Environmental Impact Assessment Report

NISA
North Irish Sea Array

Volume 9: Appendices (Offshore)

Appendix 10.2
Marine Physical Processes Numerical Modelling

Statkraft CIP Copenhagen Infrastructure Partners GoBe APEM Group ARUP

North Irish Sea Array (NISA) Offshore Wind Farm

Appendix 10.2:

Marine Physical Processes Numerical Modelling

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Commercial in Confidence

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Disclaimer

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1 Definitions

1.1 Units and Conventions

The following list describes the units and conventions used in this report. Units have been expressed using the International System of Units (SI) convention.

- Wave direction is expressed in compass points or degrees, relative to true North [°T], and describes the direction **from** which the waves are propagating.
- Wave heights are expressed in metres [m].
- Wave periods are expressed in seconds [s].
- Current direction is expressed in compass points or degrees, relative to true North [°T], and describes the direction **towards** which the currents are flowing.
- Current speeds are expressed in metres per second [m/s].
- Water levels are expressed in metres [m].
- All times are quoted in Coordinated Universal Time [UTC].

1.2 Glossary of commonly used terms

The following list describes common metocean terms used throughout this report.

Waves	Description
Hm0	Significant wave height. Approximately the average height of the highest one third of the waves in a defined period, estimated from the wave spectrum as $4\sqrt{m_0}$.
m_0, m_1, m_2	The zeroth, first and second moments of the wave spectrum respectively.
Tp	The spectral peak wave period. The wave period at which most energy is present in the wave spectrum.
Tm02	The mean zero-crossing wave period. Estimated from the wave spectrum as $\sqrt{m_0/m_2}$.
DWR	Datawell Directional Wave Rider buoy. Equipment for measuring offshore wave conditions.
AWAC	Nortek equipment for measuring waves and currents using acoustic means (Acoustic Waves And Currents)
Levels	**Description**
LAT	Lowest Astronomical Tide. Minimum level of sea surface due to tidal forcing alone.
MSL	Mean Sea Level. Mean sea surface elevation over a prolonged period of time.
Currents	**Description**
Current speed	Magnitude of local current flow.
Offshore Construction	**Description**
TSHD	Trailing suction hopper dredger. Self-propelled vessel able to vacuum sediments from the seafloor to a hopper in the hull, for subsequent discharge elsewhere.
ECC	Offshore Export Cable Corridor.
WTG	Wind Turbine Generator.
OSP	Offshore Substation Platform.
HDD	Horizontal Directional Drilling. Method of installing underground cables using a drill.

2 Introduction

2.1 Background

GoBe Consultants Ltd contracted MetOceanWorks (working in partnership with Cooper Marine Advisors) to deliver the Marine Geology, Oceanography and Physical Processes Environmental Impact Assessment Report (EIAR) Chapter, and to provide relevant marine processes modelling services, for the North Irish Sea Array (NISA) Offshore Wind Farm (hereinafter the proposed development).

At its closest, the proposed development is located 11.3 km off the coast of counties Dublin, Meath and Louth, in water depths of approximately 34 to 63 m relative to Lowest Astronomical Tide (LAT). A subsea cable will link the wind farm with the power delivery network at the adjacent coast. Figure 2.1 shows the proposed development boundary and the proposed export cable corridor (ECC). Numerical modelling has been carried out to assess the likely impact of the construction and operation of the proposed development and its associated infrastructure, on the marine environment.

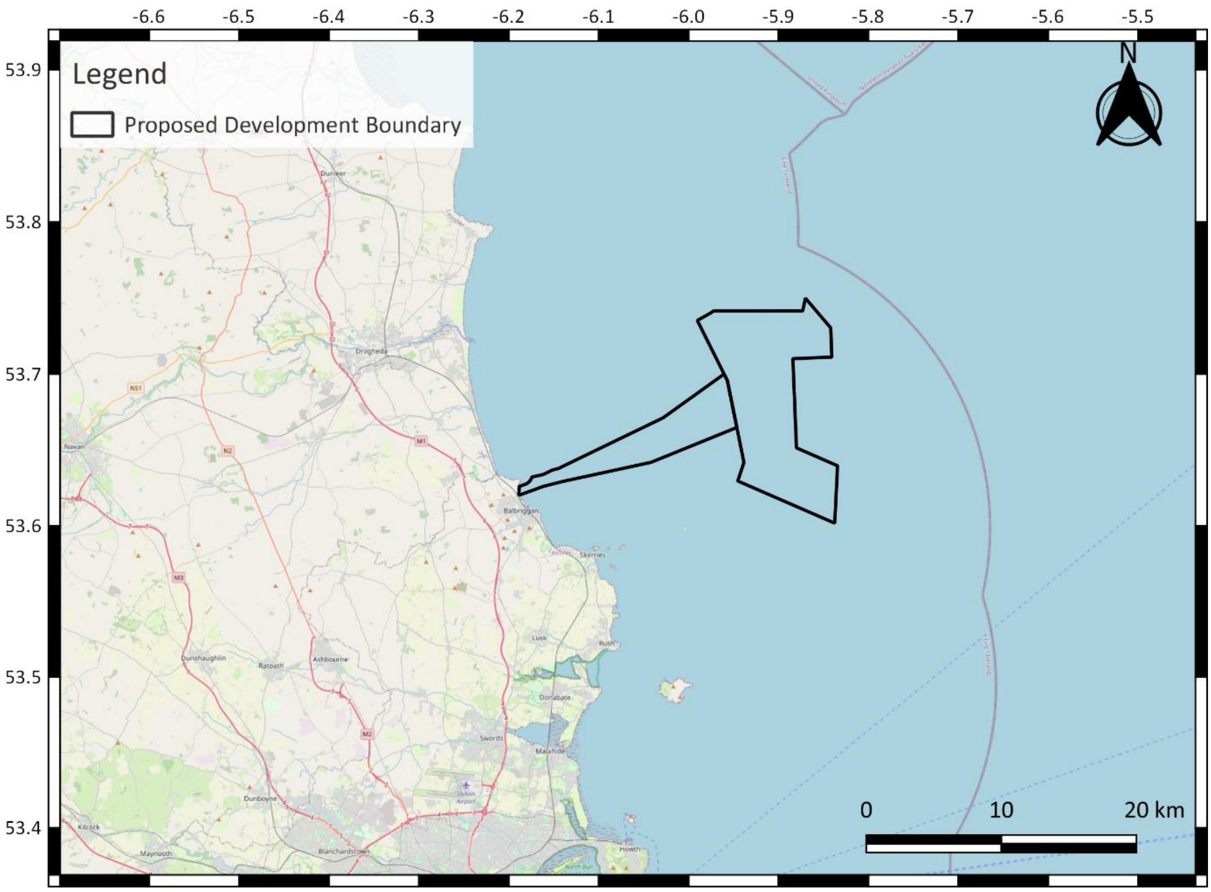


Figure 2.1: Proposed development boundary.

2.2 Report Structure

This document describes the various data sources, marine process models and analysis methods used throughout the study. This document is a companion document to Appendix 10.1 [1] and Appendix 10.3 [2].

Modelling details are discussed in Sections 3 to 6, initially introducing common model inputs (Section 3) before moving onto the models themselves. By way of introduction to the overall approach:

- **Hydrodynamics** were modelled using the MIKE21FM 2D flexible mesh modelling package. Modelled currents and water levels have been validated against measurements from several locations. See Section 4 for details. The validated hydrodynamic model was then used to drive the particle tracking module, and to simulate blockages to flows caused by the presence of the built structures.
- The **Particle Tracking** module was used to simulate the extent and fate of sediments disturbed during construction activities (Section 6).
- **Waves** were modelled with a bespoke SWAN (Simulating Waves Nearshore) model with high resolution regional nests. The model has been extensively validated against measured datasets in the region. See Section 5 for details. The model was then used to simulate blockages to waves caused by the presence of the built structures.

Thereafter, Section 7 provides a description of the results. The document concludes with a list of the references used throughout.

3 Common Modelling Inputs

3.1 Bathymetry

A representative bathymetry dataset was required as input to the wave and hydrodynamic models. This was achieved by merging four different datasets which originated from:

- European Marine Observation and Data Network (EMODnet) (regional composite);
- OceanWise (regional composite);
- SeaDataNet (individual surveys - regional); and
- The proposed development's survey data [3] for the proposed development boundary.

Far-field bathymetry data for the models were sourced from the EMODnet Bathymetry Data Portal [4]. EMODnet provides a service for viewing and downloading a harmonised Digital Terrain Model (DTM) for the European sea regions that is generated by an ever-increasing number of bathymetric survey data sets provided by national hydrographic institutions, research bodies and academia (including Geological Survey Ireland). As of 2023, these data are available at a grid resolution of approximately 130 m (and for the areas surrounding Ireland, represent a reduced-resolution version of the data procured from SeaDataNet (described below).

These data were then augmented with OceanWise raster charts supplied by MarineFIND and which have a resolution of 1 arc-second (or approximately 25 m, depending on latitude), whereby physical features such as trenches, ridges, sand banks and sand waves are well-represented. Figure 3.1 shows the available coverage of OceanWise data with the tiles procured highlighted in green.

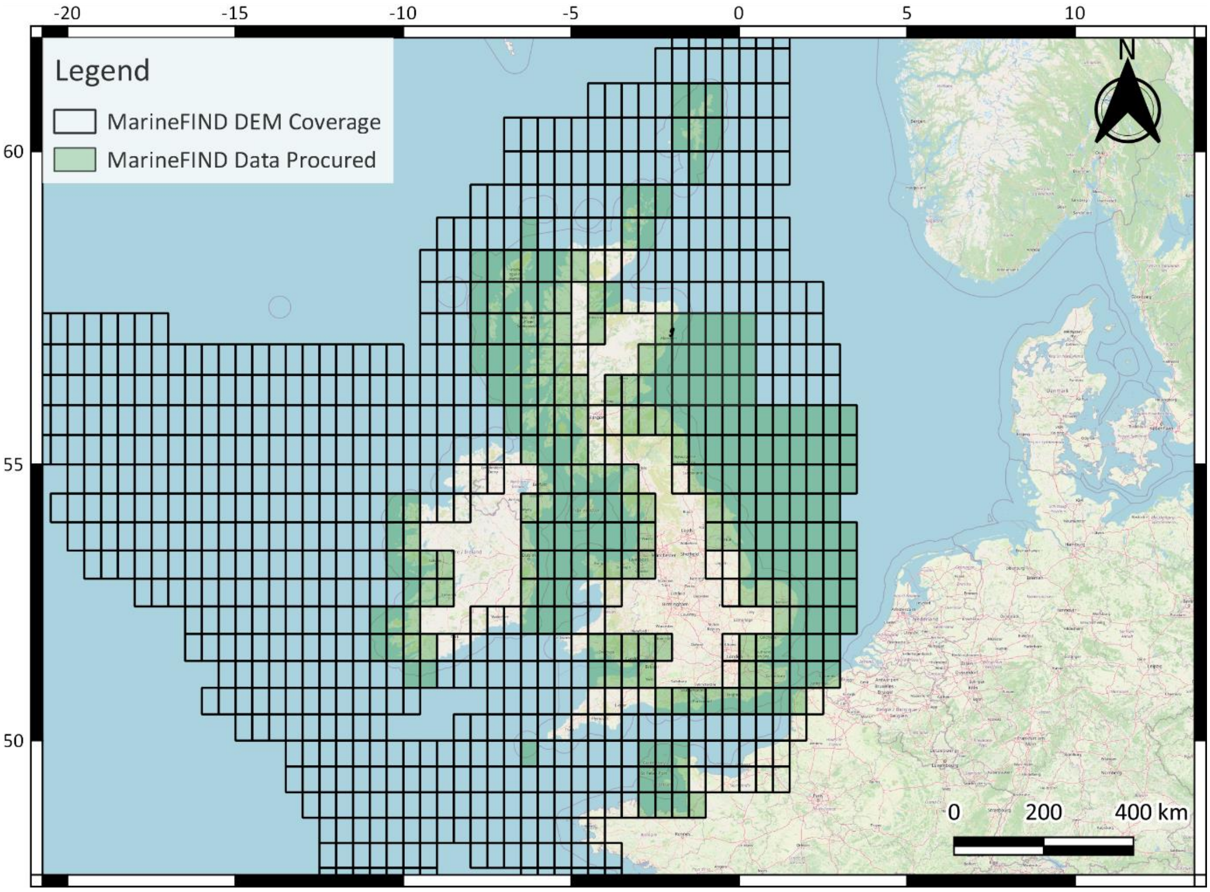


Figure 3.1: Coverage of OceanWise data, and DTM tiles procured shown in green.

To provide the highest possible resolution input data for the Western Irish Sea, individual survey datasets were procured from SeaDataNet. The merged survey datasets in the region of the project are shown in Figure 3.2 and have various resolutions between approximately 4 and 11 m. Overlapping or duplicated datasets were removed, leaving 24 individual survey datasets which were merged, and any small gaps were filled using interpolation.

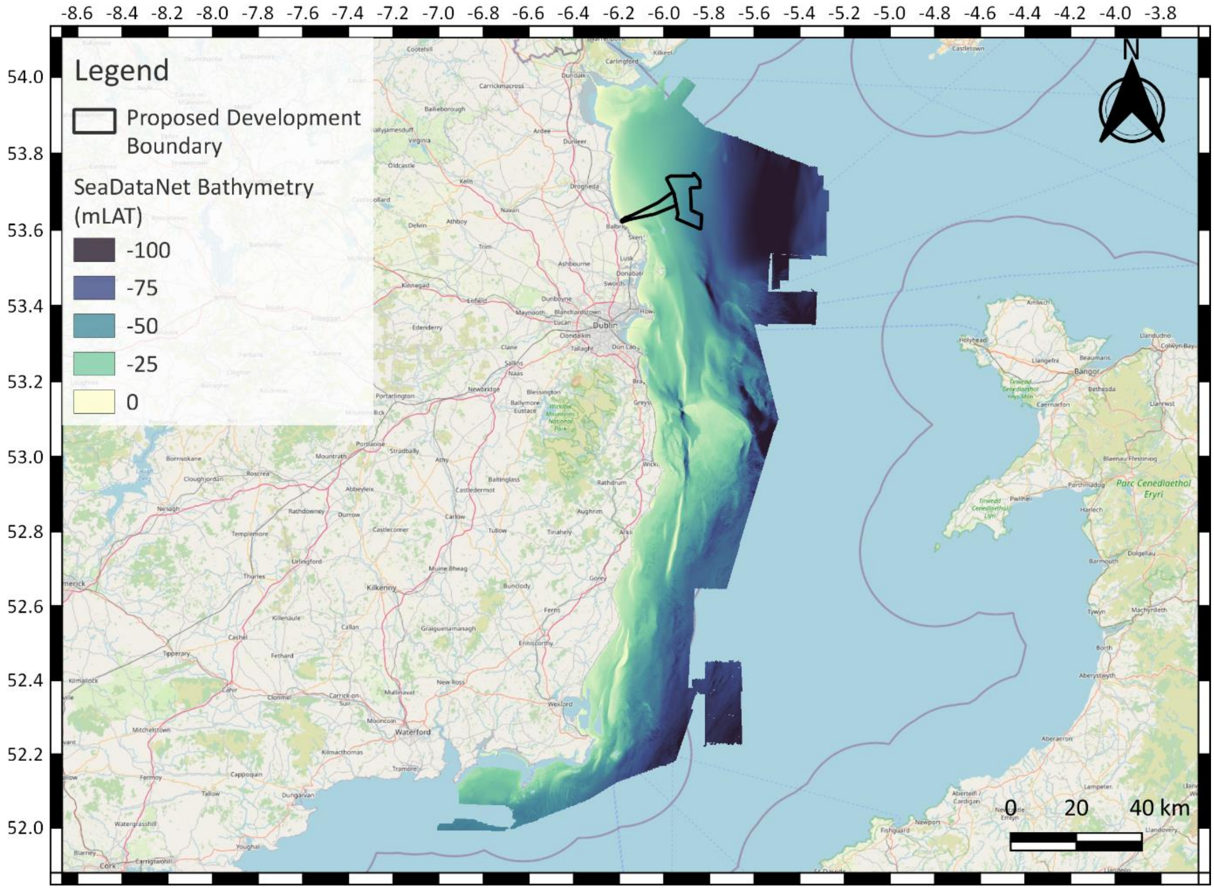


Figure 3.2: Coverage of SeaDataNet survey bathymetry.

These individual surveys were merged (as shown in Figure 3.2), before merging with the bathymetry supplied by the proposed development[3]. Data from two survey campaigns were provided, covering the array area [3] and the ECC [5]. After merging, the total coverage of both NISA supplied surveys is shown in Figure 3.3.

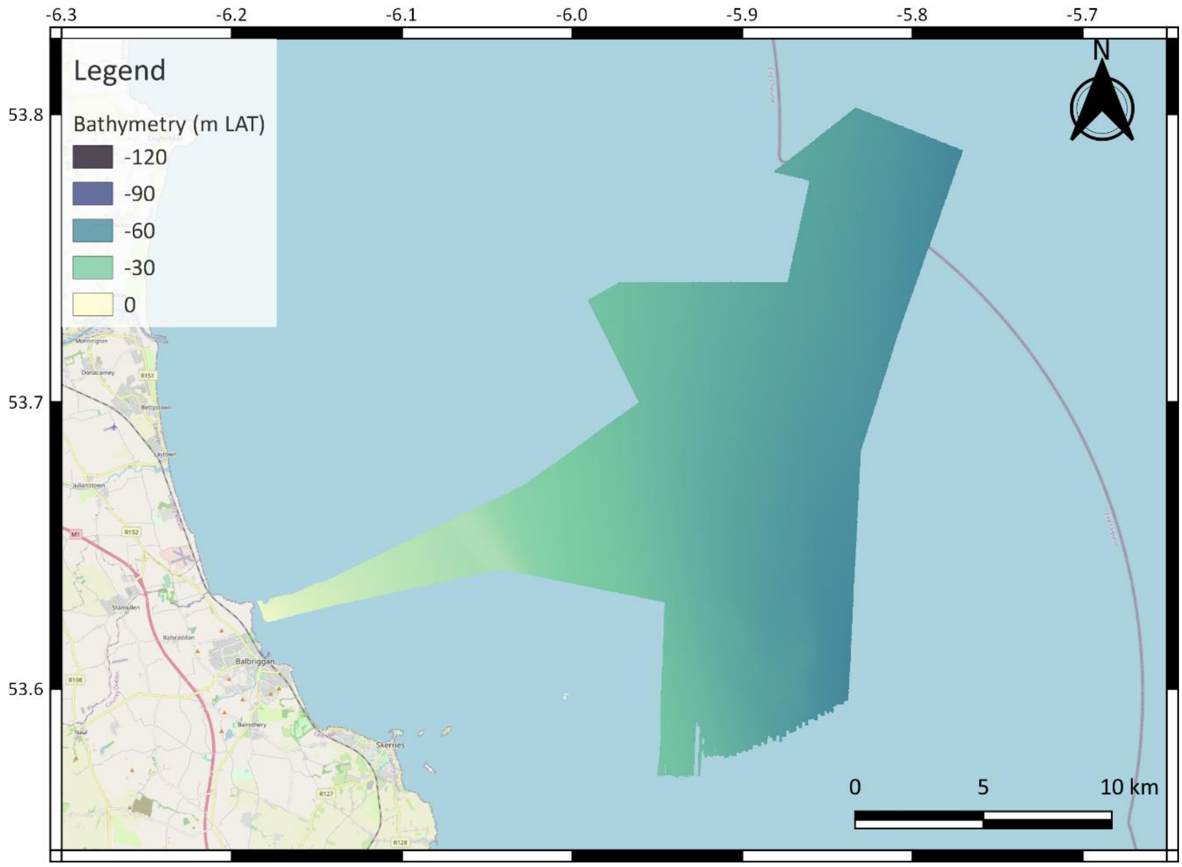


Figure 3.3: Coverage of NISA's supplied site-specific survey bathymetry.

Finally, the bathymetry data were converted from LAT to MSL datum prior to use, as required by both the SWAN and MIKE21 modelling software. These datum differences were calculated from the Finite Element Solution FES2014 dataset, a 35-constituent, global tidal database available from AVISO [6].

3.2 Coastline

The coastlines of England, Scotland and Wales were discretised using the Boundary-Line™ mean high water mark vector product, from the Ordnance Survey, which describes the position of Mean High-Water Springs. For continental Europe, the island of Ireland, and the Isle of Man, the coastline layer from OpenStreetMap was used. These data were used in conjunction with satellite imagery to provide the most accurate and appropriate coastline description for the models. Furthermore, for Ireland, they were found to have a better scaled representation of coastal features than equivalent data available from the Ordnance Survey Ireland.

3.3 Wind

European Centre for Medium-Range Weather Forecasts (ECMWF) ReAnalysis 5 (ERA5) wind data was used to drive the hydrodynamic and wave models. ERA5 is the fifth and latest major global reanalysis produced by ECMWF. Hourly wind speeds are available for the period 1979 to near-present at various levels (including at 10 m above sea level, as used to drive the wave and hydrodynamic models) are available on a 0.25° by 0.25° resolution grid via the Copernicus Climate Change Service (C3S) Climate Data Store (CDS). Prior to use, the raw ERA5 data is calibrated using a bespoke adjustment developed by MetOceanWorks which improves performance in driving models.

4 Hydrodynamics

Current and water level parameters were produced using a European, basin-scale flexible mesh hydrodynamic model. Depth-averaged currents and water levels were produced to drive the particle tracking model (described in Section 6), and to predict the blocking effect of the built structures.

Prior to use in the assessments, the performance of the model in representing currents and water levels was ascertained by comparison against several measured data sources. These are described in Section 4.1.

4.1 Measured Hydrodynamic Data

To support calibration and validation of the hydrodynamic model, measured data were acquired from the British Oceanographic Data Centre (BODC) UK National Tide Gauge Network, the Office of Public Works, Ireland (OPW), and the Marine Institute (Ireland), as well as those provided by the proposed development from the metocean survey (Site A and B). An overview of the measured datasets can be found in Table 4.1 and Figure 4.1.

Table 4.1: Measured datasets considered for hydrodynamic model validation.

Dataset	Parameter	Supplier	Location	Time Period	* Water Depth [mLAT]
Port Oriel	Water Levels	OPW	53.7990°N, 6.2217°W	17-Apr-2007 to near-present	Coastal
Howth	Water Levels	Marine Institute Ireland	53.3915°N, 6.0683°W	13-Feb-2007 to 26-Nov-2019	Coastal
Port Erin	Water Levels	BODC	54.0854°N, 4.7681°W	1-Jan-1998 to near-present	Coastal
Site A	Water Levels and Currents	NISA	53.7441°N, 5.8064°W	26-Apr-2022 to 30-Jun-2022	61
Site B	Water Levels and Currents	NISA	53.5945°N, 5.9115°W	21-Jan-2022 to 03-Oct-2022	45

* The term "*Coastal*" is used to denote an instrument mounted to a harbour wall or pier.

Sites A and B lie outside of the present the proposed development boundary, but were inside the original Maritime Area Consent (MAC) boundary at the time of the survey design.

The measurements were carefully reviewed prior to use and in general required no additional quality control beyond that which was undertaken by the originator. Current profiles were reduced to equivalent depth-average values by averaging the horizontal velocity components that occurred between 30% and 50% of the height above bed. This is in-line with the theoretical power law whereby depth-average currents occur at approximately 40% of the height above bed. With regards to water level data quality, the highest confidence can be placed in measurements from the maintained coastal tide gauges, owing to their fixed-position nature and levelling to a vertical datum.

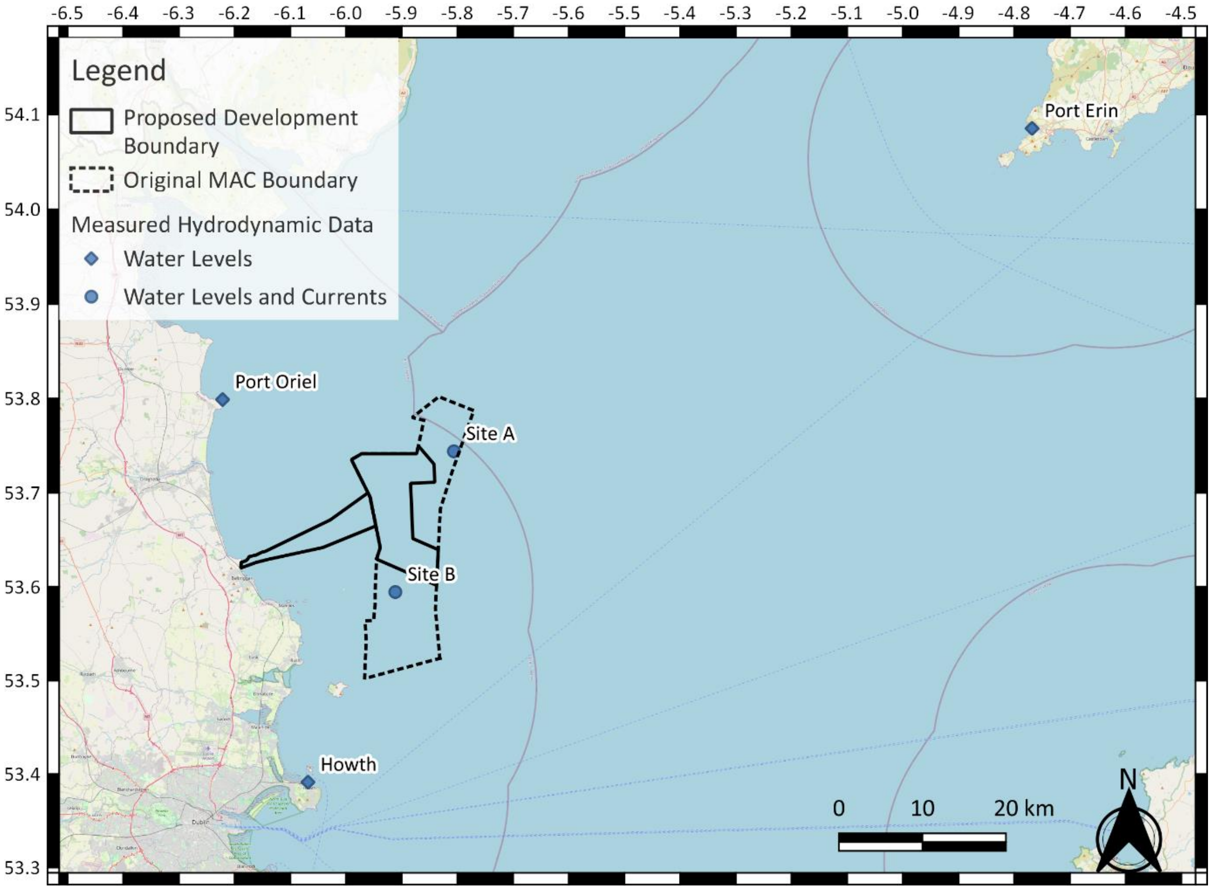


Figure 4.1: Measured datasets considered for hydrodynamic model validation.

4.2 Modelling Software

The hydrodynamic model has been developed using the MIKE21FM (Flexible Mesh) 2D modelling package [7] [8], a comprehensive modelling system for two-dimensional water modelling developed by DHI.

4.3 Model Boundary Conditions and Spatial Extent

Tidal boundary conditions to the European model originate from the Finite Element Solution FES2014 dataset. This 35 tidal constituent global data-set has been produced using numerical modelling which assimilates satellite observations of water level and has, in our opinion, the best skill of any publicly-available global tide model. The dataset includes tide elevations (amplitude and phase) and tide currents on a 0.0625-degree grid (approximately 7.0 km in latitude and 3.8 km in longitude in the region of interest). The model was driven using water levels varying along three open boundaries, as shown in the top left panel of Figure 4.2.

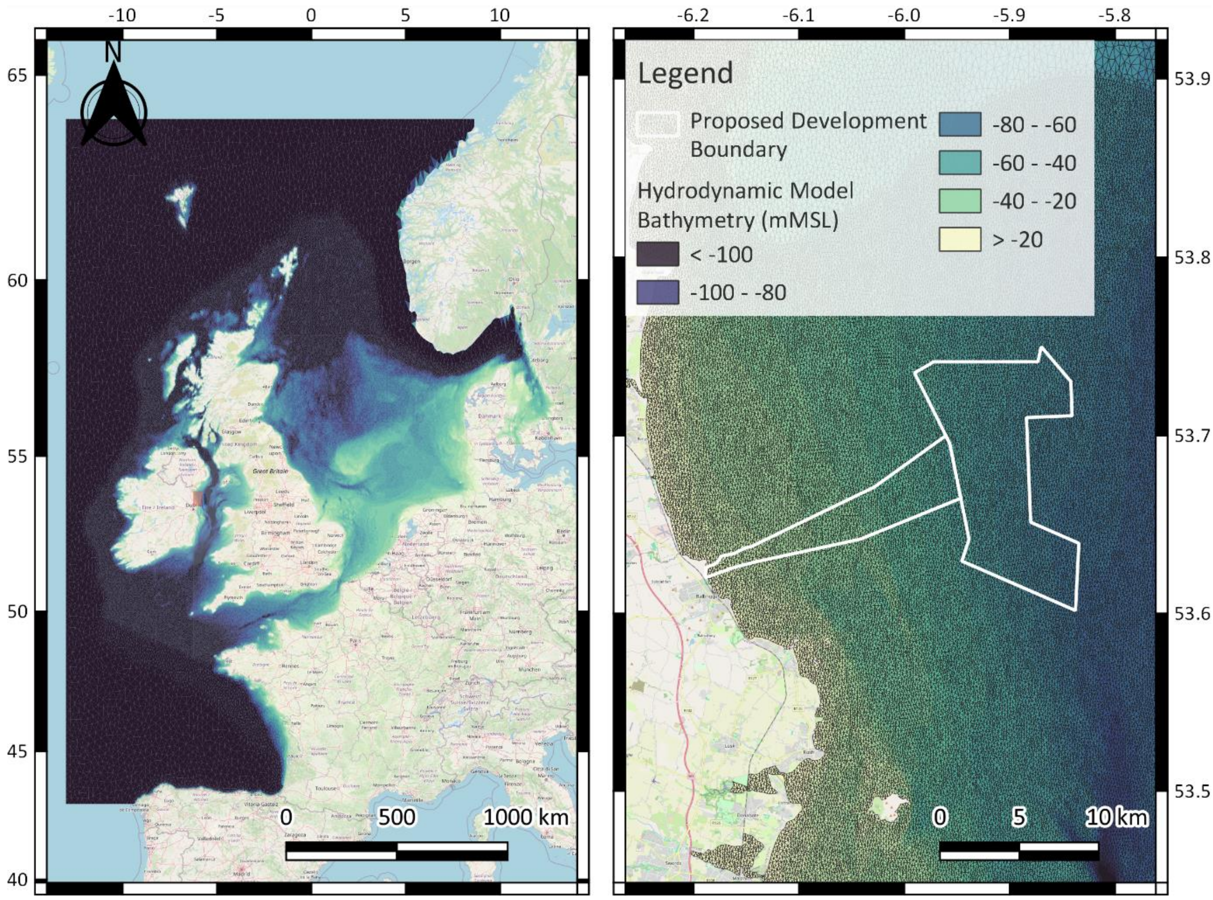


Figure 4.2 European MIKE21 flexible model mesh. Bathymetry in m MSL.

The model had a spatial resolution of 150 m within a 11 km buffer of the proposed development boundary and ECC. Outside of this area, within the 20 m contour, a resolution of 150 m was also used, and then a resolution of 250 m was used within the 40 m contour, followed by a 375 m resolution within the 70 m contour. A 1 km resolution is used in the remainder of the Irish Sea.

Atmospheric forcing for the hydrodynamic model originated from the ECMWF ERA5 dataset and was applied to ensure that atmospheric surge effects were properly represented in the model. This comprised of MetOceanWorks-adjusted wind speeds, unadjusted wind directions, and unadjusted pressure fields.

4.4 Model Validation

Predicted water levels are compared against water level measurements in Figure 4.3 to Figure 4.7 to demonstrate model performance. With low mean error, a correlation coefficient close to unity and a low scatter index, this comparison demonstrates excellent model skill in representing the equivalent measured values.

Current speed validation plots and time series plots are presented in Figure 4.8 to Figure 4.13. These statistical and time series comparisons of modelled and measured depth-averaged current speeds and directions demonstrate good overall model performance.

From	01-Jan-2018
To	25-Sep-2019
Mean (X)	0.00
Mean (Y)	0.00
N	86221
Bias	0.00
AME	0.07
RMS	0.08
SI	0.03
CC	1.00
R^2	1.00

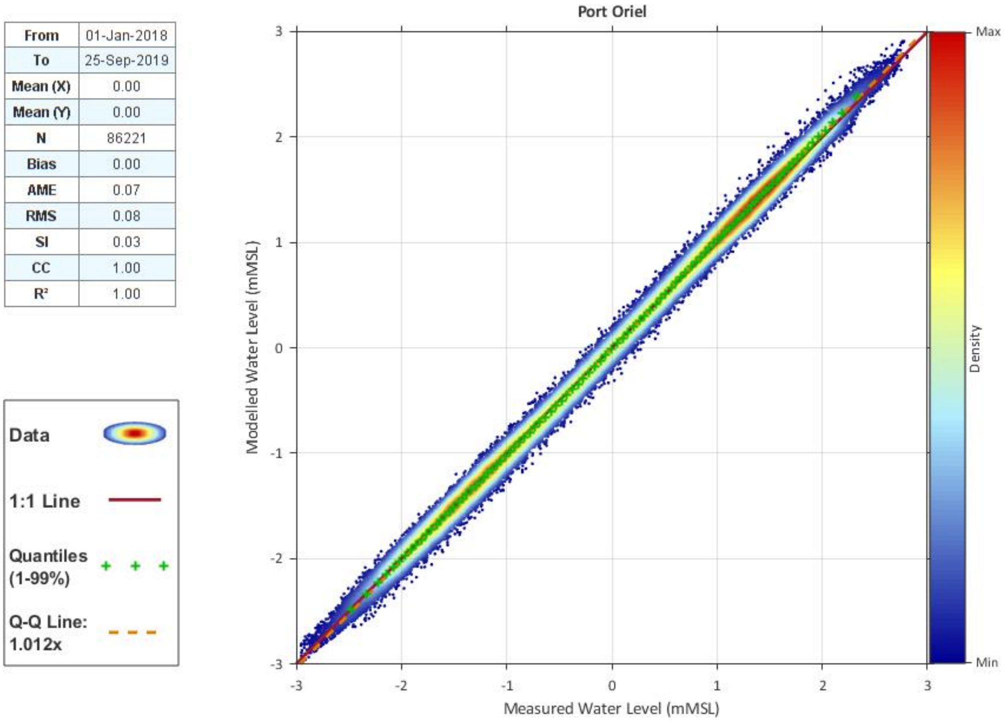


Figure 4.3: Comparison of measured and modelled water levels at Port Oriel.

From	01-Jan-2018
To	26-Nov-2019
Mean (X)	-0.00
Mean (Y)	-0.00
N	83724
Bias	-0.00
AME	0.07
RMS	0.09
SI	0.04
CC	1.00
R^2	0.99

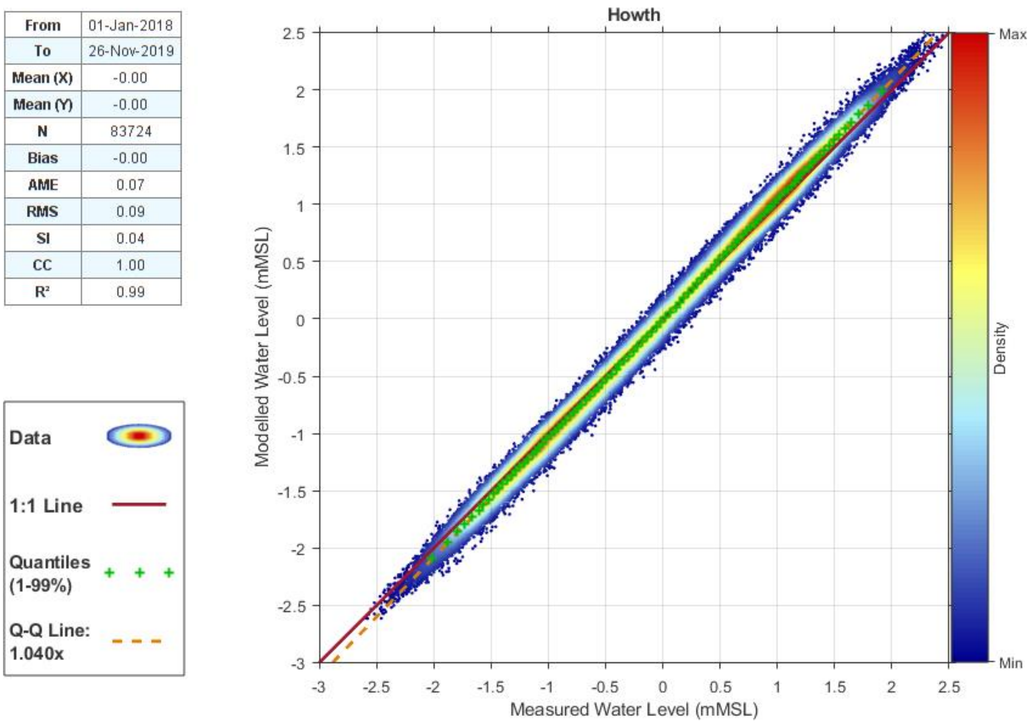


Figure 4.4: Comparison of measured and modelled water levels at Howth.

From	01-Jan-2013
To	31-Dec-2013
Mean (X)	-0.00
Mean (Y)	-0.00
N	17509
Bias	-0.00
AME	0.08
RMS	0.11
SI	0.03
CC	1.00
R^2	1.00

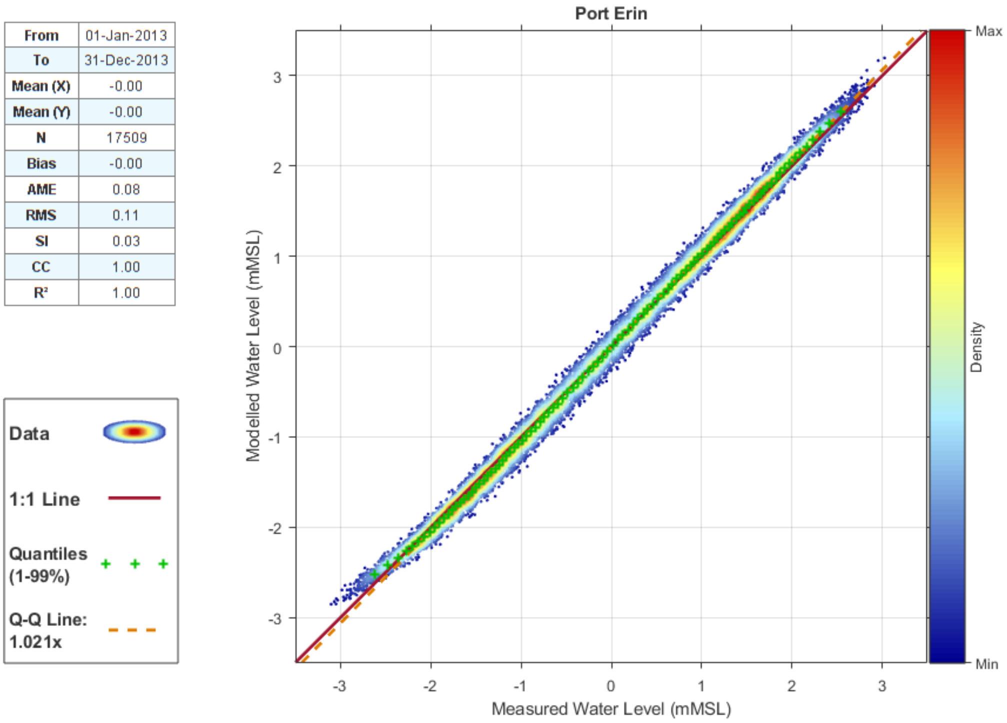


Figure 4.5: Comparison of measured and modelled water levels at Port Erin.

From	26-Apr-2022
To	30-Jun-2022
Mean (X)	0.00
Mean (Y)	-0.00
N	9358
Bias	-0.00
AME	0.07
RMS	0.08
SI	0.03
CC	1.00
R^2	1.00

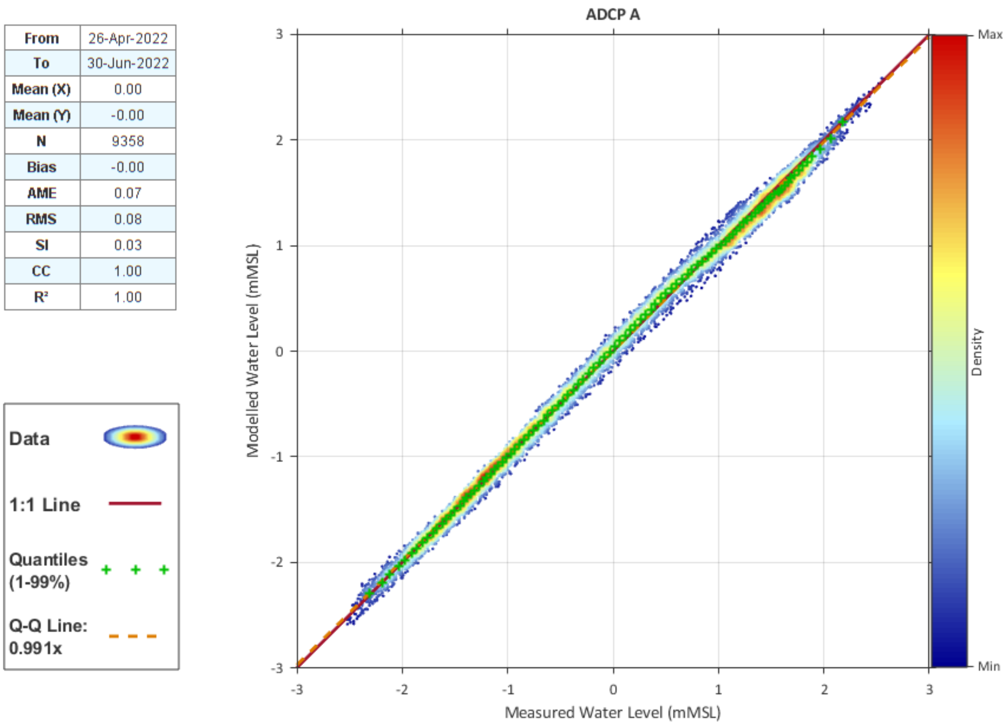
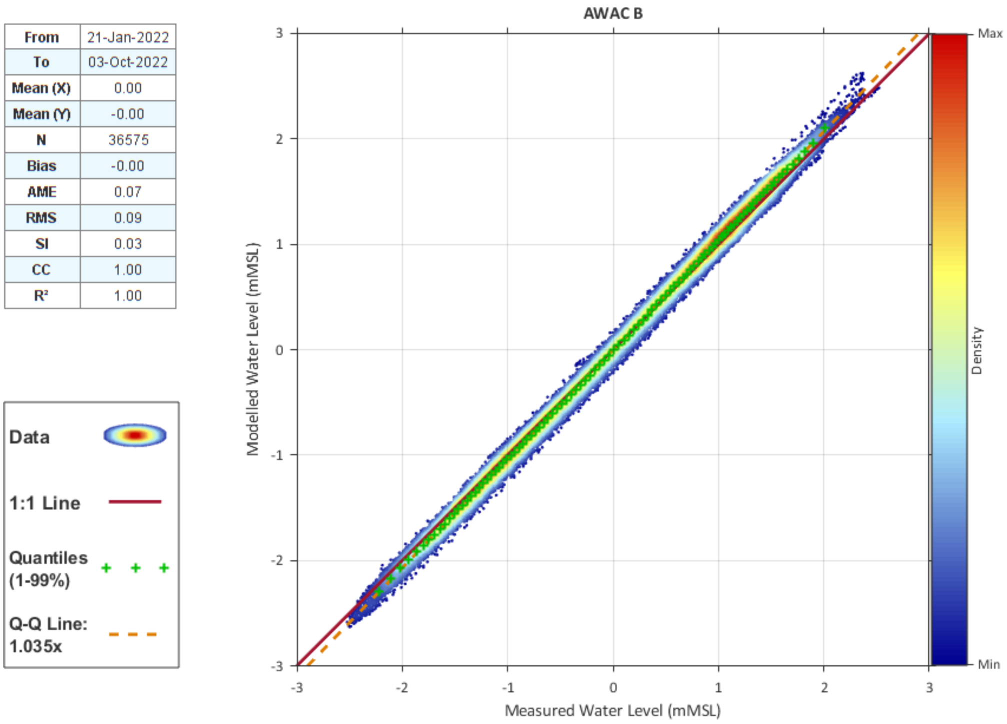


Figure 4.6: Comparison of measured and modelled water levels at Site A.



From	21-Jan-2022
To	03-Oct-2022
Mean (X)	0.00
Mean (Y)	-0.00
N	36575
Bias	-0.00
AME	0.07
RMS	0.09
SI	0.03
CC	1.00
R^2	1.00

Figure 4.7: Comparison of measured and modelled water levels at Site B.

From	26-Apr-2022
To	30-Jun-2022
Mean (X)	0.21
Mean (Y)	0.22
N	9358
Bias	0.00
AME	0.04
RMS	0.04
SI	0.21
CC	0.92
R^2	0.84

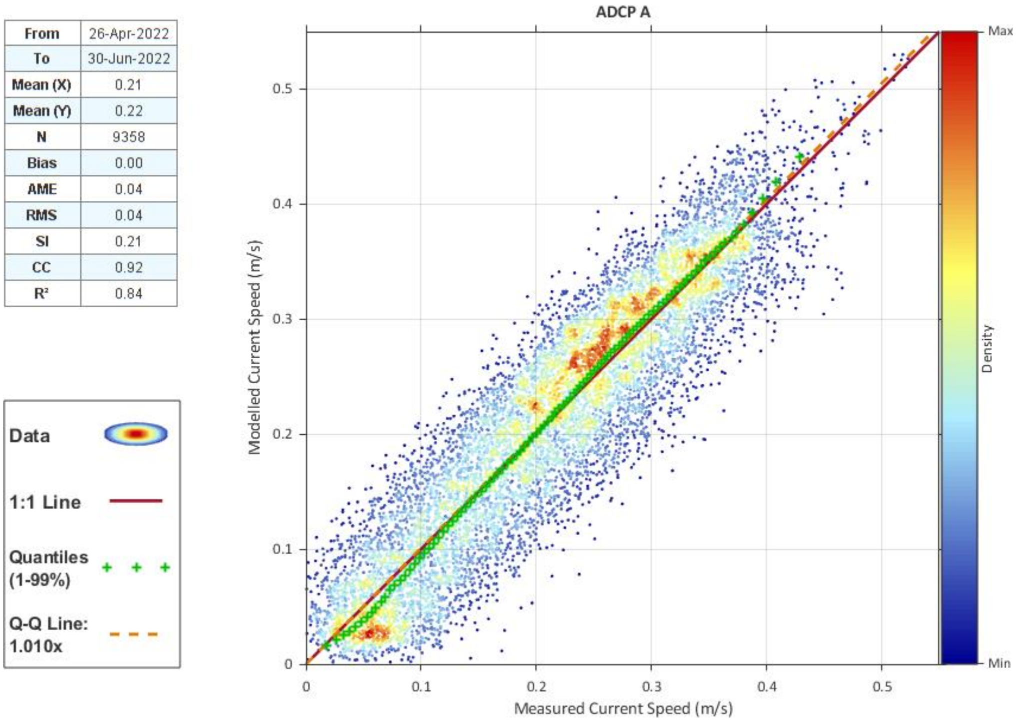


Figure 4.8: Comparison of measured and modelled depth-average currents, Site A.

From	21-Jan-2022
To	03-Oct-2022
Mean (X)	0.29
Mean (Y)	0.30
N	36575
Bias	0.01
AME	0.05
RMS	0.06
SI	0.20
CC	0.93
R^2	0.87

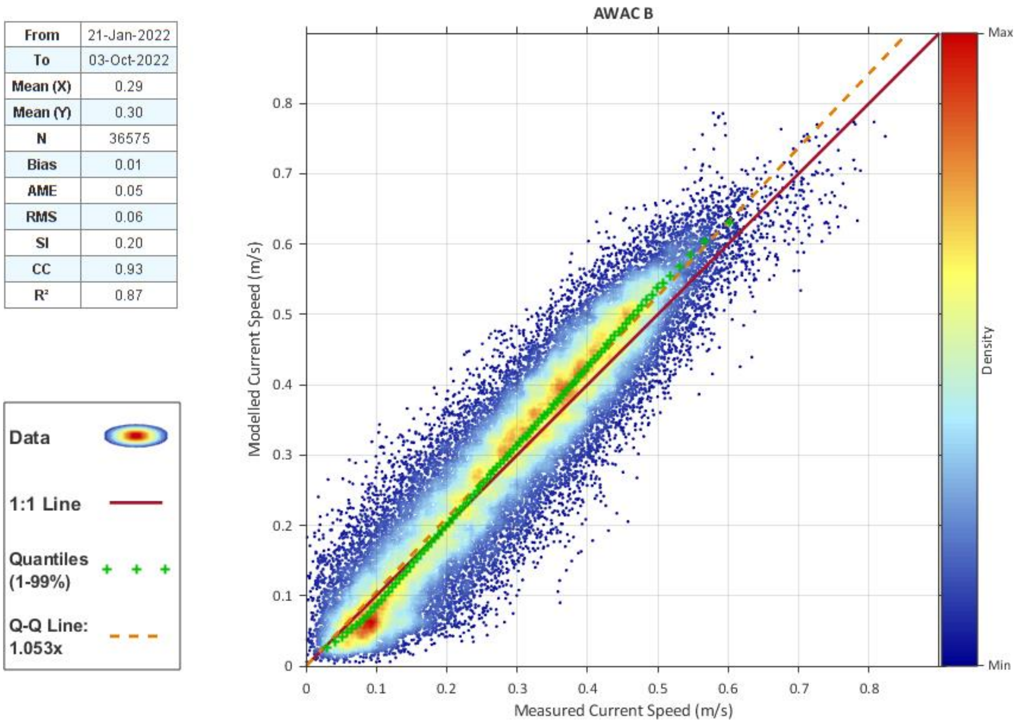


Figure 4.9: Comparison of measured and modelled depth-average currents, Site B.

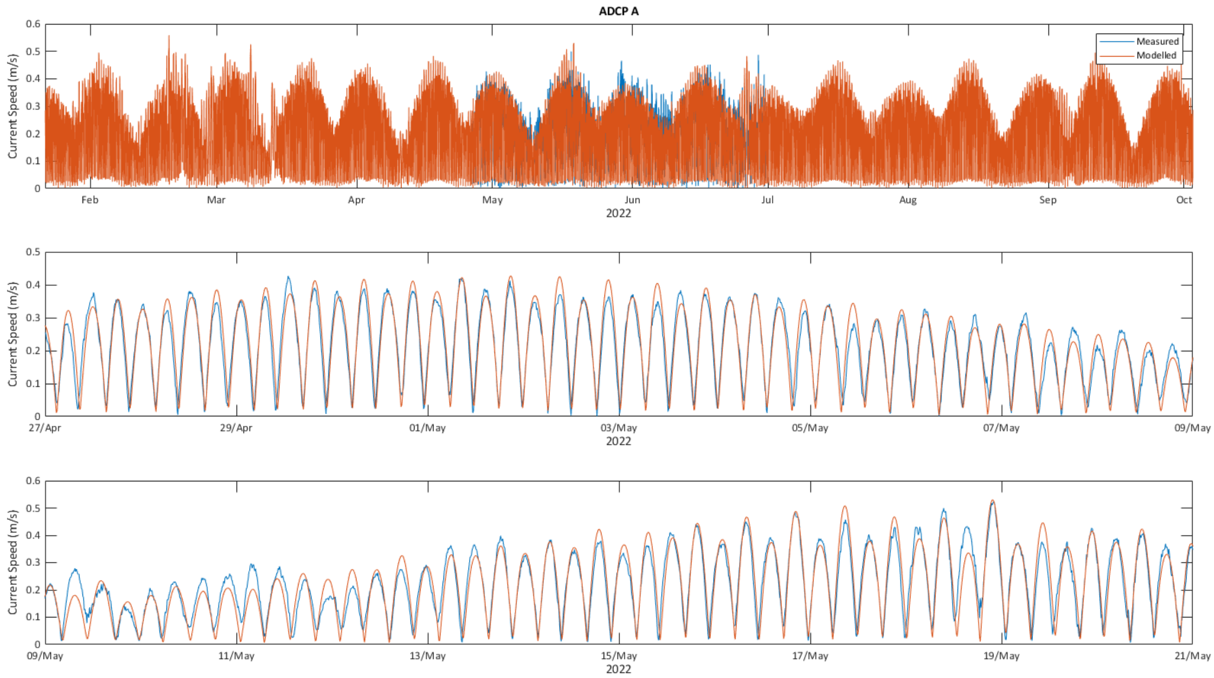


Figure 4.10: Time-series comparison of modelled and measured depth-average current speeds, Site A.

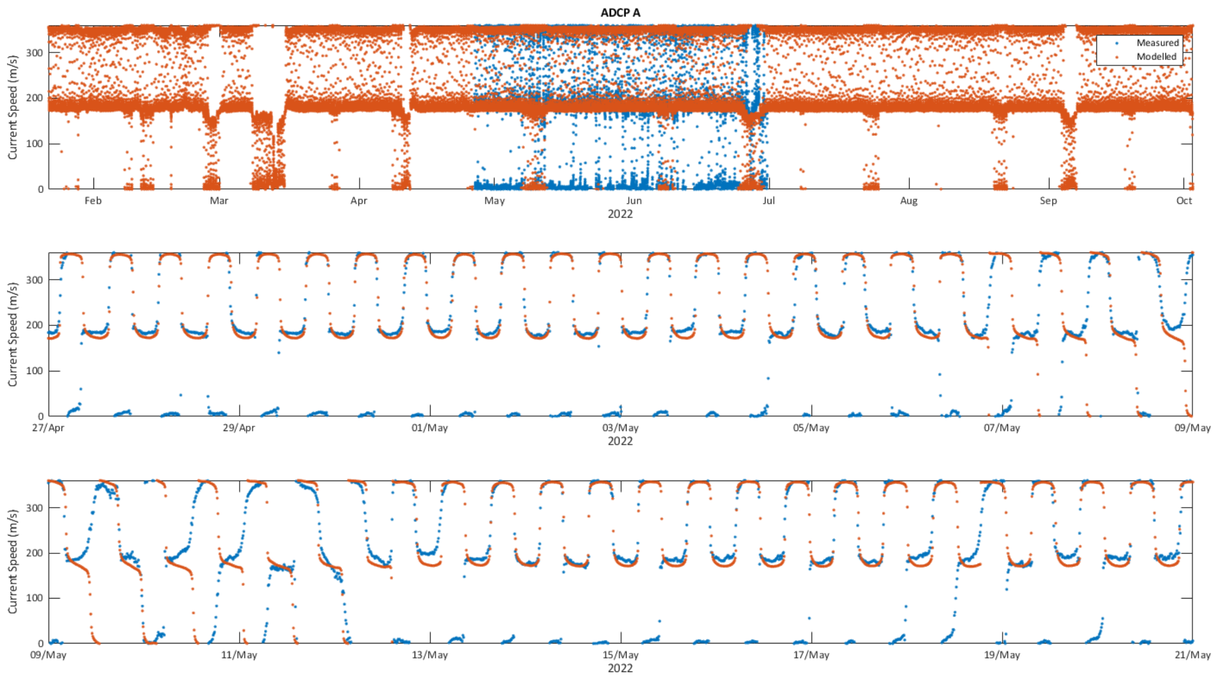


Figure 4.11: Time-series comparison of modelled and measured depth-average current directions, Site A.

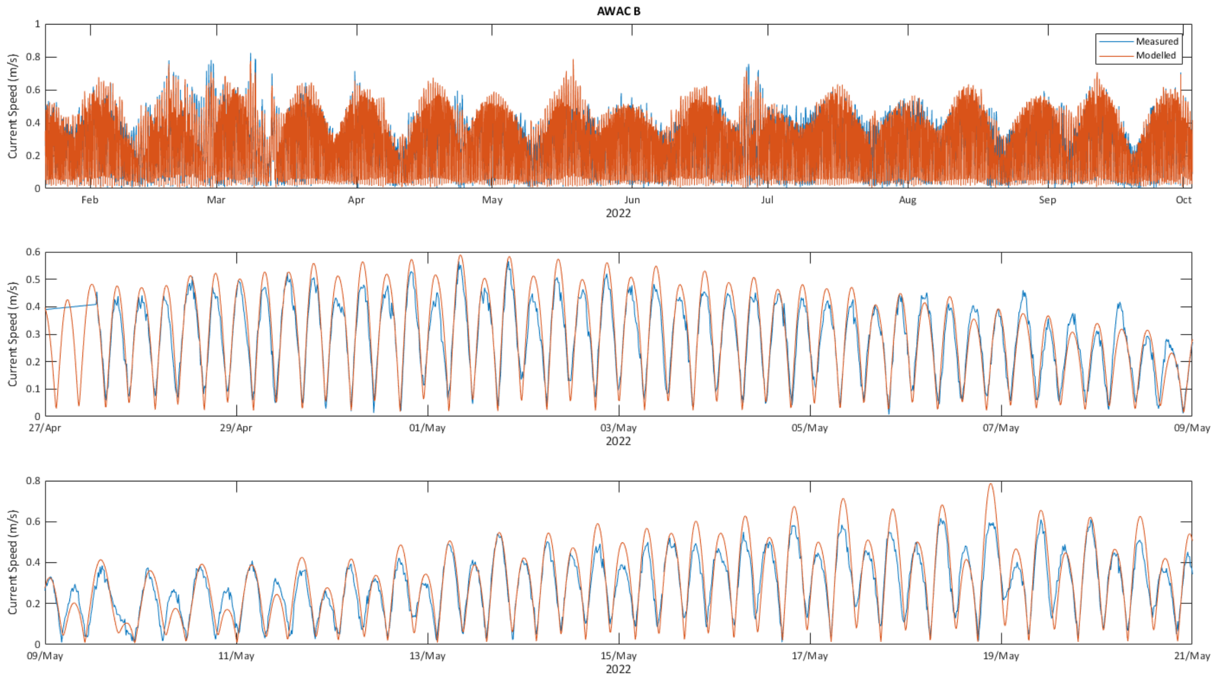


Figure 4.12: Time-series comparison of modelled and measured depth-average current speeds, Site B.

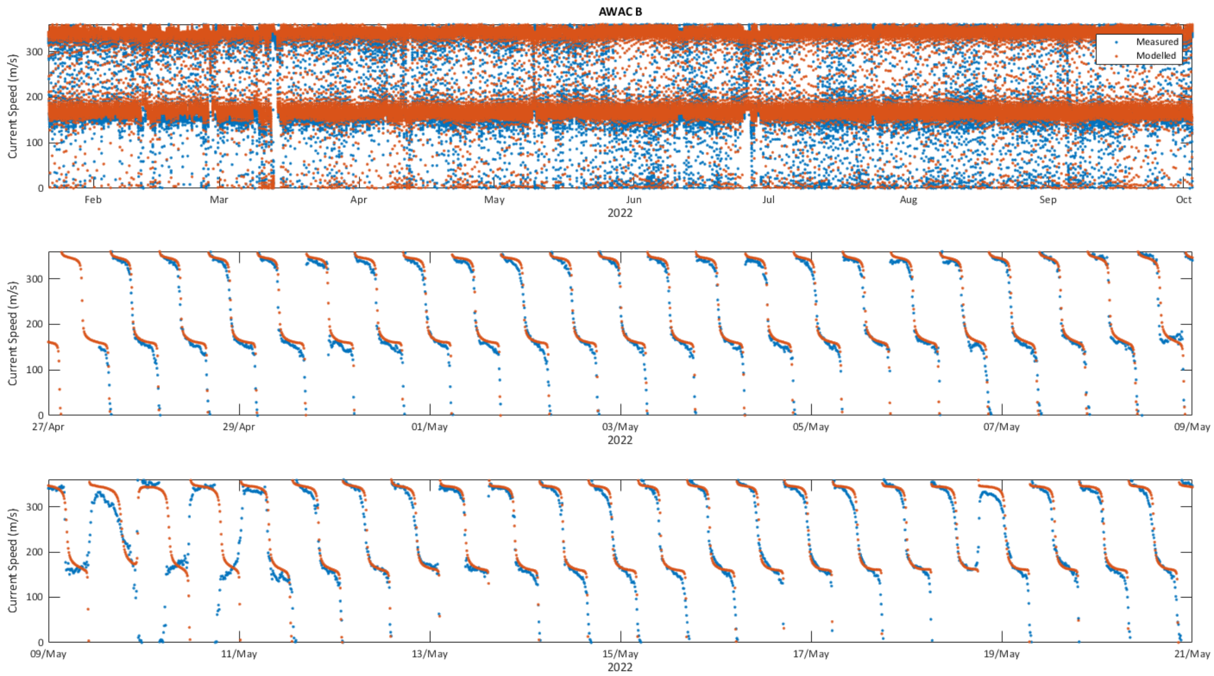


Figure 4.13: Time-series comparison of modelled and measured depth-average current directions, Site B.

In general, the direction and phasing of the tide are both extremely well-predicted by the model at all sites. The model performs slightly better at Site A to the north of the array area, compared to Site B to the south of the array area.

4.5 Selection of Tidal Events

Four tidal events were selected for modelling of hydrodynamic blockage and for particle tracking modelling to encompass the largest (spring) and smallest (neap) likely tidal advection pathways on both flood (northerly) and ebb (southerly) phases of the tide. These are shown in Table 4.2:

Table 4.2: Events selected for hydrodynamic modelling.

Event Name	Description	Date and Time
Peak Spring flood	Flood (northerly) current speed that would be exceeded approximately seven times per year (therefore in the top 1% of peak flood current speeds)	22-Feb-2015 10:00
Peak Neap flood	Flood (northerly) current speed that would not be exceeded approximately seven times per year (therefore in the bottom 1% of peak flood current speeds)	01-Mar-2004 02:40
Peak Spring ebb	Ebb (southerly) current speed that would be exceeded approximately seven times per year (therefore in the top 1% of peak ebb current speeds)	21-Feb-2015 15:20
Peak Neap ebb	Ebb (southerly) current speed that would not be exceeded approximately seven times per year (therefore in the bottom 1% of peak ebb current speeds)	02-Mar-2004 23:20

Each of the events above lasts approximately six and a half hours (i.e., the tide is flooding or ebbing for six and a half hours), with the peak tidal flow occurring approximately halfway through the tidal state (e.g., three hours after the beginning of ebb or flood flow).

In each construction scenario (i.e., the particle tracking modelling described in Section 6), the sediment releases were timed to begin at the slack water preceding the tidal events described above. After the release is finished, the model is then allowed to run for a further 48 hours to allow the far-field fate of the material to be ascertained. This time period allows all material to settle out from suspension.

4.6 Hydrodynamic Blockage Modelling

To assess the array-scale effect of the presence of the built wind farm on flows and water levels, blockage modelling was used. Blockage modelling uses a sub-grid scale parameterisation of each foundation structure to represent the blockage to flows caused by the wind farm. The particular wind farm scenario that was modelled is defined in Appendix 10.1 [1] for impact pathway O-02. Two different structure types were modelled: the wind turbine generators (WTGs), and the OSP. WTG are numbered for the purposes of modelling to enable descriptions of model input parameters. The MIKE21 FMHD software allows the user to provide a description of the geometry of the structure in terms of its geographical position, plan shape, height and width, over any number of vertical sections. The model then uses a simple drag law to capture the increasing resistance imposed by the structures as the flow speed increases.

The model was run for the four tidal events described in Table 4.2 to establish a baseline condition. The model was then re-run for the same conditions, but this time including the representation of the wind farm foundation structures in the model. The difference between these two results was calculated for each of the tidal events, providing the predicted difference in flow speeds and water levels caused by the presence of the wind farm.

5 Waves

Waves were modelled using a Southern North Sea SWAN model in conjunction with a higher resolution nested model of the Greater Wash. SWAN cycle III version 40.91ABC [9] was used.

Model parameters should be considered as representative of a three-hour sea-state.

5.1 Measured Wave Data

To support calibration and validation of the wave model, measured data were acquired from Cefas, and the NISA metocean survey. The Cefas measurements at the AFBI_038a buoy, and project measurements at Site A originate from a Datawell Directional Waverider MkIII. As such, they provide a valuable set of high-quality measurements against which to calibrate and validate the wave model(s). The measurements from Site B originate from a 600 kHz Nortek AWAC mounted on a bed frame. Details of these datasets are provided in Table 5.1 below and illustrated in Figure 5.1 overleaf.

Table 5.1: Measured datasets used for wave model validation.

Dataset	Provider	Location	Time Period	Water Depth [mLAT]
AFBI_038a	Cefas	53.7838°N, 5.6367°W	16-Sep-2019 to 16-Jul-2021	92 m
Site A DWR	NISA	53.7469°N, 5.8014°W	26-Apr-2022 to 08-Aug-2022	61 m
Site B AWAC	NISA	53.5945°N, 5.9115°W	21-Jan-2022 to 03-Oct-2022	45 m

The measurements were carefully reviewed prior to use. In terms of performance, data from AFBI_038a and Site A Datawell Waverider buoys were considered to be of the highest quality owing to the type of instrumentation used in the measurements.

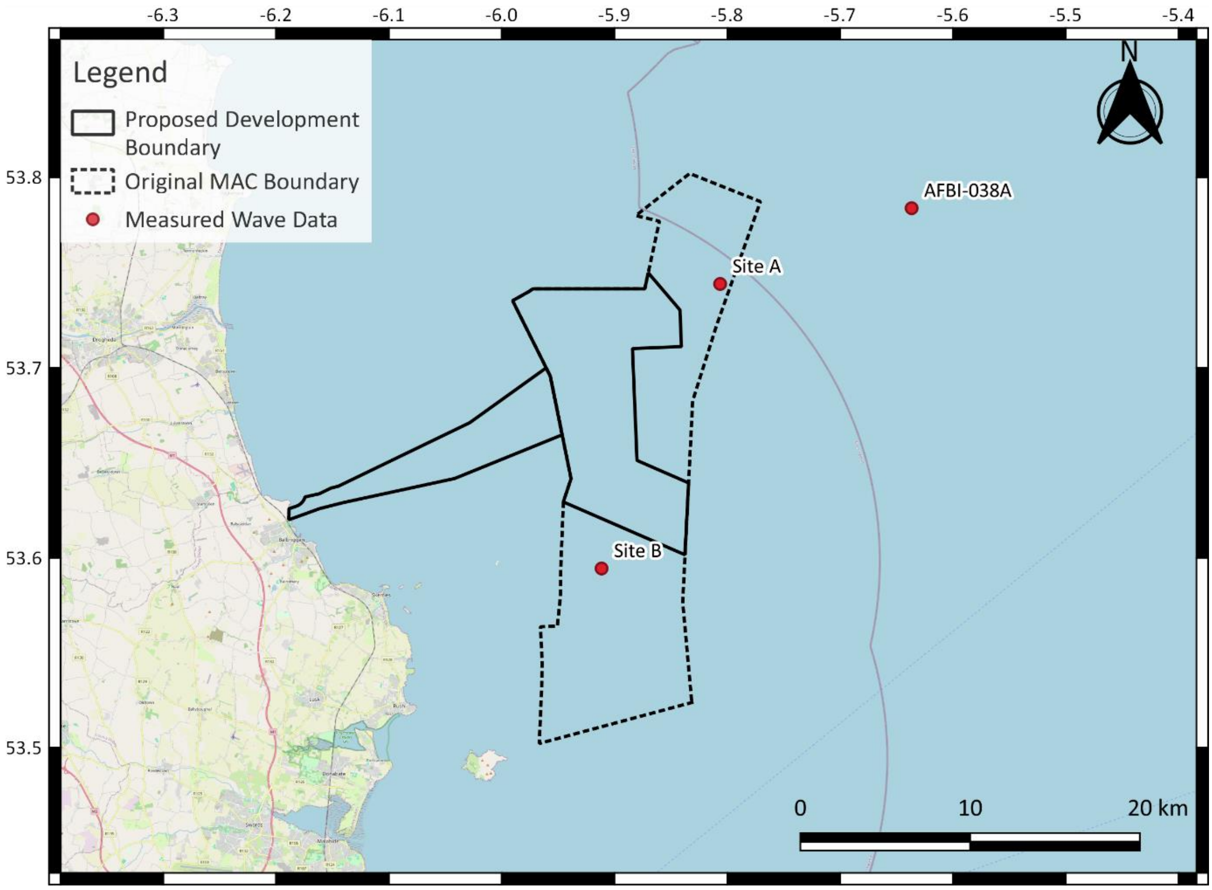


Figure 5.1: Locations of the wave measurement devices.

5.2 Modelling Software

A bespoke SWAN wave model was deployed, with a high-resolution regional nest. SWAN is a third-generation wave model, developed at Delft University of Technology, which computes random, short-crested wind-generated waves in coastal regions and inland waters. SWAN accounts for the following physics:

- Wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth;
- Wave generation by wind;
- Three- and four-wave interactions;
- White-capping, bottom friction and depth-induced breaking;
- Wave-induced set-up;
- Transmission through and reflection (specular and diffuse) against obstacles; and
- Diffraction approximation.

For the model validation, a large-scale regional model was deployed with a spatial resolution of 5 km, followed by a nested regional model with resolution 2.7 km. The nested high-resolution local model used a horizontal resolution of 140 m which covers the array and ECC area. The large-scale model takes boundary wave spectra from the ERA5 model described in Section 5.3, and then generates boundary spectra for the nested regional model, which in turn generates boundary spectra for the high-resolution local model. The wave model extents are described in Table 5.2, and shown in Figure 5.2 below.

Table 5.2: Wave model domains.

Wave Model	Geographical Extents
5 km Wave Model	50.00°N, 9.04°W to 56.03°N, 1.96°W
2.7 km Wave Model	51.49°N, 7.02°W to 55.01°N, 2.48°W
14 0m Wave Model	53.26 °N, 6.40°W to 54.26°N, 5.60°W

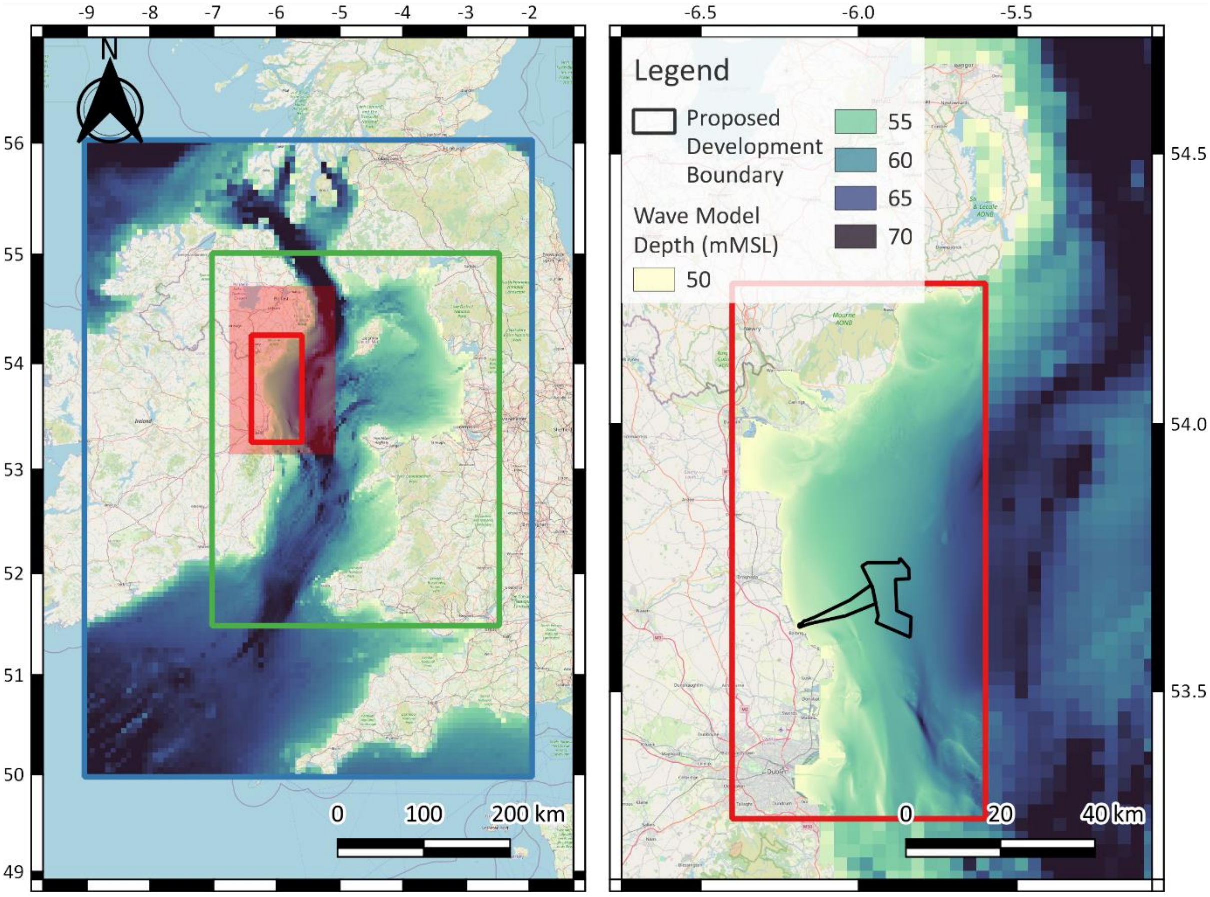


Figure 5.2: Wave model domains.

For the wave blockage modelling, the two largest-scale regional models were not used and instead the high-resolution local model was driven at its boundaries with parameters specified to create the desired conditions at the wind farm.

5.3 Model Boundary Conditions

Spectral wave boundary conditions to the large domain 5 km model originated from ECMWF ReAnalysis 5 (ERA5). ERA5 incorporates a model with three fully coupled components for the atmosphere, land surface, and ocean waves. The wave model is based on the Wave Analysis Model (WAM) approach (Komen et al, 1994 [10]).

The horizontal resolution of the output wave data is 0.5-degree (approximately 56 km in latitude and 30 km in longitude in the region of interest) and wave spectra are discretised using 24 directions and 30 frequencies from 0.0345 to 0.5473Hz. Data are available every hour between 1979 and present. MetOceanWorks adjusted ERA5 wind fields (see Section 3.3) were applied to the sea surface at hourly intervals.

5.4 Model Validation

The wave model has been extensively validated against the measured wave data detailed in Table 5.1 with pertinent results presented in the following pages. Scatter plots with overlaid Quantile-Quantiles are presented and generally yield high correlation coefficients, relatively low scatter indices and slopes close to unity.

Mean (X)	1.17
Mean (Y)	1.14
N	16060
Bias	-0.04
AME	0.14
RMS	0.19
SI	0.16
CC	0.97
R^2	0.94

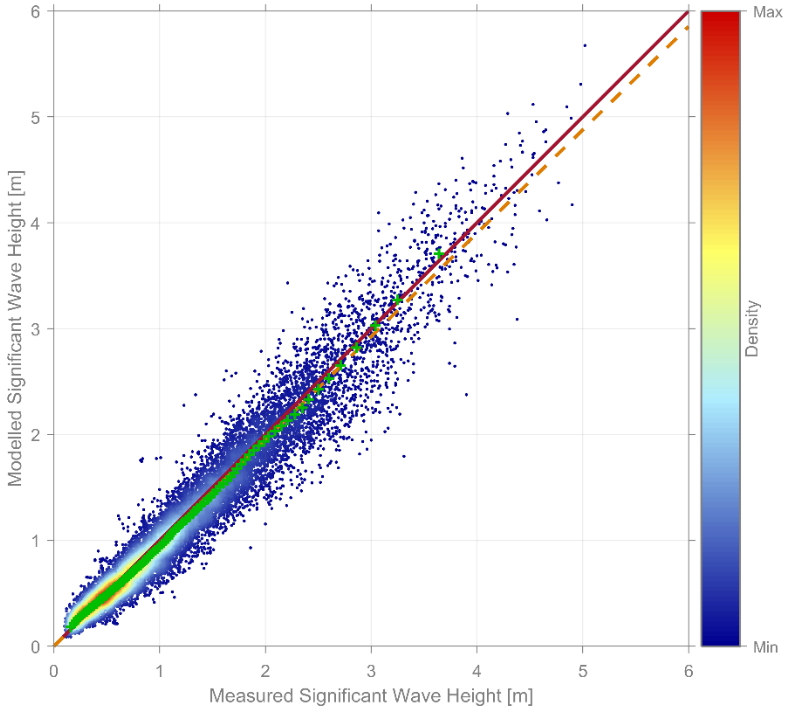


Figure 5.3. AFBI_038a, Hm0 validation, all data.

Mean (X)	5.47
Mean (Y)	5.31
N	12796
Bias	-0.16
AME	0.67
RMS	1.31
SI	0.24
CC	0.70
R^2	0.48

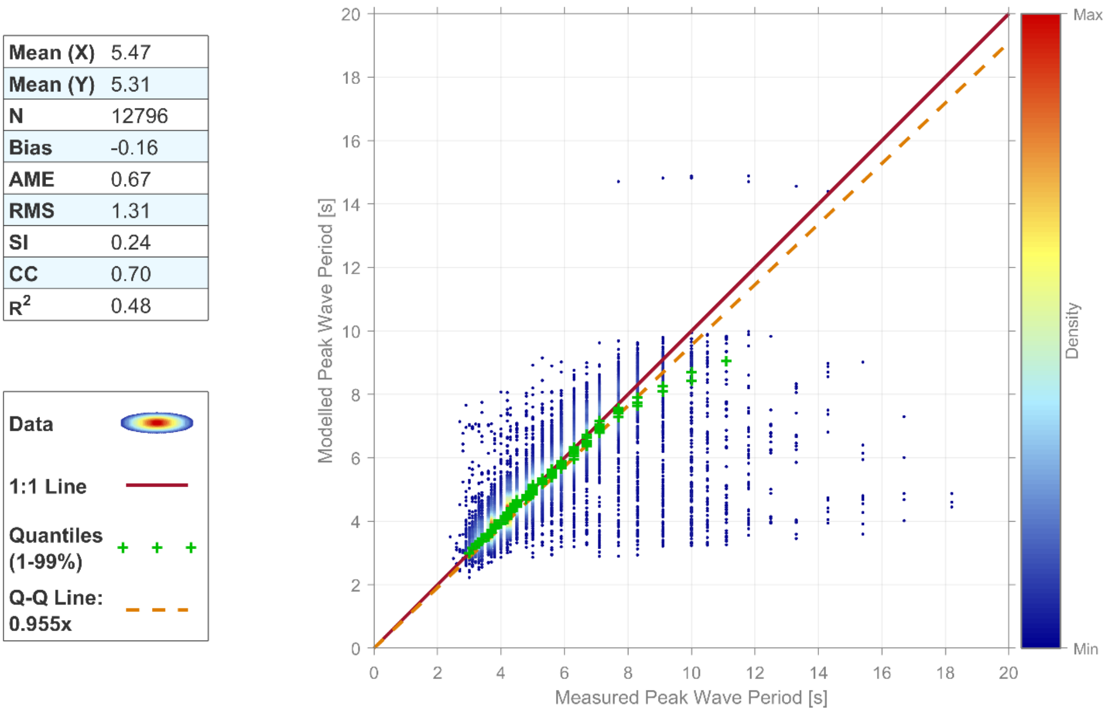


Figure 5.4. AFBI_038a, Tp validation, all data.

Mean (X)	3.88
Mean (Y)	3.79
N	16060
Bias	-0.09
AME	0.25
RMS	0.38
SI	0.09
CC	0.92
R^2	0.84

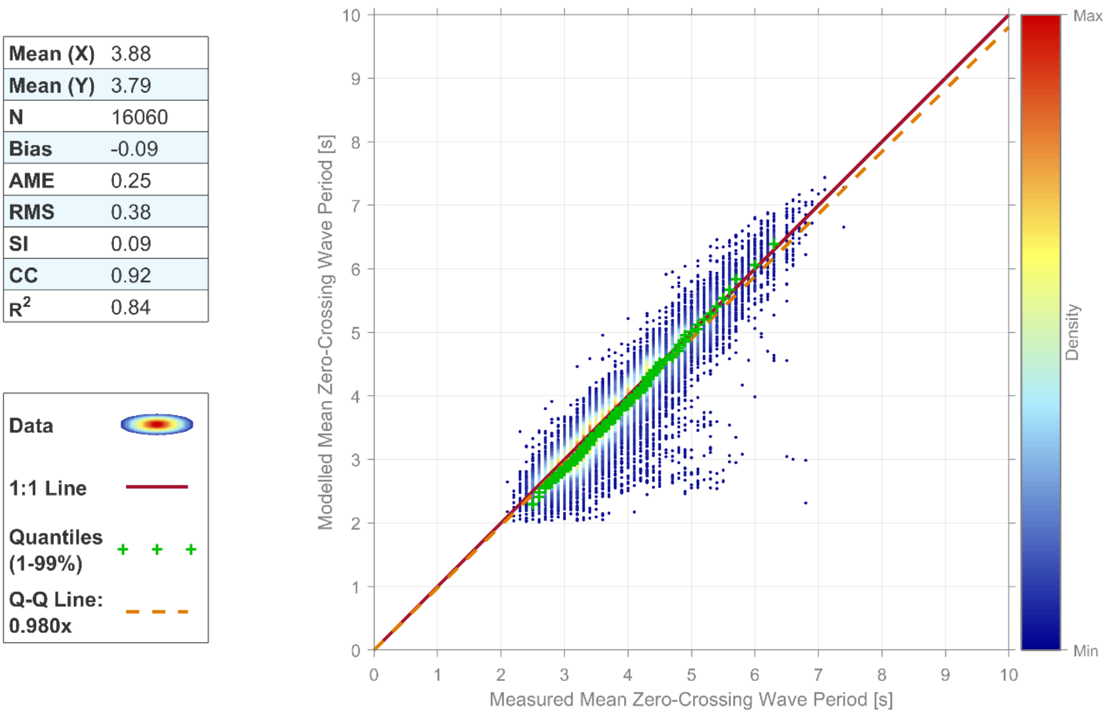


Figure 5.5. AFBI_038a, Tm02 validation, all data.

Mean (X)	0.64
Mean (Y)	0.66
N	2262
Bias	0.02
AME	0.10
RMS	0.13
SI	0.21
CC	0.94
R^2	0.89

Data
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Quantiles (1-99%)
Q-Q Line: 1.026x

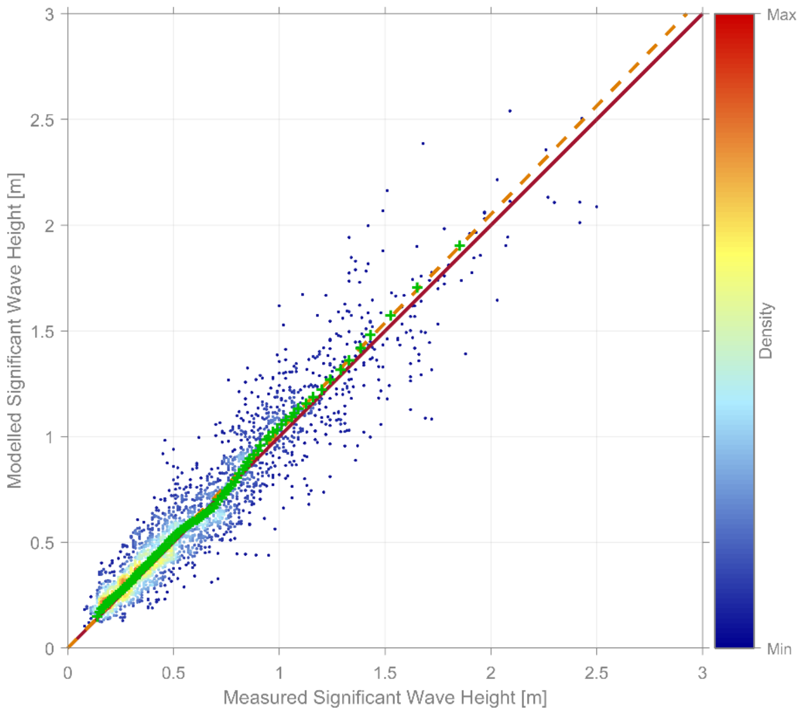

Figure 5.6. Site A, Hm0 validation, all data.

Mean (X)	4.46
Mean (Y)	4.45
N	1199
Bias	-0.02
AME	0.50
RMS	0.87
SI	0.20
CC	0.71
R^2	0.50

Data
1:1 Line
Quantiles (1-99%)
Q-Q Line: 0.980x

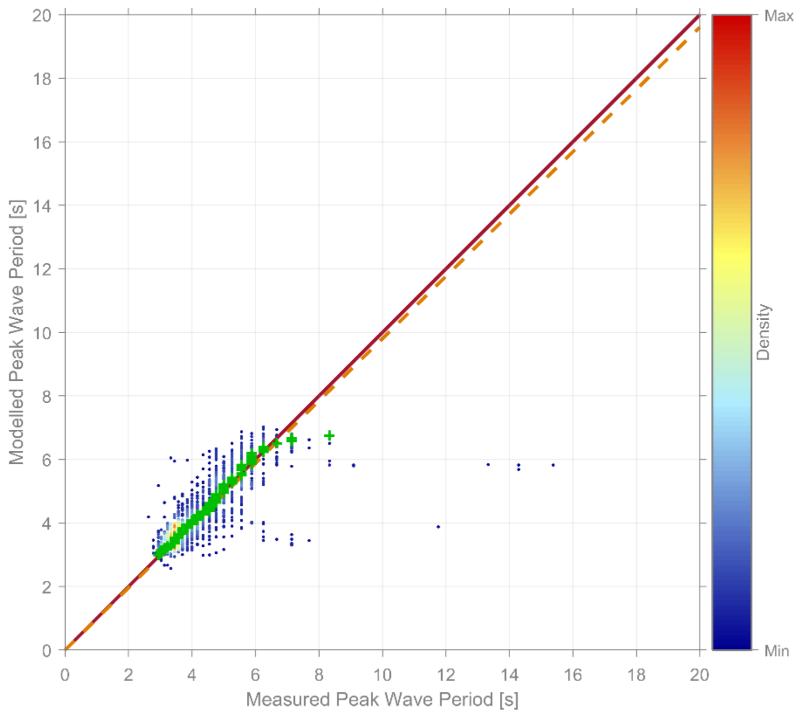

Figure 5.7. Site A, Tp validation, all data.

Mean (X)	3.24
Mean (Y)	3.12
N	2262
Bias	-0.12
AME	0.26
RMS	0.40
SI	0.12
CC	0.78
R^2	0.61

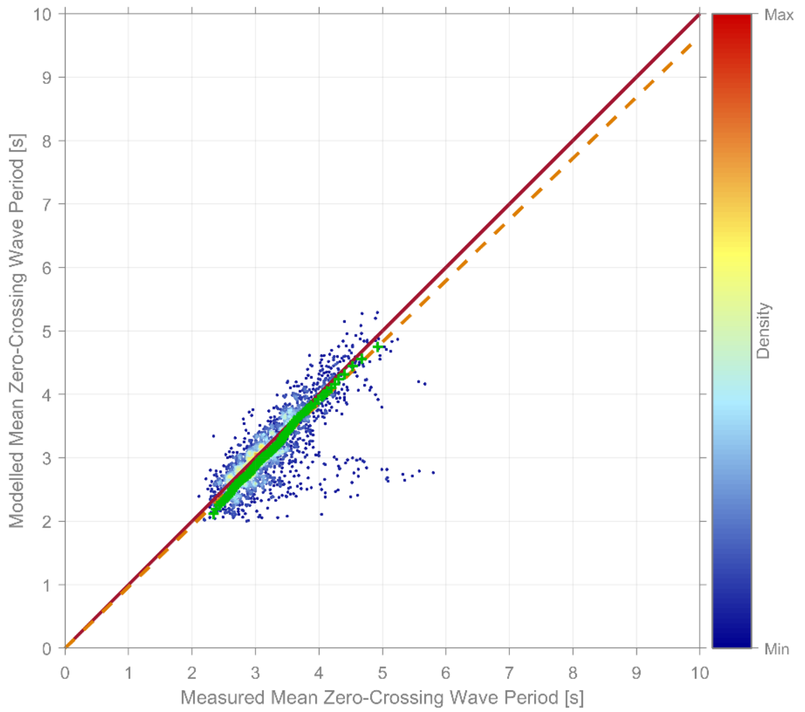

Figure 5.8. Site A, Tm02 validation, all data.

Mean (X)	0.74
Mean (Y)	0.78
N	6083
Bias	0.04
AME	0.11
RMS	0.16
SI	0.21
CC	0.96
R^2	0.92

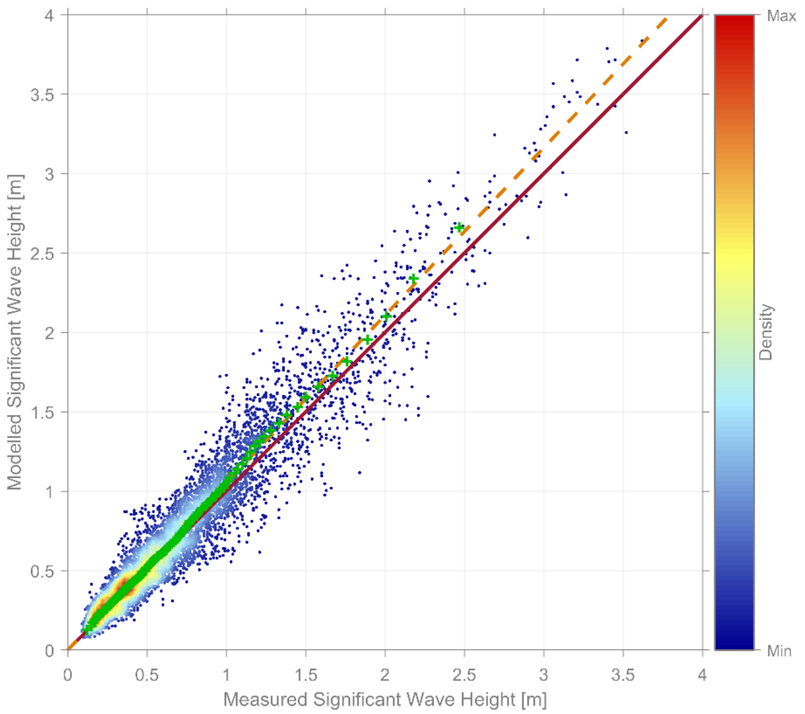

Figure 5.9. Site B, Hm0 validation, all data.

Mean (X)	4.69
Mean (Y)	4.81
N	3771
Bias	0.12
AME	0.60
RMS	0.94
SI	0.20
CC	0.71
R^2	0.51

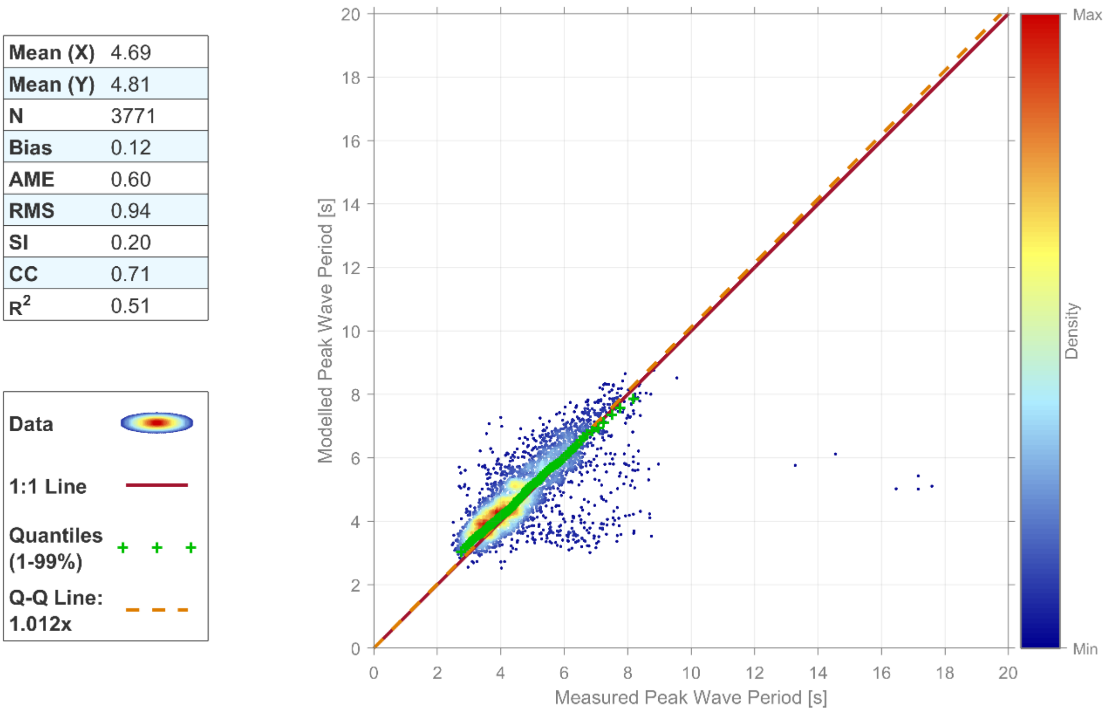

Figure 5.10. Site B, Tp validation, all data.

Mean (X)	3.32
Mean (Y)	3.29
N	6083
Bias	-0.03
AME	0.27
RMS	0.38
SI	0.12
CC	0.86
R^2	0.73

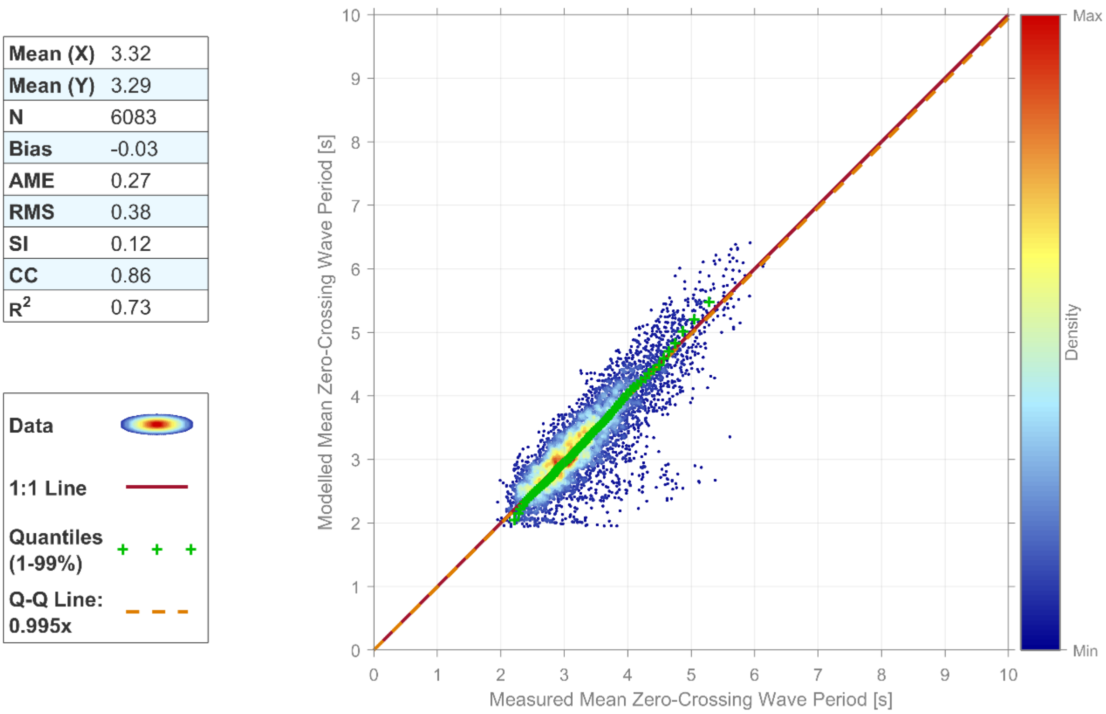

Figure 5.11. Site B, Tm02 validation, all data.

These assessments demonstrate good model skill in terms of reproducing measured wave height and period under both ambient and storm conditions.

Care has been taken when comparing mean zero-crossing periods (Tm02) to ensure both modelled and measured values are derived using the same method. Parameters derived from higher order spectral moments, such as Tm02, can be sensitive to how high frequency wave energy is treated in their derivation. In particular, for the AFBI_038a and Site A datasets, Tm02 as output directly by the SWAN model *does* make use of a theoretical high frequency extrapolation, whilst that reported by the DWR measurements at these locations does *not*. Direct comparison of these parameters can be misleading, the inclusion of such a tail generally being expected to reduce the Tm02 values. In order to more fairly compare, modelled Tm02 have been recalculated from modelled *spectra*, without including a high frequency extrapolation and instead using the same high frequency cut-off as the DWR measurements. It is these values which are compared to the measured Tm02 below.

5.5 Selection of Wave Events

The wave model was run for multiple events – p50 (median), 1 in 1, 10 and 50 year return period extreme waves, originating from the east-north-east (68°N), and from the south-south-east (156°N). These directions were chosen from a wave rose at the centre of the array, using 30° sectors. The prevailing direction from the 30° sector centred on 150°N along with the 30° sector centred on 60°N, which is most direct onto the adjacent shoreline. These sectors were then further refined to 156°N and 68°N to align with the WTG rows and columns to develop the greatest chance of disrupting waves across the array.

Metocean conditions (i.e., the wave conditions), were ascertained from our report 'Preliminary Metocean Design Criteria - NISA South West' [11]. We carried out an analysis of the directionality of the extreme waves (since only omni-directional extremes were provided in our initial criteria report [11]), and found that the relative severity (defined by the p99.9 Hm0, per sector, from the hindcast) of the two directional sectors examined was either 1, or 0.99. Therefore, the omni-directional values were used for both directions.

The high-resolution model boundary conditions (input wind speed and wave parameter boundaries) were adjusted such that conditions at the same location in the model matched the following conditions as defined in NISA initial metocean design criteria report [11] at the 'NISA SW' location.

Table 5.3: Wave conditions modelled.

Event Name	Direction [°N from]	Hm0 [m]	Tp [s]
P50	68	0.7	4.5
P50	156	0.7	4.5
1 in 1 year	68	4.1	8.8
1 in 1 year	156	4.1	8.8
1 in 10 year	68	4.9	9.6
1 in 10 year	156	4.9	9.6
1 in 50 year	68	5.5	10.0
1 in 50 year	156	5.5	10.0

5.6 Wave Blockage Modelling

To assess the array-scale effect of the wind farm foundations on waves, blockage modelling was used. Blockage modelling uses a sub-grid scale parameterisation of each foundation structure to represent the blockage effects to waves caused by the wind farm. The particular wind farm scenario that was modelled is defined in Appendix 10.1 [1] (representing impact pathway O-01). Two different structure types are modelled: the WTGs, and the OSP. The SWAN software allows the user to provide a description of the structure as a coefficient of transmission through specified model grid cells (in this case, the cells containing the WTGs or OSP).

After a run of the model with no structures present (baseline conditions), the model was then re-run for the same conditions, but this time including the representation of the wind farm foundation structures. The difference between these two results was calculated for each of the events, providing the predicted difference in wave conditions caused by the imposition of the wind farm.

6 Particle Tracking

The Particle Tracking module of MIKE 21 Flow Model FM (Flexible Mesh) is used for modelling the transport and fate of suspended and sedimented substances discharged in estuaries and coastal areas or in the open sea. The material is considered as particles forming a sediment plume being advected with the surrounding water body and dispersed as a result of random (turbulent) processes in three dimensions. Multiple sediment classes can be simulated. The particles from each class settle with a constant settling velocity. A mass is attached to each particle. The following processes are attached to individual particle classes:

- Settling;
- Moving sources (if applicable); and
- Horizontal and vertical dispersion.

In this study, four representative sediment classes were used. These are detailed in Table 6.1.

The model calculates the path of each particle and outputs the instantaneous concentrations of individual classes in two dimensions, as well as the settled mass. The output concentration is based on the mass of particles present in the volume of water in a given model cell. The settled mass is converted to a deposition depth by dividing by the settled density of the material under consideration. For the purpose of the present assessment, re-erosion of settled material is conservatively not considered, to ensure the maximum depth of deposition is determined.

The hydrodynamic model (and therefore the output grid) has a spatial resolution featuring a triangular mesh with 150 m resolution in the proposed development boundary and within a 11 km buffer of the proposed development boundary and ECC. For the purposes of environmental assessment, a minimum material concentration of 1 mg/l above background was chosen to be resolved by the model. Given that some releases are modelled near to the shallow coastal waters (for instance, Bentonite release), the model was also required to resolve these minimum concentrations in areas of relatively shallow water. A cut-off water depth of 1.5 m was chosen for resolving the minimum required concentrations in the model. Assuming that the triangular mesh is composed of triangles tending toward an equilateral shape, and a water depth corresponding with mean sea level, the volume of water in an individual mesh element with water depth 1.5 m is 33,765 m^3. In order to resolve to 1 mg/l in this volume of water, each particle must have a maximum mass of 34 kg. Therefore, a sufficiently high number of particles was released in each run such that each particle was assigned a maximum mass of 34 kg in the model. Although each particle has a representative maximum mass 34 kg, it inherits the settling velocities of its class from Table 1 of Appendix 10.1 [1]. The relevant part of the table is reproduced here as Table 6.1.

Table 6.1: Details of the representative sediment types.

Sediment type (Wentworth Scale [12])	Size range (mm)	Representative size (mm)	Settling velocity (m/s)
Fine sand	0.125 to 0.250	0.188	0.018
Very fine sand	0.063 to 0.125	0.094	0.005
Coarse silt	0.031 to 0.063	0.047	0.0014
Medium silt / muds	< 0.031	0.023	0.0003

Coarser sediment types with a faster settling velocity are not considered in the particle model as they will fall to the seabed relatively quickly and are not subject to wider advection or dispersion to form part of any sediment plume. Where coarse sediments are released remote from their point of origin (such as spoil disposal) then their fate is considered separately (i.e., Appendix 10.3 [2] for spoil mounds).

Brief details of the model set-up for each of the scenarios follows. More details of realistic worst-case scenarios that these are based on can be found in Appendix 10.1 [1]. With the exception of the drilling for foundation installation scenario, for each scenario, four different current events were simulated, as described in Section 4.5. These are high and low current speeds, flowing northward (ebb) and southward (flood).

For the drilling for foundation installation scenario, the drilling event is expected to continue for around 140 hours, much longer than the 48-hour model runs used for the other scenarios. Therefore, in this case, only two scenarios were run (spring and neap – since flood and ebb tidal cycles lose significance over such long time period), and these runs were allowed to continue for the full 140-hour drilling period, plus 48 hours after the end of drilling operations.

The geographical positions of each of the sediment release locations described below are shown in Figure 6.1. In each case, these locations are associated with the highest concentration of fine sediments in the seabed which are expected to lead to the largest suspended sediment concentrations within the short-term duration of plume development. Other locations with a lower amount of fine sediment are expected to develop smaller suspended sediment concentrations within associated plumes.

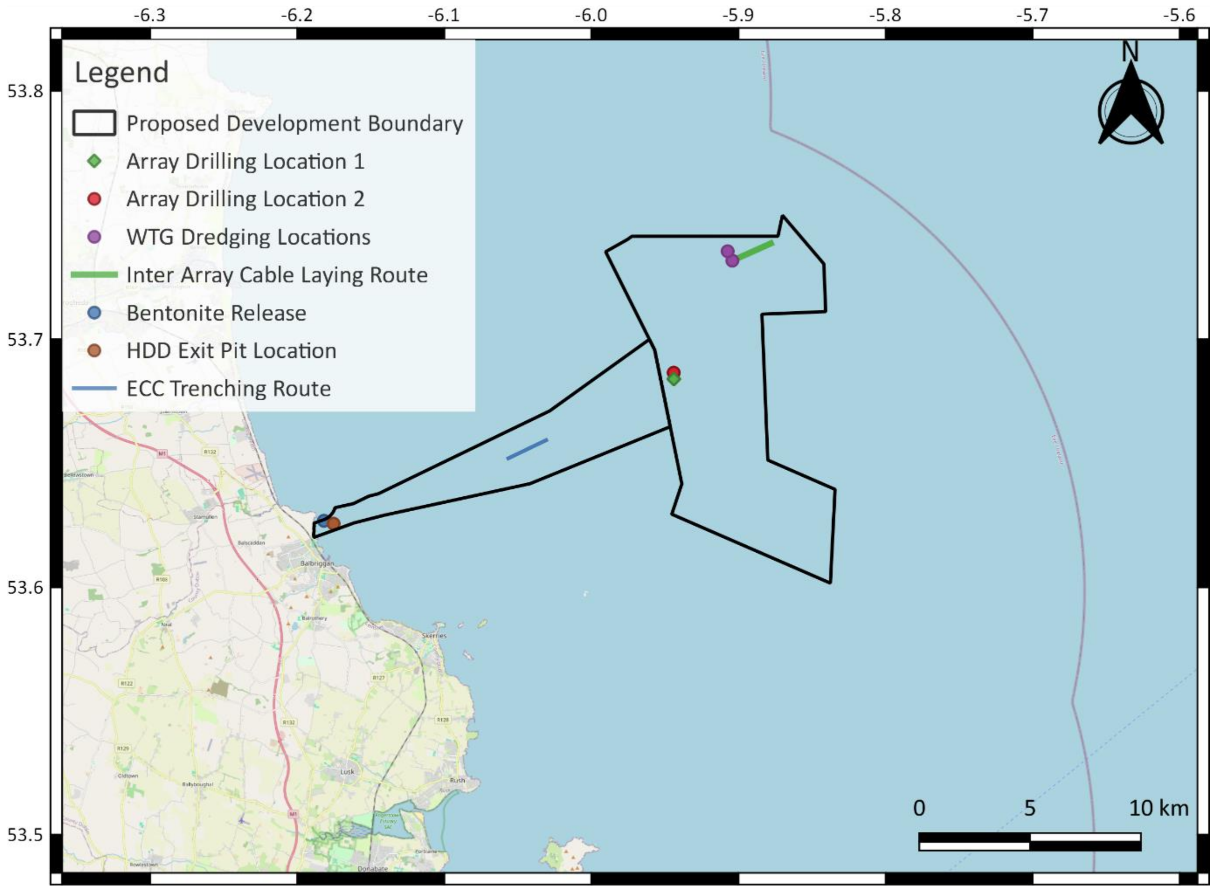

Figure 6.1. Locations used in particle tracking modelling.

6.1 Array Area

6.1.1 Inter Array Cabling – Jetting

The jetting tool is simulated to be moving along the line from WTG 22 to 24 at a rate of 300 m per hour, meaning that the trenching between these two WTGs takes just under six and a half hours. In each case, the jetting is simulated to start just over three hours before the current speed peak, meaning that the current speed peak events occur approximately halfway along the jetting route. The disturbed fine sediments are released into the model at a height of three metres above the bed. To convert the settled mass from the model into a depth in mm, a settled density of 311 kg/m³ was used. This scenario represents impact pathway C-03.

6.1.2 Foundation Installation – Drilling

Two locations were simulated for drilling of foundations of an OSP, with slightly different input parameters used for each. Accordingly, the sensitivity of the model results when using slightly different input parameters and locations can be compared. Plots showing the comparison between the outputs from the two drilling scenarios are provided in Section 7.

6.1.2.1 Foundation Installation – Drilling Location 1

A single location for drilling is simulated 285 m south of the OSP. The release of drill arisings is simulated to persist for 68 hours, followed by a four-hour pause, followed by another 68-hour period of drilling, with the current speed peak occurring two and a half hours into the release period. To convert the settled mass from the model into a depth in mm, a settled density of 872 kg/m³ was used. This scenario represents impact pathway C-02.

6.1.2.2 Foundation Installation – Drilling Location 2

A single location for drilling is simulated at the OSP. The release of drill arisings is simulated to persist for 86 hours, followed by a four-hour pause, followed by another 86-hour period of drilling, with the current speed peak occurring approximately 71 hours into the release period. To convert the settled mass from the model into a depth in mm, a settled density of 1,046 kg/m³ was used. This scenario also represents impact pathway C-02, albeit for a slightly different set of input parameters.

6.1.3 Foundation Installation – Dredging

A 50% provision is planned for seabed levelling around jacket foundations to establish a stable platform for scour protection. Seabed levelling with a trailer suction hopper dredger (TSHD) represents the WCS option. A single TSHD hopper load is simulated as being filled (including overspill discharges), and then discharged at an adjacent dump site. The foundation site where overspill from the hopper commences is WTG24, and the dump site is approximately 470 m to the north-northwest (in between adjacent WTG locations). The overspill phase from the TSHD lasts 40 minutes at the WTG location. There is then a 30-minute break in discharge during demob and transit to the dump site, before a 6-minute dumping period at the dump site. The current speed peaks occur approximately during the dumping phase. For the overspill phase the material is released into the model at the water surface, and for the dumping phase the material is released 16 m below the surface. To convert the settled mass from the model into a depth in mm, a settled density of 311 kg/m³ was used (n.b. this is the estimated initial density whereas over a longer period of time dewatering will increase the bulk density). This scenario represents impact pathway C-01.

6.2 Export Cable Route

6.2.1 HDD Punch-out - Bentonite Release

A single location for Horizontal Directional Drilling (HDD) punch-out and associated Bentonite release is simulated. The location is approximately 420 m from shore to the north of the cable corridor. The release of Bentonite is simulated to last for 24 hours (initial punch-out followed by a reaming phase), with the current speed peak occurring three hours into the release period. To convert the settled mass from the model into a depth in mm, a settled density of 100 kg/m³ was used (n.b. this is the estimated initial density of very fine particles whereas over a longer period of time dewatering will increase the bulk density). This scenario represents impact pathway C-06.

6.2.2 Cable Trenching

The jetting tool is simulated to be moving along a 1.89 km section of the cable route approximately 9.3 km offshore at a rate of 300 m per hour, meaning that the trenching takes almost six and a half hours. In each case, the excavation is simulated to start just under three hours before the current speed peak, meaning that the current speed peak events occur approximately halfway along the excavation route. The material is released into the model at three metres above the bed. To convert the settled mass from the model into a depth in mm, a settled density of 1,393 kg/m³ was used (n.b. this is the estimated initial density of sand sized particles whereas over a longer period of time dewatering will increase the bulk density). This scenario represents impact pathway C-04.

6.2.3 Mass Flow Excavation of HDD Exit Pits

A single release location is simulated, where sediment is discharged for a period of 11.5 hours, followed by a one-hour break whilst the equipment is relocated to the second pit location (although these two locations are likely to be close, so only a single location is simulated in the model), followed by a further period of sediment release of 11.5 hours. The current speed peaks occur two hours and 20 minutes after the beginning of the operations. The material is released into the model at 2.5 m above the seabed. To convert the settled mass from the model into a depth in mm, a settled density of 1,359 kg/m³ was used (n.b. this is the estimated initial density of sand sized particles whereas over a longer period of time dewatering will increase the bulk density). This scenario represents impact pathway C-05.

7 Results

Model outputs were provided to GoBe Consultants Ltd in GIS format for interpretation in the relevant EIAR chapters. For the wave blockage modelling, raster GeoTIFFs are used, and for all other results, ESRI-format vector shapefiles were used. In the case of the vector shapefiles, all parts of the shapefile where the concentration of raised levels of suspended sediment is zero, were removed.

- Two output parameters are provided for particle tracking scenarios:
  - Sedimented (showing the depth of sediment that has settled on the seabed after release). Note that re-suspension was switched off in the model.
  - Suspended (showing the depth-averaged concentration of sediment that is in suspension after release).
- For particle tracking scenarios, for each of the current events, and for each output parameter, the following were provided:
  - The situation at 0, 1, 2, 3, 4, 5, 10, 15 and 20 hours (and for the array drilling scenario, additionally 24, 48, 72, 96, 120, 144, 168, and 188 hours) after the beginning of dredge operations.
  - Time series at selected locations relevant to environmental receptors.
  - The maximum of sedimented and suspended. This represents the largest value that occurred in each model grid cell over the entire simulation period. It is not representative of any single instant in time, but does provide a useful indication of the maximal extent of the plume and associated sedimentation.
- For particle tracking scenarios the units of 'suspended' are depth-averaged mg/l. The units of 'sedimented' are mm.
- For wave blockage scenarios, the following four output parameters are provided:
  - Hm0 = significant wave height. Units = metres.
  - Tm02 = mean zero-crossing wave period. Units = seconds.
  - Tp = peak wave period. Units = seconds.
  - mDIr = mean wave direction. Units = degrees relative to north (or absolute degrees for the difference layer)

  for each of three output types:
  - NO_BLOCKAGE = no wind farm included in the model
  - BLOCKAGE = wind farm included in the model
  - Diff = scheme results minus baseline results
- For the hydrodynamic blockage scenarios, the following three parameters are provided:
  - Current speed and difference in current speed (units = depth averaged current speed m/s)
  - Current direction and difference in current direction (Units = depth averaged current direction °T, or absolute ° for the difference layer)
  - Surface elevation and difference in surface elevation (Units = m MSL or absolute m for the difference layer).

  for each of two output types:
  - Baseline = no wind farm included in the model
  - Difference = scheme results minus baseline results

As discussed in Section 6.1.2, a sensitivity test of the particle tracking model was undertaken to assess the differences that would result from two slightly different sets of inputs parameters and locations for the array drilling scenario. The results are shown in Figure 7.1 and Figure 7.2.

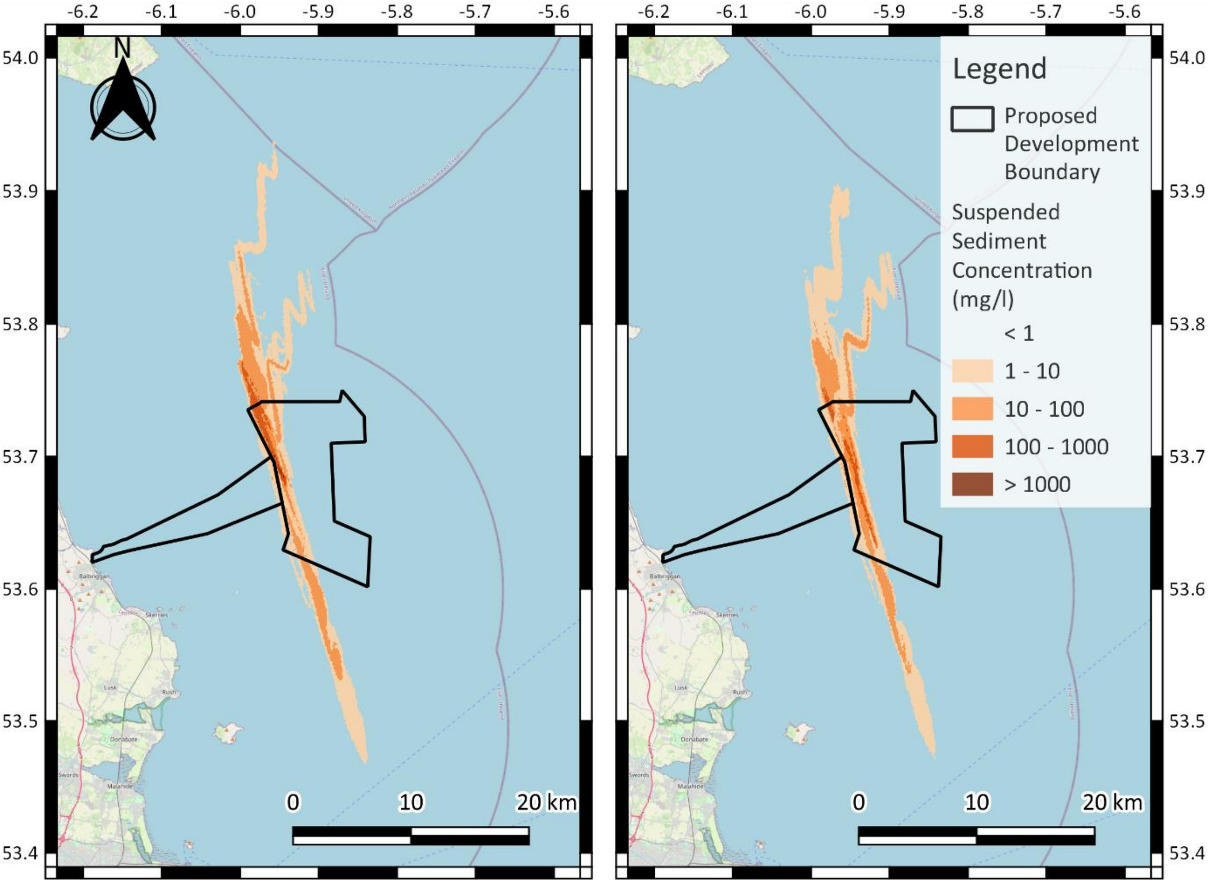

Figure 7.1. Maximum suspended sediment concentrations from the foundation installation scenarios (left panel = drilling location 1, right panel = drilling location 2).

The differences between the two scenarios for suspended sediment concentrations (left and right panel) are small in terms of geographical spread and concentration.

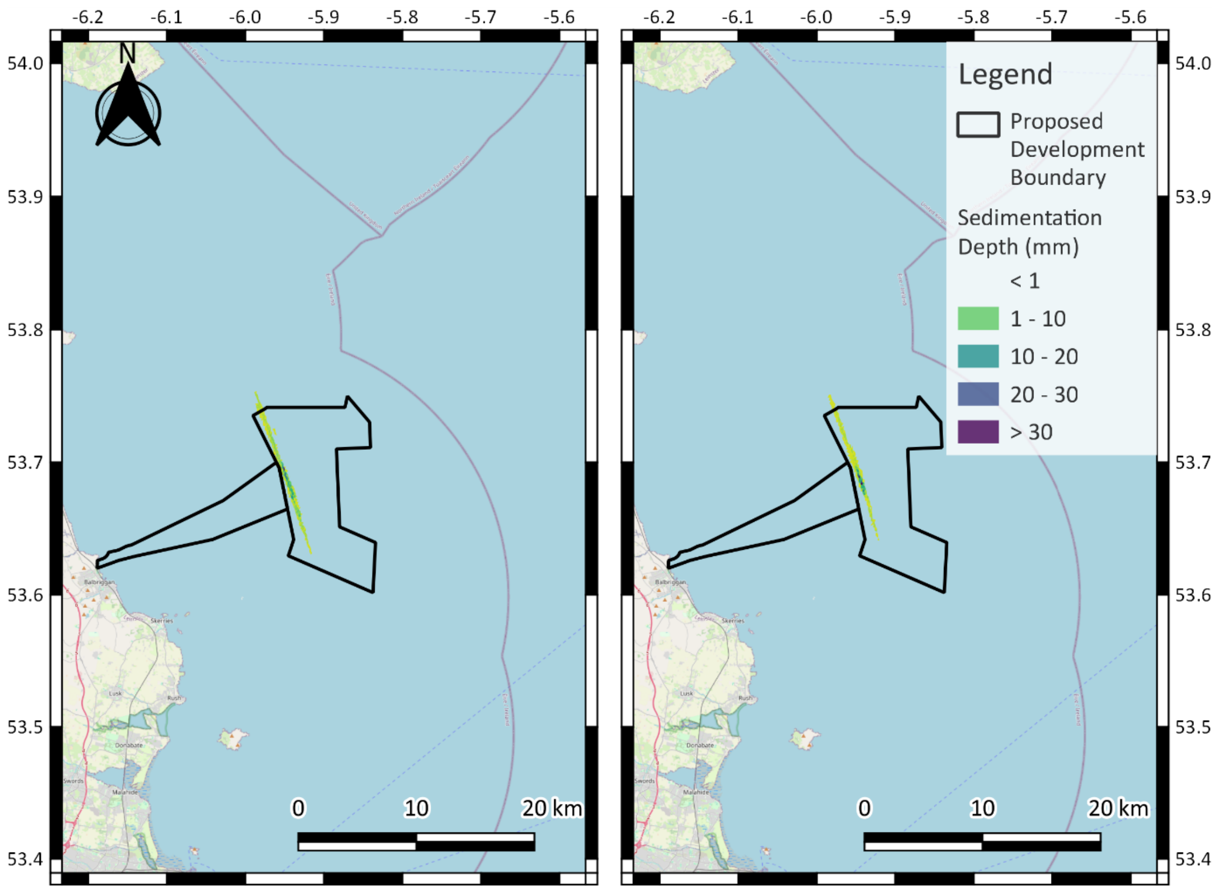

Figure 7.2. Maximum sediment deposition depths from the foundation installation scenarios (left panel = drilling location 1, right panel = drilling location 2).

Similar to the results for suspended sediment concentrations, the differences between the two scenarios for sedimentation depth (left and right panel) are also small in terms of geographical spread and depth of sedimentation.

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