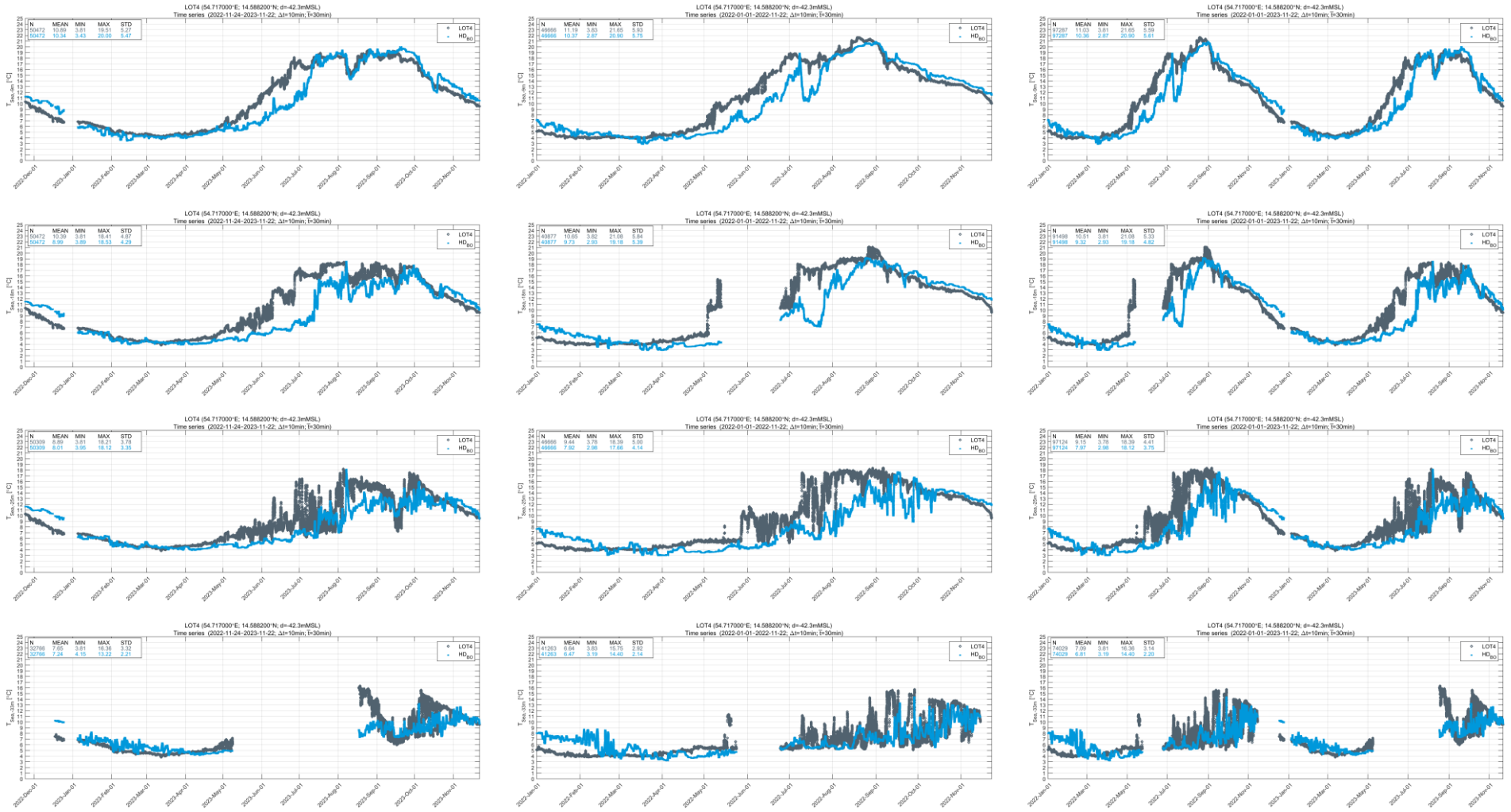

Figure 7.2 Comparison of measured and modelled water temperature at LOT4

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”. From top is shown 9 m, 18 m, 25 m and 33 m.

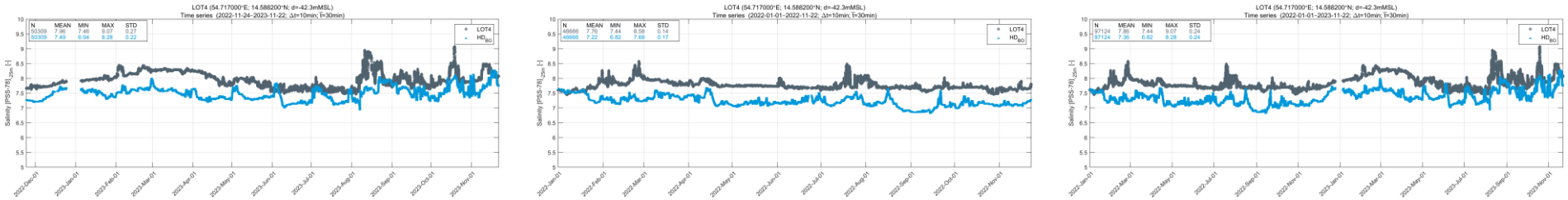

Figure 7.3 Comparison of measured and modelled salinity at LOT4, 25 m depth

Left: “New measurements”, Middle: “Measurements from data report [1]” and, Right: “Measurements from data report [1] and new measurements”.

8 References

[1] DHI, “Energy Island Baltic Sea, Metocean Site Conditions Assessment, Part A: Description and VerificatIon of Data Basis,” 2024.

[2] DHI, “Energy Island Baltic Sea, Metocean Site Conditions Assessment, Part B: Data Analysis,” 2024.

[3] UL Solutions, “Evaluation Report Site Conditions - Metocean Conditions Part A (Report No. R14772968-0-2, Rev. 0, 2024-03-19),” 2024.

[4] UL Solutions, “Evaluation Report Site Conditions - Metocean Conditions Part B (Report No. R14772968-0-3, Rev. 0, 2024-03-19),” 2024.

[5] UL Solutions, “Evaluation Report Site Conditions - Measurement Campaign for Wind and Metocean Conditions (Report No. R14772968-0-5, Rev. 1, 2024-03-19),” 2024.

[6] DNV, “DNV-RP-C205 Environmental conditions and environmental loads,” DNV AS, 2021.

[7] IEC, “61400-3-1, Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines,” 2019.