Environmental Resources Management

Humber Gateway Offshore Wind Farm Model Calibration and Validation

Date:	February 2008
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Summary

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by E.ON, through Environmental Resources Management Ltd (ERM), to undertake a coastal process study for the proposed Humber Gateway Offshore Wind Farm (HGOWF). The proposed development site is within the Greater Wash area, located approximately 8km to the north-east of Spurn Head at the entrance to the Humber Estuary. This report provides a description of the numerical modelling undertaken to assess the potential impacts of the proposed development.

The modelling utilised the Danish Hydraulic Institute's (DHI) MIKE21 system. Five modules were applied in the study, MIKE21-FM-HD (Hydro-Dynamic model), MIKE21-FM-SW (Spectral Wind-wave model), MIKE21-ST (Sand Transport model), MIKE21-PA (Particle Analysis model) and MIKE-LITDRIFT (Littoral Drift model).

This document provides details of the models, their set-up and the calibration and validation exercises undertaken for the hydrodynamic, wave and sediment transport models, to ensure that the models are 'fit for purpose'.

The hydrodynamic model has been configured using the MIKE21-FM-HD module. MIKE21-FM-HD is a 2-Dimensional (2D), depth-averaged model, which applies a flexible mesh (FM) element grid and is used to provide a description of tidal flows. The hydrodynamic model has been successfully calibrated for the period 30/10/04 - 13/11/04, results from which are shown to be within the Environment Agency (EA) statistical guidelines for model calibration and validation. A detailed assessment shows that the tidal flows are represented accurately both at the proposed wind farm site and within the Humber Estuary. The accuracy of these results has been validated for an alternative time period (between 16/10/04 - 30/10/04) at the same 3 sites within the study area, used for the model calibration.

The SW model was calibrated for a month incorporating a 1 in 1 year event, previously identified within the metocean report R1159b (ABPmer, 2005). The set-up used the same bathymetry and mesh as the hydrodynamic model with the additional inputs of water depth, boundary conditions and a wind field. Sensitivity tests were carried out to determine whether currents and wind affected wave heights. These tests showed that while currents showed little or no significant change to wave heights, wind was considered a necessary variable to apply over the model domain to enable wave growth within the study area. The model was calibrated against wave measurements extracted from a location within the Met Office's European Wave Model. The wave model results indicate a good level of agreement, with the model simulating changes both in wave height and direction.

The sediment transport model (MIKE21-ST) has been applied to assess potential changes in transport rates across the far-field environment. The model provides a potential transport vector from which the resultant value can also be derived. The model was run for a spring-neap cycle, with water levels and wave heights extracted from the hydrodynamic and wave models, and a mean grain size representative of the sediments within the study area. The model was calibrated against measured data collated for a section of the Holderness coastline

for the Humber Estuary Coastal Authority Group Shoreline Management Plan (HECAG SMP), (Posford Duvivier, 1998).

In order to determine any potential changes to the sediment transport within the nearshore zone as a consequence of changes to the wave regime caused by the proposed offshore wind farm, the LITDRIFT littoral transport model has been applied. Calibration of the model used eight 1D beach profiles from along the Holderness and North Lincolnshire coasts, including the cable landfall at Easington, Spurn Head and Donna Nook. The outputs from each profile were then checked against observed and previously modelled rates at each site, taken from the HECAG SMP and the Southern North Sea Sediment Transport Study: Phase 2 (SNSSTS2), to ensure that representative rates and directions for a 1 in 1 wave event were being produced for each site. Calibration was undertaken through adjustment of the main calibration parameter, bed roughness. Due to the lack of available data, it was not possible to undertake a validation exercise for this model. However, achievement of a good calibration would suggest that the model performs well and is able to provide some indication of the potential impacts of the proposed wind farm upon the baseline physical environment, particularly when considered in conjunction with the understanding gained from all other model outputs.

The results presented in Section 3 of the report show that the suite of numerical models have been successfully calibrated against field data to provide a realistic representation of hydrodynamic, wave and sediment regimes within the study area. The calibration processes involves parameters being adjusted until the model data reaches an acceptable ‘fit’ with the field data. While each of the models is calibrated within the error limits specified within the guidance document, it is not possible for the models to provide an exact representation of reality, however, the EA guidance helps to ensure that the net error is small and remains within acceptable limits.

Although the modelling approach carries a small net error, to a large extent this is removed at the scenario testing stage, as results will be comparable to the calibrated baseline, i.e. (Baseline ±error) - (Scheme ±error) = Effect of scheme, hence the error is effectively removed. This approach ensures that when the offshore wind farm is assessed within the HGOWF Environmental Statement, only the effects of the scheme are measured against the baseline and therefore, do not incorporate the net errors from the calibration stage. Consequently, as the models accuracy meets the specified criteria they are considered ‘fit for purpose’ and can be utilised as a tool to assess the effects of the HGOWF on coastal processes.

Abbreviations

1D	One-dimensional
2D	Two-dimensional
ABPmer	ABP Marine Environmental Research Ltd
ADCP	Acoustic Doppler Current Profiler
DHI	Danish Hydraulic Institute
EA	Environment Agency
FM	Flexible Mesh
HD	Hydro-dynamic
HECAG	Humber Estuary Coastal Authority Group
HGOWF	Humber Gateway Offshore Wind Farm
IECS	Institute of Coastal and Estuarine Studies
HW	High Water
LW	Low Water
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
ODN	Ordnance Datum Newlyn
PA	Particle Analysis
PE	Peak Ebb
PF	Peak Flood
RMS	Root Mean Squared Error
SMP	Shoreline Management Plan
SSC	Suspended Sediment Concentrations
ST	Sand Transport
SW	Spectral Wind-wave

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1. Introduction

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by E.ON, through Environmental Resources Management Ltd (ERM), to undertake a coastal process study for the proposed Humber Gateway Offshore Wind Farm (HGOWF). The proposed development site is within the Greater Wash area, located approximately 8km to the north-east of Spurn Head at the entrance to the Humber Estuary. This report provides a description of the numerical modelling undertaken to assess the potential impacts of the proposed development.

The modelling utilised the Danish Hydraulic Institute's (DHI) MIKE21 system. Five modules were applied in the study:

1. MIKE21-FM-HD (Hydro-dynamic model);
2. MIKE21-FM-SW (Spectral Wind-wave model);
3. MIKE21-ST (Sand Transport model);
4. MIKE21-PA (Particle Analysis model); and
5. LITDRIFT (Littoral Drift model).

This document provides details of the models, their set-up and the calibration and validation exercise undertaken for the hydrodynamic, wave and sediment transport models, to ensure that the models are 'fit for purpose'.

2. Model Type

To effectively model the physical processes within the current study area a 2-dimensional horizontal (2DH) model was selected. The selected model type was considered suitable as the water column in proximity to the HGOWF is vertically well mixed and therefore, there is limited evidence of a vertical flow structure.

As such the extent of the model can be defined by the following boundaries:

- Northern coastal boundary: Offshore perpendicular to Flamborough Head;
- Western inshore boundary: Flamborough Head to Donna Nook. Note that this includes the outer section of the Humber Estuary;
- Southern coastal boundary: Offshore perpendicular to Donna Nook; and
- Eastern offshore boundary: Silver Pit.

2.1 Tidal Modelling

The tidal model has been configured using the MIKE21-FM-HD (Hydro-Dynamic) module. MIKE21-FM-HD is a 2-Dimensional (2D), depth-averaged model, which applies a flexible mesh (FM) element grid and is used to provide a description of tidal flows. The flexible mesh enables the far-field, near-field and structure scale processes to be accounted for in one model, with approximate mesh element dimensions ranging between 100m by 100m to 2,000m by 2,000m. The mesh is shown in Figure 1.

Additional information with regard to tidal characteristics within the study area can be found within Section 3 of the baseline assessment report (R1332, ABPmer, 2007).

2.2 Wave Modelling

The wave modelling approach requires the MIKE21-FM-SW (Spectral Wind-wave) modelling software. This model applies the same flexible mesh as the HD model, and enables waves to be simulated from a variety of user specified directions (based on frequency analysis of Met Office data), without altering the orientation of the grid.

2.2.1 Flexible Mesh Wave Model

The flexible mesh is suitably refined so as to allow a roughness map to be overlain and varied at specified elements, to simulate the presence of the turbine support structures during scenario testing. The mesh and bathymetry used for the wave modelling is identical to that for the hydrodynamic modelling, which provides consistency when interpreting model output.

Wave events are defined in the metocean report (R1159b, ABPmer, 2005), which uses data from the Met Office European Wave Model to predict extreme offshore wave conditions. Those extreme wave conditions are defined in Table 1, with the associated wind speed.

Table 1. Extreme wave conditions at 54.0'N, 0.34'E for various return periods

Return Period (Years)	330 degrees			000 degrees			030 degrees		
	Wave Height, Hs (m)	Period, Tz (s)	Wind Speed (m/s)	Wave Height, Hs (m)	Period, Tz (s)	Wind Speed (m/s)	Wave Height, Hs (m)	Period, Tz (s)	Wind Speed (m/s)
0.1	2.3	5.97	19.2	3.3	6.85	24.9	2.2	5.70	17.0
1	3.7	7.39	28.8	4.8	8.27	34.6	3.6	7.06	26.0
10	4.7	8.35	35.7	6.0	9.10	42.4	4.9	8.00	34.3
50	5.3	9.15	39.8	6.9	9.75	48.2	5.7	8.90	39.4

The wave model was run to simulate each of the return period wave events specified within Table 1, with the associated wind speed at the open boundaries and a fixed water level. A fixed water level was used to eliminate the effects of the tidal state as this affects wave heights by changing the friction waves experience when interacting with the seabed. As such, the Mean High Water Spring (MHWS) water level (measured by the AWAC device within the wind farm site) was applied to the extreme waves.

2.3 Sediment Modelling

The sediment modelling incorporated the simulation of sediment transport, sediment plumes (as a result of turbine construction) and littoral drift, which required selected outputs from the hydrodynamic and wave models. Sediment transport modelling involves the simulation of sediment transport pathways within the study area, based upon the sediment grain size within the 'live-bed' regime. The appropriate grain size was determined by analysing the 55 grab samples taken during the benthic survey carried out by the Institute of Coastal and Estuarine Studies (IECS), University of Hull.

The sediment plume modelling involved the application of a Lagrangian 'particle-tracking' model to assess the fate of sediments mobilised as a result of pile driving/drilling activities associated with the installation/construction of the foundation structures. In addition, the 'particle tracking' model was used to assess the in-combination effects of turbine foundation installation and aggregate dredging activities at neighbouring sites. The amount of material released for both the foundation installation and aggregate extraction activities was estimated using information specified within the Humber Gateway Environmental Statement Project Description and active dredge areas for the Humber region from the Crown Estate (The Crown Estate, 2007).

The littoral drift modelling required a time-series of wave conditions based on an annual wave climate. An additional MIKE21-SW run was carried out using the same flexible mesh as the MIKE21-SW extreme wave runs, where results were extracted at the location of each beach profile. This data was extracted from the wave results files after the model had finished running, using the MIKE FM toolbox extraction tool. In addition to wave conditions, the littoral drift model also required a grain diameter and the profile's angle of orientation relative to the coastline.

The sediment transport modelling approach required the MIKE21-ST, MIKE21-PA and MIKE21-LITDRIFT modelling software. The first two modules operate with a rectilinear grid instead of a flexible mesh, while the MIKE21-LITDRIFT module uses individual one-dimensional (1-D) profiles rather than a mesh or a grid. The 2-D grid has grid dimensions of 150m by 150m, which covers the same extent as the flexible mesh and incorporates the same bathymetry. Essentially the 2-D grid is a direct representation of the 2-D mesh. Each of the 1-D profiles required beach profile data; sedimentological data, wave data and water level data. The bathymetry comprised of heights/depths spaced at 10m intervals. The top of the profile was located approximately 500m from the cliff line, which extended offshore to a specified closure depth.

3. Calibration and Validation

The comparison of modelled water levels and currents against field data is the standard approach to calibrating a hydrodynamic model. This process requires adjustment of certain model parameters to achieve the best performance of the model. Further validation of the model without any additional adjustment to the model parameters is carried out using data covering an alternative period. This is undertaken before applying to the model to assess sediment transport processes.

In each of the tables presenting model calibration results, the differences are derived by subtracting observed or predicted values from model values. For levels and peak speeds, a positive value, therefore, indicates that the model is over-predicting observed values. For phase errors a positive error indicates the model is in advance of field measurements. Where errors are expressed as percentage differences, these are determined by dividing the modelled-measured differences by the measured value before multiplying by 100 and taking a mean.

3.1 Tidal Model

3.1.1 Calibration of Water Levels and Currents

The model was calibrated for a 14-day period (30/10/2004 to 13/11/2004). To achieve calibration, adjustments were made to water levels along the offshore boundaries as well as minor changes to the bed roughness, until the required level of accuracy was achieved. Model tidal elevations were compared against measured data at the AWAC site, local tide gauge data and/or predicted tidal data from the Admiralty's TotalTide software package, at selected locations to provide a quantitative assessment of errors in tidal amplitude and phase. It was necessary to use the TotalTide data for comparison of water levels at Bridlington and Spurn, as other field measurements were either of insufficient quality or unavailable. Average values for these errors are provided in Table 2 for four sites within the model. The locations of these sites are in the vicinity of the wind farm development site and surrounding area. Specific locations are identified in Figure 2.

Comparing the model against the field measurements (Figures 3 and 4), the maximum error in low water level is found at Bridlington where heights are over predicted by up to 0.18m. This represents 4.0% of a mean spring tidal range and, therefore, satisfies the performance requirements of Bartlett (1998). High water levels here are reproduced to a higher level of accuracy, with levels being under predicted by 0.01m.

Analysis of phase errors identifies that the model is early by up to 17.9 minutes relative to observed values over high waters, but behind by up to 0.3 minutes over low waters. Maximum phase differences occur at Immingham (located in the Humber Estuary) during high waters (±20.2 minutes). These greater phase differences are more noticeable away from the area of interest, where the bathymetry is not so detailed and the model was therefore unable to account for such variations.

Table 2. Water level and phase errors (for calibration period)

Location	Level Diff. (m)		Phase Diff. (minutes)	
	HW	LW	HW	LW
AWAC	+0.02	-0.05	+2.0	-8.9
Spurn Head	-0.14	-0.01	+0.7	-7.9
Immingham	-0.03	+0.13	+20.2	+0.1
Bridlington	-0.01	+0.18	+17.9	-0.3

To further quantify model calibration, Root Mean Squared (RMS) percentage errors have been calculated for current speeds and directions over a mean a spring-neap-spring cycle and are presented in Tables 3a and 3b. Current speeds are replicated to varying degrees of accuracy within the model, however results from each of the four sites show both current speeds and directions on the whole fall within the guidelines specified by the Environment Agency (Bartlett, 1998; current speeds to within ±10-20% of observed speed and current directions to within ±20°). Current speeds are reproduced by the model particularly well at the AWAC site.

Table 3a. Calibration of model flow speeds against tidal stream data

Location	Model u_{mean} (m/s)	TotalTide/Field u_{mean} (m/s)	Model u_{RMS} (m/s)	TotalTide/Field u_{RMS} (m/s)	RMS % Difference
AWAC	0.49	0.56	0.278	0.291	-4.47
SN017U	0.47	0.43	0.253	0.225	12.44
SN017AD	0.46	0.60	0.260	0.310	-16.13
SN017P	0.28	0.35	0.144	0.155	-7.10

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 3b. Calibration of model flow directions against tidal stream data

Location	Model Dir_{mean} (°)	TotalTide/Field Dir_{mean} (°)	Model Dir_{RMS} (°)	TotalTide/Field Dir_{RMS} (°)	RMS % Difference
AWAC	227.75	186.97	107.47	82.38	30.46
SN017U	130.97	138.63	108.57	115.94	-6.36
SN017AD	238.17	246.25	95.13	95.42	-0.30
SN017P	202.88	202.14	105.62	110.48	-4.40

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

The range in accuracy is partly due to the complex bathymetric features located near the entrance of the Humber Estuary such as Chequer Shoal and the Binks, and depressions further offshore namely New Sand Hole and Silver Pit. These features contribute towards creating complex current patterns, which are difficult to reproduce without high definition bathymetric survey data covering the full extent of the study area. Despite these variations the model is still considered fit for purpose, which is further verified by the low RMS error percentages for current speeds at the AWAC site (-4.47%), illustrated in Figure 5A. Current directions at the AWAC site, however, fall just outside of the criteria specified by Bartlett, because of natural variability due to small scale turbulence that cannot be resolved by either the HGOWF or TotalTide models. Figure 5B highlights the subtle changes in direction over a spring-neap cycle.

At site SN017U, located south of New Sand Hole and the entrance to the Humber Estuary, current speeds for the first half of the spring-neap cycle are replicated well, as shown in Figure 6A. During the second half of the cycle (from neap to spring) the model overestimates current speeds by 0.1m/s on average. This results in these values skewing the very good level of calibration that is achieved within the first part of the cycle, resulting in a reasonable level of calibration for the whole cycle. However, this trend is not replicated for current directions where an excellent level of calibration is achieved throughout, with an RMS value of -6.36% for the spring-neap period, illustrated in Figure 6B.

Site SN017AD is situated to the north of the AWAC site, approximately 6km offshore of Easington in a water depth of around 15mODN. Current speeds are reproduced well during the second half of the spring-neap cycle (neap to spring), however, during the first part of the cycle the model appears to underestimate speeds by 0.3m/s on average. This trend is shown in Figure 7A. It should be noted that while it is possible that the tidal model is unable to properly account for the effect of a certain harmonic constituent, the calibration data at this site is taken from the TotalTide software package, which is predicted data based on constituents obtained from measured data, the age and quality of which are unknown. It is likely that the model provides better predictions than those from the TotalTide model and, therefore, results from the model could be a closer representation of reality. Current directions are calibrated well, with error calculations indicating an RMS of only -0.30% over the spring-neap period. The overall fit between the model and TotalTide data is good, showing only a slight difference in phase at the turn of the tide (Figure 7B), which is likely to be related to the accuracy of the bathymetry close to site SN017AD.

Further to the north of site SN017AD lies site SN017P which achieves an excellent level of calibration for current speeds and directions. In comparison to site SN017AD, current speeds at SN017P are lower by approximately 0.3m/s. The reduction in current speeds makes it slightly harder to achieve such a good level of calibration, however, current speeds are still reproduced to a good level of accuracy (-7.10% RMS). Figure 8A illustrated that calibration is improved for the second part of the spring-neap cycle (neap to spring), which suggests that the model has difficulty replicating the different nearshore and offshore processes. Current directions show an excellent level of calibration throughout the tidal cycle which is shown in Figure 8B.

Although hydrodynamic calibration is shown to be generally acceptable, some caution must be used when considering some of the sites which exhibit complex current patterns. In terms of calibration, the model is shown to predict tidal conditions to an acceptable level of accuracy in the vicinity of the development site. On the whole, current directions are particularly well predicted by the model.

3.1.2 Validation of Water Levels and Currents

The validation of water levels and currents predicted by the regional model was assessed and validated over an alternative 14-day period (16/10/2004 to 30/10/2004). Figures 9 and 10 compare water levels, current speeds and current directions from the model with field measurements or TotalTide data at all four sites. The largest differences between modelled high and low water levels occur at Spurn Head for the validation period and are within the range ±0.17m, which is equivalent to 2.83% of a representative mean spring tidal range of ~6m. Phase differences at the AWAC and Spurn Head are low, as for the calibration period, ranging between +0.7 to -8.9 minutes as indicated in Table 4. However, the accuracy of the model in replicating the phasing of the water levels appears to diminish towards the extremities of the study area, which is evident in the results achieved at Immingham and Bridlington. It should be noted that unlike the other 3 sites, Immingham is also located within the Humber Estuary. Bartlett makes an allowance for changes in physical processes by increasing the validation guidelines from ±15 minutes for coastal areas to up to ±25 minutes for estuaries.

Table 4. Water level and phase errors (for validation period)

Location	Level Diff. (m)		Phase Diff. (minutes)	
	HW	LW	HW	LW
AWAC	+0.06	-0.07	+4.4	-9.7
Spurn Head	+0.05	-0.17	-3.9	-13.4
Immingham	-0.07	+0.08	13.2	0.6
Bridlington	+0.10	+0.08	11.0	-9.7

Modelled current speeds and directions for the same four sites as used for the model calibration were compared with measured values for the defined validation period and are shown in Figures 11 to 14. Mean peak flood and ebb current speed and direction differences are presented in Tables 5a and 5b.

Table 5a. Validation of model flow speeds against tidal stream data

Location	Model u_{mean} (m/s)	TotalTide/Field u_{mean} (m/s)	Model u_{RMS} (m/s)	TotalTide/Field u_{RMS} (m/s)	RMS % Difference
AWAC	0.60	0.64	0.296	0.307	-3.58
SN017U	0.56	0.41	0.265	0.214	23.83
SN017AD	0.56	0.42	0.275	0.342	-19.59
SN017P	0.36	0.34	0.148	0.148	-0.02

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 5b. Validation of model flow directions against tidal stream data

Location	Model Dir_{mean} (°)	TotalTide/Field Dir_{mean} (°)	Model Dir_{RMS} (°)	TotalTide/Field Dir_{RMS} (°)	RMS % Difference
AWAC	231.96	169.89	105.24	83.12	26.61
SN017U	119.77	140.48	102.63	117.00	-12.28
SN017AD	236.53	246.53	95.32	95.33	-0.01
SN017P	207.94	202.57	104.19	110.51	-5.72

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

In RMS percentage terms, the differences in the model's predicted current speeds are less than 20%, with the exception of site SN017U, placing them within the recommended guidelines of 10-20% (Bartlett, 1998). Validation results in Tables 5a and 5b show a similar trend to those in Tables 3a and 3b, indicating that a good level of validation is achieved for both current speed and direction, as was the case for the calibration period.

In summary, the validation results confirm that the model is fit for purpose.

3.2 Wave Model

The SW model allows the simulation of the growth, decay, and transformation of locally wind generated waves and swell in offshore and coastal areas using a directionally decoupled parametric formulation. The SW model is run using the same bathymetry and mesh as for the hydrodynamic model. In addition to these parameters the model also requires the following inputs:

- Water depth;
- Boundary conditions; and
- Wind field.

3.2.1 Sensitivity Testing

Prior to the calibration of the wave model a number of sensitivity tests were carried out to determine the effect of a range of variables, such as current and wind stress on wave heights and the development of wave growth. The results of which are described in the section below:

Test 1
Sensitivity tests were carried out to determine whether the effect of currents was significant. Initially the wave model was run for peak flood and peak ebb, with and without currents. Results indicated little or no significant change, as shown in Figure 15 and, therefore, currents were not included within the subsequent wave modelling.

Test 2
In addition to currents, tests were also carried out to consider how a wind stress applied at the boundaries could effect the development of wave growth. Results indicated that when coming from offshore wind played an important role in increasing wave heights (Figure 16), enabling growth and producing the required heights to be achieved at the AWAC site for calibration purposes. Therefore, wind is considered a necessary variable to apply to gain an acceptable level of calibration.

A number of further tests were carried out to determine the necessary wind stress to be applied at the boundaries. It was found that wind speeds derived from the Met Office time-series dataset provided the correct wind strength to be applied.

3.2.2 Calibration

For calibration purposes the wave model was run as a time-series for a month from 05/09/2004 to 04/10/2004. This duration incorporates Event 3, which occurred on 24th September 2004 during deployment 3 of the AWAC device, previously identified within the metocean report R1159b (ABPmer, 2005). The model was run with a varying water level, using the data recorded at the AWAC site for the corresponding period.

Wave measurements from the field were only available at one location, namely the AWAC site. To supplement this data, a 10 year time-series from the Met Office's European Wave Model was extracted at a location close to the northern offshore boundary of the study area (54.0'N, 0.34'E), illustrated as a wave rose in Figure 17, and was used in the wave model calibration and validation process. This data was applied on the northern, eastern and southern boundaries of the wave model, along with additional wind-wave growth.

The results of the model were compared against data gathered at the AWAC site. The level of calibration achieved by the wave model is shown in Figure 18 with a quantitative statistical assessment provided in Tables 6 and 7. Figure 18 compares modelled data (using the SW model) at the AWAC site with measured data at the AWAC site and Met Office data from the northern (offshore) boundary. Results indicate a good level of agreement, with the model simulating changes both in wave height and direction.

The model error was derived from the average difference in significant wave height related to the observed data. Table's 6a and 6b show that, on average, the model under-predicts wave heights by 11%. This error could be reduced if the wave conditions used at the boundaries were also decreased. However, it was considered more important to enable the model to achieve the maximum wave height during Event 3 on the 24th September, than being calibrated to moderate fluctuations in wave height. Table 7 shows the improved level of calibration achieved for both significant wave height and wave direction for Event 3. Although the model was calibrated to the largest wave event, it reproduces the changes in wave height well for the duration of the calibration period, shown in Figure 18B. Although this technique may reduce the accuracy of the calibration, it provides a conservative solution ensuring that maximum wave heights can be achieved during the scenario testing in the next stage.

Table 6a. Calibration of wave heights at the AWAC site

Period	Model Hs_{mean} (m)	Field Hs_{mean} (m)	Model Hs_{RMS} (m)	Field Hs_{RMS} (m)	RMS % Difference
5th September - 4th October 2004	1.41	1.12	0.017	0.019	-10.52

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 6b. Calibration of wave directions at the AWAC site

Period	Model Dir_{mean} (º)	Field Dir_{mean} (º)	Model Dir_{RMS} (º)	Field Dir_{RMS} (º)	RMS % Difference
5th September - 4th October 2004	191.40	178.18	113.65	128.02	-11.22

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 7. Comparison between measured and modelled wave data during Event 3

Event (2004)	Model Hs (m)	Field Hs (m)	Diff. (m)	RMS % Diff.	Model Direction (º)	Field Direction (º)	Diff. (°)
3 (24th September)	2.92	3.14	-0.22	-7.01	354.70	11.11	16.41

Wave directions are within 20° of the field data. While waves are wind generated (i.e. coming from the shore) their direction matches that of the wind direction. Only when the offshore waves begin to dominate (approaching approximately from between 0°

and 90°) does the wave direction improve. This trend is shown in Figure 18B. Wave heights are generally well reproduced although exhibit greater variability when wind generated. Therefore, the wave model is considered to be well calibrated within its limits of operation and use.

3.2.3 Validation

Validation was carried out by comparing model results (wave height and direction) with AWAC data for a week over each of the three other wave events identified in the Metocean study. Comparisons in wave height and wave direction are tabulated below, showing mean values for each validation period (Tables 8a and 8b) and individual comparisons during each event when the maximum significant wave height is achieved (Table 9).

Table 8a. Validation of wave heights at the AWAC site

Period	Model Hs_{mean} (m)	Field Hs_{mean} (m)	Model Hs_{RMS} (m)	Field Hs_{RMS} (m)	RMS % Difference
27th April - 5 May 2004	1.75	1.23	0.640	0.619	3.39
7th - 13th July 2004	1.76	1.63	0.878	0.707	24.19
9th - 15th November 2004	1.82	1.62	0.710	0.769	-7.67

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 8b. Validation of wave directions at the AWAC site

Period	Model Dir_{mean} (°)	Field Dir_{mean} (°)	Model Dir_{RMS} (°)	Field Dir_{RMS} (°)	RMS % Difference
27th April - 5th May 2004	53.60	81.50	77.62	103.66	-25.12
7th - 13th July 2004	236.29	252.55	141.06	155.74	-9.43
9th - 15th November 2004	144.09	120.82	153.87	148.28	3.77

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

Table 9. Comparison between measured and modelled wave data for Events 1, 2 and 4

Event (2004)	Model Hs (m)	Field Hs (m)	Diff. (m)	RMS % Diff.	Model Direction (º)	Field Direction (º)	Diff. (°)
1 (29th April)	3.02	3.56	-0.54	-17.88	6.04	17.83	-11.79
2 (8th July)	3.77	3.80	-0.03	-0.80	47.98	60.35	-12.37
4 (12-13th November)	3.32	3.79	-0.47	-12.40	359.00	0.96	-1.96

* Positive RMS difference percentages indicate that model is over-predicting alternatively negative values show under-prediction.

The results plotted in Figures 19A, 20A and 21A show a similar level of accuracy in wave height for each of the validation runs, compared to those achieved for calibration. There is no consistency between the differences in results shown in Tables 6 and 8. The validation run for the period 7th-13th July shows that the model is capable of replicating the highest maximum wave height recorded during the total deployment period at the AWAC site, to an accuracy of -0.8%.

A similar trend in current directions is observed during validation as in calibration (Figure 19B, 20B and 21B), that while waves are wind generated the level of validation achieved is less accurate than when waves from offshore dominate. Wave directions vary on average by ±10° compared to the field data.

Given the data available, the wave model is considered to reach an acceptable level of validation.

3.2.4 Scenario Testing Note

The calibration and validation runs utilised a varying water level to ensure successful calibration and validation of the SW model, however, it was not realistic to apply this approach for the scenario testing given the number of runs required. Instead a constant water level (equivalent to MHWS) recorded at the AWAC site was applied to the model. Given the conditions within the area of interest this does not effect the accuracy of the results, as all other parameters used remain the same as those applied for the calibration and validation set ups. By using a fixed water level of MHWS for all scenario testing, results can be compared directly.

In addition, it should be noted that once calibrated, the model was only run for a single time-step for the scenario testing to represent a specific return period, as corresponding water level time-series data is limited. In addition, running with a varying water level creates a large overhead on computational time. Given the fine resolution of the flexible mesh it was not possible to run the model for a spring-neap cycle. Instead, wave conditions were ran for a single time-step based on a number of extreme wave conditions, specifically 10 in 1, 1 in 1, 1 in 10 and 1 in 50, from the directional sectors with the highest wave heights (330º, 0º and 30º) derived from the Met Office dataset.

3.3 Sediment Transport Pathways Model

3.3.1 Calibration

The sediment transport model has been applied to assess potential changes in transport rates across the far-field environment. The model provides a potential transport vector from which the resultant value can also be derived and presented as a colour contour map. The model was run for a spring-neap cycle, with water levels and wave heights extracted from the hydrodynamic and wave models, and a mean grain size representative of the sediments within the study area.

The model was calibrated against measured data collated for a section of the Holderness coastline for the Humber Estuary Coastal Authority Group Shoreline Management Plan (HECAG SMP), (Posford Duvivier, 1998) and sediment transport directions inferred from bedform asymmetry on Admiralty charts 1190, 1408 and 1610 within the Southern North Sea Sediment Transport Study: Phase 2 (SNSSTS2).

3.4 Littoral Drift Model

In order to model the longshore drift rates, and any impact that the presence of the offshore wind farm may have on these, the engineering software package LITPACK, developed by the Danish Hydraulic Institute (DHI), was used. The LITDRIFT component of the package, capable of modelling longshore currents and littoral drift rates, was used for the study.

LITDRIFT models sediment transport as a function of a cross-shore profile and hydrodynamic regime and enables the calculation of net/gross littoral transport over a specific design period. LITDRIFT consists of a hydrodynamic model and a sediment transport model and requires a number of input data in order to run. The main input data needed for LITDRIFT are:

- Beach profile data;
- Sedimentological data;
- Wave data;
- Water level data.

3.4.1 Calibration

The LITDRIFT model has been applied to determine any potential changes to the sediment transport within the nearshore zone as a consequence of changes to the wave regime caused by the proposed offshore wind farm.

Eight 1D beach profiles from along the Holderness and North Lincolnshire coasts, including the cable landfall at Easington, Spurn Head and Donna Nook, have been used. The location of these is illustrated in Figure 2. Once profiles had been extracted from the bathymetric data and formatted for LITPACK they were input, into LITDRIFT enabling longshore transport rates and directions to be determined. These were calculated by considering the distribution of sediment transport across a profile and the variation on hydrodynamic climate.

The outputs from each profile were then checked against observed and previously modelled rates at each site, taken from the HECAG SMP and the SNSSTS2, to ensure that representative rates and directions for a 1 in 1 wave event were being produced for each site. Calibration took place via the main calibration parameter, bed roughness. Due to the limited information regarding the sediment properties at all profiles, a representative D_{50} value of 170µm was used. This corresponds to a fine sand sized material.

The modelled and observed littoral drift characteristics against which each profile was calibrated are given in Table 10 and illustrated in Figure 22.

Table 10. Sediment transport rates and directions for each of the eight profiles used in the calibration of the LITDRIFT module.

	Potential net sediment transport (m³/year)		Potential direction of sediment transport	
Profile ID	Modelled	Observed	Modelled	Observed
97	117,131	10,000 - 40,000	South	South
108	46,397	100,000 - 350,000	South	South
109	124,242		South	South
110	135,364		South	South
123	254,572		South	South
133	14,477	-	West	West
DN A	7,683	-	East	East
DN B	8,755	-	West	East

Due to the lack of available data, it was not possible to undertake a validation exercise for this model. However, the good calibration reached would suggest that the model performs well and is able to provide some indication of the potential impacts of the proposed wind farm upon the baseline physical environment when considered in conjunction with the understanding gained from all other model outputs.

3.5 Summary of model calibration and validation

The results presented in Section 3 show that the suite of numerical models have been successfully calibrated against field data to provide a realistic representation of hydrodynamic, wave and sediment regimes within the study area. The calibration processes involves parameters being adjusted until the model data reaches an acceptable 'fit' with the field data. For the purpose of this study guidelines specified by Bartlett, 1998 have been used to determine whether the models produce an acceptable fit. While each of the models is calibrated within the error limits specified within the guidance document, it is not possible for the models to provide an exact representation of reality, however, the guidance helps to ensure that the net error is small and remains within acceptable limits.

Although the modelling approach carries a small net error, to a large extent this is removed at the scenario testing stage, as results will be comparable to the calibrated baseline, i.e. (Baseline ±error) - (Scheme ±error) = Effect of scheme, hence the error is effectively removed. This approach ensures that when the offshore wind farm is assessed within the HGOWF Environmental Statement, only the effects of the scheme are measured against the baseline and therefore, do not incorporate the net errors from the calibration stage. Consequently, as the models accuracy meets the specified criteria they are considered 'fit for purpose' and can be utilised as a tool to assess the effects of the HGOWF on coastal processes.

4. References

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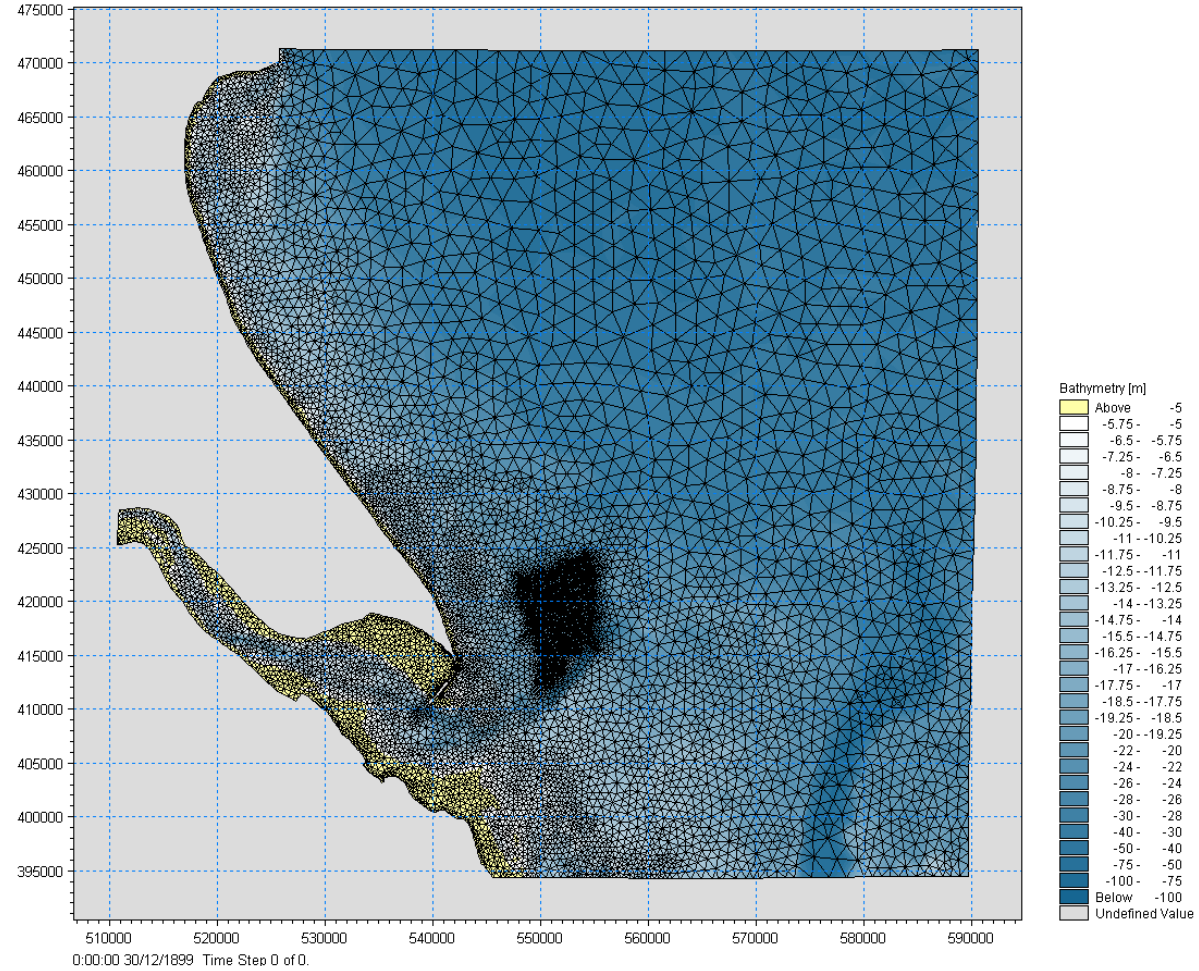
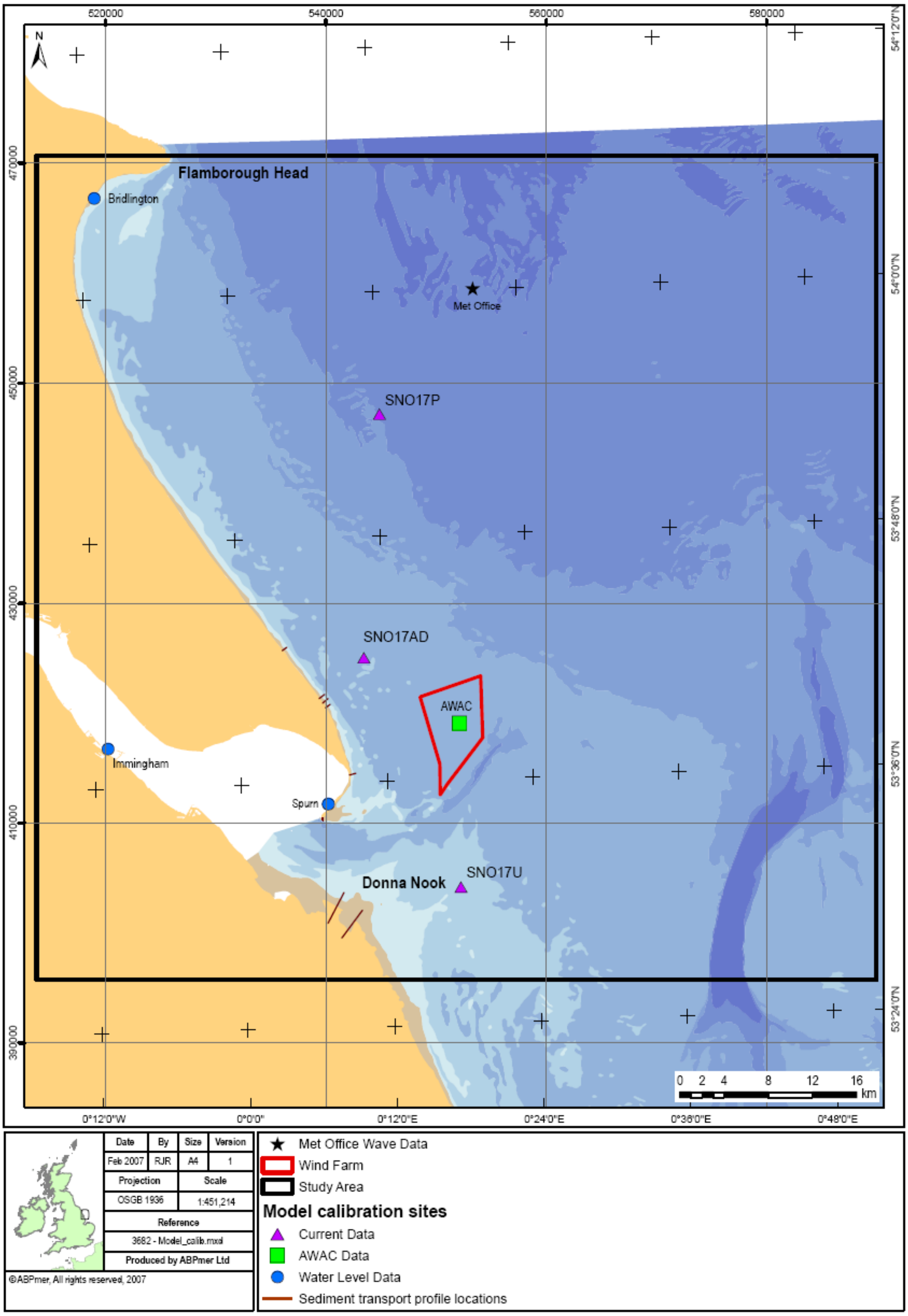
Figures



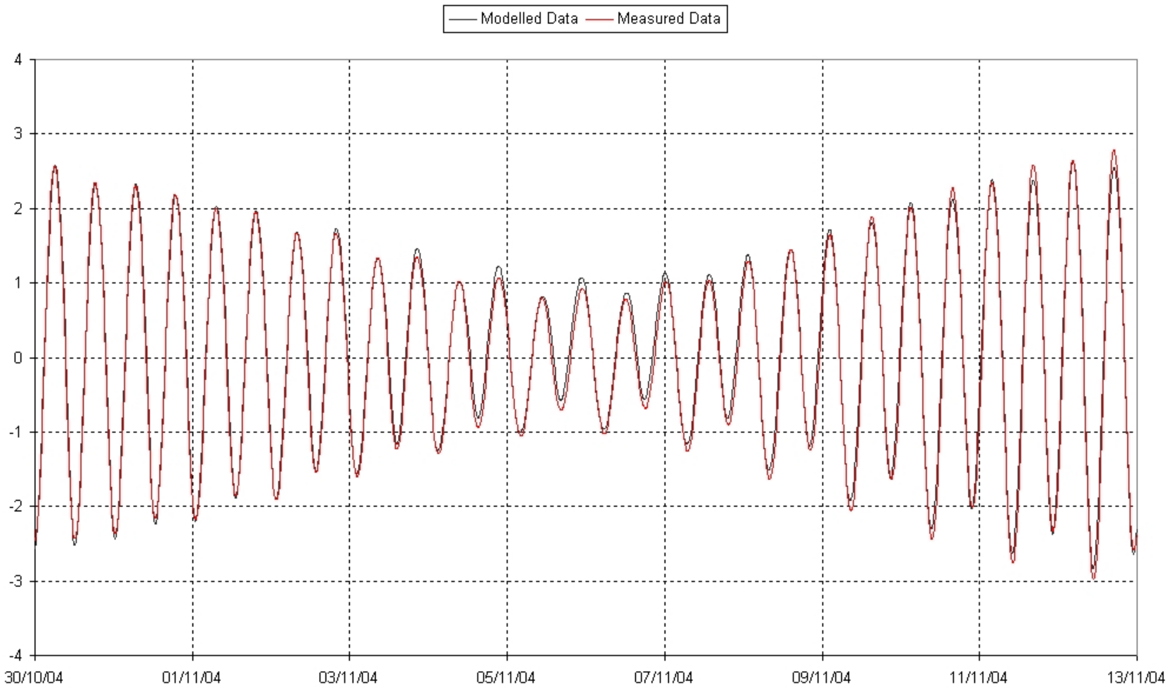
Model mesh and bathymetry

Figure 1



ABP mer marine environmental research	Location of model calibration sites	Figure 2

(A)



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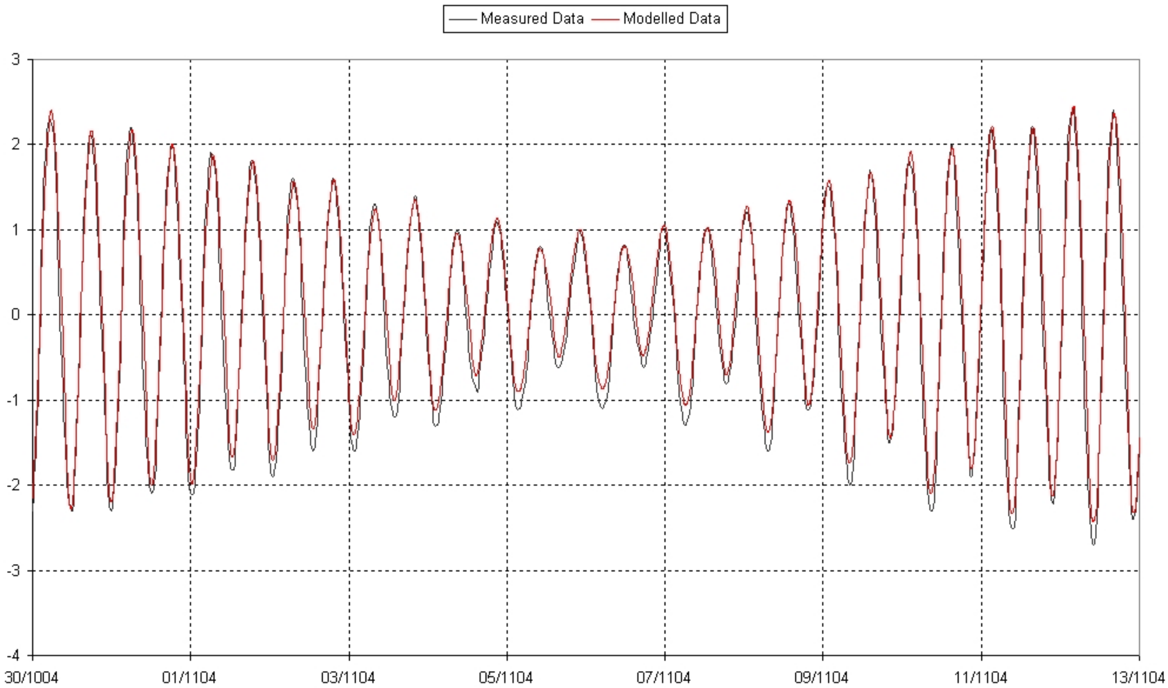
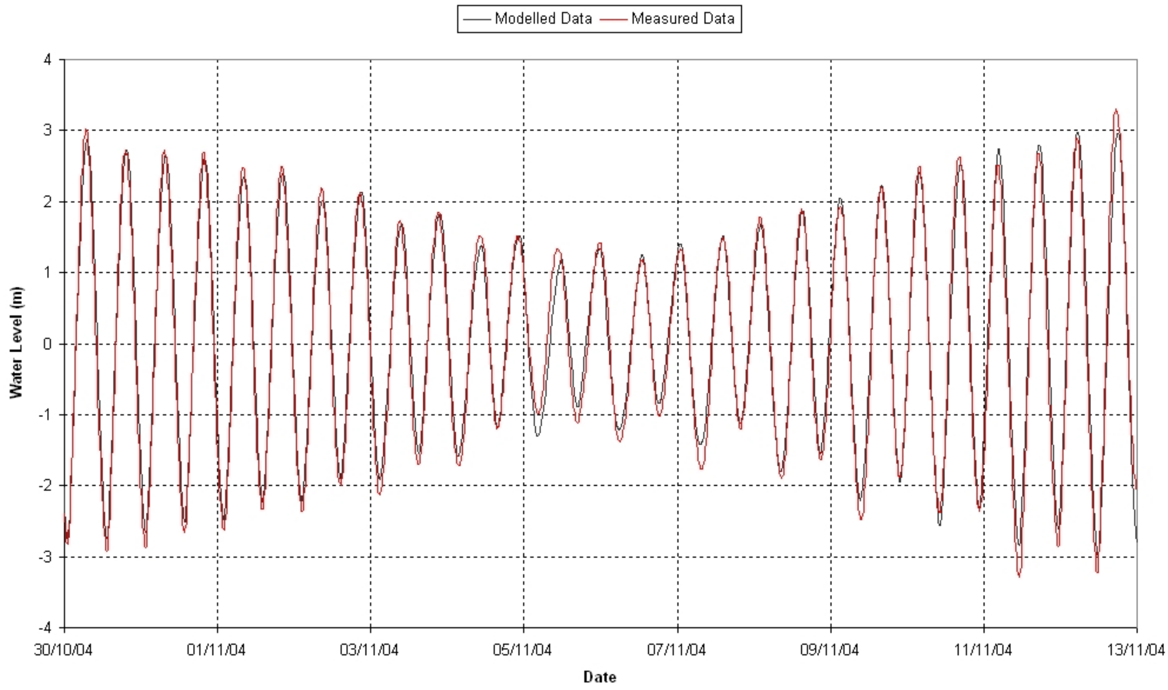


ABP mer marine environmental research	Comparison between measured and modelled water level data at (A) the AWAC site and (B) Bridlington for the calibration period	Figure 3

(A)



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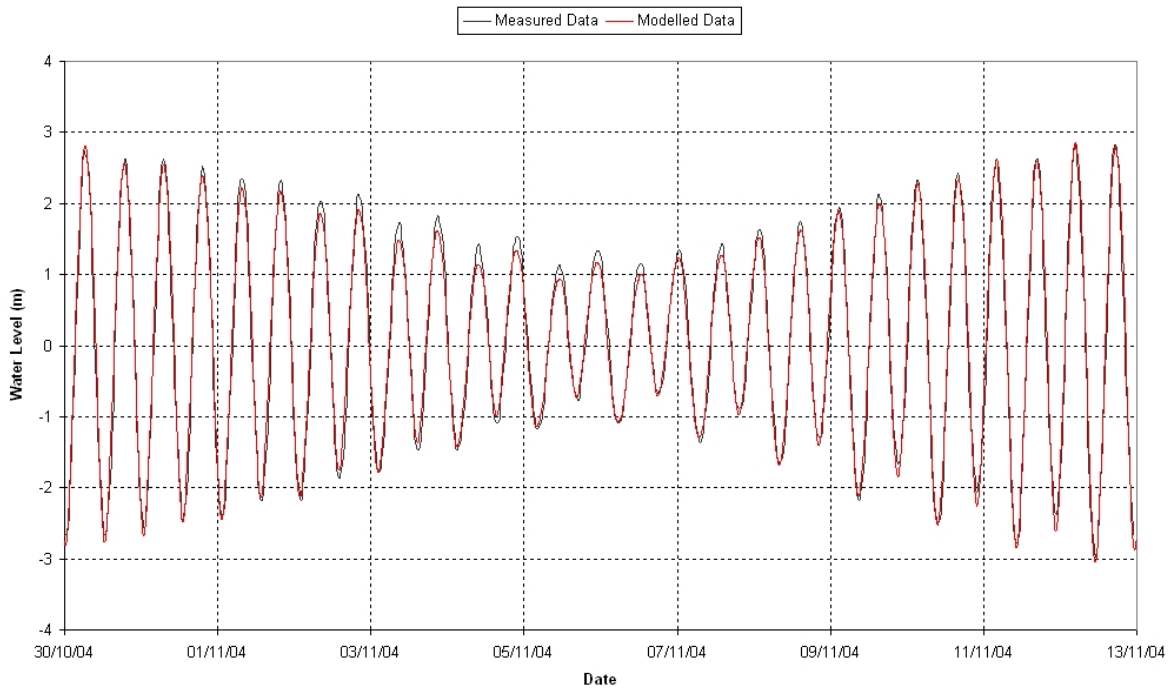
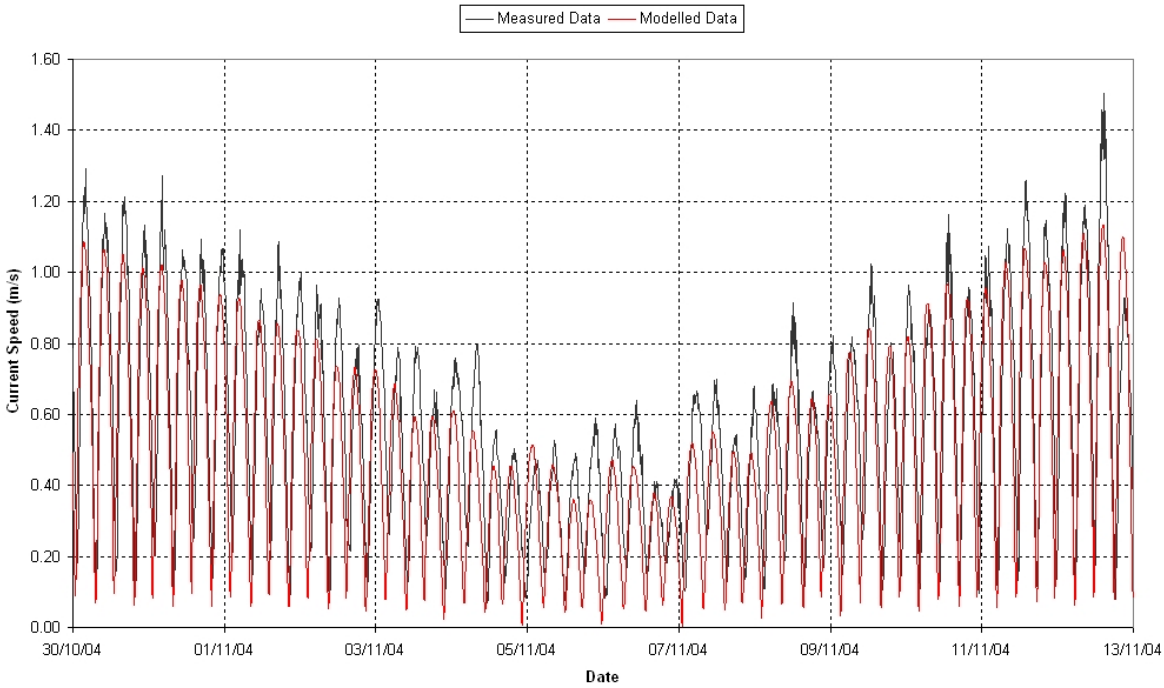


	Comparison between measured and modelled water level data at (A) Immingham and (B) Spurn for the calibration period	Figure 4

(A)



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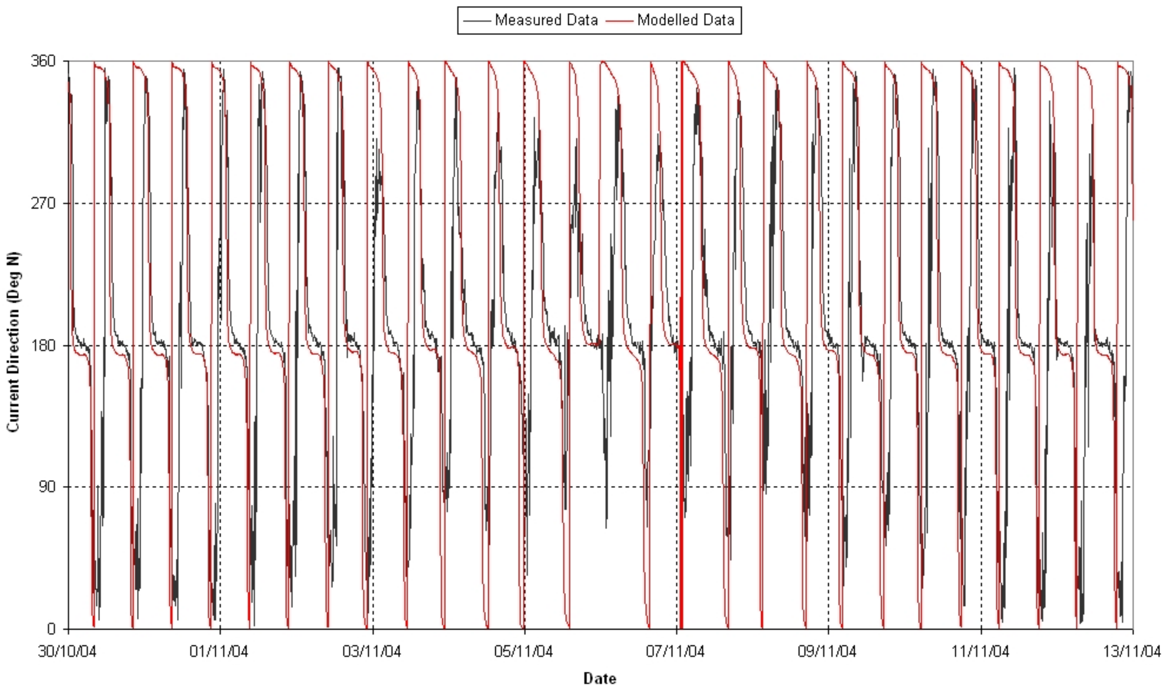
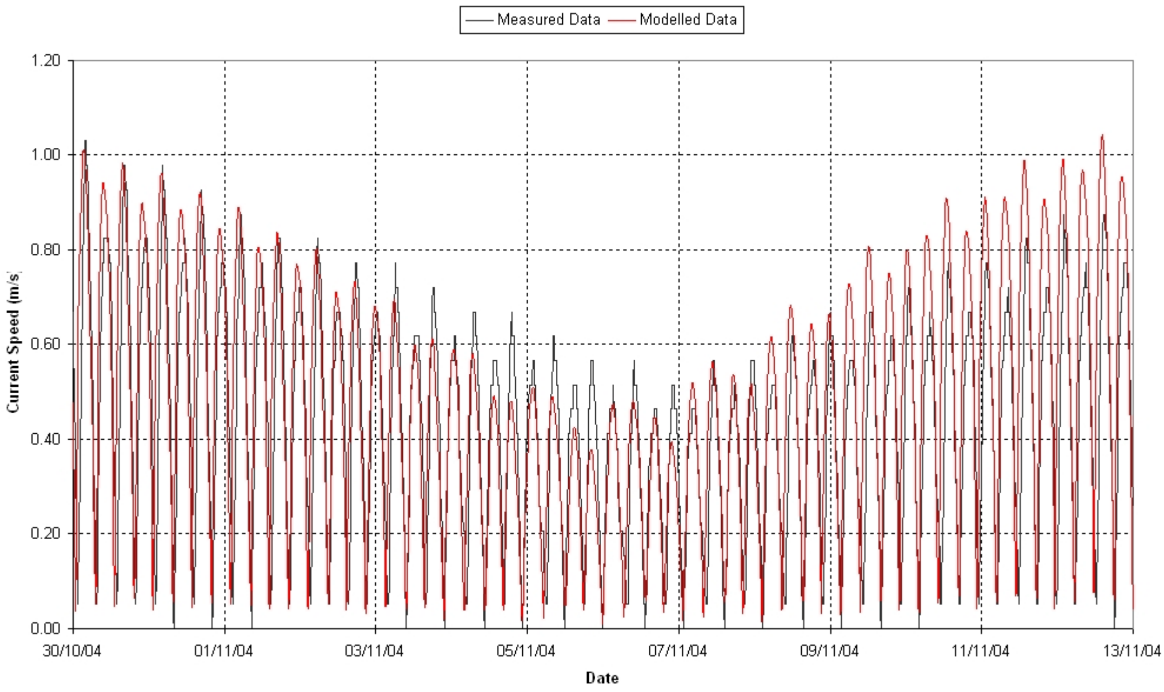


	Comparison between measured and modelled current speed (A) and direction (B) data at the AWAC site for the calibration period	Figure 5

(A)



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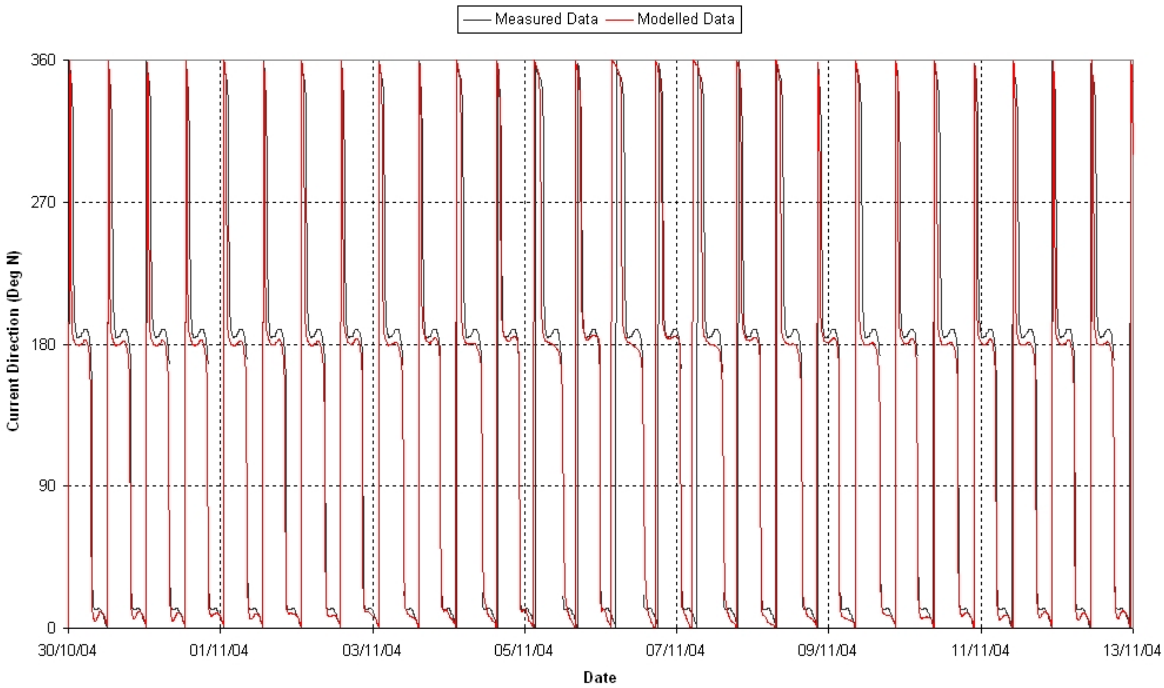
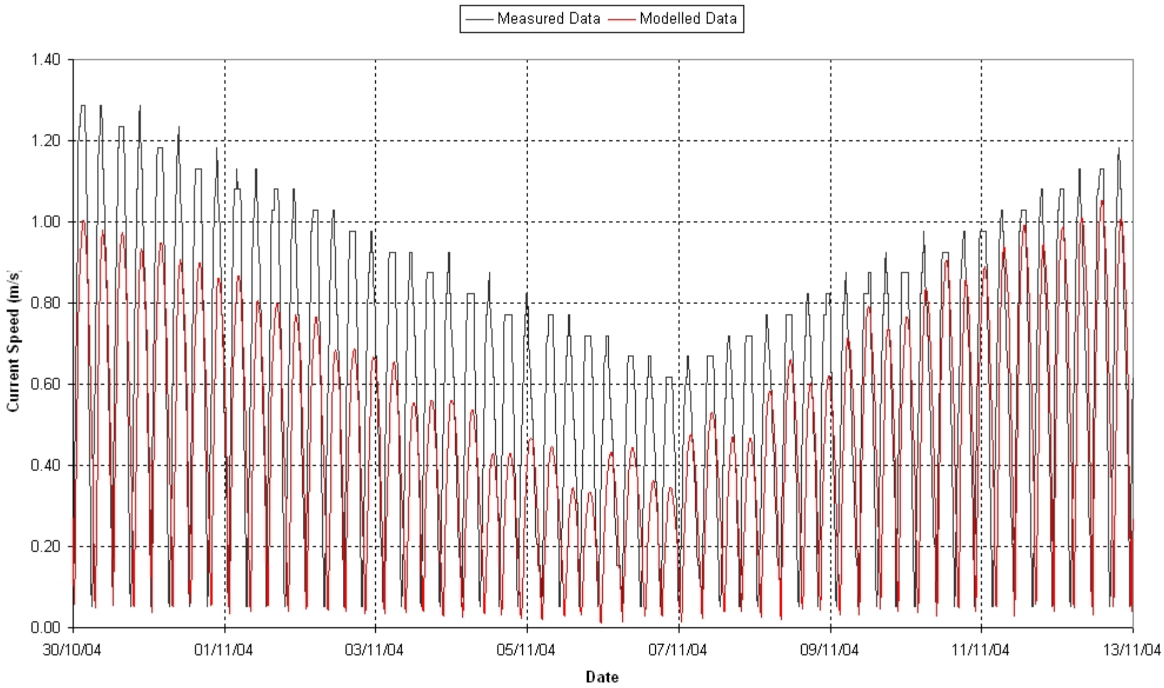


ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at site SN017U for the calibration period	Figure 6

(A)



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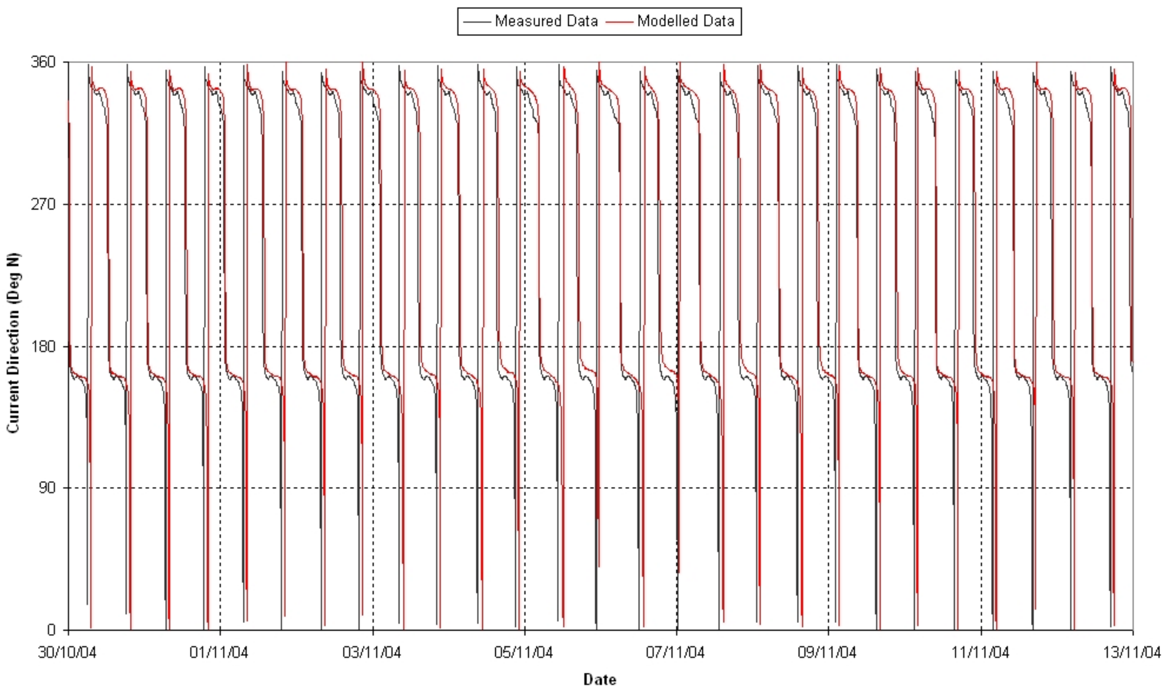
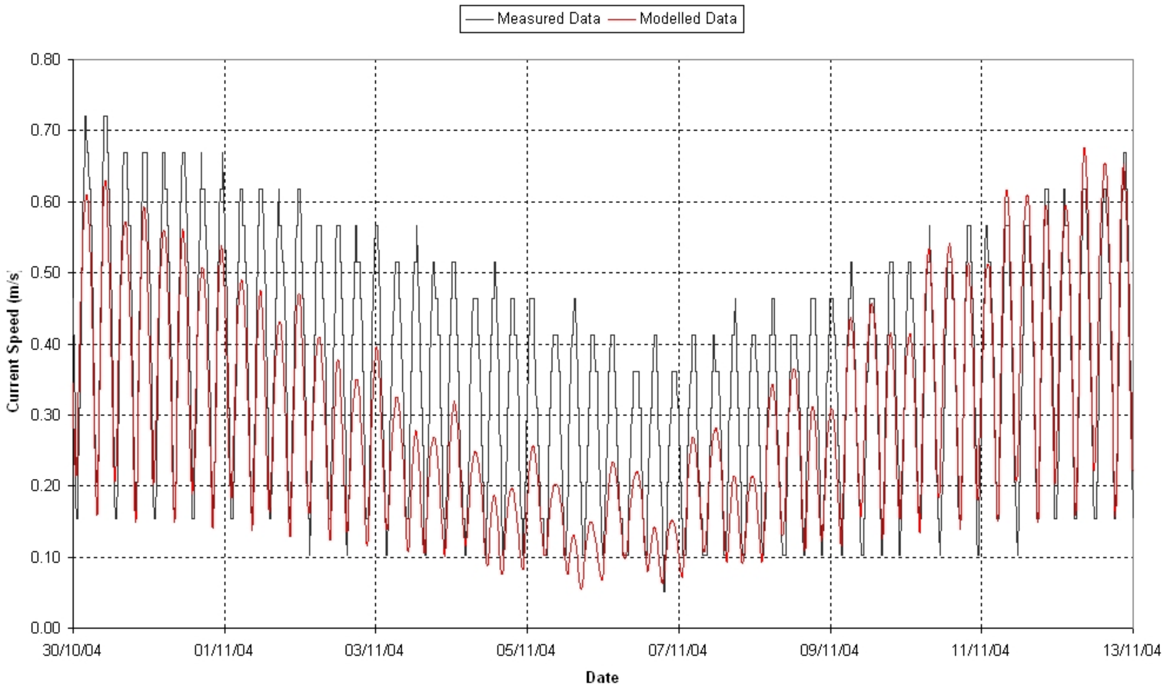


ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at site SN017AD for the calibration period	Figure 7

(A)



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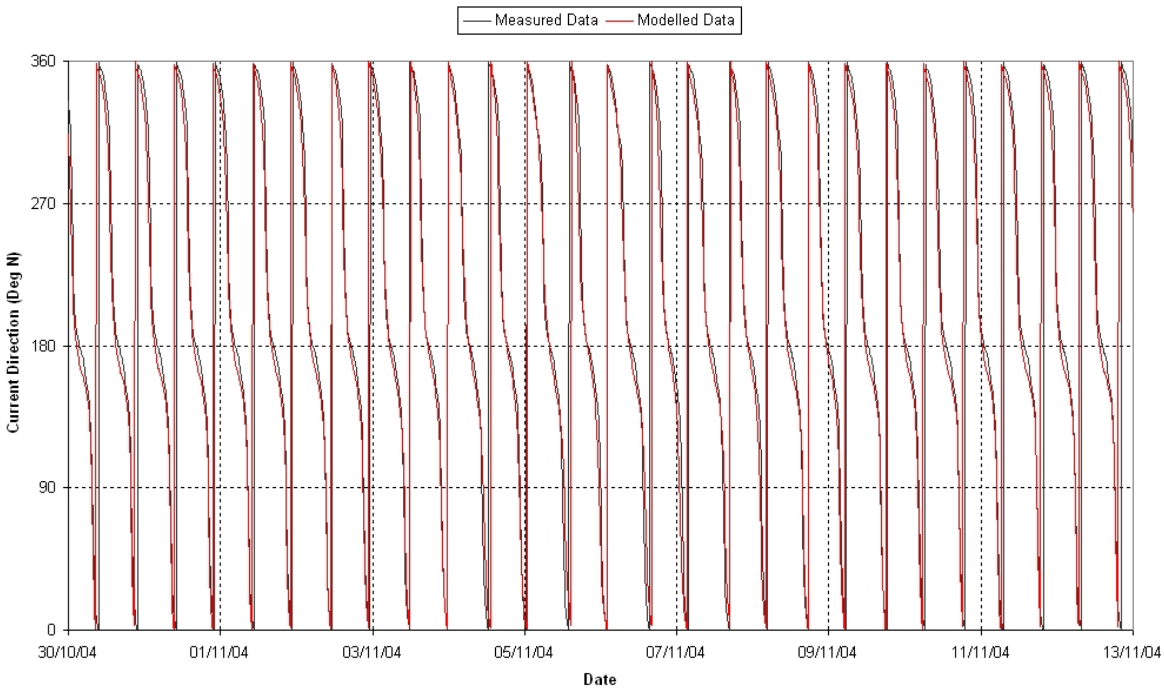
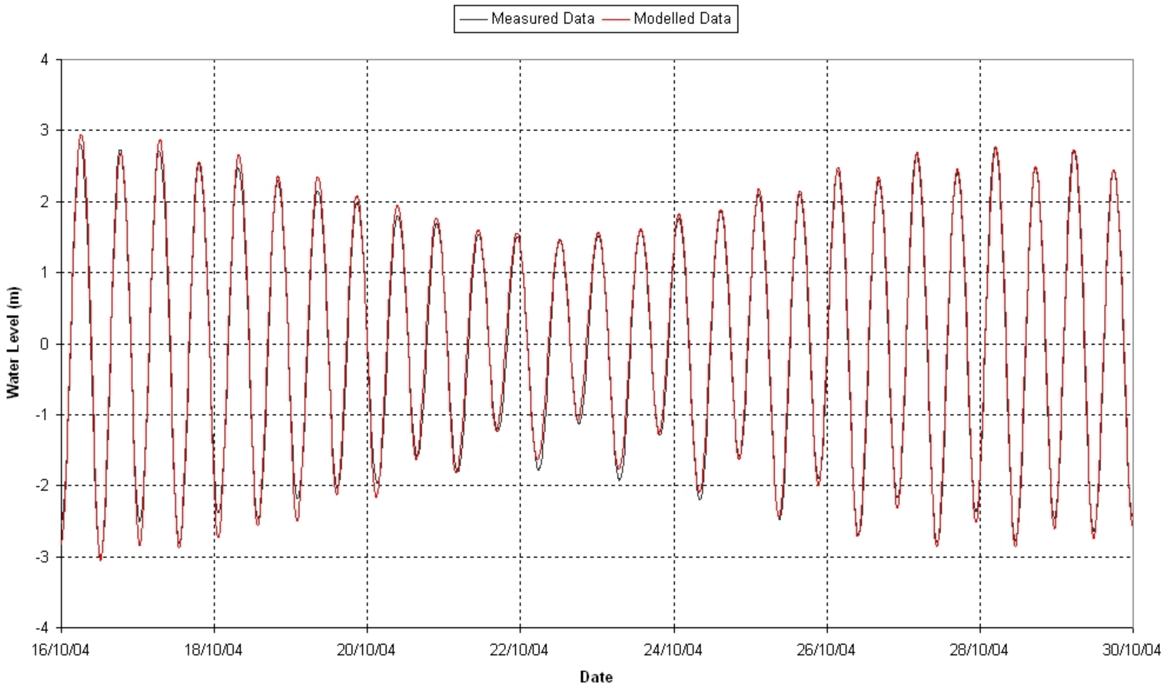


ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at site SN017P for the calibration period	Figure 8

(A)



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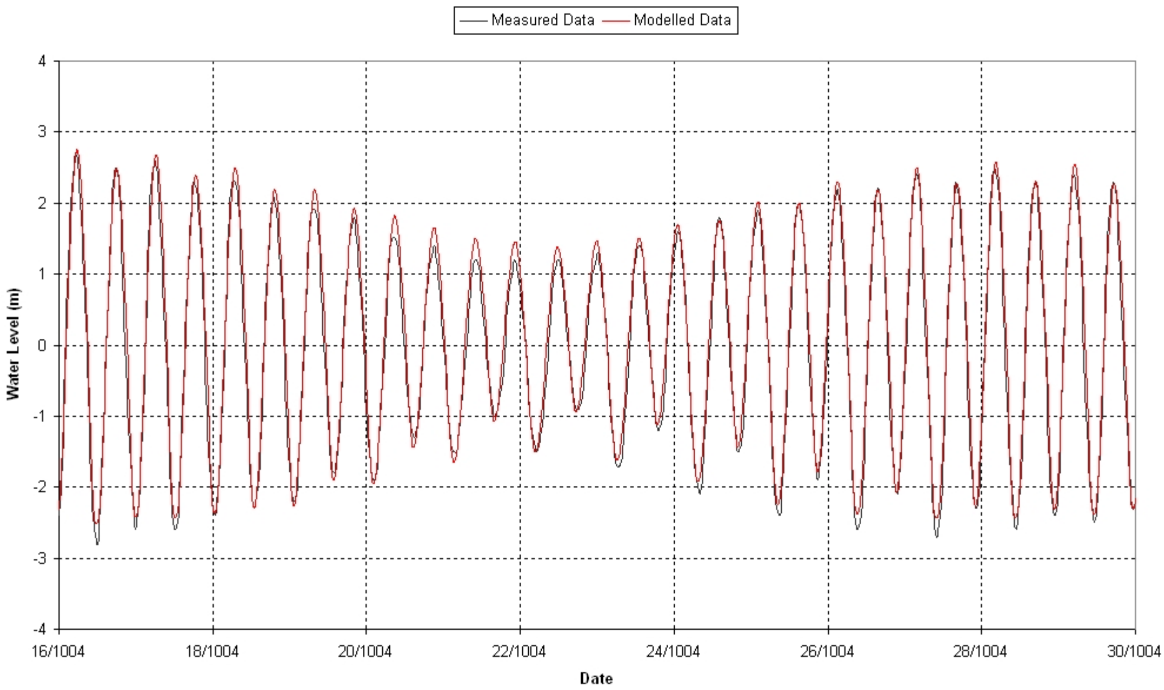
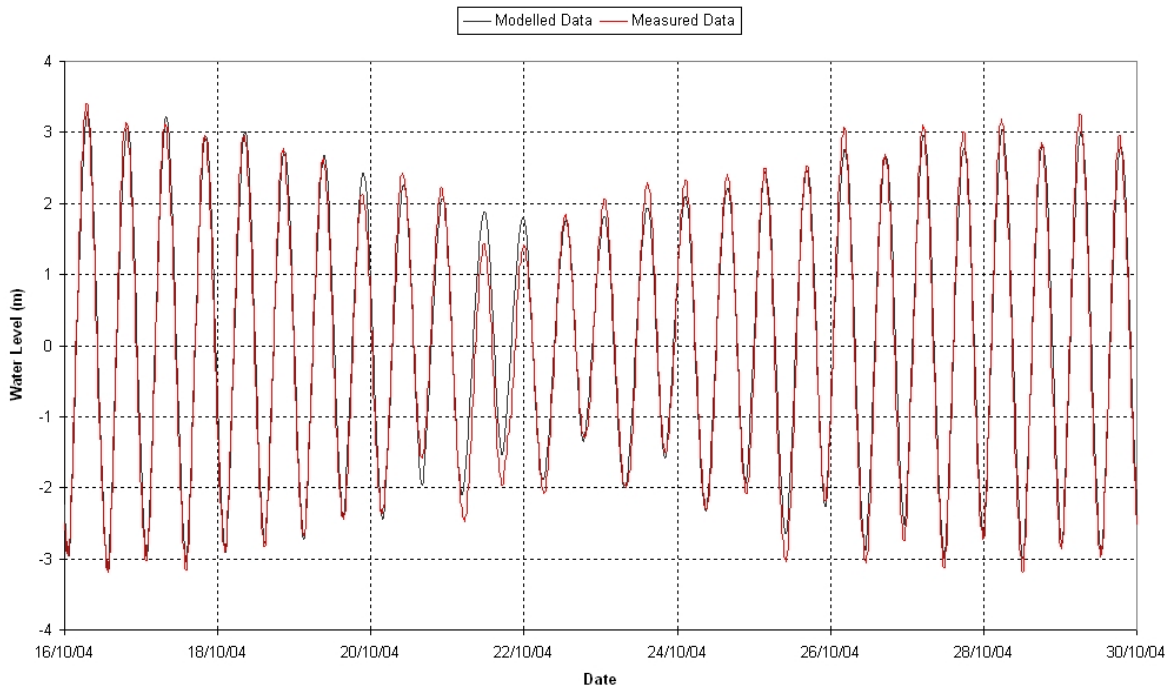


	Comparison between measured and modelled water level data at (A) the AWAC site and (B) Bridlington for the validation period	Figure 9

(A)



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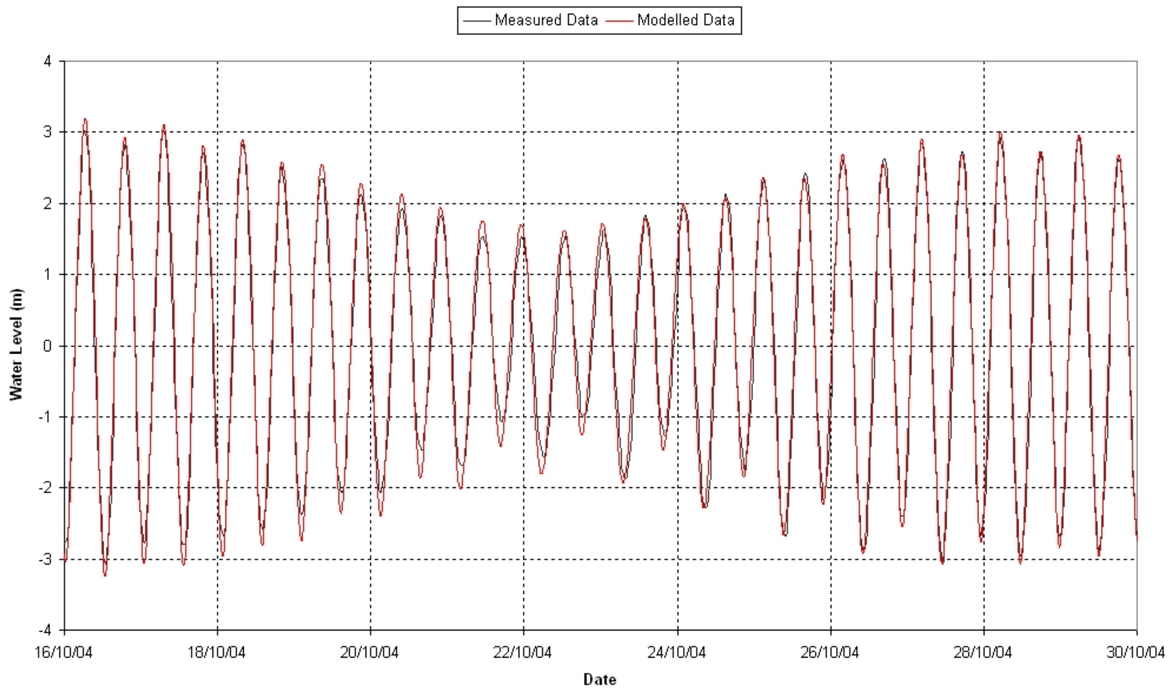
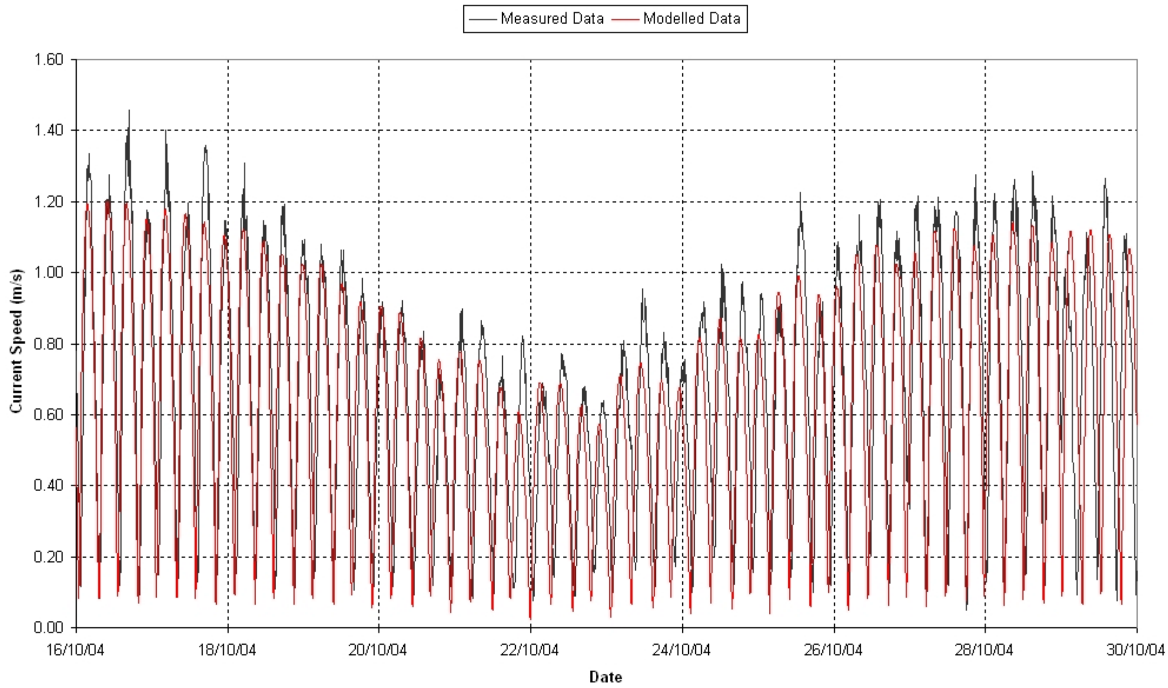


ABP mer marine environmental research	Comparison between measured and modelled water level data at (A) Immingham and (B) Spurn for the validation period	Figure 10

(A)



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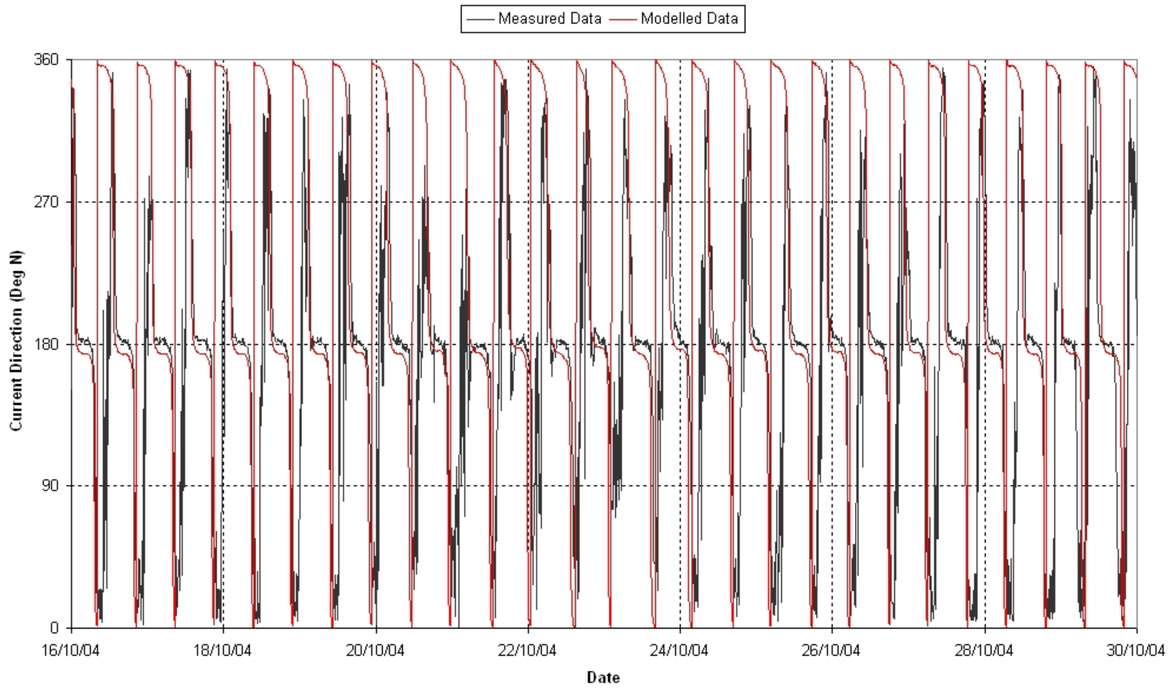
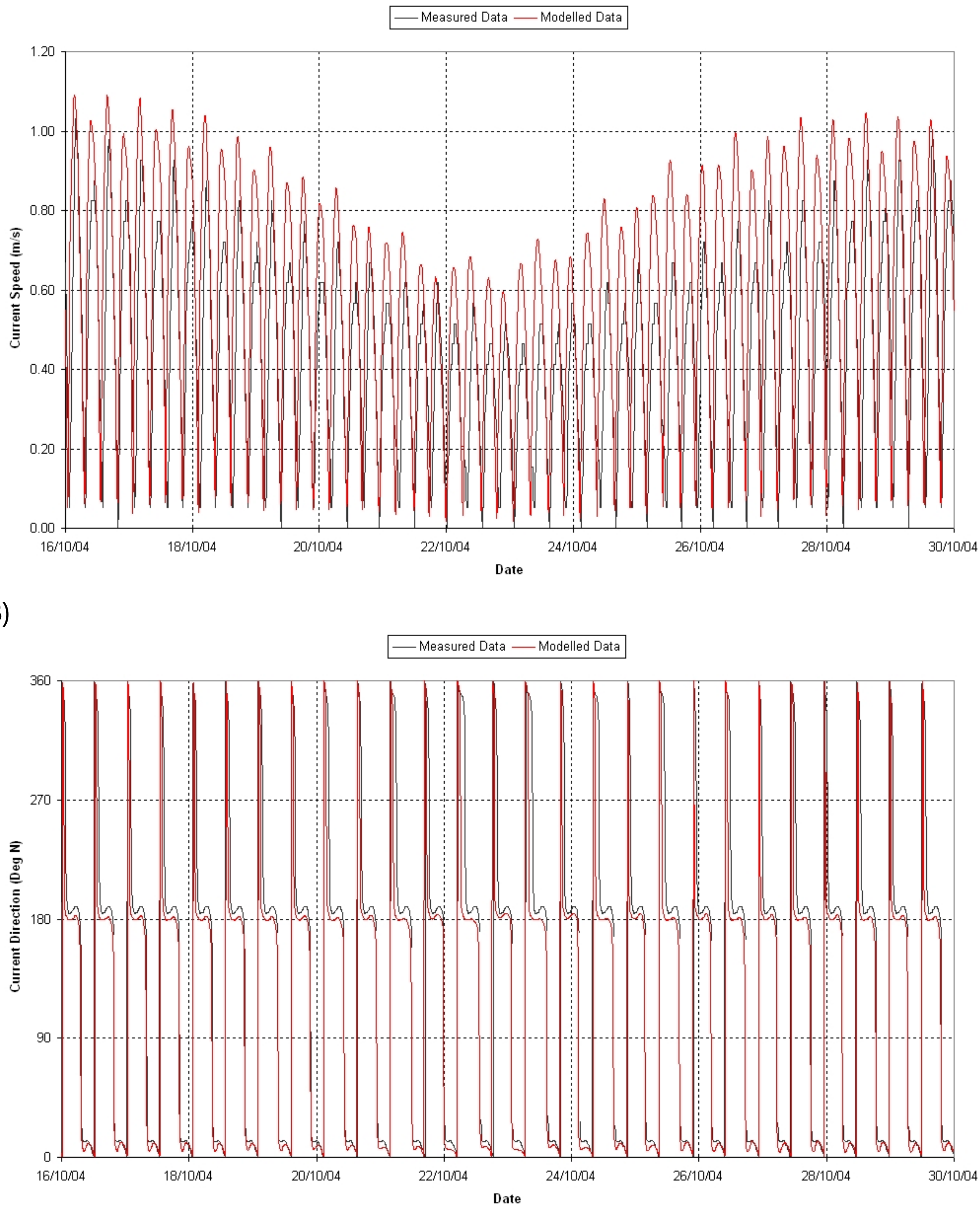


ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at the AWAC site for the validation period	Figure 11

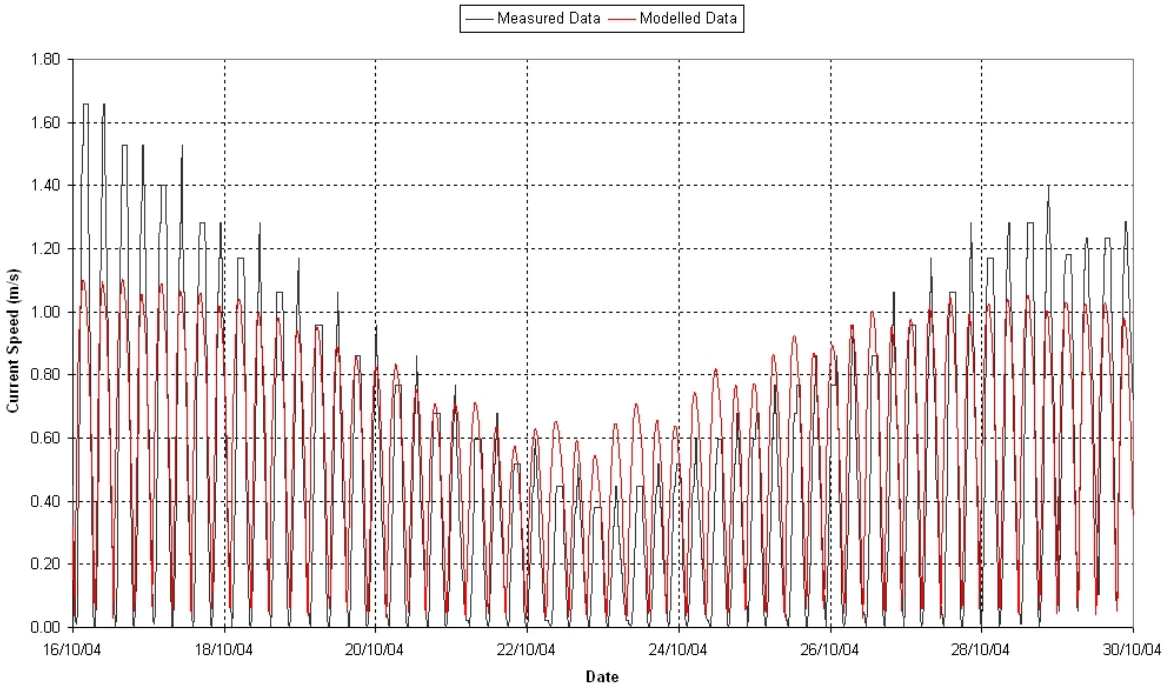
(A)

(B)

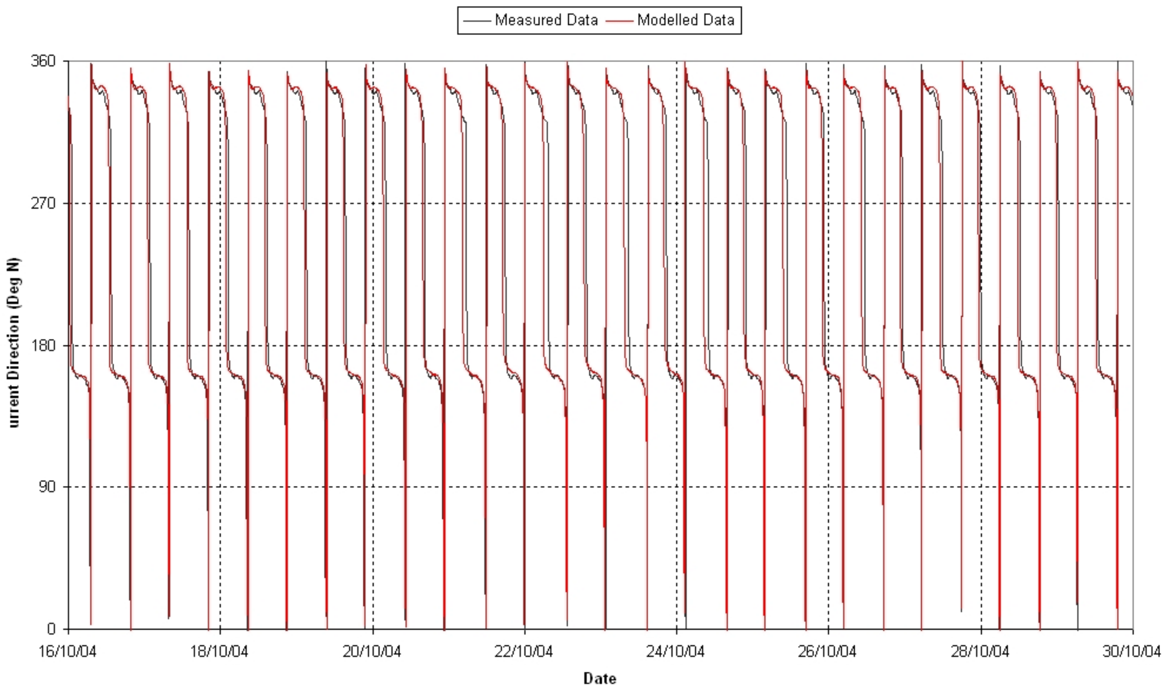


ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at site SN017U for the validation period	Figure 12

(A)



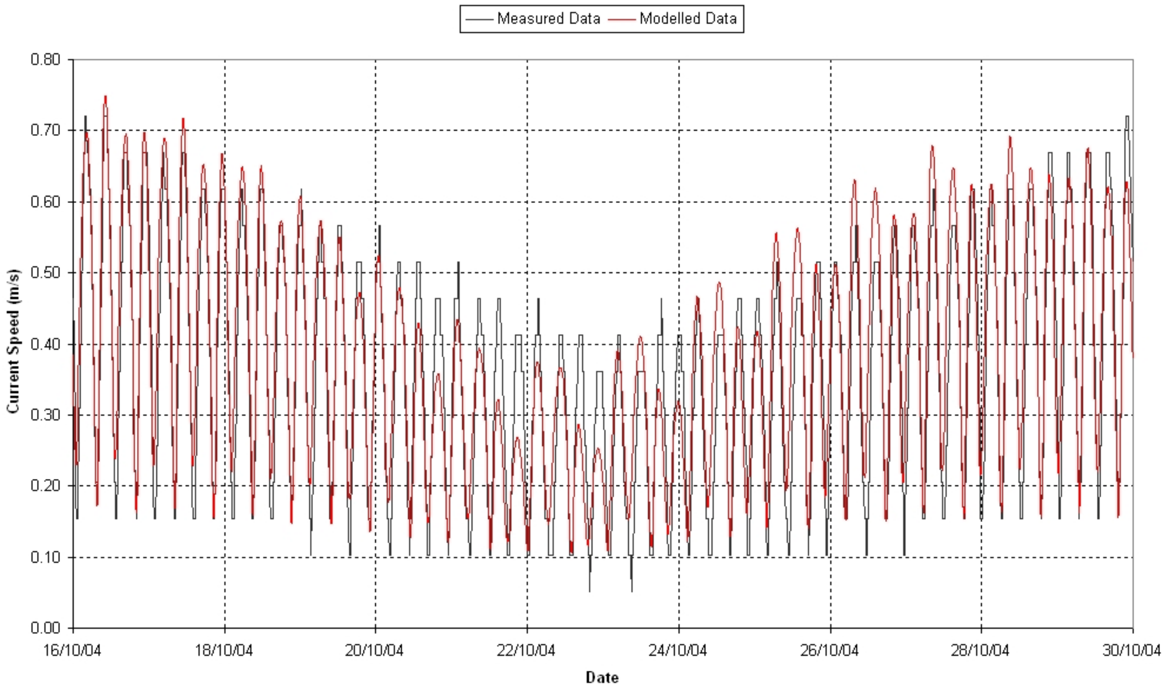
(B)



Comparison between measured and modelled current speed (A) and direction (B) data at site SN017AD for the validation period

Figure 13

(A)



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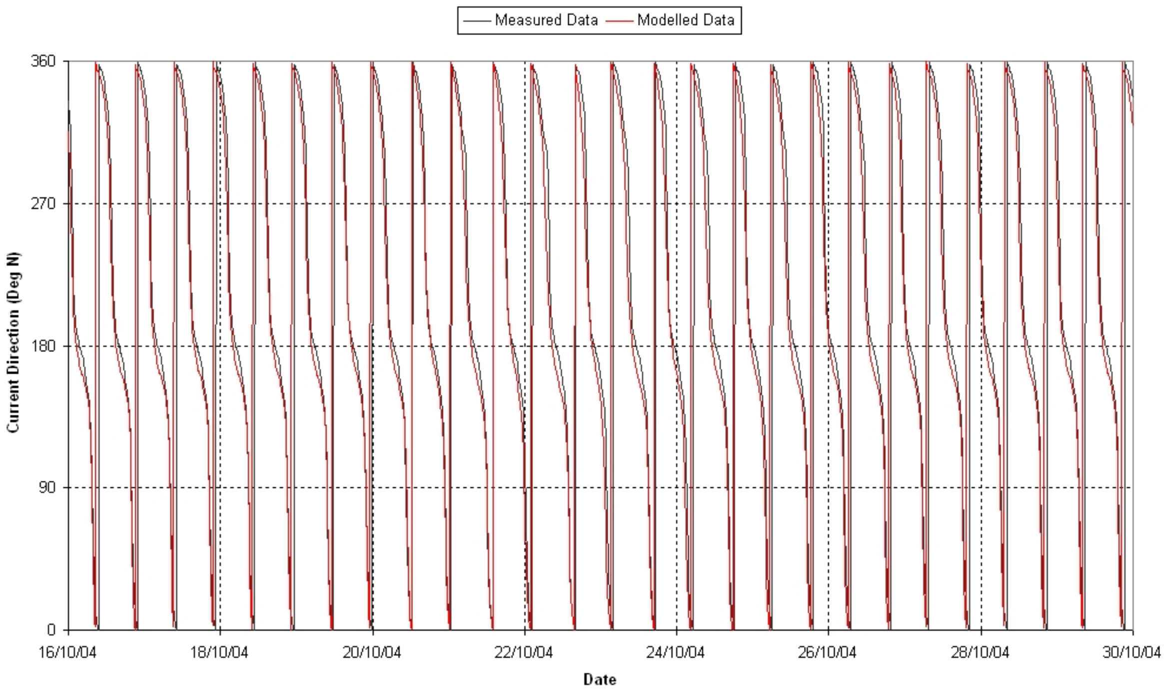
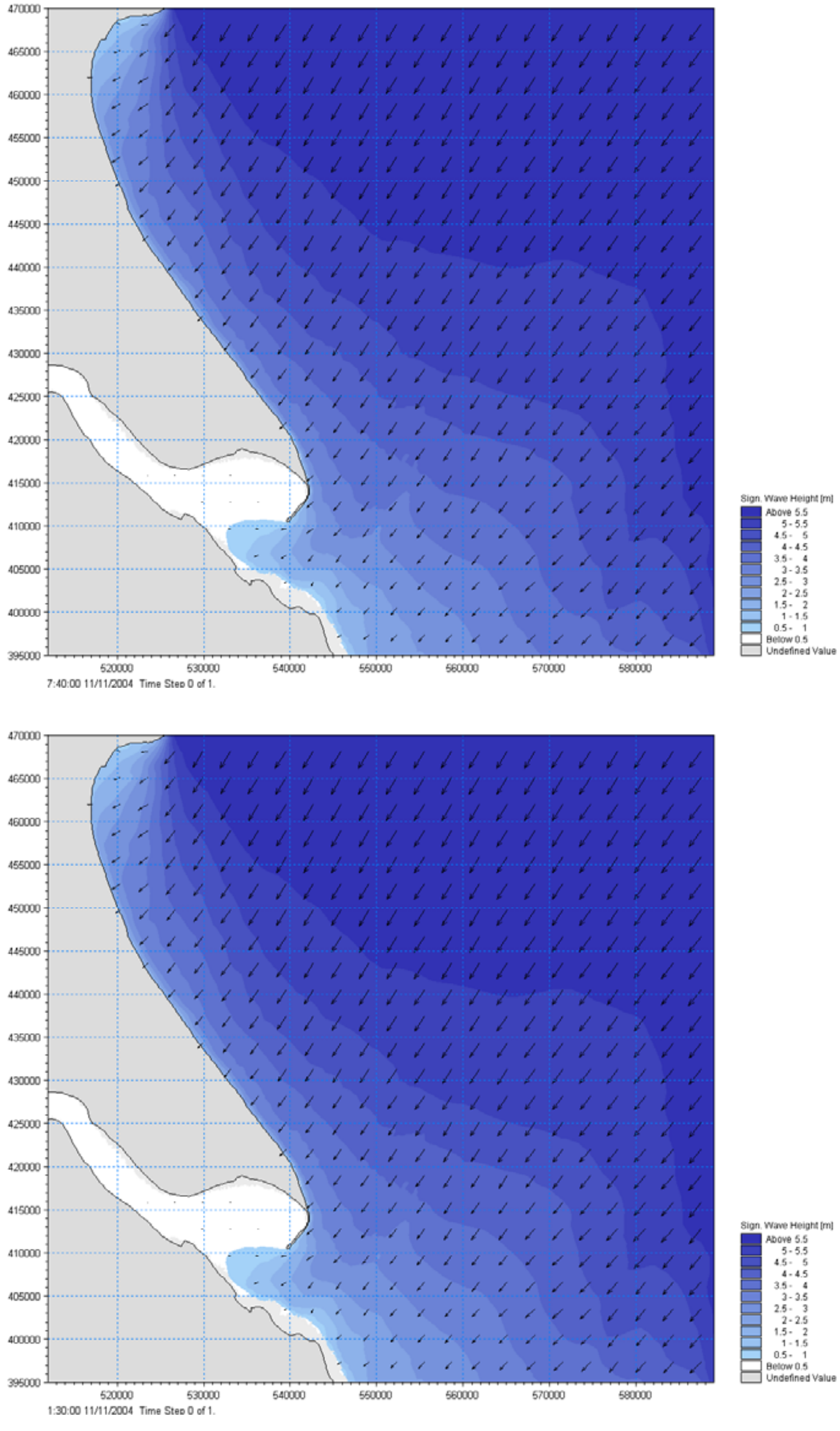
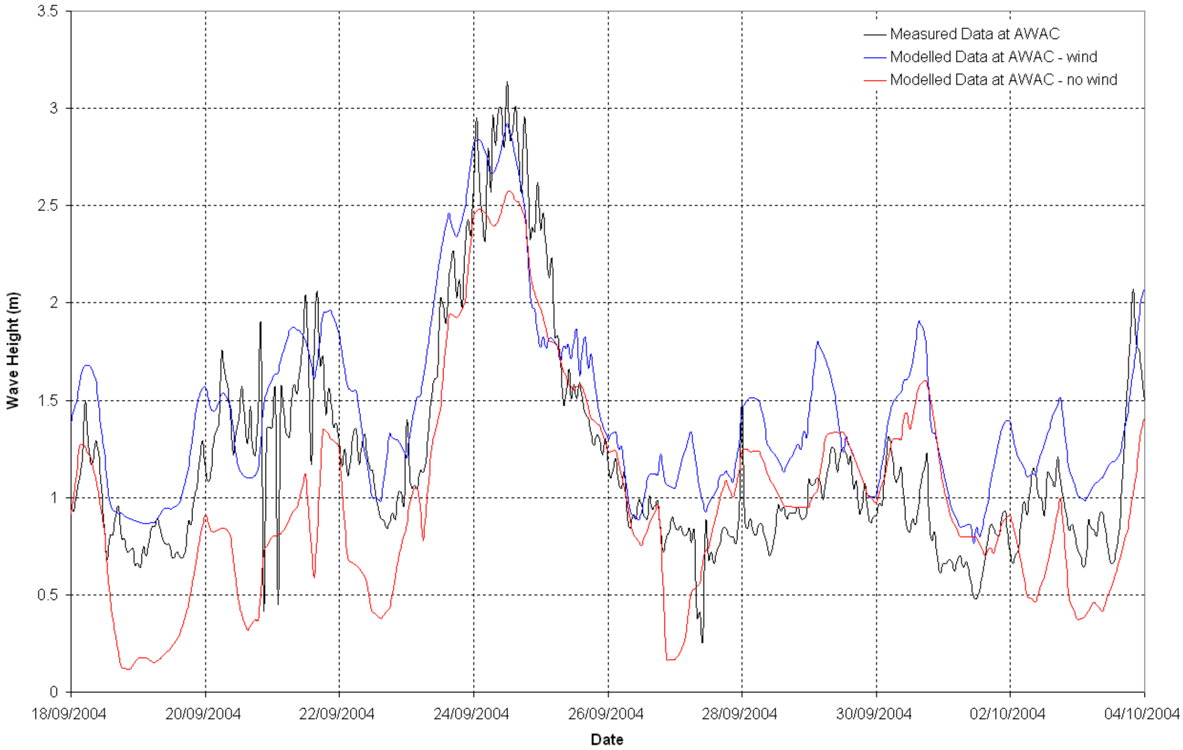


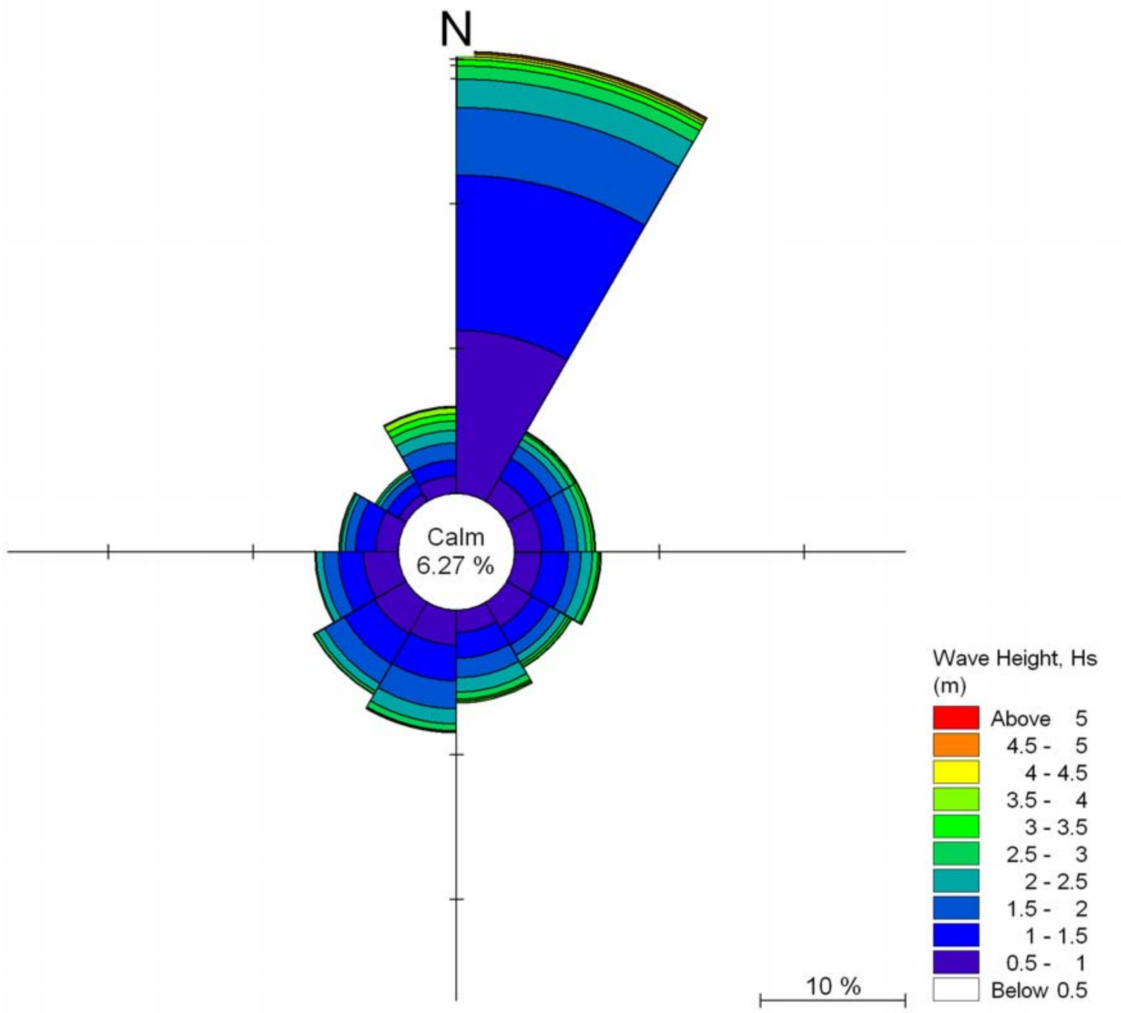
ABP mer marine environmental research	Comparison between measured and modelled current speed (A) and direction (B) data at site SN017P for the validation period	Figure 14



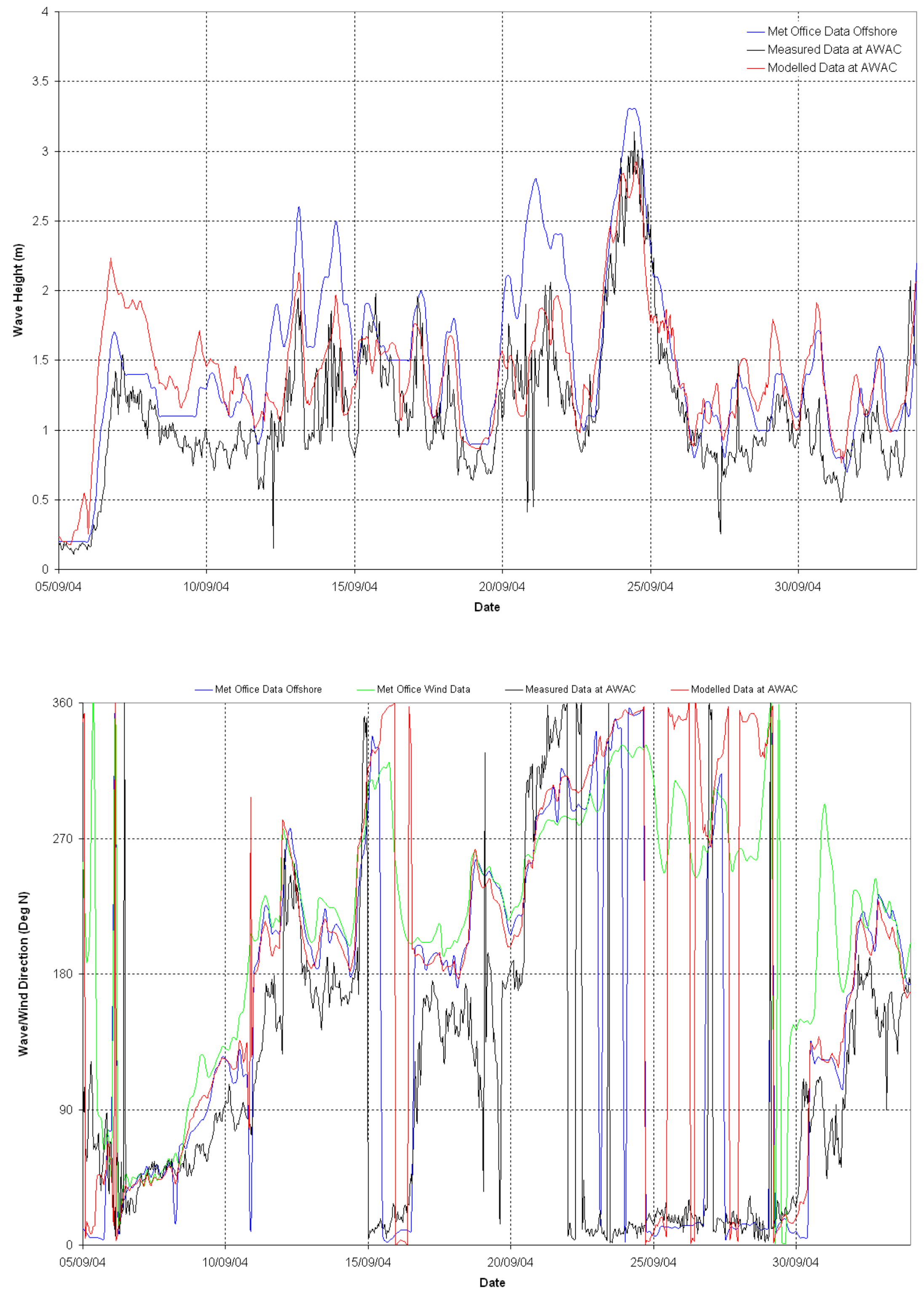
ABP mer marine environmental research	Wave sensitivity results for test 1 or a 1 in 50year return period at peak flood for (A) with and (B) without currents	Figure 15



ABP mer marine environmental research	Wave sensitivity results for test 2: with and without wind	Figure 16



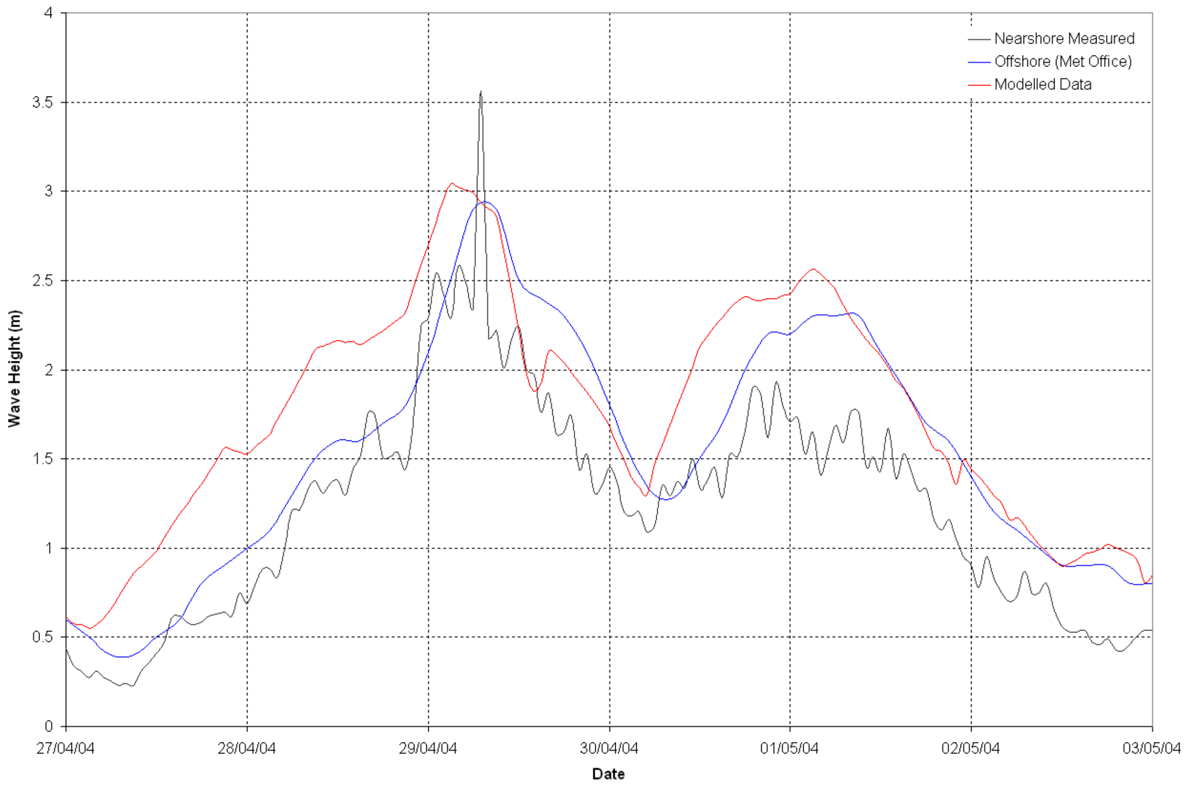
ABP mer marine environmental research	Wave rose of Met Office wave data between 1997-2006 (located at 54.0'N, 0.3'E)	Figure 17



Comparison between modelled and measured wave height (A) and direction (B) data at the AWAC site for the calibration period

Figure 18

(A)



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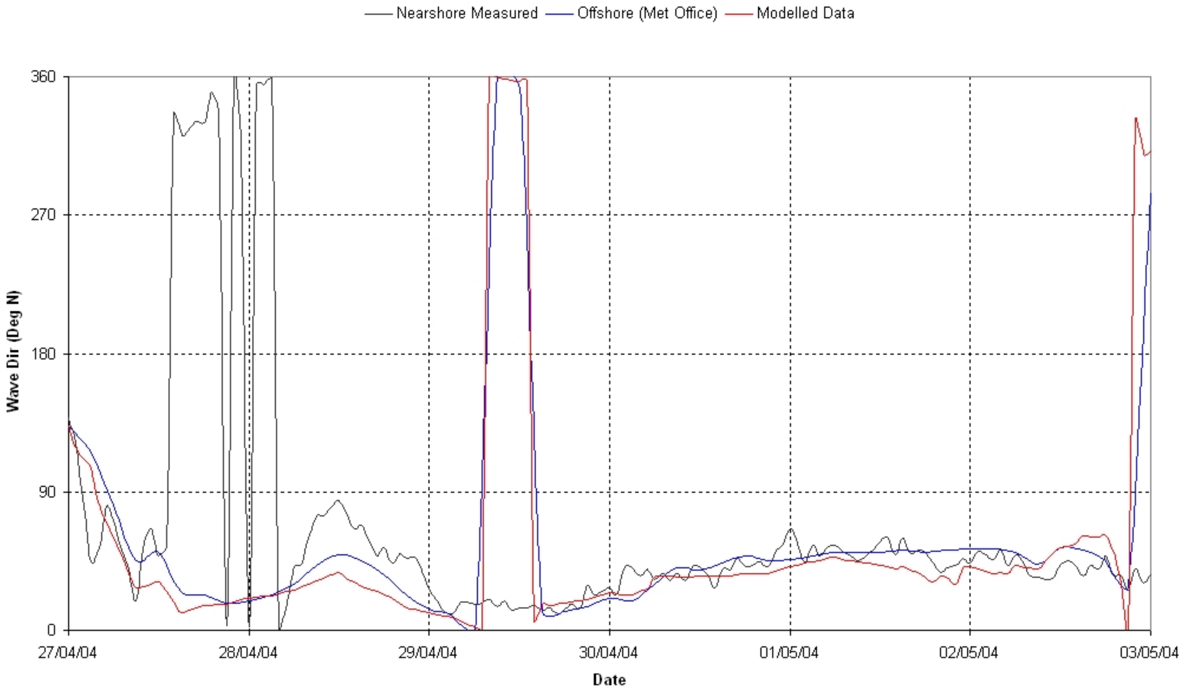
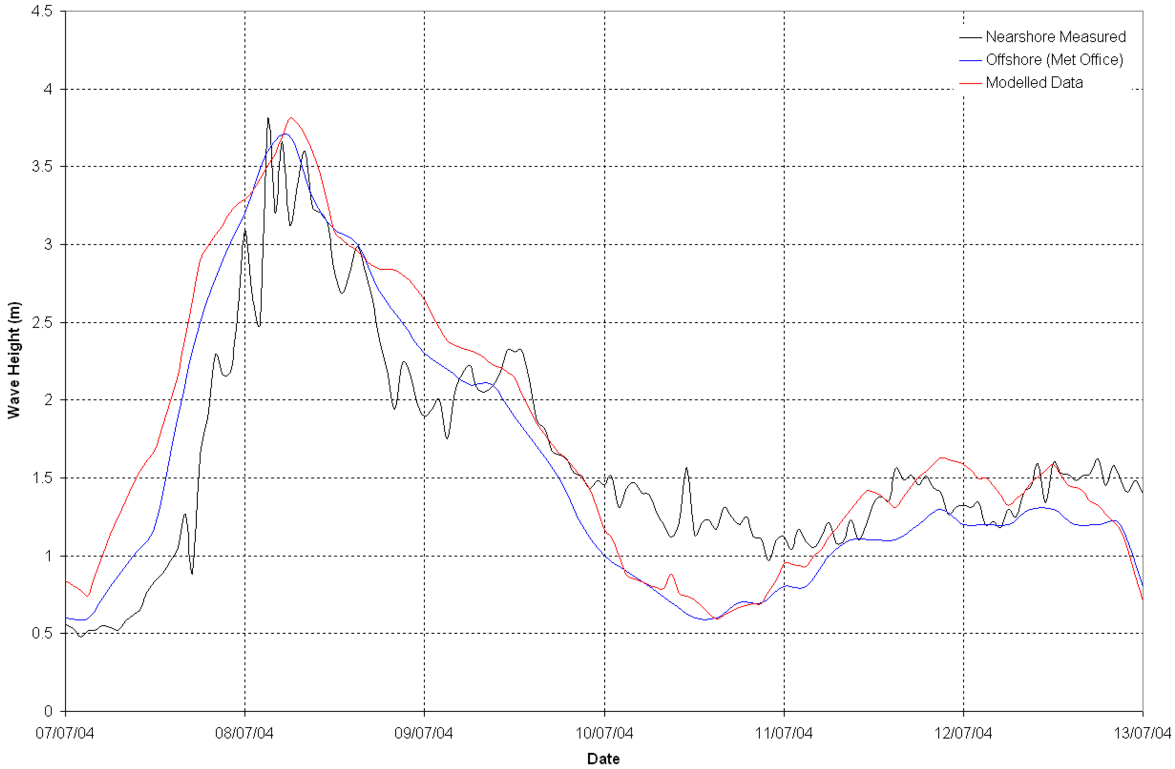


ABP mer marine environmental research	Comparison between modelled and measured wave height (A) and direction (B) data at the AWAC site during Event 1 (validation)	Figure 19

(A)



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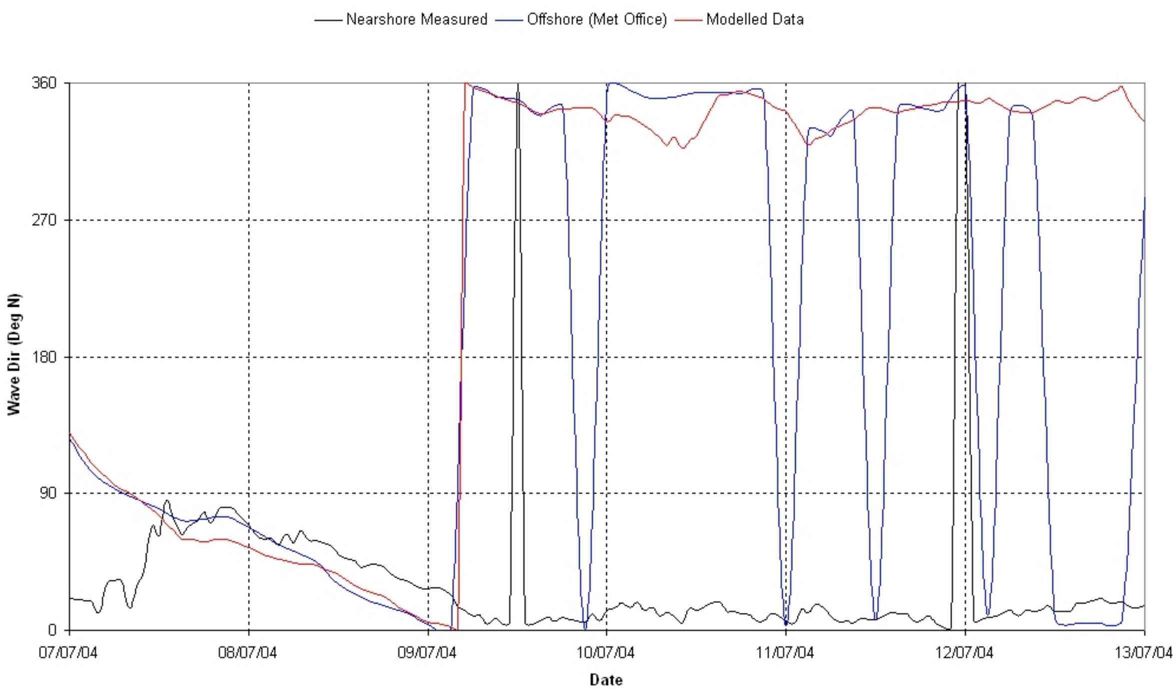
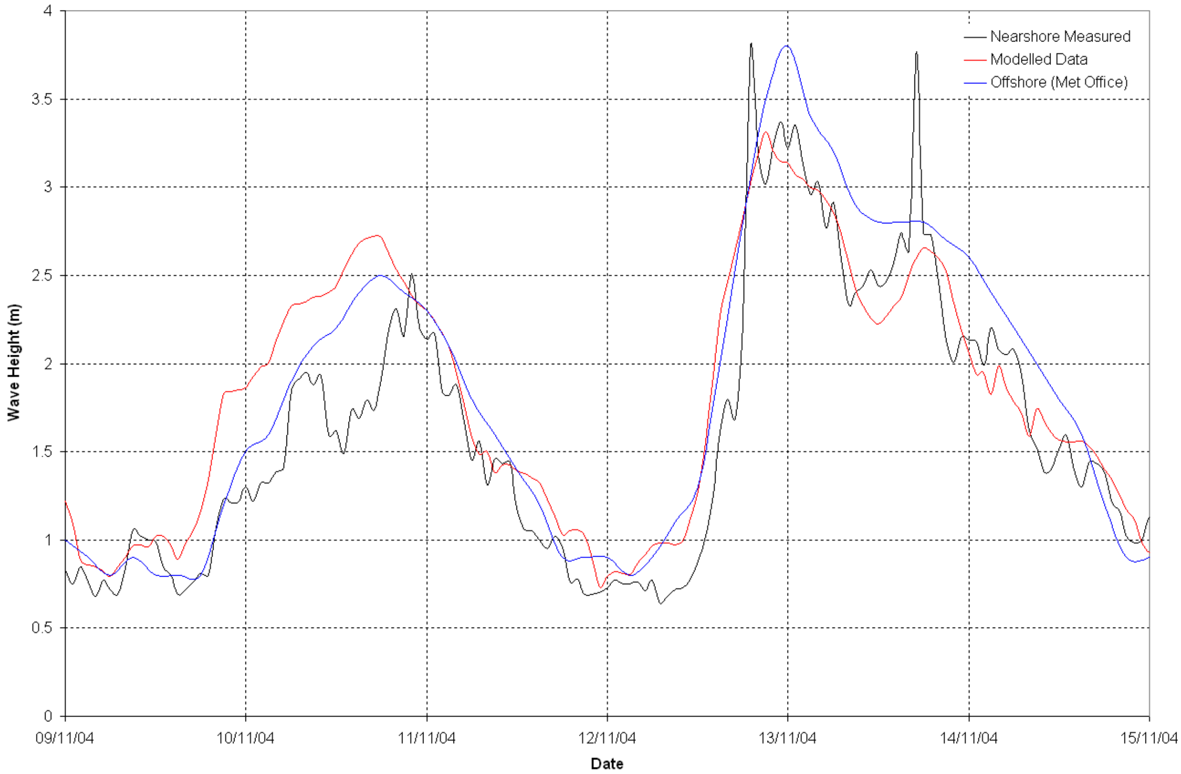


ABP mer marine environmental research	Comparison between modelled and measured wave height (A) and direction (B) data at the AWAC site during Event 2 (validation)	Figure 20

(A)



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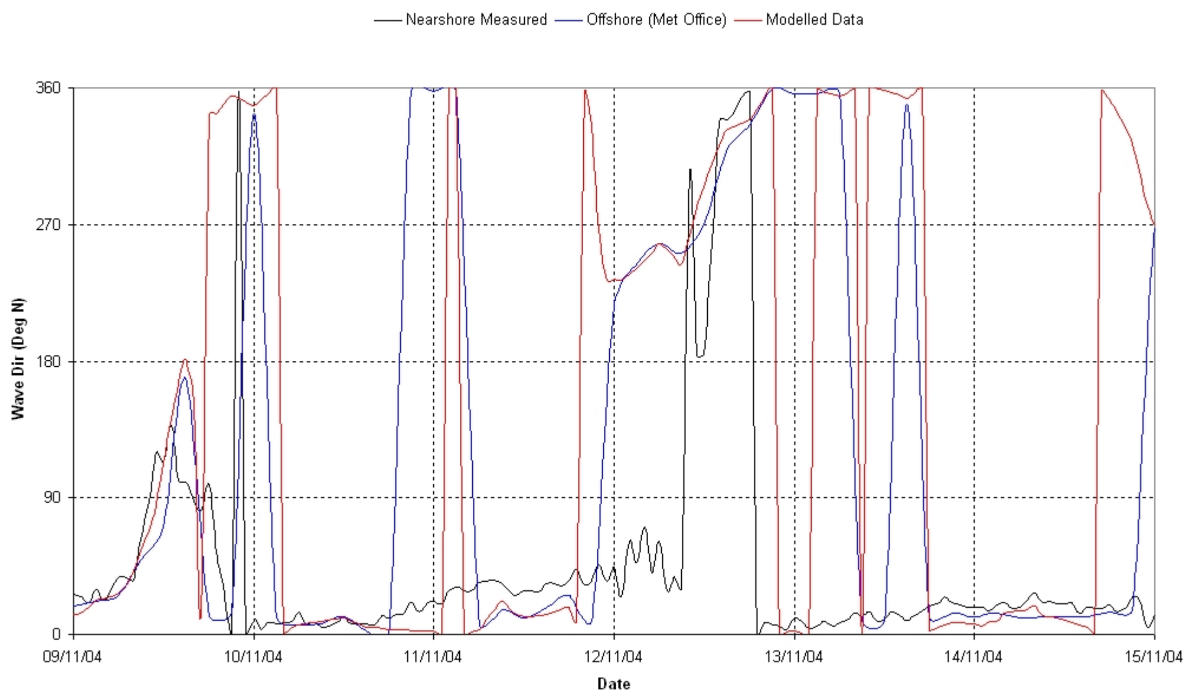
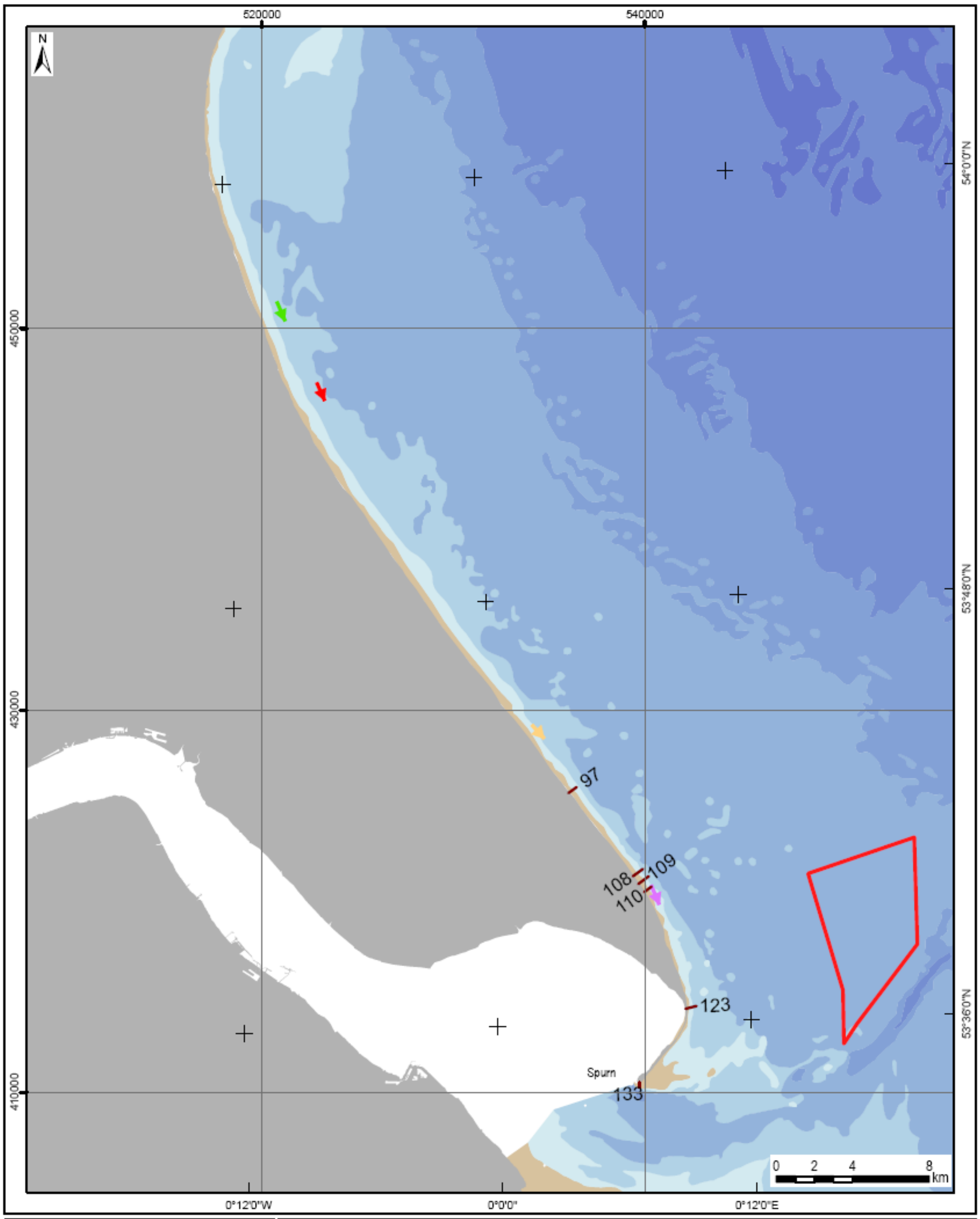


Comparison between modelled and measured wave height (A) and direction (B) data at the AWAC site during Event 4 (validation)

Figure 21



Date	By	Size	Version
June 2007	MCE	A4	1
Projection		Scale	
OSGB 1936		1:280,000	
Reference			
3682 - Fig_Sed_Transport.mxd			
Produced by ABPmer Ltd			

Sediment transport rates along the Holderness coast	Figure 22

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