Inch Cape Offshore Wind Farm

New Energy for Scotland

Offshore Environmental Statement:
VOLUME 2C
Appendix 10C: Hydrodynamic and Spectral Wave Model Calibration and Validation

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INCH CAPE & NEART NA GAOITHE OFFSHORE WIND FARMS COASTAL PROCESSES ASSESSMENT

HYDRODYNAMIC AND SPECTRAL WAVE MODEL CALIBRATION AND VALIDATION

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GLOSSARY

ADCP	Acoustic Doppler Current Profiler
BODC	British Oceanographic Data Centre
CD	Chart Datum
Cdis	White Capping Coefficient
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CFL	Courant-Friedrich-Lévy
DELTAdis	White Capping Coefficient
DHI	Danish Hydraulic Institute
ECNS	English Channel and North Sea (model)
FTMS	Forth and Tay Modelling System
FWR	Foundation for Water Research
GMT	Greenwich Mean Time
HD	hydrodynamic
H_s	Significant wave height
HW	High Water
LAT	Lowest Astronomical Tide
LW	Low Water
MCA	Marine and Coastguard Agency
MSL	Mean Sea Level
NGR	National Grid Reference
POL	Proudman Oceanographic Laboratory
ODN	Ordinance Datum Newlyn
OSGB36	Ordinance Survey Great Britain 1936 horizontal datum

OWF	Offshore Wind Farm
RNEUK	Repsol Nuevas Energias UK Limited
SEPA	Scottish Environment Protection Agency
STW	Scottish Territorial Waters
SW	Scottish Water
T_p	Peak Wave Period
UKHO	United Kingdom Hydrographic Office
UKMO	United Kingdom Meteorological Office
z_{ch}	Charnock Parameter

ADMIRALTY TIDE TABLES: an annual publication that detail the times and heights of high and low waters for over 230 standard and 6000 secondary ports and subsidiary information.

ADMIRALTY TIDAL STREAM ATLASES: display, in diagrammatic form, the major tidal streams for selected waters.

ADMIRALTY MANUAL OF TIDES (NP120): a largely mathematical, detailed description of tidal theory and its application to the analysis and prediction of tides and tidal streams.

ADMIRALTY TIDAL HANDBOOKS (NP122 1-3): three volumes outline the Admiralty method of harmonic tidal analysis for long and short observation periods and include information on datums for hydrographic surveys.

CHART DATUM (CD): the datum to which levels on a nautical chart and tidal predictions are referred; usually defined in terms of a low-water tidal level. Chart Datum is not a horizontal surface, but may be considered so over a limited local area.

COLLECTOR CHARTS: bathymetric charts showing the original survey lines and bed levels, sometimes referred to as fair charts. Largely superseded by modern digital data collection methods.

DATUM: a fixed reference point from which measurements are made.

LOWEST ASTRONOMICAL TIDE (LAT): the lowest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions; often used to define CHART DATUM

MEAN SEA LEVEL (MSL): the arithmetic mean of hourly heights observed over some specified period (sometimes 19 years); often used as a datum for surveys.

ORDNANCE DATUM NEWLYN (ODN): UK national vertical datum. Defined as mean sea level at Newlyn Cornwall in the period May 1915 to April 1921.

UNITED KINGDOM HYDROGRAPHIC OFFICE (UKHO): Part of the UK Ministry of Defence (Admiralty) responsible for the survey and production of navigational charts.

1 INTRODUCTION

This document has been prepared for Repsol Nuevas Energias UK Limited (RNEUK) by Metoc Limited (Intertek METOC) as part of an investigation of meteorological/oceanographic and coastal processes of the Scottish Territorial Waters Round 2 offshore wind farm (OWF) sites. RNEUK is acting as the lead contact for the coastal processes assessments and are the developers for the Inch Cape OWF. The other developer is Mainstream Renewable Power Ltd (Mainstream), who is developing the Neart na Gaoithe OWF.

1.1 Background and Objectives

Intertek METOC has been commissioned to undertake the coastal process assessments for both the Inch Cape and the Neart na Gaoithe OWFs. The study requires the delivery of a calibrated and validated hydrodynamic and spectral wave model. This model will be used for the assessment of the baseline conditions (together with the use of field data and other relevant information). The model will then be configured with the proposed developments in order to undertake the assessment of impacts from these developments on the metocean and sediment regimes, both locally around the development sites and regionally over the wider area. The potential impacts will then be included in the Coastal Processes section of the Environmental Impact Assessment (EIA) reports being prepared by the clients.

The first element of the study, a hydrodynamic and spectral wave model is presented in this document. The report describes the modelling approach, model construction, model calibration, and model validation of the Forth and Tay Modelling System (FTMS). The scope and specification of the FTMS was previously agreed with the Clients and Marine Scotland (representing all relevant stakeholders) subsequent to the methodology presentation in the Intertek METOC Report 2550[1].

The ultimate aim of this report is to provide stakeholders with sufficient evidence to demonstrate that the FTMS is suitable for use in the future baseline and impact assessments for the coastal processes assessments for the STW OWFs.

1.2 Geographical Overview

The coverage of the FTMS model extends from Flamborough Head (south of Scarborough) to north of Peterhead on the Moray Coast. More specifically the coverage is defined by latitudes 54.11°N and 57.72°N and longitudes 3.8°W and 0.34°E. The model also encompasses the upper reaches of the Forth of Firth and the Forth of Tay. The area sufficiently covers:

- The two key STW OWF areas (Inch Cape and Neart na Gaoithe) at high resolution;
- Round 3 Zone 2 (Firth of Forth) at lower resolution (which can be upgraded later if required);
- A distance offshore to capture more regional impact effects;

- The coastal sediment transport cells that might potentially be affected by the STW developments; and
- The adjacent coastal areas that might potentially be affected by STW developments at a reasonable resolution.

1.3 OCEANOGRAPHIC DESCRIPTION

Tidal Currents

East Scotland's offshore tidal currents are dominated by the semi-diurnal tide i.e. two high waters and two low waters per lunar day. The Atlantic tidal wave (Kelvin wave) floods into the North Sea through the Pentland Firth and progresses south along the east coast of Scotland towards the Dover Straits[2] (Pugh, 1987).

Other conditions contributing to the total current flow, such as storm surges, general circulation and surface wind drift, are either small, infrequent or variable in nature. These conditions are not modelled in this study as they do not represent the general tidal circulation.

The local tidal currents around the coast are determined by the local bathymetry. In general the flows will be lengthways through channels; into and out of estuaries/firths; around headlands; and rectilinear and parallel to open coasts. It should be noted, however, that the exact bathymetry, combined with the prevailing tidal and meteorological conditions, may result in the small-scale circulation, eddying flow reversals, slack waters, and other localised features. This is further complicated by the non-tidal flow components which may at times comprise part of the tidal current flow.

The MIKE21 hydrodynamic module has the capacity to include river outflow in the calculations. Large river discharges may have an effect on local oceanographic conditions. For this reason, a representation of the main river flows has been included in the model.

Wave Climate

Off the east coast of Scotland the wave climate is predominately driven by conditions in the North Sea. Autumn and winter meteorological conditions tend to result in rough seas as the wind direction can lead to large fetches or fetch unlimited sea states.

Offshore wave conditions are experienced between 200°N and 340°N with the majority of wave conditions occurring between 20°N and 90°N. Significant wave heights (H_s) over 4 m can be experienced from any direction in the easterly sector but are most common from 0°N and 120°N. Swell wave conditions are largely dominated by waves generated from 20°N and 60°N. Little swell is experienced from other directions due to either restricted fetch lengths or due to insufficient wind duration[3] (Ramsay and Brampton, 2000).

1.4 TIME AND SPACE COORDINATE DEFINITIONS

All dates and times are specified in Greenwich Mean Time (GMT).

Unless otherwise stated, horizontal positions (latitudes and longitudes in degrees, or Eastings and Northings, in metres) are expressed in the Ordnance Survey of Great Britain 1936 (OSGB36) coordinate system.

Unless otherwise stated, vertical positions are expressed to local Mean Sea Level (MSL). Conversions to vertical datums of Ordnance Datum Newlyn (ODN) and local Chart Datum (CD) are provided based on data provided by the UK Hydrographic Office[4] – (UKHO, 2010).

Model element locations, expressed as (x,y) coordinates, are referenced to Ordnance Survey of Great Britain 1936 (OSGB36).

Current direction refers to the direction towards which the current is flowing, in degrees clockwise from true north (°T). Current vectors point in the direction of current flow.

Wind direction refers to the direction from which the wind is blowing, in degrees clockwise from true north (°T).

2 MODELLING APPROACH

2.1 Requirement for Modelling

The construction of a hydrodynamic and spectral wave modelling system is a key part of delivering a technically robust, scientifically defensible analysis tool to quantify and categorise the impacts of the OWF developments. Impacts need to be assessed both in general terms, on the existing current, waves and sediment regimes, as well with specific reference to sensitive receptors.

The primary reasons for adopting a complex, technically advanced approach towards the metocean and coastal processes assessments, are to provide:

- Additional knowledge and insight into the often complex patterns of water movement resulting from current, wave and wave current interaction in offshore and coastal waters;
- A flexible tool capable of assessing coastal processes impacts that may arise during the construction phase (laying foundation or dredging cables); and
- A predictive tool for assessing the local and far-field post-construction impacts of individual developments and the cumulative and in-combination effects of the both developments in the short term and long term (up to 25 years).

2.2 Purpose of Models and Model Domain Selection

The model described in this report has been built specifically for undertaking metocean and coastal processes assessments. The specification for the FTMS area was determined by the modelling requirements outlined below:

- Spatial resolution sufficiently high to resolve all pertinent features of the sea bed within both OWF sites, the Round 3 Zone 2 (Firth of Forth) and nearby coastline;
- A model covering the coastal sediment cells adjacent to both OWF developments;
- Able to assess the impact of the OWF development on any near-field or far-field sensitive receptors where required;
- Any sediment plume should have the space to advect, disperse and settle over a sufficient time, without being lost over the boundaries of the model, and
- Boundaries sufficiently far from the area of interest that flow perturbations usually observed very close to the boundaries would not affect the impact assessment.

After consideration of these factors the model specification was determined as:

- Type: 2 dimensional, flexible mesh, dynamic
- Domain: Flamborough Head, Yorkshire to Scotstown Head, Aberdeenshire
- Mesh resolution (at its finest): <4000 m2 (element side length approx. 60 m)
- Total mesh elements: 131582

The selected model mesh refinements provide the best balance between model resolution and spatial extent, thus ensuring that computer processing requirements are kept within workable limits.

2.3 CALIBRATION/VALIDATION APPROACH

To ensure a model can accurately represent for the processes to be modelled, and provide the relevant regulators with high confidence of the model performance, the model needs to be calibrated and validated against field data. Calibration is achieved by fine tuning the key model parameters, such as bed resistance coefficients. Model calibration is generally undertaken against data of high quality - data with less confidence (such as tidal diamonds) are used for secondary calibration, model validation or general visual checks.

The calibration and validation data utilised for the assessment consists of:

- Water level data collected at a number of temporary and permanent tide gauges sites in the area of interest. This data includes published tide level predictions and harmonics (UKHO / Admiralty Tide Tables)[5], fixed tide gauges forming part of the Institute of Science (IOS) UK Network, from port, harbour or other permanent gauges, and temporary gauges from various field surveys.
- Acoustic Doppler Current Profiler (ADCP) data collected as part of a specific survey for the study. These data provide tidal elevations and current speeds and directions.
- British Oceanographic Data Centre (BODC) data purchased for this study. These data provide current speeds and directions from historical field surveys.
- Wave parameter data collected at a number of temporary and permanent directional wave buoys in the sites of interest. This data includes H_s, peak wave period (T_p), wave directional and directional spreading from the Forth and Tay Metocean Survey and the Cefas WaveNet network of buoys.

The data used for calibration and validation for the hydrodynamic model are described in detail in Section 4.

Following common practice, calibration for the hydrodynamic model was undertaken for spring tidal conditions. Validation was carried out for neap tide conditions, to confirm that calibration parameters are valid across the normal range of tidal conditions.

The data used for calibration and validation for the spectral wave model are described in detail in Section 5.

Calibration for the spectral wave model was undertaken for a range of representative wind and wave conditions. Validation was carried out for similar, but independent, range of conditions, to confirm that calibration parameters are valid across the normal range of metocean conditions.

2.3.1 Tidal Data Analysis

Tidal analysis is based on the observation that there is a close relationship between the movements of the moon and sun, and tidal elevations. Historically, there have been many attempts to relate the positions of the sun and moon to measured tidal levels, culminating in the work of Doodson[6] and Doodson and Warburg[7] which treats the observed tides as the sum of a finite number of harmonic constituents, which are characterised by angular speeds and phases[1].

Tidal analysis of measured data was primarily developed as a tool for shipping and navigation, but has subsequently been adopted as a powerful tool to provide an understanding of the hydrodynamics of an area and its responses to tidal forcing.

Implicit in this approach are the assumptions that the responses of the sea to tidal forcing do not change with time and that analysis of a sufficiently long time series of tidal data will provide a true value for each constituent. The longer the period of data available for analysis, the more accurately harmonic constituents can be determined and the more accurate the subsequent tidal predictions. In general a 30 day time series of water level or current velocity is required for robust harmonic analysis.

The tidal analysis procedure has the advantage that it removes short-term meteorological and wave action effects. Harmonic constituents can be recombined to produce predictions of water levels and current velocities, for any period of time, that represent only the tidal component of the measured signal. Subtraction of this tidal component from the original signal produces a residual, which represents meteorological effects on water level and current speed.

Tidal harmonic analysis is a powerful tool that has a number of benefits:

- Tidal signals measured over a very wide range of time frames can be analysed and the harmonic constituents recombined for a single, common time frame.
- By removing meteorological effects the meteorological conditions during the survey period do not need to be known. This can be important as the accurate definition of meteorological conditions, across a large study area over a data collection period, presents a number of problems:
    a) Meteorological conditions may not have been recorded during tidal data collection studies;
    b) Where meteorological data have been collected, the spatial and temporal extent of the data is generally limited, and frequently

cannot be applied to the whole study period and model domain; and

c) Meteorological forcing may occur through a number of complex processes over large areas of sea / ocean. These processes cannot be fully represented within a local coastal model, or would require significantly more meteorological data than can practicably be collected during a marine survey campaign.

- Data sets from a range of time frames can be used in the calibration process within a single time frame. This ensures that the number of model simulations is minimised providing a very time efficient process; and
- In the overwhelming majority of model builds, boundary conditions are based on other tidal models. As these other tidal models do not generally include meteorological forcing, harmonic analysis allows the comparison of tidal model output with the tidal component of measured field data.

The mean spring tidal range at Leith, near to the midpoint of the FTMS, is of the order of 4.8 m metres. Harmonic analysis of the measured data (see Appendices A and B) indicate that tidal forcing dominates in this area and the influence of non-tidal forcing is small. A harmonic analysis and tidal prediction approach to measured data has therefore been adopted in this study.

3 MODEL CONSTRUCTION

3.1 MODELLING SYSTEM AND DOMAIN

The FTMS model has been constructed using an unstructured flexible mesh dynamic modelling system. This is a sophisticated two-dimensional modular based modelling system, and has the capacity to run both hydrodynamic and spectral wave models. It may be used to predict the physical properties of tidal currents and deep water waves, and the interactions between these, for any specified area.

A flexible mesh model has the advantage of using a spatial varying resolution, so that the complex bathymetries and coastal topographic features can be sufficiently resolved by the model.

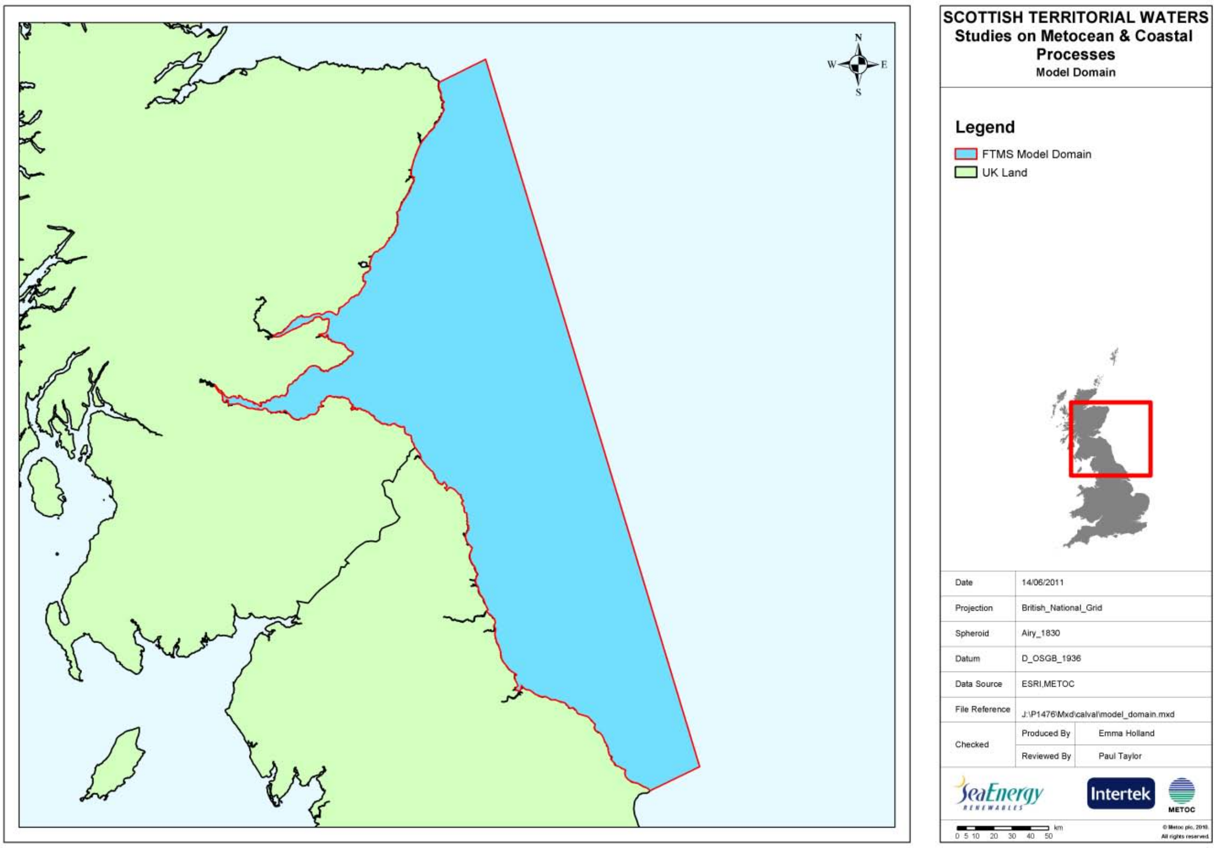
3.1.1 Model Resolution (HD and SW)

The FTMS model was built with a spatial resolution varying from approximately 60 m in the area of interest to approximately 2500 m offshore. A total of 131582 triangular elements are used in the model. This allows adequate representation of the physical processes. The model covers an area of approximately 33,462 km^2. Table 3-1 gives the locations of the corners of the grid and the coordinates of the extremities of the boundaries. Figure 3-1 shows the model domain of the FTMS model, as determined by the modelling requirements outlined in Section 2.2:

Table 3-1: Model coverage

Domain	Easting		Northing	
South-West Corner	525841		470444	
South-East Corner	558563		486269	
North-East Corner	430073		867755	
North-West Corner	410792		857591	
Boundaries	Start		End	
	Easting	Northing	Easting	Northing
South Boundary	525841	470444	558563	486269
East Boundary	558563	486269	430073	867755
North Boundary	430073	867755	410792	857591

Figure 3-1: Domain of the FTMS model



3.1.2 Model Bathymetry (HD and SW)

The bathymetry was created using:

- Digitised contour and depth sounding data taken from the appropriate resolution provided by the MIKE C-MAP dataset;
- The mean high water springs line from the Ordnance Survey Boundary-Line data set;
- Multi-beam site surveyed bathymetric data at the Inch Cape OWF site; and
- Multi-beam site surveyed bathymetric data at the Neart na Gaoithe OWF site and proposed export cable corridors.

The coverage of the bathymetric data used for the model construction is shown in Figure 3-2.

All data sets were reduced to a common vertical datum of MSL, by adapting the method from the UKHO's Integrated Coastal Zone Mapping Project[8] (ICZMap® project, Ruth Adams, 1994).

Co-range lines are contours that describe areas of equal tidal range. By tracing the co-range contours and relating these values to available onshore MSL information at ports MSL data was more accurately interpolated offshore. Subsequently a datum correction map was created and applied to any data relative to CD across the model domain. The datum correction map is presented in Figure 3-3.

A widely used natural neighbour interpolation technique was adopted to generate the model bathymetry. The bathymetry generated was checked visually against the original charts to ensure consistency.

Figure 3-4 shows the overall model mesh and bathymetry.

Figure 3-2: Coverage of bathymetric data

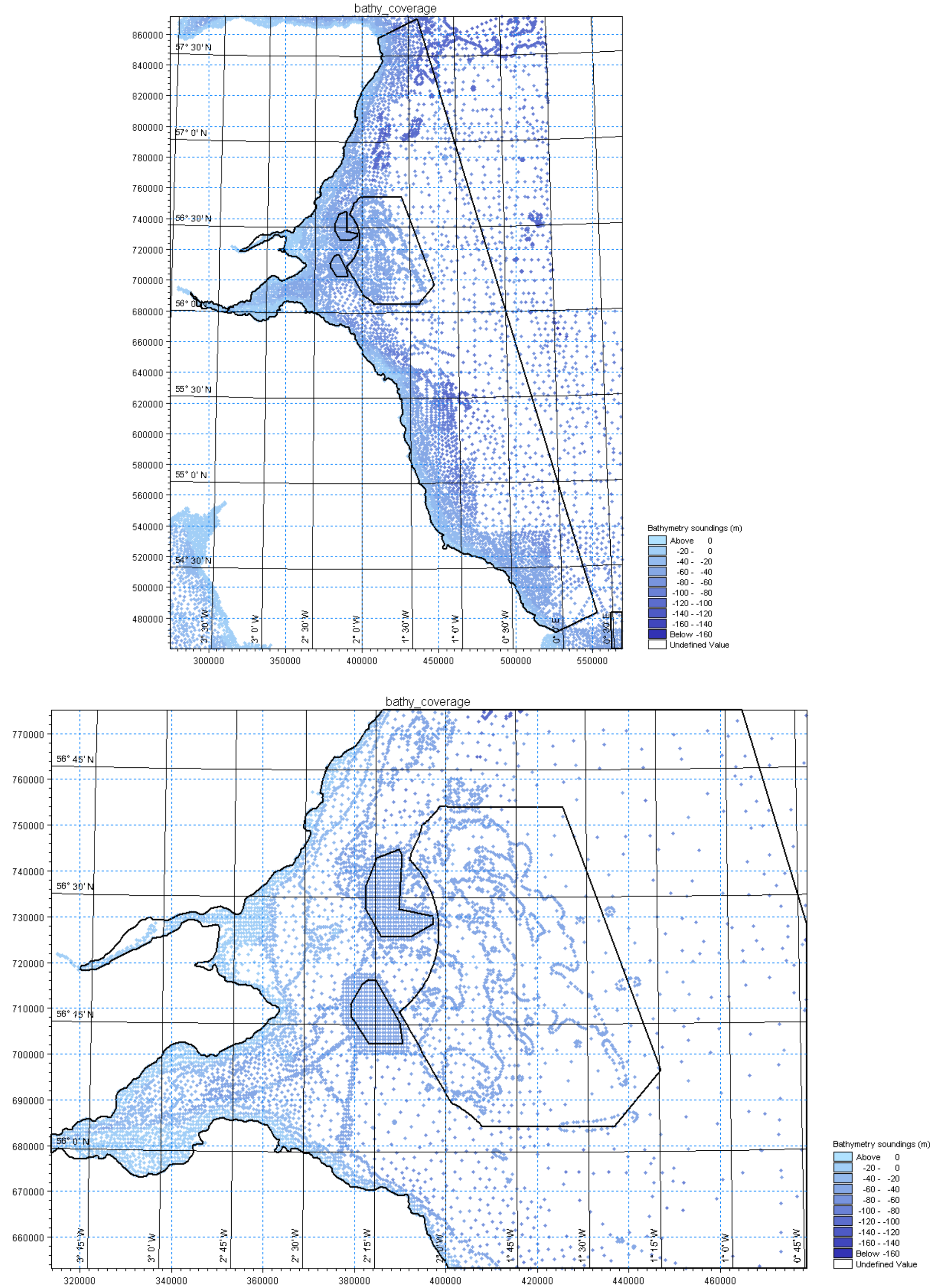


Figure 3-3: FTMS datum correction map

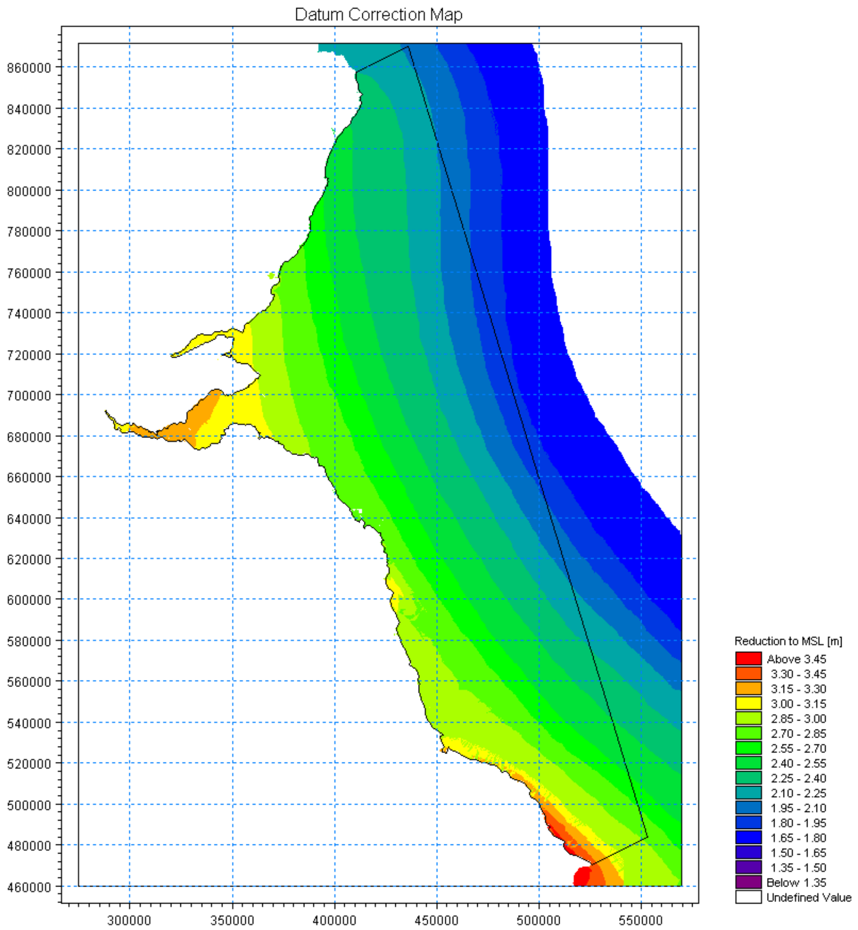
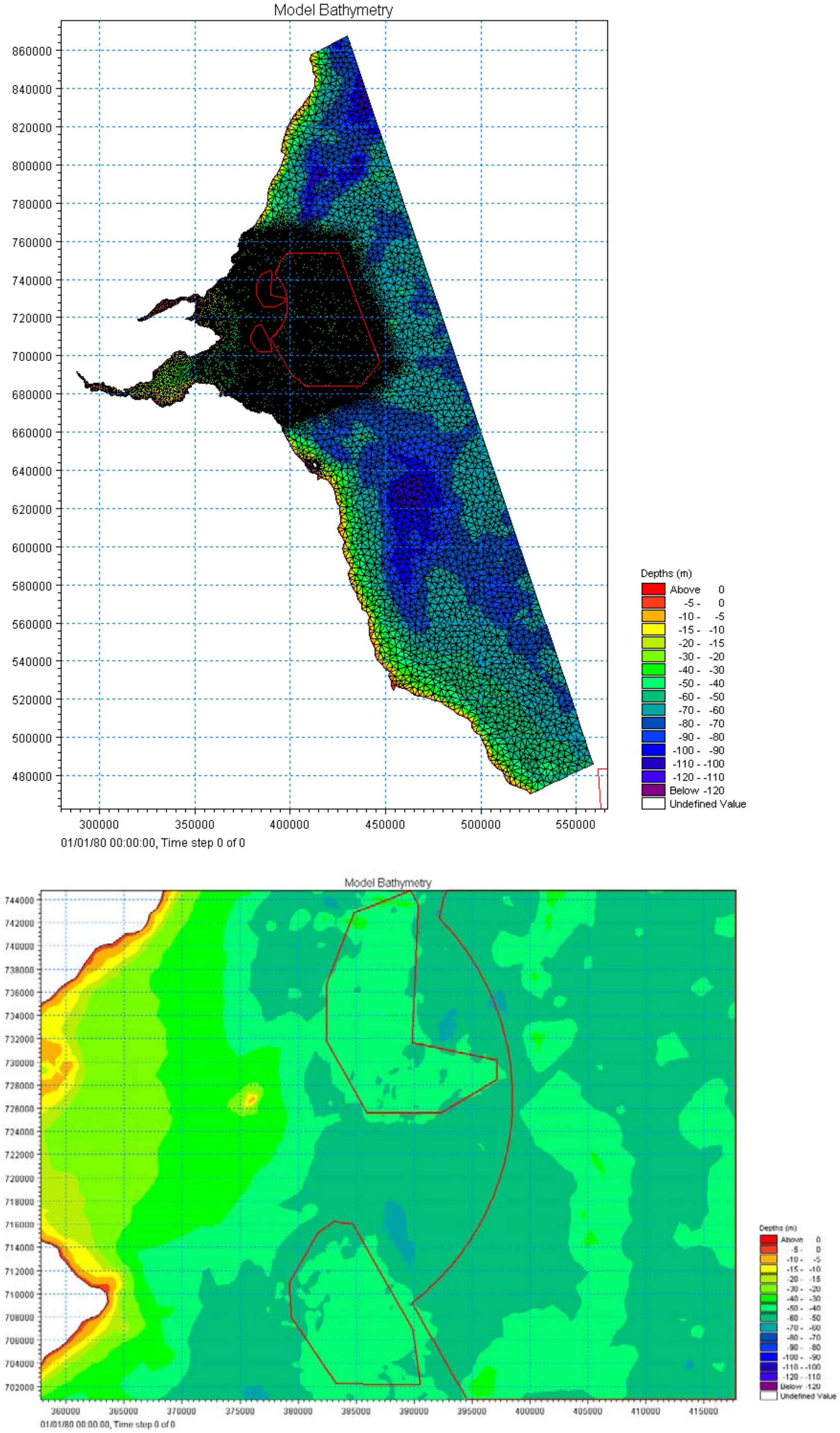


Figure 3-4: FTMS model mesh and bathymetry



3.1.3 Model Boundaries (HD and SW)

Hydrodynamic Open Boundaries

The hydrodynamic model is run for a specified set of boundary conditions (which take the form of time series of water elevation or flux along the model boundaries). The resulting model output requires calibration against existing field data in order to ensure accurate representation of the current flow.

Open boundary time series were derived from Intertek METOC's existing English Channel and North Sea (ECNS) model This regional model has a regular grid size of 1350 m, covering an area which includes the entire English Channel and the southern and northern North Sea. The ECNS model has been previously calibrated and validated. Prior to use for deriving boundaries the ECNS Sea model was checked against available field data in the study area, and found to provide an acceptable level of performance.

The hydrodynamic model is driven at its open boundaries as follows:

- North: Flux (momentum)
- East: Water Level
- South: Flux (momentum)

Internal Boundaries

The hydrodynamic model may be influenced by larger river discharges. These have been accounted for by entering the key rivers as sources of flow into the model. River inputs are represented as internal time-series discharges at each river's most upstream location in the model (typically the tidal limit of the river). The rivers included in the model, and typical flow statistics (taken from the UK Hydrometric Register (2008)[8]) are provided in Table 3-2.

Table 3-2: River flow statistics included in the FTMS model

No.	Station no.	River	River Catchment area (km^2)	Mean flow (m^3/s)	95% ile flow (m^3/s)	10% ile flow (m^3/s)
1	11001	Don	1273	20.64	5.36	40.3
2	12002	Dee	1844	46.93	8.48	96.2
3	13007	North Esk	732	19.1	3.17	39.3
4	13008	South Esk	488	12.27	2.17	25.6
5	15006	Tay	4581.1	*168.17*	*42.81*	*333.4*
	15013	Almond [Firth of Tay]	174.8	*5.25*	*0.73*	*11.5*
	16004	Earn	782.2	*28.81*	*3.72*	*64.9*
				combined as one source = 202.23	47.26	409.8
6	14001	Eden	307.4	*3.94*	*0.24*	*8.1*
	14005	Motray Water	60	*0.55*	*0.09*	*1.2*
				combined as one source = 4.49	0.33	9.3
7	17002	Leven [Firth of Forth]	424	6.45	1.12	13.6
8	18011	Forth	1036	*46.96*	*5.48*	*115*
	18013	Black Devon	56.2	*0.94*	*0.16*	*2.1*
	18002	Devon	181	*4.54*	*1.02*	*9.5*
	18005	Allan Water	210	*6.83*	*0.93*	*15.6*
	18014	Bannock Burn	23.7	*0.86*	*0.2*	*1.9*
				combined as one source = 60.13	8.91	157.7
9	19001	Almond [Firth of Forth]	369	5.99	0.96	13.7
10	19007	Esk	330	4.17	0.96	8.8
11	20001	Tyne [East Lothian]	307	*2.81*	*0.57*	*5.6*
	20006	Biel Water	51.8	*0.56*	*0.15*	*1*
				combined as one source = 3.37	0.72	6.6
12	21009	Tweed	4390	*80.88*	*14.1*	*169.5*
	21022	Whiteadder Water	503	*6.58*	*1.11*	*13.1*
				combined as one source = 87.46	15.21	182.6
13	23001	Tyne [NE England]	2175.6	*45.42*	*6.17*	*102.3*
	23007	Derwent	242.1	*2.52*	*0.81*	*4.9*
				combined as one source = 47.94	6.98	107.2
14	24009	Wear	1008.3	14.56	3.06	32.3
15	25009	Tees	1264	*19.04*	*2.93*	*44.3*
	25005	Leven [NE England]	196.3	*1.88*	*0.25*	*4.2*
				combined as one source = 20.92	3.18	48.5

Spectral Wave Open Boundaries

The spectral wave model is run for a specified set of boundary conditions (which take the form of time series of H_s, T_p, mean wave direction and spreading). The resulting model output requires calibration against existing field data in order to ensure accurate representation of total waves (wind-sea and swell).

Open boundary time series were obtained from the United Kingdom Meteorological Office (UKMO) Wave Watch III (WWIII) model at two locations. The Wave Watch III model is a suite of global and regional nested grids. The global model has a spatial resolution of 1° x 1° latitude – longitude grid extending from 78° S to 78° N. Ocean buoy observations are separated into geographical regions and compared to model output from the same locations.

Time series wave parameter data were obtained from the WWIII at two locations, Grid Point 1 (GP1) and Grid Point 2 (GP2). The eastings and northings of these locations are provided in Table 3-3 and presented in Figure 3-5. The northern boundary of the FTMS was driven by wave parameter data from GP1. The southern boundary was driven by wave parameter data from GP2. The eastern boundary was driven by wave parameter data combined from both GP1 and GP2. From the northeast corner of the model to the nearest location on the boundary to GP1, the wave parameter data is GP1. From the southeast corner of the model to the nearest location on the boundary to GP2 the wave parameter data is GP2. The area between the points is an interpolation of the two data sources.

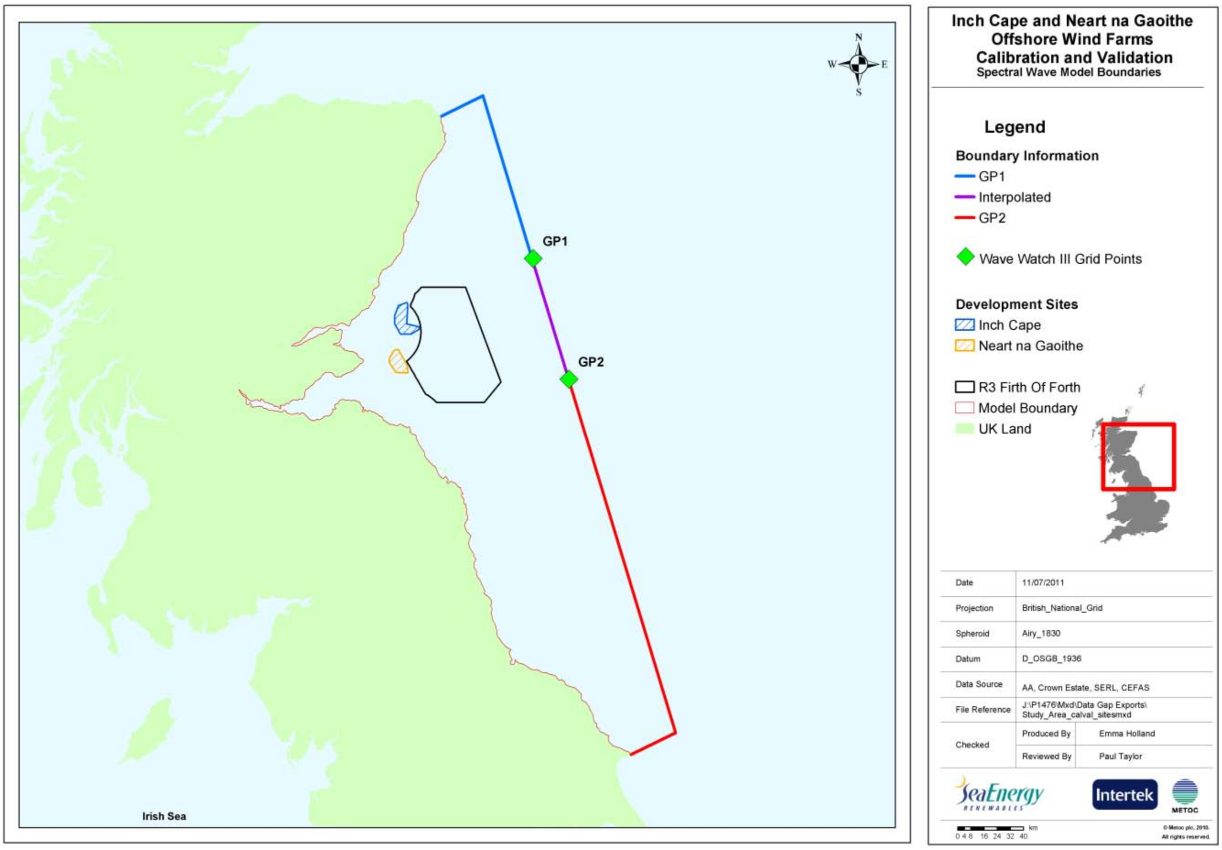
Table 3-3: Locations of UKMO Grid Points

UKMO Grid Point	Easting	Northing
GP1	488161	698382
GP2	466508	771460

The FTMS spectral wave model is driven at its open boundaries and summarised as follows (Figure3-5):

- North: H_s, T_p, Dirn, spreading (GP1)
- East: H_s, T_p, Dirn, spreading (combined)
- South: H_s, T_p, Dirn, spreading (GP2)

Figure 3-5: Spectral wave model boundaries



3.1.4 Model Time Step (HD and SW)

FTMS hydrodynamic and spectral wave models were run with a maximum time step of 30 seconds. However, the time steps for the calculations are dynamically calculated during the model simulations to satisfy stability criteria. The model uses an explicit scheme, and the computational time step interval is selected so that the Courant-Friedrich-Lévy (CFL) number is always less than 1.

All model runs are given an initial warm up period of at least 18 hours to allow water levels, current flow fields and wave propagation to stabilise.

Table 3-4 shows the start and end dates of the calibration/validation hydrodynamic run, as well as the number of time steps.

Table 3-4: Hydrodynamic model period

Parameter	Value
Start Date	29/12/2009 11:15
End Date	15/01/2010 11:15
Number of time steps	48960
Maximum time step	30 seconds

The spectral wave model was run over several storm events and offshore wind conditions to represent the typical range of metocean conditions. Table 3-4 shows the start and end dates of the calibration/validation model runs, as well as the associated wind and wave directions.

Table 3-5: Spectral wave model runs with metocean conditions

Start Date	End Date	Metocean Conditions		Calibration/Validation
		Wind Direction	Wave Direction	
09/01/2010 18:00	12/01/2010 06:00	E	E	Calibration Event
27/03/2010 06:00	29/03/2010 06:00	Predominantly SW	Predominantly SW	Calibration Event
18/06/2010 12:00	21/06/2010 00:00	N	N	Calibration Event
15/01/2010 09:00	17/01/2010 21:00	SE	SE	Validation Event
04/07/2010 12:00	07/07/2010 00:00	Predominantly W	Predominantly W	Validation Event

3.1.5 Bed Roughness (HD only)

Bed friction is one of the major factors that influence the hydrodynamics of a water body. This bed resistance is represented in the hydrodynamic model by the Manning's number, M ($m^{1/3}s^{-1}$). Manning's number is inversely proportional to the bed roughness. The Manning's number may be entered as a single value over the entire model area or as a bed resistance map corresponding to the model mesh.

Through the calibration process a number of different bed resistance values were tested, and it was determined that a constant value of bed roughness of 40 $m^{1/3}/s$ across the whole model domain provided the best model performance.

3.1.6 Eddy Viscosity (HD only)

Eddy viscosity is represented using a Smagorinsky formulation, which provides a sub-grid scale eddy viscosity model.

Model sensitivity to the Smagorinsky coefficient was checked, and it was found that the model is not particularly sensitive to this coefficient in terms of hydrodynamic predictions. Therefore, a typical Smagorinsky coefficient of 0.28 was adopted in the model.

3.1.7 Wind Forcing (SW only)

The wind field is one of the principle forces driving of the spectral wave model. Wind is represented in the model by the wind speed and direction and the growth of waves is dependent on friction velocity which can be determined from a sea roughness parameter. The sea roughness in the model is assumed to be the Charnock parameter $z_{ch} = 0.01$.

Wind forcing was determined as the average of wind predictions from the two Wave Watch III grid points. The wind forcing was generated at 3-hourly intervals from the 25 November 2008 to 30 April 2011, and applied uniformly over the model domain.

3.1.8 Bottom Friction (SW only)

Bottom friction for wave modelling is represented using the Nikuradse roughness parameter applied as a constant across the domain.

Model sensitivity to the Nikuradse roughness parameter was checked, and it was found that the model is not particularly sensitive to the parameter in terms of predicted wave conditions. Therefore, a typically Nikuradse roughness of 0.02 m was adopted in the model.

3.1.9 White Capping (SW only)

Energy dissipation due to white capping is included in the model by specifying the two dissipation coefficients Cdis and DELTAdis.

The Cdis and DELTAdis coefficients are applied as a constant across the domain. In offshore applications the fully spectral model has previously been found to under-estimate wave heights and wave periods. Therefore, model sensitivity to both coefficients was checked and it was found that the model performed best with a Cdis value of 4.5 and a DELTAdis value of 0.5.

4 HYDRODYNAMIC CALIBRATION AND VALIDATION

The hydrodynamic model was calibrated by comparing model output against field data for spring tide conditions, and validated by comparing model performance with neap tide data.

The primary sources of field data are described in Section 4.2.

For each model run, calibration was undertaken primarily by varying the bed roughness coefficient within the model.

Final calibration was achieved using a single roughness value over the model domain.

4.1 CALIBRATION/VALIDATION GUIDELINES

Calibration is achieved by fitting the model output to observed data, by varying the calibration coefficients. The degree of fit between model and observation determines the level of model calibration: poor fit suggests poor calibration, good fit suggests good calibration. The degree of fit will vary from location to location, depending on local conditions and how well these can be represented in the model. The quality of the observed data is also a significant factor in interpreting model performance, and is a function of the type of observation data, instrument type, accuracy, resolution, deployment location, environmental conditions and human error.

Model fit to field data can be assessed in two ways:

- Visual comparison of the model output against observed data: the shape, trend, range and limits of model output and observed data; and
- Statistical comparison of the difference between observation and the model to determine the frequency with which the model fits observation within defined limits.

In practise both methods should be used, as no single method provides a full assessment of model performance.

Intertek METOC assess model performance using guidelines set out in a number of technical reports, (e.g. Foundation for Water Research (FWR)[10] Framework, SEPA Standards for Models[11]), and accepted by the UK Water Industry and Environment Regulators. We also employ our own experience gained from calibrating a wide range of models over many years.

The various guidelines provide a good basis for assessing model performance, but experience has shown that they can sometimes be too prescriptive, particularly in situations of low tidal flow (<0.2 m/s^{-1}) where:

- Guidelines are either too easily achieved (if an absolute criteria, e.g. ± 0.1 ms^{-1}, is applied), or unachievable (if a relative criteria, e.g. ± 10% of observed speed, is applied); or

- The guideline error is lower than the accuracy of the survey instrumentation (i.e., a 10% error is 0.02 m/s^{-1}, this is close to the resolution of most current meters).

It is generally very difficult to meet a current direction standard of <15°, particularly in coarse grid models or where instruments and measuring techniques cannot resolve direction to this level of accuracy. A directional range of ± 30° is generally considered more appropriate, and has been used and accepted by regulators previously.

Under certain conditions, models can meet the statistical calibration standards but appear to perform poorly; conversely, seemingly accurate models can fall short of the guidelines. In such cases the guidelines alone cannot be used when assessing the performance of the model, and it is necessary for experienced modellers and oceanographers to offer a critical assessment of model performance, based on the overall weight of evidence and taking all the information into account.

4.1.1 Calibration Performance Criteria Applied to the Model

The hydrodynamic and spectral wave model calibration performance criteria applied to the FTMS model are shown in Table 4-1 and Table 4-2 respectively. These are taken from the FWR guidelines for coastal models.

Table 4-1: Hydrodynamic model calibration tolerances

	Tolerance Applied	
	Absolute	Relative
Water Level	± 0.1 m	± 10%[1]
Current speed	± 0.1 ms^{-1}	± 10%
Current direction	± 30°	± 30°
Phase[2]	±15 minutes	N/A

Notes:

1 10% of observed spring tidal ranges, and 15% of observed neap tidal ranges

2 There should be a sound relationship between phasing of currents and elevations

A statistical analysis of the hydrodynamic model fit requires that the tolerances in Table 4-1 are achieved over the majority of the calibration period. It is unlikely that these tolerances will be achieved throughout the calibration of a model. There will inevitably be some factors that cannot be fully accounted for in the model numerical scheme, input data and calibration coefficients, particularly in shallow coastal and estuarine waters. However, model calibration should seek to achieve these tolerances over the majority of the position/time combinations evaluated. In an effort to qualify the level of calibration, and allow comparison between sites, a qualitative scale of model to data fit is adopted, based on the frequency with which tolerance criteria are achieved, as follows:

Excellent Fit Calibration tolerances are achieved **>90%** of the time

Very Good Fit Calibration tolerances are achieved **>80%** of the time

Good Fit	Calibration tolerances are achieved **>70%** of the time
Reasonable Fit	Calibration tolerances are achieved **>60%** of the time
Poor Fit	Calibration tolerances are achieved **<60%** of the time

These qualitative terms are based on the FWR guidelines for coastal models, and are also similar to those that might be used when describing fit based on visual assessment criteria. They therefore allow an objective comparison between visual and statistical evaluation to be made.

4.2 CALIBRATION AND VALIDATION DATA

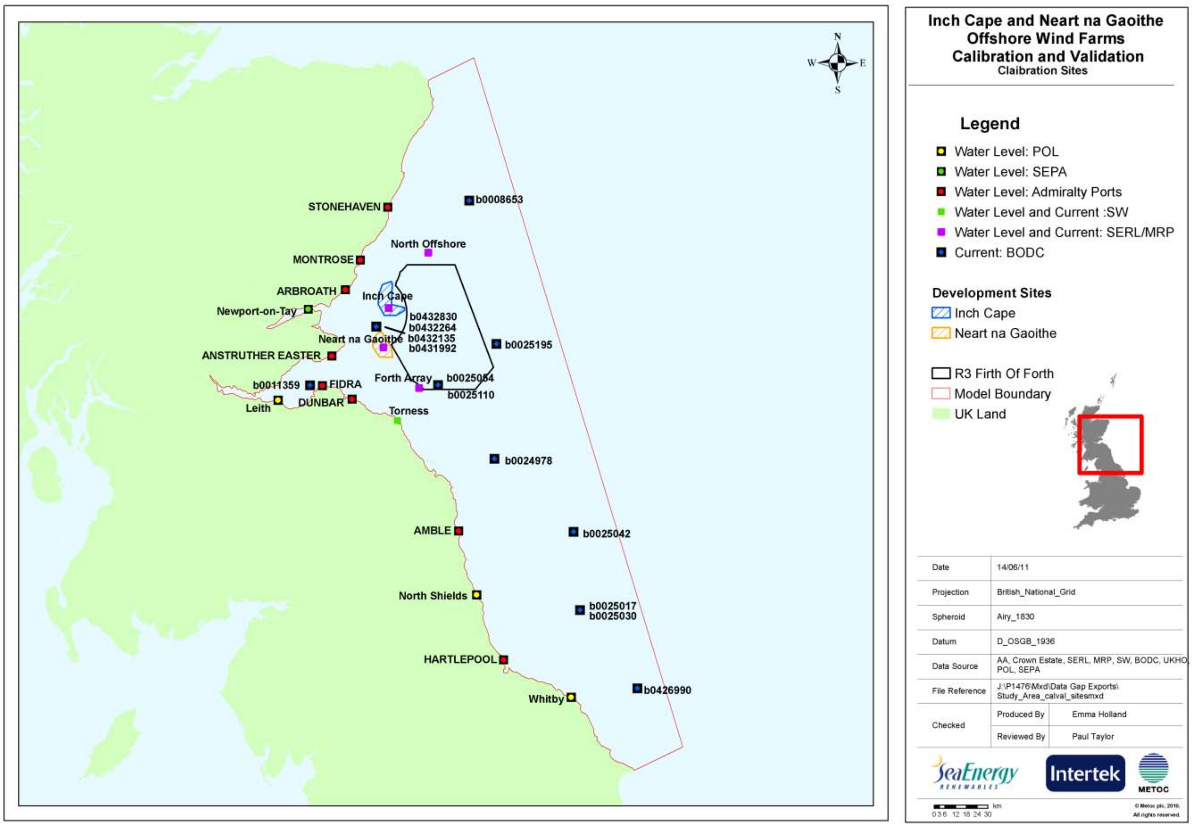
Figure 4-1 shows the locations at which the field data used in this study were collected. These were selected based on the quality and location of the data. They specifically include data at the proposed development sites, as collected during the bespoke metocean survey campaigns commissioned by the clients. They also include data from other sources which together provide a sufficient calibration/validation dataset across the whole model domain.

The calibration and validation consist of the following types:

a) Water levels

b) Currents (speeds and directions)

Figure 4-1: Model domain and field data locations



4.2.1 Water Levels

Tidal elevation data were obtained from:

Site-Specific Temporary Tide Gauges (Forth and Tay Metocean Survey Campaign) Temporary tide gauges were established at four sites during the Forth and Tay Metocean survey campaign, commissioned by the clients. Data from these time series were harmonically analysed, and reduced to the model datum

Admiralty Tide Tables[4]. These contain tidal constituents (four key constituents and two amplitude multipliers) for numerous Standard and Secondary Ports around the UK coast. The quoted constituents were used to predict time series of tidal height for the same periods as the neap and spring model runs to allow comparison with model output. The use of a relatively small number of constituents will result in a good but not exact approximation of actual tidal heights. The associated error may be as much as 10%, but will typically be less than 5% (based on previous comparisons of Tide Table elevation series against series generated using a greater number of constituents).

Fixed Tide Gauges (UK Tidal Gauge Network) Three Proudman Oceanographic Laboratory (POL) tide gauges are situated within the FTMS model domain. Fourteen tidal constituents are published for each Class A (best quality) site. These 14 constituents were used to predict tidal elevations for the calibration and validation process. Measured time series data for the survey and calibration periods were also obtained from POL.

Fixed Tide Gauge (SEPA) There is one SEPA operated tide gauge located at Newport-on-Tay. Time series data were harmonically analysed, and reduced to the model datum.

Temporary Tide Gauge (East Scotland Hydrodynamic Survey) Temporary tide gauge data was also available from a previous survey undertaken by Scottish Water. These data were made available to Intertek METOC by Scottish Water, and were checked, harmonically analysed and reduced to the model datum.

Table 4-2 shows the locations of the available tidal elevation data. Details on the instrument deployment of the survey data are also provided.

Table 4-2: Tidal gauge and admiralty port locations

Location	Easting	Northing	Start Date	End Date	Interval	Source
Forth Array	405204	684910	08/12/2009	12/07/2010	15mins	RNEUK/Mainstream
Neart na Gaoithe	385304	707754	10/12/2009	26/06/2010	15mins	RNEUK/Mainstream
Inch Cape	388270	729731	10/12/2009	26/06/2010	15mins	RNEUK/Mainstream
North Offshore	410427	760813	10/12/2009	25/06/2010	15mins	RNEUK/Mainstream
Torness Point	382432	672216	04/08/2009	09/09/2009	15mins	Scottish Water
Newport-on-Tay	343226	729396	03/03/1995	present	15mins	SEPA
Leith	326469	678055	2006	present	N/A	POL

Location	Easting	Northing	Start Date	End Date	Interval	Source
North Shields	436623	568320	2000	present	N/A	POL
Whitby	490469	511394	2002	present	N/A	POL
Stonehaven	387841	786160	N/A	N/A	N/A	UKHO
Montrose	372447	756552	N/A	N/A	N/A	UKHO
Arbroath	364141	739919	N/A	N/A	N/A	UKHO
Anstruther Easter	356592	702889	N/A	N/A	N/A	UKHO
Fidra	351235	686252	N/A	N/A	N/A	UKHO
Dunbar	368080	679176	N/A	N/A	N/A	UKHO
Amble	427487	604454	N/A	N/A	N/A	UKHO
Hartlepool	452646	532349	N/A	N/A	N/A	UKHO

The tidal constituents supplied and / or derived from all data sets are provided in Tables A-1 to A-17 in Appendix A. Measured and predicted tidal elevations at each site, where available, are given in Figure A-1 to Figure A-6. Where long data sets are analysed, data are shown for a single representative month for clarity.

4.2.2 Currents

Current velocity data were obtained from:

Site specific Surveys (Forth and Tay Metocean Survey Campaign) Current velocities were measured as part of the field survey at four locations. During this survey ADCP current meters were deployed for a period of 197 days.

Previous Survey (East Scotland Hydrodynamic Survey)) Current velocities were measured as part of the field surveys commissioned by Scottish Water for the purpose of model calibration at Torness Point. During this survey ADCP current meters were deployed for a period of 35 days. This data was provided to the project by Scottish Water.

BODC Current Moorings sets from a number of historical current meter deployments were collated from a number of sources. These data were initially checked and assessed in terms of suitability for model calibration. Data where instrument deployment conditions were unsuitable (e.g. bed / surface mounted instruments that may be adversely affected by boundary effects) were excluded. Data sets were then cross-checked, and any that were considered to be of poor quality were excluded. Remaining data were processed to produce tidal harmonics, where data length was sufficient.

The locations of the current meter sites are provided in Table 4-3. Details on the instrument deployment of the survey data are also provided.

Table 4-3: Current velocity field data locations

Location	Easting	Northing	Start Date	End Date	Water Depth ODN (m)	Sensor Depth (m)	Source
Forth Array	405204	684910	08/12/2009	12/07/2010	61	Depth Avg	RNEUK/Mainstream
Neart na Gaoithe	385304	707754	10/12/2009	26/06/2010	53	Depth Avg	RNEUK/Mainstream
Inch Cape	388270	729731	10/12/2009	26/06/2010	52	Depth Avg	RNEUK/Mainstream
North Offshore	410427	760813	10/12/2009	25/06/2010	92	Depth Avg	RNEUK/Mainstream
Torness Point	382432	672216	04/08/2009	09/09/2009	32	Depth Avg	Scottish Water
b0008653	433517	790005	08/03/1976	22/04/1976	73	23	BODC
b0011359	344383	686524	19/10/1977	01/12/1977	26	23	BODC
b0024978	447605	645063	10/08/1981	19/06/1981	72	37	BODC
b0025017	495422	560214	09/05/1981	15/06/1981	71	51	BODC
b0025030	495422	560214	09/05/1981	15/06/1981	71	31	BODC
b0025042	491899	604023	10/05/1981	18/06/1981	78	53	BODC
b0025054	416023	686660	10/05/1981	20/06/1981	65	35	BODC
b0025110	416023	686660	10/05/1981	20/06/1981	65	50	BODC
b0025195	448708	709635	11/05/1981	19/06/1981	67	47	BODC
b0426990	527591	516386	06/10/1989	05/11/1981	68	44	BODC
b0431992	381534	719317	06/02/1993	01/04/1993	52	46	BODC
b0432135	381534	719317	01/04/1993	09/05/1993	52	46	BODC
b0432264	381522	719395	09/04/1993	03/07/1993	52	46	BODC
b0432830	381392	719306	17/05/1994	04/06/1994	49	43	BODC

The tidal constituents supplied and derived from these analyses are provided in Table B-1 to B-19 in Appendix B. Measured and predicted current speeds and directions are given in Figure B-1 to Figure B-19.

4.3 CALIBRATION RESULTS

As discussed previously, the model was calibrated on a spring tide by iteratively adjusting key calibration parameters, in particular the bed friction parameter (Manning's number). Results were compared with field data, taking note of differences in the magnitude and phasing of tidal height, current speed and current direction. Successive iterations allowed the optimum bed roughness conditions within each model grid to be determined.

A constant Manning's number of $40m^{1/3}s^{-1}$ produced overall best model performances. This value is within the typical range for open coastal areas of between 25 to 45 $m^{1/3}s^{-1}$ for the Manning's number.

The calibration results are discussed below, with the figures provided in Appendix C.

4.3.1 Elevation

Initial calibration of the model was undertaken against water level data. Adjustment of bed friction at this stage allows for the speed of propagation of the tidal wave to be correctly defined, such that the timing of high and low water is correct, and the amplitude, phase and shape of the tidal curve are correctly reproduced by the model.

Plots of model output against harmonic prediction from published harmonic constituents and those derived from the field data are presented in Appendix C (Figures C-1 to C-17). A summary of the statistical analysis of model fit and visual analysis of the calibration plots is provided in Table 4-4. The model fit, or agreement, is presented as the percentage of model outputs achieving the calibration tolerances set out in Table 4-1.

At all the calibration sites the model predicts water levels to a very high level of agreement. The shape of the curve, the tidal amplitude and the tidal phasing produced by the model correlate well with the tide gauge data and the tide tables data.

The statistical analysis shows model agreement with the field data for over 90% of the data, indicating that the performance of the model is Excellent (Section 4.2).

4.3.2 Velocity

Following the successful water level calibration, the model was calibrated against the current velocity data.

Plots of model output against harmonic prediction (from harmonic constituents derived from the field data) are presented in Appendix C (Figures C-18 to C-36). A summary of the statistical analysis of the model fit, and visual analysis of the calibration plots is provided in Table 4-4. The model fit, or agreement, is presented as the percentage of model data achieving the calibration tolerances set out in Table 4-1.

At the majority of the calibration sites the model predicts tidal current velocities to a very high level of agreement. The shape, the magnitude and the tidal phasing of the tidal current velocities produced by the model correlate well with the ADCP and current meter data.

There are two locations where the statistical analysis indicated poorer performance:

Figure C-24 presents the current velocities predicted by the model and the BODC current meter b0011359. The model accurately predicts the current direction, diurnal equality, and the tidal phasing. However, the model does not fully reproduce the shape of the curve and slightly over-estimates the magnitude of currents. This may be due to the complex bathymetry at the site of the current meter within the Firth of Forth estuary.

Figure C-32. presents the current velocities predicted by the model and the BODC current meter b0426990. The model accurately predicts the shape of the curve. The model does lag the peak velocities by approximately 30 minutes and slightly over-estimates the magnitude. This may be due to the proximity of the calibration site to the eastern and southern boundaries.

It should be noted that the locations of these two calibration points are not within the main area of interest.

Overall the model performs well across the domain, performing within the guideline tolerances for over 90% of the data for the current speed and 90% for the current direction. This indicates that the model is performing Excellently (Section 4.2).

4.4 VALIDATION RESULTS

Hydrodynamic validation was undertaken against neap tide datasets. Adopting the same calibration parameters the model was validated for independent datasets from those used in the calibration process (spring tide data). Results were compared with field data, taking note of the differences in the magnitude and phasing of tidal height, current speed and current direction in the same was as for the model calibration. Model validation figures are provided in Appendix D.

4.4.1 Elevation

Plots of model output against survey data are presented in Appendix D (Figures D-1 to D-17). A summary of the statistical analysis of model fit and visual analysis of the calibration plots are provided in Table 4-5

At all 17 validation sites the calibrated model is predicting water levels with an excellent degree of fit. The shape of the curve, the tidal amplitude and the tidal phasing produced by the model correlates well with tide gauge data and tide table data.

The statistical analysis shows model agreement with the field data for over 90% of the data, indicating that the performance of the model is Excellent (Section 4.2).

4.4.2 Velocity

Plots of model output against surveyed velocity data are presented in Appendix D (Figures D-18 to D-36). A summary of the statistical analysis of model fit and visual analysis of the calibration plots are provided in Table 4-5.

At the majority of the validation sites the model predicts tidal current velocities to a very high level of agreement. The shape, the magnitude and the tidal phasing of the tidal current velocities produced by the model correlate well with the ADCP and current meter data.

Figure D-23 presents the validation results for the BODC current meter b08653. Current directions are very good, however, the model does slightly lead the predicted field data and the magnitudes are slightly over-estimated.

Figure D-24 presents the validation results for the BODC current meter b0011359. Although statistical analysis of this calibration site classifies it as poor the phasing is very good and the shape and magnitude of the curve is reasonable. Current directions are good especially considering this current meter is located within the Firth of Forth estuary.

Overall the calibrated model performs well across the domain, agreeing within the guideline tolerances for over 90% of the time/position combinations for both the current speeds and current directions. This indicates that the model is performing Excellently (Section 4.2).

The FTMS hydrodynamic model has been well calibrated and validated against appropriate field data, and has been demonstrated to be performing excellently across the model domain. The FTMS is therefore fit for the purpose of undertaking the coastal processes assessment for the Inch Cape and Neart na Gaoithe OWFs.

Table 4-4: Summary of hydrodynamic model fit with calibration data

Location	Figure Number	Elevation		Current speed			FIT	Comment
		Level %	Phase min	Speed %	Dir %	Phase min		
Forth Array	C-1	100.0	0				Excellent	Visually excellent fit
Neart na Gaoithe	C-2	100.0	0				Excellent	
Inch Cape	C-3	100.0	0				Excellent	
North Offshore	C-4	100.0	0				Excellent	
Torness Point	C-5	100.0	0				Excellent	
Newport-on-Tay	C-6	84.6	-10				Very Good	Visually a very good fit. Model leads on the flooding tide. Tidal range is excellent.
Leith	C-7	97.3	0				Excellent	Visually excellent fit
North Shields	C-8	100.0	0				Excellent	
Whitby	C-9	100.0	0				Excellent	
Stonehaven	C-10	100.0	0				Excellent	
Montrose	C-11	100.0	0				Excellent	
Arbroath	C-12	96.9	-5				Excellent	
Anstruther Easter	C-13	98.2	0				Excellent	
Fidra	C-14	94.0	-10				Excellent	
Dunbar	C-15	95.8	-5				Excellent	
Amble	C-16	99.7	0				Excellent	
Hartlepool	C-17	95.1	0				Excellent	
Average Elevation		98.1	0				Excellent	

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Location	Figure Number	Elevation		Current speed			FIT	Comment
		Level %	Phase min	Speed %	Dir %	Phase min		
Forth Array	C-18			100	100	0	Excellent	Visually excellent fit
Neart na Gaoithe	C-19			100	100	0	Excellent	
Inch Cape	C-20			100	98.2	0	Excellent	
North Offshore	C-21			99	94.8	0	Excellent	
Torness Point	C-22			98.7	91.7	0	Excellent	
b0008653	C-23			90.1	97.4	+4	Excellent	
b0011359	C-24			33.0	82.6	-5	Poor	Visually a good fit to very good. Model represents diurnal inequality and the phasing is good. Model does over estimate the speeds. Directions are very good.
b0024978	C-25			94	94.7	+10	Excellent	Visually excellent fit
b0025017	C-26			93.5	98.4	+10	Excellent	
b0025030	C-27			97.1	92.5	0	Excellent	
b0025042	C-28			94.5	98.4	+5	Excellent	
b0025054	C-29			93.8	98.4	+5	Excellent	
b0025110	C-30			94.5	93.2	0	Excellent	
b0025195	C-31			93.5	94.5	+5	Excellent	
b0426990	C-32			73.2	70.1	+10	Good	Visually a good to very good fit. Model lags the predicted field data by approx 30 mins. Directions are good.
b0431992	C-33			95.3	99.5	0	Excellent	Visually excellent fit
b0432135	C-34			99.2	90.6	0	Excellent	
b0432264	C-35			91.7	92.7	0	Excellent	
b0432830	C-36			92.2	97.9	0	Excellent	
Average Velocity				91.2	94.0	0	Excellent	

Table 4-5: Summary of hydrodynamic model fit with validation data

Location	Figure Number	Elevation		Current speed			FIT	Comment
		Level %	Phase min	Speed %	Dir %	Phase min		
Forth Array	D-1	96.0	0				Excellent	Visually excellent fit
Neart na Gaoithe	D-2	98.8	0				Excellent	
Inch Cape	D-3	98.1	0				Excellent	
North Offshore	D-4	98.8	0				Excellent	
Torness Point	D-5	94.8	-5				Excellent	
Newport-on-Tay	D-6	93.2	-10				Excellent	Visually a very good fit. Model leads on the flooding tide. Slightly over estimates high and water.
Leith	D-7	94.3	0				Excellent	Visually excellent fit
North Shields	D-8	100.0	0				Excellent	
Whitby	D-9	100.0	0				Excellent	
Stonehaven	D-10	100.0	0				Excellent	
Montrose	D-11	100.0	0				Excellent	
Arbroath	D-12	100.0	0				Excellent	
Anstruther Easter	D-13	100.0	0				Excellent	
Fidra	D-14	100.0	0				Excellent	
Dunbar	D-15	100.0	0				Excellent	
Amble	D-16	100.0	0				Excellent	
Hartlepool	D-17	100.0	0				Excellent	
Average Elevation		98.7	0				Excellent	

Continued next page

Location	Figure Number	Elevation		Current speed			FIT	Comment
			Phase	Speed	Dir	Phase		
		%	min	%	%	min		
Forth Array	D-18			100	83.9	0	Excellent	Visually excellent fit
Neart na Gaoithe	D-19			100	99.2	0	Excellent	
Inch Cape	D-20			100	94.8	0	Excellent	
North Offshore	D-21			97.9	95.3	0	Excellent	
Torness Point	D-22			97.7	90.6	-5	Excellent	
b0008653	D-23			75.6	84.2	-10	Good	Visually a good fit. Model lags the predicted field data. Model under-estimates velocities, directions are good
b0011359	D-24			39.0	80.3	0	Poor	Visually a good fit. Phasing is good and model represents diurnal equality. Shape of the curve is poor.
b0024978	D-25			86.0	83.3	0	Very Good	Visually very good to excellent fit. Phasing is excellent. Over-estimates speed, directions are very good.
b0025017	D-26			95.5	96.1	0	Excellent	Visually excellent fit
b0025030	D-27			93.8	93.5	-10	Excellent	
b0025042	D-28			100	96.6	0	Excellent	
b0025054	D-29			100	96.6	0	Excellent	
b0025110	D-30			100	95.3	0	Excellent	
b0025195	D-31			100	96.1	0	Excellent	
b0426990	D-32			91.2	64.4	0	Excellent	
b0431992	D-33			93.5	90.4	0	Excellent	
b0432135	D-34			99.2	88.6	0	Excellent	
b0432264	D-35			98.2	95.1	0	Excellent	
b0432830	D-36			97.9	86.8	+10	Excellent	
Average Velocity				92.9	90.1	0		

5 SPECTRAL WAVE CALIBRATION AND VALIDATION

The spectral wave model was calibrated by comparing model output against field data from three different wave conditions; two representative onshore storm events (one approaching from the east and one from the north), together with one offshore wind-driven even (winds primarily from the southwest).

The primary sources of field data are described in section 5.1.

For each model run, the model was driven by wave and wind forcing obtained from the UKMO UK waters wave model. Specific events were selected from the 10-year time series of wave model data that coincided with events also measured at the five wave buoys located within the area of interest (see section 5.1 below).

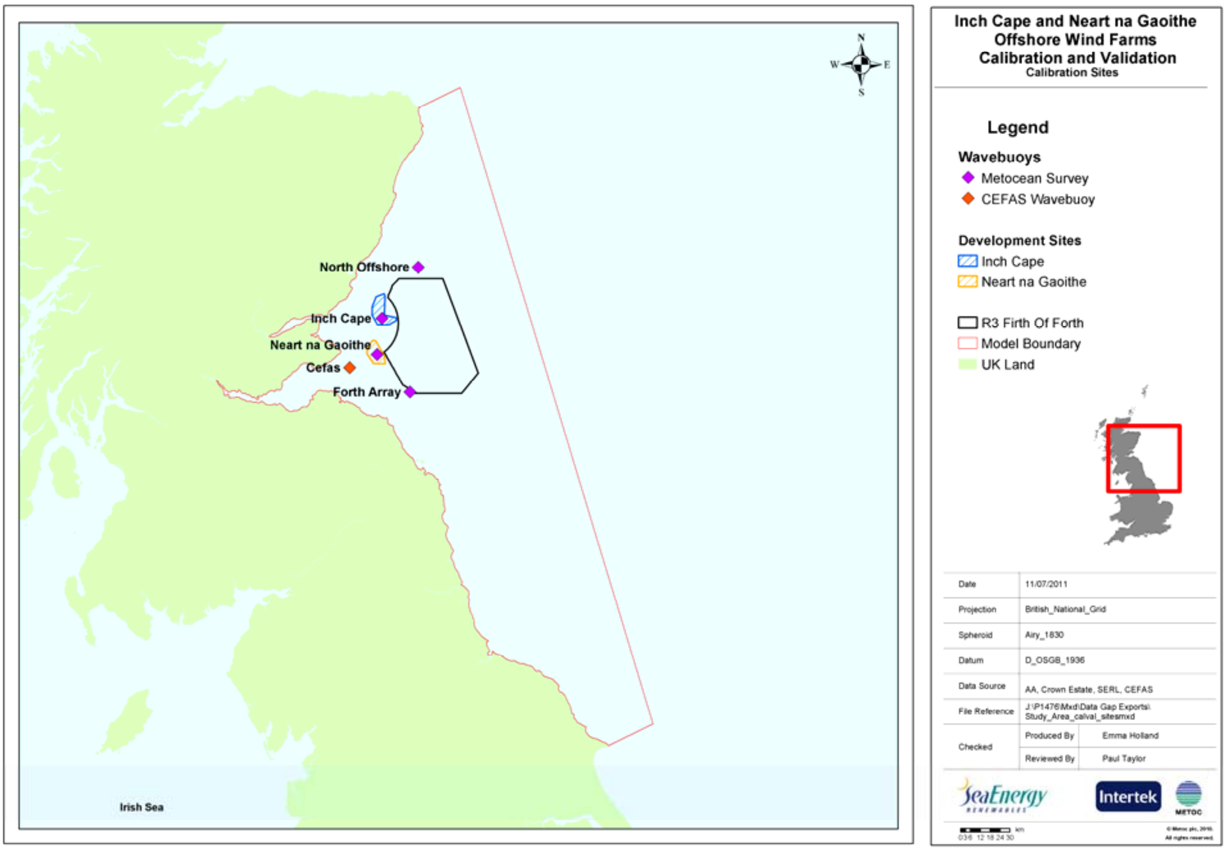
Model calibration was undertaken primarily by varying the white capping parameters, in order to improve model performance in terms of predicted wave parameters. Modelled output of significant wave height (H_s), peak wave period T_p), and wave direction were compared with the same wave parameters obtained from five wave buoys.

The spectral wave model was then validated by running the calibrated model (without further adjustment to model parameters) under two independent wave conditions – one onshore storm event from the southeast, and one offshore wind-driven event. The same modelled outputs were compared as in the calibration process.

5.1 CALIBRATION AND DATA

Calibration and validation data was obtained at five wave buoys located within the area of interest, which include four buoys deployed as part of the site-specific metocean survey campaign commissioned by the clients. The details of these buoys are provided in Table 5-1, and shown in Figure 5-1.

Figure 5-1: Model domain and field data locations



5.1.1 Wave Parameters

Wave parameter data were obtained from:

Site-specific (temporary) directional wave buoys

Temporary Datawell directional wave buoys were established at four sites during the Forth and Tay Metocean survey period. These data underwent WaveNet Cefas quality control checks.

Fixed wave buoy (Cefas)

The data collected at the Firth of Forth's Datawell directional waverider buoy is part of a network of wave buoys located around the UK coast. The purpose of the fixed wave buoy is to monitor waves in areas at risk of flooding. This telemetered wave parameter data is automatically quality controlled using a series of routines that have been well documented.

The locations of the wave buoy sites are provided in Table 5-1 with details of deployment, duration and data quality.

Table 5-1: Wave buoy locations

Wave Buoy	Owner	Easting	Northing	Details
Forth Array	RNEUK/ Mainstream	405325	684932	Hs, Tp, Dirn and spreading data collected from 08/12/2009 to 12/07/2010 at irregular 0.5 – 1 hr intervals. Wave buoys performed very well, returned 100% good data12 (Partrac, 2010)
Neart na Gaoithe	RNEUK/ Mainstream	385337	707755	Hs, Tp, Dirn and spreading data collected from 10/12/2009 to 12/07/2010 at irregular 0.5 – 1 hr intervals. Wave buoys performed very well, returned 100% good data12 (Partrac, 2010)
Inch Cape	RNEUK/ Mainstream	388367	729664	Hs, Tp, Dirn and spreading data collected from 10/12/2009 to 26/06/2010 at irregular 0.5 – 1 hr intervals. Wave buoys performed very well, returned 100% good data12 (Partrac, 2010)
North Offshore	RNEUK/ Mainstream	410348	760833	Hs, Tp, Dirn and spreading data collected from 10/12/2009 to Hs, Tp, Dirn and spreading data collected from 25/06/2010 at irregular 0.5 – 1 hr intervals. Wave buoys performed very well, returned 100% good data12 (Partrac, 2010)
Firth of Forth	Cefas	368723	699685	Hs, Temp, Tp, Tz, Wave Dir, spreading obtained from19/08/2008 to 20/07/2010 at 0.5hr intervals. Telemeted data underwent automatic quality control.

5.2 CALIBRATION RESULTS

Model runs were undertaken for the spectral wave model in order to produce the optimum model performance when compared against field data. Calibration was undertaken on two storm events and one offshore wind event. The figures for the spectral wave model calibration are shown in Appendix E.

The primary means of calibration was by the adjustment of the whitecapping parameters (Cdis and DELTAdis). Results were compared with field data, taking note of differences in the magnitude and phasing of H_s, T_p and mean wave direction. Successive iterations allowed the optimum white capping conditions within each model grid to be determined.

A constant Cdis number of 4.5 and a constant DELTAdis number of 0.5 produced best model performances overall. These values are within the typical range for offshore areas.

It should be noted that there are no formal guidelines for the assessment of wave model performance as there are for hydrodynamic models. Assessment is therefore based on visual analysis, and on modelling and oceanographic experience and expertise.

5.2.1 Easterly Storm Event

Plots of model output against survey data are presented in Appendix E (Figures E-1 to E-5). A summary of model fit with a visual analysis of the calibration plots are provided in Table 5-2.

At all five calibration sites the calibrated model is overall predicting H_s, T_p and wave direction with an excellent to very good degree of fit. The shape of the curve and the phasing produced by the model correlates well with the wave buoy data at all sites. At the Forth Array and Neart na Goaithe sites however the model does slightly under-predict the peak H_s.

5.2.2 Offshore Wind Event

Plots of model output against survey data are presented in Appendix E (Figures E-6 to E-10). A summary of model fit with a visual analysis of the calibration plots are provided in Table 5-2.

At all five calibration sites the calibrated model is overall predicting H_s, T_p and wave direction with a good to excellent degree of fit. The shape of the curve produced by the model correlates well with wave buoy data. However, the model does lag the measured data. The observed lag is due to the use of wind data from the offshore (eastern) boundary, to drive winds coming from the west of the model domain.

5.2.3 Northerly Storm Event

Plots of model output against survey data are presented in Appendix E (Figures E-11 to E-15). A summary of model fit with a visual analysis of the calibration plots are provided in Table 5-2.

At all five calibration sites the calibrated model is overall predicting H_s, T_p and wave direction with an excellent to very good degree of fit. The shape of the curve and the phasing produced by the model correlates well with wave buoy data. At all sites however the model does slightly under-predict the peak T_p.

Table 5-2: Summary of spectral wave model fit with calibration data

Easterly Storm Event					
Location	Figure No.	Hs	Tp	Dirn	Overall Fit/Comment
Forth Array	E1	Very good	Very good	Excellent	Very good overall. Slightly under-predicts the peak Hs and Tp
Neart na Gaoithe	E2	Very good	Excellent	Excellent	
Inch Cape	E3	Excellent	Excellent	Excellent	Overall excellent fit
North Offshore	E4	Excellent	Excellent	Excellent	
Cefas Wavebuoy	E5	Excellent	Excellent	Excellent	
Offshore Wind Event					
Location	Figure No.	Hs	Tp	Dirn	Overall Fit/Comment
Forth Array	E6	Good	Very good	Excellent	Under-predicts the peak Hs
Neart na Gaoithe	E7	Excellent	Very good	Excellent	Overall excellent fit
Inch Cape	E8	Excellent	Very good	Excellent	
North Offshore	E9	Good	Very good	Excellent	Slightly under-predicts the peak Hs
Cefas Wavebuoy	E10	Excellent	Excellent	Excellent	Overall excellent fit
Northerly Storm Event					
Location	Figure No.	Hs	Tp	Dirn	Overall Fit/Comment
Forth Array	E11	Very good	Very good	Excellent	Overall very good to excellent fit. Slightly under-predicts Tp
Neart na Gaoithe	E12	Excellent	Very good	Excellent	
Inch Cape	E13	Excellent	Very good	Excellent	
North Offshore	E14	Excellent	Very good	Excellent	
Cefas Wavebuoy	E15	Excellent	Very good	Excellent	

5.3 VALIDATION RESULTS

Spectral wave model validation was undertaken against one storm event and one offshore wind event. Adopting the same calibration parameters the model was validated for separate and independent wave scenarios to demonstrate the model is performing well under all scenarios, and is not biased to the calibration events. Results were compared with field data, taking note of the differences in the magnitude and phasing of H_s, T_p and wave direction. The model validation figures are shown in Appendix F.

5.3.1 Southeasterly Storm Event

Plots of model output against survey data are presented in Appendix F (Figures F-1 to F-5). A summary of model fit with a visual analysis of the validation plots are provided in Table 5-3.

At all five validation sites the model is overall predicting H_s, T_p and wave direction with an excellent to very good degree of fit. The shape of the curve and the phasing produced by the model correlates well with wave buoy data.

5.3.2 Offshore Wind Event

Plots of model output against survey data are presented in Appendix F (Figures F-6 to F-8). A summary of model fit with a visual analysis of the validation plots are provided in Table 5-3.

There was only data available for this event at three of the five validation sites as the Inch Cape and North Offshore wave buoys had already been retrieved before this event occurred. This event was chosen as the only suitable period in the data (in addition to the offshore calibration event) showing sustained offshore winds.

At all three validation sites the calibrated model is overall predicting H_s, T_p and wave direction with an excellent degree of fit. The shape of the curve produced by the model correlates well with the wave buoy data. As with the offshore wind-generated calibration event, the model lags the measured data, due to the application of offshore winds at the onshore boundary.

Table 5-3: Summary of spectral wave model fit with validation data

South-Easterly Storm Event					
Location	Figure No.	Hs	Tp	Dirn	Overall Fit/Comment
Forth Array	F1	Excellent	Very good	Excellent	Overall very good to excellent fit.
Neart na Gaoithe	F2	Excellent	Very good	Excellent	
Inch Cape	F3	Excellent	Very good	Excellent	
North Offshore	F4	Excellent	Very good	Excellent	
CEFAS Wavebuoy	F5	Excellent	Very good	Excellent	
Offshore Wind Event					
Location	Figure No.	Hs	Tp	Dirn	Overall Fit/Comment
Forth Array	F6	Excellent	Excellent	Excellent	Overall excellent fit but model lags measured data in phase.
Neart na Gaoithe	F7	Excellent	Excellent	Excellent	
Cefas Wavebuoy	F8	Excellent	Excellent	Excellent	

The FTMS spectral wave model has been well calibrated and validated against appropriate field data, and has been demonstrated to be performing within acceptable limits across the model domain. The FTMS is therefore fit for the purpose of undertaking the coastal processes assessment for the Inch Cape and Neart na Gaoithe OWFs.

6 CONCLUSIONS AND RECOMMENDATIONS

A flexible mesh hydrodynamic and spectral wave model of the offshore and coastal areas on the eastern coast of Scotland and England from north of Peterhead Head, Ayrshire to Flamborough Head, Yorkshire has been constructed. The model has mesh resolution ranging from approximately 60 m in the near field around the proposed OWF developments, to approximately 2500 m in the far field. Final model specification is summarised in Table 6-1

Table 6-1: FTMS model specification

Origin	525841E 470444N
Rotational angle	0°N
Mesh Element Size	Min 60 m, Max 2500 m
Mesh Area	33422 km^2
Vertical Datum	MSL
HD Boundary Type	Flux (north); Level (east); Flux (south)
SW Boundary Type	H_s, T_p, Dirn, spreading
Boundary Time Step	15 minutes
Model Time Step	30 seconds (max CFL number 0.8)

The hydrodynamic model has been calibrated and validated against available survey and published data describing water levels at seventeen locations and current velocities at nineteen locations in the model domain. Final calibration coefficients are presented in Table 6-2.

Table 6-2: FTMS hydrodynamic calibration coefficients

Parameter	Value	Comment
Manning Number (M)	$40m^{1/3}s^{-1}$	Single value across the entire domain
Eddy Viscosity (Smagorinsky Number)	$0.28ms^{-1}$	Single value across the entire domain

The spectral wave model has been calibrated and validated against available survey data describing H_s, T_p, and wave direction, at five locations in the model domain. Final calibration coefficients are presented in Table 6-3.

Table 6-3: Final Calibration Coefficients

Parameter	Value	Comment
Cdis	4.5	Single value across the entire domain
DELTAdis	0.5	Single value across the entire domain

A high level of calibration was achieved throughout the FTMS, but in particular the level of calibration in the areas of interest is considered to be excellent.

The level of validation achieved is considered, overall, to be excellent throughout the model domain.

6.1 RECOMMENDATIONS

The FTMS is considered to be calibrated and validated. The model is considered to be fit for use for application to the metocean and coastal processes assessment of the impacts OWF developments on the local and far field environment.

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Appendix A Tidal Elevations: Field Data

Table A-1: Forth Array: ADCP - 36 Constituents

Constituent	Amplitude (m)	Phase (deg)
Z0	0.0023	0
MM	0.0527	64.88
MSF	0.0841	261.65
ALP1	0.0062	267.25
2Q1	0.0133	330.84
Q1	0.0408	9.86
O1	0.1223	63.77
NO1	0.0167	101.65
K1	0.116	239.54
J1	0.0118	247.41
OO1	0.0049	83.31
UPS1	0.0033	90.12
EPS2	0.0086	236.79
MU2	0.0471	343.69
N2	0.3311	34.99
M2	1.4422	55.21
L2	0.0703	53.51
S2	0.4851	107.22
ETA2	0.0036	138.03
MO3	0.0146	356.88
M3	0.0113	11.07
MK3	0.0197	176.63
SK3	0.0044	254.83
MN4	0.0153	121.98
M4	0.0251	190.67
SN4	0.0118	21.5
MS4	0.0366	301.19
S4	0.0093	74.18
2MK5	0.0041	140.53
2SK5	0.0006	139
2MN6	0.0031	166.02
M6	0.0058	186.94
2MS6	0.0051	243.32
2SM6	0.0018	305.6
3MK7	0.0007	185.69
M8	0.0012	16.58

Table A-2: Neart na Gaoithe ADCP - 36 Constituents

Constituent	Amplitude (m)	Phase (deg)
Z0	0.001	0
MM	0.0291	21.05
MSF	0.0876	268.99
ALP1	0.0065	276.57
2Q1	0.0105	340.88
Q1	0.0413	10.69
O1	0.1245	61.87
NO1	0.0156	87.8
K1	0.1278	236.16
J1	0.0152	223.1
OO1	0.0079	77.57
UPS1	0.0056	91.05
EPS2	0.0043	253.07
MU2	0.0443	333.16
N2	0.3309	30.8
M2	1.5082	49.38
L2	0.0564	65.34
S2	0.4889	102.24
ETA2	0.0122	196.45
MO3	0.0146	354.2
M3	0.0135	7.4
MK3	0.0198	169.74
SK3	0.0033	230.33
MN4	0.0193	128.22
M4	0.0417	176.41
SN4	0.014	32.84
MS4	0.0391	286.82
S4	0.0081	84.66
2MK5	0.0046	151.32
2SK5	0.0016	179.95
2MN6	0.0064	170.81
M6	0.0127	197.81
2MS6	0.013	255.36
2SM6	0.003	327.73
3MK7	0.0015	49.39
M8	0.0044	63.1

Table A-3: Inch Cape ADCP - 36 Constituents

Constituent	Amplitude (m)	Phase (deg)
Z0	0.0013	0
MM	0.0475	75.69
MSF	0.0617	272.26
ALP1	0.0078	282.12
2Q1	0.0129	332.44
Q1	0.0384	5.49
O1	0.1233	60.65
NO1	0.0193	91.92
K1	0.1157	235.8
J1	0.0093	234.26
OO1	0.0066	60.6
UPS1	0.0043	83.74
EPS2	0.0049	226.62
MU2	0.046	335.54
N2	0.3299	23.67
M2	1.4445	44.31
L2	0.0605	42.72
S2	0.4957	96.34
ETA2	0.0064	96.77
MO3	0.0127	352.22
M3	0.0113	350.61
MK3	0.0166	173.93
SK3	0.0028	255.31
MN4	0.0239	111.99
M4	0.0423	156.68
SN4	0.0109	24.85
MS4	0.0351	261.16
S4	0.0086	70.44
2MK5	0.0039	154.25
2SK5	0.001	100.37
2MN6	0.0082	152.25
M6	0.0129	175.17
2MS6	0.0132	241.74
2SM6	0.0035	308.04
3MK7	0.001	114.33
M8	0.0062	44

Table A-4: North Offshore ADCP - 36 Constituents

Constituent	Amplitude (m)	Phase (deg)
Z0	0.0017	0
MM	0.0095	67.91
MSF	0.0389	255.18
ALP1	0.0051	274.22
2Q1	0.0097	299.17
Q1	0.0337	357.12
O1	0.1243	60.69
NO1	0.0162	84.94
K1	0.0943	226.94
J1	0.0104	219.49
OO1	0.0045	59.66
UPS1	0.0031	79.47
EPS2	0.002	242.99
MU2	0.0268	328.75
N2	0.2803	11.44
M2	1.2803	36.52
L2	0.0433	66.38
S2	0.4764	82.28
ETA2	0.0072	189.52
MO3	0.0085	359.3
M3	0.0108	339.7
MK3	0.0126	168.38
SK3	0.0064	221.16
MN4	0.0187	97.99
M4	0.0387	147.39
SN4	0.006	350.79
MS4	0.03	244.4
S4	0.005	49.55
2MK5	0.0041	151.43
2SK5	0.0007	133.21
2MN6	0.0041	79.04
M6	0.0081	147.65
2MS6	0.0097	202.13
2SM6	0.0021	315.27
3MK7	0.0004	0.21
M8	0.006	46.49

Table A-5: Torness Point ADCP (Scottish Water Tide Guage) - 36 Constituents

Constituent	Amplitude (m)	Phase (deg)
Z0	0.0149	0
MM	0.0278	138.71
MSF	0.0139	100.12
ALP1	0.0132	280.06
2Q1	0.0082	70.42
Q1	0.0526	6.94
O1	0.1476	67.23
NO1	0.0145	11.68
K1	0.1255	233.24
J1	0.0124	259.72
OO1	0.0043	32.51
UPS1	0.0111	178.72
EPS2	0.0195	61.96
MU2	0.0433	83.8
N2	0.3441	24.94
M2	1.6166	57
L2	0.0621	109.61
S2	0.659	105.28
ETA2	0.011	149.69
MO3	0.0144	13.77
M3	0.0134	39.45
MK3	0.0225	211.09
SK3	0.0083	233.92
MN4	0.0074	103.4
M4	0.0362	174.39
SN4	0.013	327.69
MS4	0.0448	305.82
S4	0.0155	93.49
2MK5	0.0058	168.16
2SK5	0.0015	304.86
2MN6	0.0065	179.44
M6	0.0105	205.89
2MS6	0.015	260.51
2SM6	0.0048	321.59
3MK7	0.0014	53.76
M8	0.0022	79.68

Table A-6: Newport-on-Tay (SEPA Tide Gauge) - 60 Constituents

Constituent	Amplitude (m)	Phase (deg)	Constituent	Amplitude (m)	Phase (deg)
Z0	3.2432	0	M2	1.6328	71.6
SSA	0.06	62.25	MKS2	0.0212	209.86
MSM	0.0689	272.27	LDA2	0.0345	70.89
MM	0.0163	175.79	L2	0.1103	85.63
MSF	0.0386	346.93	S2	0.5218	116.17
MF	0.0371	103.87	K2	0.1395	116.63
ALP1	0.0053	313.46	MSN2	0.0211	299.2
2Q1	0.0122	351.47	ETA2	0.0064	177.91
SIG1	0.0039	317.27	MO3	0.0177	58.55
Q1	0.0344	10.59	M3	0.0166	47.61
RHO1	0.0098	36.36	SO3	0.0092	130.36
O1	0.1331	76.94	MK3	0.0198	222.79
TAU1	0.0058	265.03	SK3	0.01	271.39
BET1	0.0085	68.82	MN4	0.0064	135.91
NO1	0.0088	67.51	M4	0.0384	247.44
CHI1	0.0058	221.07	SN4	0.0075	61.24
P1	0.0426	232.89	MS4	0.0426	357.24
K1	0.1099	234.34	MK4	0.0145	16.62
PHI1	0.0088	180.78	S4	0.0113	151.08
THE1	0.0055	12.2	SK4	0.0105	134.1
J1	0.0043	325.45	2MK5	0.0052	92.79
SO1	0.0064	80.61	2SK5	0.0009	330.06
OO1	0.0075	24.01	2MN6	0.0274	236.81
UPS1	0.0069	72.93	M6	0.0558	261.71
OQ2	0.0062	130.68	2MS6	0.0575	302.02
EPS2	0.0241	123.81	2MK6	0.0143	311.33
2N2	0.0277	53.26	2SM6	0.0112	354.06
MU2	0.0559	145.65	MSK6	0.0073	4.73
N2	0.2988	48.13	3MK7	0.0034	123.04
NU2	0.0561	56.86	M8	0.0126	149.1

Table A-7 : Leith POL Tide Gauge Published - 14 Constituents

Constituent	Amplitude (m)	Phase (deg)
Q1	0.042	1.17
O1	0.147	59.66
P1	0.038	190.77
K1	0.127	222.08
J1	0.007	297.5
2N2	0.041	20.87
N2	0.343	31.23
M2	1.795	55.4
S2	0.612	96.37
K2	0.175	93.81
M3	0.023	13.12
M4	0.078	184.45
MS4	0.069	300.3
M6	0.047	288.91

Table A-8: North Shield POL Tide Gauge Published - 14 Constituents

Constituent	Amplitude (m)	Phase (deg)
Q1	0.037	23.54
O1	0.139	76.21
P1	0.035	216.61
K1	0.125	243.61
J1	0.008	252.73
2N2	0.038	57.17
N2	0.307	64.84
M2	1.602	89.1
S2	0.538	131.69
K2	0.152	129.24
M3	0.015	65.44
M4	0.023	108.11
MS4	0.018	90.61
M6	0.007	21.95

Table A- 9: Whitby POL Tide Gauge Published - 14 Constituents

Constituent	Amplitude (m)	Phase (deg)
Q1	0.039	28.94
O1	0.145	82.36
P1	0.036	227.1
K1	0.133	252.37
J1	0.009	261.15
2N2	0.039	71.7
N2	0.318	79.69
M2	1.66	104.21
S2	0.558	147.53
K2	0.159	145.32
M3	0.014	90.02
M4	0.03	72.96
MS4	0.032	102.17
M6	0.011	0.26

Table A- 10: Stonehaven Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.38	31
S2	0.48	71
K1	0.12	202
O1	0.14	56
F4	0.019	139
F6	0.003	56

Table A- 11: Montrose Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.46	50
S2	0.49	93
K1	0.18	231
O1	0.11	67
F4	0.039	146
F6	0.006	359

Table A- 12: Arbroath Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.64	45
S2	0.56	83
K1	0.15	219
O1	0.16	55
F4	0.013	109
F6	0.003	54

Table A- 13: Anstruther Easter Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.62	52
S2	0.57	92
K1	0.13	217
O1	0.15	61
F4	0.011	132
F6	0.003	60

Table A- 14: Fidra Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.71	55
S2	0.6	97
K1	0.13	219
O1	0.14	61
F4	0.02	69
F6	0.006	98

Table A- 15: Dunbar Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.61	57
S2	0.55	97
K1	0.11	222
O1	0.15	69
F4	0.018	70
F6	0.003	70

Table A- 16: Amble Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.53	81
S2	0.51	125
K1	0.11	236
O1	0.13	76
F4	0.004	298
F6	0.001	149

Table A- 17: Hartlepool Admiralty Tide Tables - 6 Constituents

Constituent	Amplitude (m)	Phase (deg)
M2	1.68	95
S2	0.58	137
K1	0.13	242
O1	0.15	81
F4	0.009	247
F6	0.004	76

Figure A- 1: Forth Array Measured and Predicted Tidal Elevations

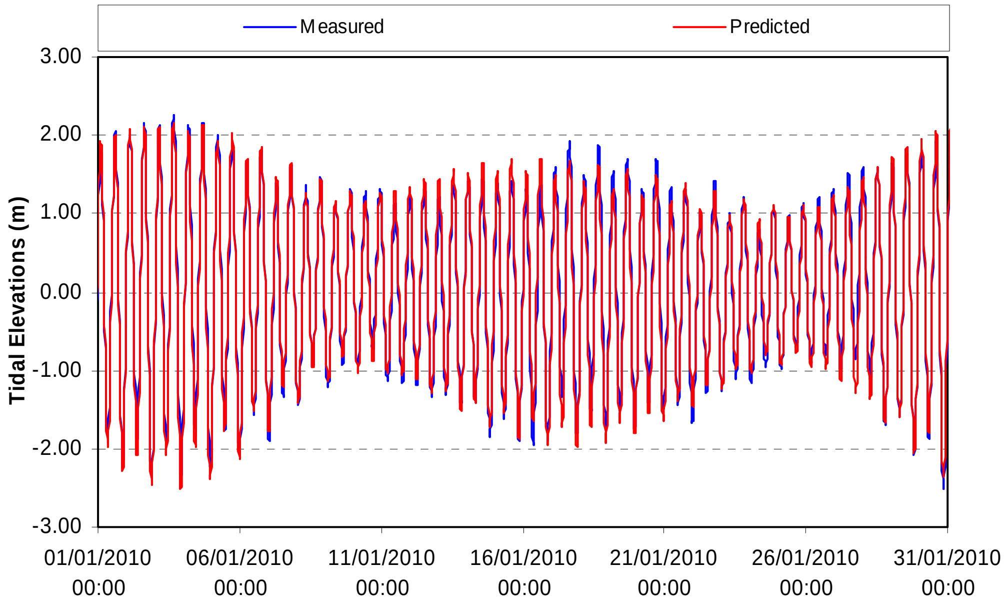


Figure A- 2: Neart na Gaoithe Measured and Predicted Tidal Elevations

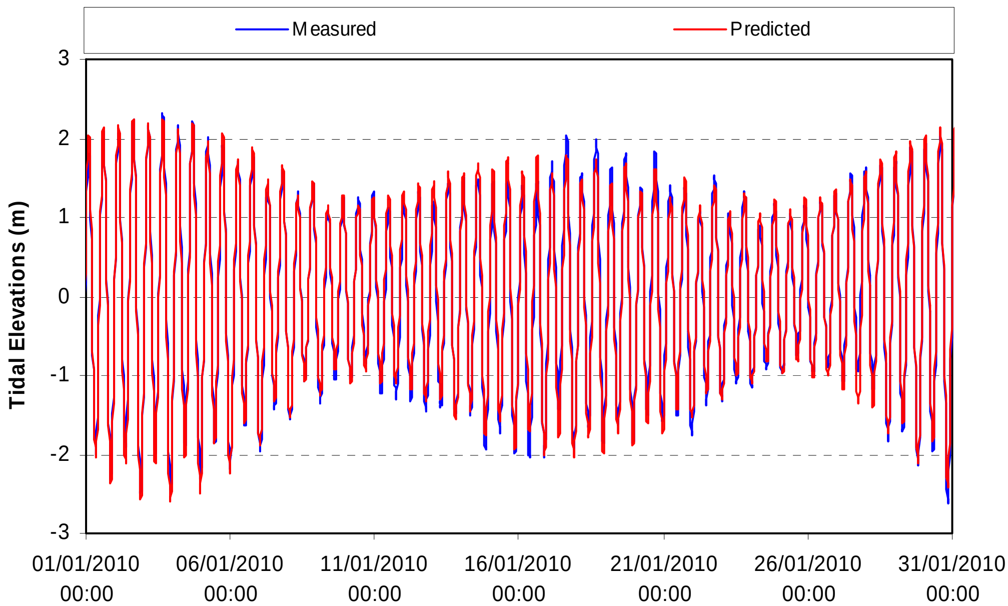


Figure A- 3: Inch Cape Measured and Predicted Tidal Elevations

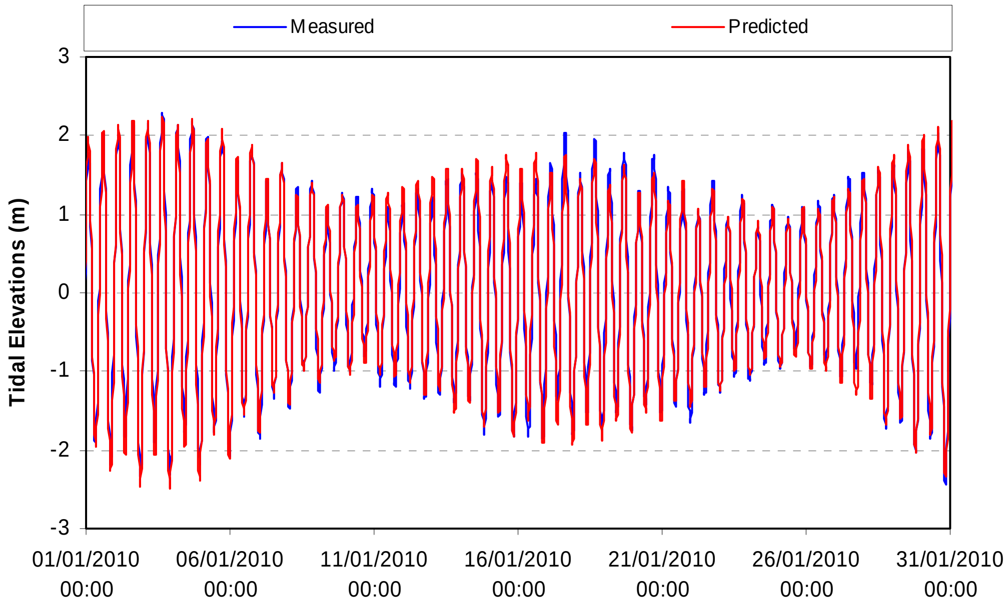


Figure A- 4: North Offshore Measured and Predicted Tidal Elevations

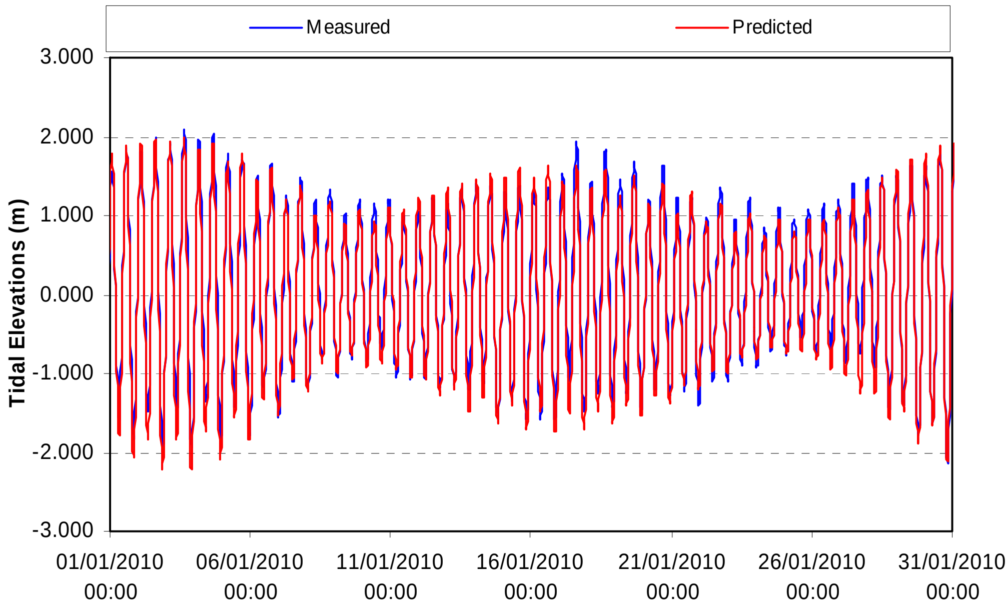


Figure A- 5: Torness Point Measured and Predicted Tidal Elevations

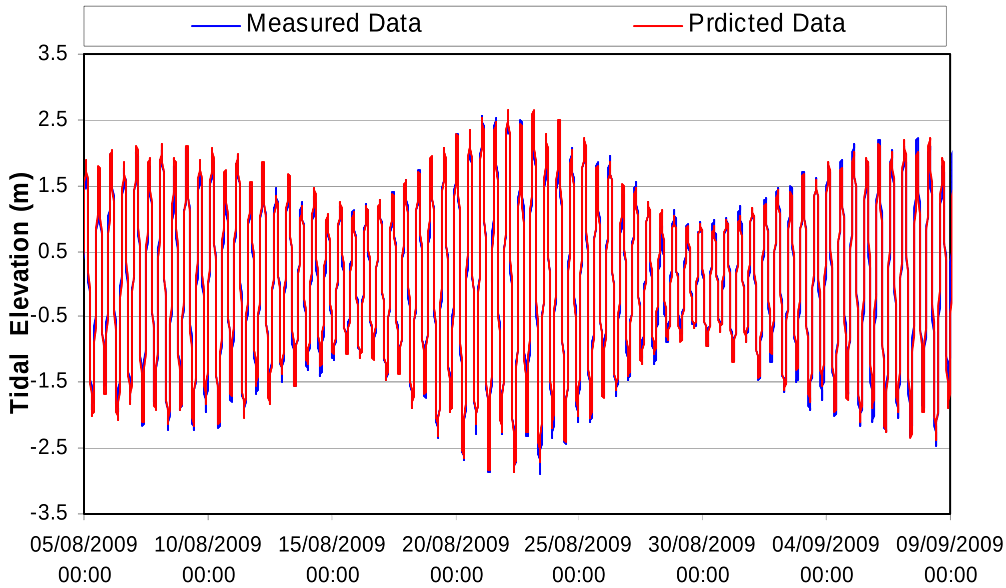
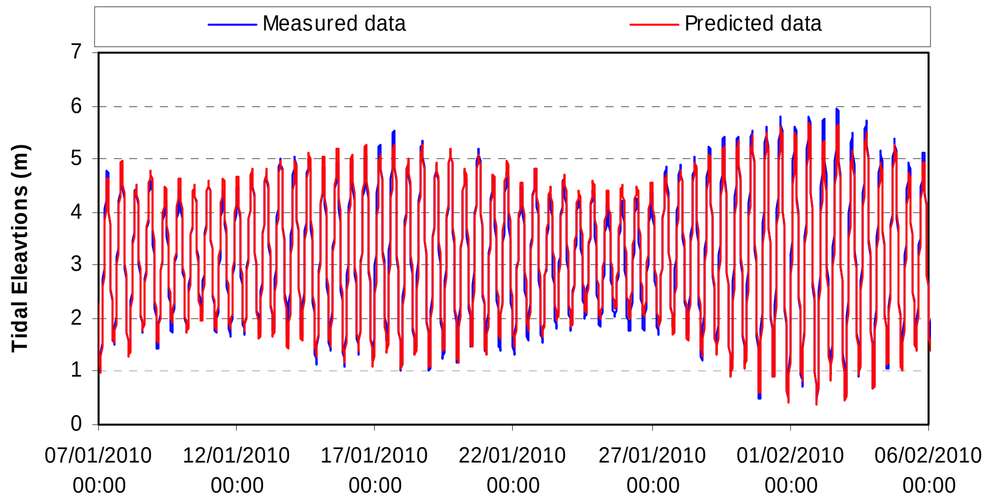


Figure A- 6: Newport-on-Tay Measured and Predicted Tidal Elevations



Appendix B Tidal Velocities: Field Data

Table B- 1: Forth Array ADCP - 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.044	0	22.8	180
MM	0.017	0.001	56.7	131.2
MSF	0.021	0.001	94.3	257.4
ALP1	0.002	0	27.6	117.5
2Q1	0.005	0.002	114.2	131.7
Q1	0.009	0.002	123.2	174
O1	0.029	0.001	122	230.9
NO1	0.006	0	125.3	283.4
K1	0.027	0	125.8	53.6
J1	0.004	-0.001	123.9	355.6
OO1	0.003	0.001	123.6	217.1
UPS1	0.002	0	111.3	297.9
EPS2	0.003	-0.001	103.3	75.1
MU2	0.012	0.003	115.4	161.5
N2	0.071	0.018	124	217.3
M2	0.295	0.091	124.1	238.8
L2	0.012	0.004	131.7	241.3
S2	0.103	0.032	123.4	289.5
ETA2	0.003	0	158.3	12.4
MO3	0.003	-0.002	156.5	229.1
M3	0.003	0.001	126.7	196.5
MK3	0.003	0	125.2	44.9
SK3	0.001	0	75.8	180
MN4	0.009	0	178.6	57.3
M4	0.018	0.003	0.4	274.3
SN4	0.004	0	5.8	99.2
MS4	0.015	0.001	171.3	176.7
S4	0.003	0.001	158.2	342.1
2MK5	0.003	0	165.8	53.7
2SK5	0.001	-0.001	0.1	179.8
2MN6	0.002	0.001	112.5	67.4
M6	0.005	0.002	138.7	137
2MS6	0.003	0.001	146	185.9
2SM6	0.002	0	167.4	255
3MK7	0.002	0	56.1	6.6
M8	0.002	0.001	157.2	1.8

Table B- 2: Neart na Gaoithe ADCP - 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.03	0	55.7	180
MM	0.022	0.003	48.7	28.9
MSF	0.028	-0.005	56.2	316.5
ALP1	0.002	0	105.2	285.4
2Q1	0.004	0	70.9	105.1
Q1	0.007	0.001	69.7	163
O1	0.025	-0.001	96	216.7
NO1	0.005	-0.002	62.3	276
K1	0.029	0	95.4	34.9
J1	0.005	-0.001	128	332.6
OO1	0.004	-0.001	122	221.6
UPS1	0.003	0	118.2	291.8
EPS2	0.005	-0.003	85.4	13.1
MU2	0.011	0.001	98.2	128.6
N2	0.067	0.021	85	185.4
M2	0.305	0.098	86	206.1
L2	0.01	0.005	66.1	192.2
S2	0.101	0.031	86.2	259.1
ETA2	0.002	0	49.6	72.5
MO3	0.004	0	87.7	138.1
M3	0.005	0	84.1	160.5
MK3	0.004	0.001	15.1	258.4
SK3	0.002	-0.001	166.4	27.2
MN4	0.005	0	176.4	54.8
M4	0.011	0.001	169.7	112.3
SN4	0.005	0.002	38.2	134.3
MS4	0.013	0.007	174.2	195.3
S4	0.003	0.002	160	301
2MK5	0.003	0	49.5	298.1
2SK5	0.001	0	163.3	165.9
2MN6	0.002	0.001	67.8	22.2
M6	0.007	0.002	25.8	3.2
2MS6	0.005	0	11.3	17.1
2SM6	0.001	0	10.8	300.1
3MK7	0.002	0	24.4	185.1
M8	0.002	0.002	147.2	359.3

Table B- 3: Inch Cape ADCP - 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.042	0	29.9	180
MM	0.019	-0.002	70.8	72.3
MSF	0.017	0.006	48.9	292.4
ALP1	0.004	-0.001	165.6	260.1
2Q1	0.004	-0.001	59.4	113.4
Q1	0.008	0	77.6	149.8
O1	0.033	0	77.9	210.4
NO1	0.007	-0.001	73.6	270.2
K1	0.029	-0.004	77.7	32.5
J1	0.004	0.001	71	326.4
OO1	0.002	-0.001	26.5	233.1
UPS1	0.002	0	134.5	238.3
EPS2	0.003	0.001	33.3	319.1
MU2	0.014	0	77.9	132.7
N2	0.089	0.009	76.3	173.2
M2	0.394	0.048	75	193.7
L2	0.016	0.003	62.1	183.1
S2	0.139	0.018	76	245.6
ETA2	0.002	0	95.8	181.7
MO3	0.005	-0.001	76	109.4
M3	0.005	0.002	81.4	132.1
MK3	0.005	-0.001	86.3	276.8
SK3	0.001	-0.001	28.2	133.4
MN4	0.009	-0.001	176	43.9
M4	0.016	0.002	169.6	75.1
SN4	0.003	0.001	51	140
MS4	0.011	0.008	138.5	128.2
S4	0.003	0.001	40.6	167.4
2MK5	0.001	0	73.5	206
2SK5	0.001	0	78.2	307.7
2MN6	0.003	0.001	38.3	348.3
M6	0.006	0.001	34.5	336.7
2MS6	0.004	0.001	40.6	64.7
2SM6	0.001	0	22	8.7
3MK7	0.001	0	76	324.3
M8	0.002	0.002	101.5	272.1

Table B- 4: North Offshore ADCP - 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.035	0	117.5	180
MM	0.008	0.004	27	353.1
MSF	0.014	-0.004	116.3	249.3
ALP1	0.002	0.001	72	350.2
2Q1	0.005	0.001	80	68.3
Q1	0.01	-0.001	67.1	136.2
O1	0.043	0	75	209.6
NO1	0.006	-0.001	83.3	263.5
K1	0.036	0.001	75	19.6
J1	0.005	0	81.7	359
OO1	0.002	0	82.9	174.4
UPS1	0.002	0.001	58.4	221.6
EPS2	0.002	0	16.7	2.2
MU2	0.013	0.001	77.8	123.9
N2	0.101	0.005	74.7	160.4
M2	0.464	0.022	75.9	185.4
L2	0.017	0	79.7	212.2
S2	0.176	0.012	75.2	231.5
ETA2	0.004	0	70.8	334.1
MO3	0.003	0.001	72.9	99.5
M3	0.005	0.001	69	120.3
MK3	0.004	0.003	75.5	295.8
SK3	0.001	0	101.9	324.5
MN4	0.005	-0.002	130.4	131.6
M4	0.011	-0.005	161.5	163.9
SN4	0.002	0	91	86.2
MS4	0.012	0.001	23.3	33
S4	0.003	0	55.5	157.7
2MK5	0.001	0	77.1	257.6
2SK5	0.001	0	84.5	219.4
2MN6	0.001	0	53.5	294.2
M6	0.004	0	35.1	270.1
2MS6	0.004	-0.001	47.4	329.7
2SM6	0.002	-0.001	83.8	6.6
3MK7	0.001	0	46.7	86.6
M8	0.003	0	145.7	22.9

Table B- 5: Torness Point ADCP (Scottish Water) - 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.042	0	158.6	180
MM	0.021	-0.001	156.8	20.9
MSF	0.018	0.001	133.2	72.1
ALP1	0.004	0.001	144	67.2
2Q1	0.002	0	107.8	5.4
Q1	0.01	0.001	169.1	207.5
O1	0.023	-0.002	153.6	252
NO1	0.01	-0.001	159.1	204.7
K1	0.027	0	167.8	66.1
J1	0.007	0.003	159.2	50
OO1	0.006	0	136.5	258.5
UPS1	0.005	0.001	152.9	269.1
EPS2	0.005	0.001	150.9	294.1
MU2	0.005	0	136.9	251.8
N2	0.046	0.003	158.3	223.6
M2	0.22	0.014	159.4	263.7
L2	0.01	-0.003	163.9	318.4
S2	0.092	0.009	162.6	315.9
ETA2	0.004	0	178.1	344.9
MO3	0.002	0	63.3	345.6
M3	0.005	0	134.2	230.3
MK3	0.005	-0.001	168.3	99.6
SK3	0.004	-0.002	136.1	209.7
MN4	0.002	0	144.9	272.1
M4	0.004	-0.001	6.9	249.6
SN4	0.003	0	157.4	257.5
MS4	0.008	0.001	151.7	211
S4	0.003	0.001	117.4	99.5
2MK5	0.002	-0.001	137.1	134.5
2SK5	0.001	0	111.3	216.4
2MN6	0.003	0	158.3	121.8
M6	0.007	0	166	170.7
2MS6	0.007	-0.001	148.6	190.5
2SM6	0.002	-0.001	125.4	344.4
3MK7	0.001	0	141.3	355.6
M8	0.002	0	124.6	28

Table B- 6: BODC Mooring No. b0008653- 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.04	0	112.5	180
MM	0.045	0.002	68.2	4.3
MSF	0.015	-0.002	102.4	161.4
ALP1	0.006	-0.003	47.8	211.6
2Q1	0.007	-0.001	60.9	31.6
Q1	0.027	-0.001	82.1	135.3
O1	0.04	-0.005	64.2	212.1
NO1	0.011	0	44.5	229.8
K1	0.028	0.006	55.7	350.5
J1	0.01	0.002	78.5	24.9
OO1	0.007	-0.002	57.9	78.8
UPS1	0.007	0.004	44.5	268.7
EPS2	0.008	-0.005	22.2	27
MU2	0.021	-0.006	72.6	105.4
N2	0.117	0	71.7	159.4
M2	0.485	-0.003	70.2	184.6
L2	0.034	-0.008	77.5	223.1
S2	0.197	0.008	69.3	219.3
ETA2	0.015	0.007	40.9	173.9
MO3	0.006	-0.002	24.4	160
M3	0.006	0.002	63.2	62.1
MK3	0.004	0	92.3	202.8
SK3	0.008	0.003	19.4	249.4
MN4	0.004	-0.003	62.9	210.2
M4	0.014	0	33.3	295.2
SN4	0.006	0.001	65	73.3
MS4	0.015	0.001	54	32.2
S4	0.009	-0.002	48.8	132.3
2MK5	0.005	0.001	10.4	348.9
2SK5	0.003	0.001	66.7	256.4
2MN6	0.003	0.001	112.7	275.5
M6	0.009	-0.003	56	228.2
2MS6	0.013	-0.004	54.9	270.2
2SM6	0.004	-0.002	97.7	320.3
3MK7	0.005	0.001	166.2	164.2
M8	0.007	-0.003	104.1	28.6

Table B- 7: BODC Mooring No. b0011359 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.087	0	39.7	180
MM	0.042	-0.001	33.4	108.5
MSF	0.024	0.001	33.5	100.3
ALP1	0.01	-0.001	41.7	331.4
2Q1	0.009	-0.001	36.7	130.5
Q1	0.012	-0.002	38.6	172.8
O1	0.004	0	10	125.4
NO1	0.011	0.005	71	282.7
K1	0.019	-0.002	48.3	297.3
J1	0.003	-0.003	93.8	215.3
OO1	0.025	0.002	54.3	40.7
UPS1	0.01	0.005	20.7	58
EPS2	0.02	-0.008	24	146.6
MU2	0.005	-0.003	39.3	89.9
N2	0.051	0.005	45.1	151.3
M2	0.284	0.03	40.3	154.7
L2	0.011	-0.001	6.6	55.1
S2	0.096	0.006	38	179.7
ETA2	0.023	-0.011	16.3	54.9
MO3	0.01	-0.001	51.9	193.1
M3	0.011	-0.003	52.5	29
MK3	0.008	-0.004	57	178.9
SK3	0.005	-0.002	43.9	187.6
MN4	0.007	0.004	29	168.6
M4	0.01	-0.004	92.4	342.9
SN4	0.01	0.001	169.3	277
MS4	0.03	-0.003	39.7	49.7
S4	0.006	-0.001	21.6	105.8
2MK5	0.007	-0.001	51.5	32.7
2SK5	0.003	0	46.6	287.1
2MN6	0.013	0.002	20.9	29.5
M6	0.022	0	29.7	43
2MS6	0.021	-0.001	28.4	85.1
2SM6	0.004	0	39.9	81.3
3MK7	0.003	-0.001	33.6	274.3
M8	0.005	0.001	52.7	302.8

Table B- 8 BODC Mooring No. b0024978 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.009	0	3.9	180
MM	0.019	0.006	110.6	266.9
MSF	0.013	0.002	43.1	317.5
ALP1	0.008	-0.002	97.2	124.9
2Q1	0.007	0.001	97.5	132
Q1	0.018	-0.002	118.2	183.5
O1	0.041	-0.003	113.6	228
NO1	0.008	-0.003	149.5	23.7
K1	0.05	0	112.7	23.5
J1	0.006	0.002	72.3	40.7
OO1	0.005	-0.002	172.7	154.2
UPS1	0.008	-0.003	178.1	138.7
EPS2	0.012	-0.009	19	211.1
MU2	0.017	0.002	78.1	191.5
N2	0.101	0.005	113.3	208.8
M2	0.426	0.014	116.4	245.2
L2	0.03	-0.003	134.2	286.6
S2	0.126	0.006	118	274.8
ETA2	0.004	0.003	156.4	7.7
MO3	0.006	-0.002	175.1	222.6
M3	0.005	0.001	164.4	232.7
MK3	0.002	0.001	173.1	69.4
SK3	0.004	-0.001	19.6	262.8
MN4	0.006	-0.003	130	96.7
M4	0.009	0.001	95.7	135
SN4	0.004	0	168.2	294.6
MS4	0.011	0.006	97.8	183.9
S4	0.005	0.001	13.2	208.9
2MK5	0.002	-0.001	51.7	173
2SK5	0.002	0	92.6	264.3
2MN6	0.006	0.001	102.5	349.6
M6	0.011	-0.002	93.7	46.7
2MS6	0.009	-0.002	77.3	82.6
2SM6	0.002	-0.001	52.2	68.2
3MK7	0.003	0	138.7	169.9
M8	0.003	0	26	185.1

Table B- 9: BODC Mooring No. b0025017 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.012	0	141.5	180
MM	0.004	0.002	83.3	259.8
MSF	0.008	0	124	45
ALP1	0.001	-0.001	42.6	145.9
2Q1	0.006	-0.001	149	145.7
Q1	0.01	0.003	120.8	189.8
O1	0.035	0.004	125.5	241.8
NO1	0.005	0	123.5	74.7
K1	0.034	0.005	129.1	33.4
J1	0.006	-0.001	91.9	80.3
OO1	0.005	-0.002	159.6	171.9
UPS1	0.005	-0.001	119.6	123.3
EPS2	0.003	-0.001	130.9	171.8
MU2	0.018	0	87.1	188.4
N2	0.076	0.019	114.6	227.4
M2	0.332	0.081	114.6	258.4
L2	0.017	0.005	113.9	280.4
S2	0.104	0.028	113.7	285.9
ETA2	0.005	0.001	151.4	348.9
MO3	0.005	0.001	125.9	331.8
M3	0.003	0	114.6	220.9
MK3	0.002	0	130.5	106.9
SK3	0.003	0	89.8	160.6
MN4	0.003	-0.002	133	98.1
M4	0.007	-0.003	91.6	164
SN4	0.001	0	83.9	279.9
MS4	0.01	0.001	110.1	212.9
S4	0.003	0.003	7.5	179.4
2MK5	0.001	0	159.7	156.2
2SK5	0.002	-0.001	167.3	259.4
2MN6	0.004	0	102.9	327.2
M6	0.007	0	89.5	7.8
2MS6	0.004	0	103.6	51.2
2SM6	0.003	0	114.5	82.4
3MK7	0.001	0	34.8	94.5
M8	0.002	0	84.7	183.5

Table B- 10: BODC Mooring No. b0025030 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.036	0	159.5	180
MM	0.01	0	78.3	3.8
MSF	0.012	-0.001	43.9	68.9
ALP1	0.005	-0.001	76	118.5
2Q1	0.008	0.002	127.2	169.2
Q1	0.011	0.004	114.5	187.4
O1	0.037	0	109	235.8
NO1	0.005	0	74.5	18.5
K1	0.033	0.001	114.7	18.7
J1	0.006	-0.003	74.3	93.5
OO1	0.008	-0.001	144.5	143
UPS1	0.006	0	90.2	137.4
EPS2	0.011	-0.006	42.3	184.4
MU2	0.024	-0.003	72	191
N2	0.087	0.013	117.6	232.9
M2	0.38	0.04	119.8	267.1
L2	0.023	0.003	156.6	321.6
S2	0.13	0.012	122.4	298.1
ETA2	0.008	-0.003	96.3	8
MO3	0.002	0.001	170	332.6
M3	0.004	-0.001	131	253.4
MK3	0.001	0	175.8	49.6
SK3	0.004	0	132.6	133.1
MN4	0.006	0.001	10.2	127.1
M4	0.015	0.001	56.3	184.5
SN4	0.005	-0.004	30.5	46.9
MS4	0.01	0.002	73.9	228.9
S4	0.008	-0.005	18.3	263.5
2MK5	0.003	-0.001	11	172.7
2SK5	0.002	-0.001	123.3	23.3
2MN6	0.004	0	57.3	264.7
M6	0.004	0.002	150.9	85.8
2MS6	0.004	-0.002	127.9	123.9
2SM6	0.006	-0.002	173.2	146.8
3MK7	0.002	0	162.7	62.1
M8	0.002	0	150.2	208.1

Table B- 11: BODC Mooring No. b0025042 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.011	0	164.3	180
MM	0.011	0.004	148.5	226.8
MSF	0.021	0	111.9	356.5
ALP1	0.003	0.002	122.5	117.1
2Q1	0.006	-0.001	133.7	149.8
Q1	0.012	0.004	116.4	204
O1	0.03	0.004	119.2	247.8
NO1	0.005	0.002	115.8	84.5
K1	0.037	0.004	119.6	30.7
J1	0.007	0	87.4	65
OO1	0.007	-0.001	148.1	198.9
UPS1	0.005	-0.003	145.8	140.8
EPS2	0.004	0	103.7	158.3
MU2	0.012	0	84.6	187.7
N2	0.066	0.021	107.4	219.3
M2	0.302	0.087	107.6	250.7
L2	0.017	0.005	109.2	262.7
S2	0.091	0.028	104.4	278
ETA2	0.002	-0.001	171.1	124.8
MO3	0.004	0	158.5	315.6
M3	0.003	0	139.4	263.2
MK3	0.002	-0.001	34.3	232.7
SK3	0.002	0	12.9	298
MN4	0.005	-0.003	87.1	155.2
M4	0.012	-0.003	103.9	152.6
SN4	0.004	0.001	140.9	232.6
MS4	0.01	0	123.7	199.7
S4	0.002	0.001	109.9	236.1
2MK5	0.001	-0.001	160.2	25.2
2SK5	0.001	0	34.9	43.1
2MN6	0.003	-0.001	60.1	19.3
M6	0.004	-0.002	73.6	24.7
2MS6	0.003	-0.002	52.5	104.4
2SM6	0.001	0	126	48.5
3MK7	0.001	0	21	39.2
M8	0.002	0.001	129.1	193.4

Table B- 12: BODC Mooring No. b0025054 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.028	0	174.2	360
MM	0.015	0	124.6	266.1
MSF	0.012	0.005	10.3	257.3
ALP1	0.002	0.002	16.7	76.7
2Q1	0.006	-0.001	109	115.3
Q1	0.016	0	111	190.8
O1	0.028	0.005	114.4	234.4
NO1	0.006	0	120.2	74.4
K1	0.032	0.004	110	20.4
J1	0.005	-0.001	92.1	81.2
OO1	0.004	-0.003	107.8	162.9
UPS1	0.008	-0.003	43.3	178.3
EPS2	0.004	0.002	112.2	68.6
MU2	0.012	0.001	56.3	146.2
N2	0.066	0.022	104.3	202.4
M2	0.306	0.093	106.8	232.5
L2	0.021	0.002	125.8	284.5
S2	0.097	0.025	111.7	267.7
ETA2	0.012	-0.006	23.6	58.7
MO3	0.003	-0.001	153.8	318.7
M3	0.004	0	8.6	43.4
MK3	0.004	0	169.3	15.9
SK3	0.004	-0.001	68.1	281.6
MN4	0.003	-0.002	102.8	81
M4	0.017	-0.005	134.9	109.7
SN4	0.003	0.002	137.5	211.2
MS4	0.014	0.001	138.4	172.2
S4	0.002	0.001	44.6	95.9
2MK5	0.002	0	94.2	244.8
2SK5	0.003	0.001	14.7	185.8
2MN6	0.002	0.001	82.9	31.9
M6	0.004	0	139.4	85.8
2MS6	0.005	0.001	118.2	146.8
2SM6	0.001	0	144.5	146.3
3MK7	0.001	0	7	256.4
M8	0.003	-0.002	99.1	33.7

Table B- 13: BODC Mooring No. b0025110 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.015	0	166.4	360
MM	0.01	0	131.8	238.7
MSF	0.009	0.001	101.8	353.8
ALP1	0.002	0.001	10.6	41
2Q1	0.007	-0.002	136.3	94
Q1	0.014	0.001	119.3	198.3
O1	0.027	0.004	122.1	235.4
NO1	0.005	0	144.1	81
K1	0.032	0.008	132.7	26
J1	0.002	0	14.2	260.8
OO1	0.008	-0.003	137.2	135.8
UPS1	0.003	-0.001	60.7	183.4
EPS2	0.005	0.004	14	329.6
MU2	0.013	0.007	86	155.9
N2	0.06	0.028	115	203.6
M2	0.265	0.114	106.3	224.2
L2	0.012	0.005	110.6	262.6
S2	0.082	0.039	115.6	262
ETA2	0.006	-0.003	60.5	61.5
MO3	0.002	-0.002	10.4	93.3
M3	0.003	0.001	147.9	235.3
MK3	0.004	0.001	74.6	258.4
SK3	0.001	0	80.3	360
MN4	0.004	-0.003	129.5	96.4
M4	0.016	-0.007	149.5	103.3
SN4	0.004	0	162.5	224.9
MS4	0.013	-0.001	146.6	167.2
S4	0.002	0	177.4	206.4
2MK5	0.002	0	118.6	129
2SK5	0.002	0	68	46.8
2MN6	0.004	0.002	58.9	252.6
M6	0.005	0.002	17.2	238.8
2MS6	0.003	0.001	169.2	74
2SM6	0.002	0	118.4	223
3MK7	0.003	-0.001	158.8	324.1
M8	0.002	-0.001	154.2	348.9

Table B- 14: BODC Mooring No. b0025195 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.006	0	13.9	180
MM	0.006	-0.001	43.5	215
MSF	0.012	0.003	83.4	344.4
ALP1	0.003	0	104.6	96.1
2Q1	0.004	-0.001	98.8	121.3
Q1	0.014	0.001	109.2	190.5
O1	0.027	0.004	95.6	220
NO1	0.006	-0.001	120.1	62.8
K1	0.033	0.004	100.5	10.1
J1	0.005	0	85.3	58.3
OO1	0.005	0	98	158.9
UPS1	0.004	-0.003	146.6	163.1
EPS2	0.006	-0.002	46.8	82.4
MU2	0.01	-0.001	40.1	115
N2	0.073	0.02	79.6	171.4
M2	0.318	0.092	80.6	202.7
L2	0.018	0.006	86	223.1
S2	0.095	0.029	77.3	229.6
ETA2	0.005	0.002	51.5	312.6
MO3	0.002	0	160.7	292.1
M3	0.002	0	105.8	155.3
MK3	0.003	0	15.3	230.1
SK3	0.004	0.001	34.2	329.7
MN4	0.005	-0.003	81.6	126.2
M4	0.012	-0.005	147.4	113.2
SN4	0.002	0.001	11.5	90
MS4	0.007	0.003	152.6	181
S4	0.003	0	178.5	284.8
2MK5	0.003	0	161.6	78.6
2SK5	0.002	0	22.2	266.7
2MN6	0.003	-0.001	135.4	112.7
M6	0.005	-0.003	116.3	135.8
2MS6	0.004	-0.002	168.9	139.5
2SM6	0.002	-0.002	86.4	199.6
3MK7	0.001	0	172.2	220.3
M8	0.003	-0.001	155.4	21.9

Table B- 15: BODC Mooring No. b0426990 – 30 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.017	0	51	180
MSF	0.032	-0.003	112.4	250.3
2Q1	0.011	-0.002	122.3	98.1
Q1	0.022	0.003	140.1	204.7
O1	0.038	0.002	129.8	259.9
NO1	0.01	-0.002	138.5	117.5
K1	0.039	0.007	125.3	41.3
J1	0.004	0.002	121.9	354
OO1	0.004	0.001	115.9	221.1
UPS1	0.003	0.001	104.4	209.8
N2	0.11	0.019	122.4	252.8
M2	0.439	0.08	121.2	275.4
S2	0.18	0.04	122.8	299.2
ETA2	0.005	0.001	162.6	24.2
MO3	0.008	0.002	140.9	295.8
M3	0.004	0.002	19.4	81.3
MK3	0.005	0.003	150.3	130.9
SK3	0.005	-0.003	74	112.1
MN4	0.01	0.004	77.1	200.2
M4	0.018	0.003	69.3	202.5
MS4	0.014	0.001	98.9	252.8
S4	0.004	0	79.8	266.3
2MK5	0.005	0.001	89.8	212.5
2SK5	0.005	0.001	66.9	148.2
2MN6	0.005	-0.004	48.6	2.3
M6	0.014	-0.006	81.4	19.6
2MS6	0.011	-0.006	83.3	45
2SM6	0.004	-0.003	66.2	49.8
3MK7	0.002	-0.001	142.8	27.4
M8	0.008	-0.001	76.7	187

Table B- 16: BODC Mooring No. b0431992 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.011	0	173.2	360
MM	0.043	0.002	50.3	216.3
MSF	0.018	0.007	80.3	20
ALP1	0.003	0.001	72.1	132.4
2Q1	0.005	0	41.3	98.9
Q1	0.012	-0.004	91.1	153.1
O1	0.023	0.002	89.3	230.9
NO1	0.006	-0.001	55.4	21.7
K1	0.013	-0.002	91.3	37
J1	0.008	0	89.1	20.2
OO1	0.004	0.001	98.4	128.2
UPS1	0.004	-0.001	100.7	283.1
EPS2	0.011	-0.002	163.5	51.1
MU2	0.032	0.003	74.8	150.2
N2	0.08	0.017	74.3	179.6
M2	0.283	0.071	69.6	195.8
L2	0.028	-0.001	80.9	64.1
S2	0.13	0.037	72.3	241.1
ETA2	0.012	-0.009	33.2	25.8
MO3	0.004	-0.001	4	155.7
M3	0.005	0.002	99.6	161.4
MK3	0.003	0	49.4	303.5
SK3	0.001	0	63.3	156.6
MN4	0.006	0.001	39.3	201.7
M4	0.01	0.008	129.9	44.3
SN4	0.002	0.001	179.7	238.3
MS4	0.012	0.003	78.9	69.9
S4	0.006	-0.002	48.8	179.6
2MK5	0.002	0.001	169.2	156.4
2SK5	0.002	0.001	1.2	97.4
2MN6	0.004	0.001	77.3	265.9
M6	0.004	0	109.1	292.8
2MS6	0.002	0	138.5	323.2
2SM6	0.005	-0.001	142.9	4.1
3MK7	0.002	0.001	144.6	66
M8	0.002	0	160.2	90.9

Table B- 17: BODC Mooring No. b0432135 – 36 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.014	0	174.2	360
MM	0.013	-0.001	107.3	61.7
MSF	0.012	0.005	35	240.7
ALP1	0.002	-0.001	115.8	115.7
2Q1	0.004	0.002	93.5	98.2
Q1	0.011	-0.004	66.7	129.8
O1	0.022	-0.004	93	211.6
NO1	0.002	-0.001	76.8	334.6
K1	0.019	0.001	91.6	347.8
J1	0.002	0.001	152.6	220.3
OO1	0.001	0	52.6	199.1
UPS1	0.001	-0.001	86.5	85.6
EPS2	0.007	-0.004	72.2	188.2
MU2	0.021	0.002	62.7	169.8
N2	0.059	0.017	76.7	163.3
M2	0.282	0.077	70.5	193.7
L2	0.019	-0.007	34.5	233.1
S2	0.11	0.032	72.3	220.6
ETA2	0.006	-0.001	176	19.2
MO3	0.004	-0.001	100.7	89.8
M3	0.007	-0.001	66	127.4
MK3	0.003	-0.002	17.2	352.8
SK3	0.003	-0.002	61.4	330.6
MN4	0.003	0.001	20.3	192
M4	0.01	0.002	172.8	68.6
SN4	0.004	0	50.4	83
MS4	0.004	0.002	117.1	59.1
S4	0.005	0	99.6	80.9
2MK5	0.002	0	94.4	299.4
2SK5	0.001	0.001	49.3	258.4
2MN6	0.002	0	140.1	326.6
M6	0.004	-0.001	72.6	282.9
2MS6	0.001	0	84.2	312.2
2SM6	0.002	-0.001	79.4	90.7
3MK7	0.002	0	48.1	106.3
M8	0.002	0.001	102.1	330.1

Table B- 18: BODC Mooring No. b0432264 - 36Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.01	0	11	180
MM	0.015	-0.004	68.2	6.5
MSF	0.017	-0.001	62.8	48.1
ALP1	0.003	0	57.8	352.2
2Q1	0.004	-0.003	84.8	323.6
Q1	0.008	-0.001	86.7	139.2
O1	0.023	-0.003	86.6	221.8
NO1	0.003	0	102.7	274.7
K1	0.028	-0.002	86.2	8.8
J1	0.002	0	34.3	73.2
OO1	0.003	0.001	149.4	107.1
UPS1	0.004	0.002	119	295
EPS2	0.005	-0.001	103.7	357.7
MU2	0.006	-0.001	2.8	214.1
N2	0.048	0.018	62.9	165.1
M2	0.303	0.092	67.4	192.7
L2	0.021	0.006	57.4	262.4
S2	0.074	0.024	67.1	228.5
ETA2	0.011	0	78.6	266.1
MO3	0.007	-0.001	30.7	112.6
M3	0.006	0	78.6	139.5
MK3	0.005	-0.001	45.2	250.6
SK3	0.002	0.001	94.9	324.4
MN4	0.006	0.001	34.5	82.8
M4	0.009	0	170.7	13.2
SN4	0.003	-0.001	86.4	351.4
MS4	0.01	-0.002	88.1	124.1
S4	0.002	-0.001	14.8	260.9
2MK5	0.003	-0.002	38.6	186.2
2SK5	0.001	0.001	58.5	318.3
2MN6	0.003	-0.001	108.3	306
M6	0.008	0	93.2	12.7
2MS6	0.006	0.001	86	63.3
2SM6	0.002	0	74.3	99.1
3MK7	0.002	0.001	19.4	271
M8	0.002	0.001	113.6	333.4

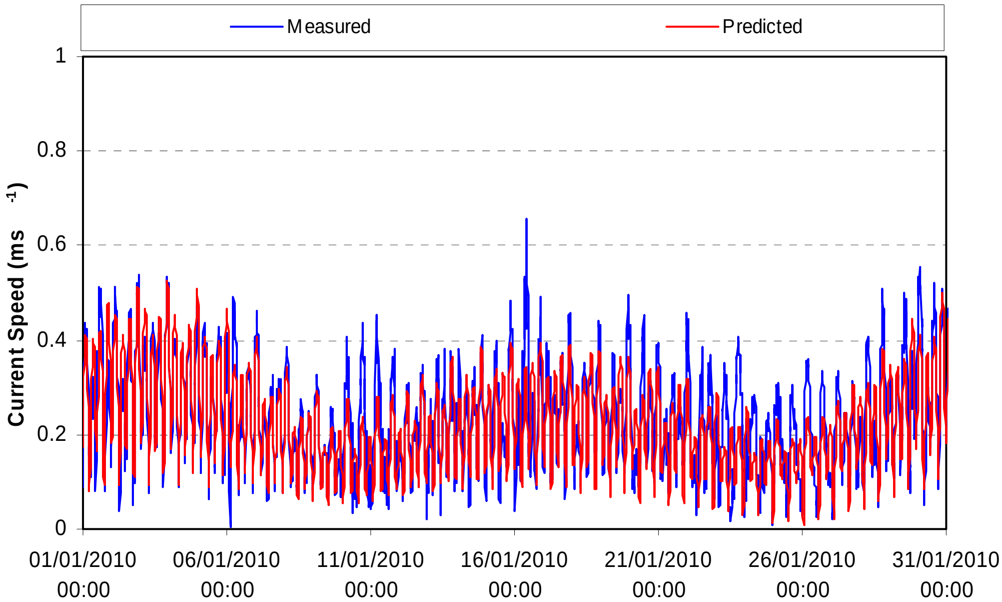
Table B- 19: BODC Mooring No. b0432830 – 18 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.015	0	15.3	180
MSF	0.026	-0.015	104.8	65
O1	0.027	-0.002	111.2	226.7
K1	0.026	-0.005	78.8	7.6
M2	0.299	0.092	73.2	195.8
S2	0.085	0.011	81.3	238.8
M3	0.01	-0.001	36.9	78.5
SK3	0.002	0	174.2	280.6
M4	0.011	0.003	118.2	349.4
MS4	0.009	0.003	55.5	82.8
S4	0.004	-0.001	13.8	6.4
2MK5	0.006	-0.001	4.8	263.9
2SK5	0.002	0.001	78.7	271
M6	0.01	-0.004	26	48.5
2MS6	0.005	0.003	138.8	248.6
2SM6	0.004	-0.001	145.2	207.9
3MK7	0.002	0	140.8	30.2
M8	0.003	0	99.9	359.3

Table B- 20: BODC Mooring No. b0432829 – 18 Constituents

Constituent	Major Amplitude (cm/s)	Minor Amplitude (cm/s)	Inclination	Phase
Z0	0.058	0	63.7	180
MSF	0.03	-0.002	33.4	104.4
O1	0.028	-0.006	60.3	221.2
K1	0.035	-0.001	94.1	2.5
M2	0.374	0.021	74.4	207.6
S2	0.104	0.01	70.1	242.1
M3	0.005	-0.003	87.6	172.2
SK3	0.002	-0.001	122.7	4.2
M4	0.019	-0.006	58	279.8
MS4	0.02	0.004	41	95
S4	0.012	-0.004	43.5	152.9
2MK5	0.003	0	97.7	49.6
2SK5	0.003	-0.001	37.6	299.1
M6	0.014	-0.011	44.8	299
2MS6	0.011	-0.007	26.5	322.5
2SM6	0.005	0.003	3.1	354.3
3MK7	0.004	0	67.1	322.4
M8	0.005	0.003	26.9	141.4

Figure B- 1: Forth Array Measured and Predicted Current Speed and Direction



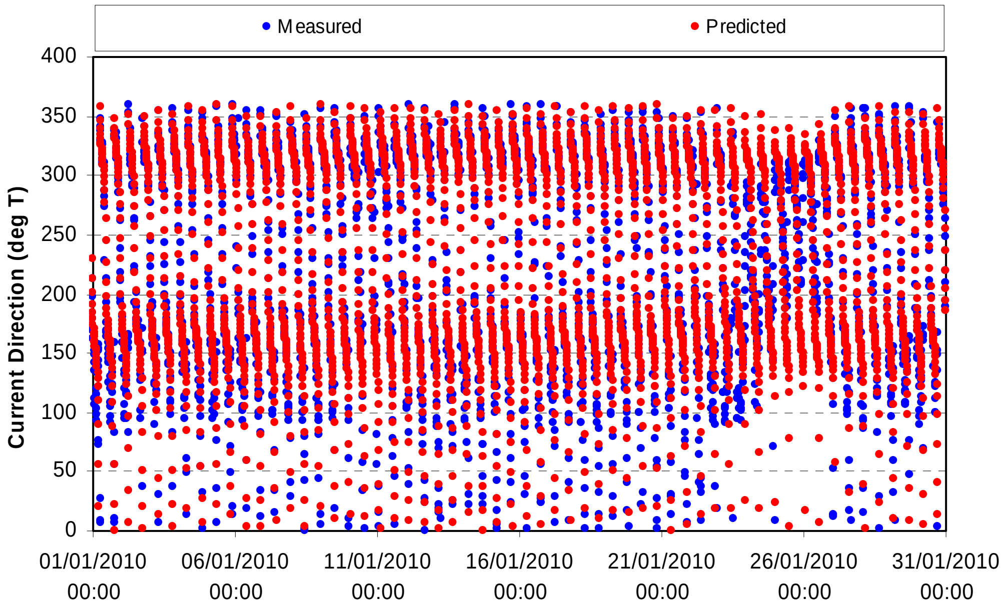
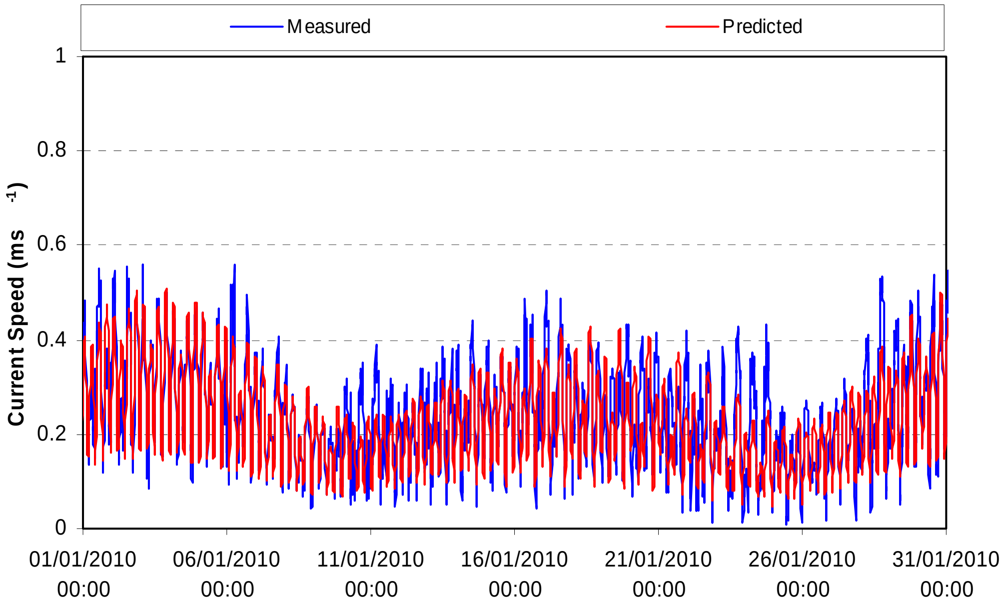


Figure B- 2: Neart na Gaoithe Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



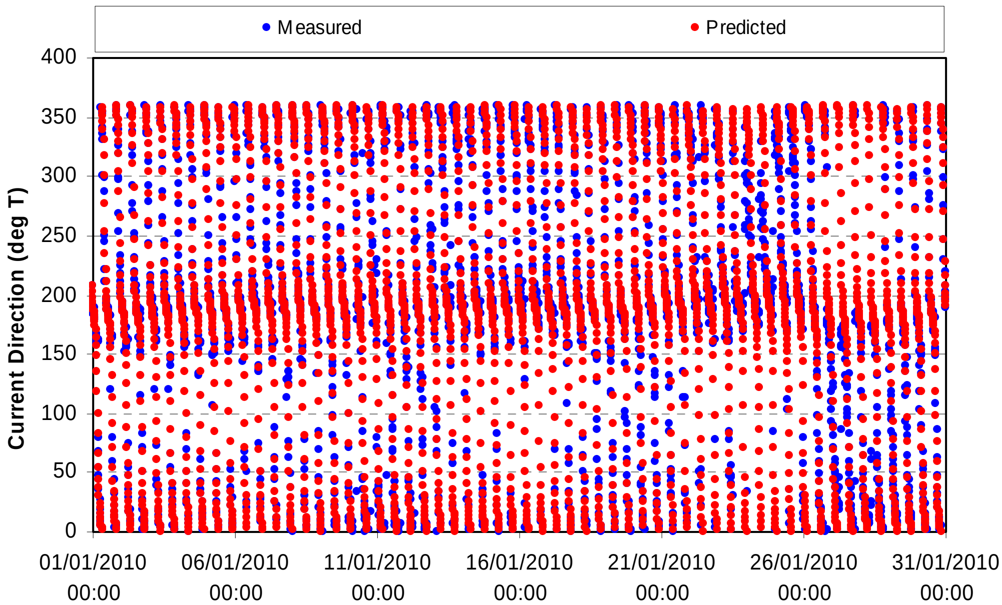
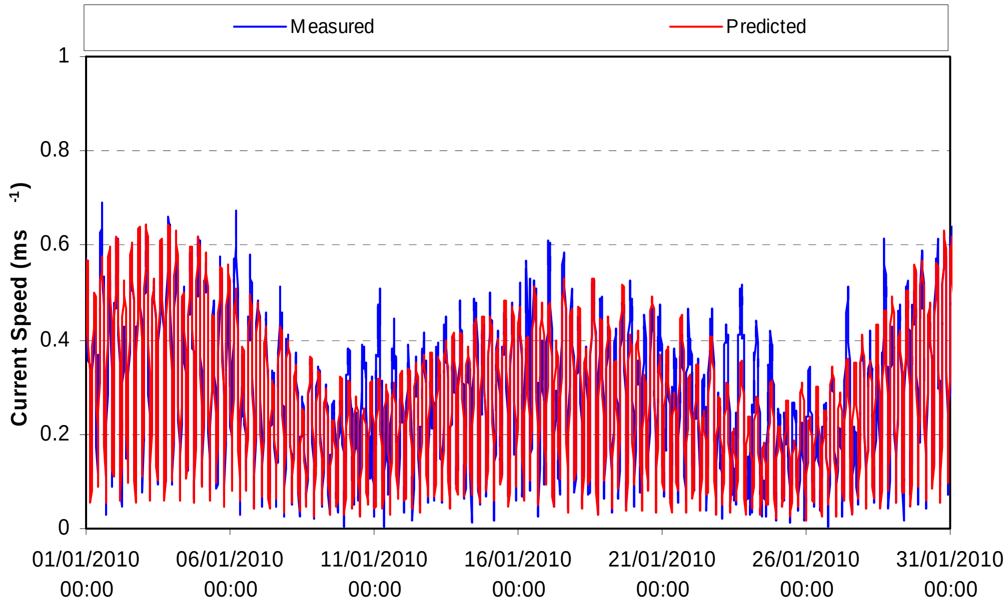


Figure B- 3: Inch Cape Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



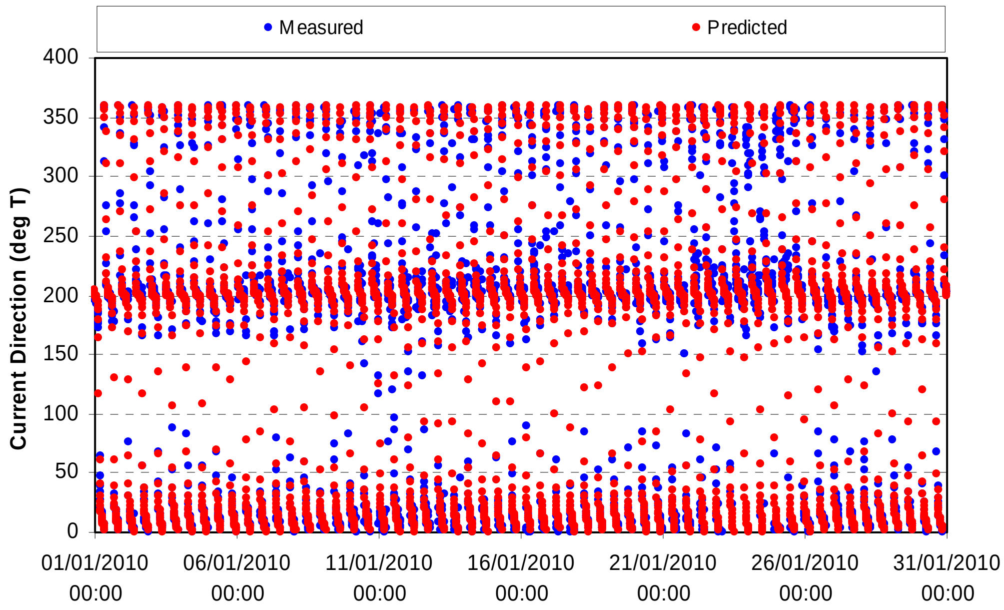
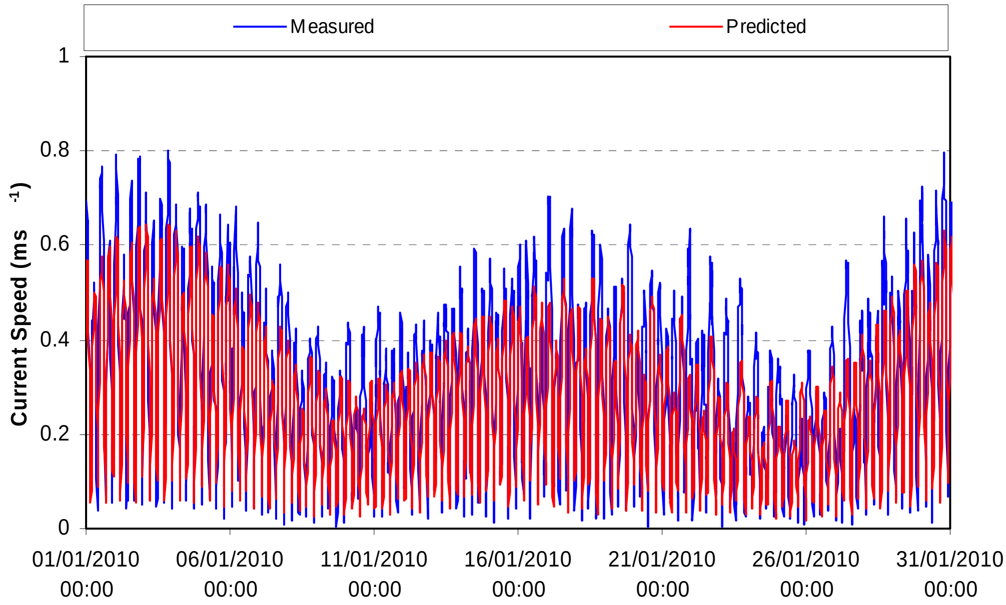


Figure B- 4: North Offshore Measured and Predicted Current Speeds (ms[1]) and Directions (deg T)



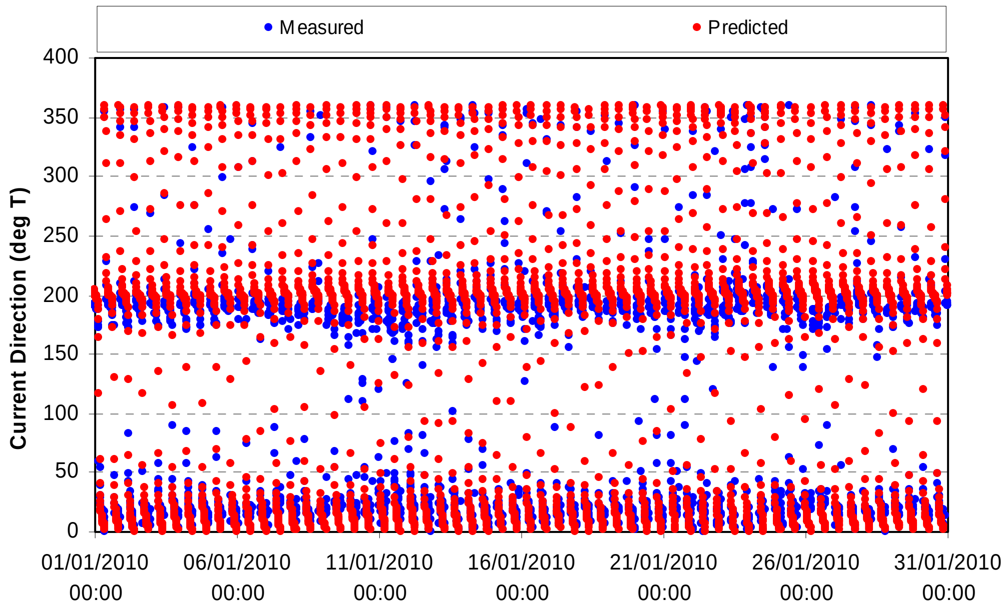
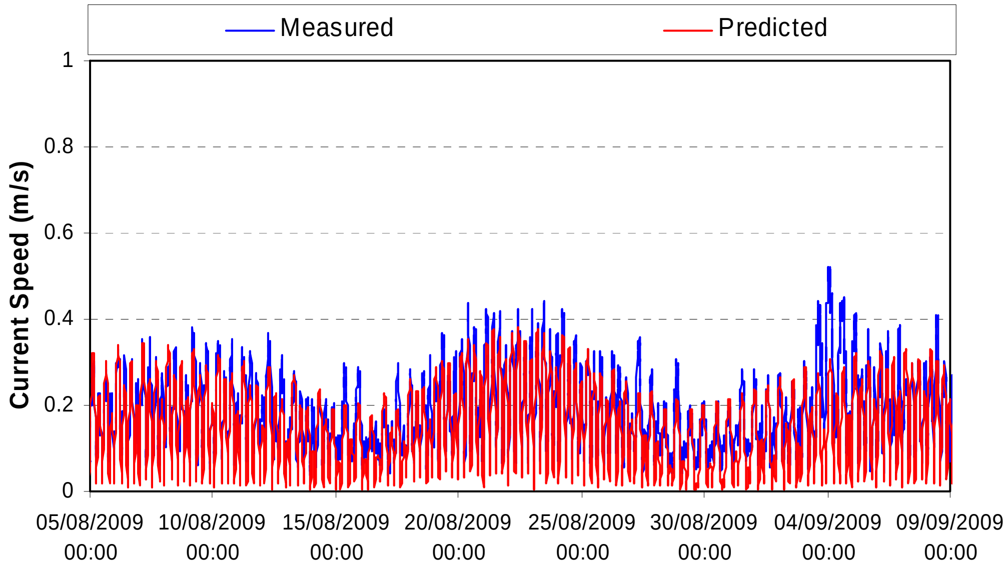


Figure B- 5: Torness Point Measured and Predicted Current Speeds (ms^{1}) and Directions (deg T)



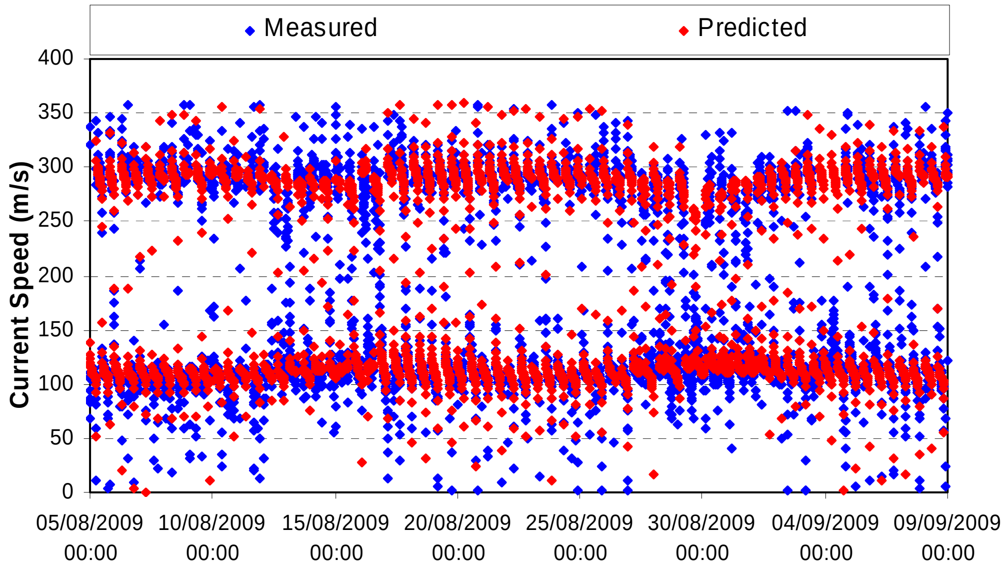
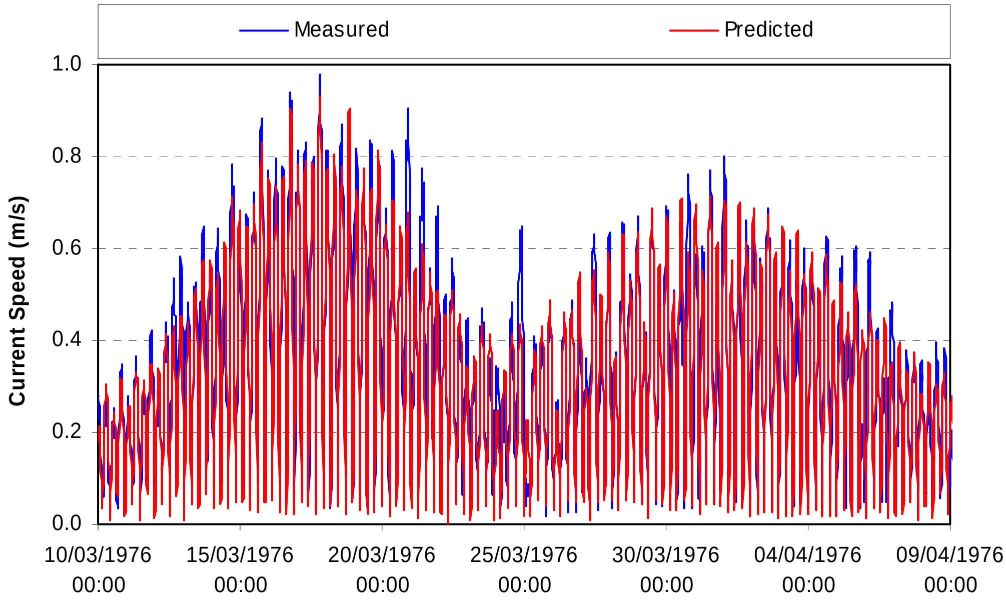


Figure B- 6: b0008653 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



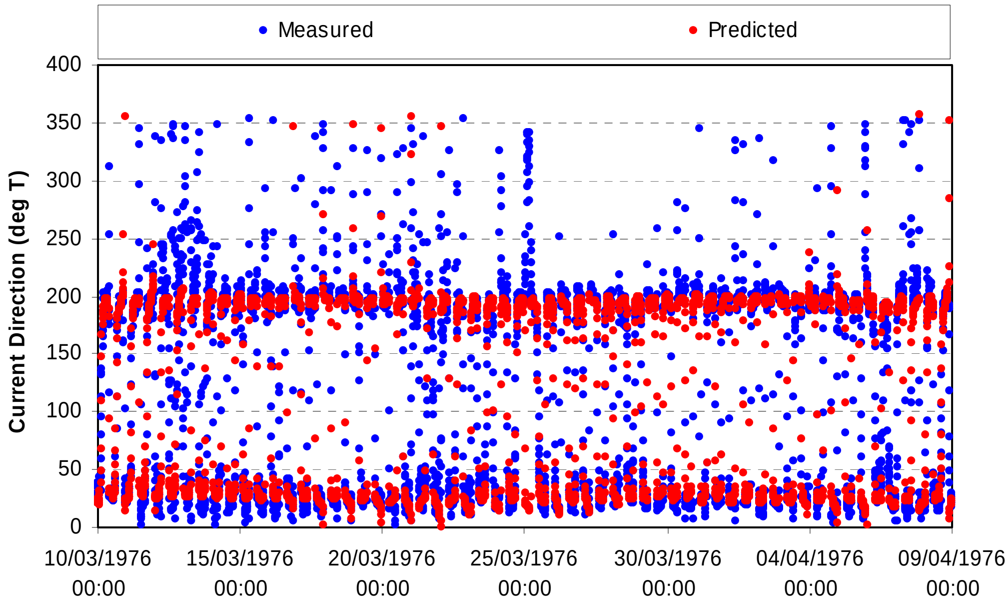
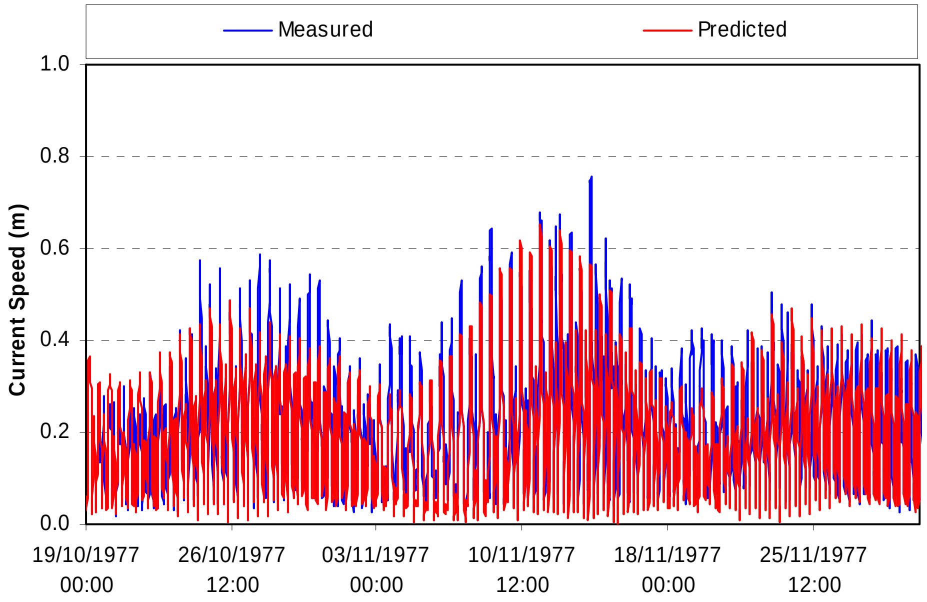


Figure B- 7: b0011359 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



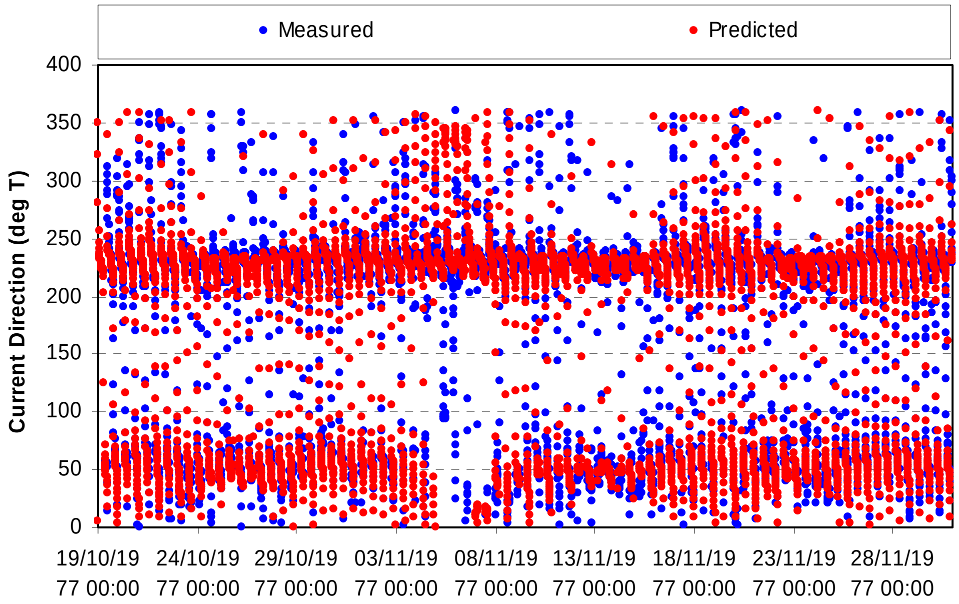
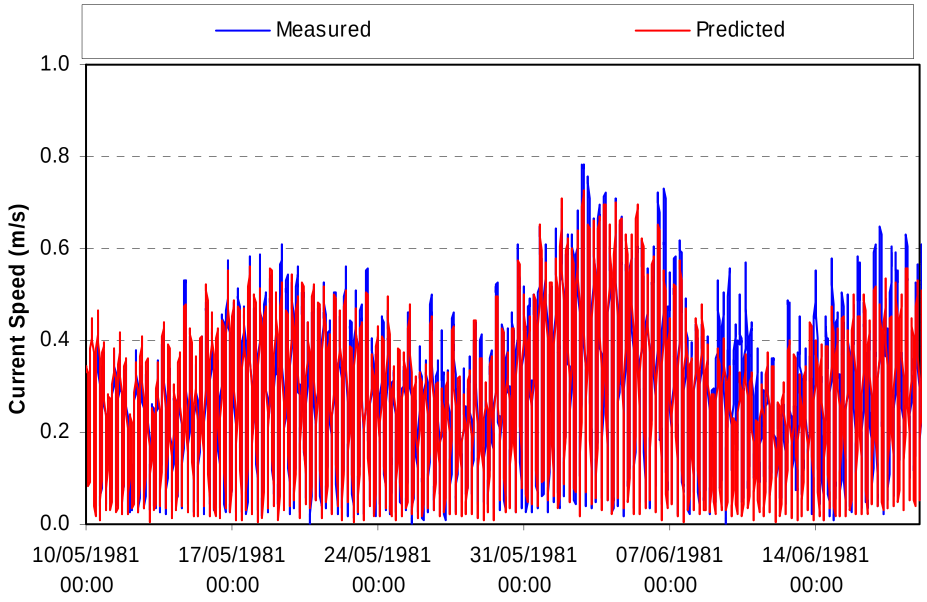


Figure B- 8: b0024978 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



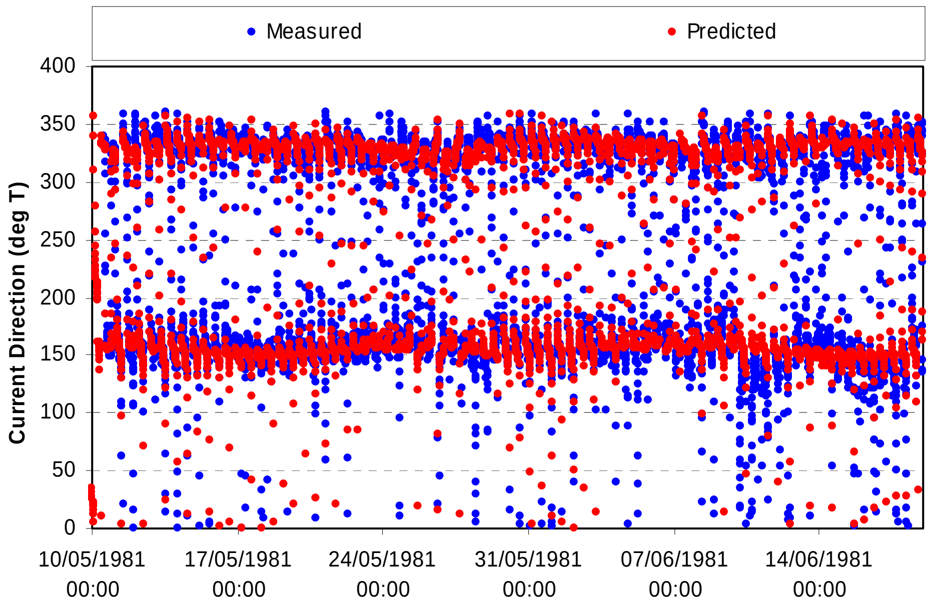
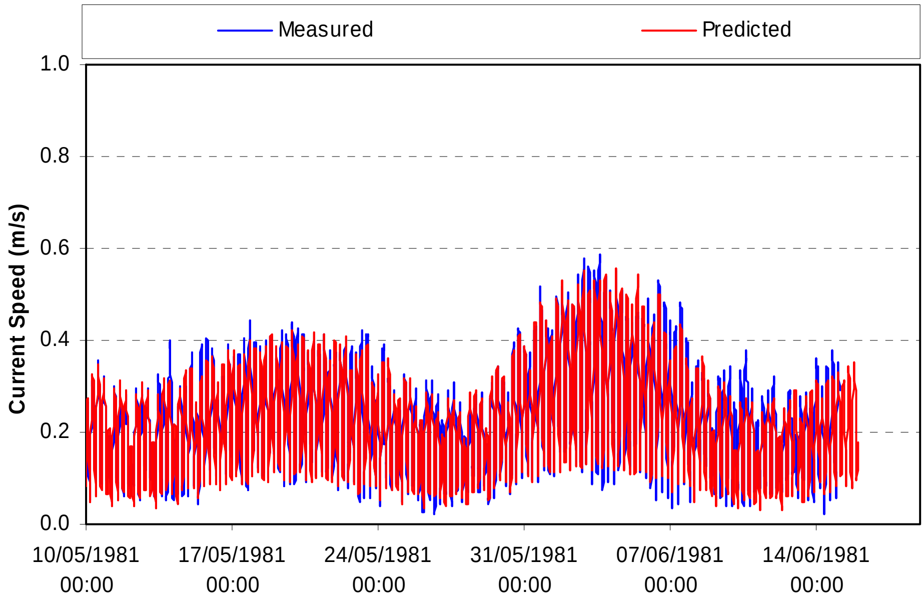


Figure B- 9: b0025017 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



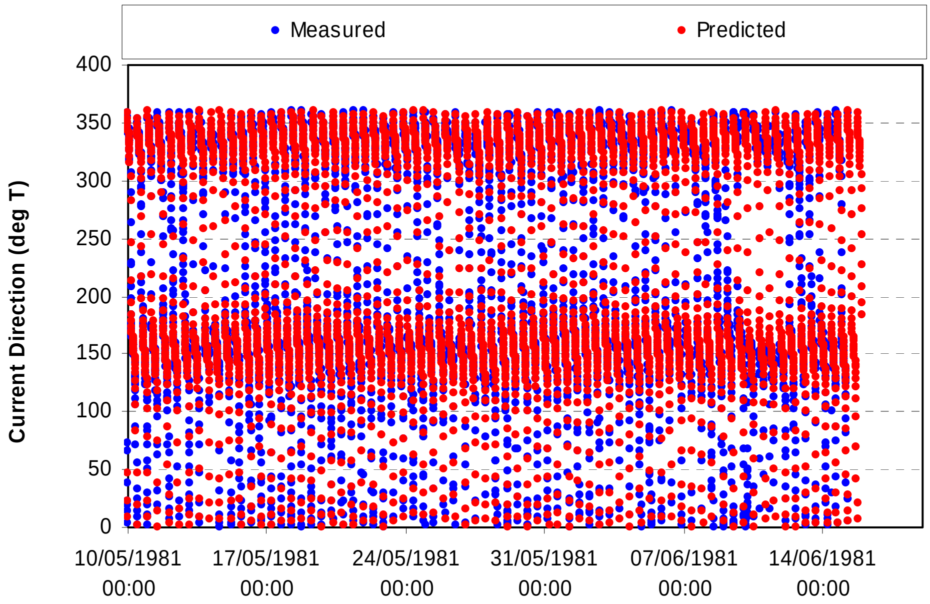
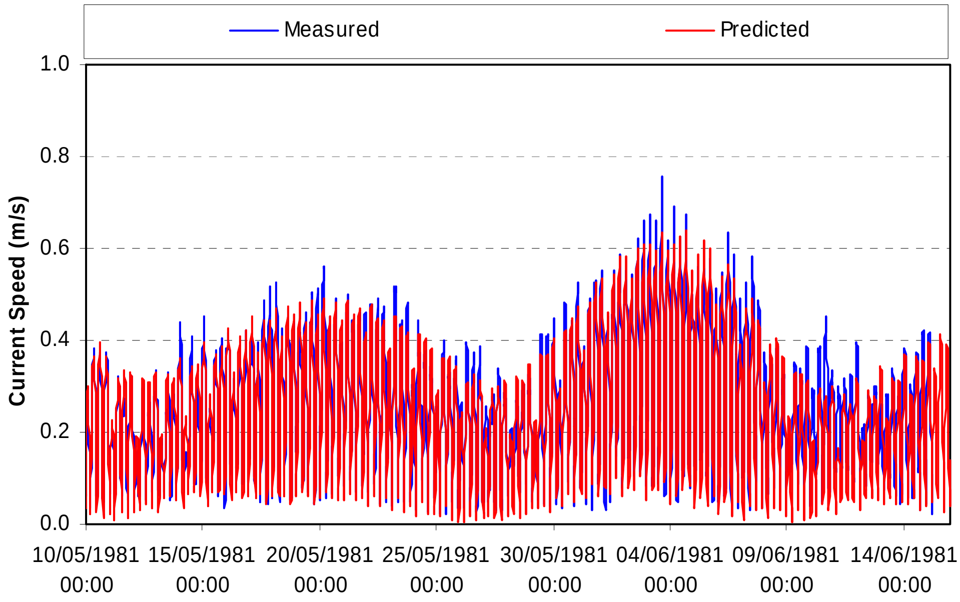


Figure B- 10: b0025030 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



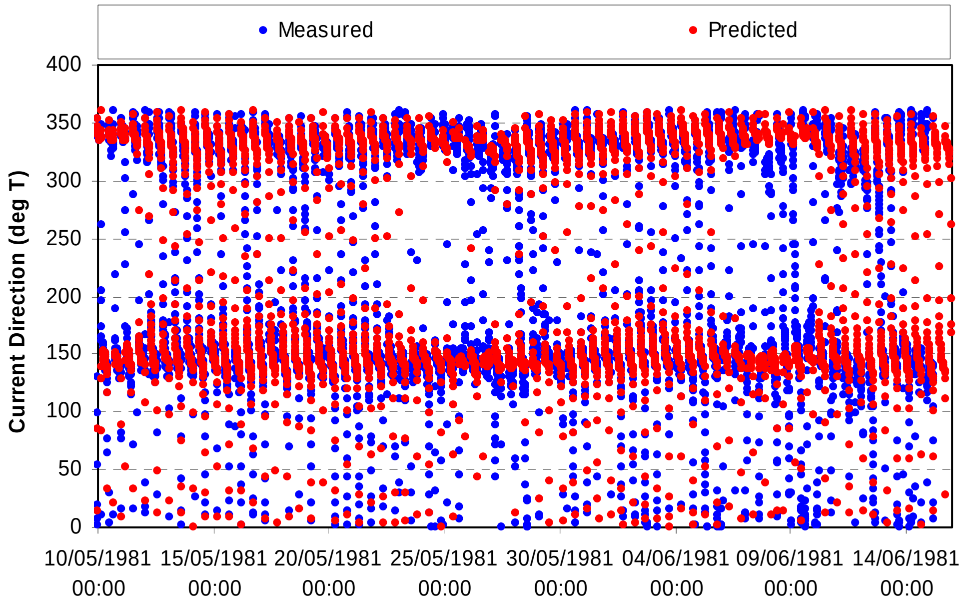
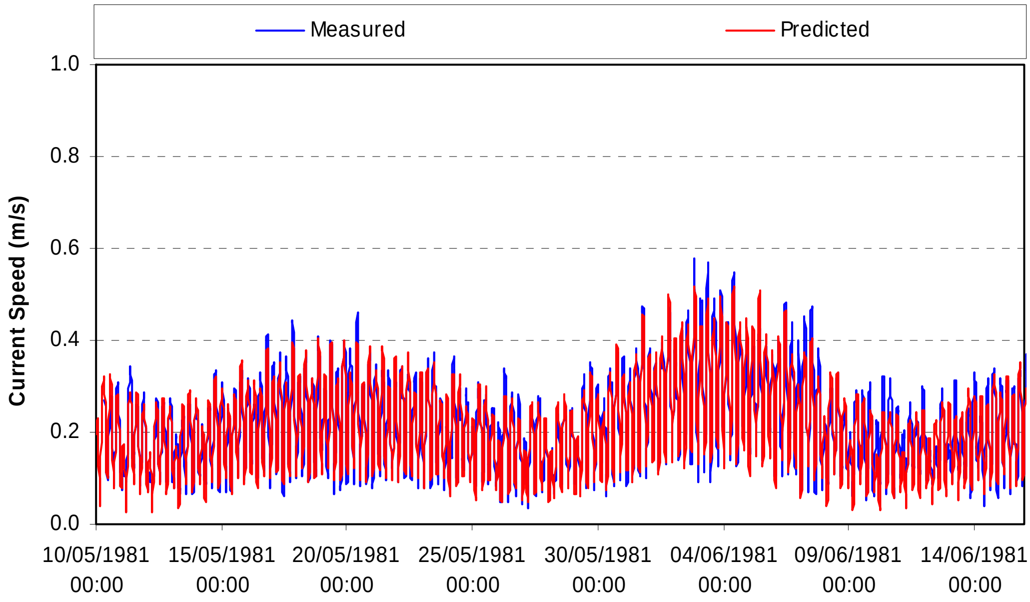


Figure B- 11: b0025042 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



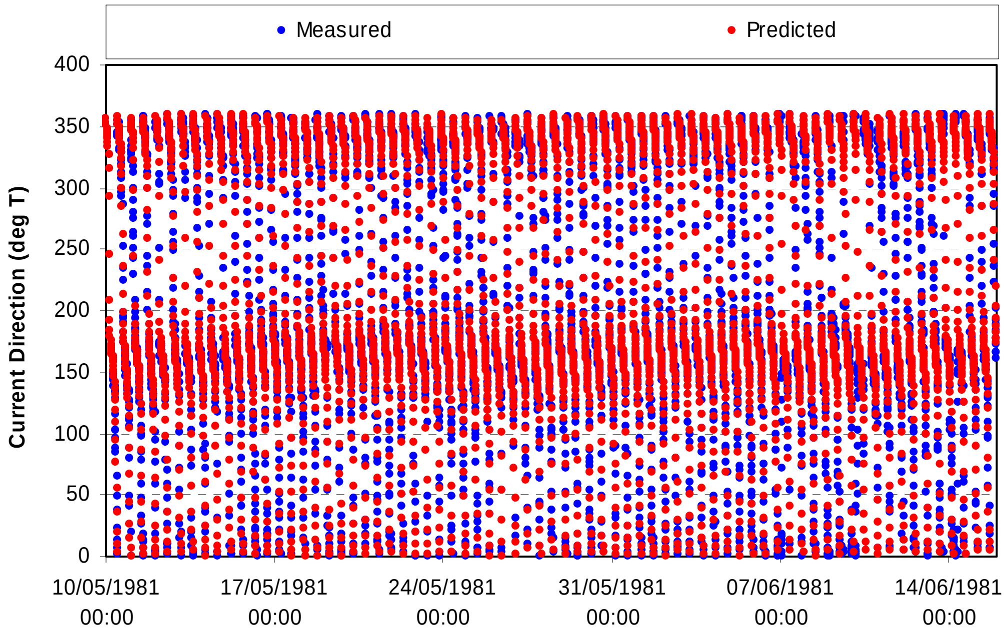
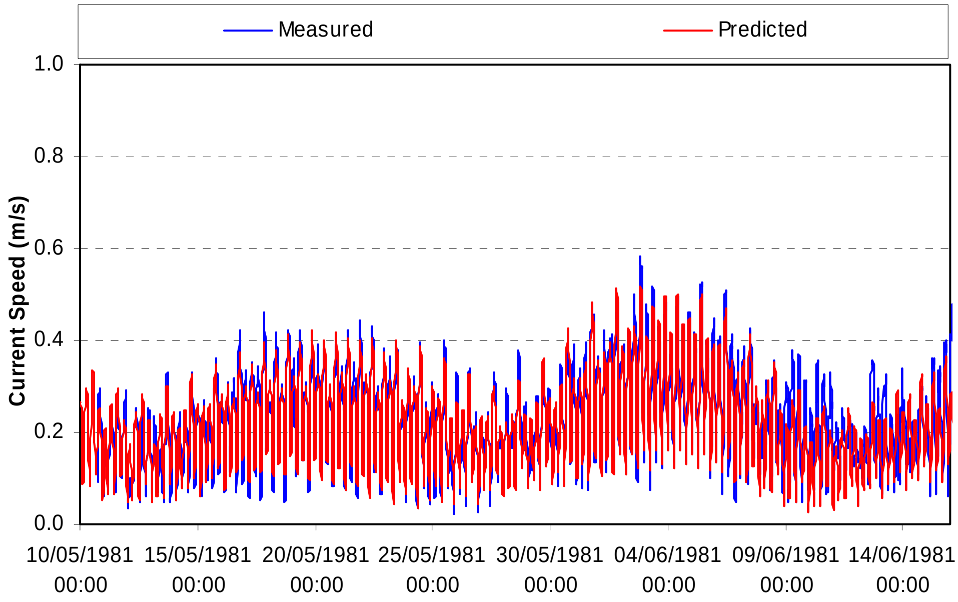


Figure B- 12: b0025054 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



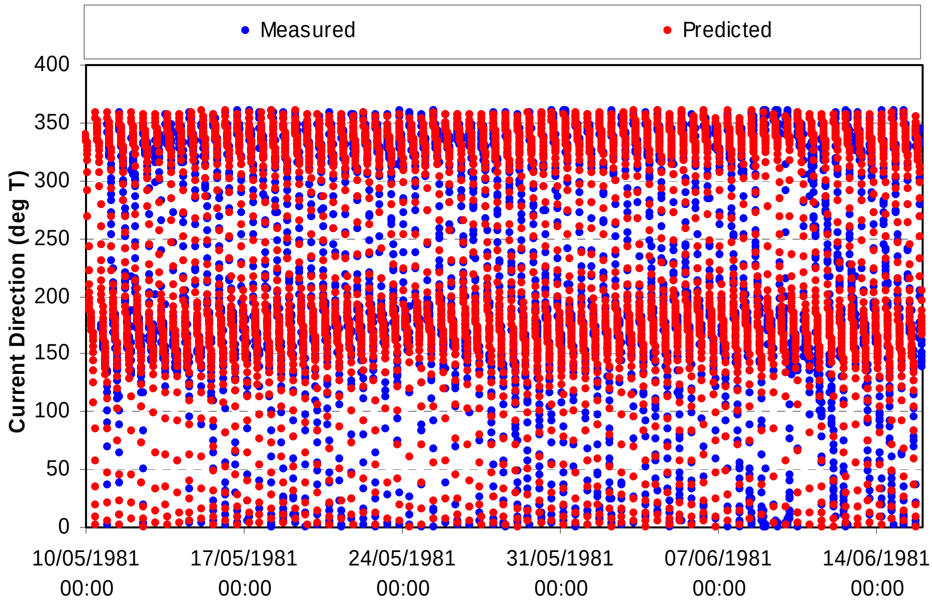
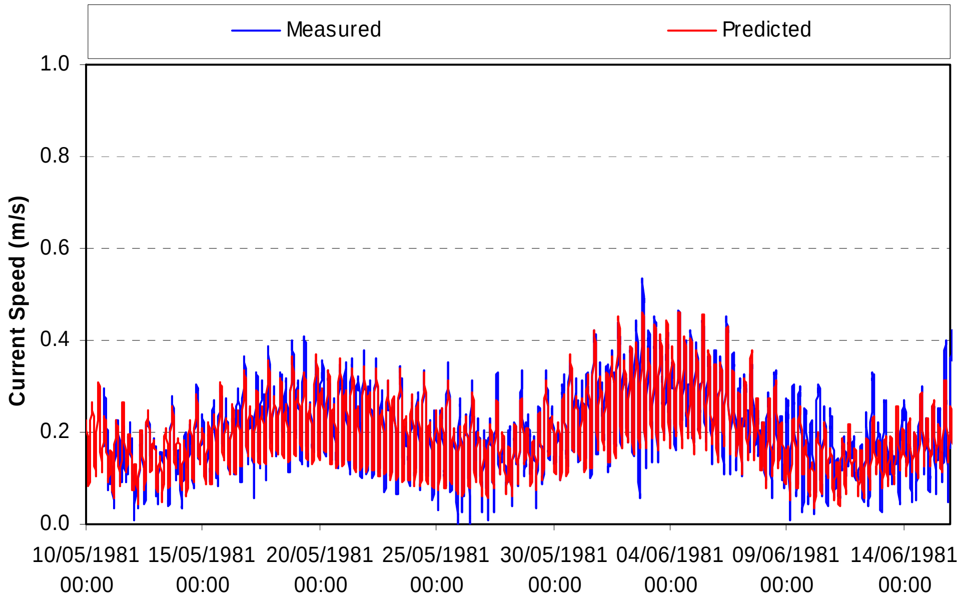


Figure B- 13: b0025110 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



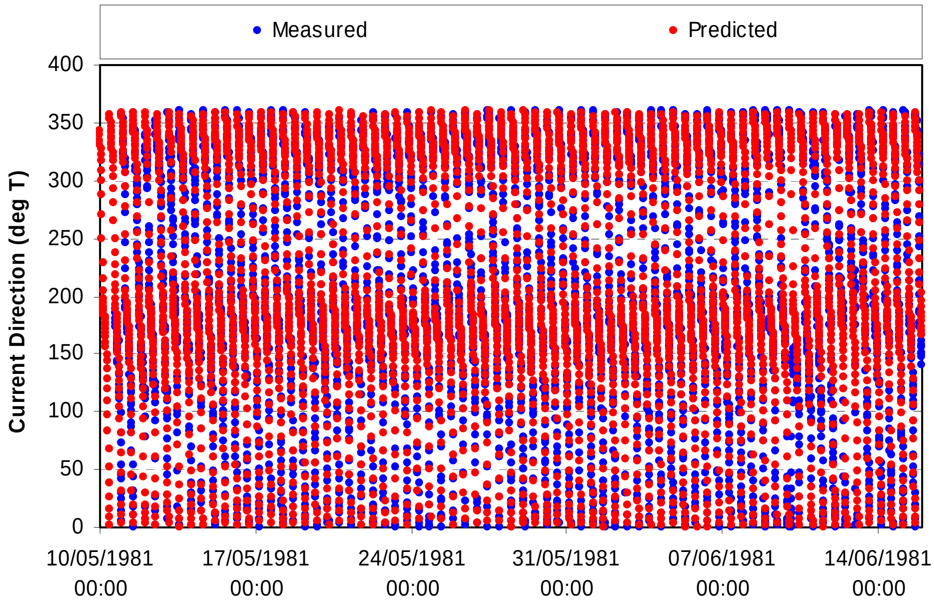
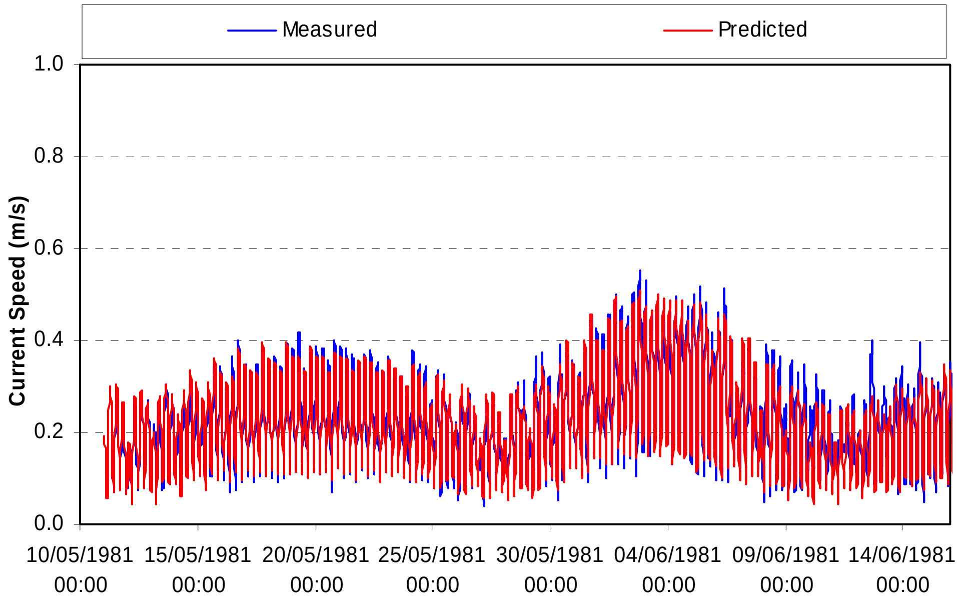


Figure B- 14: b0025195 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



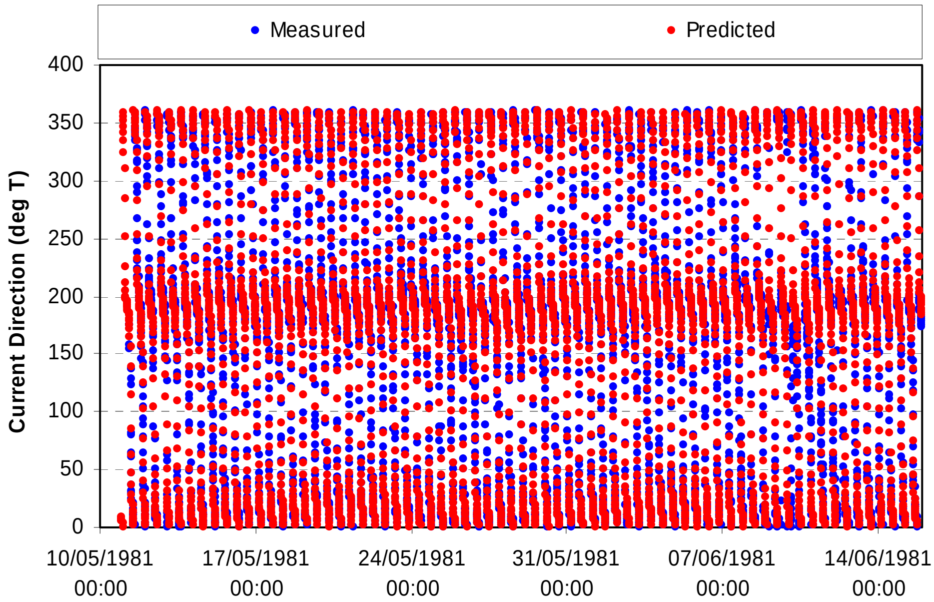
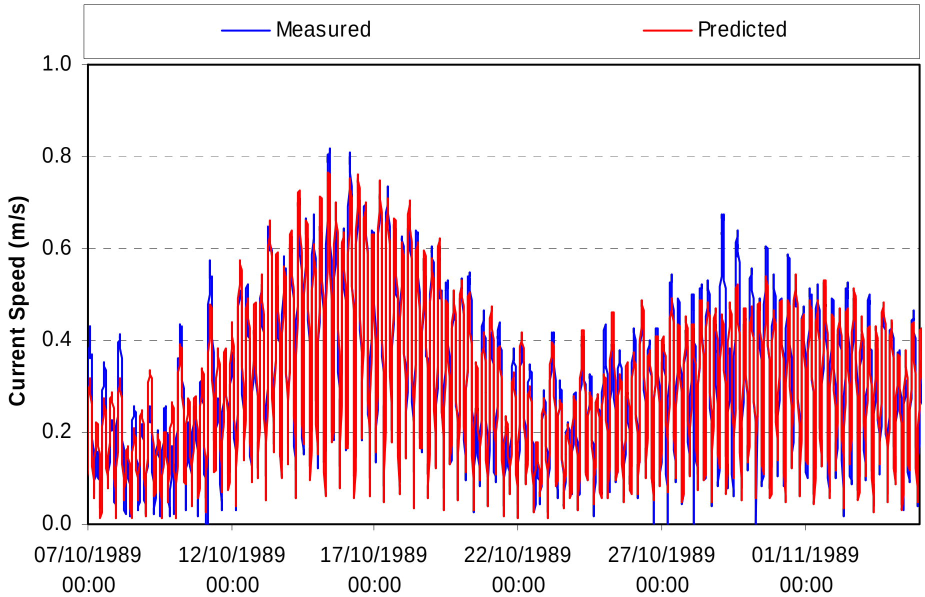


Figure B- 15: b0426990 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



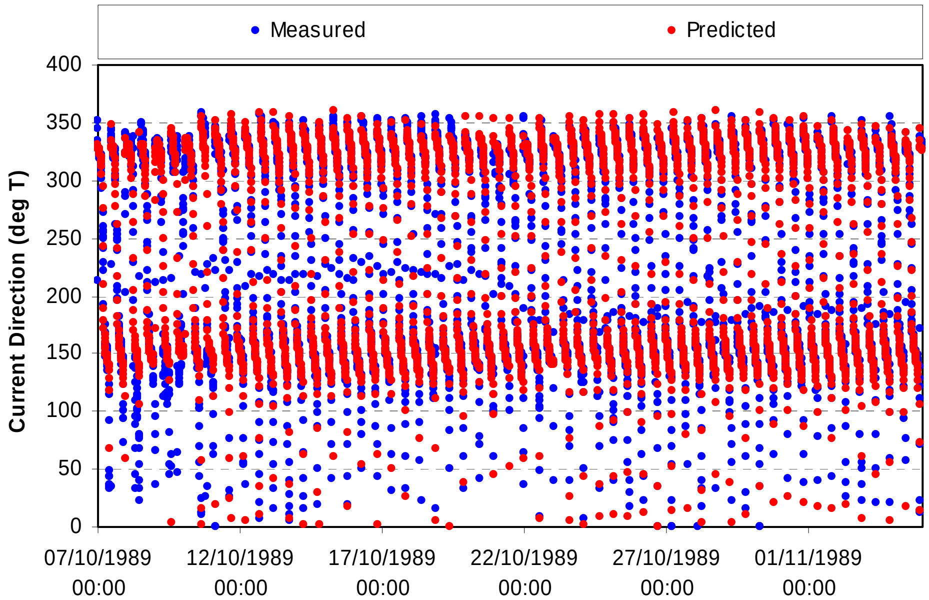
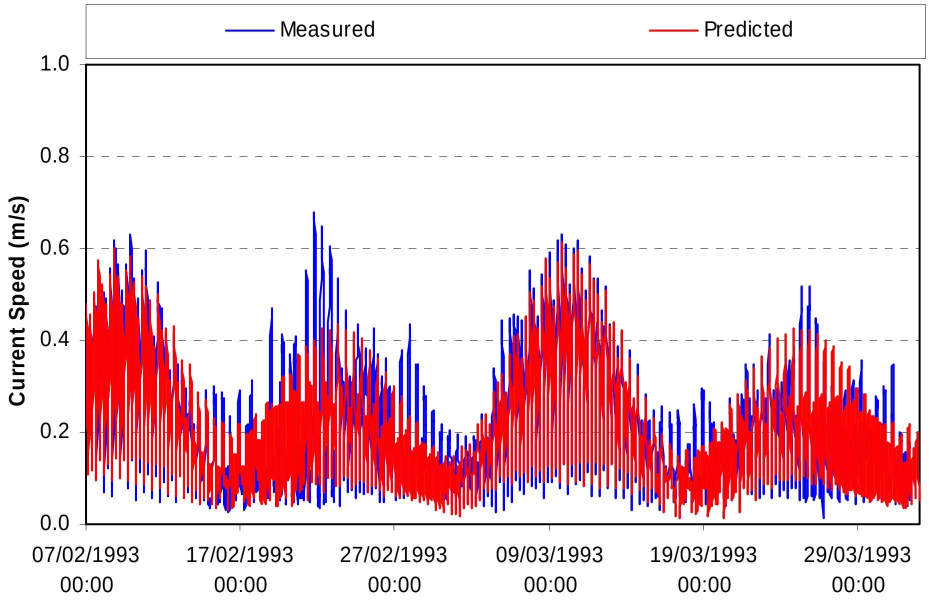


Figure B- 16: b0431992 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



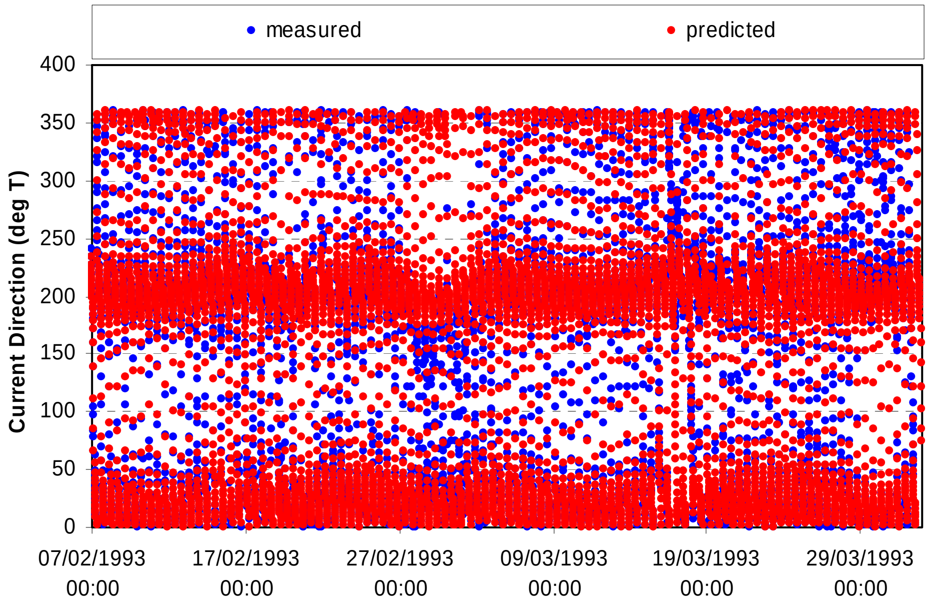
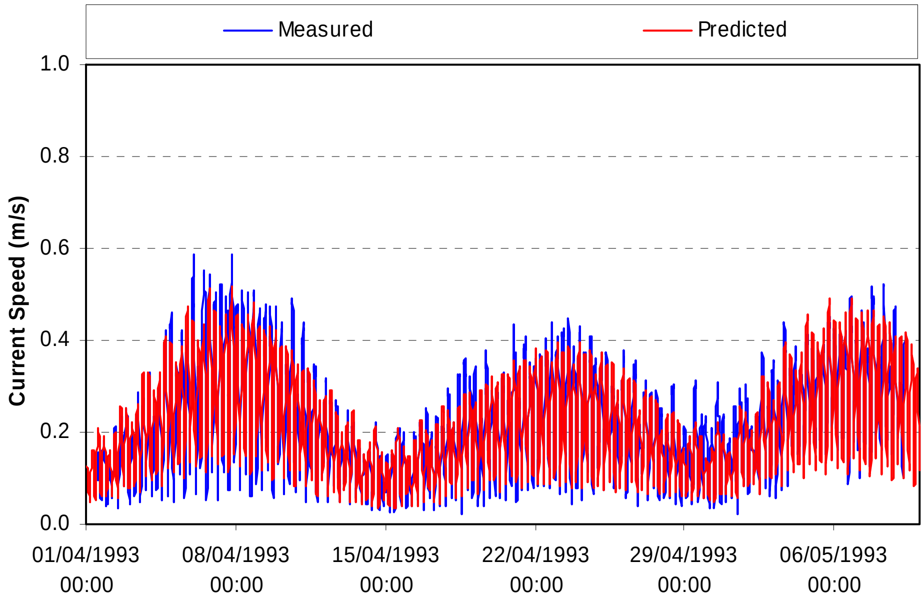


Figure B- 17: b0432135 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



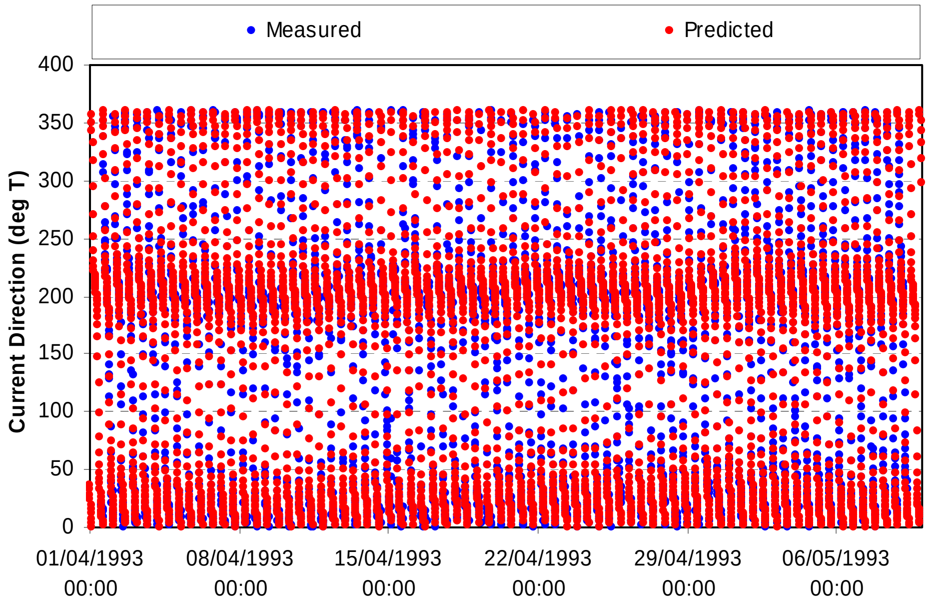
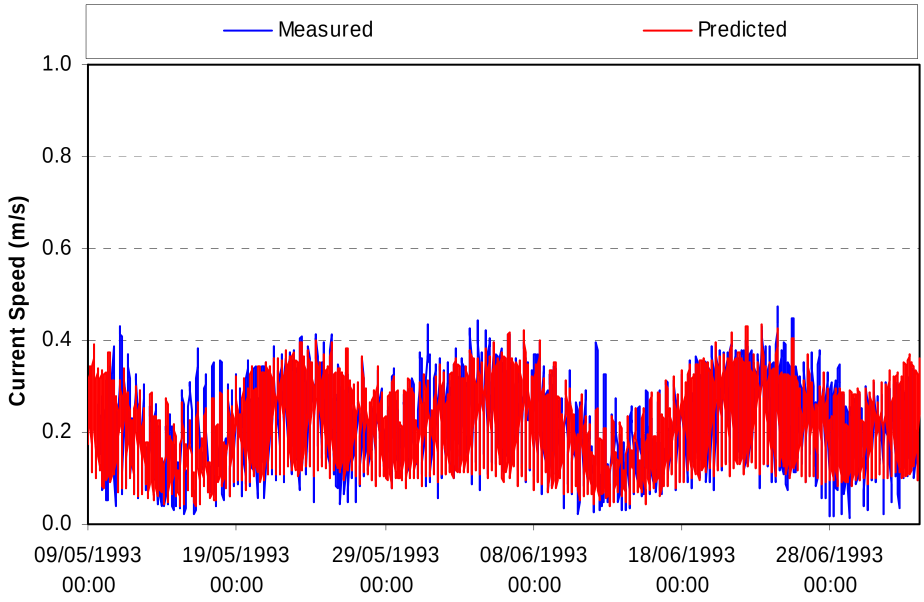


Figure B- 18: b0432264 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)



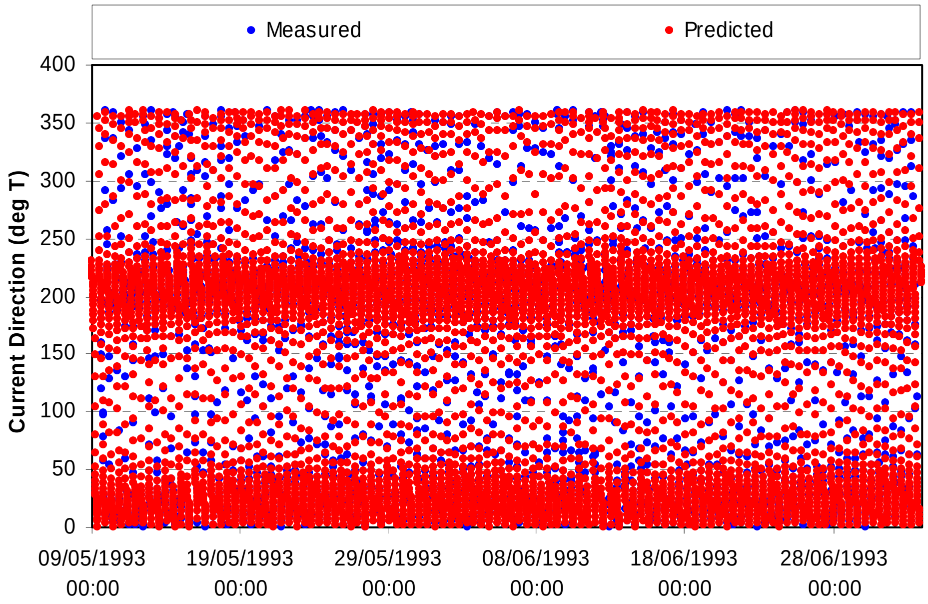
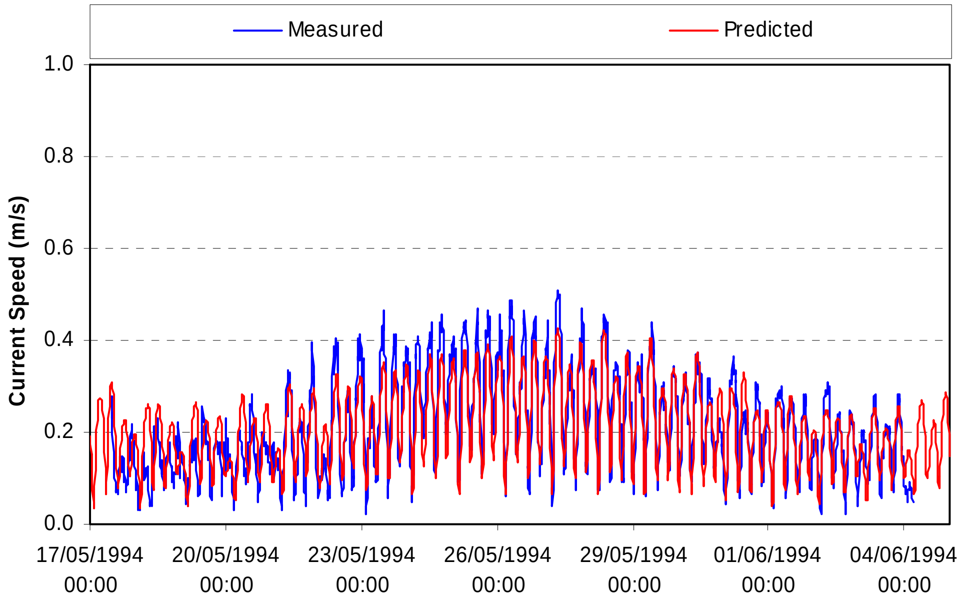
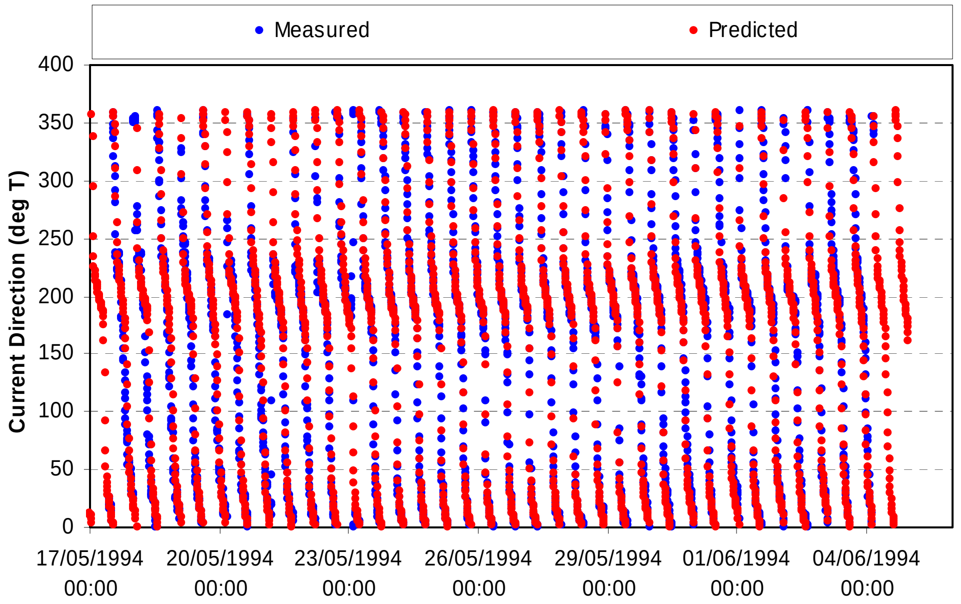


Figure B- 19: b0432830 Measured and Predicted Current Speeds (ms^{-1}) and Directions (deg T)





Appendix C Hydrodynamic Model Calibration Results

Figure C- 1: Forth Array ADCP Modelled Tidal Elevations (m) against Predicted Field Data

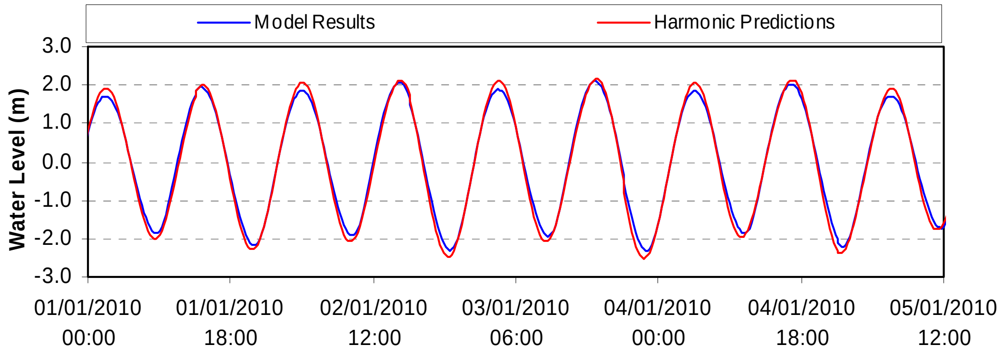


Figure C- 2: Neart na Gaoithe ADCP Modelled Tidal Elevations (m) against Predicted Field Data

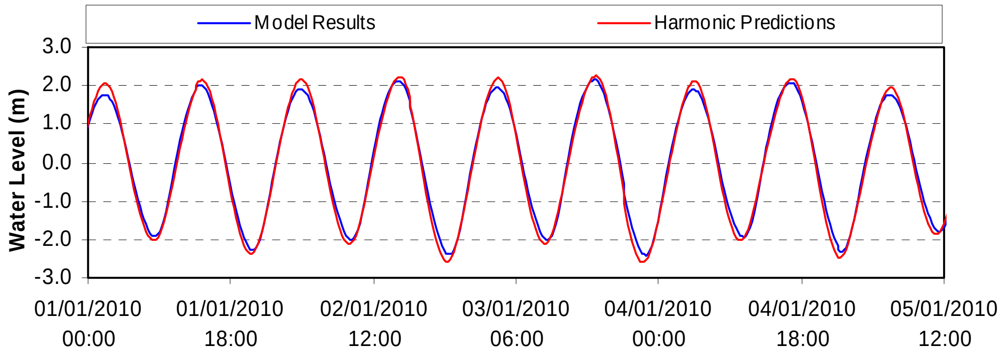


Figure C- 3: Inch Cape ADCP Modelled Tidal Elevations (m) against Predicted Field Data

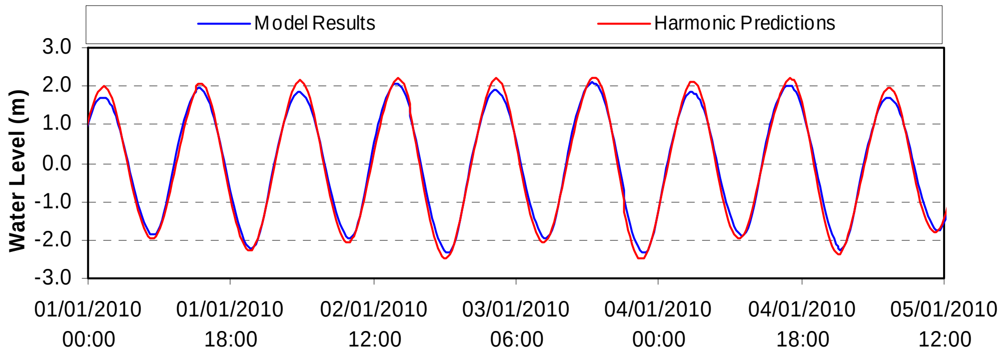


Figure C- 4: North Offshore ADCP Modelled Tidal Elevations (m) against Predicted Field Data

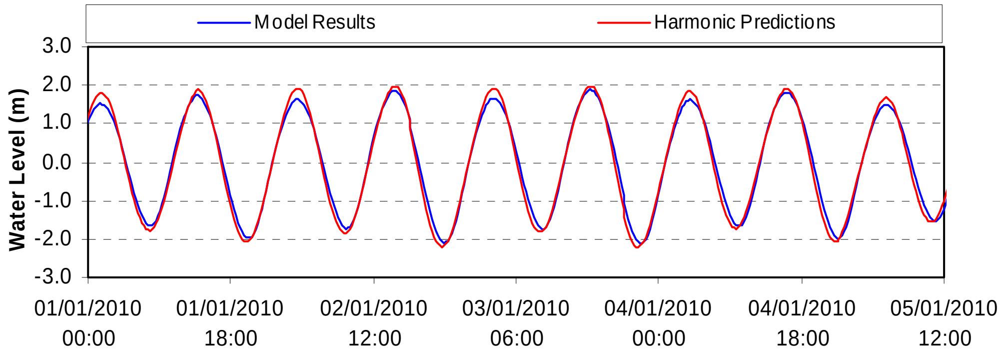


Figure C- 5: Torness Point, Scottish Water ADCP Modelled Tidal Elevations (m) against Predicted Field Data

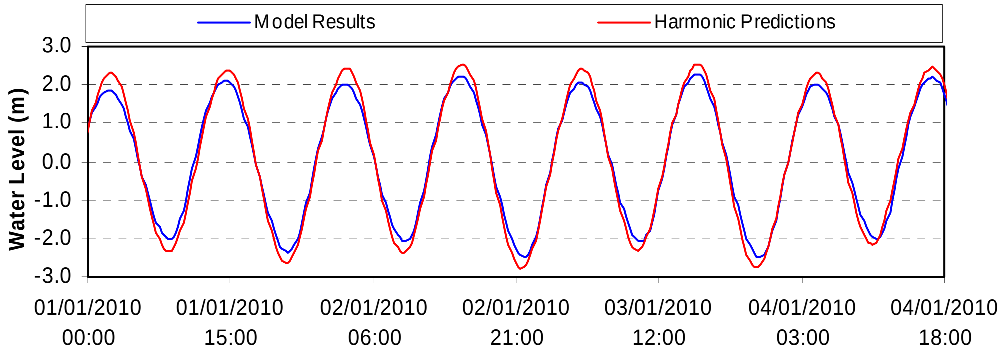


Figure C- 6: Newport-on-Tay SEPA Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

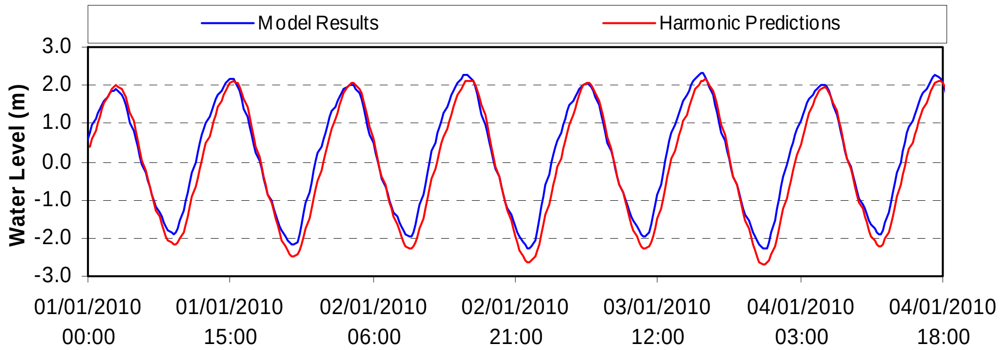


Figure C- 7: Leith POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

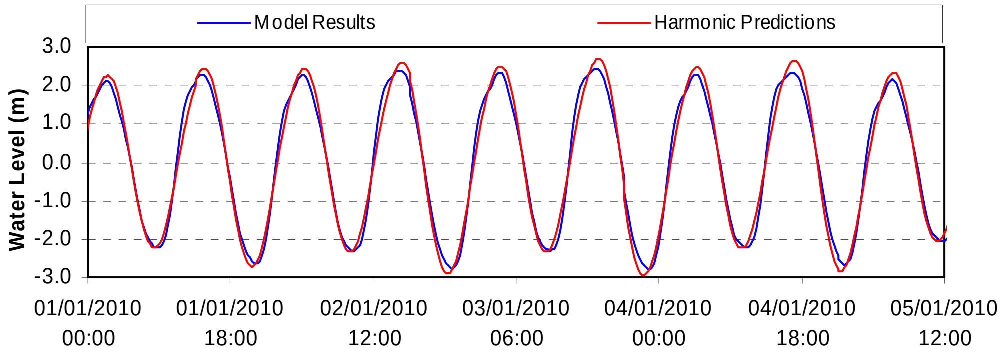


Figure C- 8: North Shields POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

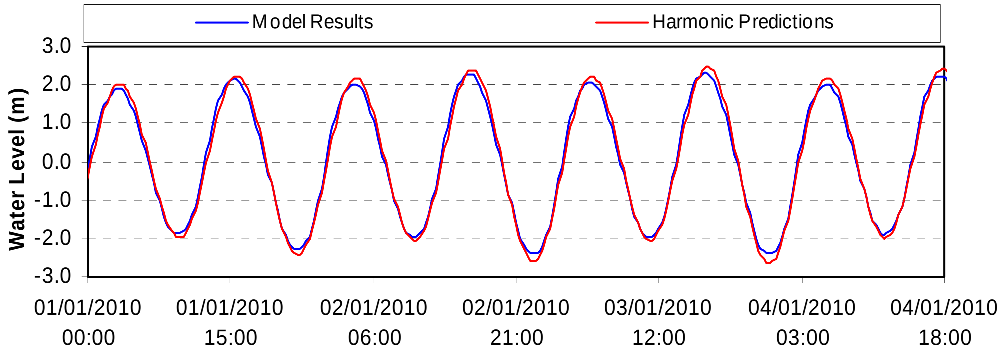


Figure C- 9: Whitby POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

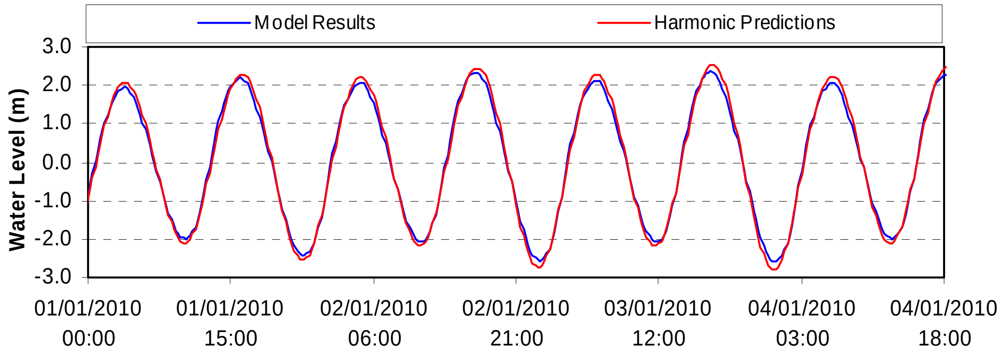


Figure C- 10: Stonehaven Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

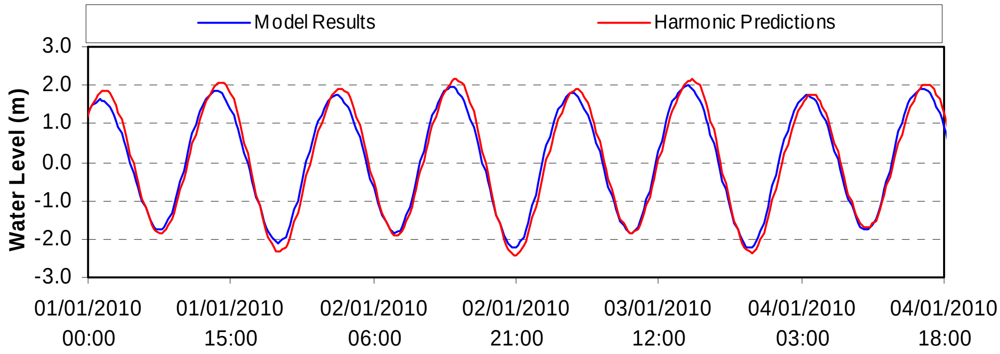


Figure C- 11: Montrose Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

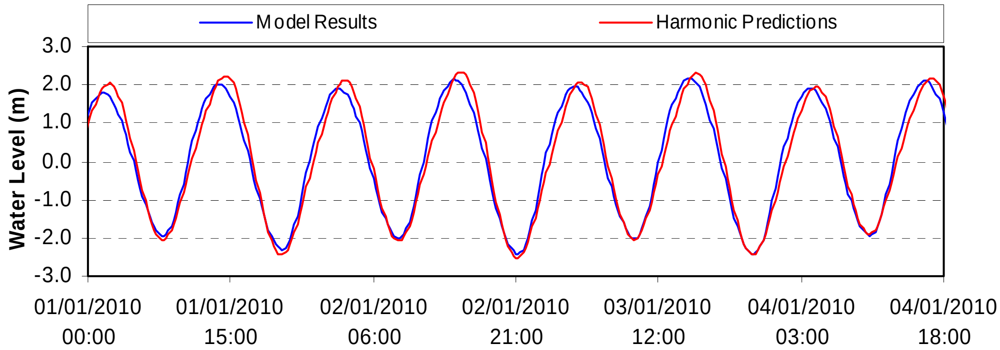


Figure C- 12: Arbroath Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

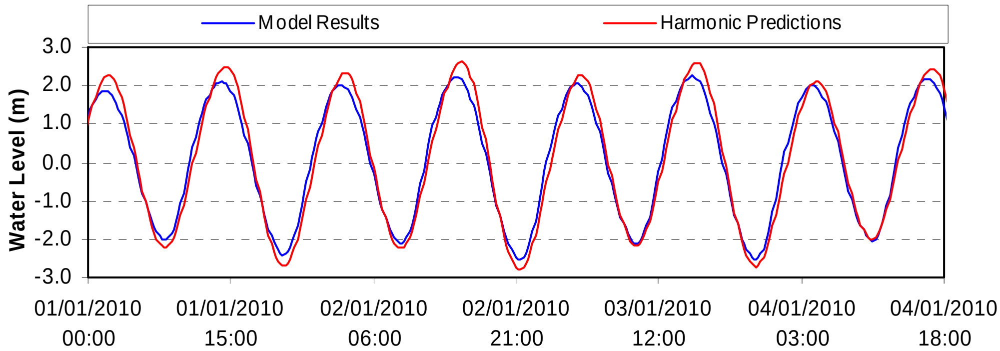


Figure C- 13: Anstruther Easter Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

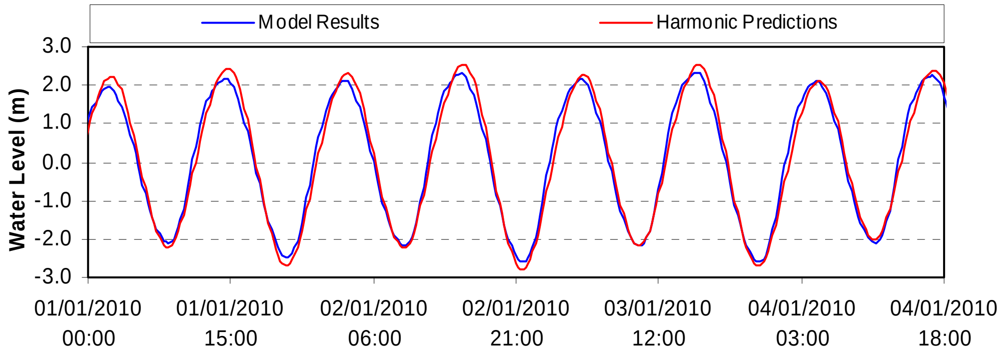


Figure C- 14: Fidra Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

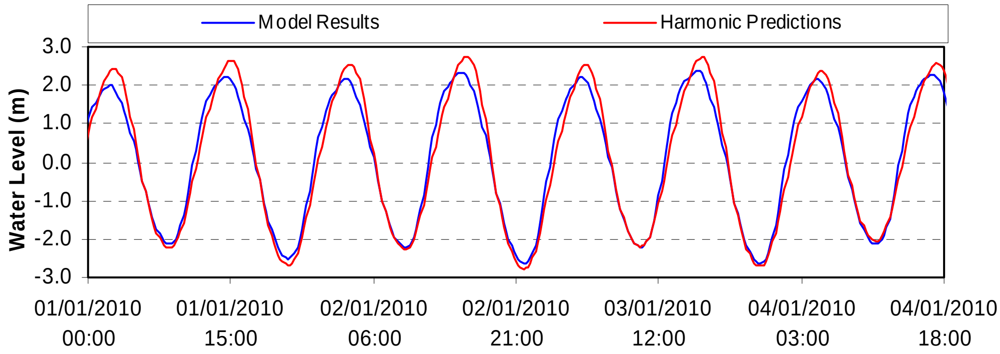


Figure C- 15: Dunbar Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

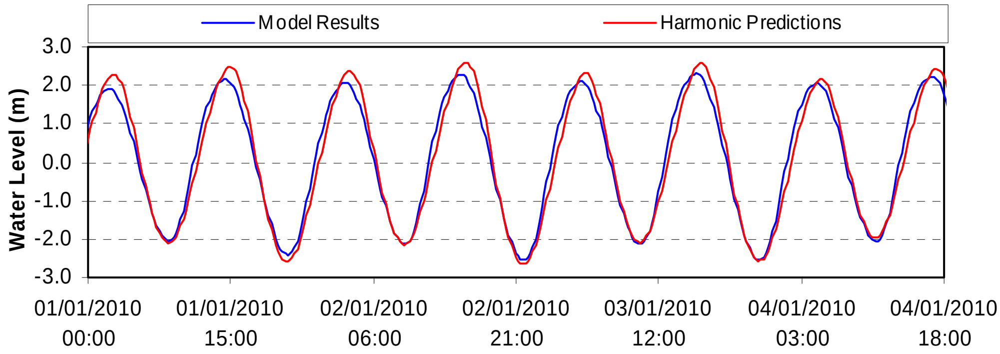


Figure C- 16: Amble Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

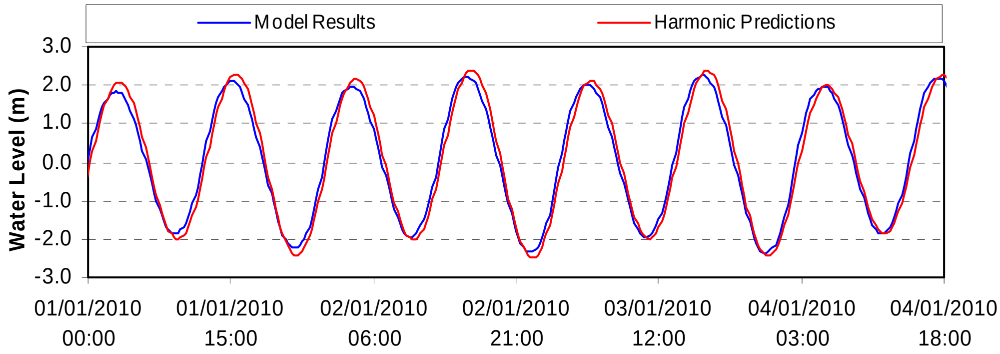


Figure C- 17: Hartlepool Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

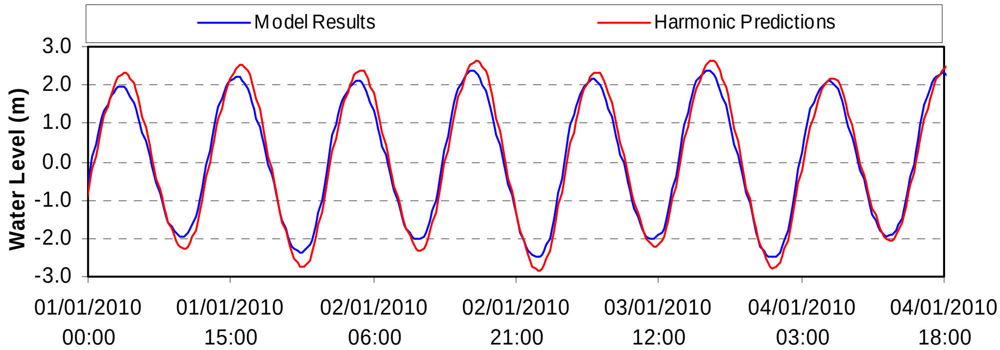


Figure C- 18: Forth Array ADCP Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

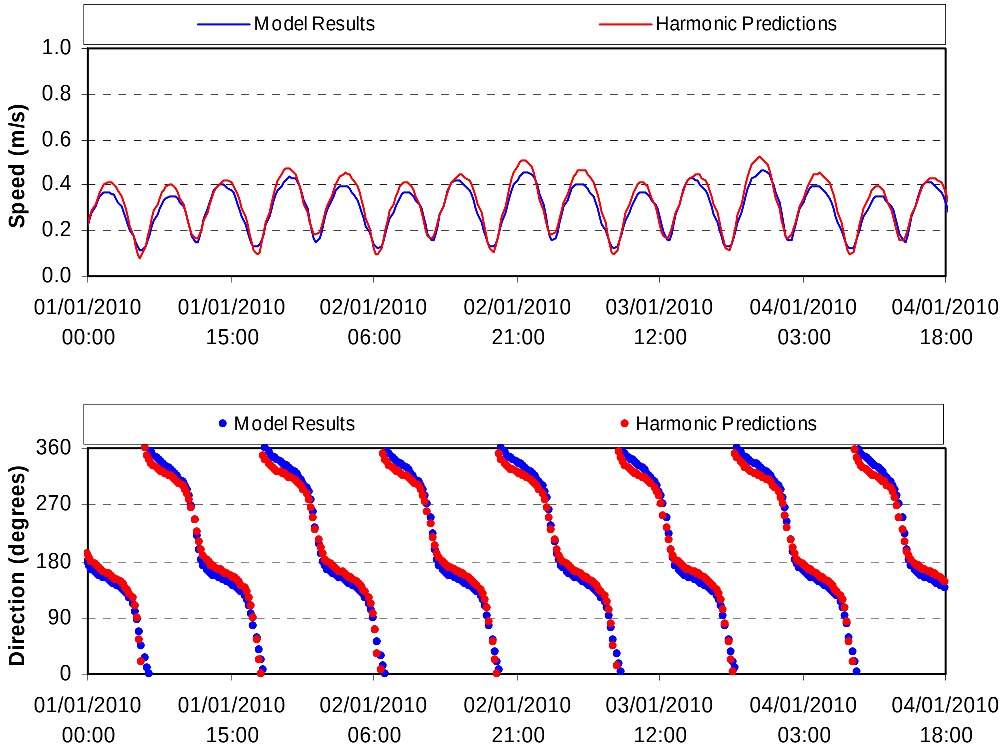


Figure C- 19: Neart na Gaoithe ADCP Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

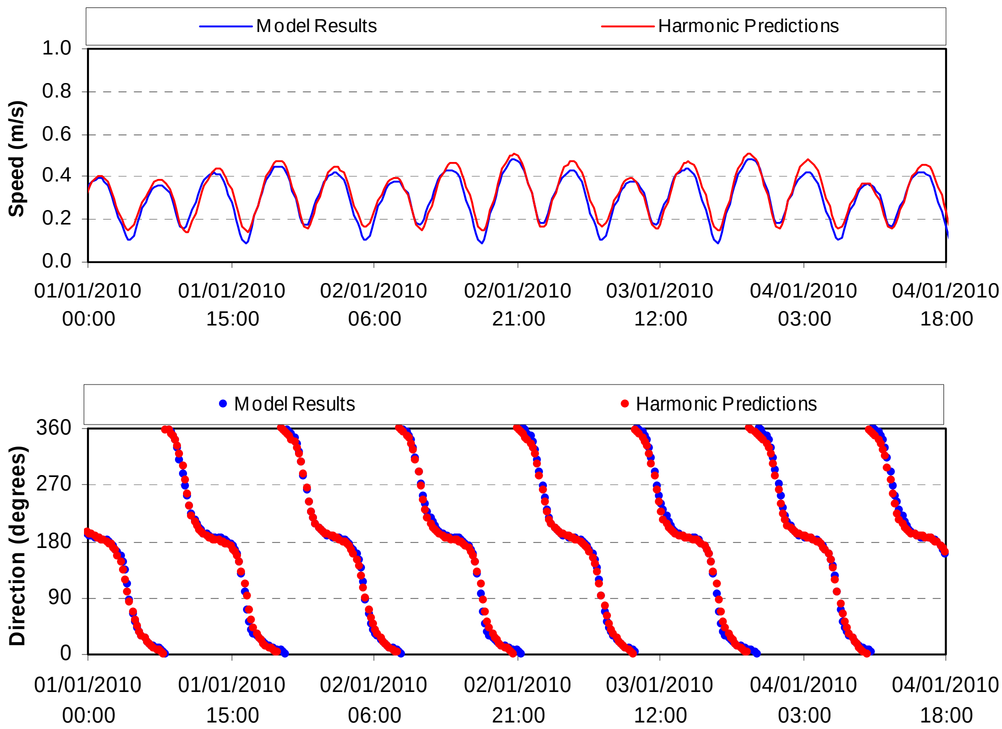


Figure C- 20: Inch Cape ADCP Modelled Tidal Currents Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

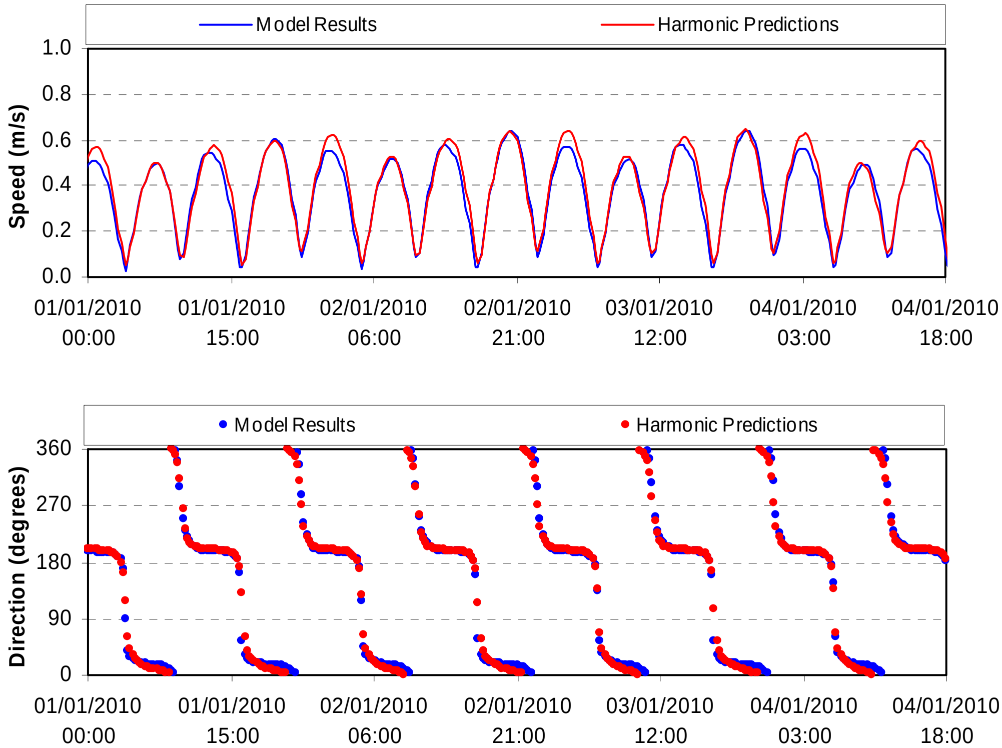


Figure C- 21: North Offshore ADCP Modelled Tidal Currents Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

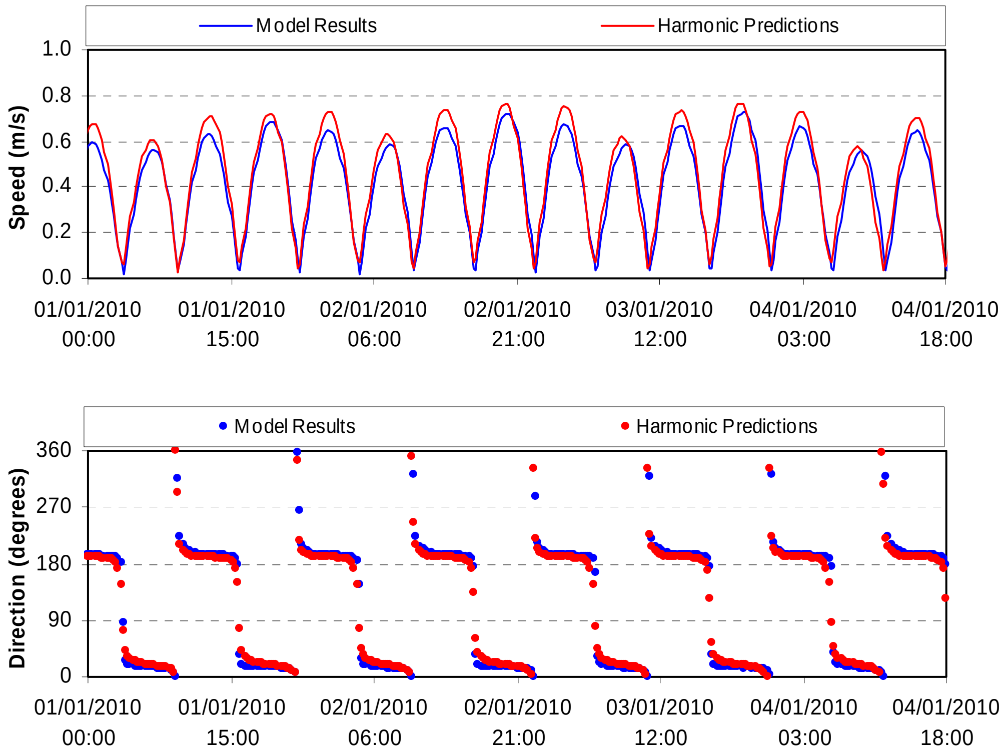


Figure C- 22: Torness Point, SW ADCP Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

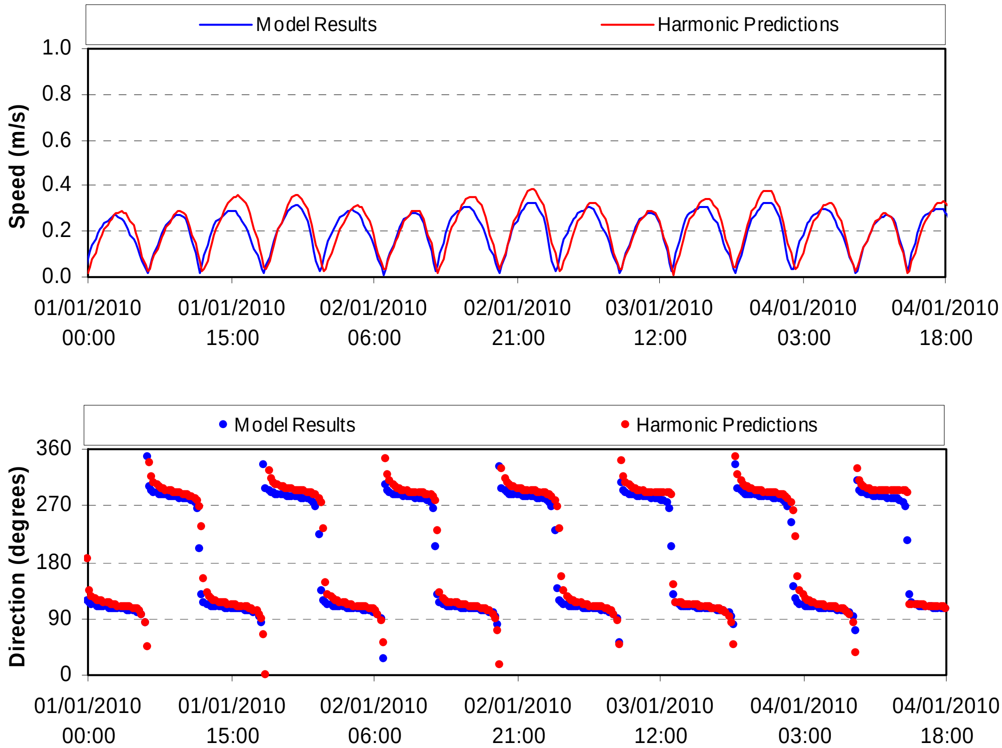


Figure C- 23: b0008653, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

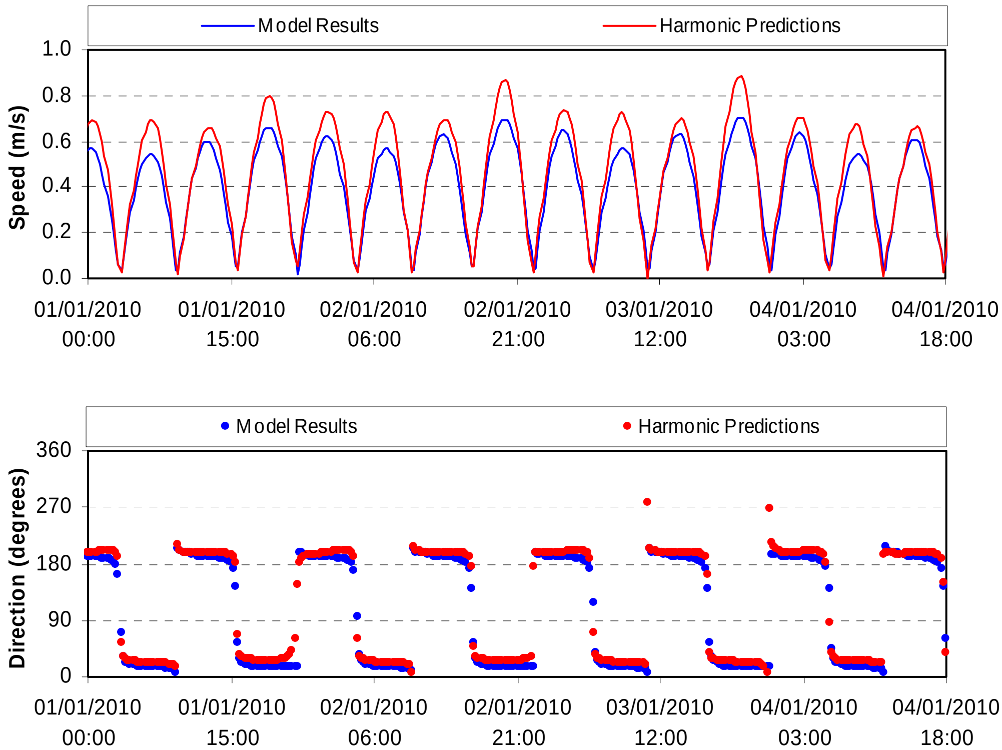
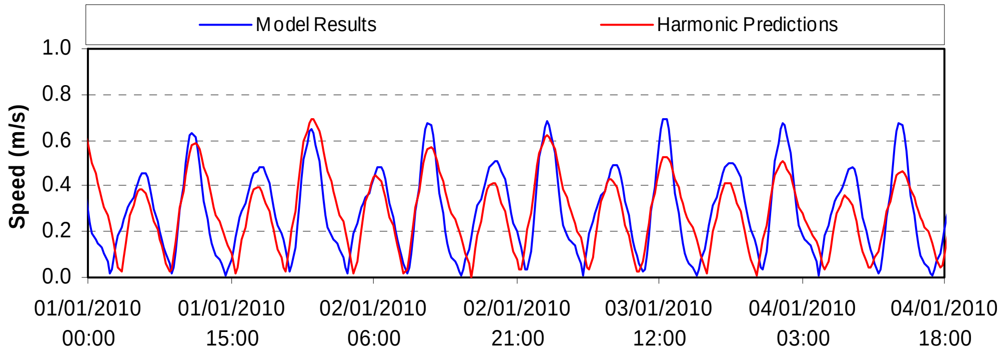


Figure C- 24: b0011359, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data



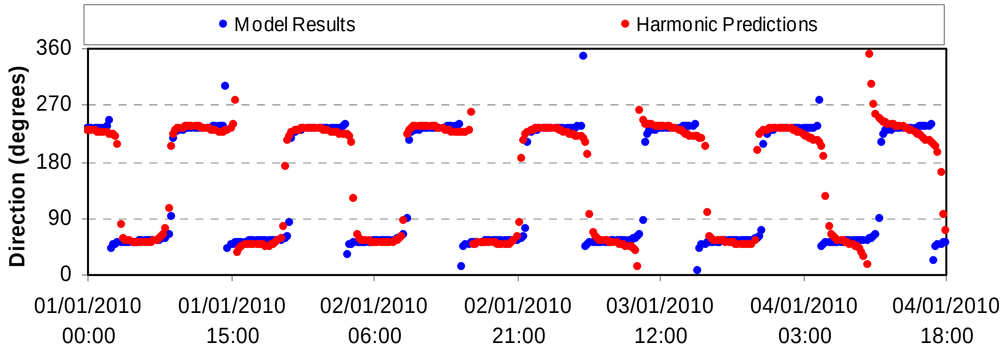
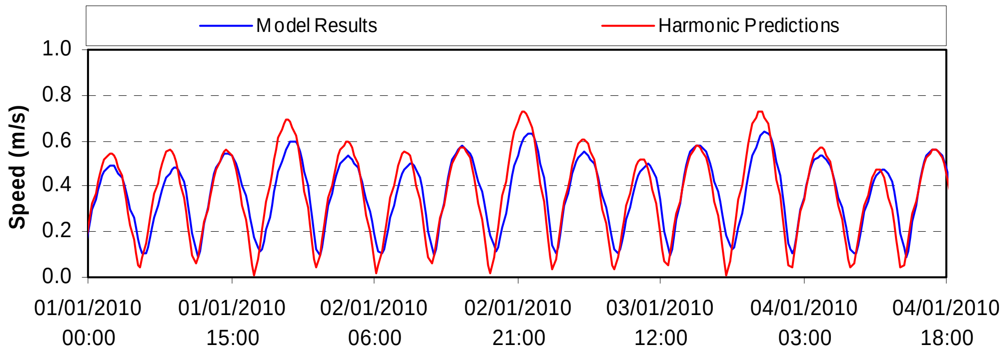


Figure C- 25: b0024978, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data



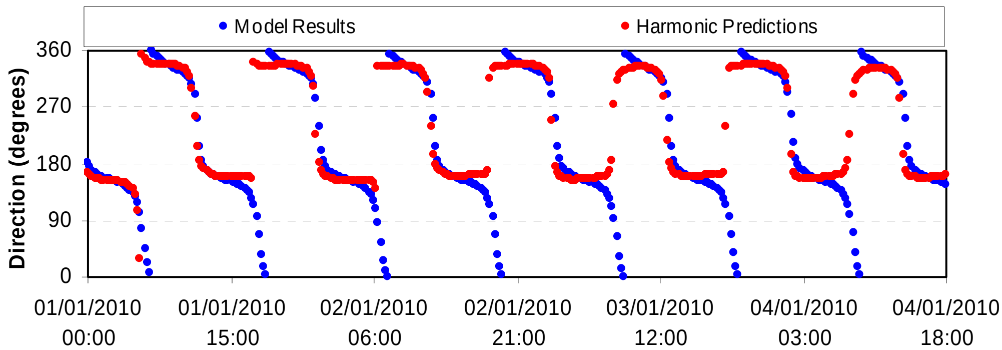
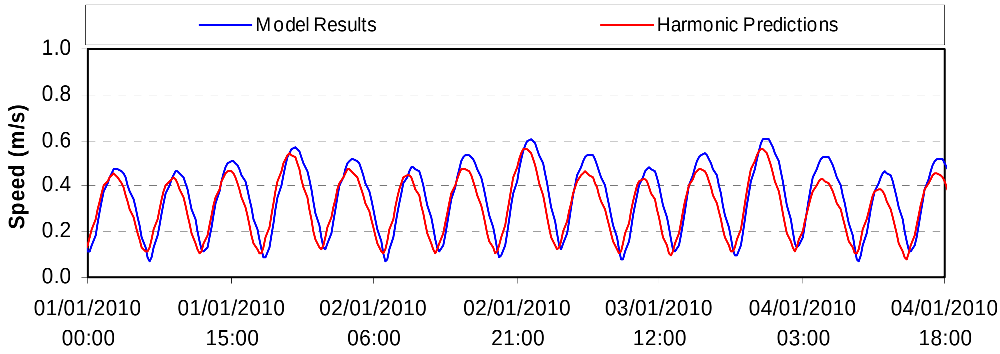


Figure C- 26: b0025017, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data



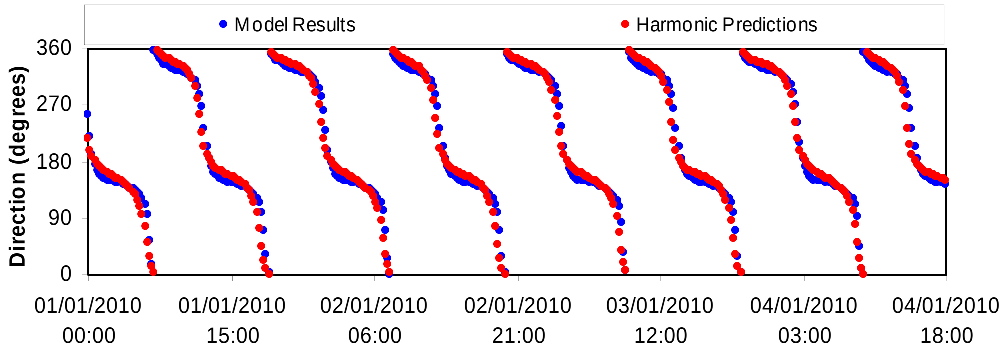
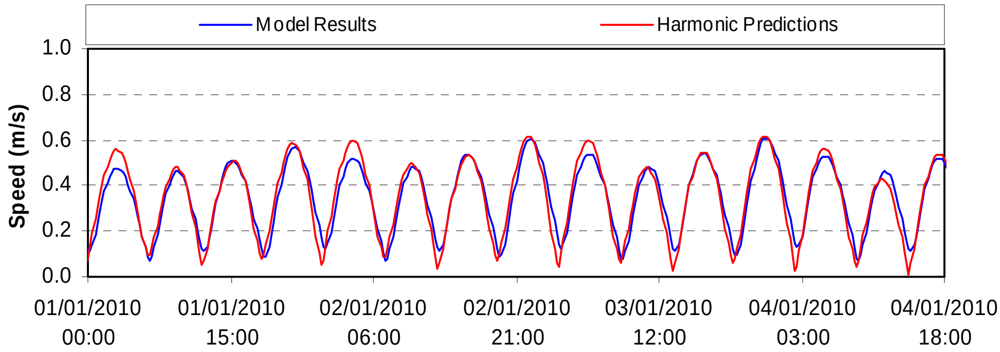


Figure C- 27: b0025030, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data



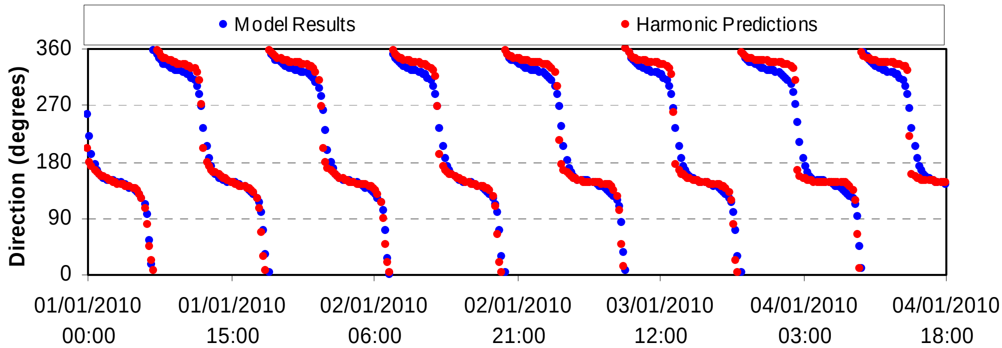


Figure C- 28: b0025042, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

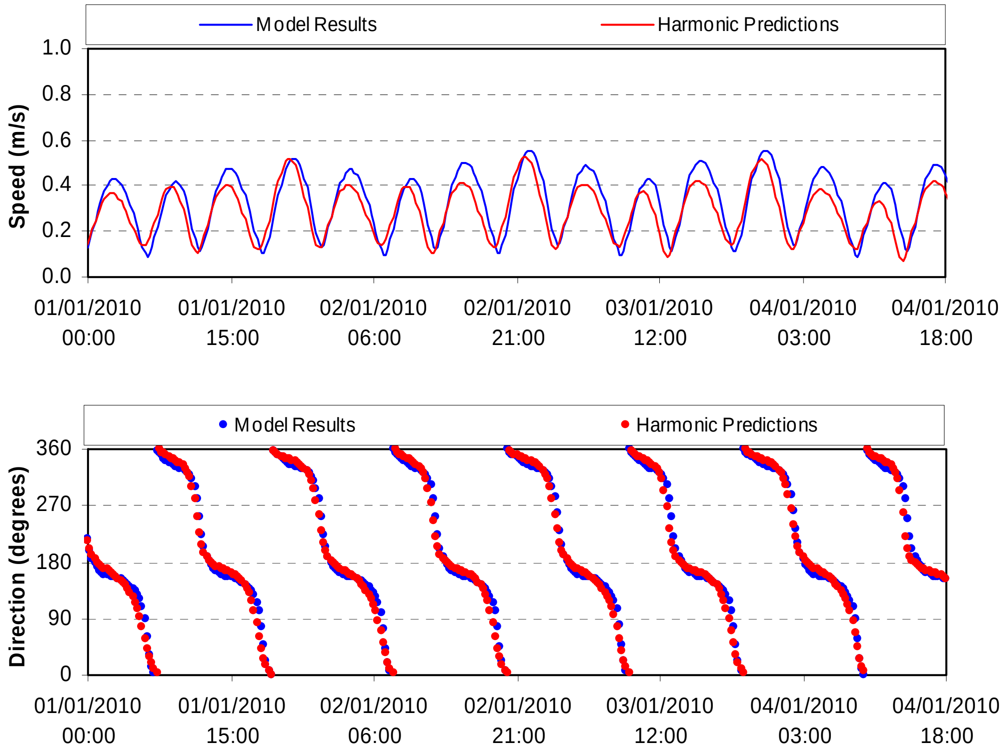


Figure C- 29: b0025054, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

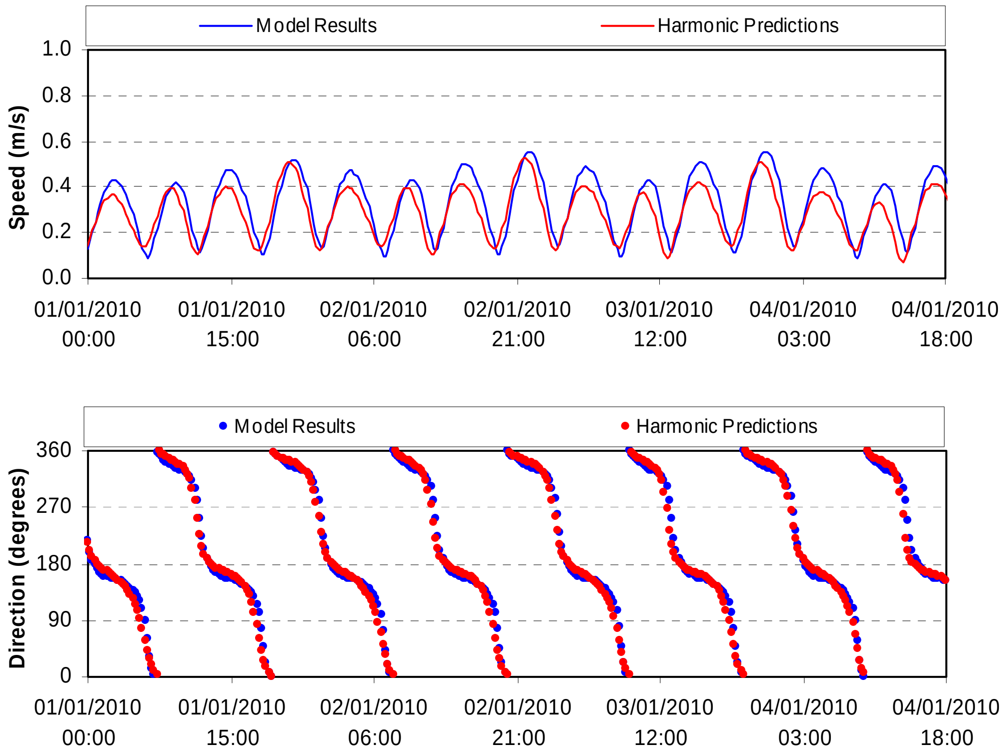


Figure C- 30: b0025110, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

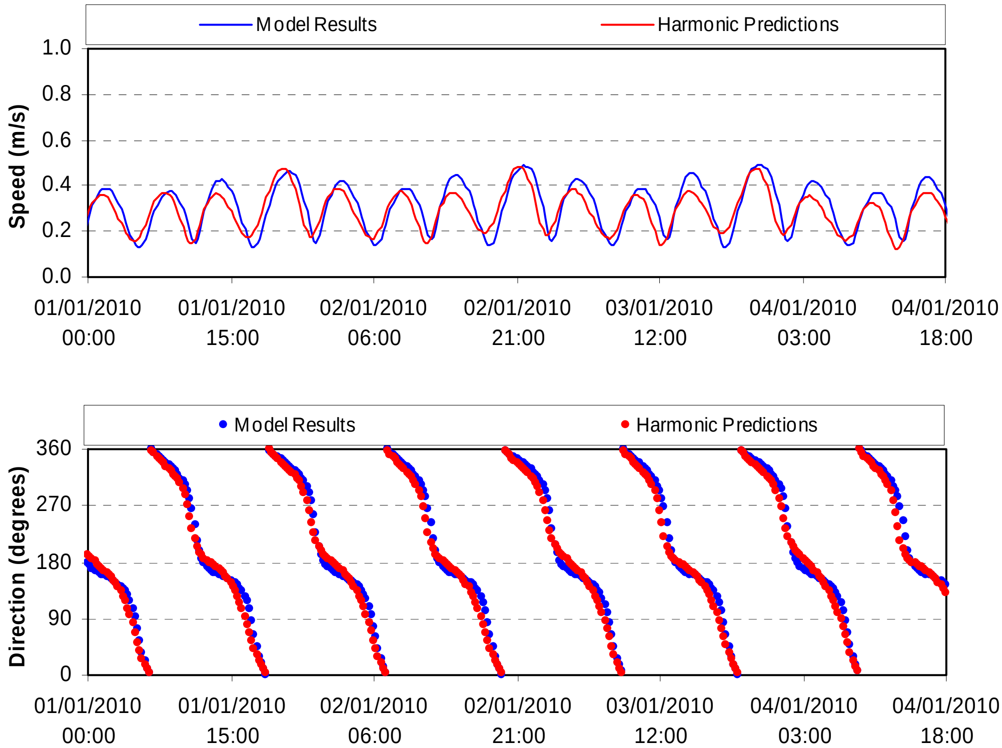


Figure C- 31: b0025195, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

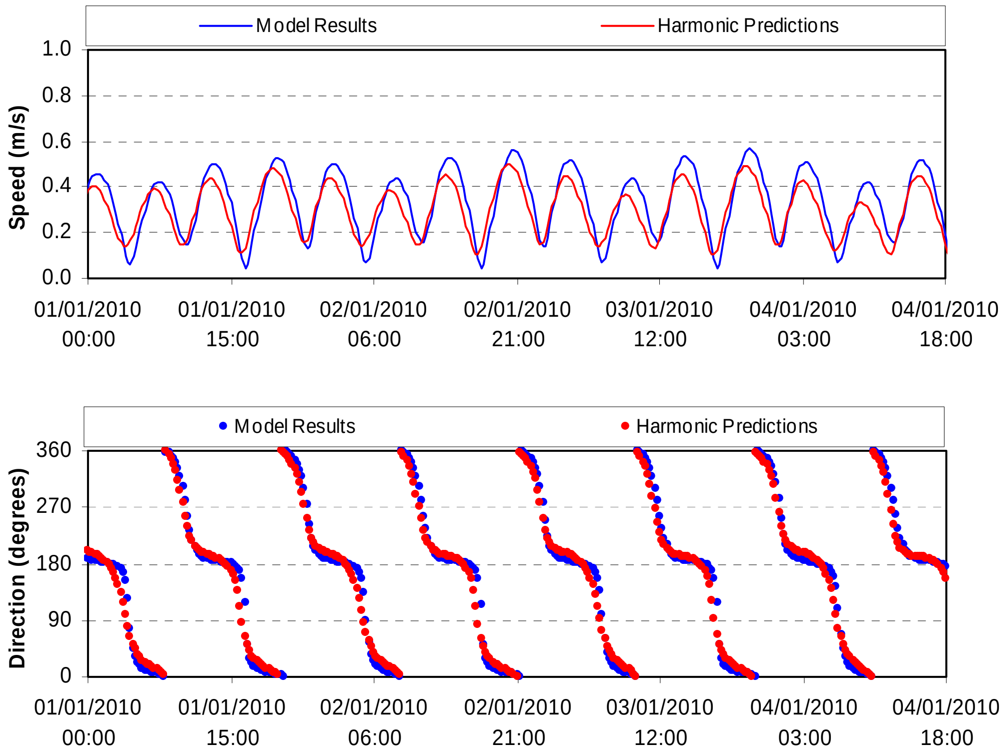


Figure C- 32: b0426990, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

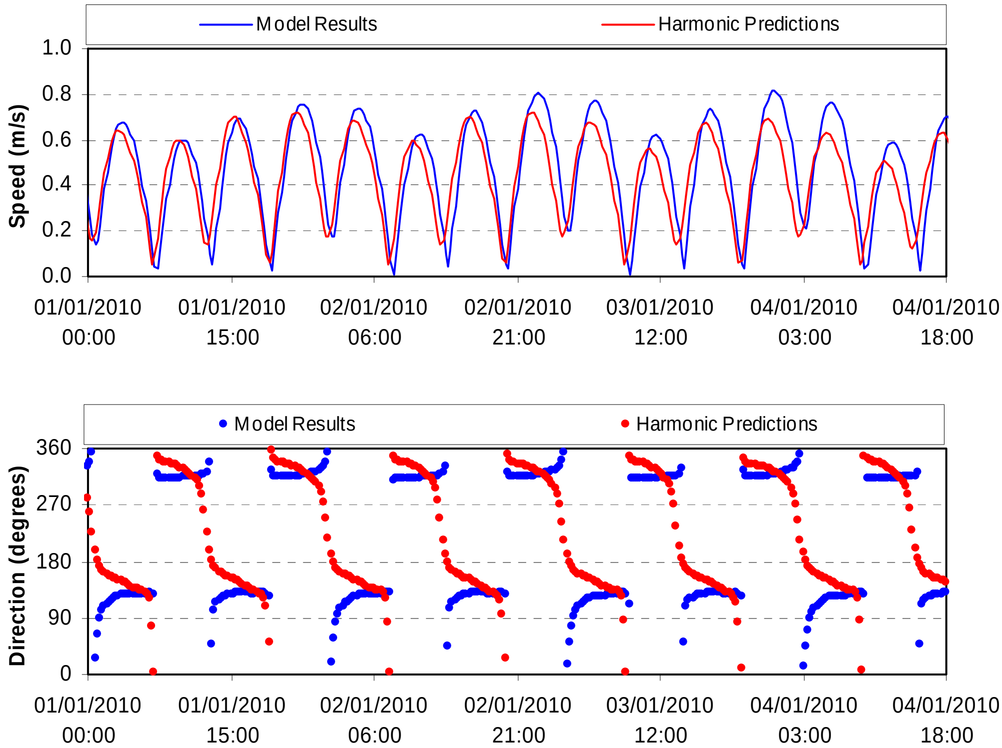


Figure C- 33: b0431992, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

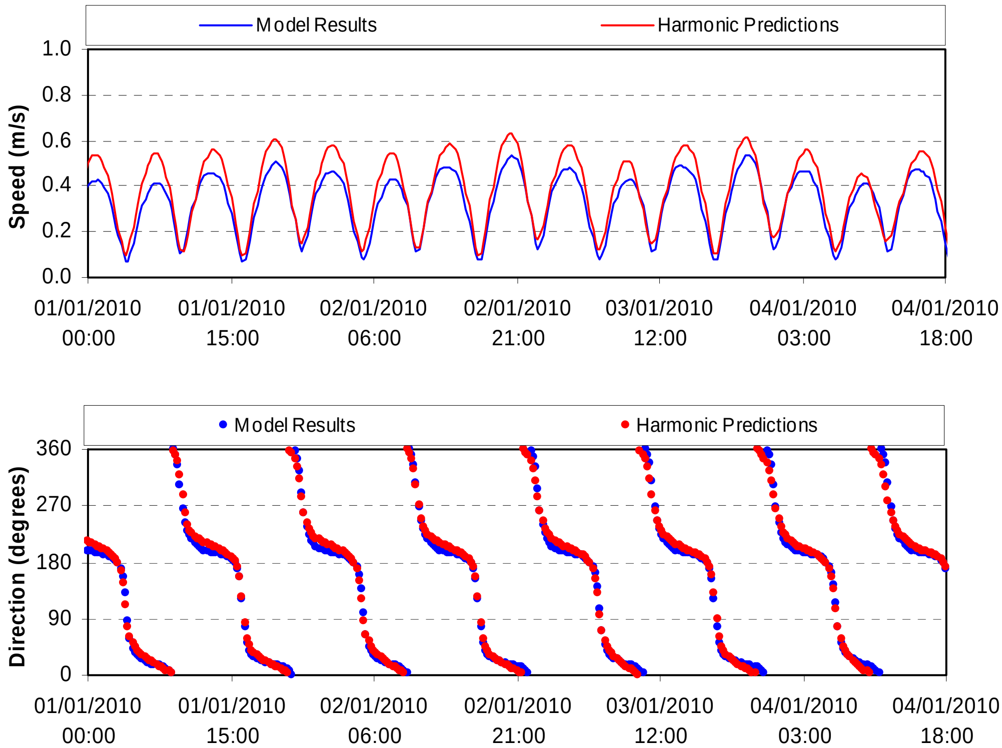


Figure C- 34: b0432135, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

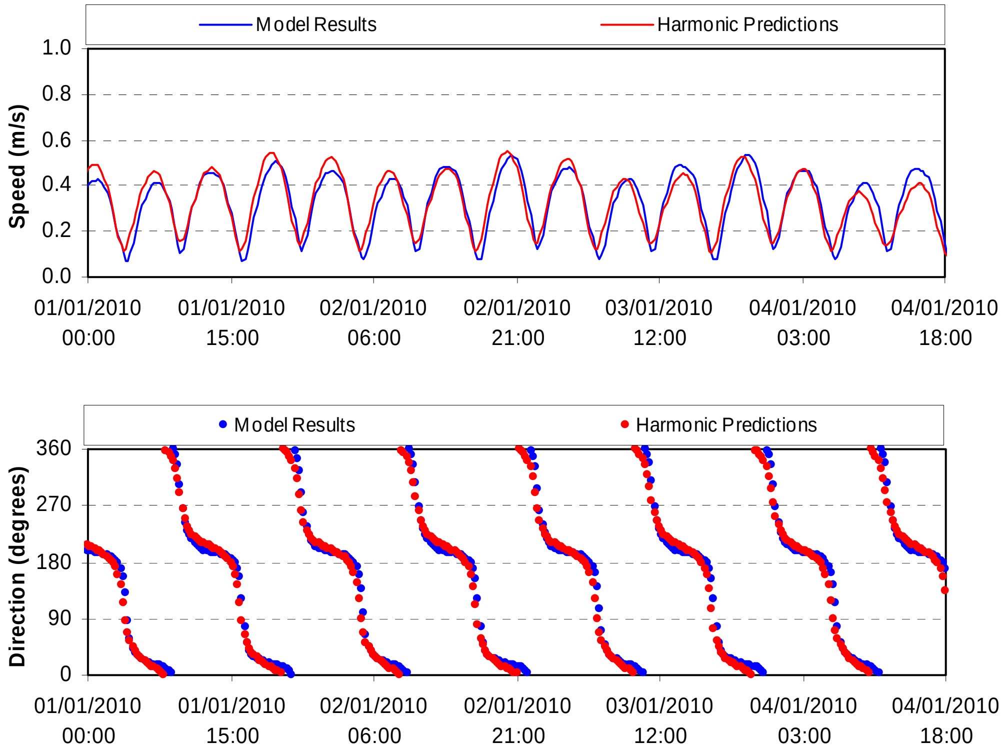


Figure C- 35: b0432264, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

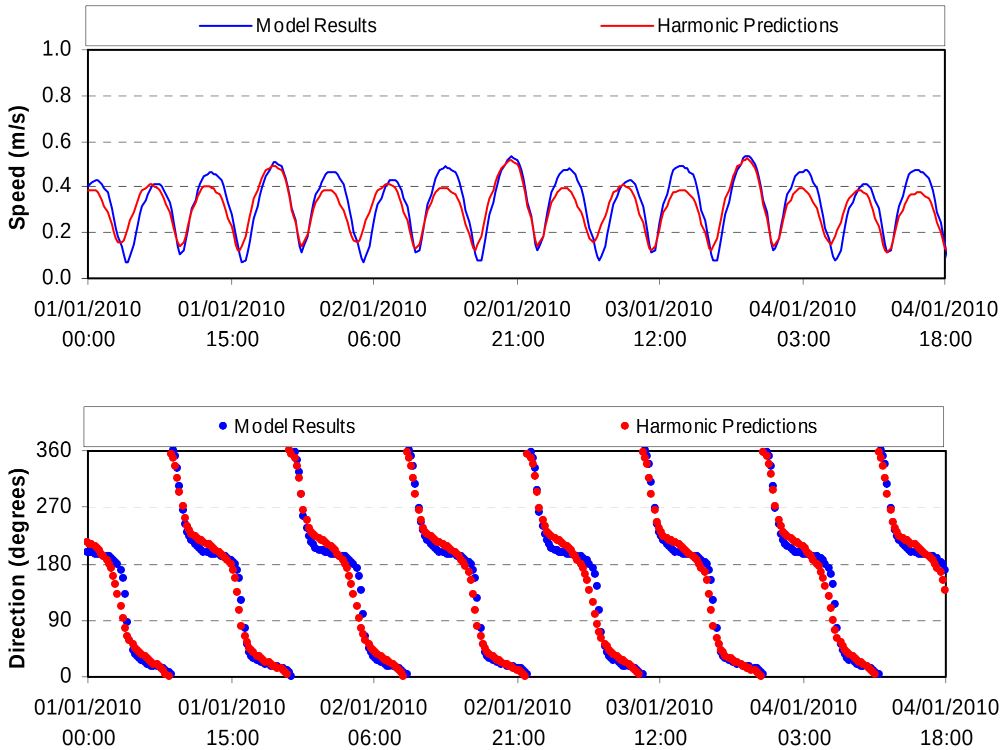
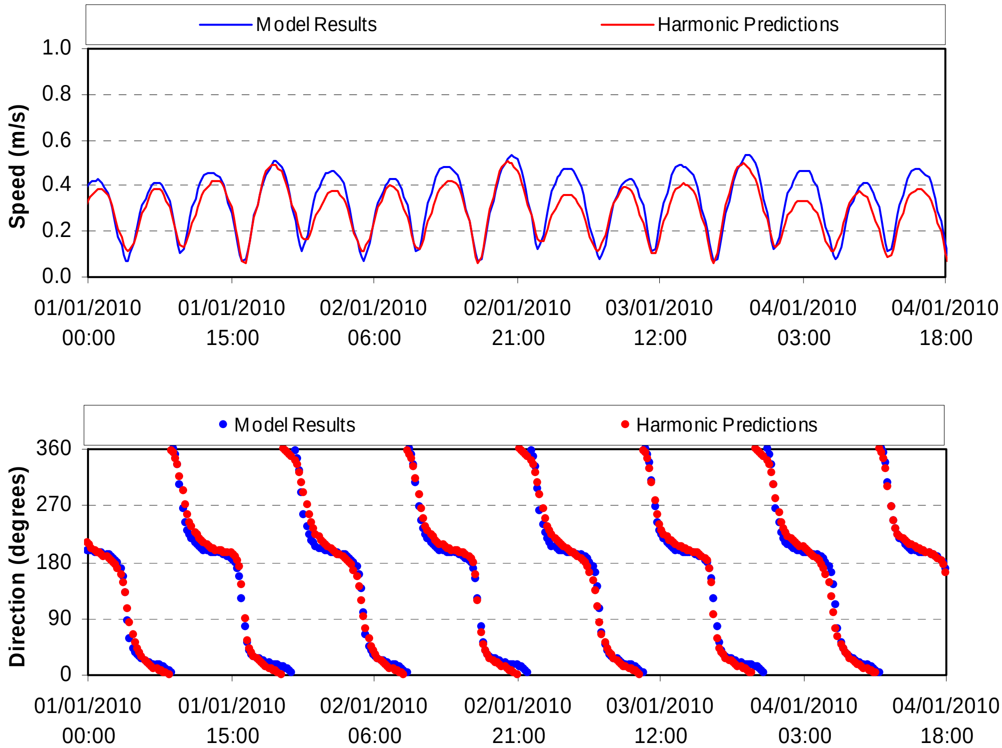


Figure C- 36: b0432830, BODC Current Meter Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data



Appendix D Hydrodynamic Model Validation Results

Figure D- 1: Forth Array ADCP Modelled Tidal Elevations (m) against Predicted Field Data

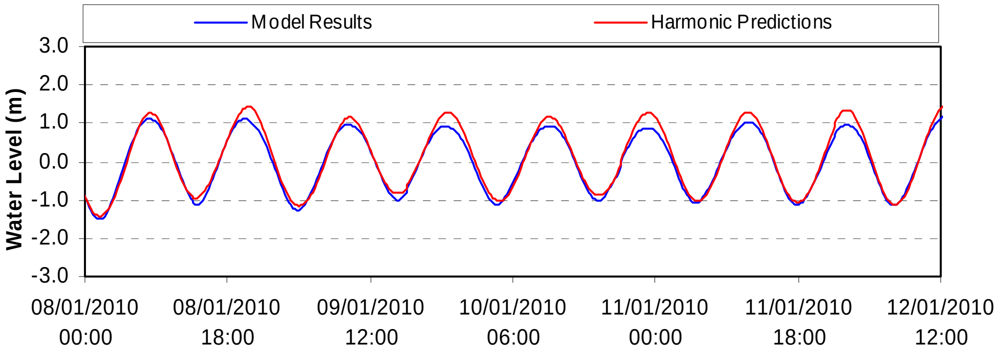


Figure D- 2: Neart na Gaoithe ADCP Modelled Tidal Elevations (m) against Predicted Field Data

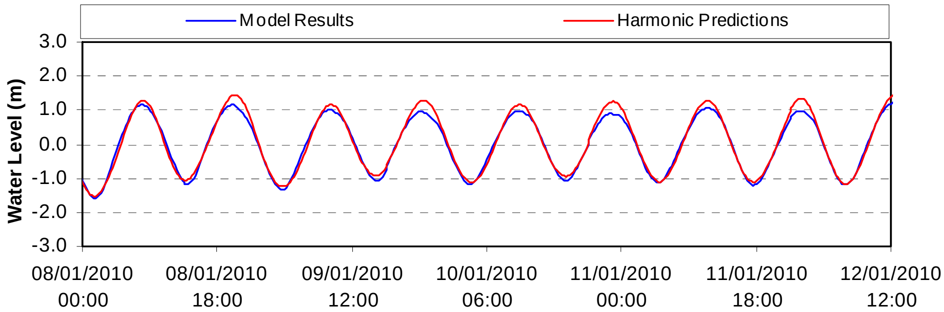


Figure D- 3: Inch Cape ADCP Modelled Tidal Elevations (m) against Predicted Field Data

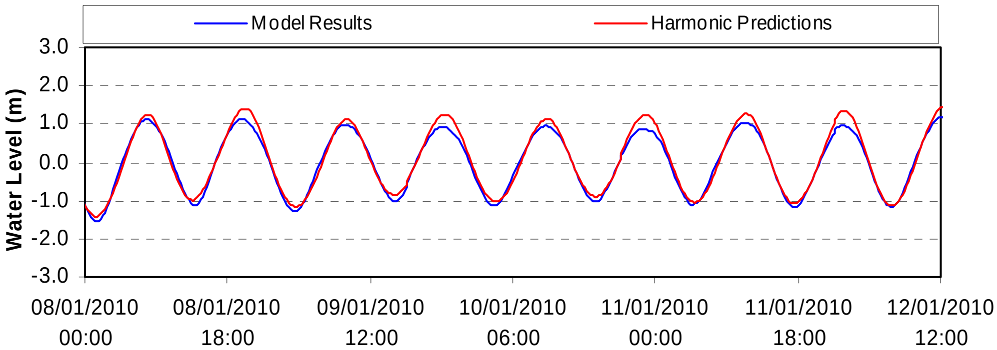


Figure D- 4: North Offshore ADCP Modelled Tidal Elevations (m) against Predicted Field Data

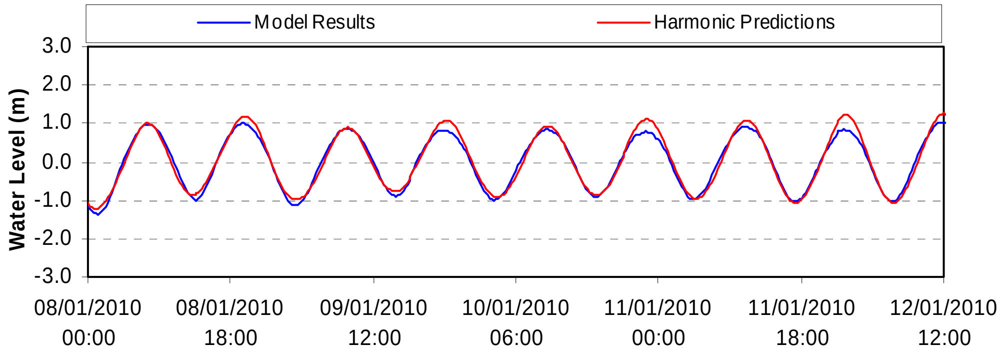


Figure D- 5: Torness Point Scottish Water ADCP Modelled Tidal Elevations (m) against Predicted Field Data

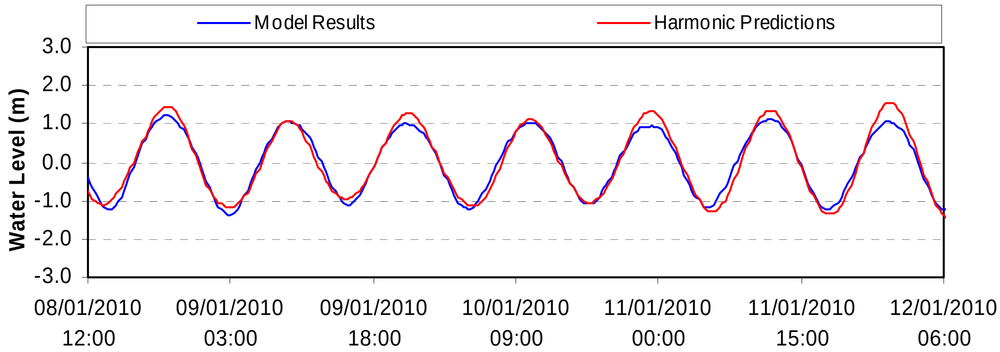


Figure D- 6 Newport-on-Tay SEPA Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

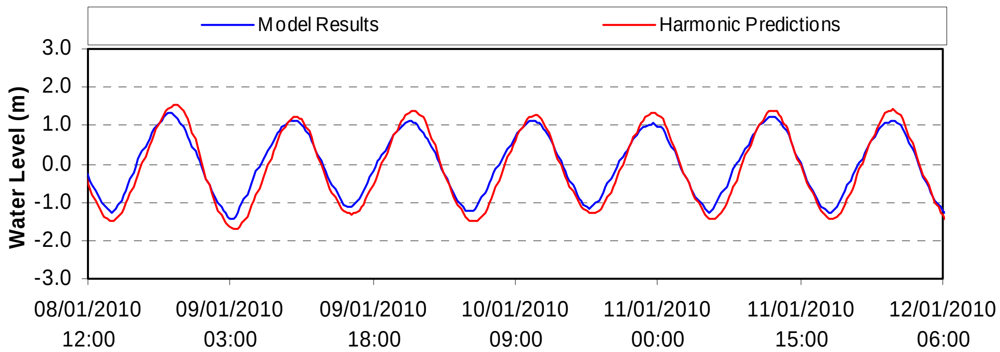


Figure D- 7 Leith POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

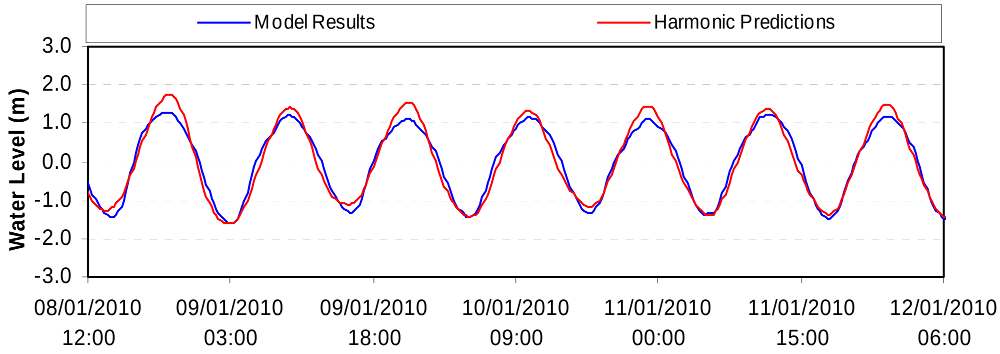


Figure D- 8 North Shields POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

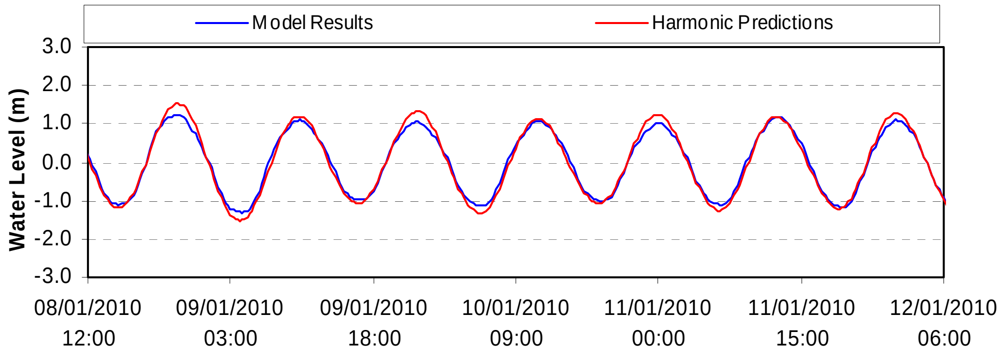


Figure D- 9 Whitby POL Tide Gauge Modelled Tidal Elevations (m) against Predicted Field Data

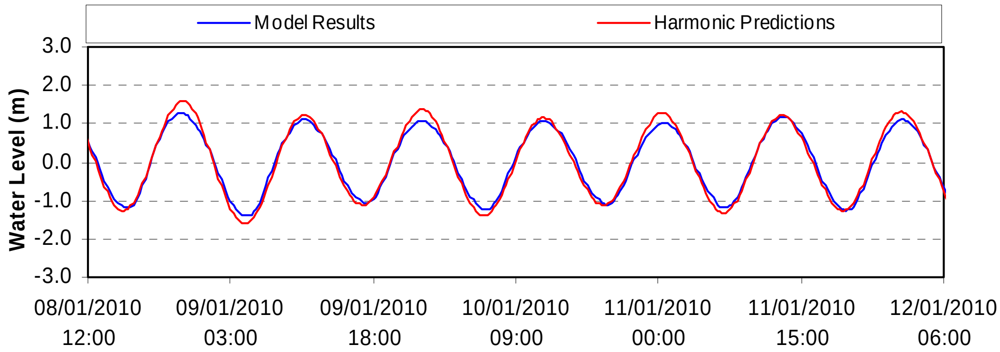


Figure D- 10 Stonehaven Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

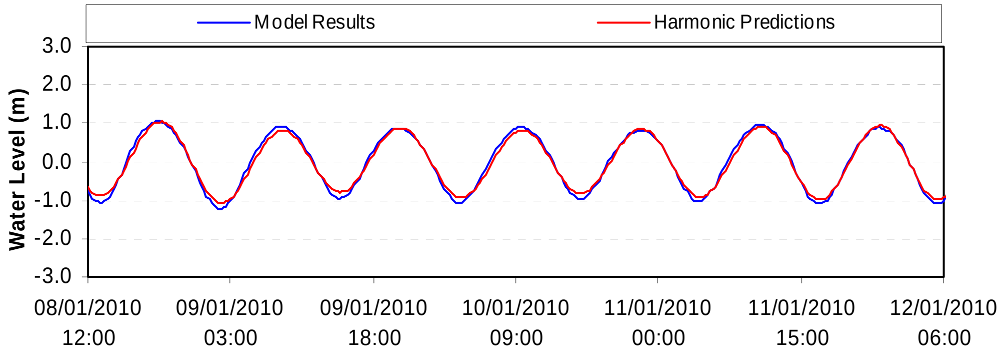


Figure D- 11 Montrose Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

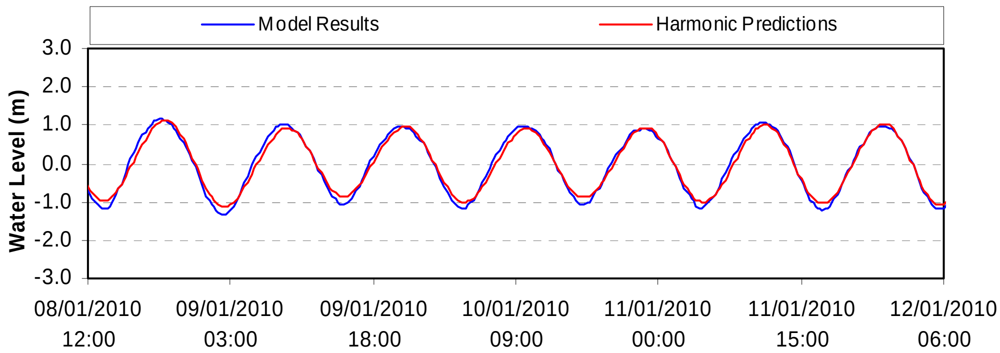


Figure D- 12 Arbroath Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

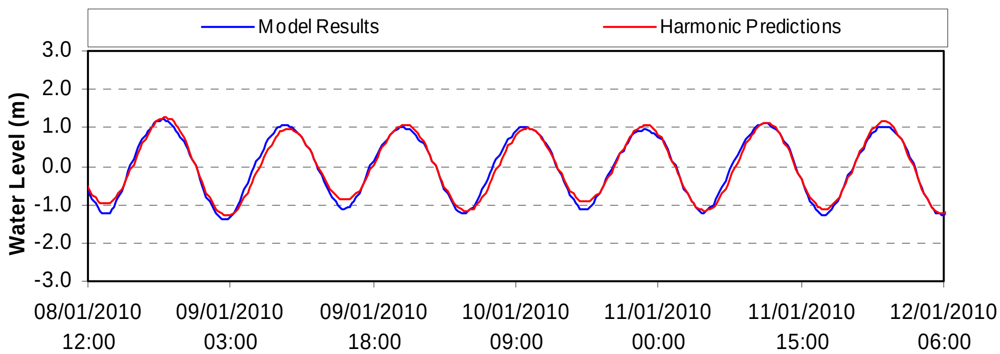


Figure D- 13 Anstruther Easter Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

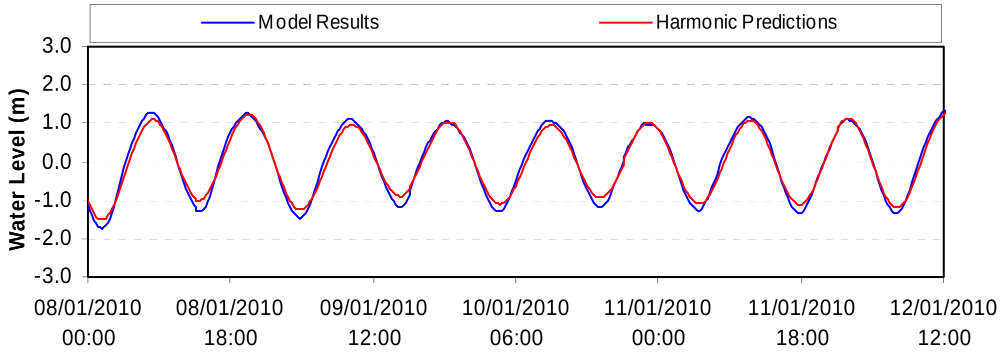


Figure D- 14 Fidra Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

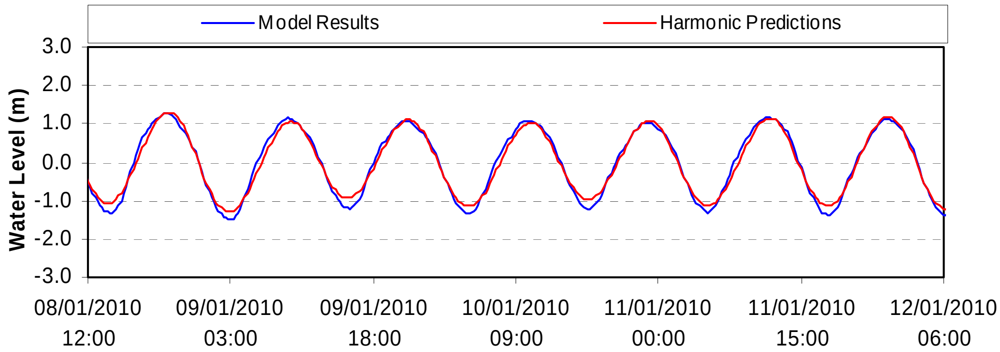


Figure D- 15 Dunbar Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

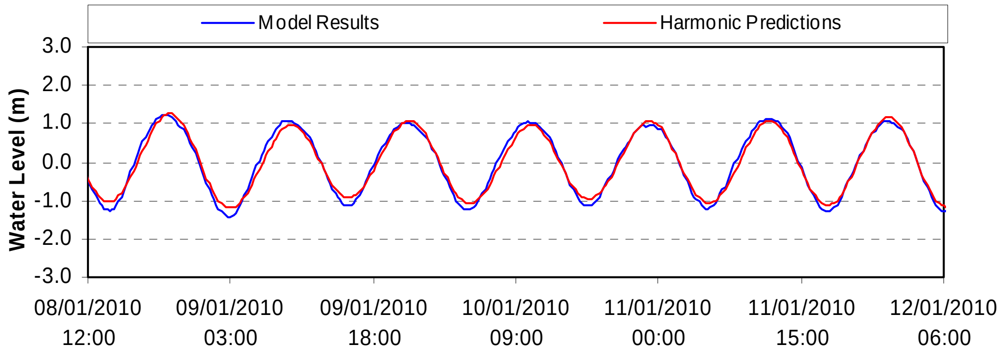


Figure D- 16 Amble Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

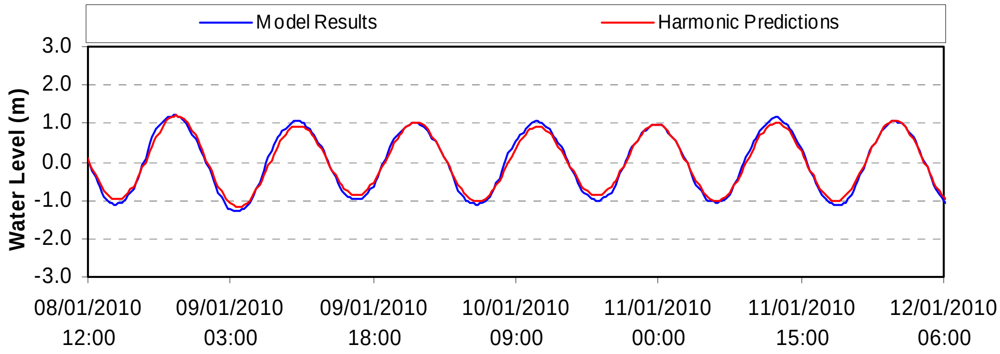


Figure D- 17 Hartlepool Admiralty Tide Tables Modelled Tidal Elevations (m) against Predicted Field Data

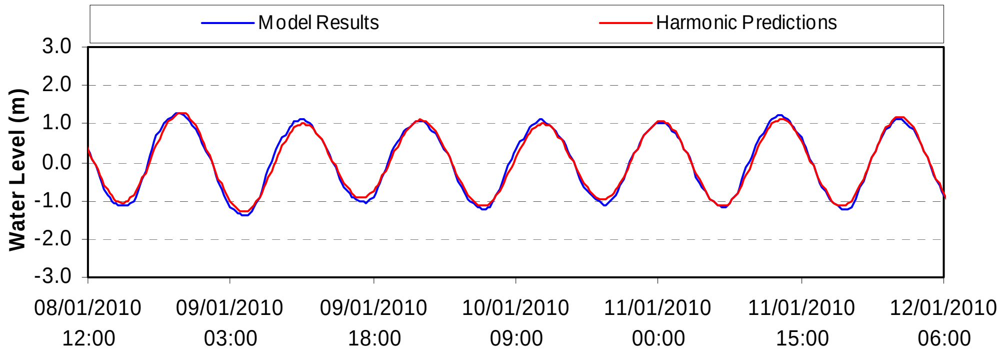


Figure D- 18: Forth Array ADCP Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

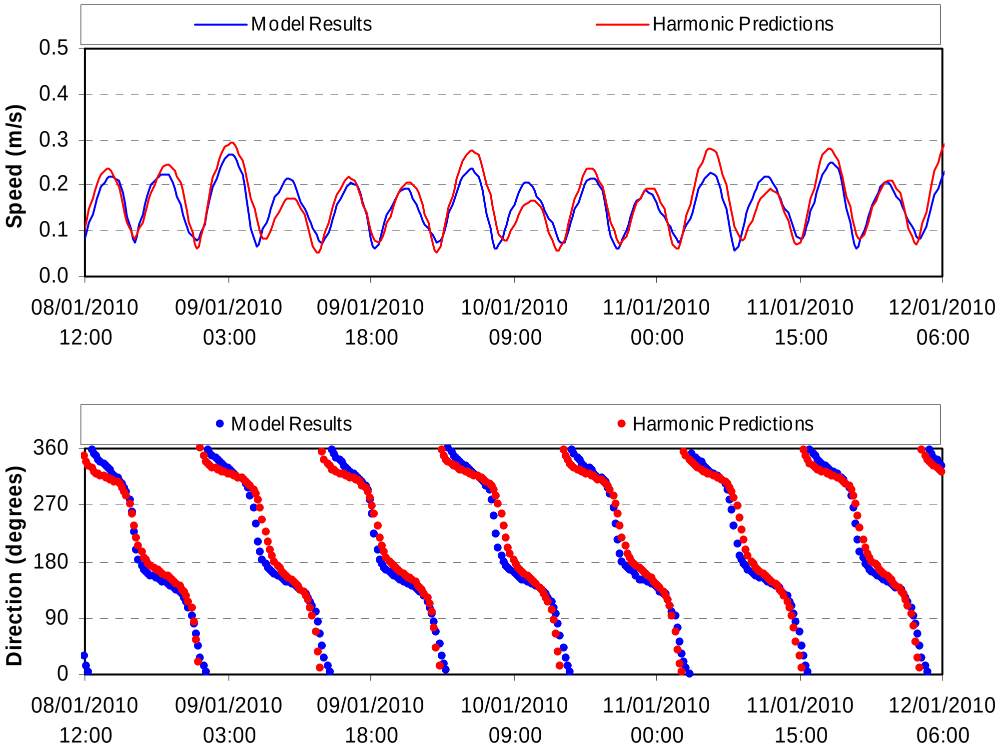


Figure D- 19 Neart na Gaoithe ADCP Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

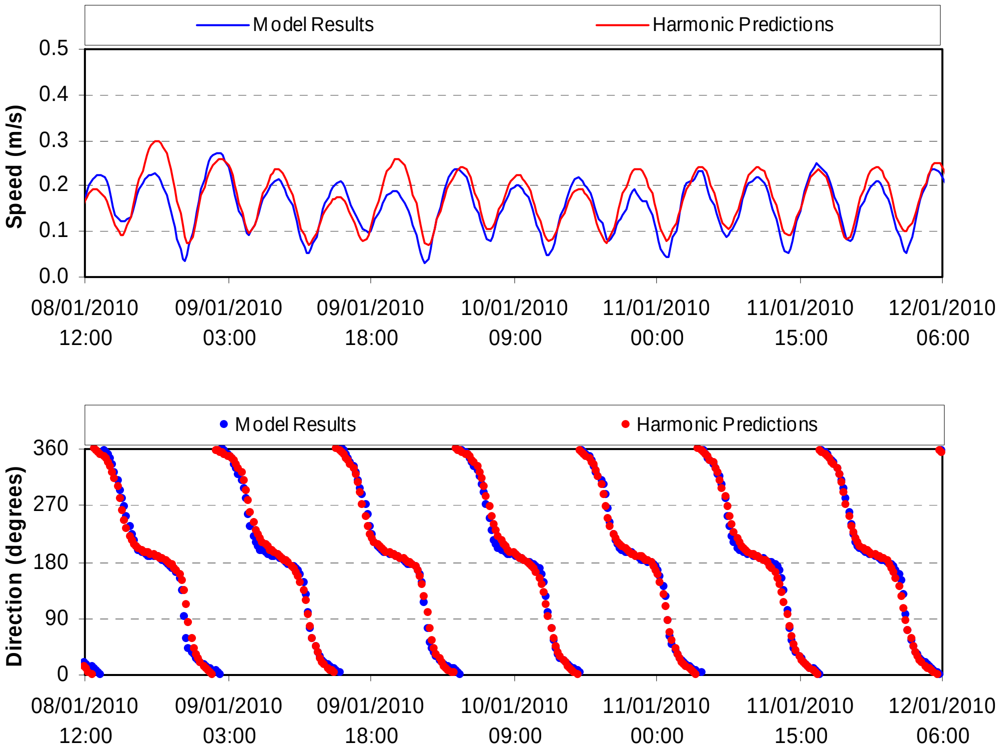


Figure D- 20: Inch Cape ADCP Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

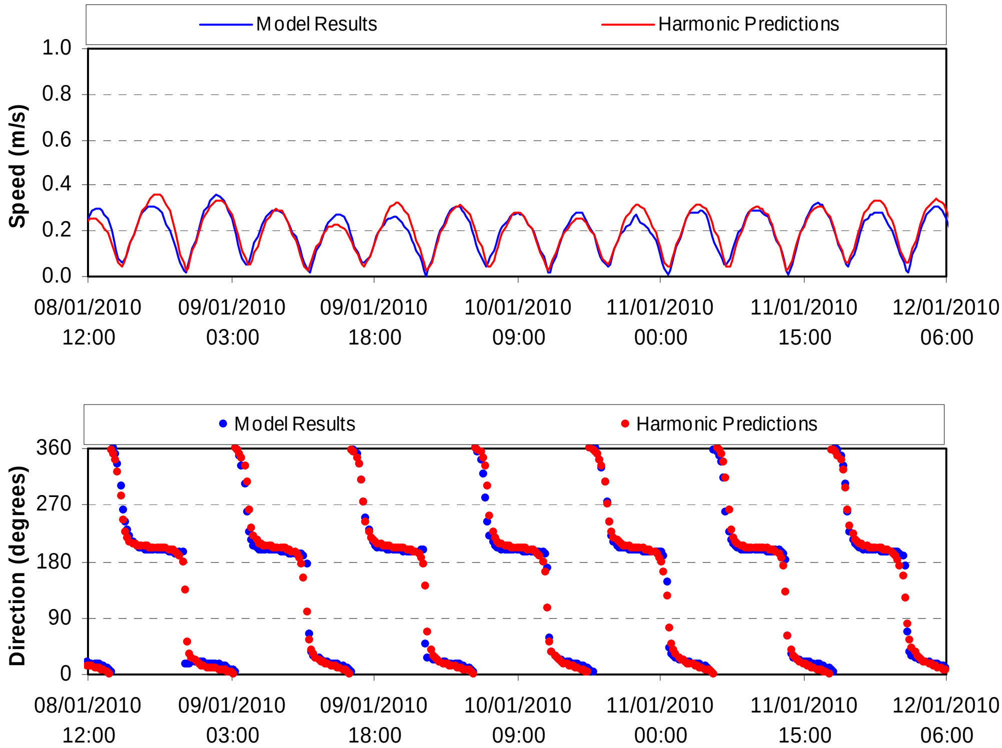


Figure D- 21: North Offshore ADCP Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

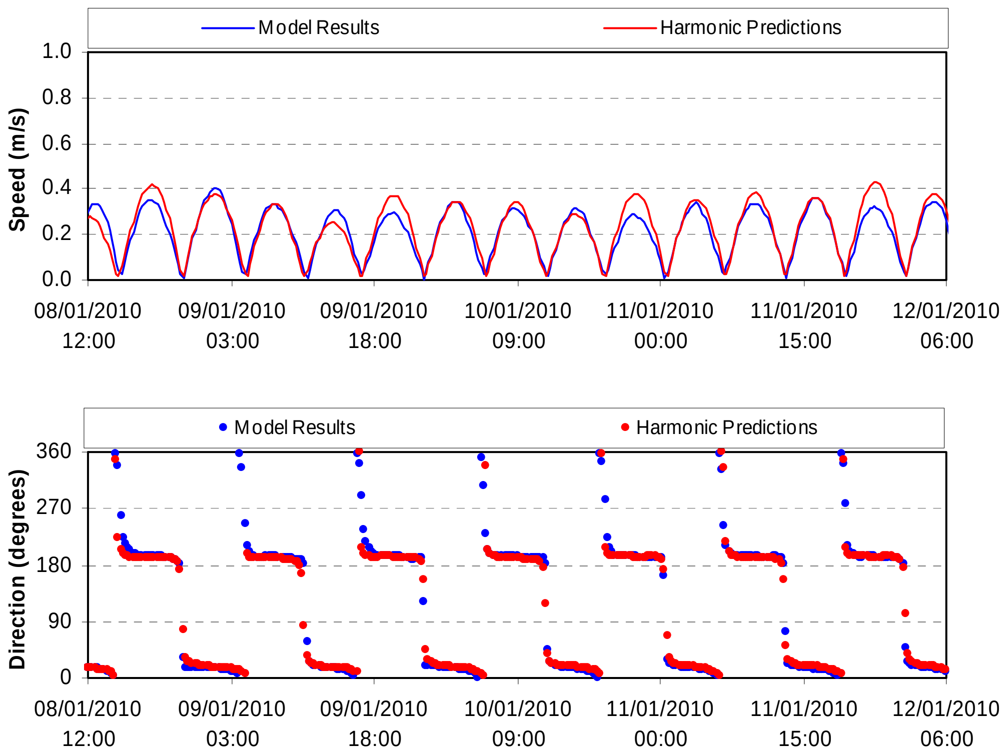


Figure D- 22 Torness Point, Scottish Water ADCP Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

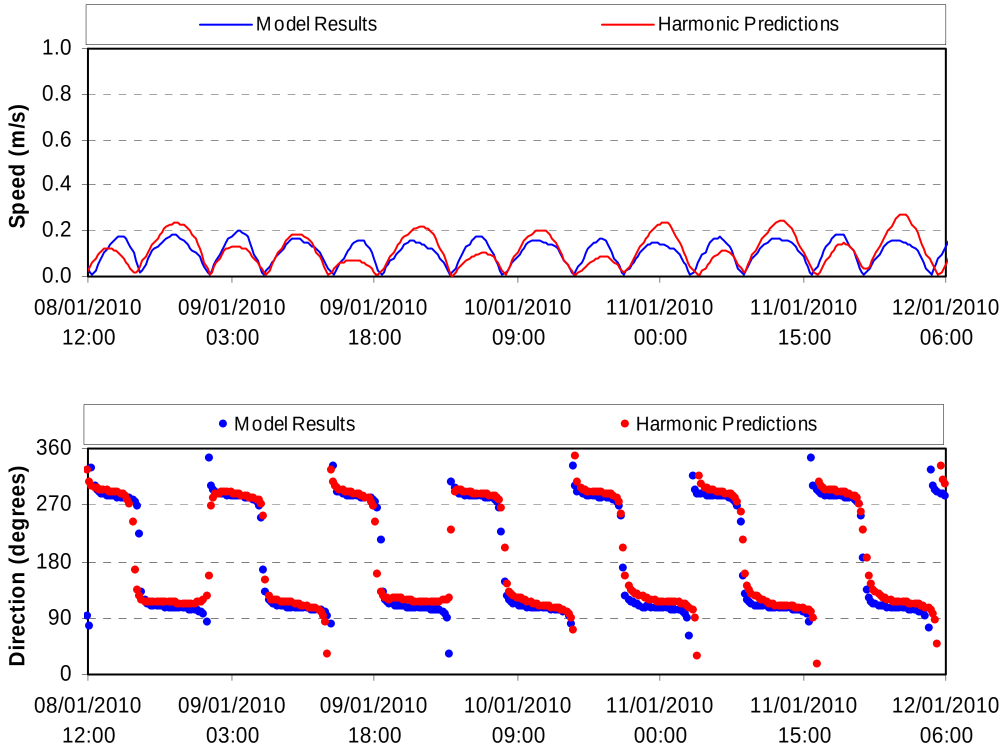


Figure D- 23: b0008653, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

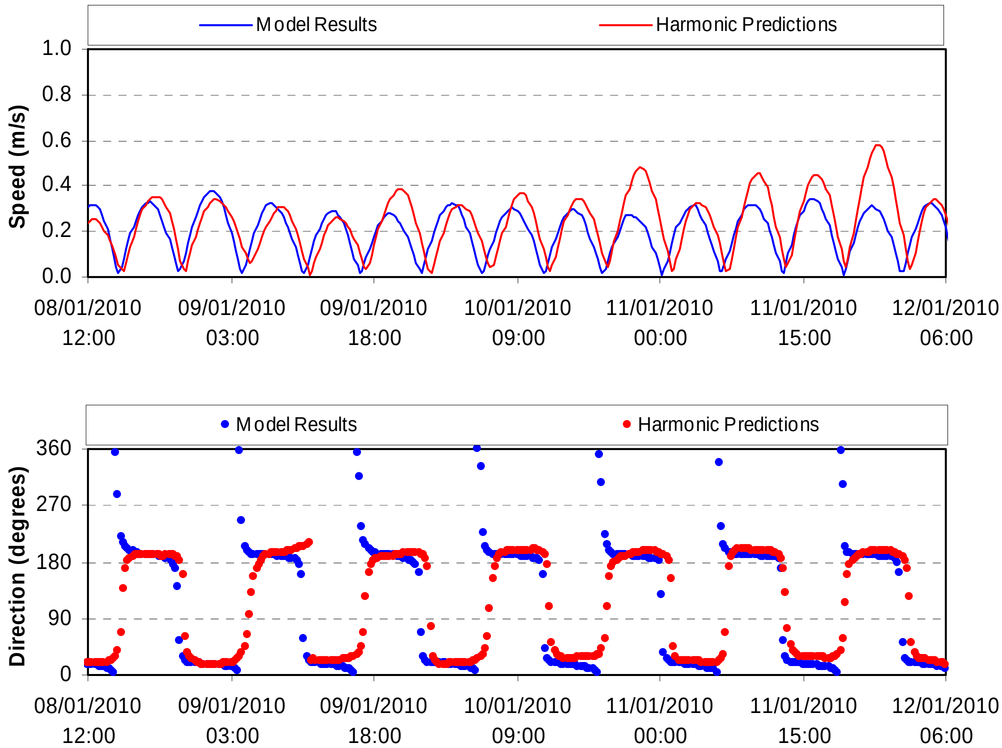


Figure D- 24: b0011359, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

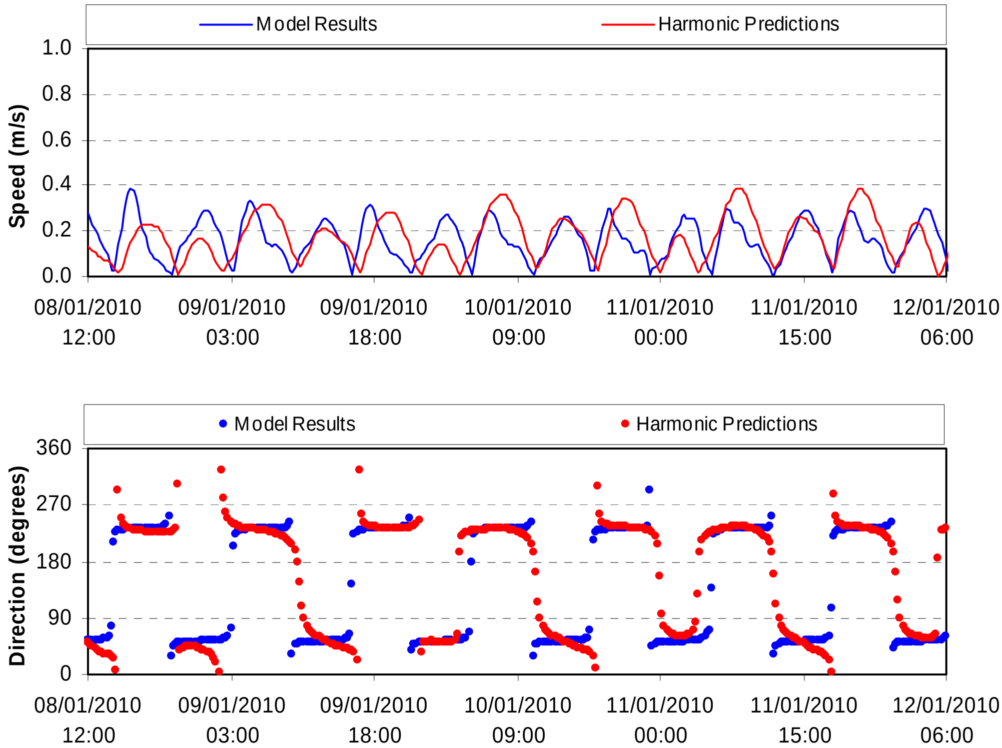


Figure D- 25: b0024978, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

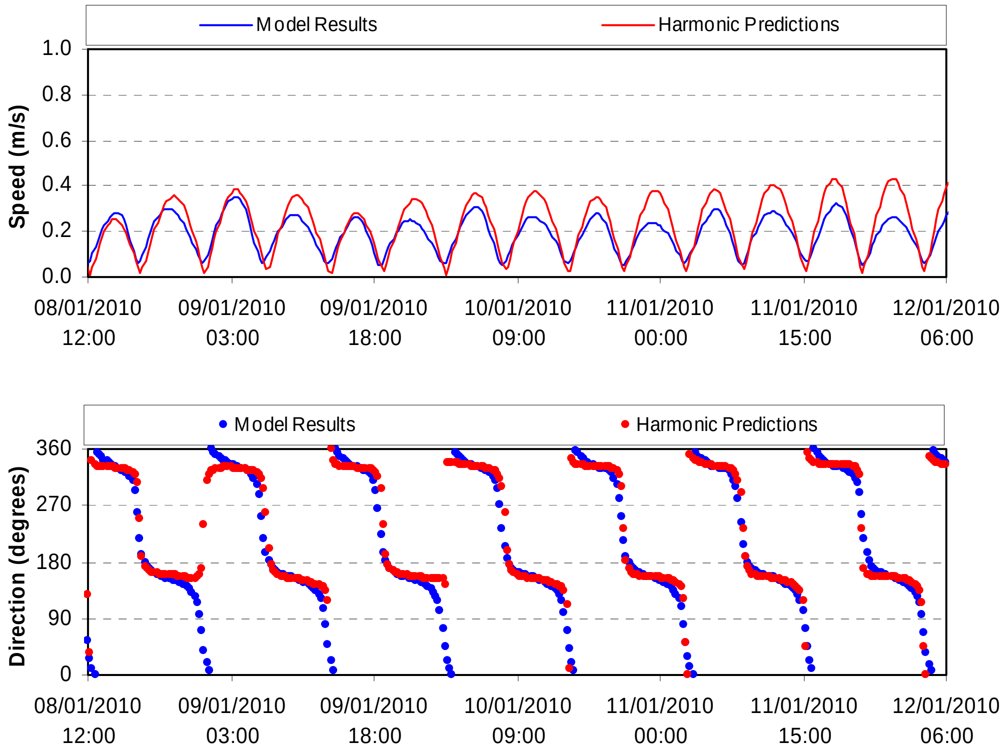


Figure D- 26 b0025017, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

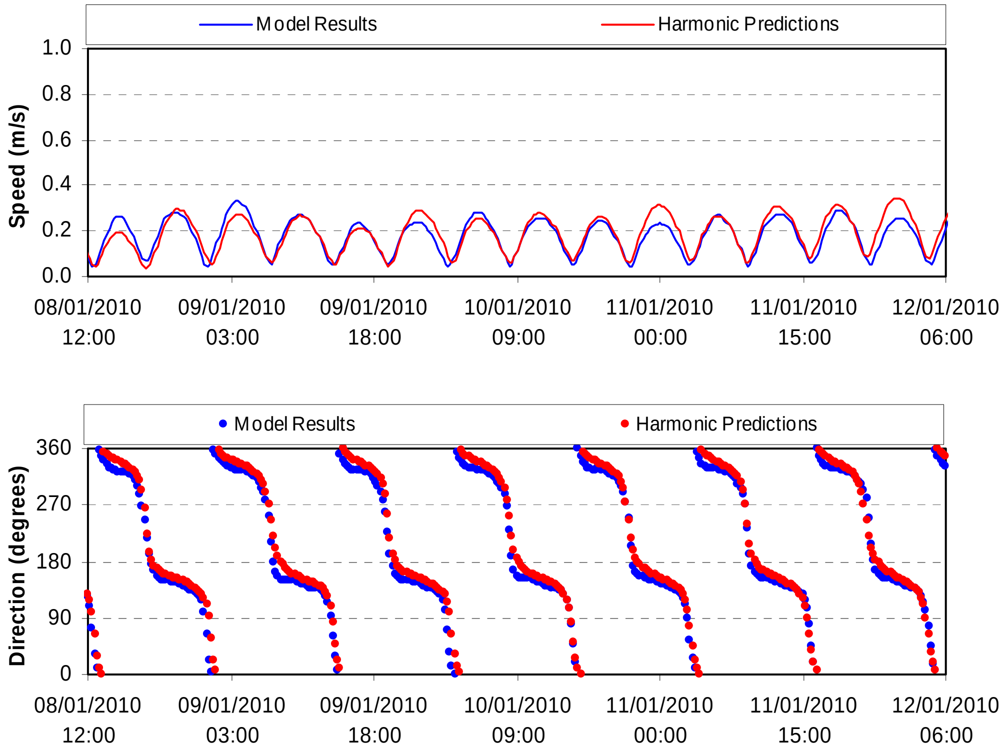


Figure D- 27: b0025030, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

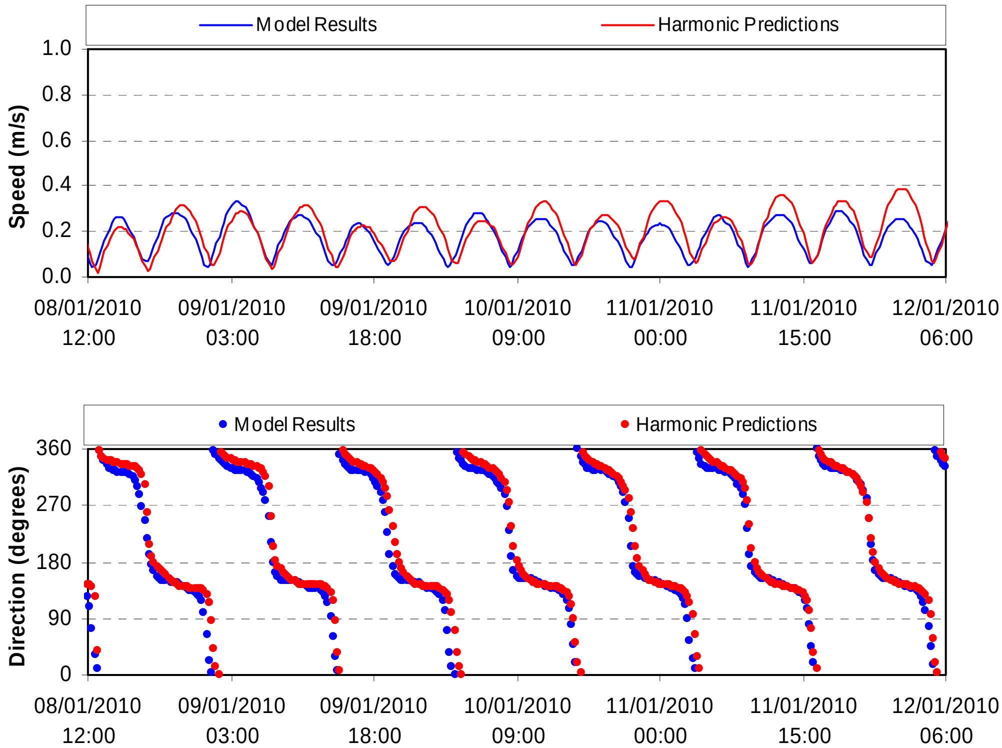


Figure D- 28: b0025042, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

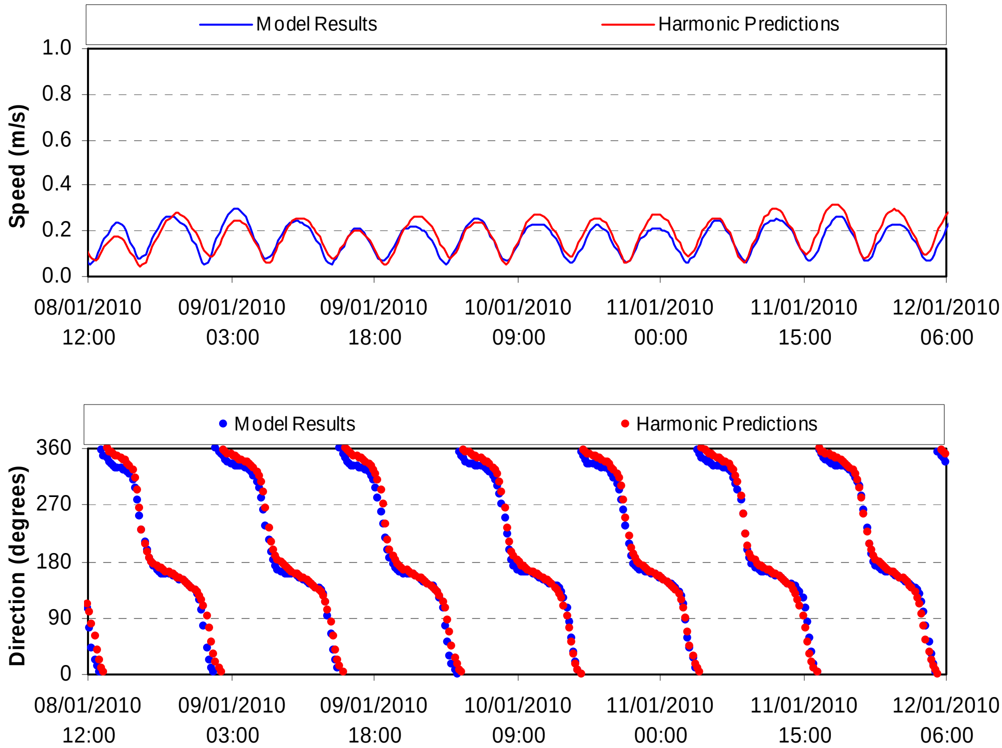


Figure D- 29: b0025054, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

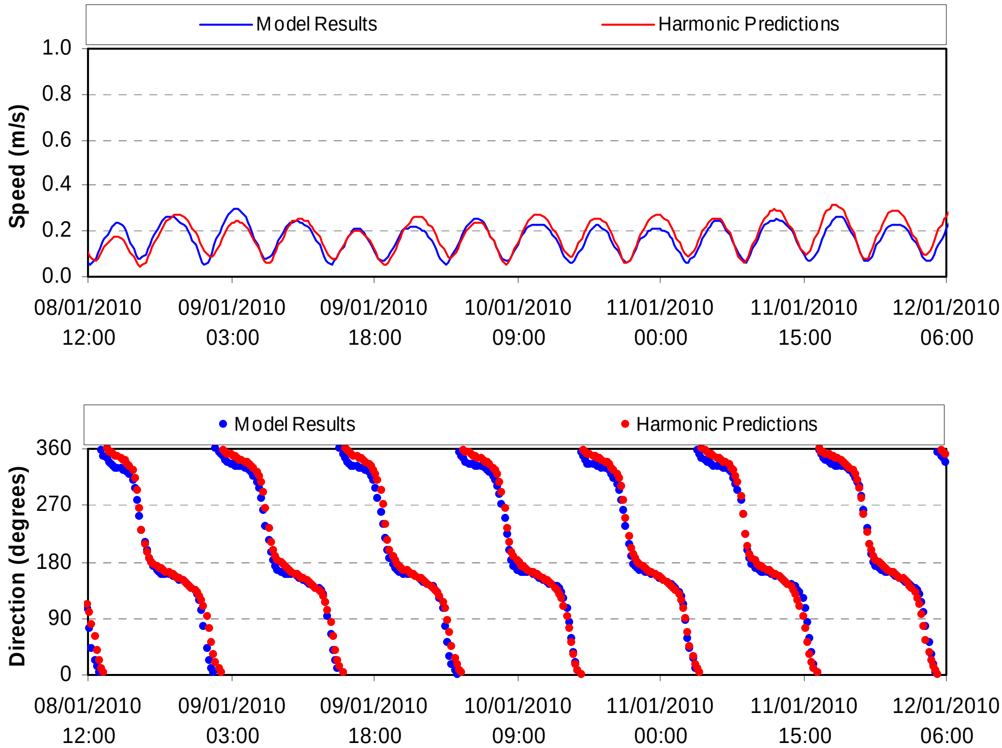


Figure D- 30: b0025110, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

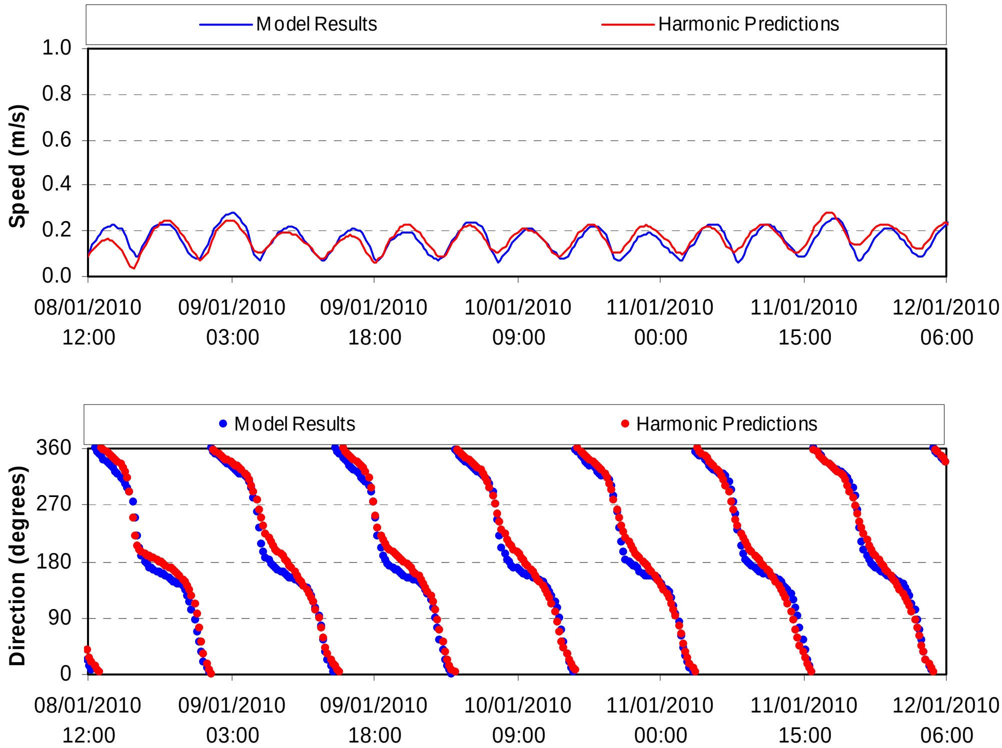


Figure D- 31: b0025195, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

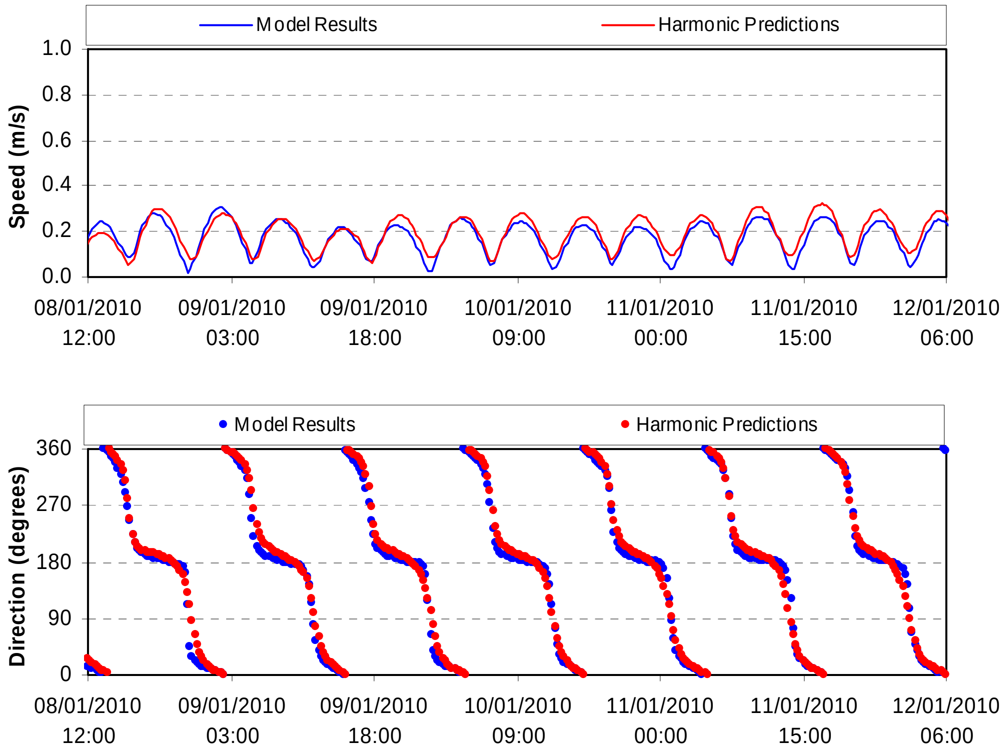


Figure D- 32: b0426990, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

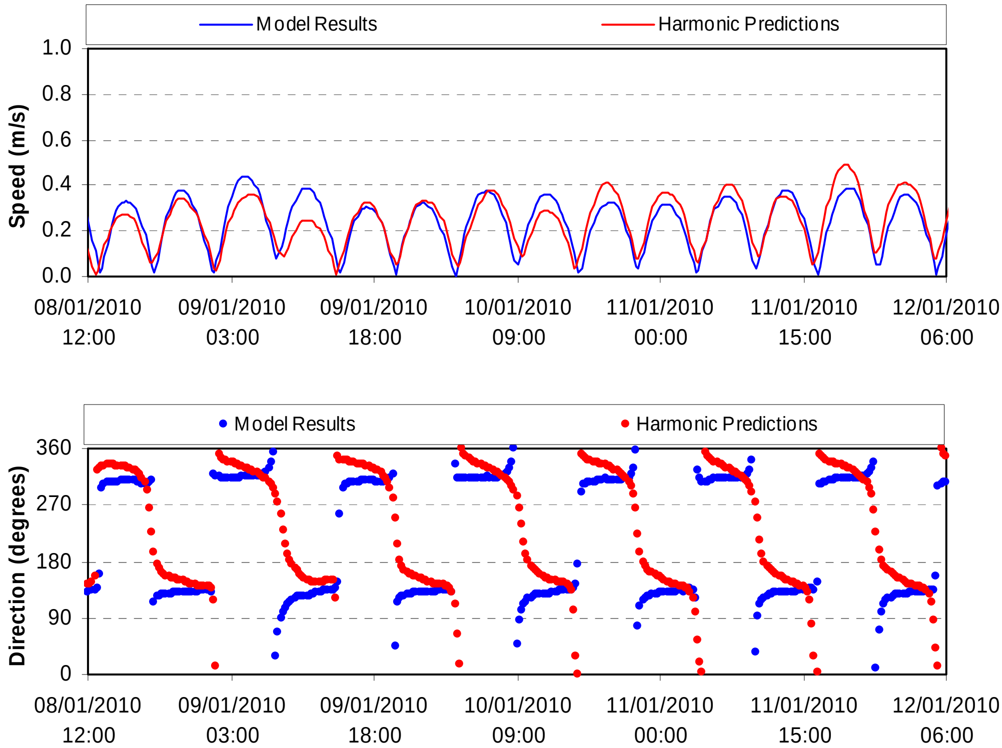


Figure D- 33: b0431992, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

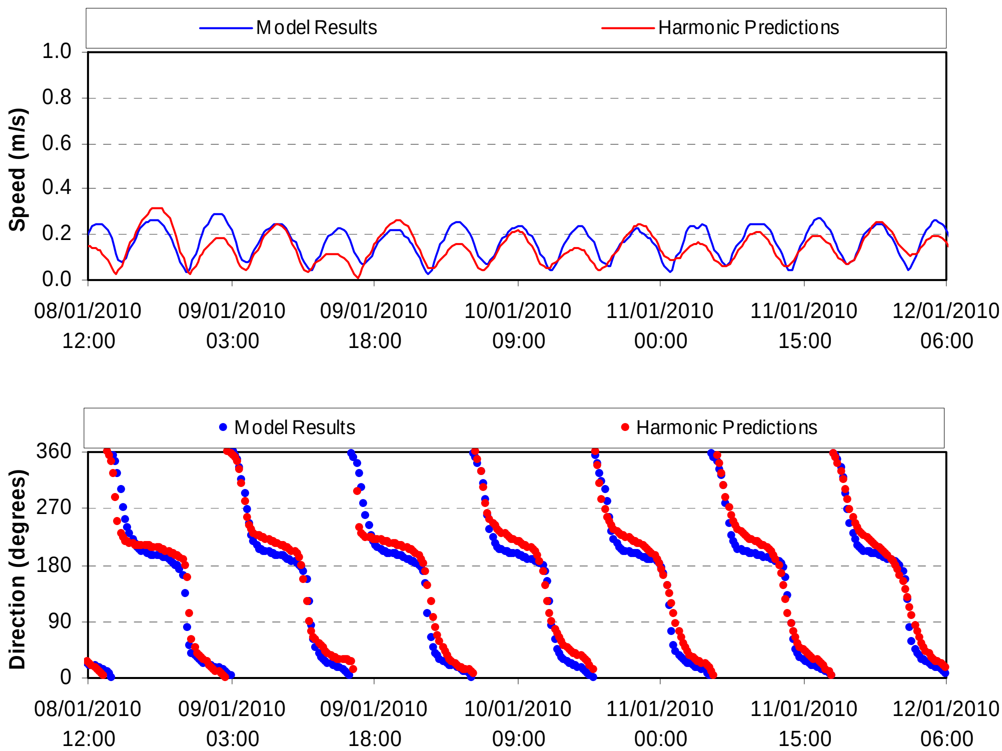


Figure D- 34: b0432135, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

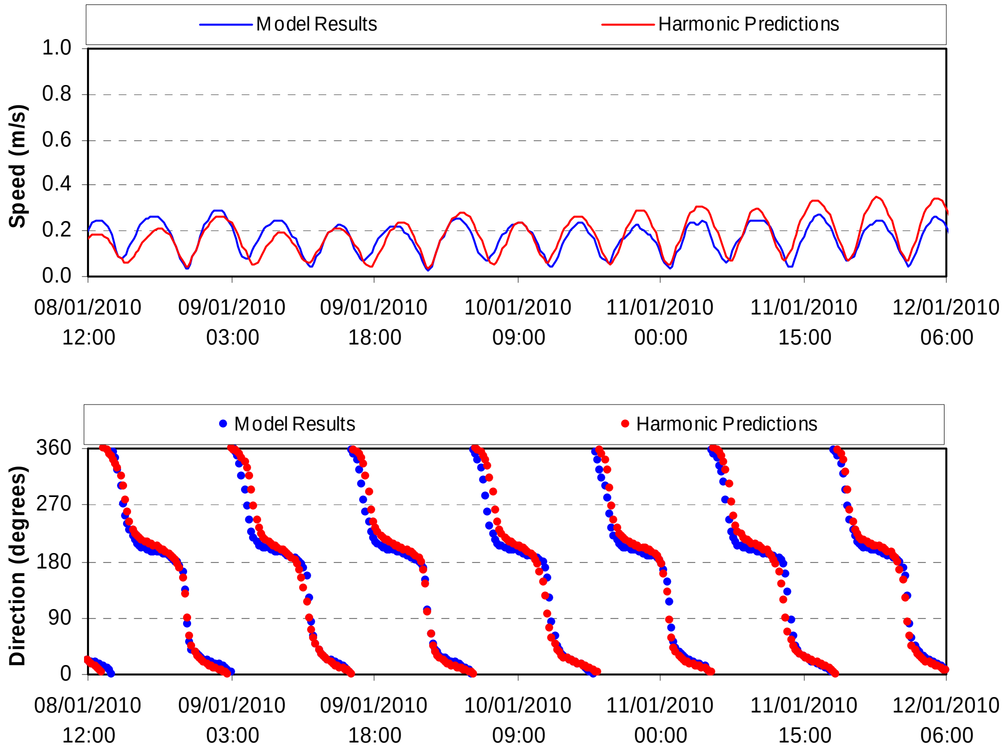


Figure D- 35: b0432264, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

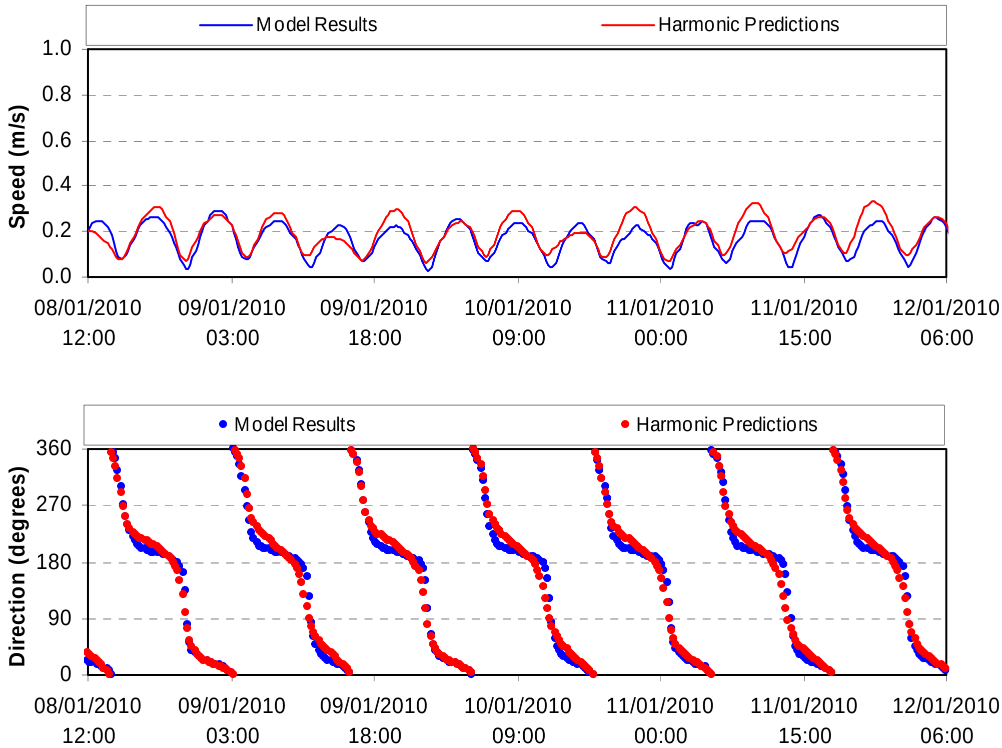
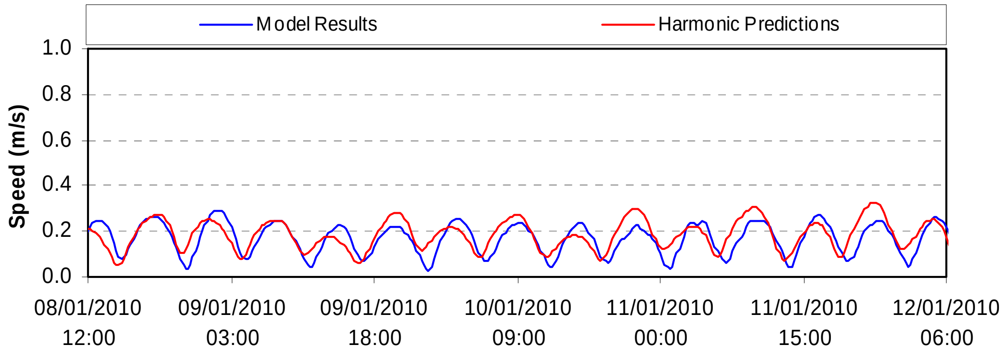
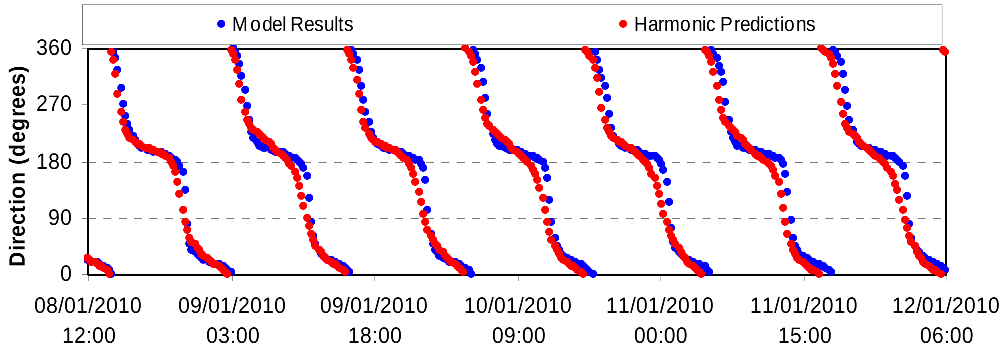


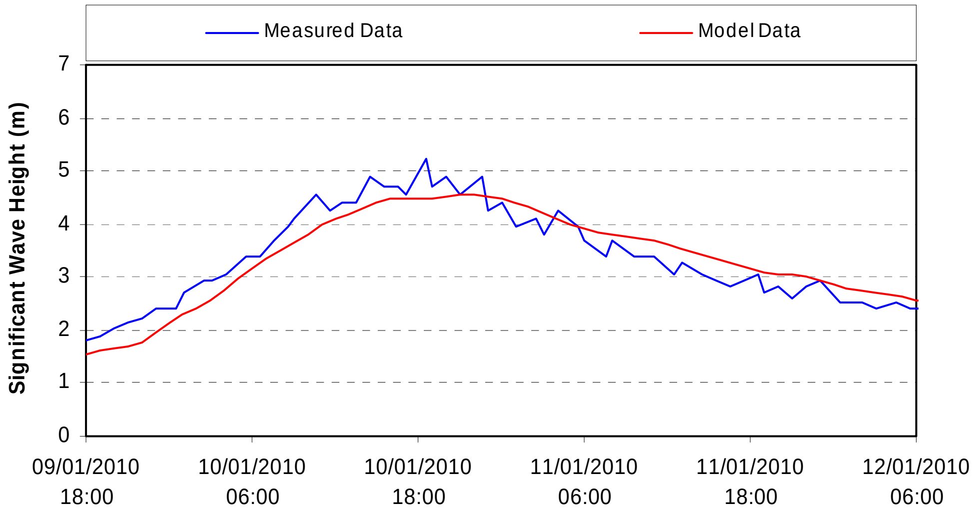
Figure D- 36: b0432830, BODC Current Meter Modelled Tidal Current Speed (ms^{-1}) and Current Direction (deg T) against Predicted Field Data

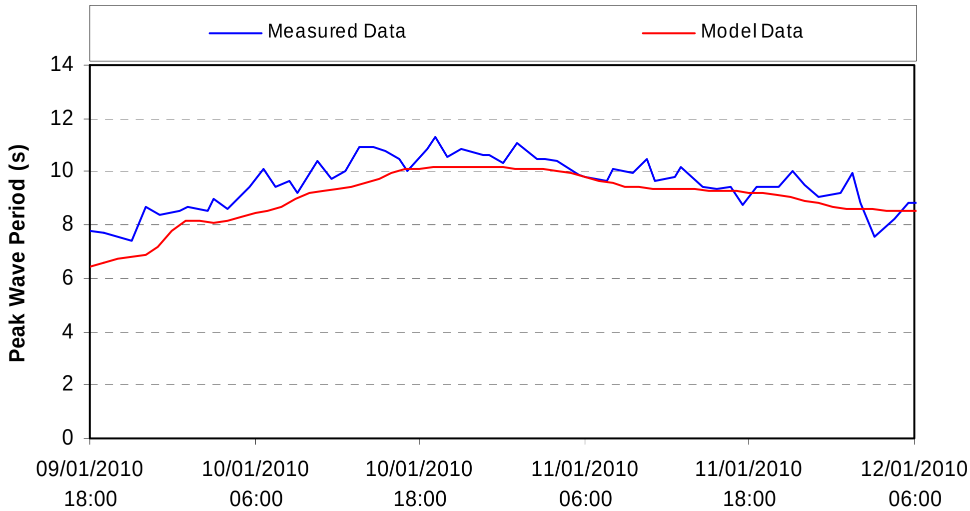




Appendix E Spectral Wave Model Calibration Results

Figure E- 1: Easterly Storm Event - Forth Array, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





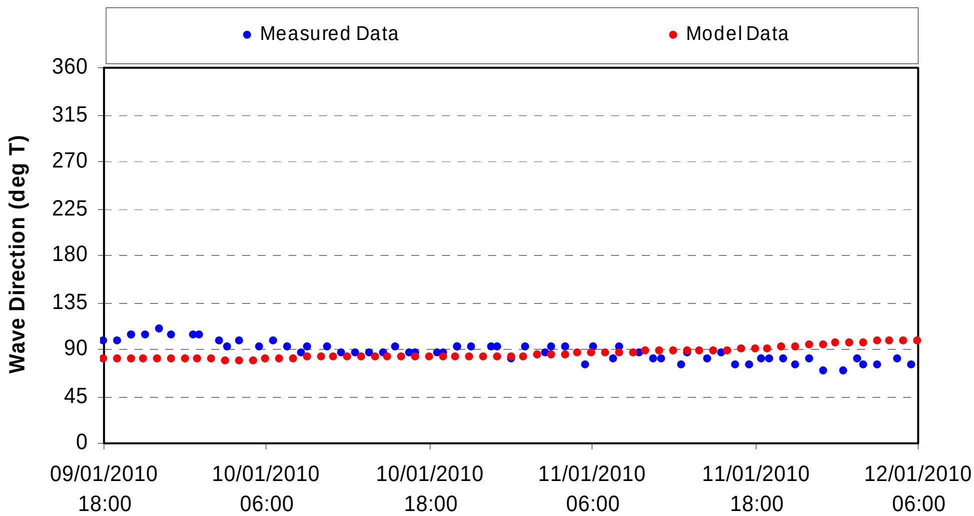


Figure E- 2: Easterly Storm Event - Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

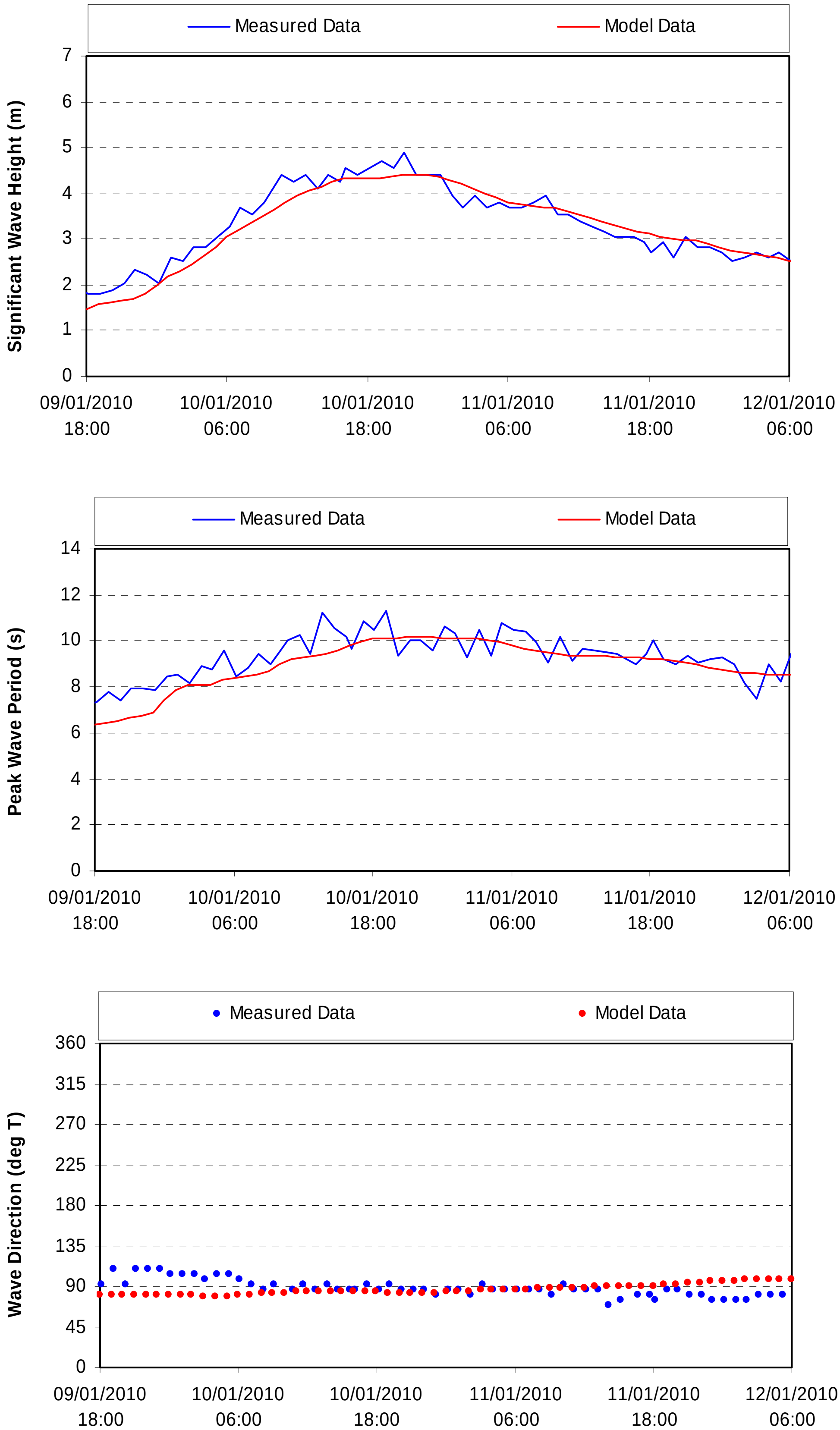
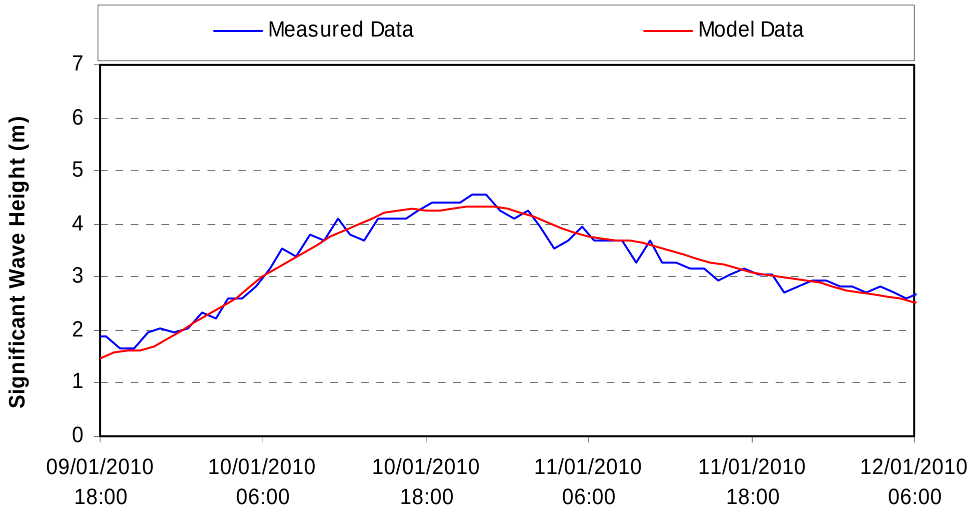
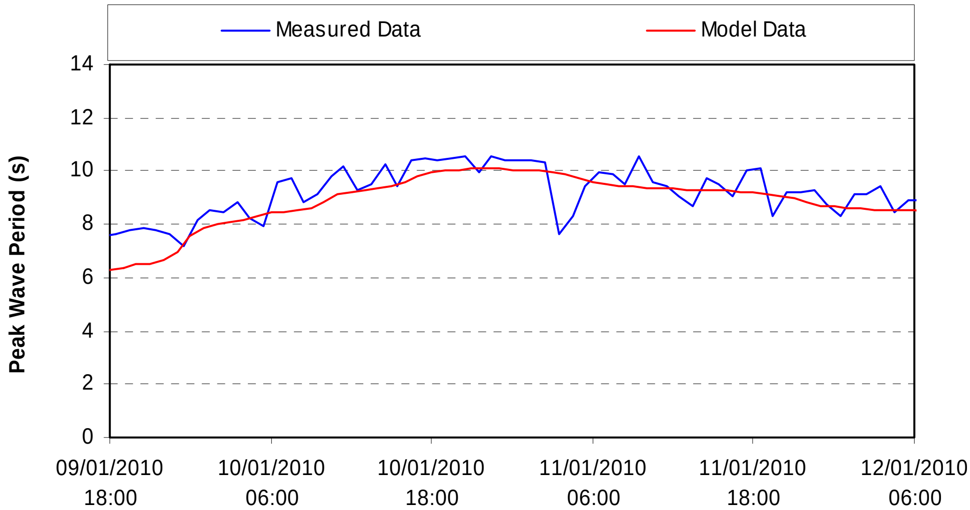


Figure E- 3: Easterly Storm Event - Inch Cape, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





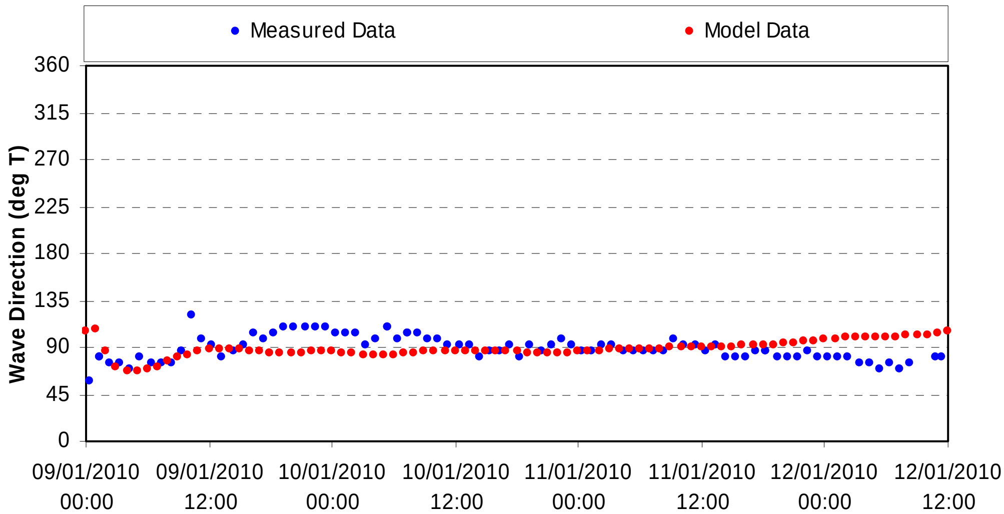
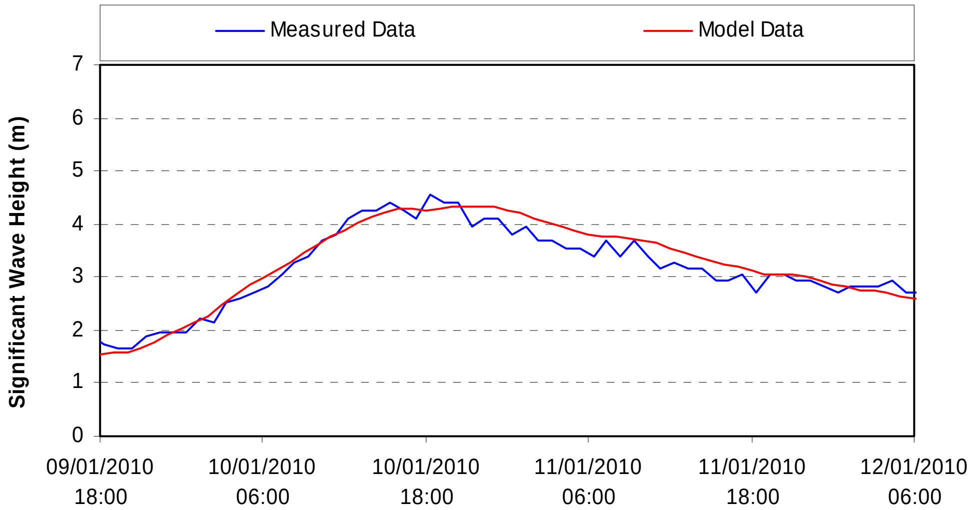
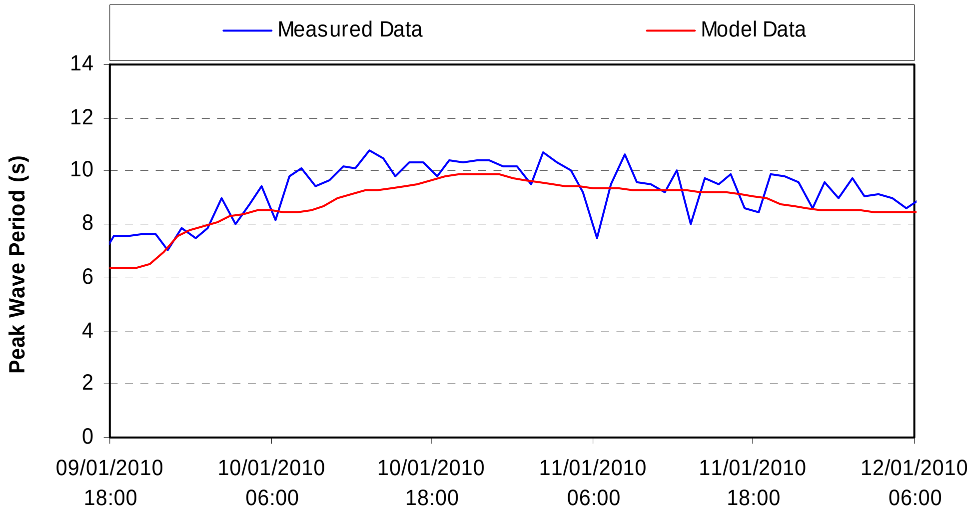


Figure E- 4: Easterly Storm Event - North Offshore, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





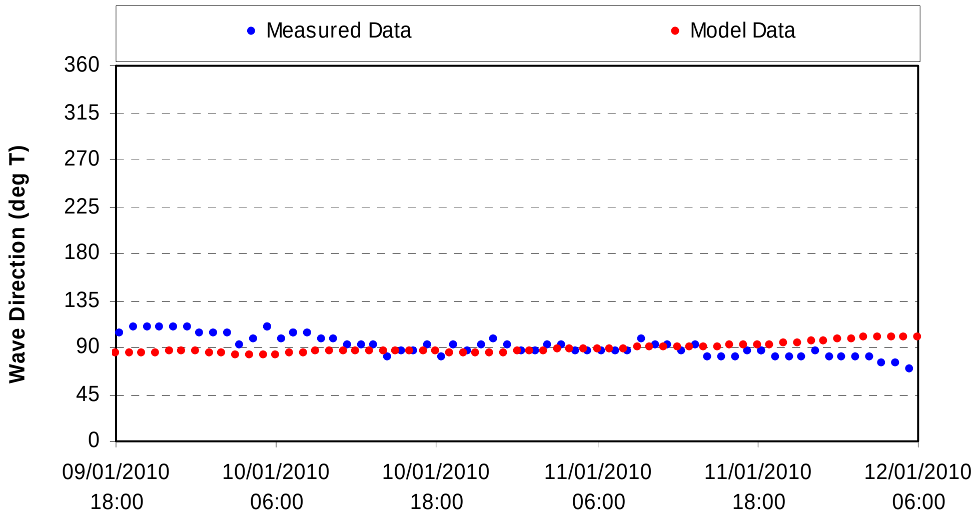
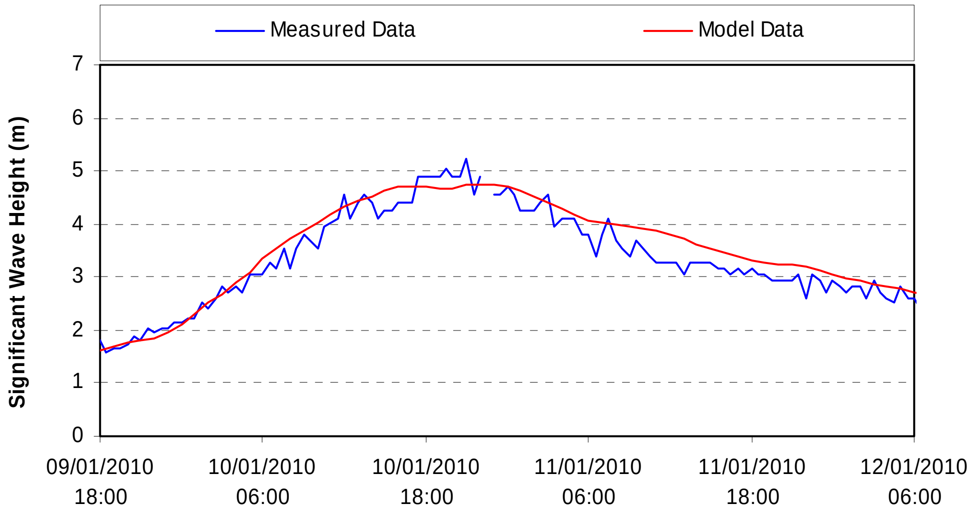
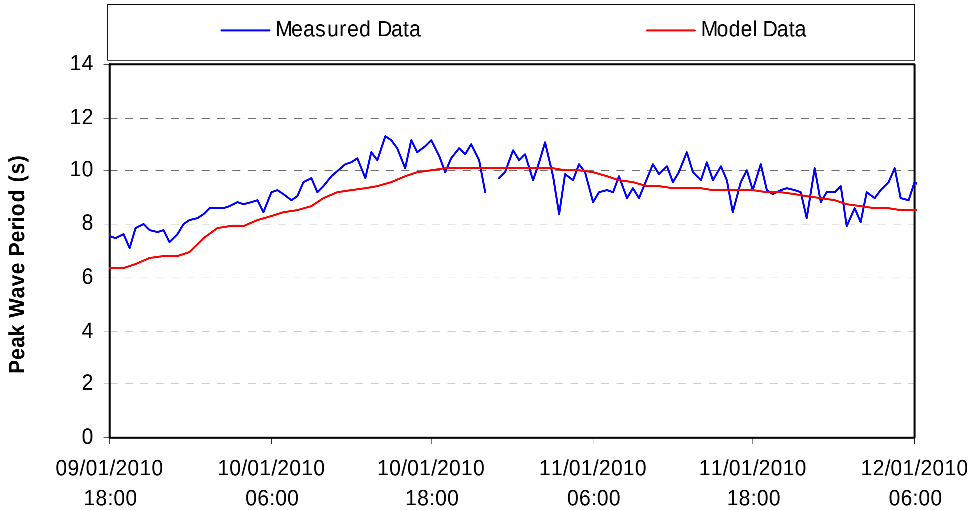


Figure E- 5: Easterly Storm Event - Firth of Forth, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





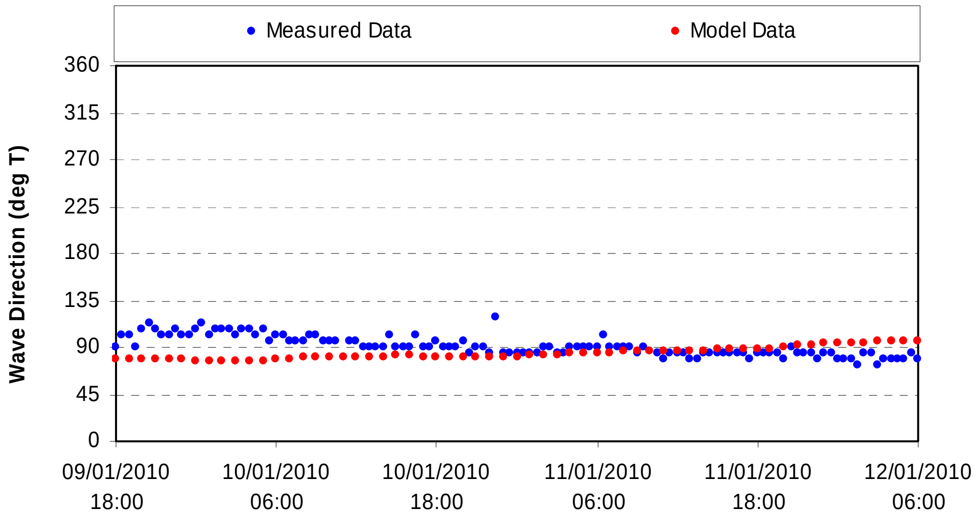
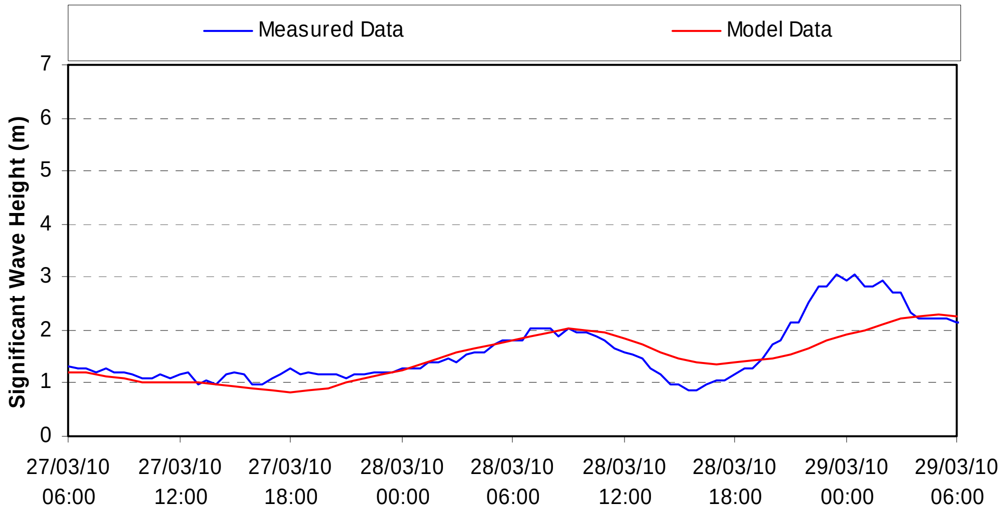
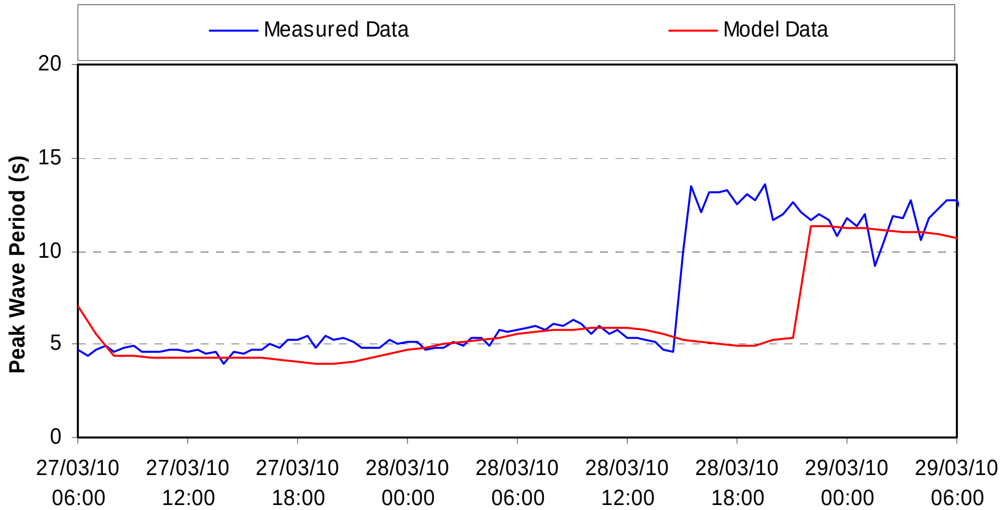


Figure E- 6: Offshore Wind Event - Forth Array, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





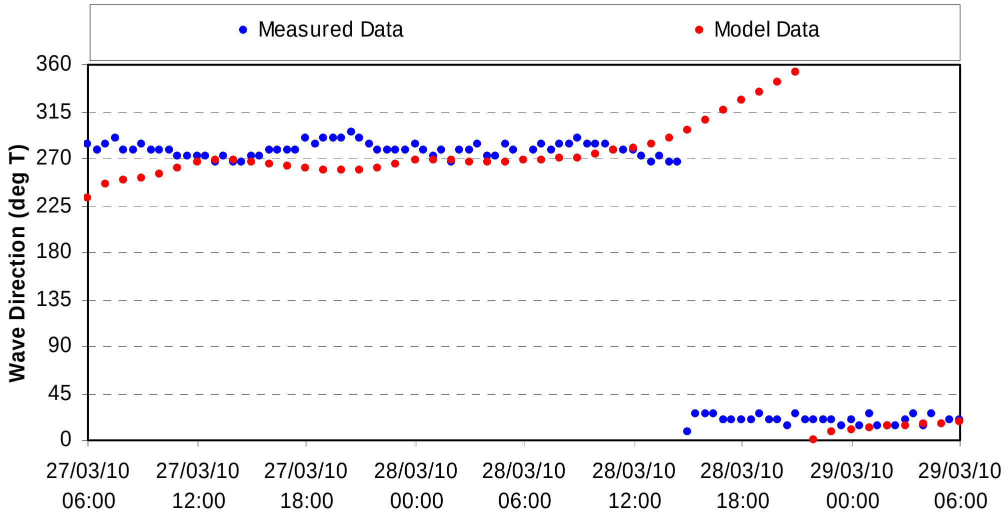


Figure E- 7: Offshore Wind Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

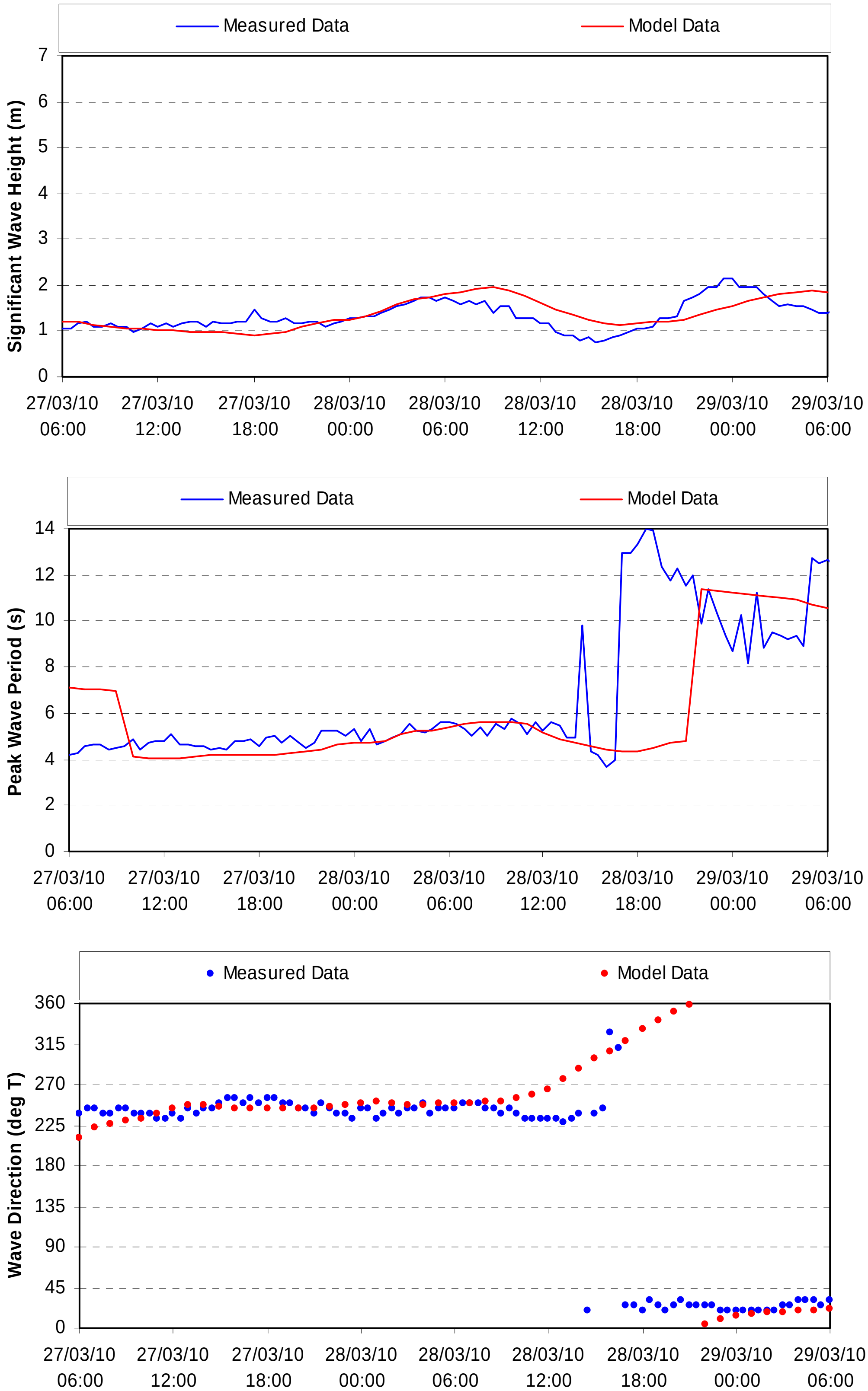


Figure E- 8: Offshore Wind Event – Inch Cape, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

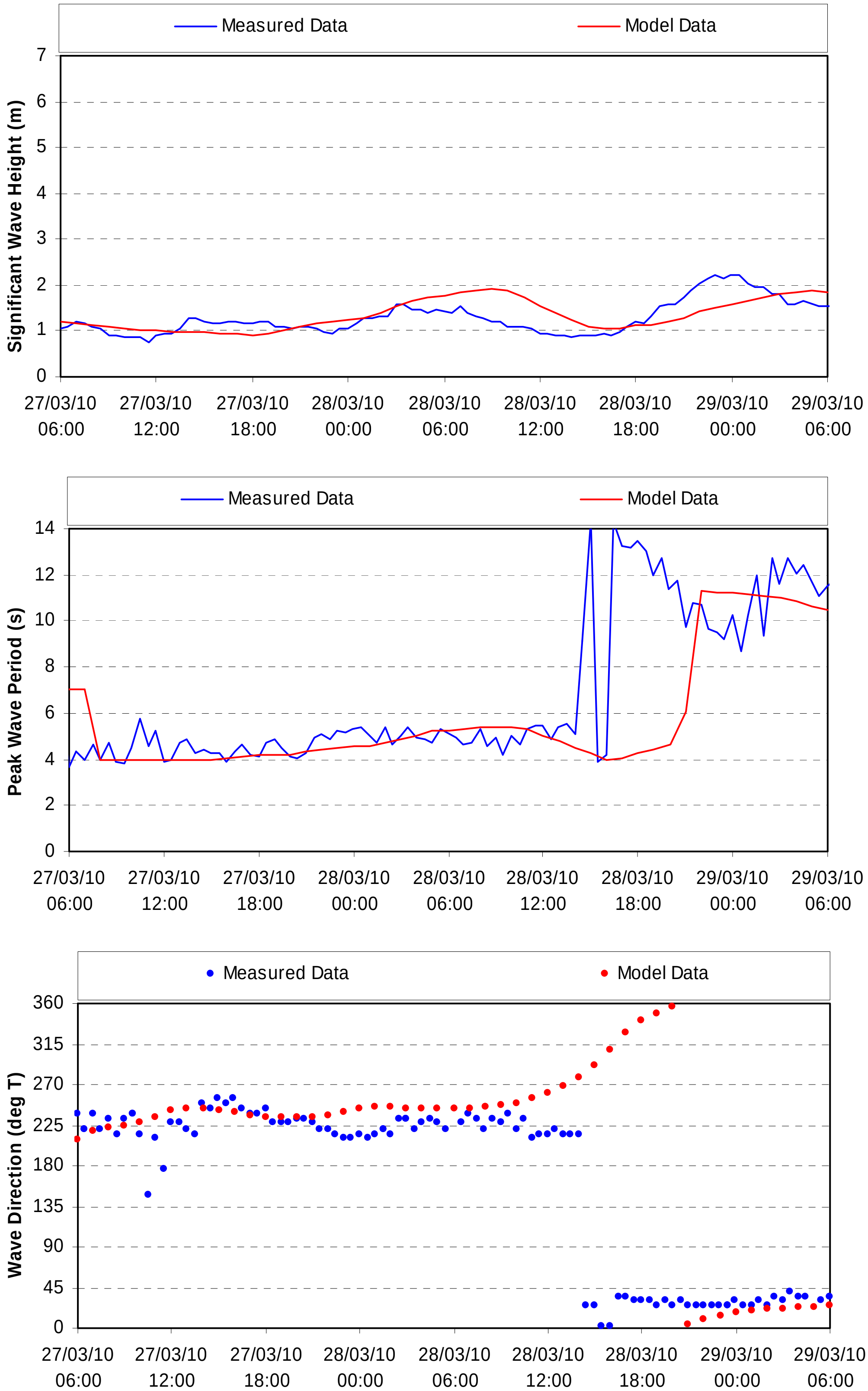
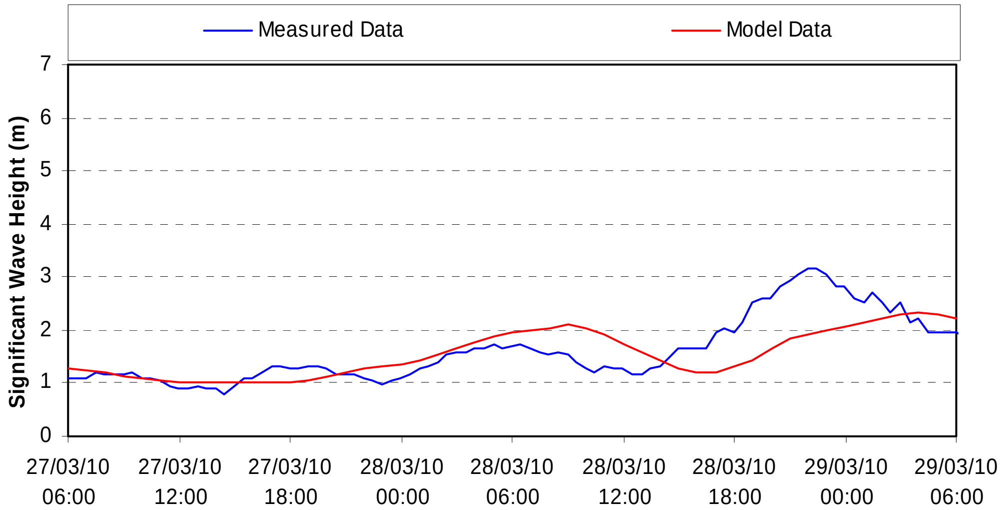
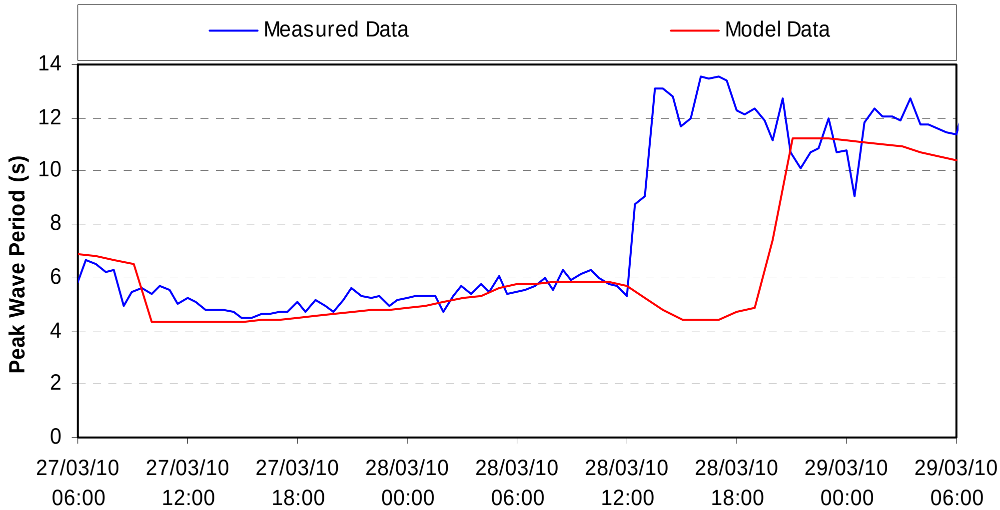


Figure E- 9: Offshore Wind Event – North Offshore, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





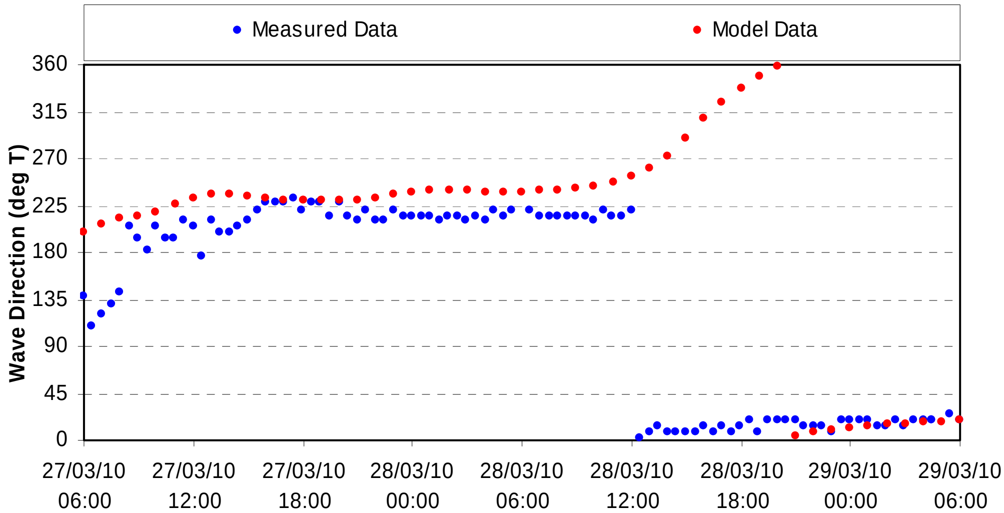


Figure E- 10: Offshore Wind Event – Firth of Forth, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

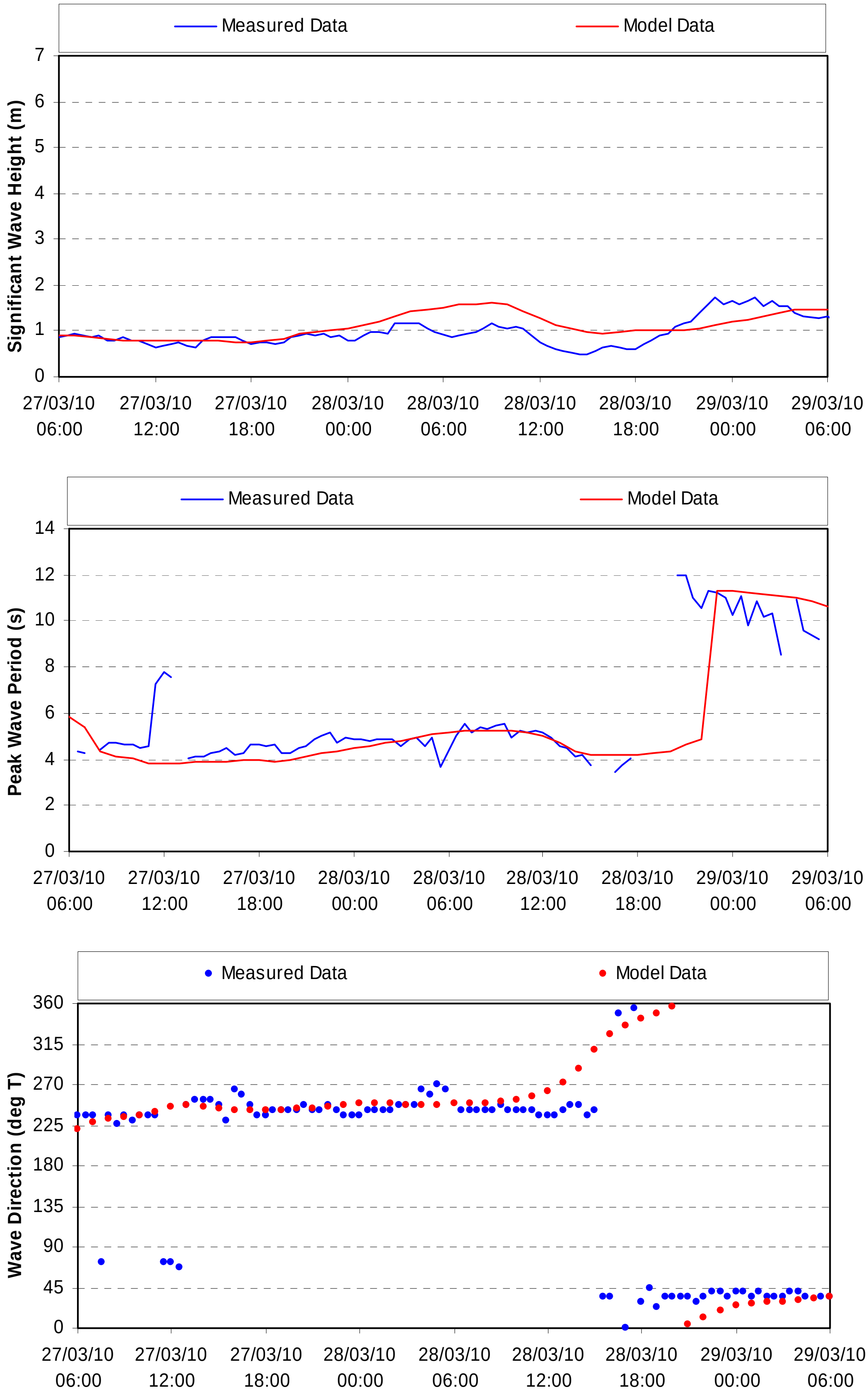


Figure E- 11: Northerly Storm Event - Forth Array, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

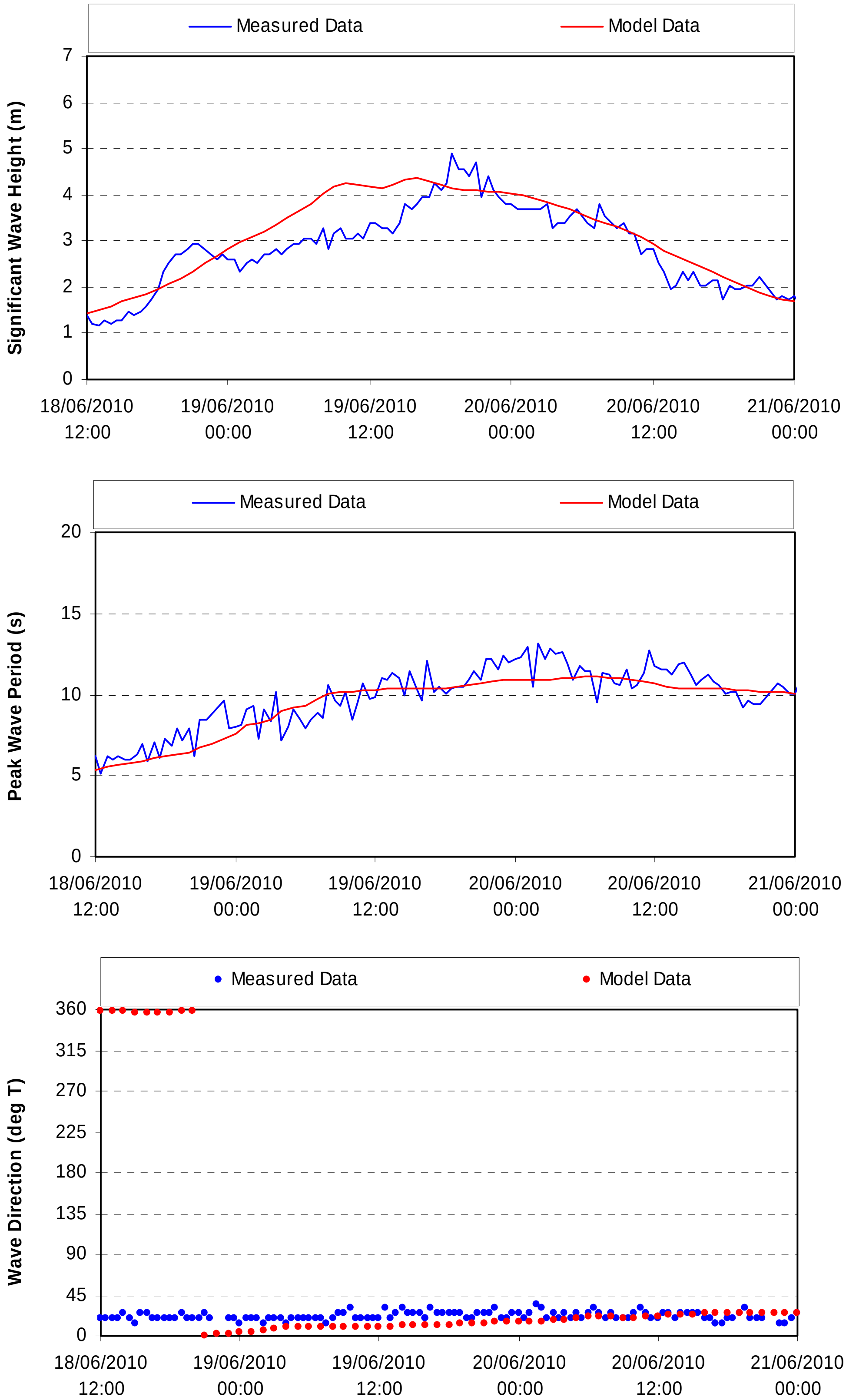


Figure E- 12: Northerly Storm Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

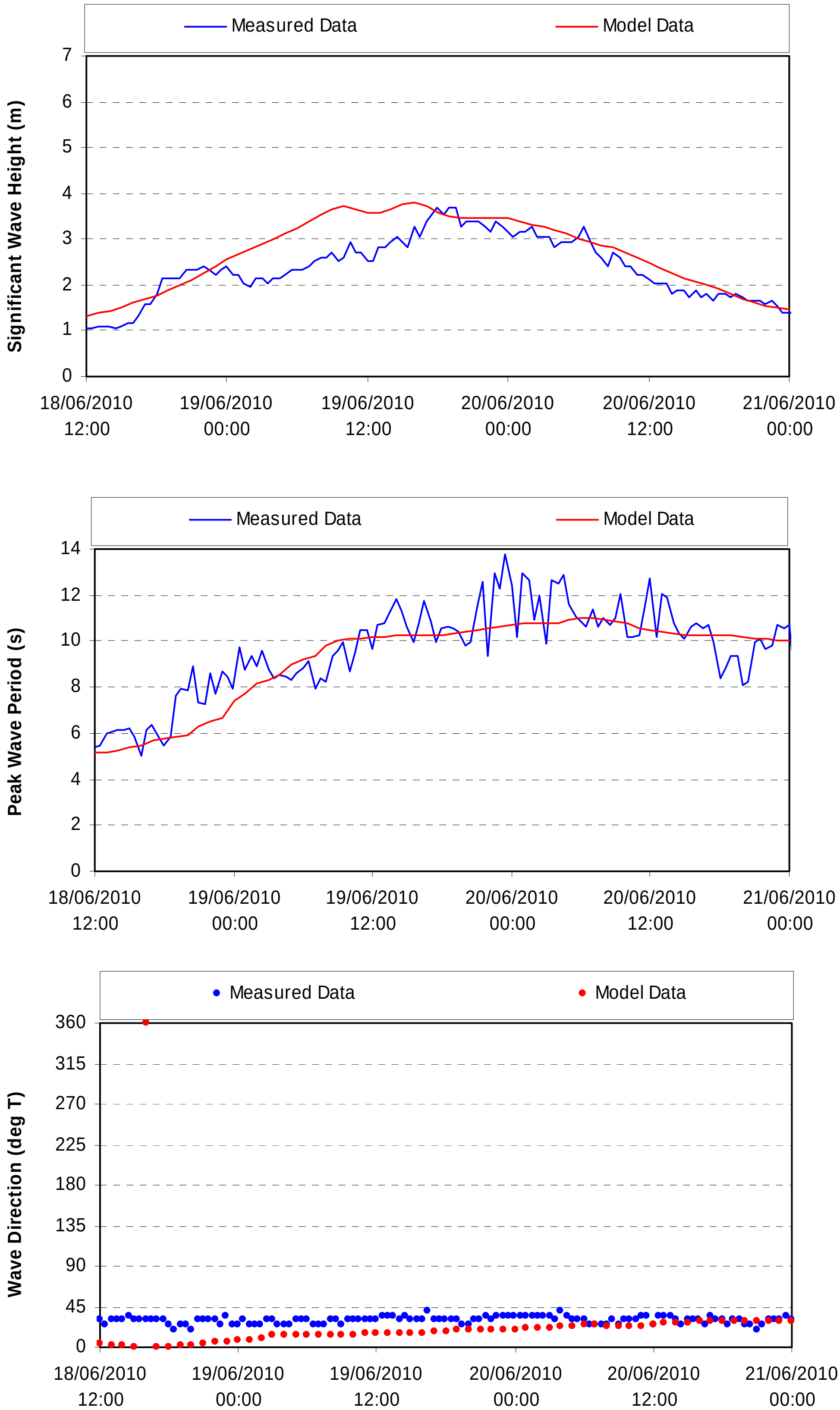
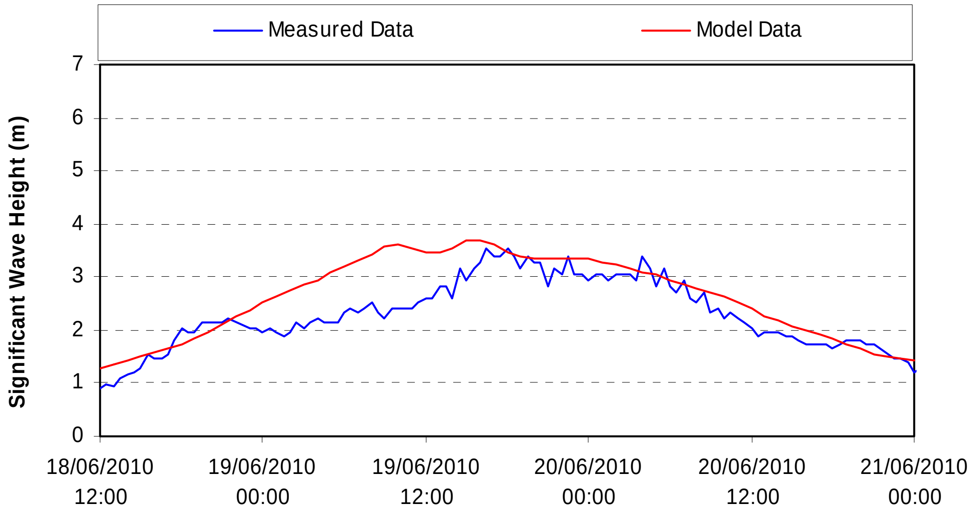
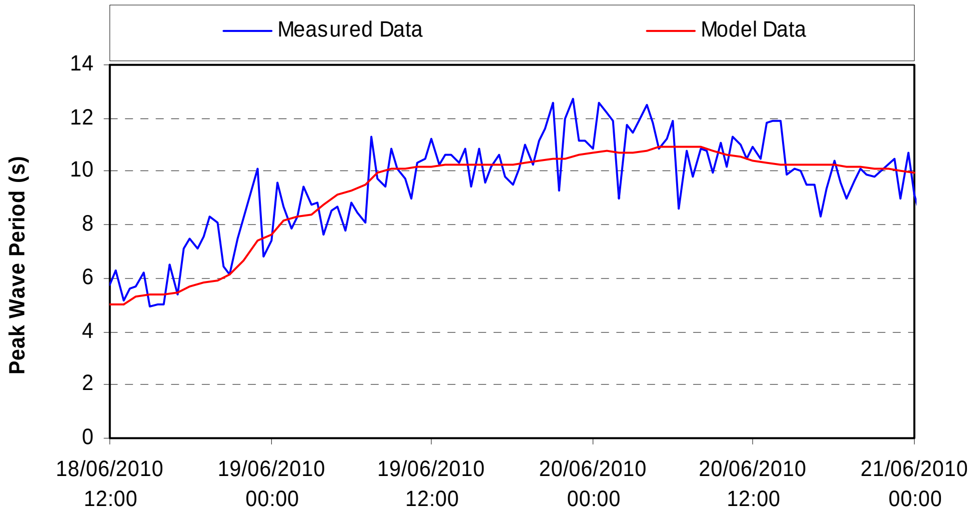


Figure E- 13: Northerly Storm Event – Inch Cape, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





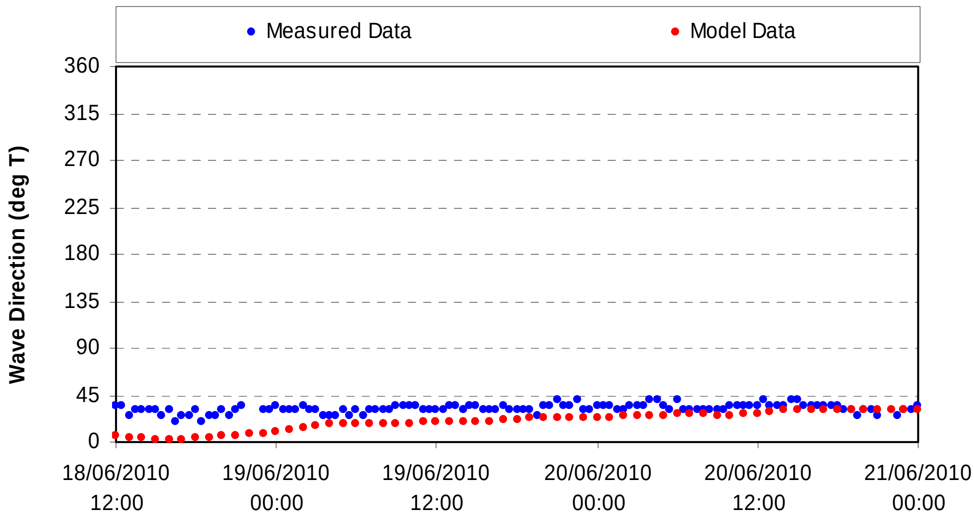


Figure E- 14: Northerly Storm Event – North Offshore, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

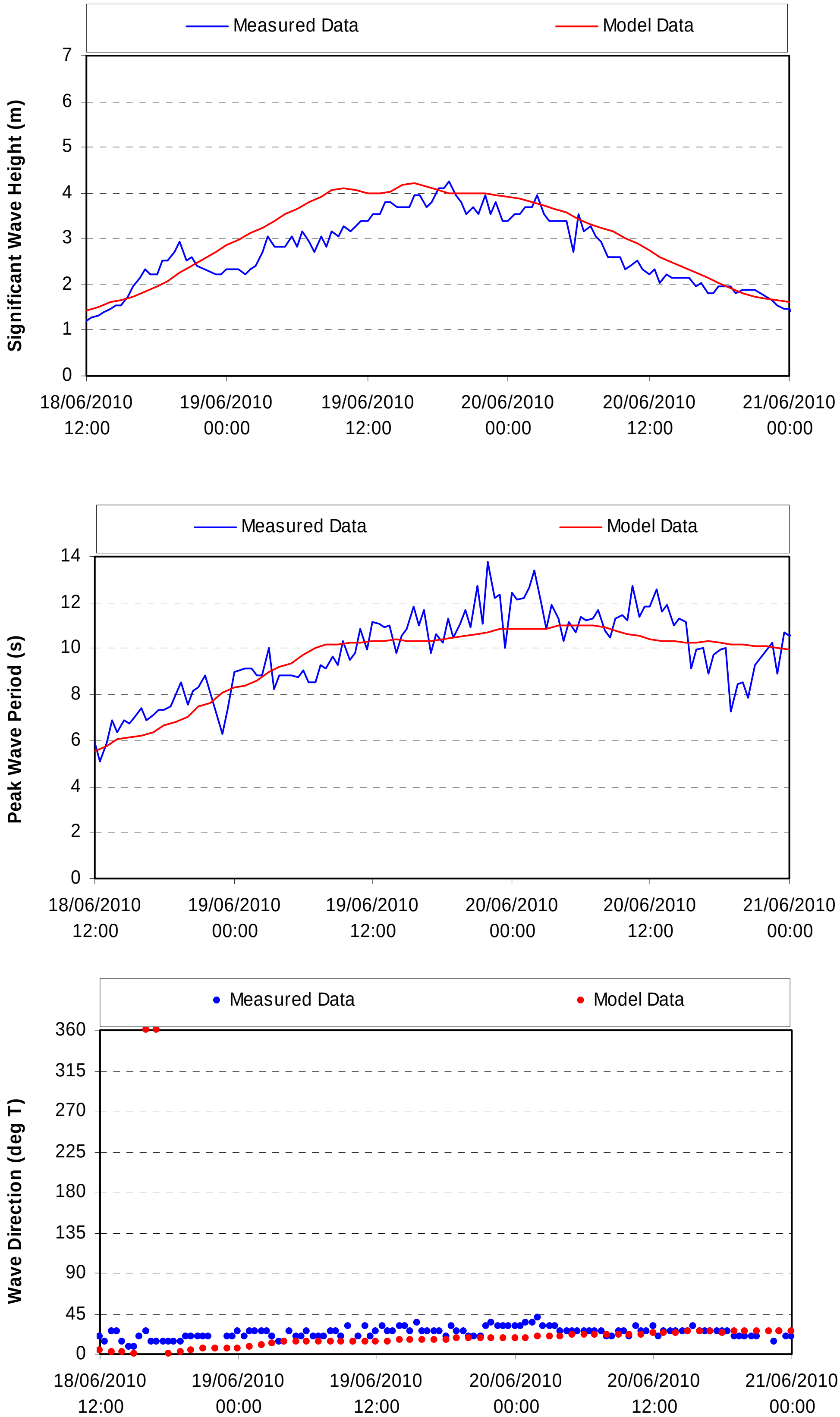
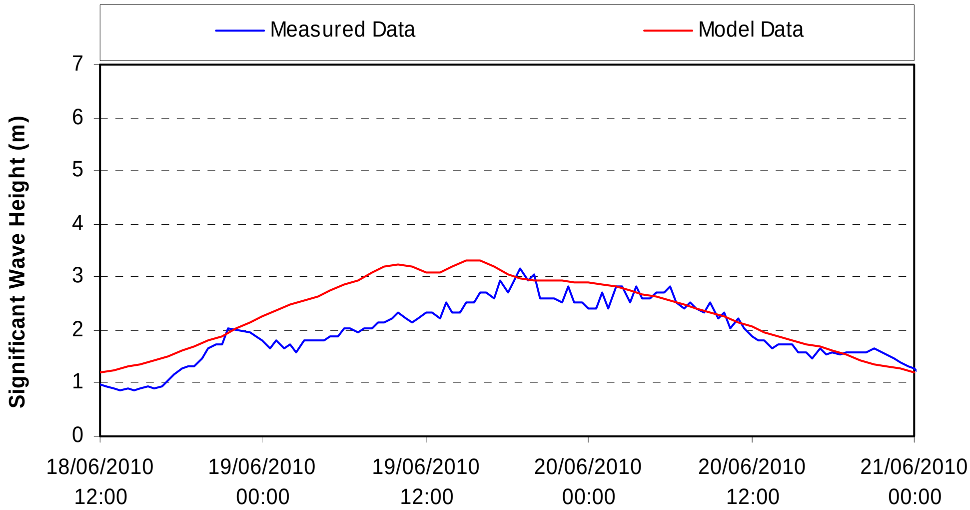
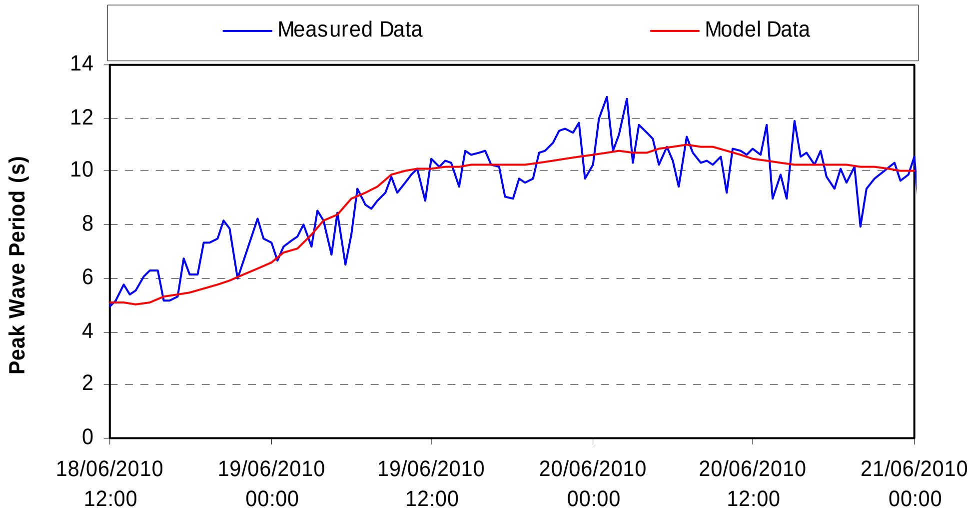
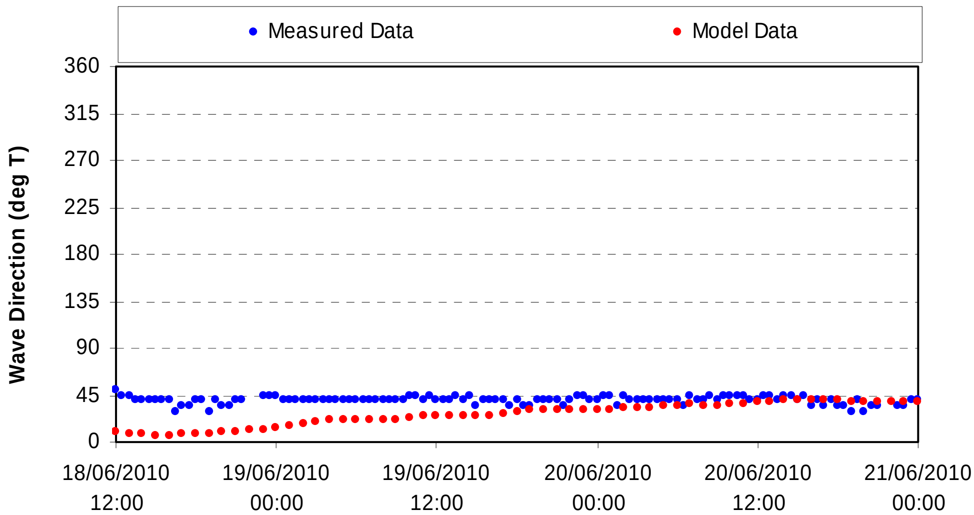


Figure E- 15: Northerly Storm Event – Firth of Forth, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

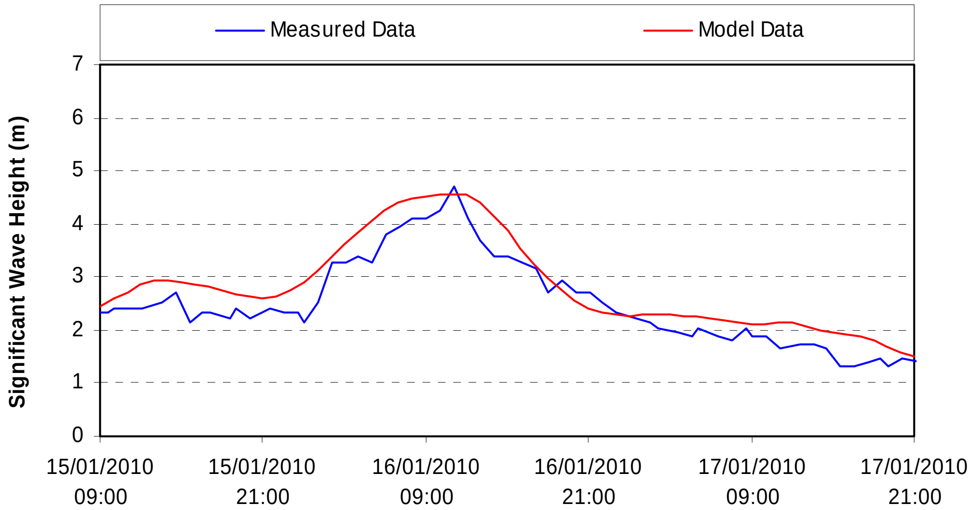


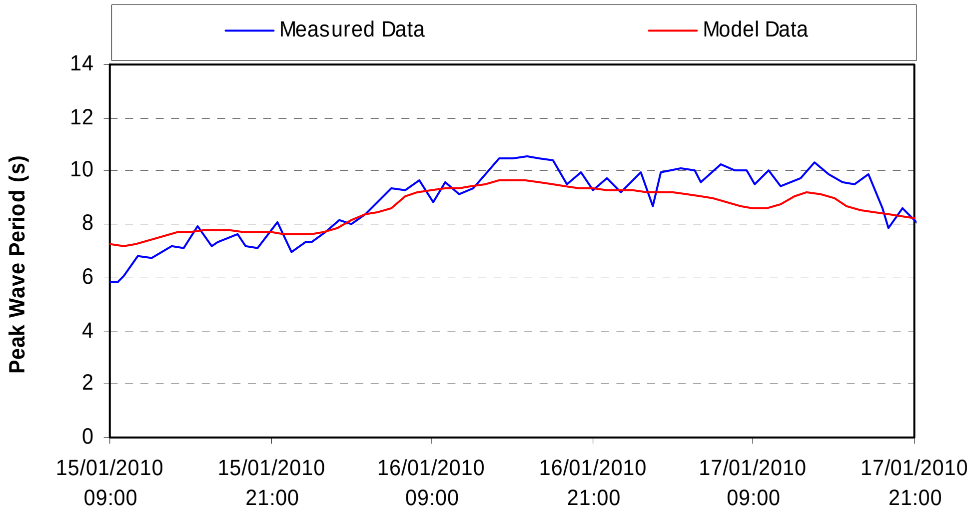




Appendix F Spectral Wave Model Validation Results

Figure F- 1: Southeasterly Storm Event - Forth Array, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





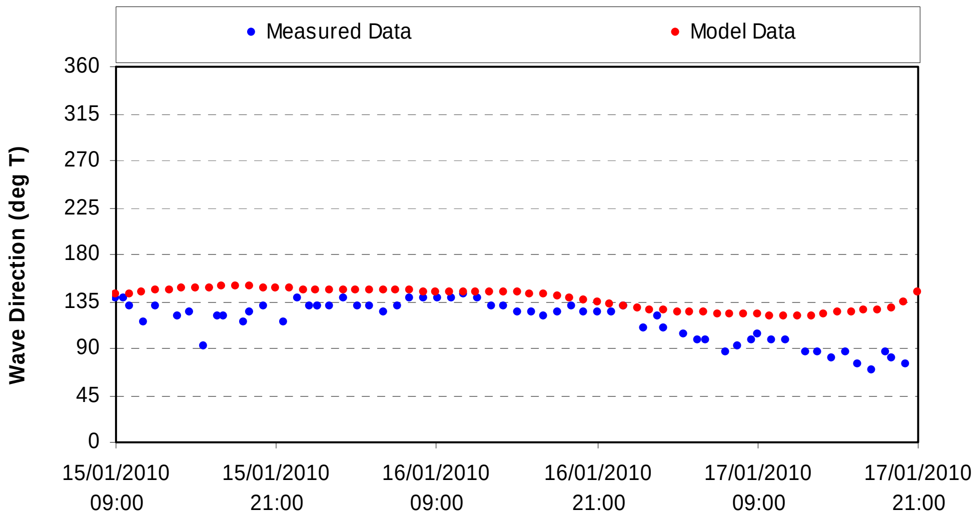


Figure F- 2: Southeasterly Storm Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

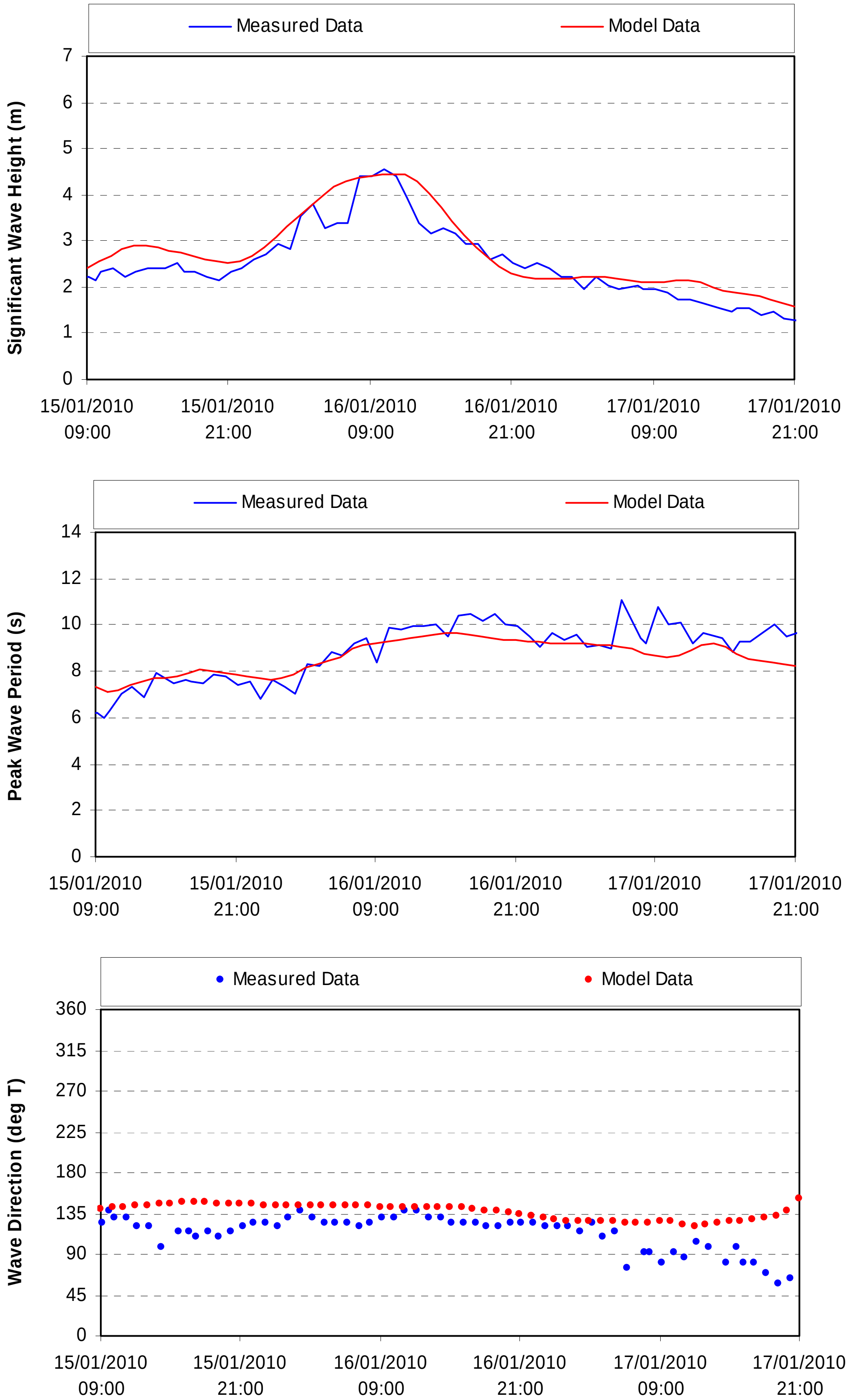


Figure F- 3: Southeasterly Storm Event – Inch Cape, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

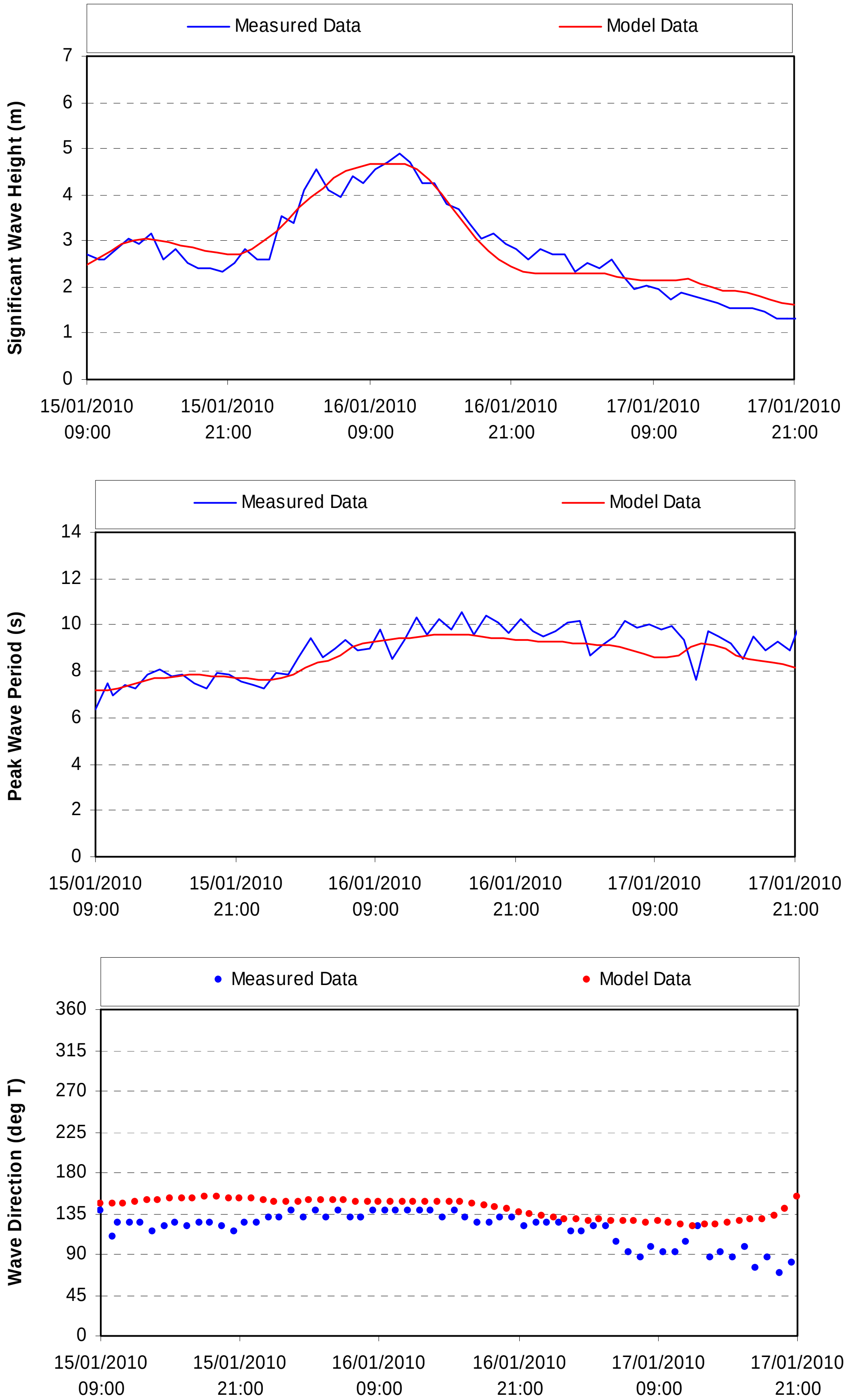


Figure F- 4: Southeasterly Storm Event – North Offshore, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

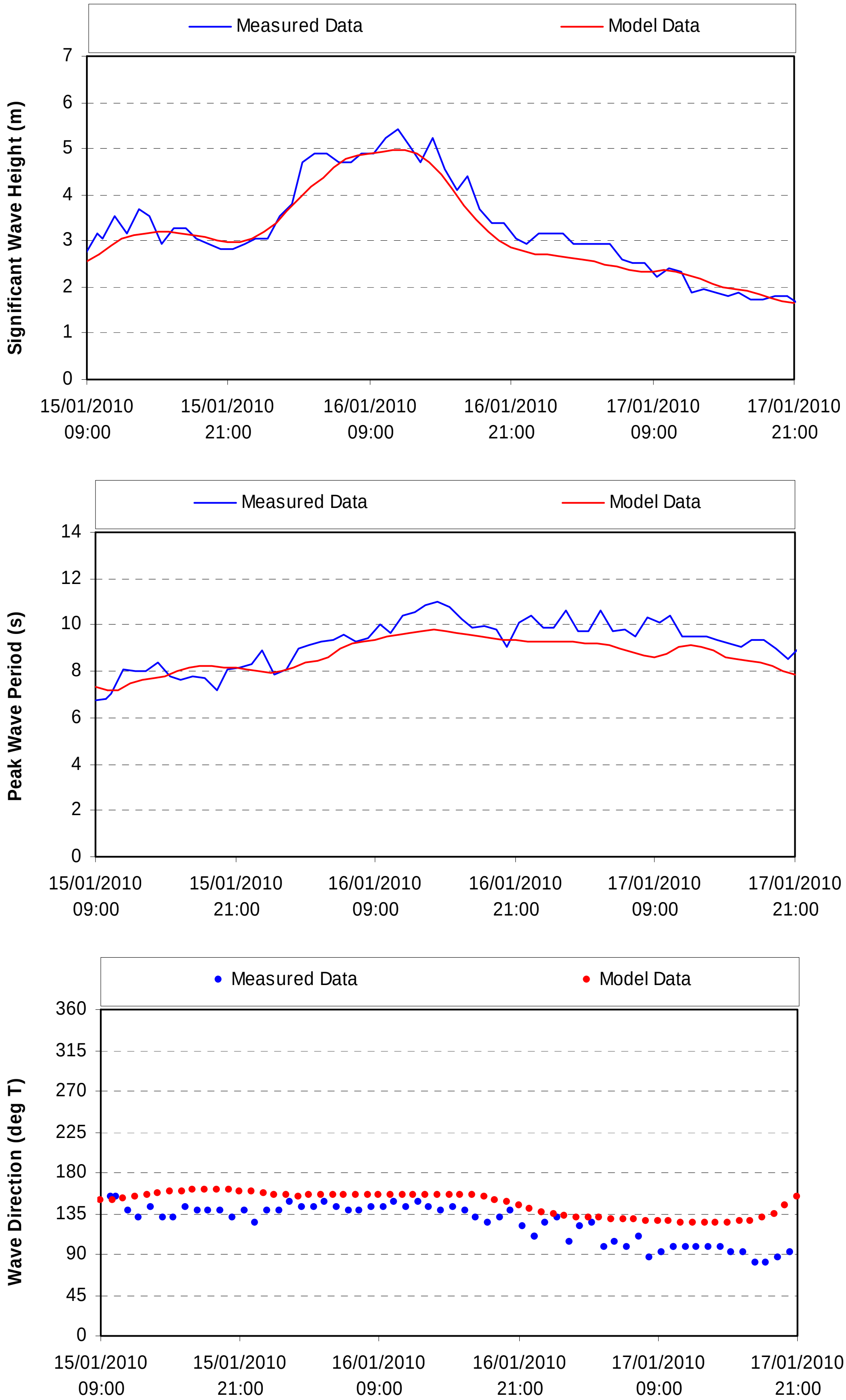
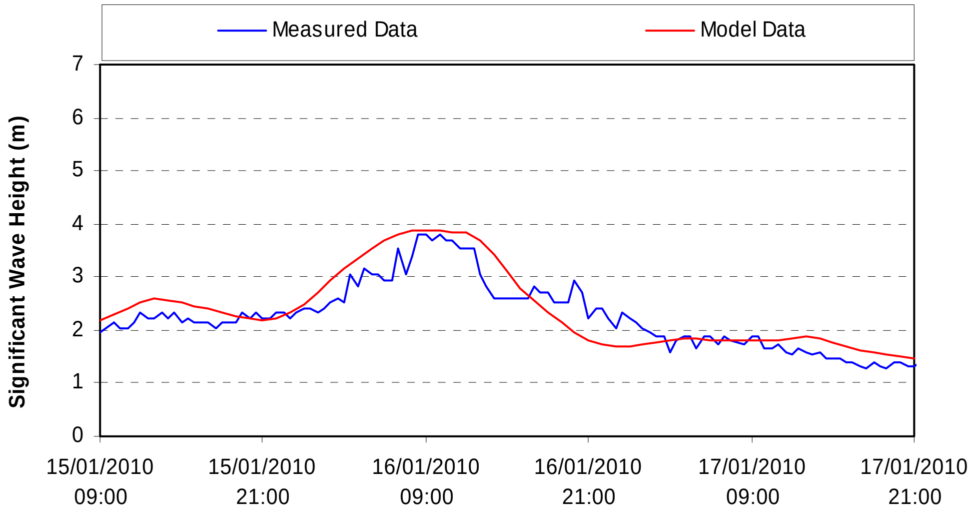
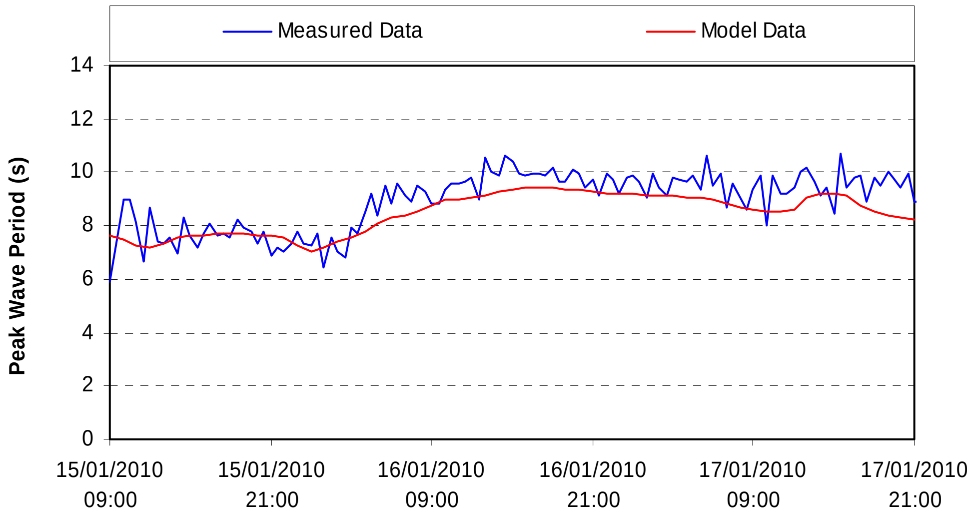


Figure F- 5: Southeasterly Storm Event – Firth of Forth, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





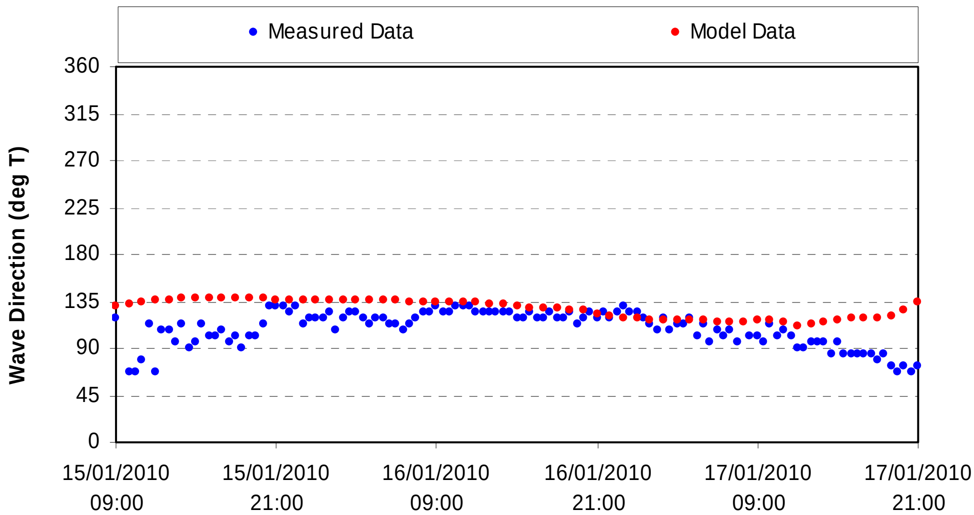


Figure F- 6: Offshore Wind Event - Forth Array, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

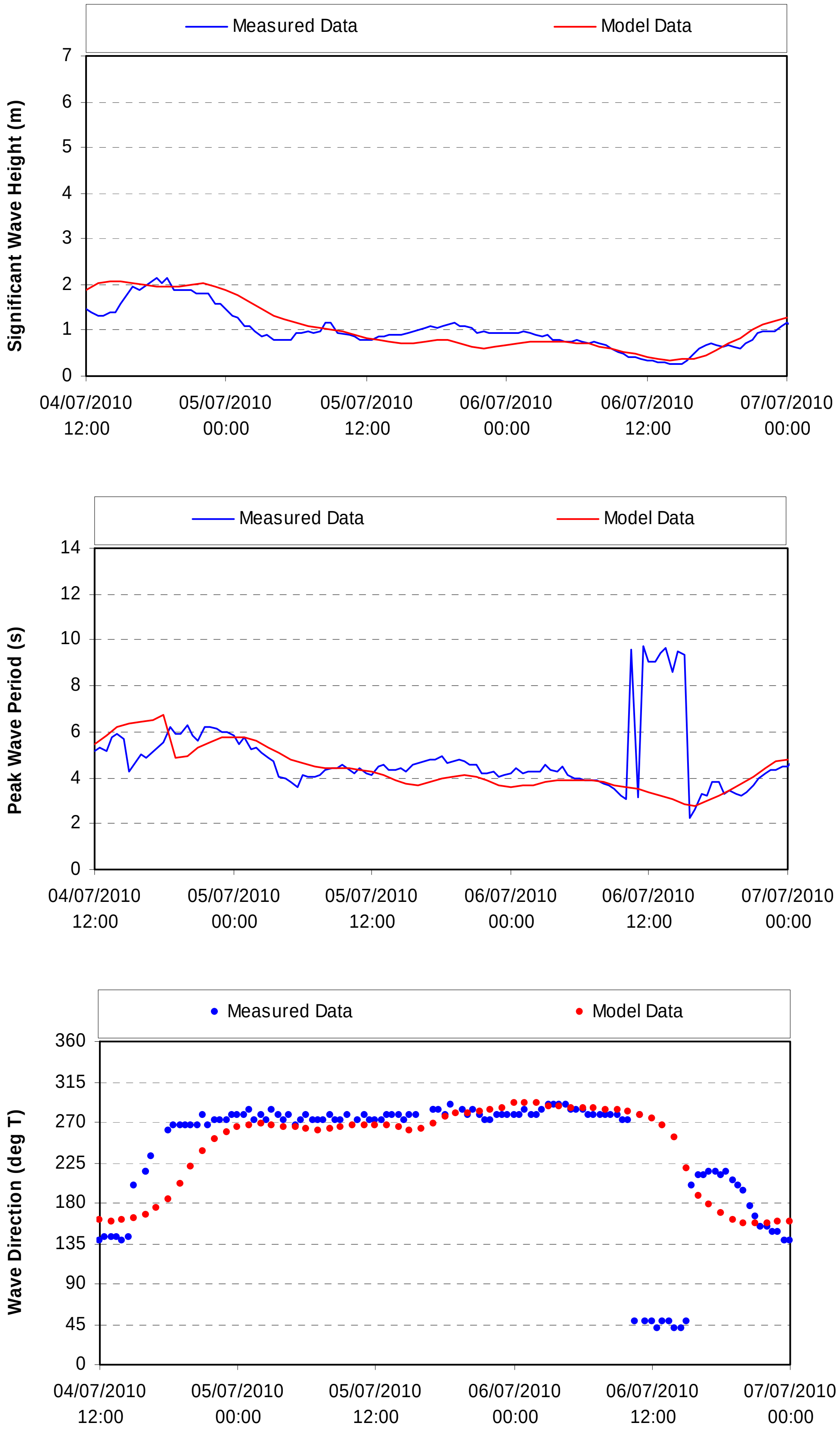
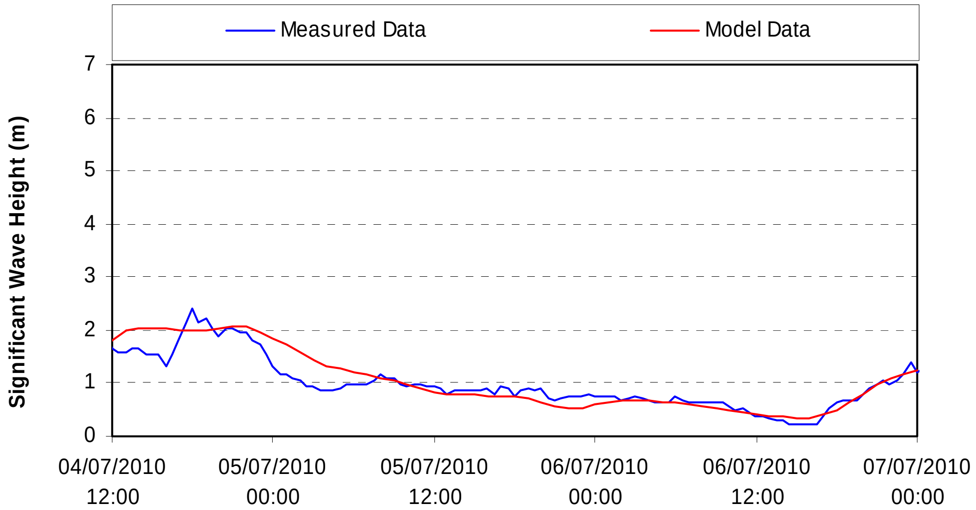
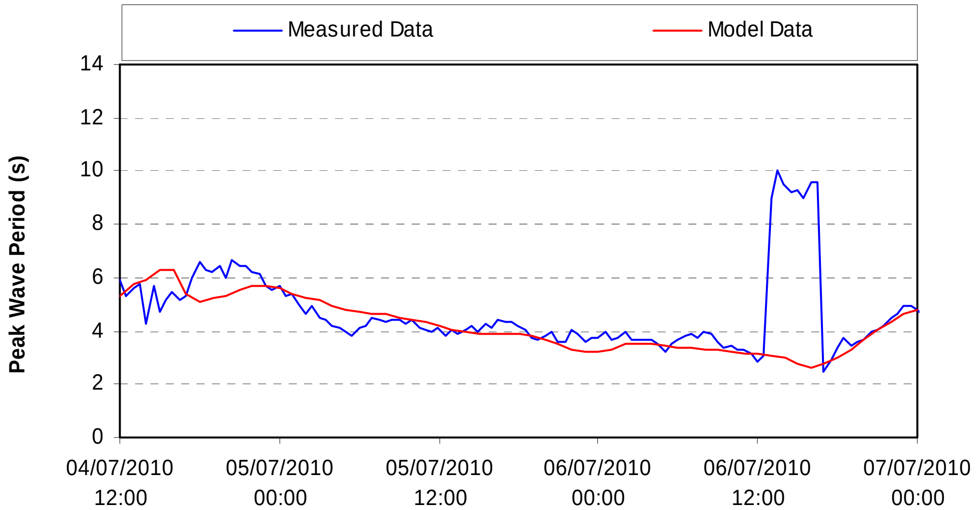


Figure F- 7: Offshore Wind Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data





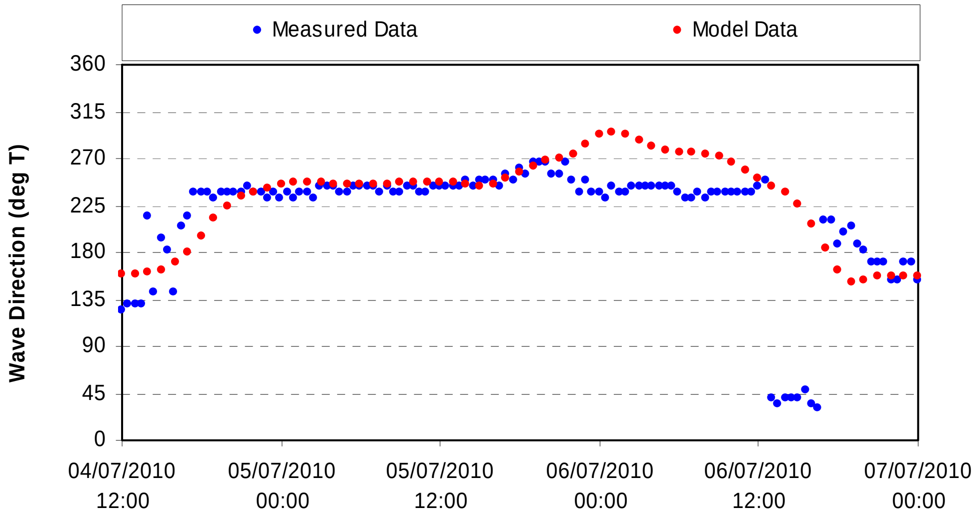


Figure F- 8: Offshore Wind Event – Firth of Forth, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data