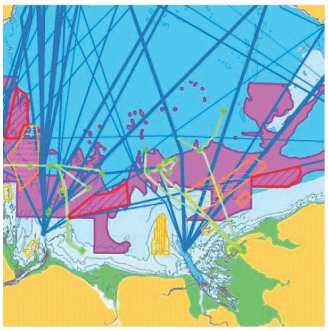
White Paper

SEASTATES
North West European Continental Shelf Tide and Surge Hindcast Database

Model validation report

March 2017

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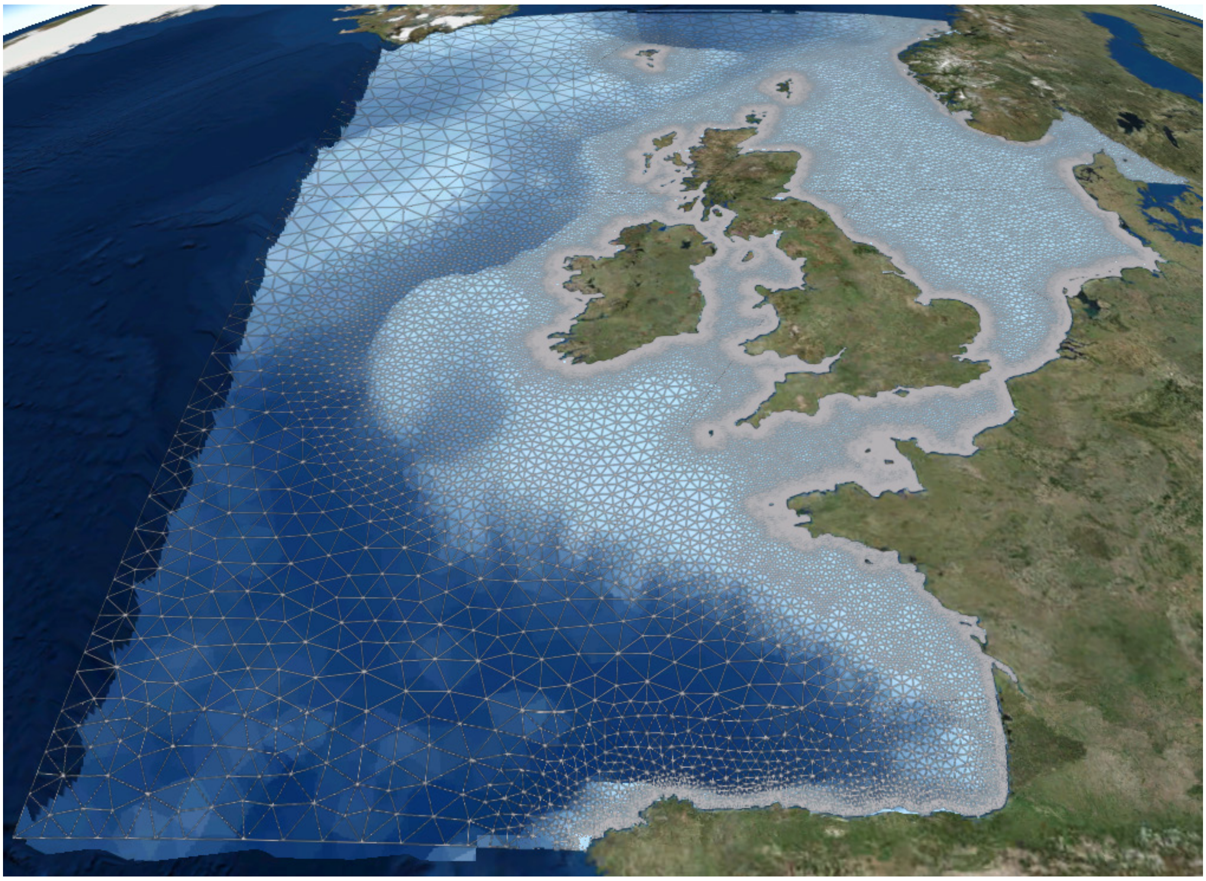

Document Information

Document History and Authorisation		
Title	SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database	
	Model validation report	
Commissioned by	White Paper	
Issue date	March 2017	
Document ref	R.2784	
Project no	R/1400/1618	
Date	**Version**	**Revision Details**
06/03/2017	1	Issued for public release

Prepared (PM)	Approved (QM)	Authorised (PD)
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Suggested Citation

ABPmer, (2017). SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database, Model validation report, ABPmer Report No. R.2784. A White Paper, produced by ABPmer, March 2017.

Notice

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Summary

SEASTATES is ABPmer's metocean information service (http://www.seastates.net).

We have developed the SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database to provide water level and flow parameters (generated by both astronomic (tidal) and meteorological forces) across the North West European Continental Shelf and North Sea.

The hindcast model is run from the beginning of January 1979 and is updated regularly. At the time of writing, the hindcast provides a 38 year database of tide and surge hydrodynamic parameters suitable for applications including site characterisations, metocean analysis and local model boundary conditions.

A detailed assessment of the SEASTATES Tide and Surge Hindcast Model has shown that the hindcast model accurately represents the total water level and flow conditions at various stations in the model domain, as well as the individual components of tide and surge.

Contents

Tables

Figures

1 Introduction

ABPmer is an experienced provider of metocean services to a wide range of clients for a variety of design and operational purposes. In order to enhance the provision of these services ABPmer developed the SEASTATES wave hindcast service (http://www.seastates.net) first brought online in 2013, which provides a long-term (>38 year) wave hindcast database for the North West European shelf and Baltic Sea.

In order to expand the availability of metocean data for ABPmer services, and for external clients, ABPmer has developed a tide and surge hindcast to provide the astronomical and surge components of water level and flow in the same region.

Using a state of the art hydrodynamic model, the SEASTATES Tide and Surge Hindcast Model provides tide, surge and total water level and depth-averaged flow information for the North West European Continental Shelf. The model utilises up to date bathymetry and long-term wind field and pressure data from 1979 to the present day. The data from the SEASTATES Tide and Surge Hindcast Model provides the information necessary to characterise the hydrodynamic regime within the model domain as well as the time-series data required for extreme value analysis.

This report describes the setup and inputs to the hindcast, and demonstrates the performance and accuracy of the SEASTATES Tide and Surge Hindcast Model. Comparisons have been made between model result time-series and measurements from tide gauges and Acoustic Doppler Current Profiler (ADCP) deployments throughout the model domain.

It is demonstrated that the SEASTATES Tide and Surge Hindcast Model provides a high level of accuracy in representing both water levels and currents.

2 Modelling Approach

2.1 Overview

The SEASTATES North West European Continental Shelf Tide and Surge Hindcast Model has been built using the state of the art Danish Hydraulic Institute (DHI) software package MIKE21FM (Flexible Mesh). The modelling system was developed by DHI for applications within oceanographic, coastal and estuarine environments. MIKE21 Hydrodynamic Model (HD) simulates the water level variation and two-dimensional depth averaged flows in the area of interest.

2.2 Grid Design

The SEASTATES Tide and Surge Hindcast Model covers the area of the North West European Continental Shelf and North Sea between approximately 43 °N to 65 °N and 20 °W to 13 °E. The model extents are shown in Figure 1. The relatively wide model extents to the west of the North West European Continental Shelf allow the development and propagation of storm events from the model boundaries through the model domain onto the continental shelf. Likewise the representation of tidal dynamics has been found to be better simulated by allowing a wide model domain rather than an 'on-shelf' boundary.

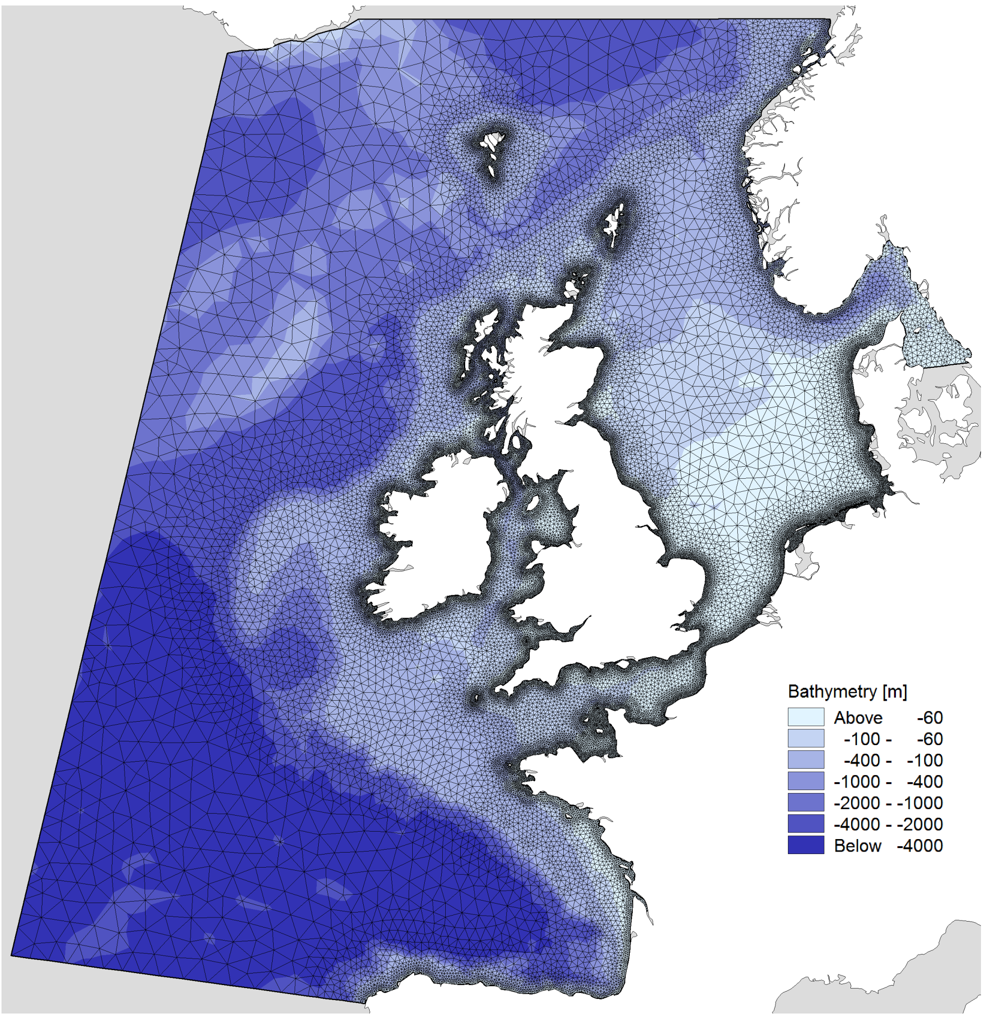

Figure 1. SEASTATES Tide and Surge Hindcast Model extents (bathymetry m MSL)

A flexible mesh design is used, employing a finer spatial resolution in areas of interest or importance, e.g. in nearshore and shallow water areas, and across significant features such as the continental shelf edge. Table 1 summarises the grid resolution for particular areas of interest. The model mesh has one vertical layer, providing depth averaged current speed and direction.

Table 1. Model Grid Resolution

Area	Equivalent Rectilinear Side Length (km)
Within 10 km of the UK, Irish and northern French coastlines	2 km
Within 40 km of the UK, Irish and northern French coastlines	3 km
Within 10 km of the western coast of France and north coast of Spain	3 km
Mid English Channel	6 km
Netherlands coast	2 km
Norwegian coast	3 km
North Sea	10 km
Irish Sea	6 km
Shelf Edge	12 km
Deep water Atlantic	35 km

2.3 Model input parameters

2.3.1 Bathymetry

The accuracy of the bathymetry which informs the model mesh is critical to the performance of the model. Accurate bathymetry ensures the movement of correct volumes of water, particularly through nearshore regions or where flow is restricted. Previous large-scale HD modelling projects by ABPmer have shown a high level of model sensitivity to relatively small depth corrections over wide areas, related to obtaining the most accurate vertical reference correction.

For offshore regions the European Marine Observation and Data Network (EMODnet) Composite Digital Terrain Model was utilised (http://www.emodnet.eu/bathymetry). This database compiles survey data from hydrographic offices and gridded bathymetry from other models such as GEBCO (General Bathymetric Chart of the Oceans) hosted by the British Oceanographic Data Centre (BODC).

For coastal regions, data from the archive of United Kingdom Hydrographic Office (UKHO) survey data, available via the 'INSPIRE' portal (https://data.gov.uk/inspire). These represent the highest resolution and most accurate measured data freely available, although they have limitations in the variability of measurement date (in some cases dating back to 1961) and the spatial coverage of data, which is restricted to coastal UK.

The bathymetry of the model mesh was interpolated from (in order of priority):

- UKHO survey data (https://data.gov.uk/inspire); and
- EMODnet global bathymetry (http://www.emodnet.eu/bathymetry).

2.3.2 Tidal boundaries

The tidal element of the model is forced using four open tidal water level boundaries. Three are located offshore of the continental shelf break and one at the entrance to the Baltic Sea (see Figure 2).

Water levels vary in both space and time along the open boundaries. The boundary water levels are predicted using the DTU10 global database of 10 major tidal harmonic constituents. (http://www.space.dtu.dk/english/Research/Scientific_data_and_models/Global_Ocean_Tide_Model).

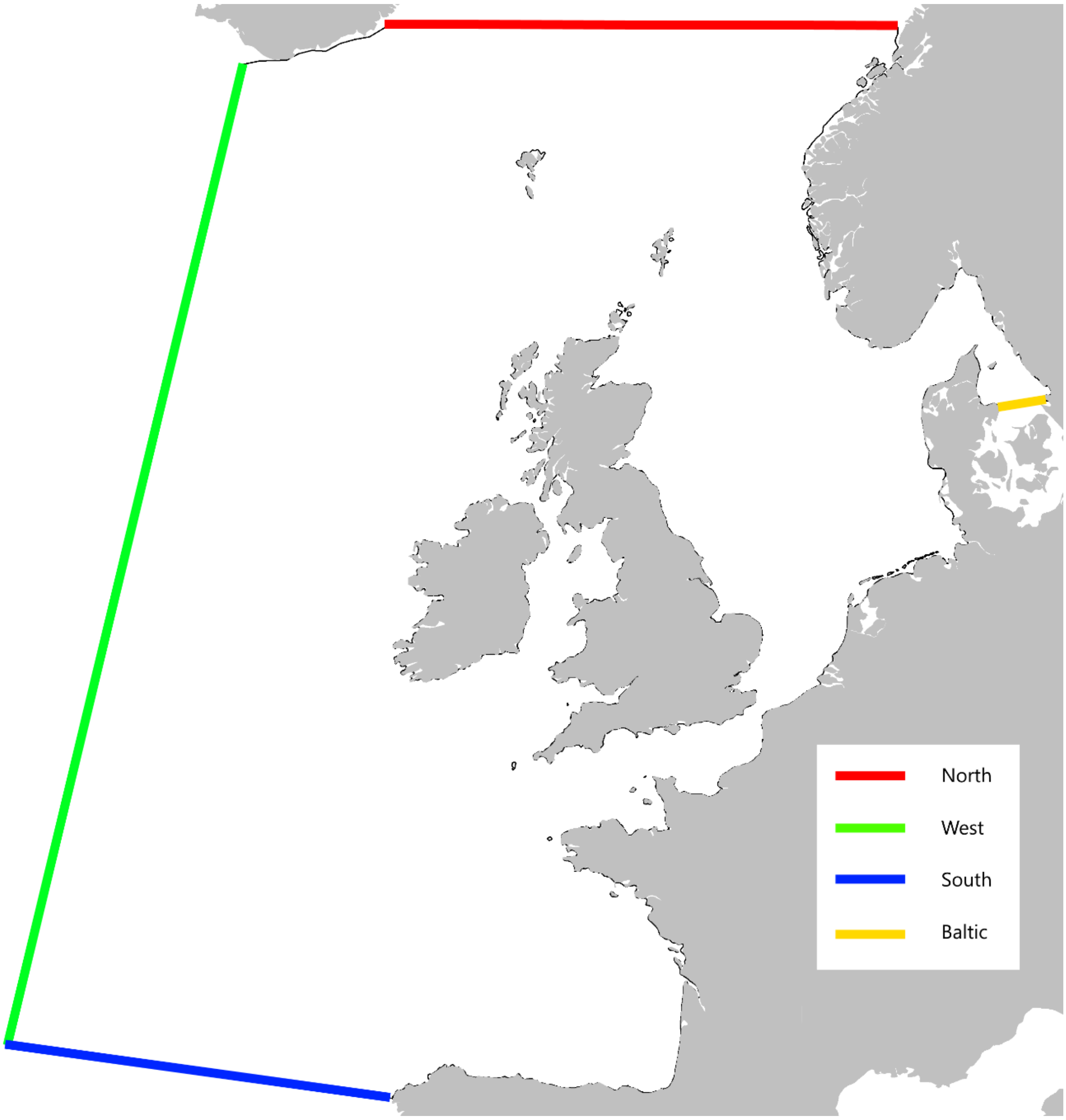

Figure 2. Locations of the open tidal boundaries

2.3.3 Meteorological forcing

The SEASTATES Tide and Surge Hindcast Model is driven by wind and pressure fields sourced from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) (http://rda.ucar.edu/datasets/ds093.1/) and Climate Forecast System v2 (CFSv2) (http://rda.ucar.edu/datasets/ds094.1/) hindcast databases. The data archive is managed by the National Center for Atmospheric Research (NCAR).

The meteorological data are available at hourly time steps, which are linearly interpolated by the model to inform sub-hourly points in the simulation.

The spatial resolution of the source data is:

- Winds: 0.2 degrees (approximately 22.2 by 12.7 km in the model extent); and
- Pressure: 0.5 degrees (approximately 55.6 by 31.9 km in the model extent).

2.3.4 Roughness

In the marine environment, bed roughness naturally varies as a result of differences in seabed type. For example, rocky, gravelly, sandy or muddy seabed types can be expected to present varying amounts of friction; the additional presence of bedforms and other macro scale seabed features will further increase friction at the seabed.

Bed roughness in the model describes the friction from the seabed 'felt' by moving water. Changing the magnitude of bed roughness locally affects the rate at which water moves in that area and so can affect tidal water level range and phasing, and (mainly the speed of) tidal currents. Applying spatially varying bed roughness within the model domain can produce a more complex effect. As such, bed roughness is a key variable in the model that can be varied to optimise the local model validation in comparison to coincident measured data.

A spatially varying bed roughness map informed by both water depth and seabed type is used in the model.

2.4 Hindcast database parameters

The following parameters are available from the SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database:

- Water level elevation;
- Depth averaged current speed; and
- Depth averaged current direction.

Data are available for the total (tide and surge) condition and for the separate tide and surge components.

Data are available at 10 minute intervals, providing a suitably detailed representation of tidal and non-tidal variation, and better resolving the peak high and low waters of the tide.

The local spatial resolution of the model is dependent on the location(s) of interest (see Section 2.2).

3 Tide and Surge Model Validation

3.1 Validation data

A variety of primary (observed) and secondary (derivative) data were compared with the model results to assess the accuracy of the model in reproducing tidal and surge behaviour. Data sources used are listed below:

- Water Levels:
  - UK tide gauges from National Tide and Sea Level Facility (NTSLF) (https://www.ntslf.org/);
  - French tide gauges from service hydrographic et oceanographic de la marine (SHOM) (http://data.shom.fr/);
  - Norwegian tide gauges from Kartverket (http://kartverket.no/);
  - TotalTide software, tidal co-range and co-phase charts, and other tide table publications providing key tidal levels and offsets, as well as information on the general expected pattern of tidal propagation in the domain, from the Admiralty (https://www.admiralty.co.uk/).
- Current speed and directions:
  - Crown Estate Marine Data Exchange (http://www.marinedataexchange.co.uk/) various water level and current survey data from the development of wind farms in the UK.

The locations of all datasets used in the validation are shown in Figure 3. Water level stations are indicated by the blue icons, and current speed at direction locations are indicated by the orange icons. More detailed maps of individual areas are provided in Section 3.3.1.

Details of the various datasets are provided in Section 3.1.1 and 3.1.2.

Figure 3. All model validation locations: (blue) water levels; (orange) current speeds

3.1.1 Tide Gauge water level data

Observations of (total) water level elevation from 67 tide gauges in the model extent have been considered when validating the accuracy of the hindcast.

Observations by tide gauges as well as harmonically predicted astronomical tidal elevation are available from 42 locations in the UK, from NTSLF (https://www.ntslf.org/). Of the available locations, two stations (Harwich and Sheerness) have recording quality issues during the chosen validation period, leaving 40 stations available. These are:

- Lerwick
- Wick
- Aberdeen
- Leith
- North Shields
- Whitby
- Immingham
- Cromer
- Lowestoft
- Dover
- Newhaven
- Portsmouth
- Bournemouth
- Weymouth
- Devonport
- Newlyn
- St. Marys
- Ilfracombe
- Hinkley Point
- Portbury
- Newport
- Mumbles
- Milford Haven
- Fishguard
- Barmouth
- Holyhead
- Llandudno
- Liverpool
- Heysham
- Workington
- Port Erin
- Portpatrick
- Millport
- Tobermory
- Ullapool
- Stornoway
- Kinlochbervie
- Portrush
- Bangor
- St Helier

Observations by tide gauges are available from seven locations in France, from the SHOM online data service (http://data.shom.fr/). These are:

- Dieppe
- Dunkerque
- Le Conquet
- Le Havre
- Les Sables D'Olonne
- Roscoff
- Saint Malo

Observations by tide gauges are available from locations on the Norwegian coast, from Se havnivå (http://www.kartverket.no/en/sehavniva/). Three tide gauge locations were identified and the data extracted for model validation. These are:

- Austre Skogsfjord
- Harøyfjorden
- Humresundet

Observations by tide gauges are available from locations on the Irish coast, from Ireland's Digital Ocean portal (http://www.digitalocean.ie/). 15 tide gauge locations were identified and the data extracted for model validation. These are:

- Aranmore
- Ballycotton
- Ballyglass
- Castletownbere
- Dublin
- Dundalk
- Dunmore
- Galway
- Howth
- Killybegs
- KishBank
- MalinHead
- Skerries
- Sligo
- Wexford

3.1.2 Crown Estate current data

The Crown Estate holds an archive of metocean information containing records from measurement campaigns undertaken as part of wind farm developments. There is a requirement that developers make these data publicly available and so there are no licence restrictions on the use of these data.

Databases containing current data were identified and acquired from the Crown Estate. Datasets containing processed current speed and direction data were prioritised over raw data measurement files.

Data from six sites around the English coastline were identified and processed for comparison with the hindcast model data (shown by the orange icons in Figure 3). This database provides a source of high quality measured data (in most cases lasting several months in duration) against which to compare the hindcast outputs. All comparisons have been undertaken using the 'Total' water measurements including both tide and surge influences.

Table 2. Measured Current Meter Deployments

Name	Latitude	Longitude	Start Date	End Date
Zone 7	50.55362	-1.71957	Nov 2011	July 2012
Zone 9	53.62417	-4.31472	Jan 2011	Oct 2012
Blyth Demonstrator	55.14914	-1.46667	Jan 2011	Oct 2011
Race Bank	53.31457	0.746933	May 2006	Dec 2006
Docking Shoal	53.15772	0.647683	May 2006	Apr 2007
Gunfleet Sands	51.74023	1.278283	Jan 2002	Dec 2002

Note: The geographical locations in Table 2 are for the first deployment of each database – there is some local variation between measurement sites with multiple deployments. Records are not necessarily continuous between start and end dates, most measurement series consist of multiple deployments with some breaks in-between.

3.2 Water level validation

3.2.1 Approach

During the model development process, calibration of the SEASTATES Tide and Surge Hindcast Model has been achieved by varying the model coefficients (mainly bed roughness), boundary conditions and mesh refinement to obtain the best achievable fit between measured and predicted hydrodynamic characteristics at locations throughout the model domain. Comparisons have been made considering the total (tide and surge) level characteristics as well as the separate components of tidal and residual signal in order to more thoroughly assess the model capabilities.

The level of agreement between the SEASTATES Tide and Surge Hindcast Model and measurements has been assessed using two approaches:

- Visual comparisons between the model and observed data to assess the shape, trend, range and limits of model output and observed data; and
- Statistical comparison of the differences between the Tide and Surge Model and observed data to determine the degree to which the model fits the observations.

Validation statistics have been generated for a period of 15 days between 25 November 2013 and 10 December 2013. This period encompasses a spring and neap tide as well as being coincident with a significant surge event experienced along the east coast of the United Kingdom on the 5 December 2013.

3.2.2 Water level statistics

The following statistics have been calculated for all available gauge sites for the total, tide and surge components of water level:

- Mean difference: This is calculated by interpolating the measured data onto a regular timestamp coincident with the modelled output. The difference (model – measured) between coincident data points during the 15 day validation period is then calculated and an average of all differences is presented. A positive difference means the model tends to overestimate the level, while a negative value shows an underestimation;
- Mean absolute difference: The MAE measures the average magnitude of the errors in the modelled data in relation to the measurements, without considering their direction;
- Mean absolute difference as a percentage of the spring tidal range: This parameter has been calculated for the tide only component of water level validation;
- Root mean square difference: The RMSE is a quadratic scoring rule which measures the average magnitude of the difference. A value closer to 0 is the smallest error;
- Standard deviation of modelled – measured difference: measures the dispersion of the data values from the mean. For a normally distributed data set ~68% of the data will be within 1 standard deviation of the mean; and
- Correlation coefficient: Measures the statistical relationship between the modelled and hindcast datasets. A value of 1 represents a perfectly correlated dataset, while closer to 0 the statistical relationship is weaker.

3.3 Water level validation results

There is close visual agreement between measured and modelled water level data for total water level, tidal water level and surge water level. There is no clear regional bias evident from the time-series comparisons (presented in Figure 5 to Figure 76). The validation statistics provided in Sections 3.3.2 to 3.3.4 provide the details of the validation performance at individual station locations. Water level validation statistics were calculated for a period between 25 November 2013 and 10 December 2013.

In summary there are no clear regional trend in the model performance. The mean differences between the measured and modelled water levels over the 15 day validation period are very small in absolute and relative terms across the range of locations for the tide, surge and total water level components of sea surface height. For the English and French coastlines mean differences are less than 0.02 m. The Irish and Norwegian gauges show a slightly greater difference up to a maximum of 0.09 m for the Norwegian surge data. Looking at the time-series there appears to be a consistent offset in the surge levels which may be related to the reference datum being different between datasets. The resolution of the model around the Norwegian coast may also not be sufficient to capture unique environments within the entrances to fjords, and a number of small islands around the coast are not included in the model setup due to grid size. The hindcast therefore provides and overview in this area and calibrates well but may require further refinement via a local model if a site specific study is required here.

3.3.1 Water level time-series validation plots

Time-series show very close agreement between the modelled and measured total and tidal water levels. At the time of peak surge events the hindcast captures the magnitude of the surge events accurately. This is true of the majority of validation sites (see Table 3 to Table 14). The detail and variation of the surge shape is not always completely captured by the model, which is likely due to the hourly temporal resolution of the input data driving the surge component: Sub-hourly variation in water surface cannot be captured without the data to inform it.

North and East Scotland

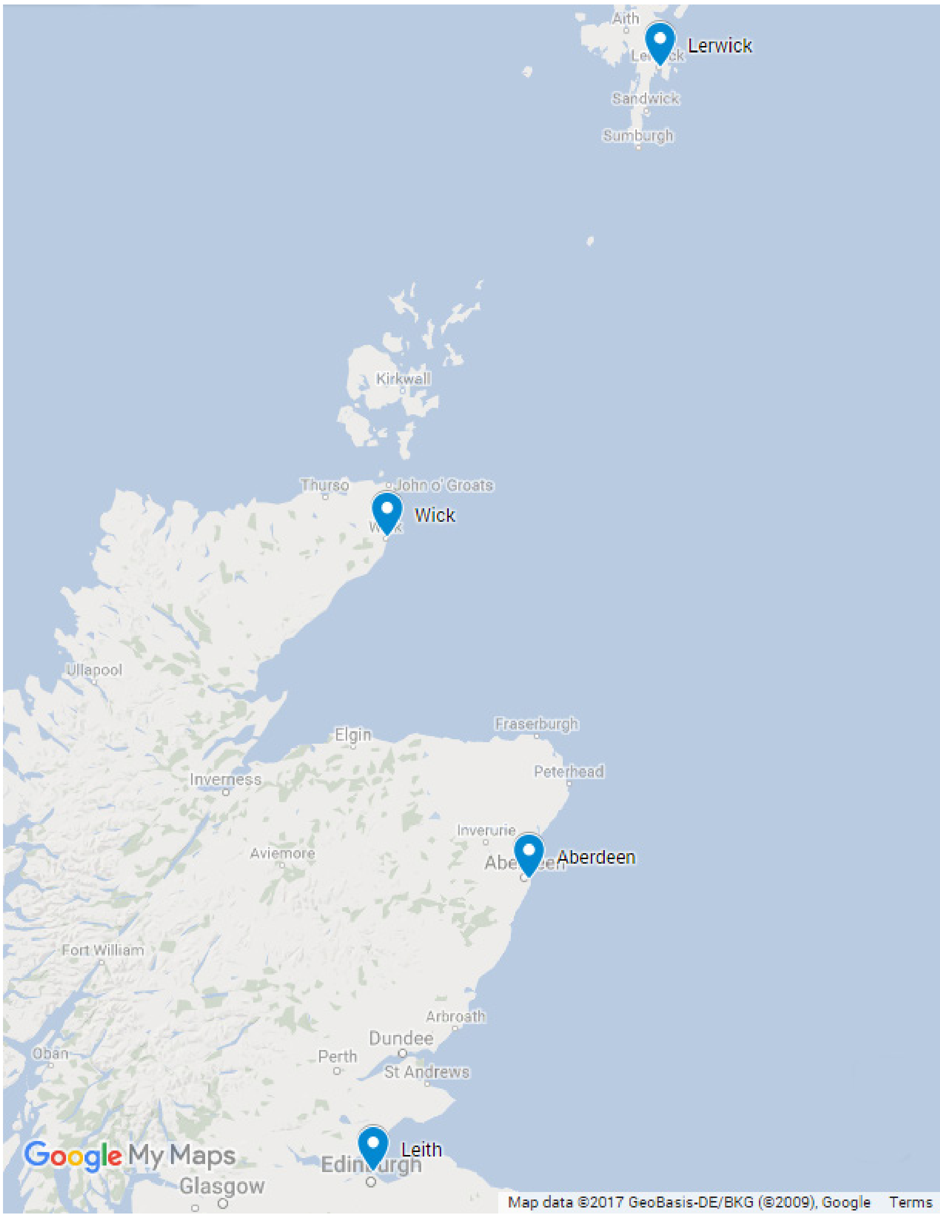

Figure 4. North and East Scotland validation locations

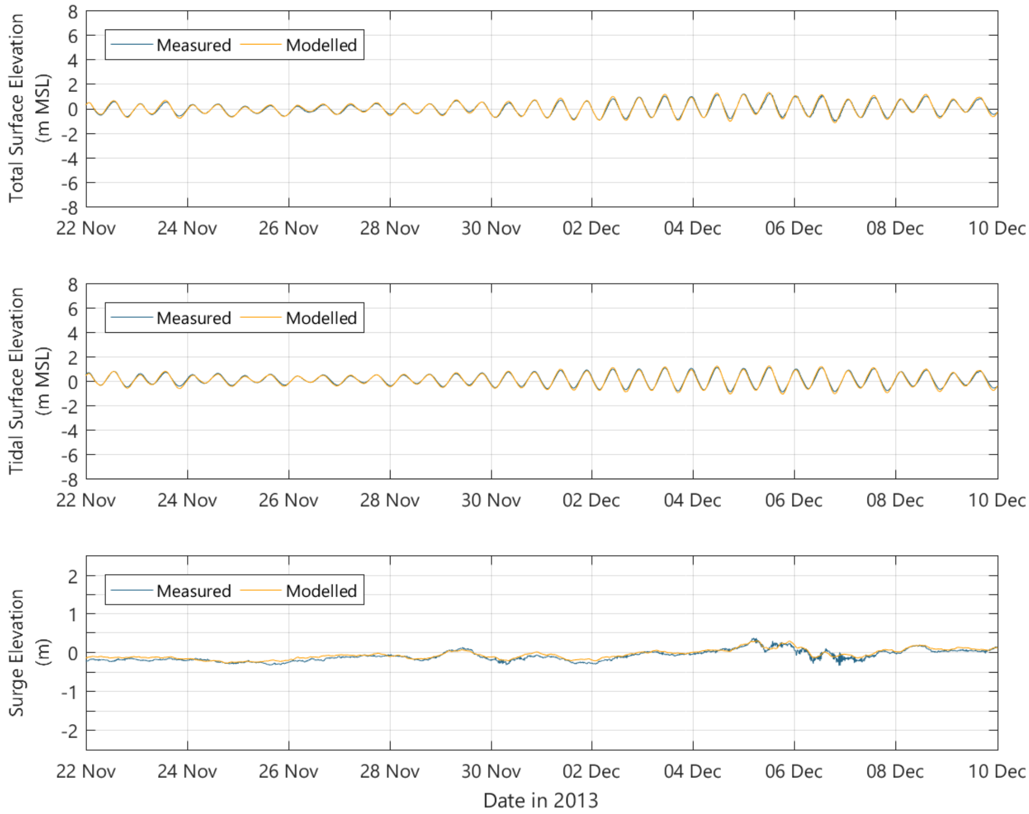

Figure 5. Model validation at Lerwick

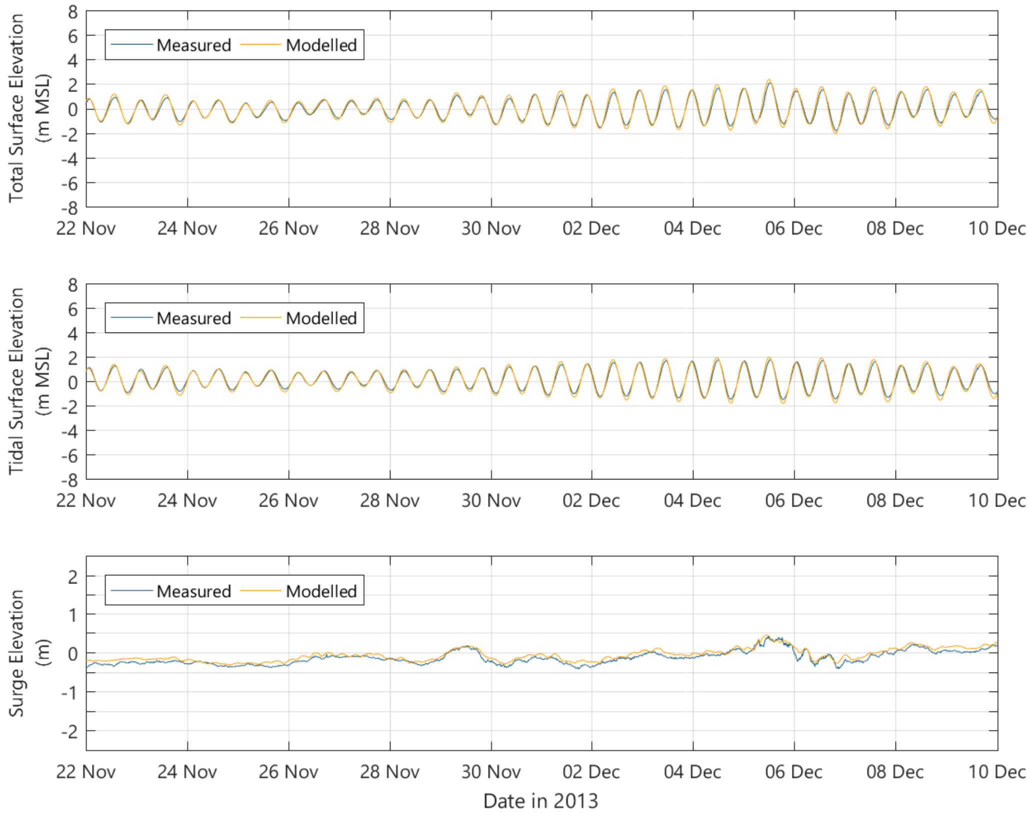

Figure 6. Model validation at Wick

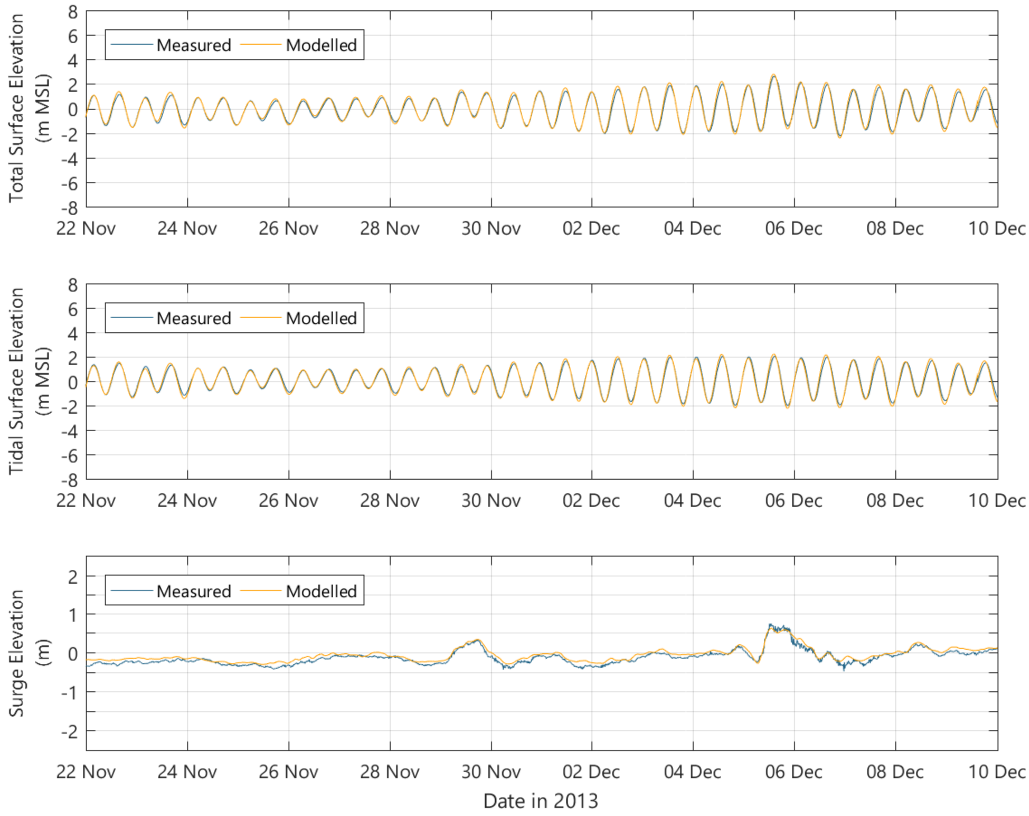

Figure 7. Model validation at Aberdeen

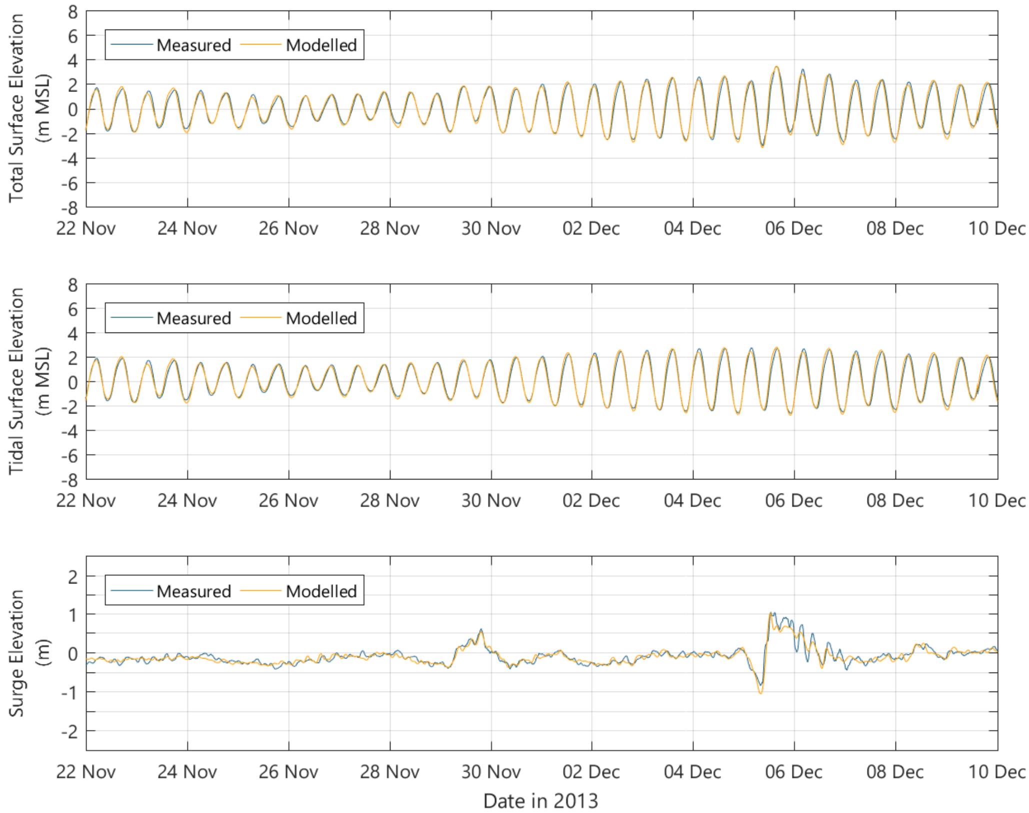

Figure 8. Model validation at Leith

England East coast

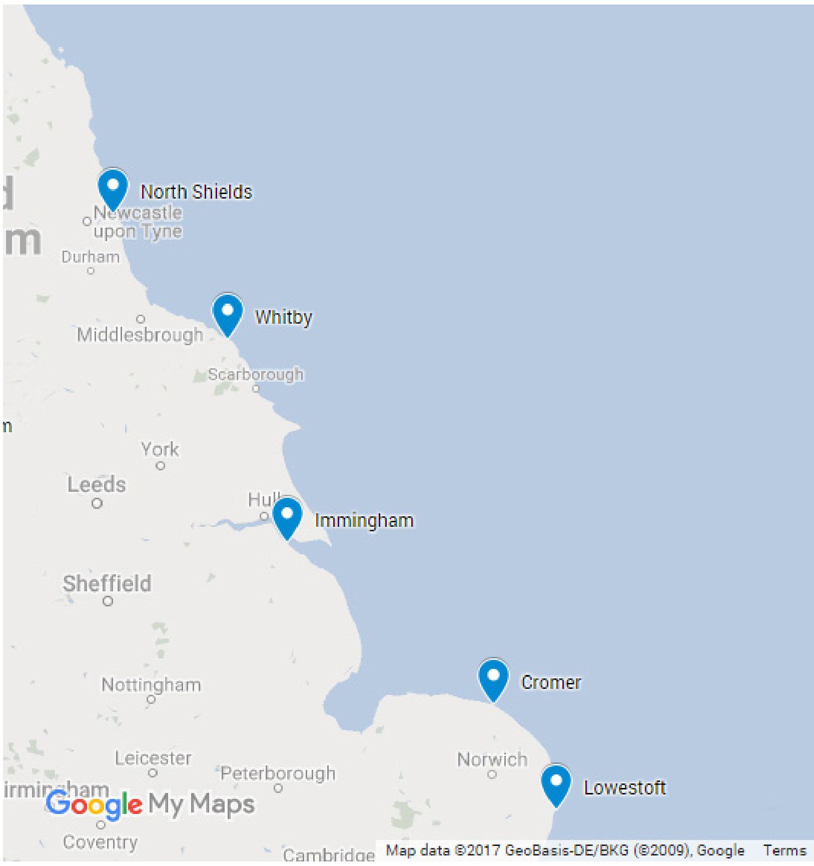

Figure 9. England East coast validation locations

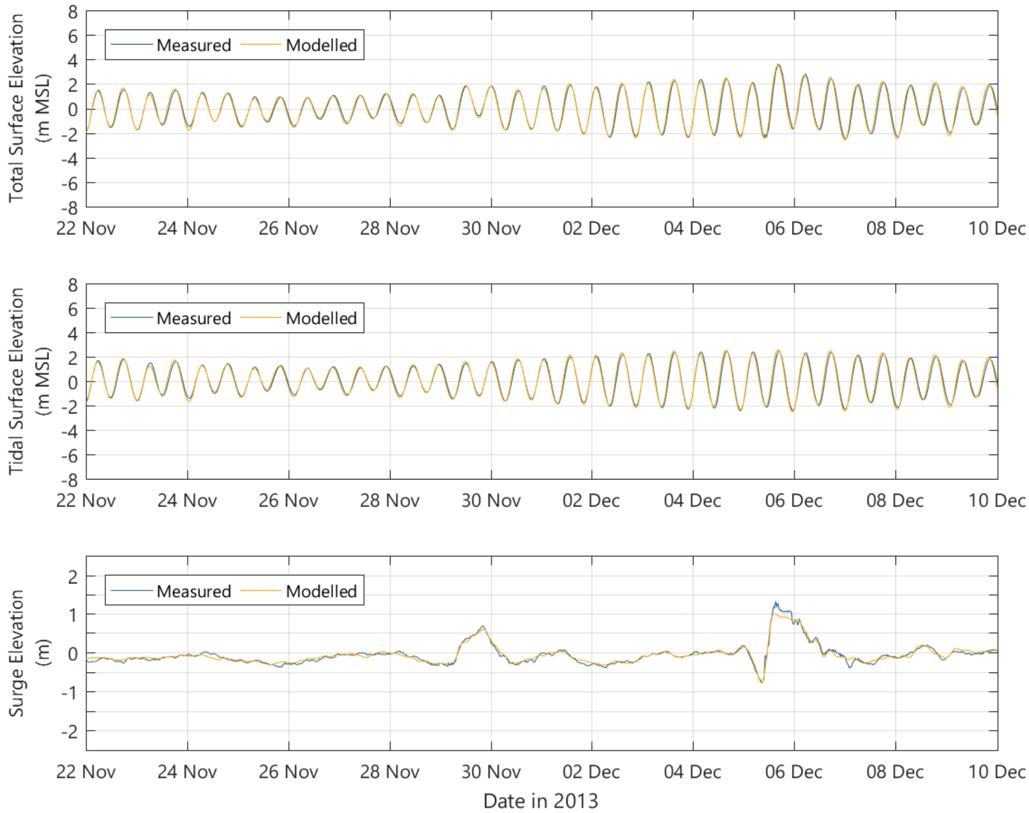

Figure 10. Model validation at North Shields

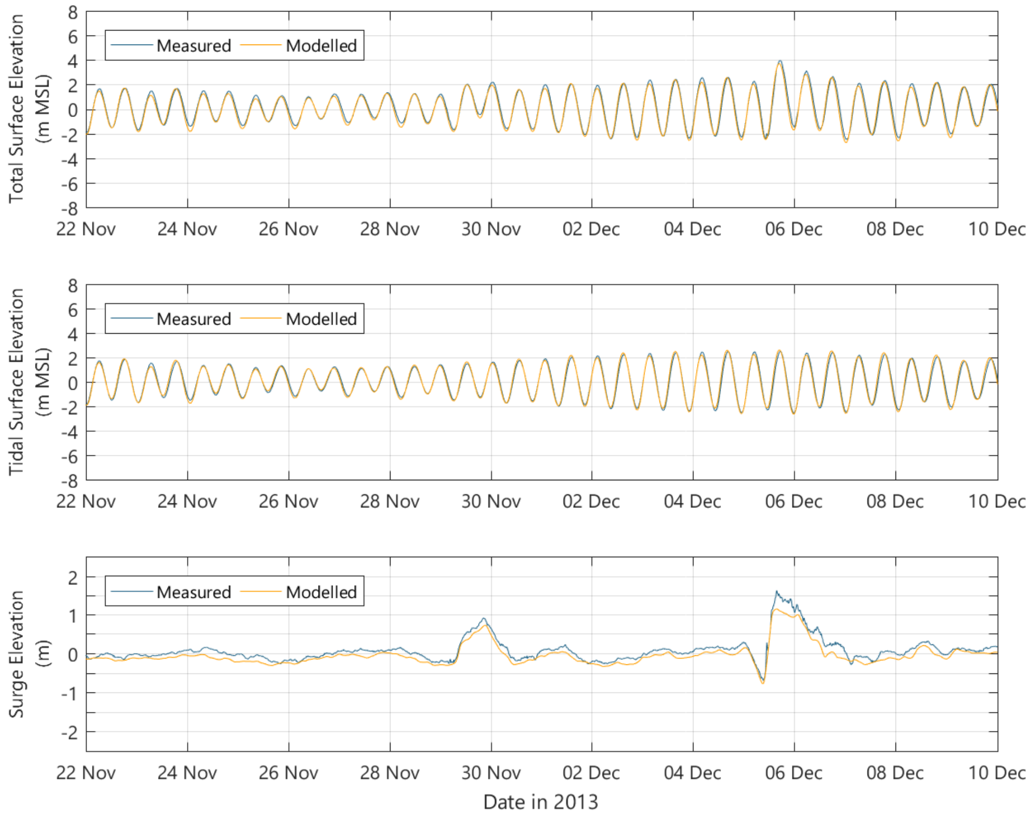

Figure 11. Model validation at Whitby

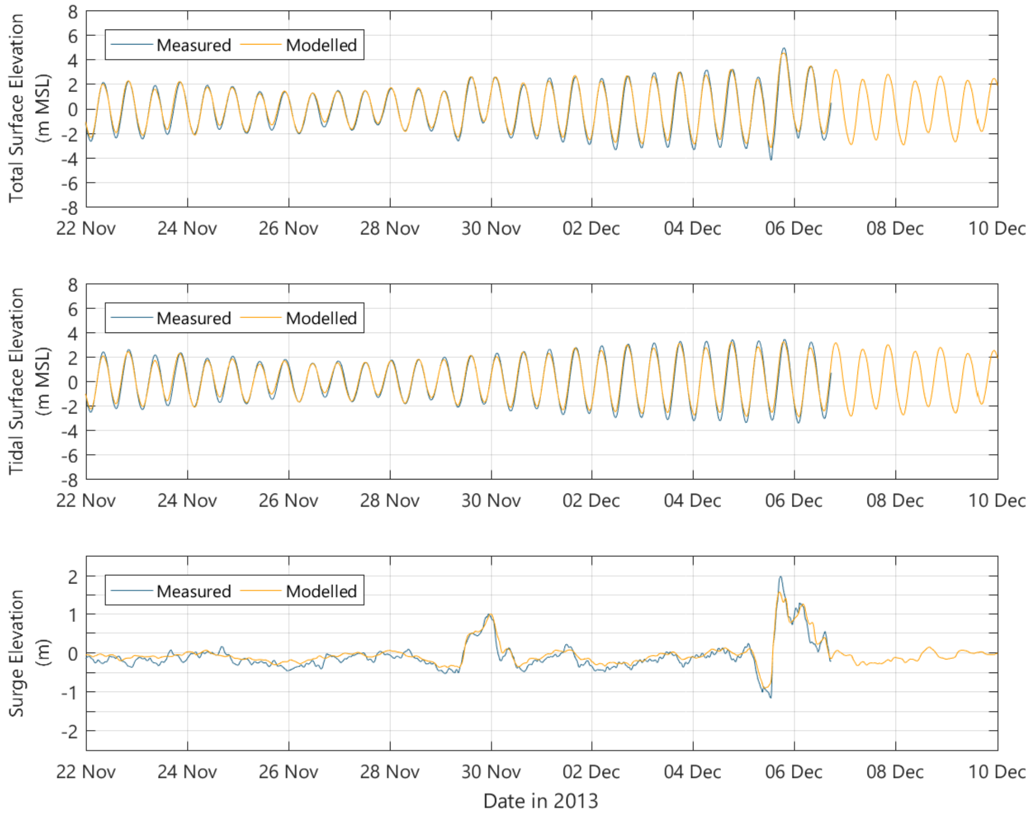

Figure 12. Model validation at Immingham

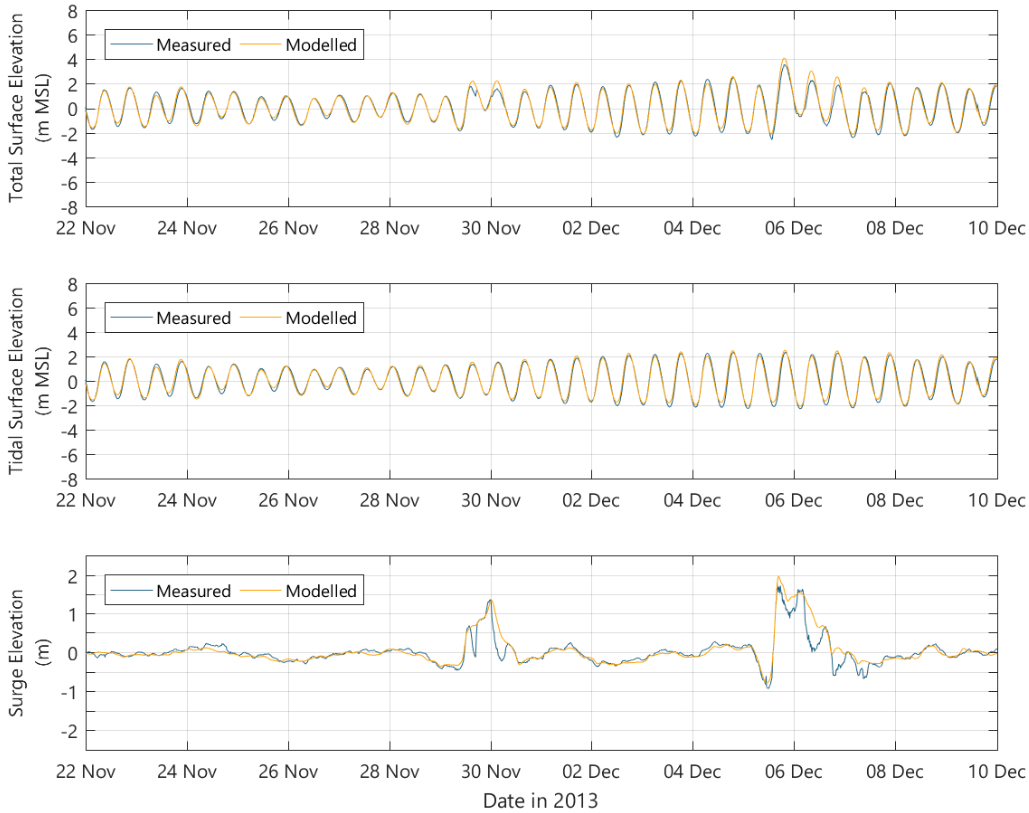

Figure 13. Model validation at Cromer

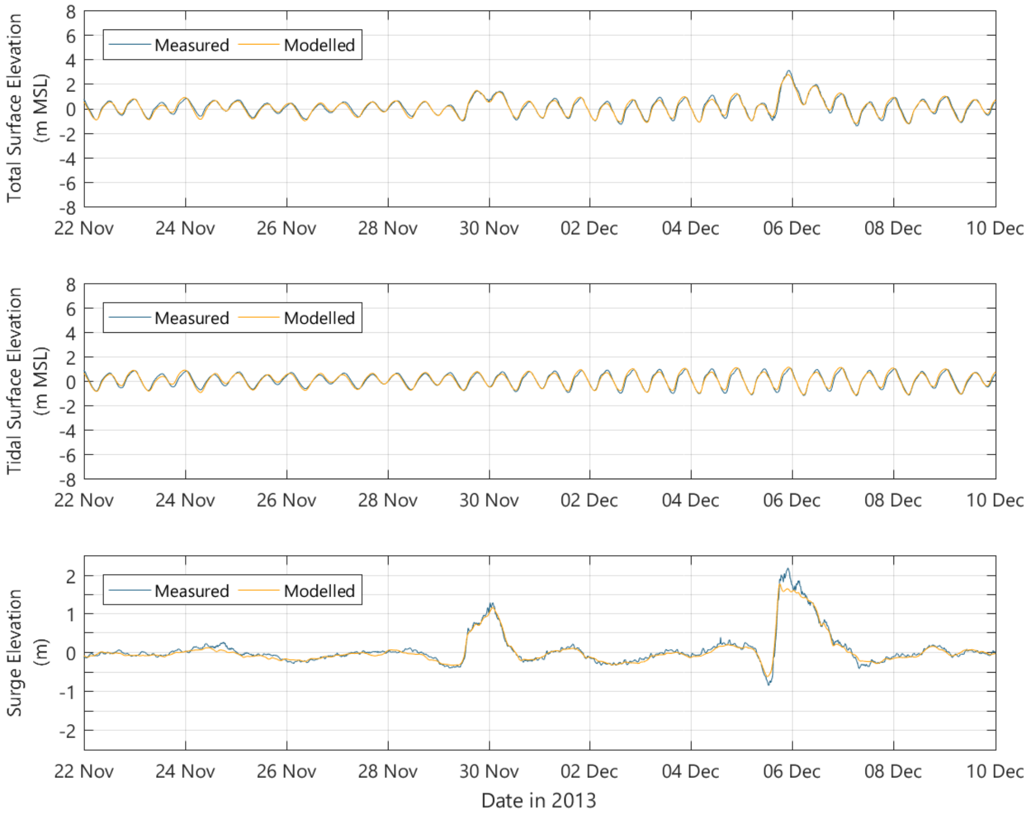

Figure 14. Model validation at Lowestoft

England South coast

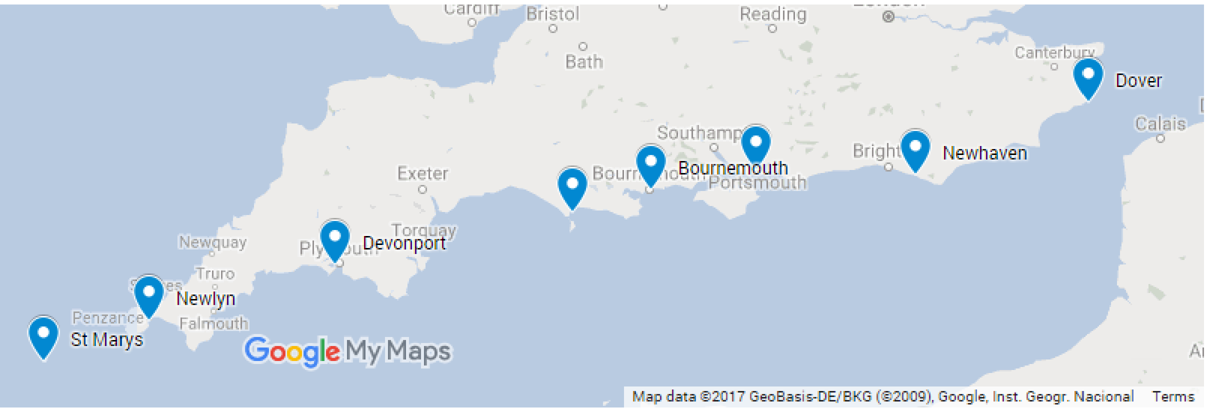

Figure 15. England South coast validation locations

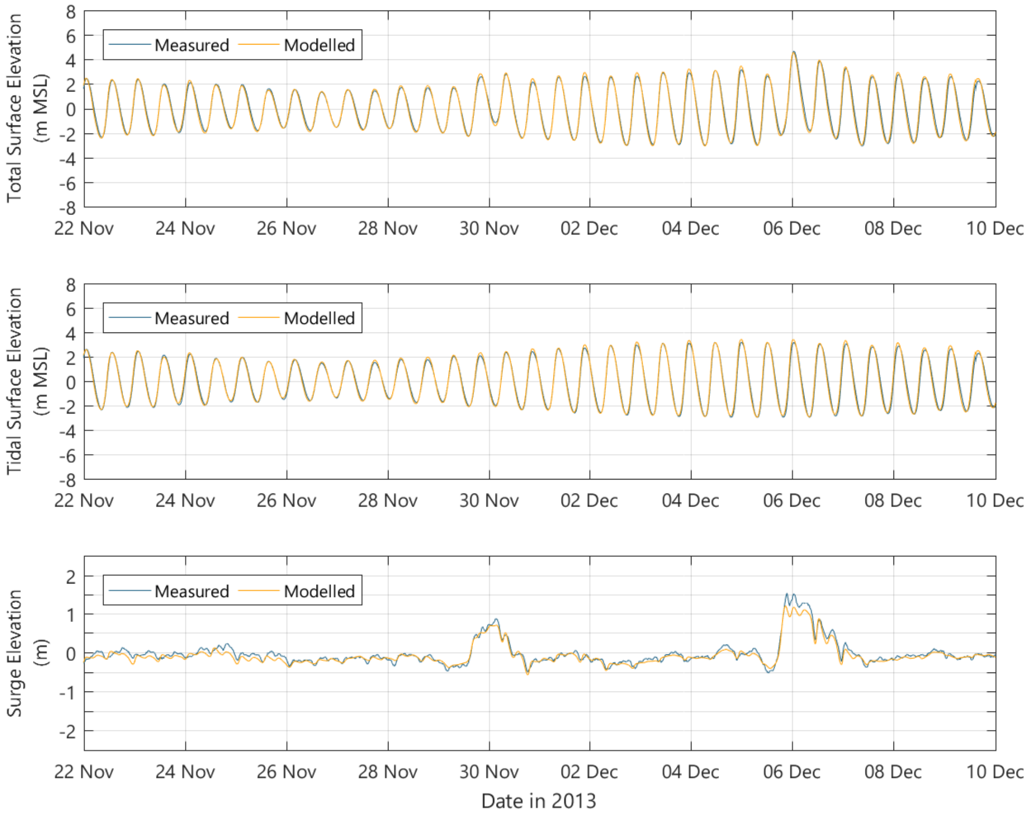

Figure 16. Model validation at Dover

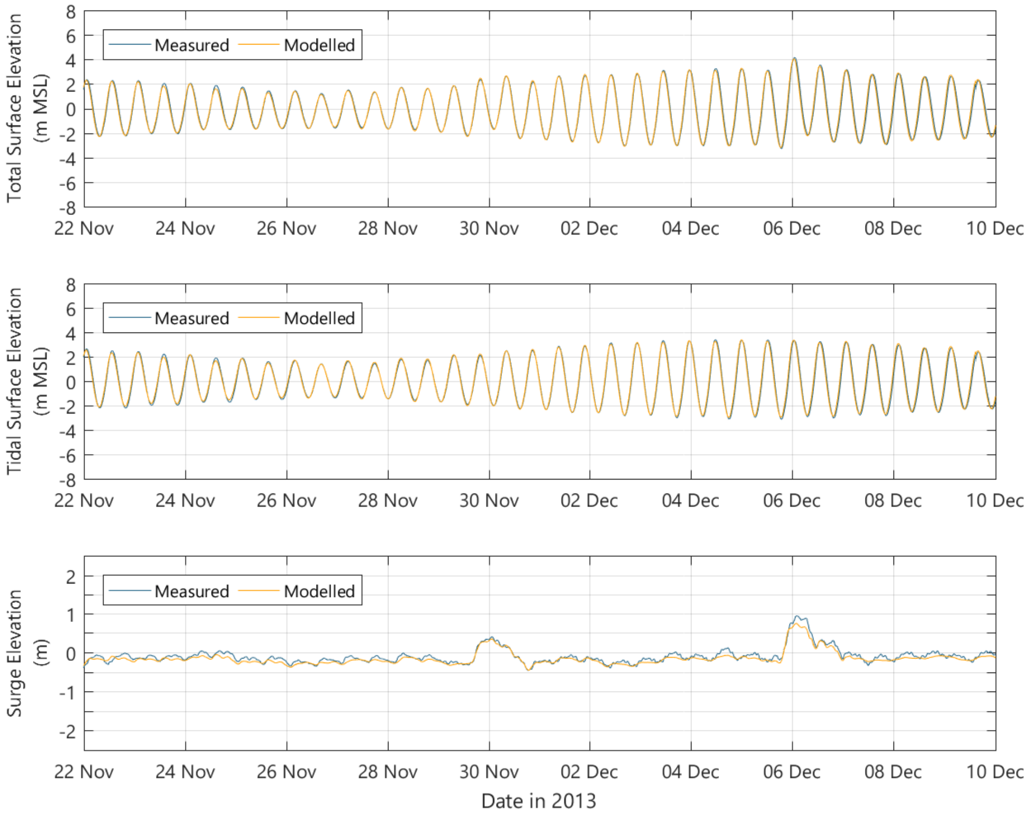

Figure 17. Model validation at Newhaven

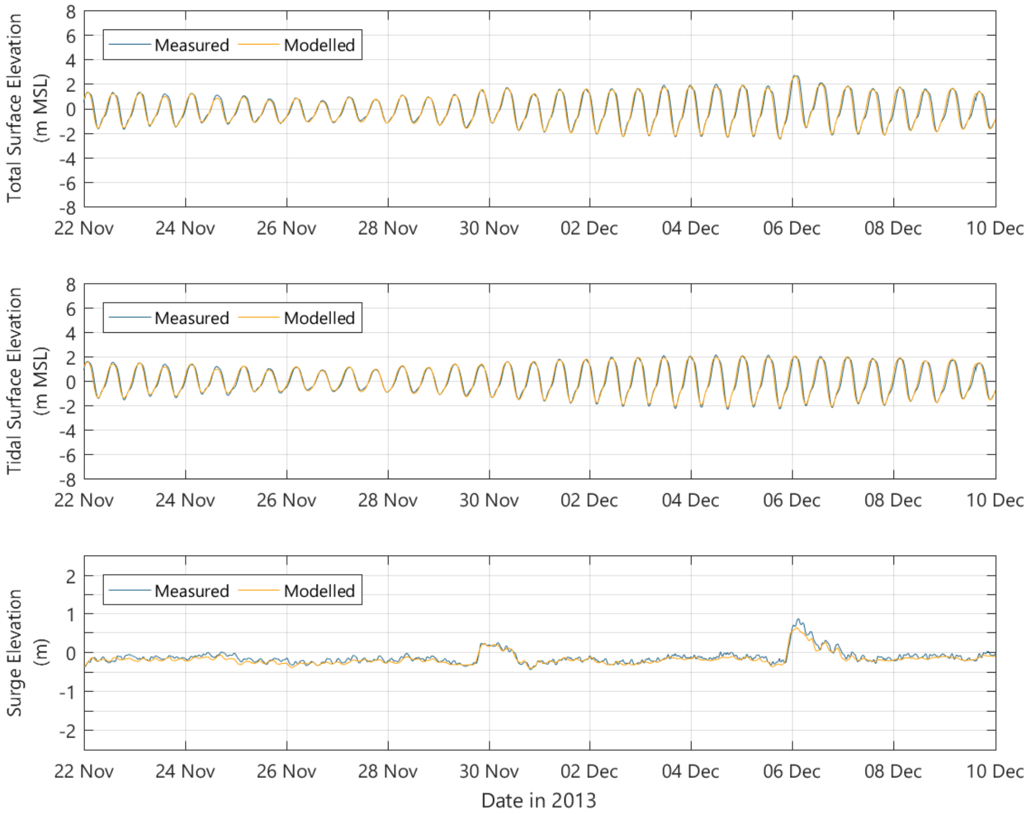

Figure 18. Model validation at Portsmouth

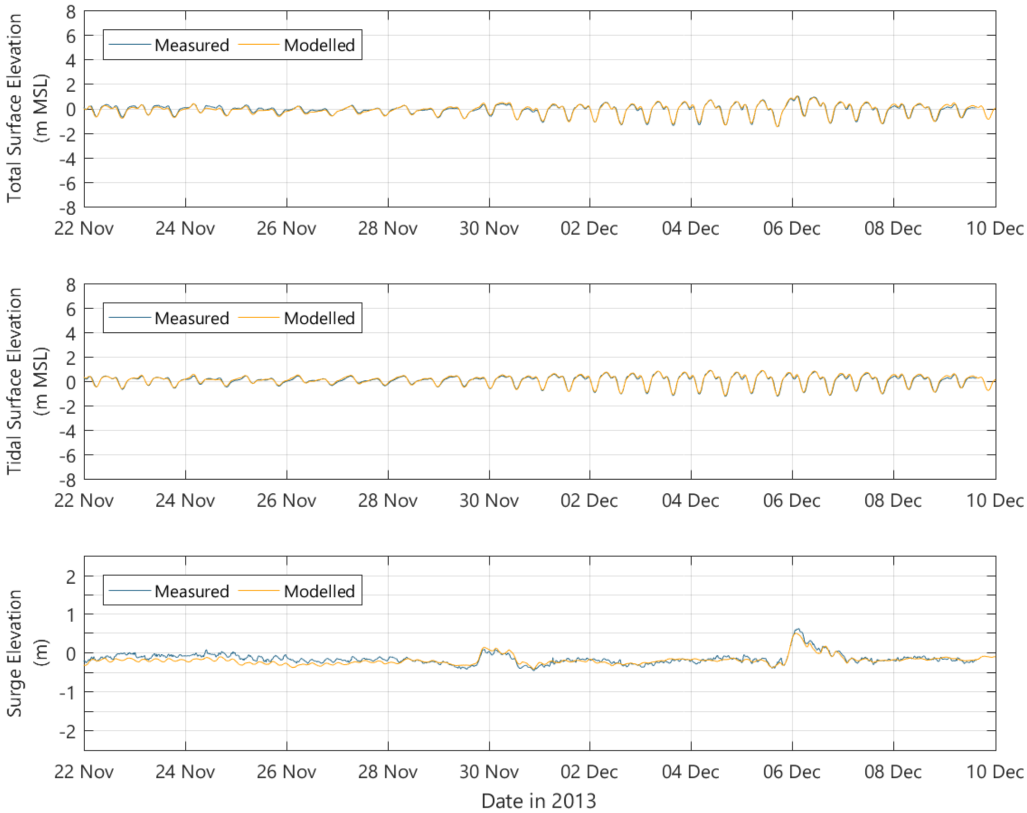

Figure 19. Model validation at Bournemouth

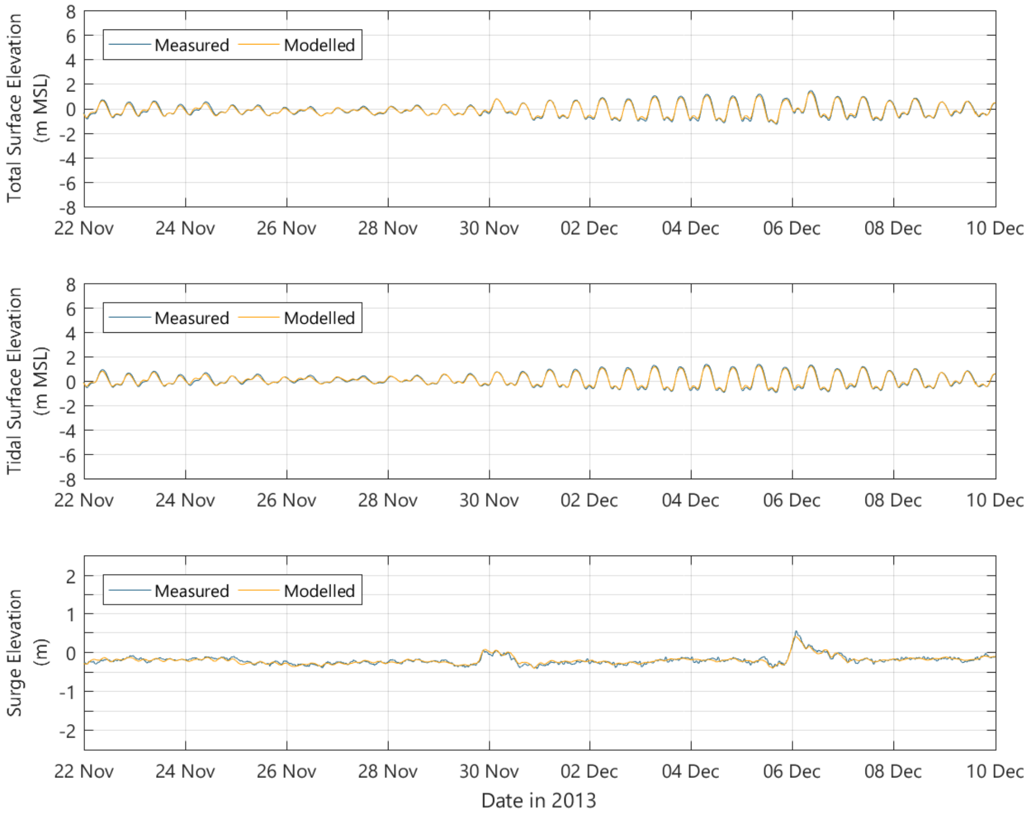

Figure 20. Model validation at Weymouth

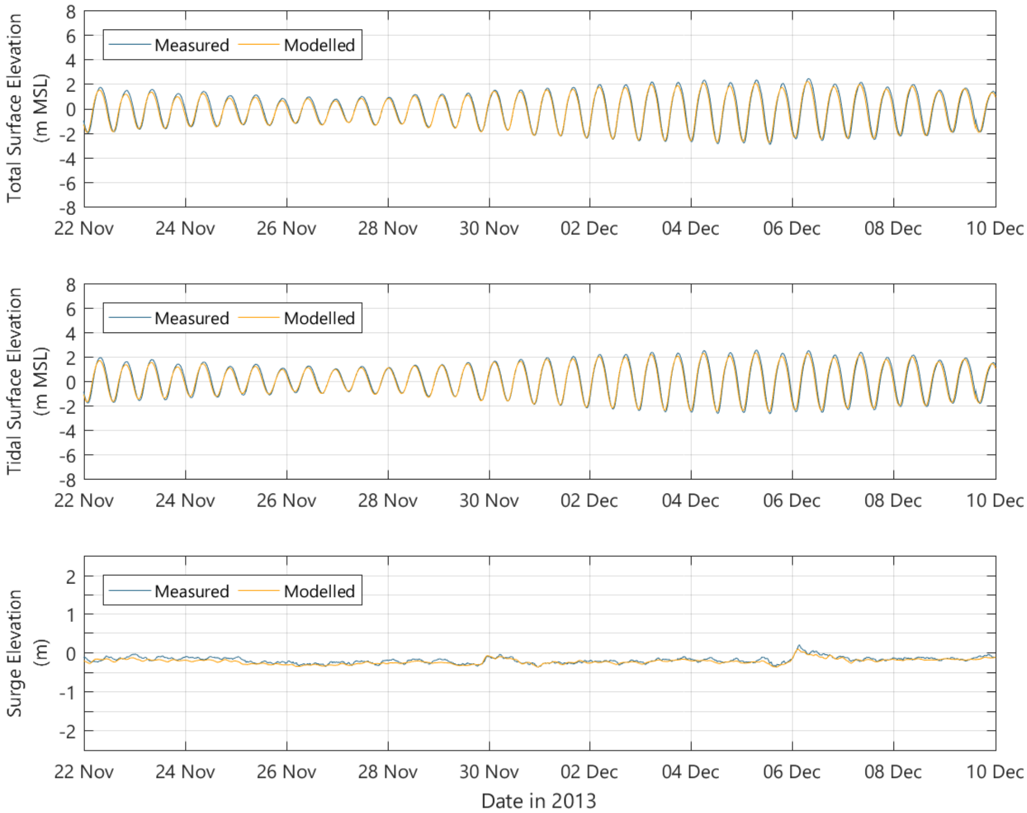

Figure 21. Model validation at Devonport

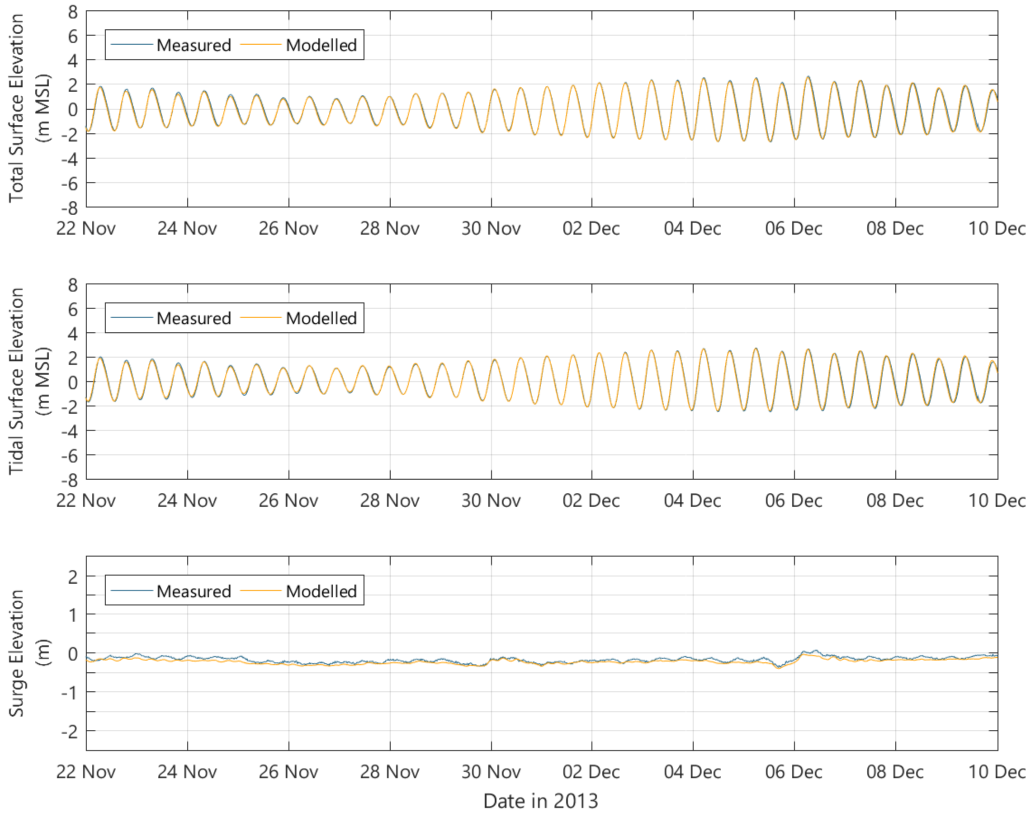

Figure 22. Model validation at Newlyn

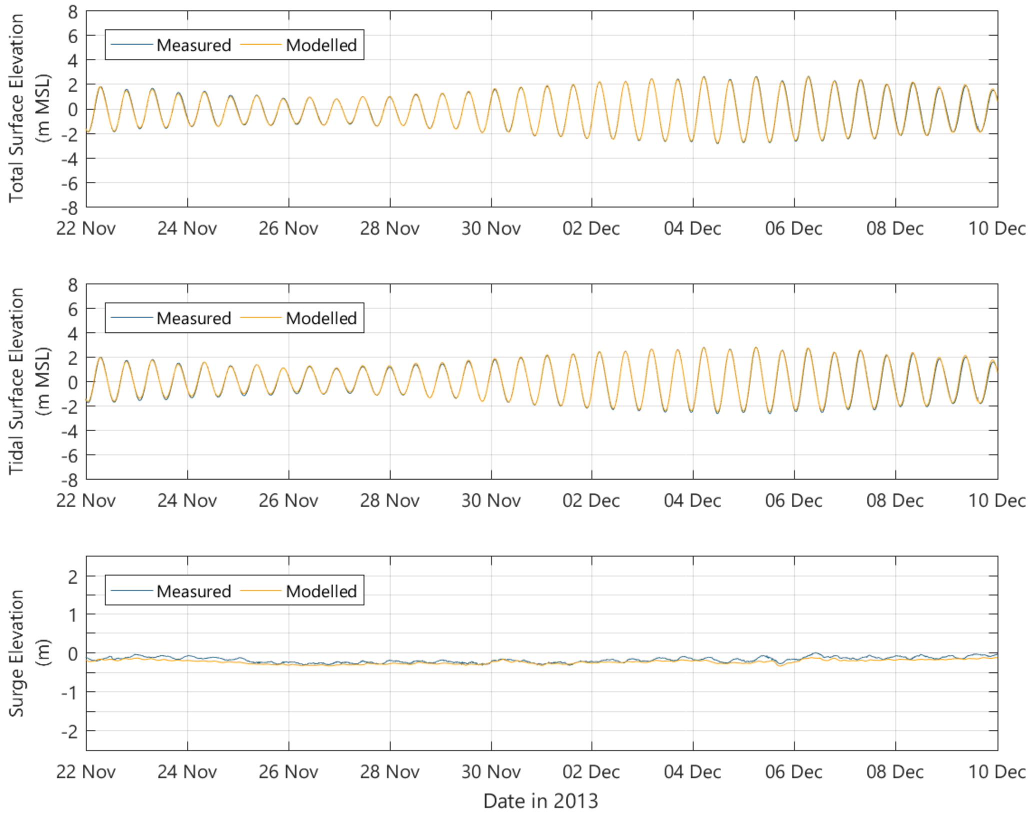

Figure 23. Model validation at St Marys

The Bristol Channel and the Severn Estuary

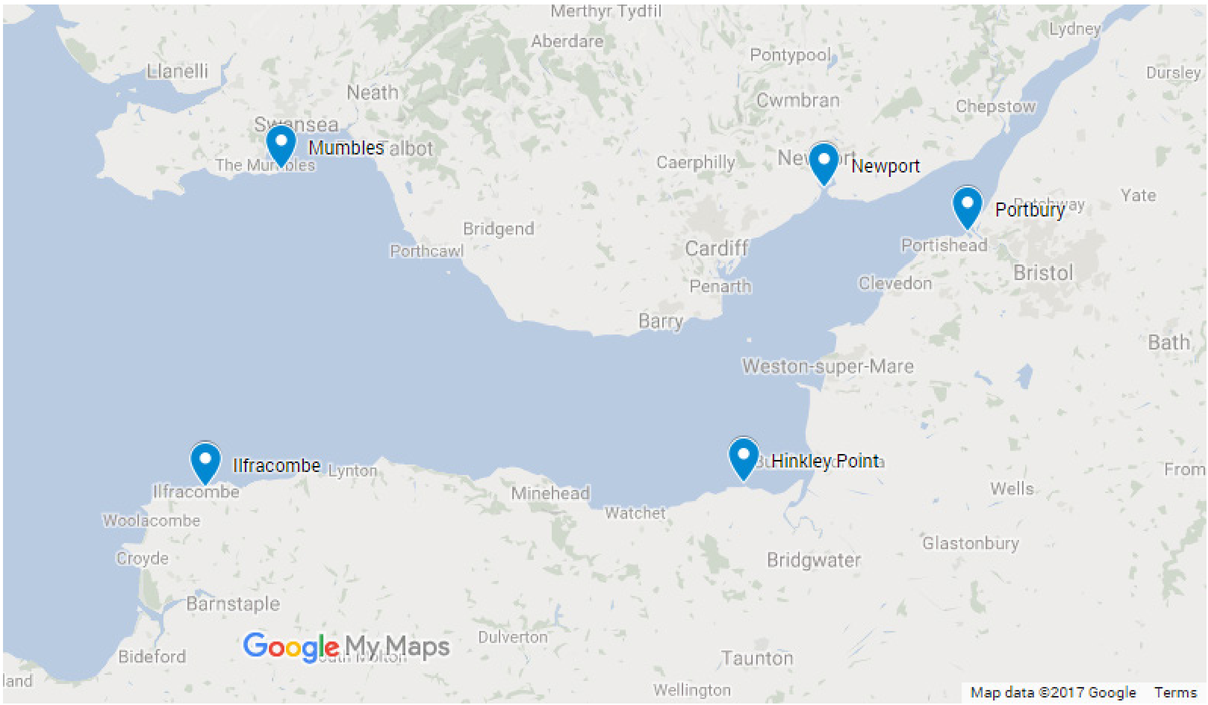

Figure 24. Bristol Channel and Severn Estuary validation locations

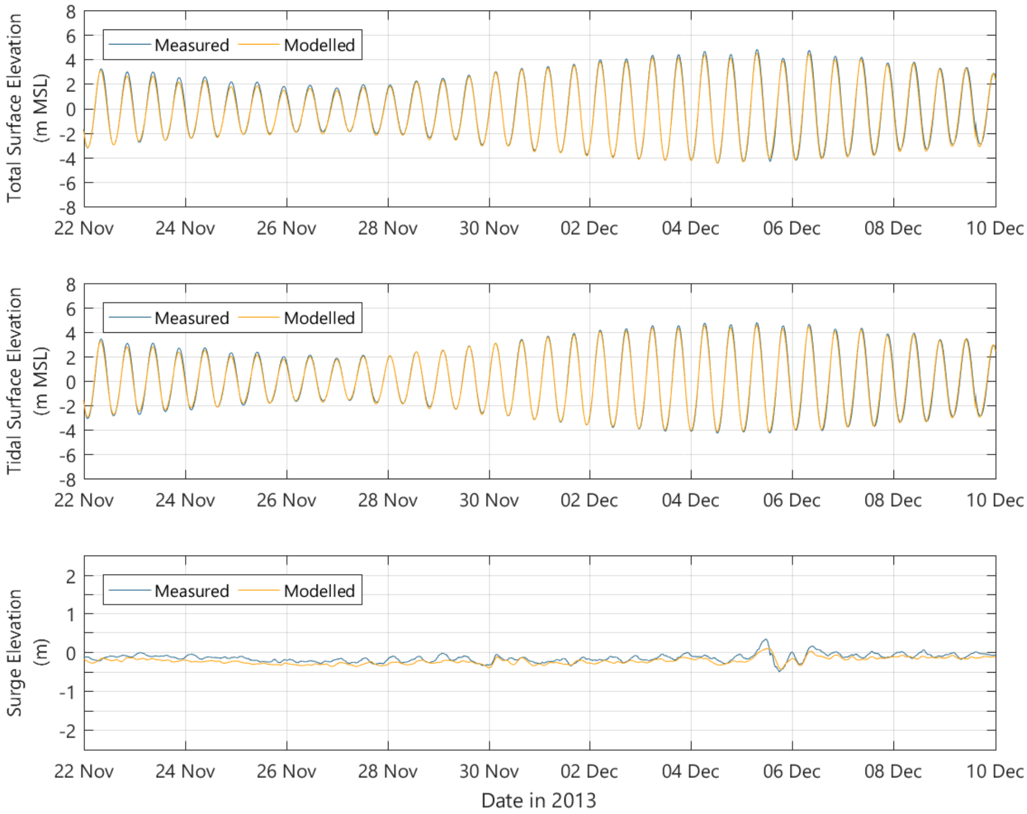

Figure 25. Model validation at Ilfracombe

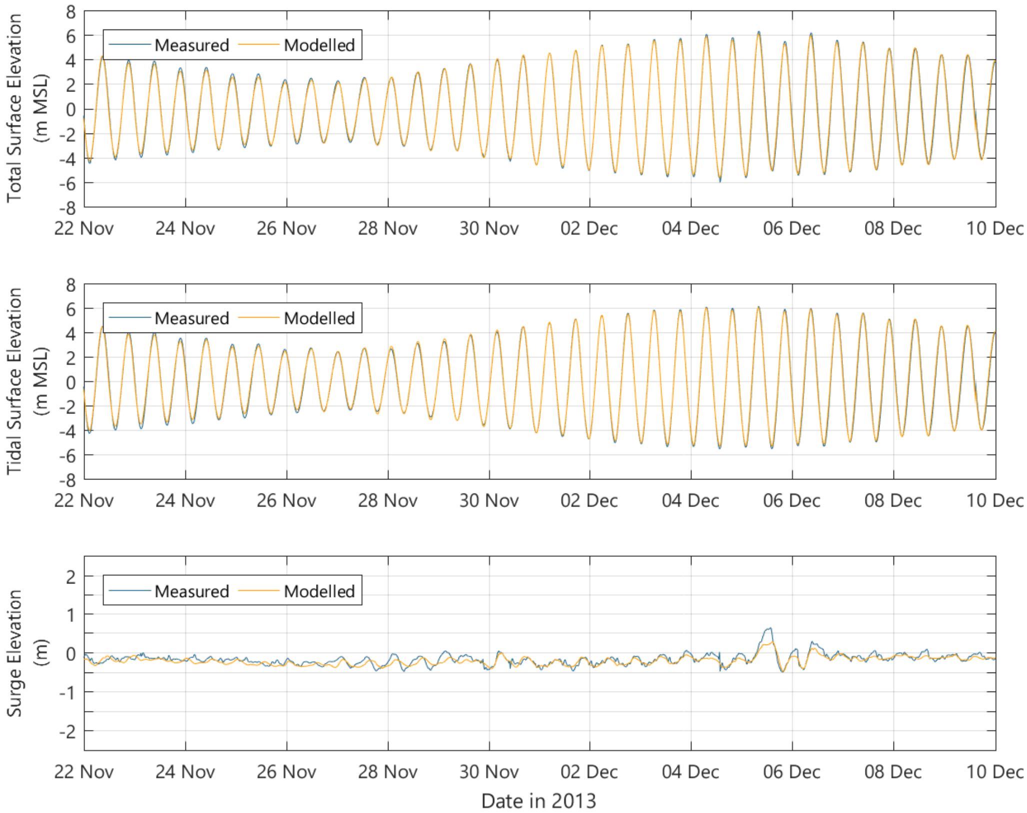

Figure 26. Model validation at Hinkley Point

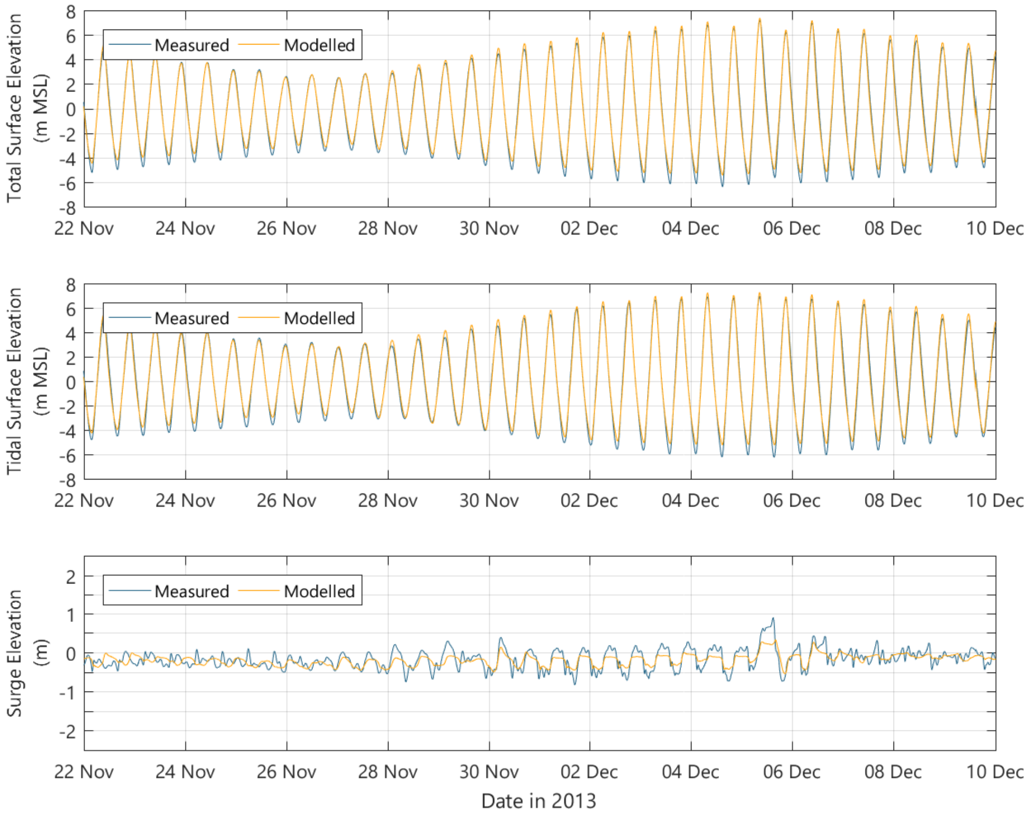

Figure 27. Model validation at Portbury

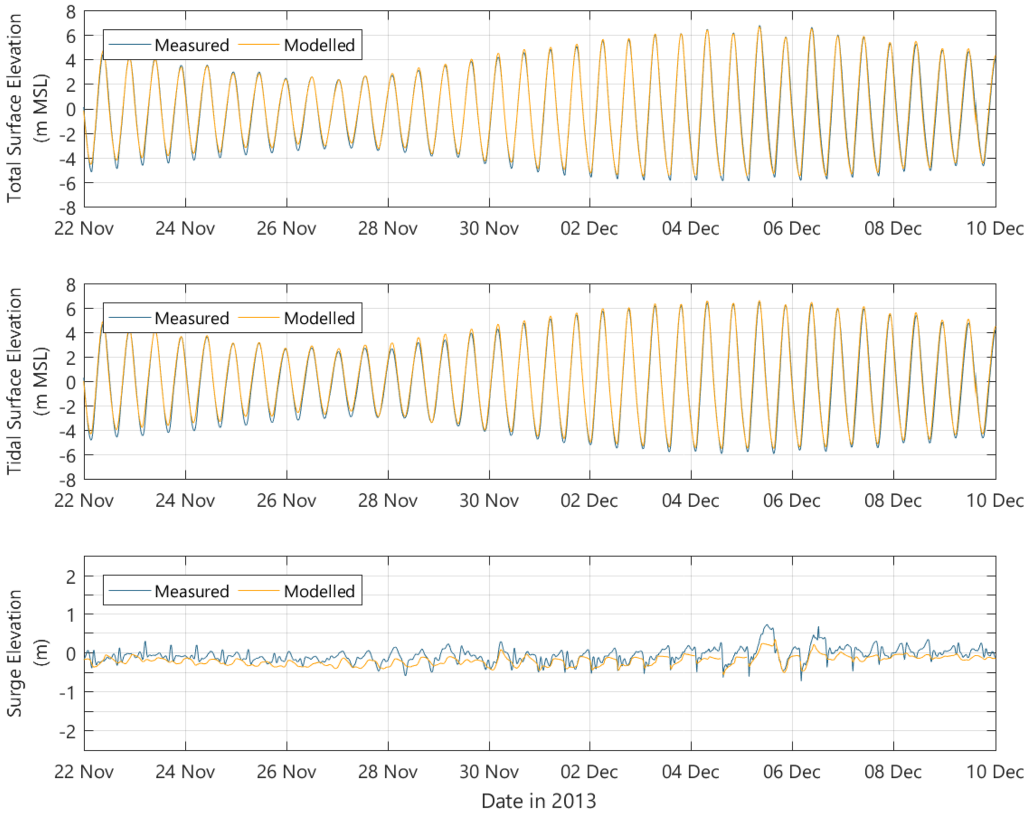

Figure 28. Model validation at Newport

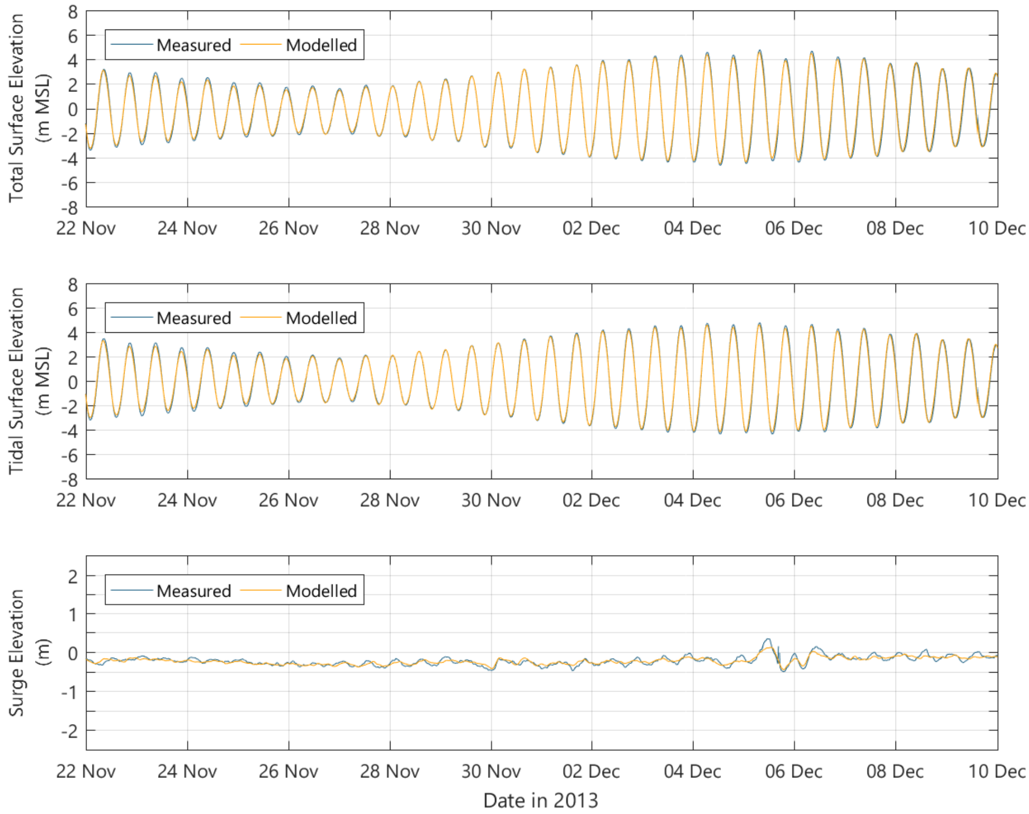

Figure 29. Model validation at Mumbles

Wales

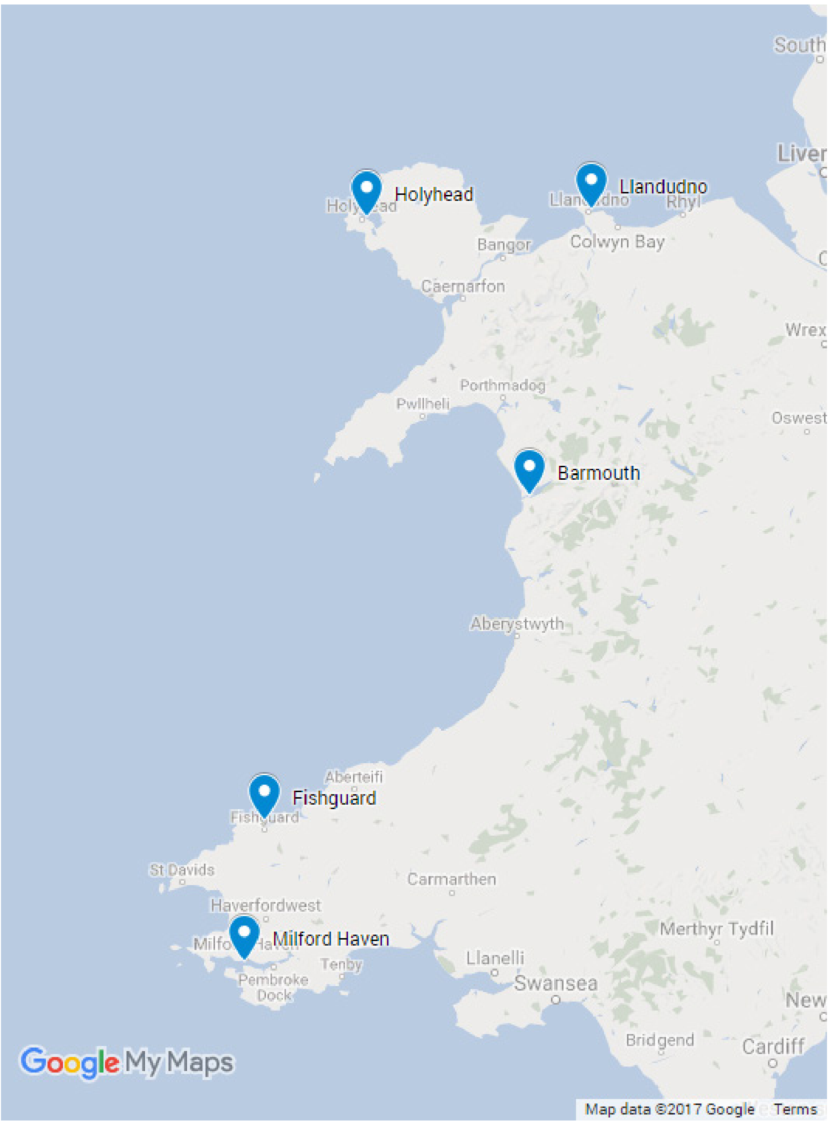

Figure 30. Wales validation locations

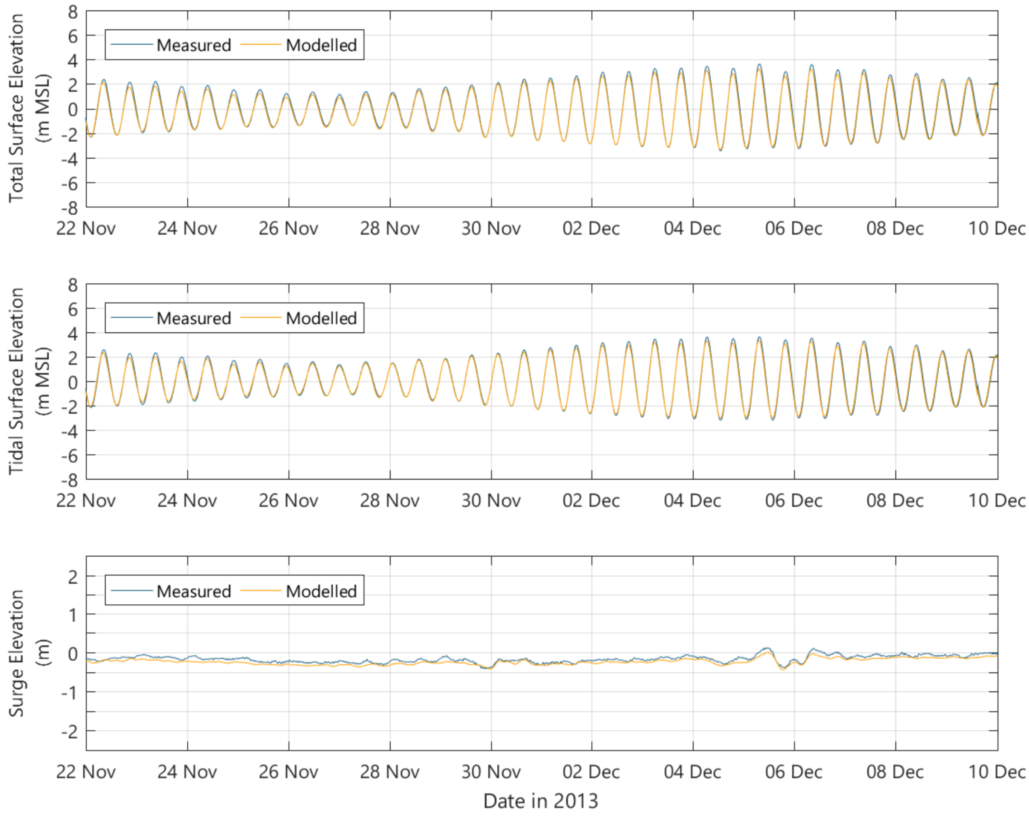

Figure 31. Model validation at Milford Haven

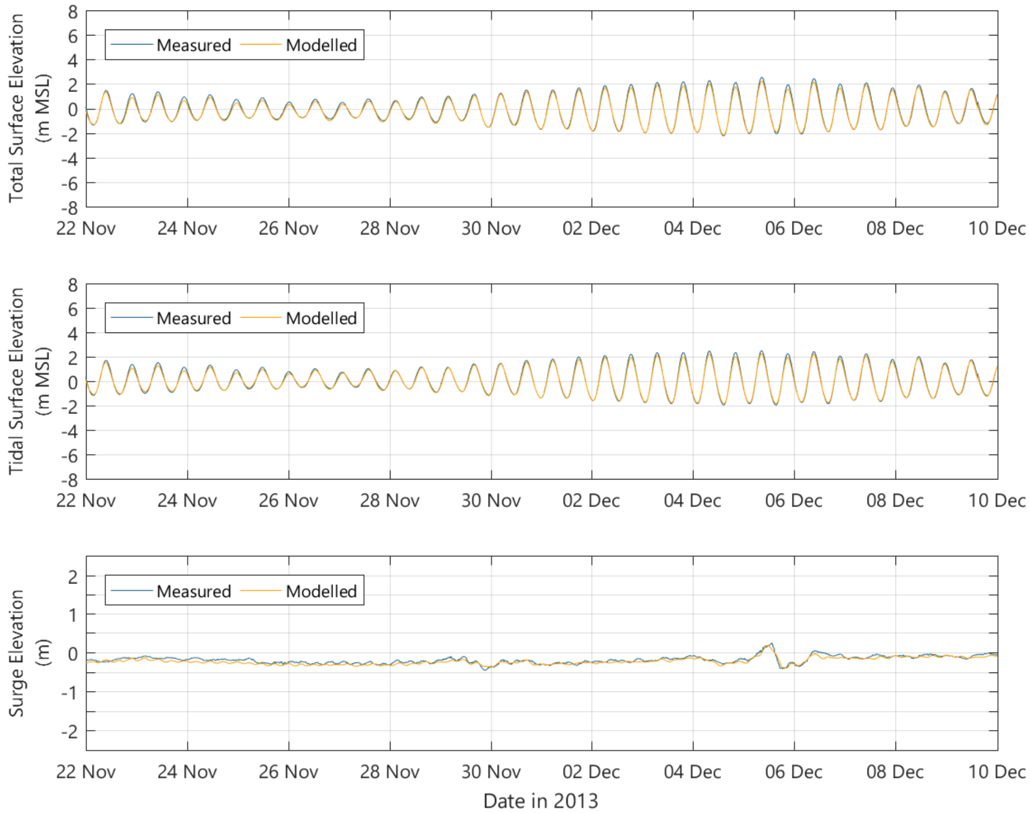

Figure 32. Model validation at Fishguard

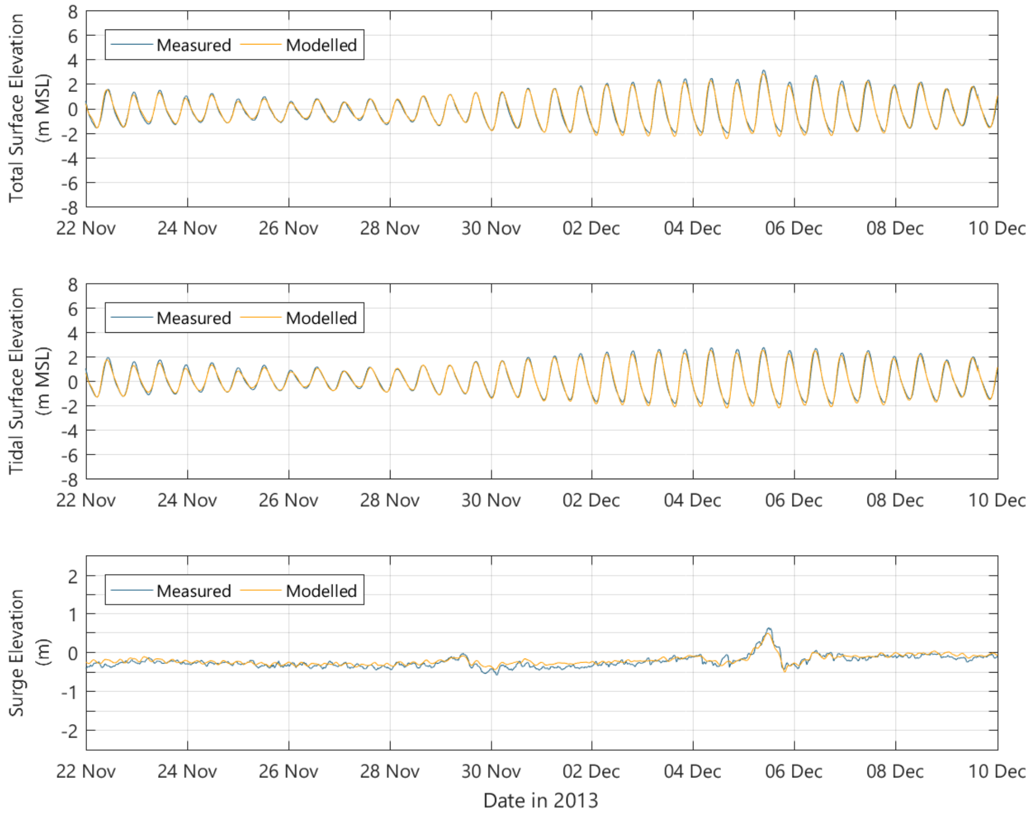

Figure 33. Model validation at Barmouth

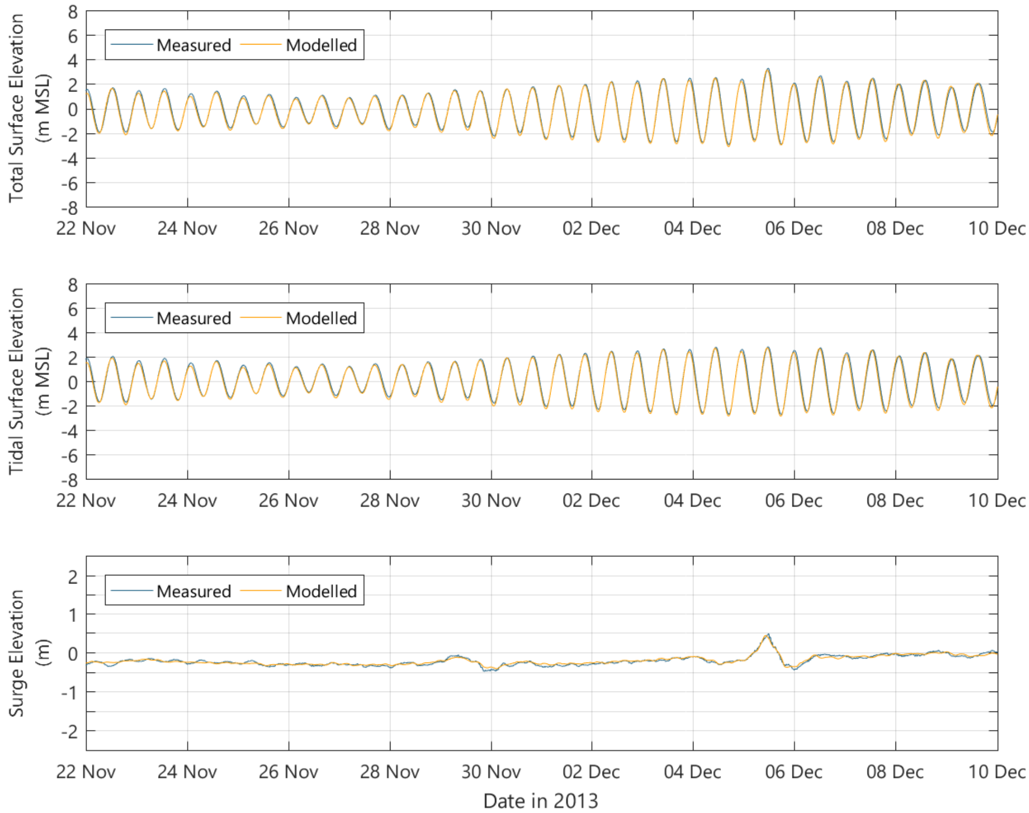

Figure 34. Model validation at Holyhead

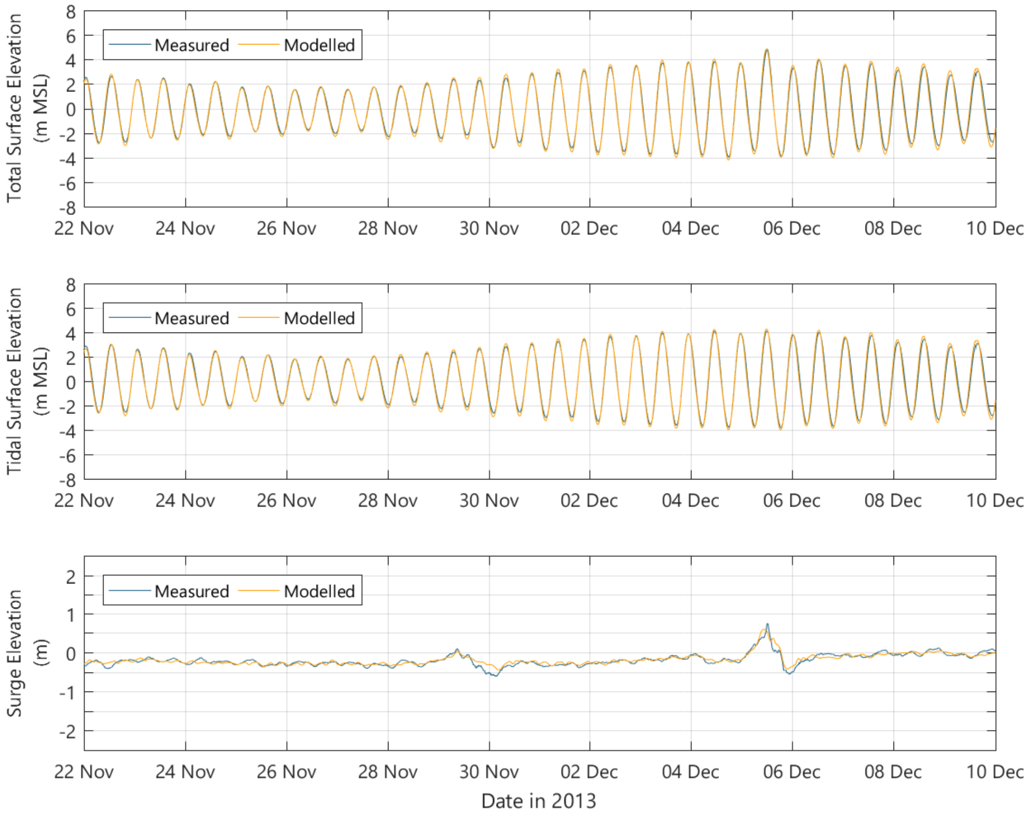

Figure 35. Model validation at Llandudno

England West coast and the Irish Sea

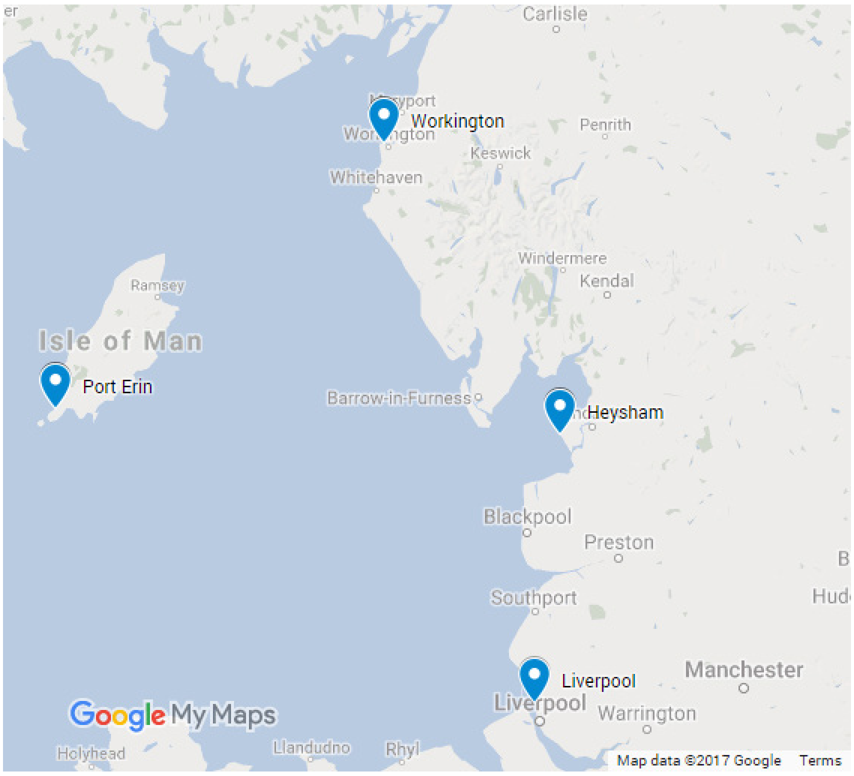

Figure 36. England West coast and Irish Sea validation locations

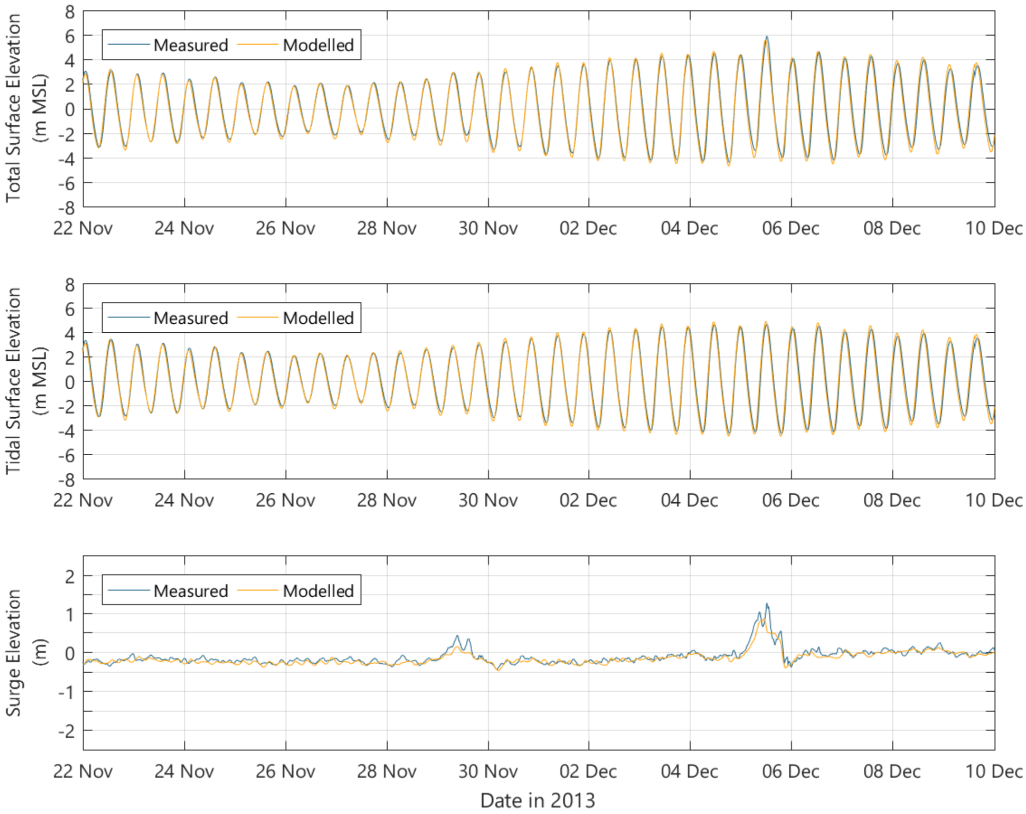

Figure 37. Model validation at Liverpool

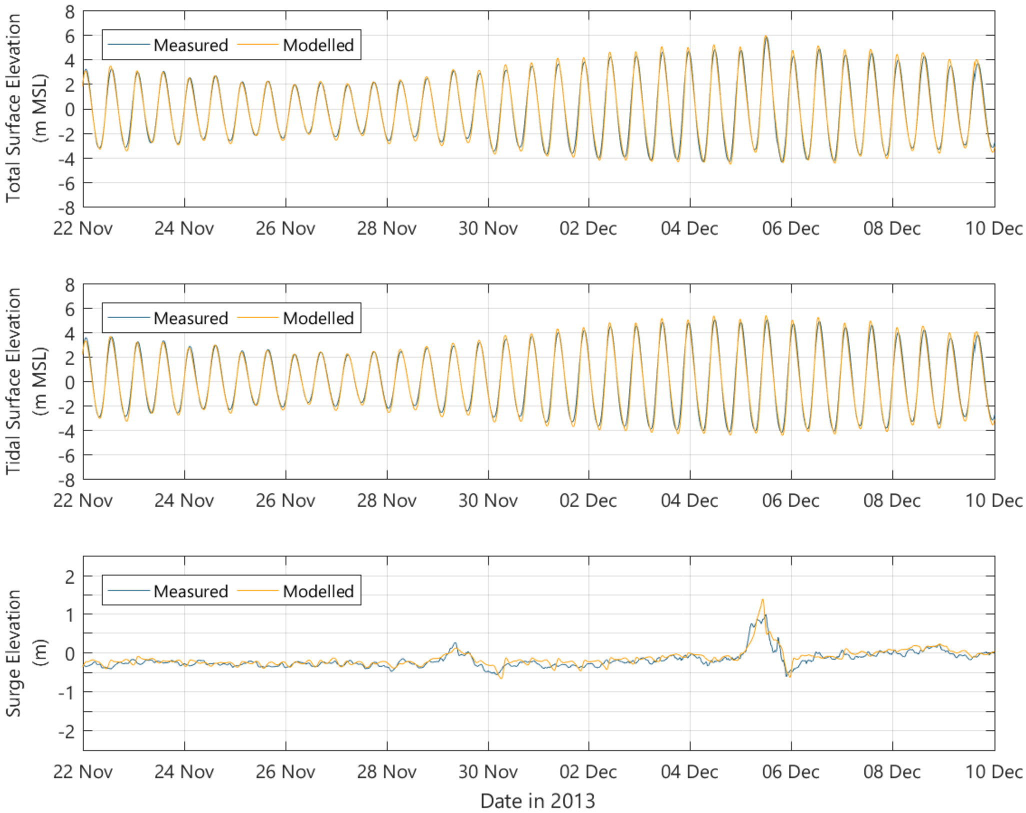

Figure 38. Model validation at Heysham

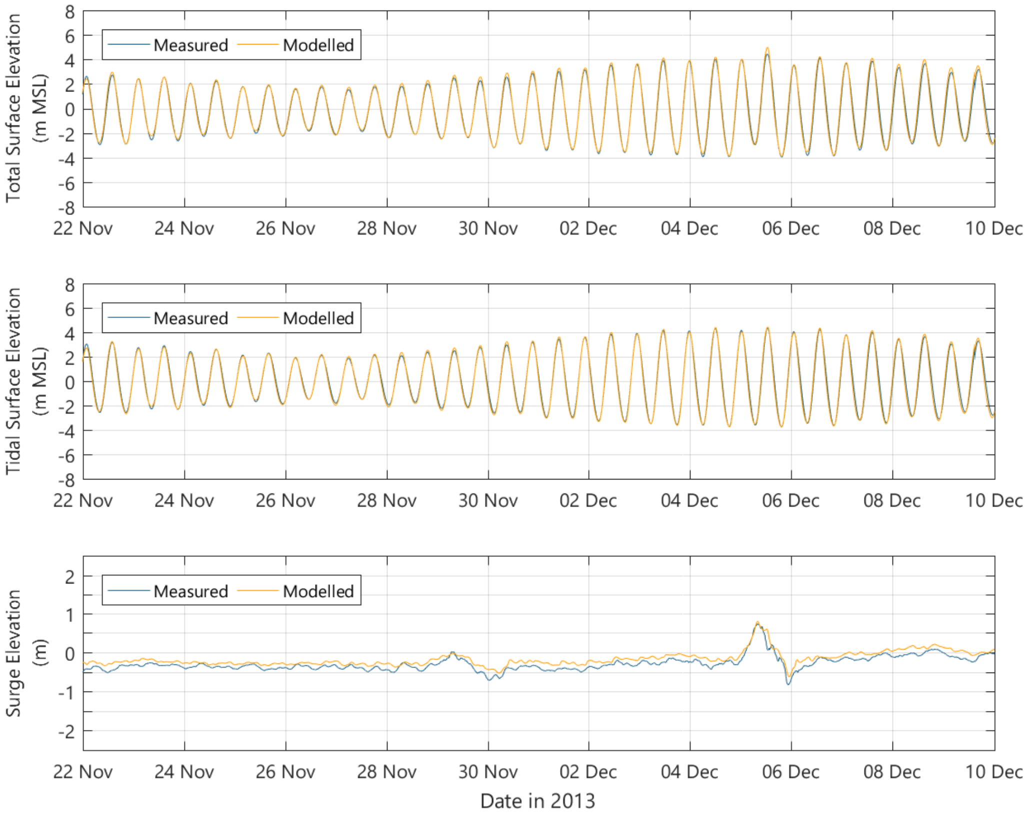

Figure 39. Model validation at Workington

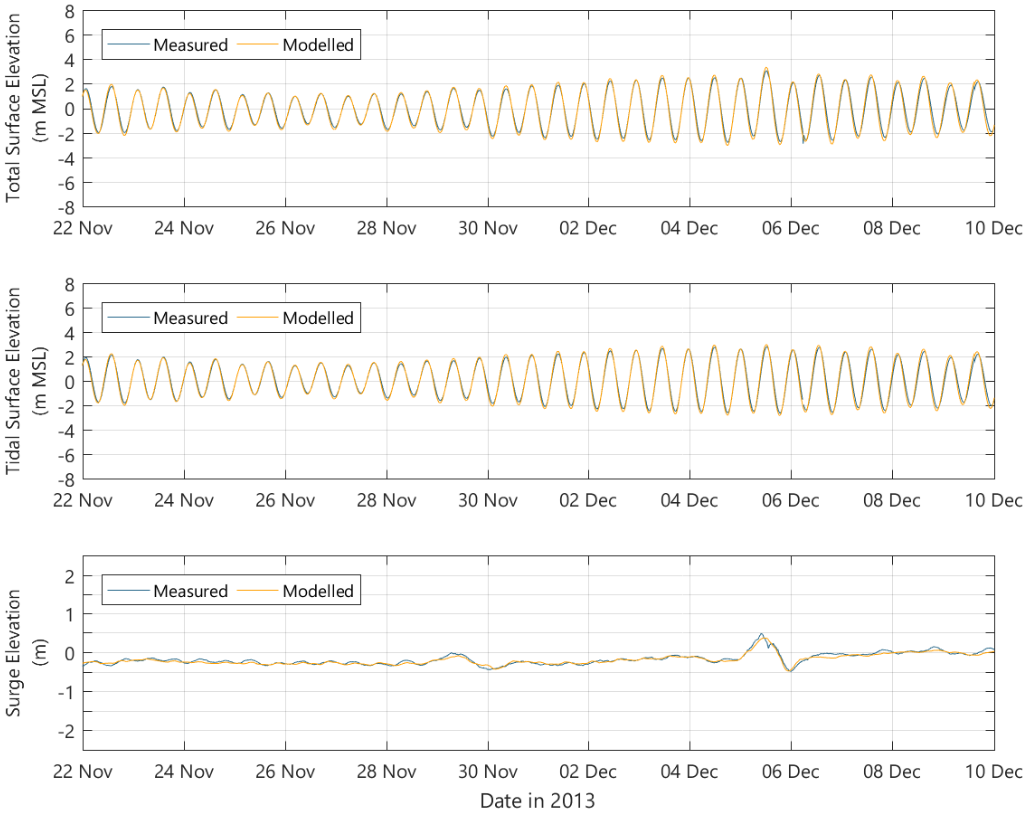

Figure 40. Model validation at Port Erin

Scotland West coast

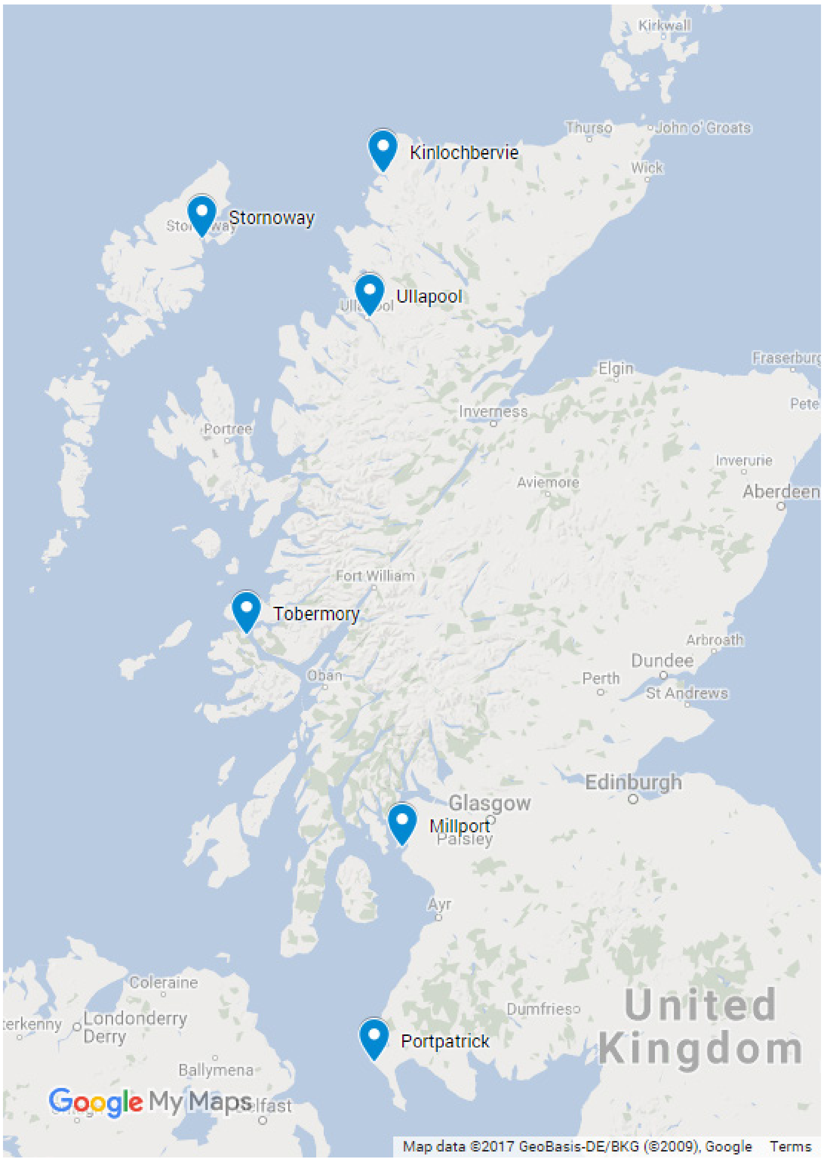

Figure 41. Scotland West coast validation locations

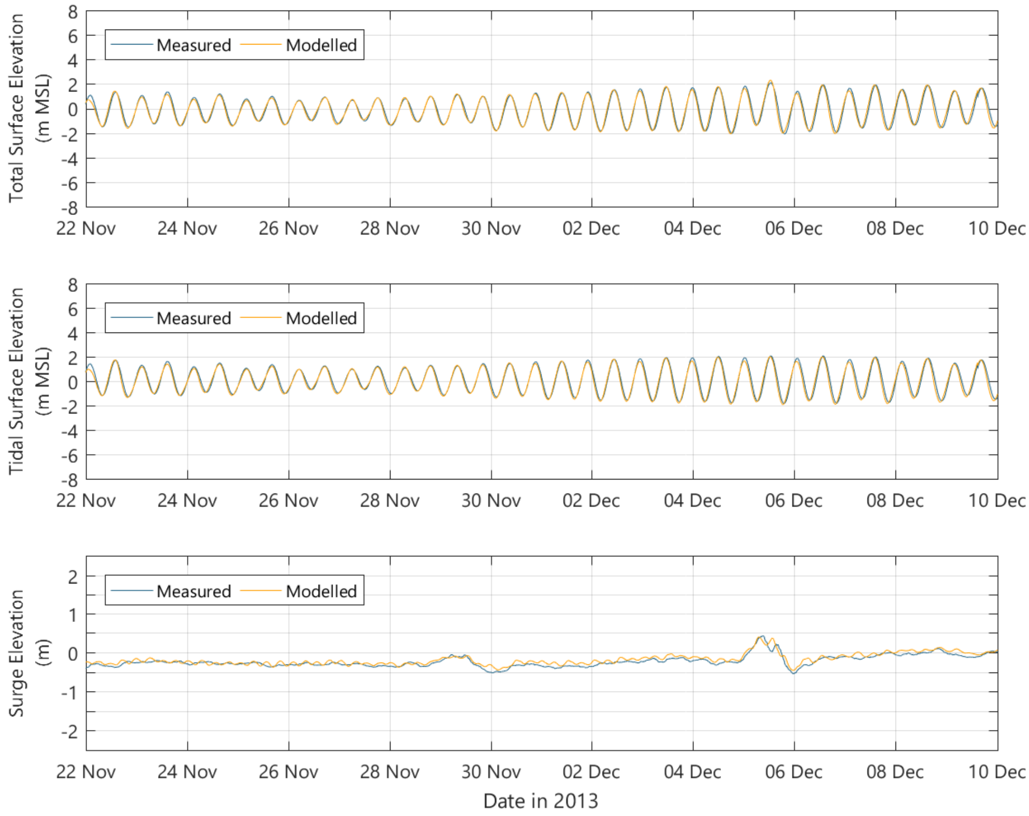

Figure 42. Model validation at Portpatrick

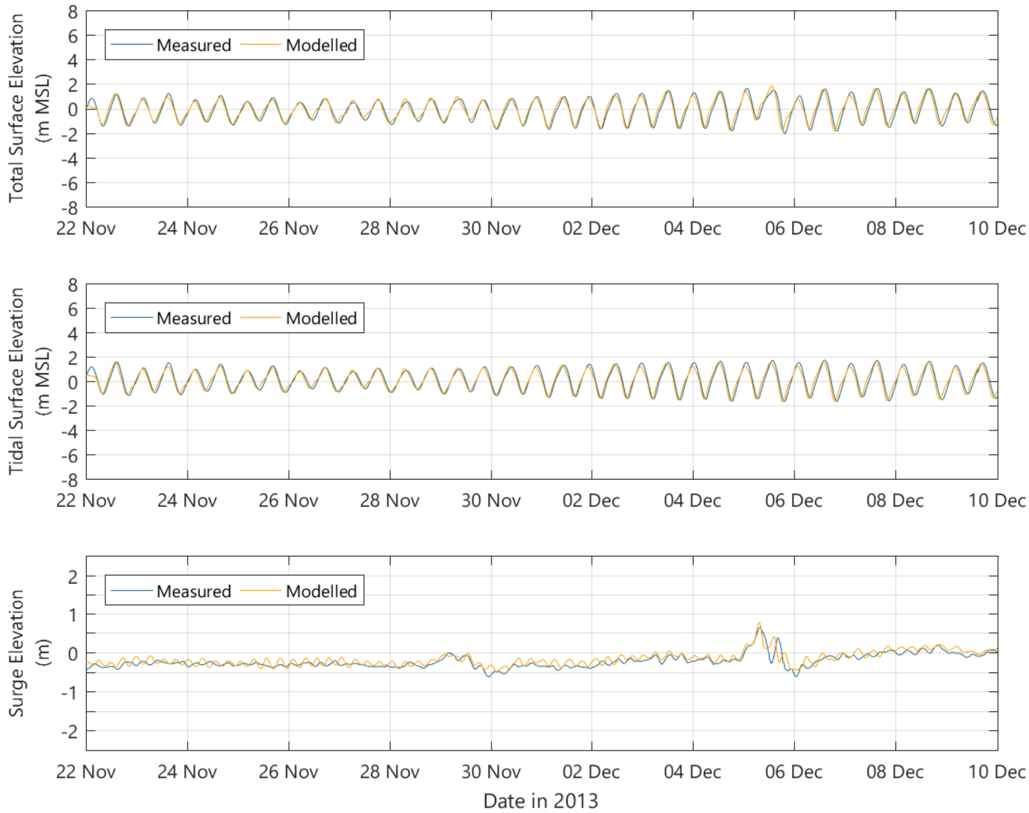

Figure 43. Model validation at Millport

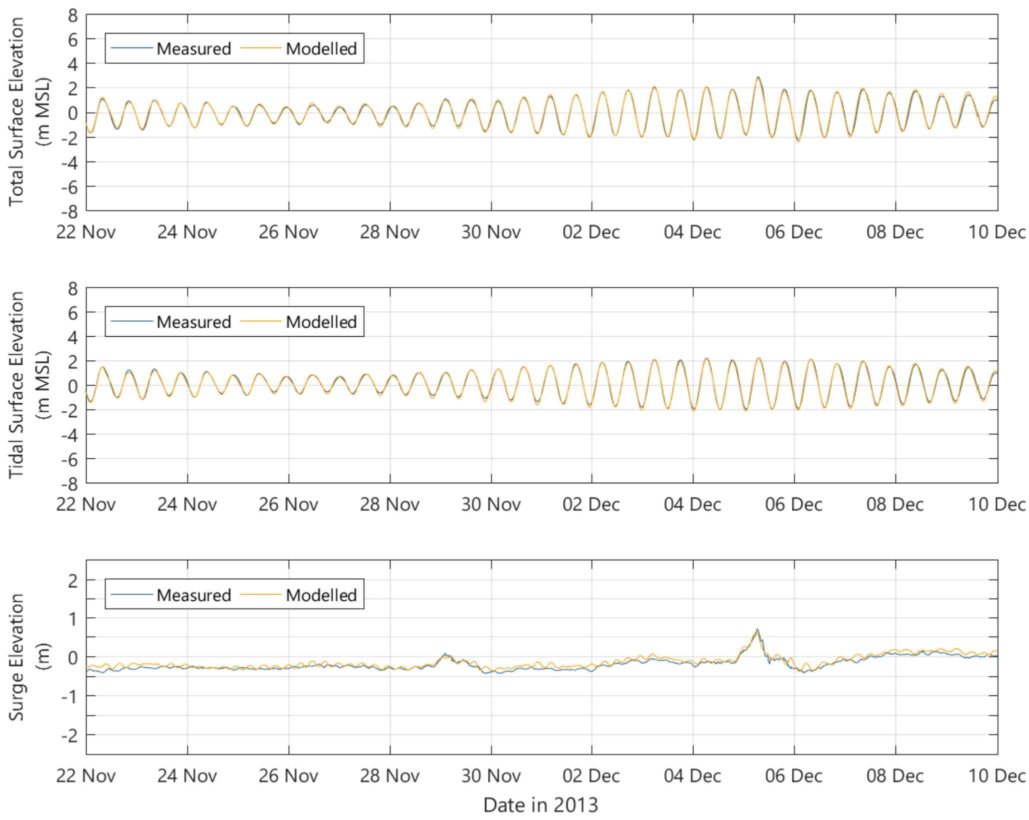

Figure 44. Model validation at Tobermory

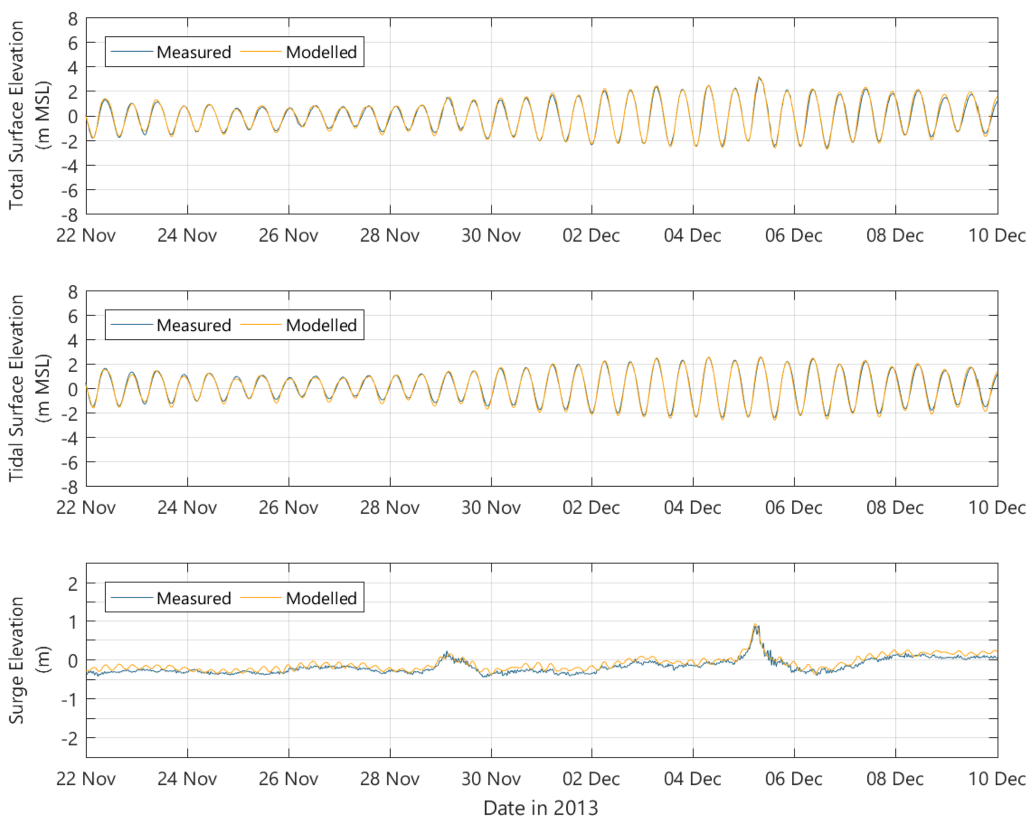

Figure 45. Model validation at Ullapool

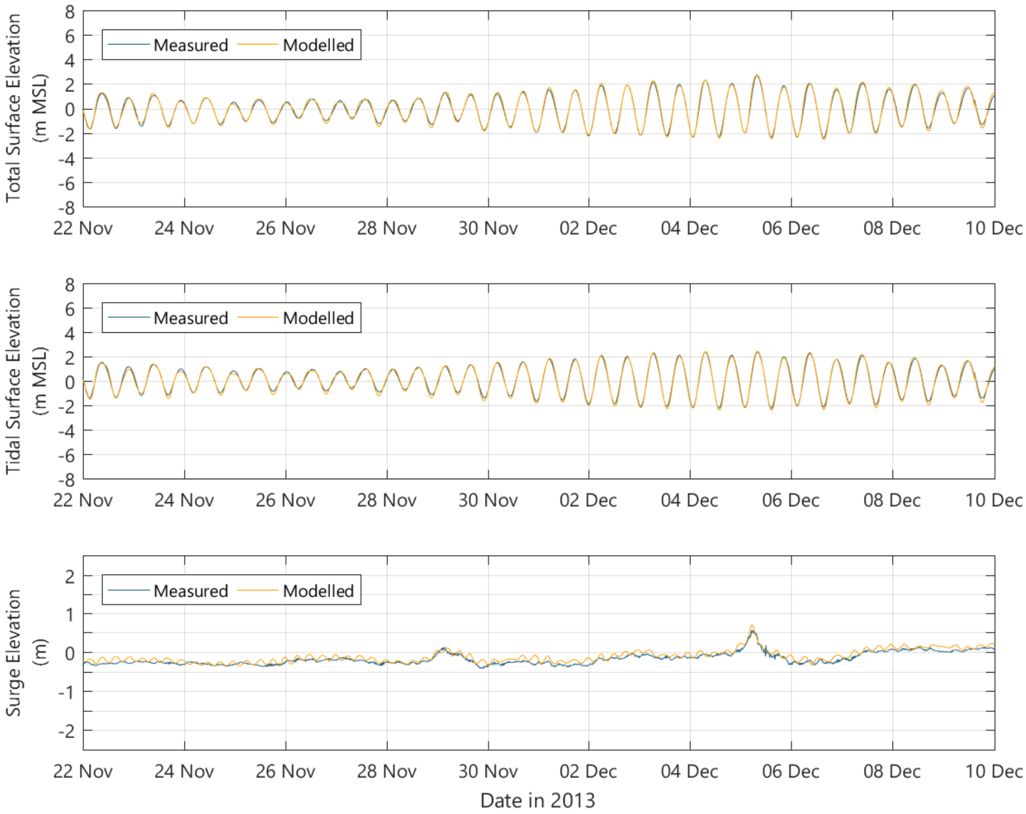

Figure 46. Model validation at Stornoway

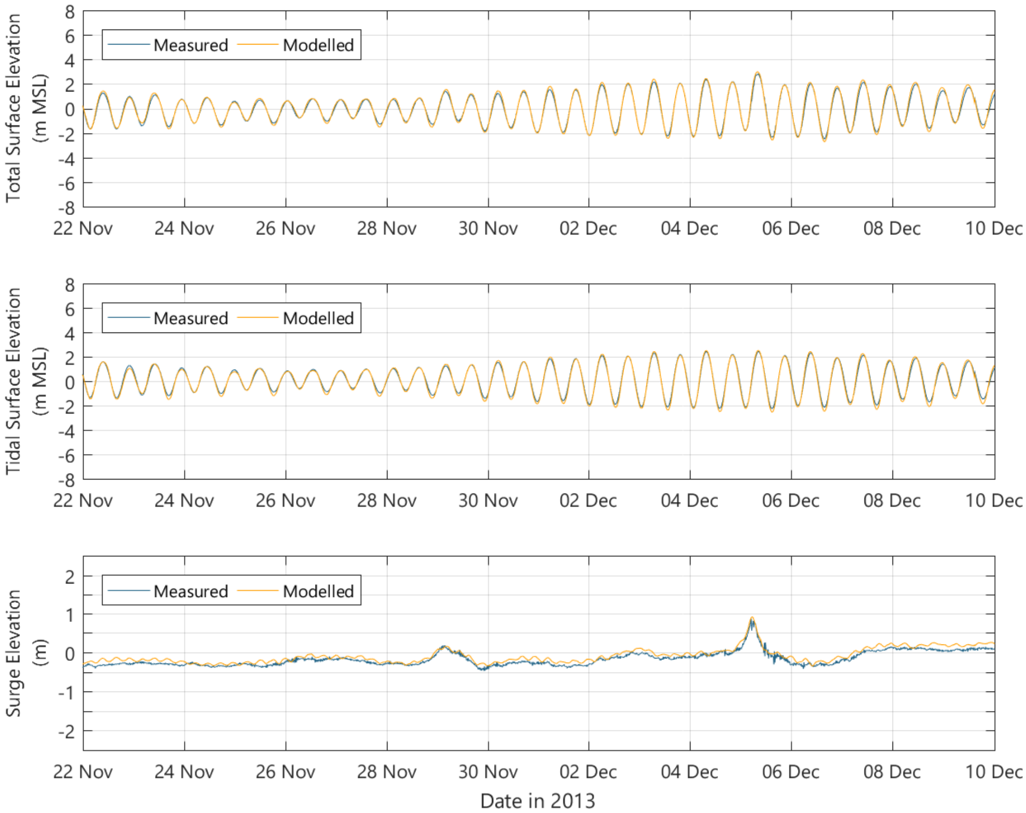

Figure 47. Model validation at Kinlochbervie

Northern Ireland

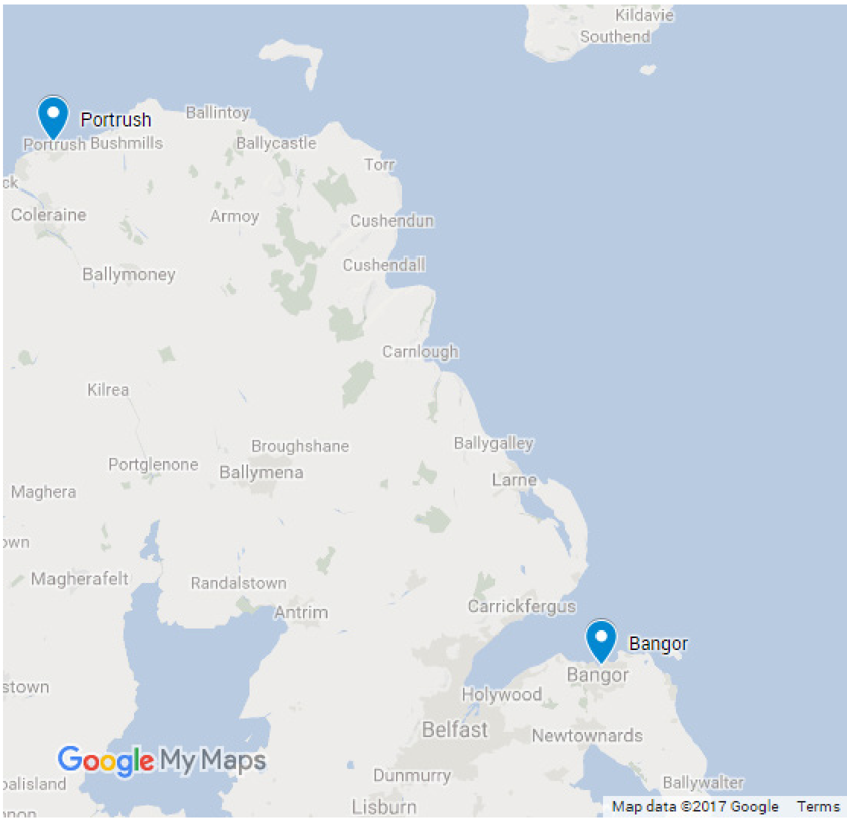

Figure 48. Northern Ireland validation locations

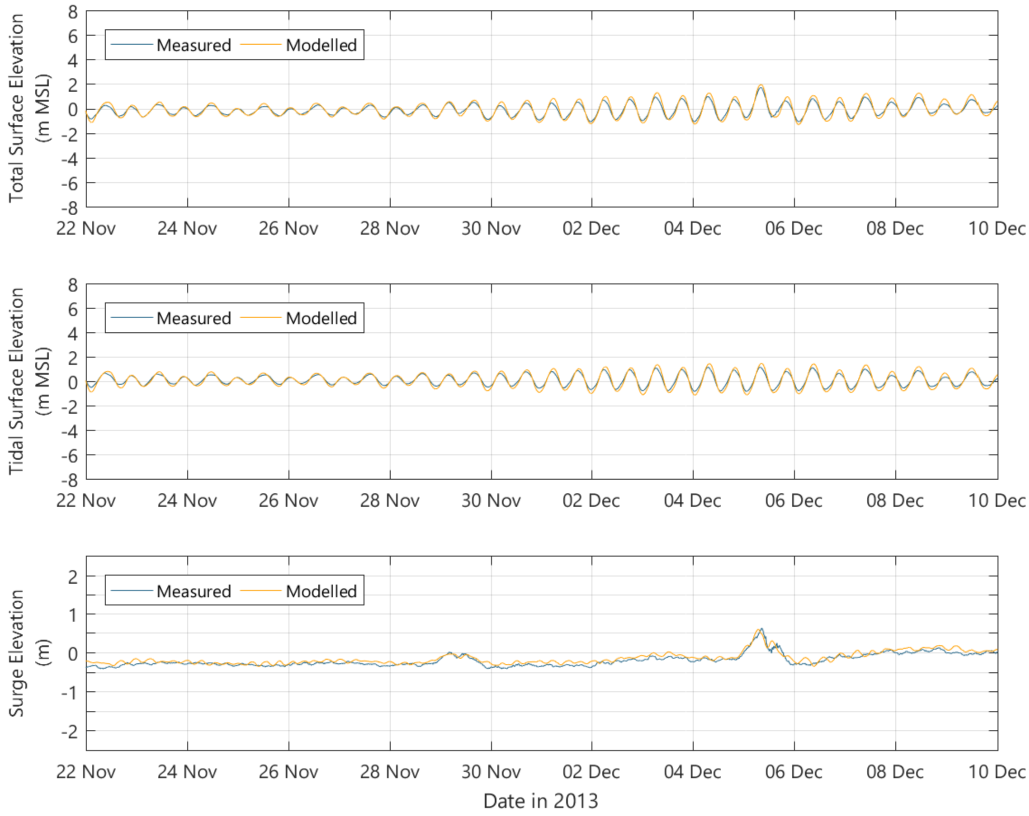

Figure 49. Model validation at Portrush

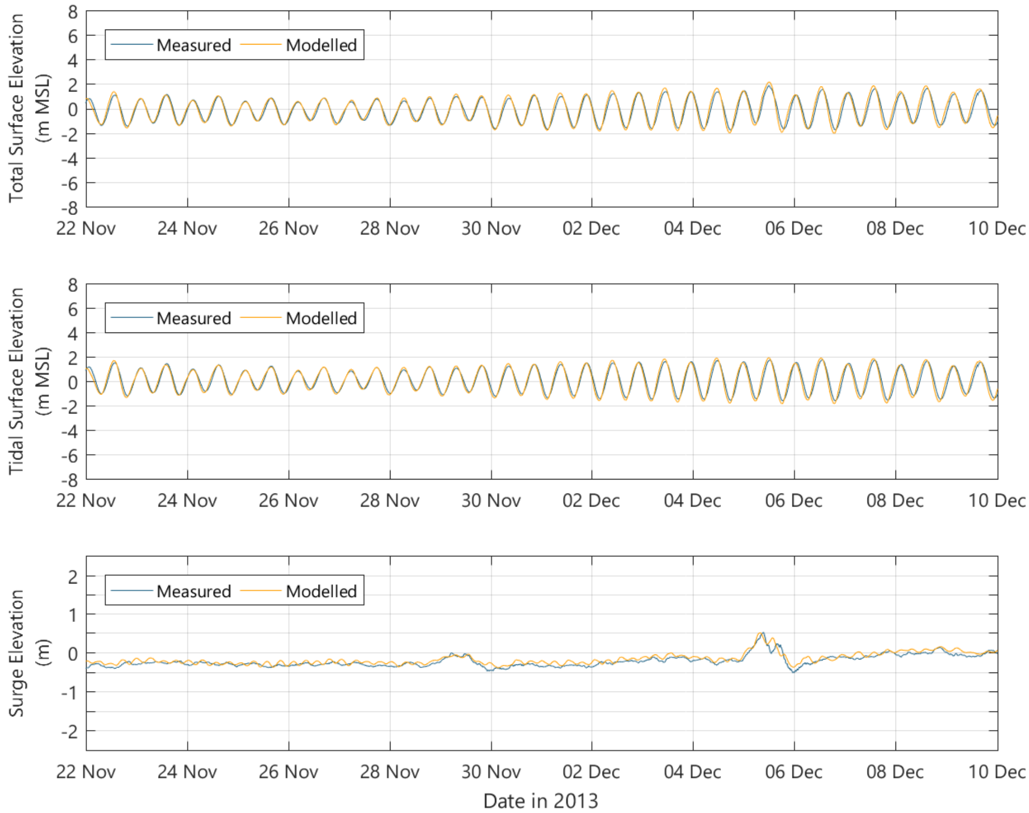

Figure 50. Model validation at Bangor

Republic of Ireland

Figure 51. Republic of Ireland validation sites

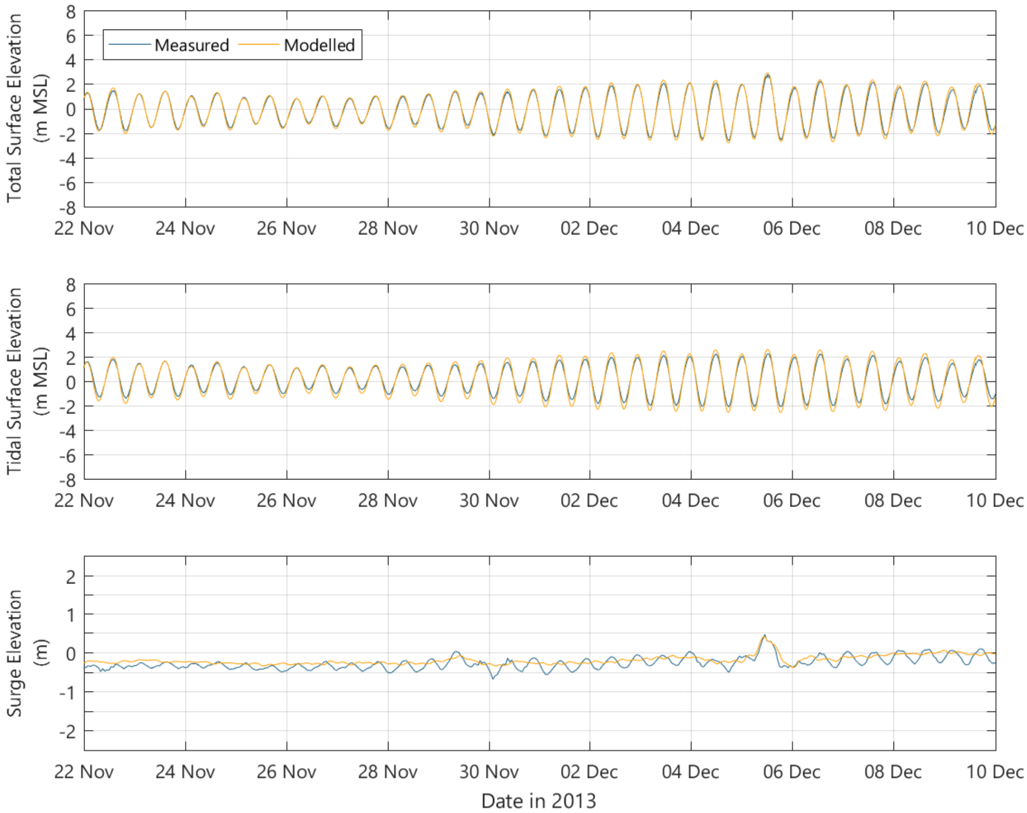

Figure 52. Model validation at Skerries

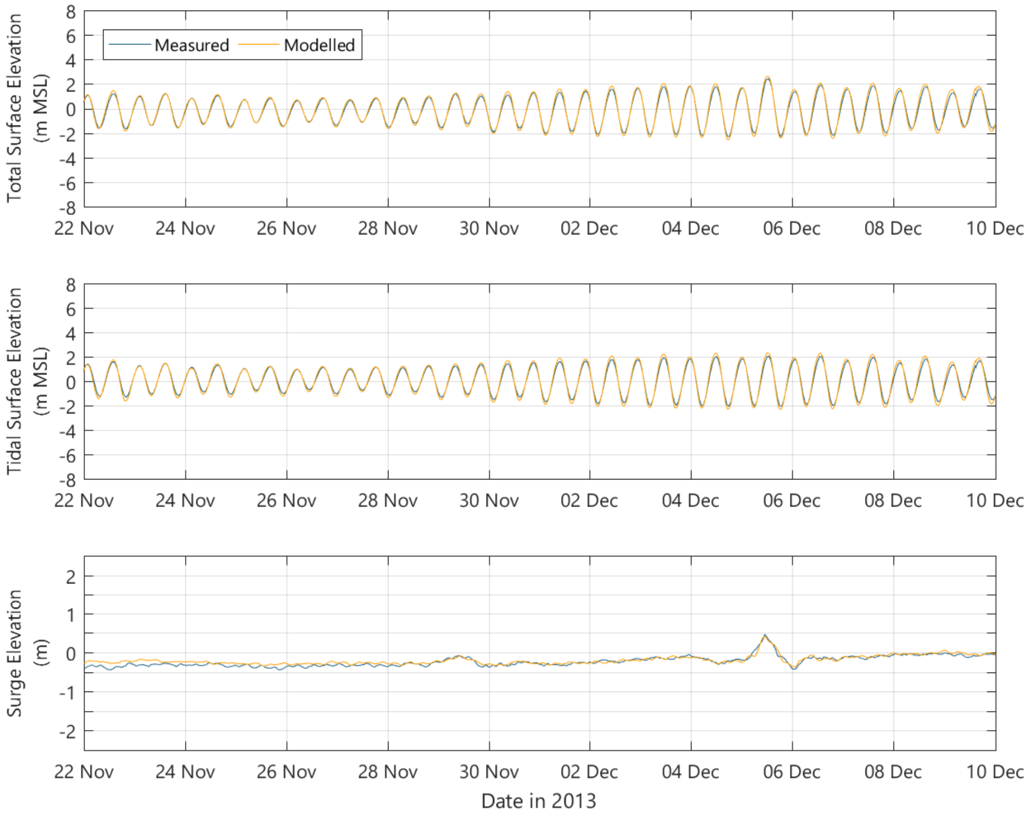

Figure 53. Model validation at Howth

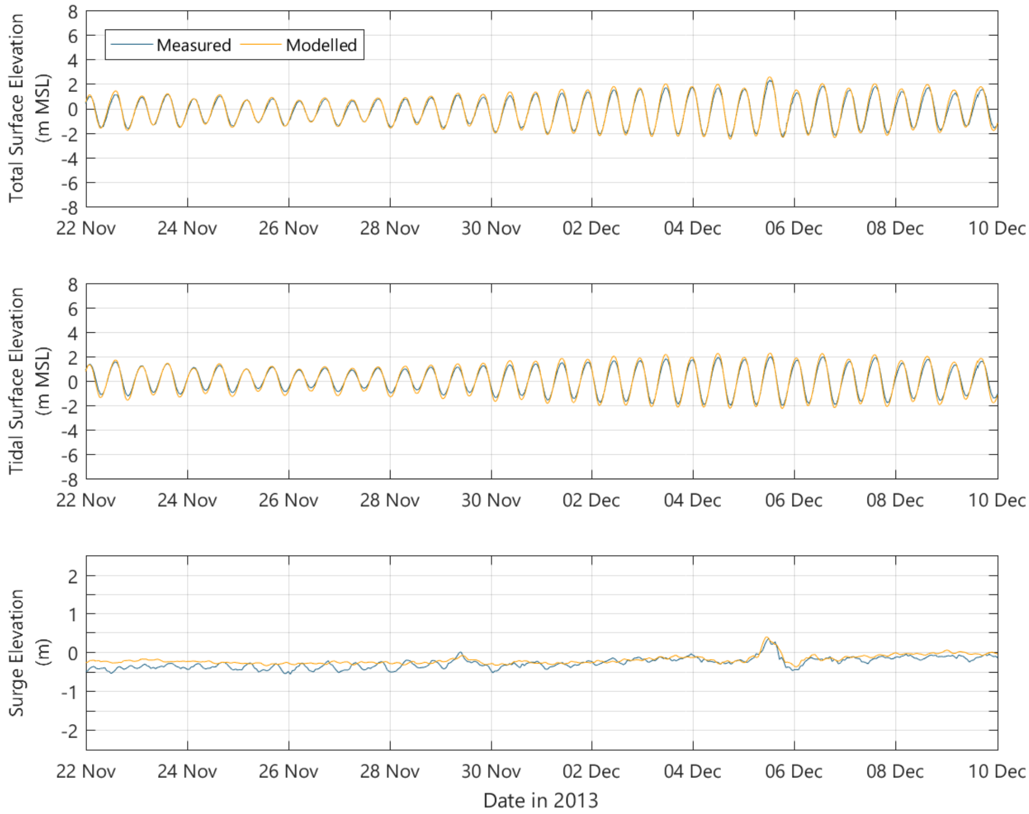

Figure 54. **Model validation at Dublin**

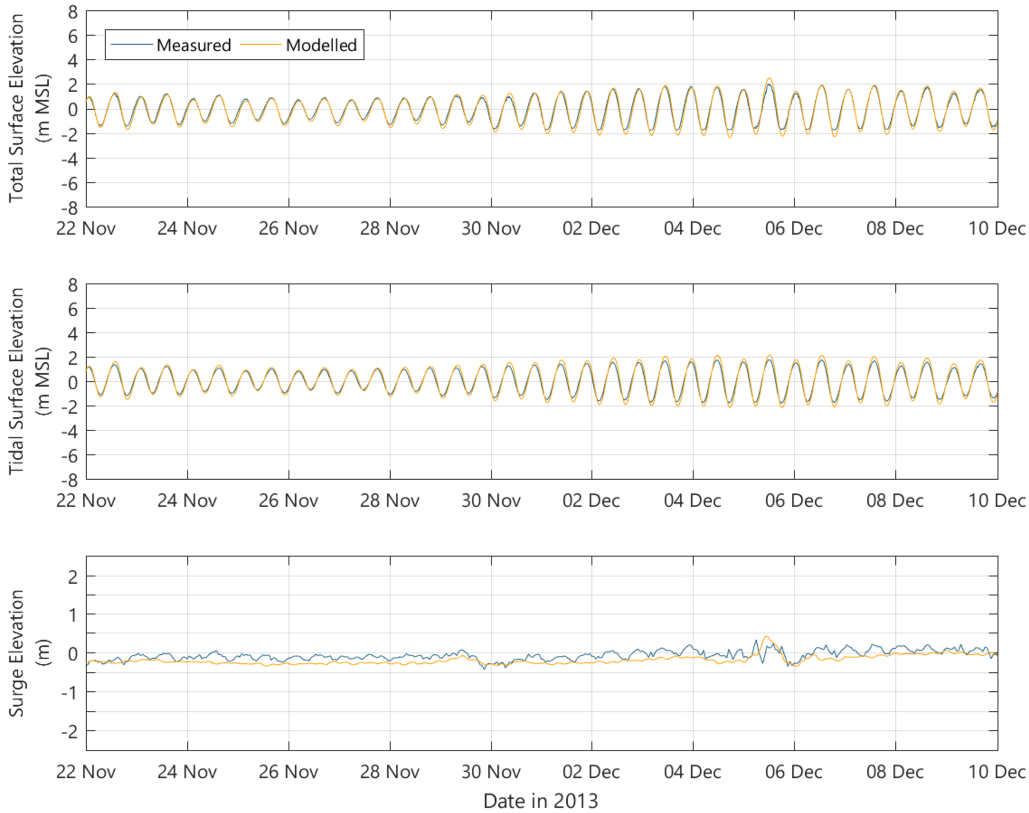

Figure 55. **Model validation at Kish Bank**

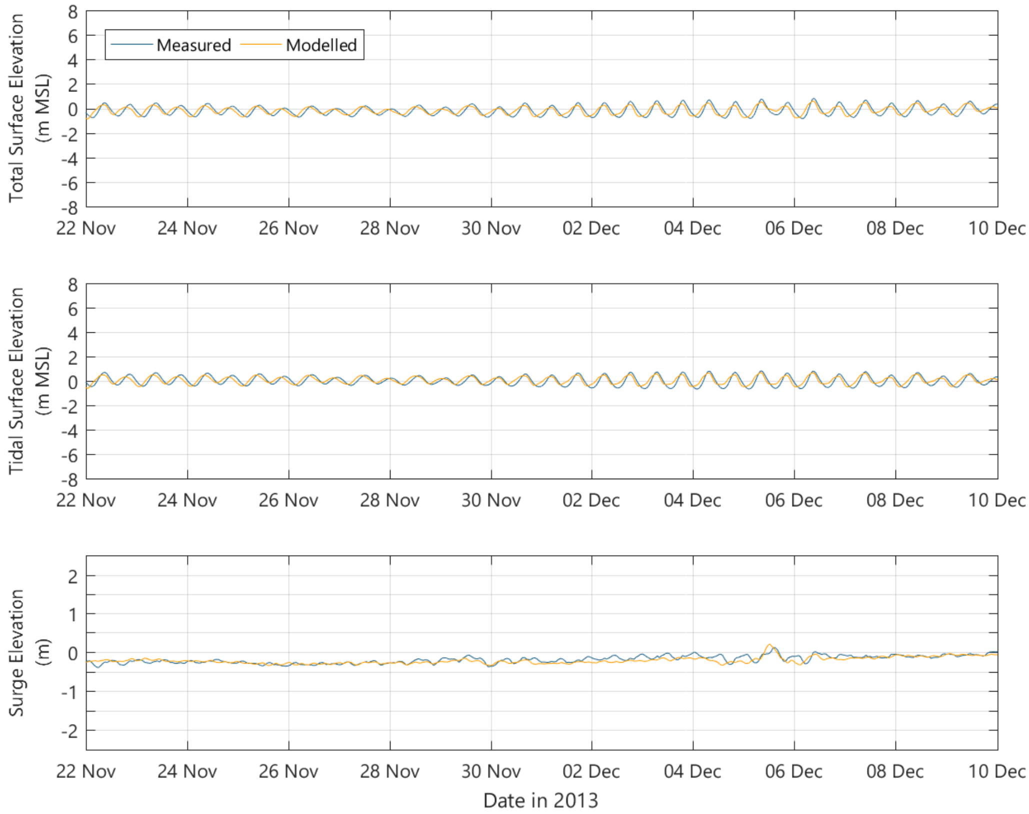

Figure 56. Model validation at Wexford

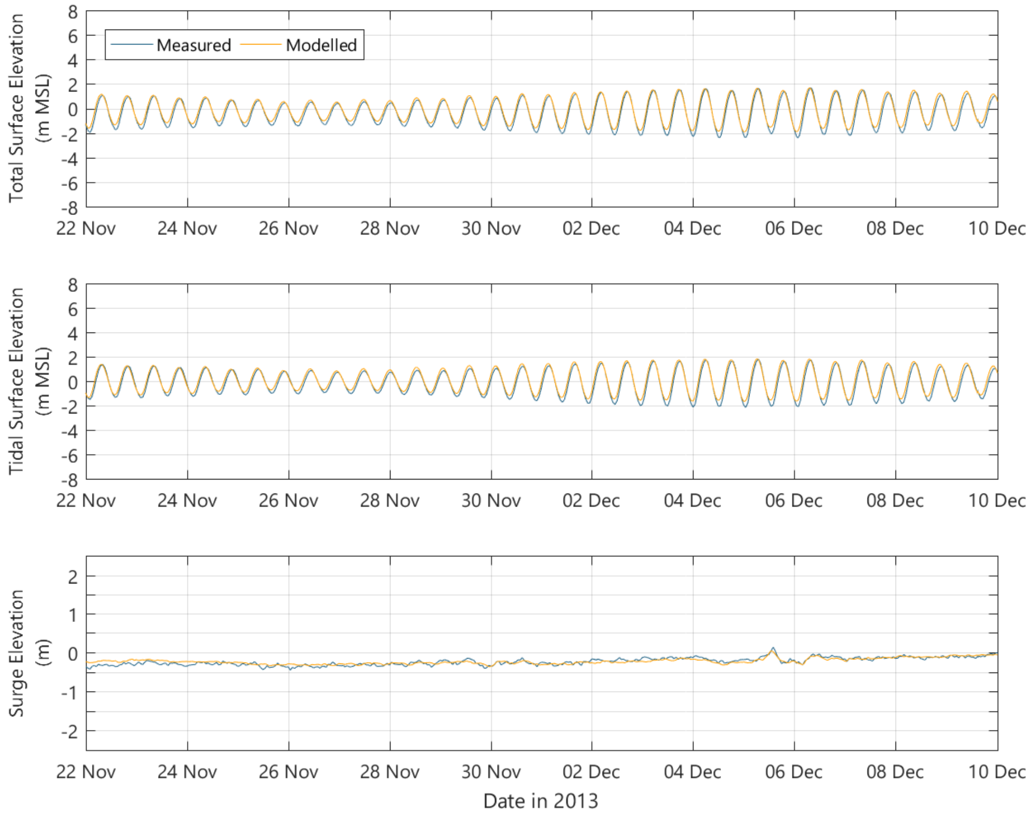

Figure 57. Model validation at Dunmore

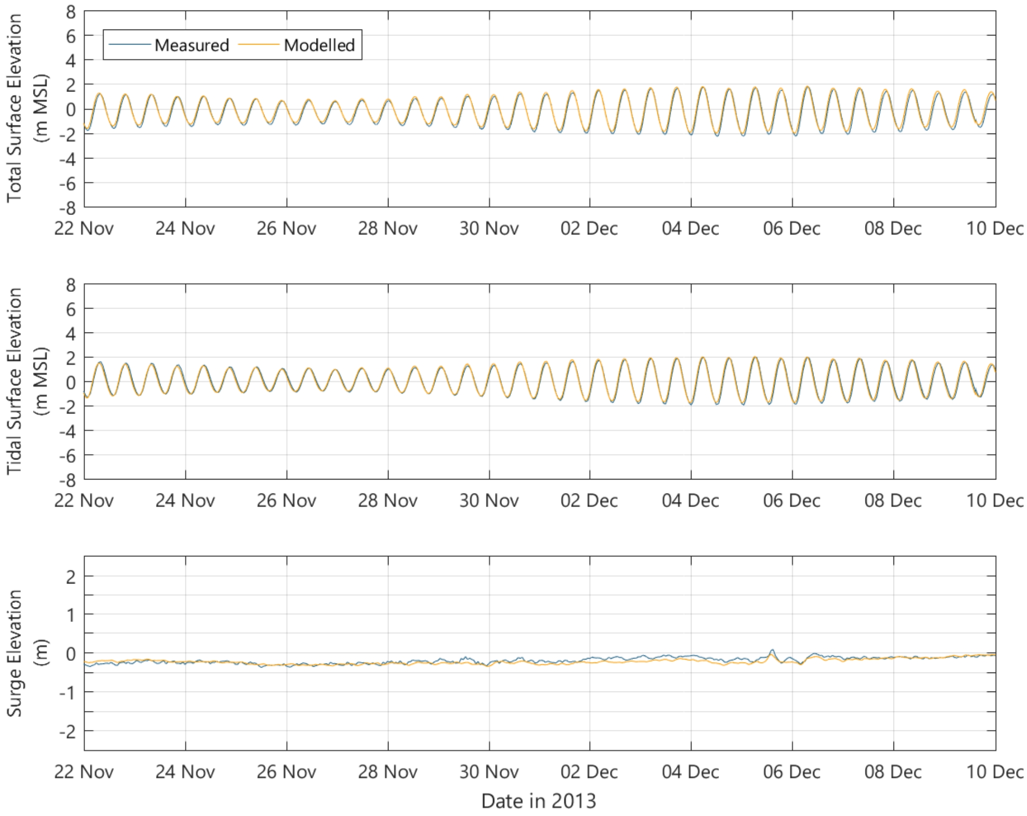

Figure 58. Model validation at Ballycotton

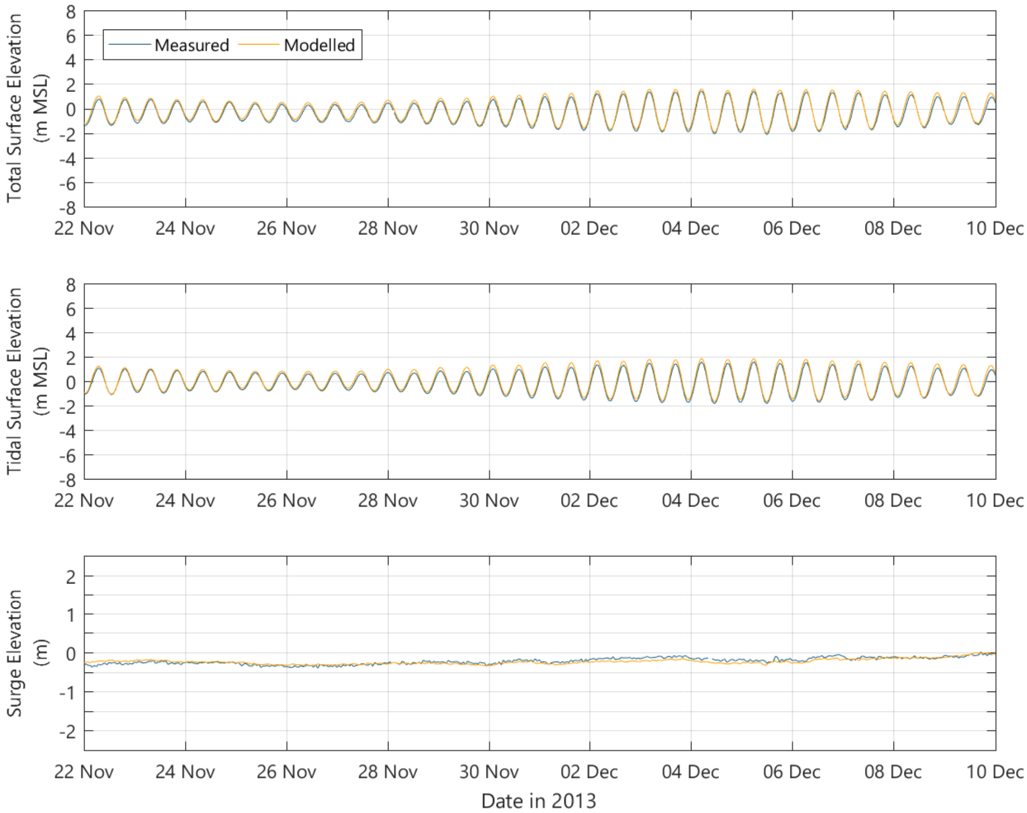

Figure 59. Model validation at Castletownbere

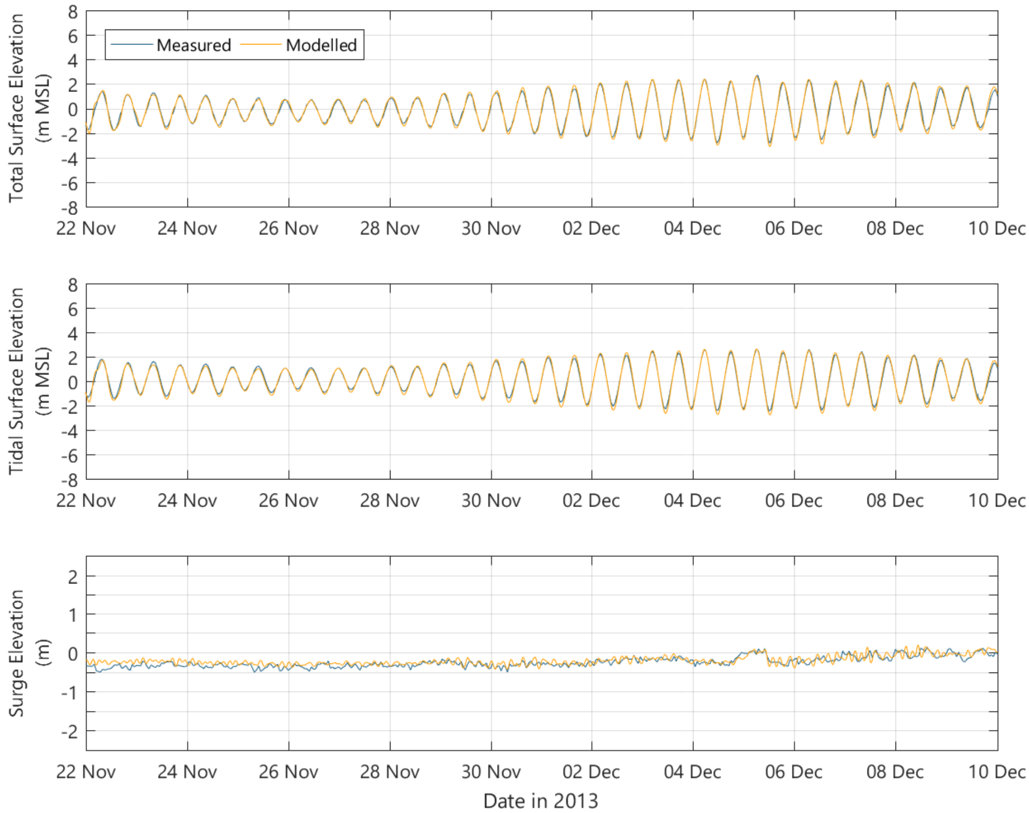

Figure 60. Model validation at Galway

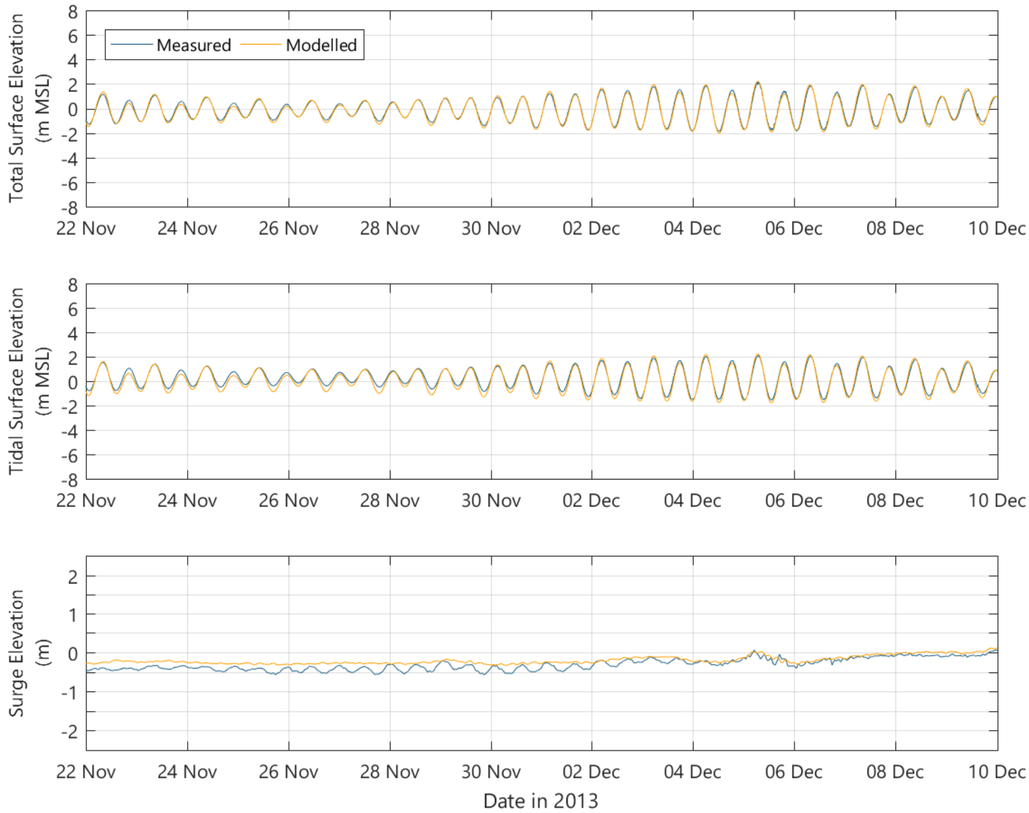

Figure 61. Model validation at Ballyglass

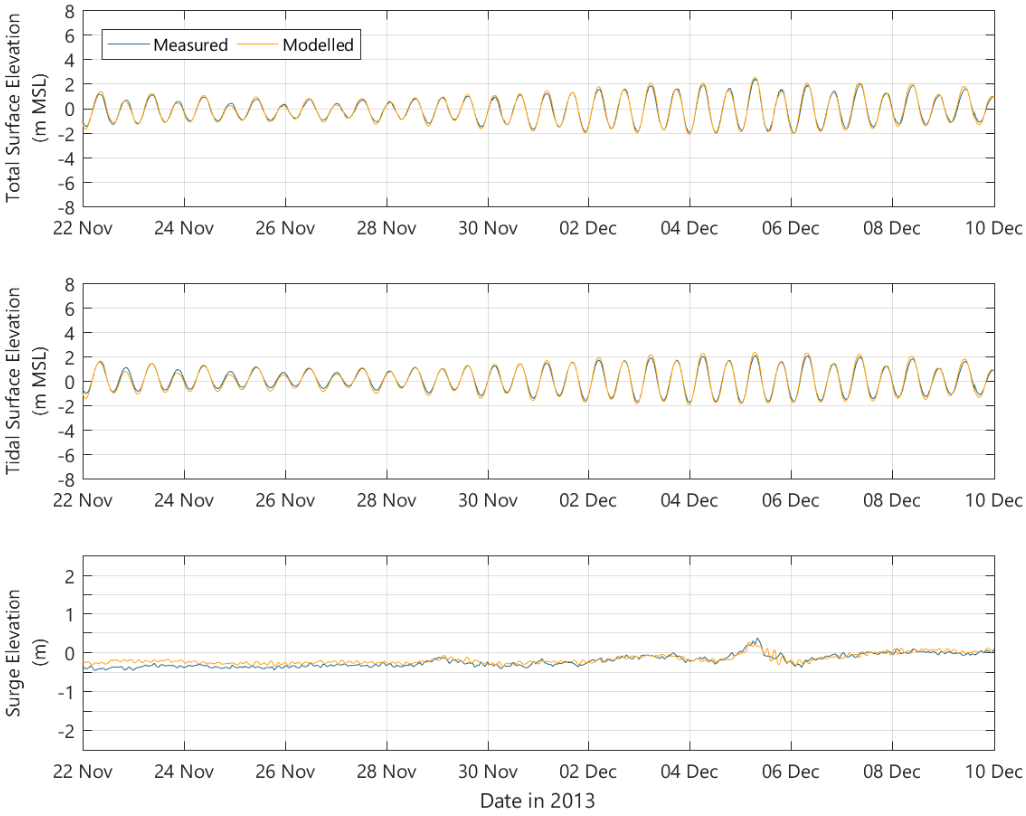

Figure 62. Model validation at Killybegs

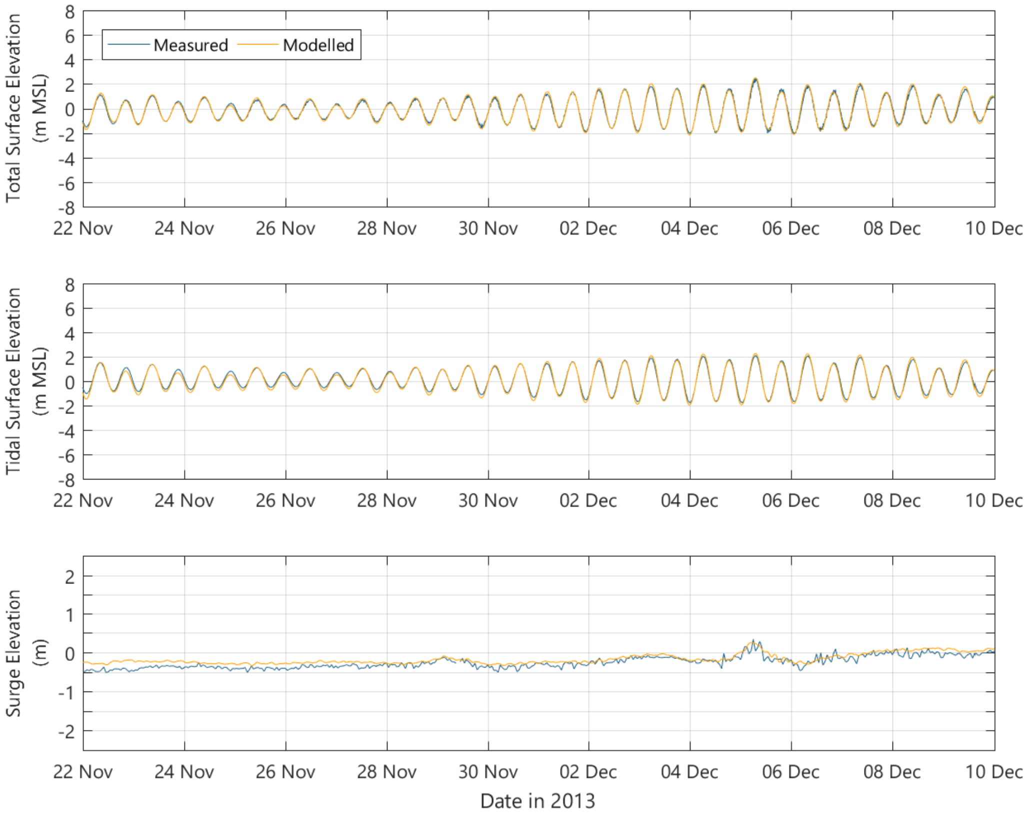

Figure 63. Model validation at Aranmore

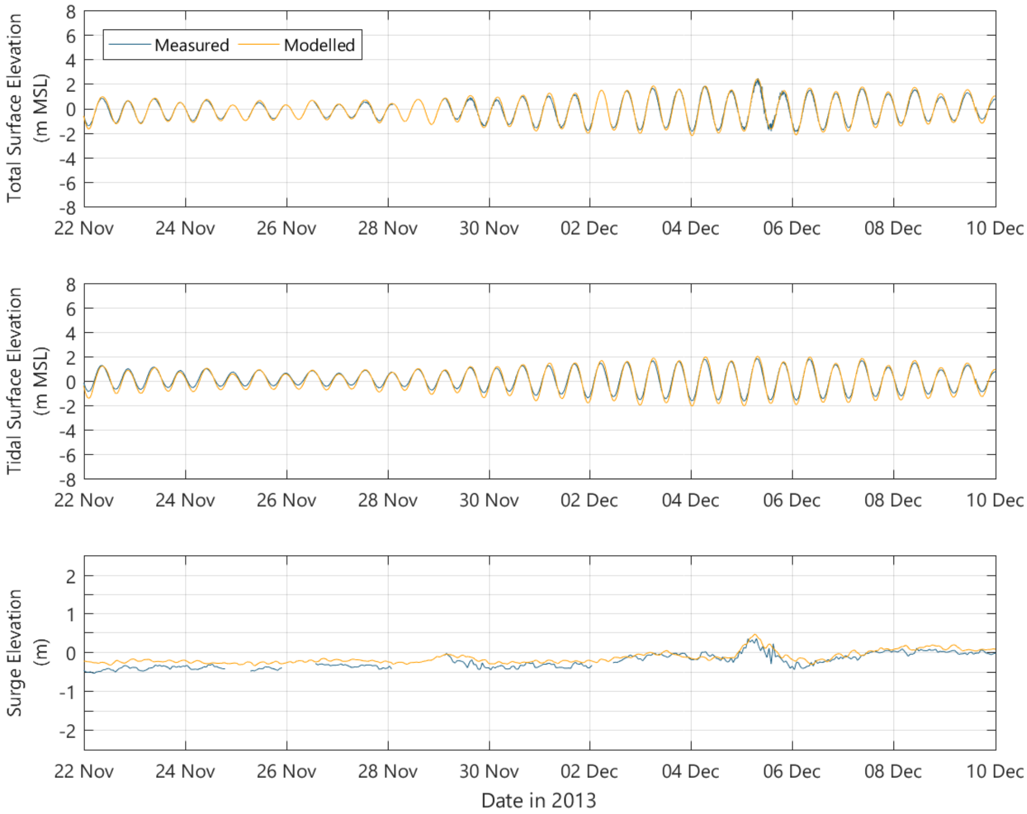

Figure 64. Model validation at Malin Head

France

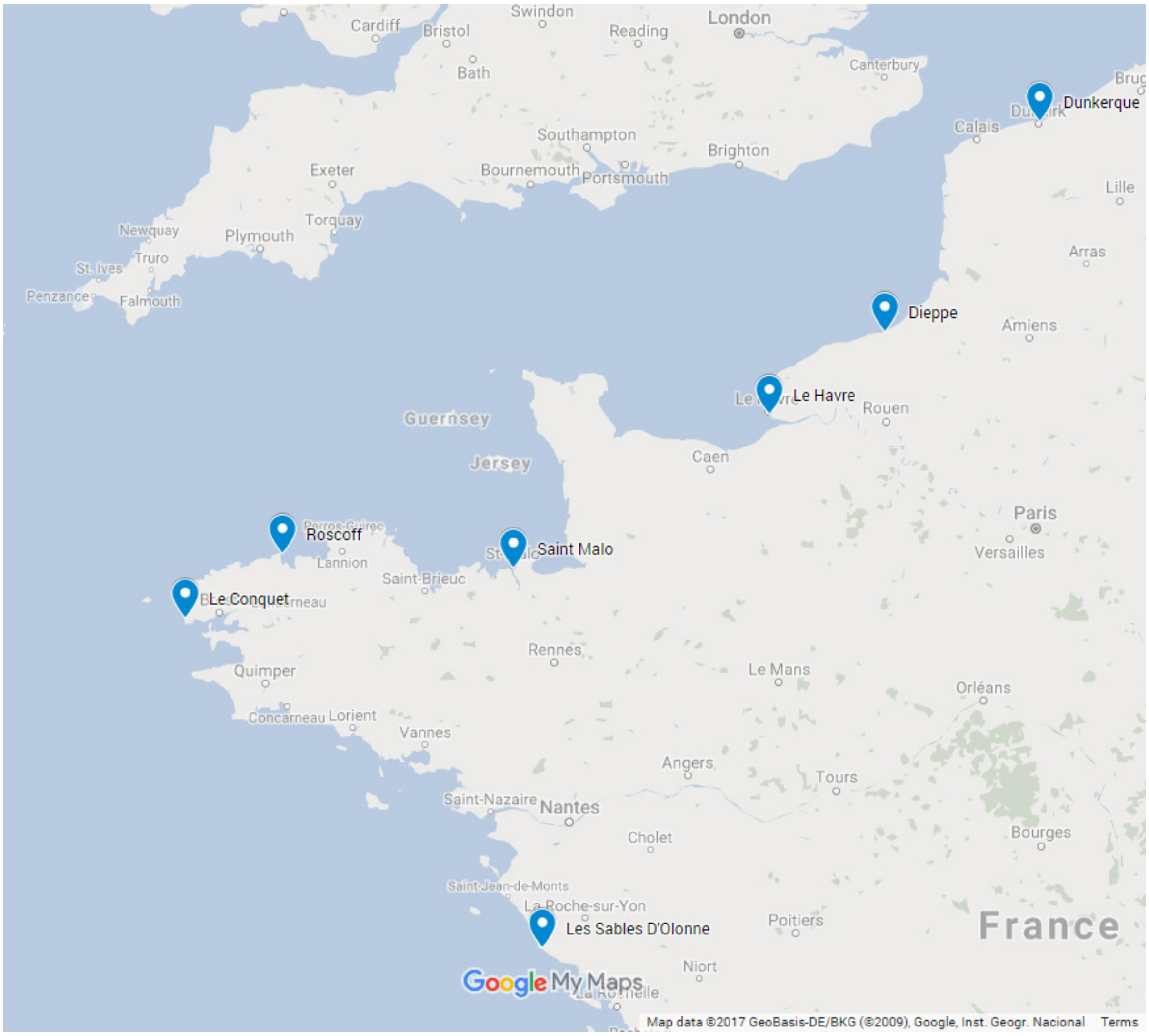

Figure 65. France validation sites

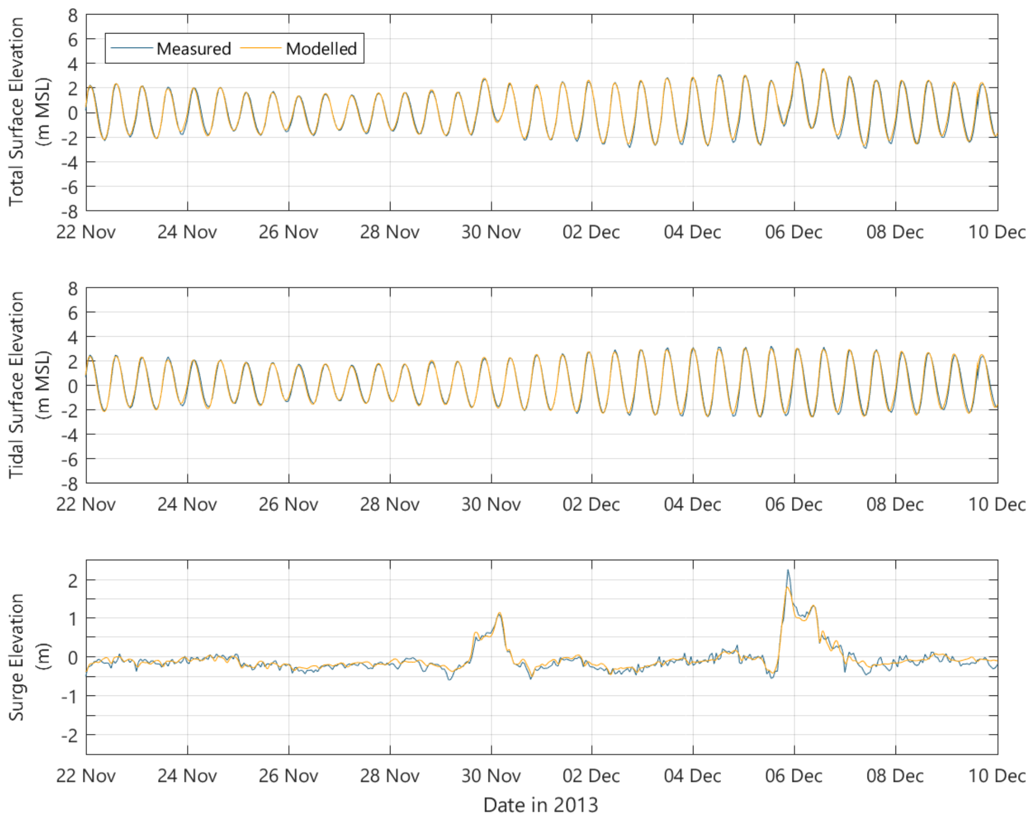

Figure 66. **Model validation at Dunkerque**

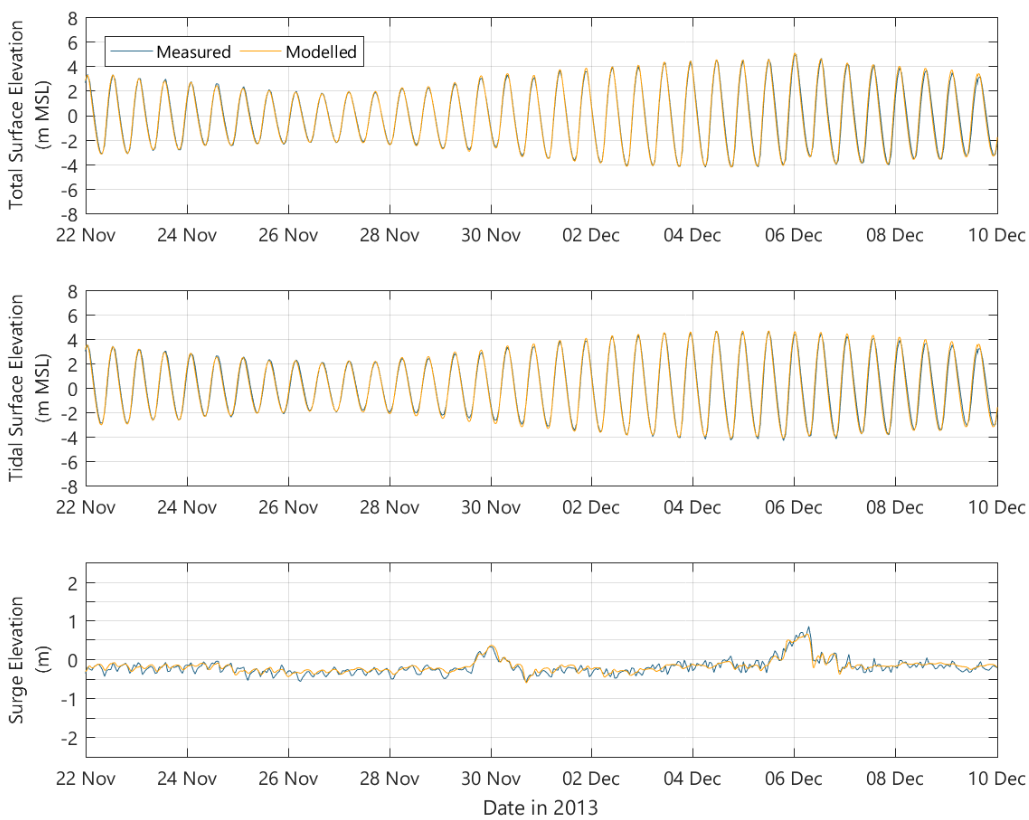

Figure 67. **Model validation at Dieppe**

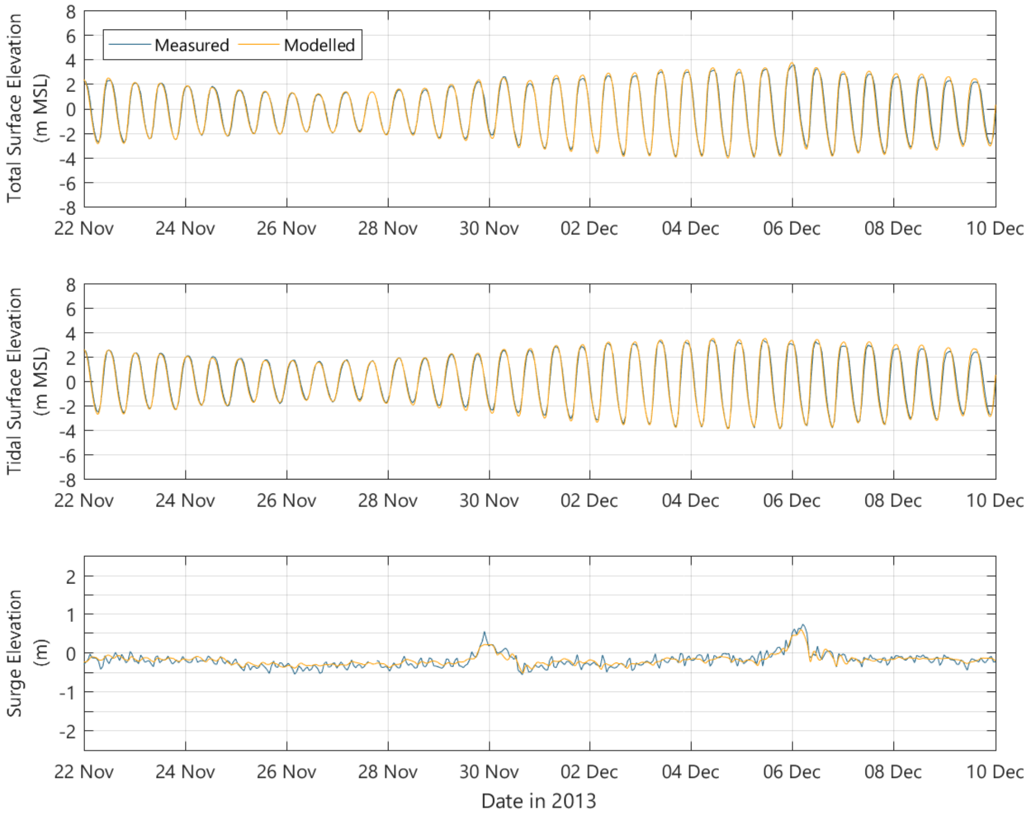

Figure 68. Model validation at Le Havre

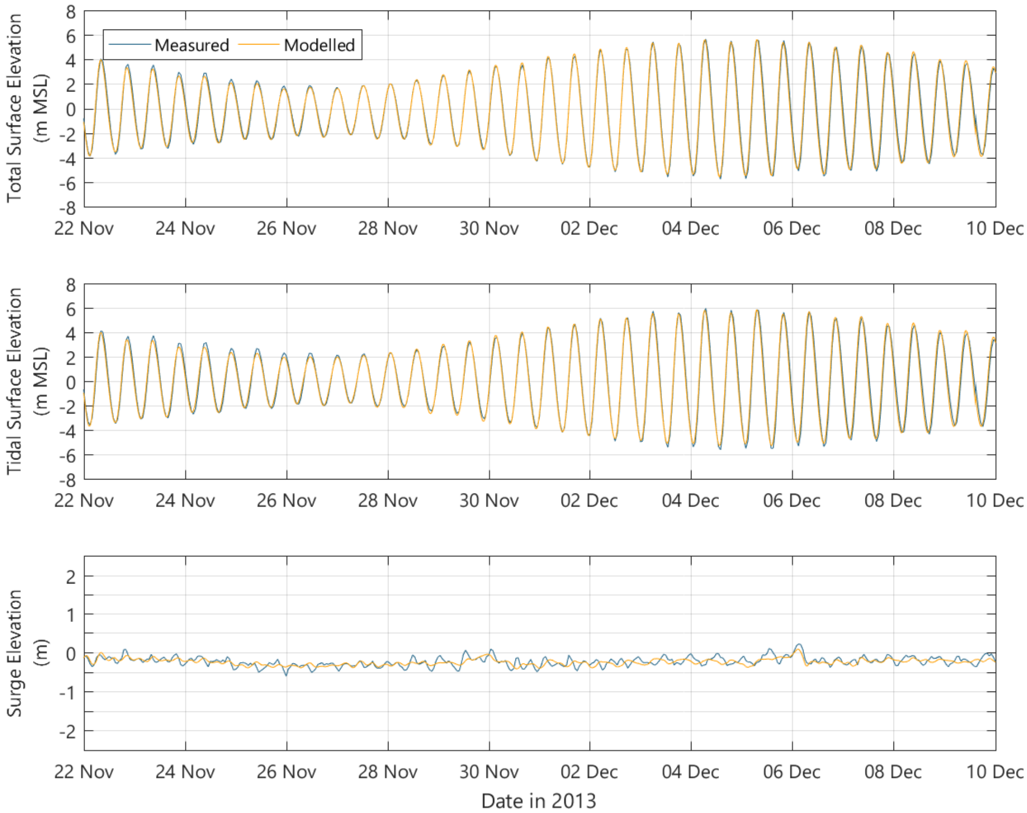

Figure 69. Model validation at Saint Malo

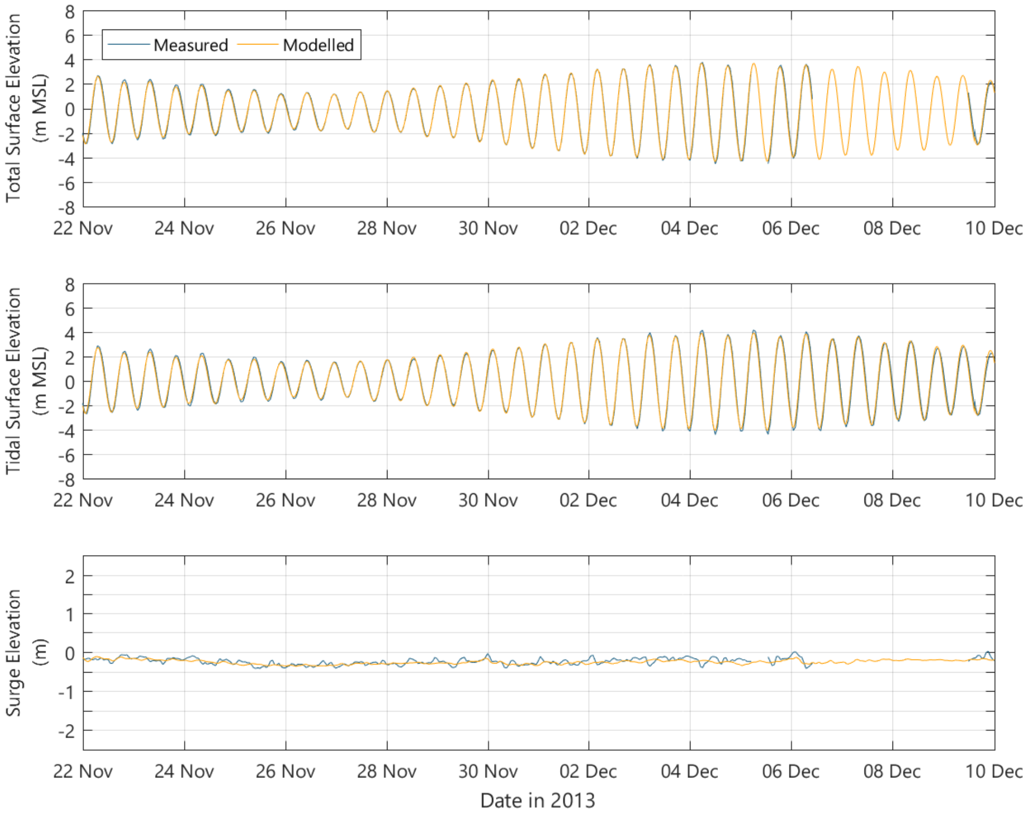

Figure 70. **Model validation at Roscoff**

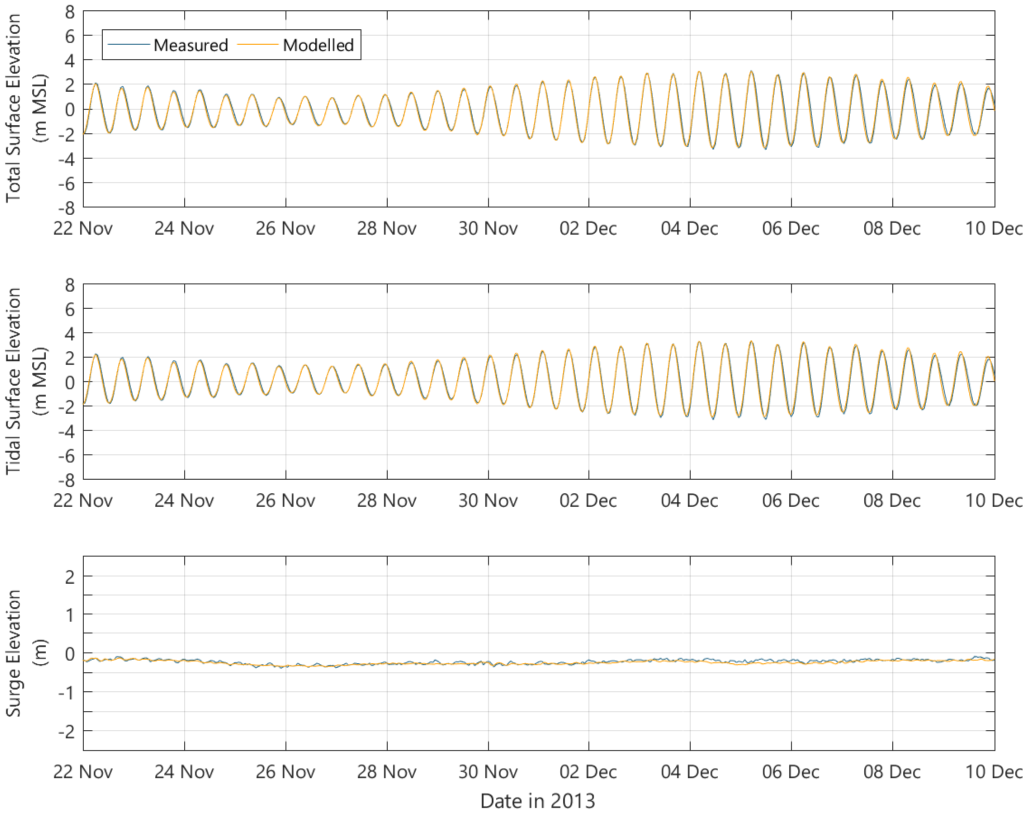

Figure 71. **Model validation at Le Conquet**

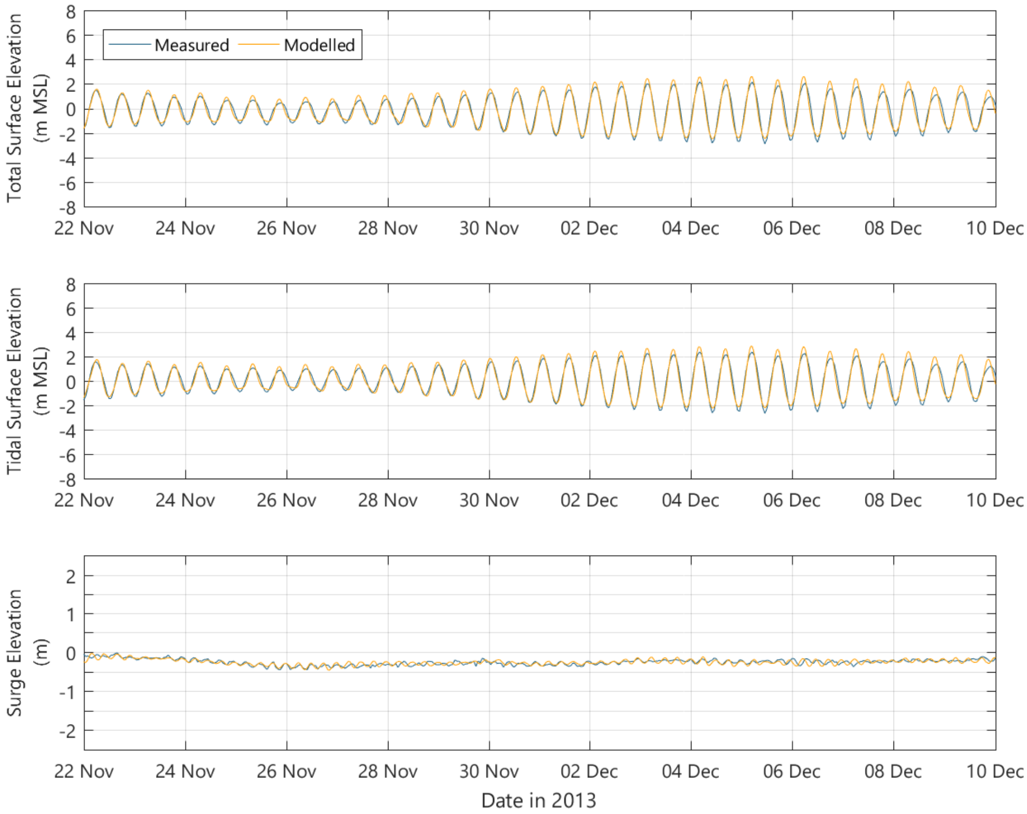

Figure 72. Model validation at Les Sables d'Olonne

Norway

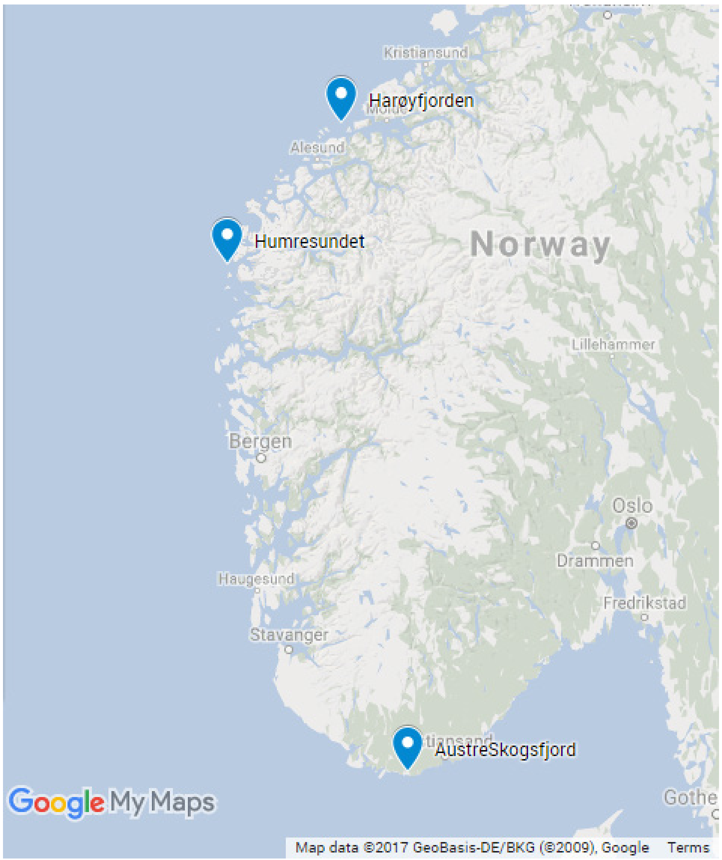

Figure 73. Norway validation sites

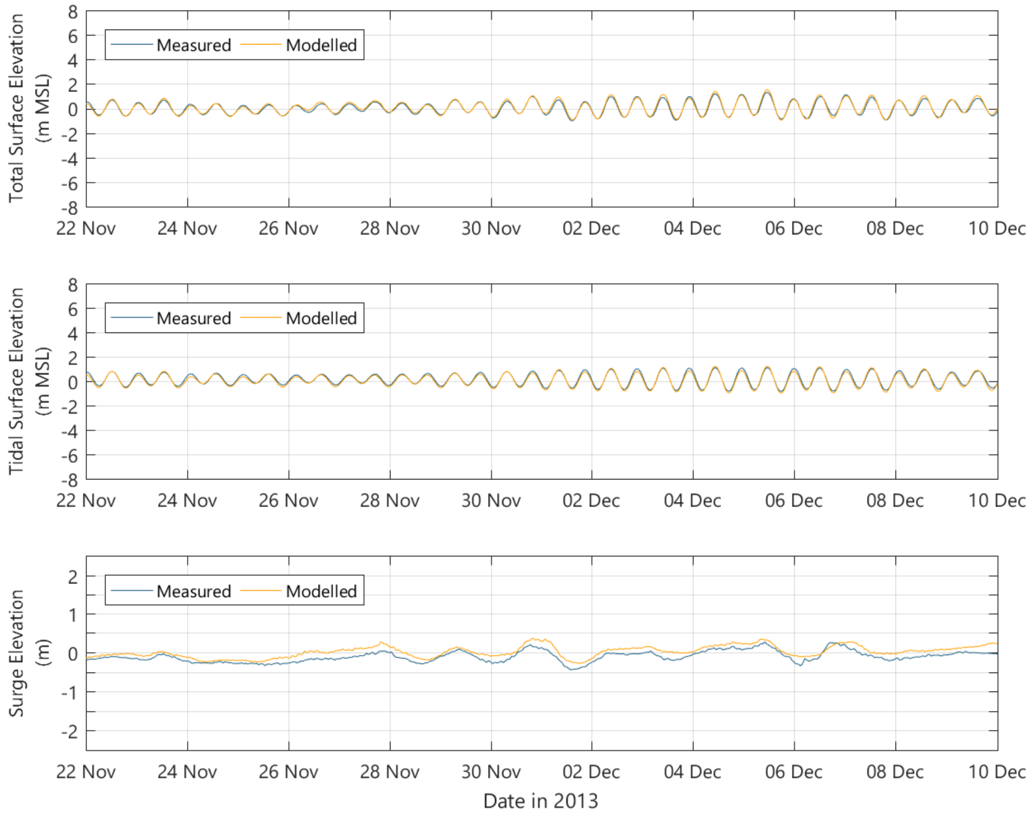

Figure 74. Model validation at Harøyfjorden

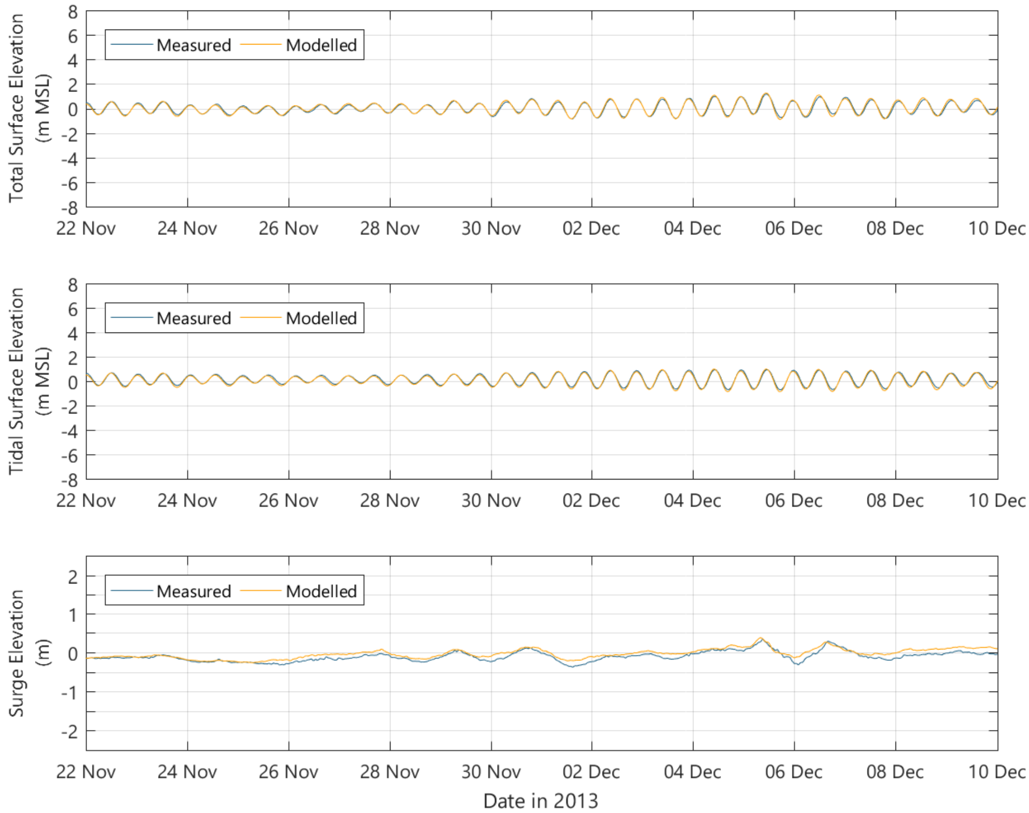

Figure 75. Model validation at Humresundet

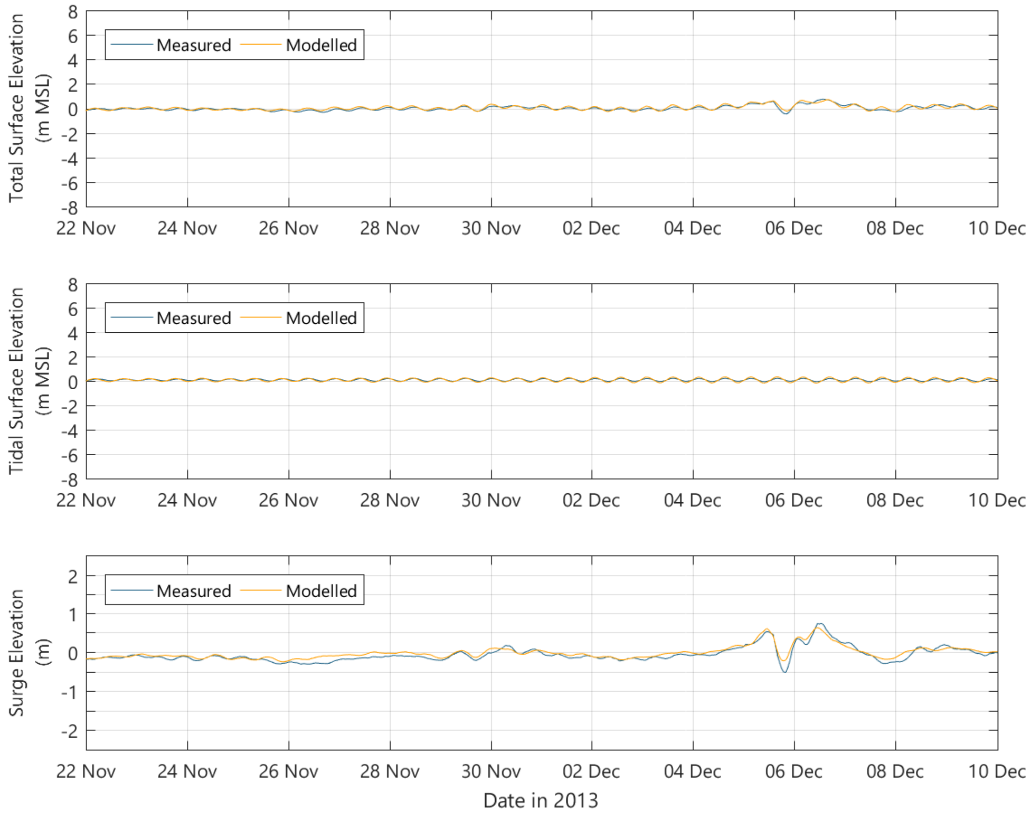

Figure 76. Model validation at Austre Skogsfjord

3.3.2 Total water level statistics

Correlation coefficients between measured data and modelled results for total water level are equal to or greater than 0.97 in the majority of cases. Where correlation coefficients fall below this level of agreement the time-series plots in Figure 5 to Figure 76 can be viewed to provide further detail.

Table 3. Total Water Level Validation Statistics: UK

Area	Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
North and east coast of Scotland	Lerwick	0.01	0.08	0.10	0.09	0.99
	Wick	0.04	0.17	0.21	0.21	0.98
	Aberdeen	0.05	0.16	0.20	0.19	0.99
	Leith	0.01	0.23	0.30	0.30	0.98
East coast of England	North Shields	0.01	0.19	0.25	0.25	0.98
	Whitby	-0.12	0.22	0.26	0.23	0.99
	Immingham	0.11	0.17	0.25	0.23	0.99
	Cromer	0.07	0.20	0.27	0.26	0.98
	Lowestoft	0.00	0.12	0.15	0.15	0.98
South coast of England	Dover	-0.02	0.20	0.25	0.25	0.99
	Newhaven	-0.02	0.21	0.27	0.27	0.99
	Portsmouth	-0.05	0.20	0.30	0.29	0.97
	Bournemouth	0.01	0.07	0.09	0.09	0.98
	Weymouth	0.00	0.07	0.09	0.09	0.99
	Devonport	-0.10	0.22	0.28	0.26	0.98
	Newlyn	-0.06	0.13	0.17	0.16	0.99
	St. Marys	0.01	0.08	0.11	0.11	1.00
Bristol Channel and Severn Estuary	Ilfracombe	-0.11	0.18	0.23	0.20	1.00
	Hinkley Point	0.01	0.18	0.23	0.23	1.00
	Portbury	0.11	0.29	0.36	0.35	1.00
	Newport	0.14	0.32	0.62	0.61	0.98
	Mumbles	0.00	0.17	0.22	0.22	1.00
Wales	Milford Haven	-0.13	0.19	0.24	0.20	0.99
	Fishguard	-0.09	0.11	0.14	0.11	1.00
	Barmouth	0.01	0.12	0.16	0.16	0.99
	Holyhead	-0.12	0.18	0.23	0.20	0.99
	Llandudno	-0.03	0.22	0.28	0.28	0.99
West coast of England and Irish Sea	Liverpool	-0.10	0.37	0.44	0.43	0.99
	Heysham	-0.05	0.27	0.34	0.34	0.99
	Workington	0.05	0.22	0.28	0.28	0.99
	Port Erin	-0.06	0.19	0.24	0.23	0.99
West coast of Scotland	Portpatrick	-0.03	0.19	0.23	0.23	0.98
	Millport	0.02	0.25	0.31	0.31	0.94
	Tobermory	0.03	0.10	0.13	0.13	0.99
	Ullapool	0.04	0.13	0.16	0.16	0.99
	Stornoway	0.03	0.11	0.14	0.14	0.99
	Kinlochbervie	0.04	0.13	0.16	0.16	1.00
Northern Ireland	Portrush	0.04	0.15	0.19	0.19	0.98
	Bangor	0.04	0.23	0.29	0.29	0.96
Jersey	St Helier	-0.11	0.23	0.30	0.27	1.00
UK Average		**-0.01**	**0.18**	**0.24**	**0.23**	**0.99**

Table 4. Total Water Level Validation Statistics: France

Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
Dieppe	-0.01	0.24	0.30	0.30	0.99
Dunkerque	0.02	0.19	0.24	0.24	0.99
Le Conquet	-0.06	0.20	0.27	0.26	0.99
Le Havre	0.01	0.23	0.31	0.31	0.99
Les Sables D'Olonne	-0.01	0.27	0.32	0.32	0.97
Roscoff	-0.06	0.59	1.15	1.15	0.84
Saint-Malo	-0.04	0.30	0.39	0.39	0.99
France Average	**-0.02**	**0.29**	**0.43**	**0.42**	**0.97**

Table 5. Total Water Level Validation Statistics: Norway

Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
AustreSkogsfjord	0.05	0.08	0.10	0.09	0.90
Harøyfjorden	0.05	0.09	0.12	0.10	0.98
Humresundet	0.03	0.08	0.10	0.09	0.98
Norway Average	**0.04**	**0.08**	**0.11**	**0.10**	**0.95**

Table 6. Total Water Level Validation Statistics: Republic of Ireland

Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured difference	Correlation Coefficient
Aranmore	0.02	0.12	0.15	0.15	0.99
Ballycotton	0.14	0.19	0.24	0.19	0.98
Ballyglass	-0.03	0.12	0.14	0.14	0.99
Castletownbere	0.19	0.19	0.21	0.09	1.00
Dublin	0.06	0.16	0.20	0.19	0.99
Dunmore	0.22	0.25	0.30	0.21	0.98
Galway	0.01	0.14	0.17	0.17	0.99
Howth	0.04	0.16	0.19	0.19	0.99
Killybegs	0.01	0.12	0.14	0.14	0.99
Malin Head	-0.03	0.24	0.41	0.41	0.92
Skerries	0.01	0.16	0.20	0.20	0.99
Wexford	0.02	0.23	0.26	0.26	0.75
Republic of Ireland Average	**0.05**	**0.17**	**0.22**	**0.20**	**0.97**

3.3.3 Tidal water level statistics

In the case of the tide only water level comparison (Table 7 to Table 10) the mean absolute error has been related to the mean spring tidal range at the site.

Table 7. Tidal Water Level Validation Statistics: UK

Area	Location	Mean Difference (m)	Mean Absolute Error (m)	Mean Absolute Error as % of Mean Spring Range	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
North and east coast of Scotland	Lerwick	-0.03	0.07	4	0.09	0.09	0.99
	Wick	-0.04	0.16	6	0.20	0.20	0.98
	Aberdeen	-0.02	0.15	4	0.19	0.19	0.99
	Leith	0.02	0.22	4	0.28	0.28	0.98
East coast of England	North Shields	0.00	0.19	4	0.24	0.24	0.98
	Whitby	0.00	0.17	4	0.22	0.22	0.99
	Immingham	0.05	0.18	3	0.27	0.26	0.99
	Cromer	0.03	0.17	4	0.21	0.21	0.99
	Lowestoft	0.02	0.11	6	0.14	0.14	0.97
South coast of England	Dover	0.02	0.19	3	0.25	0.25	0.99
	Newhaven	0.03	0.19	3	0.25	0.25	0.99
	Portsmouth	-0.01	0.20	5	0.28	0.28	0.97
	Bournemouth	0.04	0.07	6	0.08	0.07	0.99
	Weymouth	0.00	0.07	6	0.09	0.09	0.99
	Devonport	-0.07	0.22	5	0.27	0.26	0.98
	Newlyn	-0.01	0.12	3	0.16	0.16	0.99
	St. Marys	0.06	0.09	2	0.12	0.10	1.00
Bristol Channel and Severn Estuary	Ilfracombe	-0.04	0.15	2	0.19	0.19	1.00
	Hinkley Point	0.05	0.16	1	0.21	0.20	1.00
	Portbury	0.14	0.31	3	0.38	0.36	1.00
	Newport	0.23	0.32	3	0.39	0.31	1.00
	Mumbles	0.01	0.15	2	0.20	0.20	1.00
Wales	Milford Haven	-0.07	0.17	3	0.21	0.20	0.99
	Fishguard	-0.05	0.09	2	0.12	0.11	1.00
	Barmouth	-0.03	0.12	3	0.15	0.15	0.99
	Holyhead	-0.13	0.19	4	0.23	0.19	0.99
	Llandudno	-0.05	0.21	3	0.26	0.26	0.99
West coast of England and Irish Sea	Liverpool	-0.05	0.37	5	0.44	0.44	0.98
	Heysham	-0.09	0.28	3	0.35	0.34	0.99
	Workington	-0.07	0.21	3	0.28	0.27	0.99
	Port Erin	-0.04	0.19	4	0.23	0.23	0.99
West coast of Scotland	Portpatrick	-0.09	0.20	6	0.25	0.23	0.98
	Millport	-0.04	0.25	9	0.30	0.30	0.94
	Tobermory	-0.02	0.09	2	0.12	0.12	0.99
	Ullapool	-0.04	0.13	3	0.16	0.15	0.99
	Stornoway	-0.03	0.12	3	0.14	0.14	1.00
	Kinlochbervie	-0.04	0.13	3	0.16	0.15	1.00
Northern Ireland	Portrush	-0.01	0.16	9	0.19	0.19	0.98
	Bangor	-0.02	0.23	8	0.28	0.28	0.96
Jersey	St Helier	-0.05	0.17	2	0.22	0.21	1.00
UK Average		**-0.01**	**0.17**	**4**	**0.22**	**0.21**	**0.99**

Table 8. Tidal Water Level Validation Statistics: France

Location	Mean Difference (m)	Mean Absolute Error (m)	Mean Absolute Error as % of Mean Spring Range	Root Mean Square Error	Standard Deviation of Model-Measured diffeRence	Correlation Coefficient
Dieppe	-0.02	0.26	3	0.32	0.32	0.99
Dunkerque	0.00	0.20	4	0.25	0.25	0.99
Le Conquet	-0.04	0.21	4	0.27	0.26	0.99
Le Havre	0.01	0.24	4	0.31	0.31	0.99
Les Sables D'Olonne	-0.01	0.26	5	0.31	0.31	0.97
Roscoff	0.01	0.22	3	0.27	0.27	0.99
Saint-Malo	-0.02	0.34	3	0.42	0.42	0.99
France Average	**-0.01**	**0.25**	**4**	**0.31**	**0.31**	**0.99**

Table 9. Tidal Water Level Validation Statistics: Norway

Location	Mean Difference (m)	Mean Absolute Error (m)	Mean Absolute Error as % of Mean Spring Range	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
AustreSkogsfjord	0.00	0.06	19	0.07	0.07	0.94
Harøyfjorden	-0.08	0.10	5	0.12	0.09	0.99
Humresundet	-0.05	0.08	5	0.10	0.08	0.99
Norway Average	**-0.05**	**0.08**	**9**	**0.09**	**0.08**	**0.97**

Table 10. Tidal Water Level Validation Statistics: Republic of Ireland

Location	Mean Difference (m)	Mean Absolute Error (m)	Mean Absolute Error as % of Mean Spring Range	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
Aranmore	-0.05	0.13	3	0.15	0.14	0.99
Ballycotton	0.47	0.47	13	0.51	0.21	0.99
Ballyglass	-0.13	0.19	6	0.22	0.18	0.99
Castletownbere	0.22	0.22	8	0.24	0.10	1.00
Dublin	0.00	0.20	6	0.23	0.23	0.99
Dunmore	0.22	0.25	7	0.31	0.21	0.98
Galway	-0.02	0.13	3	0.16	0.16	1.00
Howth	0.02	0.17	5	0.21	0.21	0.99
Killybegs	-0.02	0.13	4	0.15	0.15	0.99
Malin Head	-0.08	0.18	5	0.22	0.20	0.99
Skerries	-0.06	0.26	5	0.30	0.30	1.00
Wexford	0.05	0.21	14	0.24	0.24	0.78
Republic of Ireland Average	**0.05**	**0.21**	**6**	**0.25**	**0.19**	**0.97**

3.3.4 Surge water level statistics

Table 11. Surge Water Level Validation Statistics: UK

Area	Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
North and east coast of Scotland	Lerwick	0.04	0.05	0.06	0.04	0.95
	Wick	0.07	0.08	0.09	0.05	0.96
	Aberdeen	0.06	0.07	0.08	0.05	0.97
	Leith	-0.01	0.07	0.09	0.09	0.93
East coast of England	North Shields	0.00	0.04	0.06	0.06	0.98
	Whitby	-0.12	0.12	0.14	0.07	0.98
	Immingham	0.05	0.08	0.12	0.10	0.96
	Cromer	0.04	0.10	0.18	0.18	0.91
	Lowestoft	-0.02	0.06	0.08	0.08	0.99
South coast of England	Dover	-0.04	0.06	0.09	0.08	0.98
	Newhaven	-0.05	0.06	0.08	0.05	0.97
	Portsmouth	-0.04	0.05	0.07	0.05	0.96
	Bournemouth	-0.02	0.05	0.07	0.07	0.89
	Weymouth	0.00	0.03	0.04	0.04	0.95
	Devonport	-0.03	0.04	0.04	0.03	0.90
	Newlyn	-0.05	0.05	0.06	0.03	0.92
	St. Marys	-0.05	0.05	0.06	0.03	0.90
Bristol Channel and Severn Estuary	Ilfracombe	-0.07	0.08	0.09	0.05	0.86
	Hinkley Point	-0.04	0.07	0.09	0.08	0.87
	Portbury	-0.03	0.14	0.17	0.17	0.80
	Newport	-0.10	0.20	0.51	0.50	0.25
	Mumbles	0.00	0.05	0.06	0.06	0.89
Wales	Milford Haven	-0.07	0.07	0.07	0.03	0.95
	Fishguard	-0.03	0.04	0.05	0.04	0.92
	Barmouth	0.04	0.06	0.08	0.07	0.92
	Holyhead	0.01	0.03	0.04	0.04	0.97
	Llandudno	0.01	0.05	0.07	0.07	0.92
West coast of England and Irish Sea	Liverpool	-0.05	0.07	0.10	0.09	0.92
	Heysham	0.05	0.08	0.11	0.10	0.91
	Workington	0.12	0.12	0.13	0.06	0.96
	Port Erin	-0.01	0.03	0.04	0.04	0.96
West coast of Scotland	Portpatrick	0.05	0.06	0.08	0.06	0.93
	Millport	0.06	0.09	0.12	0.10	0.85
	Tobermory	0.06	0.07	0.08	0.06	0.95
	Ullapool	0.08	0.09	0.10	0.06	0.94
	Stornoway	0.07	0.07	0.09	0.06	0.93
	Kinlochbervie	0.08	0.08	0.09	0.05	0.97
Northern Ireland	Portrush	0.06	0.07	0.08	0.06	0.94
	Bangor	0.06	0.07	0.08	0.06	0.92
Jersey	St Helier	-0.06	0.09	0.12	0.10	0.71
UK Average		**0.00**	**0.07**	**0.10**	**0.08**	**0.91**

Table 12. Surge Water Level Validation Statistics: France

Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
Dieppe	0.02	0.07	0.08	0.08	0.92
Dunkerque	0.03	0.07	0.09	0.09	0.98
Le Conquet	-0.02	0.03	0.04	0.04	0.81
Le Havre	0.00	0.07	0.09	0.09	0.88
Les Sables D'Olonne	0.00	0.04	0.05	0.05	0.63
Roscoff	-0.07	0.10	0.13	0.10	0.65
Saint-Malo	-0.02	0.08	0.10	0.10	0.59
France Average	**-0.01**	**0.07**	**0.08**	**0.08**	**0.78**

Table 13. Surge Water Level Validation Statistics: Norway

Location	Mean Difference (m)	Mean Absolute Error (m)	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
AustreSkogsfjord	0.05	0.07	0.09	0.07	0.94
Harøyfjorden	0.13	0.13	0.14	0.06	0.92
Humresundet	0.08	0.09	0.10	0.05	0.93
Norway Average	**0.09**	**0.10**	**0.11**	**0.06**	**0.93**

Table 14. Surge Water Level Validation Statistics: Republic of Ireland

Location	Mean Difference	Mean Absolute Error	Root Mean Square Error	Standard Deviation of Model-Measured Difference	Correlation Coefficient
Aranmore	0.07	0.08	0.10	0.06	0.90
Ballycotton	-0.33	0.33	0.37	0.16	0.40
Ballyglass	0.10	0.10	0.13	0.07	0.89
Castletownbere	-0.03	0.04	0.05	0.05	0.85
Dublin	0.07	0.08	0.10	0.07	0.85
Dunmore	-0.01	0.04	0.05	0.05	0.87
Galway	0.03	0.07	0.09	0.08	0.78
Howth	0.02	0.04	0.05	0.05	0.94
Killybegs	0.03	0.06	0.07	0.06	0.90
Malin Head	0.06	0.18	0.33	0.33	0.36
Skerries	0.07	0.11	0.13	0.11	0.73
Wexford	-0.04	0.06	0.07	0.07	0.75
Republic of Ireland Average	**0.00**	**0.10**	**0.13**	**0.10**	**0.77**

3.4 Current validation

3.4.1 Approach

Following the same approach as the water level validation, current speeds and directions have been assessed using two methods:

- Visual comparisons between the model and observed data to assess the shape, trend, range and limits of model output and observed data; and
- Statistical comparison of the differences between the model and observed data to determine the degree to which the model fits the observations.

Validation statistics have been generated for a periods of time where coincident measured and modelled data are available with no data gaps in the record. This is as a minimum 19 days, but is mostly significantly more. This enables comparisons to be undertaken over both spring and neap periods of the tide. Validation has been undertaken on the total current speeds and directions which include both tide and surge elements of flow.

In the majority of cases the measured records contain a processed dataset of depth averaged flow conditions which have been compared directly with the hindcast model outputs. The exception to this is Gunfleet sands where only near bed (0.5 m above sea bed) records are available. These have been transformed to representative depth mean speeds using a 7th power law adjustment based on Soulsby (1997).

Current statistics

The following statistics have been calculated for all available measurements sites for the total (tide and surge) flows.

- Mean flow speed difference (at peak flood and ebb). Calculated as the mean difference between the magnitudes at peak flood and ebb time of the tide. This is also calculated as a percentage value relative to the maximum observed speed;
- Standard deviation of the flow speed difference (at peak flood an ebb). Variation from the mean flow speed difference at peak and ebb tide;
- Mean flow direction difference (at peak flood and ebb). Calculated as the mean of the difference in flow direction recorded at times of peak flood and ebb period of the tide; and
- Standard deviation of the flow direction difference (at peak flood and ebb). Variation from the mean flow direction difference at peak and ebb tide.

The best practice standards set out below and reported in ABPmer (2013) state recommended values that the model aims to meet:

> *"Modelled speeds should be within ±10% to 20% of peak observed speeds, while modelled directions should be within ±10° of observed directions".*

3.4.2 Summary

The current speed and direction validation sites used are shown in Figure 77.

Figure 77. Current speed and direction validation sites

Time-series comparison plots presented in Figure 78 to Figure 83, and UV scatter plots in Figure 84 generally show a very good agreement between the measured and modelled records. This is true of all sites with the exception of Gunfleet sands.

At seven of the eight locations presented visual agreement between the measured and modelled data is good. The time-series show good agreement in terms of magnitude and the direction. The U V scatter plots are clearer in highlighting the discrepancies in the measured and modelled distributions, but still the agreement between measured and modelled appears acceptable, and considering the shallower sandbank environment of some of the sites, the model is considered accurate.

At Gunfleet Sands it is important to note that the measured current speeds are recorded in a shallow water column of only 8 m in an area of rapidly changing bathymetry reasonably close to the shore.

In order to quantify model performance a set of validation statistics has been produced for each of the validation locations. These are presented in Table 15 and discussed in Section 3.4.3.

3.4.3 Total current speed and direction statistics

Table 15. Validation Statistics for Flow Parameters

Site name	Zone 7	Zone 9	Blyth Demo	Race Bank	Docking Shoal	Gunfleet Sands (N)
Start date	01/01/2012 00:00	01/01/2011 00:00	21/03/2011 17:40	24/06/2006 16:10	16/05/2006 16:50	30/08/2002 09:00
End date	22/07/2012 13:10	19/01/2011 11:30	02/06/2011 09:30	21/08/2006 08:30	21/08/2006 06:50	30/09/2002 12:12
No of ebb tides	393	35	141	111	183	60
No of flood tides	394	36	140	111	184	60
Mean ebb speed difference (modelled - observed)	-0.07	-0.06	-0.01	-0.07	-0.10	0.09
Mean flood speed difference (modelled - observed)	-0.06	-0.09	0.03	-0.04	0.03	0.55
Standard deviation of ebb speed difference	0.08	0.05	0.04	0.08	0.08	0.05
Standard deviation of flood speed difference	0.08	0.06	0.03	0.10	0.13	0.10
Mean ebb % difference relative to max observed speed	-5	-5	-1	-7	-11	9
Mean flood % difference relative to max observed speed	-4	-8	8	-3	2	94
Mean ebb direction difference	4.14	0.32	10.61	18.73	22.81	-10.72
Mean flood direction difference	1.13	-0.71	3.75	6.66	10.64	-26.31
Standard deviation of ebb dir difference	15.60	2.46	5.34	9.42	28.75	1.99
Standard deviation of flood dir diff	11.61	1.74	6.17	8.39	10.89	39.57
Red highlighted values are those where the target validation standard has not been met						

Table 15 shows that in the comparison of current speeds all sites meet the recommended validation criteria of agreement within ±20% of peak observed speeds with the exception of Gunfleet Sands on the flood tide. In this case the measurements show a greatly reduced flood speed while the model shows a similar magnitude of slow on ebb and flood. This discrepancy may be due to a unique flow regime across a sandbank, as discussed previously. Notes from the measurement report indicate that the current flows change significantly throughout the year, and that the ebb/flood asymmetry observed in the period of validation is not observed throughout. There is the possibility that sensor abnormalities may have led to misleading current records however the variable conditions and comparison between the sites suggest this could be a real phenomenon.

At all other sites the agreement between measured and modelled speeds is well within the validation requirements.

Agreement in flow directions is more variable and a number of sites fall outside the desired ±10° agreement of flow directions on flood or ebb. Direction difference statistics presented in Table 15 are calculated at the moment of peak ebb and flood speed, so are a snapshot of that particular moment but not necessarily provide a full description of overall performance. Understanding can be increased by looking at the U and V scatter plots of flow presented in Figure 84.

Both Race bank and Docking Shoal have very rounded, rather than rectilinear tidal ellipses, meaning that higher speeds occur from a wider range of directions rather from a fixed narrow sector. It is therefore unsurprising that directional agreement in the statistics is poorer. However the visual representation of the agreement seems satisfactory. Local predictions of currents on and around these and other similar sandbanks might benefit from further localised flow modelling at a higher resolution, for which the SEASTATES Tide and Surge Hindcast can provide a robust source of boundary conditions.

3.4.4 Total current speed and direction time-series plots

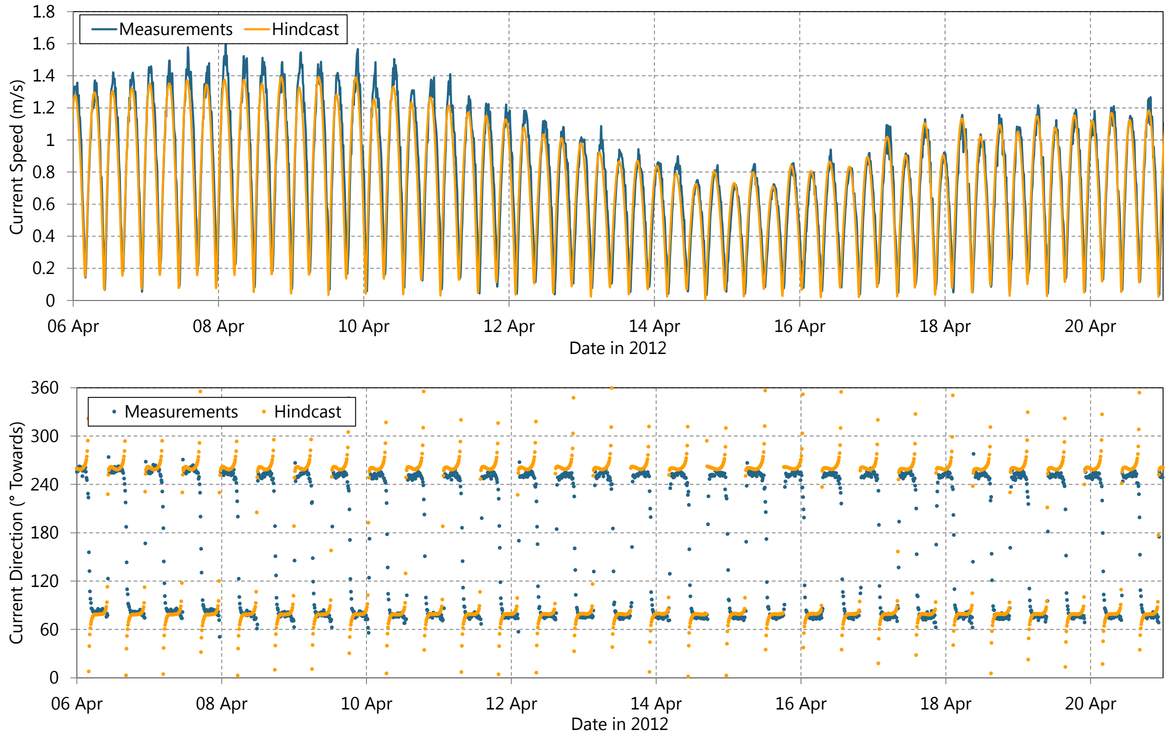

Figure 78. Current speed (top pane) and direction (lower pane) time-series comparison – Zone 7

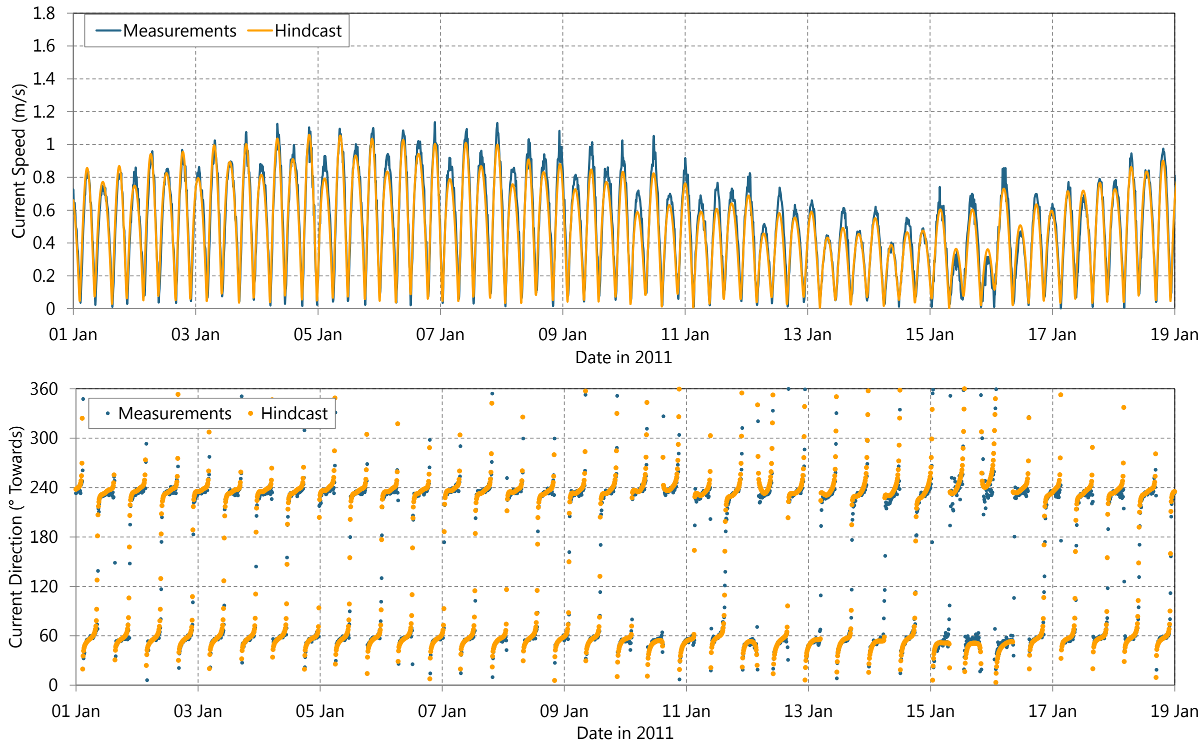

Figure 79. Current speed (top pane) and direction (lower pane) time-series comparison – Zone 9

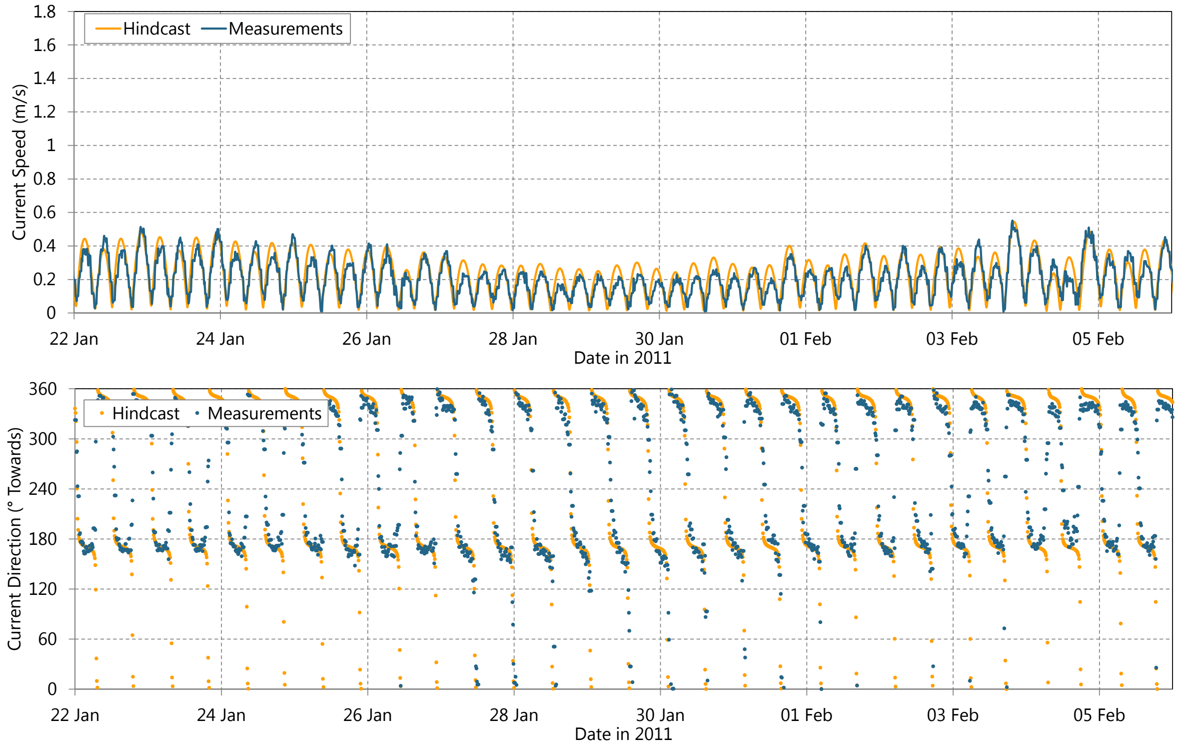

Figure 80. Current speed (top pane) and direction (lower pane) time-series comparison – Blyth Demonstrator

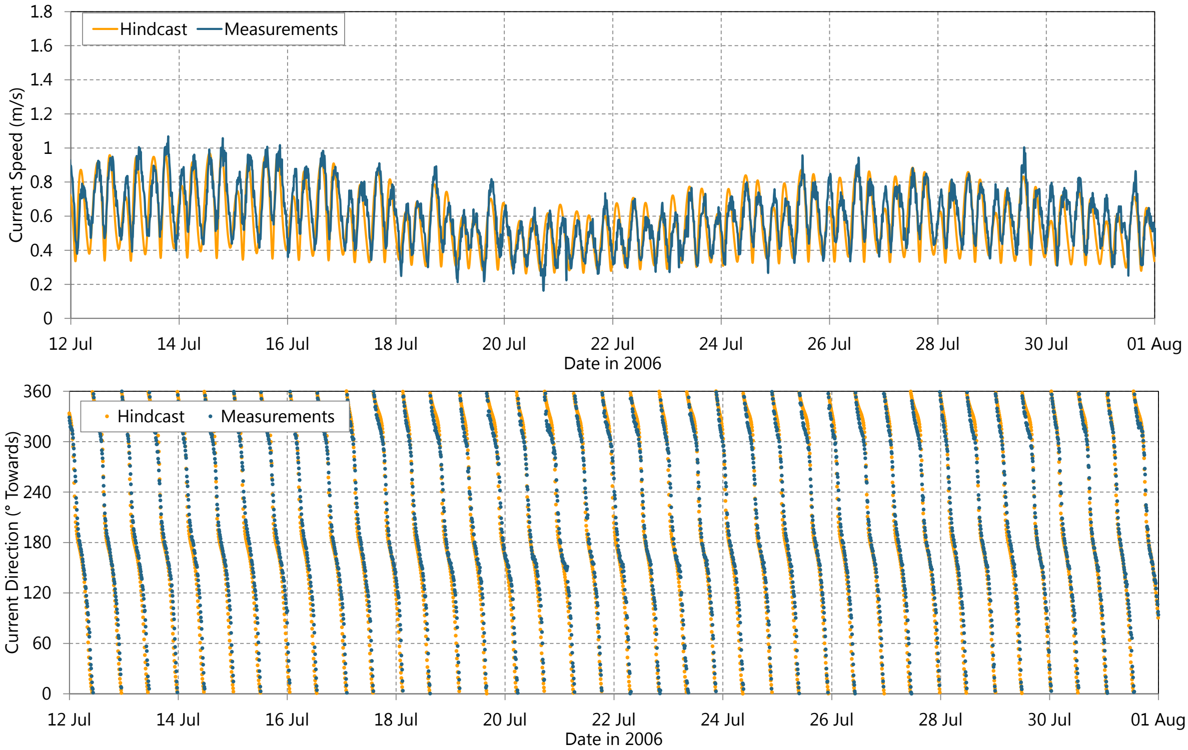

Figure 81. Current speed (top pane) and direction (lower pane) time-series comparison – Race Bank

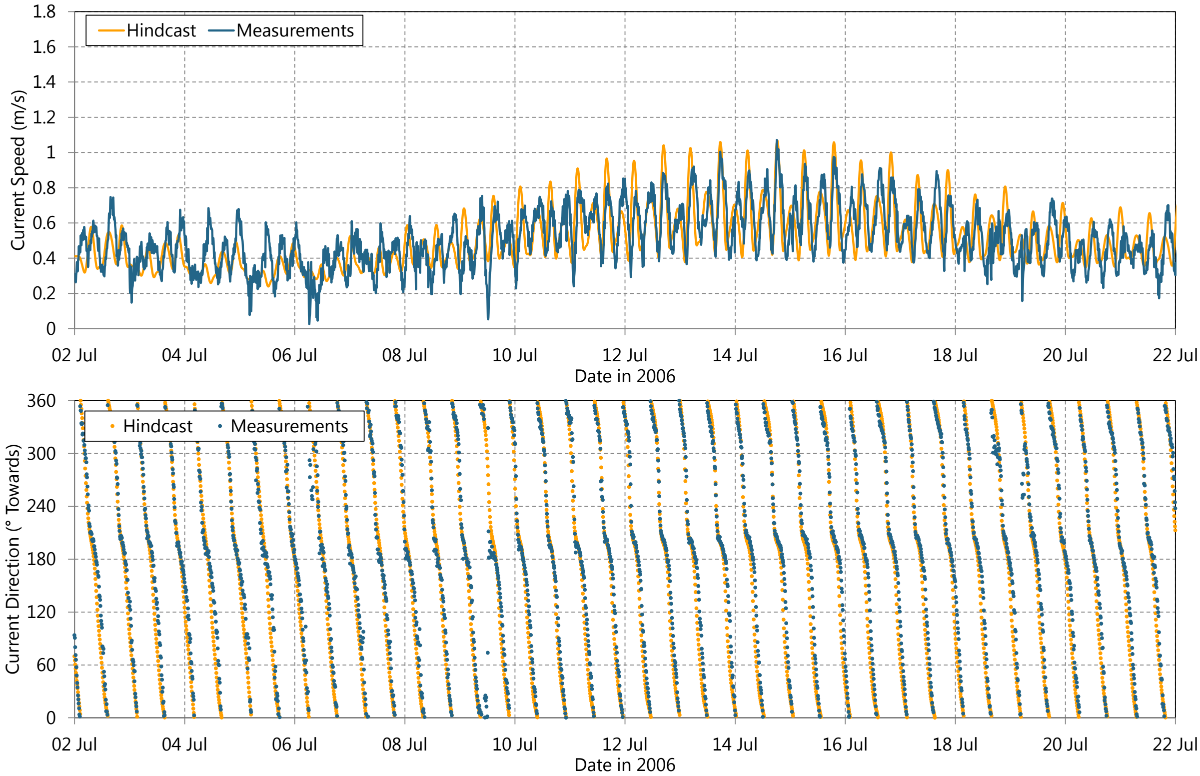

Figure 82. Current speed (top pane) and direction (lower pane) time-series comparison – Docking Shoal

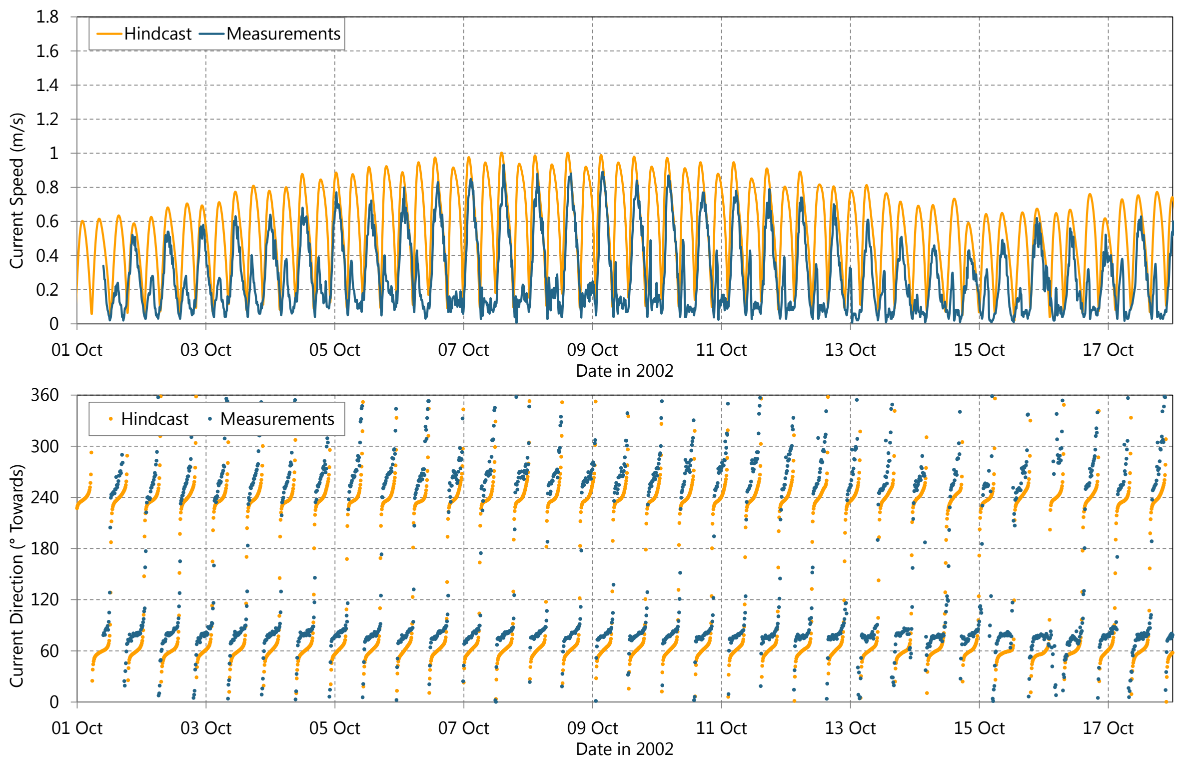

Figure 83. Current speed and direction time-series comparison – Gunfleet Sands

3.4.5 U and V Scatter Plots

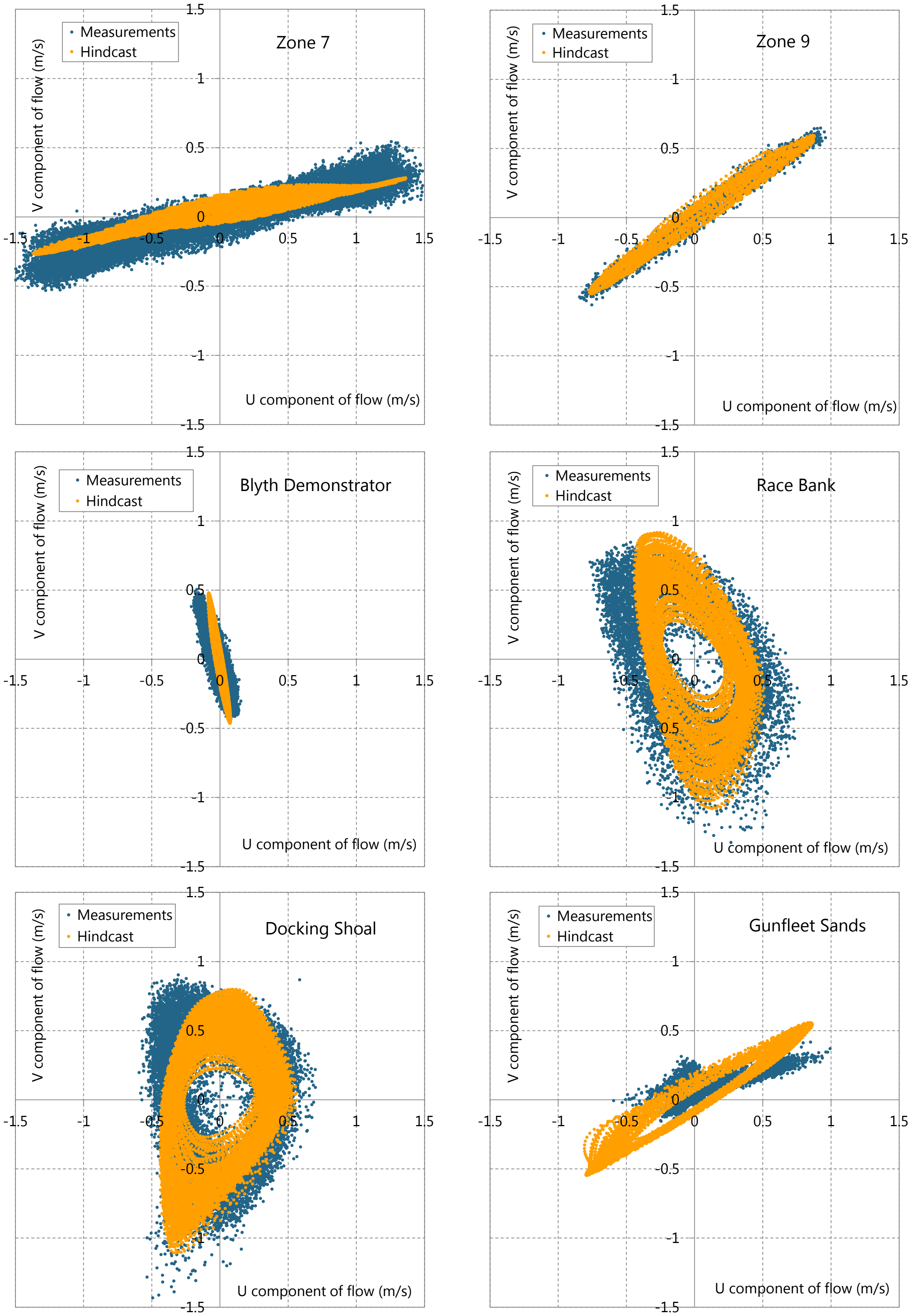

Figure 84. UV scatter plots hindcast against measurements

4 Summary

A detailed assessment of the SEASTATES Tide and Surge Hindcast Model has shown that the model is accurate in representing the water level and flow for total, tide, and surge components around the North West European coast.

The range of validation locations assessed allows the reader to ascertain details of model performance across the model domain to assess suitability for individual project applications.

As well as providing a regional scale set of hydrodynamic parameters across the model domain, the Tide and Surge Hindcast is intended to be a source of model boundary conditions for local scale models. Such local scale models can use finer grid resolution to derive hydrodynamic characteristics in areas of shallow water or rapidly changing bathymetry, particularly close to the coast.

5 References

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Soulsby, R. (1997). Dynamics of Marine Sands. Thomas Telford Publications. ISBN: 0 7277 2584.

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