Awel y Môr Offshore Wind Farm

Category 6: Environmental Statement

Volume 4, Annex 2.2: Physical Processes Model Calibration

Date: April 2022

Revision: B

Application Reference: 6.4.2.2.

Pursuant to: APFP Regulation 5(2)(a)

REVISION	DATE	STATUS/ REASON FOR ISSUE	AUTHOR:	CHECKED BY:	APPROVED BY:
A	August 2021	PEIR	ABPmer	RWE	RWE
B	March 2022	ES	ABPmer	RWE	RWE

www.awelymor.cymru

RWE Renewables UK
Swindon Limited

Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
T +44 (0)8456 720 090
www.rwe.com

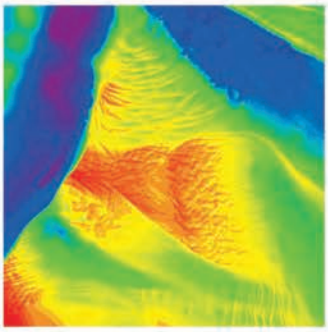
Registered office:
RWE Renewables UK
Swindon Limited Windmill
Hill Business Park Whitehill
Way
Swindon

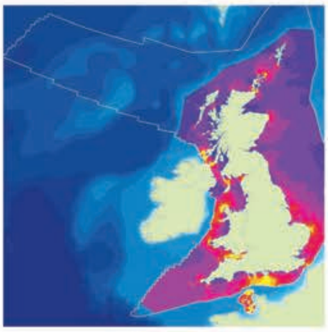
GoBe Consultants Ltd

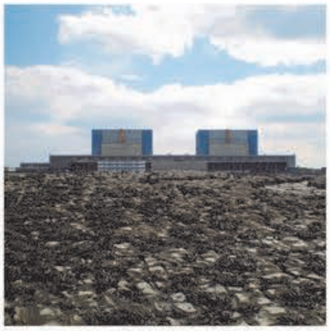
Awel y Môr Offshore Windfarm

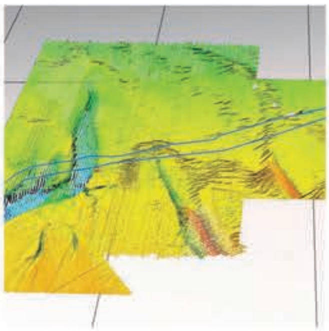
Volume 4, Annex 2.2: Model Design and Validation

July 2021









Innovative Thinking - Sustainable Solutions

Page intentionally left blank

Awel y Môr Offshore Windfarm

Volume 4, Annex 2.2: Model Design and Validation

July 2021

Document Information

Document History and Authorisation		
Title	Awel y Môr Offshore Windfarm	
	Volume 4, Annex 2.2: Model Design and Validation	
Commissioned by	GoBe Consultants Ltd	
Issue date	July 2021	
Document ref	R3624	
Project no	4913	
Date	**Version**	**Revision Details**
09/7/2021	2	Issued for Client use

Prepared (PM)	Approved (QM)	Authorised (PD)
Anthony Brooks	David Lambkin	Heidi Roberts

Suggested Citation

ABPmer, (2021). Awel y Môr Offshore Windfarm, Volume 4, Annex 2.2: Model Design and Validation, ABPmer Report No. R3624. A report produced by ABPmer for GoBe Consultants Ltd, July 2021.

Notice

ABP Marine Environmental Research Ltd ("ABPmer") has prepared this document in accordance with the client's instructions, for the client's sole purpose and use. No third party may rely upon this document without the prior and express written agreement of ABPmer. ABPmer does not accept liability to any person other than the client. If the client discloses this document to a third party, it shall make them aware that ABPmer shall not be liable to them in relation to this document. The client shall indemnify ABPmer in the event that ABPmer suffers any loss or damage as a result of the client's failure to comply with this requirement.

Sections of this document may rely on information supplied by or drawn from third party sources. Unless otherwise expressly stated in this document, ABPmer has not independently checked or verified such information. ABPmer does not accept liability for any loss or damage suffered by any person, including the client, as a result of any error or inaccuracy in any third party information or for any conclusions drawn by ABPmer which are based on such information.

All content in this document should be considered provisional and should not be relied upon until a final version marked '*issued for client use*' is issued.

ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
[redacted]

Contents

Tables

Figures

1 Introduction

1.1 Overview

ABPmer has been commissioned by GoBe Consultants to undertake numerical modelling to inform the Environmental Impact Assessment (EIA) for the proposed Awel y Môr Offshore Wind Farm (hereafter referred to as AyM). A range of numerical models have been developed to address the following aims:

- Hydrodynamics: Characterise the impact of wind farm foundations on the hydrodynamic regime (tidal currents and water levels) during the operation phase.
- Sediment plumes: Characterise the patterns of elevated suspended sediment concentration (SSC) and sediment deposition resulting from sediment disturbance during the construction phase.
- Waves: Characterise the impact of wind farm foundations on the wave regime (wave height, period and direction) during the operation phase.

This report presents information about the design and validation of the above models. This report does not directly consider the potential impacts or implications of any reported changes.

The maximum design scenarios modelled, and presentations and discussion of the results from the modelling are not contained in this report but may be found in the Technical Assessment Report (Volume 4; Annex 2.3 Marine Geology, Oceanography and Physical Processes Impact Assessment Annex), an annex to the Preliminary Environmental Information Report (PEIR)).

1.2 General approach to modelling

The numerical modelling for this study has been undertaken using the MIKE21FM (flexible mesh) software package from the Danish Hydraulic Institute (DHI), which has been developed specifically for application in oceanographic, coastal and estuarine environments.

When used by an experienced modeller, and in conjunction with suitable data inputs, these models provide reliable and realistic representations of both baseline environmental conditions and the potential effects of offshore wind farm infrastructure and other construction related activities.

The hydrodynamic modelling described in this report is undertaken using a 2D (depth averaged) tidal model, utilising a flexible mesh with high resolution in the study area. The model is run in a tide only mode (no effect of winds or air pressure) to simulate a continuous timeseries of water levels and currents over a representative spring-neap period.

The sediment plume modelling described in this report is undertaken using a particle tracking approach, whereby particles representing discrete amounts of sediment are released and subject to advection and dispersion within the simulated flow fields from the hydrodynamic model.

The wave modelling described in this report is undertaken using a spectral wave model, utilising a flexible mesh with high resolution in the study area. The model is run in a quasi-stationary mode to simulate a range of discrete representative seastates. The wave model is not required to simulate historical timeseries of actual wave conditions.

2 Tidal Currents and Water Levels

2.1 Overview

This section describes the design and inputs to a hydrodynamic model simulating tidal currents and water levels in the EIA study area for AyM. The model will be used to simulate baseline conditions, and the impact of wind farm foundations on baseline conditions. This hydrodynamic model also provides the flow field inputs for the sediment plume model described in Section 3.

Scenario specific information and model inputs are described in a separate report (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:

- Time period of simulation (typically one representative spring-neap cycle)
- Foundation type, dimensions, number and layout for
- AyM (maximum design scenario)
- Other nearby wind farms (as built).

Scenario specific results are also provided in (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:

- Patterns of:
- Baseline water levels, current speed and direction;
- Baseline residual current speed and direction;
- Baseline (current related) sediment transport rate and direction;
- Baseline (current related) residual sediment transport rate and direction;
- Patterns of change to all of the above as a result of the presence of wind farm foundations.

2.2 Tidal model design

2.2.1 General design

The tidal model is built using the MIKE21FM Hydrodynamic (HD) module, which simulates the propagation of the tidal wave and associated movements of water volume in offshore and coastal settings.

The tidal model creates a timeseries simulation of tidal water levels and depth averaged current speed and direction throughout the model domain.

The tidal model is based on the ABPmer SEASTATES validated regional-scale European Shelf Tide and Surge model, used in a tide-only mode, with locally enhanced resolution in the study area. The design and performance of the regional model are described in a separate report (ABPmer, 2017).

2.2.2 Tidal model mesh extent and resolution

The tidal model grid is based on that used by the ABPmer SEASTATES European Shelf Tide and Surge model (ABPmer, 2017). The extent of the model mesh and the distribution of mesh resolution is shown in Figure 1. A flexible mesh design is used (interlocking triangular 'elements' of varying shape and orientation), providing tailored spatially variable resolution within a single model mesh.

The (variable) resolution of the mesh outside of the study area is sufficient and suitable to simulate the general progression of the tidal wave and associated movement of water volume around the European continental shelf, up to the edges of the local study area.

Resolution is increased to approximately 100 m throughout the main study area between Liverpool Bay and Anglesey, including AyM and the surrounding wind farms, and extending approximately 25 km offshore. The relatively high resolution provides a more detailed description of the key bathymetric and coastal features affecting flow patterns in these areas, including Constable Bank and Rhyl Flats. The higher resolution is also relevant to the resolution of outputs from the sediment plume model described in Section 3.

To assist the assessment, individual model grid elements have been located around the actual ('as built') locations of foundations in the nearby operational windfarms (Gwynt y Môr, Rhyl Flats, North Hoyle, Burbo Bank and Burbo Bank Extension), as well as around the indicative locations of foundations for different design options in the AyM array area.

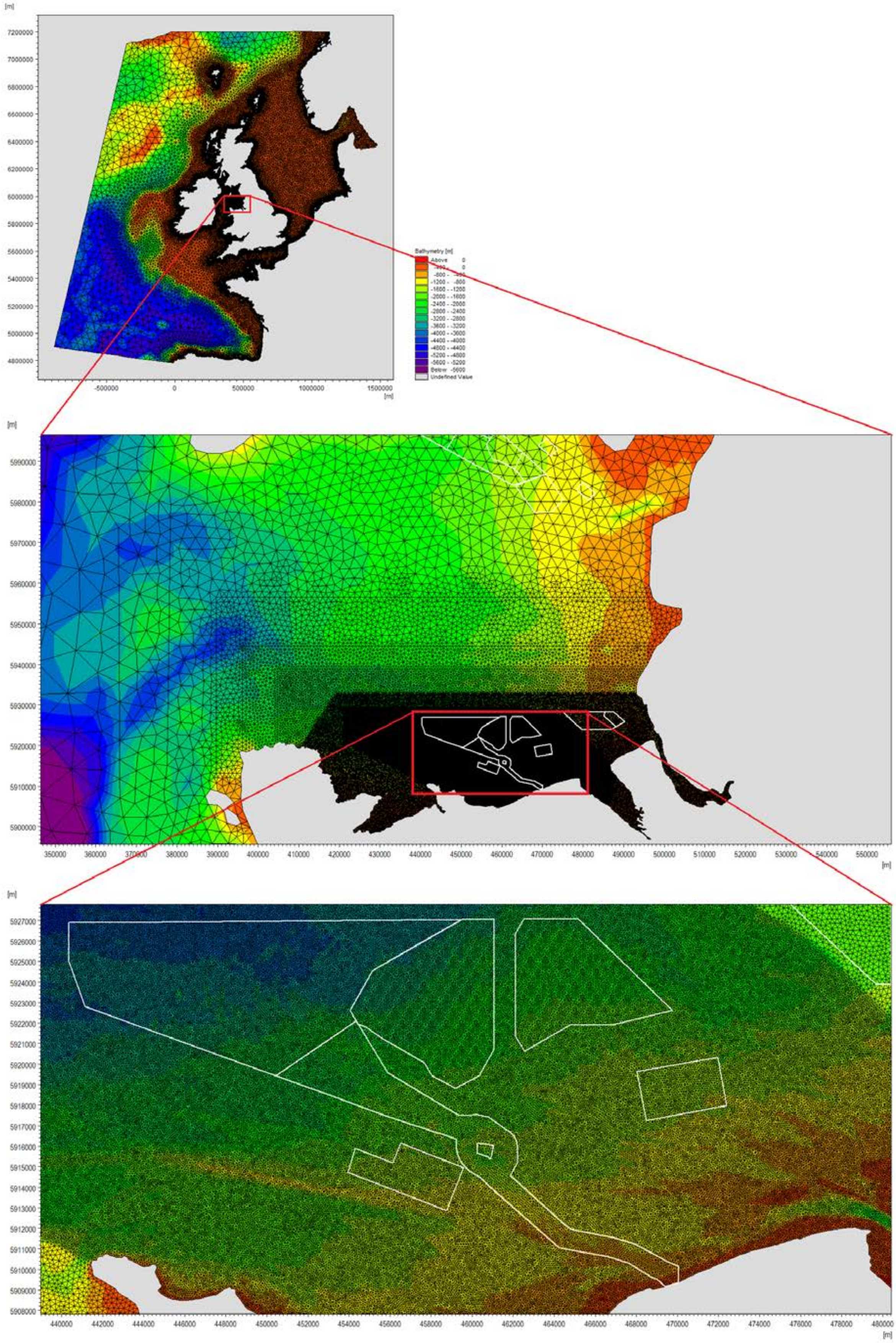


Figure 1. Extent of the tidal model mesh, showing regional and locally enhanced resolution. Lower plot also shows the extent of AyM and other adjacent windfarms.

2.2.3 Tidal model bathymetry

The tidal model bathymetry outside of the AyM study area is the same as used by the original ABPmer SEASTATES European Shelf Tide and Surge model. The regional bathymetric data is sourced from EMODnet [redacted] which is a freely available and generally reliable data source. The good level of validation achieved by the model with respect to water levels and currents (ABPmer, 2017) provides indirect validation of the bathymetry data source.

Additional higher resolution survey data from AyM and from the United Kingdom Hydrographic Office (UKHO) are used instead of the regional data within area of higher mesh resolution in the AyM study area.

Spatially varying adjustments are made to convert the bathymetry data from the standard Lowest Astronomic Tide (LAT) datum at source, to Mean Sea Level (MSL), as is required for use in the model. Adjustments are made using a combination of VORF (Vertical Offshore Reference Frames, UCL and UKHO, 2005) and tidal water level statistics from tide gauges for locations elsewhere in Europe outside of the VORF data extent.

2.2.4 Tidal model boundary conditions

Offshore tidal boundaries

The tidal model has four open water level boundaries, shown in Figure 2.

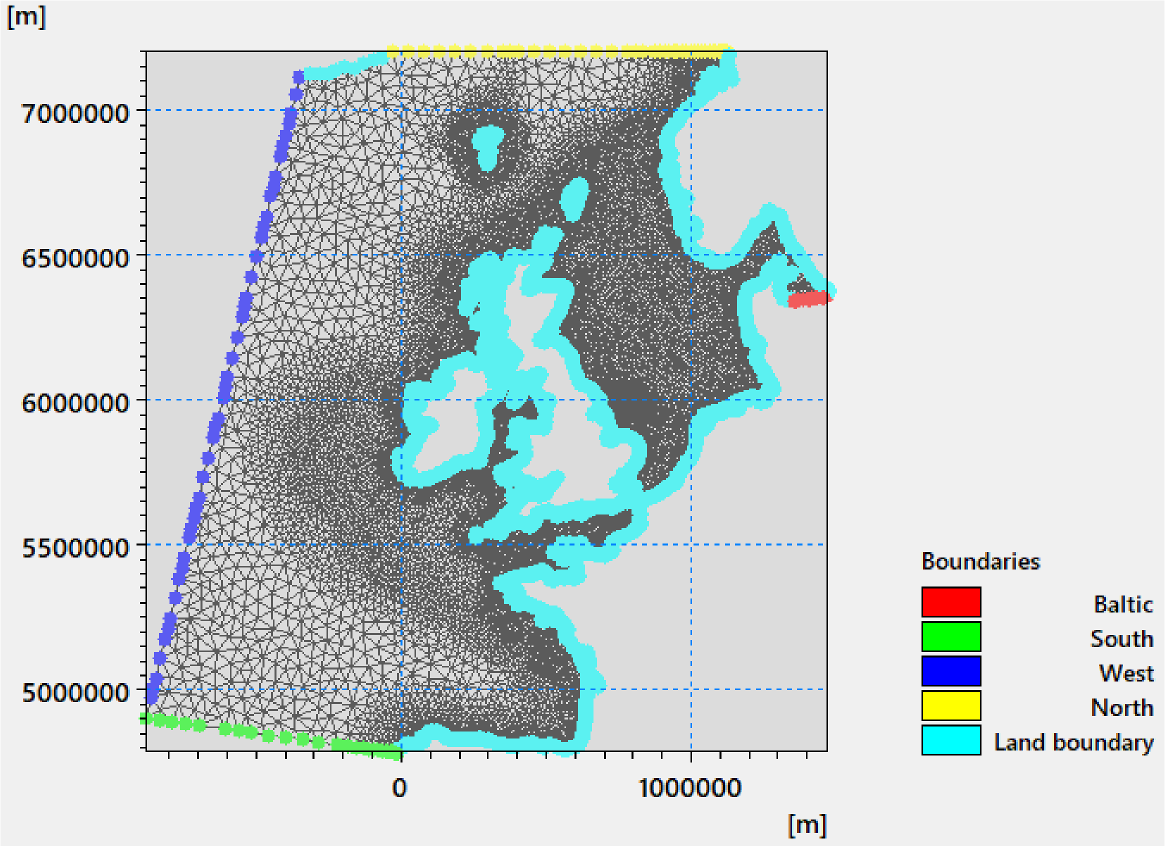


Figure 2. Tidal model boundaries

Temporally and spatially varying tidal water levels are applied at these boundaries, representing the passage of the deep ocean tidal wave from the North Atlantic onto the European shelf (and smaller exchanges with the Baltic Sea). Tidal boundary data are obtained using the DTU10 (DTU, 2010) database of harmonic constituents. The good level of validation achieved by the model with respect to water levels and currents (ABPmer, 2017) provides indirect validation of the tidal boundary data source.

Meteorological boundaries

The effect of winds and air pressure (for non-tidal surge related influences) are not included in this (tide-only) model.

2.2.5 Tidal model bed roughness

Bed roughness in the model describes the friction from the seabed 'felt' by moving water. Changing the magnitude of bed roughness locally effects the rate at which water moves in that area and so can affect both tidal range and phasing, and (mainly the speed of) tidal currents. As such bed roughness is a key variable in the model that can be varied to optimise the model performance in comparison to coincident measured data.

The ABPmer SEASTATES European Shelf Tide and Surge model utilises a bespoke spatially varying map of bed roughness, created by combining information about the distribution of seabed and sediment type, and water depth. The good level of validation achieved by the model with respect to regional scale patterns of water levels and currents (ABPmer, 2017), which provides indirect validation of the bed roughness values.

The same validated spatially variable bed roughness distribution is applied in the present study, with no adjustments made.

2.3 Tidal model validation

The regional SEASTATES tide model largely controls the timing, magnitude and direction of water levels and currents entering and propagating through the local study area. The regional model has been separately validated against the tide gauge and current meter data in numerous locations around the European continental shelf, including tide gauges at Liverpool, Llandudno and Holyhead (ABPmer, 2017).

The tidal model has also been locally validated against two sets/periods of measured current and water level data from within and nearby to the AyM study area. The measurements were all made using Nortek Acoustic Wave And Current (AWAC) profilers, deployed on seabed frames.

Measured data were collected at three locations within the main AyM study area (GyM_A, GyM_B and GyM_C, shown in Figure 3) to support consenting and design of the adjacent Gwynt y Môr (GyM) wind farm. The data were collected during February and March 2005, and include water levels and profiles of current speed and direction.

Measured data were also collected at three locations (DCWW_1, DCWW_2 and DCWW_3, shown in Figure 3) by Dwr Cymru Welsh Water (DCWW) to support consenting and design of waste water outfalls. The data were collected during October and December 2015, and include water levels and profiles of current speed and direction.

Four of the locations (GyM_A, GyM_B, GyM_C and DCWW_1) are within the main AyM study area and are most relevant to the objectives of the modelling to inform EIA. The other two locations (DCWW_2 and DCWW_3) are further away and in areas unlikely to be affected by the construction or operation of AyM.

Comparisons of the measured (total, including tide and surge effects) and modelled (tide only) water levels, depth averaged current speed and direction at the six survey locations are provided in Figure 4 to Figure 9.

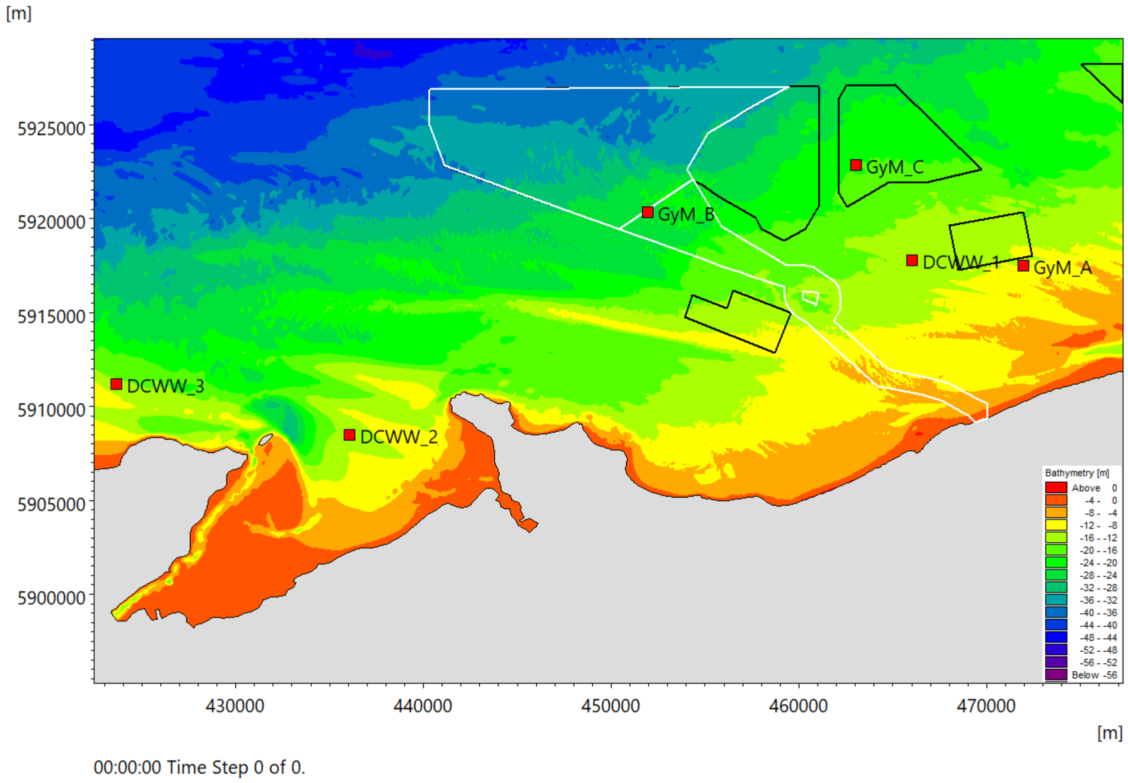
The plots generally show that the tide model provides a good representation of the overall magnitude, timing and variance of water levels, current speed and direction at the four locations within the main AyM study area.

The time varying water level is important for the correct simulation of time varying total local water depth, which is a relevant factor in the calculation of suspended sediment concentration and time for sediment settlement in the plume modelling. The model is shown to provide an accurate description of the absolute water level and the timing of variation in water level (especially relative to currents).

The main axis and direction of rotation of tidal currents, and the relative variation in peak current speed between adjacent flood/ebb tides are all important for the realistic simulation of local tidal asymmetry and net drift, which affect sediment plume advection and dispersion. The direction of currents throughout the tide and the rate and direction of flow rotation are generally well represented by the model in the main AyM study area. The model is also shown to simulate a similar pattern of asymmetry in peak current speed at each location.

The modelled conditions (peak current speed and high and low water levels) are typically close in magnitude to either the corresponding or adjacent observed tide within a 12 or at most 24 hour period. The differences are, small in absolute and relative terms, and within the range of variability from tide to tide.

Some minor differences are observed between the sites where the model simply cannot be calibrated further to simultaneously reproduce all details of all tides at all locations. Some differences may also be the result of local effects of complex bathymetry that are either not represented in the available bathymetry data, or not fully resolved by the 100 m resolution of the model. On individual tides, there may also be intermittent meteorological influence in the observed data, when compared to the tide only model prediction.



GyM_A (nearshore, east of the AyM export cable corridor);
GyM_B (southern edge of the AyM array area);
GyM_C (~5km east of the AyM array area);
DCWW_1 (east of the central section of the AyM export cable corridor);
DCWW_2 (nearshore, Conwy Bay);
DCWW_3 (nearshore, Anglesey);
Also showing the outline of OWF array areas.

Figure 3. Locations of the measured data used for tidal model validation.

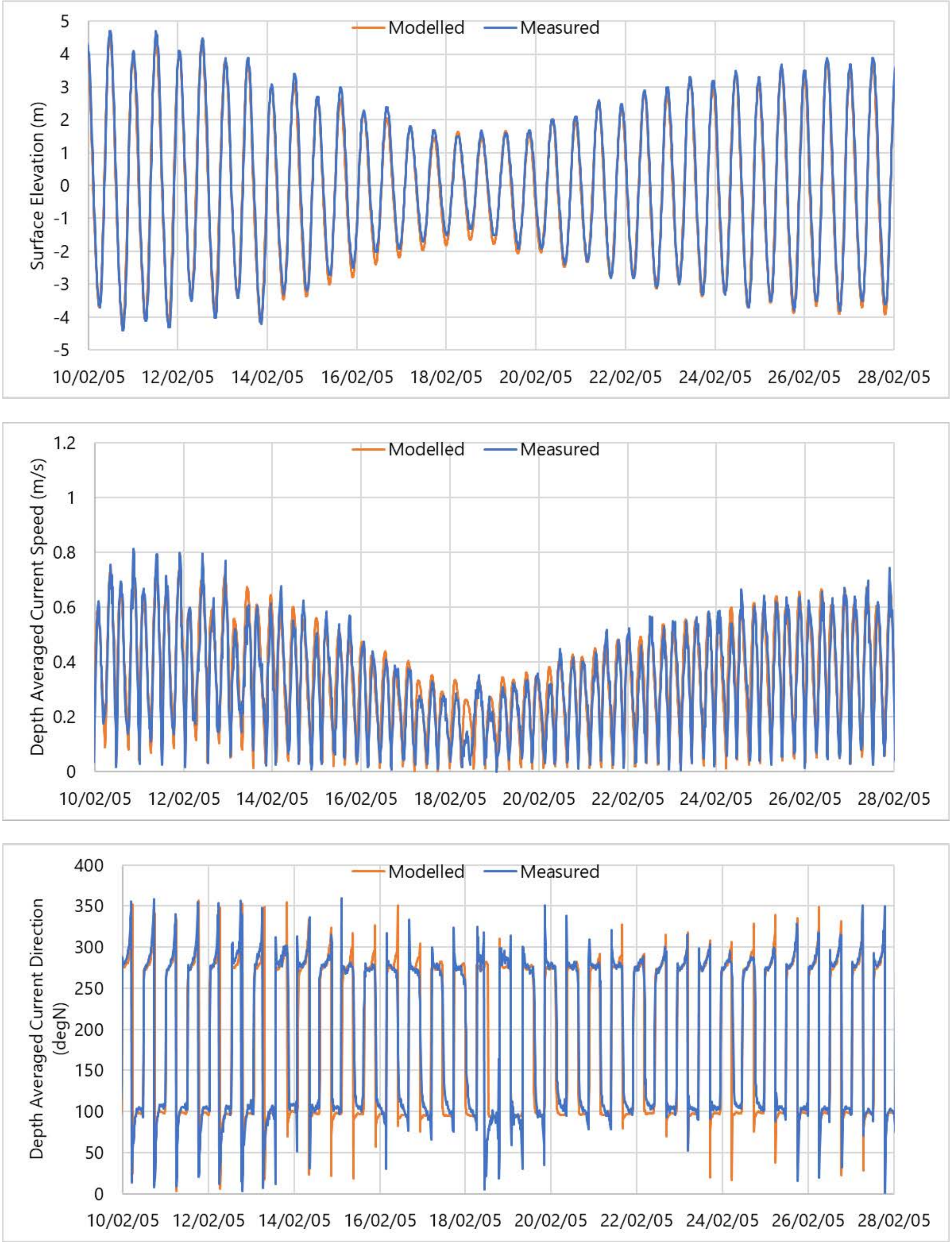


Figure 4. Comparison of measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location GyM_A (nearshore, east of the AyM export cable corridor)

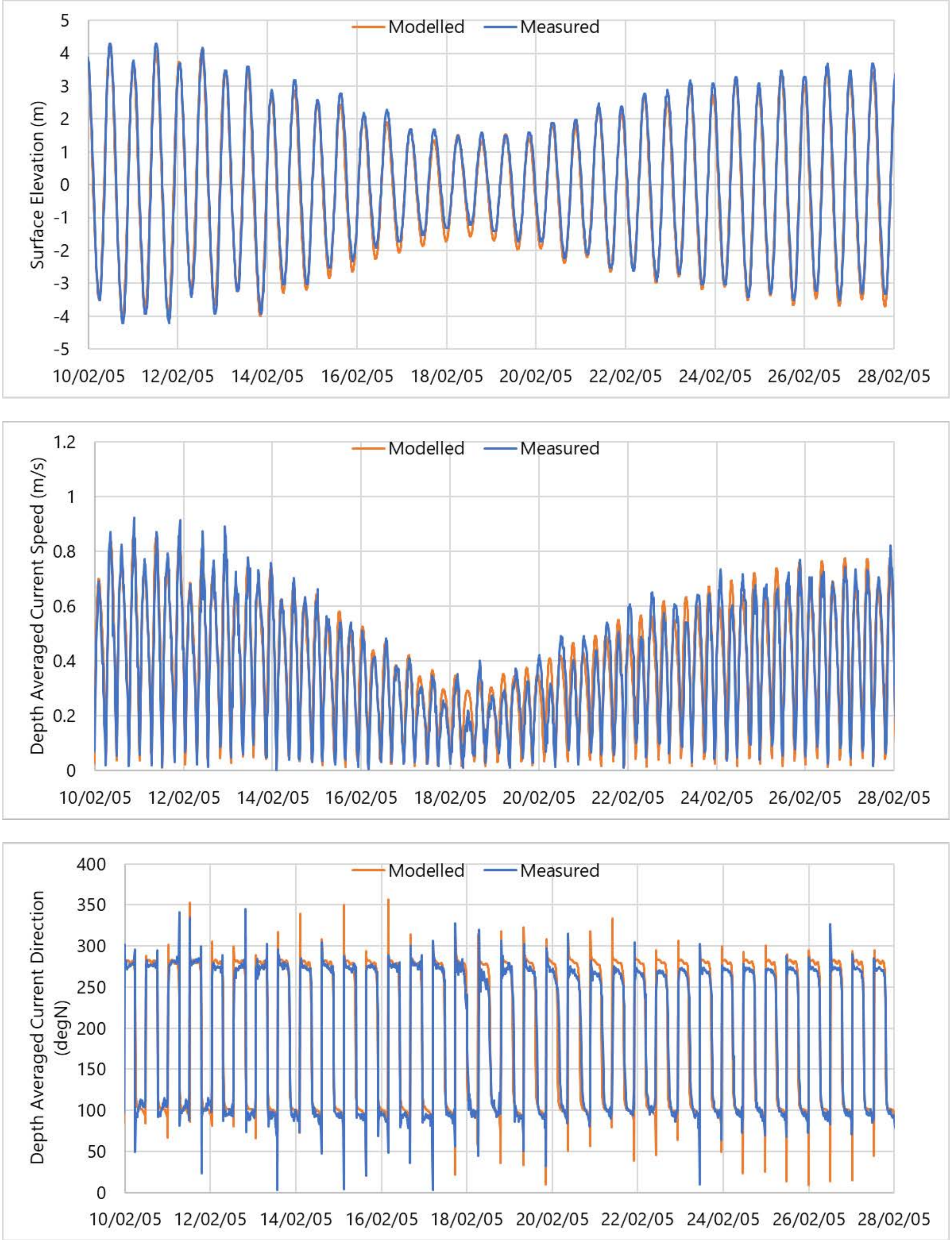


Figure 5. **Comparison of measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location GyM_B (southern edge of the AyM array area)**

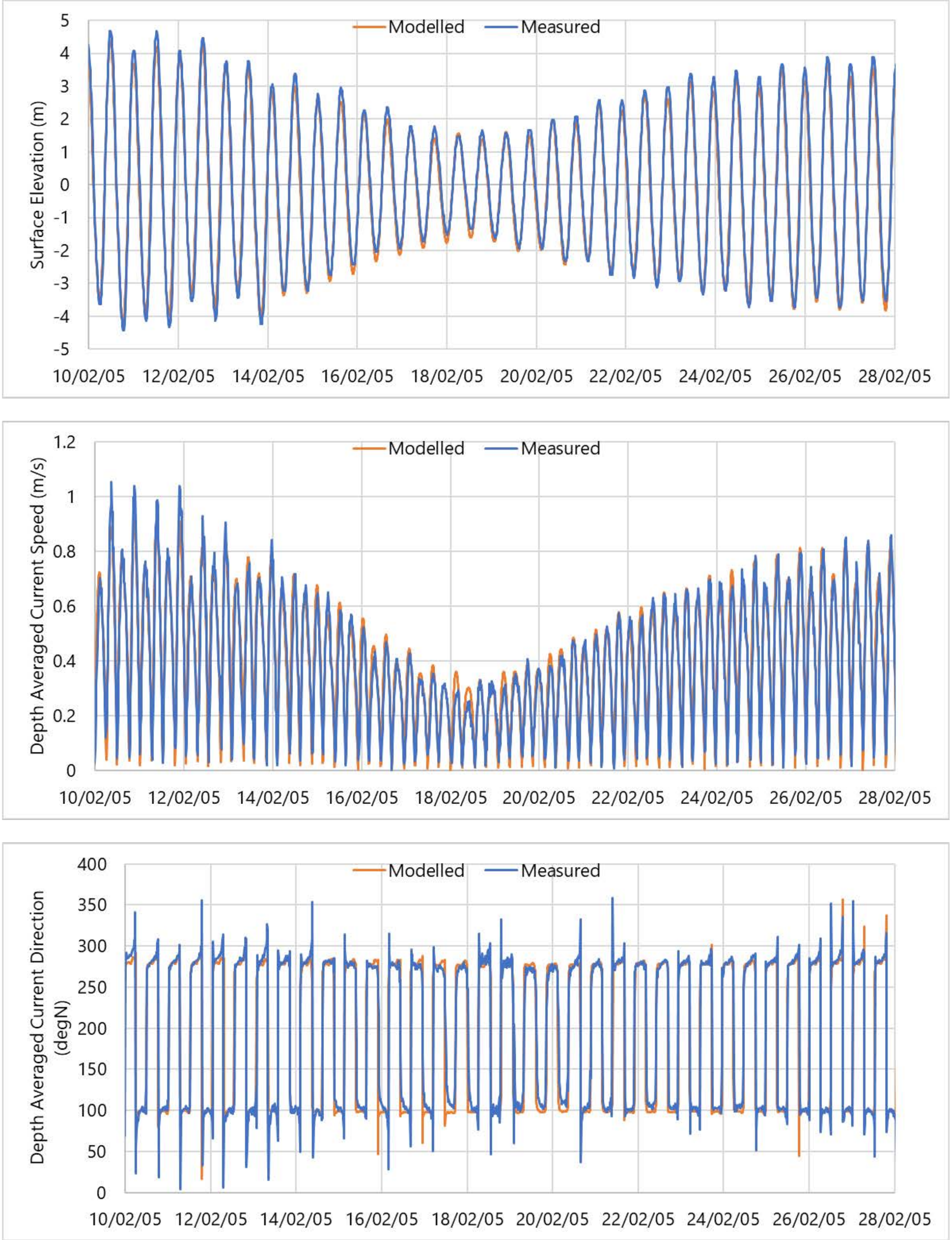


Figure 6. **Comparison of measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location GyM_C (~5km east of the AyM array area)**

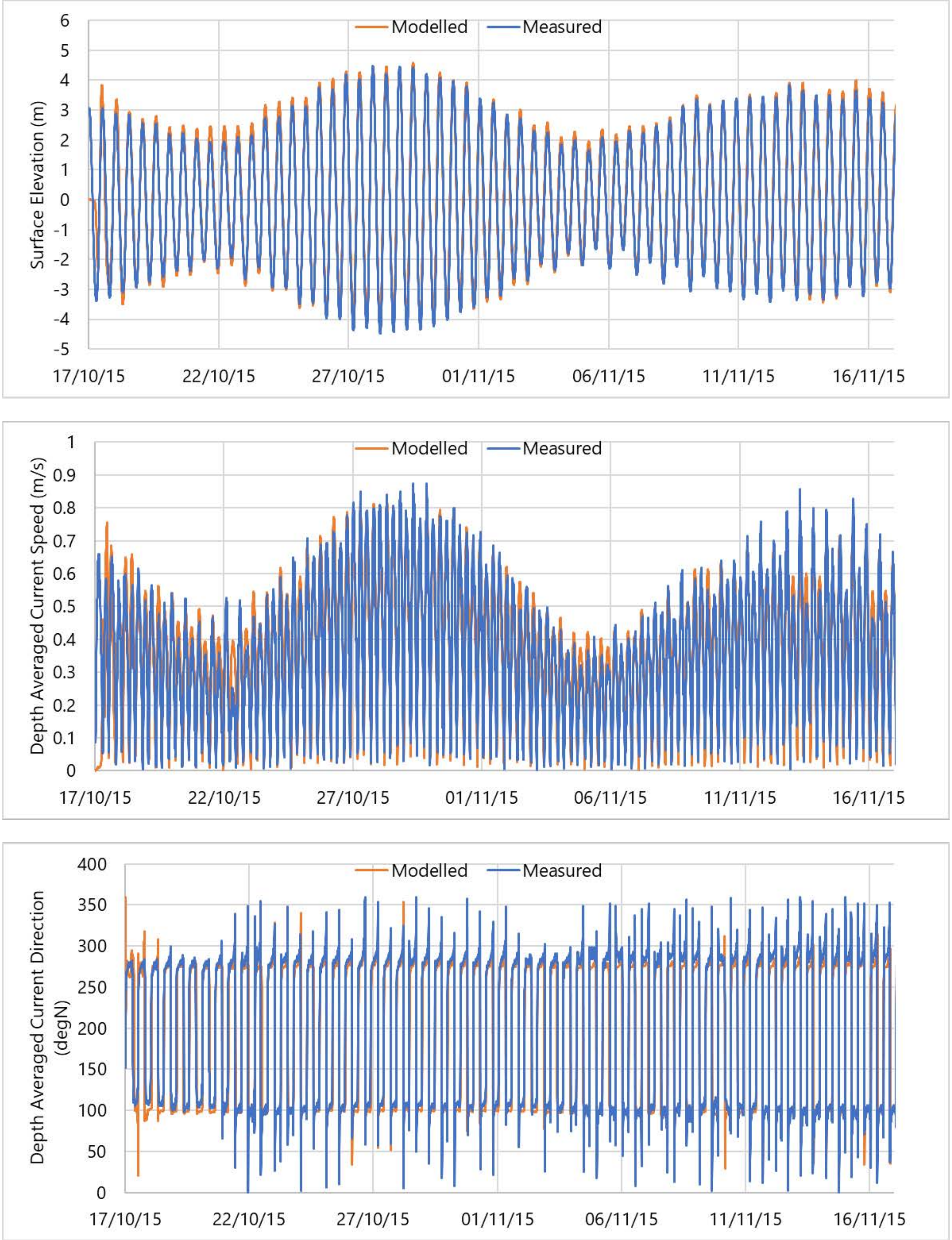
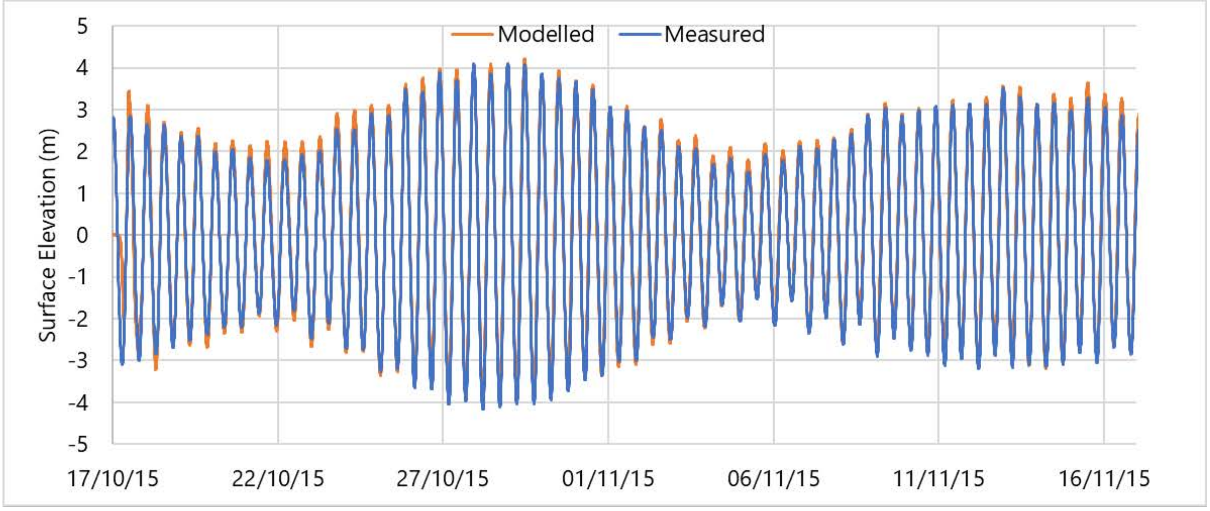
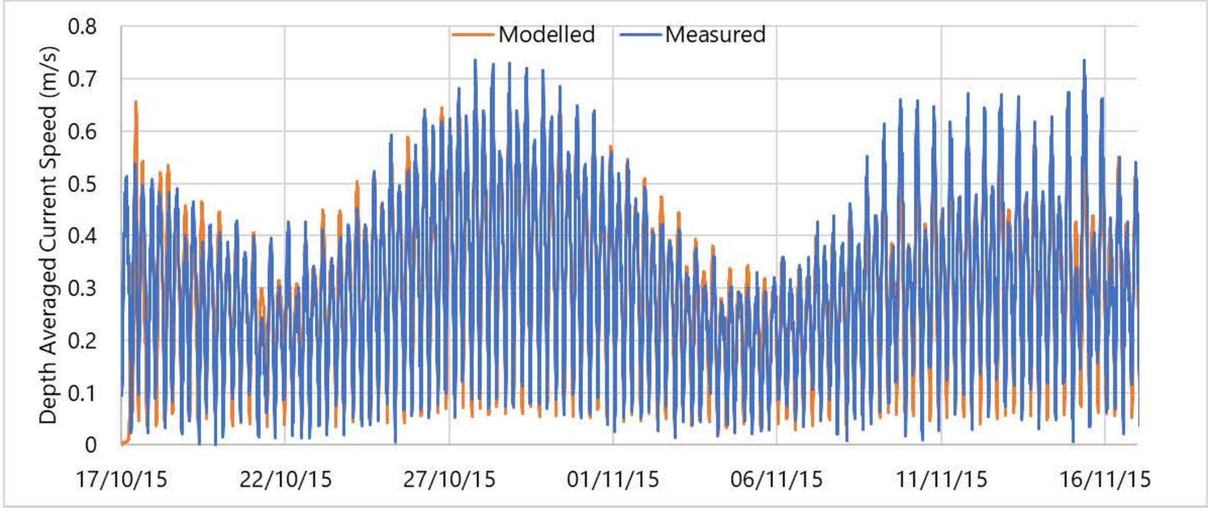


Figure 7. **Comparison of measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location DCWW_1 (east of the central section of the AyM export cable corridor).**





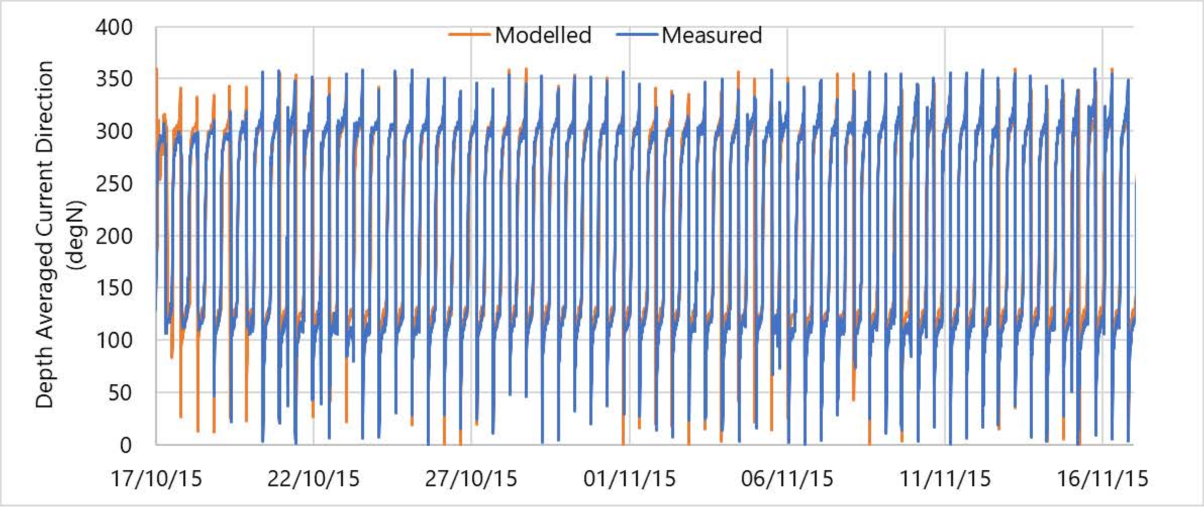


Figure 8. **Comparison of measured measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location DCWW_2 (nearshore, Conwy Bay).**

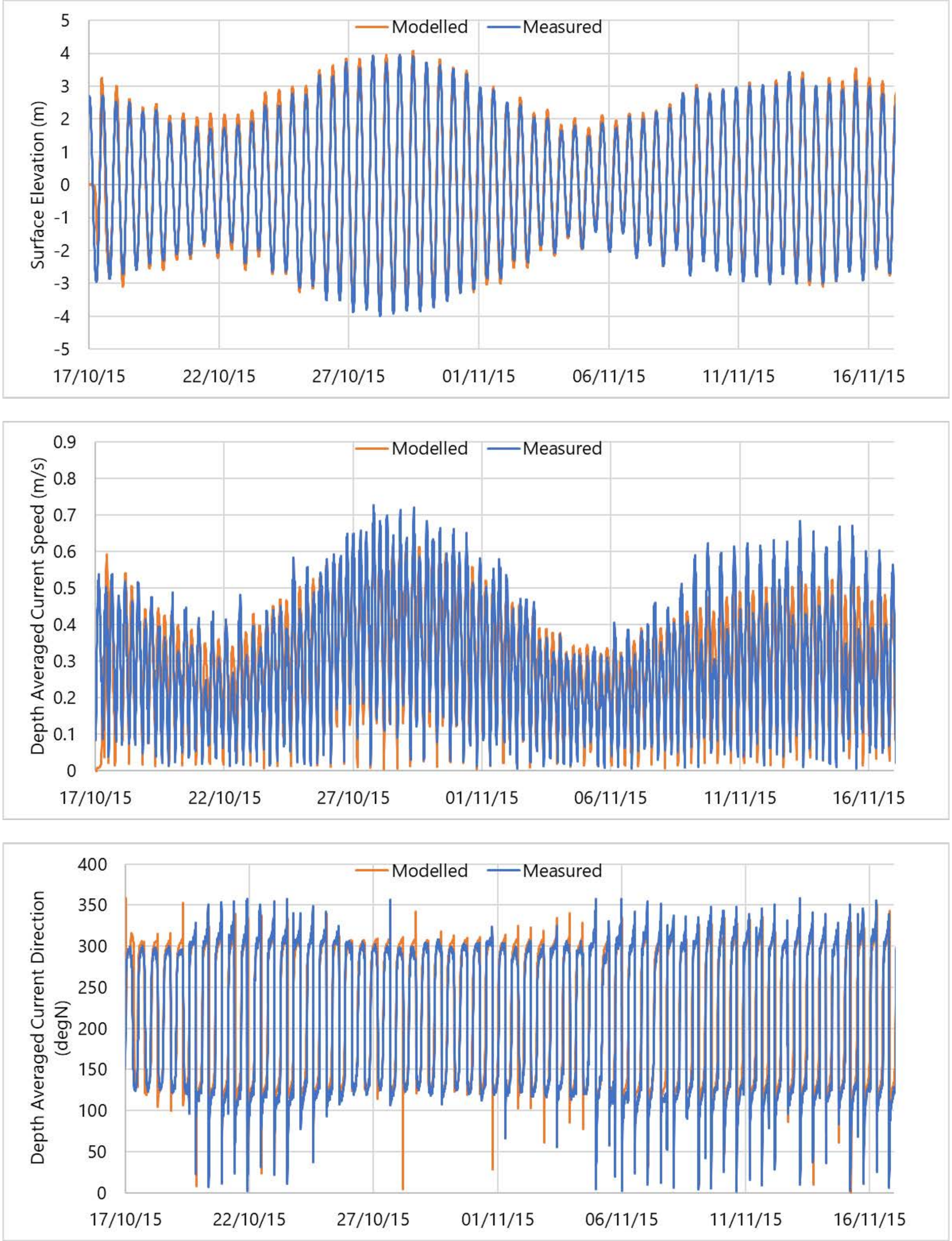


Figure 9. **Comparison of measured (total tide and surge) and modelled (tide only) hydrodynamic parameters at location DCWW_3 (nearshore, Anglesey).**

3 Sediment Disturbance

3.1 Overview

This section describes the design and inputs to a sediment plume model simulating patterns of suspended sediment concentration and resulting sediment deposition thickness in the EIA study area for AyM. The model will be used to simulate the impact of various activities that may disturb sediment in relation to the planned wind farm infrastructure.

Scenario specific information and model inputs are described in a separate report (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:

- Activity type;
- Location;
- Rate of movement of the source or static release;
- Height of sediment release in the water column;
- Rate of sediment release; and
- Proportion of sediment in each grainsize category.

Scenario specific results are also provided in (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:

- Distribution of SSC at the end of active disturbance and one and three days thereafter;
- Distribution of maximum instantaneous SSC at any time during and up to three days after the end of active disturbance;
- Timeseries of SSC at the site of active disturbance and at nearby observation points during and after the end of active disturbance; and
- Distribution of resulting sediment deposition thickness.

3.2 Sediment plume model design

3.2.1 General design

The sediment plume model provides a timeseries simulation of SSC and settled sediment thickness in response to sediment release, advection and dispersion within the model domain. The sediment plume model is built using the MIKE21FM Particle Tracking (PT) module which simulates the horizontal and vertical advection and dispersion of sediment, represented as numerous discrete particles, within a temporally and spatially varying flow field.

3.2.2 Sediment plume model extent, resolution, bathymetry and hydrodynamic inputs

The sediment plume model utilises the same model grid and the flow field timeseries generated by the validated hydrodynamic model described in Section 2. The model is therefore able to consider a range of tidal conditions over a range of representative (e.g. spring and neap) tidal conditions. A relatively high level of spatial resolution (~100 m) is used in the area of the proposed sediment releases, including the export cable corridor.

3.2.3 Sediment plume model sediment types, settling, dispersion and erosion rates

Five different sediment grain size fractions are considered in the plume dispersion modelling, although only certain grades may be relevant to specific scenarios. The sediment grain size fractions considered and their associated settling rates (from Soulsby, 1997) are summarised in Table 1.

Table 1. Sediment grain size fractions used

Sediment Fraction Name	Representative Grain Size	Representative Settling Velocity
Gravel	~8,000 µm	0.5 m/s
Coarse sand	~1,000 µm	0.1 m/s
Medium sand	~250 µm	0.03 m/s
Fine sand	~150 µm	0.01 m/s
Silt	~10 µm	0.0001 m/s

A higher than default horizontal dispersion rate of 1.0 m^2/s is applied to all sediment grain size fractions. Smaller values (0.1 and 0.01 m^2/s) were also considered but resulted in very narrow plumes with a very limited footprint of effect that did not appear to measurably disperse over the model simulation period. The value used is within the (relatively wide) range of generally reported values based on observations of this parameter. As a result, the rate of increase in plume width with time is (slightly) increased, which provides a more conservative indication of area of effect. The corresponding SSC values are (slightly) reduced but are still realistically elevated in comparison to typical baseline values. A vertical dispersion rate of 0.01 m^2/s is applied to all sediment grain size fractions.

Once deposited to the seabed, sediment in the model is made unable to be eroded and will remain *in situ*. In practice, sediment in a plume that has been deposited to a similar area of seabed will immediately re-join the natural sedimentary environment and will be naturally eroded at the same time and rate as all other naturally present sediment in that location. By restricting re-erosion, the area and thickness of initial deposition from the sediment plume can be observed in more detail.

3.3 Sediment plume model validation

Predictive location specific plume models are not normally validated, as location specific observations of the activities being simulated are rarely available. However, this type of modelling approach, in conjunction with validated hydrodynamic inputs, is generally accepted to provide a realistic description of sediment plumes in the marine environment.

The following additional points also support confidence in the modelling process and results:

- Section 2.3 validates the accuracy and representativeness of the water level, current speed and direction data that control the rate and direction of sediment plume advection in the particle tracking model.
- The representative rate of dispersion is controlled by the model settings but can be variable in practice depending on other environmental conditions (e.g. wave conditions).
- The inputs and settings used in the model and the definitions of the sediment disturbance activities are considered to be conservatively realistic. The modelling process and analysis of the results are undertaken by an experienced coastal processes modeller.

4 Waves

4.1 Overview

This section describes the design and inputs to a wave model simulating patterns of wave height, period and direction in the EIA study area for AyM. The model will be used to simulate baseline conditions, and the impact of the wind farm foundations on baseline conditions.

Scenario specific information and model inputs are described in a separate report (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:
- Foundation type, dimensions, number and layout for
- AyM (maximum design scenario)
- Other nearby wind farms (as built).

Scenario specific results are also provided in (Volume 4, Annex 2.3: Marine Geology, Oceanography and Physical Processes Technical Assessment), including:
- Patterns of baseline wave height and wave direction;
- Patterns of change to wave height, wave period and wave direction as a result of the presence of wind farm foundations.

4.2 Wave Model Design

4.2.1 General design

The wave model is built using the MIKE21FM Spectral Wave (SW) module, which simulates the propagation of the tidal wave and associated movements of water volume in offshore and coastal settings.

The wave model creates discrete simulations of wave height, period and direction throughout the domain, for a representative range of selected everyday and extreme wave conditions (return periods and directions).

4.2.2 Wave model extent and mesh resolution

The extent and resolution of the wave model mesh is shown in Figure 10. A flexible mesh design (interlocking triangular ‘elements’ of varying shape and orientation) is used, providing tailored spatially variable resolution within a single model mesh.

Whilst the overall extent of the model is smaller than that of the HD and PT model, the resolution of the mesh is the same, with a resolution of approximately 100 m throughout the area between Liverpool Bay and Anglesey, extending approximately 25 km offshore from the adjacent coastlines.

To assist the study, individual model grid elements have been centred on the actual locations of wind turbine and offshore substation foundations in operational windfarms Gwynt y Mor, Rhyl, Hoyle and Burbo Bank, as well as the proposed locations of AyM.

4.2.3 Wave model bathymetry

The bathymetry data used for the SW model is the same as that used within the same extent of the hydrodynamic and sediment plume models. See Section 2.2.3 for more details.

The wave model is run with a constant mean water depth (no tidal water level variation). This provides a central description of the range of total water depths that might be experienced within the study area. The timing of larger extreme wave events is independent of the timing of tidal processes (high water/low water/spring/neap). A relatively higher water level might allow larger waves to extend further onto or beyond otherwise shallower areas of the domain (e.g. Rhyl Flats, Constable Bank), or *visa versa*. However, the main effect of the foundations on waves is within the relatively deep offshore array area (approximately 18 to 45 m to mean sea level), where there is only a relatively small difference in total water depth between a mean tidal water level and a mean spring high or low water (±3.25 m). Sensitivity testing of the model indicates minimal difference as a result.

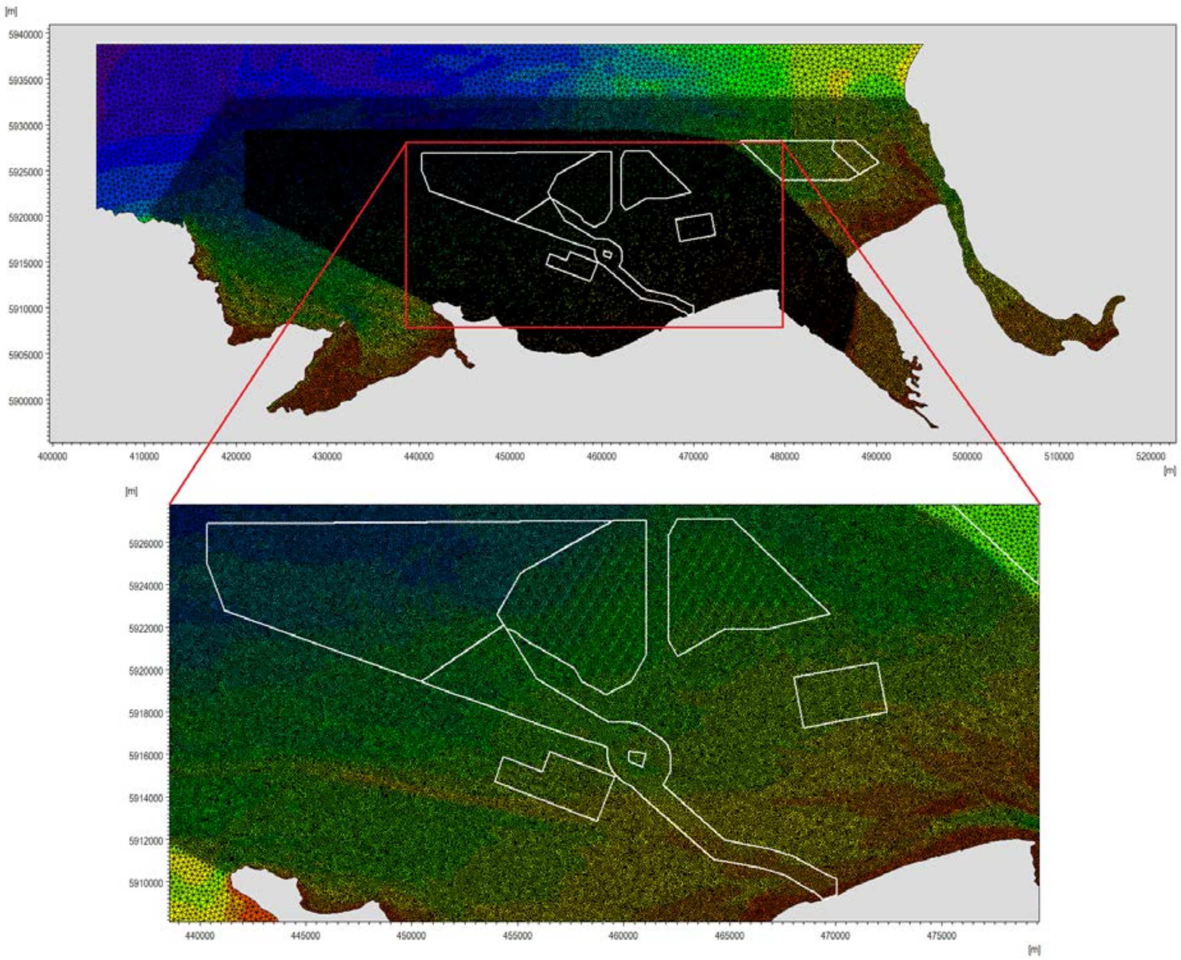


Figure 10. **Extent of the wave model mesh, showing locally enhanced resolution. Lower plot also shows the AyM windfarm extent and adjacent windfarms.**

4.2.4 Spectral and time formulations

A fully spectral formulation is used. The fully spectral formulation is based on a wave action conservation relationship where the directional-frequency wave action spectrum is the dependent variable. Of the available choices, this formulation is considered to be the most accurate for the nature of the processes being simulated with respect to both general wave propagation and the effect of the wind farm foundations.

A quasi-stationary time formulation is used. Time is removed as an independent variable and a steady state solution is calculated for each seastate being simulated. This choice is appropriate for the limited size of the model domain, within which waves are likely to achieve an equilibrium state dependant on the input wave and wind boundary conditions.

A logarithmic distribution of 36 spectral frequencies are resolved, equivalent to wave periods in the approximate range from 1 to 30 s, with smaller intervals at smaller wave periods. This exceeds the default number and range (25 spectral frequencies, from 1.8 to 18 s) in order to better resolve a wider range of wave periods.

Directional calculations are made using 32 directional sectors (each sector covering a range of 11.25°). This exceeds the default number (16 directional sectors, 22.5°) in order to reduce the occurrence of small magnitude ‘radial artefacts’ in the scheme effect results when obstacles representing the offshore wind farm infrastructure are included in the model. The baseline wave maps are largely unaffected by the difference.

4.2.5 Wave model boundary conditions

The wave model is forced by wave conditions (height, period, direction and directional spreading) at the two offshore wave boundaries (along the northern and western extents of the model domain), and by a constant wind speed and direction applied over the whole domain. The wave model is run with a constant mean water depth (no tidal water level variation) and no currents.

The wave condition scenarios considered by the model for the assessment are:

- Wave coming directions (W, WNW, NW, NNW and N); and
- Return periods (50% non-exceedance, 0.1 yr; 1 yr; 10 yr; 50 yr; 100 yr).

An understanding of the potential impacts of OWF infrastructure within this range of conditions will inform the assessments regarding potential impacts on sedimentary/coastal processes and flood risk. These conditions were initially determined using Extreme Value Analysis (EVA) for a location in the central part of the AyM array area, using hindcast timeseries data from the separately validated ABPmer SEASTATES NW European Shelf Wave Hindcast Model (see Section 4.2.6). The extreme values for the array area have been adjusted upwards by 25% for application on the boundary, based on a comparison of timeseries wave height data from the AyM array area and a location in the centre of the northern offshore wave boundary. Wave height is adjusted upwards by 25% and wave period by √25%, in order to evenly scale the overall wave energy between the two locations.

The wave boundary condition is applied uniformly along the two offshore wave boundaries. The condition is defined by the significant wave height (Hs), peak wave period (Tp), mean wave direction (DirM) and directional standard deviation (DirStd). The directional return period wave boundary conditions tested are listed in Table 2. The shortest return period is the wave condition not exceeded 50% of the time, representing a relatively frequent, everyday wave condition; more severe but infrequent conditions are described by the associated ‘return period’ (RP) or likelihood of occurrence expressed in years.

The wind boundary condition is applied uniformly across the whole model domain area, representing the wind speed at 10 m above sea level normally associated with the target seastate. The associated wind direction is the same as the wave direction at the boundary. The wind boundary condition is required for natural patterns of wave propagation and development through the model domain from the offshore boundaries. Wind is also a realistic mechanism contributing to wave recovery in the lee of the wind farm. The associated directional return period values of wind speed and direction used are also shown in Table 2.

Table 2. Wave and wind boundary conditions for each of the directional return period seastate conditions tested.

Directional Sector	Case (Return Period)	Significant Wave Height (m)	Peak Wave Period (Tp, s)	Mean Wave Direction (°N)	Wind Speed @10 m (m/s)	Wind Direction (°N)
W	50% no exc	1.01	5.21	270	5.9	270
	0.1 yr RP	2.61	6.76	270	11	270
	1 yr RP	4.40	8.77	270	15	270
	10 yr RP	6.05	10.28	270	17	270
	50 yr RP	7.15	11.18	270	21.4	270
	100 yr RP	7.70	11.60	270	21.4	270
WNW	50% no exc	1.14	5.75	292.5	6.5	292.5
	0.1 yr RP	3.30	7.86	292.5	12.7	292.5
	1 yr RP	5.50	10.14	292.5	17.3	292.5
	10 yr RP	7.70	12.00	292.5	21.4	292.5
	50 yr RP	9.08	13.03	292.5	22.3	292.5
	100 yr RP	9.76	13.51	292.5	26	292.5
NW	50% no exc	0.91	5.20	315	4.9	315
	0.1 yr RP	3.03	7.54	315	12	315
	1 yr RP	4.95	9.64	315	16.3	315
	10 yr RP	6.88	11.36	315	21	315
	50 yr RP	8.25	12.45	315	22.3	315
	100 yr RP	8.80	12.86	315	22.3	315
NNW	50% no exc	0.83	4.89	337.5	5.3	337.5
	0.1 yr RP	2.75	7.16	337.5	11	337.5
	1 yr RP	4.54	9.19	337.5	15.5	337.5
	10 yr RP	6.33	10.85	337.5	19.8	337.5
	50 yr RP	7.56	11.87	337.5	24	337.5
	100 yr RP	8.11	12.29	337.5	21.3	337.5
N	50% no exc	0.71	4.50	0	4.37	0
	0.1 yr RP	2.61	6.98	0	11	0
	1 yr RP	4.40	9.06	0	15	0
	10 yr RP	6.05	10.63	0	17	0
	50 yr RP	7.15	11.56	0	21.4	0
	100 yr RP	7.70	11.99	0	21.4	0

4.2.6 Wave breaking, bottom friction and other wave transformation parameters

The settings and values below are either default settings or within the range of normally recommended values and are consistent with numerous similar recent offshore wind farm modelling studies undertaken by ABPmer.

Depth-induced wave breaking is the process by which waves dissipate energy when the waves are too high to be supported by the water depth, i.e. reach a limiting wave height/depth-ratio. Wave breaking is described in MIKE21SW by standard equations that are scaled by a coefficient 'Gamma'. A constant Gamma value of 0.8 was used.

Bottom friction is relevant where, as waves propagate into shallow water, the orbital wave velocities penetrate throughout the full water depth and the source function due to wave-bottom interaction becomes important. A large part of the model domain (towards the adjacent coastlines) is shallow enough, relative to the waves being simulated, to be affected by choices relating to the implementation of bottom friction. The dissipation source function used in the spectral wave module is based on the quadratic friction law and linear wave kinematic theory. The dissipation coefficient depends on the hydrodynamic and sediment conditions. Sediment roughness is characterised in the MIKE21SW wave model by a Nikuradse Roughness length value of 0.04 m.

The MIKE21SW wave model also takes account of the following wave transformation processes (using default settings):

- White capping (Dissipation coefficients, constant Cdis = 4.5, constant DELTAdis = 0.5)
- Quadruplet-wave interaction

4.3 Wave model validation

The wave model is not required to provide historical (hindcast) predictions of wave conditions in a timeseries mode, therefore, no direct validation of the new wave model against measured timeseries data is required.

Hindcast data from the ABPmer SEASTATES NW European Shelf Wave Hindcast Model are used to inform the boundary conditions described in Section 4.2.4. The SEASTATES wave hindcast model has already been regionally validated against numerous wave buoys (ABPmer, 2013). The SEASTATES wave hindcast model is also further locally validated in Figure 11 and Figure 12, against measured data from two offshore locations within the AyM study area (GyM_B and GyM_C, shown in Figure 3), originally collected during February and March 2005 to inform the GyM OWF EIA.

Without adjustment, the SEASTATES wave hindcast model typically slightly underpredicts the measured Hs values at GyM_B (by around 10%) but less so at GyM_C. Tp and DirM are a consistently closer match at both sites, with some scatter but no obvious consistent bias. The difference in Hs is because the SEASTATES hindcast model has a relatively coarse resolution (approximately 5 km) in this coastal region and the mesh elements from which the model data are extracted represent shallower water depths (-16.3 m at GyM_B and -18.4 m at GyM_C) than the actual measurement locations (-25.2 m and -21.3 m, respectively). The difference in local depth is more pronounced at GyM_B, hence the greater difference in modelled Hs.

The SEASTATES wave hindcast model timeseries has been adjusted upwards by 10% to optimise the comparison between modelled and measured data at GyM_B and GyM_C. Wave height is adjusted upwards by 10% and wave period by √10%, in order to evenly scale the overall wave energy. Figure 11 and Figure 12 show that the adjusted SEASTATES wave hindcast model provides a close representation of the magnitude, timing and variance of Hs, Tp and DirM at these two offshore locations within and nearby to the main AyM study area. The same (10%) adjustment is made to the timeseries extracted from the centre of the array area that is used to inform the AyM site specific extreme values.

The above information validates the (adjusted) SEASTATES hindcast model data to provide a realistic representation of wave conditions and climate within the AyM array and study area, and further offshore at the northern wave boundary.

The local wave model performance is not validated explicitly. However, the important components of the model design and inputs (extent, resolution, bathymetry, coastlines and boundary conditions) have been individually validated to be realistic, accurate and detailed. The resulting model is therefore expected to perform to a similar level.

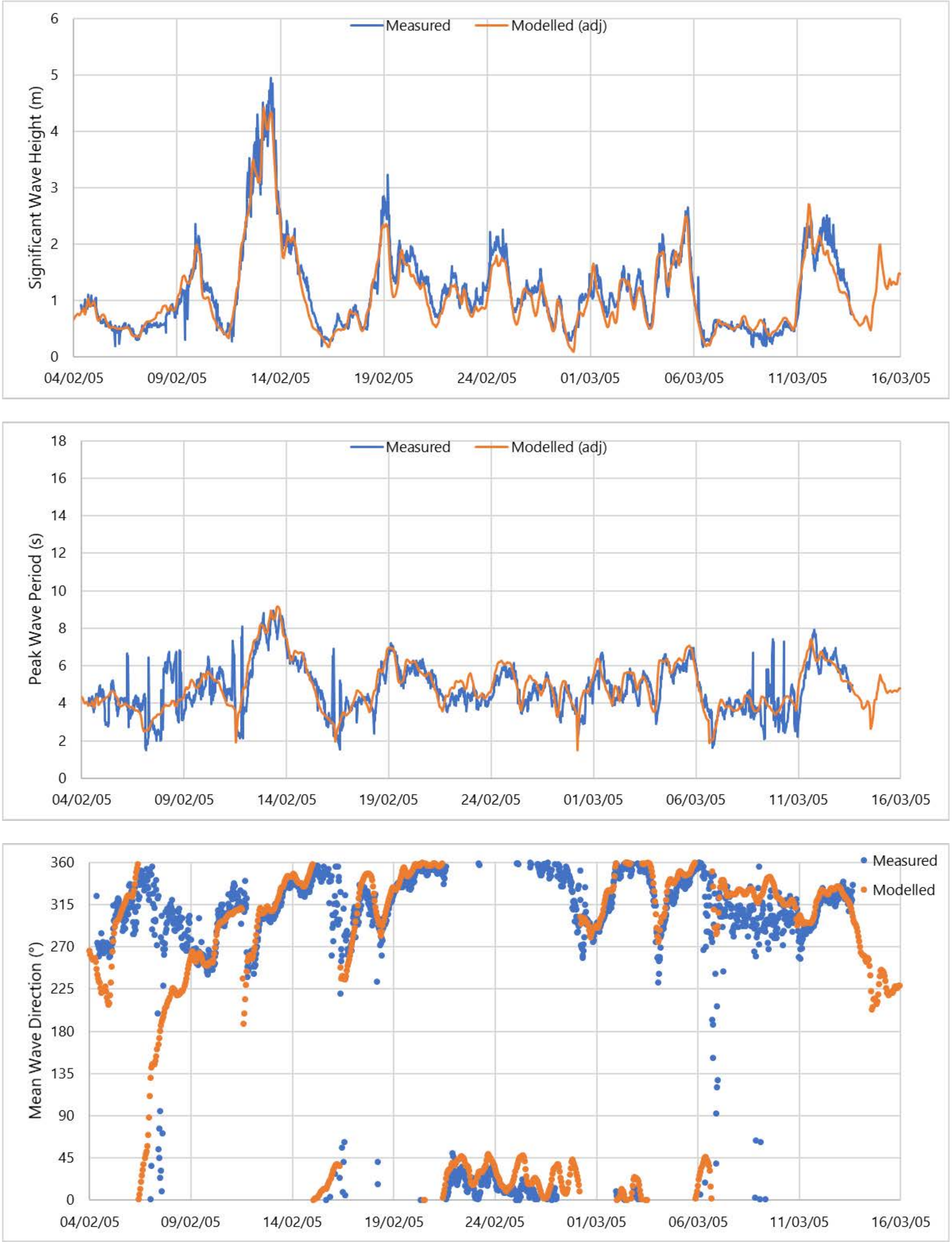


Figure 11. Comparison of measured and modelled wave parameters at location GyM_B (southern edge of the AyM array area).

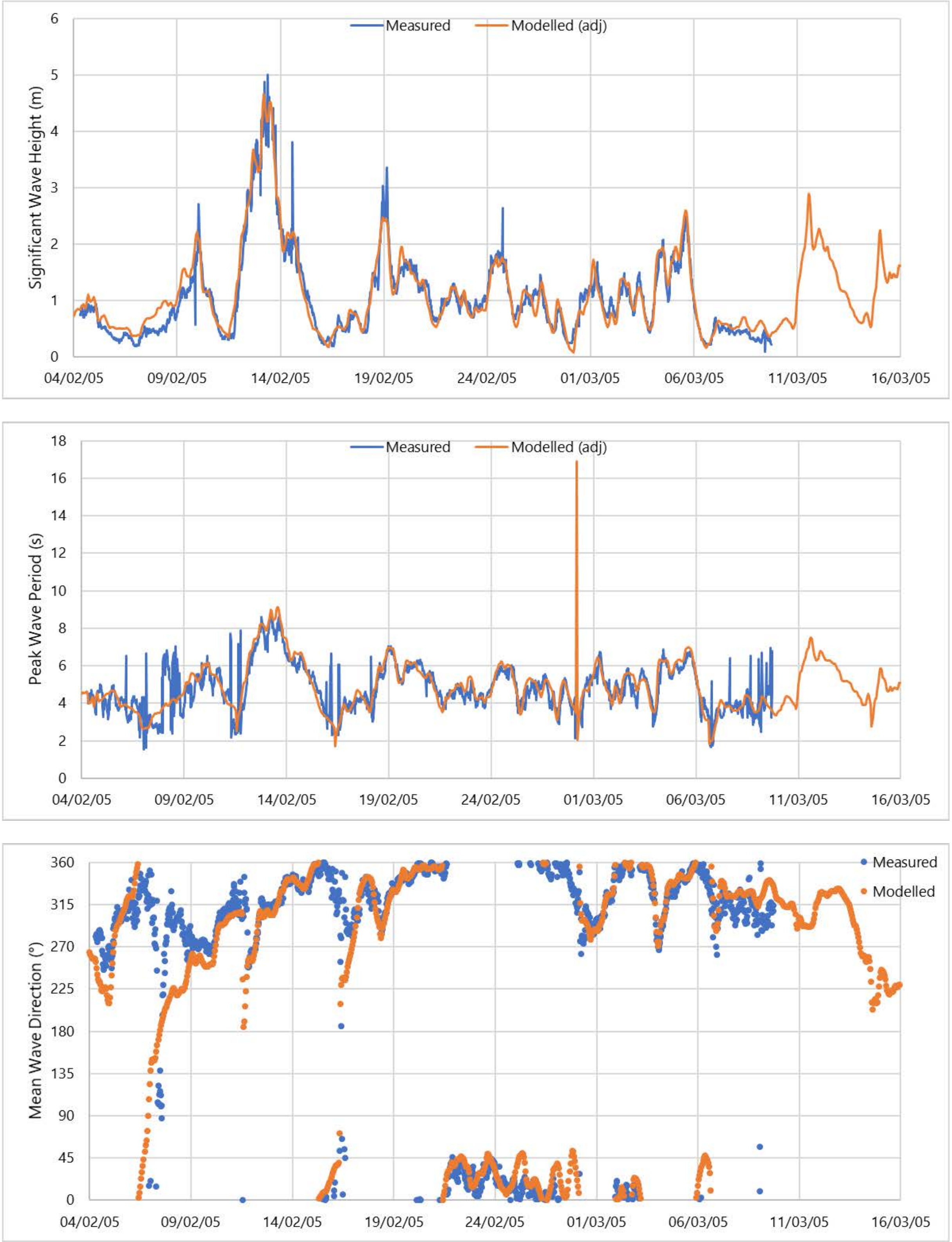


Figure 12. **Comparison of measured and modelled wave parameters at location GyM_C (~5 km east of the AyM array area).**

5 References

ABPmer, (2013). SEASTATES Wave Hindcast Model, Calibration and Validation Report, August 2013. Available from [redacted]

ABPmer, (2017). SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database, Model validation report, March 2017. Available from [redacted]

ABPmer, (2021). Awel y Môr Offshore Wind Farm: Environmental Impact Assessment, Physical Processes Technical Report. Annex to the PEIR Chapter.

Becker, J., van Eekelen, E., van Wiechen, J., de Lange, W., Damsma, T., Smolders, T., van Koningsveld, M. (2015) Estimating source terms for far field dredge plume modelling. Journal of Environmental Management. Volume 149 p282-293.

DTU. (2010) Global Ocean Tide Model. [redacted]

EMODnet: [redacted]

RWE (2021). Awel y Môr Offshore Wind Farm: Consent Project Description Spreadsheet. Issue 5.0. 29 February 2021.

Soulsby, R. (1997) Dynamics of Marine Sands. Thomas Telford, London. pp249.

UCL and UKHO. (2005) Vertical Offshore Reference Frames (VORF). [redacted]

6 Abbreviations/Acronyms

AWAC	Acoustic Wave and Current Meter
AyM	Awel y Môr
DCWW	Dwr Cymru Welsh Water
DHI	Danish Hydraulic Institute
DirM	Mean wave direction (coming from)
DirStd	Directional standard deviation of wave energy
DTU	Danish Technical University
EMODnet	European Marine Observation and Data Network
FM	Flexible Mesh (mesh or model type)
GoBe	GoBe Consultants Ltd
GyM	Gwynt y Môr
HD	Hydrodynamic (MIKE21FM_HD model)
Hs	Significant wave height
LAT	Lowest Astronomical Tide
MDS	Maximum Design Scenario
MSL	Mean Sea Level
OWF	Offshore Wind Farm
PT	Particle tracking (MIKE21FM_PT model)
SSC	Suspended Sediment Concentration
SW	Spectral Wave (MIKE21FM_SW model)
Tp	Peak wave period
UK	United Kingdom
UKHO	United Kingdom Hydrographic Office
UTM	Universal Transverse Mercator
VORF	Vertical Offshore Reference Frames

Cardinal points/directions are used unless otherwise stated.
SI units are used unless otherwise stated.

Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
SO14 2AQ

T +44 (0) 23 8071 1840
F +44 (0) 23 8071 1841
E enquiries@abpmer.co.uk

www.abpmer.co.uk

Fferm Wynt Alltraeth
AWEL Y MÔR
Offshore Wind Farm

RWE Renewables UK
Swindon Limited

Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
T +44 (0)8456 720 090
www.rwe.com

Registered office:
RWE Renewables UK
Swindon Limited Windmill
Hill Business Park Whitehill
Way
Swindon